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Recent Topics on Harbour Tranqulity on Ship Motions

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1. INTRODUCTION

This paper discusses on recent topics on harbour tranquility base on ship motions. Harbour tranquility is mainly discussed only wave height inside a harbour at the first research period. In these twenty years, researches to improve harbour tranquility have been focused on ship motions to reduce mooring troubles facing to open seas.

The countermeasures to improve harbour tranquility are classified as followings:

(1) To reduce wave height inside a harbour by improving breakwater and so on

(2) To reduce ship motion by improving mooring system

(3) To predict wave condition on the view point of berth operation

In this paper, recent topics focusing on ship motion during mooring and maneuvering entering into port and departing from the port are introduced. Topics shown in the paper are wave estimation systems for berth operation, the allowable ship motion as an index of harbour tranquility, reduction ship motion by improving mooring systems and so on.

2. WAVE ESTIMATION FOR MOORED SHIP MOTION

2.1 Wave Estimation

Mooring problems remain serious issues in port construction and operation. Although moored vessel motions and long period waves have been studied extensively, most harbours facing the open seas do not have effective countermeasures. On the other hand, operators need to have detailed wave information near harbours when sea conditions become serious. Many meteorogical and coastal engineering studies have been performed to predict waves. In the field of meteorology, waves are forecasted for a very wide area ground the earth or ocean to provide overall weather information for vessels or airplanes at the sea. Thus, numerical methods are based on an energy balance equation. These are mainly developed to forecast wave distributions around the earth or the Pacific Ocean, such as the third generation model. Although huge amounts of data are required for input to the calculation, the accuracy has become better as the performance of computers has improved.

On the other hand, cargo handling operators would clearly have precise information on waves near harbour than weather information for larger areas. Also, the predicted wave information is needed at least 1-3 days in advance from of view of berth operation. And in the sense of operator, they would like to the information of waves by simplicity model by use of less data. Then, the presented prediction model can be used with less data than meteorological models. A new numerical model is constructed to predict wave conditions due to typhoons for use in mooring criteria (Shiraishi et al., 2003). The model is based on Kalman Filter theory, wave estimates inside typhoons and wave decay as swells. This prediction model does not require the huge amount of input data that is needed for meteorological models. The accuracy was verified for "A Port," which faces the Pacific Ocean, for swells and wind waves propagating

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from typhoons under various conditions. Moreover, the prediction model can be used for other locations that face the Pacific Ocean. This new model allows predictions of the mooring criteria under the influence of typhoons between one half and two days in advance.

Fig.1 shows an example of the predicted results 2 days and 18 hours after generation of the typhoon. The power of the typhoon grows as it approaches Japan.

Although the predicted wave heights are a bit less than the observed values at the mooring criteria, the results may be influenced by prediction errors for typhoons. The overall trend can be predicted, as shown in the figure. The mooring criteria are met 16 hours from the prediction point. This is sufficient time to judge the mooring criteria and decide on emergency operations beforehand in the harbour.

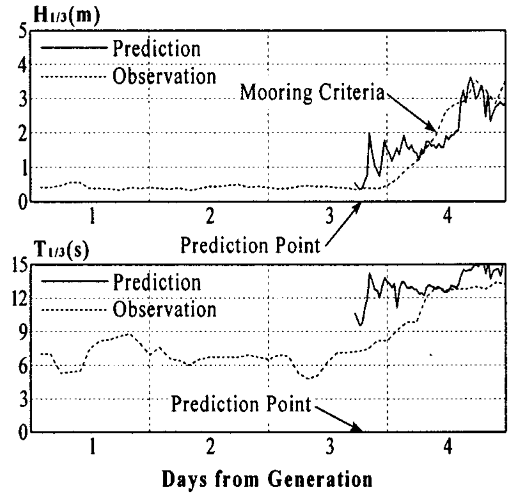

Fig. 1. Predicted results for wave growth (Case P-2-A at 2 days and 18 hours).

