

The Evaluation of Ship Motions in a Harbor along the Entrance Channel by Field Observation

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Abstract : Maritime transportation consists of various situations such as navigation in the ocean, ship handling at harbor entrances, cargo handling and mooring in harbors. Generally, ships are built for the purpose of carrying people and materials upon the seas. In order to accomplish the mission, a ship must be built to withstand the rigors of heavy weather and waves. In particular, the safety of ship motions at the entering/departing harbor and mooring under the effects of waves is very important for ship operation from the viewpoint of marine engineering. Therefore, safety and efficiency during entrance, departure, and mooring are extremely important aspects in the evaluation of ship operations from viewpoints of ship motions. However, the ship motions near a harbor entrance are not observed or studied as much. In this paper, to evaluate the difficulty of ship operations, field observations were performed using a new observation system with high accuracy in typhoon seasons, and grasp was done concerning about the time series characteristic that ship motions change rapidly within a harbor. Namely, such observations enable the quantitative safety evaluation under the effects of waves during ships entering and departing harbors in heavy weather.

Key words : Ship motions, Maritime transportation, Field observation, New observation system

1. Introduction

Recently, ports have been promoting their facilities as international competition for shipping business increases. For example, large ports aim to provide full logistics functions, 365-day operations, punctual service, reliability, and efficiency. Particularly, higher port working ratio and wharf operation ratio are needed for the port and quay using a container to maintain on-time service.

Classifications of "Good" and "Convenient" are used for harbors that function safely and efficiently in each stage of operation (Kubo et al., 1988). However, even ports that have excellent facilities will reduce their range of operation, if they are forced to close during heavy weather.

Ship operations within a harbor are divided into two categories, as shown in Fig. 1. One category is ship entering and departing issues near harbor entrance considering wave and wind effects. The other category is mooring issues in harbor due to long period waves and tsunami.

Ship operations safety is of the utmost importance in a harbor in the stage of maritime transportation. During maritime transportation, safety is affected by oceanographic conditions, such as waves, wind and current, which are not as influential in the case of air transportation. However, the entrance and departure of ships is limited when ports face open seas subjected to severe wave and wind conditions.

Therefore, safety and efficiency during entrance, departure, and mooring are extremely important aspects in the evaluation of ship operations.

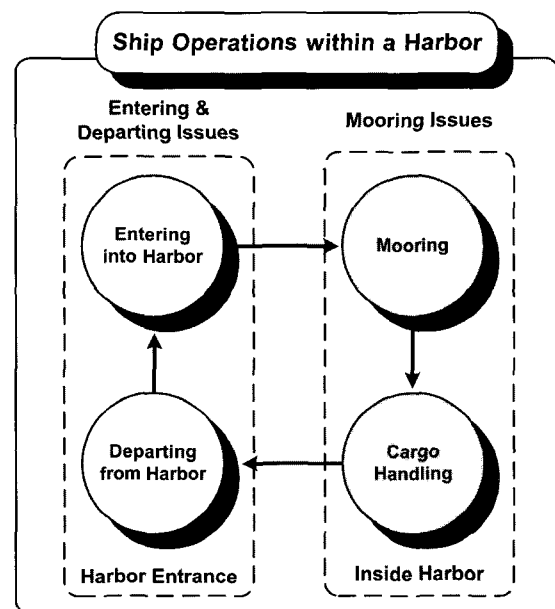


Fig. 1 Pattern of ship operations within a harbor

This paper contains an estimate of ship operations based on field observations of large ships in a harbor facing the Pacific Ocean. Navigation is most threatened as ships enter and depart harbors in waves propagated by typhoons,

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particularly as they approach quays.

In order to evaluate the difficulty of ship operations, field observations were performed, and grasp was done concerning about the time series characteristic that ship motions change rapidly as a ship enters a harbor. Namely, such field observations enable the quantitative evaluation of the effects of waves on the safety of ships entering and departing harbors in heavy weather.

2. Problems of Ship Operations

Fig. 2 shows the relationship of the motions of a ship with each situation encountered in maritime transportation (Sasa et al., 2003a). It illustrates that a ship's most important motions change depending on the situation.

