Characteristics of Capsizing Phenomena of Fishing Vessels

Akihiko Matsuda, Daisuke Terada, and Hirotada Hashimoto

Abstract The second generation intact stability criteria have been finalized at International Maritime Organization. The criteria are developed for 5 stability failure modes, those are pure loss of stability, broaching-to, dead ship condition, parametric rolling and excessive acceleration. The authors have carried out free running capsizing model experiments in following and quartering seas for more than 18 fishing vessels. The series of experiments demonstrated pure loss of stability, broaching-to and bow-diving are major phenomena resulted in capsizing for fishing vessels while parametric rolling is not.

Keywords Fishing vessels · Broaching-to · Bow-diving · Pure loss of stability · Harmonic roll · Model experiments

1 Introduction

In 2008, a 135GT Japanese purse seiner capsized in anchored condition. It was reported by JTSB in M2010-4. In 2009, a 135GT Japanese purse seiner capsized in quartering heavy seas. It was reported M2011-4. In 2010, a Japanese trawler capsized in head seas. It was reported M2011-8. More than 30 fishermen's lives were lost in these accidents. To prevent capsizing accidents, the authors have been conducting free running capsizing model experiments for fishing vessels.

The second generation intact stability criteria finalized at the International Maritime Organization (IMO) are aimed at securing the safety against 5 stability

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failure modes, those are dead ship condition, pure loss of stability, broaching-to, parametric rolling and excessive acceleration. The Level 1 and Level 2 vulnerability criteria for these 5 stability failure modes can be calculated without any model experiments. Although ship-dependent characteristics of dangerous phenomena can be qualitatively assessed by the vulnerability criteria, detailed characteristics of capsizing phenomena cannot be evaluated without model experiments. In addition, the applicability of the current vulnerability criteria to a specific type or a new type of vessels is an important issue.

So far, we have conducted free running capsizing model experiments for more than 18 fishing vessels. In this study, the experimental results are summarized to highlight major failure modes for fishing vessels. Then, an example of time history of capsizing for each failure mode is presented. Finally, we discuss the cause of sub-harmonic roll observed for a European fishing vessel.

2 Model Experiments

2.1 Instrumentation and Procedures

In the experiments that had been carried out before 2009, the Tele-tele System of Osaka University (developed by Hamamoto et al. [1]) was used (see Fig. 1). For the experiments carried out after 2009, the Model Motion Tracking System of the National Research Institute of Fisheries Engineering (developed by Matsuda et al, [7]) was used (see Fig. 2). In both systems, ship models were controlled by autopilot for course keeping using proportional rudder gain of 1.0 and constant propeller revolution. All model experiments were conducted following the Recommended Procedure of ITTC [3]. Free-running model experiments were conducted at Marine Dynamics Basin of National Research Institute of Fisheries Engineering shown in Fig. 3. In the last 20 years, we have conducted free running model experiments using not only Japanese fishing vessels but also European fishing vessels and commercial vessels.

2.2 Subject Ships

Fishing vessels used for the experiments are shown in Table 1. The total number of vessels is 16. Ship A to Ship J are purse seiners, Ship K to Ship N are trawlers, Ship O is a fishing vessel for set net, ship P to ship R are fishing vessels for pacific saury and Ship S is a North European purse seiner. The general arrangements of 4 vessels are shown in Figs. 4, 5, 6 and 7. We have executed more than 2000 runs in total for capsizing model experiments.

