CHAPTER 59

GENERATION MECHANISM OF ABNORMAL WAVES ALONG THE JAPAN COAST

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Abstract

The conditions under which abnormal waves occur in the western part of the Japan Sea and the northwestern part of the Pacific Ocean are examined. A numerical study of the abnormal waves was performed for a selected monsoon condition in winter. The mechanism of abnormal wave development is clarified using a wave spectrum model. It was found from the directional spectra that the effect of wind duration plays a key role in abnormal wave generation. For typhoon conditions, the relation between a standard project typhoon and the abnormal waves induced, is considered and the simulation method of the typhoon model is improved by introducing the typhoon stagnation effect. Finally, it was shown that abnormal waves generated by typhoons are due to long typhoon stagnation.

1. Introduction

Recently, as urbanization develops around the coastal zone, more regard to safety against coastal disaster is required. It is essential to take the enormous disaster potential of the low probability of occurrence of storm surge, high waves, etc. into account when planning and designing coastal structures. Abnormal waves which are the primary cause of coastal disasters

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along the Japan coast, are generated by monsoons in winter and typhoons in summer. They often cause severe damage to the coast, so prevention of coastal disaster by predicting the possibility of occurrence for waves of long return period, location of appearance, etc. is important. Unfortunately, even in this day and age, the mechanism of abnormal wave development is still not satisfactorily clear.

The major causes of abnormal wave generation are geographical features, such as sea bottom topography, and wind properties, such as wind duration. The effect of wind duration is of particular importance in developing waves. Figure 1 shows the location map of Japan and the representative typhoon courses. The Japan Sea, located between Japan and the Asiatic continent is almost enclosed by Sakhalin, Hokkaido, Korea and Kyushu. During winter, convection currents, the so-called monsoon, occur between the Asiatic continent and the Pacific Ocean and low pressures often take place. If low pressure stagnation occurs on the northern side of

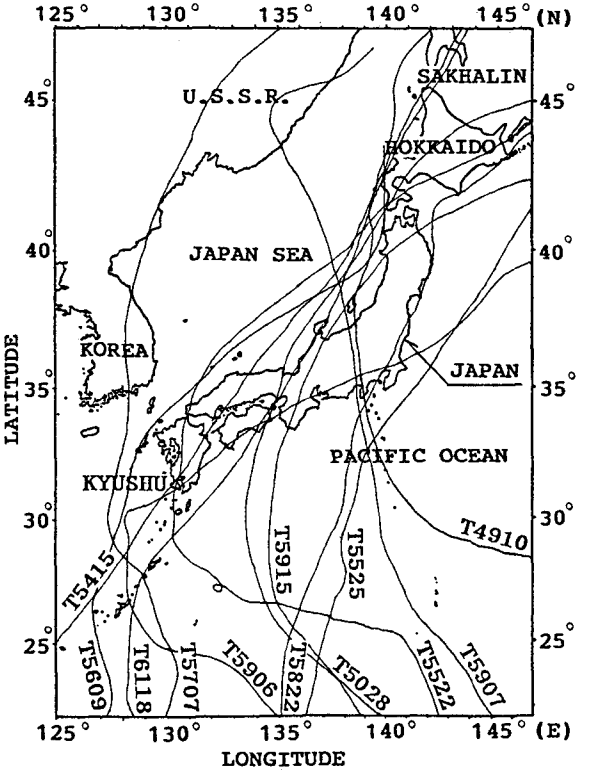


Figure 1. Location map of Japan and representative typhoon courses

Hokkaido, the typical meteorological condition of winter exists and waves develop to a great extent due to duration of the monsoon.

In a typhoon situation, on the other hand, high waves are also generated. These also cause damage. A typhoon is a very large air vortex and wind field, so it is considered that waves induced by typhoons yield duration-limited wave growth curves. In general, a typhoon first moves in low latitude from south to north or northwest, but a change of course to Japan mainland occurs. Stagnation of the typhoon occurs at this turning point. If a typhoon stagnates at low latitude, swell develops rapidly due to the long duration propagating from the wind fields to the coast. This can occur from distances even as great as 2000 km.