2.2 Proposed New Pridiction System of Waves for Mooring Criteria Including User Interface

The prediction model can almost estimate vessel mooring criteria for conditions when swells or wind waves propagate from typhoons. Although moored vessel motions have been studied extensively, effective countermeasures are not standardized. One reason may be the very large budget that is necessary to construct breakwaters or mooring systems. Thus, a system to predict vessel's mooring criteria is very important for port operation. Fig.2 shows the proposed mooring criteria prediction system.

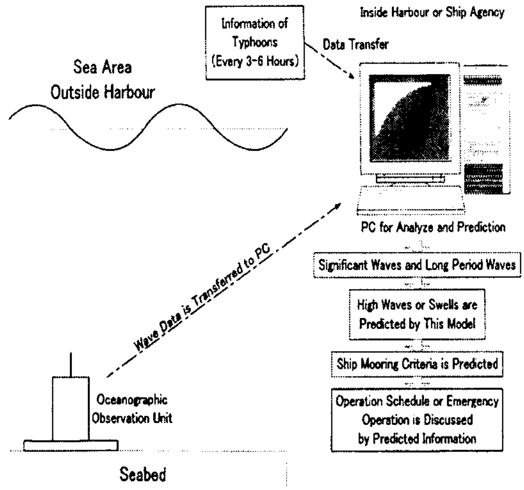

Fig. 2. Mooring criteria prediction system.

This system consists of an oceanographic observation system, which includes systems for data transfer and analysis. The oceanographic observation unit is located offshore from the harbour and measures the surface elevation of waves hourly. The relationship between significant waves and long period (about 1-3 minutes) waves of the observed data is evaluated. Observed wave data is transferred to the personal computer, as shown in Fig.2. In addition, the Meteorological Agency provides current information on typhoons every 3-6 hours after a typhoon is generated. This data is used to predict parameters of typhoons using the Kalman Filter and can be obtained on a public web site. Once the prediction model is installed in the personal computer, the system can predict wave growth conditions due to typhoons for various locations. The significant wave parameters are predicted, so the long period waves must be determined for the conditions. Long period waves can be estimated from significant waves at any point by using statistical analysis (Sasa et al., 2001) (Shiraishi et al., 2001). The analysis can be carried out using the data accumulated at each location. The moored vessel motions can then be determined using predicted wave conditions that include both significant waves and long period waves. Fig.3 shows the flow of the analysis for predicting moored vessel motions in harbours.

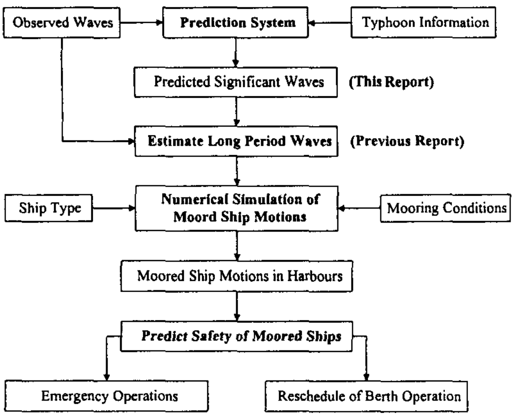

Fig. 3. System for predicting moored vessel motions from predicted waves.

3. ALLOWABLE SHIP MOTION

3.1 Outline of Research

Cargo handling at a wharf may occasionally be interrupted and/or suspended if vessel motions exceed the allowable ones. The wharf operation efficiency, then, should be defined based on the allowable ship motions for cargo handling in terms of the type and size of a ship and cargo handling equipment. P. Burm (1981a, 1981b) proposed allowable ship motions moored at a quay wall as a new concept of harbour calmness index. Ueda and Shiraishi (1988) investigated interruption and suspension during cargo handling in Japanese ports and proposed allowable ship motions for cargo ship, grain carrier, ore carrier and tanker. PIANC WG24 (1995) compiled the allowable ship motions by using previous studies.

