運輸省港湾技術研究所 (25th Anniversary Issue)

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REPORT OF THE PORT AND HARBOUR RESEARCH INSTITUTE

MINISTRY OF TRANSPORT

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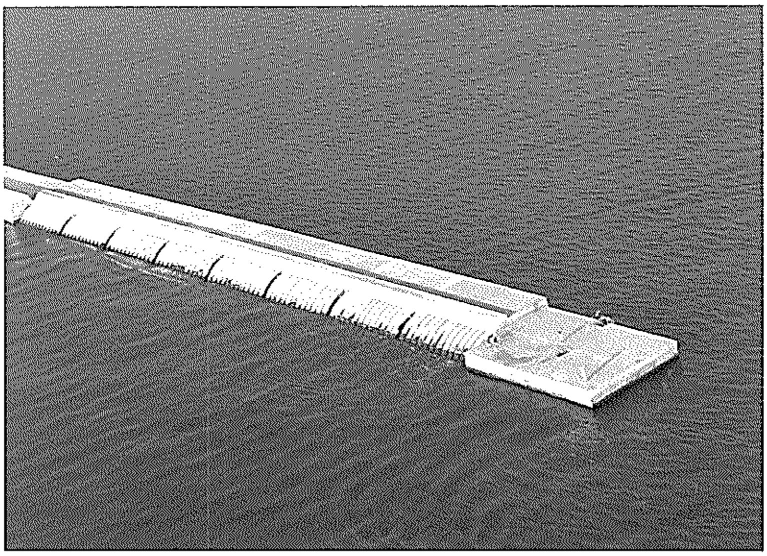
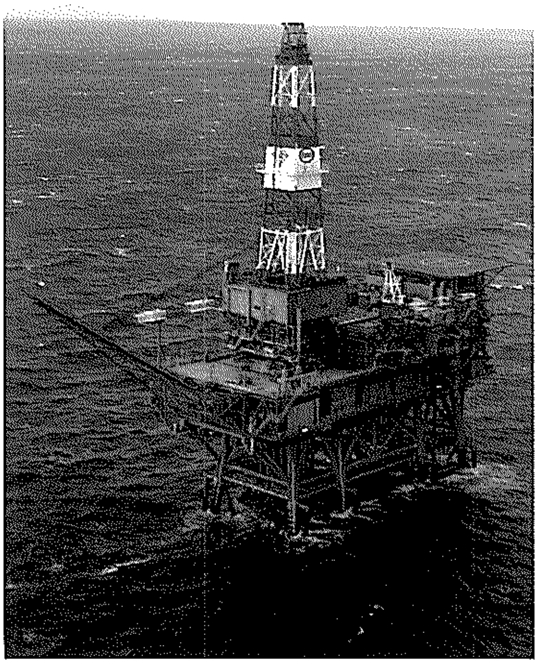
NAGASE, YOKOSUKA, JAPAN



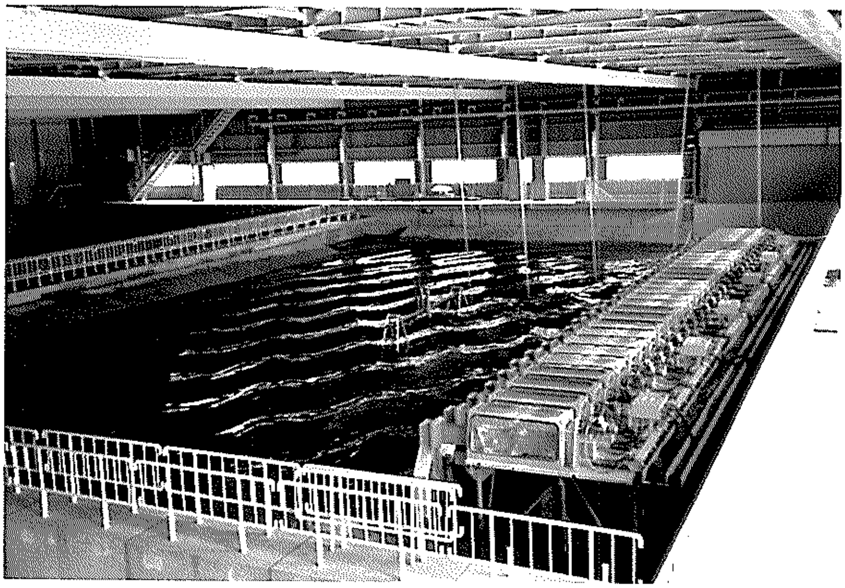
Curved Slit Caisson Breakwater

View of curved slit caisson breakwater completed in the construction at the port of Funakawa. (Courtesy of Akita Port Construction Office, the First District Port Construction Bureau, Ministry of Transport)



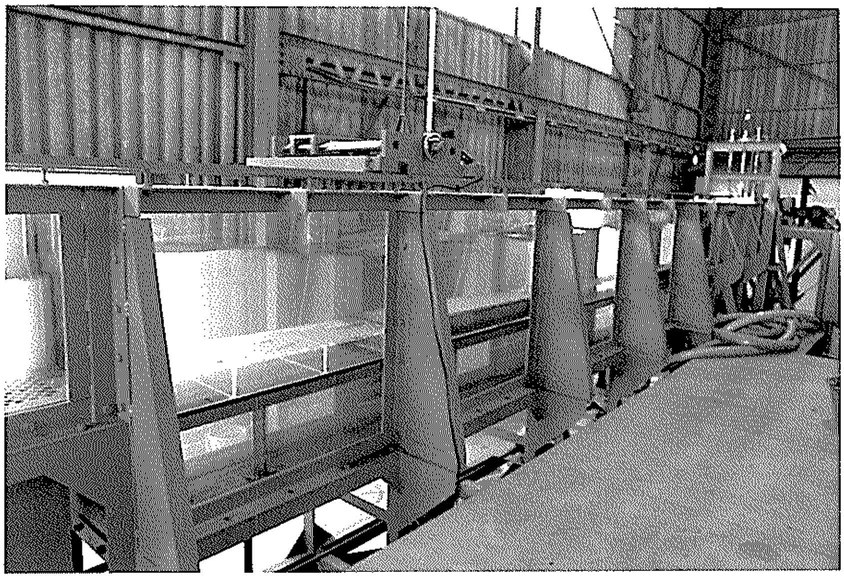
Facilities for Ocean Directional Wave Measurement

Four step type wave gauges and a two-axis directional current meter with a pressure sensor are installed on the legs of an offshore oil rig. They are operated simultaneously for detailed directional wave analysis.



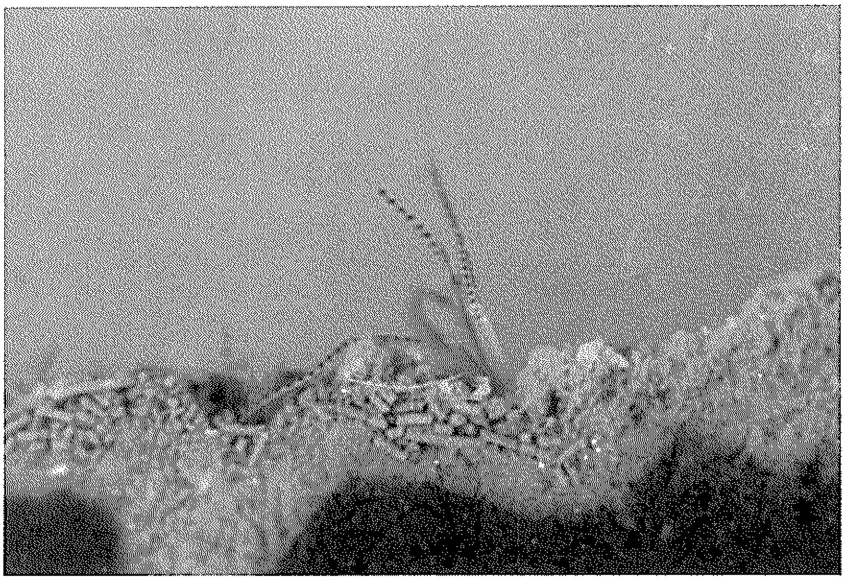
Serpent-type Wave Generator

The photograph shows the serpent-type wave generator in the short-crested wave basin and the superimposition state of two different oblique waves generated by the generator.



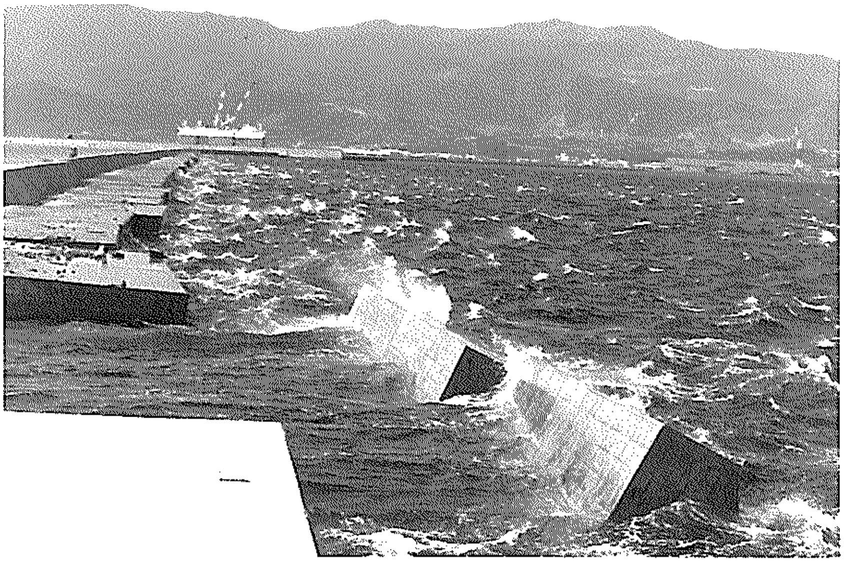
Wave-soil Tank

The experiments concerning the wave-soil interactions are conducted in this tank. The soil tank and the test section are located at the center of the tank. A movable floor is provided at the bottom of the test section and the level of the interface of mud layer and water can easily be adjusted to the level of the flume bottom.



Pararionospio Pinnata

The biomass of benthos is one of the most sensitive indices to know the effect of sea-bed sediment treatments on the marine environmental improvement. The picure shows a kind of benthos, *pararionospio pinnata,* which preferentially exists in the polluted sea-bed.



Breakwater Damaged by Storm

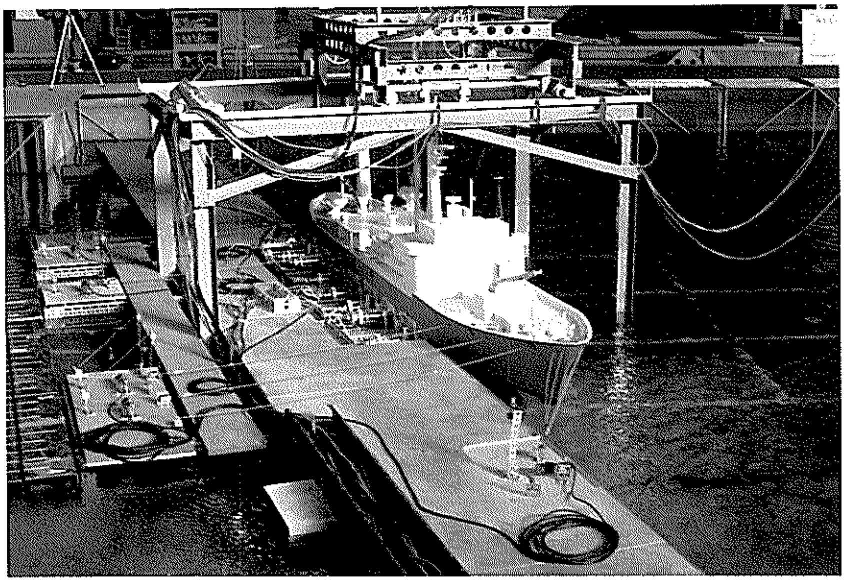
This photograph shows a breakwater damage by a storm.
The breakwater is of the composite type with concrete caisson on a rubble mound. Two caissons were severly damaged due to the instability of a rubble mound.

Nondestructive Evaluation of Pavement

Nondestructive methods for evaluating the load carrying capacity of airport concrete pavements have been developed by using Falling Weight Deflectometer(FWD).

Seismic Damage to Gravity Quaywall

The 1983 Nipponkai-Chubu earthquake(Magnitude : 7.7)caused serious damage to port facilities in northern part of Japan. This photo shows the damage to gravity quaywall. The concrete cellular block walls were collapsed and completely submerged.

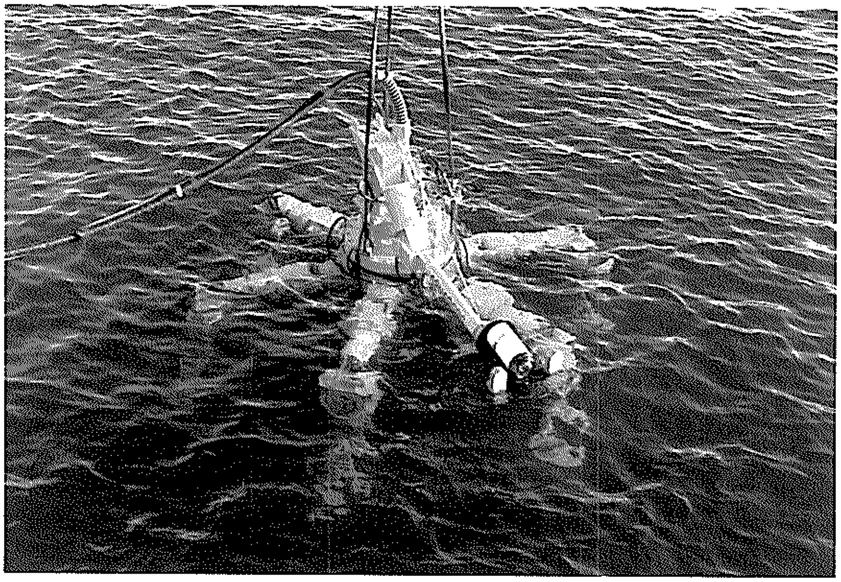


Model Experiment of Mooring Ship

Model ship is moored at a quay wall with fenders and mooring ropes subjected to gusty wind and/or irregular waves.

Vessel Congestion in Japan

As Japan is surrounded by the sea, there are many crowded water areas with various sizes and types of vessels. Arround there, many construction works were planned such as ports and harbours, off-shore airports, huge bridges and so on, so that many marine traffic observations and marine traffic simulations have been carried out.



Underwater Inspection Robot

This is the six-legged articulated underwater inspection robot named "AQUAROBOT". The robot controlled by a computer can walk on uneven sea bed without making water muddy.

Foreword

The Port and Harbour Research Institute is a national laboratory under the Ministry of Transport, Japan. It is responsible for solving various engineering problems related to port and harbour projects so that governmental agencies in charge of port development can execute the projects smoothly and rationally. Its research activities also cover the studies on civil engineering facilities of air ports.

Last April we have celebrated the 25th anniversary of our institute because the present organization was established in 1962, though systematic research works on ports and harbours under the Ministry of Transport began in 1946. As an event for the celebration, we decided to publish a special edition of the Report of the Port and Harbour Research Institute, which contains full English papers only. These papers are so selected to introduce the versatility of our activities and engineering practices in Japan to overseas engineers and scientists. It is also intended to remedy to a certain extent the information gap between overseas colleagues and us.

The reader will find that our research fields cover physical oceanography, coastal and ocean engineering, geotechnical engineering, earthquake engineering, materials engineering, dredging technology and mechanical engineering, planning and systems analysis, and structural analysis. Such an expansion of the scope of research fields has been inevitable, because we are trying to cover every aspect of technical problems of ports and harbours as an integrated body.

The present volume contains eleven papers representing six research divisions of the institute. The materials introduced in these papers are not necessarily original in strict sense, as some parts have been published in Japanese in the Reports or the Technical Notes of the Port and Harbour Research Institute. Nevertheless they are all original papers in English and are given the full format accordingly. We expect that they will be referred to as usual where they deserve so.

It is my sincere wish that this special edition of the Report of the Port and Harbour Research Institute will bring overseas engineers and scientists more acquainted with our research activities and enhance the mutual cooperation for technology development related to ports and harbours.

December 1987
Yoshimi Goda
Director General

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9. Motitons of Moored Ships and Their Effect on Wharf Operation Efficiency

Shigeru UEDA*

Synopsis

This paper discusses the harbour calmness index and factors concerned with the calculation of the harbour calmness index. Motions of model ships were measured simultaneously during wave diffraction tests. The result of the model tests indicate the inadequacy of calculating the harbour calmness index based solely on the wave height in front of a berth when ship motions are influenced by long period waves. A calculation method for the wharf operation efficiency based on the revised definition of the harbour calmness index is proposed.

The relation between ship motions and factors affecting these motions, such as the load-deflection characteristics of the mooring systems, the irregularity of waves and the fluctuation of wind, is also examined. Numerical simulation of ship motions was carried out in order to achieve an increase of the wharf operation efficiency and it was found that this might be obtained from an improvement of the mooring systems.

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* Chief of the Offshore Structures Laboratory, Structures Division

港湾技術研究所報告
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9. 係留船舶の動揺とその港湾の稼働率に及ぼす影響について

上 田 茂*

要 旨

本論文においては，泊地の静穏度とその計算に係わる要因について記述する。港内静穏度実験において，模型船を係留し，その動揺を同時に測定した。模型実験の結果は，係留船舶が長周期波の影響を受けて動揺する場合には，泊地の静穏度の計算を単に係留施設の前面の波高のみに基づいて行うのは適当でないことを示唆している。

係留船舶の動揺とこれに影響を及ぼす要因，たとえば，係留システムの変位復元力特性，波の不規則性，風の変動性などとの関係が示されている。港湾荷役の稼働率を改善するために，係留船舶の動揺計算を実施し，その結果係留システムの改善が効果的であることがわかった。

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*構造部 海洋構造研究室長

Contents

1. Introduction

Currently in Japan, the harbour calmness index is calculated as the yearly total of days when the wave height in front of a berth is less than 50 or 70 cm. It is generally considered that a harbour is calm, which means a harbour is well sheltered, if the rate of yearly total of days when the wave height is less than 50 or 70 cm exceeds 90 or 95% of the whole year. Because the wave period is not considered as a factor for the calculation of the harbour calmness index within this current method, ship motions in a newly constructed port located facing the Pacific Ocean become large when a ship is subjected to long period waves even though the wave height in front of a berth is less than the designed values above. Cargo handling operations at a wharf may sometimes be interrupted or suspended if the ship motions exceed allowable designed values. In such a case, it is not correct to define the harbour calmness index based solely on the wave height. Therefore, the harbour calmness index should be defined based on the allowable ship motions for cargo handling operations in terms of the type and size of ship and the cargo handling method. Thus, discussion is made in this paper on the harbour calmness index and factors relating thereto, and also a proposal is made that ship motions should be considered for the calculation of the harbour calmness index.

The relation between ship motions and factors affecting them is then considered. Here, attention is given to such factors as the load-deflection characteristics of the mooring systems, the irregularity of waves and the changes of wind speed and direction. Descriptions are made on case studies of large ship motions in several ports in the United States and South Africa with their possible causes and on the results of surveys in several ports in Japan on the interruption and suspension of cargo handling operations due to ship motions. In addition to these, motions of model ships were measured simultaneously during wave diffraction tests. The results of the model tests indicate the inadequacy of calculating the harbour calmness index based solely on the wave height in front of a berth when ship motions are affected by long period waves.

The mooring systems on a berth in a harbour in Japan which faces the Pacific Ocean were replaced with an improved system in order to increase the wharf operation efficiency. After the improvement, reduced ship motions were noted and consequently the wharf operation efficiency was increased.

Finally, a calculation method for the wharf operation efficiency based on the revised definition of the harbour calmness index is proposed.