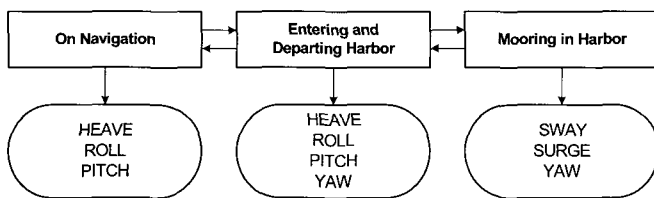


Fig. 2 Ship motions in relation to various situations

2.1 Entering and Departing Harbor

Breakwaters, which are built to protect harbors from waves and create an area of calm water in a basin, should be designed so as to provide safe navigation in and out of harbors, safe mooring, and efficient cargo handling at miscellaneous port facilities (Tsinker, 1997). Breakwaters may, however, become an obstacle to navigation in and out of a harbor. To maintain safety during the entrance to and departure from a harbor, it is necessary to give attention to ship motions, such as heave, roll, pitch, and yaw, as shown in Fig. 2.

2.2 Mooring in a Harbor

Mooring lines frequently break and fenders are often damaged in many harbors, particularly when they face the Pacific Ocean. The main cause of this damage is the large motion of moored vessels due to long-period waves. When ships moor in a harbor, it is necessary to pay attention to ship motions, such as surge, sway, and yaw, to prevent such problems.

Without observation results, it is impossible to accurately evaluate and analyze the safety of ship operations in each situation.

Consequently, in this paper, field observations performed in each situation (during navigation, entering and departing

a harbor, and mooring) using ship motions measurement system is used to analyze data from observations as ships enter, depart, and moor in harbors.

3. Composition of the Measurement System

3.1 Calculation Conditions

The new observation system was developed to evaluate the safety of shipping operations during navigation and entering, departing, and mooring in a harbor.

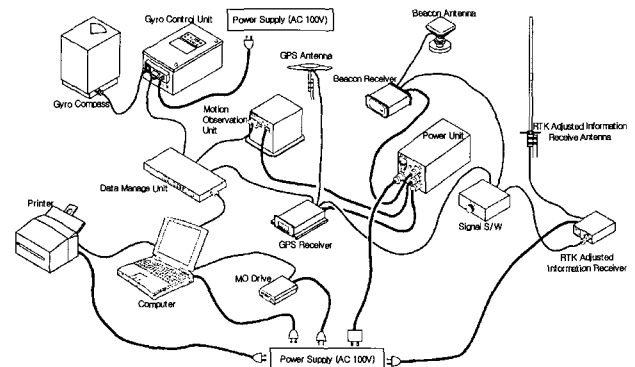


Fig. 3 Measurement equipment of ship motions on board

This observation system consists of three systems of measurement: GPS, optical fiber gyros, and a gyro compass. GPS is used to observe the positions, motions, including sway, surge, and heave, and velocity and acceleration of ships in each direction, shown in Fig. 3. The optical fiber gyro is used to observe the ship motions of pitch, roll, and yaw and the velocity and acceleration of motions of rotations. The gyro compass is used to observe the course of a ship and a ship's yaw. The data observed in each system are transferred to a personal computer through a data management unit. These transferred data are calculated in the computer, and each observation parameter is obtained in each time step. These data are finally recorded to an MO disk drive. Three modes of GPS are available: RTK (Real-Time Kinematic), DGPS, and normal. The RTK mode requires that a base station ashore, shown in Fig. 4, calculate the positions by the difference between the ship station and the base station. The accuracy of the observation is within 1cm in this system, although this mode is only usable within a 2km range of the base station. In contrast to the RTK mode, the DGPS and normal modes do not require a base station. The accuracy is within 1m when the DGPS mode is used for the observation in a coastal zone. When ship motions are observed, an appropriate mode of GPS has to be selected for various

conditions of ships and sea areas (Sasa et al., 2003a).