Satoh et al. (2003a, 2003b) investigated instances of interruption and suspension of cargo handling due to ship motions for container ships and ferries. They estimated the allowable ship motions for container ships and ferries through executing numerical simulations for each instance of interruption and suspension of cargo handling. They also evaluated and revised the estimated values respecting opinions of cargo handling operators, and finally proposed the allowable ship motions for container ships and ferries.

3.2 Proposed Allowable Ship Motions

Fig. 4 shows the cumulative distribution of ship motions for container ship. The curve is obtained by means of vessel motions obtained by numerical simulation of ship motions for each instance of interrpution or suspension of cargo handling. As result of simulation of vessel motion, the provisional figures of allowable ship motions for cargo handling are proposed. The total number of mooring troubles cases used in the study are 25 for container ship and 108 for ferries, respectively.

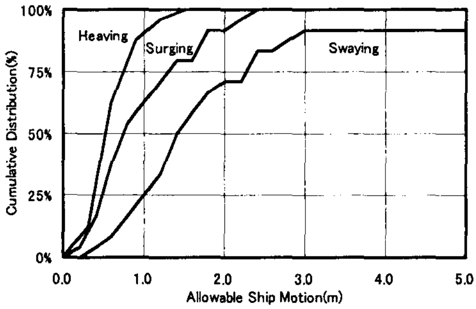

Fig. 4. Cumulative distribution of vessel motions for container ship.

Table 1 and Table 2 show the provisional figures of allowable ship motion for container ships and ferries. Figures proposed by PIANC WG24 are also shown in the table.

The provisional figures of allowable ship motions for cargo handling are examined through the questionnaire for cargo handling operators. Fig. 5 show the evaluation result of provisional figures of allowable ship motion for cargo handling by questionnaire for cargo handling operators.

Table 1. Provisional figures for container ships

	Container ship		PIANC WG	
	50% Efficiency	100% Efficiency	50% Efficiency	100% Efficiency
Surging	±1.0	±0.5	±1.0	±0.5
Swaying	+1.5	+0.8	+1.2	+0.6
Heaving	±0.6	±0.4	±0.6	±0.4
Rolling	±5.0	±2.5	±3.0	±1.5
Pitching	±1.0	±0.5	±1.0	±0.5
Yawing	±1.5	±0.8	±0.75	±0.5

Unit ; Surging, Swaying, Heaving (m)
Rolling, Pitching, Yawing (deg)

Table 2. Provisional figures for ferries

	Ferry		PIANC WG
	Short distance	Long distance	Side Ramp
Surging	±0.4	±0.4	±0.3
Swaying	+0.4	+0.4	+0.6
Heaving	±0.3	±0.3	±0.3
Rolling	±1.0	±1.0	±1.0
Pitching	±0.5	±0.5	±0.5
Yawing	±0.5	±0.5	±0.5

Unit ; Surging, Swaying, Heaving (m)
Rolling, Pitching, Yawing (deg)

Evaluated ranks at questionnaire for cargo handling operators in Fig.5 are following five categories.

+2 :the allowable ship motion is rather as larger as and 1.5 times of the provisional figures,

+1 :the allowable ship motion is a little larger than the provisional figures,

0: the allowable ship motion is equivalent to the provisional figures,

-1 :the allowable ship motion is a little smaller than the provisional figures,

-2: the allowable ship motion is under 0.7 times of the provisional figures.

For example, in case of rolling for container ship shown in Fig.5, many answers from cargo handling operators concentrated in the rank (-2), then, allowable ship motion shall be less than the provisional figures. Fig.6 also shows the evaluation of provisional figures of allowable ship motion for long distance ferries.

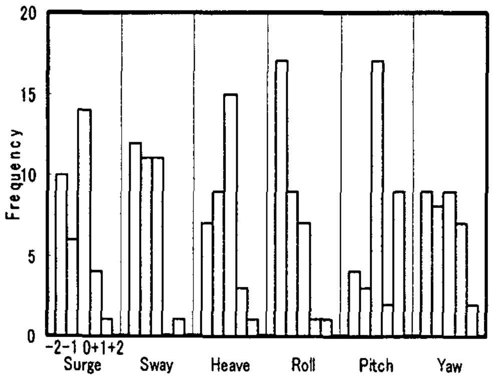

Fig. 5. Evaluation of provisional figures by questionnaire (Container ship, 100% efficiency).

