25 knots appeared 2 hours after the start of the observation, the wind velocity during observation period was 12 ~20 m/s, and the significant wave height developed from 1 m to a peak of 5.3 m. Power spectrum analysis and harmonic analysis were done, and the aspect of relation between significant wave and elementary wave and the appearance of the elementary wave was examined.

The significant wave heights had about 5 times the maximum elementary wave height with a maximum elementary wave height less than 0.8 m, and they increased rectilinearly. However, the significant wave height slightly increased with a maximum elementary wave height over 0.8 m. The largest elementary waves had 1.83 m wave height, 10.3 seconds period in observation.

There was a high correlation between the maximum elementary wave period and the period estimated by the power spectrum analysis, and the relation was a one-to-one.

The average appearance of elementary waves numbers was 23.1, and its maximum numbers were 29, and about 60 percents of the wave had a period of 4~10 seconds.

From the time series of elementary waves, the aspect in which elementary wave of large wave height gradually appears in the long period was proven.

Finally, the authors deeply thank the crew of TS Hokusei maru for their help with data collection.

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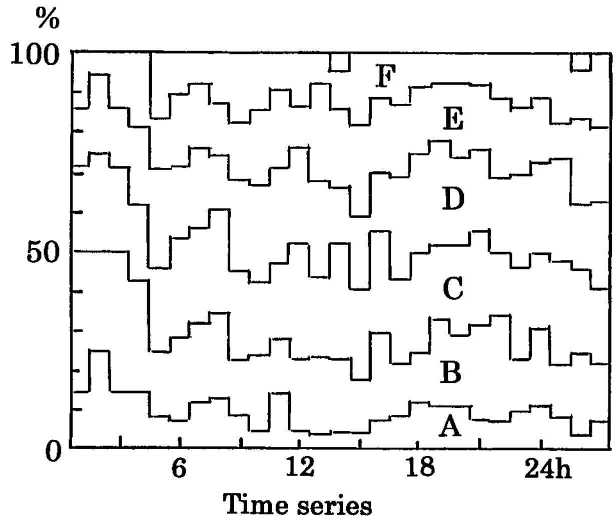

Fig. 6 Accumulation frequency distribution (%) of elementary wave numbers in each periods.
Range of period (sec) are shown as follow: A<4, 4≦B<6, 6≦C<8, 8≦D<10, 10≦E<12, 12≦F<14

Table 1. Mean value and standard deviation of elementary wave numbers in each periods. Range of period(sec) are shown as follows:
A<4, 4≦B<6, 6≦C<8, 8≦D<10, 10≦E<12, 12≦F<14, 14≦G

Period	Total	A	B	C	D	E	F	G
Wave number	648	60	127	144	136	109	70	3
Mean number	23.1	2.1	4.5	5.1	4.9	3.9	2.5	0.1
Standard deviation	3.81	0.85	1.17	1.08	1.35	1.23	1.32	0.31