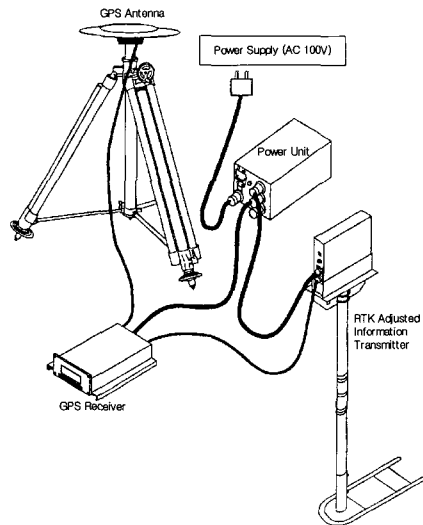


Fig. 4 Measurement equipment of ship motions on shore

4. Field Observation in Typhoon Seasons

4.1 Observation Condition

In this paper, field observations were conducted using the measurement system in typhoon seasons. Two kinds of ships were used for these observations. One was the "Sun Flower Satsuma," which is the car ferry of the Shosen Mitsui Ferry Company that ran between Osaka and Shibushi from 2001 through 2002. The other is the "Ferry Kochi" of the Osaka Kochi Express Company that ran between Osaka and Kochi from 2003 through 2004 (Cho, 2005).

Table 1 Dimensions of target ships

Name	Sun Flower Satsuma	Ferry Kochi
L.O.A (m)	186.0	118.14
Breadth (m)	25.5	21.0
Displacement (t)	14,120	6,375
Draft (m)	6.0	4.5
G.M. (m)	3.25	1.5

Table 1 shows the dimensions of those target ships. Fig. 5 shows the navigation tracks and target ships, and view of the observation system in the ferry.

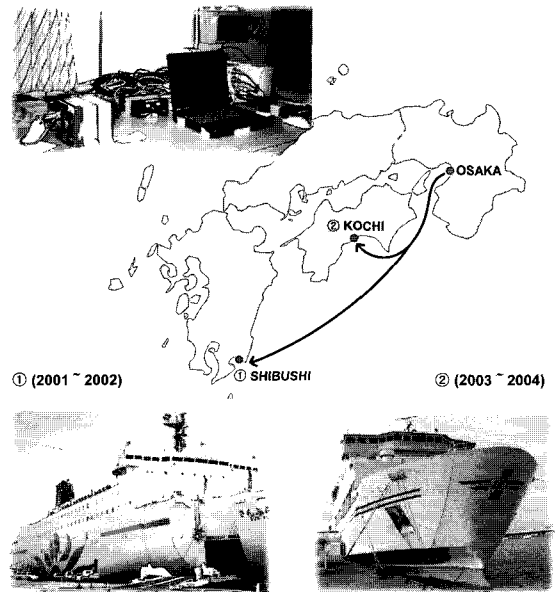


Fig. 5 Tracks of the navigation and target ships

4.2 Taking Advantage of Internet Weather Information

Currently, many Internet websites provide free weather information that includes forecasts, wave size, and warnings of earthquakes and tsunamis. Also when conducting this experiment, it referred to information such as the course of typhoon and real situation of significant wave information.

By using Internet weather information, ship safety may improve as risks from typhoons and atmospheric depressions are reduced.

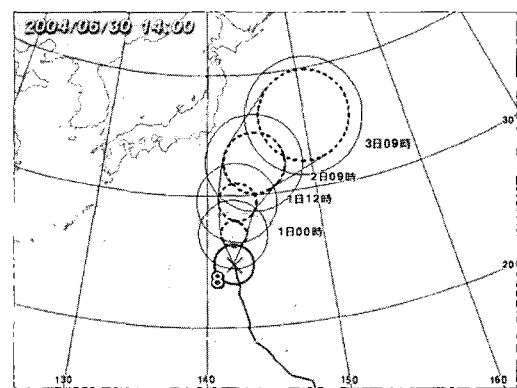


Fig. 6 Typhoon information (<http://www.jma.go.jp>)

5. Observation Result of Ship Motions

5.1 Ship Motions near the Harbor Entrance at Kochi

Breakwaters are built in order to reduce wave effects however, they become a significant obstacle to ships

entering and departing a harbor. Usually a ship enters a harbor at sufficient speed to maintain maneuverability.

A ship's motion may change suddenly and violently at the harbor entrance as a result of waves and swells. Therefore, entrance to a harbor may become more difficult. In other words, ship motions near a harbor entrance are one of the most important factors to evaluate when assessing the difficulty of ship handling.

Fig. 7 is an illustration of the routes of a target ship approaching the harbor entrance of the port of Kochi. When swells propagate from the southeast, a ship usually navigates under the head sea while departing. Consequently, the ship motions change remarkably at the harbor entrance. Moreover, the lower table show the weather information at the time of field observation.