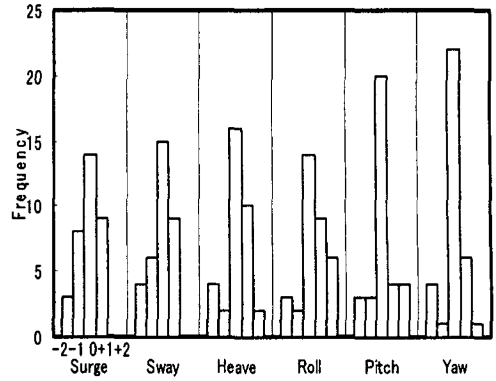

Fig. 6. Evaluation of provisional figures by questionnaire (*Long distance ferries*).

Table 3 shows proposed allowable ship motions for container ship and ferry proposed by Satoh et al. The figures are modified by use of the result of questionnaire.

Table 3. Proposal of allowable ship motions

	Container ship		Ferry	
	50% Efficiency	100% Efficiency	Short distance	Long distance
Surging	±1.0	±0.5	±0.4	±0.4
Swaying	+1.0	+0.5	+0.5	+0.5
Heaving	±0.6	±0.4	±0.4	±0.4
Rolling	±3.0	±1.5	±1.0	±1.0
Pitching	±1.0	±0.5	±0.5	±0.5
Yawing	±1.0	±0.5	±0.5	±0.5

Unit ; Surging, Swaying, Heaving (m)
Rolling, Pitching, Yawing (deg)

4. REDUCTION OF MOORED SHIP MOTIONS

4.1 Reduction of Sub-harmonic Motions

When harbours are planned, the influence of external forces, such as waves and wind, is usually considered. The influence is especially serious in harbours that face open seas, such as those on the Pacific Ocean or the Sea of Japan. Vessels cannot moor in some harbours due to large amplitudes of motions.

One type of resonance in mooring problem is known as sub-harmonic motion. Sub-harmonic motion appears in a system that has a strong anti-symmetric reaction force characteristics.

Fig. 7 shows two type of rubber fenders which are roughly classified. One is buckling type fender, and the other is pneumatic type fender. The buckling type is advantageous in view that it has high energy absorption performance since it buckles when deflection of the fender is large. The pneumatic type is advantageous in view that reaction force of the fender is small when deflection of the fender is small, resulting in small amplitude of motion of ships or floating bodies in horizontal direction.

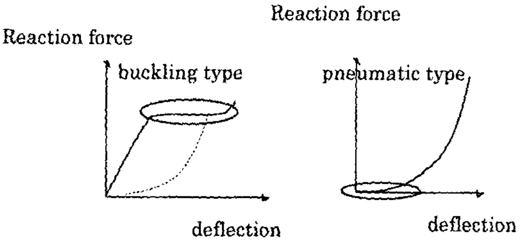

Fig. 7. Characteristics of two types of fenders.

It is known that sub-harmonic motions are brought about when the period of the incident wave is close to the multiple of the resonance frequency in case that the mooring system has reaction characteristics of large anti-symmetry. That is, when the vessel goes apart form the quay wall, the spring coefficient of the mooring system k_- is small since the restoring force appears from the taut rope. When the vessel goes close to the quay wall, the spring coefficient k_+ is far large due to the fender at quay walls. Large ratio of k_+/k_- means the large anti-symmetric nature. When a vessel is moored to a quay wall and the vessel goes close to the quay, the vessel is subject to large mooring load from fender (k_+). On the other hand, when it goes away from the quay, only small reaction force works on the vessel from ropes (k_-). The ratio k_+/k_- is somewhat between 100 and 1000 in case of moored vessel at quay.