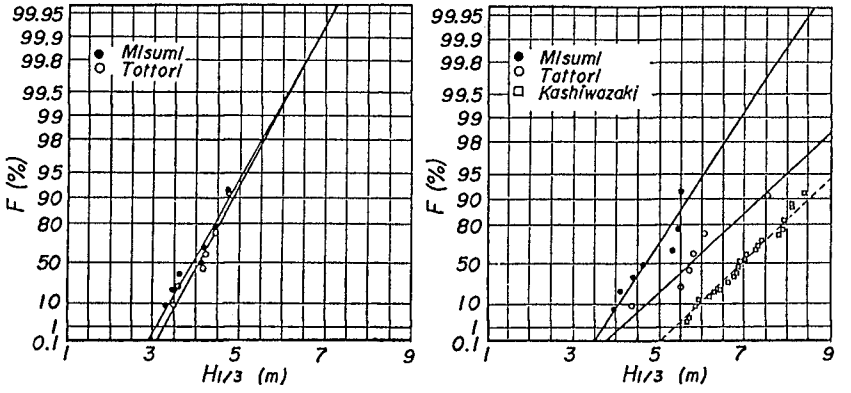
One of the ways to investigate the occurrence and conditions of abnormal waves is statistic approach using observed and hindcasted wave data (Yamaguchi et al., 1978) and wave prediction model studies for the greatest typhoon to date (Yamaguchi et al., 1986). In Japan, the typhoon model simulation is usually employed. This is an effective method for the investigation of abnormal waves induced by a typhoon. Nevertheless, it does not satisfactorily take the effect of typhoon stagnation into account, so the mechanism of abnormal waves of very long return periods is not made clear. As mentioned above, waves can develop great energy due to the long duration and it is considered that the wind field of a typhoon is a duration-limited condition. Therefore, abnormal waves induced by a typhoon can be predicted using an extension of typhoon model by introducing the typhoon stagnation effect.

In this paper, using the wave data observed at harbors on the western Japan Sea coast, extremal wave statistics are examined to consider the actual wave conditions induced by monsoons and typhoons in the Japan Sea. The mechanism of abnormal wave development was then clarified using a wave spectrum model. For typhoon conditions, a method for direct investigation of abnormal waves is considered and the typhoon model was improved by introducing the typhoon stagnation effect. Consequently, the statistic properties of duration of typhoons were examined. Furthermore, using the improved typhoon model, it is shown that if a typhoon stagnated at a low latitude and the duration is extremely long, waves would develop to a remarkable extent along the Japan coast.

2. Methodology

2.1 Wave conditions in the Japan Sea

First, we discuss the actual wave conditions for the occurrence of abnormal waves in the western part of the Japan Sea. Extremal statistics of wave heights observed at Misumi and Tottori harbors on the Japan Sea coast were obtained. These are shown in Figure 2. It is confirmed that the waves induced by monsoons are indeed larger than those from typhoons, at both locations.



(1) Typhoon (induced waves) (2) Monsoon (induced waves)

Figure 2. Applicability of Gumbel distribution to extremal wave statistics. Locations of each harbor are indicated in Figure 3.

As already mentioned, the Japan Sea is almost closed, so that it is considered that waves induced by monsoons follow the fetch-limited wave growth curves. Monsoon wind speeds are generally lower than those of typhoons. Even so, in the winter monsoon condition, the wind direction is nearly constant and the duration is very long, so waves receive great energy from them. If a monsoon wind changes its direction, waves turn into large swell and wind waves rapidly develop in the new direction. These waves interfere with each other. It can be assumed herein that abnormal waves induced by monsoon may be generated as a result of a combination of energy from swell that develop due to long duration and wind waves. Using a wave model, the mechanism of this process is confirmed for a selected monsoon condition.

2.2 Wave model

The model used for the numerical experiments is the wave spectral model proposed by Yamaguchi and Tsuchiya (1979). It is a so-called Second Generation (SWAMP, 1985) spectral wave model based on the two-dimensional properties of ocean waves. The total energy is evaluated by integrating the energy balance equation(Hasselmann, 1968)

$$\frac{\partial \mathbb{E}(f,\theta,\mathbf{X},t)}{\partial t} + \nabla(\mathbb{E}(f,\theta,\mathbf{X},t)\cdot \mathbb{C}g) = S(f,\theta,\mathbf{X},t) \qquad (1)$$

where E is the two-dimensional energy density spectrum for frequency f and direction θ at x, y, and t, and Cg is the group velocity derived from linear theory. The source function S is represented for the three stages of the sea state, i.e. the growing, decaying and opposing wind states.