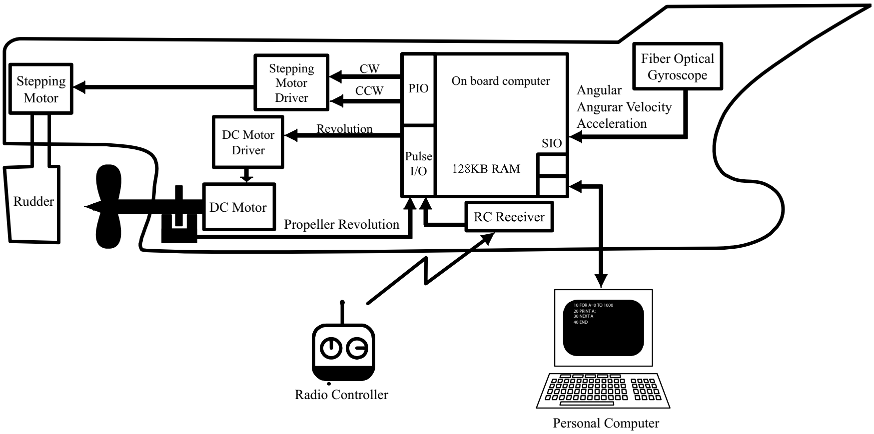

Fig. 1 Tele-tele system

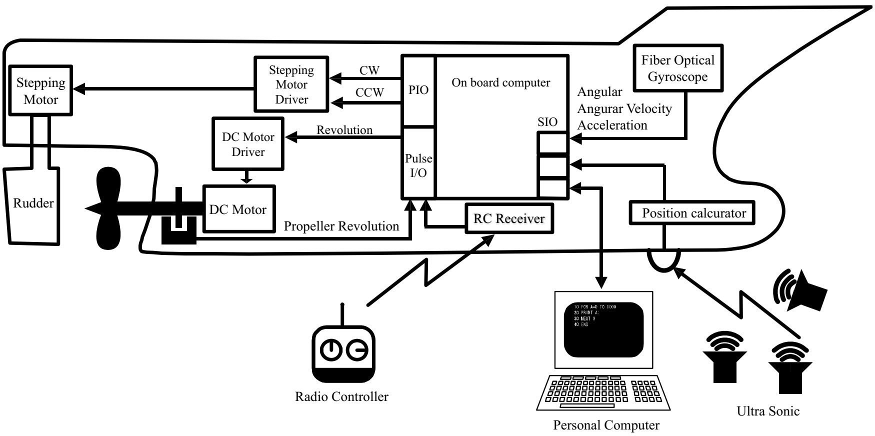

Fig. 2 Model motion tracking system

3 Experimental Results

3.1 Capsizing Modes

Experimental results, including a past result by Umeda et al. [8], are summarized in Table 2. Here the check mark denotes the occurrence of capsizing in the experiment. For Japanese fishing vessels, capsizing due to pure loss of stability, broaching-to and bow-diving were observed. No capsizing due to parametric rolling/harmonic roll occurred. A European fishing vessel (Ship S) capsized due to harmonic roll

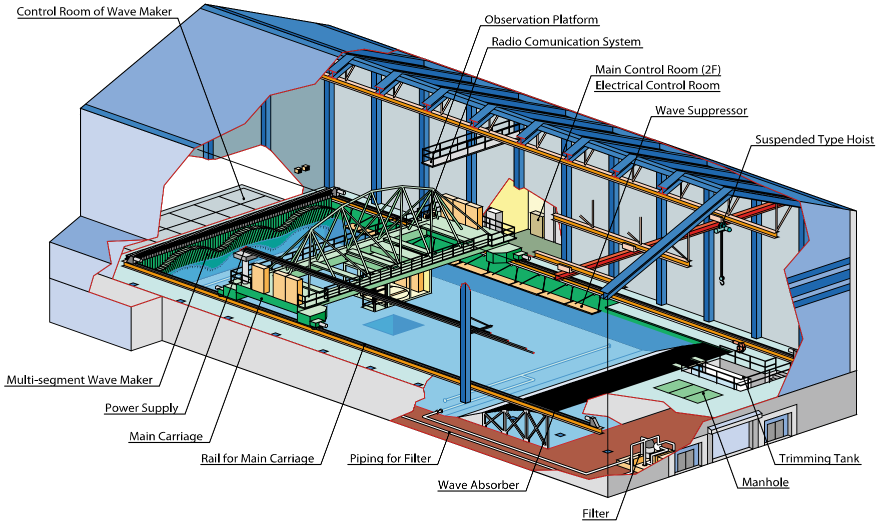

Fig. 3 Marine dynamics basin

Table 1 Subject ships

	Length (Lpp) (m)	Breadth (B) (m)	Depth (D) (m)	Max nominal Froude number (Fn)
Ship A	34.5	7.6	3.07	0.43
Ship B	29.0	6.8	2.6	0.46
Ship C	28.8	7.5	2.6	0.4
Ship D	30.0	7.9	2.78	0.33
Ship E	29.0	6.9	2.58	0.38
Ship F	23.0	5.9	2.15	0.43
Ship G	21.2	6.35	2.41	0.46
Ship H	20.35	5.83	1.76	0.43
Ship I	37.0	7.90	3.23	0.35
Ship J	46.0	10.6	5.57	0.34
Ship K	26.85	5.9	2.6	0.44
Ship L	26.85	6.6	2.85	0.38
Ship M	17.8	3.24	2.24	0.39
Ship N	11.35	5.1	2.1	0.49
Ship O	21.2	4.82	1.26	0.43
Ship P	21.35	5.21	1.22	0.5
Ship Q	19.8	4.80	1.99	0.41
Ship R	22.4	4.58	1.71	0.41
Ship S	55.0	12.0	7.6	0.24