A hybrid type fender (Iijima 2002, 2003a, 2003b) is a combination of the buckling type fender and the pneumatic type fender which are put together in serial. A mechanical stopper is equipped with at the pneumatic type fender. As long as the deflection is small under normal weather condition, the fender has almost the same reaction force characteristics as the pneumatic type fender. Once the deflection is over a defined point under storm condition, the stopper works and the fender has the same characteristics as the buckling type. Therefore, the hybrid type fender has advantages of both of the pneumatic type and the buckling type (Fig. 8). The performance of hybrid fender is examined by onsite experiment carried out in 2001 and 2002 at Yokosuka, Japan.

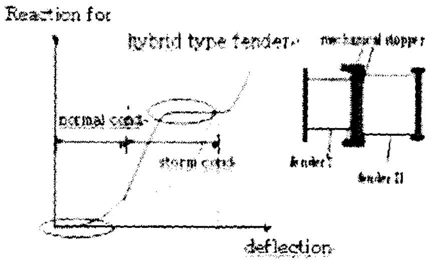

Fig. 8. Characteristics of two types of fenders.

The hybrid type fender is helpful since it has small initial spring coefficient. The hybrid type fender could be utilized as mooring of ships for reduction of sub-harmonic motions which sometimes give troubles to loading and unloading works at quays. Such case was examined for investigations (Fig. 9). The vessel is a cargo ship of 40,000DWT. Supposing that the berthing speed is 10cm/s, fender design was conducted. The buckling type fender: height 1150mm. Hybrid type fender: combination of buckling type fender of 1000mm height and pneumatic type fender of 1330mm height. The significant wave period is 10s and the wave height is 0.5m.

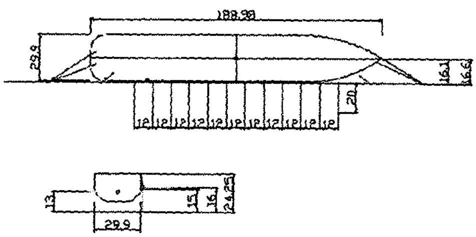

Fig. 9. Mooring of a vessel to a quay wall.

The results of sway motion are shown in Fig.10. The calculated results for buckling type fender is also shown for comparison. In case of buckling type fender, slowly varying response with period of 60s is observed. However, by using the hybrid type fender, the long period component is markedly reduced.

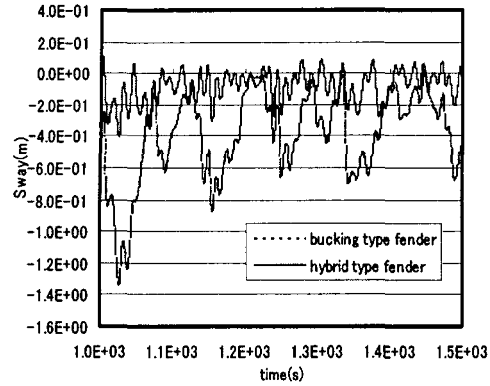

Fig. 10. Horizontal response of moored ship.

4.2 Reduction of Low-frequency Motions Due to Long Period Waves

Another type of resonance in mooring problem is known as low-frequency vessel motion due to long period wave. In the 1990s, there are many studies on this topic in the field of coastal engineering and port construction. However, it is clear that long period waves around 60-180s are the main cause of mooring difficulties. Long period waves have been studied in detail from the viewpoint of the design of harbour facilities, such as breakwaters.

It is difficult to achieve the effective countermeasures for reducing low-frequency ship oscillations. Shiraishi (1998) showed an example of mooring system countermeasures to reduce low-frequency ship motions in a Japanese port.

