CHAPTER 7

PROBLEMS OF CAPSIZING WITH SPECIAL REFERENCE TO THE TOYA MARU DISASTER [71]

7.1 Introdoction

Typhoon No. 15 (Marie) landed on Kyushu in the early morning of September 26, 1955 and took the course of running northward through the Sea of Japan. She was different from the usual ones, being characteristic in that she moved with an extraordinary speed of 100 km/h and developed into a very strong wind storm in the night of the same day, when she hit Hokkaido, and capsized five ferry-boats including Toya Maru and wrecked many other ships. The disaster was so great that it is still vivid in our memory.

In the case of Toya Maru, the disaster was the worst—as a matter of fact the worst since the tragedy of the Titanic, as it claimed the lives of 1,172 persons out of the 1,198 passengers and 133 crew aboard the ship. Naturally, it invited serious public attention, creating a strong cry for exhaustive investigations into the causes, which was connected with the problem of compensation for the bereaved family.

In accordance with the request of the Marine Disasters Inquiry Agency, KATO, SATO and MOTORA jointly conducted experiments in order to investigate its technical causes. In the experiments the two specific cases of Toya Maru (passenger boat) and Tokachi Maru (freighter) were dealt with as representatives of the wrecked ferry boats.

The subject report is devoted to the investigation of the technical causes of the disaster, and it does not pertain to be a study from a judicial standpoint which, for example would trace up the location of responsibility for the departure of the ship from port.

7.2 Meteorological Condition at the Time of Disaster

7.2.1 Course, degree of central pressure and speed of typhoon

Typhoon No. 15 landed on the southern part of Kyushu at 2 o'clock of September 26. She traversed Kyushu up to the Inland Sea and took her course along the west coast of Japan as illustrated in Fig. 7.1. In that evening she reached Aomori Prefecture.

The speed of Typhoon No. 15 reached 130 km/h at the climax. This was quite extraordinary as the speed of a usual typhoon is known to slow down to 20～30 km/h after landing. Another characteristic of this

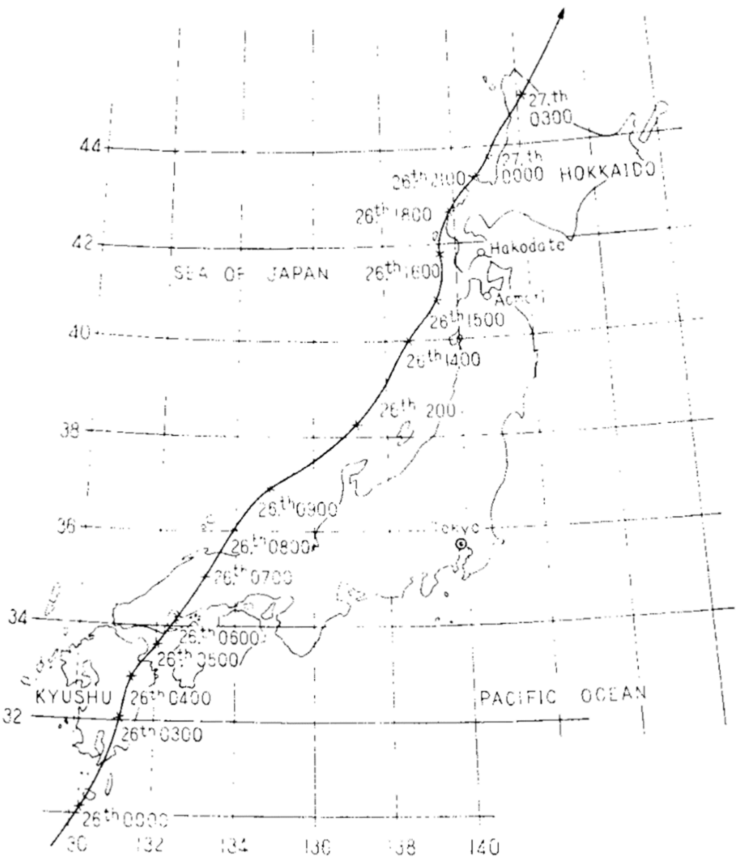

FIG. 7.1 COURSE OF TYPHOON NO. 15

typhoon, which is also considered extraordinary, is that the degree of its central pressure became low—that is, it grew up—with her running northward.

It should be perceived then that these extraordinary characteristics constituted the underlying causes of a calamity. However, typhoons of a big scale with a great storm circle like Typhoons No. 12 and 14, which successively attacked the east coast of Japan a few days before, rapidly weakened after they landed and had not exercised a great power, and therefore it was perhaps forgivable that there was a lack of precautions to the disaster among the people.

Judging from the information that Typhoon No. 15 was running northward and also considering her speed of 110 km/h, Hakodate Oceanic Weather Bureau issued a gale alarm at 11 h. and further-more gave the following warning at 16 h.

"Typhoon No. 15 is at 15 h. about 100 km west of Aomori prefecture, 41.0° N and 139.5° E, and her central pressure is showing 968 milibars. She is still running north-eastward with the speed of about 110 km/h. It is considered that, if she runs with this speed, she would traverse Oshima peninsula at about 17 h. and pass through Hokkaido this night. It is estimated, therefore, that in Oshima and Hiyama districts a heavy wind with the maximum velocity of 25 m/sec would blow at about 17 h. and later the wind direction would change to north-west. The wind may cease after midnight."

Since typhoons swirl anticlockwise in the northern hemi-sphere, the III and IV quadrants or the right side in Fig. 7.2 would be the dangerous side in which the translation speed of the typhoon is cumulative to the velocity of swirling wind. On the other hand, Hakodate has such geographical features that, screened by mountains in the northward and opening southward to the Tsugaru Straits, there is a lack of resistance against the south wind.

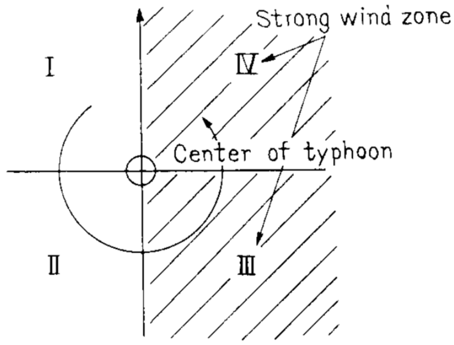

FIG. 7.2 DANGEROUS QUADRANTS

The condition of Hakodate harbour, therefore, is usually vulnerable to the course of a typhoon, whether she passes eastward or westward of Hakodate. When the typhoon centre passes westward, Hakodate is included in the dangerous III and IV quadrants and the waves grow up in face of the south wind (Fig. 7.3). When she passes eastward, on the contrary, it is included in the comparatively safe I and II quadrants. Then it receives the northern wind and no waves grow in Hakodate harbour due to the screening by mountains.

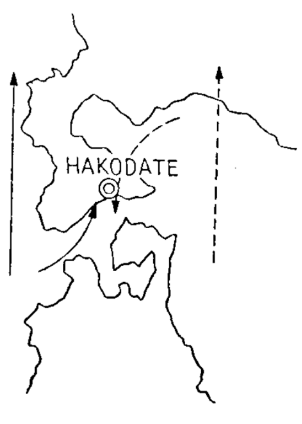

FIG. 7.3 TWO PASSES OF TYPHOON, SAFE AND DANGEROUS TO HAKODATE

When we consider the afore-mentioned weather forecast with this preliminary knowledge, the judgement might have been based upon the assumption that the typhoon centre would pass eastward of Hakodate. When, in fact, we observe the course of typhoon during 14~15 h. from Fig. 7.1, it can not be blamed that they set up such a presumption.

What really happened was, however, that she suddenly turned west at 15 h. and passed westward of Hakodate.

One of the other causes which aggravated the disaster was the sudden change of the speed of the typhoon. The typhoon, which had been running with the speed of 110 km/h till 16 h., suddenly lowered her speed and hit Hakodate at the time, when she should have passed there if she had kept the same speed. In addition the typhoon centre was stagnant, and consequently the south wind blew upon the Tsugaru straits for a long period and grown-up waves beated upon Hakodate harbour.

It was found afterward that the cause of this phenomenon was the sub-low produced eastward of the Tsugaru Straits.

7.2.2 Wind velocity, atmospheric pressure and waves at Hakodate

Fig. 7.4 illustrates the atmospheric pressure and wind velocity observed by the Hakodate Oceanic Weather Bureau. Wind velocity here is

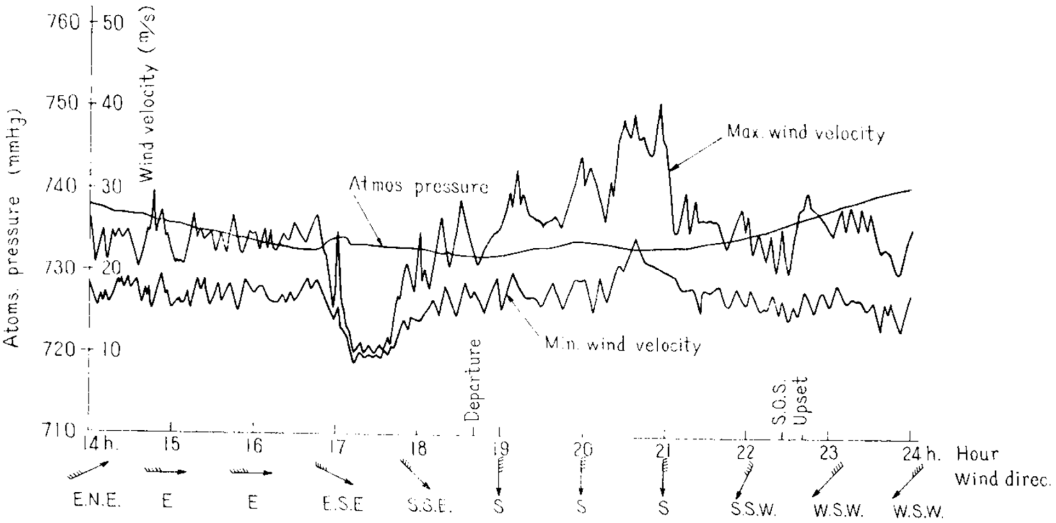

FIG. 7.4 WIND VELOCITY, WIND DIRECTION AND ATMOSPHERIC PRESSURE

the average value over ten minutes, so that the maximum instanteneous velocity should be considerably greater.

As already mentioned, the typhoon centre swept westward over Hakodate, the atmospheric pressure showed the minimum value from 16 to 18 h. and the wind lulled. This fact obviously indicates the passage of the typhoon centre. Ironically enough, Toya Maru departed the pier at 18.40 h. when the typhoon centre was passing through the Hakodate.

With the passage of the typhoon centre the wind blew back after 18 h. and its direction changed to south and then to southwest. The south-west wind continued its blowing due to the stagnation of the typhoon centre. Consequently Hakodate was faced with grown-up waves.

Wind velocity was 18.4 m/sec at 19.01 h. when Toya Maru anchored and 23 m/sec at 22.12 h. when she was drifting with her engine at both sides stopped. In addition, there was a report from the ship that there was a gust of 55 m/sec at 21.25 h. Record at Arikawa pier by National Railroad Bureau shows fairly consistent figures.

Since the above values indicated the velocities of the wind in the harbour, it is considered that those in the Tsugaru Straits should be somewhat greater, say about 1.5 times. Accordingly the velocity might have been 30~35 m/sec in average and 50~60 m/sec at a maximum instant.

On the other hand there is a dirth of available data as to the observed value of the wave, however, summarizing the information of the crew of Toya Maru and witnesses ashore, a wave height of 6 metres is considered a fair value. Since in cases of visual observation, attention is apt to be drawn to comparatively high waves, this value may be considered to be close to the significant wave height.

