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THE RELATION ANALYSIS BETWEEN TYPHOONS AND WAVES ON THE VIEW OF SHIP MOORING CRITERIA IN HARBOURS

船舶の係留限界の観点から見た台風経路と波浪の関係について

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船舶の係留限界の観点から見た台風と波浪の関係について

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要　旨

外洋に面した海域の港湾において，係留船舶の動揺に起因した係留障害は港湾運用の観点から非常に深刻な問題である．このような背景より，係留船舶の長周期動揺に対する係留対策がいくつか提案されているが，これらが現場で実用化されている港湾はほとんどないのが実情である．これより係留システムとは異なった観点から，波浪や台風のデータベースをもとにした運用システムが必要であると考えられる．本研究において，太平洋に面した海域に立地する港湾を検討対象に抽出し，まず 1997～1999 年に発生した係留障害に関する事例を調査した．これより，多くの係留障害の事例が台風に起因したうねりや長周期波の影響によって生じていることが明らかとされた．本報告においてはナウファスの波浪観測データ，台風データを用いた相関分析を実施し，有義波，天気図および台風経路および諸パラメーターが係留限界時にどのような関係となっているかについて調査した．これらより，波浪予測の基礎資料として有効と考えられるいくつかの相関式が求められた．

キーワード：外洋性港湾，波浪の発達状況，台風，係留限界，ナウファス

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The Relation Analysis Between Typhoons and Waves on the View of Ship Mooring Criteria in Harbours

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Synopsis

Mooring troubles due to moored ship motions are very serious problem in a harbour facing the open sea from the point of view of the port operation. Some countermeasures are proposed against moored ship motions. However, there are few harbours with mooring systems considering long period ship motions. This shows that other operational systems are necessary using database of waves or typhoons. In this study, we focus on a harbour facing the Pacific Ocean, and research on mooring troubles which are happened in 1997-1999 at first. It is cleared that most of mooring troubles happens under the condition with the influence of swells or long period waves due to typhoons. Thus, relational analyses are carried out using observed wave data by NOWPHAS system and typhoon data. Some relations can be found among mooring troubles, observed wave conditions, and typhoons as the basic information of the wave prediction.

Key Words: Harbours Facing to the Open Sea, Wave growth, Typhoon, Mooring Criteria, NOWPHAS

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1.Introduction

Recently, the importance of moored ship motions in a phase of harbour planning is recognized as one of the main factors of the field of coastal engineering as well as the port operation(Shiraishi, et al., 1999). Some studies concerning the suspension of cargo handling or breaking troubles of mooring equipment due to moored ship motions are carried out(Hiraishi, et al, 1997), then it is shown that the existence of long period waves around 1-3 minutes is a main factor to cause long period moored ship motions(Shiraishi, et al., 1996). It is shown that the decreasing of ship motions becomes possible by a modification of mooring lines and fenders. Even so, the present countermeasure is not still enough to restrain ship motions fundamentally. Moreover, it seems difficult to introduce the countermeasure at most of berths, because a lot of budgets are necessary to modify to the new mooring system. In these situations, there may be few possibilities to accomplish the improvement of mooring systems at most harbours. It shows that different countermeasures for the operation of moored ships will become necessary. On the other hand, it is enacted that moored ships have to evacuate to outside harbour in the operational standards, when it becomes stormy weather conditions. Then, it is natural that the prediction of waves at the stormy weather becomes very important. A lot of studies about a weather forecasting are carried out using the statistical method such as multi regression analysis or the meteorological one(Goto, et al., 1993). However, the accuracy of the prediction still has some problems, especially in the case of rapid wave growth patterns.

In this study, we mainly analyze the relation between mooring troubles and growth patterns of waves due to observed data by NOWPHAS(Nationwide Ocean Wave information network for Port and HArbourS) system (Nagai, et al., 1994). Harbours(A port and B port) are selected as targets, which are facing to the Pacific Ocean. At first, we research on weather situations at each mooring accident in A port. Also, we compare growth patterns of significant waves between A port and B port to know the time difference of the propagation of waves. Mooring troubles in A port are mainly caused by the influence of typhoons, so it is necessary to know the relation between typhoons and wave growth patterns. There are some studies on properties of observed waves due to typhoons(Aoki, et al., 1997). However, relations between typhoons and mooring criteria are not discussed in those papers. The relational analysis is carried out using each parameter of typhoons and observed waves including long period waves. Some relations between mooring criteria, waves and typhoons can be explained well in case of the propagation of swells. We carry out regression analysis to estimate these relations. It is cleared that types of typhoons should be divided into some patterns to explain the propagation and growth of swells or high waves that cause mooting criteria. By these results, we examine about the possibility to apply for the prediction of waves in order to judge the mooring criteria by combining database of NOWPHAS, typhoons and other weather information. Also, it is necessary to know properties of long period waves by analyzing observed wave data, too. The final purpose of this study is to construct the prediction model for wave growth offshore harbours facing to the Pacific Ocean. These points will be discussed and studied in the next and future reports.

2.Background and flow of this study

There are a lot of studies about wave prediction and forecasting by now. However, most of them are not focused on the situation of mooring criteria due to moored ship motions in harbours. When we consider about the influence of moored ship motions in harbours, it is necessary to know about berth operation from the point of view of ship mooring. Though the cargo handling criteria becomes to consider in a stage of port construction, mooring criteria are not focused in a field of port planning and operation. **Figure 2.1** shows the flowchart about the typical pattern of the berth operation of moored ships at stormy weather conditions.

The information about wave growth is necessary before the entrance into harbours and during the cargo handling. The evacuation to outside harbour costs a lot in the middle of the cargo handling, because extra charges of pilot, tugboats and berth become necessary. There is a tendency that operators of moored ships hate to evacuate to outside harbour when they don't finish the cargo handling, even if the wave condition becomes a bit serious. Although the time length of ship mooring is different from each condition of ships, cargoes and berths, most of them are within three days. This shows that an accuracy of the wave prediction is required in two to three days ahead. Present methods of the wave prediction do not have enough accuracy and time length to predict a rapid growth pattern of waves for two to three days. Therefore, we construct the flowchart of this study as shown in **Figure 2.2**.

In this study, we consider a situation of ship mooring criteria as well as the berth operation to the wave prediction. Also moored ship motions become large by the influence of long period waves or swells, even if wave heights are not so large. Former studies are only focused on the prediction of significant wave heights. However, it is necessary to research on the propagation of swells or long period waves. We focus on the tendency of the growth pattern of wave periods as well as wave heights. The influence of the wave propagation is researched between different observation points located in open sea area. The phenomenon of the propagation is focused about long period waves around 1-3 minutes as well as significant waves around 5-15s. Therefore, observed time series of waves is necessary to analyze the existence of long period waves. In Japan, wave network observation system is constructed in offshore harbours. It is called NOWPHAS(Nationwide Ocean Wave HArbourS) that is used in this study.

A typical pattern from arrival to departure of a ship at stormy weather conditions is shown in **Figure 2.1**. If weather conditions become serious, ship's captain have to decide whether stay in a harbour or evacuate to outside(Kubo, et al., 1998). Then, the prediction technology of the wave growth becomes very important, however, most of the studies about forecasting waves are not focused on the accurate prediction model of waves from the point of view of the mooring criteria.

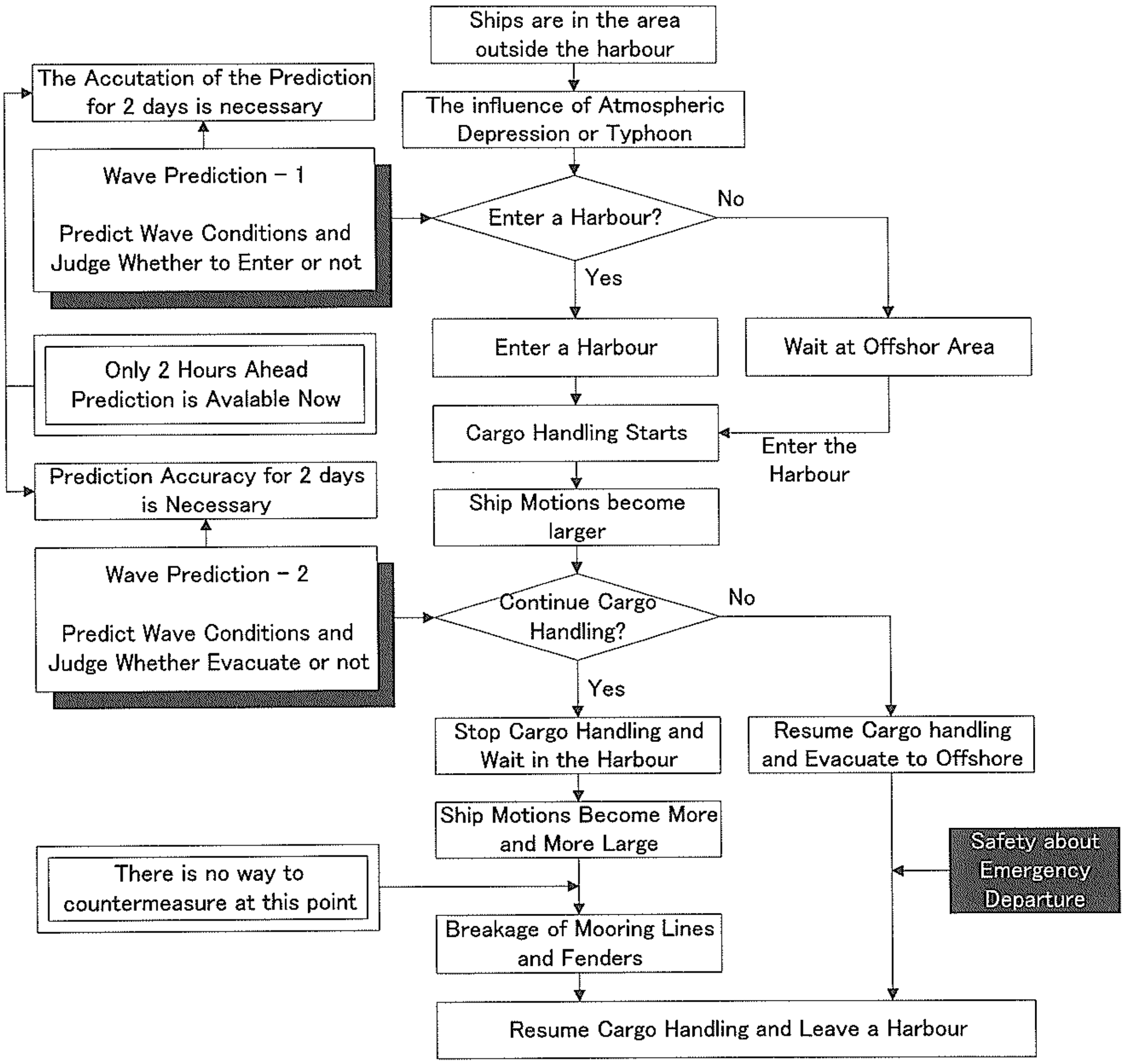


Figure 2.1 Typical pattern of the berth operation of moored ships at stormy weather

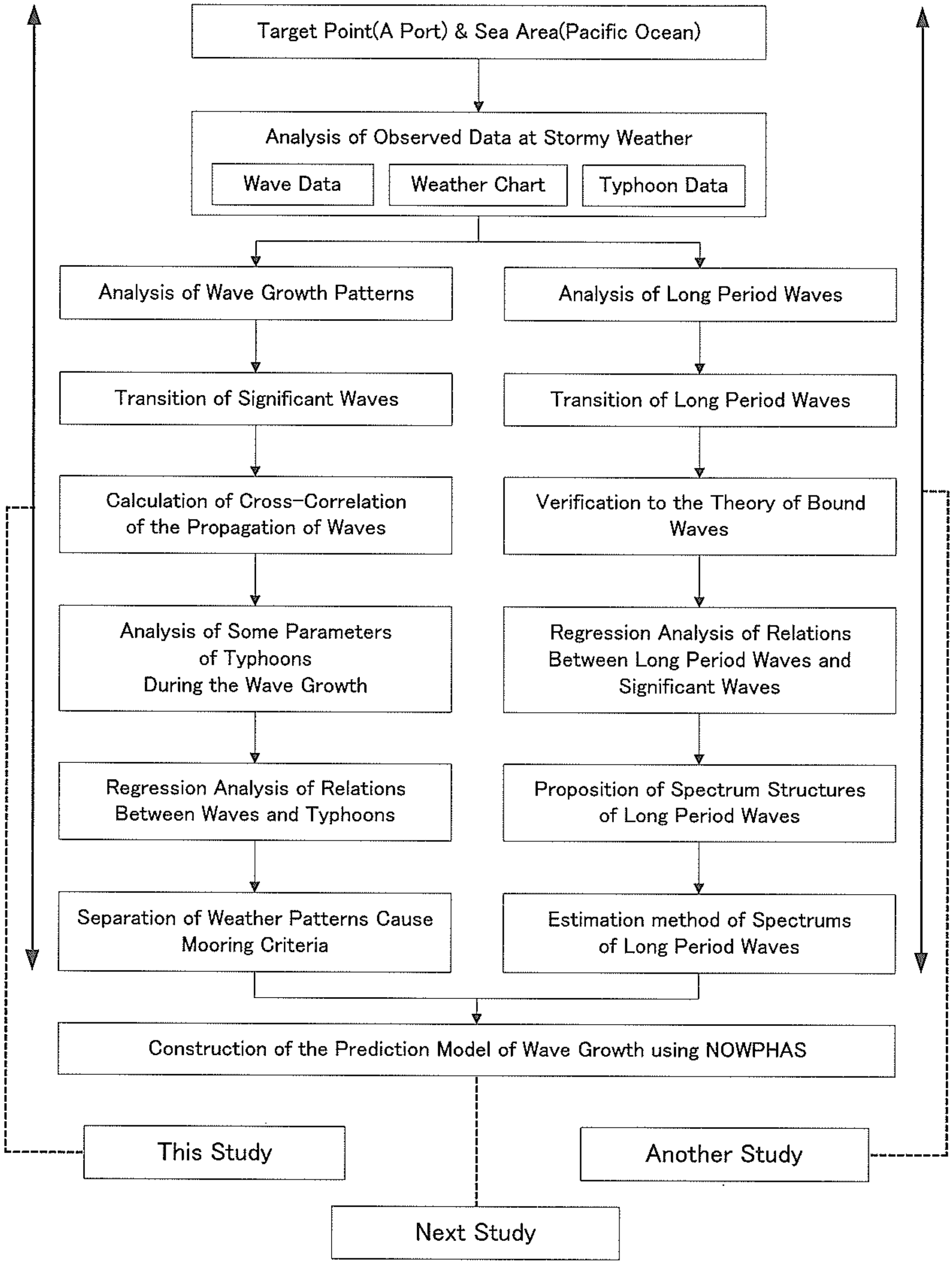


Figure 2.2 Flow chart of this study

3. Harbours and mooring troubles focused on this study

If we research on the relation between wave growth pattern and mooring criteria, observed wave data is required to analyze them. There are 2 types of waves offshore harbours in open sea in Japan. One is that faced to the Pacific Ocean, another is that faced to the Sea of Japan. Although properties of waves are so different from each other, mooring troubles in a harbour occurs in both areas when weather conditions become serious. Coastal areas facing to the Pacific Ocean have the influence of swells or high waves due to typhoons or atmospheric depressions. On the other hand, coastal areas facing to the Sea of Japan have the influence of high waves due to atmospheric depressions in winter season. It is very hard to analyze wave data about all the observation points of NOWPHAS, so we focus on an appropriate point which is offshore harbour facing to the Pacific Ocean.

In this study, harbours with mooring problems have to be chosen as a target of the study. We focus on A port, which is located in south-west part of Japan. Also, B port is extracted to know the influence of the propagation of waves with some distances. B port locates in south-west islands of Japan. So, the time difference of the propagation of waves can be researched by comparing wave data in both points. It is reported that A port has mooring problems at some berths by the influence of high waves, swells and long period waves from the Pacific Ocean(Hiraisihi, et al., 1996). The information about mooring troubles occurred at 1997-1999 in this port is shown in **Table 3.1**.

This shows that most of mooring troubles is caused by the influence of typhoons. However, some troubles are caused by the atmospheric depression in winter or spring seasons, like the trouble on February, 1998. In A port, breakage of mooring lines or fenders is mainly reported at the grain berth or the ferry berth. Typical ship size of grain carriers is about 30,000-50,000 ton class, and that of ferries is about 5,000-10,000 ton class. Although a long breakwater is constructed for the safety of these berths, these troubles show that the workability or the mooring criteria can not be raised only by the construction of breakwaters. The influence of swells and long period waves may not reduced even in the harbour, especially because the ferry berth is located in comparatively inner part. Despite those circumstances, any effective countermeasures are not carried out like the modification of mooring systems at the present stage. Therefore, at first, some patterns of wave growth have to be analyzed for the safety operation of moored ships.

Table 3.1 Main mooring troubles in A port (1997-1999)

Year	Month & Date	Weather Reason	Situations of Ferry Berth	Situations of Grain Berths
1997	April 22nd-23rd	Typhoon 9701	Shift to another berth	Evacuate to outside harbour
1997	June 18th-21st	Typhoon 9707	Cancel the navigation	
1997	June 27th-30th	Typhoon 9708	Depart the harbour earlier	Evacuate to outside harbour
1997	July 23th-28th	Typhoon 9709	Cancel the navigation	Evacuate to outside harbour
1997	August 17th-19th	Typhoon 9713	Shift to another berth	Wait for entering at outside harbour
1997	October 20th-22nd	Typhoon 9724	Shift to another berth	
1997	November 4th-7th	Typhoon 9725	Evacuate to outside harbour	Evacuate to outside harbour
1998	February 13th-14th	A.D.		11 mooring lines are broken
1998	April 29th-May 1st	A.D.		1 mooring line is broken
1998	August 28th	Typhoon 9804		2 mooring lines are broken
1998	September 15th-16th	Typhoon 9805		6 mooring lines and 1 fender are broken
1998	September 21st	Typhoon 9806	Evacuate to another harbour	
1998	September 27th	Typhoon 9809		2 mooring lines are broken
1998	October 15th	Typhoon 9815	Cancel the navigation	2 mooring lines are broken
1998	November 7th	A.D.		3 mooring lines are broken
1999	July 22nd			7 mooring lines are broken
1999	July 26th	Typhoon 9905	1 fender and ship hull are broken	1 fender is broken
1999	July 28th	Typhoon 9905	Ferry cannot berth	
1999	August 1st-4th	Typhoon 9907	Evacuate to outside harbour(4th) Ship hull is broken	Evacuate to outside harbour(1st) 1 mooring line is broken
1999	August 5th-6th	Typhoon 9908	Shift to another berth	Evacuate to outside harbour(5th 15:00)

(Note) A.D. means Atmospheric Depression

Table 3.1 shows that situations of mooring impossible exist almost during a year, and troubles due to typhoons are happened from April to November. So we have to pay attention to the influence of moored ship motions in other seasons as well as in main typhoon seasons(July, August and September). Also, a basic knowledge for the prediction of the wave growth is expected to obtain by analyzing waves and typhoons. In this study, we try to carry out some relational analysis among typhoons, waves and mooring troubles.

4.Analysis of significant wave of NOWPHAS system

4.1 Wave growth patterns of significant waves

At first, it is necessary to know the transition of significant wave heights and periods at A port and B port. In this chapter, some growth patterns of significant waves are focused on database for 5 years(1995-1999). **Figure 4.1.1** and **Figure 4.1.2** show transitions of significant waves in A port and B port on July and September, 1995.