2. Wharf Operation Efficiency and Harbour Calmness Index

2.1 Factors Affecting Wharf Operation Efficiency

The major function of a harbour is defined as the provision for a ship of a sheltered basin during rough weather and a safe mooring for the efficient prosecution of cargo handling operations. A port is a terminal on the route for cargo transportation through sea and land. The majority of both exported and imported goods and domestic cargoes go through a port. In 1985 in Japan the total amount of foreign and domestic cargo was 859 million tons and 1,981 million tons respectively including cars transported by ferry boats. Nowadays, a port is recognised not only as a terminal on the route between sea and land, but also as the nucleus or focal point of an industrial area. In an industrial port, raw materials are unloaded at the wharves and are transported to factories located close to the port. After processing, both finished and half-finished goods are loaded on a ship at the wharves. Those manufactured goods have been given added value. Thus, it can be said that a port is a place of production and a basis of the economy of a country. Therefore, efficient wharf operation is the most important function of a port.

Ideally, it should be possible to carry out cargo handling operations at any time and in any weather conditions. However, there are many reasons why cargo handling operations are interrupted and/or suspended. Several investigations have been done in some of the District Port Construction Bureaus, Ministry of Transport1),2) and by Kubo et al.,3) Kobe University of Mercantile Marine. There are many reasons why a ship cannot be moored to a berth as soon as she has arrived at a port or cannot start cargo handling operations as soon as she has been moored at a berth. A ship must wait sometimes in an anchoring basin until an appropriate berth becomes available either because of the delayed departure of an earlier vessel, or until the berth at which the incoming ship is to be moored is determined, or until the environmental and meteorological conditions improve to allow for safe berthing and mooring.

Ship cargo handling operations can sometimes be interrupted due to bad weather conditions such as rough waves or strong winds, breakdown or malfunction of the cargo handling equipment, accidents or quarantine. Cargo handling operation stoppages are generally classified into two groups. One group is weather related and the other is stoppages caused by berth or equipment conditions. Monji and Fujiwara4) reported that, on the average, bad weather conditions account for 66% of incidents of the interruption of cargo handling operations which occurred in the ports belonging to the administrative district of the First District Port Construction Bureau. But it was 80 to 90% in several other ports such as Naoetsu, Niigata and Fukui. The execution of cargo handling operations in those ports are greatly influenced by the weather conditions. Factors of weather conditions are rain, snow, wind and waves. The degree of influence values is depending on the kind of goods to be handled. The handling of such goods as general cargoes, ores, grains and certain types of oils or bulk liquid cargoes is largely dependent on weather conditions. In particular, the handling of timbers, types of oils, timber chips, and gernal cargoes is much affected by wind and waves. Kubo et al.3) investigated instances of the interruption and suspensin of cargo handling operations and their causes at several ports where cargo handling operations are considered to be relatively weather dependent by means of a questionnaire. Analysis of the responses revealed that major causes of the interruption and suspension of cargo handling operations are the falling or dropping of loads, difficulty to bring in and take out cargoes through hatches, movement or slippage of timbers, collisions between ship and cargoes, turning movement of grabs, getting wet in the rain, and wind blown scattering. They analysed the relation between these causes and the types of packing and found that cartons and bags often fell from pallettes because of movements of both the ship and the cargo handling equipment. They concluded that the type of packing is important for the efficiency of cargo handling operations. They also considered the relative motions between a ship and the cargo handling equipment, and found that ship motion are usually larger than the motions of cargo handling equipment installed on the breth. The smaller the ship size, the larger the ship motion becomes. Distortion of shape of cargoes due to ship motions have been observed for ships less than 6,000 GT, and most of them were on ships less than 1,000 GT. The author believe that the major components of ship motions are both heave and roll motions which cause distortions of cargoes and/or the turning or swinging movements of cargoes lifted by the ship's cranes or hoists.

The movement of ships which may be the cause of the interruption of cargo handling operations is often observed at some recently constructed ports which are located facing the Pacific Ocean when a typhoon is approaching or a depression is growing off the coast, and also at ports which are located facing the Sea of Japan where the wind blows for long periods continuously during the winter season. At VLCC, LPGC and LNGC sea berths which are located in the outer areas of a port, moored ships are very susceptible to the wind and because the stiffness of the mooring ropes is relatively so weak that the natural period of moored ship motions becomes large and the oscillation does not decrease quickly. The author has observed long period oscillations of VLCCs several times at the Port of Kashima5). The period of both surge and sway motions were 100 to 200 seconds. The motions might have been induced by gusty winds and wave drift forces which vary in a period of around 100 seconds.

2.2 Current Method for the Calculation of the Harbour Calmness Index

(1) Definition of the Technical Standard for Port and Harbour Facilities in Japan

It is described as follows in the Technical Standard for Port and Harbour Facilities in Japan (hereafter, the Technical Standard).

A basin should provide appropriate calm shelter with regard to ordinary sea or storm conditions respectively. A basin in front of a berth should provide calm conditions to allow mooring for days corresponding to 90 or 95% or more of the year (or of each season when seasonal variations of calmness are extreme). However, this may not be applied when the frequency of mooring is low, and when the critical mooring conditions are determined separately.

For achieving the above mentioned calmness, a proper plan shall be made with regard to the arrangement, lengths and crest height of breakwaters, and to the construction of wave breaking works to decrease the influence of environmental conditions such as diffracted waves, overtopping waves and reflected waves.

The critical wave height for cargo handling operations in a basin in front of a berth for small ships and other large ships are 30 cm and 50 to 70 cm respectively. However, this may not be applied to a basin in front of berthing facilities for VLCCs.

(2) Basis of the definition of the Technical Standard

The critical wave heights mentioned above were determined based on the results of investigations carried out in the First District Port Construction Bureau, in 1973 and 1979[1),2)]. Table 1 is a list of the wave and wind conditions when cargo handling operations were interrupted and/or suspended due to rough weather conditions and were resumed on improvement of the conditions. For the handling of timber, raft making operations become difficult if the wave height is about 40 cm to 50 cm. Thus, it is not sufficient to consider only the ship motions, the possibility for the safe prosecution of all kinds of harbour must be considered. Ore handling was interrupted due to strong winds of about 10 m/s and over. For a ship handling timber chips, cargo handling operations were interrupted due to excess motions of

Table 1 Wave and Wind Conditiong when Cargo Handling Operation was interrupted and/or suspended and resumed

Kind of goods	Name of Port	Time Sheets	Questionnairs	Interruntion, Suspenson			Discontinue Resumed		
				Wind Speed (m/s)	$H_{1/3}$ (m)	H_{max} (m)	Wind Speed (m/s)	$H_{1/3}$ (m)	H_{max} (m)
Timber	A	Strong Wind & Rough Sea	Raft making and towing difficult	12.4	0.42	0.92	D 20.0	0.91	1.35
	A	Strong Wind & Rough Sea	Raft making and towing difficult Snow	4.7	0.19	0.31	D 8.4	0.25	0.40
	N	Rough Sea	Raft making and towing difficult	11.8	0.56	1.11	R 6.0	0.43	0.77
Ore	A	Strong Wind	Operation of cargo handling equipment difficult	9.0	0.14	0.26	D 13.0	0.41	0.71
	A	Strong Wind & Snow	Operation of Cargo handling equipment difficult, Scattering, wet in the rain and Snow	17.8	0.46	0.75	R 5.6	0.14	0.33
	N	Strong Wind	Operation of cargo handling equipment difficult	17.2	—	—	R 15.0	0.4	0.55
Timber chips	N	Strong Wind & Rough Sea	Ship motions	13.0	0.41	0.98	R 10.0	0.23	0.42
	N	Strong Wind & Rough Sea	Ship motions	9.4	0.41	0.60	D 7.6	0.98	1.61

D : Discontinue, R : Resumed

the ship. In several cases, operations were resumed when the wave height and/or wind speed reduced. The significant wave period for the above mentioned incidents are in the range of 3 to 6 s. The major components of ship motions which affect cargo handling operations are surging and heaving. Table 2 is a list of causes of interruption of cargo handling operations, and the critical wave height and wind speed to each type of material. It can be said that the difficulty of safe cargo handling operation increases if the significant wave height becomes larger than 50 cm.

(3) Calculation of Wharf Operation Efficiency

According to the definition of the Technical Standard above mentioned, a planner counts the number of days when the wave height in front of a berth is less than 50 to 70 cm for each berth in a harbour by use of the distribution of occurrance of waves based on the observed data and the ratio of the wave height in front of the berth to the deep water wave height obtained from the wave diffraction test or the wave diffraction computation. The following is an instance of the calculation of the wharf operation efficiency of the S Port. Figure 1 shows the layout of the S Port. The wharf operation efficiency is calculated as listed in Table 3 for each basin in front of the berth drawn in Fig. 1. The critical wave height is also listed in

Table 2 Causee of the interruption of Cargo Handling Operation and the Critical Wave Height and Wind Speed

Causes & Reason / Kind of goods	Wave		Wind and Rand (Snow)		
	Critical Wave Height	Conditions	Critical Wind Speed	Conditions (Wind)	Conditions (Rain)
Bulk cargo coal, coke, ore, phosphate pattassium chloride	0.5～1.0m	• Ship motions	10m/s	• Scattcsiog (Wind) • Crane Operation on the wharf difficult • Ship motions	• Wet in the rain and snow (70%)
Packed fertilizer, rice, grians	0.5～1.0m	• Ship motions	15m/s	• Ship motions (60%) • Crane operation on the wharf difficult	• Wet in the rain and snow
Heavy machines	0.5m	• Ship motions	10m/s	• Cargo motions (35%) • Ship motions(35%) • Crane Operation on the Wharf difficult (25%)	• Wet in the rain and snow (35%) • Poor visibility • Slippery (50%)
Timbers (on the wharf)	0.5～1.0m	• Ship motions	10m/s	• Ship motion (50%) • Cargo motions (50%) • Crane operation on the wharf difficult (20%)	• Deep Snow (40%) • Poor visibility
Oil	0.5～1.0m	• Ship motions	10m/s	• Sbip metions	
Stone material Sulfaric acid	—	—	15m/s 25m/s	• Crane Operation on the wharf difficult	• Wires becomes slippery

Table 3 Wharf Operation Efficiency of the S Port

Name of Pier	Operation Efficiency
P1	96.0
P2	80.0
P3	97.5
P4～7	98.6
P	78.8
T-s	94.1

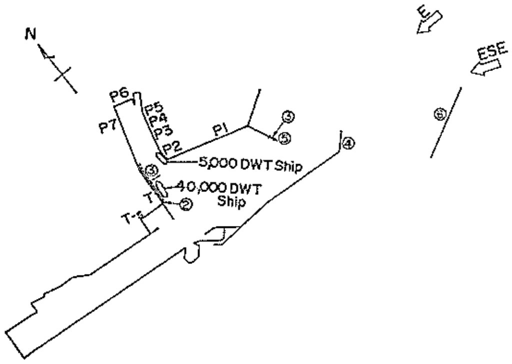


Fig. 1 Layout of the S Port

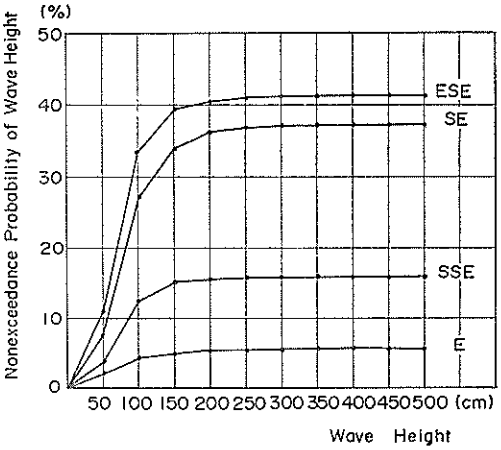


Fig. 2 Non-Exceedance Probability of Wave Height

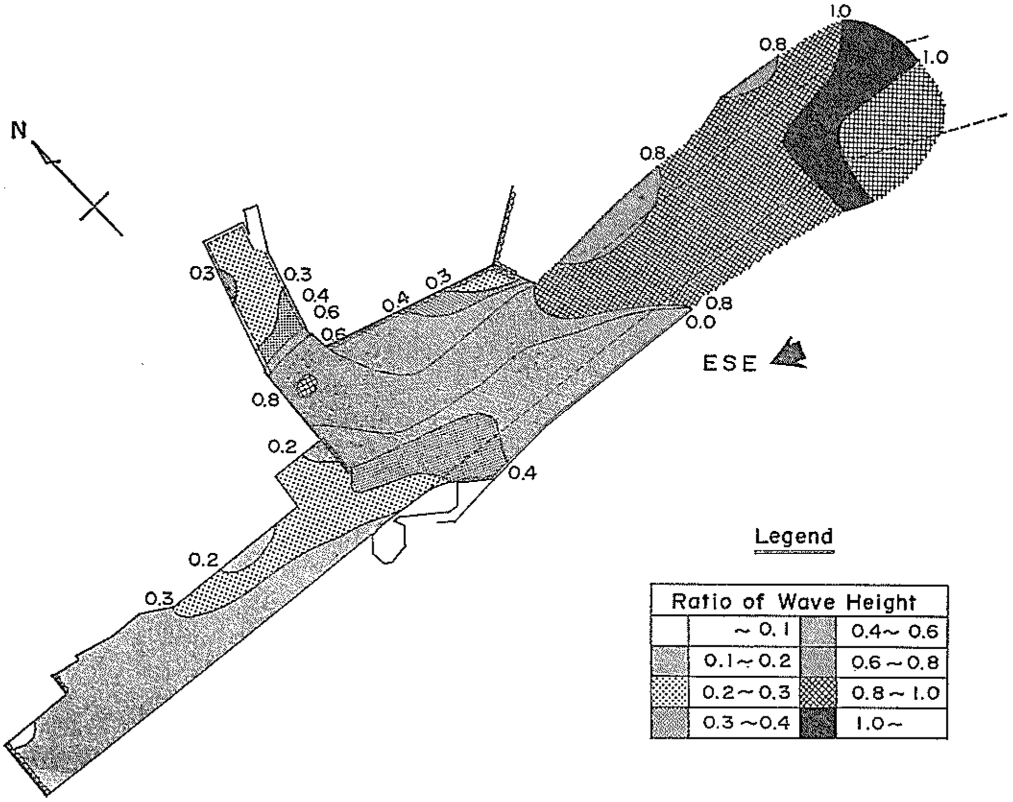


Fig. 3 Ratio of Wave Height in a Basin to Deep Water Wave Height

Table 3 according to the Technical Standard. By reference to the table of frequency occurrance of wave direction, the probability of non-exceedance was calculated. Here, the wave direction north of East was included in East and south of SSE was included in SSE. The non-exceedance probability of wave height is shown in Fig. 2 for each wave direction ESE, SE, SSE, and E. The ratio of wave height in front of the berth to the deep water wave height was calculated according to the wave diffraction computation, and the mean value of the ratio of the Wave height in the harbour was calculated for each direction. Figure 3 is an instance showing the ratio of the wave height in a harbour to the deep water wave height. Table 4 lists the mean value of the ratio of the wave height in front of the berth to the deep water wave height. Then, the critical wave height for cargo handling oerations is divided by the mean value of the ratio of the wave height in front of the berth to the deep water wave height and the critical deep water wave height for cargo handling operation for each wave direction is derived. By reference to the nonexceedance probability of the deep water wave height in each wave dirction, the wharf operation efficiency is calculated for each wave direction and are summed up to get wharf operation efficiency of the harbour. Figure 4 shows the wharf operation efficiency calculated for each berth. Although many berths provide wharf operation efficiencies of more

Table 4 Mean Value of the Ratio of Wave Height in front of a Berth to the Deep Water Wave Height

	E	ESE	SE	SSE
P1	0.23	0.51	0.27	0.23
P2	0.26	0.66	0.21	0.25
P3	0.17	0.34	0.15	0.16
P4~7	0.15	0.28	0.10	0.14
T	0.33	0.68	0.22	0.22
T-s	0.28	0.23	0.08	0.12

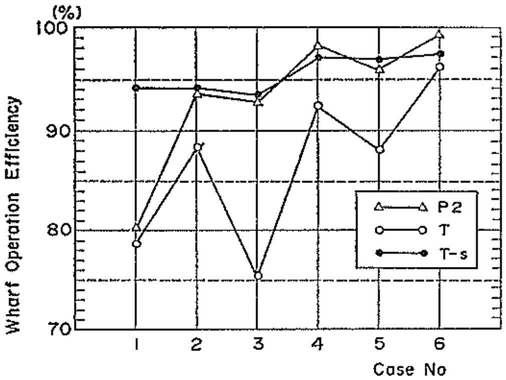


Fig. 4 Wharf Operation Efficiency for Each Berth

than 90 or 95%, there are several berths for which the wharf operation efficiencies are less than 90 to 95%. The inadequate calmness may be improved by reinforcing other port facilities such as breakwaters and wave breaking works.

The current method for calculating the wharf operation efficiency is as described above. However, this method would appear to ignore the effect of wave period on ship motions and the ship motions themselves. The ship motions are influenced by such factors as ship size, wave height, wave period, wave direction, wind speed, wind direction, fluctuation of wind speed, the load-deflection characteristics of the mooring systems, water depth and the structure of berth. Therefore, if we consider whether or not the ship motions are within the allowable movements for cargo handling operations, it cannot be calculated in such a simple manner. It becomes more complicated if we consider all of the factors above mentioned. However, at least wave conditions relating ship motions need to be considered in the calculation of the Harbour Calmness Index.

2.3 Measurement of Ship Motions in the Wave Diffraction Test

(1) Background of the model test

The critical wave height for cargo handling operations defined in the Technical Standard is based on the investigation of the interruption and/or suspension of cargo handling operations carried out in the First District Port Construction Bureau[1),2)]. The significant wave periods were in the range from 3 to 6 s with reference to those ships investigated. But, long period waves can occasionally enter some of the recently constructed ports which are located facing the Pacific Ocean. As an instance, the occurrance of long period waves with a period longer than 10 s as the significant wave period is 23.2% of all of the data gathered at the S Port from 1979 to 1982 (Table 12). Since the long period waves have so much influence on ship motions, some consideration must be given in the calculation of the wharf operation efficiency. Currently, in Japan, only the waves are measured and only the ratio of the wave height in front of the berth to the deep water wave height is calculated in the were diffraction test. But, when considering the effect of ship motions on cargo handling operations, it is recommended that the ship motions should be simultaneously measured as well as the waves. As mentioned above, there are several factors which influence ship motions. Therefore, ship motions cannot simply be calculated according only to the wave height.