In the growing stage, the generation term is composed of a linear (Phillips, 1957) and exponential growth (Miles, 1957), such as A + B*E. In the model, the term A represents Phillips' external turbulent pressure forcing and the term B*E corresponds to the Miles' linear feedback mechanism. The numerical values of A and B are calculated using two formulae proposed by Inoue(1967). The fully developed JONSWAP spectrum is assumed and the energy-subtracting term is introduced according to the hypothesis that a fully developed sea state exists in equilibrium. Using the modified parameter as written down by Barnett(1968), the resonant nonlinear wave-wave interaction effects are also incorporated. In the second decaying stage, dissipation due to the nonlinear effect is assumed to play a part. For opposing winds conditions, adding the second stage, it is assumed that the winds produce the reverse effect to Miles' exponential growth.

2.3 Hindcast results

Numerical studies on the mechanism of wave development and propagation for a selected monsoon condition experienced in 1989 were conducted. High waves were observed along the Western Japan Sea coast on that occasion. Figure 3 shows the computational domain of the study. The domain covers the total Japan Sea area. Points A, B, C and D indicate the locations of Misumi, Tottori, Kyogamisaki and Kashiwazaki. Estimated significant wave heights and periods are compared with those measured at these points. Figure 4 shows comparisons of measured and estimated values at point C. As shown in this figure, it is concluded that the wave characteristics can be predicted satisfactorily by this wave model.

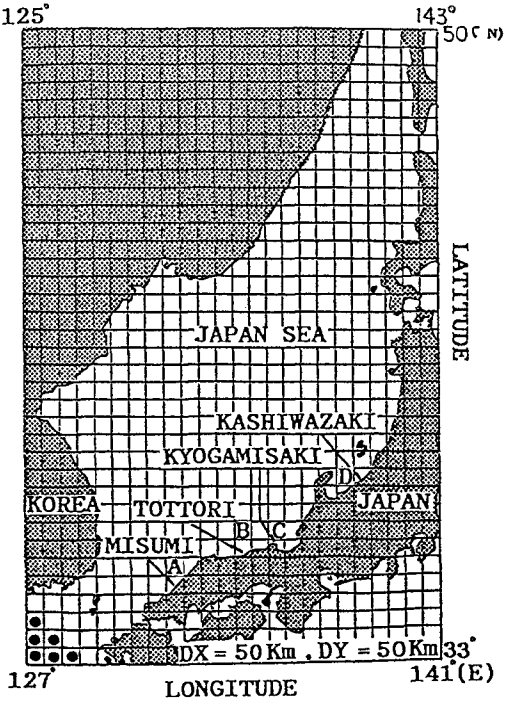


Figure 3. Computational domain for monsoon condition

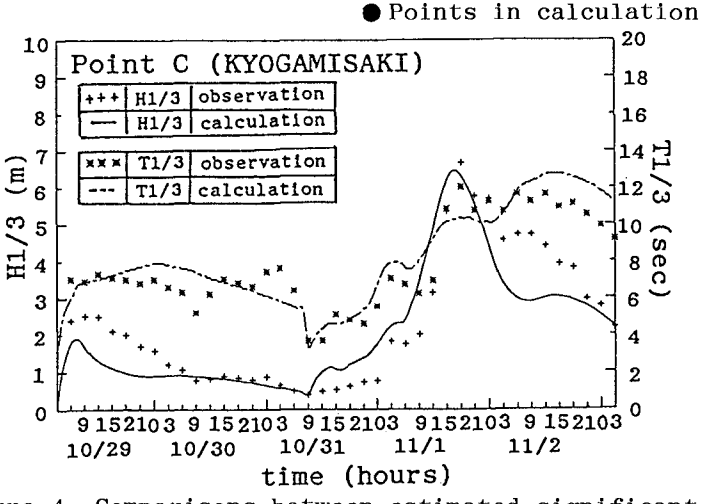


Figure 4. Comparisons between estimated significant wave heights and periods and those measured at point C(KYOGAMISAKI)