Fig. 8 are time series of ship motions, showing the heave, pitch, roll, yaw, speed, and course observed at Case 1(July 1, 2004) and Case 2(Aug. 26, 2004), near the Kochi harbor entrance. The ship motions suddenly increase as the ship passes a breakwater. When the ship departs at Kochi, the maximum amplitude of heave is 2 meters(A1), and roll and pitch is 4 degrees(B1 and C1).

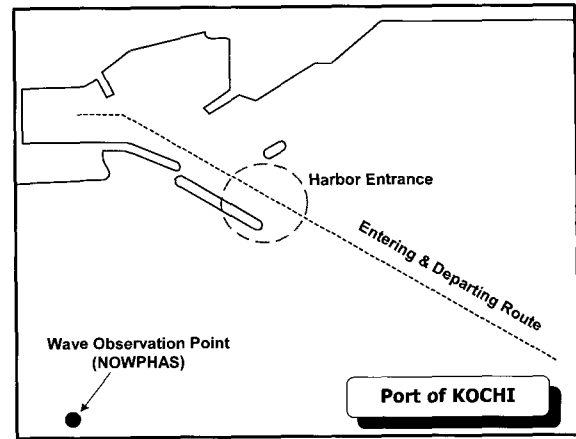
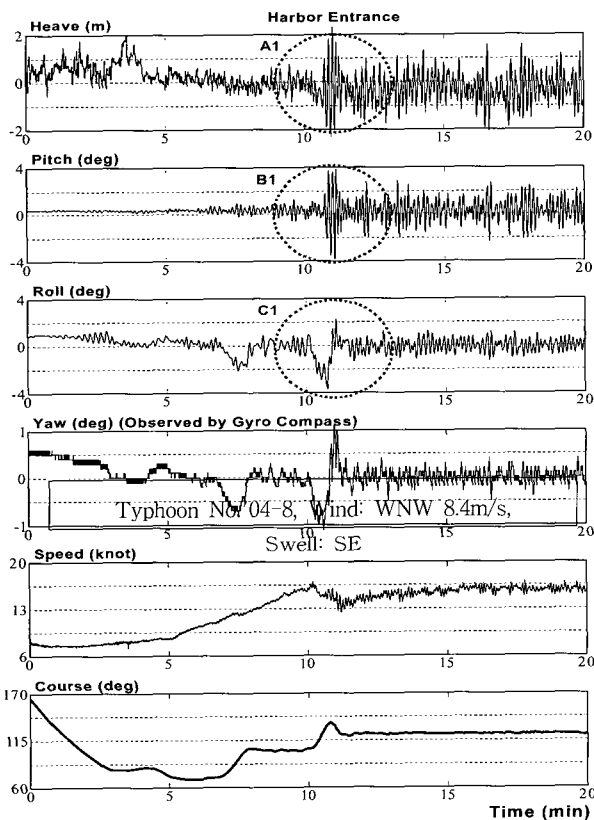


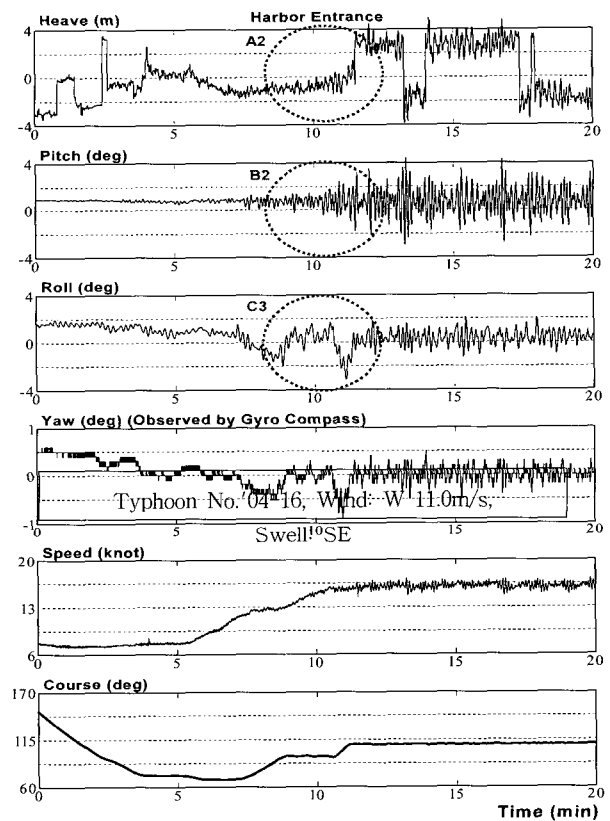
Fig. 7 Route of the target ships near a harbor entrance

5.2 Ship Motions near the Harbor Entrance at Shibushi

Shibushi is in southern Japan and faces the Pacific Ocean. Grain carriers or small container carriers, in addition to the daily ferry service, enter the harbor. It has been reported that mooring is difficult in some berths when swells or waves are propagated by winds from typhoons or atmospheric depressions.