The measurement was carried out in a wave diffraction test of the S Port. The purpose of this test was not so much the precise measurement, but more an exercise in demonstrating that ship motions are larger when subjected to long period waves. Model ships were moored to berths denoted T and P2 in Fig. 2. The ship moored

Table 5 Properties of Model Ships

Kind of Ship	40, 000DWT	5, 000DWT
Ship Length (m)	1. 315	0. 835
Ship Width (m)	0. 182	0. 146
Ship Depth (m)	0. 089	0. 090
Draught (m)		
Half Laden	0. 040	0. 035
Ballasted	0. 017	—

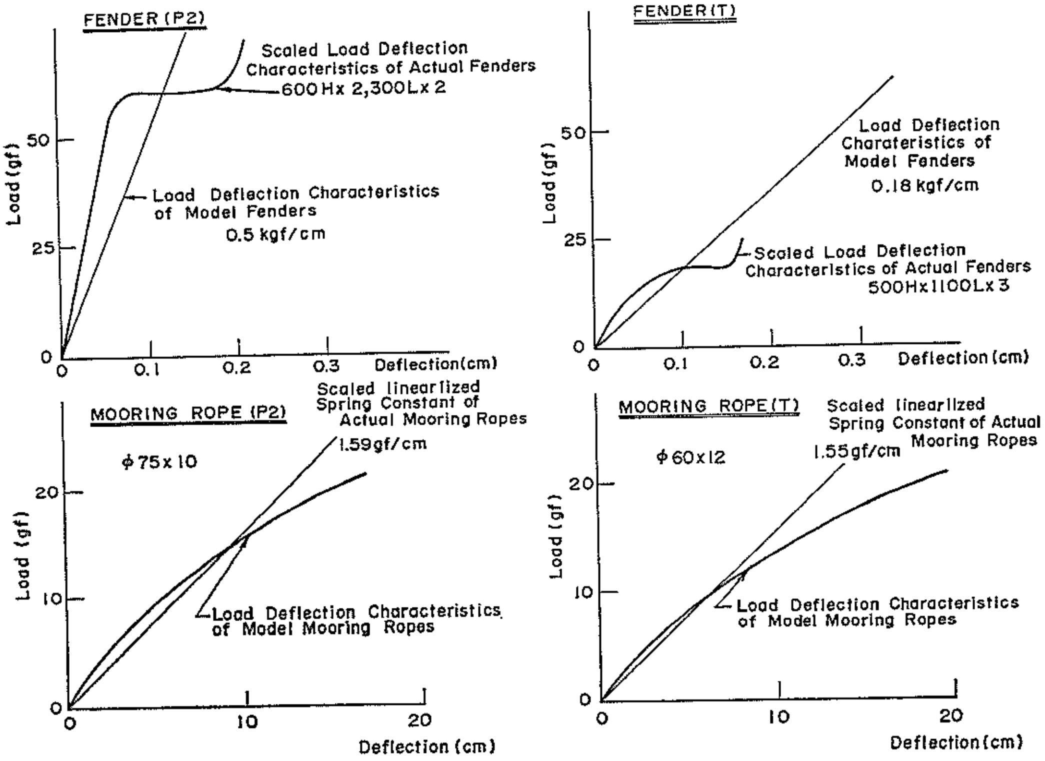


Fig. 5 Load-Deflection Characteristics of Mooring Systems

at the T berth was a model 40,000 DWT ship and the other moored at the P2 berth was a model 5,000 DWT ship. The model ships were not made to exactly match those ships expected to be moored at these berths, but, were selected from several model ships belonging to the laboratory which most nearly match the characteristics of those ships. Table 5 lists the characteristics of the model ships in both half laden and ballasted conditions of 40,000 DWT ship and in half laden of 5,000 DWT ship. The scale of the wave diffraction test was 1:150 which seemed a little small for measuring ship motions because it is difficult to simulate the load-deflection characteristics of the mooring systems consisting of fenders and mooring ropes as shown in Fig. 5.

In this series of model tests, the mooring system consisted of two fenders and two ropes. Model fenders were made of coil spring. The load-deflection characteristics differ from those actually installed, but, the stiffness against initial deformation between 0 to 30% of the fender height is made similar. Fenders actually installed on the T berth are buckling type rubber fenders of 600 H × 2,300 L on 7.6 m centres. Two out of the twelve fenders are thought to work for each bow and stern side contact when the ship moves when subjected to waves. The linearized resultant spring constant of the model fenders was 0.5 kgf/cm. Fenders actually installed on the P2 berth are buckling type rubber fenders 500 H × 1,100 L on 1 m centres. Three are assumed to work on each dolphin when the ship moves when subjected to waves.

The linearized resultant spring constant of the model fenders is 0.18 kgf/cm. Mooring ropes were made of rubber strings which are used for golf balls. Though ten and twelve mooring ropes of 70 and 50 mm in diametre are assumed for the 40,000 and 5,000 DWT ships, a simple arrangement of the mooring ropes consisting of just the bow and stern lines was adopted in this model test. Length, the angle between the face line of the berth and the spring constant of mooring ropes were 45.3 cm, 41 degrees and 1.59 gf/cm respectively for a ship moored at the T berth, and 46.5 cm, 50 degrees and 1.55 gf/cm respectively for a ship moored at the P2 berth. Although the model mooring ropes were made similar to the load-deflection characteristics of the actual ones, it should be noted that the characteristics of the overall model system might have been marginally affected by the cables which were used to measure acceleration of ship motions which could, to some small extent, have acted as additional mooring lines. Therefore, ship motions might be smaller than those expected. Unfortunately no control measurement was made without the cables.

Added to this, the deep water wave height chosen in the diffraction test was larger than the actual one, because the purpose of the wave diffraction test was to determine the ratio of the wave height in front of a berth to the deep water wave height. Consequently, the ship motions in the model test are somewhat larger than actual.

As shown in Fig. 1, several countermeasures were considered to increase the harbour calmness index such as the construction of a deep water breakwater, extension of breakwaters and the construction of wave breaking works as. Results were obtained for several cases, either the present state of port facilities (No. 1), or the construction of wave breaking works along the T berth (No. 2), or the extension of the north breakwater and construction of wave breaking works along the west revetment (No. 3), or, in addition to cases Nos. 2 and 3, the extension of the south

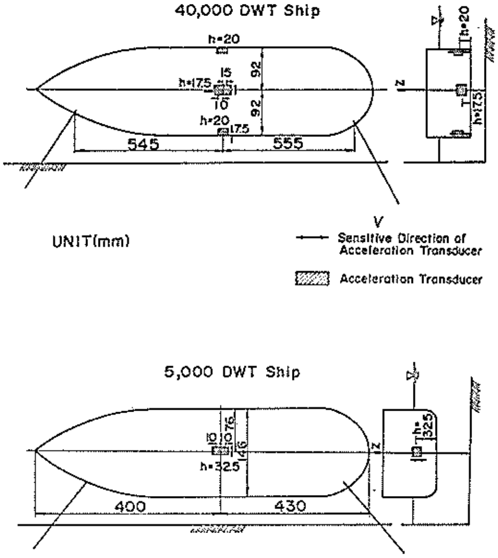


Fig. 6 Setting of Acceleration Transducers

breakwater (No. 4), or the further elongation of the north breakwater (No. 5), or the completion of a deep water breakwater (No. 6). Those facilities to be newly constructed are noted as Nos. 2, 3, 4, 5 and 6 respectively on Fig. 1. These numbers correspond to the case numbers of the test. In cases Nos. 2 and 3, only the countermeasure noted in the figure was taken, while in cases Nos. 4 to 6, the countermeasure noted No. 3 will be also taken together with the countermeasure corresponding to the case number. In case No. 2, because the wave breaking works were set in front of the T berth it was not possible to moor the model ship, therefore motions of only the 5,000 DWT ship were measured. The wave directions in the model test were both E and ESE as shown in Fig. 1. With regard to the countermeasures, the effects were expected for the waves from the ESE direction.

The measurement of the ship motions was carried out by the use of acceleration transducers of 2G capacities made by Kyowa Electronic Instrument Co., Ltd., and they were installed on the ship as shown in Fig. 6. Four acceleration transducers were used for measuring the surge sway, heave and roll motions of the 40,000 DWT ship moored at the T berth, and two were used for measuring the sway and heave motions of the 5,000 DWT ship moored at the P2 berth. In respect of the heave and roll motions, acceleration transducers were set both on the starboard and port sides to obtain the resultant vertical acceleration from those motions. Those records were resolved into the separate vertical accelerations from the heave and roll motions respectively. Those data were recorded by a data recorder.

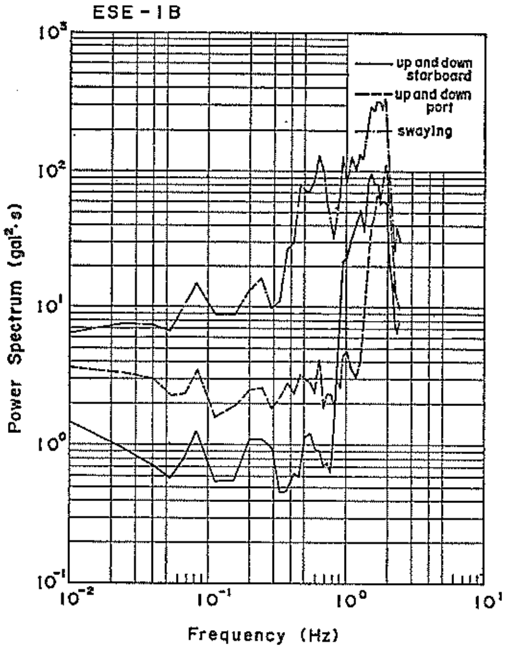


Fig. 7 Frequency Spectrum of Acceleration of Sway and Up and Down

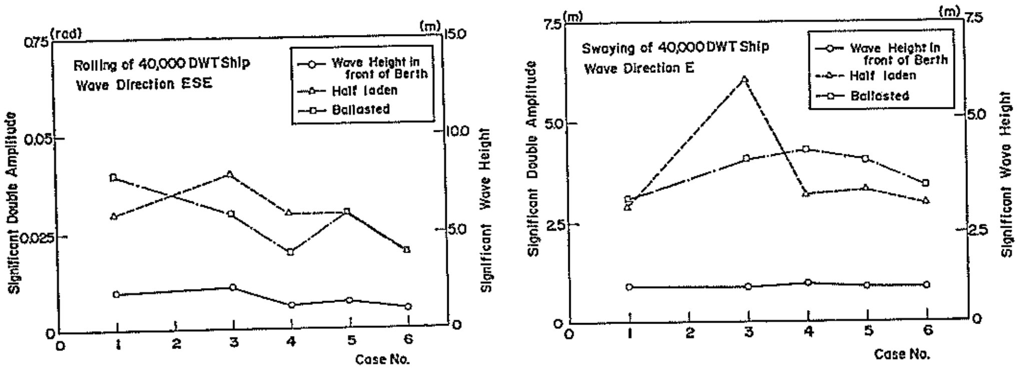
(2) Model Experiment and Results

Accelerations obtained in the model tests were transformed to digital data by the use of an A-D transducer made by TEAC Corporation. The data were integrated by the Fourier Integration Method by use of the ACOS-1000 computer in the Port and Harbour Research Institute. For the integration, attention was paid to the selection of the frequency band for each component of motions. Figure 7 shows the frequency spectrum of the accelerations obtained from each acceleration transducer installed on the 40,000 DWT ship for measurement of the accelerations of sway and up and down of both boards. It is obvious that the acceleration obtained by the transducer installed in order to get the sway acceleration includes the acceleration caused by roll motion, and the reverse is also true. According to the free oscillation in heave and roll motion, the natural period of heave motion were estimated at 0.63 s half laden, 0.57 s ballasted, and those of roll motion were estimated at 0.52 s half laden, 0.50 s ballasted respectively for the 40,000 DWT ship, and 0.57 s in heave and 0.50 s in roll motions for the 5,000 DWT ship. Therefore, it was decided to divide the frequency spectrum into two parts at 1.37 Hz. With regard to surge and sway motions, the frequency bands were set between 0.1 to 1.37 Hz, and in respect of heave and roll motions, the frequency band was set between 1.37 to 10.0 Hz.

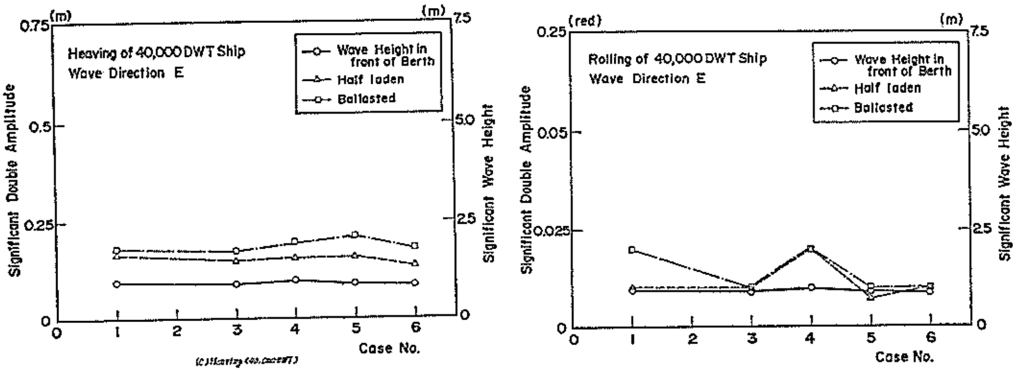
Figures 8-(a) to (f) and Figs. 9-(a) to (f) show the results of ship motions due to the waves from E and ESE directions respectively for each case Nos. 1 to 6. Those are ship motions of surge, sway, heave and roll of the 40,000 DWT ship and sway and heave of the 5,000 DWT ship. In respect of the results for the waves from the E direction, there is not such a significant difference with the results from cases Nos. 1 to 6 because the waves come directly into the basin. The wave heights in front of both the T and P2 berths are nearly equal in every case where the wave heights drawn in these figures are those of standing waves. Although there is some deviation between cases, ship motions are also nearly equal in each case. With regard to the results for the waves from the E direction, the wave height is smaller than for the waves from the ESE direction, because of the effect of the north breakwater, and there is some difference of the ship motions in each case. If the deepwater breakwater were constructed, the wave height would be significantly decreased compared to the present state. But, the wave height is somewhat larger than for the waves from the E direction, because the north breakwater was not effective for this wave direction. Accordingly, ship motions are larger for the waves from the E direction than for the waves from ESE direction. Surge and sway motions were in the range of 2.0 to 3.5 m and 3.0 to 6.5 m respectively for the 40,000 DWT ship for the waves from the E direction and those for the waves from the ESE direction were from 2.5 to 4.0 m and from 5.0 to 13.0 m. Sway motions for the 5,000 DWT ship was in the range of 3.5 to 5.0 m for the waves from the E direction and from 5.0 to 13.0 m for the waves from the ESE direction. As previously mentioned, the deep water wave height was set about five times larger than the actual one. Even it is assumed that the ship motion is proportional to the wave height, a moored ship at both the T and P2 berths would move about 1 to 2 m in sway and surge. Although the wave diffraction tests were carried out for waves with a significant period of 9 s, ship movements will be larger when exposed to long period waves.

(3) Comparison with the numerical simulation and discussion

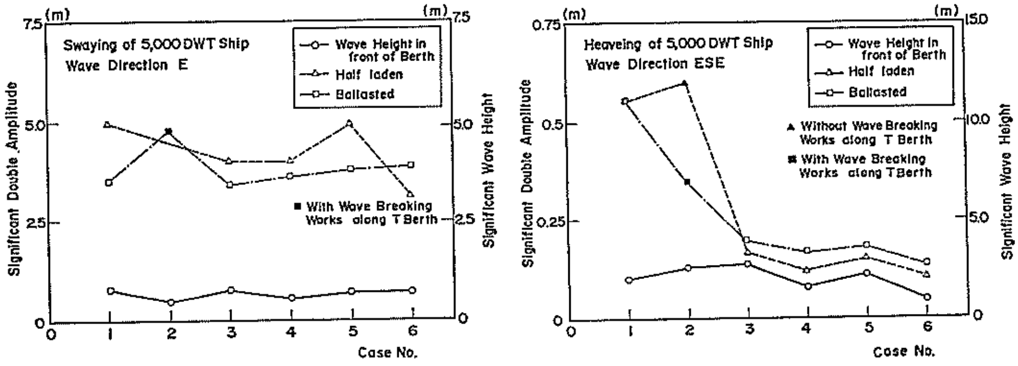
For practical purposes, the numerical simulation of ship motions shall be used



(a) Surge (40,000 DWT)　　(b) Sway (40,000 DWT)

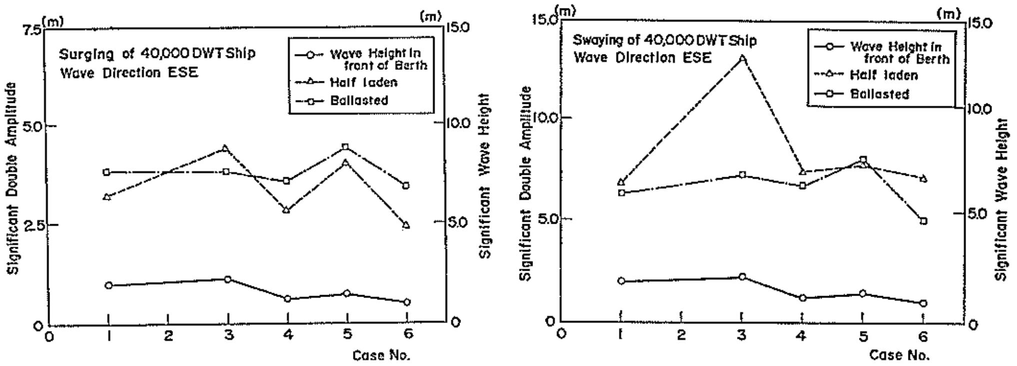


(c) Heave (40,000 DWT)　　(d) Roll (40,000 DWT)



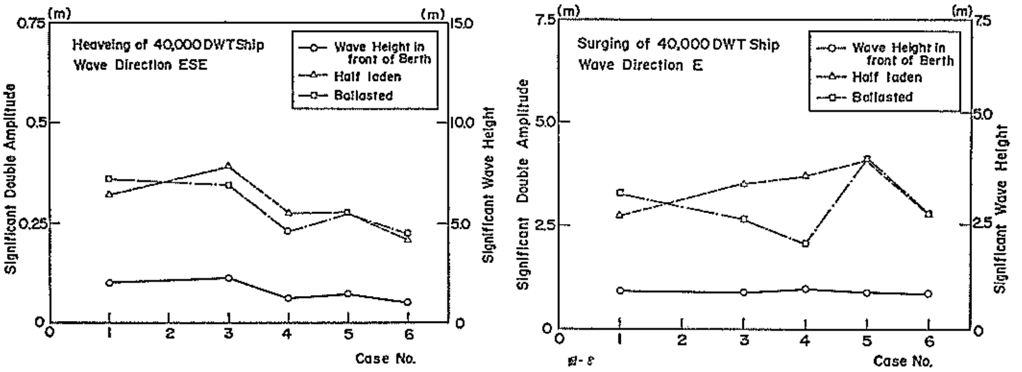
(e) Sway (5,000 DWT)　　(f) Heave (5,000 DWT)

Fig. 8 Ship Motions for waves in Direction E (Model Test)



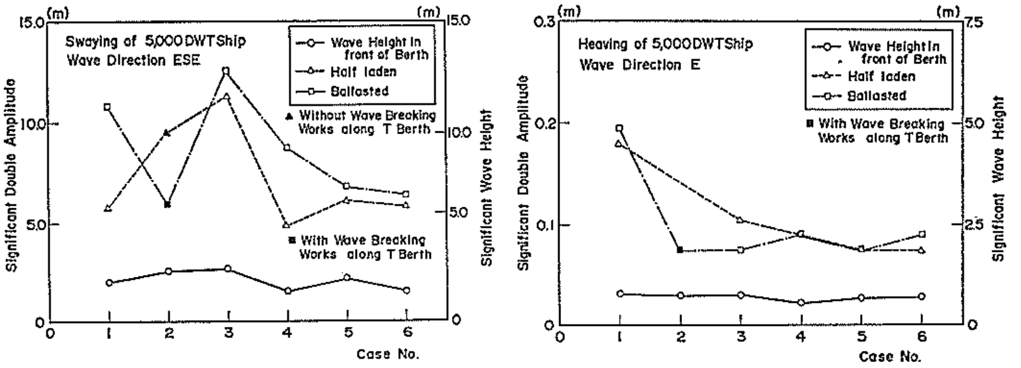
(a) Surge (40,000 DWT)

(b) Sway (40,000 DWT)



(c) Heave (40,000 DWT)

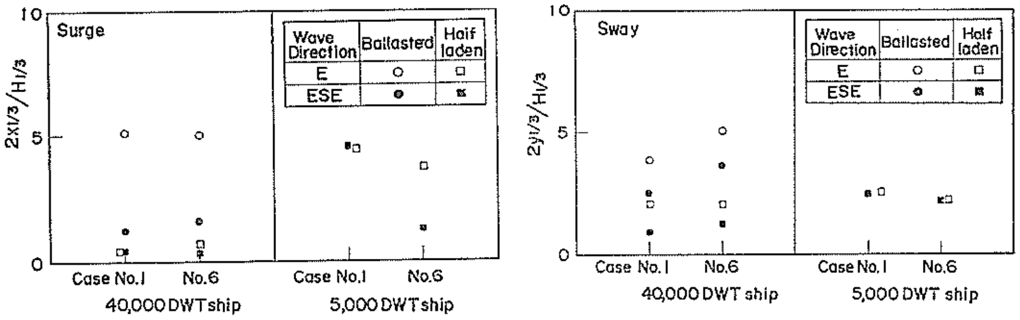
(d) Roll (40,000 DWT)



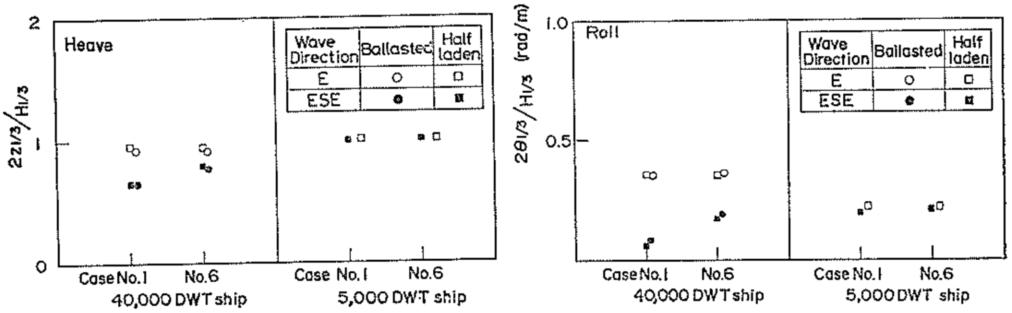
(e) Sway (5,000 DWT)

(f) Heave (5,000 DWT)

Fig. 9 Ship Motions for waves in Direction ESE (Model Test)



(a) Surge (b) Sway



(c) Heave (d) Roll

Fig. 10 Ship Motions for waves in Direction E and ESE (Numerical Simulation)

in future or the calculation of the harbour calmness index. Therefore, here the comparison is made between the results of the model test and the numerical simulation. The computation was made only for both cases Nos. 1 and 6 which corresponded to those of the existing conditions, and the extension of the north breakwater together with the construction of wave breaking works along the west revetment and adding to these the completion of the deep water breakwater. Ships moored to the T berth and P2 berth are subjected to waves of 1.6 m significant height and 9 s significant period. Figures 10-(a) to (d) show the results of the computation. Those of surge, sway, heave and roll motions show good correlation with the results of the model tests shown in Figs. 8 and 9.