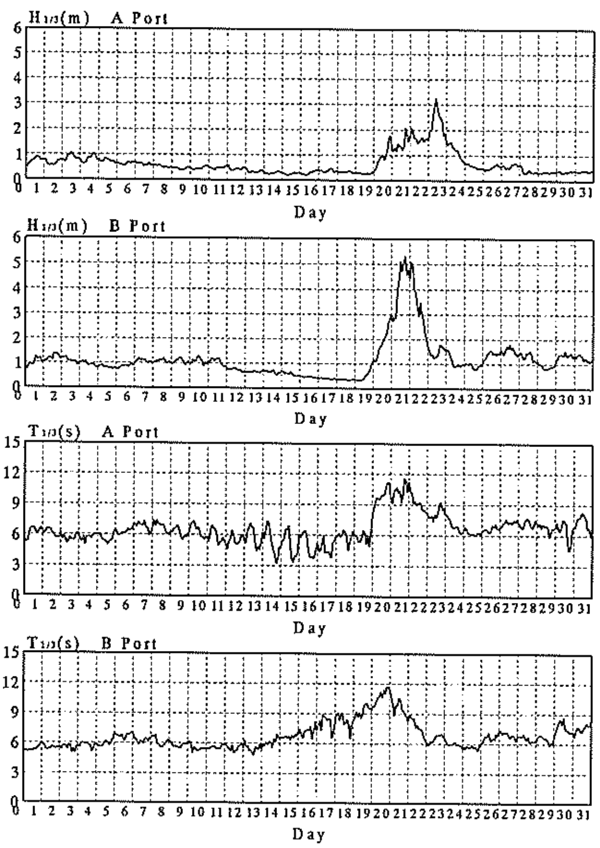


Figure 4.1.1 Transition of significant waves on July, 1995

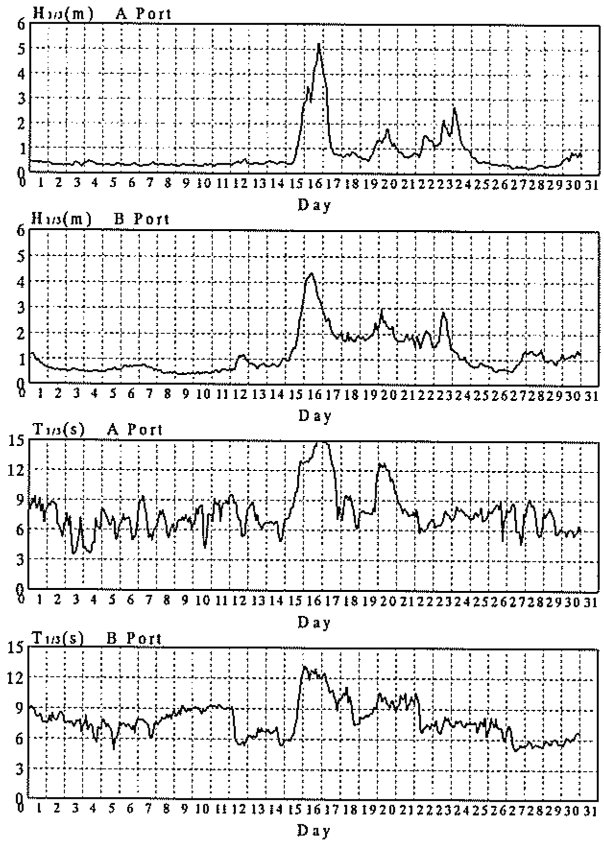


Figure 4.1.2 Transition of significant waves on September, 1995

In **Figure 4.1.1**, start points of the wave growth(July 20th) is almost the same, however, growth patterns are so different each other. Consuming time to the peak point is larger in A port than B port. Peak values of wave heights are so different each other, too.

In **Figure 4.1.2**, start points(September 15th)and peak points(September 16th) of the wave growth is almost the same. The peak value of wave heights is a bit larger in A port than in B port in this case. The growth pattern is so rapid in this case. Wave heights exceed 5m within one day from 0.5m in A port. Also, wave periods are longer in A port(15s) than in B port(12s). It is presumed that wave periods become a bit large because fetch is a bit larger in A port. Swells around 2-3m are observed at September 20-24th both in A port and B port.

Figure 4.1.3, **Figure 4.1.4** and **Figure 4.1.5** show transitions of significant waves on May, August and November, 1996.

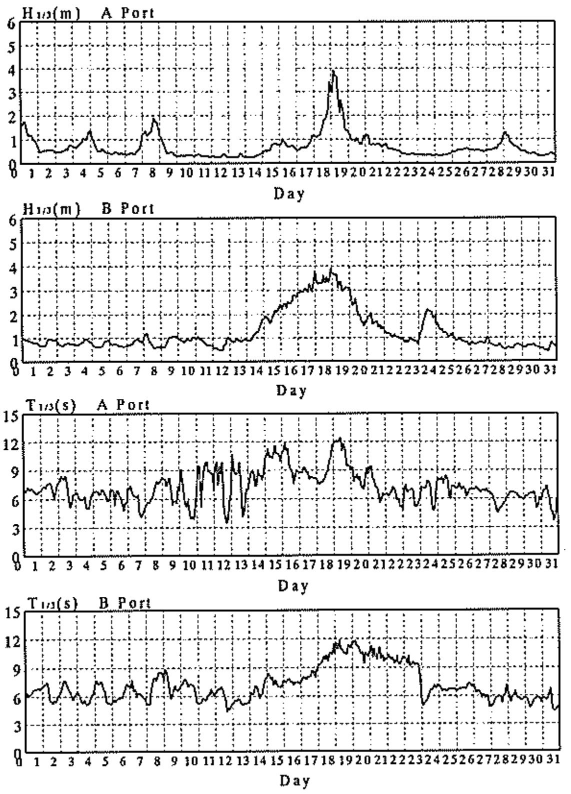


Figure 4.1.3 Transition of significant waves on May, 1996

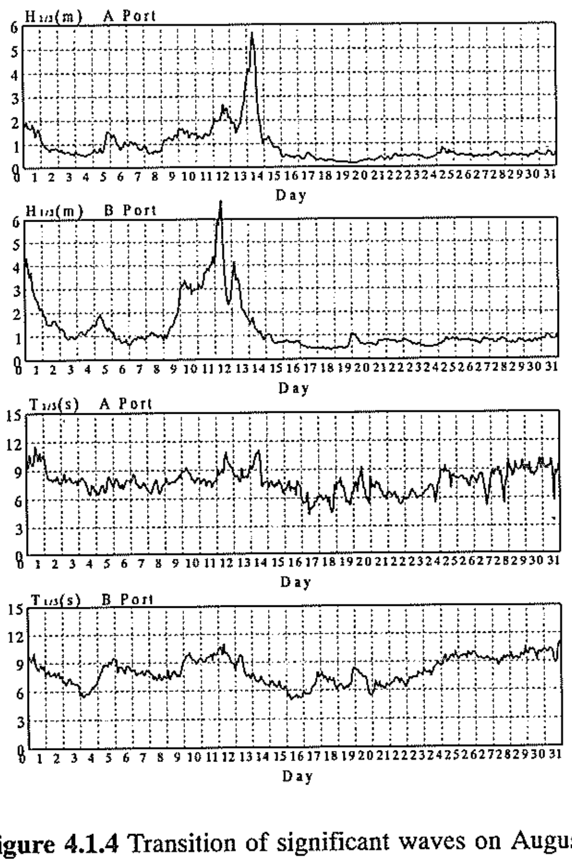


Figure 4.1.4 Transition of significant waves on August, 1996

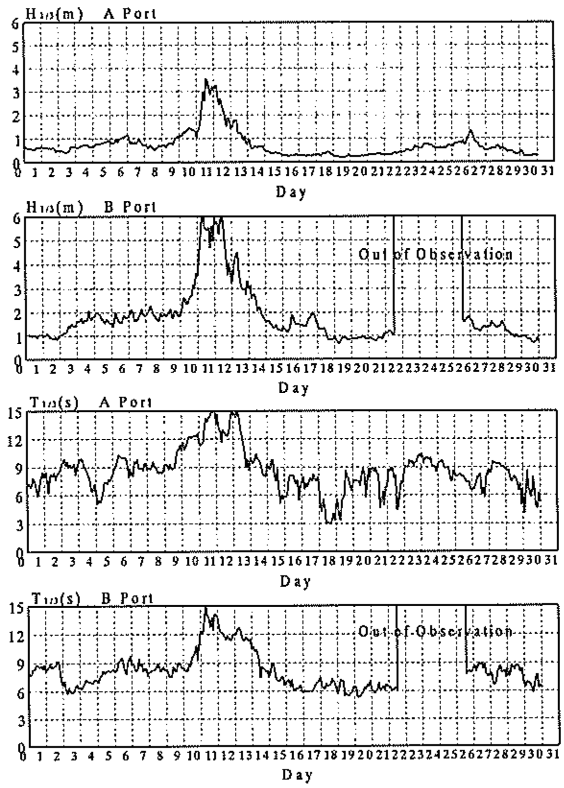


Figure 4.1.5 Transition of significant waves on November, 1996

In **Figure 4.1.3**, it may be the rare case that high waves around 4m are observed in May. Although peak points of wave heights are almost the same(May 19th), growth patterns are pretty different between A port and B port. The growth pattern in A port is so rapid, consuming time of the growth is almost one day from 1m to 5m(May 18th). On the other hand, consuming time is almost 4 days in B port from 1m to 5m. Wave periods are almost the same(12s).

In **Figure 4.1.4**, there is a remarkable wave growth in the middle of August in both ports. Peak wave heights are a bit similar, however, growth patterns are so different. In both cases, waves rise to 2-3m at first, then rapid growth to 6-7m is happened within a half day.

In **Figure 4.1.5**, the propagation of strong swells is recognized on November 10th-13th in both ports. Although the peak wave height in A port(3.5m) is almost half of B port(7m), growth curves are so similar each other. Wave heights rise rapidly to peak values from 1-2m with a half day, too. It is presumed that the difference of wave heights is due to the distance from the typhoon in this case. Wave periods are about 15s in both cases, strong and matured swells may influence to ships and harbours facing to the Pacific Ocean in south-west part of Japan.

Figures 4.1.6-4.1.11 show transitions on April, June, July, and November in 1997, September in 1998 and

September, 1999.

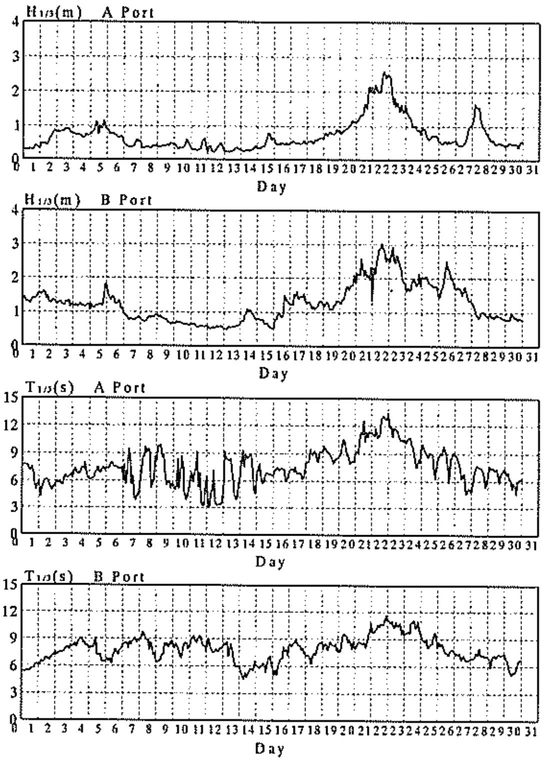


Figure 4.1.6 Transition of significant waves on April, 1997

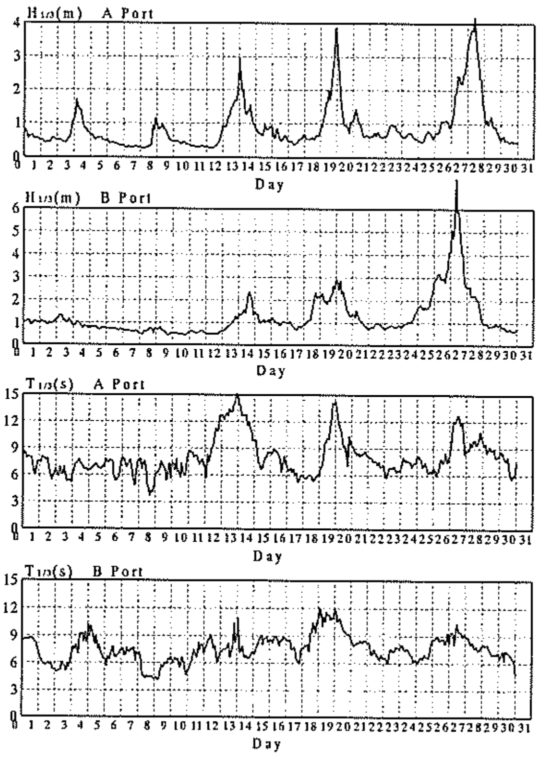


Figure 4.1.7 Transition of significant waves on June, 1997

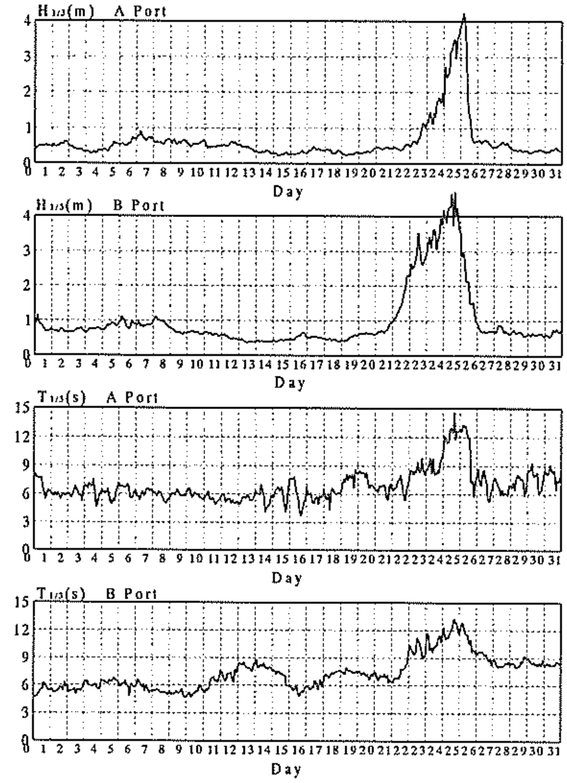


Figure 4.1.8 Transition of significant waves on July, 1997

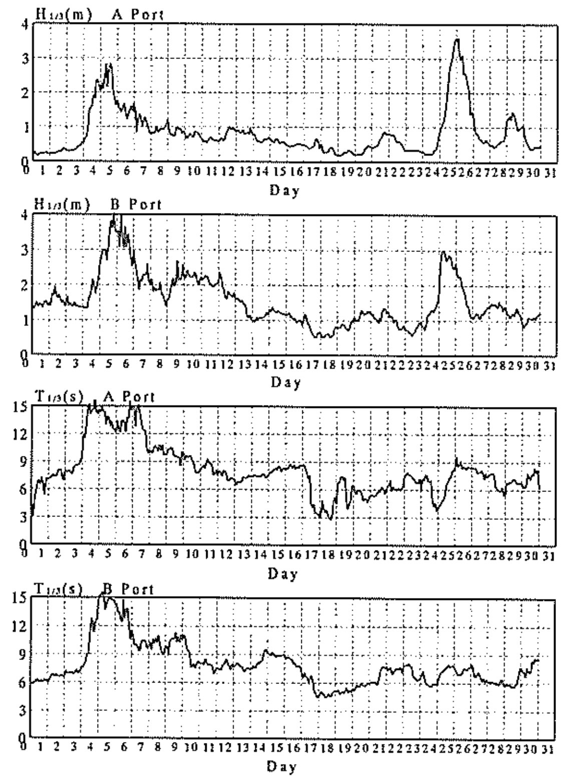


Figure 4.1.9 Transition of significant waves on November, 1997

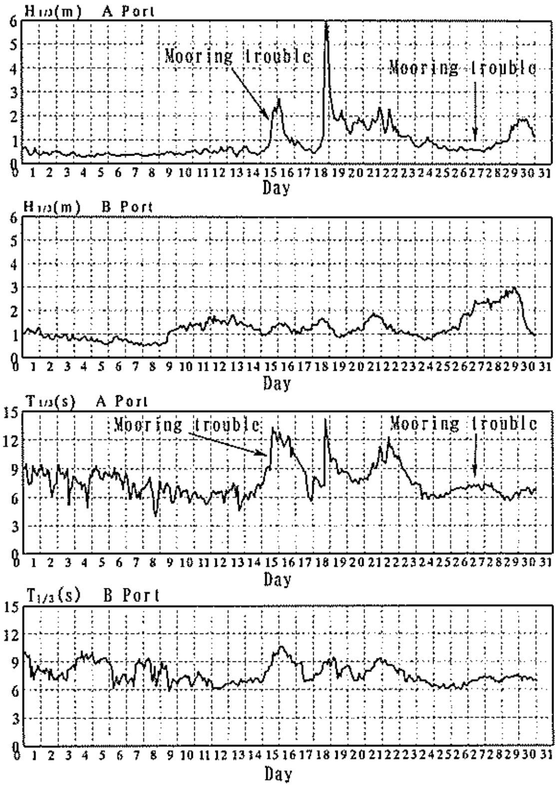


Figure 4.1.10 Transition of significant waves on September, 1998

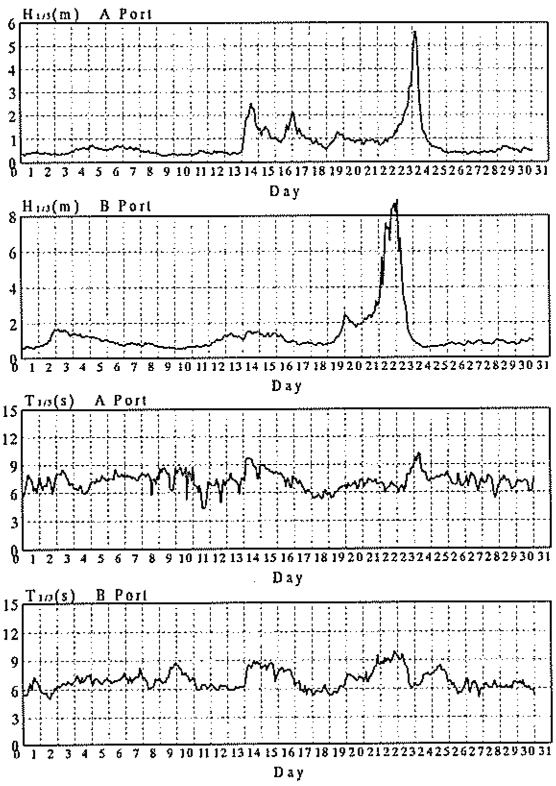


Figure 4.1.11 Transition of significant waves on September, 1999

The relationship between mooring troubles at A port and the transitions of significant wave data is researched.

In **Figure 4.1.6**, the propagation of swells on the 20th-23rd can be seen in A and B ports. Its significant wave heights and periods are about 2-3m and 10-13s respectively. In this case, the growth of wave heights is not so rapid. Also the time difference of the wave growth between A and B port is so little.

In **Figure 4.1.7**, there are three rising points of waves more than 2m. These propagations of waves are caused by swells due to typhoons. The first rising point is on 13th-14th. The rapid growth of waves is recognized at the midnight of 13th in A port, from 2m to 3m. The time difference between A and B port is very few, too. On the other hand, wave periods are different each other. In A port, peak values are about 12-15s. However, in B port, they are about 9-11s. The second rising point is on 18th in A port. The wave growth is rapidly in this case, from 1m to 4m for one day. The growth pattern is so different from B port as shown this figure. Wave periods are larger in A port (14s) than B port (12s), too. The time difference of the wave growth seems to be about 1 day. The third point is 27th-28th in A port, the growth pattern is slower than the second rising point. On the other hand, the peak of wave heights in B port is 26th-27th, so the time difference is about one day, too. However, the peak value of wave heights is much larger in B port (7m) than A port (4m). The difference of wave periods is almost the same as other cases in the figure.

In **Figure 4.1.8**, there is one rising point of waves exceeded 4m. In this case, wave heights rise slowly, for 3-4 days. The time difference is about half a day (peak point), although growth curves of waves are a little different (The difference of starting points of the growth is one day). Wave periods exceed 12s in both ports.

In **Figure 4.1.9**, there are two rising points of waves. Especially, the first rising point on the 4th-6th is a typical propagation of strong swells which significant wave periods are about 15s, so the evacuation of the moored grain carrier is happened. The time difference of the wave propagation between A and B port is about one day (comparing peak points). However, it is characteristic that waves propagate to A port sooner than B port. So, the forecast of wave propagation due to typhoons in the Pacific Ocean is more difficult than them in the Sea of Japan. Because patterns of the propagation and the growth are so complicated. Therefore, it is shown that we cannot predict wave growth patterns only by using the time difference of wave growth between two points in the Pacific Ocean.