The Custer diagrams shown in Figures 5(a) and (b) show wave fields using the calculated wind fields. The unit arrows in each figure indicate the wind direction and mean wave direction. As can be seen in the figures, the wind first blew from SW in the same direction. When the wind field changed its direction from SW to NE because of the low pressure movement, waves develop sufficiently from the NE direction due to the long duration and long fetch. Furthermore, after the low pressure passed through the Japan Sea, it became the typical monsoon condition of winter and the wind blew strongly from the NW or N direction. The influence of this wind caused waves to change into large swell and wind waves developed from the NW direction. The net results of this process is that the waves change their directions from NE to NW and came to the Western Japan Sea coast.

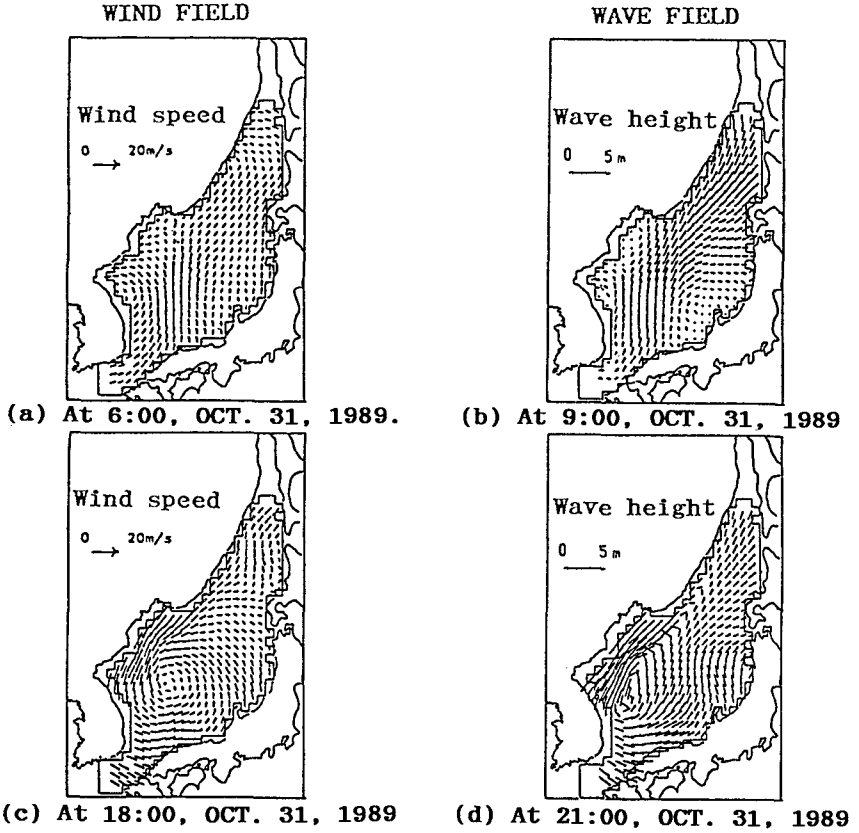


Figure 5(a). Changes in wind and wave field calculated
(see also Figure 5(b))