2.4 Necessity Considering Motions of Moored Ships

As described above a ship has large motions when exposed to long period waves. Therefore, it is recommended that port planners should consider ship motions when calculating the wharf operation efficiency. This manner of planning of port facilities has been adopted in European countries and in the United States because the problems associated with ship mooring have been recognised since the early nineteen hundreds, especially in those ports located facing the Atlantic and Pacific Oceans. Model tests have been employed to estimate motions of moored ships. Those tests were carried out in basins belonging to several hydraulic laboratories such as the Netherlands Ship Model Basin and the Hydraulics Research Station amongst others. However, now that the numerical simulation is employed, the model test is still useful in order to establish the details of the phenomena under simulated site conditions including topography. The manner of the application for port planning is as follows. Ship motions of a vessel moored at a berth and subjected to certain wind and wave conditions are estimated, then these are compared with the critical or the allowable ship motions for cargo handling operations. The critical and the allowable ship motions for cargo handling operations have been proposed by several researches as follows. Bratteland[6] presented the acceptable wave height for different sizes of ships and acceptable ship movements for ships smaller than 250,000 DWT. Brunn[7] presented the allowable maximum movement for large vessels in excess of 200 m in length at berth for unloading in periods of oscillations 60 to 120 s by summarising several other contributions. Bloom and Posch[8] describe the studies undertaken to define container ship motions acceptance criteria, and their use in selecting terminal layouts to ensure that the recommended marine facilities provide a protected harbour. Slinn[9] has investigated the rate of handling containers by use of a simulator and found that loading rates of 26 containers per hour with stiff moorings for surge movements of 0.92 m (101.5 s) and sway movements of 0.48 m (40 s) and of 19 containers per hour with soft moorings for surge movement of 3.6 m (195 s) and sway movements of 2.84 m (110 s). Viggosson[10] presented the criteria for the maximum value of ship movements for working conditions and for safe mooring conditions at berth. Those data are available in Appendixes.

Although the current method of calculating the wharf operation efficiency is simple, sometimes there are cases when a ship makes large movements though the wave height is less than the values designated in the Technical Standard. Such occurrences might cause rumours amongst captains and ship owners that the harbour and berths do not provide a safe haven with consequent loss of trade. Therefore, ship motions must be considered in calculating the wharf operation efficiency.

3. Ship Motions and Their Effect on Wharf Operation Efficiency

3.1 Characteristics of Ship Motions and Related Factors

(1) Conditions of Model Test and Computation

In this section, description is made on the effect of the load-deflection characteristics of the mooring systems and external forces to motions of moored ships in accordance with the model tests and numerical simulations. Here, the differences of ship motions in waves with and without the action from wind will be presented relating to two different load-deflection characteristics of the mooring systems.

The model ship is a 10,000 DWT cargo ship scaled into 1:30 to the size of 440 cm in length and 41 cm in depth. The draughts of the model ship are 27.7 cm, 22.6 cm, and 14.4 cm in full laden, in half laden and in ballasted conditions, respectively. The model ship is moored to a model quay wall with six mooring ropes and two fenders as shown in Fig. 11. As the structure of the quay is a vertical wall, the model ship moves under the action both of incident and reflected waves.

Type Nos. 1 and 3 model fenders were mainly used from three types of model fenders. The load-deflection characteristics of the model fenders are shown in Fig. 12. The load-deflection characteristic of type No. 1 model fender exhibits the steady reaction force in loading against the deflection in the range of about 15 to 35% of its height and also exhibits large hysteresis in unloading. Type No. 3 model fender exhibits a hyperbolic load-deflection characteristic and small hysteresis.

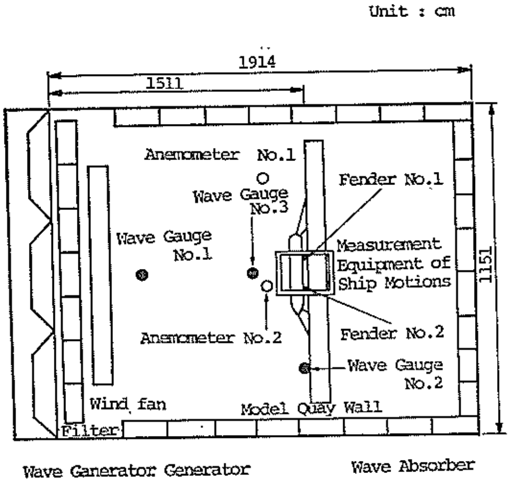


Fig. 11 Mooring of Model Ship

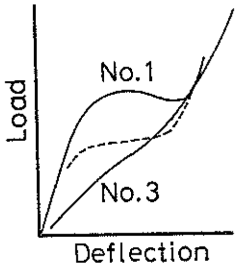


Fig. 12 Load-Deflection Characteristics of Model Fenders

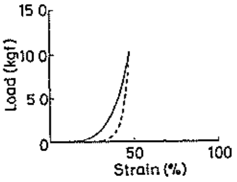


Fig. 13 Load-Deflection Characteristics of Model Mooring Ropes

Model mooring ropes are made by twisting together strips taken from nylon stockings. The load-deflection characteristic of the mooring ropes is shown in Fig. 13. Both model fenders and model mooring ropes exhibit quite similar load-deflection characteristics to those of prototypes.

Several interesting phenomena were observed especially in the sway motions due to the effects of wind, waves and the load-deflection characteristic of the mooring systems. The characteristics of ship motions are described in the following sections with comparisons of both the results of the hydraulic model tests and numerical simulations.

(2) Effect of Wind

Figures 14-(a), (b) show the typical time histories of the sway motions of the model ship obtained from both the hydraulic model tests and numerical simulations to show the effect of wind. The model ship was in ballasted condition and was moored to the model quay wall with the type No. 1 fenders and six mooring ropes. Here, both the wave and the wind directions are 90°. This series of the hydraulic model tests is designated ABQH in this paper. The uppermost diagram is the time history of the sway motions just in regular waves without any wind. The second to the last diagrams are the time histories of the sway motions in irregular waves with the

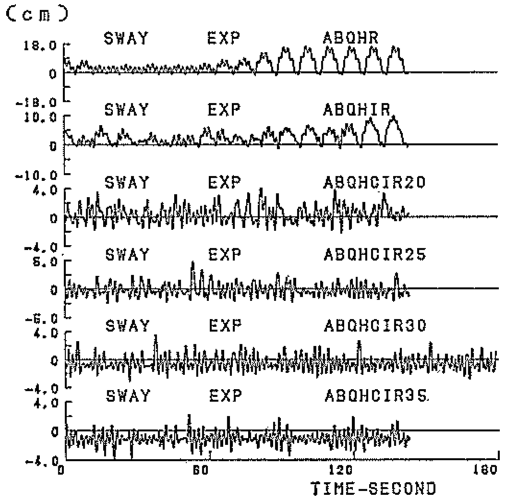


Fig. 14-(a) Tiime Histories of Sway Motions (Model Test)

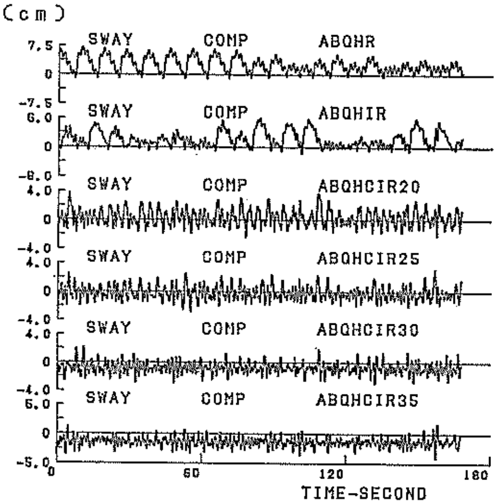


Fig. 14-(b) Time Histories of Sway Motions (Numerical Simualtion)

without the action of wind. The significant wave height is 1.67 cm, the significant wave period is 2.19 s, and the wind speeds are 0, 3.65, 4.56, 5.48, and 6.39 m/s respectively. In this figure, the horizontal axis corresponds to the location of the face line of the fenders, the positive side corresponds to offshore motions and the negative side corresponds to onshore motions. Suffixes R and IR in the case number indicate that the waves are regular and irregular respectively. A suffix of CIR indicates that the waves are irregular and the wind is steady. The figures of 20, 25, 30, and 35 at the end of each case number indicate that prototype wind speeds are 20, 25, 30, and 35 m/s respectively.

When the wind speed is 0 m/s, the offshore sway motions under both the regular and irregular waves becomes large and the period of sway motions becomes three to four times the wave period. This motion is called the subharmonic motion caused by the asymmetry of the load-deflection characteristics of the mooring systems consisting of fenders and mooring ropes when the steady force is not so strong. With the increase of the wind speed from the seaside, compression of the fender increases according to increase of the steady wind force, then the neutral position of the sway motions moves nearer to the fender side. But the amplitudes of the sway motions decrease when the wind speed increases, because of the deformation of fenders the asymmetry of the load-deflection characteristics of the mooring systems becomes weaker. In these hydraulic model tests, the fender has been so designed that the deflection becomes about 10% of its height when the model ship is subjected to a wind of 6.39 m/s mean wind speed. Therefore, the asymmetry of the load-deflection characteristics of the mooring systems previously mentioned becomes relatively weaker in relation to an increase of the deformation of the fenders which corresponds to an increase of wind speed.

The time histories of the sway motions of the model ship obtained from the numerical simulations are very similar to those of the hydraulic model tests. Although, the maximum amplitude of the sway motions differs a little bit, the characteristics of

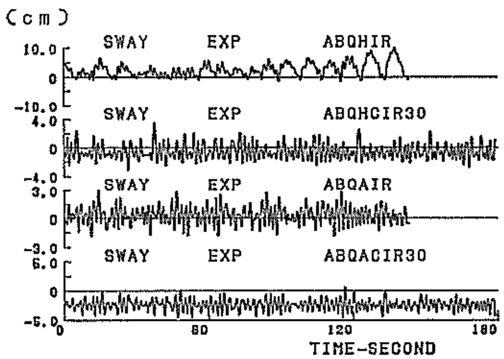


Fig. 15-(a) Time Histories of Sway Motions (Model Test)

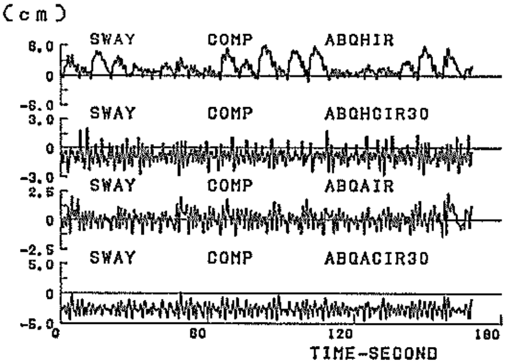


Fig. 15-(b) Time Histories of Sway Motions (Numerical Simualtion)

the sway motions of both the hydraulic model tests and numerical simulations are very similar.

(3) Effect of Characteristics of Mooring System

Figure 15-(a) shows the time histories of the sway motions of the model ship, subjected to wind and waves from the 90° direction where the significant wave height and wave period of irregular waves are 1.67 cm and 1.83 s respectively. The upper two diagrams correspond to cases with type No. 1 model fenders while the lower two diagrams are for cases with type No. 3 model fenders. The series of the hydraulic model tests using the type No. 3 model fenders is designated ABQA in this paper. For each pair of diagrams, the upper set represents the case without the action of wind and the lower set is the case with the action of a steady wind of 5.48 m/s (the figure of 30 at the end of the case number indicates the prototype wind speed being 30 m/s).

When the wind speed is 0 m/s, the difference in the time histories of the sway motions between cases using type Nos. 1 and 3 model fenders can be easily found. This phenomenon is caused by the asymmetry of the load-deflection characteristics of the mooring system. Because the asymmetry of the load-deflection characteristics of the mooring system with the type No. 1 model fenders is strong, large offshore long period sway motions are observed. As for the type No. 3 model fenders, the asymmetry of the load-deflection characteristics of the mooring system is relatively weak, therefore, the period of the sway motions does not become so large. Figure 15-(b) shows the time histories of the sway motions of the model ship obtained from the numerical simulations corresponding to those of the hydraulic model tests The same sort of ship motions are obtained from the numerical simulations.

Figure 16 shows the frequency spectrums of the sway motions obtained from both the hydraulic model tests and numerical simulations for those cases ABQHIR (type No. 1 fenders, irregular waves, no wind), ARQAIR (type No. 3 fenders, irregular waves, no wind), ABQHCIR30 (type No. 1 fenders, irregular waves, steady wind) and ABQACIR30 (type No. 3 fenders, irregular waves, steady wind) where the significant wave height, wave period and the wind speed were 1.67 cm, 1.83 s and 5.48 m/s respectively. In the frequency spectrum of the sway motions of ABQHIR, there are peaks of power at 10 and 1.83 s, and the intensity of power at 10 s is

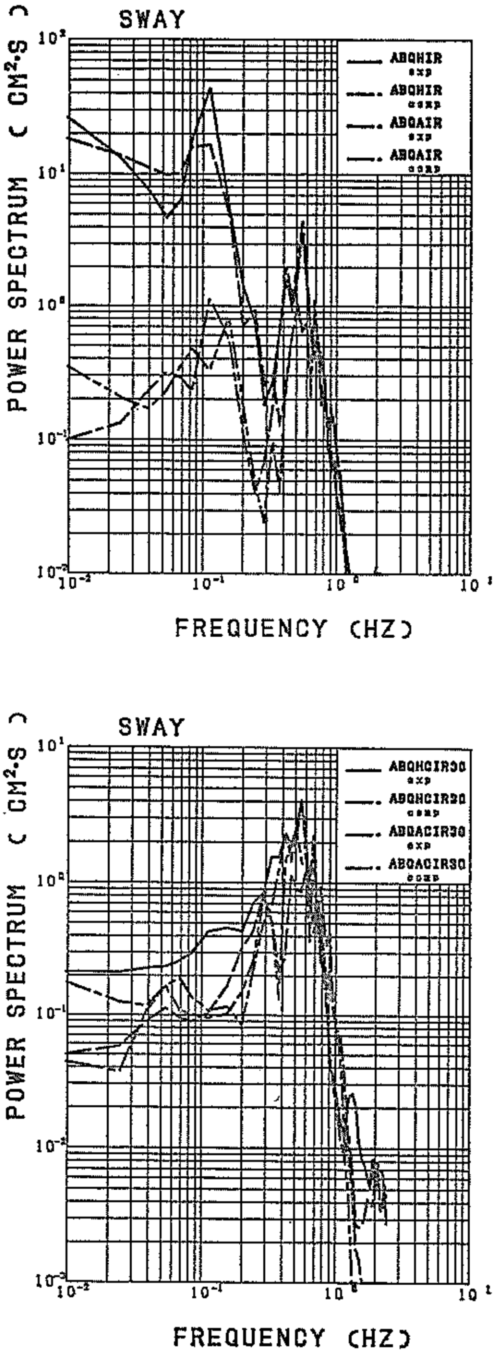


Fig. 16 Frequency Spectrum of Sway Motion

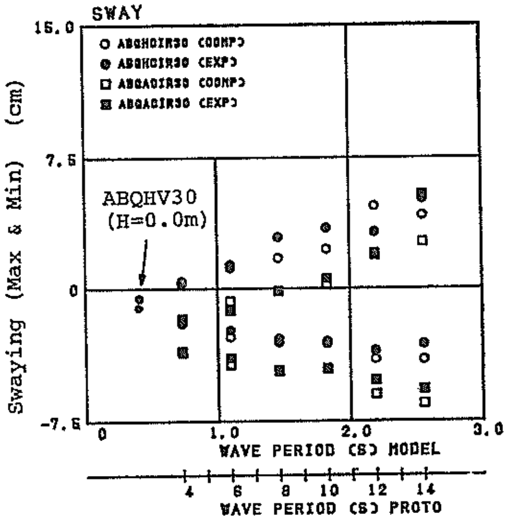


Fig. 17 Maximum Amplitude of Sway Motion (Wave Direction 90°)

larger than that of 1.83 s. But the frequency spectrum of the sway motions of ABQAIR, the intensity of power at 10 s is smaller than not only that of 1.83 s but also that of ABQHIR. Frequency spectrums both of ABQHCIR30 and ABQACIR30 show almost the same characteristics. Good agreements of frequency spectrums were obtained between the hydraulic model tests and numerical simulations.

(4) Effect of Waves

Figure 17 shows the maximum amplitudes of the offshore and onshore sway motions for those cases of ABQHCIR30 and ABQACIR30 comparing both the results of the hydraulic model tests and numerical simulations. The open and closed symbols indicate the maximum (denoted Max) and minimum (denoted Min) motion of the numerical simulations (denoted as COMP) and hydraulic model tests (denoted as EXP) respectively. Here conditions of wind and waves are the same as those in Fig. 16. Generally, the amplitude of ship motion increases when the wave period becomes longer. Good agreements were obtained between both the results of the hydraulic model tests and numerical simulations. In these figures, data are plotted which are obtained on the condition when the significant wave height is 0 m and the gusty wind of 5.48 m/s mean wind speed acts to the model ship from the same directions with those cases above mentioned. The amplitude of the sway motions is considerably smaller when the wave height is 0 m, therefore in this case study, it can be said that the gustiness of the wind does not affect ship motions so much as do waves.

