CHAPTER 9

WAVES OFF TAICHUNG COAST OF TAIWAN

by

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SYNOPSIS

Many coastal engineers have made studies on the characteristics of waves, but most of them concentrated on waves of the open ocean. Due to the environmental difference, the result drawn for open ocean waves may not be applied to straits or the continental shelf. Based on the observed data, the authors intend to obtain some characteristics or tendency of wave condition in the Taiwan strait. Correlationship among wave parameters and meteorological factors is also examined. Comparisons to the result for open ocean waves are made to supply information for planning, design and construction of coastal structures on the coast of the strait. These studies are also useful for wave prediction in the strait area.

GEOGRAPHICAL AND METEOROLOGICAL CONDITIONS

The Taichung coast, on the central-west part of the island of Taiwan, faces the Taiwan strait as shown in Fig. 1. The climate in this area may be classified as winter monsoon, summer and the transitional seasons. The speeds of NNE-NE winds prevailing during the monsoon season beginning in October to the next March are generally higher than those of S-SW winds in summer season from May to August. Due to frequent change of

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wind directions, the months of April and September are regarded as the transitional season. However, during the period of July to September, this island is frequently hit by typhoons. Paths of seven typhoons from 1971 to 1975 were plotted in Fig. 2.

DATA COLLECTION

An ultrasonic wave gauge was set at a water depth of 19 meters below low water level in the Taichung harbor construction area off the coast. The gauge was installed in July 1971 to record waves of 20 minute intervals for two hours. Among the wave series, 150 waves were chosen to represent to wave record of this time interval. Parameters of the average wave, the one-third highest wave or the significant wave, the one-tenth highest wave and the maximum wave were calculated. The reference wind speed was compiled from the anemometer records established on this coast. Location of the wave gauge and the anemometer are shown in Fig. 3.

ANALYSIS

The relative occurrence frequency of the significant wave height and that of the significant wave period were calculated by month, by season and finally by 4 years, the duration of all records. In order to investigate the central value and the scatter of probability distribution, both mean and variance of wave characteristics were computed. Since the waves change with the meteorological factors, thus, the difference of wave height statistics for each month and each season is examined. The same procedure is followed for studying the probability distribution of the significant wave period. Moreover, the correlation coefficient between the significant wave height and its reference wind speed for each month was calculated. The coefficient is useful to wave prediction. Because wave steepness plays an important role on the development of coast, the deepwater wave steepness H_0/L_0 has been studied.

For comparisons of the wave condition of this strait area with the open ocean. Two sources of open ocean wave data are selected. One was obtained by Hogben and Lumb (1966) in the ocean area off the north and east coasts of Taiwan and also analyzed by Bretschneider (1973). The other was collected by Jade Dattatri (1973) off the Mangalore harbor located on the west coast of India as shown in Fig. 4.

Because typhoon waves control the design condition of coastal structures, seven typhoon wave sequences as shown in Fig. 2 have been studied. Correlation coefficient between typhoon wave height and wind speed was calculated and discussed. The relationship between the significant wave height $H_{1/3}$ and period $T_{1/3}$ is also examined with the equation suggested by Bretschneider (1973).

$$T_{1/3} = 3.86\sqrt{H_{1/3}} \qquad (1)$$

The above equation is derived from wave date of open ocean. The unit of $H_{1/3}$ is meter and $T_{1/3}$ is second.

In order to check whether the theoretical Reyleigh's law will apply to strait waves, ratios among wave heights of the significant wave, the one-tenth highest wave, the average wave and the maximum wave are studied. The results are compared with the equations presented by Longuet-Higgins (1952)

$$H_{1/3} = 1.6\ H_{ave} \qquad (2)$$

$$H_{1/10} = 1.27\ H_{1/3} \qquad (3)$$

$$H_{max} = 1.583\ H_{1/3} \qquad (4)$$

RESULTS AND DISCUSSIONS

1. Periodicity of Wave Condition

The distributions of the significant wave height for each season are shown in Fig. 5 and Fig. 6. The accumulated probability of wave height is also shown in Fig. 7. All deviate slightly from the Rayleigh's curves.

The significant wave period for each season was shown in Fig. 8. The accumulated probability is also shown in Fig. 9. The distribution of $T_{1/3}$ for each season nearly follows the normal law. It seems that the variation of meteorological condition in each season doesn't change the type of wave period distribution as illustrated in these diagrams.

Mean values of monthly significant wave heights and periods with their 90% confidence interval are shown in Fig. 10 and 11 respectively. The periodicity of monthly occurrence of $H_{1/3}$ and $T_{1/3}$ is also shown in Fig. 12. Oceanic condition in summer is quite calm. From May to August, monthly mean of wave height is less than 0.8 meter and wave period less than 5.5 second. Concerning the transitional season, both mean values of monthly wave height and period in September are larger than those in April. As to the monsoon season, mean values of wave heights in October has the largest confidence interval while that in March has the smallest. Comparison of the variance coefficients of wave heights and periods for each month is made in Fig. 13. It is clear that the variation coefficient of $H_{1/3}$ is always larger than that of wave period. Since the typhoon hits this island occasionally, the variation coefficient of wave height in summer is quite high. However, the yearly recurrence of the significant wave period is quite obvious. Typhoons also affect the monthly mean value of wave height, but it has little effect on that of wave period. Meanwhile, the monthly correlation coefficients between wave height and wind speed are also calculated as shown in Table 1 which shows no distinct difference for winter and summer seasons.