Although there are also no available observed values as to the length and period of waves, the summarization of various information obtained afterward indicates that the wave length seemed approximately equal to the length of the ship.

When we compute, according to the theory of wave forecasting, the characteristics of the wave produced by the wind which had been blowing for 5 hours with the average velocity of 25 m/sec, we obtain

According to the Sverdrup-Munk's theory (1):

Significant wave height	5.8 m
Wave length	62.3 m
Wave period	6.3 sec

According to Bretschneider (2):

Significant wave height	5.7 m
Wave length	137 m
Wave period	9.4 sec
Wave slope	7.5°

Whilst wave height is approximately equal between the above two theories, wave length and period vary to a great extent. In this investigation, accordingly, experiments were carried out with a wave height kept at 6 metres and wave periods varied from 6 to 9 sec.

However, inasmuch as the results of experiments and previous data indicate that the results of Bretschneider provides nearer value, it would be advisable to consider the wave length as approximately 100 metres and period as about 8 sec.

7.3. Movements and Circumstances of Each Ship at the Time of Disaster

Following are the summary of information obtained mainly by the statements of the survived crew in regard to the movements of the 5 capsized ferry-boats and barely escaped 2 other ships and their circumstances of the disaster. (It should be understood that there might be some inconsistencies with the affidavits obtained at Maritime Court, etc. as to the details of the time and particular description.)

Fig. 7.5 illustrates the movement of each ship in Hakodate harbour, in which figures put in by each position of the ship indicate the time.

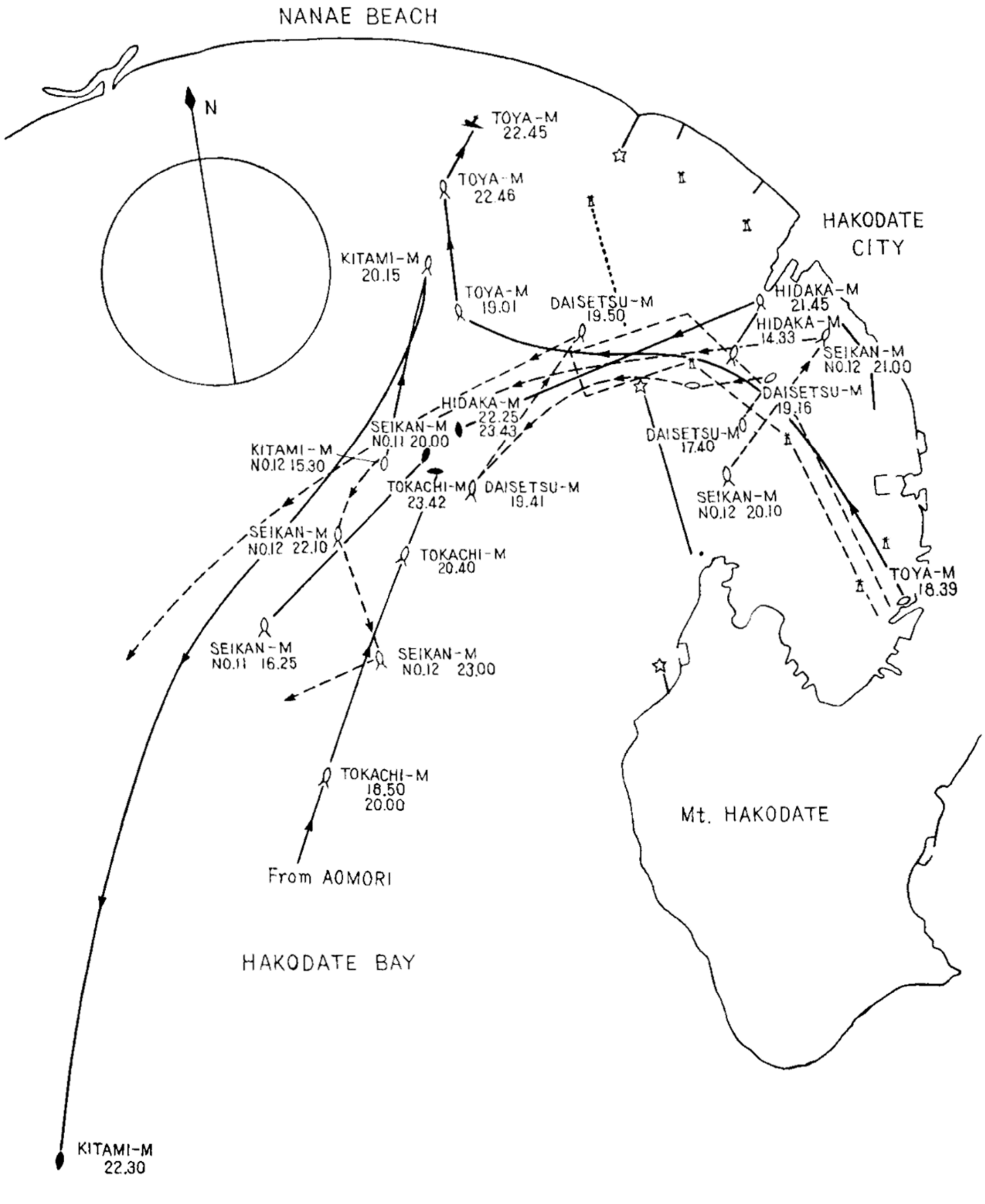

FIG. 7.5 MOVEMENTS OF EACH SHIP

(1) Toya Maru

18.39 h. of 26th day: Left Hakodate pier for Aomori with 1,198 passengers and 133 crew aboard.

18.55: Passed the light house at the breakwater bank.

19.01: As the wave and wind were unexpectedly strong, anchor was dropped at a place 0.85 mile from light house in the direction of 300°. Four chain cables were drawn out at first. As the anchor dragged, however, the portside anchor was dropped when 6 shots of cable were drawn out; thus shots of drawnout cables were made to 8.

19.30 (about): Recognized the flooding of waves upon the waggon deck from the stern opening.

20~21: Wind at its strongest, the maximum instantaneous velocity being 58 m/sec. The ship swang by an azimuth of 180°.

20.40 (about): Sea water began to leak in the engine and boiler rooms from the skylight.

22.00 (about): The centrifugal pump and the circulating pump in the port side were flooded and failed to be operated. The port engine then stopped. At about the same time, the list changed from to port to starboard.

22.08: The list reached 20°—30° to starboard. The centrifugal pump in starboard also failed to be operated due to flooding. Sent out the signal: "Unable to operate the main engines." By this time the ship became parallel to the coast line and rolled considerably in the waves while wind came athwartship.

22.13: Sent out the signal: "Being drifted due to failure of main egines." The engines completely stopped. The engine and boiler rooms were considerably flooded and therefore all the personnel in the engine room evacuated. Had been trying to keep an anchorage with the thrust of ship up to this time, but it became inevitable to drag anchor after stopping the engines.

22.27: All the lights went out.

22.29: Sent out the signal: "Stranded at 22.26." Felt a shock several times at the bottom of ship.

22.40: Sent out SOS signal. The ship listed about 40° to 45° to starboard and didn't recover it. Gradually increased the list and the ship finally overturned at the point about 500 metres from the coast (the Nanae-Beach). The darkness of the night claimed 1,172 lives. There was no sign of the falling of freight cars up to the list of about 40°, but a loud noise of falling was heard while the ship overturned.

(2) Tokachi Maru

18.50: Arrived at Hakodate Port from Aomori. The harbour was so crowded and the wind so strong, that anchors were dropped at the point 3.3 miles from the Kattoshi light house which was in the direction of 62° from the north. Used 4 shots in starboard and 6 in port, respectively.

19.25 (about): Started the main engine.

19.50: Flooding started in the engine and the boiler rooms.

20.42: Southwest wind with the velocity of 30—35 m/sec was blowing. Sometimes a gust with 40 m/sec. Rolled 40° to right and 28° to left. Advanced at half speed.

21.20: Water rose in the boiler room and it became difficult to fire the furnace.

22.20: The operation of the generator became impossible. All lights were out.

22.40: All the personnel in the engine room were evacuated.

23.40: (about): The list gradually increased and the ship then overturned. Just before the overturning a loud noise was heard from the falling of freight cars.

By examining all the shipwreck herein reported, the findings are made as follows.

(1) In spite of considerable flooding, Toya Maru didn't overturn when she was staying in a head wind with a help of anchoring. She however, overturned after approaching near the shore where she had waves and wind athwartship and stranded.

(2) The sequences of Toya Maru's overturning are as follows. She listed considerably to starboard with an angle of 40° to 45° and halted a while and then gradually increased her list, until she finally lay on her side. From reports of a survivor who was in the third class passenger room that the above happened just at the time when water poured in through a stairway like a waterfall, it is believed that with a large list the promenade deck dipped in water and a large amount of water came aboard through stairway openings, non-water-tight doors and windows, resulting in a complete loss of stability. Based on the above fact, it was considered in calculating the limit of her stability that her stability was null at a larger angle than about 40° when her promenade deck would dip in water.

(3) Every freight train ferry boat (Tokachi-maru type) overturned, staying in a head wind with a help of satisfactory anchoring in deep water. Kitami-maru suddenly changed her list from to port to starboard, the original list to port being recovered with a trimming pump. Hidaka-maru listed to starboard, even though she had waves and wind from her starboard side. From these facts it is considered that GMs of these ships

were negative at that moment due to the flooding.

(4) It is commonly said in every case that there is no proof to verify, the falling of freight cars as a cause of overturning ship. These freight cars began to fall down at the angle larger than 60°, after the ship had started to overturn. In the case of Seikan-maru No. 11 there were some cars hanged with chains from the deck which were completely up side down.

(5) Both Daisetsu-maru and Seikan-maru No. 12 which did not capsize, had no cargo loaded and kept moving with the engine driven to stay in a head wind. These are the points which were different from the cases of the ships sunken.

Observing these facts listed above, the main interest of this experiment was focused on the following three items.

(1) To study the mechanism and to measure the volume of water poured in through the stern opening of the waggon deck, while the ship was anchored, heaved to, or advanced in the waves.

(2) To study the effect of water stagnant on the waggon deck or flooded in the engine and the boiler rooms on a stability of ship. That is, to calculate the critical velocity of wind against which the ship can withstand when a certain flooding is assumed.

(3) To study the effect of bottom contact on the stability of a ship, especially for the case of Toya-maru. For this purpose, an experiment was made by causing surfs in the experiment tank with a false bottom set with a scale of about 1/57 of the Nanae Beach.

Toya-maru was chosen as a typical passenger boat type and Tokachi-maru as a typical cargo boat type, and tests were conducted on these two ships. Other three ships are considered to be very close to Tokachi-maru.

7.4. Types and Principal Dimensions of Ships Studied

Seikan ferry is composed of passenger train ferry boats and train ferry boats, some of which have passenger accomodations on their boat decks. Among five ships sunken Toya-maru belongs to the former type and Tokachi-maru, Hidaka-maru, Kitami-maru and Seikan-maru No. 11 to the latter. Seikan-maru No. 11 has also passenger accomodations. As mentioned in the previous section, Toya-maru and Tokachi-maru were chosen in the tests as ships representing each type of ferry boat.

7.4.1 Principal dimensions of Toya-maru and Tokachi-maru

Principal dimensions of Toya-maru and Tokachi-maru are as follows.