Figure 18 shows the maximum amplitude of the offshore and onshore sway motions obtained from the model test for those cases with different wave directions of 30°, 60°, and 90° without wind. Sway, heave and roll motions decrease when the wave direction backs round from 90° to 30°. On the other hand, surge and yaw motions are larger when the wave direction is 60°.

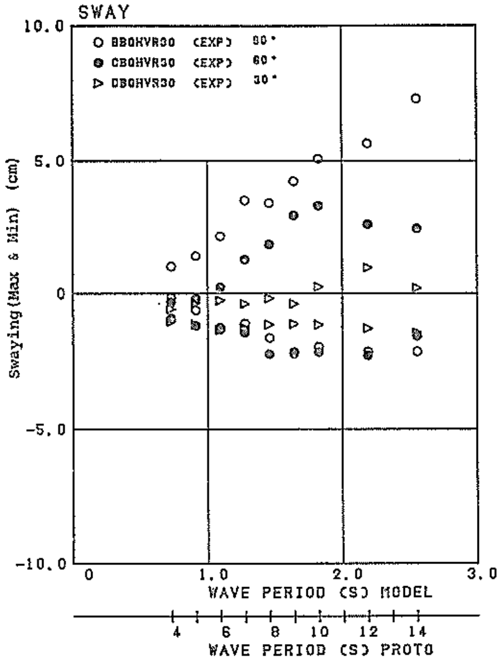


Fig. 18 Maximum Amplitude of Sway Motions (Wave Direction 30°, 60°, 90°)

(5) Consideration of Long Period Ship Motions Subjected to Wind and Waves

In this section description is made on the effect of the fluctuation of wind on the ship motions examined by means of the numerical simulation method. Objective vessels are 258,000 DWT and 237,000 DWT oil tankers. Ships were moored at a fixed type deep water terminal with several synthetic ropes. Gusty wind is generated by use of the Davenport frequency spectrum. The results of the computation show the possibility of a large long period oscillation caused by the fluctuation of wind speed.

Table 6 Properties of VLCC

Items	Ship A	Ship B
DWT	258, 000 tf	237, 000 tf
LOA	321m	321m
LPP	310m	304m
B	58m	52m
D	29. 5m	25. 7m
d(Full)	19. 5m	19. 9m
d(Ballasted)	9. 9m	7. 34m
DT(Full)	291, 000 tf	271, 000 tf
DT(Ballasted)	136, 400 tf	91, 000 tf

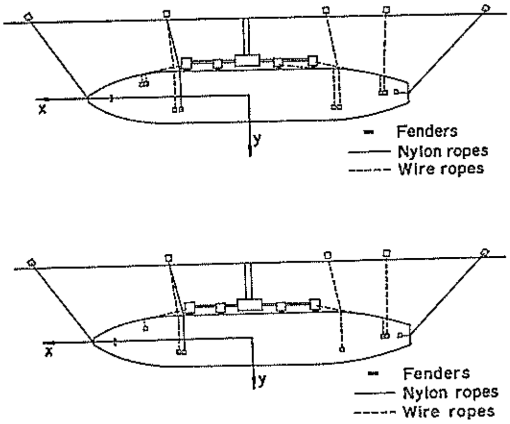


Fig. 19 Scketch of Mooring Ship

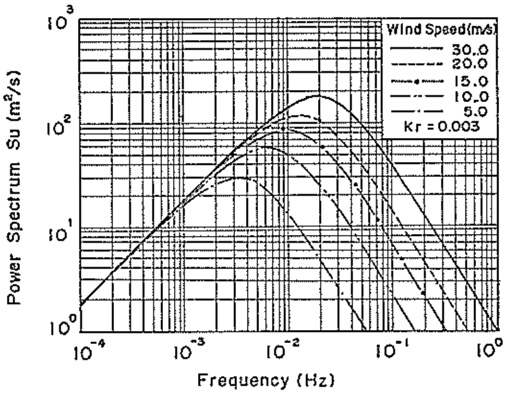


Fig. 20 Frequency Spectrum of Gusty Wind

Table 7 Ship Motion Caused by Gusty Wind

No.	DWT $\times 10^3$	Wind		Wave			Surge(cm)			Sway(cm)		
		Dir	V(m/s)	Dir	$H_{1/3}$ (m)	$T_{1/3}$ (s)	Max	Min	Ave	Max	Min	Ave
1	258	0	5	—	—	—	−5.6	−20.9	−13.1	−0.0	−0.1	−0.1
2	258	0	10	—	—	—	−2.4	−80.2	−52.2	−0.1	−0.4	−0.3
3	258	0	15	—	—	—	−53.1	−177.4	−117.0	−0.3	−0.9	−0.6
4	258	0	20	—	—	—	−90.2	−316.3	−206.0	−0.5	−1.8	−1.1
5	258	0	30	—	—	—	316.7	−874.9	−299.7	25.7	−8.3	4.0
6	258	0	5	0	1.5	10	3.5	−35.1	−13.1	0.0	−0.2	−0.1
7	258	0	10	0	1.5	10	−16.4	−91.6	−52.1	−0.1	−0.4	−0.3
8	258	0	15	0	1.5	10	−47.1	−185.7	−116.9	−0.2	−1.0	−0.6
9	258	0	20	0	1.5	10	−79.4	−325.0	−206.0	−0.4	−1.8	−1.1
10	258	0	30	0	1.5	10	318.2	−871.0	−300.6	25.9	−8.5	4.0
11	237	0	5	—	—	—	−10.0	−32.8	−21.6	−0.1	−0.2	−0.1
12	237	0	10	—	—	—	−40.6	−129.5	−85.5	−0.2	−0.6	−0.4
13	237	0	15	—	—	—	−88.5	−292.1	−187.4	−0.4	−1.5	−0.9
14	237	0	20	—	—	—	−101.1	−504.7	−307.1	−0.5	−3.0	−1.6
15	237	0	30	—	—	—	25.6	−915.1	−487.0	16.2	−9.9	−1.7
16	237	0	5	0	1.5	10	4.0	−46.0	−21.6	0.0	−0.2	−0.1
17	237	0	10	0	1.5	10	−32.8	−143.2	−85.5	−0.1	−0.7	−0.4
18	237	0	15	0	1.5	10	−82.6	−301.5	−187.2	−0.4	−1.6	−0.9
19	237	0	20	0	1.5	10	−96.8	−508.4	−307.1	−0.4	−3.1	−1.6
20	237	0	30	0	1.5	10	21.4	−919.7	−490.5	16.1	−9.7	−1.7

The properties of ships are listed in Table 6. Ships are moored at dolphins with rubber fenders and mooring ropes made of nylon as shown in Fig. 19. As described later, the surge motions of the 237,000 DWT tanker seemed larger than the 258,000 DWT tanker, the arrangement of mooring ropes was revised so as to make the spring constant of ropes small. Figure 20 shows the frequency spectrum of gusty wind generated by using the Davenport frequency spectrum. As shown in the figure, the peak frequency becomes smaller with the increase of wind speed. Because the dominant period gusty wind is longer than 50 s, attention must be paid to the surge motion. Then in this case study, the wind direction was set at zero which means the wind blows from head to stern. The significant wave height is 1.5 m and the significant wave period is 10 s. In this computation, wave drift force is not considered.

Table 7 lists the results of the computations. Here, only the surge and sway motions are discussed. Examining the results of cases Nos. 1 to 10, it seems that there is no difference between the results with and without the action of waves. Therefore, it may be said that the effect of waves to those motions is not significant. Comparing the results of cases Nos. 6 to 10 with the results of cases Nos. 16 to 20, the motions of the 237,000 DWT tankers are larger than those for the 258,000 DWT tanker. As the resultant longitudinal spring constant of the mooring ropes for 237,000 DWT tankers is calculated at about 38.5 tf/m, the virtual natural period of the surge motions comes close to the dominant period of the gusty wind. Figure 21 shows the frequency spectrum of the surge motions of both the 258,000 and 237,000 DWT

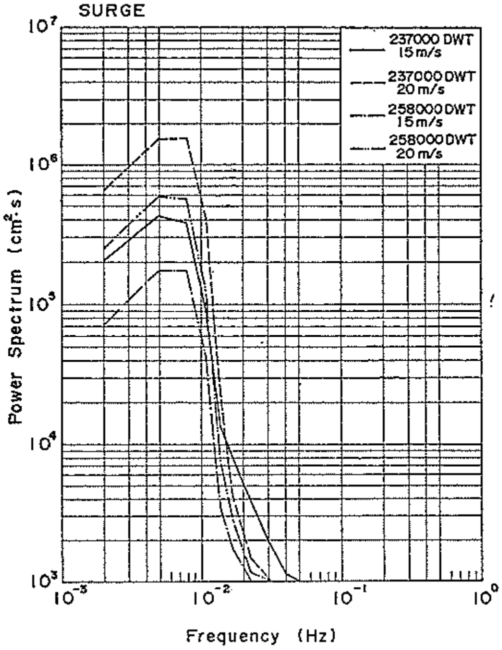


Fig. 21 Frequency Spectrum of Surge Motion

tankers respectively subjected to winds of 10 minute mean speeds of 15 and 20 m/s.

3.2 Review of the Problems Caused by Ship Motions

(1) Instances in Japan

As mentioned in 2, there are several investigations on the effect of ship motions on cargo handling operations. Kubo[11)] analysed time sheets of cargo handling operations at the A Port and obtained results that show the long period waves which cause the ship motions was ranked as the second reason (4.1%) of interruption and suspension of cargo handling operations, while rain was the first reason (7.6%).

The effect of ship motions on cargo handling operations was also indicated in the report of the investigation carried out in the First District Port Construction Bureau[1)]. Mooring ropes of a ship moored at the berth in the N Port were broken when subjected to winds of 10 m/s mean speed which had been blowing for nearly one day and one night.

The author has investigated the damage of fenders at several ports which are located in the southern part of Hokkaido facing the Pacific Ocean and found that fenders installed on those berths located nearer the outer areas of the port were more damaged than those installed on inner berths[12)].

The author also measured motions of VLCC moored to the dolphin type sea berth at the K Port and obtained a record of the long period surge and sway motions of around 100 to 200 s[5)]. The sea berth is located 2,000 m inside the breakwater head. The harbour is well sheltered throughout the year. But if a northerly wind blows continuously in winter and the beginning of spring, the long period waves diffracted at the breakwater and reflected at the coast come into the basin. Sometimes, the wind speed was 20 m/s and the significant wave height and period were 1.3 m and 12 s respectively while a ship was moored. Subjected to wind and waves, a moored VLCC moved in long period 2.4 m in the surge direction and 2.0 m in the sway direction. Fenders installed on the dolphins deformed about 20 cm over a duration of about 20 to 30 s. These long period ship motions were caused by the action of long period waves and gusty winds, and the soft load-deflection characteristics of the mooring ropes and the asymmetry of the load-deflection characteristics of the mooring system as mentioned in 3.1.

(2) The Port of Cape Town[13)]

The Port of Cape Town is located facing Table Bay at the north foot of the Table Mountain. When a northerly wind blows continuously, long period waves enter the Duncan Basin and cause seich. The observation was made at the basin in 1945. Although the amplitude of the surface elevation was 15 cm, its period was around one minute. Ships moored at the C berth and the D berth which were 6,400 GT and 13,400 GT respectively moved 50 and 100 cm, and 75 and 50 cm in the surge and sway directions respectively. These motions caused the breaking of mooring ropes and interrupted the cargo handling operations. The cause of these accidents was concluded to be the long period waves coming into the basin and secondary seich which then occurred. Breakwaters have been constructed to protect the basin from long period waves and ships put out extra mooring ropes to secure them tightly.

(3) The Port of Los Angeles[14)]

On the west coast of the United States, it has been ascertained that long period waves with periods in the range of 1 to 60 minutes exist. According to the records made over several days from 23rd., April, 1944, the amplitude of the surge and sway motions were in the range of 1.8 to 3.2 m, and 2.2 to 2.3 m, and with periods of 250 and 500 s respectively. The record was obtained before the completion of the mole. The significant wave heights were 45 cm and 6 cm for significant wave periods of 15 s and 6 min respectively. Vanoni and Carr[14)] described that the long period waves were generated in the oceans of the southern hemisphere far away from the United States and were propagated to the U.S. coast. Seich occurred when the period of long waves coincided with the natural period of the basin. The countermeasure taken was the extension of the breakwater in order to narrow the entrance from 630 to 180 m. As a result, the wave height of the long period waves inside the harbour decreased about 50%. They also indicated the improvement of the mooring systems, but no practical countermeasures were taken at the time.

(4) Marcona Pier, San Nicolas Bay[15)]

At the Marcona Pier, Peru, long period ship motions were measured. The pier is designed for 150,000 DWT ore carriers made of pre-stressed concrete. The berth is built out from the coast to seaward and is oriented to the north. Cylindrical fenders of 9 inches outer diametre, 8 inches inner diameter and 21 inches long were installed. When the long period waves which are generated in the low latitudes of the southern hemisphere sometimes come to the pier, ships must stand off from the pier for three or four days. The wave period is about 16 s. The period of the sway motion was in the range of 50 to 150 s. Fenders were damaged and mooring ropes were broken during ship motion. It was thought that the cause was the harbour surge because the period of the ship motions was as long as 1 to 3 min and long period waves of 20 min were observed on the tide record. The movement of the bow and the stern of a 74,730 DWT ore carrier was measured. The bow or stern made a circle in a period of 16 s and with each four or five repititions of this motion the ship made a long period motion of about 100 s in between successive impacts on the pier. Model experiments were carried out to clarify the phenomenon. The motion above mentioned was also observed in the model test. This motion is well known sub-harmonic motion which is caused by the asymmetry of the load-deflection characteristics of the mooring system.

3.3 Interruption of Cargo Handling Operations Caused by Ship Motions

(1) Out Line of the Investigation

The investigation of the interruption of cargo handling operations caused by ship motions was carried out by the author and his colleagues at several ports which are located facing the Pacific Ocean in which cargo handling operations were reported to be influenced by ship motions induced by the action of long period waves. The data obtained in this investigation are now under analysis to obtain the critical and allowable ship motions for cargo handling operations in terms of the kind and size of ships. In this paper, brief results of the analysis for the S Port and the O Port are presented, and full paper will be published in the coming year.

The interruption and suspension of cargo handling operations was investigated by use of the work diary of operators. Items for investigation were date and time of the interruption and/or the suspension of cargo handling operation, the berth, properties of the ship, wind and wave conditions, kinds of goods handled, method of cargo handling, structures of the mooring facilities, type and size of fenders, arrangement and type of mooring ropes. The wave meter was set outside the breakwater in both ports, but nothing was placed inside the basin. The wave height in the basin was calculated according to the results of the wave diffraction test. Although the wave diffraction computation was also carried out by use of the computer program developed in the Port and Harbour Research Institute[16], the ratio of the wave height in front of the berth to the deep water wave height differs to that obtained from the wave diffraction test. Therefore, the results of the wave diffraction test are adopted in this paper. Ship motions are to be computed for each case of interruption and suspension of cargo handling by use of the computer program developed in the Port and Harbour Research Institute[17]. The interruption and/or suspension of cargo handling operations is defined in this report such that cargo handling operations were interrupted and/or suspended by any reason. The suspension of cargo handling includes standing off a berth in a basin or outside the harbour breakwaters and waiting for the cargo handling operations to commence after mooring to a berth. For all of the incidents of the suspension investigated in the above two ports, ships had been standing off a berth outside the breakwaters.

(2) Incidents of Interruption and Suspension of Cargo Handling Operation at the S Port

The investigation was made for two berths at the S Port. They are the P2 and P3 berths indicated in Fig. 1(2.). Data were obtained over two years in 1983 and 1984. Data were analysed and the instances of the suspension of mooring the berths due to an increase of the wave height and the interruption of cargo handling operations due to large ship motions were obtained. Table 8 lists the number of ships calling and the occurrence of the interruption and/or suspension of cargo handling operations which might have been caused by large ship motions during the two years. This shows 11.5 and 3.1% respectively. Table 9 lists the monthly number of interruptions and suspensions of cargo handling operations. It seems that interruption and suspension of cargo handling operations frequently occurred from April to May and from September to October. Figures 22-(a), (b), (c) show the relation between the gross tonnage (GT) of those ships for which cargo handling operations were interrupted and the significant wave height or the significant wave periods. Figures 23-(a), (b), (c) show the relation between the gross tonnage (GT) of those ships which waited outside the breakwater and the significant wave height or the significant wave period. It can be said that the smaller the ship, the

Table 8 Number of Ships Calling and Interruption and/or Suspension of Cargo Handling Operations (S Port)

Name of Pier	Year	Number of Ships Calling	Number of Suspension	Number of Interruption
P2	1983	53	7	2
	1984	62	11	1
P3-C	1983	178	15	3
	1984	133	15	9
P3-D	1983	188	17	4
	1984	159	24	5
Total	1983	419	39	9
	1984	353	50	15
1983～1984		773	89	24

Table 9 Monthly Number of Interruption and Suspension of Cargo Handling Operations (S Port)

Month	Number of Suspension	Number of Interruption
1	4	3
2	7	—
3	8	—
4	16	4
5	6	1
6	8	1
7	7	1
8	8	—
9	9	4
10	8	3
11	5	3
12	3	4

(P-2 and P-3
1983~1984)

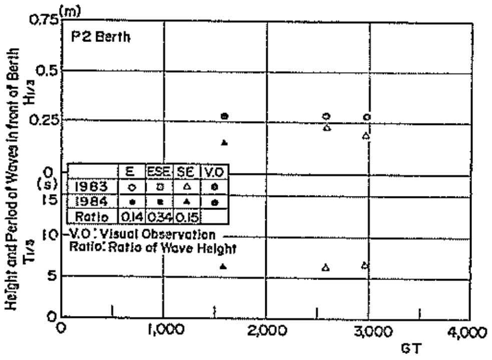
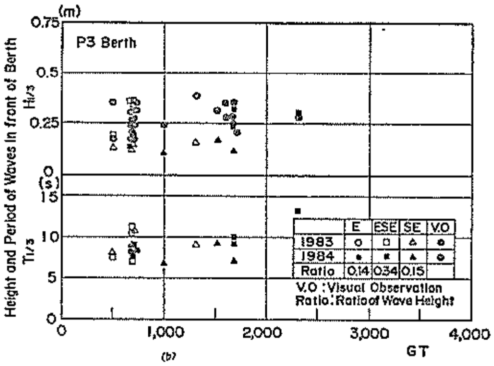


Fig. 22-(a) Relation between GT and Wave Height when Cargo Handling Operation was Interrupted and/or Suspended(S Port, P 2 Berth)



(b) Relation between GT and Wave Height when Cargo Handling Operation was Interrupted and/or Suspended (S Port, P 3-C Berth)

higher the wave height and the longer the wave period is, the more frequently cargo handling operations were interrupted and/or suspended. In any event, there are many cases when the wave height was less than 30 cm in front of the berth when cargo handling was interrupted and/or suspended. That the critical wave height may be smaller depends on the wave direction and wave period. Therefore, it is concluded that it is not correct to apply the definition of the current Technical Standard in the S Port. The availability of berths in the S Port will be presented later in 4.