In **Figure 4.1.10**, there are some rising points from the middle of September in 1998 due to typhoons. The first point on the 15th-16th causes the breakage of 6 mooring lines and a fender, maybe because of the influence about the rapid growth of significant waves for several hours.

In these cases, mooring troubles are strongly related to rapidly growing swells within a day.

There is half day time lag of the wave propagation at the second wave rising point in **Figure 4.1.9**, however, it scarcely exist the time lag between A and B port at the first point in **Figure 4.1.10**. On the other hand, there is no correlation of waves between A and B port in **Figure 4.1.10**. Therefore, the prediction of the wave growth isn't enough exact to use significant wave data only between two points, because wave propagation patterns are so various. So it is necessary to show the data analysis of typhoons that causes the swells or long period waves.

In **Figure 4.1.11**, there are 2 rising points of waves(exceed 2m) in A port. The first growth pattern (September 14th) is recognized only in A port. This pattern has the rapid growth from 0.5m to 2.5m within half a day. The second pattern is recognized in both ports. This pattern has the rapid growth(1m to 6m), too.

4.2 Cross-correlation of the wave propagation

In the previous chapter, the time difference of the wave propagation is researched to know the wave growth pattern. Then it is necessary to analyze the correlation of the wave propagation numerically. In this chapter, the cross-correlation analysis is carried out to research on the correlation of the wave propagation. The cross-correlation function $C_{xy}(\tau)$ is calculated as follows.

$$C_{xy}(-\tau) = \lim_{T\to\infty} \frac{1}{T}\int_0^T x(t)y(t-\tau)dt\,, \quad (4.2.1)$$

where, T: Time length of the calculation, τ: Time lag between data x and y. In this case, data $x(t)$ corresponds to the observed significant wave height every 2 hours, and data $y(t-\tau)$ is significant wave heights of long period waves in each time period band every 2 hours. In this study, the length of T is set to be 4 to 5 days.

In this section, the cross-correlation of significant waves is researched in between A and B port in 1997. **Figure 4.2.1-Figure 4.2.5** show calculated results of them on April, June, and November, 1997 and September, 1998.

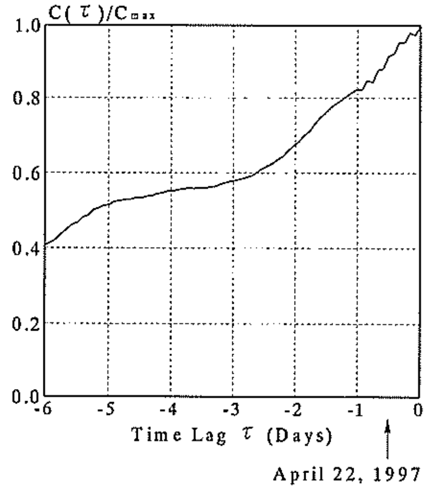


Figure 4.2.1 Calculated result of cross-correlation function (April 17th-23rd, 1997)

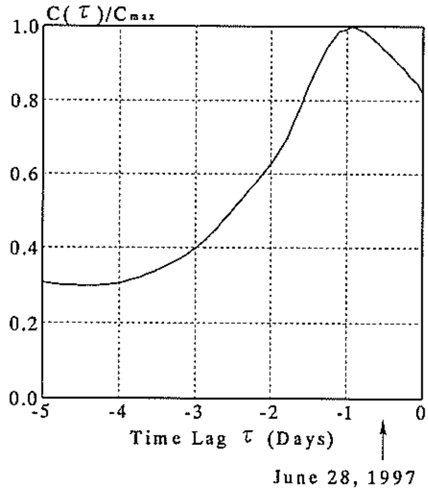


Figure 4.2.2 Calculated result of cross-correlation function (June 24th-28th, 1997)

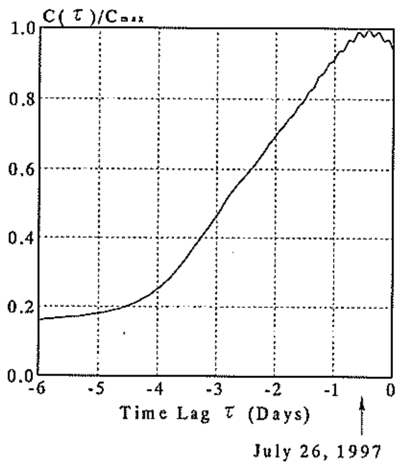


Figure 4.2.3 Calculated result of cross-correlation function (July 21st-26th, 1997)

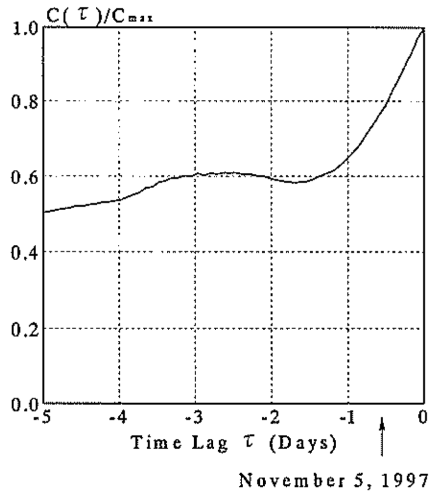


Figure 4.2.4 Calculated result of cross-correlation function (November 1st-5th, 1997)

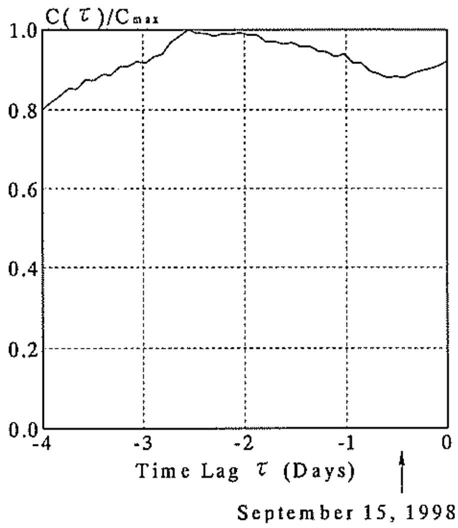


Figure 4.2.5 Calculated result of cross-correlation function (September 12th-15th, 1998)

Values of $C(\tau)$ is maximum when τ=0 in **Figure 4.2.1** and **Figure 4.2.4**. This shows that waves propagate to A port at the same time or at sooner than B port. On the other hand, $C(\tau)$ becomes maximum when τ =12-24 hours in **Figure 4.2.2, Figure 4.2.3**. These cases are typical patterns that waves propagate from southern point to northern point with some time differences. However, values of $C(\tau)$ do not change for 4-5 days in **Figure 4.2.5**. This may show that the correlation between A and B port does not exist about the wave growth in A port. It is necessary to calculate cross-correlation functions to analyze the wave growth patterns by significant waves in different points numerically. Time lags of the wave propagation more than 24 hours cannot be seen in these results. Also, there is so little correlation in some cases between A port and B port, despite influences of the same typhoons. This shows that more observation points will be necessary to know the propagation of waves by this way. However, it is shown that propagation patterns are not able to calculate only by observation points in coastal zones. Typhoons or atmospheric depressions are generated and moving in wide area of the Pacific Ocean. Some wave observation points should be placed in far sea area of the Pacific Ocean, if we predict the propagation of high waves or swells. All the observation points are placed in coastal zones in NOWPHAS system. On the other hand, present wave forecasting and hindcasting tends to be examined by numerical forecasting models considering whole regions of the earth. Also, observation buoys in the Pacific Ocean will be changed to drifting types. This shows that it is not easy to construct these systems soon. It may be effective to correct forecasted values by combining with other observation systems like meteorological observation buoys in the Pacific Ocean. This point will be another research theme in the future. On the other hand, the analysis of weather conditions or long period waves is very important to know the wave growth patterns, too. Thus, we will research on other parameters that seem to be related to the growth of significant waves.

5.Analysis of weather charts at stormy weather conditions

In chapter 4, some patterns of the wave growth are researched by transition of significant wave heights and periods. It is shown that wave growth patterns are more complicated in each case, so the prediction of the growth is hard only by the information of significant wave data. These results show that it is necessary to analyze weather charts at stormy weathers and compare them with the growth of significant waves.

Table 5.1 shows analyzed cases of observed wave data at stormy weather conditions in 1995-1999(31 cases). Most of these cases are at stormy weather conditions due to typhoons. In some cases, typhoons approach to A port within very short distances. In other cases, swells propagate from typhoons that don't land to Japan. Also, cases that mooring troubles happen in spite of the low wave heights and periods.

Figure 5.1 and **Figure 5.2** show weather charts of case 1 and case 2 in 1995. **Figure 5.3** and **Figure 5.4** show weather charts in case 5 and case 8 in 1996. **Figure 5.5** and **Figure 5.6** show weather charts in case 16 and case 22 in 1997. **Figure 5.7** and **Figure 5.8** show weather charts in case24 and case 28 in 1998 and 1999.

Table 5.1 Extracted cases of the data analysis in 1995-1999

Case	Year	Month & Date	Weather Condition
1	1995	July 16th-23th	Typhoon 9503
2	1995	September 12th-16th	Typhoon 9513
3	1995	September 18th-24th	Typhoon 9514
4	1995	October 17th-21st	Typhoon 9518
5	1996	May 13th-19th	Typhoon 9603
6	1996	July 6th-10th	Typhoon 9605
7	1996	July 13th-18th	Typhoon 9606
8	1996	July 25th-31st	Typhoon 9609
9	1996	August 8th-14th	Typhoon 9612
10	1996	October 20th-24th	Typhoon 9623
12	1996	November 6th-12th	Typhoon 9624
13	1997	April 17th-23th	Typhoon 9701
14	1997	May 26th-30th	Typhoon 9704
15	1997	June 10th-14th	Typhoon 9706
16	1997	June 16th-20th	Typhoon 9707
17	1997	June 24th-28th	Typhoon 9708
18	1997	July 21th-26th	Typhoon 9709
19	1997	August 3th-7th	Typhoon 9711
20	1997	August 12th-18th	Typhoon 9713
21	1997	September 10th-14th	Typhoon 9719
22	1997	November 1st-5th	Typhoon 9725
23	1998	August 24th-29th	Typhoon 9804
24	1998	September 12th-16th	Typhoon 9805
25	1998	September 25th-30th	Typhoon 9809
26	1998	October 11th-15th	Typhoon 9810
27	1999	September 10th-14th	Typhoon 9916
28	1999	September 20th-24th	Typhoon 9918

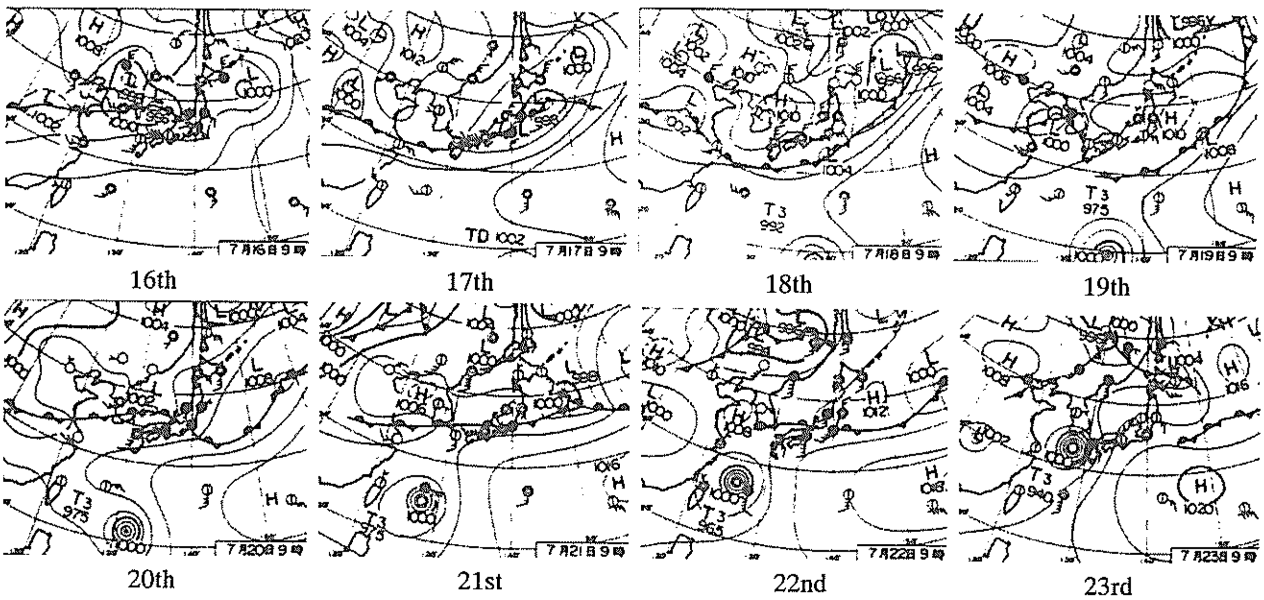


Figure 5.1 Weather charts in case 1(July, 1995)

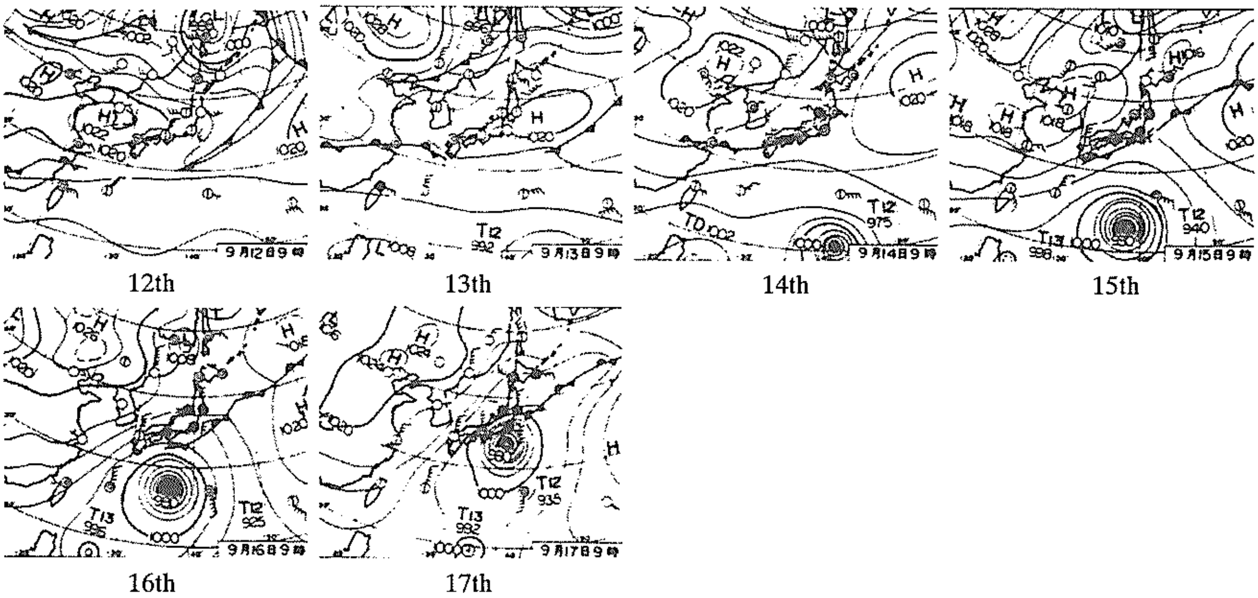


Figure 5.2 Weather charts in case 2(September, 1995)

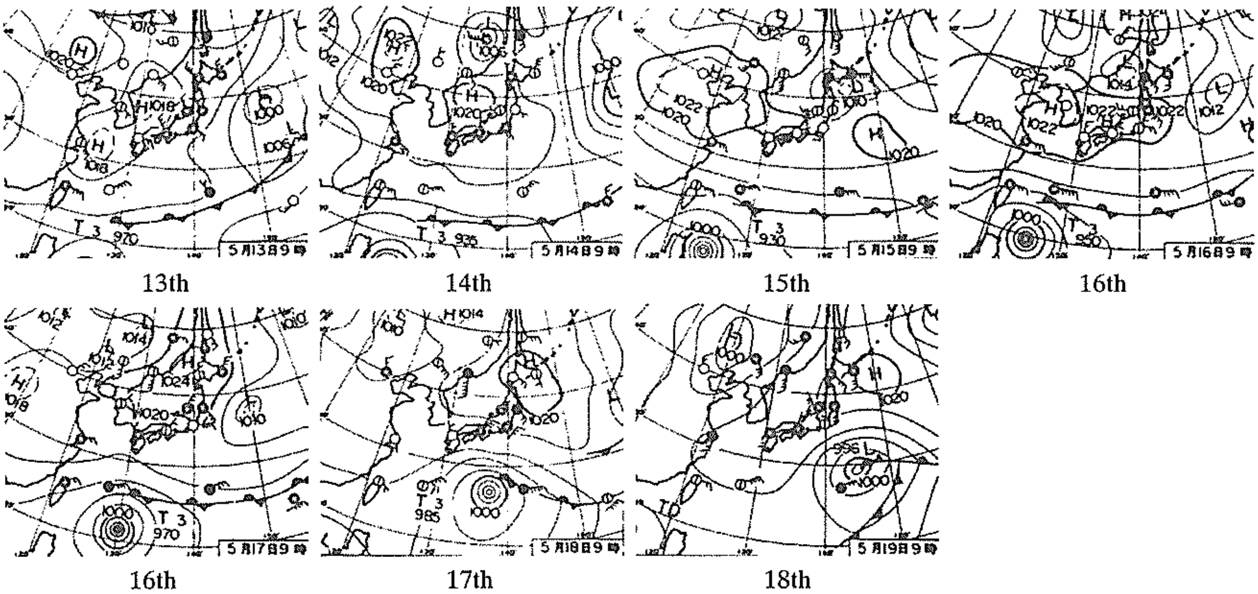
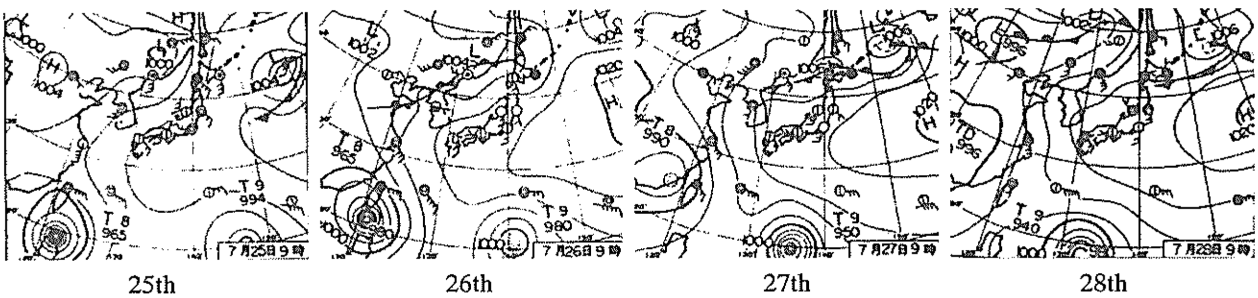
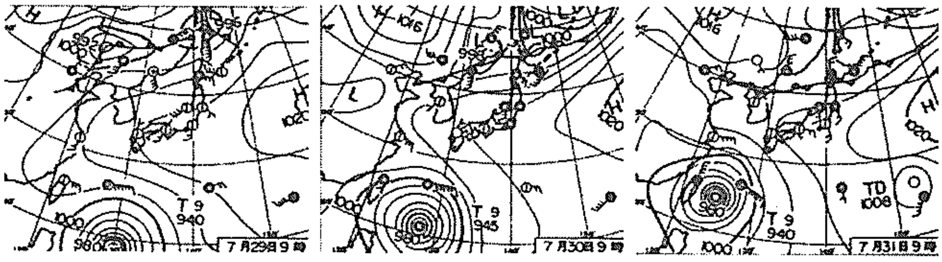


