CHAPTER 62

Relationship of a moored vessel in a harbour and a long wave caused by wave groups

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Abstract

Loading operations failed at a berth in Sendai New Harbour in 1992. The vessels continuously moved along the berth, in spite of small wave heights and weak winds, which were much less than the criteria for loading operation at the berth. To clarify the cause of the failures, the authors analyzed the observed wave data. The phenomenon related to the time characteristics of wave groupiness. The vessels' motions were caused by the long waves that were bounded by wave groups. Mean Wave Group Period ($\overline{Tg}$) proposed here, can explain the phenomenon.

1. Introduction

The harbour tranquility should be evaluated not only by the wave height at a berth but by the wave period, wind condition, the scale of vessels and so on.

An experienced berth master decides when the loading operation should start considering wave heights, wave periods and wind conditions. But it is frequently reported that due to the continuous motion of a moored vessel, the vessel has to be released, or at worst the mooring devices get damaged, even when the wave heights are small and the winds are weak. Since these failures of the loading operations reduce the rate of effective working days and the safety of working, it is very important to reveal the cause of the failure.

With the observed wave data from the *NOWPHAS* (Nationwide Ocean Wave information network for Ports and HArbourS,Nagai et al,1994) and the situation

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of the failure, we investigated the wave characteristics and the situation, and clarified the cause of the operation failure and proposed a new parameter for the harbour tranquility in this report.

2. Location and condition of the field study

Sendai New Harbour is located in Miyagi prefecture in Japan as shown in Figure 1. The harbour faces the Pacific Ocean, and it is sheltered by the outer breakwaters and an offshore breakwater that is under extension work. The yearly averaged wave direction is in between SE and SSE. The berth studied here is No. 1 berth owned by Tohoku Oil Company.

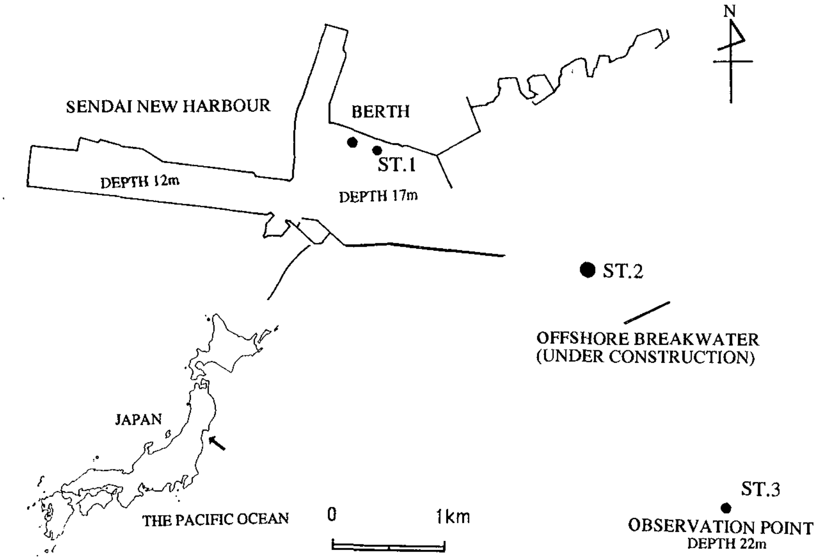


Figure 1 Location of Sendai New Harbour

Wave conditions are measured at three points. One(ST.1) is located at the east side of the berth where the water depth is $17m$, operated by the Tohoku Oil Company. The second(ST.2) is located behind the breakwater, where the water depth is $18m$. The third(ST.3) is located at $2.4km$ offshore from the harbour mouth where the water depth is $22m$, one of the *NOWPHAS* offshore observation stations operated by the Second District Port Construction Bureau of the Ministry of Transport. Wave heights are measured by a ultrasonic-type wave gage (USW), and the horizontal currents are measured by an ultrasonic-type current meter (CWD). The sampling interval is $0.5s$, and the data are recorded for 20 minute in every two hours due to *NOWPHAS* standard. The winds are measured at the height of $20m$ above the land of the berth.

The conditions of the loading operations are recorded for every operations. The duration time in which a vessel is moored at the berth and waiting time at offshore is also recorded. The beginning time of the loading operation is equal to the time that the berth master judges if the loading operation is possible. At first, the data of ST.1 and ST.3 are analyzed from June to October in 1990 and 1991 and the two cases in which the operation failed in 1992 are also analysed. Futhermore the data of ST.1, ST.2 and ST.3 are analyzed from January to February in 1994.