At a 60,000DWT bulk carrier berth in a horbour, breaking accidents of mooring ropes frequently occurred during severe weather conditions. A usual mooring rope arrangement under the stormy weather sometimes makes large vessel motions, namely, 6-8m surge and 1-2m sway movement. Moreover large compressions and shearing deformations of fenders are generated. So at an early time, the moored vessel is compelled to escape from the berth. Against the above urgent circumstance, investigations of inside and outside harbour waves, winds and weather conditions at the rope accidents are carried out. It is found that long period waves (approximate T=150s, H=0.4m) exist inside harbour at the accident. And it is estimated that the large and low-frequency ship motions are caused by a resonance of both the natural period of surge and the low-frequency ship motions are caused by a resonance of both the natural period of surge and the long period waves. By using a numerical simulation, comparisons for moored ship motions and mooring forces are carried out in the existing mooring system and in some substitution under waves which is similar to the waves and winds at the rope accident. After the investigations, a counter measures by mooring system, which means a control of the natural periods of the moored ship, is performed. The natural period of mooring system become 80s after the countermeasures by means of combination of mooring ropes and low-frequency ship motion becomes half of the amplitude by original mooring system.

Yoneyama et al. (2003) carried out fundamental model experiment of reduction system for low-frequency ship motions. The system is capable of effectively reducing the low-frequency motions of the moored ship. They also proposed the system as one construction method for countermeasures against long period waves. The reduction system of low-frequency ship motions can reduce the surge motions of a moored ship by preventing the resonance with the long period waves. This is implemented by forcibly changing the natural period of the mooring system with the mooring winches automatically controlled by a personal computer. In the study, they verified the effectiveness of the reduction system of low-frequency ship motions by fundamental model experiments, and carried out trial design of an actual system in consideration for on-site applications.

5. SHIP MOTIONS AT ENTERING INTO AND DEPARTING FROM HARBOURS

Some topics related harbour tranquility based on ship motion moored quay wall is discussed in the paper. On the other hand, safety is very important as ships enter and depart from harbours in severe seas. Safety while entering and departing harbours has been thoroughly studied, in many cases, with the use of ship simulators. However, usually, the influence of winds and currents is usually considered. It is beyond the scope of the present study to consider the overall safety of ships using harbours that face the open sea. Studies have been conducted on ship handling as small fishery boats enter and depart from harbours subjected to winter storm waves. Kubo et al. (2000) proposed a new concept involving the difficulty of entering a harbour to evaluate the safety of ship handling in heavy waves. It then becomes necessary to understand the properties of ship motions as a ship enters and departs from harbours subjected to severe waves. It is important to study these problems in harbours facing the Pacific Ocean and for large ships. Sasa et al. (2003b) carry out some hearing researches about the difficulty of navigating ships near harbours during entry and departure. Some important problems can be solved relative to navigating ships near a harbour entrance, particularly those involving large ferries that navigate the Pacific Ocean. Ship motions in large ferries are repeatedly observed as they entered and departed harbours facing the Pacific Ocean during typhoon swells in 2002 by using GPS and Gyro system (Sasa et al. 2003a).

S port is selected as the target harbour. It is located in the southern part of Japan and faces the Pacific Ocean. Grain carriers or small container carriers enter the harbour in addition to the daily ferry service. It has been reported that mooring is difficult in some berths when swells or waves propagate as a result of the winds from typhoons or atmospheric depressions. S port layout and navigation route from the harbour entrance are illustrated in Fig. 11.

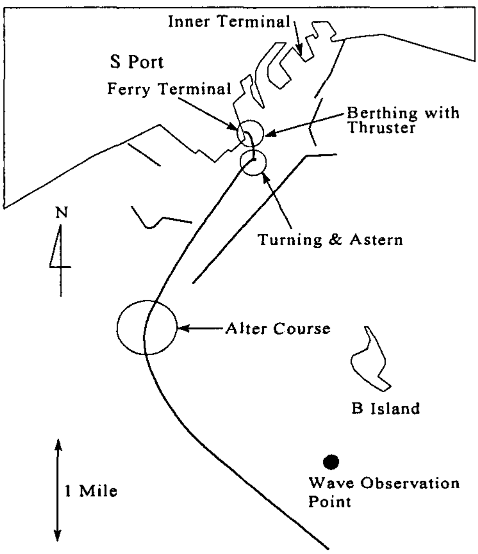

Fig. 11. S port layout and navigation route at harbour entrance (Sasa et al., 2003b).