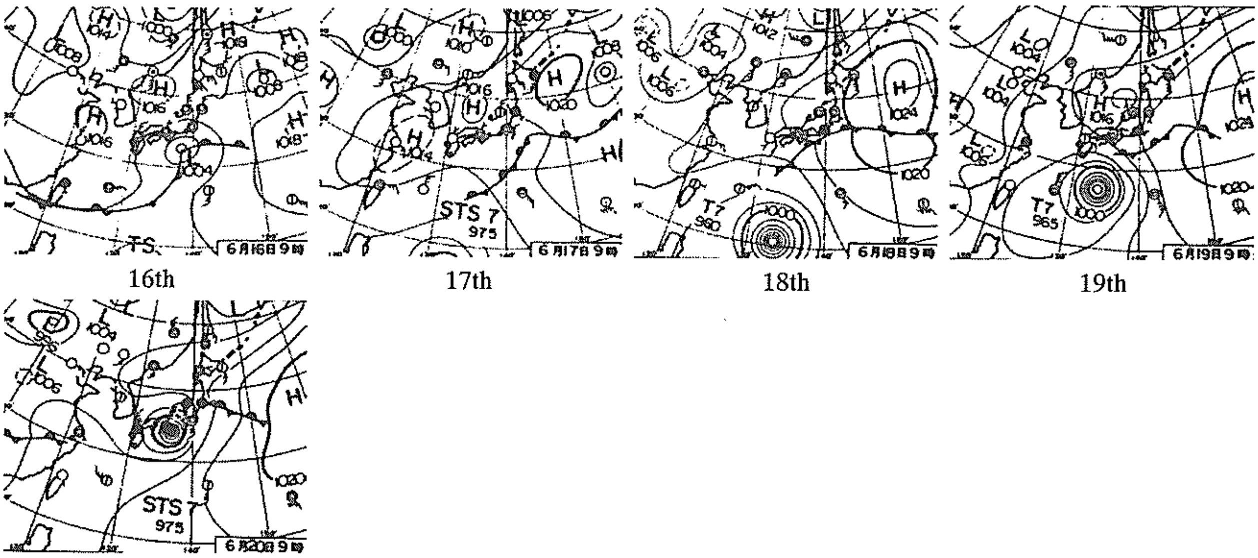
Figure 5.3 Weather charts in case 5(May, 1996)





29th 30th 31st

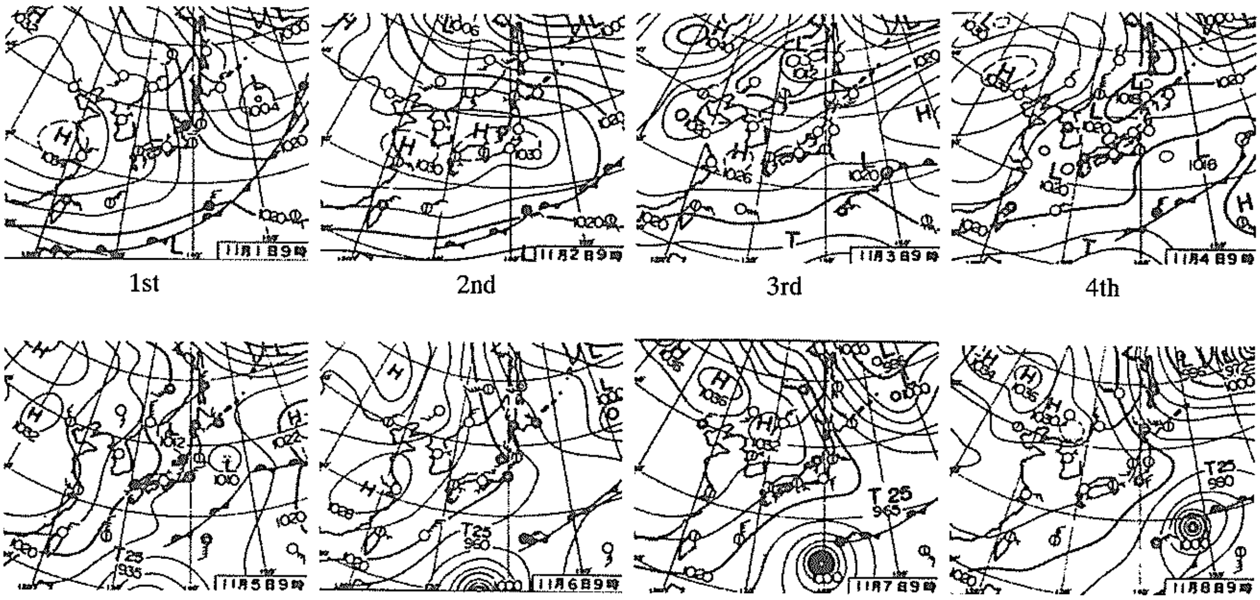
Figure 5.4 Weather charts in case 8(July, 1996)



16th 17th 18th 19th

20th

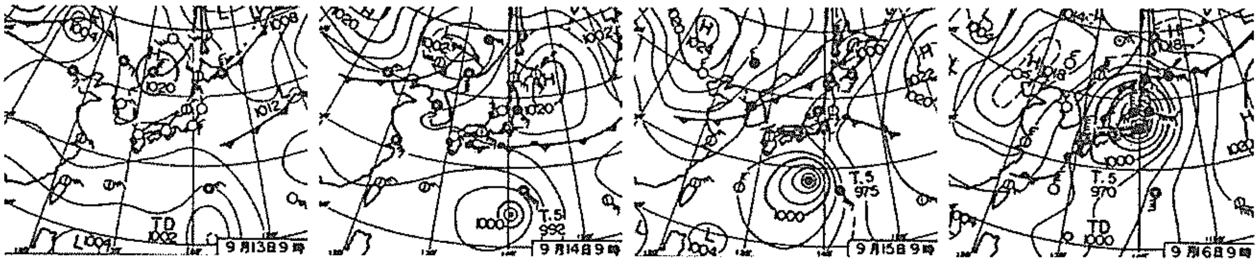
Figure 5.5 Weather charts in case 16(June, 1997)



1st 2nd 3rd 4th

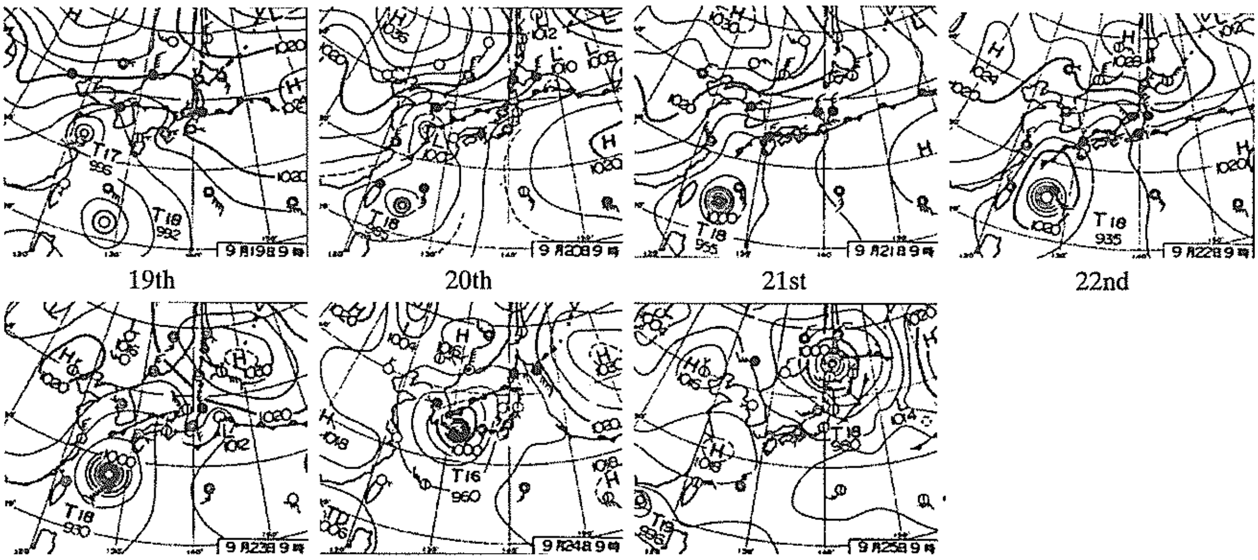
5th 6th 7th 8th

Figure 5.6 Weather charts in case 22(November, 1997)



13th 14th 15th 16th

Figure 5.7 Weather charts in case 24(September, 1998)



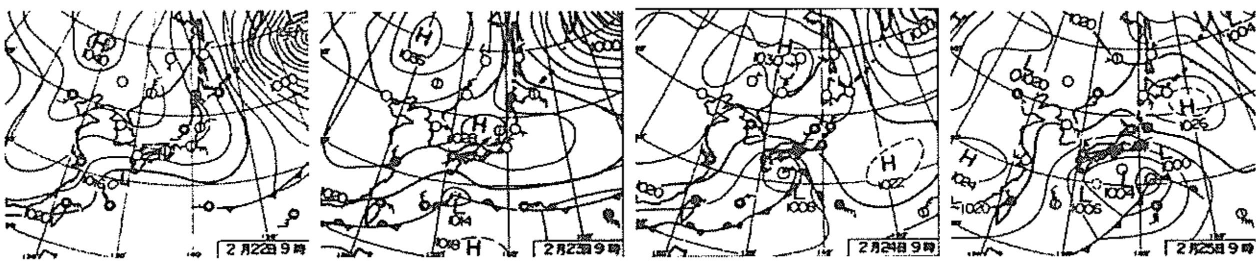
19th 20th 21st 22nd

23rd 24th 25th

Figure 5.8 Weather charts in case 28(September, 1999)

It is shown that stormy weathers in these cases are caused by typhoons. However, typhoons' course, atmospheric pressures, distances to A port have various patterns in each case. **Figure 5.3** and **Figure 5.6** are typical cases of the propagation of swells from typhoons at far south-east sea area. On the other hand, **Figure 5.2**, **Figure 5.4** and **Figure 5.8** are cases that typhoons land to Japan with the propagation of high waves and swells.

It is shown that the mooring trouble happens in winter season, too. These weather conditions are due to atmospheric depression as shown in **Table 3.1**. It is necessary to research on waves and weather charts for these situations. However, waves data can not be obtained on February, 1998, because of the trouble of the wave gauge offshore A port. Weather charts at the mooring trouble in February, 1998 are shown in **Figure 5.9**.



22nd 23rd 24th 25th

Figure 5.9 Weather charts on February, 1998

This is an example that atmospheric depression locates and grows in southern sea area of Kyushu district. The phenomenon is similar with the stormy weather condition of the Sea of Japan in winter season.

6.Analysis of typhoon data

It is explained that the analysis of typhoon data is necessary in order to know trends of wave growth patterns that happened at A port. Firstly, typhoons corresponding to each stormy weather case at A port in 1995-1999 are extracted by watching daily weather charts. Secondly, positions, atmospheric pressures and routes of each typhoon are analyzed by the meteorological database of "Himawari"(Japan Weather Association, 1999; 2000; 2001). Some relationships between wave growth patterns observed by NOWPHAS in A port and these parameters of typhoons are researched.

6.1 Routes of Typhoons

Routes of typhoons extracted in this study are shown in **Figure 6.1.1.**

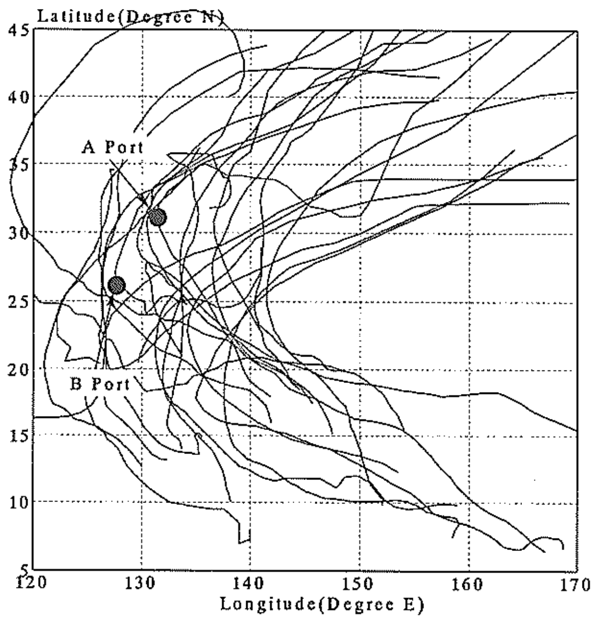


Figure 6.1.1 Routes of typhoons in 1995-1999

This contains them when they are tropical cyclones, so the following tendencies are found.

(1) Most of them are generated below 20 degrees of the north latitude, and there are five cases that are generated at east areas beyond 150 degrees of the east longitude.

(2) Typhoons which come from south-east sea areas tend to have long moving distances before they approach to Japan. On the other hand, typhoons which come from south-west sea areas relatively have shorter moving distances than former ones.

(3) There are some cases that typhoons don't land to Japan, however, mooring troubles at A port are happened by these typhoons, too.

The relation between observed waves at A port and typhoons is examined. **Figure 6.1.2** shows the long period wave heights corresponding to the distance between typhoon and A port and the difference of the atmospheric pressure between the central of typhoons and A port. Details of the calculation about long period waves from observed wave time series is stated in our another report(Sasa, et al.,2001).

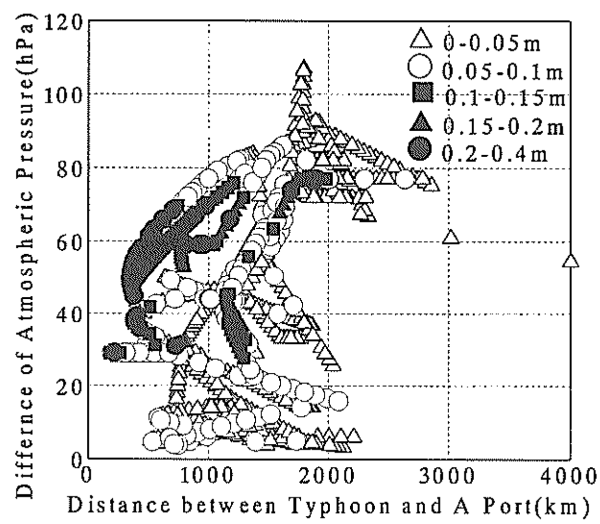


Figure 6.1.2 Relation among long period wave heights, atmospheric pressures and distances to A port(1997-1998)

Long period wave heights tend to become large when the difference of the atmospheric pressure is more than 40hPa and the distance is within 1000km. However, long period waves more than 0.1m generate when distances are about 2000km or differences of the atmospheric pressure are less than 40hPa in a few cases.

Figure 6.1.3 shows plotted long period wave heights at polar-coordinate whose origin is A port.

Long period waves that are more than 0.1m are concentrated in the fourth quadrant of this polar-coordinate graph. Long period wave heights are so different each other even if distances and directions from A port are close. It is said that the influence of long period waves or that of swells cannot be explained by only the distance between typhoons and A port. Therefore, we find that further analysis of typhoon data is necessary.

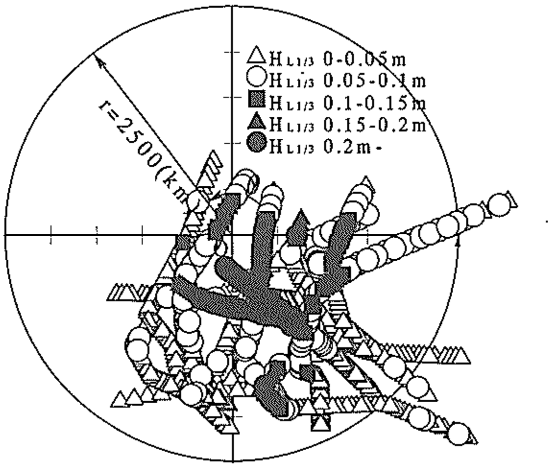


Figure 6.1.3 Relation between long period wave heights and typhoon's positions(1997-1998)

6.2 Relations between typhoons and the wave growth

Thus, we consider the transition of accumulation of moving distance from the generation point, atmospheric pressures, maximum wind speeds, as well as the distance between the present position and A port. These distances are expressed by navigation ones, because moving ranges of typhoons are so wide. Moreover, the criteria of a ship mooring is different from a ship type, ship size, or mooring way, etc. According to some study results about moored ship motions due to long period waves, it is generally said that large ships like more than 10,000DWT class can't moor in ordinal mooring ways when long period wave height is more than 0.1-0.15m(Nagai, et al, 1994b). Long period wave heights in past studies are calculated from waves consisted on components at 20-300s in a general way, so the critical long period wave heights for ship mooring are defined as follows.

a) The criteria of long period wave heights consisted on components of 20-180s as 0.15m.
b) The criteria of long period wave heights consisted on components of 60-180s as 0.1m.
c) The criteria of significant wave heights is defined as 2m, because of the corresponding to long wave period heights of 0.1-0.15m.

We remark the condition that significant wave periods become more than 10s, because of the influence of long period waves that is started to become notable. In this section, we research on the relation between typhoons and waves in each case. Some of them are shown as follows. In these cases, we show some transitions of typhoons and positions of each limit condition of ship mooring defined above in 1995-1999.

(1) Case 1

Figure 6.2.1 and **Figure 6.2.2** show the route and transitions of the Typhoon 9503 and observed waves offshore A port.

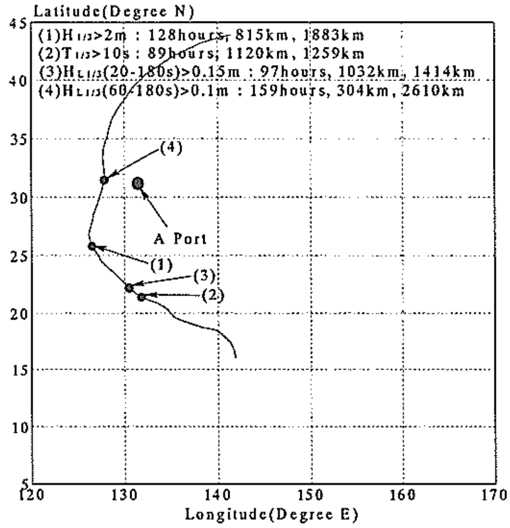


Figure 6.2.1 Route and points of the mooring criteria of Typhoon 9503 on July, 1995

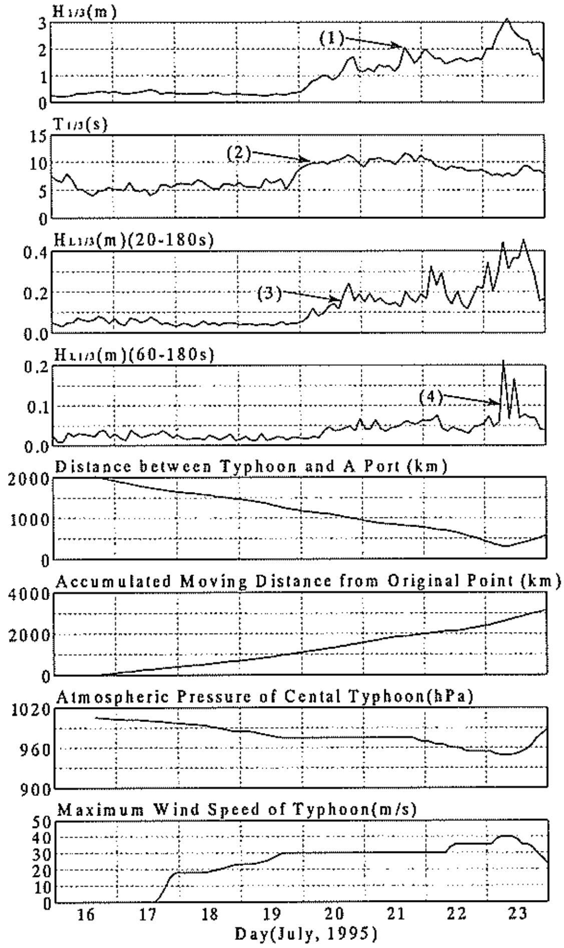


Figure 6.2.2 Transition of wave conditions and each typhoon parameter of Typhoon 9503 on July, 1997

The typhoon generates around 15 degrees of north latitude, 140 degrees of east longitude. Its course is relatively north bound. Although $T_{1/3}$ exceeds 10s after 89 hours from the generation, it takes about 128-159 hours to exceed limit conditions of $H_{1/3}$ or $H_{L1/3}$(60-180s). $H_{L1/3}$(60-180s) grow rapidly when the distance between the typhoon and A port is the shortest(300km). When the accumulative moving distance is about 2000km, the mooring of ships would be difficult in A port. The atmospheric pressure of central typhoon becomes the lowest value(950hPa) when the distance is the nearest to A port.