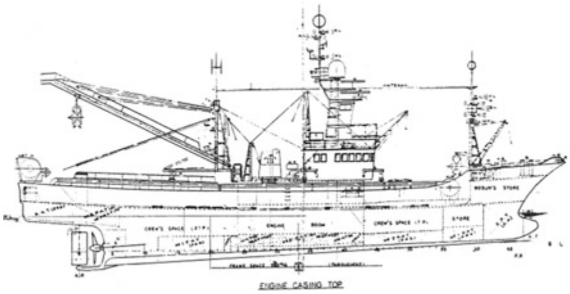

Fig. 4 Ship A (135GT Purse seiner)

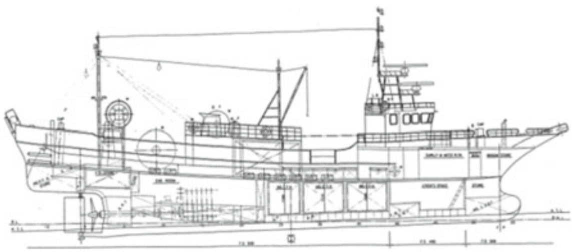

Fig. 5 Ship K (Trawller)

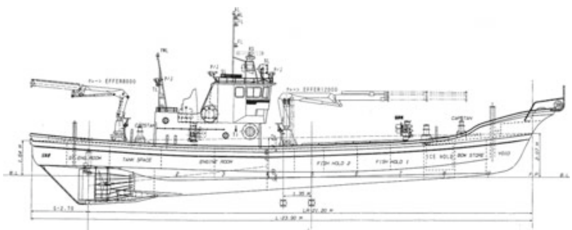

Fig. 6 Ship O (Fishing Vessel for Set net)

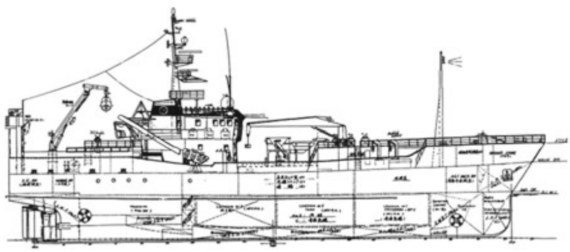

Fig. 7 Ship S (North European Purse Seiner)

Table 2 Experimental results

	Pure loss of Stability	Broaching -to	Bow-diving	Parametric rolling/Sub-harmonic Roll
Ship A	✓	✓		
Ship B	✓	✓	✓	
Ship C	✓		✓	
Ship D	✓			
Ship E	✓		✓	
Ship F	✓	✓		
Ship G		✓		
Ship H				
Ship I	✓			
Ship J				
Ship K	✓		✓	
Ship L				
Ship M	✓	✓		
Ship N		✓		
Ship O	✓	✓	✓	
Ship P		✓	✓	
Ship Q		✓		
Ship R		✓		
Ship S				✓

while capsizing due to pure loss of stability, broaching-to and bow-diving were not observed.

3.2 Pure Loss of Stability

A time series of capsizing due to pure loss of stability is shown in Fig. 8 and sequence snapshots are done in Photo 1. In this case, the ship was running in quartering seas at a speed close to the wave celerity and stayed on a wave crest for a time and capsized after a while. Thus, it can be judged the ship capsized due to pure loss of stability.