Detailed information regarding the waves propagated from these typhoons offshore from S port is necessary. Waves are observed offshore from S port by the Nationwide Ocean Wave Information Network for Ports and Harbours (NOWPHAS). The wave gauge is installed in the seabed at –35m. Surface elevations are observed every two hours for 20 minutes with an interval of 0.5s. The transition of significant wave heights and wave periods at S port on July, 2002 are shown in Fig.12.

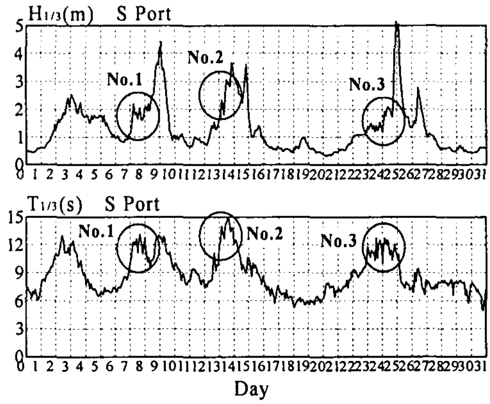

Fig. 12. Transition of significant wave heights and wave periods (Sasa et al., 2003b).

Ship motions increased at two points, as shown in Fig.13. The first motion increase occurred as the ferry altered its course to enter the harbour. The pitch, roll, and yaw increased at this point. The phenomenon of heeling (3 degrees) occurred as a result of altering the course. A similar phenomenon has been reported as fishing boats entered the harbour in waves created by wind. This phenomenon may result from the influence of reflected waves from the breakwater and the heel of the ship due to rudder forces. The second increase occurred near the quay of the ferry terminal inside the harbour. After the ferry entered the breakwater, the ship motions decreased for a short time. However, the roll reached ±2-3 degrees for about 10 minutes when the ferry is berthing the quay wall by reversing the engine and using the thruster. The captains reported that berthing the ship is difficult because of the rolling motion caused by the waves. The forward speed is almost zero during this procedure. The increasing rolling motion inside the harbour is typical in spite of the smaller waves.

The study shall be continued and compare with numerical simulations, and in the future new index for ship maneuvering index to harbour shall be established.

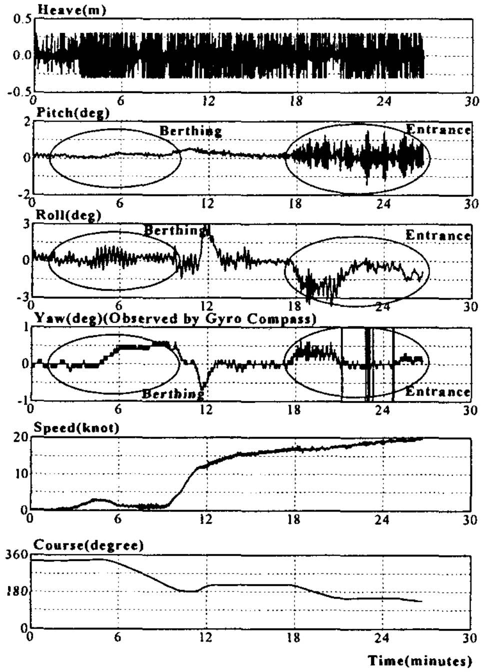

Fig. 13. Time history of ship motions at harbour entrance for observation in case 1 (Sasa et al., 2003b).

6. CONCLUSION

In this paper, recent topics on harbour tranquility on ship motions are discussed. For the improvement of harbour calmness focusing on ship motion reduction. In this field, further studies are required on control ship motions by means of modified mooring system or automatically control system of ship motions.

In these years, wave predicting technology have been progressed and wave deformation analysis including long period waves are also modified remarkably. In this paper, such information can not introduced. Combining wave estimation technology and ship motion reduction technology, harbour tranquility shall be improved in the future.

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