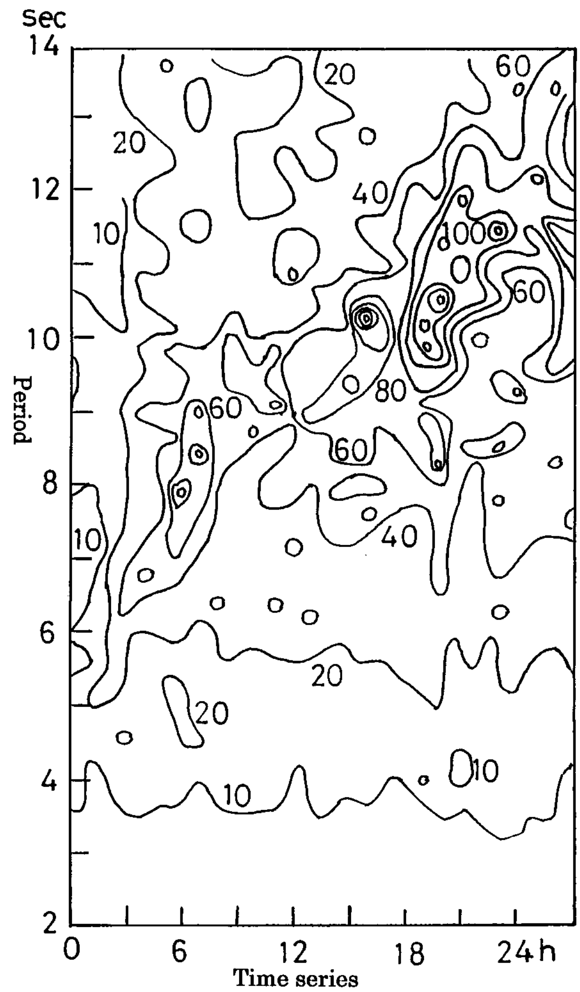

Fig. 7 Time series distribution of elementary wave height (cm).

tary wave period was almost a one-to-one. This shows the result that the maximum energy of the wave depends on the maximum elementary wave. Therefore, a maximum elementary wave period is an ocean wave period too. Fig. 6 displays peak in the frequency of appearance number of elementary wave, determined by harmonic analysis of the time series. In the initial stage in which the wave was in the undeveloped stage, the frequency of appearance of elementary waves was around 15. However, the number increase with the development of the wind wave and the peak appears after 5 hours at 28. Though it decreased to around 22 afterwards, it gradually increased from after 15 hours, and the peaked after 22 hours. The period independence, average appearance number of elementary wave and the standard deviation are shown in Table 1. The period had 4 second or less, 4~10 second, 10~14 seconds in about 10%, 60%, and 30% of appeared elementary waves, respectively, ($N=648$). Newly generated elementary waves seemed to grow gradually into long-period waves. However, the elementary waves seem not to grow into longer period with fluctuation of wind direction and wind velocity. Fig. 7, which has the period in Y-axis and elapsed time in X-axis, is displayed the distribution of the elementary wave high in the time series. A wave of about 0.1 m in height was generated with a period around 4 seconds, and a wave of about 0.2 m in height was generated with a period around 5~6 seconds. In the observation initial stage, the elementary wave of longer period, which exceeded 11 seconds, did not appear, and maximum elementary wave height was also around 0.2 m in height. After 3 hours observation, elementary waves with periods of 6~8 seconds and wave height around 0.4 m began to appear, and then, wave height and period together increased with elapsed time. After 15 hours, the wave height developed to over 1.0 m, and the period increased to 10~11 seconds. However, the wave attenuated after 24 hours.

Summary

The effect of a depression that advanced at a speed of

ses, and then soon gradually weakened (Fig. 2C). Significant wave height peaked after 5 hours (4.1 m), and then, 4.5 m was recorded after 13 hours, and 5.3 m was recorded after 20 hours, after which it decreased (Fig. 2D). The maximum elementary wave height gradually increased as well with the significant wave height and peaked at 1 m after 6∼7 hours, after which it decreased. However, it peaked again at 1.7 m after 17 hours and 1.8 m after 21 hours (Fig. 2E).

Significance period was 6 second or less after 3 hours, 7 second order after 7 hours, 8 second order after 18 hours and finally 9 second order from the observation start (Fig. 2F). The maximum elementary wave period was 7 seconds or less 3 hours after the observation start, increased to 8∼9 seconds after 18 hours, increased to 10 ∼12 second, and reached a maximum of 12.3 seconds after 25 hours (Fig. 2G). The period estimated from the maximum value of the power spectrum showed a tendency similar to that of the maximum elementary wave period (Fig. 2H). The relationship between significant wave height and maximum elementary wave height is shown in Fig. 3. The relation was expressed as an exponential function ($Y=aX^{\alpha}$) , and coefficients ($a=4.24$, $\alpha=0.675$) were determined using least squares regression. The correlation coefficients γ was 0.932. However, this regression line not seemed to well fit. In the initial stage of the development of the wave, wind direction and elementary wave direction seems to be same. Therefore, the ocean wave seems to be linear proportion to the development of elementary wave. However, with the change of wind direction, an elementary wave with a new direction is generated, and it interferes, so it presumably does not develop into a large ocean wave. The relationship between maximum elementary wave height and maximum elementary wave period is shown in Fig. 4. The elementary wave height also increased with increasing period. The maximum value of the elementary wave height was 1.83 m and the period was 10.5 seconds. However, the wave height has decreased, even as the period increased. The relationship between significance period, period of the largest power spectrum value and maximum elementary wave period is shown in Fig. 5. There was the respectively high correlation. The relation between maximum elementary wave period (X) and significance period (Y_s) is