	Toya-maru	Tokachi-maru
Builder	Mitsubishi Kobe Shipyards	Mitsubishi Yokohama Shipyards
Plying limit	Coasting	Coasting
Length, overall (m)	118.70	118.008
Lngth, between perpendiculars, (m)	113.20	113.20
Breadth, moulded, (m)	15.85	15.85
Depth, moulded, (m)	6.80	6.80
Draught, full load, (m)	4.90	5.033
light load, (m)	3.778	3.233
Block coefficient	0.547	0.591
Displacement, full load, (t)	5,285	5,458
Gross tonnage	4,337	2,911
Dead weight, (t)	1,563	2,415
No. of crew	163	96
No. of passengers, 1st class	69 (91)	—
2nd class	297	—
3rd class	843	—
Date of launching	Mar. 26, '47	Mar. 22, '47
Date of completion	Nov. 2, '47	Mar. 15, '48

General arrangements of Toya-maru and Tokachi-maru are shown in Fig. 7.6 and 7.7 respectively.

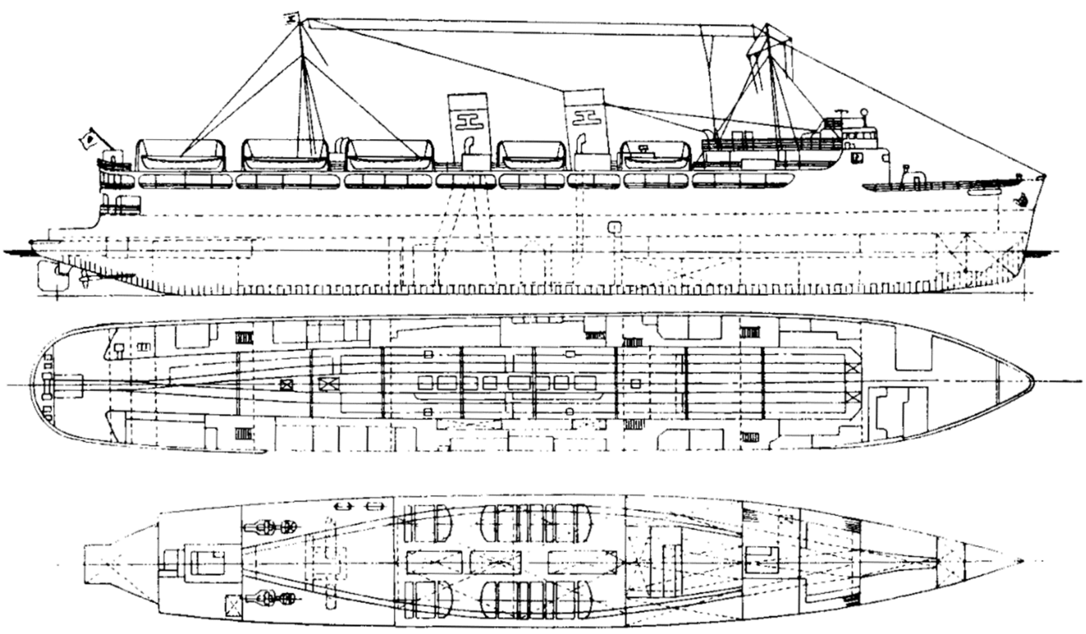

FIG. 7.6 GENERAL ARRANGEMENT OF TOYA MARU

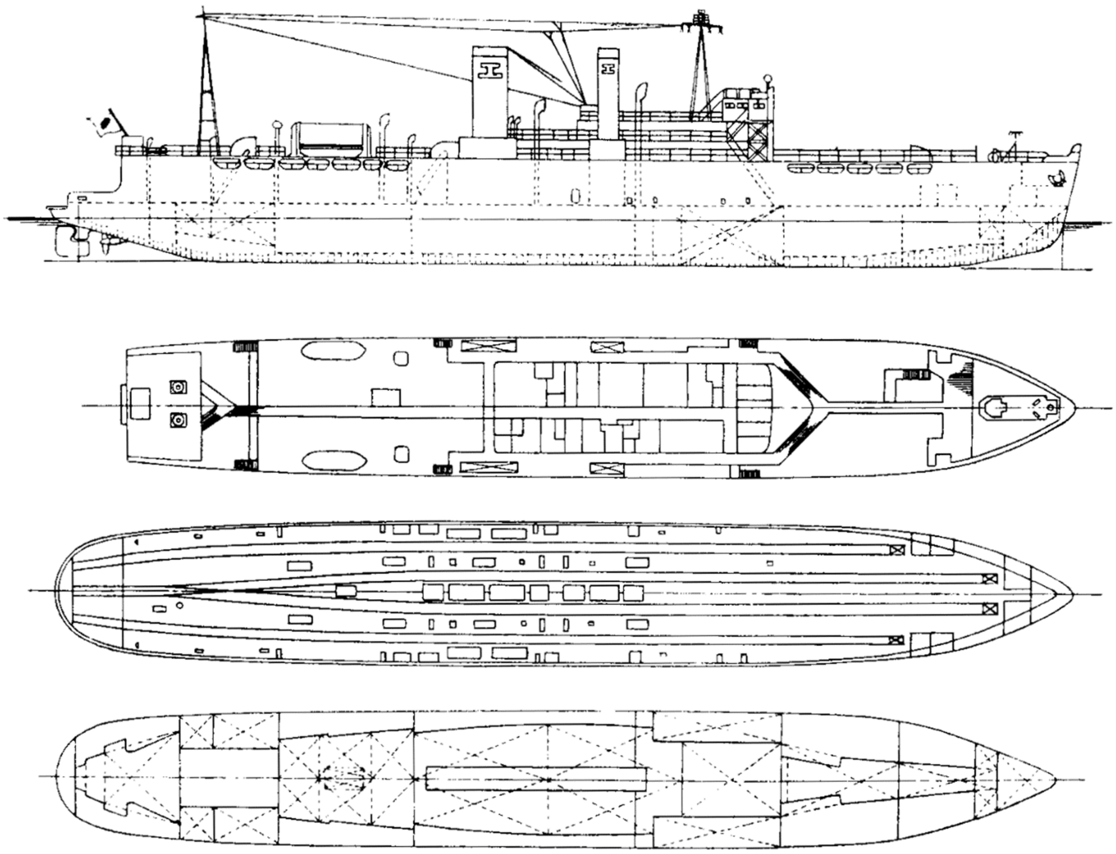

FIG. 7.7 GENERAL ARRANGEMENT OF TOKACHI MARU

7.4.2 Conditions of Toya-maru and Tokachi-maru on the day of disaster

Based on the decision of the Marine Disasters Inquiry Agency, the following conditions are assumed for Toya-maru departuring Hakodate on the day of disaster and for Tokachi-maru arriving out side of Hakodate on the same day.

	Toya-maru	Tokachi-maru
Displacement, tons.	5,173.5	4,974.0
〃 (without appendages) tons.	5,120	4,930
Draught, fore, (m)	4.556	4.366
aft, (m)	5.053	4.994
mean, (m)	4.805	4.680
KM (m)	7.337	7.365
KG (m)	6.139	5.239
GM (m)	1.198	2.128
Complete rolling period, (sec.)	12.5	7.6

7.4.3 Ship models

Models were made of woods with a length between perpendiculars

2.00 metres which is 1/56.6 of the length of ships. Compartments were provided under the waggon deck, so that a desired amount of water could be poured in the engine and the boiler rooms. Upper structures on the waggon decks were made precisely with brass sheet and openings were provided at the places of non-watertight windows, doors and openings, so that water could come aboard through them. Pictures of models are shown in Figs. 7.8 and 7.9.

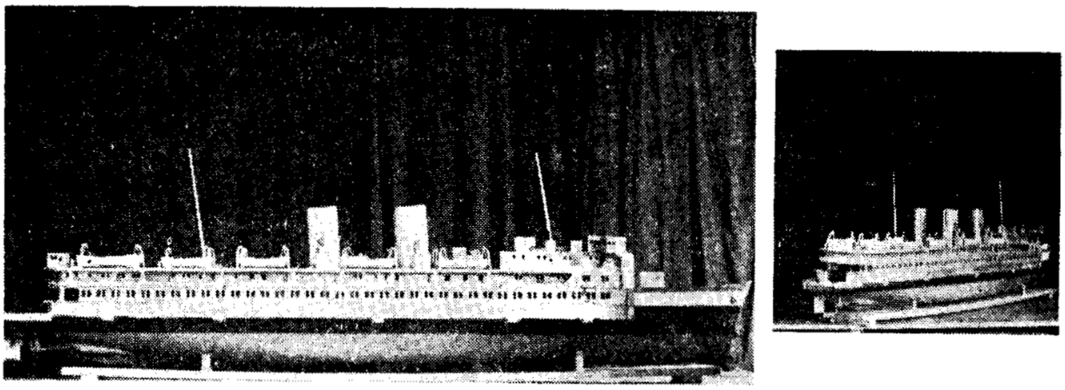

FIG. 7.8 THE MODEL OF TOYA MARU

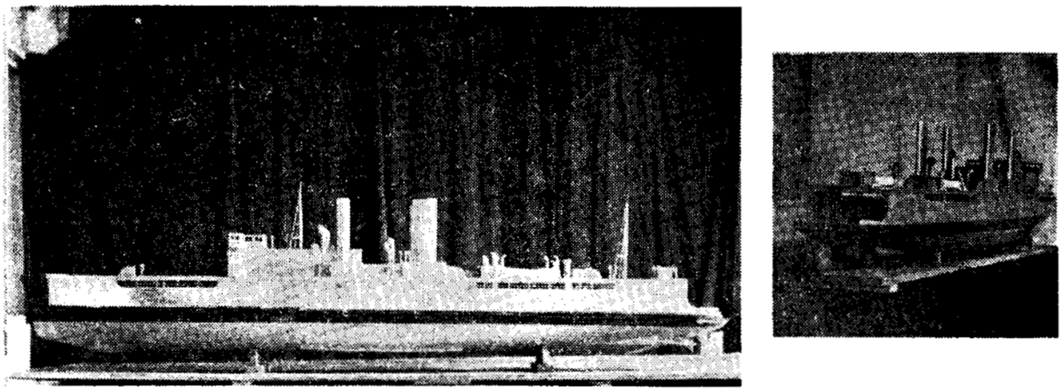

FIG. 7.9 THE MODEL OF TOKACHI MARU

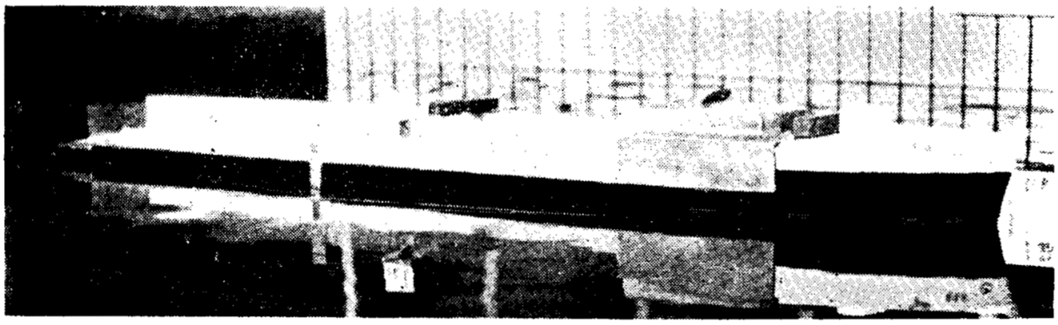

FIG. 7.10 THE PLASTIC MODEL OF TOYA MARU

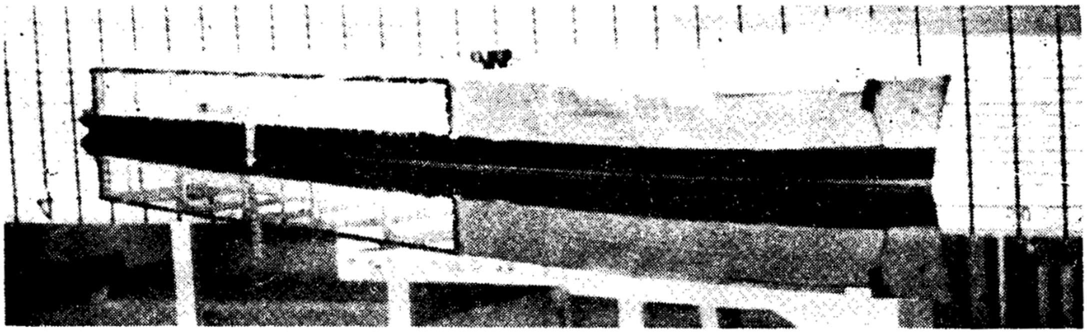

FIG. 7.11 THE PLASTIC MODEL OF TOKACHI MARU

To examine water poured in under head seas, the side wall of the waggon deck house was made of transparent plastic sheet. (Figs. 7.10 and 7.11).