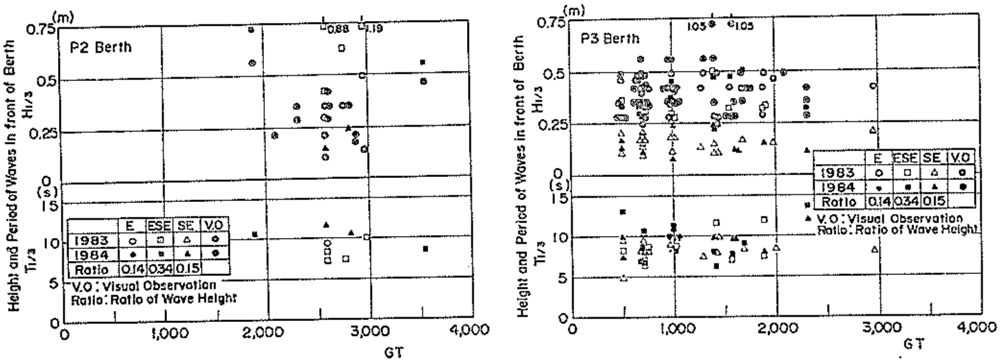


Fig. 23-(a) Relation between GT and wave Height when Ships stood off a Berth Outside of Harbour Breakwater (S Port, P2 Berth)

(b) Relation between GT and wave Height when Ships stood off a Berth Outside of Harbour Breakwater (S Port, P3-C Berth)

(3) Incident of Interruption and Suspension of Cargo Handling Operation at the O Port

The investigation was made for several berths at the O Port. They are P1, P2, P3, P4, P7, F and O berths indicated in the Plan View of the O Port (Fig. 24). Data were obtained from October 1979 to December 1984. Data were analysed and the instances of the suspension of mooring the berths due to an increase of the wave height and the interruption of cargo handling operations due to large ship motions were obtained. Table 10 lists the number of ships calling and the occurrence of the interruption and/or suspension of cargo handling operations which might have been caused by large ship motions during the 5 years. This shows 0.28 and 0.14% respectively. The interruption and the suspension of cargo handling operations occurred rather more frequently at berths P1, P3, and F. It seems that the ratio of interruption and suspension of cargo handling operations in the O Port is not so large compared to the S Port. This is the effect of the breakwaters which protect the harbour from waves in the East to South direction. Figure 25 shows the relation of the gross tonnage (GT) and the wave height or the wave period of the deep

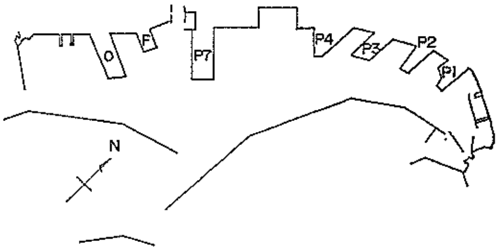


Fig. 24 Layout of the O Port

Table 10 Number of Ships Calling and Interruption and/or Suspension of Cargo Handling Operations (O Port)

Name of Pier	Number of Ships Calling	Number of Suspension	Number of Interruption
P1	2825	16	2
P2	2317	6	1
P3	3544	24	11
P4	5188	5	3
P7	932	5	2
F	935	13	9
O	5383	12	0

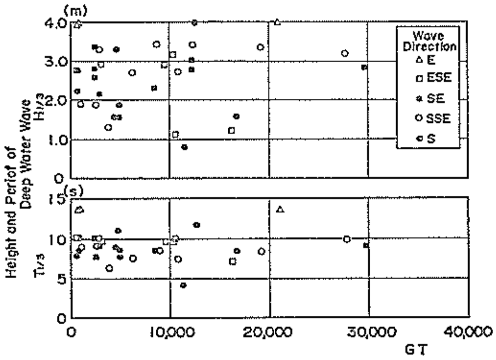


Fig. 25 Relation Between DWT and Wave Height when Cargo Handling Operation was Interrupted and/or Suspended (O Port)

water wave when cargo handling operations were interrupted and/or suspended. Though the breakwater is constructed north to south to protect almost all the berths from waves in the East direction, there are several instances of interruption and suspension of cargo handling operations when the wave direction is around East. It is difficult to say, because of the lack of wave measurements inside the breakwaters, whether there are still some disturbances or not caused by the waves in the East direction. If so, these disturbances may be caused by overtopping and/or permiated waves through the rubble mound of the opposite breakwater.

4. Improvement of Mooring Systems to Reduce Ship Motions

4.1 Present Mooring Systems and Ship Motions

As mentioned in the previous chapter, the cargo handling operation efficiency at the T, P2 and P3 berths of the S Port is less than 90% of the whole year, wwhich is lower than the other berths, because long period waves comes into the harbour from the direction E, ESE and ES, and the wave direction of those refracted waves becomes nearly perpendicular to the face line of those berths. Sway motions are dominant in those berths, and the motions are the so called subharmonic motion. This motion is caused by the asymmetry of the load-deflection characteristics of the mooring systems. Therefore, it is expected that ship motions would be reduced with improvement of the load-deflection characteristics of the present mooring systems so that the asymmetry of the load-deflection characteristics of the mooring systems becomes weaker. The present mooring system of the P2 berth consists of three buckling type fenders of 500 H × 1,100 L on 1 m centres for each dolphin and that of the P3 berth consists of seven buckling type fenders of 400 H × 1,500 L on 7 m centres.

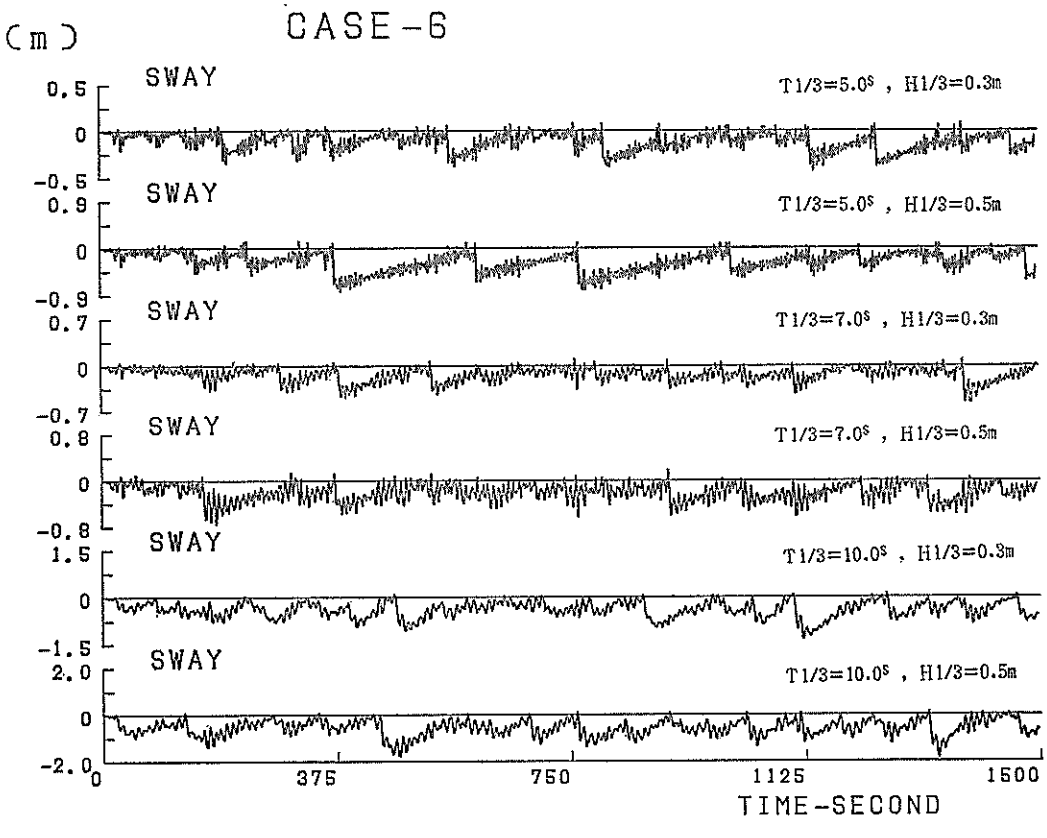


Fig. 26 Time Histories of Sway Motion (3,000 DWT)

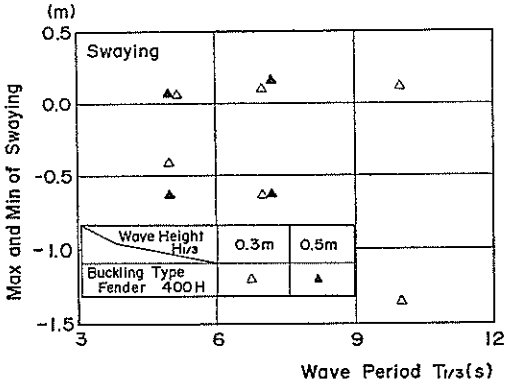


Fig. 27-(a) Maximum Movement in Sway

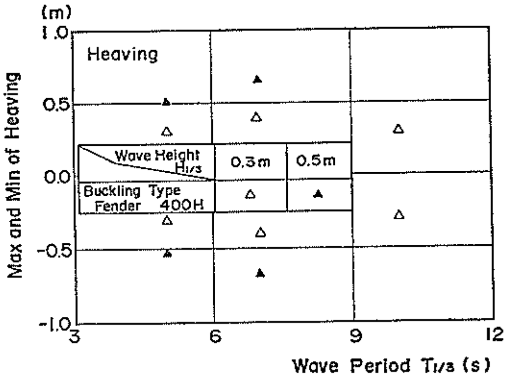


Fig. 27-(b) Maximum Movement in Heave

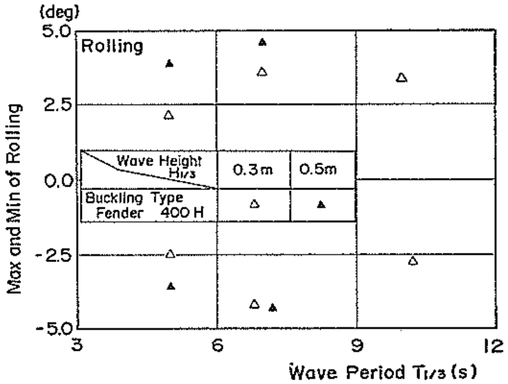


Fig. 27-(c) Maximum Movement in Roll

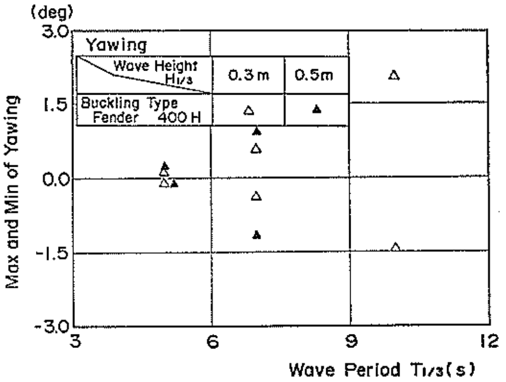


Fig. 27-(d) Maximum Movement in Yaw

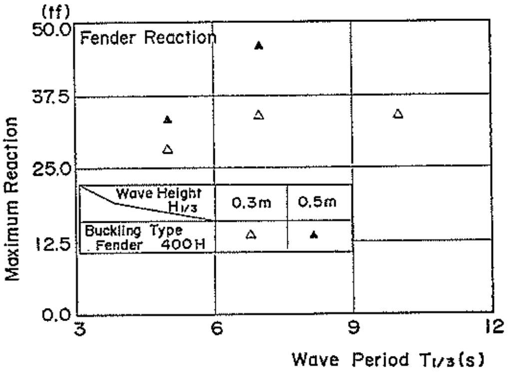
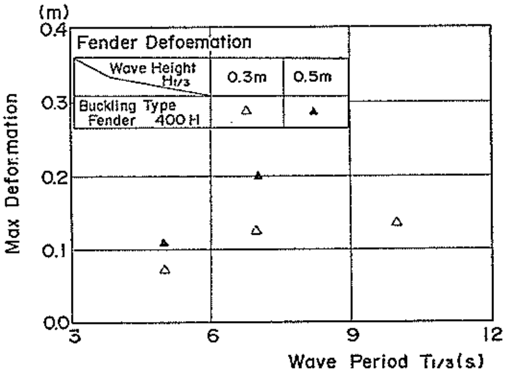


Fig. 28-(a) Maximum Reaction Force of Fenders



(b) Maximum Deformation of Fenders

Numerical simulation was carried out for a ship moored at the P3 berth as shown in Fig. 1(2.). The ship was a 3,000 DWT oil tanker. Figure 26 shows the time histories of the sway motions of a ship subjected to waves of 0.3 and 0.5 m and 5, 7 and 10 s significant wave height and period respectively. Subharmonic sway motion of with a period of about 120 s occurred. Figures 27(a), (b), (c) and (d) show the maximum movements of a ship moving in the sway, heave, roll and yaw directions. Figures 28-(a) and (b) show the maximum reaction force and the maximum deformation of a fender at the stern. Though the deformation of fenders are 8 to 15 cm, the amplitude of offshore sway motions are 40, 60, and 135 cm respectively for the 5, 7 and 10 s period waves with 30 cm significant wave height. The longer the wave period, the larger the ship motions are.

The allowable movement of an unloading arm on this berth in a direction perpendicular to the face line of a berth is 1.5 m. The above mentioned offshore sway motions is nearly equal to the allowable movement of an unloading arm. The allowable movement of the unloading arm in a vertical direction is 1.0 m. Heave motion is less than ± 40 cm, therefore the heave motion is not, in this case, critical to the cargo handling operation. The maximum rolling motion is 4° for the waves of 7 s significant wave period. The maximum yawing motion is ± 1.0° for the waves of 10 s significant wave period.

According to the results of the computations of the ship motions for a ship subjected to waves of 50 cm and 7 s significant wave height and period respectively, roll and yaw motions are larger than the results for waves of 30 cm significant wave height, while sway motion is not so different. As a result of the increase of the roll and yaw motions, deformation of the fender installed on the stern side (No. 5) exceeds 50% of its height which is larger than the rated deflection. Though no computation has been carried out for waves of 50 cm and 10 s significant wave height and period respectively, it is expected that ship motions would become larger than for waves with a significant period of 7 s.

Considering the ship motions, the height of those fenders is a little small. The stiffness of those fenders is ten times that of the mooring lines. Therefore, it is expected that if the stiffness of the fenders was decreased or the stiffness of the mooring lines was increased the asymmetry of the load-deflection characteristics of the mooring system would be reduced. Here, it was suggested to replace the present fenders with pneumatic type ones. For the selection of the fenders, the allowable motions above mentioned were taken into consideration.

4.2 Improved Mooring Systems and Ship Motions

In this case pneumatic fenders were chosen for an improved mooring system. The load-deflection characteristics of a pneumatic fender are hyperbolic and are very different to a buckling type fender. This means that the reaction force increases more or less proportionally to the deformation. The smaller the deformation, the smaller the reaction force is. Fender size was determined considering both conditions of berthing and mooring. With regard to the berthing condition, fender size was determined 800 H. But with regard to the mooring condition, fender size was determined 1,000 H or 1,200 H. Accordingly, it was decided to do a numerical simulation by use of the load-deflection characteristics of pneumatic fenders both 1,000 H and 1,200 H. Computations were made in the conditions for waves of 50 cm and 7 s significant wave height and period respectively, and of 30, 50, and 10 s significant wave height and period respectively. Figures 29-(a) to (d) show ship motions

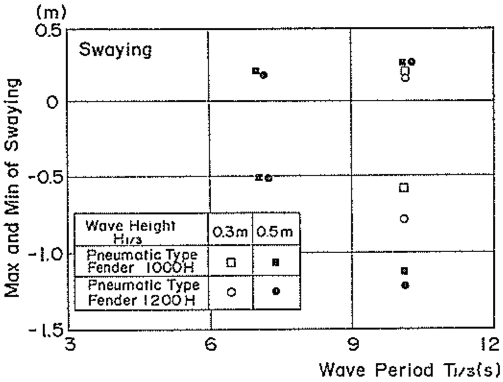


Fig. 29-(a) Sway Motion (3,000 DWT)

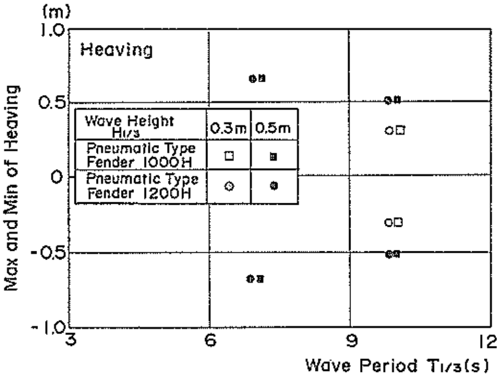


Fig. 29-(b) Heave Motion (3,000 DWT)

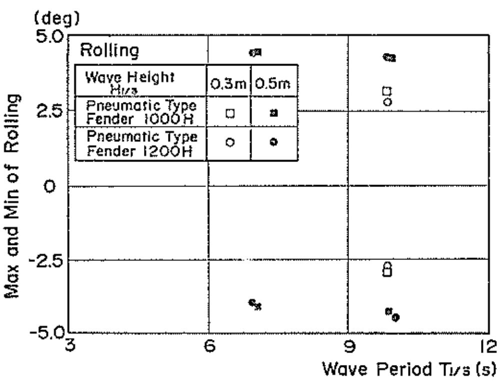


Fig. 29-(c) Roll Motion (3,000 DWT)

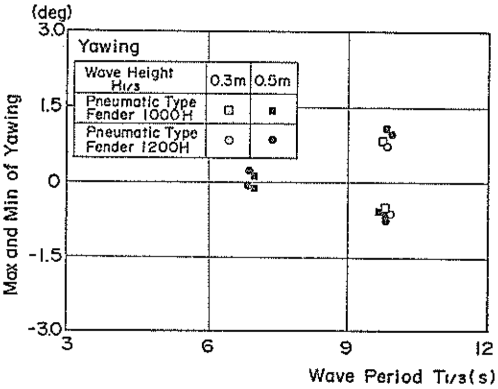


Fig. 29-(d) Yaw Motion (3,000 DWT)

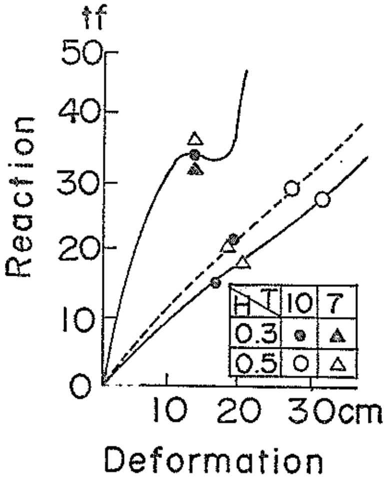


Fig. 30 Relation between Reaction Force and Deformation of Fender (Present Mooring System)

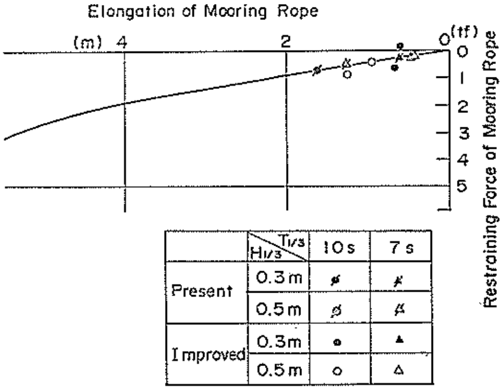
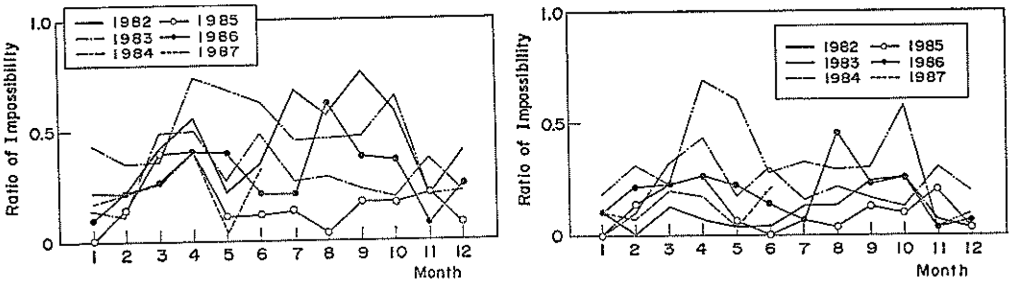


Fig. 31 Relation between Elongation and Restraining Force of Mooring Ropes (Present Mooring Systems)

in the sway, heave, roll and yaw direction. The offshore sway and yaw motions computed by use of the load-deflection characteristics of the pneumatic type fenders decreased by half of those computed by use of the load-deflection characteristics of the buckling type fenders. The amplitude of the above mentioned components of motions computed for waves 50 cm and 10 s significant wave height and period respectively are smaller than those of computed by use of the load-deflection characteristics of the buckling type fenders for waves of 30 cm and 10 s significant wave height and period respectively. But, for those component of motions such as roll and heave, it cannot be expected to be decreased. Figure 30 shows the relation between the deformation and the reaction force of a fender at the stern side in comparison with the existing and the improved mooring systems. Figure 31 shows the relation between the elongation and the restraining force of the mooring ropes. As shown in those figures, both the reaction forces of the fenders and the restraining forces of the mooring ropes decreased with the improvement of the mooring systems.