$$Y_s=0.56X+3.2 \qquad \gamma=0.917$$

The relation between maximum elementary wave period (X) and power spectrum (Y_P) is

$$Y_P=0.98X+0.2 \qquad \gamma=0.977$$

Both are very significant relationships. The relation between the power spectrum and the maximum elemen-

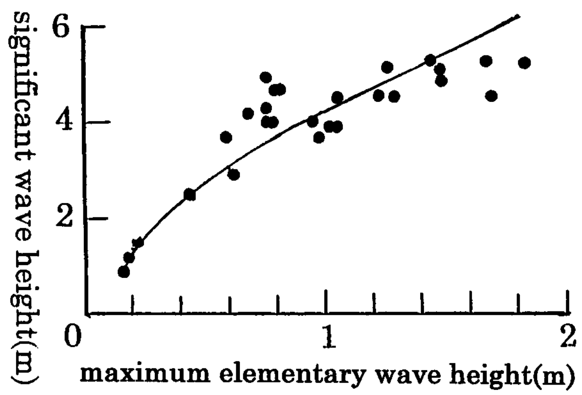

Fig. 3 Relation between maximum elementary wave height (X axis) and significant wave height (Y axis).

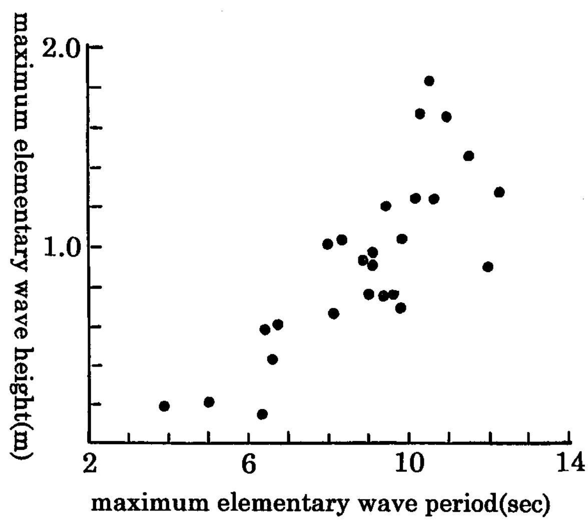

Fig. 4 Relation between wave period (X axis) and maximum elementary wave height (Y axis).

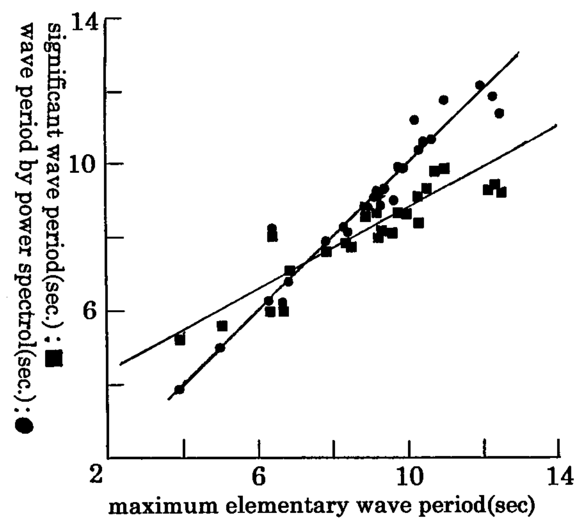

Fig. 5 Relation between maximum elementary wave period (X axis) and other periods (Y axis).
●: significant wave period, ■: wave period by power spectral