(a) Departing(Case 1)



(b) Departing(Case 2)

Fig. 8 Time series of ship motions as departing harbor

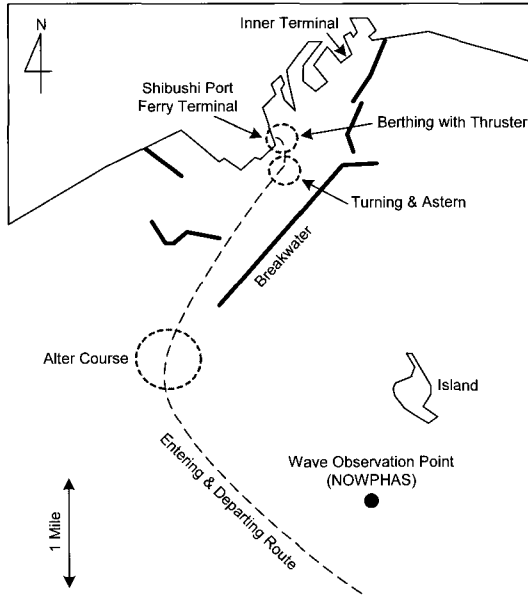


Fig. 9 Port layout and navigation route

The Shibushi port layout and navigation route at the harbor entrance are shown in Fig. 9. Long breakwaters were constructed to protect the harbor from waves

propagated from offshore. The entering ship alters its route rapidly as it approaches the harbor entrance. Since the swells propagate from the south to the southeast, the ship usually navigates at the following sea during the entering. In contrast, the departing ship faces the head seas. Hence, there is a remarkable difference in the ship motion depending on whether the ship is entering or departing the harbor(Sasa et al., 2003b).

The time history of observed ship motions, including heave, pitch, roll, yaw, speed, and course, are shown in Fig. 10. As evident from Fig. 10.(a), ship motions increased at two points. The first occurred as the ship altered course at the harbor entrance. The motions of pitch, roll, and yaw gradually increased at this point. The second change occurred near the quay of the ferry terminal within the harbor(C3-B). After the ferry entered the breakwater, the ship motions temporarily decreased.

However, the roll reached 2-3 degrees for more than 10 minutes when the ferry was berthing at the quay wall, reversing its engine, and using the thruster. Namely, berthing is especially difficult near a quay wall because of the large roll motion, even when a ship is in a harbor. This