2. Monthly Variation of Wave Steepness

The monthly mean of deepwater wave steepness with 90% confidence interval is shown in Fig. 14. During the winter monsoon season from October to March, the wave steepness is rather high, beach erosion might occur. However, due to large tidal range, only a few sand bars appear in this coast.

3. Typhoon Waves and Winds

Wind direction generally changes from NNE through N, NNW, W, WSW and SSW to S during a typhoon assault. The wind is rather steady and duration is long during the former stage. The NNE and N winds are dominant at this stage. The longest duration of N wind ever recorded is 24 hours and that of NNE wind is 20 hours. Relationships between the significant wave height and the reference wind speed for NNE and N are plotted in Fig. 15 and Fig. 16 respectively. The short vertical line, drawn in Figures, indicates the standard deviation of wave heights from their mean. The wave height increases linearly with wind speed when the peak of typhoon wave sequence is over, unsteady wind is usually observed except from SSW direction. At a later stage, the wind direction changes rapidly from time to time, as a result the duration becomes very short, no definite relationship between wave height and wind speed can be formed except the SSW direction.

Using 90% confidence interval, the ratios of the significant wave height $H_{1/3}$ to the reference wind speed $U_{Ref.}$ for NNE, N and SSW wind are obtained as follows.

$$\frac{H_{1/3}}{U_{Ref.}} = 0.110 - 0.130 \quad \text{for NNE wind}$$

$$= 0.133 - 0.147 \quad \text{for N wind}$$

$$= 0.112 - 0.128 \quad \text{for SSW wind} \qquad (5)$$

where $H_{1/3}$ is in meter and $U_{Ref.}$ is in meter per second.

The relationship of the wave height and SSW wind speed is shown in Fig. 17. The null hypothesis may be accepted in 1% significance level as follows.

$$H_{1/3} = 0.130\ U_{Ref.} \qquad (6)$$

The correlation coefficient between wind speed and wave height for each typhoon is listed in Table 2. Typhoon Nina whose center passed by the harbor has the largest correlation coefficient, while Typhoon Gloria passed the Bashi strait, southward of the island, has the least. It may be assumed that a stronger correlationship between winds and waves would result if the typhoon path is closer to the location of the wave recorder.

4. Typhoon Wave Height Distribution

The ratios among $H_{1/3}$, H_{ave}, $H_{1/10}$ and H_{max} of typhoon waves have been studied in order to ascertain the conformity to the Rayleigh distribution of wave height. In accordance with Fig. 18, 19 and 20, the relationship may be expressed as follows:

$$H_{1/3} = 1.41\ H_{ave} \tag{7}$$

$$H_{1/10} = 1.20\ H_{1/3} \tag{8}$$

$$H_{max} = 3.04\ H_{1/3} \quad \text{for } H_{max} \leq 5.8^{m}$$

$$= 1.16\ H_{1/3} \quad \text{for } H_{max} \leq 4.5^{m} \tag{9}$$

The first relationship in Eq. (9) is regarded as the upper limit and the second one, the lower limit. These equations (7, 8 and 9) indicate that the strait wave height distributions may not follow exactly Rayleigh's law. The small wave in the strait has higher probability of occurrence than that in the ocean. The mean value of H_{max} to $H_{1/3}$ ratio for each typhoon wave sequence and its standard deviation are shown in Table 3.

5. Typhoon Wave Height and Period

The correlation curve between typhoon wave height and period of 90% confidence interval is shown in Fig. 21. The scatter diagram of wave height and period is shown in Fig. 22. The most probable relationship may be represented by Eq. (10)

$$T_{1/3} = 4.56 \sqrt{H_{1/3}} \tag{10}$$

It indicate that for the same wave height, the wave period in the strait is longer than that in the ocean. Such a phenomenon is worth further study.

6. Recurrence Period of Wave Height

Based on the wave height distribution compiled from 4-year records, the recurrence period of the specified significant wave height has been calculated. Comparison of the recurrence period of wave height in the strait with that in the ocean (Bretschneider, 1973) has also been made. Bretschneider's result was drawn from ship observation of waves on the north and east coasts of Taiwan (Hogben and Lumb, 1966) as shown in Table 4 and Fig. 23. The wave height in the strait is approximately one half of that in the ocean. However, the curves shown in Fig. 23 may be modified by further observation and analysis, this study may still be used as the criteria for waves in the strait sheltered area.

7. Comparison of Monsoon Wave Distribution

The wave height and period distribution of the Taichung coast is compared with that of the Mangalore harbor on the west coast of India. It is noted from Fig. 24 and Fig. 25 that the monsoon wind on the west coast of India generates waves heavier than those generated on the Taichung coast. Nevertheless, the wind speed recorded at the Mangalore harbor was lower than that at the Taichung harbor.