(2) Case 2

Figure 6.2.3 and **Figure 6.2.4** show the route and transitions of the Typhoon 9512 and observed waves offshore A port.

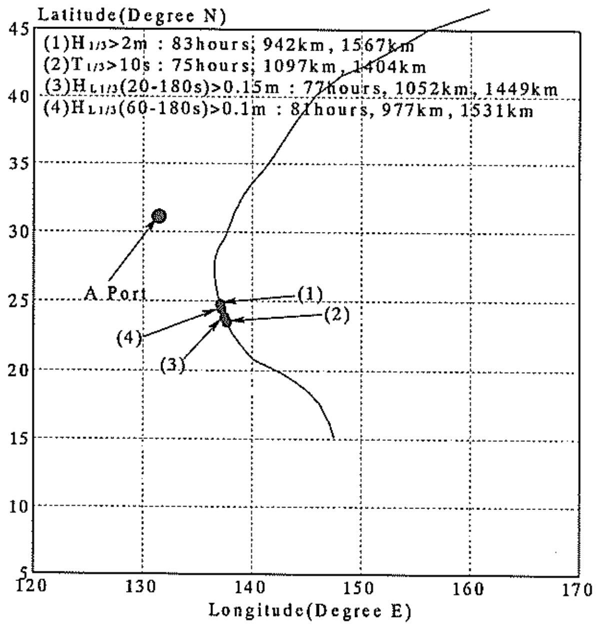


Figure 6.2.3 Route and points of the mooring criteria of Typhoon 9512 on September, 1995

The typhoon generates around 15 degrees of north latitude, 145 degrees of east longitude. The route of the typhoon is comparatively counterclockwise, bound for north-east areas. Each wave condition for the mooring criteria is almost the same timing, the distance from the typhoon is about 1000km and the accumulative moving distance is about 1500km. The mooring of ships in A port would be difficult when the typhoon locates near 25 degrees of north latitude. In this case, the atmospheric pressure of central typhoon becomes so lower(925hPa) as the typhoon approaches to Japan. Transitions of waves show that growth rates of long period waves are much larger than significant waves.

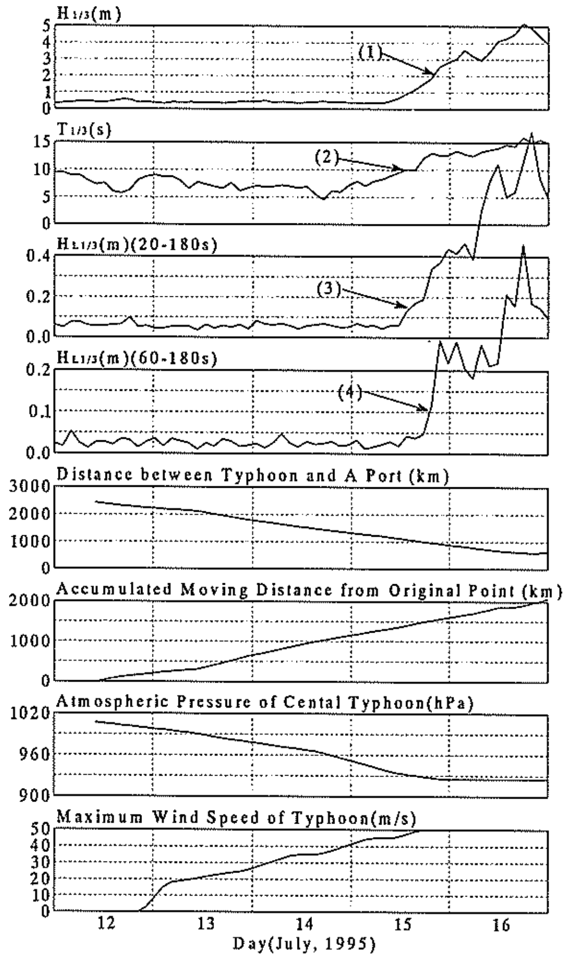


Figure 6.2.4 Transition of wave conditions and each typhoon parameter of Typhoon 9512 on September, 1995

(3) Case 4

Figure 6.2.5 and **Figure 6.2.6** show the route and transitions of the Typhoon 9603 and observed waves offshore A port.

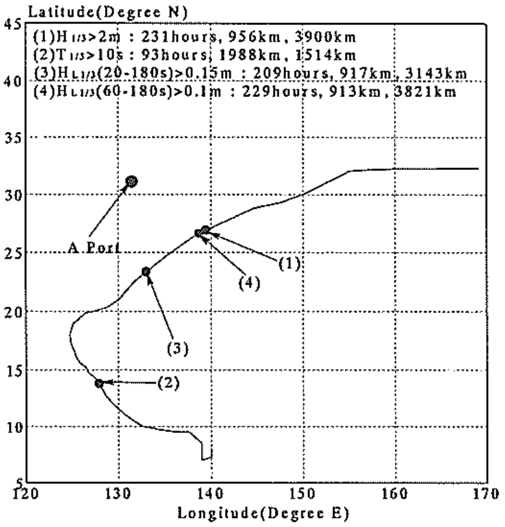


Figure 6.2.5 Route and points of the mooring criteria of Typhoon 9603 on May, 1996

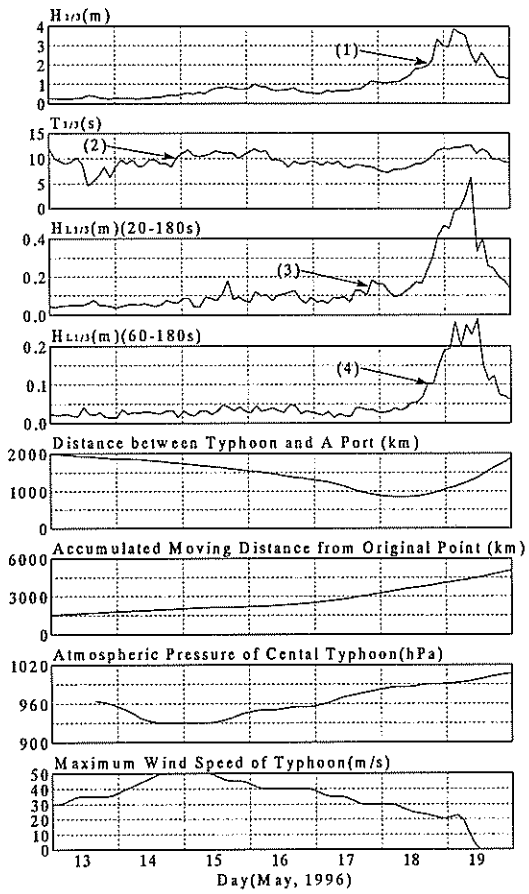


Figure 6.2.6 Transition of wave conditions and each typhoon parameter of Typhoon 9603 on May, 1996

The typhoon generates around 7 degrees of north latitude, 140 degrees of east longitude. The generation point is far south area in this case, it may be influenced of the relatively early time of year. The route of the typhoon seems to be counterclockwise, the difference of points for the mooring criteria between $T_{1/3}$ and $H_{1/3}$ or $H_{L1/3}$ is so large in this case. Although wave heights start to rise when the typhoon locates around 25 degrees of north latitude, waves more than 10s are observed from 4 days earlier. In this case, the mooring of ships would be difficult when the distance from the typhoon is 900-950km, and the accumulative moving distance is about 3500km. The property of this typhoon is so different from typhoons in case 1 or case 3. The atmospheric pressure becomes the lowest point(930hPa) on May 14th(4 days before the mooring criteria), then it rises gradually to around 1000hPa.

(4) Case 5

Figure 6.2.7 and **Figure 6.2.8** show the route and transitions of the Typhoon 9605 and observed waves offshore A port.

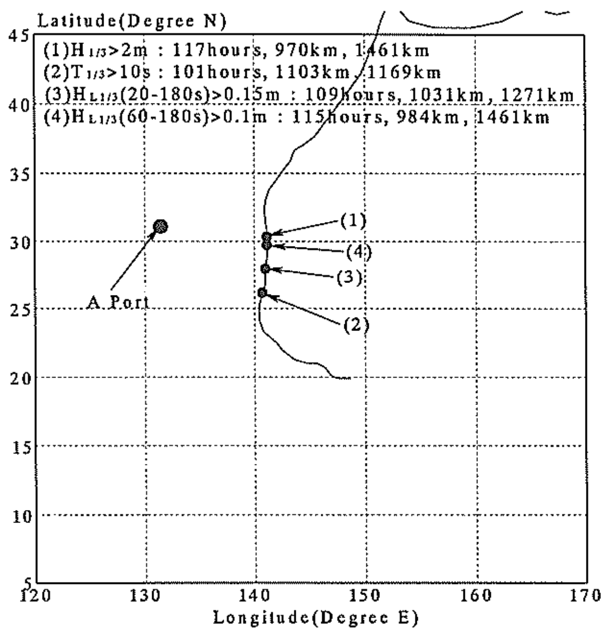


Figure 6.2.7 Route and points of the mooring criteria of Typhoon 9605 on July, 1996

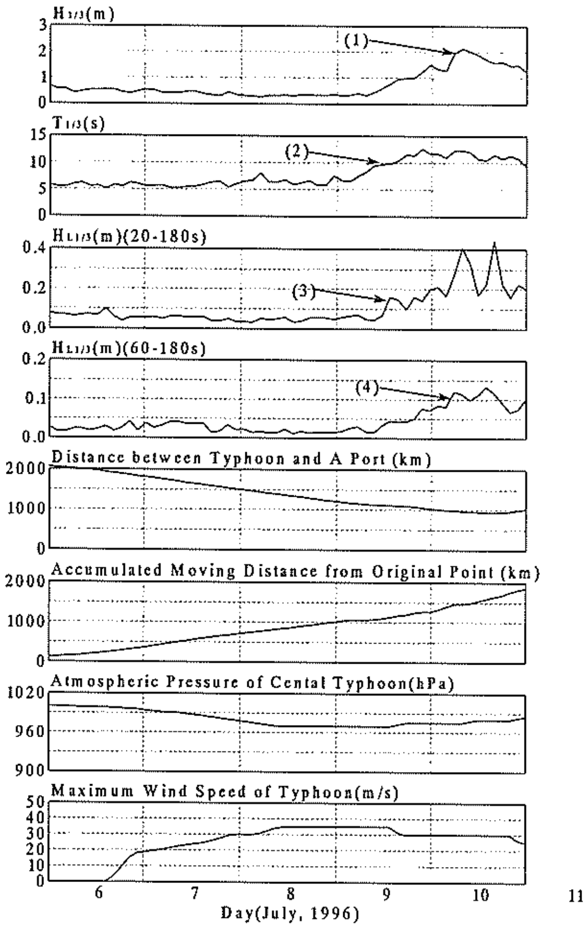


Figure 6.2.8 Transition of wave conditions and each typhoon parameter of Typhoon 9605 on July, 1996

The typhoon generates around 20 degrees of north latitude, 147 degrees of east longitude. The generation point is relatively close to Japan, its course is north bound. When the distance from the typhoon is 970-980km and the accumulative moving distance is 1460km, the mooring criteria would happen in A port. The minimum atmospheric pressure(970hPa) at 1 day before the mooring criteria.

(5) Case 6

Figure 6.2.9 and **Figure 6.2.10** show the route and transitions of the Typhoon 9606 and observed waves offshore A port.

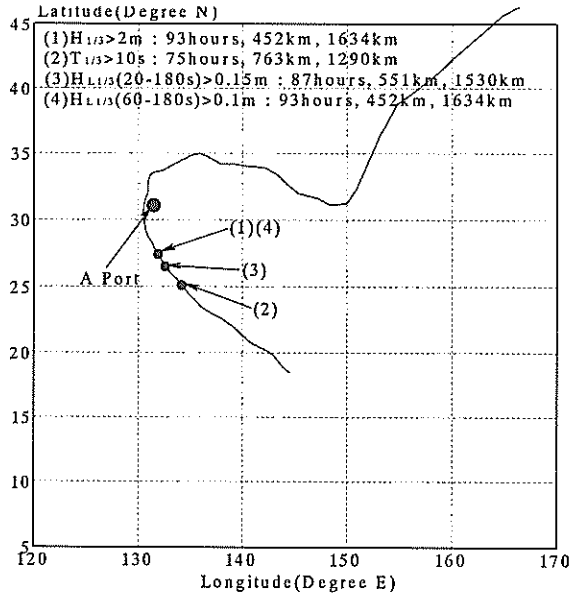


Figure 6.2.9 Route and points of the mooring criteria of Typhoon 9606 on July, 1996

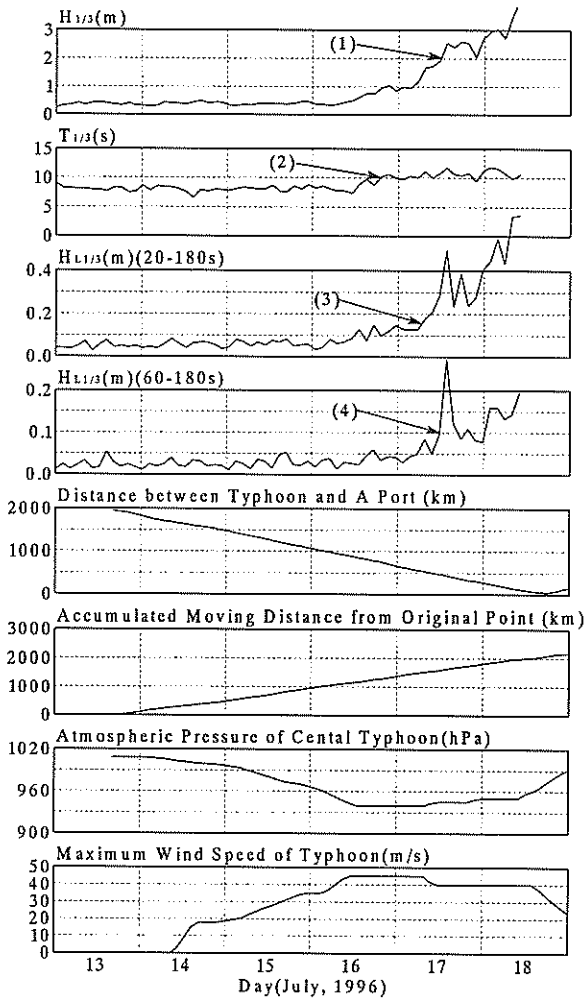


Figure 6.2.10 Transition of wave conditions and each typhoon parameter of Typhoon 9606 on July, 1996

The typhoon generates around 20 degrees of north latitude, 145 degrees of east longitude. However, its course is so different from case 5. The typhoon is heading for north-west direction at first, and is passing A port with a very short distance. Then its course changes as shown in **Figure 6.2.9**. In this case, the mooring of ships in A port could be impossible when the distance from the typhoon is 450km. **Figure 6.2.10** shows that $H_{1/3}$ and $H_{L1/3}$ rise rapidly as the typhoon approaches to A port. The minimum value of the atmospheric pressure is 940hPa.

(6) Case 7

Figure 6.2.11 and **Figure 6.2.12** show the route and transitions of the Typhoon 9609 and observed waves offshore A port.

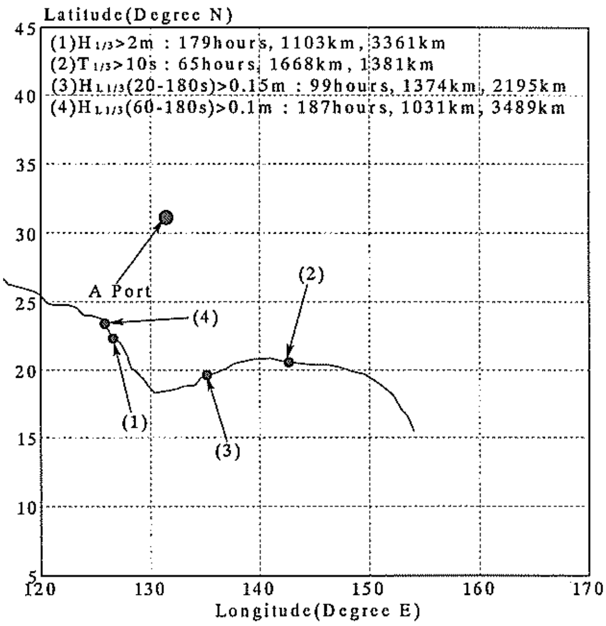


Figure 6.2.11 Route and points of the mooring criteria of Typhoon 9609 on July, 1996

The typhoon generates around 15 degrees of north latitude, 155 degrees of east longitude. The direction of the typhoon is completely different from any other cases. It bounds for west area(China), and locates 20-25 degrees of north latitude all the time. In this case, the typhoon is a bit far from Japan, however, the mooring of ships in A port would be impossible when the distance from the typhoon is 1000-1100km, and the accumulative moving distance is 3300-3500km. Although $H_{1/3}$ rises gradually, $H_{L1/3}$(60-180s) rises rapidly on July 31st. The atmospheric pressure of central typhoon continues to decrease in this period, the minimum value is 925hPa.

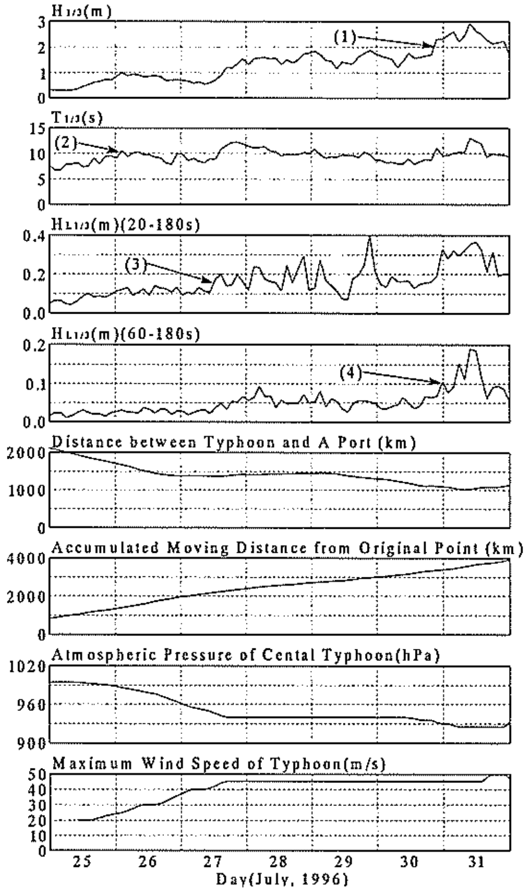


Figure 6.2.12 Transition of wave conditions and each typhoon parameter of Typhoon 9609 on July, 1996

(7) Case 8

Figure 6.2.13 and **Figure 6.2.14** show the route and transitions of the Typhoon 9612 and observed waves offshore A port.