3.3 Broaching-to

A time series of broaching-to is shown in Fig. 9 and sequence snapshots are done in Photo 2. In this case, the ship was accelerated by a following wave up to the

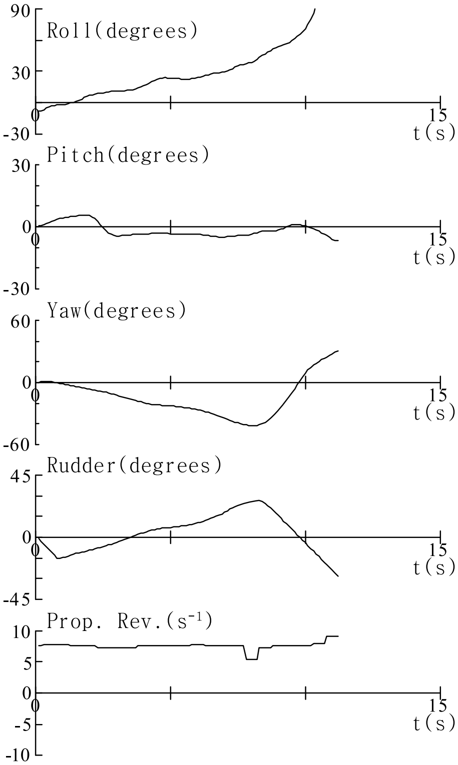

Fig. 8 Pure loss of stability of Ship F (39GT purse seiner) (Fn = 0.43, $\chi = -15°$, $\lambda/L = 1.25$, $h/\lambda = 1/9$)

wave celerity, defined as surf-riding. During the surf-riding on a wave down slope, she could not keep the desired course despite the maximum effort of auto pilot and capsized in a short time due to the centrifugal force.

3.4 Bow-Diving

In case a ship has a sufficiently large propulsion force, stable surf-riding on a wave up slope occurs after a short surf-riding on a wave down slope. If the height of bow is not high enough, she dives into a front wave slope and takes massive water on deck. Finally, she could capsize due to water on deck as well as the reduction of transverse stability on a wave crest. A time series of bow-diving is shown in Fig. 10

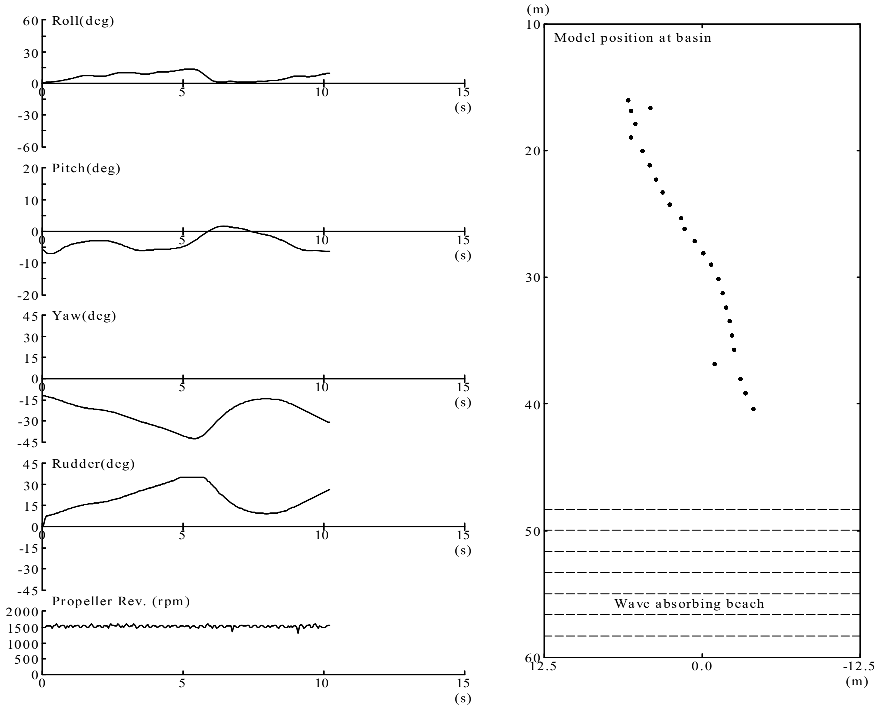

Fig. 9 Broaching-to of Ship G (19GT purse seiner) (Fn = 0.43, $\chi = -5°$, $\lambda/L = 1.5$, $h/\lambda = 1/9$)

and snapshots are shown in Photo 3. For Ship P, she never capsized due to broaching-to but capsized due to bow-diving. From the experience of past experiments, bow-diving is more dangerous phenomena leading to capsizing than broaching-to for Japanese fishing vessels.