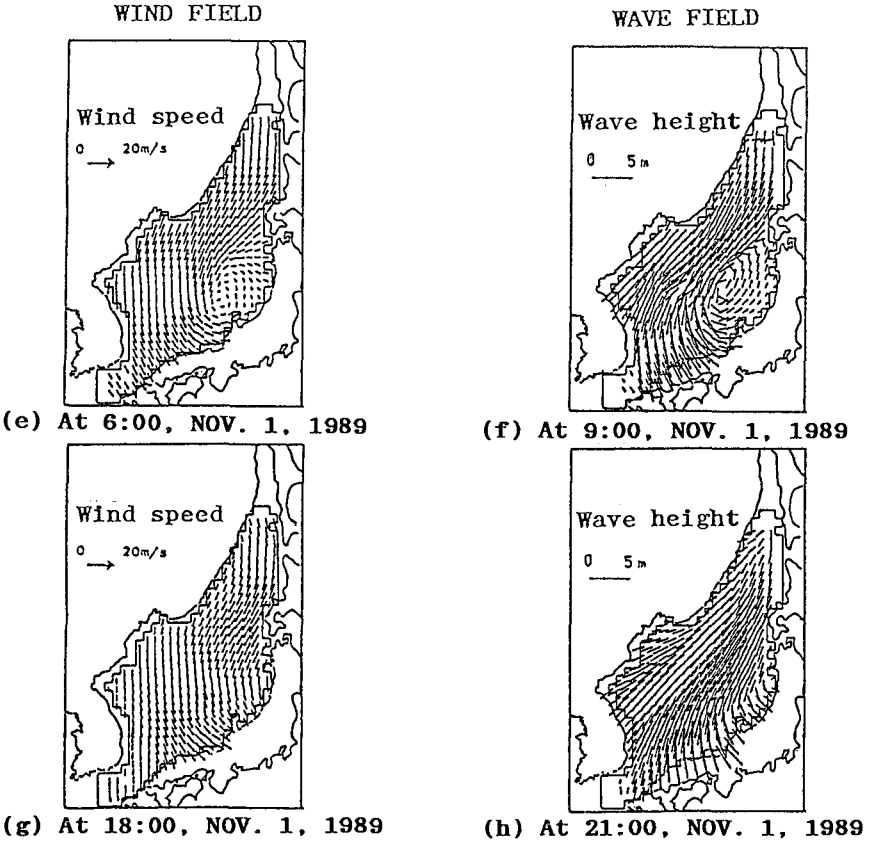
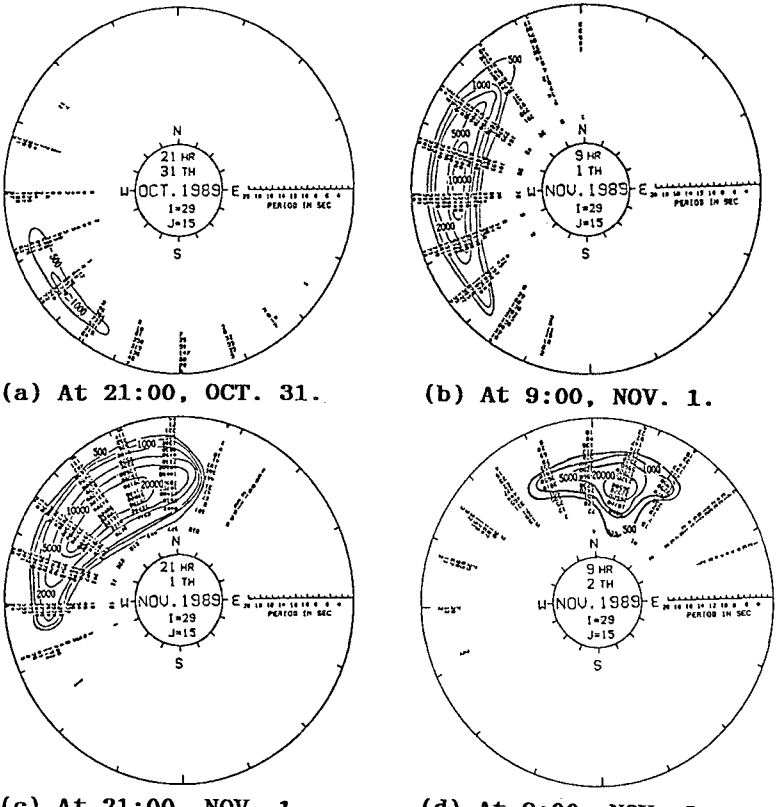


Figure 5(b). Changes in wind and wave fields calculated

2.4 Discussion

Figure 6 shows the changes of distributions of directional spectra at Point C. The top and bottom of the circle indicate the North and South direction and right and left side correspond to East and West. The energy densities of all wave components are distributed inside the circle. The center area of each circle indicates the components of swell and the area of near circumference also indicates wind waves. As can be seen, at first the energies of wind waves developed from the SW direction, but their energies are of low level. However, after the waves accumulated a lot of energies from the NW direction, swell developed rapidly and their energies increased dramatically due to the monsoon duration. It can be concluded for the Western Japan Sea that abnormal waves are generated as a result

of a combination of energy from swell that develop due to the long duration of monsoons and wind waves. Thus, we emphasize here that wind duration is an important factor in abnormal wave development.