CONCLUSIONS

The meteorological factors have little effect on the monthly distribution of wave period, which has a clear recurrence month by month. The significant wave period may be estimated from the significant wave height by Eq. (10). The wind acts as a dominant factor to the wave height. Therefore, the wave height distribution of winter monsoon differs from that of summer season. It is found that the wave height on this coast is approximately one half of that on the north and east coasts of Taiwan based on a comparison with Bretschneider's (1973) results. This phenomenon is also verified by comparing the waves off west coast of India. Though the wind speeds in the India coast area are lower, heavier seas are also observed. However, waves in the straits would have rather a longer period for a given magnitude of wave height. The distribution of strait wave height may not follow the Rayleigh's law. So that the strait wave will be overestimated by means of the result drawn by Longuet-Higgins (1952). The recurrence interval of various significant wave height shown in Table 4 and Fig. 23 may be used as the wave criteria for the structure design on the coast of the strait. Of course, the result is needed to be modified by further study.

ACKNOWLEDGMENT

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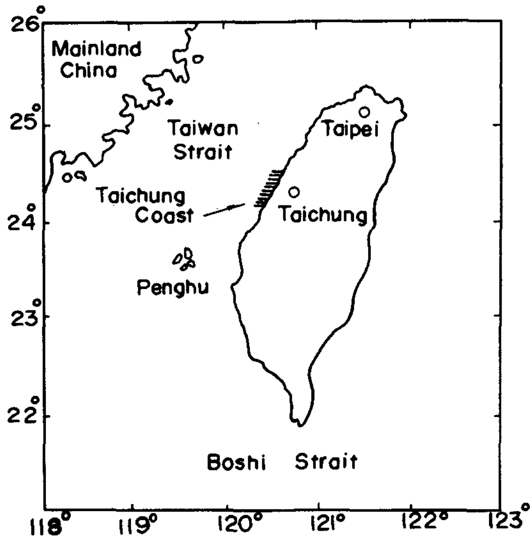

Fig. 1 Location of Taichung Coast.

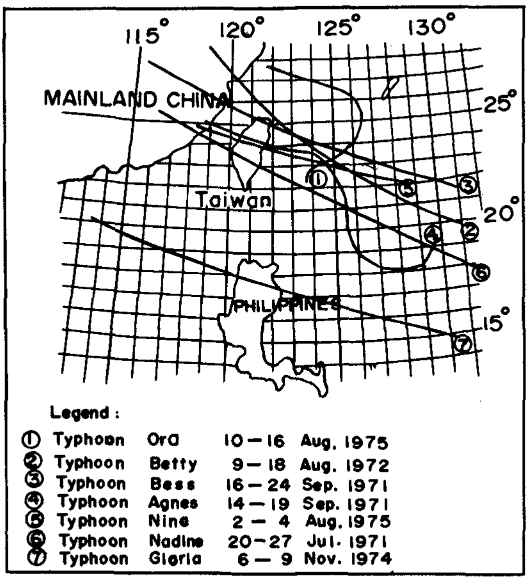

Fig.2 Location map and Tracks of seven Typhoons.

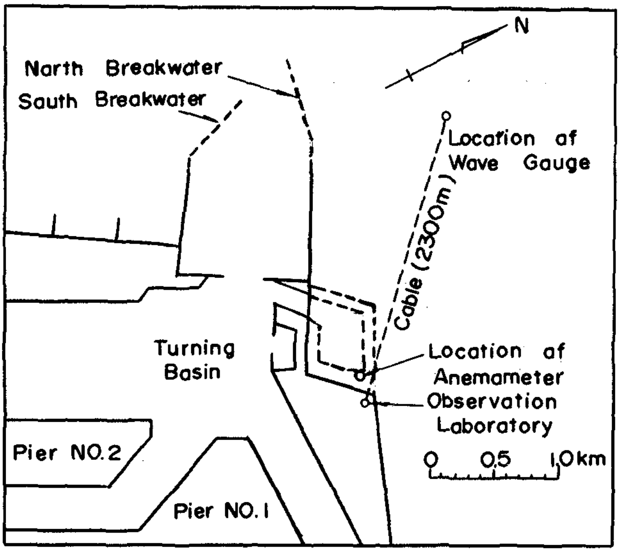

Fig. 3 Locations of Wave Gauge and Anemometer.

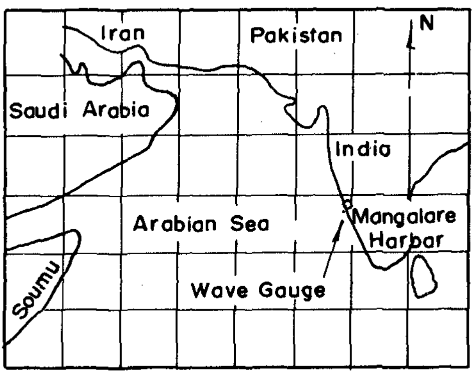

Fig. 4 Location of Mangalore Harbor.