3.5 *Sub-harmonic Roll*

Sub-harmonic roll occurs when the roll frequency is about half of the wave encounter frequency. Ship S which is a European fishing vessels suffered severe sub-harmonic roll and capsized as shown in Fig. 11 and Photo 4. Parametric rolling is known as a sub-harmonic roll in which the wave encounter frequency is 2 times large as the natural roll frequency. However, the roll period in Fig. 10 is about 8 s and it is apart from the natural roll period of 3.54 s.

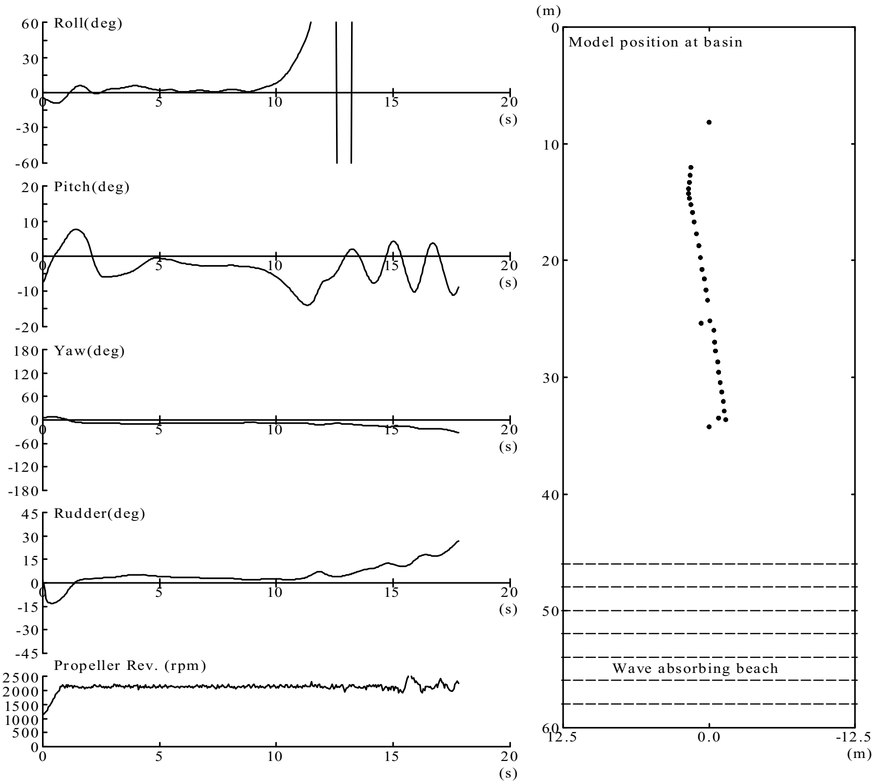

Fig. 10 Bow-diving of Ship P (fishing vessel for pacific saury) (Fn = 0.50, $\chi = -5°$, $\lambda/L = 1.5$, $h/\lambda = 1/9$)

4 Characteristics of Sub-hamonic Roll

It was demonstrated that Japanese fishing vessels could capsize due to pure loss of stability, broaching-to and bow-diving, but capsizing due to parametric rolling/sub-harmonic roll was not observed. For a European fishing vessel (Ship S), it could only capsize due to sub-harmonic roll. Hamamoto et al. [2] suggested that a ship could suffer parametric rolling if it has a hard spring type GZ curve. The GZ curve of Ship S is shown in Fig. 12 and GZ curves of Japanese fishing vessels are shown in Fig. 13. Figure 12 shows that the GZ curve of Ship S is the hard spring type. Figure 13 shows that all GZ curves of Japanese fishing vessels are the soft spring type. The difference of the type of GZ curve would be a reason why sub-harmonic roll occurred only for the European fishing vessel.

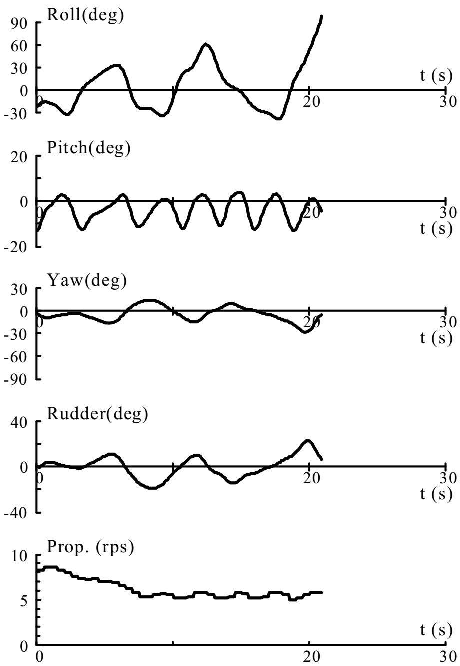

Fig. 11 Sub-harmonic roll of Ship S (European fishing vessel) (Fn = 0.30, $\chi = -5°$, $\lambda/L = 1.5$, $h/\lambda = 1/9$)