7.5 Amount of Water Came Aboard through the Stern Opening of the Waggon Deck, under Head Seas.

All the ships wrecked were anchoring outside of Hakodate Port, when the disasters happened. While the ships were there, water came aboard through the stern opening of the waggon decks and were stagnant on the decks. Some portion of the water thus detained came in the engine and the boiler rooms through the skylights of these rooms and the hatchways of the coal bunkers, resulting in the stop of the engine. Therefore, the test was made to study the mechanism of flowing of water and how much water was detained on the decks, when the ship was under head seas.

As a result, it was found that water was taken up by the stern apron in event, when the stern was lowered in pitching of the ship, and a crest of wave happened to be at the place of the stern. (Figs. 7.12 and 7.13). Next moment when the ship lowered her bow, this water flowed foreward in the ship. (Figs. 7.14 and 7.15)

FIG. 7.12

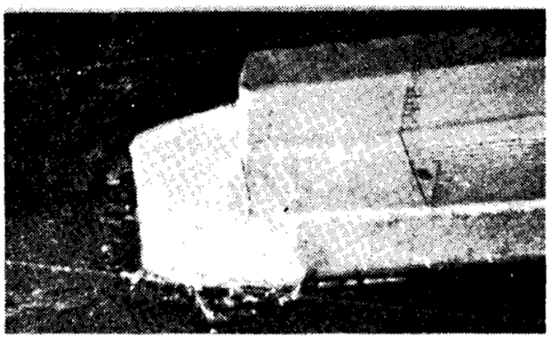

FIG. 7.13

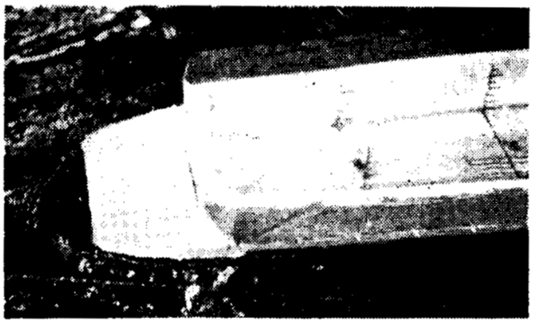

FIG. 7.14

FIG. 7.15

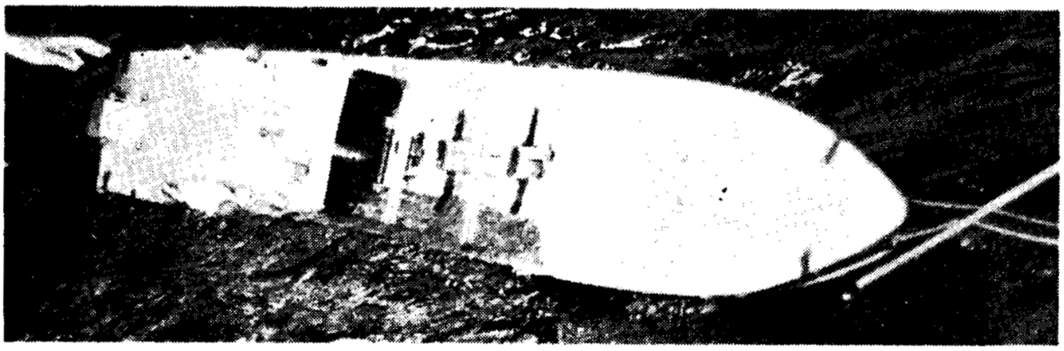

FIG. 7.16 SHOWING STAGNANT WATER ON WAGGONDECK

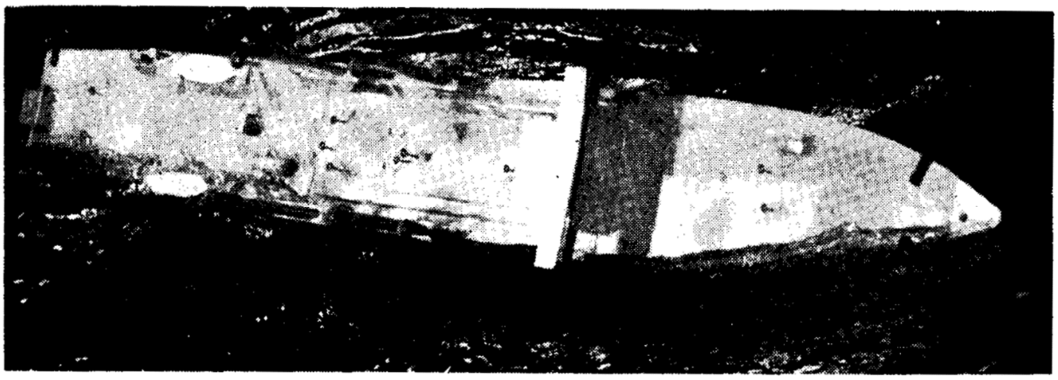

FIG. 7.17 SIMILAR CONDITION AS FIG. 16

What is noteworthy was that the flowing of water did not happen, unless the wave height became larger than 5 metres. It was also noticed that a train ferry boat (Tokachi-maru type) might overturn with a certain combination of wave length and wave height only due to the free water effect of the stagnant water on the waggon deck, as shown in Figs. 7.16 and 7.17. This is a possible reason why the train ferry boats overturned, while they were anchoring in deep water in every case. It also overturns the saying hereunto generally believed among sailors; for the best safety in a heavy storm the ship should stay in a head wind and waves. In fact, it was found by our test that the above position is the most dangerous one for this type of ship with an opening at her stern.

The flooded conditions are indicated by the following figures, for instance;

0-5 shows the flooded water of 0 tons in the eng. and boil. rooms and 500 tons on the waggon deck.

5-10 shows the flooded water of 500 tons in the eng. and boil. rooms and 1000 tons on the waggon deck.

7.5.1 Case of Toya-maru in anchoring (Using both side anchors and 5 shots of chains on each side. Corresponding water depth at anchorage being 20 metres)

When the wave height was 6 metres, no water came aboard in waves with the period less than 7 seconds. But the amount of water came aboard and detained gradually increased with the longer period, until it

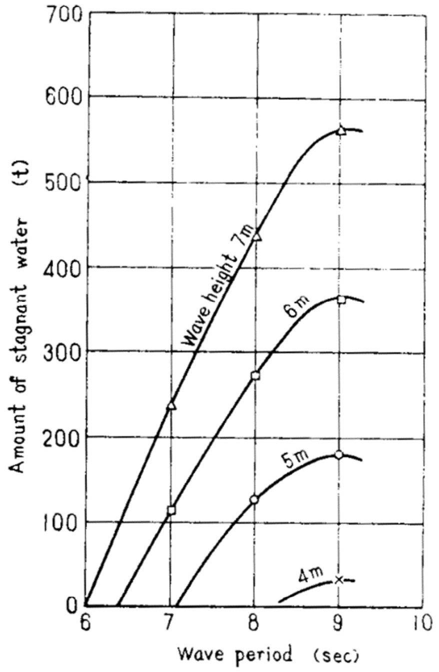

FIG. 7.18 RELATION BETWEEN THE WAVE PERIOD AND THE AMOUNT OF STAGNANT WATER ON THE WAGON DECK

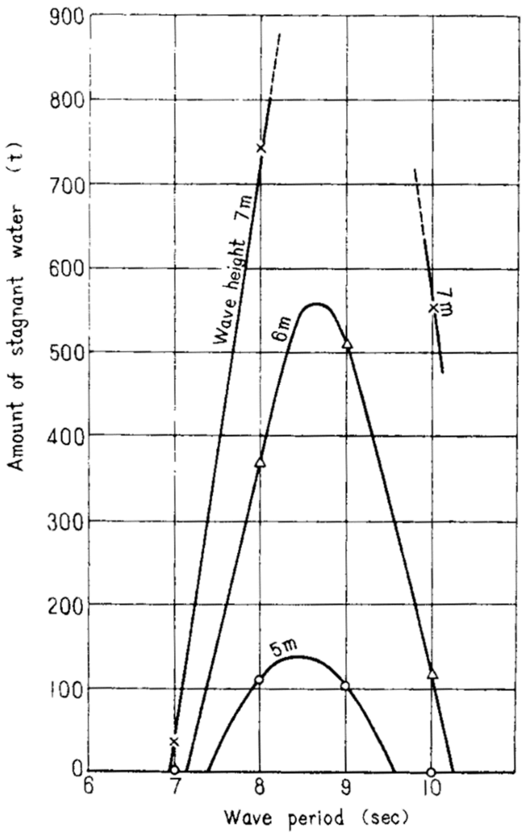

FIG. 7.20 RELATION BETWEEN THE WAVE PERIOD AND THE AMOUNT OF STAGNANT WATER ON THE WAGGON DECK

became maximum at the period of 9 seconds when the wave length was almost equal to the ship length and the pitching of ship became larger. With further increase in the period, the amount of stagnant water rather reduced, as shown in Fig. 7.18.

If a period of wave was set at 9 seconds, water did not come aboard in the waves of which height was less than 4 metres. When the wave height became greater than 4 metres, water suddenly started to flow in and the amount of water thus flowed and detained increased in proprotion to the wave height. When the period of wave was 9 seconds and the height of wave was 6 metres or 8 metres, waves coming against the ship brought the maximum volume of water. With an increase in an encountering angle the volume decreased and no water came aboard at the encountering angle larger than 60°, as noticed in Fig. 7.19.

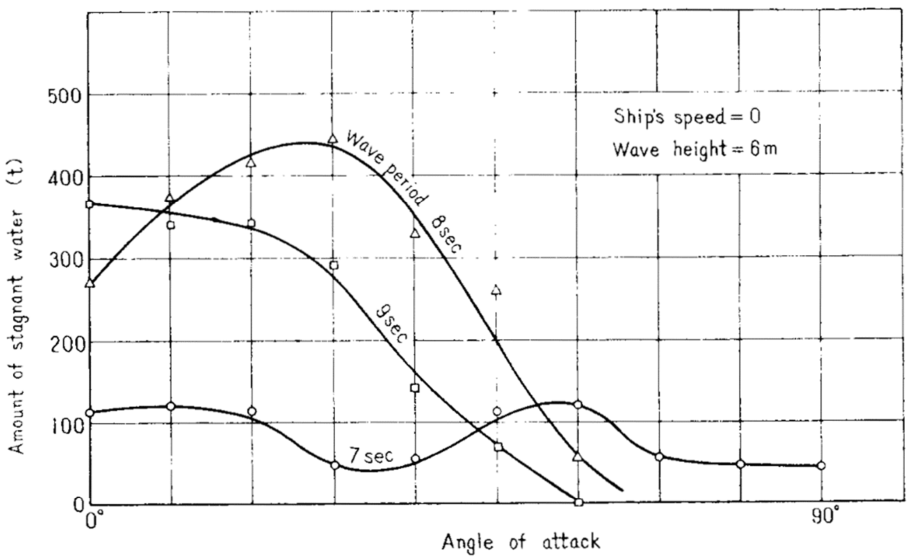

FIG. 7.19 RELATION BETWEEN THE ANGLE OF ATTACK AND THE AMOUNT OF THE STAGNANT WATER ON THE WAGGON DECK

7.5.2 Case of Tokachi-maru in anchoring (Using both side anchors and 5 shots of chains on each side. Corresponding water depth at anchorage being 20 metres.)