(a) At 21:00, OCT. 31. (b) At 9:00, NOV. 1.

(c) At 21:00, NOV. 1. (d) At 9:00, NOV. 2.

Figure 6. Directional spectra calculated by selected monsoon condition.

From the monsoon results, it is clear that wind duration plays a key role in abnormal wave generation, so a method to investigate abnormal waves directly using typhoon model simulation was considered. Usually, as a wind field of a typhoon is quite large, waves induced by typhoons yield the duration-limited wave growth curves. If a typhoon stagnates at low latitude for a very long time and the wind duration increases to an extreme, waves can develop their energies rapidly. Therefore, the generation of abnormal waves from a typhoon can be predicted by a numerical model if the typhoon duration is very long and the intensity and magnitude of the typhoon just before and after landing is taken into consideration.

Figure 7 shows correlation between Td and Pc, where Td is the wind duration when the eye of the typhoon passes from 25° N to 29° N in latitude and Pc is the central atmospheric pressure depth. The figure indicates that Td and Pc are independent of each other.

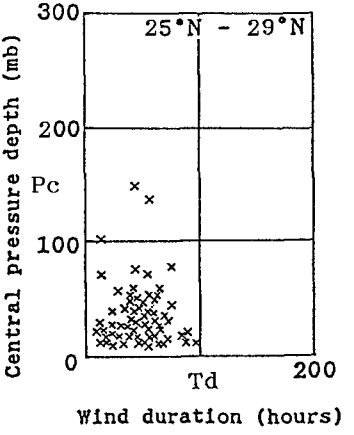


Figure 7. Correlation between central pressure depth Pc and duration of typhoon Td.

The extremal statistics of annual maximum Td are shown in Figure 8. The solid line is a regression analysis line obtained from the Gumbel distribution. The correlation coefficient between the solid line and Td is 0.969, so that applicability of the Gumbel distribution to extremal statistics of annual maximum Td is very good. It is concluded from these results that we must treat the duration of typhoon as a statistic parameter.

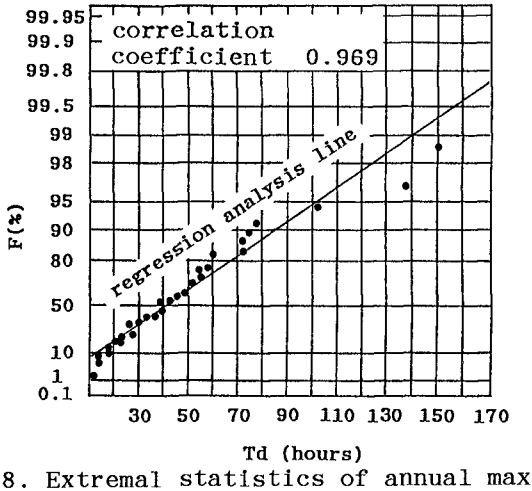


Figure 8. Extremal statistics of annual maximum duration of typhoons.

3. Simulation and Results

3.1 Improved typhoon model

In this paper, it is considered that the way to investigate abnormal waves directly is to use a typhoon which has a low probability of occurrence. As a first step, the relation between a Standard Project Typhoon (Mitsuta, 1965, Fujii and Mitsuta, 1986) and the abnormal waves induced is considered and it is concluded that the abnormal waves induced by the typhoon are predicted by a typhoon model. The statistic properties of duration of typhoon are investigated. From these results, the simulation metho of the typhoon model was improved upon by introducing the typhoon stagnation effect (Tsuchiya and Komaguchi, 1987).

Table 1 shows the return period of typhoon duration in the region of low latitude. According to the table, the extended duration of a 50 year return period is around 120 hours.

Table 1. Return period of typhoon duration in the region of low latitude.

Return period T_m(year)	Extended duration T_d(hours)
10	82.84
20	99.30
30	108.76
50	120.58
100	136.52
150	145.81
200	152.40
300	161.67
500	173.34

As already mentioned, in Japan, wave hindcast model studies are usually conducted for the greatest typhoon, such as in the case of the Isewan typhoon. The duration time of the typhoon is only 15 hours. Using the improved typhoon model, it is shown that the situation for abnormal waves can be predicted under the condition of an extremely long duration.