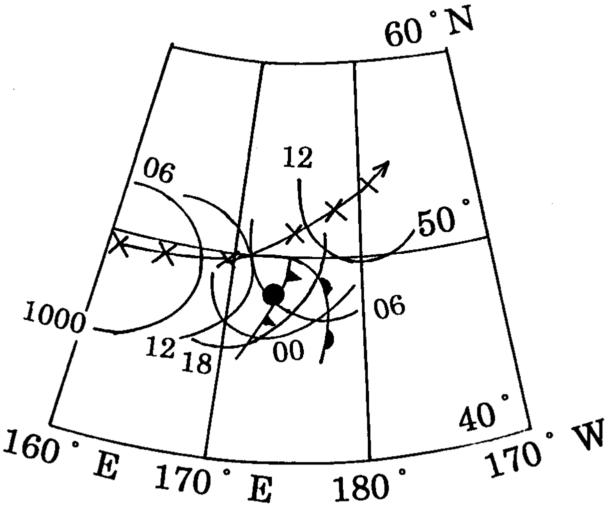

Fig. 1 Course of a depression.
●: Position of the Hokusei maru ×: Center position of a depression every 6 hours real curve shoes 1,000 hpa isobaric line

before cruise and it was confirmed that signal was accurate (an output of voltage 1v at the 1m wave height).

Measured wave data was examined using power spectrum analysis by the FT method, and the period of the ocean waves was obtained from the spectrum maximum value. In addition, harmonic analysis was done, and the elementary wave height and period were obtained. Though the ship drifted till five hours since the measurement start, after that the ship advanced slow-speed from 3 to 4 knots. Therefore, most of periods were sailing encounter period. If the minute amplitude wave theory is followed,

$$\omega_E = \omega - \omega^2 \mu \cos \theta / g$$

thereupon, θ : The angle between ocean wave and bow direction.

ω : The angle period of the original ocean wave.

ω_E:
The encounter angle period.

G : The gravitational acceleration.

μ : Vessel speed.

The period required by the analysis was changed using this equation in the original period. This method can be applied, when directions of all elementary waves are same direction. But directions of elementary waves are various and so that this method is appropriate. However, direction of maximum elementary wave seems to be identity with direction of ocean waves. The effect seems to be small for the elementary wave with a short period under the low speed, so this method was adopted.

Result and discussion

The depression had a speed of 25 knots and moved from the east to the east-northeast. The central pressure was 990~988 hpa, later declined to 992 hpa. In Fig. 1, The × mark shows the center location of the depression every 6 hours, and the real curve shows 1,000 hpa isobaric line. A warm front passed about 7 hours after the start of measurement, and the cold front is passed after 10 hours. Fig. 2 shows data of atmospheric pressure, wind direction, wind velocity, significant wave height, maximum elementary wave height, significant period, maximum elementary wave period and the period estimated from power spectrum analysis. The atmospheric pressure, which was 1010 hps at the observation start, fell to 1,000 hps after 3 hours, and then to 995 hps after 9 hours. The atmospheric pressure became almost constant afterwards, began to rise after 19 hours, and the recovery was approached (Fig. 2A). Wind blew from the south for about 10 hours, then from the southwest afterwards gradually, then from the west after 19 hours, and finally from the northwest as the atmospheric pressure rose (Fig. 2B). The average wind velocity at the beginning was 9 m/s, and peaked after 2 hours (20 m/s) and 13 hours (17~19 m/s), changed to 15~17 m/