3. Criteria for loading operation

Start time of loading operation entirely depends on the judgment of the berth master. The berth master generally decides the time considering the wave condition, weather, vessel scale, conditions of the mooring devices, duration time for the loading and so on. It is, however, true that the judgment is quite experiential.

Table1 Wave heights and periods at the berth

				OFFSHORE WAVES			VESSEL	WAVES AT THE BERTH	
				H1/3	T1/3	θ	×10,000	H1/3	T1/3
YEAR	MONTH	DAY	TIME	m	s		DWT	m	s
90	6	30	12	0.76	5.98	SE	—	—	—
90	7	7	10	0.7	7.51	SE	—	0.26	4.39
90	7	8	14	0.61	6.19	SEE	—	0.15	4.28
90	7	15	10	0.74	7.57	SE	8.1	0.24	5.5
90	7	17	12	0.76	6.90	SSE	—	0.67	4.46
90	7	18	18	0.79	7.27	SSE	—	0.2	4.04
90	8	8	16	1.06	7.46	SEE	5.4	0.16	6.93
90	8	14	12	0.48	8.36	SE	—	0.09	5.08
90	8	15	18	1.2	5.75	SSE	18.6	0.13	5.55
90	8	24	10	0.94	8.27	SSE	6.5	0.11	6.57
90	8	25	14	0.45	6.74	SSE	—	0.09	4.08
90	8	26	14	0.41	7.20	SSE	—	0.09	4.71
90	9	2	10	0.65	6.59	SE	5.7	0.18	4.33
91	6	7	12	0.73	8.97	SE	6.1	—	—
91	6	17	16	0.89	7.66	SE	—	0.26	5.65
91	6	19	10	0.93	7.11	SSE	—	0.29	5.57
91	6	20	16	0.82	7.55	SE	—	0.22	5.34
91	6	25	10	0.97	7.43	SEE	—	0.23	4.78
91	7	14	12	0.51	6.34	SEE	—	0.41	5.67
91	7	16	10	0.5	7.22	SE	—	0.44	4.23
91	8	3	10	0.5	7.61	SE	7.3	0.19	3.85
91	8	4	14	0.64	4.83	SE	6.2	0.23	3.45
91	8	10	12	0.59	7.77	SEE	—	0.15	3.46
91	8	24	10	1.19	8.07	SE	—	0.34	4.61
91	8	25	18	0.98	9.29	SE	6.1	0.2	5.96
91	8	27	12	0.54	8.42	SE	—	0.15	3.84
91	8	29	14	0.68	6.01	SSE	6.1	0.18	4.24
91	9	4	10	0.55	8.92	SE	21.2	0.14	4.61
91	9	6	12	0.47	8.48	SEE	6.2	0.16	3.43
91	9	18	10	0.78	8.06	SEE	—	0.22	4.75
91	10	3	12	0.6	7.63	S	9.6	—	—
91	10	6	12	0.47	7.48	SE	6.1	—	—
92	10	22	10	2.54	12.3	SEE	22	0.26	5.78
92	11	24	12	1.56	12.67	SE	22	0.22	5.05

θ : WAVE DIRECTION
— : MISSING OF DATA

The wave heights and periods both at the berth and at the offshore in the beginning of the loading operation are listed in Table 1. In the table, a solid line (—) denotes the missing of data. Two rows from the bottom of the table show the data for failed operations. Wave heights and periods at the berth are smaller than those of offshore as expected. The criteria of the loading operation can be estimated from the table.

The maximum wave height is about 0.5*m*, and the maximum wave period is about 6 *s* for the judgment of the berth master. The table also shows that the judgment of the berth master is generally quite reasonable. It should be noted that the wave heights are small, and periods are shorts in the failed operation.

4. Investigation of Fail-Operation

4.1 Condition of Fail-Operation

Fail-Operation is defined here as a phenomenon that the loading is not well operated or failed in spite of small wave heights and winds. As the antonym, Normal-Operation is also used. The examples of the Fail-Operation were found on Oct. the 22nd and Nov. the 10th in 1992. The former is defined as case 1 and the later is case 2. The offshore wave heights in Fail-Operations are larger than those of Normal-Operation in 1990 and 1991. But the wave heights at the berth are much less than the criteria for the loading operation as mentioned before due to the extension of the offshore breakwater in 1992.