When the wave height was 6 metres, no water came aboard in waves of which period was less than about 7 seconds, but the volume of water came aboard gradually increased with further increase in the wave period, reaching the maximum at the wave period of about 9 seconds. It then gradually decreased. When the wave height was greater than 7 metres, it was found that the ship overturned merely due to the stagnant water at the wave period of about 9 seconds, as shown in Figs. 7.20 and 7.21.

With the period of wave set at 9 seconds, the ship overturned in waves of which height was higher than 7 metres, when waves were coming against her. However, the ship still did not overturn in waves higher than 7 metres, when waves were coming aslant, making an angle of 30° or 45° with the axis of the ship, as seen in Fig. 7.22.

It is noticeable that the stagnant water on the waggon deck brought about a large list of the ship due to the free water effect and might capsize her at a certain combination of wave period and height, when the waggon deck extended whole the width of the ship as Tokachi-maru which was exclusively for transporting freight cars.

This might have some close relation with the fact that Tokachi-maru and four other similar type overturned in deep water, while staying in head wind and waves, though they were dragging anchors.

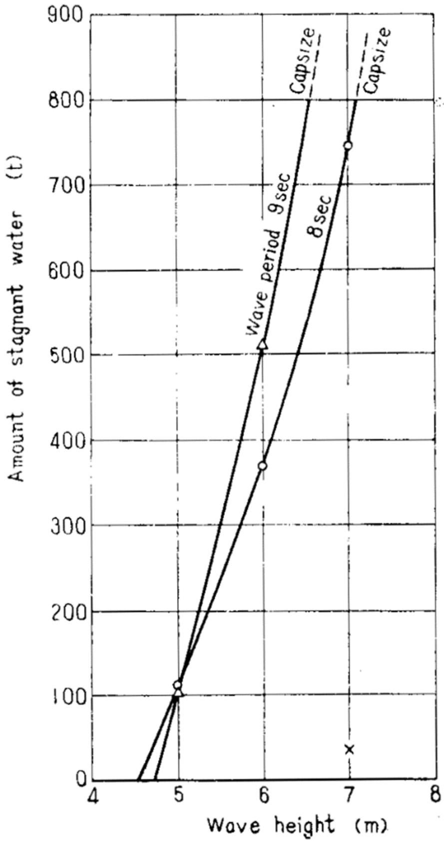

FIG. 7.21 RELATION BETWEEN THE WAVE HEIGHT AND AMOUNT OF THE STAGNANT WATER ON THE WAGON DECK

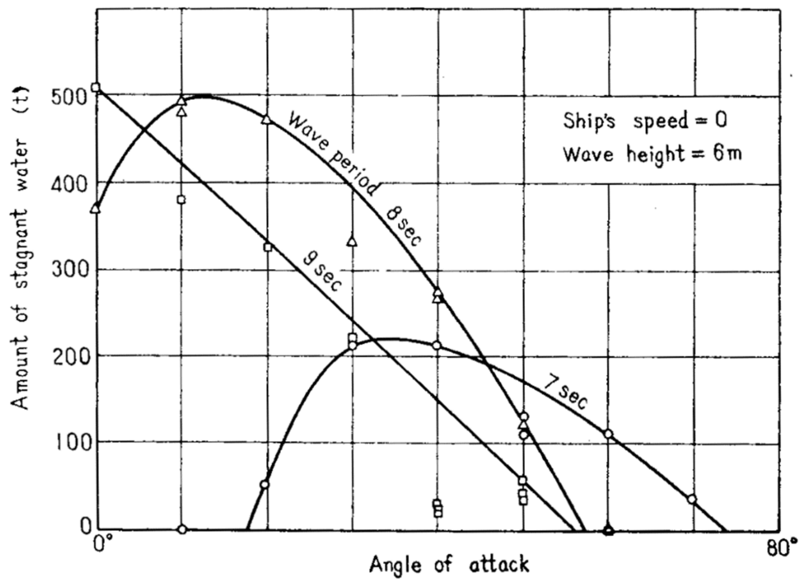

FIG. 7.22 RELATION BETWEEN THE ANGLE OF ATTACK AND THE AMOUNT OF THE STAGNANT WATER ON THE WAGGON DECK

7.6 Critical Wind Velocity for an Assumed Flooding Condition

Stability curves for Toya-maru and Tokachi-maru were constructed, assuming one or both of the volumes of the stagnant water on the waggon deck and of flooding water in the engine and the boiler rooms from the previously mentioned condition on the day of the disaster. From these curves the velocity of wind which might overturn the ship rolling in the assumed waves was found and had been called as the critical wind velocity.

Analysis was carried out with the following procedure.

1) For Toya-maru with the loading condition previously mentioned three kinds of stagnant water corresponding to 500 t, 1,000 t and 1,500 t were assumed on the waggon deck with the permeability of 100%. Three kinds of flooding water corresponding to 200 t, 500 t and 800 t were also assumed in the engine and the boiler rooms with the permeability of 100%. Furthermore the permeability was changed from 100% to 70 and 40% for the above water volumes, and the combined conditions of 121 were thus developed.

Similarly, for Tokachi-maru, two kinds of the stagnant water corresponding to 200 t and 500 t were assumed on the waggon deck and two kinds of flooding water corresponding to 300 t and 800 t were assumed in the engine and the boiler rooms. These were considered for three kinds of the permeability such as 100%, 70% and 40%, and 54 combined conditions were thus studied.

2) The statical stability curves were constructed for the above conditions by the integrator method. In this calculation the buoyancy was considered for the region under the upper promenade deck which corresponds to the superstructure deck in the case of Tokachi-maru, and the space for loading cars was excluded from the consideration. The typical stability curves for Toya-maru and Tokachi-maru are shown in Figs. 7.23

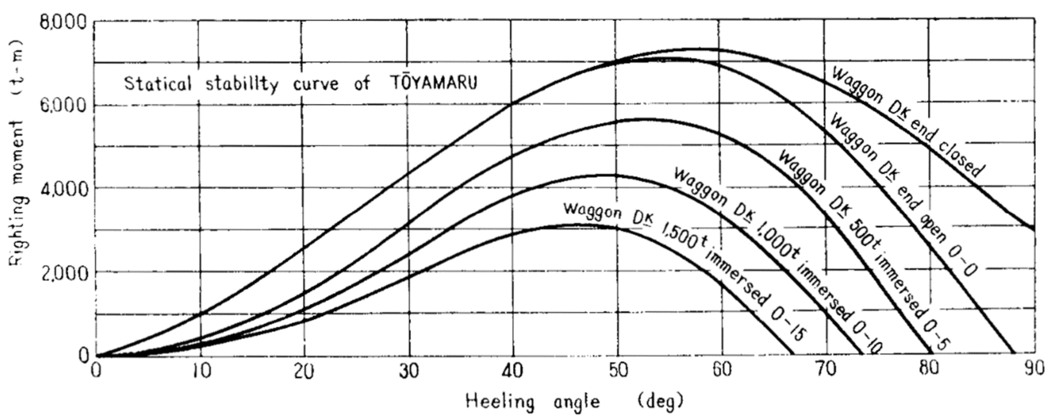

FIG. 7.23 STATICAL STABILITY CURVE OF TOYA MARU

and 7.24, respectively.

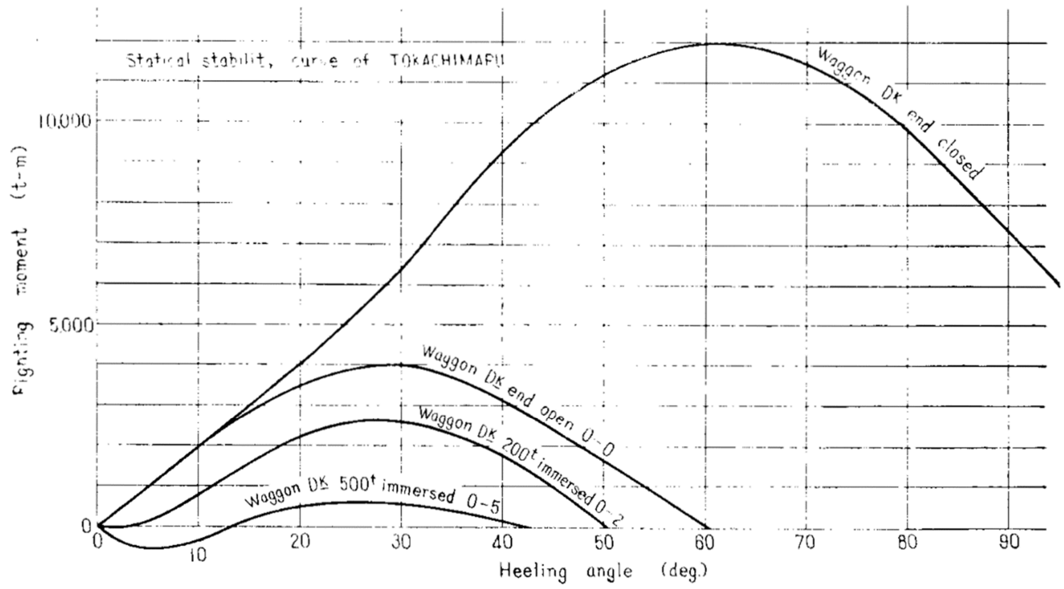

FIG. 7.24 STATICAL STABIRITY CURVE OF TOKACHI MARU

3) Moment due to wind pressure

At first the profile of the ship including the superstructure and the main outfittings were projected on the vertical plane for every 10° of the list, and the projected area, the centre of wind pressure and the centres of under water reaction were determined. As the moment due to wind pressure does not change so much with the list of ship, it was considered, for the convenience of later analysis, that the former had no relation with the latter, and therefore the moment in upright condition was used irrespective of the list of the ship. In the calculation of the moment due to wind pressure the following formula was used;

The moment due to wind pressure $=0.78\times10^{-4}\cdot C^2\cdot A\cdot v^2\cdot l$ (t-m)

where

C = wind velocity coefficient = 0.75 $OG_1^{0.21}$

OG_1 = distance of the centre of wind pressure from water line in upright condition (m)

A = area of wind pressure in upright condition (m^2)

v = wind velocity (m/sec)

l = distance between the centres of wind pressure and under water reaction (m)

Actual wind blows with fluctuation. Based on the previous studies on the fluctuation of wind, the actual wind velocity was taken as 1.25 times of the one for the assumed steady wind, and therefore the pressure as 1.5625 times. In later study, the two cases were considered; one for the assumed steady wind and the other for the fluctuating wind.

4) Rolling angle in waves

Using the models of two ships, the rolling angle in waves was found experimentally for desired flooding conditions of the ships of which loadings were as previously referred and the permeability was 100%. In this case, the stern opening of the wagon deck was closed and a certain amount of water was confined on the deck, so that the desired condition was obtained.

The rolling angle of Toya-maru under the intact condition, and the flooded conditions are shown in Figs. 7.25 and 7.26 respectively, and the rolling angle of Tokachi-maru under the flooded conditions are shown in Figs. 7.27 and 7.28 respectively.