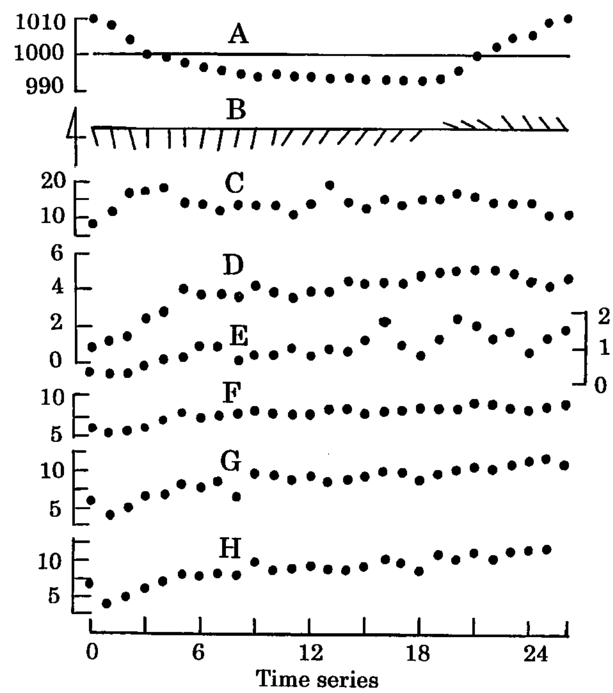

Fig. 2 Time series datas.
A: atmospheric pressure (hpa), B: wind direction (degree), C: wind velocity (m/s), D: significant wave height (m), E: maximum elementary wave height (m), F: significant wave period (sec), G: maximum elementary wave period (sec), H: wave period by power spectral (sec)

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Wave Fluctuation with the Passage of a Depression

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Abstract

Ocean waves were observed on board a vessel, when a medium-scale depression passed. A average maximum wind velocity of 20 m/s and maximum significant wave height of 5.3 m were recorded during the observation period. The period of observed ocean waves was determined by power spectrum analysis, and elementary wave and the period were determined by harmonic analysis. The period of the ocean waves agreed with maximum elementary wave period closely. From the time series distribution of the elementary wave, small elementary waves (with about a 4 second period and 0.1 m wave height) were always being generated, and they gradually developed into waves with a long period and the large wave height. The wave height of the maximum elementary wave during the observation period was 1.83 m, and the period was the 10.5 seconds.

Key words: depression, significant wave, elementary wave, wave height, Wave period

Introduction

It is possible to determine a scale of wind waves from the three elements of wind velocity, fetch and duration of wind by theoretical calculation. Wind waves are propagated as swell to other sea area. The generic name of swell and wind waves is ocean waves. In the Meteorological Agency Marine Department, ocean waves are shown in actual condition charts and forecast charts for the purpose of marine navigation safety, economic operation and marine disaster prevention. The ocean wave charts display wave height in one-meter interval, and its minimum wave height is two meters.

In the northwest North Pacific Ocean, ships such as training ships of high schools and universities, research ships of the Fisheries Agency, and marine research ships of Meteorological Agency carry out fishery practical training and oceanographic observation, and many fishing boats are active. For these small ships, which are strongly affected by wave, the ocean wave charts provide important information of hydrographic condition with the weather chart. However, the actual condition chart and forecast chart are broadcast only once a day. Therefore, it is difficult for ships to predict changes in the ocean waves, when the weather changes due to a passing depression.

The Hokkaido Univ. Faculty of Fisheries training ship is equipped with a microwave type wave height sensor (Kuwashima et al., 1984), so it is possible to measure ocean waves. The Hokusei maru carries out investigation in the northwest North Pacific Ocean from July to August every year. During one cruise, a depression approached the Hokusei maru from the west and then passed northward and headed east northeast; during this time, ocean wave were observed. These observation data were analyzed, and the process from the development of a ocean wave to its attenuation was analyzed. Such information will help contribute to improving the safety of ship near depressions.

Material and analysis method

The observation was carried out from 8 : 30 on 29 July to 9 : 30 on 30 July 1999. A total of 26 observations are recorded one-hour intervals. The position of the ship was near 48° N 173° 30'E (Fig. 1). Atmospheric pressure, wind direction, wind velocity, significant wave height, significant period and wave height were recorded. In addition, the following were estimated visually: Swell, wave direction, wave height and period. The analog signal of wave height was incorporated in a computer through an AD converter at 0.1 second intervals. The uptake data number for one time was 4096. A measuring time was 6 minutes 50 seconds, and it was short as a measurement time of ocean waves (Kuwashima, 1981). Still, wave height sensor was calibrated

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