According to the berth master, the situations in Fail-Operations are as follows;

case 1

When 220,000 DWT oil tanker was moored at the berth, the tanker began to move along the berth with a surging motion. The amplitude of motion was about 1.5*m*. When the amplitude become 1.0 *m* after 4.5 hours, the loading finally could be started.

case2

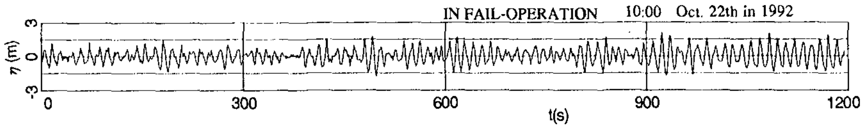
Immediately after being moored at the berth, the vessel continuously moved along the berth also with a surging motion for 24 hours. The vessel was finally had to be released without loading operation.

In both cases, the vessel was moored at the berth with mooring ropes. When the tensile force of mooring ropes achieved the breaking force of the winch, the mooring rope was released automatically, and it was rewinded adequately.

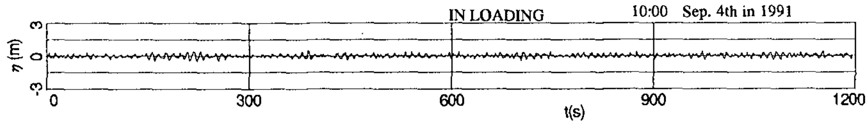
4.2 Offshore wave condition in Fail-Operations

Figure 2 shows that the time series of wave profiles of case1 and case 3, where case 3 is of Normal-Operation on Sep. 4th in 1991. The type of the vessels for each cases are all the same. The wave heights of case 1 are bigger than that of case 3. But the wave height of case 1 at the berth was 0.26*m* ,which is small enough for the loading operation.

The wave direction of case 1 was *SEE* and that of case 3 was *SE*. The offshore breakwater is quite effective to these wave directions. Figure 3 indicates a typical wave directional spectra of case 1. The wave directional spectrum was calculated by the maximum entropy method (*MEP*) developed by Hashimoto et al (1985). The



(a) case 1 Fail-Operation



(b) case 3 Normal-Operation

Figure 2 Wave profiles of offshore wave

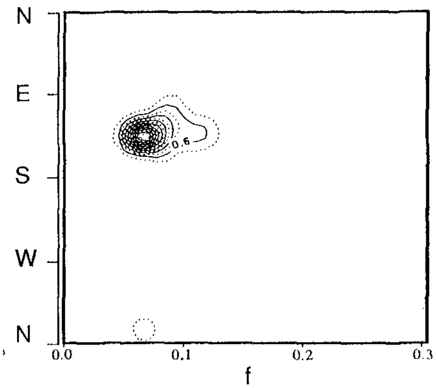


Figure.3 Directional spectrum of observed data

directional spectrum was narrow, and it had one peak. The directional spectra of case 1, case 2 and case 3 were of the same forms.

The wave trains of case 1 and case 2 are characterized by remarkable wave groups. On the contrary, the clear wave group can not be seen in the wave trains of case 3. The characteristics of the wave group are discussed in the next chapter.

5. Characteristics of Wave group

(1) Evaluation of Wave Groupiness

The eharacteristics of the wave groups are usually evaluated by Groupiness factor(GF ; Funke and Mansard(1980)), mean run length($\overline{j1}$), and envelop correlation parameter(κ ; Battjes and Vledder(1984)). Figure 4 shows the time history of GF and $\overline{j1}$ during the Fail-Operations. GF and $\overline{j1}$ of case 3 are also shown for comparison. In Figure 4, the horizontal axis is a elapsed time (hour) from the start of the operation, and the vertical axis is the value of GF and $\overline{jl}$. GF and $\overline{jl}$ do not have any difference between the Fail-Operation and the Normal-Operation. As shown in Figure 2, the wave trains of case 1 and 2 have much stronger wave groupiness than case 3. Strong wave groupiness means that the amplitude of the envelop wave is large, and the modulation of high waves is gradual / smooth.