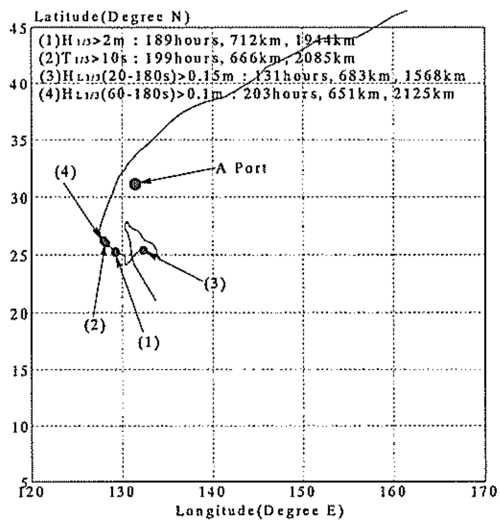


Figure 6.2.13 Route and points of the mooring criteria of Typhoon 9612 on July, 1996

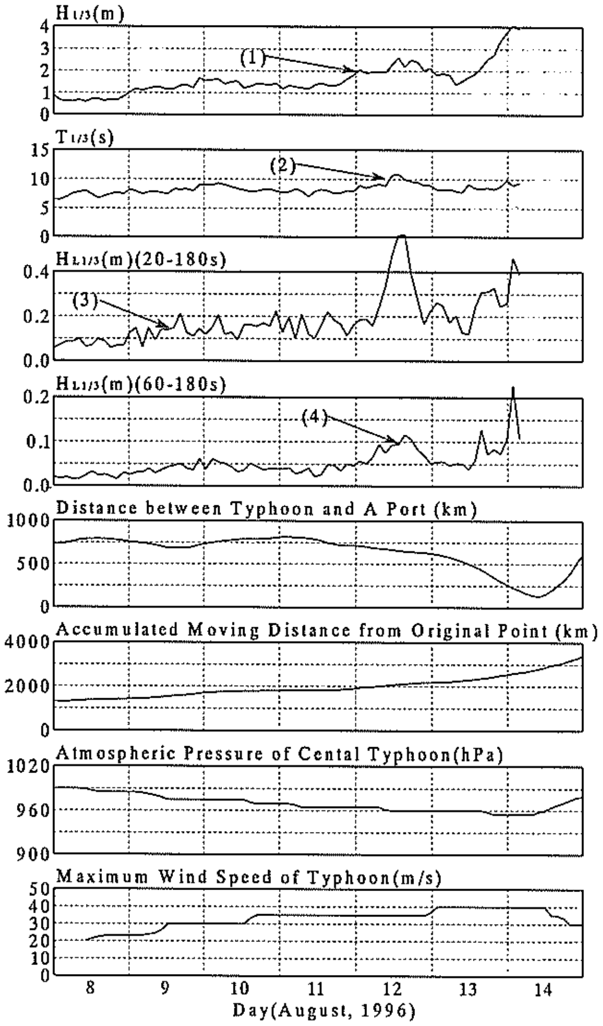


Figure 6.2.14 Transition of wave conditions and each typhoon parameter of Typhoon 9612 on July, 1996

The typhoon generates around 21 degrees of north latitude, 135 degrees of east longitude. Although the generation point is comparatively near to Japan, its course is so complicated as shown in **Figure 6.2.13**. The mooring of ships in A port would be difficult when the typhoon locates offshore 650-700km from A port. The accumulative moving distance is about 2000-2100km. $H_{1/3}$ rises more than 2m at first, and then it rises more than 4m again later. It is presumed that the growth pattern is influenced by the complicated trail of the typhoon. The atmospheric pressure(minimum value is 955hPa) decreases gradually as the typhoon approaches to Japan.

(8) Case 11

Figure 6.2.15 and **Figure 6.2.16** show the route and transitions of the Typhoon 9624 and observed waves offshore A port.

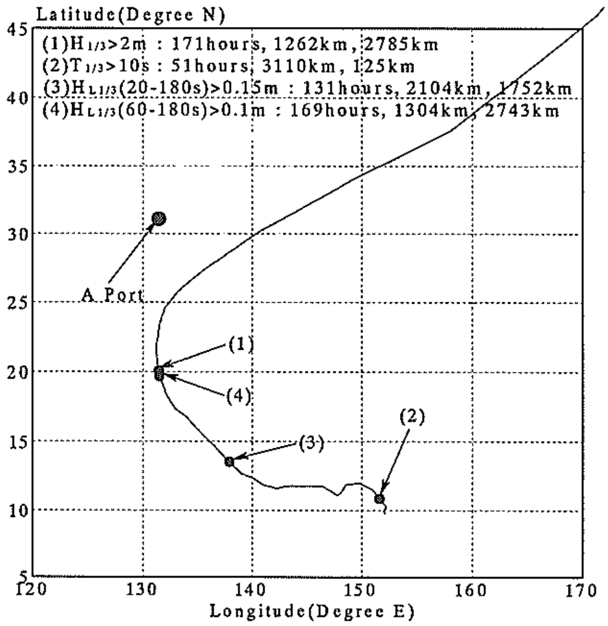


Figure 6.2.11 Route and points of the mooring criteria of Typhoon 9624 on November, 1996

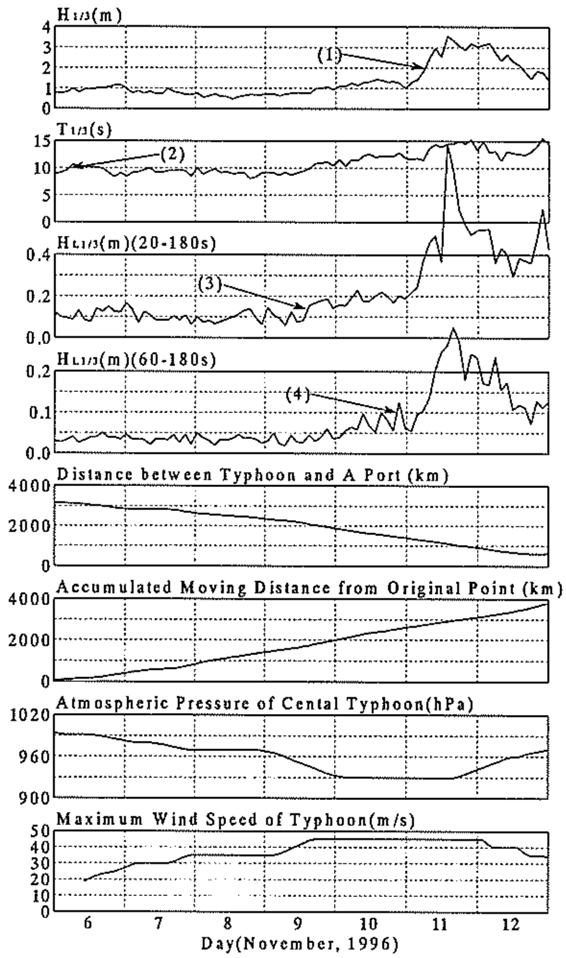


Figure 6.2.12 Transition of wave conditions and each typhoon parameter of Typhoon 9624 on November, 1996

The typhoon generates around 10 degrees of north latitude, 153 degrees of east longitude. The course of the typhoon is typical counterclockwise. The mooring of ships in A port would be impossible when the typhoon locates around 20 degrees of north latitude. The distance from the typhoon is 1200-1300km at that time. Also, the accumulative moving distance is 2700-2800km. The atmospheric pressure of central typhoon becomes the lowest(930hPa) on November 10th, it is 1 day before the mooring criteria. As $T_{1/3}$ rises gradually from 10s to 15s, it is a typical pattern of the propagation of strong swells from far area of the Pacific Ocean.

(9) Case 12

Figure 6.2.13 and **Figure 6.2.14** show the relations between the Typhoon 9701 and observed waves.

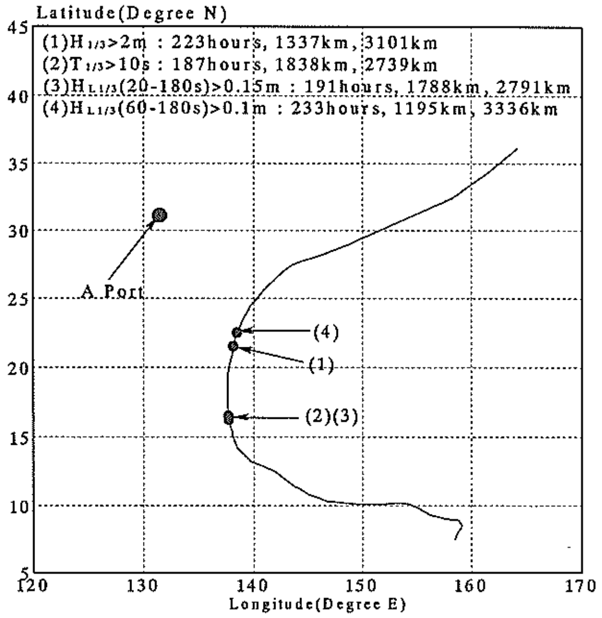


Figure 6.2.13 Route and points of the mooring criteria of Typhoon 9701 on April, 1997

Swells about 2.5m and 12s propagate to A port. The typhoon generates below 10 degrees of north latitude. It takes about 233 hours for exceeding the long period wave height around 60-180s of 0.1m. The accumulated moving distance is 3336km, and the distance to A port is 1195km. Also it takes 223 hours for exceeding the significant wave height of 2m, 187 hours of significant wave period of 10s. The atmospheric pressure becomes the minimum 2 days before the wave height becomes the maximum.

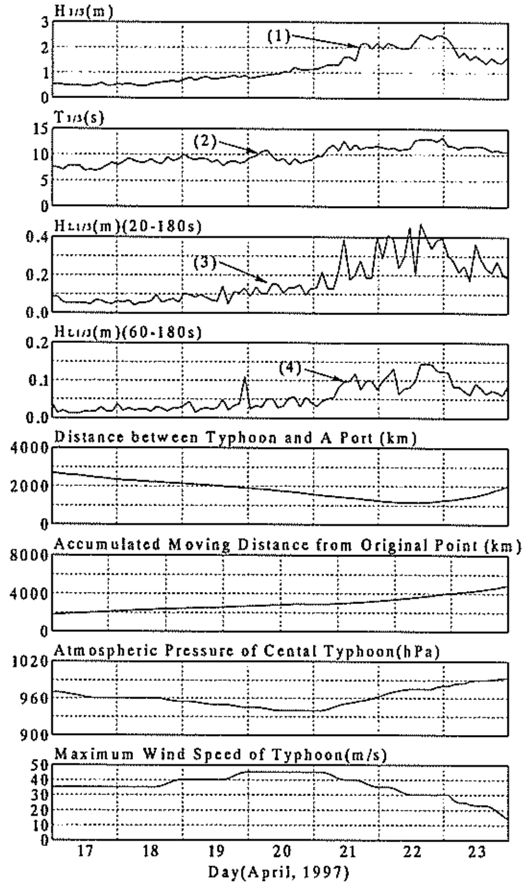


Figure 6.2.14 Transition of wave conditions and each typhoon parameter of Typhoon 9701 on April, 1997

(10) Case 13

Figure 6.2.15 and **Figure 6.2.16** show the relations between the Typhoon 9706 and observed waves in A port.

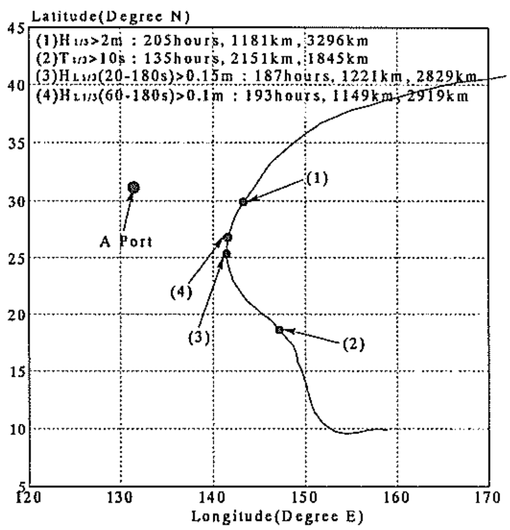


Figure 6.2.15 Route and points of the mooring criteria of Typhoon 9706 on June, 1997

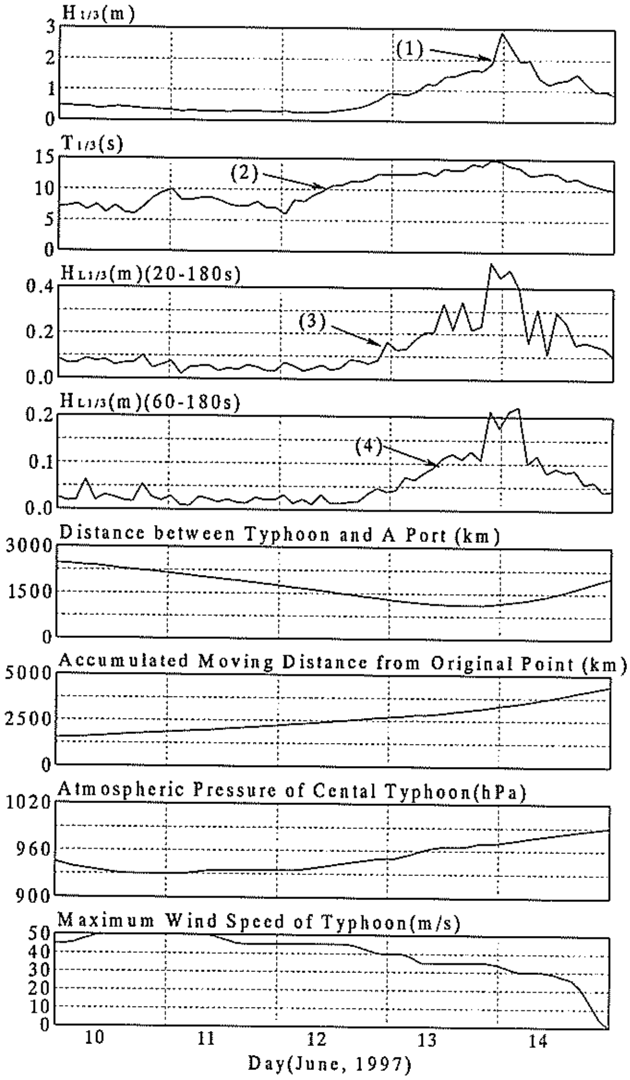


Figure 6.2.16 Transition of wave conditions and each typhoon parameter of Typhoon 9706 on June, 1997

The typhoon generates below 10 degrees of north latitude, too. Exceeding points of the mooring criteria It takes about 233 hours for exceeding the long period wave height around 60-180s of 0.1m. The accumulated moving distance is 3336km, and the distance to A port is 1195km. Also it takes 223 hours for exceeding the significant wave height of 2m, 187 hours of significant wave period of 10s. The atmospheric pressure becomes the minimum 2 days before the wave height becomes the maximum.

(11) Case 14

Figure 6.2.17 and **Figure 6.2.18** show the relations between the Typhoon 9707 and observed waves.

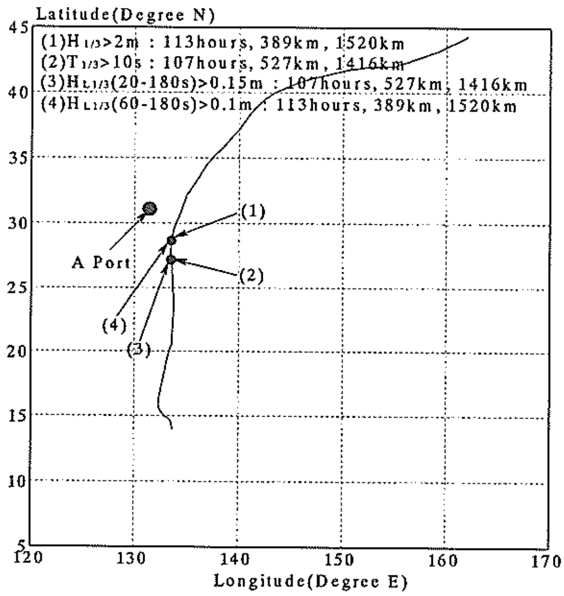


Figure 6.2.17 Route and points of the mooring criteria of Typhoon 9707 on June, 1997

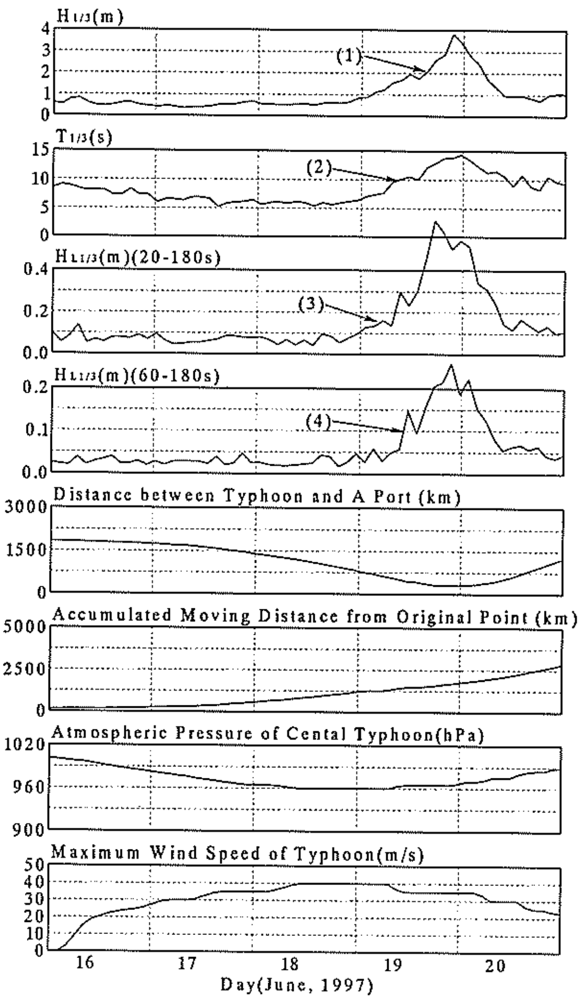


Figure 6.2.18 Transition of wave conditions and each typhoon parameter of Typhoon 9707 on June, 1997

The typhoon generates around 15 degrees of north latitude. It takes about 113 hours for exceeding the long period wave height around 60-180s of 0.1m. The accumulated moving distance is 1520km, and the distance to A port is 389km. Also it takes 113 hours for exceeding the significant wave height of 2m, 107 hours of significant wave period of 10s. The route of the typhoon is north bound, and approaches to A port with short distance. The atmospheric pressure becomes the minimum in a day before the wave height becomes the maximum.

(12) Case 15

Figure 6.2.19 and **Figure 6.2.20** show the relations between the Typhoon 9708 and observed waves.

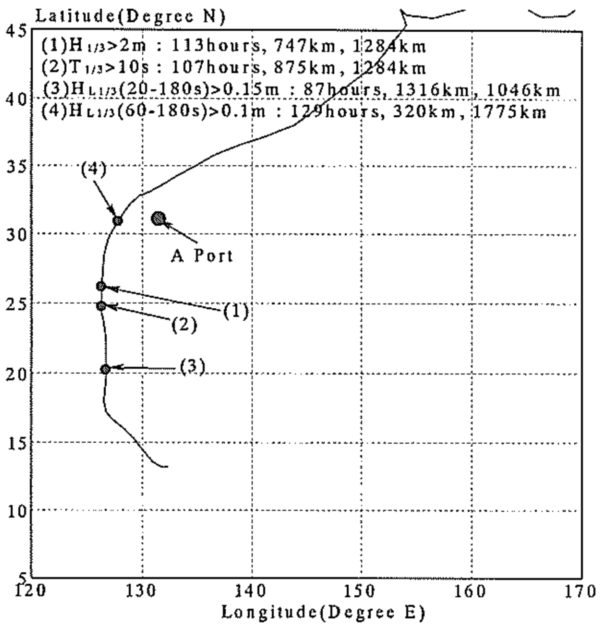


Figure 6.2.19 Route and points of the mooring criteria of Typhoon 9708 on June, 1997

The typhoon generates around 15 degrees of north latitude, too. It takes about 129 hours for exceeding the long period wave height around 60-180s of 0.1m. The accumulated moving distance is 1775km, and the distance to A port is 320km. Also it takes 113 hours for exceeding the significant wave height of 2m, 107 hours of significant wave period of 10s. The pattern of the typhoon is similar with case 3. The atmospheric pressure becomes the minimum half a day before the wave height becomes the maximum.

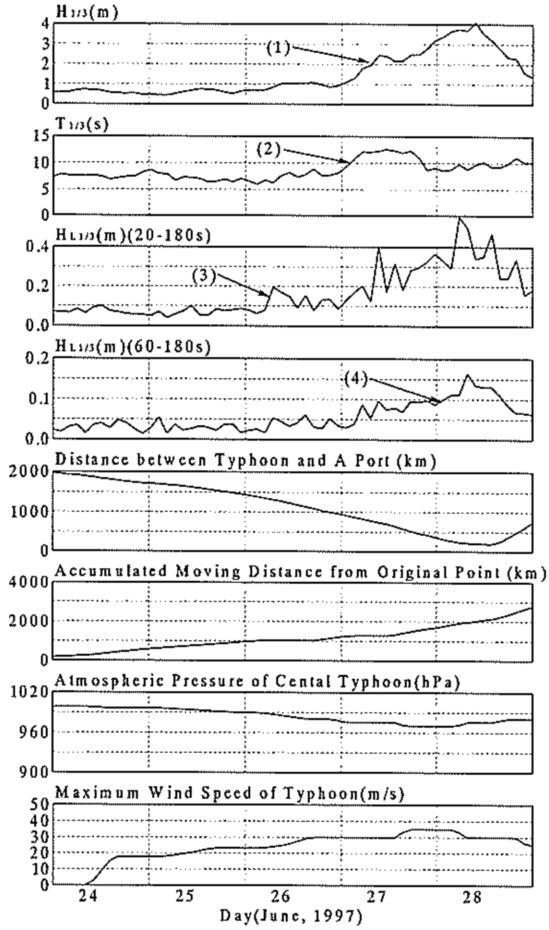


Figure 6.2.20 Transition of wave conditions and each typhoon parameter of Typhoon 9708 on June, 1997

(13) Case 16

Figure 6.2.21 and **Figure 6.2.22** show the relations between the Typhoon 9709 and observed waves.