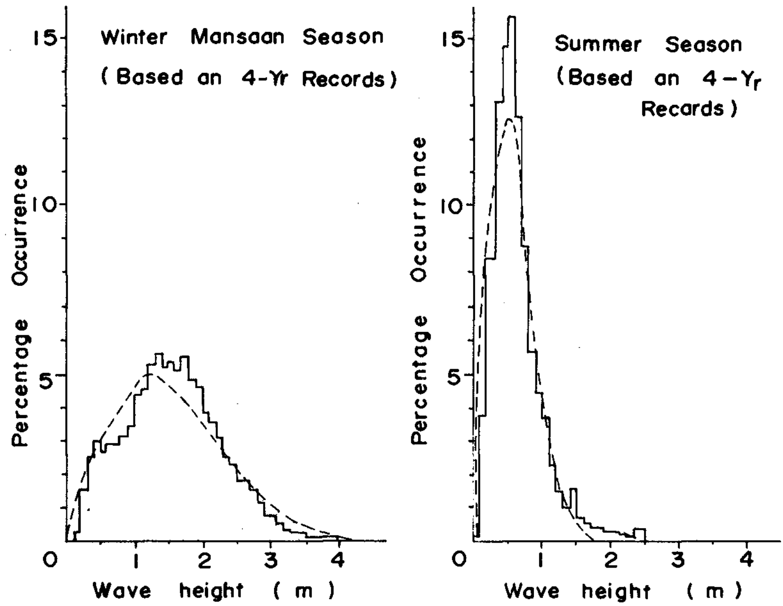

Fig. 5 Distribution of Significant Wave Height.

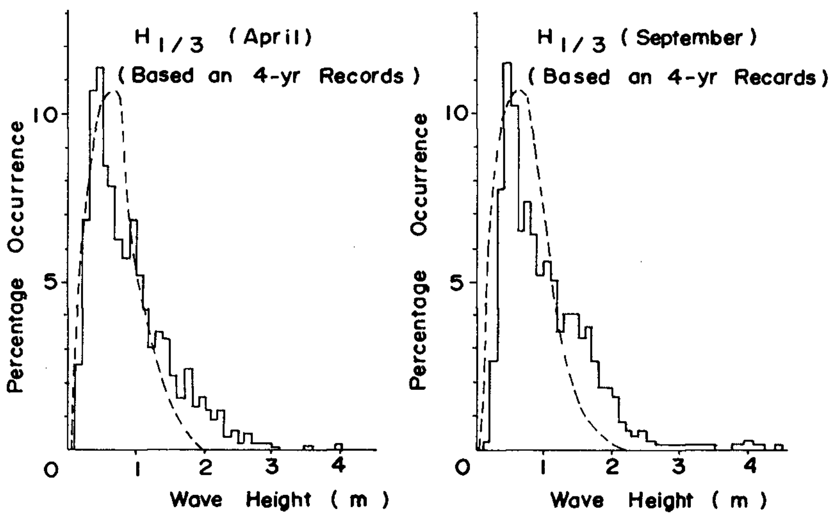

Fig. 6 Distribution of Significant Wave Height, Transition Season.

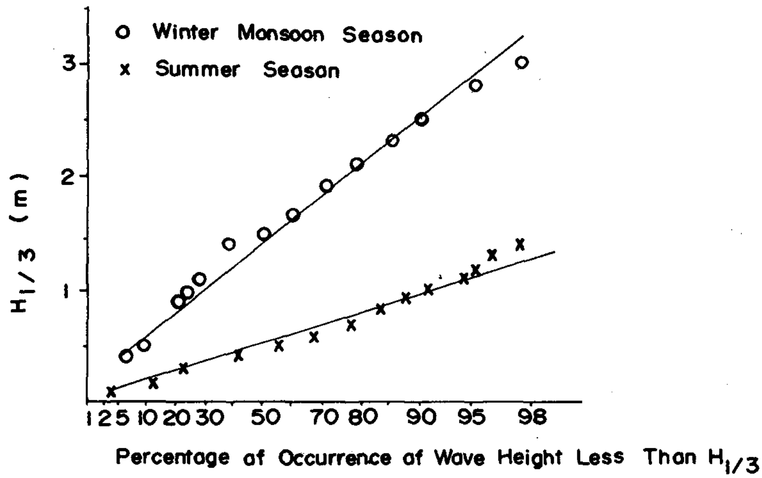

Fig 7 Accumulated Distribution of Significant Wave Height.

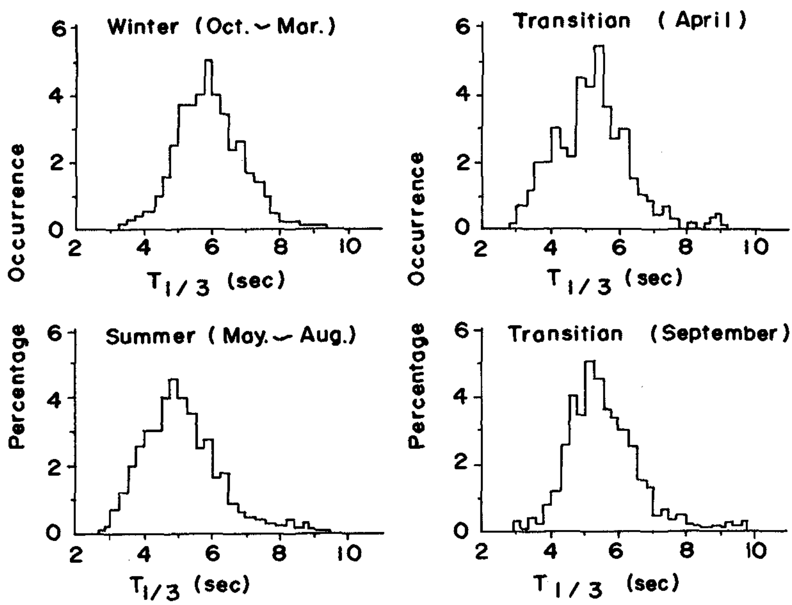

Fig. 8 Distribution of Significant Wave Period (4-Yr Records)