3.2 Results

The domain of computation for the typhoon model is shown in Figure 9. The duration time of typhoon 8218 is actually 36 hours. The conditions for calculation are DX = DY= 50 km and DT= 30 minutes. As initial and boundary wave conditions, the parametric model of Ross(1976) is used and the directional spectrum assumed to be a JONSWAP spectrum with a cosine square angular spreading.

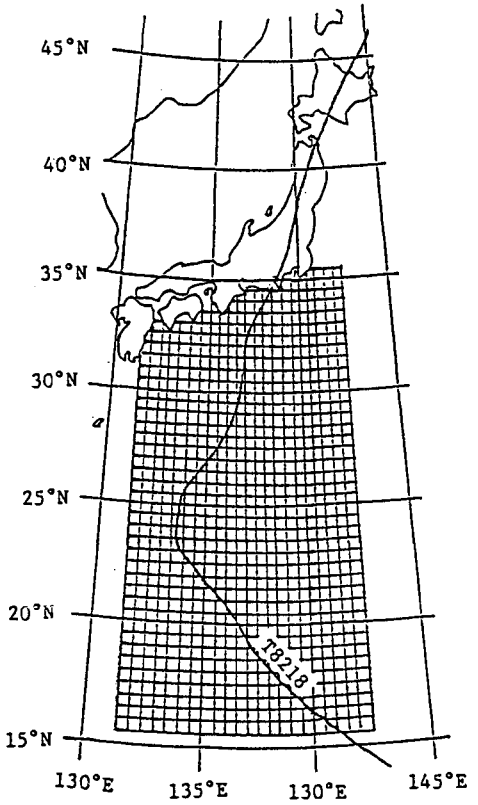
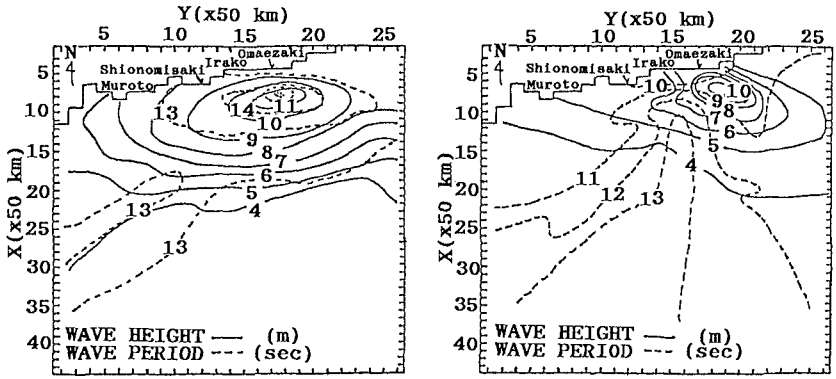


Figure 9. Domain of computation for typhoon model

Figure 10 shows a comparison of the distribution of the wave fields made in a case (a) where an extreme duration of a 500 year return period of Td was taken and compared with a case (b) where typhoon stagnation was not considered. The figures indicate that when a typhoon stagnates at low latitude and the wind duration is extremely long, waves will develop to a remarkable extent along the Northwestern Pacific Ocean coast.



(a) Typhoon stagnation occured. (b) Typhoon stagnation did not occur.

Figure 10. Comparison of the distribution of the wave field along the Northwestern Pacific Ocean coast.

4. Conclusions

The major conclusions of the study are as follows:
(1) It was considered in the Western Japan Sea that waves induced by monsoons have a possibility of obtaining energies larger than those from typhoons. From the directional spectra, it was clarified that abnormal waves are generated as a result of a combination of energy from swell that develop due to the long duration of the monsoon and wind waves.
(2) By consideration of the relation between the standard project typhoon and abnormal waves induced by the typhoon, the typhoon model was improved by introducing typhoon stagnation.
(3) The statistic properties of typhoon duration were examined. It was concluded from the results that the duration of a typhoon must be introduced as a statistic parameter.
(4) The results of numerical simulation using an improved typhoon model showed that if typhoon stagnation occurred and the duration was extremely long, waves would develop to a remarkable extent along the Japan coast.

Acknowledgement

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