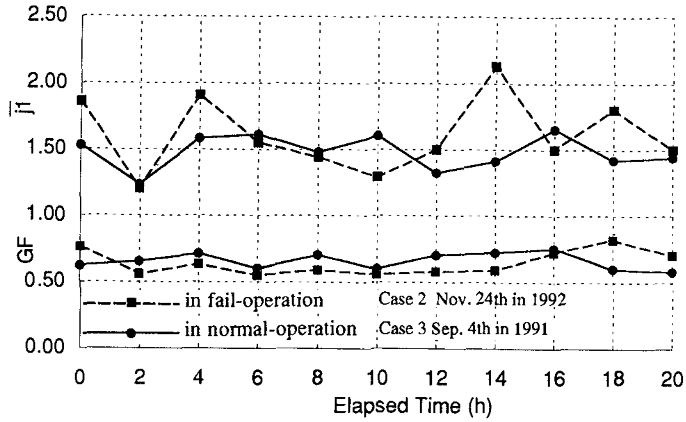


Figure 4 Time series of GF and $\overline{jl}$

GF is defined by covarience of *SIWEH* (Smoothed Instantaneous of Wave Energy History). *SIWEH* expresses the energy distribution of wave train, and is similar to the envelop. It is clear that *GF* can not express the sequence of heigh waves and magnitude of wave height because of the difinition. Therefore, if the sequences of two wave trains are same in the shape but different in the amplitude, *GF* gives a same value for both wave trains. Therefore, *GF* may have large value for the wave train without remarkable wave groups, if the sequence of high waves do not change gradually and the wave train has isolated high waves.

On the other hand, since $\overline{jl}$ is defined as the number of high waves that exceed the threshold value, $\overline{jl}$ expresses the time characteristics of wave groupiness. But, since the unit of $\overline{jl}$ is number , if the sequences of two wave trains are the same in the shape but different in the period, $\overline{jl}$ gives the same value for both wave trains. And also, the similar discussion of *GF* can be made for $\overline{jl}$. In the calculation of $\overline{jl}$, the threshold value must be known to define the run length. Since the threshold value is usually taken as a statistic value of wave train such as the significant wave height, $\overline{jl}$ can not express the difference of the magnitude of wave heights between Fail and Normal-Operation.

Figure 5 shows the time history of κ . In the figure, a white circle denotes when

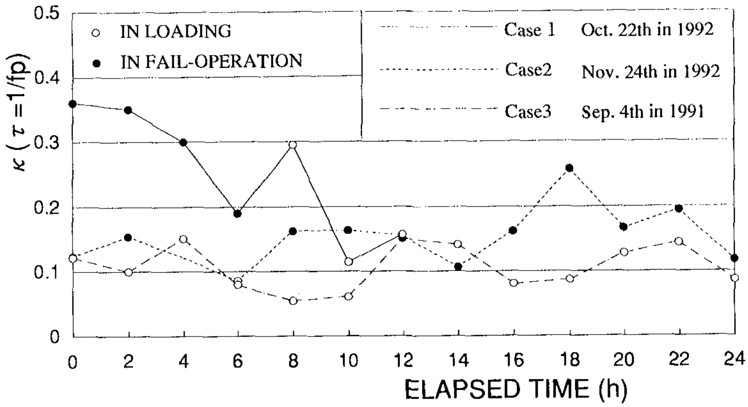


Figure 5 The comparison of κ

the loading was possible, and a black circle denotes when indicates the loading was not possible. κ in Fail-Operation, illustrated by a solid line, indicates that κ decreases with the elapsed time. When the moored ship was continuously moving, κ was about 0.35, but when the loading was possible, κ was about 0.15. The κ values can express the difference between Normal and Fail Operation, in contract with the GF and $\overline{j1}$ values. Because κ is actually auto-correlation of the amplitudes of the wave envelop with a time lag, τ. i.e., κ includes a time characteristics of wave groups. But the difference between Fail-Operation of case 2 and Normal-Operation is not clear. κ is directly calculated by a frequency spectra form based on the narrow band linear theory. If frequency spectrum form is not narrow enough, κ has some error in the calculation.

As shown above, Fail-Operation has a relationship to wave groups. Especially, the time characteristic of the wave groups is important. Since the common parameters such as GF, $\overline{j1}$ and κ can not express the difference of two Operations, a new parameter must be introduced to explain the differences.

(2) A new parameter for wave grouping

Time characteristics of wave groups are an important factor to explain the Fail-Operation. One of the time characteristics of wave groups is a time interval of wave groups. Mean wave Group Period, $\overline{Tg}$, is defined as the mean interval of each wave groups. Tg is equivalent to the total run. Tg , however, has a dimension of time. Tg is calculated by eq.(1) and also illustrated in Figure 6. (Of course, we could apply SIWEH to the method that define the wave group periods.)

$$T_g = \sum_{i=1}^{N} T_i \tag{1}$$

where, Ti is the zero-crossing wave period, N is the number of Ti, where N is equal to a total run(j2).