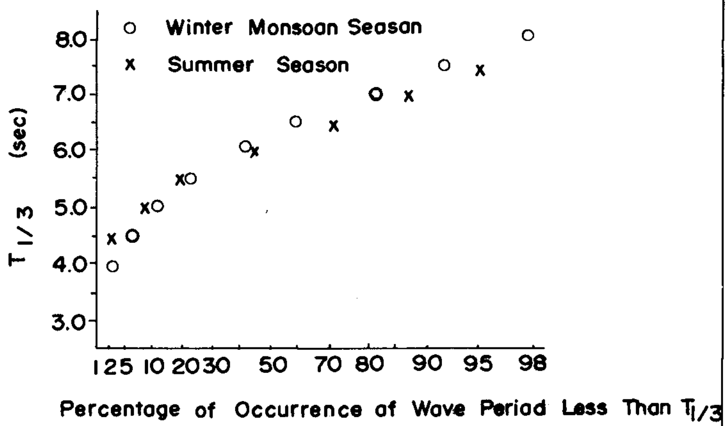

Fig. 9 Accumulated Distribution of Significant Wave Period.

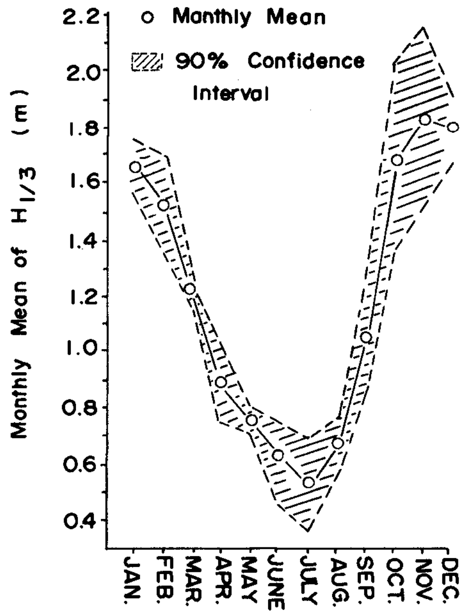

Fig. 10 Monthly Mean of Significant Wave Height.

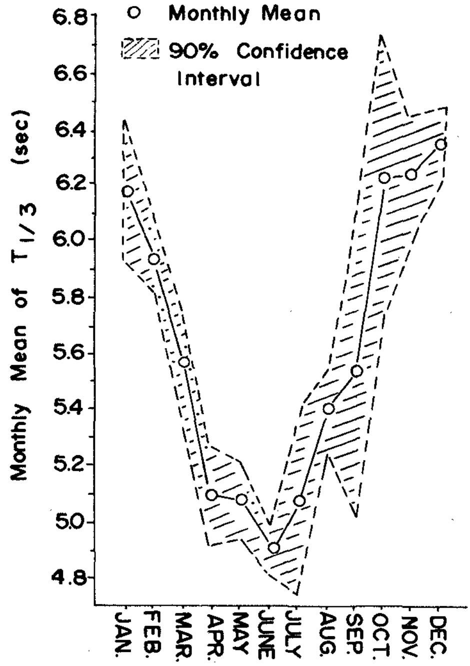

Fig.11 Monthly Mean of Significant Wave Period.

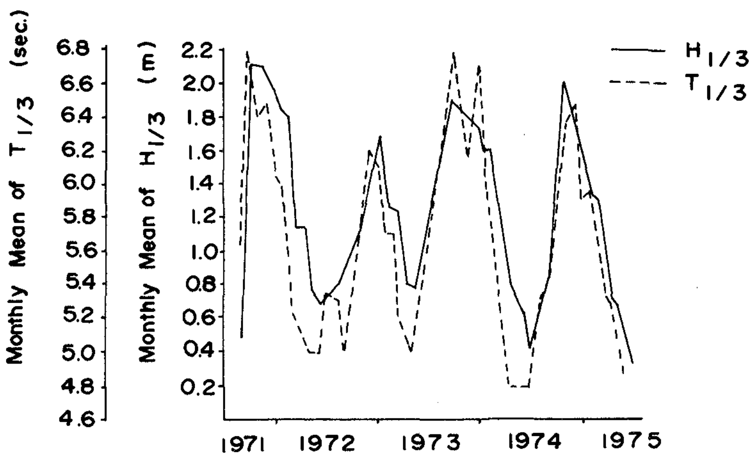

Fig.12 Tendency Comparison of Significant Wave Height and Period.