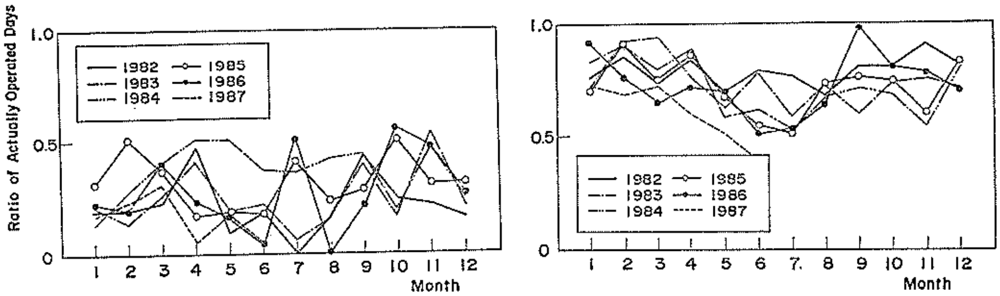
4.3 Wharf Operation Efficiency after Improvement of Mooring Systems

In this section, the wharf operating efficiency before and after improvement of the mooring systems are compared. Data have been obtained from the owner of those berths and analysed. Here, the ratio of the impossibility of execution of cargo handling operations—that is the ratio of days on which the execution of cargo handling operations was impossible to the total number of available working days—and the ratio of actually operated days to days possible to operate. In this analysis,



(a) P2 Berth (b) P3 Berth

Fig. 32 Trend of Impossibility of Execution Cargo Handling Operation



(a) P2 Berth (b) P3 Berth

Fig. 33 Ternd of Ratio of Actually Operated Days

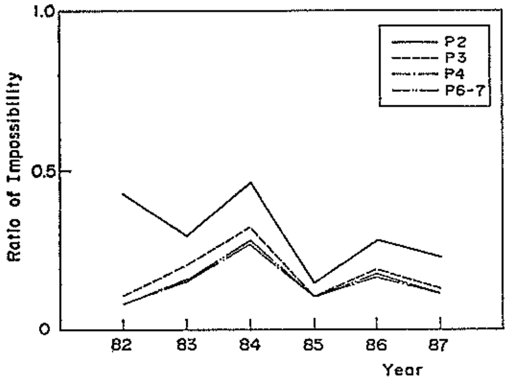


Fig. 34 Yearly Trend of Ratio of Imposibility of Execution Cargo Handling Operation

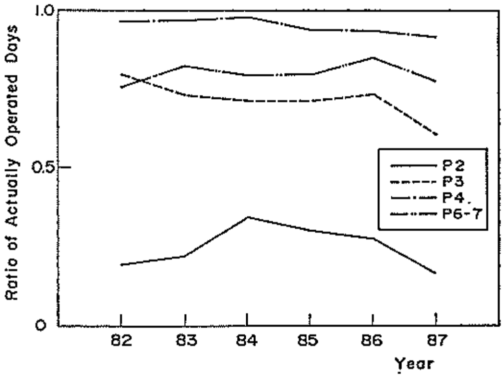
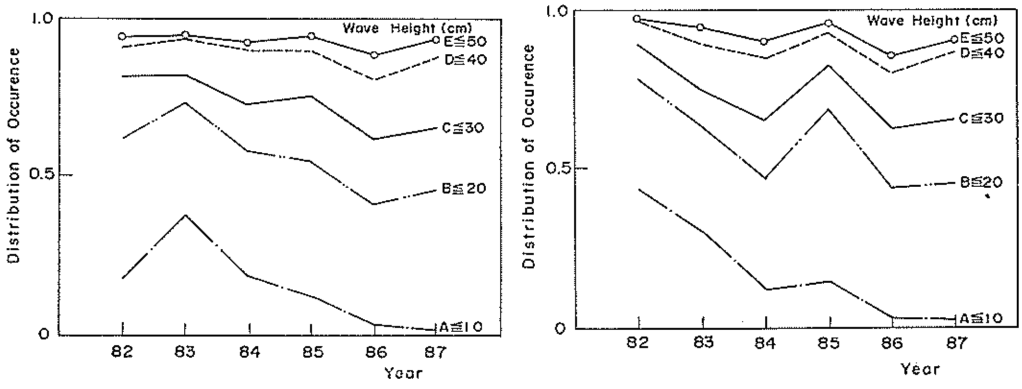


Fig. 35 Yearly Trend of Ratio of Actually Operated Days

Sundays and National Holidays when cargo handling operations were off duty are not included. Figures 32 and 33 show the monthly trend of the ratio of the impossibility of cargo handling operations and the ratio of the actually operated days for the P2 and P3 berths. Figures 34 and 35 show the yearly trend of those ratios respectively. It seems that there is some factor which depends on seasonal conditions. The ratio of impossibility of cargo handling operations is large from August to October and from April to May. These periods are related to the typhoon season and the depressions in the beginning of summer. With regard to typhoons, there are annual differences of occurrence, and, therefore, there are several years when the ratio of the impossibility of cargo handling operations are low. The ratio of the actually operated days for the P2 berth seems rather small compared to the other berths because of the higher wave height in front of the berth. Figure 36 shows the distribution of the wave height in front of those berths according to the visual observed data



(a) P2 Berth (b) P3 Berth

Fig. 36 Distribution of Wave Height in front of the P2 and P3 Berths obtained from 1982 to 1987 at the berth by the operators. The wave height in front of the T and P2 berths seems to be rather increased recently. However, looking at the yearly trend of the ratio of the impossibility of the cargo handling operations of the P3 berth as shown in Fig. 34, it is clear that in 1985 the ratio of the impossibility of the cargo handling operations of the P3 berth was decreased, and the ratio of actually operated days of the P3 berth increased because the mooring system of the P3 berth was improved by replacing the existing fenders with pneumatic ones. But, it must be mentioned that this year is exceptional because there was no typhoon occurrence. So, in 1986, the ratio of the impossibility of the cargo handling operation increased again about 20%, but it is still lower than those years before the improvement.

5. Determination of Wharf Operation Efficiency

5.1 Procedure for the Calculation of Wharf Operation Efficiency

As mentioned in the previous chapters, the calmness index of a harbour should be calculated based on the allowable ship motions for cargo handling operations. For this calculation the allowable ship motions in terms of type and size of ship must be determined. There are several contributions on this subject, and the author and his colleagues are also collecting and analysing data for this purpose. In this chapter, the wharf operation efficiency is to be calculated by berths in the S Port setting the critical wave height for each wave period based on the results of the computation

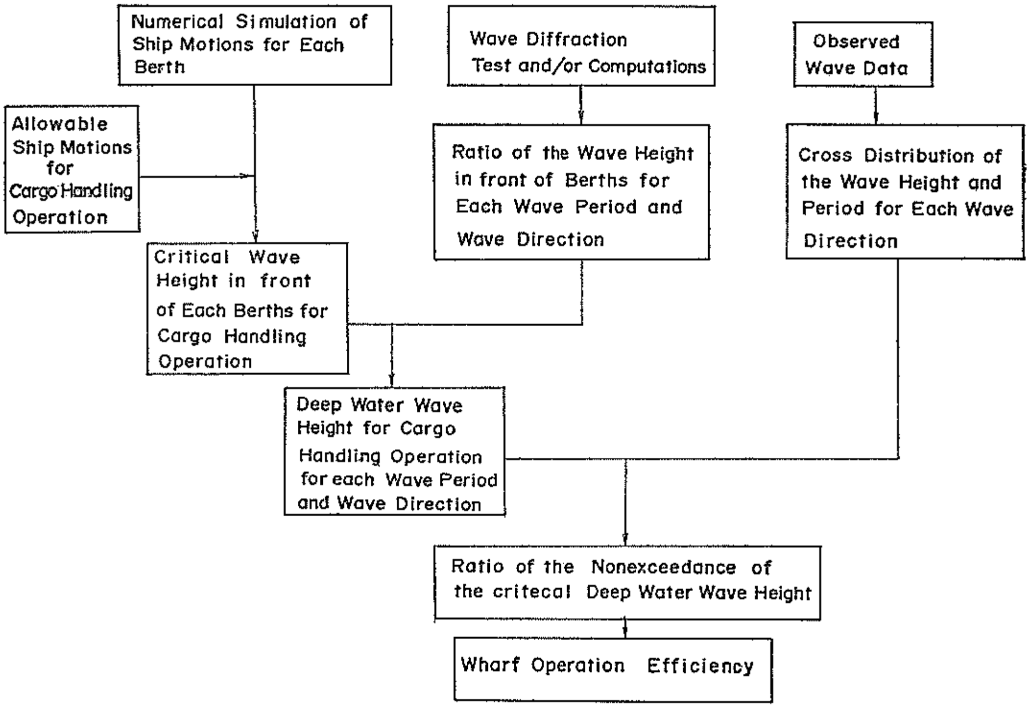


Fig. 37 Block Chart of the Calculation of the Calmness Index

described in 4.

For the strict analysis, more computations of ship motions are needed to set the critical wave height, but this calculation of the harbour calmness index should be recognized as an initial attempt to establish an alternative method of calculation to compare with the current method of calculating the harbour calmness index.

Figure 37 show the flow chart of the calculation of the harbour calmness index considering the ship motions.

(1) Obtain the cross distribution of the significant wave height and wave period for each wave direction. It is better to obtain this cross distribution from the actual observed original data.

(2) Obtain the ratio of the wave height in front of the berth to the deep water wave height for each wave direction according to the wave diffraction test or wave diffraction computation.

(3) Set the critical wave height in front of the berth in terms of the type and size of ship, and, period and direction of waves. For this procedure, the allowable ship motions in terms of the type and size of ship must be determined.

(4) Divide the critical wave height in front of the berth by the ratio of the wave height in front of the berth and obtain the critical deep water wave height for each wave direction and period.

(5) Calculate the ratio of nonexceedance of the critical deep water wave height and make a summation of those to get the total wharf operation efficiency.

Later in this chapter, a case study will be presented for calculation of the wharf operation efficiency considering the ship motions.

5.2 Allowable Ship Motions for Wharf Operation Efficiency

As described in Section **2.4**, there are several contributions on the allowable ship motions. Most of them were obtained by means of questionnaires. As listed in Appendixes, those data by Bratteland⁶⁾, Brunn⁷⁾, Bloom⁸⁾, Viggosson¹⁰⁾ are useful. But, some care must be exercised when the palnner uses the critical wave height written in such published literature as to whether or not the wave period is considered.

5.3 Computation of Ship Motions

With reference to the closing sentence of the previous section, the critical wave height must be determined considering the ship motions. As mentioned in **3**, ship motions are influenced by waves of certain direction and period, wind, and the load-deflection characteristics of the mooring system. Therefore, the numerical simulation must be carried out for the selected mooring system at the berth in every wave directions and period for every type and size of ship to be served. This procedure is comparatively complicated. It is desirable that data would be accumulated. The author and his colleagues are currently engaged on a work for this purpose, however, little data has been accumulated at the time of writing.

5.4 Calculation of Wharf Operation Efficiency

In this section, the wharf operation efficiency is calculated according to the procedures described in 5.1.

Table 11 is the joint distribution of occurrence of the significant wave height and wave period. In this table, there is no information of the wave direction. Then the joint distribution of the significant wave height and wave direction is used in order to get the joint distribution of the significant wave height and wave period for each wave direction. Table 12 is the joint distribution of occurrence of the significant wave height and wave direction and Table 13-(a) to (d) are the

Tabl 11 Joint Distribution of Occurence of Wave Height and Wave Period

														79— 1	84—12		RITU		BUNPU	HYO
T	SEION	3— 4	4— 5	5— 6	6— 2	7— 8	8— 9	9—10	10—11	11—12	12—13	13—14	14—15	15—16	16—17	17—18	18—19	19—	TOTAL	NON-Exc
SEION	0.0	0.2	0.4	0.6	0.8	0.8	0.5	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.5 (818)	3.5 (818)
0.25— 0.50	0.4	0.8	1.5	2.8	4.3	4.2	3.7	2.6	1.3	0.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	21.9 (5057)	25.4 (5875)
0.50— 0.75	0.1	0.6	1.7	4.2	7.3	7.3	4.8	2.9	1.8	1.0	0.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0	32.0 (7399)	57.5 (13274)
0.75— 1.00	0.0	0.1	0.9	2.0	4.0	4.9	3.6	1.9	1.2	0.6	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	19.7 (4560)	77.2 (17834)
1.00— 1.25	0.0	0.0	0.4	0.9	1.4	2.2	2.3	1.4	0.9	0.4	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	10.1 (2324)	87.3 (20158)
1.25— 1.50	0.0	0.0	0.1	0.5	0.5	1.0	1.2	0.9	0.9	0.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.5 (1264)	92.7 (21422)
1.50— 1.75	0.0	0.0	0.0	0.2	0.3	0.4	0.6	0.7	0.4	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.9 (670)	95.6 (22092)
1.75— 2.00	0.0	0.0	0.0	0.1	0.1	0.2	0.4	0.4	0.3	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7 (387)	97.3 (22479)
2.00— 2.50	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.4	0.3	0.3	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6 (367)	98.9 (22846)
2.50— 3.00	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6 (146)	99.5 (22992)
3.00— 3.50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2 (46)	99.7 (23038)
3.50— 4.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1 (33)	99.9 (23071)
4.00— 4.50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1 (13)	99.9 (23084)
4.50— 5.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0 (8)	100.0 (23092)
5.00— 5.50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0 (5)	100.0 (23097)
5.50— 6.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0 (0)	100.0 (23097)
6.00— 6.50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0 (0)	100.0 (23097)
6.50— 7.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0 (0)	100.0 (23097)
7.00— 8.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0 (0)	100.0 (23097)
8.00— 9.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0 (0)	100.0 (23097)
9.00—10.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0 (0)	100.0 (23097)
10.00—11.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0 (0)	100.0 (23097)
11.00—12.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0 (0)	100.0 (23097)
12.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0 (0)	100.0 (23097)
TOTL	0.5 112	1.5 338	5.0 1146	11.3 2606	18.9 4362	21.2 4902	17.3 3994	11.5 2666	7.3 1687	3.7 844	1.4 316	0.4 99	0.1 26	0.0 1	0.0 0	0.0 0	0.0 0	0.0 0	100.0 (23097)	100.0 (23097)
NON-Exc	0.5 111	1.9 450	4.9 1596	18.2 4202	37.1 8564	58.3 13466	75.6 17460	87.1 20126	94.4 21813	98.1 22657	99.5 22971	99.9 23070	100.0 23096	100.0 23097	100.0 23097	100.0 23097	100.0 23097	100.0 23097	100.0 (23097)	100.0 (23097)

NON-Exc: Non Exceedance Probability

Table 12 Joint Distribution of Occurence of Wave Heigth and Wave Direction

Wave Direction / Wave Heigth	ENE	E	ESE	SE	SSE	S	SSW	TOTL
0～50 (cm)	0.2	1.8	10.9	7.5	1.3	1.3	1.0	24.1
50～100	0.2	1.9	22.4	19.7	5.9	1.8	1.1	52.9
100～150	0.0	0.8	6,0	6.8	2.0	0.5	0.2	16.3
150～200	0.0	0.3	1,0	2.3	0.4	0.1	0.0	4.2
200～250	—	0.2	0.5	0.5	0.2	0.0	—	1.3
250～300	—	0.1	0.2	0.3	0.0	0.0	—	0.7
300～350	—	0.0	0.1	0.1	0.0	—	—	0.2
350～400	—	0.0	0.0	0.0	—	0.0	—	0.1
400～450	—	—	0.0	0.0	0.0	0.0	—	0.1
450～500	—	—	0.0	0.0	—	0.0	—	0.0
500～	—	—	0.0	—	—	—	—	0.0
TOAL	0.5	5.1	41.3	37.2	9.9	3.8	2.3	100.0

joint distributions of the significant wave height and wave period for each wave direction. Here, the wave direction north of East was included in East and south of SSE was included in SSE. It is better to derive the joint distribution of the significant wave height and wave period for each wave direction from actually observed original data of the wave observation.

Next, obtain the values of the ratio of the wave height in front of the berth to the deep water wave height for each wave period and each wave direction according to the results of the wave diffraction test. But in the case, data were available only for the waves of 9 s significant period. According to the results of the computation carried out in 4., the critical wave heights to cargo handling operations were set for each berth as listed in Table 14. The critical wave heights for cargo handling operations were set for each berth according to the results of computation for a 3,000 DWT ship moored to the P3 berth by use of the load-deflection characteristics of the mooring system in use before improvement. The critical wave height were 0.5 and 0.3 m for waves of 7 and 10 s significant period respectively. Although it was a rather determination, the critical wave heights were set as 0.5, 0.4, 0.3, 0.2 and 0.1 m for each wave for which the significant wave periods were shorter than 8, 9, 10, 11 and longer than 11 s respectively for general cargo ships. With regard to VLCCs, the critical wave heights were set at 0.7, 0.6, 0.5, 0.4 and 0.3 m for each wave period shown as case 1 in Fig. 38. With regard to a small craft, the critical wave height was set at 30 cm for any period waves.

By dividing the critical wave height by the ratio of wave height in front of the berth to the deep water height, the critical deep water wave heights were obtained for each wave period, wave direction and berth.