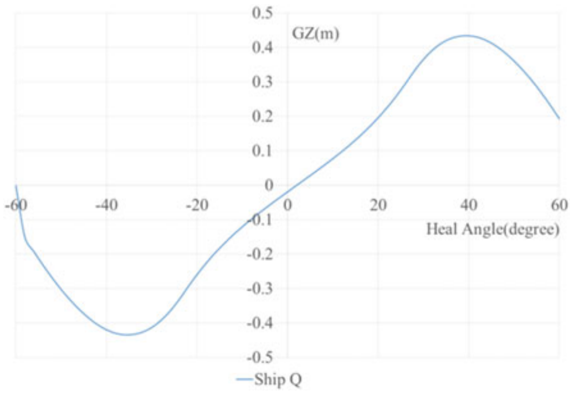

Fig. 12 GZ curve of European fishing vessel

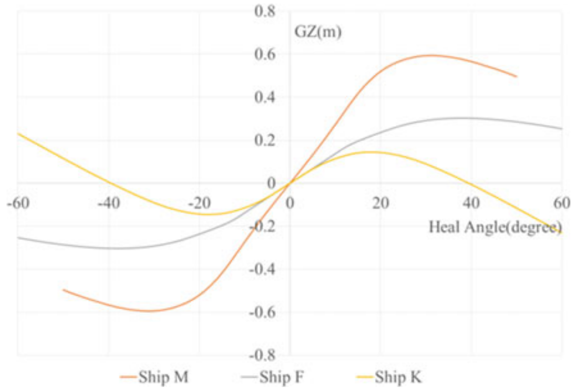

Fig. 13 GZ curves of Japanese fishing vessels

5 Conclusions

In this study, we have described a series of free-running capsizing model experiments to clarify dangerous phenomena leading to capsizing for fishing vessels. The conclusions are summarized as follows.

1. Japanese fishing vessels could capsize due to broaching-to, pure loss of stability and bow-diving in following and stern quartering seas.
2. European fishing vessels could capsize due to sub-harmonic roll in following and stern quartering seas.
3. An example of time history of each dangerous phenomenon resulted in capsizing was presented.
4. European fishing vessels having a hard spring type GZ curve could suffer sub-harmonic roll while Japanese fishing vessels having a soft spring type GZ curve could not.