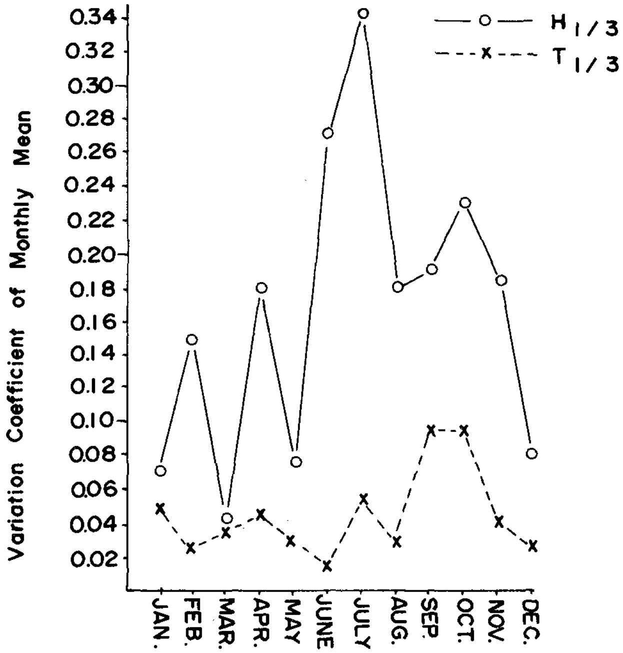

Fig. 13 Variation Coefficient Comparison Between Monthly Mean of $H_{1/3}$ and $T_{1/3}$.

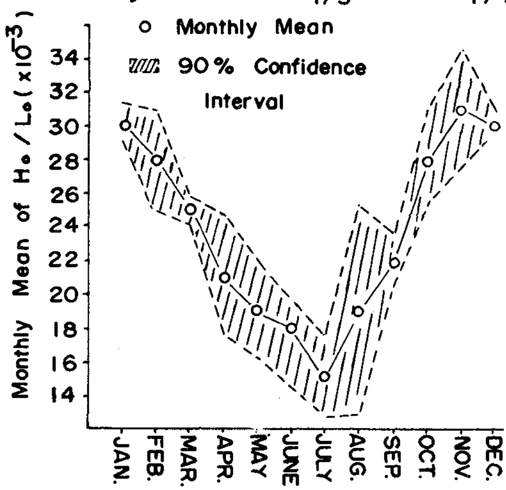

Fig. 14 Monthly Mean of Wave Steepness.

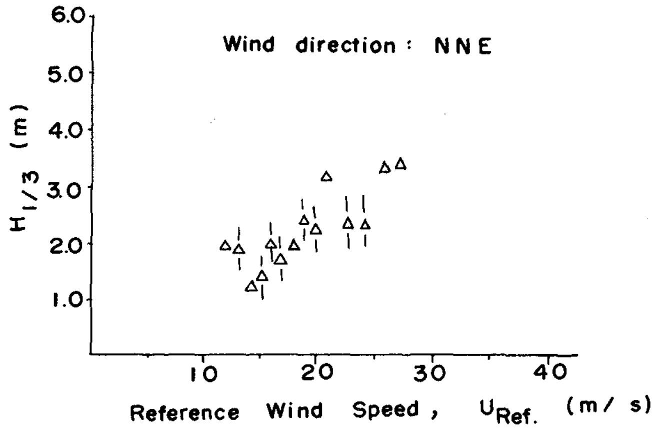

Fig.15 Relationship between Significant Wave Height and Reference Wind Speed.

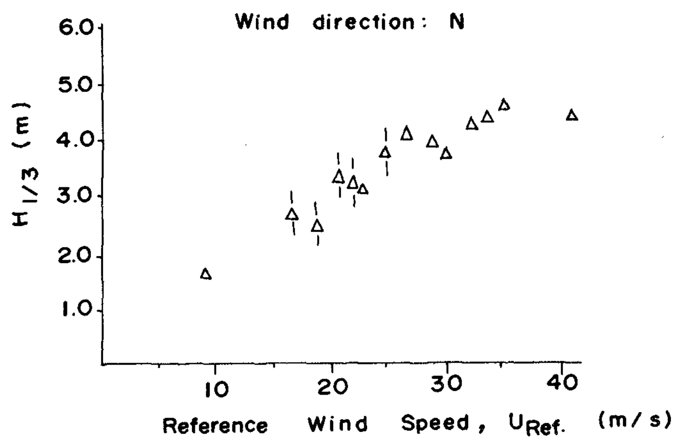

Fig.16 Relationship between Significant Wave Height and Reference Wind Speed.

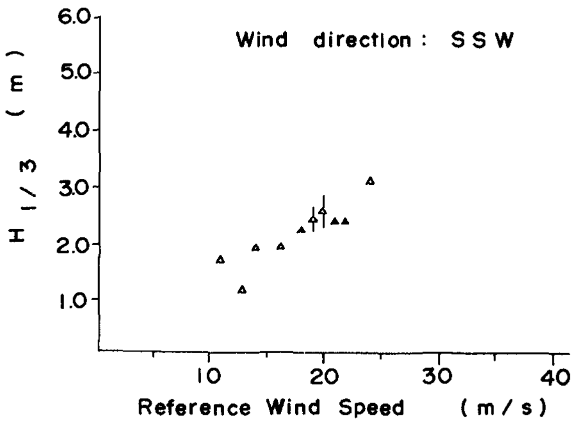

Fig.17 Relationship between Significant Wave Height and Reference Wind Speed.