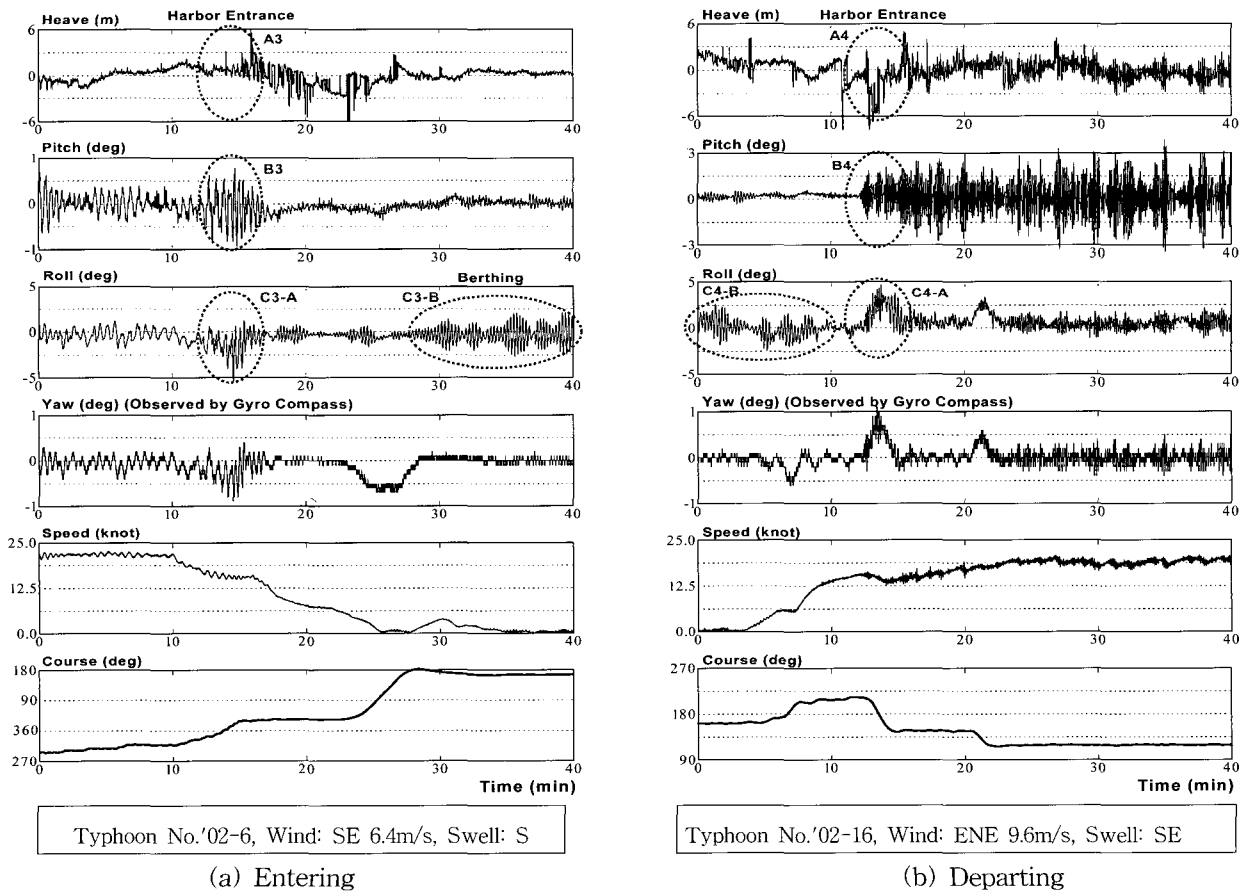


Fig. 10 Time series of ship motions near harbor entrance

is a very serious phenomenon for ships and harbors because it makes it difficult to handle a ship under these situations. The captains reported that berthing is difficult due to the rolling motion caused by waves. The forward speed is almost zero during this procedure. The increased roll motion inside a harbor is typical in spite of the small waves(Sasa et al., 2003b).

In Fig. 10.(b), the departing ship faces the head seas. Thus, the pitch motion reached 3 degrees as a result of swells beyond the harbor entrance. In addition, the maximum heave was in excess of 6m near the harbor entrance.

The maximum amplitude of ship motions at harbor entrance by field observation are shown in Table 2. When the heave motion reaches 6m, navigators have difficulty in maneuvering at harbor entrance.

Table 2 Maximum amplitude of ship motions

	Ferry Kochi	Sun Flower Satsuma
Heave	2.3 meter	6.1 meter
Pitch	3.8 deg.	1.9 deg.
Roll	3.7 deg.	5.3 deg.

6. Conclusions

This paper contains estimates of the difficulty of ship operations within a harbor. Safety evaluations are evaluated by field observations of two large ships in a harbor along the entrance channel facing the Pacific Ocean. Based on the analysis, the obtained results are summarized below.

- (1) Field observations were carried out several times to obtain numerical data of ship motions in the typhoon season. The observation method makes it possible to observe ship motion in stages of navigation as a ship enters, departs, and moors in a harbor.
- (2) The observation of ship motions can be obtained with very high accuracy using the RTK mode of GPS when ship is entering and departing harbor.

- (3) Ships are obviously affected by rough waves, especially as they enter and depart harbors. Ship motions tend to become more significant near a harbor entrance.
- (4) Berthing operations are especially difficult near a quay wall because of the large roll motion(2-3 degrees), even when a ship is in a harbor. This is a very serious phenomenon for ships and harbors.
- (5) It is necessary to develop the new evaluation index of navigation difficulty for ship motions in waves as they enter, berth, and depart a harbor.

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