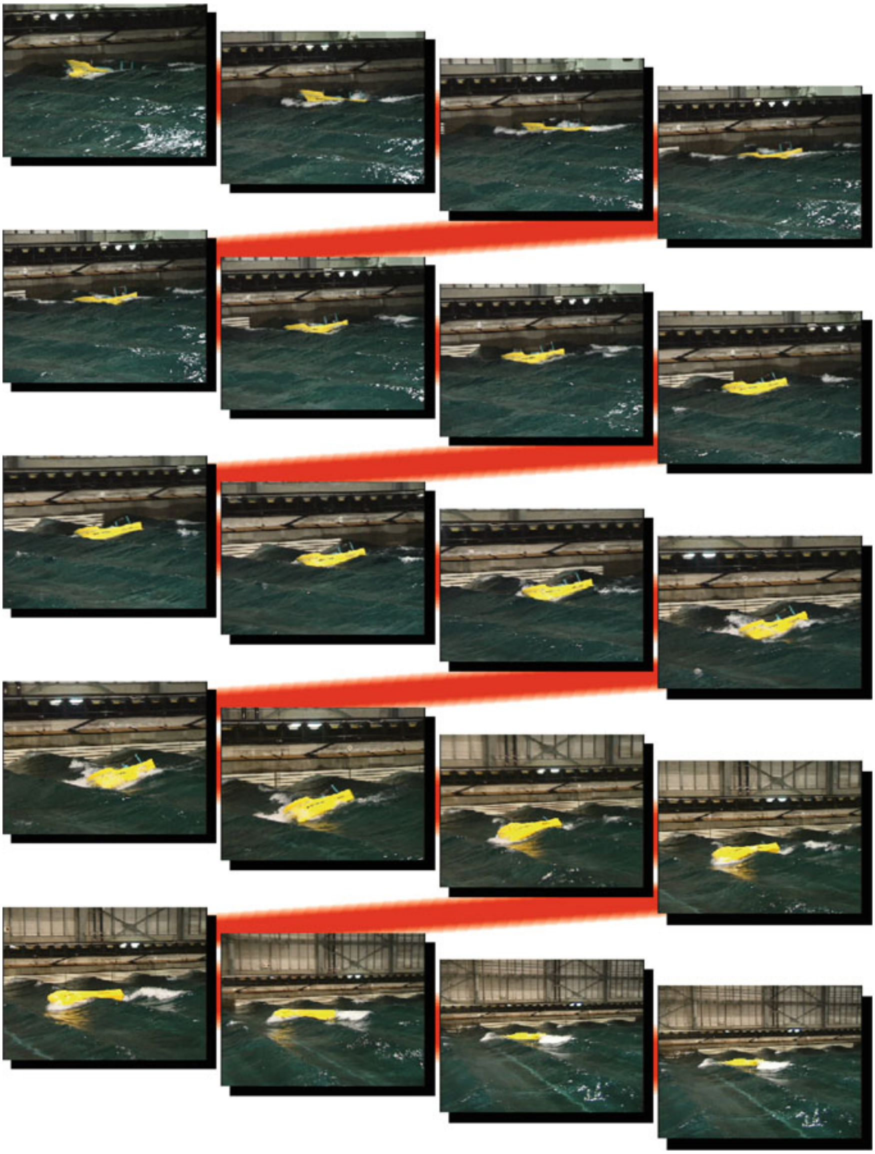

Photo 1 Pure loss of stability

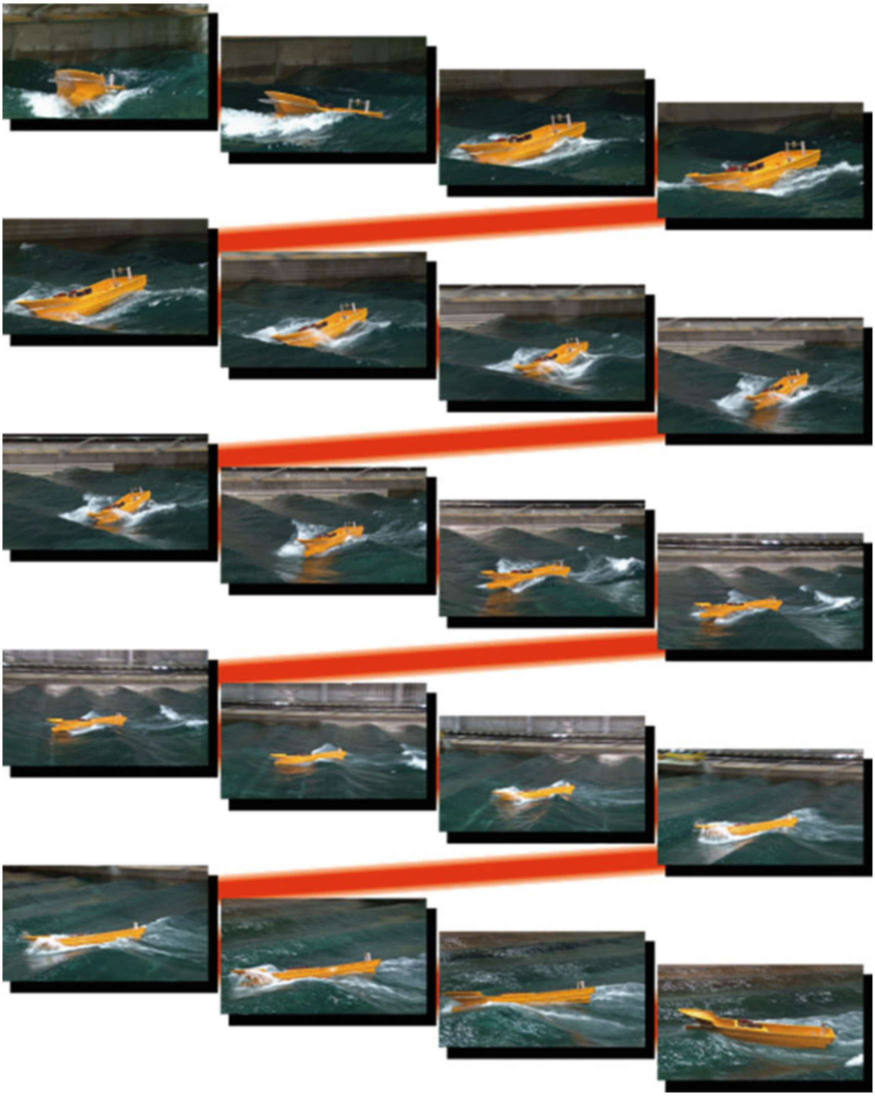

Photo 2 Broaching-to