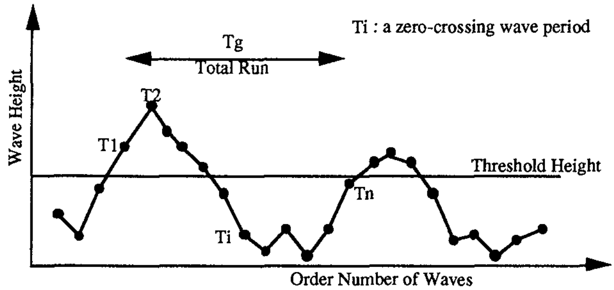


Figure 6 Definision sketch of Tg

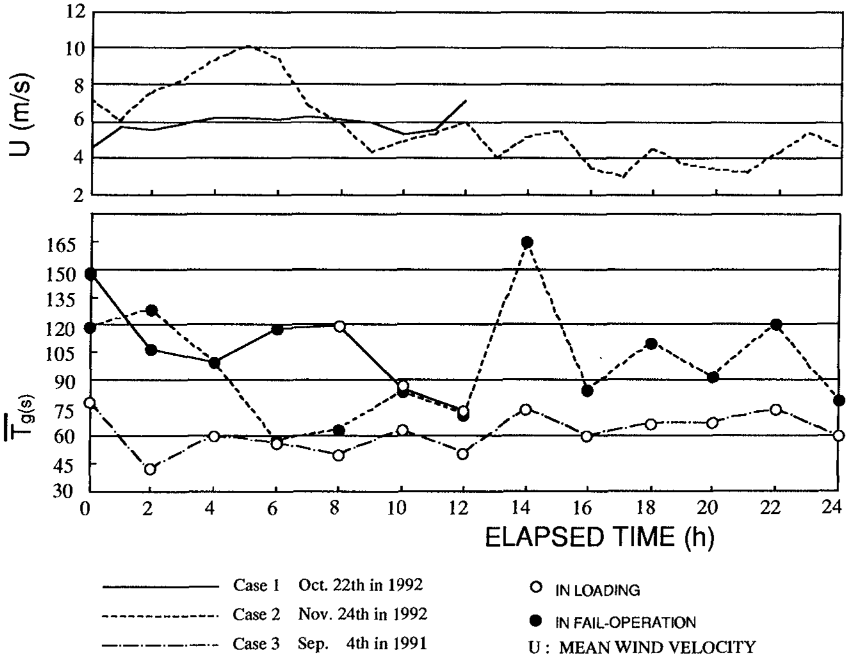


Figure 7 Time series of $\overline{Tg}$

Figure 7 shows $\overline{Tg}$ for case 1, case 2 and case 3 with the wind velocity data. In case 1, $\overline{Tg}$ ranges from 105s to 150s, when the loading was not possible. But, when the loading was possible, $\overline{Tg}$ was around 75s. $\overline{Tg}$ in case 2 was also long when the loading was not possible. On the contrary , $\overline{Tg}$ in case 3 was always around 60s.

In case 2, there is the time when the loading is not possible in spite of the relatively short $\overline{Tg}$ (from 6 to 12 of the elapsed time in the figure). This is because of the strong wind. The shorter $\overline{Tg}$ is caused by the growth of the wind waves. But, since the moored vessel at the berth was moved due to the wind, the loading was not possible.

It is clear that when the loading was not possible, $\overline{Tg}$ was long,on the other hand, when the loading was possible, $\overline{Tg}$ was short. Therefore, $\overline{Tg}$ is an useful parameter for the harbour tranquility when we consider the loading operation.

5.2 Physical meanings of $\overline{Tg}$

It is well known that the wave set-down occurs when wave groups propagatc. Assuming that temporal wave trains are homogeneous in space and wave trains propagate unidirectional, the wave set-down can be calculated after Longuet-Higgins (1962) by eq.(2) and eq.(3).

$$\bar{\zeta} = -S_x / \rho\left(gh - c_g^{\,2}\right) \tag{2}$$

$$S_x = 0.5\rho g a^2 c_g \left(2c_g / c - 0.5\right) \tag{3}$$

where, h is the water depth, ρ is the specific gravity of water, g is the gravity acceleration, a is a half of zero-crossing wave height, c is the phase velocity, cg is the group velocity, and Sx is the radiation stress. The radiation stress Sx is defined by each zero-crossing wave heights and periods, and c and cg are defined by zero-crossing wave periods.