5) List caused by waves and wind

From the curves of the stability and the moment due to wind pressure in the standard coordinate, the lists of ship caused by the steady wind and the fluctuating wind were found for Toya-maru in waves of which height and period were 6 metres and 6 and 9 seconds, and for Tokachi-maru in waves of which height and period were 6 metres and the period of synchronism.

In considering the fluctuating wind, it was assumed that the wind velocity became 1.25 times of the constant velocity at the moment when the ship started to roll to lee-side back at complete the end of the swinging

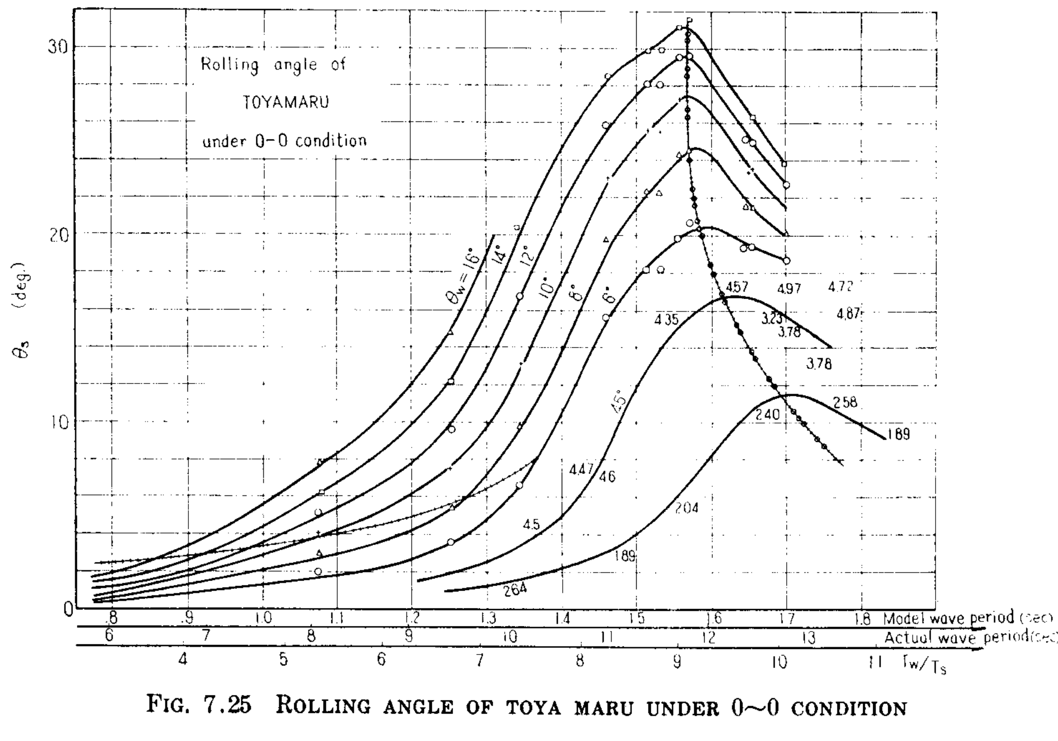

FIG. 7.25 ROLLING ANGLE OF TOYA MARU UNDER 0~0 CONDITION

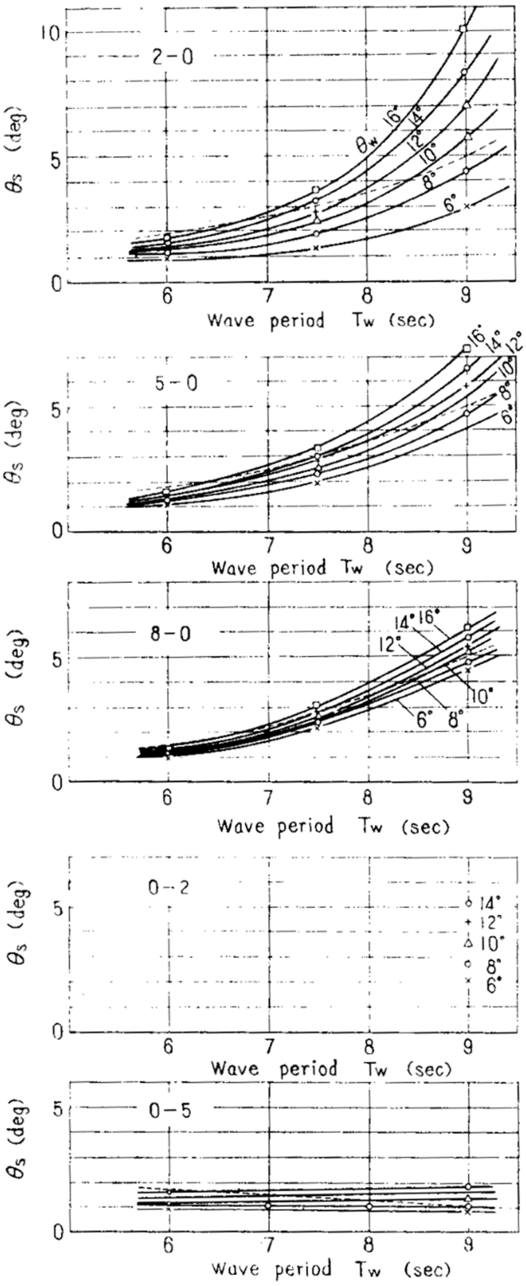

Fig. 7.26 Rolling angle of Toya Maru under flooded conditions

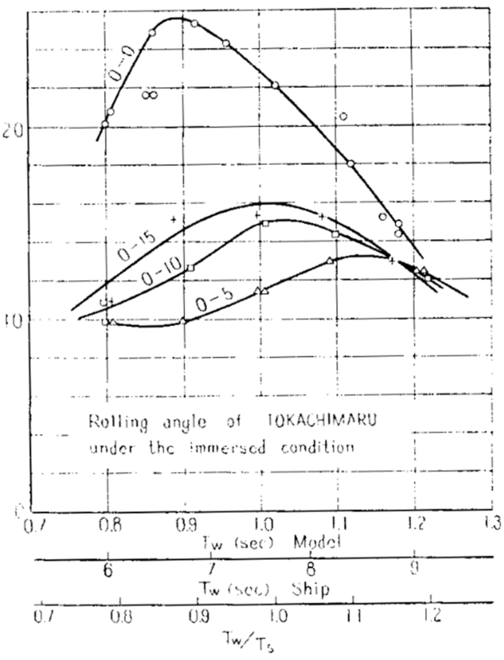

Fig. [7.27] Rolling angle of Tokachi Maru under immersed condition (Eng. and boil. rooms intact)

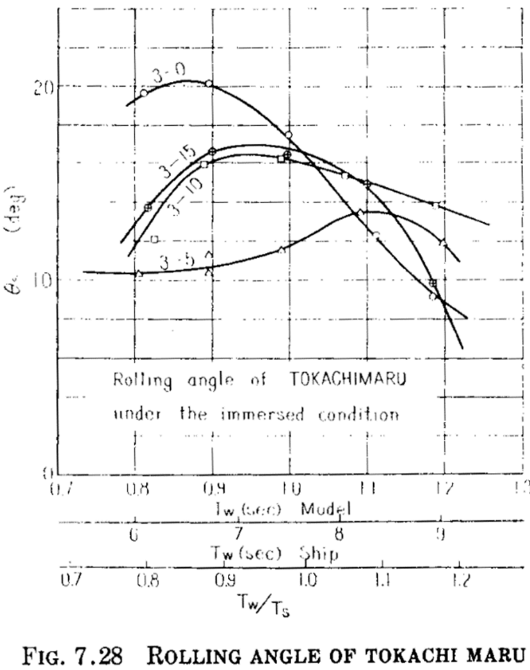

Fig. 7.28 Rolling angle of Tokachi Maru under the immersed condition

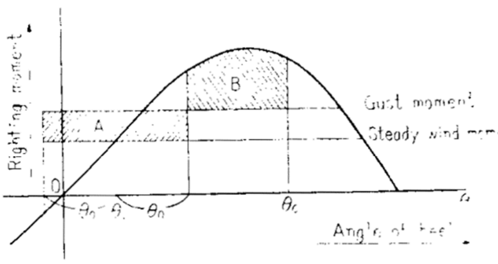

FIG. 7.29 HEELING ANGLE θ_1 DUE TO STEADY WIND MOMENT AND θ_c DUE TO ADDITIONAL GUST MOMENT

to weather side. Since the work done by the wind moment (area A in Fig. 7.29) is cancelled by the work done by the righting moment of the ship (area B in Fig. 7. 29), the ship will list to the critical angle θ_c.

Where the angle of inclination thus obtained is consistent with the second crossing point of the stability curve and the moment curve of wind pressure, the ship is generally in critical condition, and where the wind velocity is slightly greater than this, she overturns. In Tokachi-maru this angle was taken as the critical angle of inclination. According to the development of the disaster of Toya-maru, however, it is considered that she did not overturn instantaneously, but, failing to returning upright when she heeled to 40°, she gradually increased in the angle of inclination and eventually overturned. The edge of upper promenade deck just immerses approximately at this angle of inclination of 40°, and therefore it may be advisable to presume that sea water flowed into the lower compartment through the opening of downward stairway located in the passage of this deck and her stability gradually decreased, as a result of which she capsized. In this view point, therefore, in case of Toya-maru angle of inclination at which edge of upper promenade deck immersed was taken as one of the critical angles of inclination. The critical wind speed for Toya-maru and Tokachi-maru in flooded condition are shown in Fig. 7.30 a), b), and Fig. 7.31, respectively.

7.7 Model Experiment as to the Relation between Bottom Contact and Capsize in Case of Toya Maru

Since Toya-maru capsized soon after the bottom contact, it is natural to presume that the bottom contact was the direct cause of capsize.

Experiments were carried out in order to investigate the effects of bottom contact and surfs. Experimental tank was provided with a temporary bottom with the same slope as that of Nanae Beach at which she was disastered. Thus reappearance was made as to the condition how the ship drifted due to lateral wind and waves and then the bottom of the hull touched the bottom of the sea. The movement of the ship during that time was taken by 16 mm motion picture in order to make analyses. The condition under which calculation was made was that the