By use of the joint distribution of the significant wave height and wave period for each wave direction (Table 13), the wharf operation efficiency for each berth was calculated as listed in Table 15 as denoted in case 1. Comparing with the results

Table-13 Joint Distribution of Occurence of Wave Height and Wave Period for Each Wave Direction

(a) E (Wave Direction)

Wave Period(s)	0.00	8.00	9.00	10.00	11.00	12.00	13.00	14.00	15.00	
Wave Height(m)	~8.00	~9.00	~10.00	~11.00	~12.00	~13.00	~14.00	~15.00	~16.00	
0.00— 0.50	1.38	0.35	0.23	0.11	0.03	0.01	0.00	0.00	0.00	2.11
0.50— 1.00	1.28	0.33	0.19	0.12	0.06	0.03	0.01	0.00	0.00	2.00
1.00— 1.50	0.36	0.18	0.12	0.09	0.04	0.01	0.00	0.00	0.00	0.79
1.50— 2.00	0.09	0.07	0.08	0.05	0.02	0.01	0.00	0.00	0.00	0.31
2.00— 2.50	0.03	0.03	0.05	0.04	0.04	0.03	0.00	0.00	0.00	0.20
2.50— 3.00	0.00	0.02	0.02	0.02	0.03	0.02	0.00	0.00	0.00	0.10
3.00— 3.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3.50— 4.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.00— 4.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.50— 5.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5.00— 5.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	3.13	0.96	0.68	0.42	0.23	0.10	0.01	0.00	0.00	5.52

(b) ESE (Wave Direction)

Wave Period(s)	0.00	8.00	9.00	10.00	11.00	12.00	13.00	14.00	15.00	
Wave Height(m)	~8.00	~9.00	~10.00	~11.00	~12.00	~13.00	~14.00	~15.00	~16.00	
0.00— 0.50	7.64	1.91	1.27	0.59	0.18	0.05	0.00	0.00	0.00	11.65
0.50— 1.00	13.90	3.55	2.03	1.27	0.68	0.30	0.08	0.00	0.00	21.80
1.00— 1.50	2.59	1.29	0.85	0.66	0.30	0.07	0.00	0.00	0.00	5.76
1.50— 2.00	0.33	0.25	0.28	0.18	0.08	0.05	0.00	0.00	0.00	1.15
2.00— 2.50	0.08	0.08	0.15	0.11	0.11	0.08	0.00	0.00	0.00	0.60
2.50— 3.00	0.00	0.03	0.03	0.03	0.07	0.03	0.00	0.00	0.00	0.20
3.00— 3.50	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.05
3.50— 4.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.00— 4.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.50— 5.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5.00— 5.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	24.53	7.11	4.61	2.89	1.41	0.57	0.08	0.00	0.00	41.21

(c) SE (Wave Direction)

Wave Period(s)	0.00	8.00	9.00	10.00	11.00	12.00	13.00	14.00	15.00	
Wave Height(m)	~8.00	~9.00	~10.00	~11.00	~12.00	~13.00	~14.00	~15.00	~16.00	
0.00— 0.50	5.27	1.32	0.88	0.41	0.13	0.03	0.00	0.00	0.00	8.03
0.50— 1.00	12.24	3.13	1.79	1.12	0.60	0.26	0.07	0.00	0.00	19.20
1.00— 1.50	2.90	1.45	0.95	0.75	0.33	0.08	0.00	0.00	0.00	6.64
1.50— 2.00	0.74	0.57	0.63	0.40	0.17	0.11	0.00	0.00	0.00	2.61
2.00— 2.50	0.08	0.08	0.15	1.11	0.11	0.08	0.00	0.00	0.00	0.60
2.50— 3.00	0.00	0.05	0.05	0.05	0.10	0.05	0.00	0.00	0.00	0.30
3.00— 3.50	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.05
3.50— 4.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.00— 4.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.50— 5.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5.00— 5.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	21.22	6.59	4.44	2.88	1.44	0.61	0.07	0.00	0.00	37.25

(d) SSE (Wave Diraection)

Wave Period(s) Wave Height(m)		0.00 ~8.00	8.00 ~9.00	9.00 ~10.00	10.00 ~11.00	11.00 ~12.00	12.00 ~13.00	13.00 ~14.00	14.00 ~15.00	15.00 ~16.00	
0.00—	0.50	2.50	0.63	0.42	0.19	0.06	0.01	0.00	0.00	0.00	3.81
0.50—	1.00	5.48	1.40	0.80	0.50	0.27	0.12	0.03	0.00	0.00	8.60
1.00—	1.50	1.16	0.58	0.38	0.30	0.13	0.03	0.00	0.00	0.00	2.58
1.50—	2.00	0.15	0.11	0.13	0.08	0.03	0.02	0.00	0.00	0.00	0.52
2.00—	2.50	0.03	0.03	0.05	0.04	0.04	0.03	0.00	0.00	0.00	0.20
2.50—	3.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3.00—	3.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3.50—	4.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.00—	4.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.50—	5.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5.00—	5.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		9.32	2.74	1.77	1.11	0.53	0.21	0.03	0.00	0.00	15.72

Table 14 Critical Wave Heigth for Cargo Handling Operations

Wave Period (s)	0.00 ~8.00	8.00 ~9.00	9.00 ~10.00	10.00 ~11.00	11.00 ~12.00	12.00 ~13.00	13.00 ~14.00	14.00 ~15.00	15.00 ~16.00
P1	0.7	0.6	0.5	0.4	0.3	0.3	0.3	0.3	0.3
P2	0.5	0.4	0.3	0.2	0.1	0.1	0.1	0.1	0.1
P3	0.5	0.4	0.3	0.2	0.1	0.1	0.1	0.1	0.1
P4~P7	0.5	0.4	0.3	0.2	0.1	0.1	0.1	0.1	0.1
T	0.5	0.4	0.3	0.2	0.1	0.1	0.1	0.1	0.1
T-s	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3

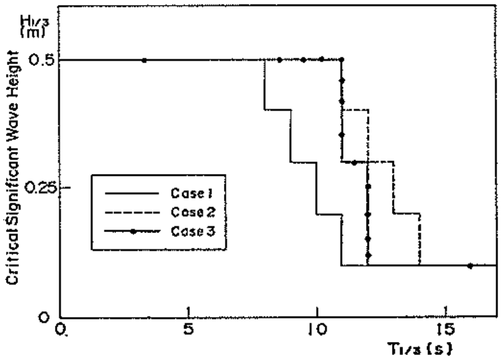


Fig. 38 Setting of the Critical wave Height for Cargo Handling Operations

Table 15 Wharf Operation Efficiency

	No. 1			No. 6		
	Case 1	Case 2	Case 3	Case 1	Case 2	Case 3
P1	83.4	90.8	89.7	96.6	99.3	98.6
P2	57.4	67.7	66.6	92.9	99.0	97.8
P3	81.8	91.1	89.4	95.1	99.5	98.4
P4-7	89.0	97.1	96.1	96.7	99.7	98.9
T	57.0	67.7	66.5	80.5	90.1	88.6
T-s	90.5	90.5	90.5	97.4	97.4	97.4

calculated based on the definition of the current Technical Standard, the values of the wharf operation efficiency calculated considering ship motions are small. For instance, in respect of the P2, P3 and T berth the wharf operation efficiencies were 80, 97.5, and 78.8% respectively calculated based on the Technical Standard, while they are 57.4, 81.8 and 57.0% respectively calculated based on the assumption in this paper for the present state of port facilities. Where Nos. 1 and 6 in Table 15 corresponds to the stage of the construction of the port facilities described in 2.3.

It was recommended in 4. to reduce the asymmetry of the load-deflection characteristics of the mooring systems. It is expected that the wharf operation efficiency should be increased if the mooring systems were improved. Then the critical wave heights in front of the berth were set according to the results of the computation by use of the load-deflection characteristics of the improved mooring systems. The critical wave height was 0.5 m for the waves of 10 s significant period. Although it was a rather rough determination, the critical wave heights were set at 0.5, 0.4, 0.3, 0.2 and 0.1 m for each wave for which the significant wave periods were shorter than 11, 12, 13, 14 s and longer than 14 s respectively for general cargo ships. With regard to VLCCs, the critical wave heights were set at 0.7, 0.6, 0.5, 0.4 and 0.3 m for each wave period above shown as case 2 in Fig. 38. With regard to a small craft, the critical wave height was set at 30 cm for any period waves. The wharf operation efficiencies were calculated as also listed in Table 15 as denoted case 2. For instance, in respect of the P2, P3 and T berths the wharf operation efficiencies were 67.7, 91.1, 67.7% respectively. If the critical wave height is set as case 3 shown in Fig. 38, so as to be 0.5, 0.3, 0.1 for each wave for which the significant wave periods were shorter than 11, 12 and longer than 12 s respectively for general cargo ships. With regard to VLCCs, the critical wave heights were set as 0.7, 0.5, and 0.3 m for each wave period above mentioned. The results are also listed in Table 15 as denoted case 3. For instance, in respect of the P2, P3 and T berths the wharf operation efficiencies were 66.6, 89.4, 66.5% respectively. In any event, the wharf operation efficiency decreased when ship motions subjected to long period waves were considered. After the completion of a deep water breakwater (No. 6), the wharf operation efficiency increases as listed in Table 15.

6. Conclusion

In this paper, consideration was made on the harbour calmness index taking account of the ship motions. This kind of evaluation of the calmness of a harbour is adopted in port planning in the European countries and the United States because they have experienced the problems of long period ship motions at ports located facing the oceans. Most of the ports constructed in Japan before the nineteen sixties are located in bays or the inland sea where the long period waves rarely enter the port, therefore there is not the problem of ship motions except when typhoons attack the port. But, with regard to those ports which have been more recently constructed facing the oceans and the open sea, long period waves can come into the ports and cause large ship motions. These long period ship motions occur even when the wave heights is small. Such occurrences might cause rumours amongst captains and ship owners that the harbour and berths do not provide a safe haven with consequent loss of trade. Therefore, it is concluded that the ship motions resulting from the action of long period waves should be considered in the calculation of the harbour calmness index. In order to validate the necessity of this consideration, the model tests of the ship motions in the wave diffraction tests and the numerical simulations were carried out. According to the results of both the model tests and numerical simulations, the necessity to consider ship motions in the calculation of the harbour calmness index was proved. Although the calculation method presented in this paper is not a very precise one, the instance of the calculation when considering ship motions gave lower wharf operation efficiencies than without consideration. The harbour calmness index might be improved with other countermeasures being taken to protect the harbour from long period waves. Countermeasures which are effective to protect the harbour from long period waves are the construction or extension of breakwaters, wave breaking devices and the improvement of the mooring systems. But, with regard to the mooring systems, there is a limitation to the gain in performance owing to the improvements of the individual elements. Therefore, in planning the location and orientation of berths, in addition to the construction of breakwaters and/or wave breaking devices, the angle between the wave direction and the face line of berth should be outside the range of 60 to 90°.

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Appendix 1. A Survey on Acceptable Ship Movements in Harbour
E. Bratteland[6)]
The Dock & Harbour Authority, Sept., 1974, pp. 175~178.

Table A-1 Acceptable Wave Heights for Fishing vessels.

Ship Size brt	Number of Observations	Acceptable Wave Heights in Metres		
		Average	Min.	Max.
<500	20	0.8	0.3	1.5
>500	7	1.30	0.5	2.0

Table A-3 Acceptable Waveh Hights of Tankers, as a Function of Incident Wave Direction Ship Size.

Sea	Ship Size 1,000 dwt	Number of Observations	Acceptable Wave Heights in Metres		
			Average	Min.	Max.
Head	200~250	8	2.0	1.0	4.5
	50~100	8	2.0	1.0	4.0
	1.5~ 30	18	1.2	0.4	2.0
Quartering	200~250	8	1.6	1.0	3.0
	50~100	8	1.9	1.0	4.0
	1.5~ 30	18	1.0	0.4	2.0
Beam	200~250	7	1.6	0.75	3.0
	50~100	9	1.4	1.0	2.0
	1.5~ 30	16	0.8	0.4	1.5

Table A-2 Acceptable Wave Heights for General Cargo Ships, as a Function of Incidnt Wave Direction and Ship Size.

Sea	Ship Size 1,000 dwt	Number of Observations	Acceptable Wave Heights in Metres		
			Average	Min.	Max.
Head	100~110	4	1.4	1.0	2.1
	35~ 70	5	1.15	0.75	1.5
	4~ 30	12	0.95	0.5	2.0
Quartering	100~110	4	1.15	0.75	1.8
	35~ 70	5	0.9	0.6	1.0
	4~ 30	11	0.8	0.2	1.75
Beam	100~110	4	0.95	0.5	1.5
	35~ 70	5	0.65	0.5	1.0
	4~ 30	12	0.8	0.25	1.5

Table A-4 Acceptable Wave Heights for Bulk Cargo Ships, as a Function of Incident Wave Direction and Ship Size.

Sea	Ship Size 1,000 dwt	Number of Observations	Acceptable Wave Heights in Metres		
			Average	Min.	Max.
Head	12~ 20	7	1.15	0.5	3.0
	7~ 10	11	0.95	0.25	1.75
	1.5~4.5	5	1.10	0.75	1.50
Quartering	12~ 20	7	0.85	0.25	2.0
	1~ 10	11	0.8	0.25	1.5
	1.5~4.5	5	0.9	0.50	1.0
Beam	12~ 20	7	0.8	0.25	2.0
	7~ 10	11	0.7	0	1.25
	1.5~4.5	5	0.75	0.50	1.0

Table A-5 Acceptable Ship Movements for Ships Smaller than 15,000 dwt.

Type of Ship Movement	Number of Observations	Acceptable Wave Heights in Metres		
		Average	Min.	Max.
Roll	17	0.70	0	2.0
Surge	12	1.05	0.50	3.0
Yaw	12	0.95	0.25	3.0
Pitch	3	1.25※)	0.25	2.0
Heave	4	0.90	0.50	1.5
Sway	4	0.55	0.25	0.75

※) This value seems unreasonably high.

Appendix 2. Port Engineering pp. 350~351
P. Brunn[7]

Table A-6 Ranges for Allowable Maximum Movements far Large Veeeels >200 Metres at Berth for Unloading Periods of Oscillations 60 to 120 s

	Surge (m)	Sway (m)	Yaw (degrees)	Heave (m)	Note
Tanker	± 2[1]	+0.5 (away from berth)	1	±0.5	Surge most important.
Ore bulk (crane unloading)	±1.5	1.0 (away from berth)	1/2 not important	±0.5	Surge most important.
Grain bulk	±0.5	+0.5 (away from berth)	1/2 not important	±0.3 dep. equipment	Surge, sway most important.
LNG	very small (v.s.) ±0.2	v.s.	v.s.	v.s.	All movements risky.
Container[2]	±0.5	+0.3 (away from berth)	~nil	±0.3	
RO/RO (side)	±0.3	+0.2 (away from berth)	~nil	±0.1	For most effective operation, all movements nil.
RO/RO (bow or stem)	±0.1	nil	~nil	±0.1	

1) Depending upon mooring forces this movement could be even large, e.g. accepted at Antifer. France.

2) In article by P. J. B. Slinn published in the *Dock and Harbour Authority,* August 1979, the results of field tests on loading of containers in a moving cell was that loading rates of 26 containers per hour were obtained with stiff moorings for surge movements of 0.92m (101.5 s) and sway movements of 0.48m (40 s).

Table A-7 Limits of Movements at Various Type Terminals

Tonnage 1000 dwt	Conventional Jetty	Multi-Buoy Mooring	Fixed Tower Mooring	Single Buoy Mooring
100	0.3 m	0.6 m	1.5 m	2.0 m
250	0.3	0.6	2.0	2.5
500	0.5		2.3	2.7

Table A-8 Various Acceptable Wave Heights

Sea	Ship Size 1,000 dwt	Number of Observations	Acceptable Wave Heights (Meters)		
			Average	Min.	Max.
Head	200~250	8	2.0	1.0	4.5
	50~100	8	2.0	1.0	4.0
	1.5~ 30	18	1.2	0.4	2.0
Quartering	200~250	8	1.6	1.0	3.0
	50~100	8	1.9	1.0	4.0
	1.5~ 30	18	1.0	0.4	2.0
Beam	200~250	7	1.6	0.75	3.0
	50~100	9	1.4	1.0	2.0
	1.5~ 30	16	0.8	0.4	1.5

Appendix 3. Container Ship Motion Criteria
Marvin J Bloom and Anthony G Posch[8)]
The Doch & Harbour Authority Dec., 1980,

Table A-9 Effect of Mooring System on Ship Movement

Motion	Soft Mooring Movement (m)	Soft Mooring Period (s)	Stiffer Mooring Movement (m)	Stiffer Mooring Period (s)
Surge	3.68	195.0	0.92	101.5
Sway	2.84	110.0	0.48	40.0

Table A-10 Acceptable Ship Motions for Container Loading/Unloading

Source	Surge (m)	Sway (m)	Heave (m)
Bruun	±0.5	±0.3	±0.3
Frankel	±0.6	±0.6	—
Hwang and Divoky	±0.49	—	—
Nagy	—	—	±0.9
Slinn	±0.46	±0.24	—
Stone	±1.0	±0.6	±0.6
Range	±0.46 to ±1.0	±0.24 to ±0.6	±0.3 to ±0.9
Average	±0.6	±0.4	±0.6

Table A-11 Container Ship Motions Acceptance Criteria

Type Motion	Acceptable Movement (m)	Estimated Shutdown Levels (m)
Surge	±0.6	±0.8 to 1.5
Sway	±0.4	±0.5 to 1.0
Heave	±0.6	±0.8 to 1.3

Table A-12 Impact of Ship Motions on Container Handling Rates at Port of Acajutla

Handling Rate/hr Stationary Ship	Container Handling Rate/hr Calculated Ship Motions Alternative 1	Alterative 2
30	28.6	27.0
20	19.3	18.7

Appendix 4. Effect of ship Movement on Container Handling Rate P. J. B. Slinn[9]
The Dock & Harbour Authority, Aug., 1979, pp. 117～120

Table A-13 Effect of Ship Movement on Container Handling Rate

	Surge	Surge	Rate
Soft Mooring	3.6m (195 s)	2.8m (110 s)	190 s (19/hr)
Stiff Mooring	0.92m (101.5 s)	0.48m (40 s)	137 s (26/hr)

Appendix 5. Field Observation of Ship Behavior at Berth
Gisli Viggosson[10]
Icelancic Harbour Authority

Table A-14 Wave Height Criteria for Safe Mooring Conditions.

Ship type	L_{oa} (m)	H_s (m) **
Open boats	5～12	0.20
Other boats	5～12	0.30
Small fishing cutters	15～30	0.30
Coasters (<2000 DWT)		0.45

This criterion is valid only if wind waves are causing the disturbance. In harbours where seiching/long periodic waves are significant, the indicated wave heignt will not be a criterion for acceptable conditions.

** H_s is the sighificant wava height equal to the mean value of the highest third of the waves in a wave train.

Table-A15 Criteria for Ship Movements (Loading/Unloading Operationa).
The movements are maximum peak-peak.

Type of Vessel	Surge (m)	Sway (m)	Heave (m)	Yaw (deg)	Pitch (deg)	Roll (deg)
Fishing Vessels[1)] (L_{oa}=25—60m)						
LO—LO	1.0~1.5	1.0~1.5	0.4~0.6	3~5	4	3~5
Elevator Crane	0.15	0.15				1.5
Suction Pump	2.0~3.0	1.5~2.0				
(L_{oa}=60—130m)						
Freighters, Coasters[1)]	1.0~2.0	1.2~1.5	0.6~1.0	1~3	1~2	2~3
Crane on the vess.	1.0~2.0	1.2~1.5	0.8~1.2	2~4	1~2	3~5
Crane on the quay						
Ferries[2)] (L_{oa}=100—150m)		0.8	1.0	1.0	1.0	2.0
Container Vessels[1)] (L_{oa}=100—200m)						
90—100% efficiency	0.6~1.0	0.6~0.8	0.6~0.9	0.5	1.5	3.0
50% efficiency	2.0	2.0	1.2	1.5	2.5	6.0

1) Frequency of these movements should be less than 1 week/year (2% of time).
2) Frequency of these movements should be less than 3 hours/year (0.3% of time).

Table-A16 Criteria for vessel movements for safe mooring conditions at berth.
The movements are peak-peak values.

Type of Vessel	Surge (m)	Sway (m)	Heave (m)	Yaw (deg)	Pitch (deg)	Roll (deg)
Fishing Vessel (L_{oa}=25—60m)						
Movement	1.2~1.5	1.2~2.0	0.6~1.0	6	4	8
Freighters/Coasters (L_{oa}=60—120m)						
Movement	1.0~2.0	1.5~2.0	1.0~1.5	3~5	2~3	6
Velocity						
Size of vessel						
about 1000 DWT	0.6 m/s	0.6 m/s		2.0 deg/s		2.0 deg/s
about 2000 DWT	0.4 m/s	0.4 m/s		1.5 deg/s		1.5 deg/s
about 5000 DWT	0.3 m/s	0.3 m/s		1.0 deg/s		1.0 deg/s

For the berth to be acceptable, the frequency of these movements should be less than 3 hours/year.