Figure 8 shows the wave set-down calculated from the time series of wave heights in case1. The amplitude of the wave set-down corresponds to the strength of the wave groups.

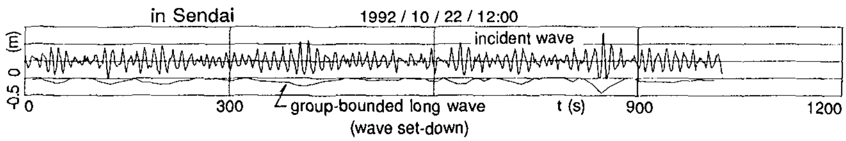


Figure 8 Group-bounded long wave (wave set-down)

Figure 9 indicates the frequency spectrum of the incident wave and the calculated wave set-down. The figure shows the variation of spectrum from Fail-Operations to Normal-Operations. Thc variation of the power in the low frequency correspond to the events of Fail or Normal-Operation. When the power in the low frequency is large, the loading is not possible. On the contrary, when the power is not large, the loading is possible. Thus, the power in the low frequency is a dominant factor to control the loading operation.

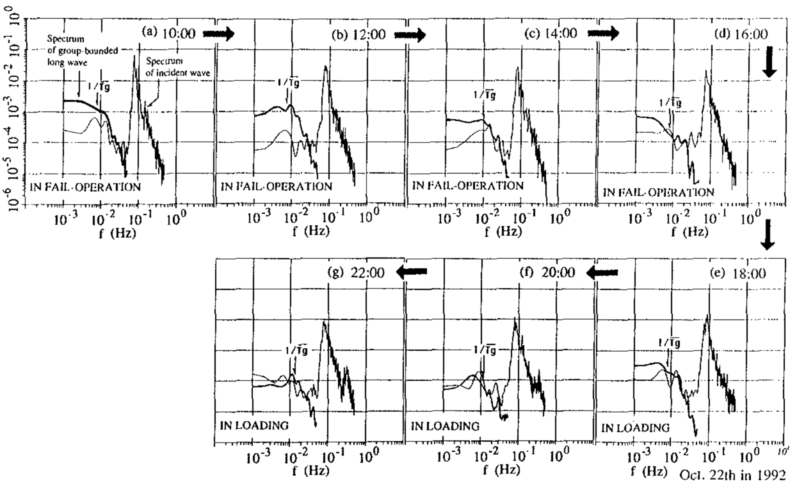


Figure.9 The frequency spectra of incident waves and group-bounded long wave

When the peak frequency in the low frequency of the incident waves is clear, e.g. (b), (c) and (g) in the Figure 9, the peak frequency of the wave set-down and $1/\overline{Tg}$ are nearly equal to the peak frequency of the incident waves. Therefore, it may be concluded that $1/Tg$ is the peak frequency of the long waves in the incident waves and the peak frequency of the wave-set down.

In Fail-Operation from (a) to (c), we can recognize the difference between the spectrum of wave set-down and one of the incident waves. This is because in the low frequency region , the incident waves are consist of the group bounded long waves and the progressive long waves, and since the observation time of wave data is only 20 min., it is not long enough to calculate the group-bounded waves.

6. Propagation of bounded long wave

It is clear now that the incident waves in Fail-Operation has strong wave groupiness, and the long waves bounded by the wave group are important to explain the difference of the wave groupiness between in Fail and Normal Operation. The discussion above, however, are limited in the offshore waves.

The berth was sheltered by the offshore breakwater, thus, the wave height was small enough for the loading operation. We can guess that the groupiness of the incident waves would disappear by the existence of the offshore breakwater, but, the group-bounded long waves can be free waves and can propagate into the harbour.

As shown in Figure 1, a new field observation point(ST.2) was set in 1994, we observed wave condition at three points. Figure10 indicates the variations of spectra from ST.1 to ST.3.