Photo 3 Bow diving

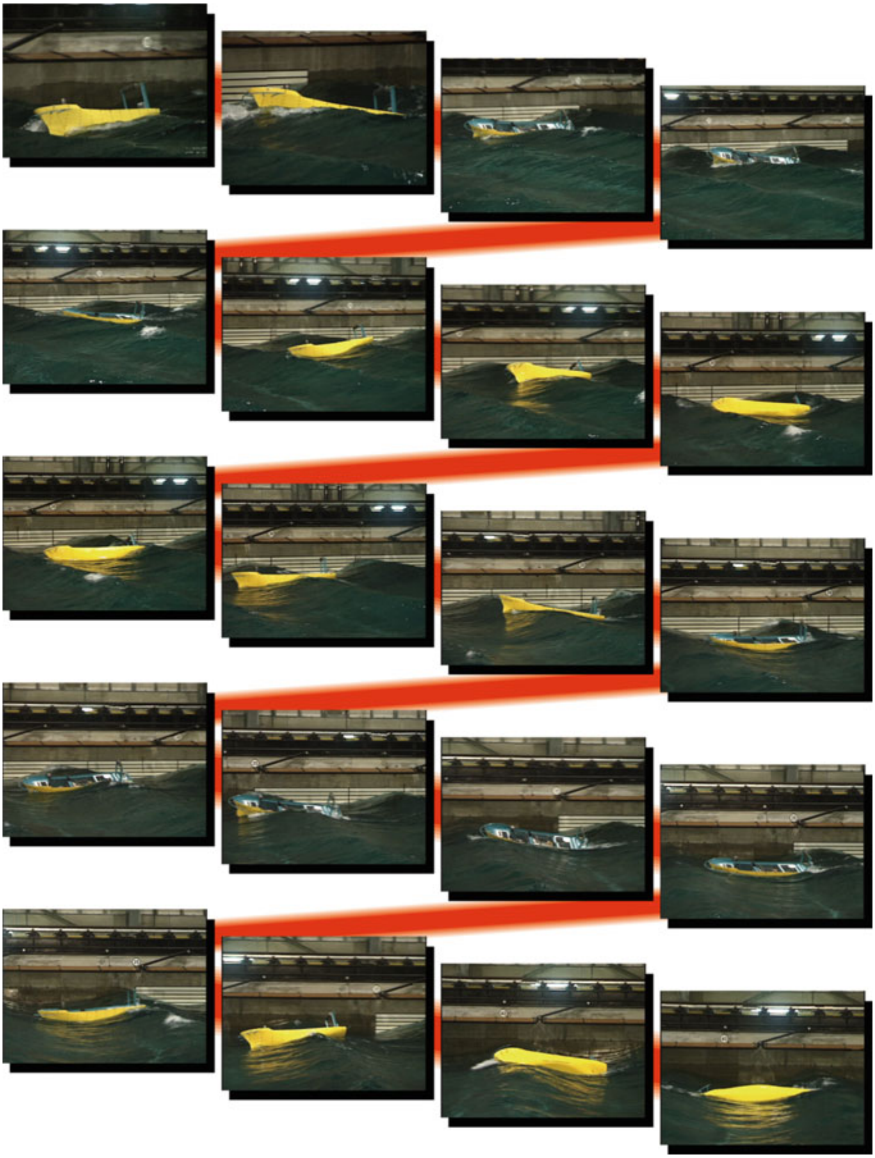

Photo 4 Sub-harmonic roll

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