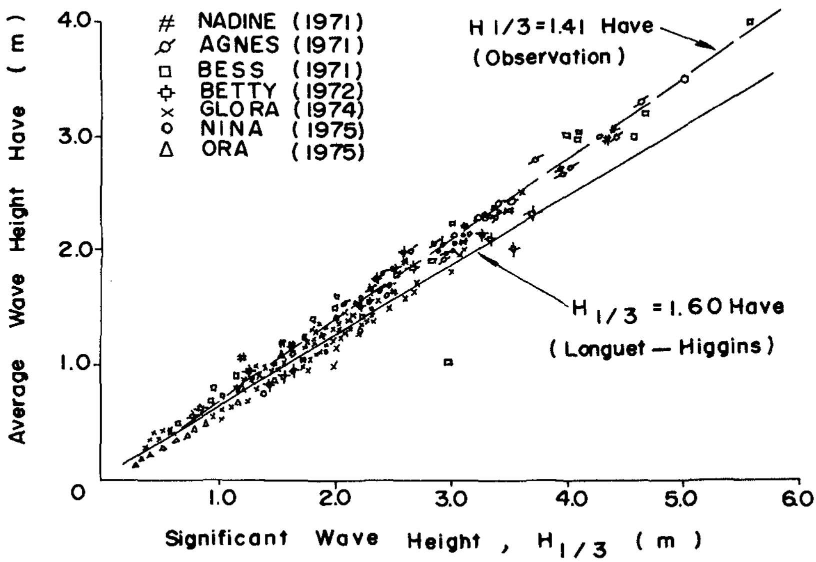

Fig.18 Average Wave Height versus Significant Wave Height .

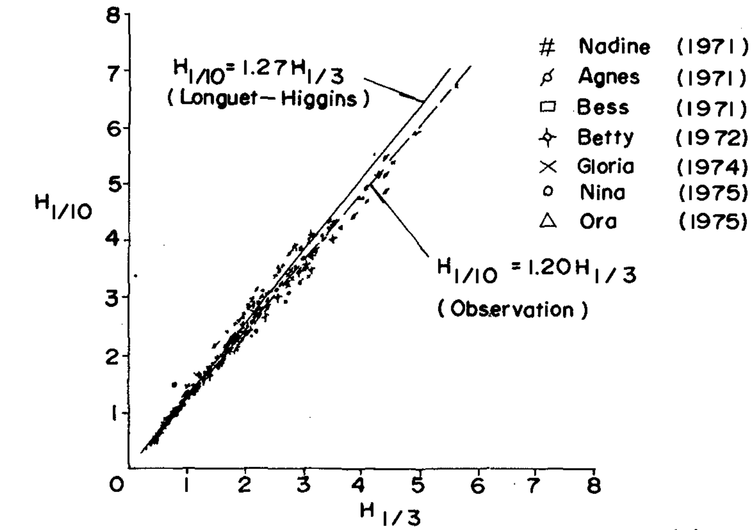

Fig.19 Mean of Highest one tenth of Wave Height versus Significant Wave Height.

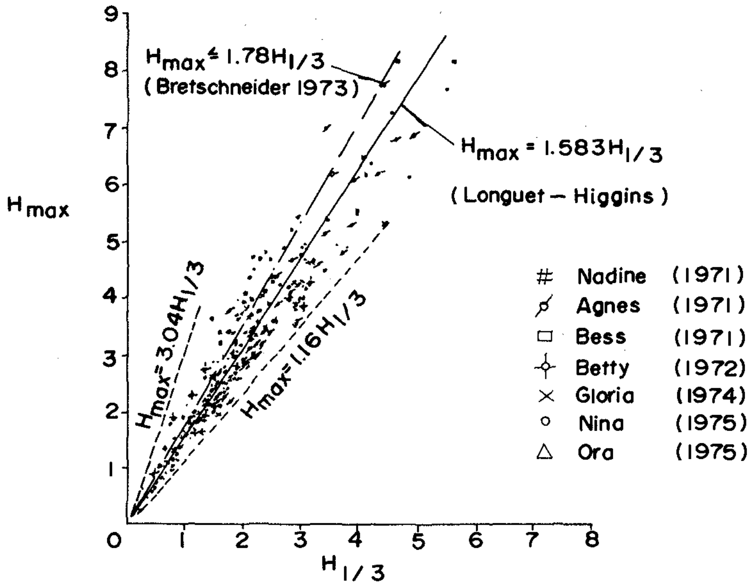

Fig.20 Maximum Wave Height versus Significant Wave Height.