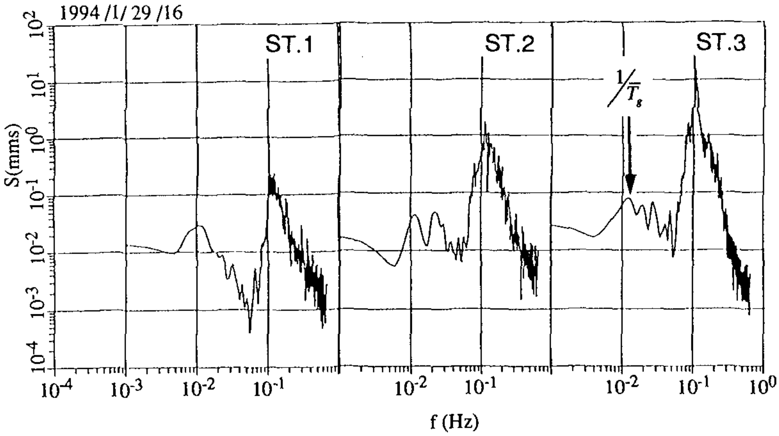


Figure 10 Variation of spectrum as propagation

The power of high frequency region which has the peek frequency around 0.1 *Hz* decrease as their propagation . On the other hand, the power of low frequency region does not denote remarkable dissipation between ST.1, ST.2 and ST.3. And, the peek frequency of low frequency region is corespond to $1/\overline{Tg}$ between ST.1, ST.2 and ST.3. Figure 11 shows comparison of statistical values between ST.2(behind offshore breakwater) and ST.3(at offshore). $\tilde{\eta}_{rms}$ is the root mean square value of low frequency components that are less than 0.05 *Hz*. The significant wave heights at ST.2 are much smaller than those of ST.3 because of the offshore breakwater. *GF* and $\overline{Tg}$ at ST.2 are also smaller than those of ST.3. $\tilde{\eta}_{rms}$ at ST.2 does not dissipate so much in spite that the waves pass the offshore breakwater. Thus, from figures 10 and 11, we may conclude that the group bounded long wave at offshore exchanges to the progressive long wave behind the offshore breakwater, and, the progressive long wave propagate into the harbour.

7. Relationship between harbour oscillation and motion of vessel

It is well known that the slow drift oscillation of vessels are caused by the low frequency modes of waves (Pinkstar(1974)). The motion of the vessel in Fail-Operation might be the slow drift oscillation. Unfortunately, the time series of wave data at the berth in Fail-Operation was not obtained. Thus, the relationship of the waves at the berth and the motion of the moored vessel can not be directly investigated. But, we can guess two causes of a moored vessel's continuous motion(slow drift oscillation) . One is that a free long wave directly attacked the moored vessel. The other is that a free long wave excites harbour oscillation.