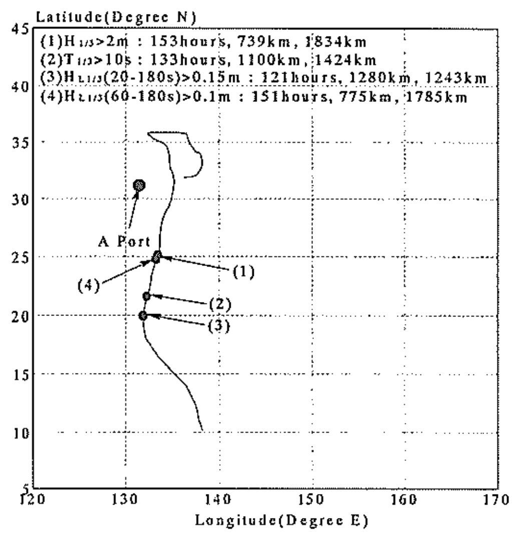


Figure 6.2.21 Route and points of the mooring criteria of Typhoon 9709 on July, 1997

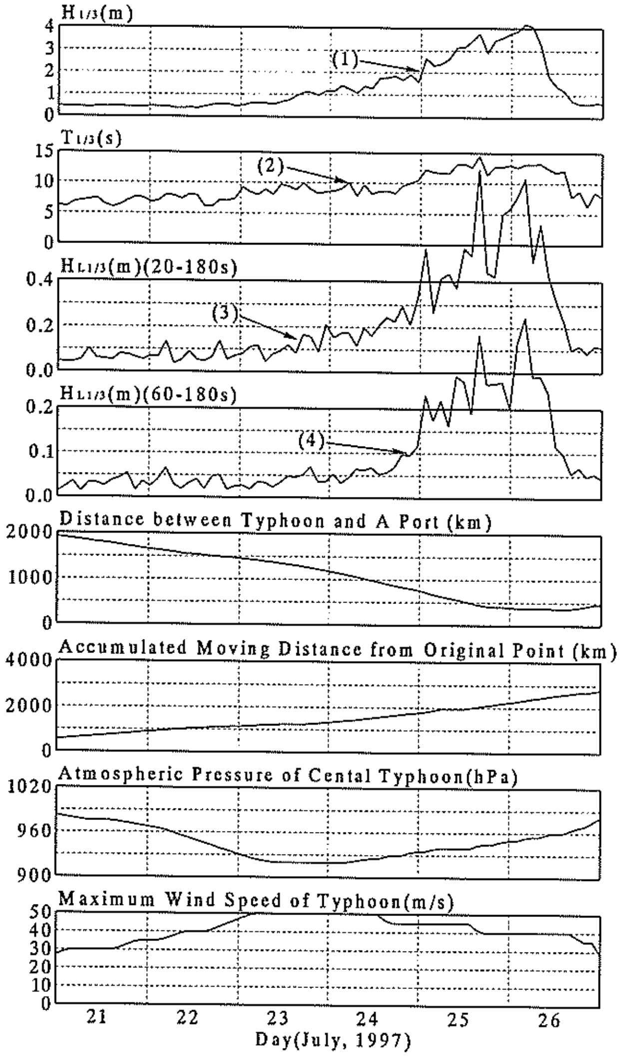


Figure 6.2.22 Transition of wave conditions and each typhoon parameter of Typhoon 9709 on July, 1997

The typhoon generates around 10 degrees of north latitude, 135 degrees of east latitude. It takes about 151 hours for exceeding the long period wave height around 60-180s of 0.1m. The accumulated moving distance is 1785km, and the distance to A port is 775km. Also it takes 153 hours for exceeding the significant wave height of 2m, 133 hours of significant wave period of 10s. Although the route of the typhoon is north bound, the accumulative moving distance is longer than case 3 or case 4. The distance to A port becomes longer. The atmospheric pressure becomes the minimum 36 hours before the wave height becomes the maximum.

(14) Case 18

Figure 6.2.23 and **Figure 6.2.24** show the relations between the Typhoon 9713 and observed waves.

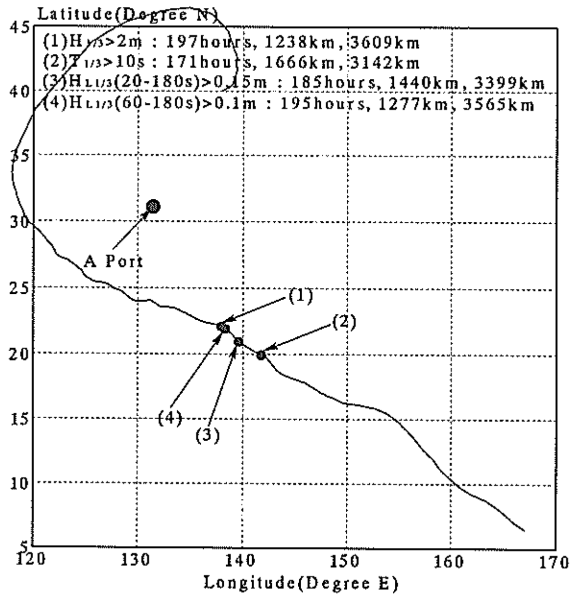


Figure 6.2.23 Route and points of the mooring criteria of Typhoon 9713 on August, 1997

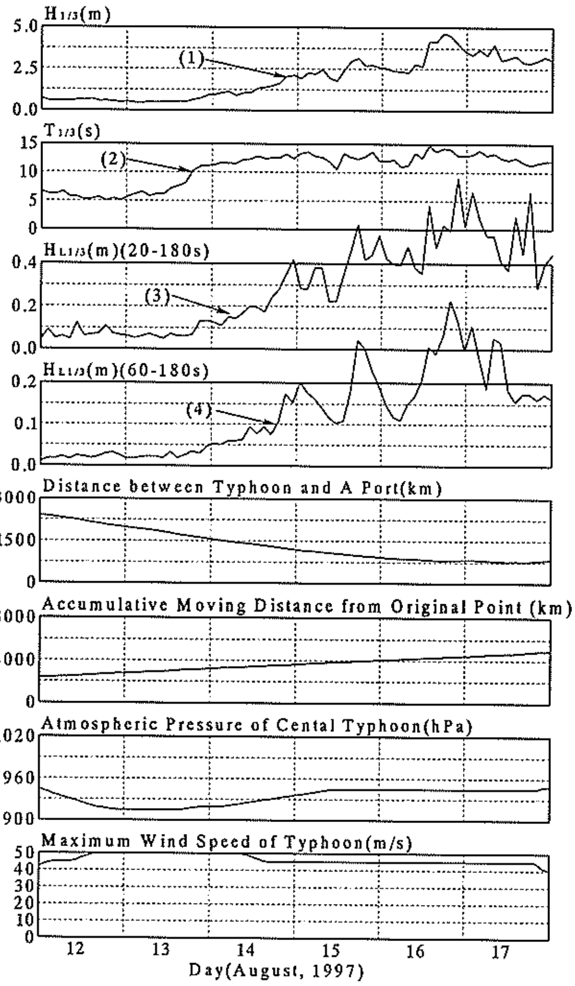


Figure 6.2.24 Transition of wave conditions and each typhoon parameter of Typhoon 9713 on August, 1997

The typhoon generates around 7 degrees of north latitude, 165 degrees of east latitude. It takes about 195 hours for exceeding the long period wave height around 60-180s of 0.1m. The accumulated moving distance is 3565km, and the distance to A port is 1277km. Also it takes 197 hours for exceeding the significant wave height of 2m, 171 hours of significant wave period of 10s. The route of the typhoon is north bound, and approaches to A port with short distance. The atmospheric pressure becomes the minimum 2 days before the wave height becomes the maximum.

(15) Case 19

Figure 6.2.25 and **Figure 6.2.26** show the relations between the Typhoon 9719 and observed waves.

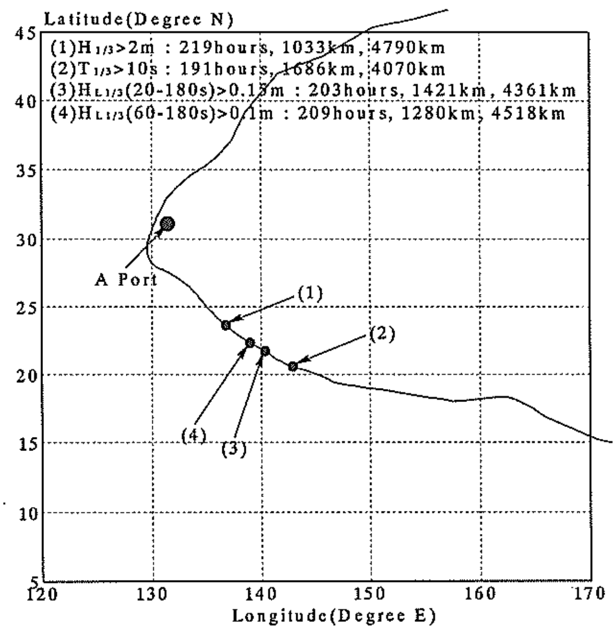


Figure 6.2.25 Route and points of the mooring criteria of Typhoon 9719 on September, 1997

The typhoon generates around 15 degrees of north latitude, 180 degrees of east latitude. It comes from far east area. It takes about 209 hours for exceeding the long period wave height around 60-180s of 0.1m. The accumulated moving distance is 4518km, and the distance to A port is 1280km. Also it takes 219 hours for exceeding the significant wave height of 2m, 191 hours of significant wave period of 10s. The route of the typhoon is north-west bound, and approaches to A port with very short distance when it lands to Japan. The atmospheric pressure becomes the minimum 2 days before the wave height becomes the maximum.

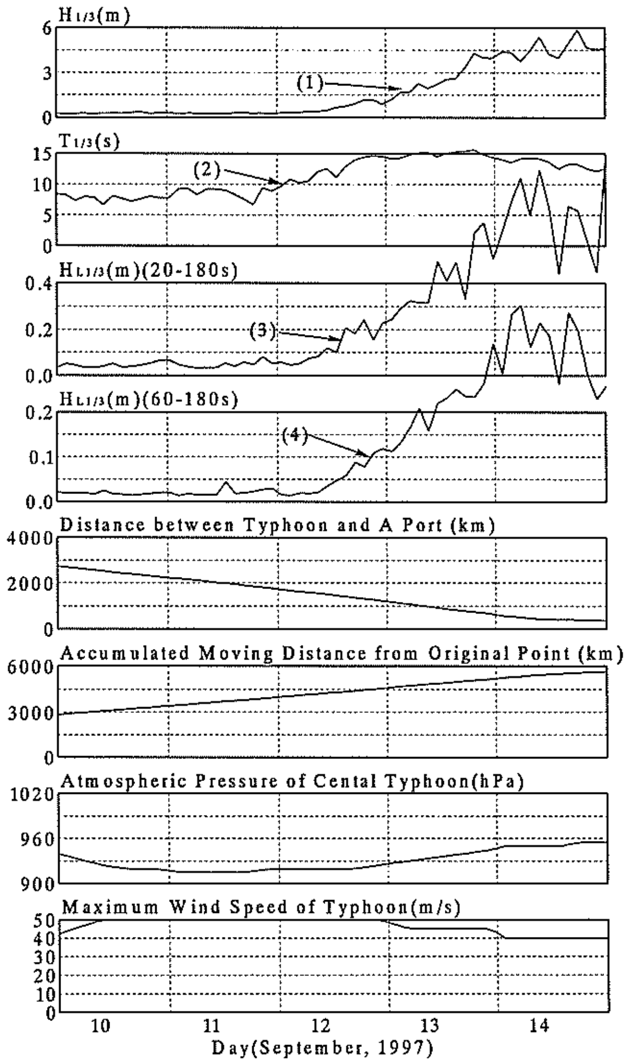


Figure 6.2.26 Transition of wave conditions and each typhoon parameter of Typhoon 9719 on September, 1997

(16) Case 20

Figure 6.2.27 shows the transition of the typhoon and positions of each limit condition of ship mooring defined above in case of Typhoon 9725 that occurred on November in 1997. In this case, grown swells about 3m and 15s propagate to A port. It is characteristic that the generation point is very far from A port, and the accumulation of moving distance of the typhoon is very long, then the most approach distance to A port is more than 1500km. Every limit conditions of ship mooring defined above are exceeded when the position of the typhoon is below 20 degrees of the north latitude. It takes 157 hours for exceeding the significant wave period of 10s, 241 hours of the significant wave height of 2m, 233 hours of the long period wave height around 20-180s of 0.15m, and 229 hours of the long period wave height around 60-180s of 0.1m.

The transition of observed waves in A port and the typhoon for 5 days are compared at **Figure 6.2.28**.

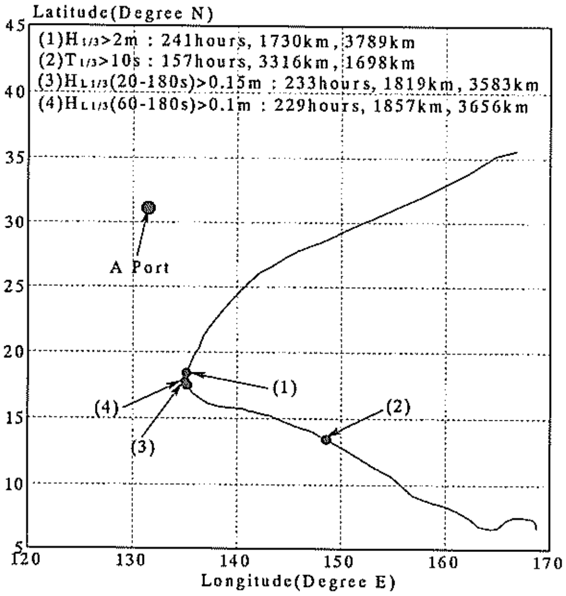


Figure 6.2.27 Route and points of the mooring criteria of Typhoon 9725 on November, 1997

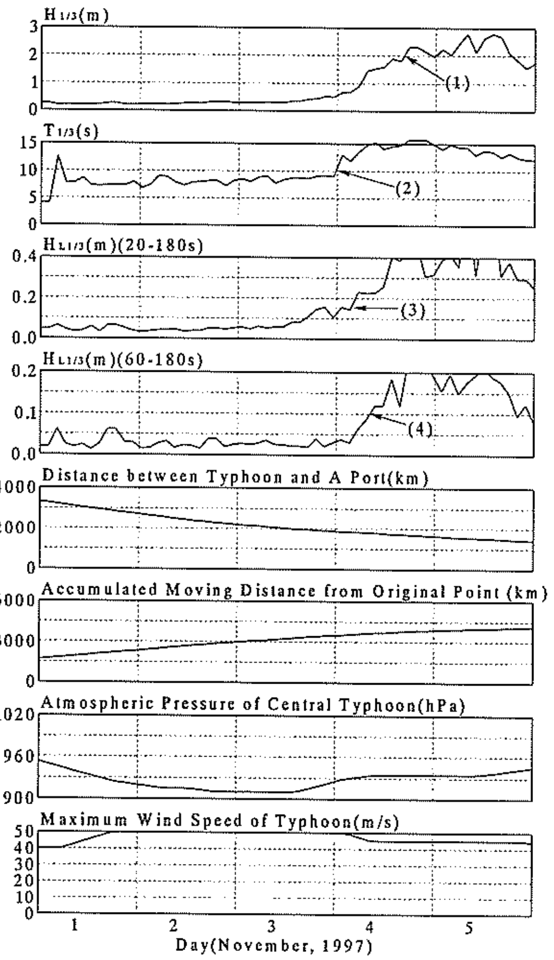


Figure 6.2.28 Transition of wave conditions and each typhoon parameter of Typhoon 9725 on November, 1997

It is found the tendency that wave heights and periods start to rise when the distance between the typhoon and A port is about 2000km, and the accumulated moving distance of the typhoon exceeds 3000km. Atmospheric pressures of the central typhoon become minimum 1-2 days previously of the wave growth at A port.

(17) Case 22

Figure 6.2.29 and **Figure 6.2.30** show routes and observed waves in A port in case of Typhoon 9805.

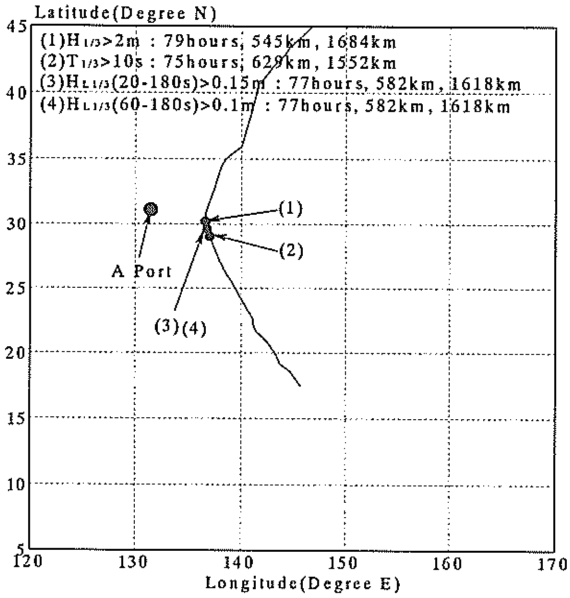


Figure 6.2.29 Route and points of the mooring criteria of Typhoon 9805 on September, 1998

In this case, the typhoon is generated around 17 degrees of the north latitude and show the rapid growth of long period waves. The nearest approach distance to A port is about 500km, and limit conditions of ship mooring are exceeded almost at the same time. Consuming time from the generation of the typhoon to the limit conditions is 75-79 hours. The accumulated moving distances are 1550-1684km, and the distance between A port and the typhoon is 540-630km. In this case, values of atmospheric pressures of the central typhoon are 975hPa when wave heights are start to rise, and the time difference between the minimum atmospheric pressure and the wave growth point is very low. It is characteristic that the rapid wave growth happens due to the influence of short distances between the typhoon and A port, although the value of minimum atmospheric pressure is not so low.

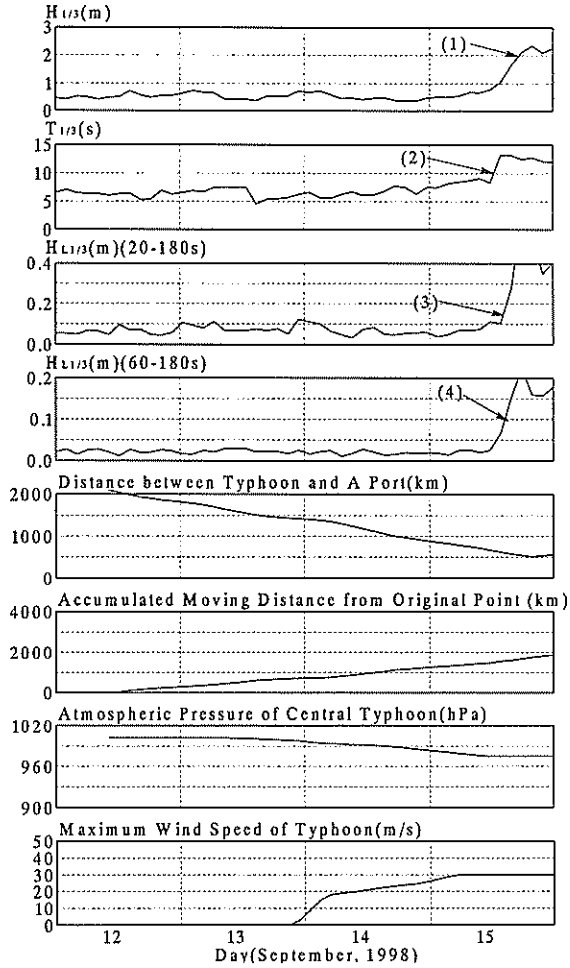


Figure 6.2.30 Transition of wave conditions and each typhoon parameter of Typhoon 9805 on September, 1998

Therefore, it is obvious that these two patterns of the generation and growth of typhoons are completely different from each other, though swells and long period waves propagate to A port in both cases. Swells propagate to A port in both cases, however, significant wave periods are 15s (the former case) and 12s (the latter case) respectively. The difference of the maturation of swells like this may depend on the accumulated moving distance and the consuming time from the original generation point. It means that well grown swells tend to be generated by typhoons come from the far south-east sea area.