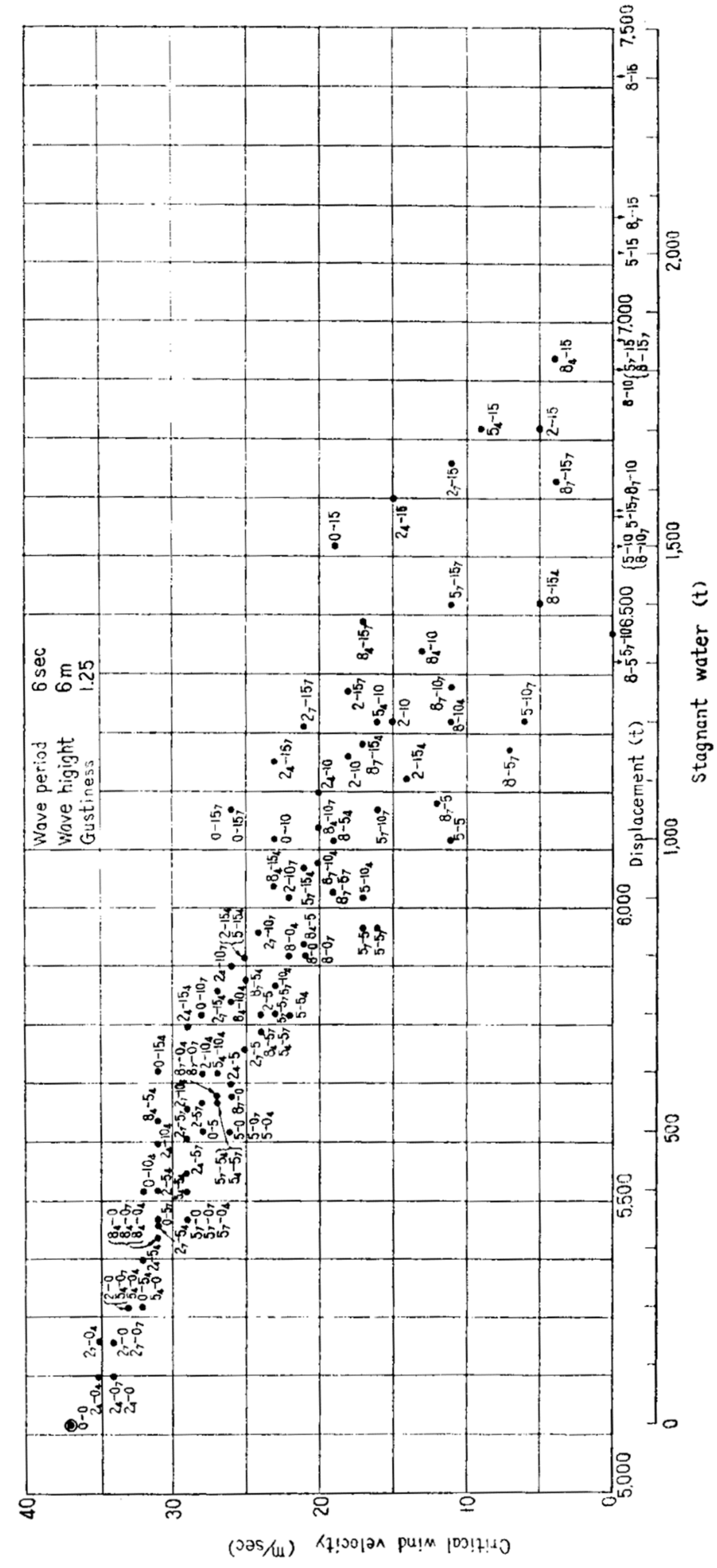

FIG. 7.30 A

CRITICAL WIND SPEED FOR TOYA-MARU

(WAVE PERIOD = 6 SEC.)

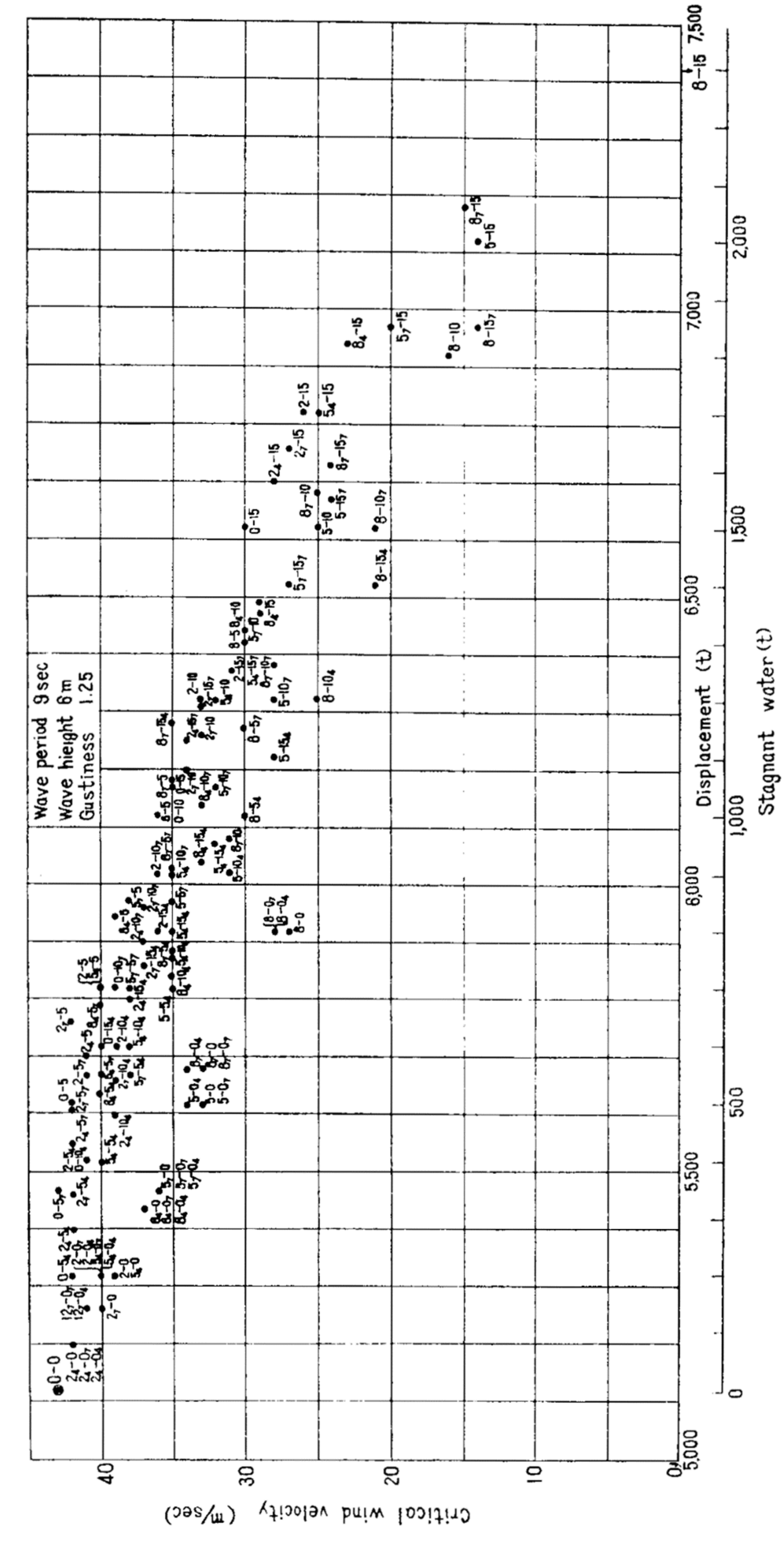

FIG. 7.30 B)
CRITICAL WIND SPEED FOR TOYA-MARU
(WAVE PERIOD=9 SEC.)

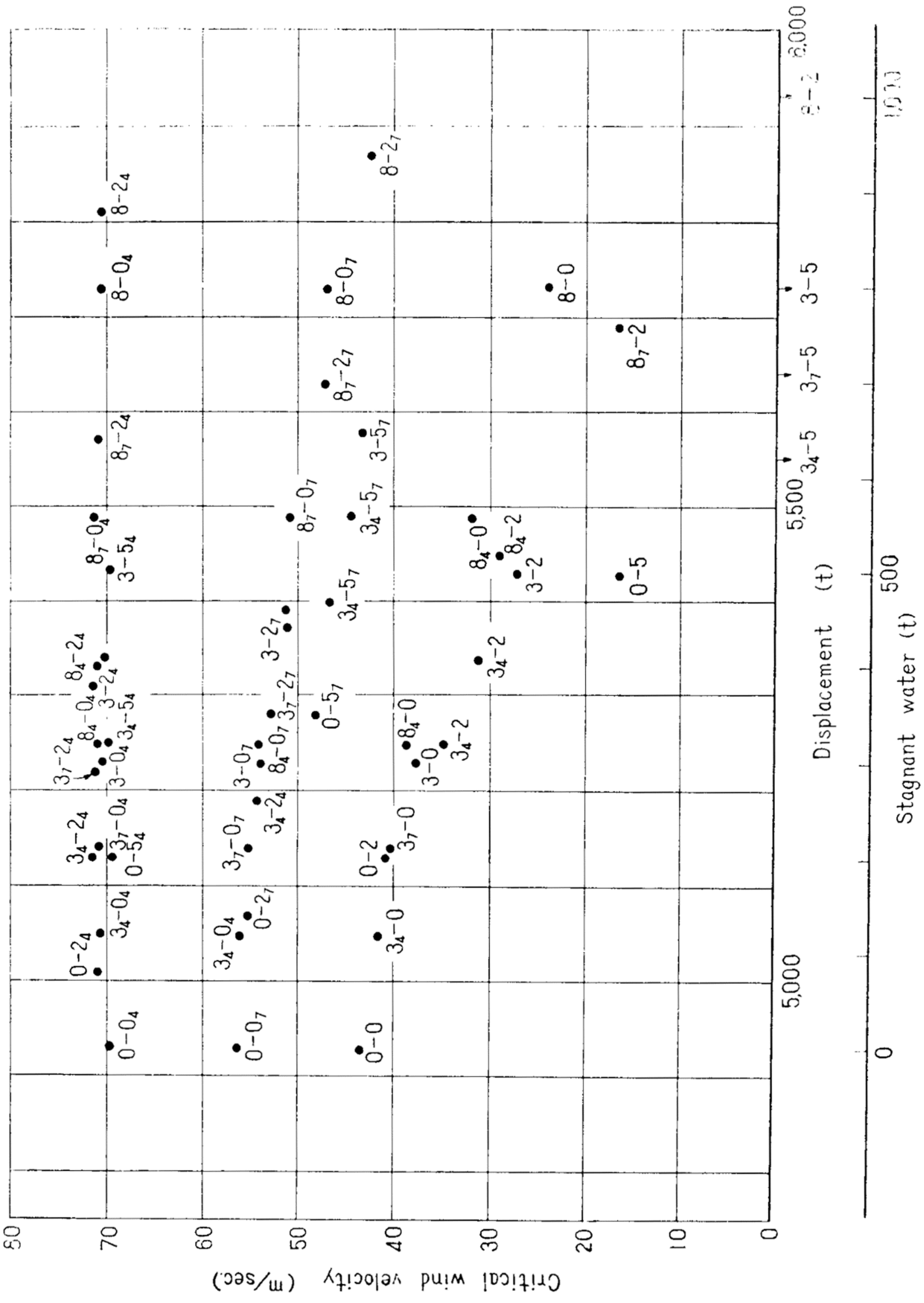

FIG. 7.31 CRITICAL WIND SPEED FOR TOKACHI-MARU

amount of flood in engine and boiler rooms was 500 tons and that of stagnant water on the waggon deck 1000 tons, and the velocity of steady wind was 30 m/sec.

7.7.1 Place of bottom contact

The spot at which the bottom contact began after drifting by the wind from the offing was the place where the depth of water was 8~10 metres when the wave height was 6 metres and period of wave was 9 sec. and 10~12 metres when the wave height was 8 metres and period of wave was 9 sec. This was approximately consistent with the place where the ship sank. As the draught of the ship was 6.75 metres when she heeled to about 15°, the above figure may be an adequate one taking into account the heaving due to wave.

7.7.2 Reaction due to bottom contact

The reaction of the hull due to bottom contact varies as the case may be, and it can not be said that the bottom contact does not always aggravate the danger of capsize. In model experiment also, the results were such that the ship sometimes capsized and sometimes stranded safe. These two different results were due to the slight difference of conditions.

(1) In case where the bottom of the sea was smooth and the hull was not restrained by cables.

In this case it was the general tendency that bottom contact took place where the ship was on the trough of the wave. In this case, however, each particle of sea water in waves moving toward offing and besides the velocity of horizontal movement was great in surfs. Accordingly bottom contact took place when the ship was drifting toward offing, and she rather tended to restore to upright at the time of bottom contact due to the forces which affects the ship to heel to windward.

There would be a danger of increasing the inclination, where the ship was pushed by the crest of the wave under the condition that the bilge keel was struck in the bottom of the sea.