We simulated the harbour oscillation by J.J.Lee's method(1971). Figure 12 shows

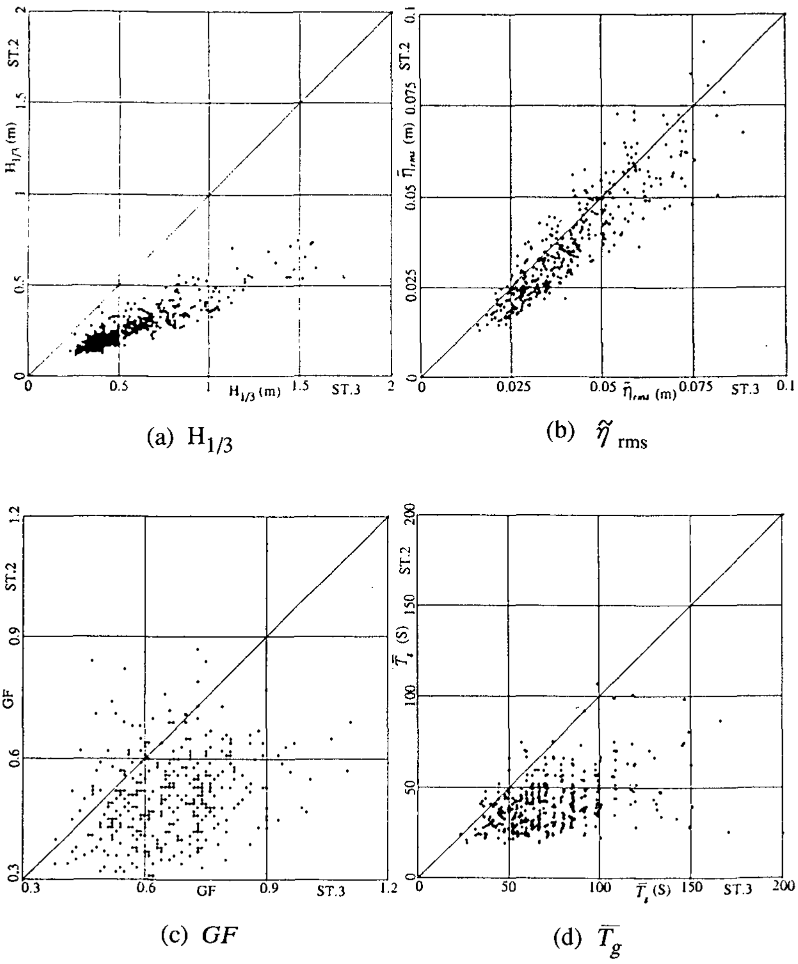
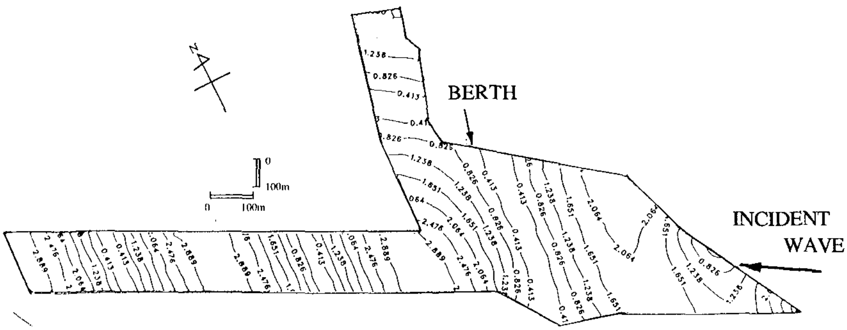


Figure 11 Comparison of statistic values between ST.2 and ST.3

the amplification factor distribution in the harbour. The period of incident wave is equal to $\overline{Tg}$ (100s). The position of the berth is near the node point, and the direction of the motion is surging direction. Therefore, the result of simulation implies that the cause of the slow drift oscillation is the harbour oscillation.

If the periods of the long waves were very close to the natural frequency of surging motion of the vessels, the slow drift oscillation would be excited.

A natural frequency of the surging motion of the vessel (220,000DWT) in Fail-



$T = 100\ s$

Figure 12 Amplification factor of numerical result

NO.	MOORING LINE	NUMBER
1	NYLON ϕ 75	4
2	WIRE ϕ 42	3
3	WIRE ϕ 42	2
4	WIRE ϕ 42	2
5	WIRE ϕ 42	2
6	NYLON ϕ 75	4

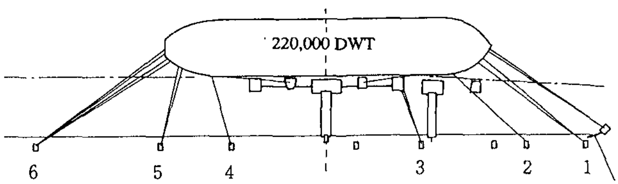


Figure 13 Mooring condition of numerical model

Operation are estimated to 82 s for the mooring system shown in Figure 13. In the estimation , it is assumed that the tensile force of each mooring rope is 3 tf, that is constant through the operation. The restoring force in the direction of the berth is also assumed to be the same as the value obtained from the steady analysis. Furthermore the added mass is not considered. As shown in 4.1, the actual operation of mooring is not steady, and the real tensile force of each mooring rope might be weaker than 3 tf. Therefore the true natural frequency must be longer than 82 s, i.e., the natural period could be close to the period of the group bounded long wave or $\overline{Tg}$.

8. Conclusion

In spite of small waves and weak winds , there was a event that the loading operation failed(Fail-Operation). By analyzing the cause of Fail-Operation, it is found that the group bounded long waves cause Fail-Operation. This means that the information related to the wave group is required for the loading operation in harbors. Wave group period, $\overline{Tg}$, proposed here can be a useful information for the harbour tranquility in controlling the loading operation. $\overline{Tg}$ represents a period of long wave that is bounded by wave groups. A long wave bounded by wave groups at offshore changes to a free long wave behind offshore breakwater, and a free long wave which propagates into a harbour excites a harbour oscillation. When the period of this long wave is close to natural frequency of vessels, and energy of the long wave is large in the harbour, fail-operation would occur.

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