6.3 Some relations between typhoons and waves

Figure 6.3.1 shows that long period wave heights (60-180s) exceed 0.1m (shown as circles) and points of minimum atmospheric pressures (shown as triangles) in typhoon routes in 1997-1998.

As observed, the atmospheric pressure of central typhoons becomes minimum when they are below 20 degrees in the north latitude and has long moving distances. Moreover, there are five cases that long period wave heights (60-180s) exceed when they are below 25 degrees in the north latitude. Ordinary, weather charts in Japanese newspapers are focused on about 20-50 degrees in north latitude, 110-160 degrees in east longitude. These ranges of weather information are not enough to know the influence to wave growth patterns including swells and long period waves. Because in some cases, the wave growth happens in the area below 20 degrees in the north latitude, especially, typhoons come from the far south-east sea area.

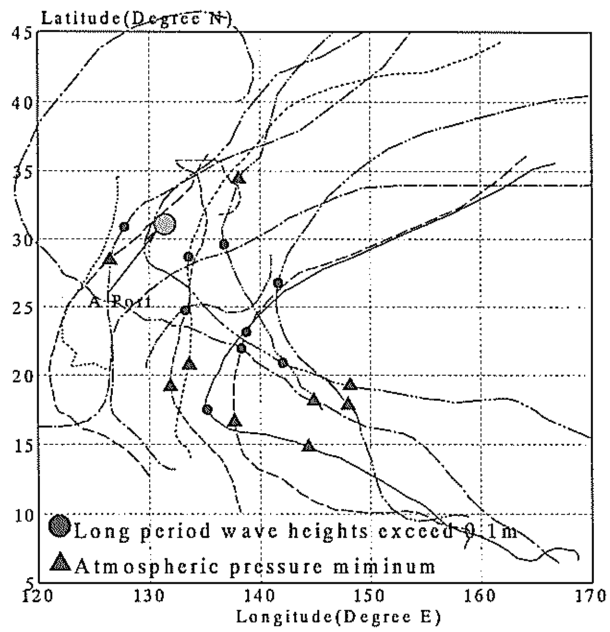


Figure 6.3.1 Points of long period waves exceed 0.1m and of minimum atmospheric pressures in each typhoon

6.4 Considerations of the relation between the mooring criteria and typhoon data

In previous chapter, it is shown that is necessary to know the influence of the growth of significant waves, swells and long period waves in each parameter of typhoons. Thus, we carry out some regression analysis between typhoon parameters and observed wave data at A port. **Figures 6.4.1-6.4.4** show that relations and regression analysis results among moving distances, distances to A port, and the consuming time in following limit conditions (a)-(d).

(a) Significant wave heights exceed 2m.
(b) Significant wave periods exceed 10s.
(c) Long period wave heights (20-180s) exceed 0.15m.
(d) Long period wave heights (60-180s) exceed 0.1m.

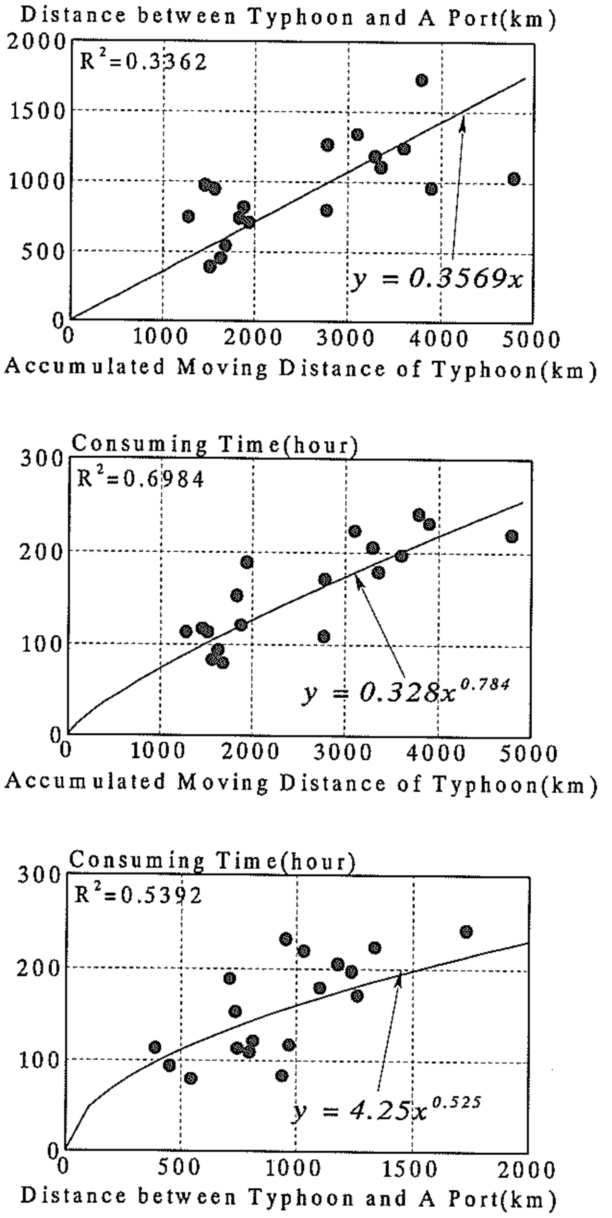


Figure 6.4.1 Relation among moving distances, distances to A port and consuming time of waves (Limit condition (a))

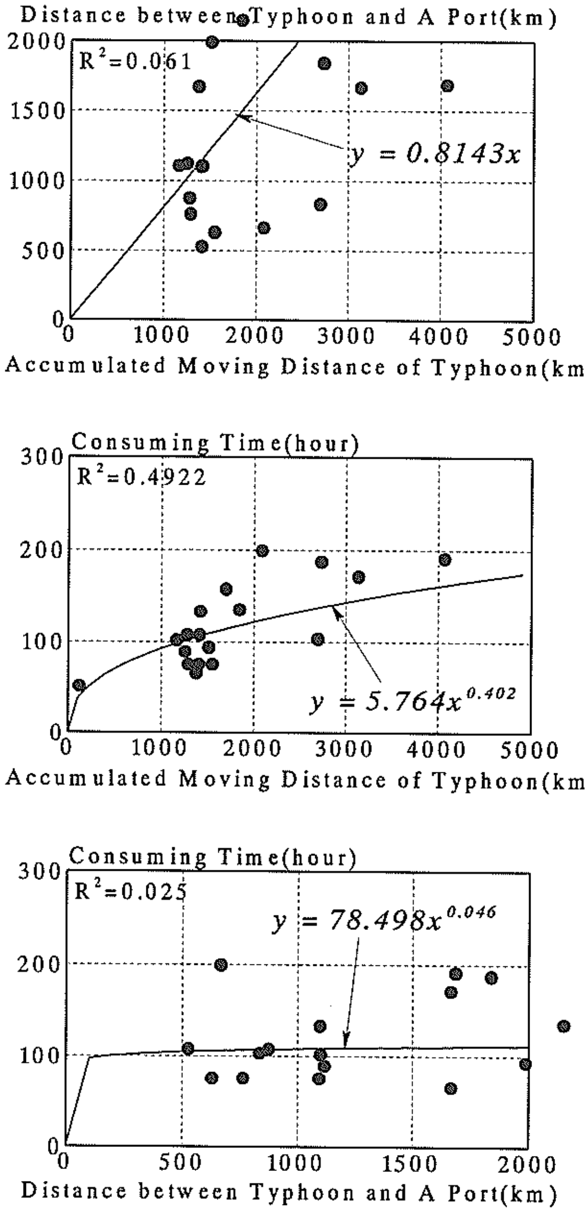


Figure 6.4.2 Relation among moving distances, distances to A port and consuming time of waves (Limit condition (b))

In **Figure 6.4.2**, values of R^2 are so little on relations about distances between typhoon and A port(R^2=0.03-0.06). The correlation is so low among these parameters in limit condition (b). This shows that mooring criteria should not be evaluated in this limit condition. It is necessary to redefine the limit condition by wave period in the future.

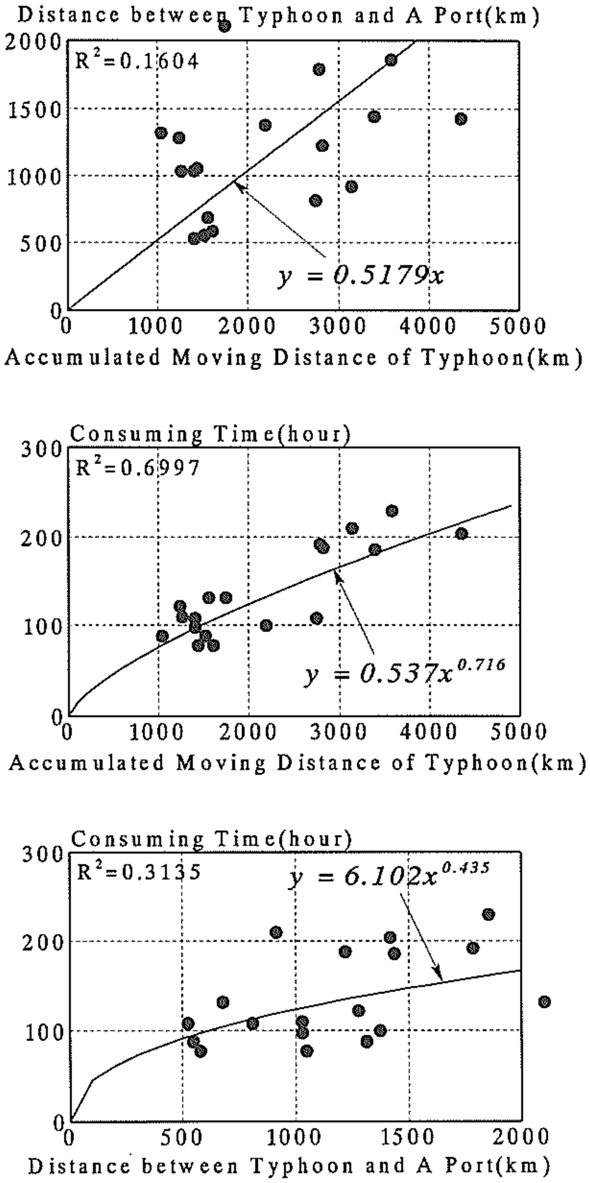


Figure 6.4.3 Relation among moving distances, distances to A port and consuming time of waves (Limit condition (c))

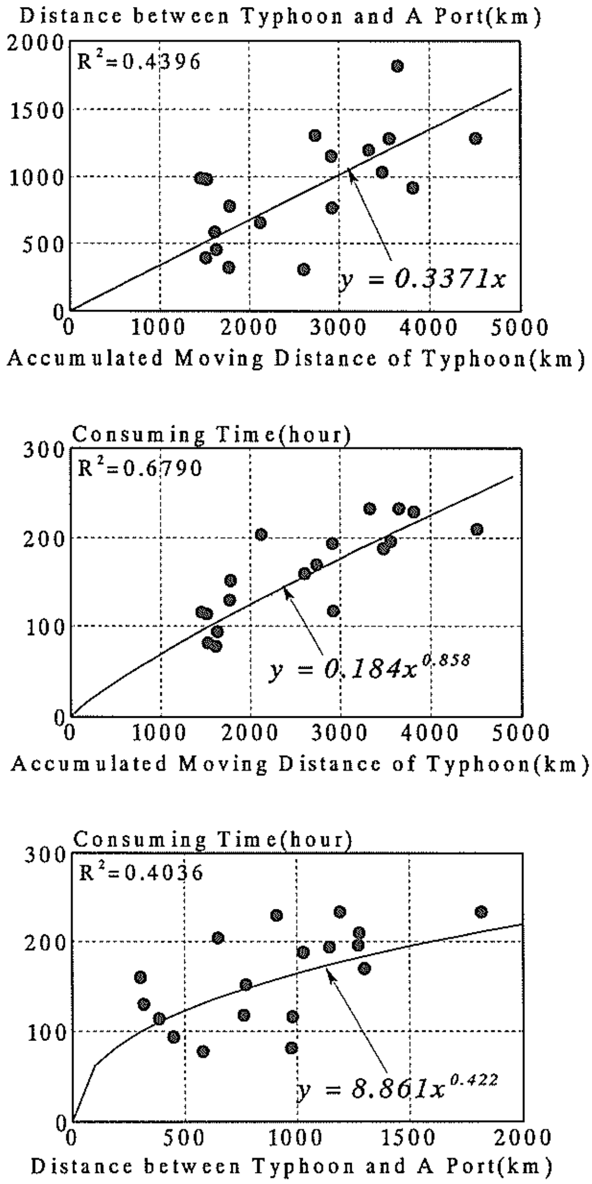


Figure 6.4.4 Relation among moving distances, distances to A port and consuming time of waves (Limit condition (d))

These figures show that the influence of long period waves becomes notable in the following cases.

(1) Typhoon patterns of the accumulated moving distance is about 1500-2000km (100-150 hours), and distances to A port are about 300-800km.

(2) Typhoon patterns of the accumulated moving distance is about 3000-4500km (200-250 hours), and distances to A port are about 1000-1800km.

As the former pattern has a high possibility of typhoon landing to Japan, typhoon warnings are relatively apt to announce in these cases. Therefore, moored ships are ordinary recommended to evacuate outside harbour beforehand. On the other hand, there is a possibility that typhoon warnings are not announced if they don't land to Japan. However, the influence to moored ship motions is considerable in these cases even if typhoons don't land or approach closely to Japan.

The previous section shows that growth conditions of propagated waves depend on atmospheric pressures of central typhoons, so the relation between minimum atmospheric pressures and time lag from minimum pressures to limit conditions of ship mooring is shown in **Figure 6.4.5**.

The minimum atmospheric pressure tends to be lower, as the time lags become large in case of $H_{1/3}$ and $H_{L1/3}$(60-180s). However, there are 2 cases of typhoons that become about 920hPa without time lags. This shows that time lags are not necessary appropriate parameter to evaluate mooring criteria. These figures show that there is less correlation between time lags and minimum atmospheric pressures.

As is examined in this chapter, the time difference between the minimum atmospheric pressure and the limit wave condition of a ship mooring may become an effective parameter for the prediction of swells and long period waves. Especially, in case of maturated swells due to typhoons with long moving distances.

7.Consideration of mooring criteria from wave data and typhoon data

In the previous chapter, it is shown that the growth of swells and long period waves can be explained by some parameters of typhoons. It is necessary to know growth situations of waves for the judgement of mooring criteria. However, it is hard to know them only by themselves for their non-stable property. Also, it is necessary for the influence of moored ship motions to know the property and the estimation of long period waves. Thus, mooring criteria should be evaluated and predicted by multi variables that consist of parameters of waves and typhoons. These points will be researched on the second report and the third report.

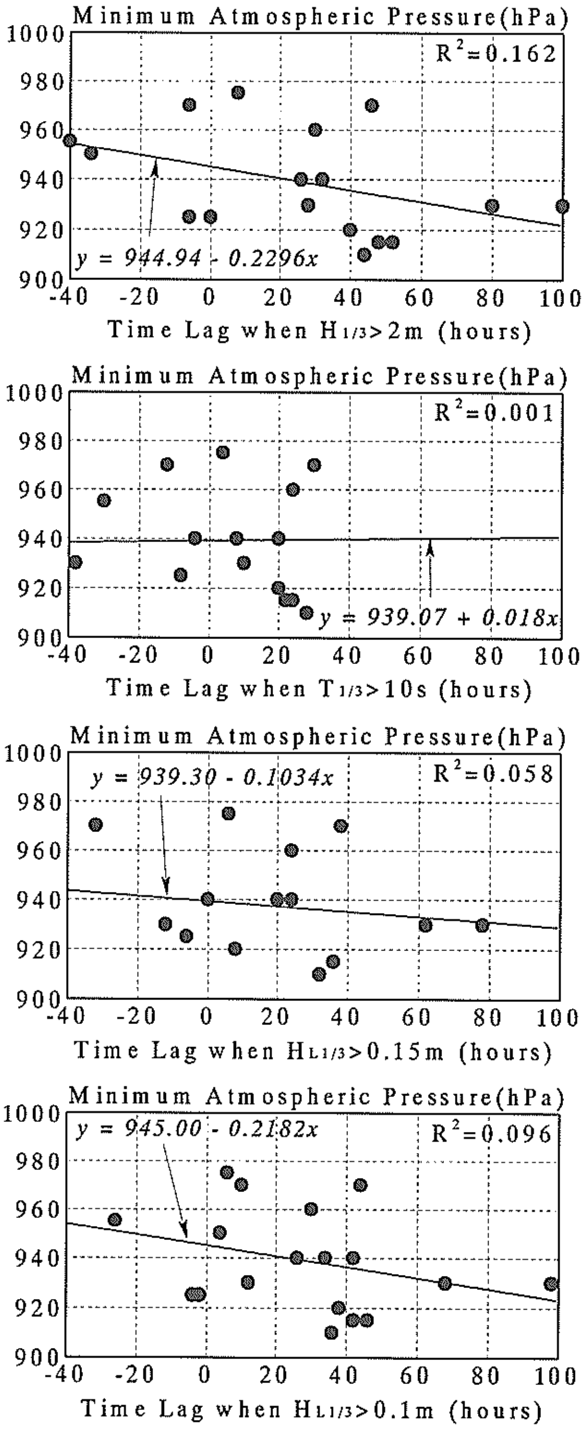


Figure 6.4.5 Relation between minimum atmospheric pressures and time lag of the wave growth

8.Conclusions

In this study, we focused on the mooring criteria at a harbour facing the Pacific Ocean from the point of view of the analysis of wave growth pattern using observed wave data by NOWPHAS system. And then the relation between mooring troubles and wave growth patterns is examined from various aspects. Conclusions are summarized as follows.

(1)Mooring troubles in A port happen at stormy weather conditions due to typhoons. However, there are few examples of mooring troubles due to atmospheric depressions in winter season. It is reported that troubles of moored grain carriers due to swells and long period waves happen from April to November.

(2)Time differences between A and B port are about 0-1 day length of the wave propagation if typhoons are north bound, nevertheless, the correlation of the wave propagation can not be seen if typhoons are north-east or north-west bound. So, more wave data of different observation points will be needed to obtain the time difference of significant waves.

(3)Long period wave heights at A port are apt to exceed 0.1m when the distance between typhoon and A port is within 1500km and the difference of atmospheric pressures between typhoons and A port is about 40-80hPa. However, long period waves that exceed 0.15m exist when the distance is about 2000km and the difference of atmospheric depressions is about 60-80hPa. And it is known that long period wave heights tend to become large when typhoons come from south-east sea areas of A port.

(4)Most of typhoons that causes mooring troubles is generated below 20 degrees of north latitude in 1995-1999, and then 7 typhoons of them are generated below 10 degrees of north latitude. So the ordinary range of present weather charts in Japanese newspapers is not enough to know the existence of typhoons correctly.

(5)There are two types of typhoons that generate larger long period waves. The former type has the relation between the accumulated moving distances of 1500-2000km and the distances to A port of 300-800km. The latter type has the relation between the accumulation of moving distances of 3000-4500km and distances to A port of 1000-2000km. Consuming time for the wave growth is 100-150 hours at the former type, and is 200-250 hours in the latter type.

(6)There is the tendency that the time difference between minimum atmospheric pressures and limit conditions is about 40 hours to exceed 0.1m of long period wave heights when the minimum atmospheric pressure is below 940hPa. On the other hand, the time difference is so little when the minimum atmospheric pressure is more than 960hPa, and those ones have relatively short moving distances and consuming times. However, there are some cases of typhoons below 940hPa without the time difference. It is necessary to research on detail in the future.

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