Namely, as illustrated in Fig.7.32 in case where

a) the ship, riding on the crest of the wave, drifted down,

b) touched the bottom of the sea when she was on the trough of the wave, resulting in which reducing the angle of heel, for a time, and then

c) she was sufficiently afloat when she was pushed by the next crest of the wave, so that the bilge keel was freed from the bottom of the sea, she would be carried to shallows as she floated upright. (Fig. 7.33) However, under the certain delicate combination between the draught,

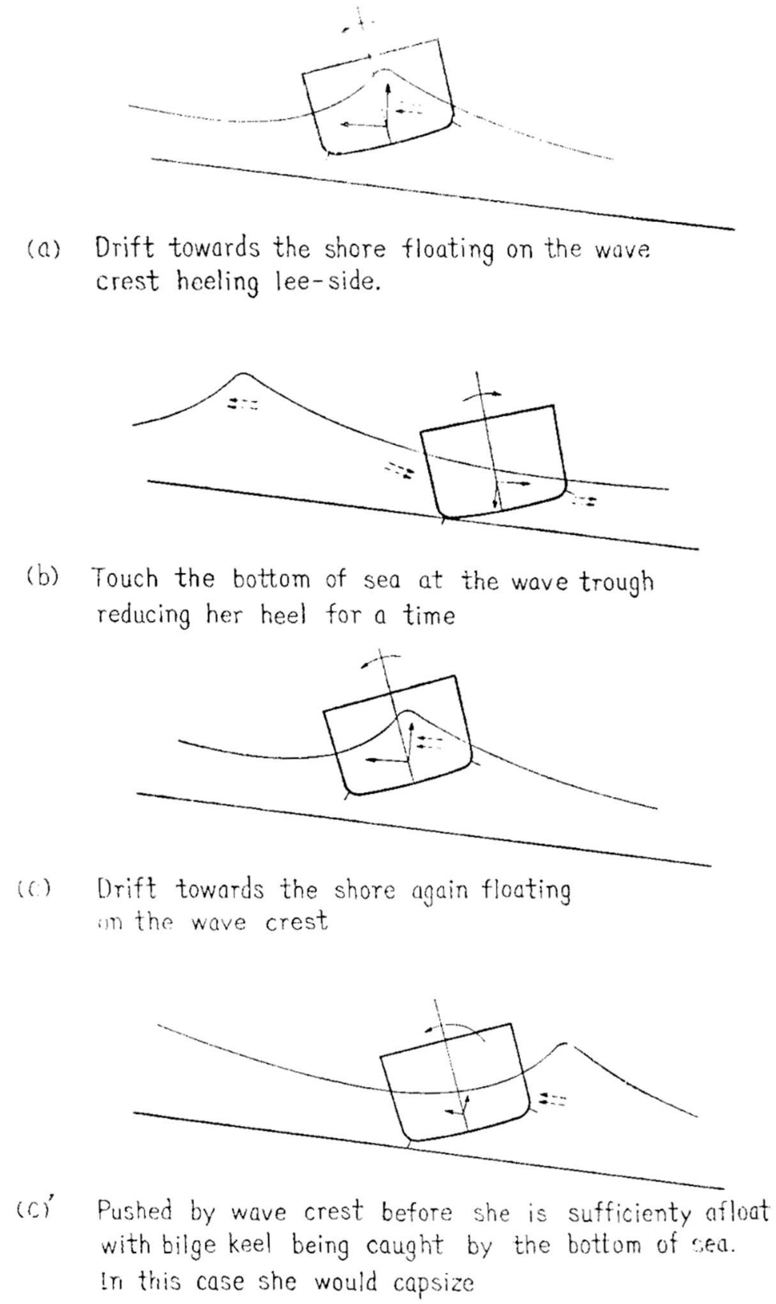

FIG. 7.32 ILLUSTRATIVE DIAGRAMS SHOWING TWO CASES OF BOTTOM CONTACT

the depth of the water and the specific inclination of the ship, in case where

c′) she was pushed by the wave as the bilge keel was caught by the bottom of the sea, she would overturn. (Fig. 7.34)

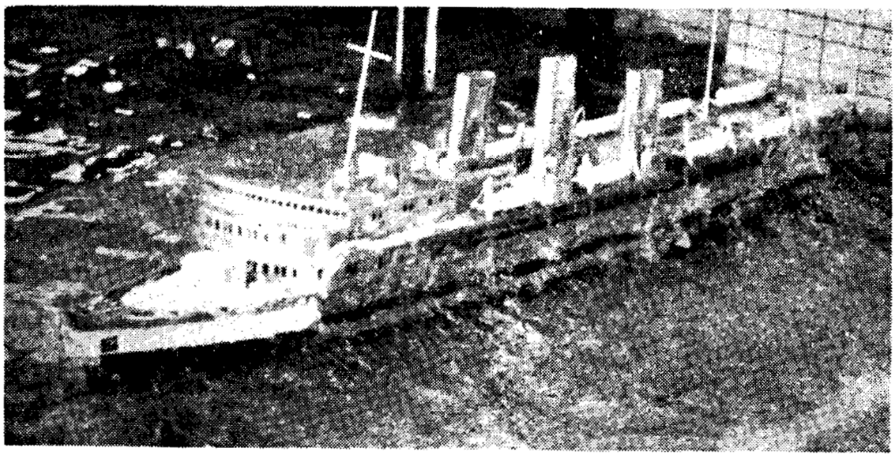

FIG. 7.33 MODEL SHIP CARRIED TO SHALLOWS AS SHE FLOATED UPRIGHT

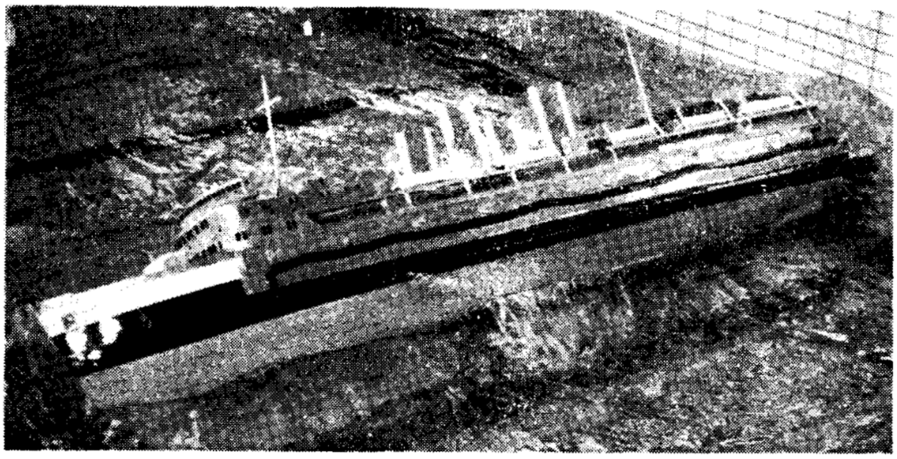

FIG. 7.34 MODEL SHIP CAPSIZED

This combination is very delicate; in fact, experiments showed that out of 10 cases there were about 8 cases that the ship stranded safe and about 2 cases that she overturned.

If the lateral drifting of the hull was not restrained, there is a strong possibility that the ship runs aground the shallows safe in upright condition after her several time of bottom contact.

(2) In case where the bottom of the sea was smooth and the hull was restrained.

Similar tendency to (1) was seen; if, however, the lateral drifting of the hull was restrained by chain cables, etc., the ship was detained at a place with the same depth of the sea, and therefore there could be a great opportunity that the ship would be driven to the dangerous condition mentioned above.

(3) In case where the bottom of the sea was rough.

In this case it was supposed that the bilge keel would stick in the projected part of the bottom of the sea in the course that the ship, riding on the crest of the wave, was drifting toward the shore. At that moment the wind and wave forces form a couple pivoted by the bilge keel, and therefore there was a sufficient probability that the ship would overturn. It could not be thought, however, that the ship touched the bottom of the sea as she moved riding on the wave, if there existed no projection on the bottom. And it would happen very rarely that the ship might touch such projection.

7.8 Conclusion

1) Flooding on the waggon deck at the time of anchoring was caused by the dipping-up of the water due to pitching of the ship. Such flooding is the heaviest when the wave length is approximately equal to the length of the ship, and the deck would not be flooded unless the ship is in full loaded condition and the wave height is more than 5 metres. The fact that there has not arisen any question for many years regarding the flooding from stern opening would be due to the lack of opportunity that the ship has encountered the wave of a length which is comparable with that of the ship.

2) Based upon the comparison between the results of experiment and the circumstances of each ship, it is presumed that the wave at that time was such that the length was approximately equal to the length of the ship, that is, 100 metres or thereabout, and the height was about 6 metres.

3) In case of freighters (Tokachi-maru type), there is a certain danger that, when the wave height is more than 6 metres, the ship overturns merely due to the flooding of sea water into waggon deck through the stern opening. It is considered that this is the reason why all of 4 freighters capsized and sank as they dropped anchors in the offing and stood facing with wind and wave.

On the contrary, in the case of passenger ferrys (Toya-maru type), the breadth of stern opening is so narrow that they do not result in capsize merely due to the flooding of the wave. The reason why Toya-maru did not overturn until she had drifted to the shore and then contacted the bottom would be this as well as the fact that the accommodation space was located at the both sides of waggon deck, which contributed to the stability of the ship. Amount of flooding of waves onto the waggon deck as the ship is running ahead with low speed does not change extensively, but sometimes increases.

4) It is generally thought that, when the ship encounters with wind storm, it is the safest way that the ship stands facing with the wave and wind. However, this would aggravate the danger in case of ships having such stern openings. In this respect one should alter his previous recognition.

5) According to the statements of survivors of Tokachi-maru, GM was presumed to have been negative before capsizing due to the flooding in engine and boiler rooms and stagnation of water on the waggon deck. From this reason it is considered that her stability was reduced to a great extent and she would be brought to perilous condition if she received lateral wave and wind.

6) In case of Toya-maru there is little probability that wind and wave then would cause her capsize merely due to the flooding, just before her bottom contact, of the assumed amount of about 200 tons in engine and boiler rooms and about 300 tons on the waggon deck. The vital cause is assumed to be the loss of stability affected by the bottom contact.

As mentioned at the beginning, it is not the purpose of this report to trace up the location of responsibility for the disaster from the judicial standpoint. It should be pointed out, however, that there is a very serious problem, as a cause by human carelessness, that the ship departed the port with passengers aboard in spite of the consciousness that the typhoon would hit.

On the other hand, we would be able to consider the following facts as an element of natural calamity.

(a) No typhoon of such a great strength had ever hit Hokkaido before.

(b) If the typhoon centre deviated slightly from Hakodate and passed the eastward, such a disaster would not have been occurred.

(c) Production of sub-low decreased the speed of typhoon, and consequently a misjudgement was induced as to the forecasting of the time for the hit of typhoon, and in addition, south wind blew in Tsugaru strait for a long time, which accelerated the growth of wave and wind.

(d) It had not been known that, contrary to the common sense of crew, it was rather dangerous to make the ship with stern opening face with the wind and wave.

(e) Regarding the effect of bottom contact, although there is rather greater probability that the ship strands safe, the ship was resulted in capsize, which was the case of smaller probability.

Through the above-mentioned analysis into the Toya-maru disaster, one may be aware that a great disaster will take place only as a result of a least probable combination of two basic underlying causes, one of which is attributed to nature and the other to human.

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Abreviations for References

J S N A	Journal of the Society of Narval Architects of Japan (Zosen Kyokai)
Kansai J S N A	Journal of the Kansai Zosen Kyokoi
T I N A	Transactions of the Institution of Naval Architects
Trans. S N A M E	Transactions of the Society of Naval Architects and Marine Engineers

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