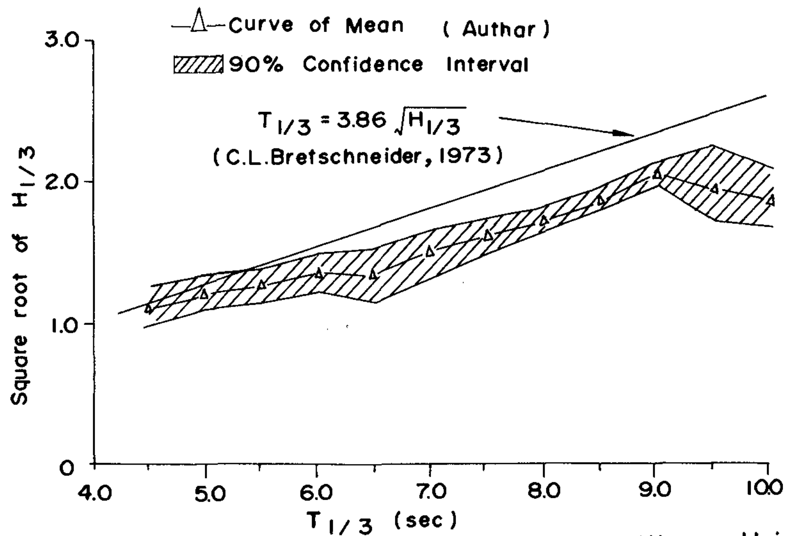

Fig. 21 Relationship between Significant Wave Height and Period.

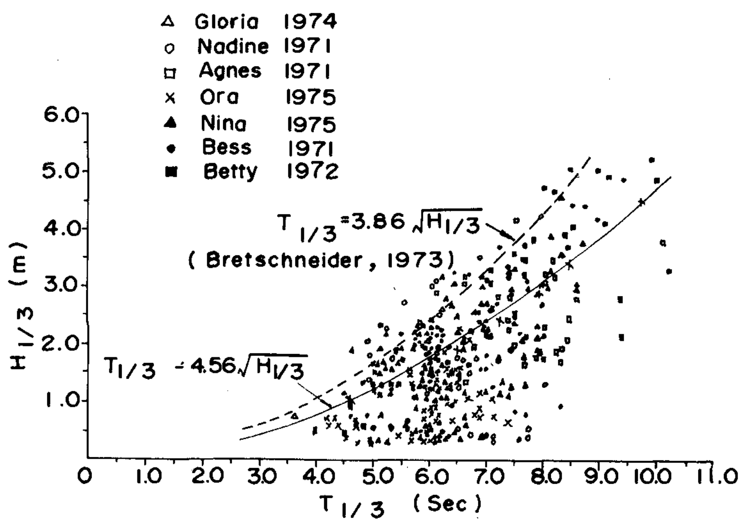

Fig. 22 Scatter Diagram Relating Significant Wave Height and Period.

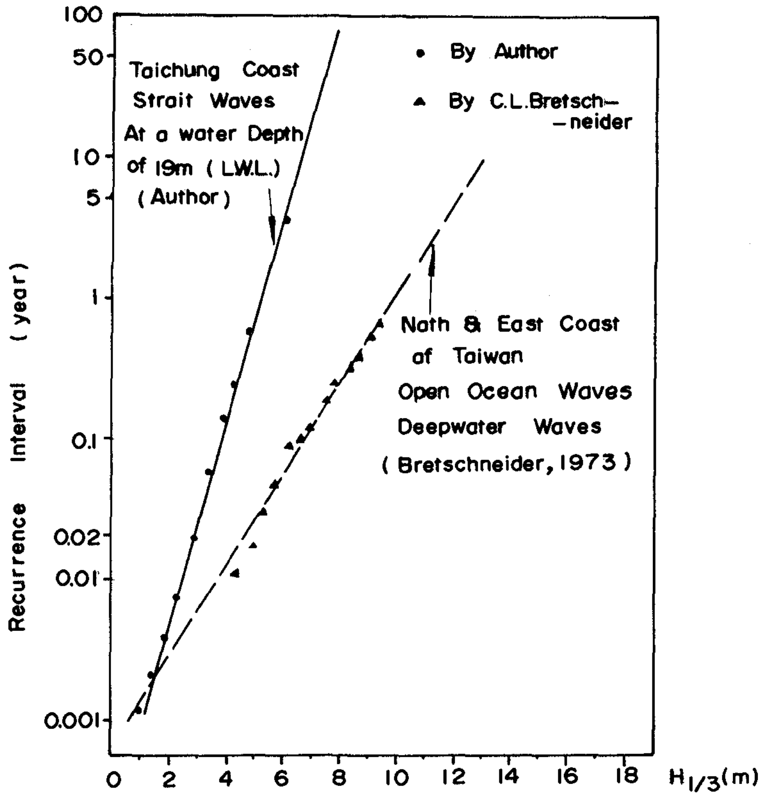

Fig. 23 Significant Wave Height versus Recurrence Interval in years.

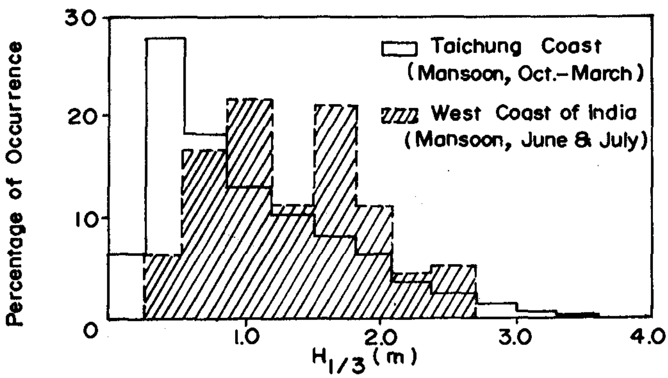

Fig. 24 Comparison of Wave Height Distribution.

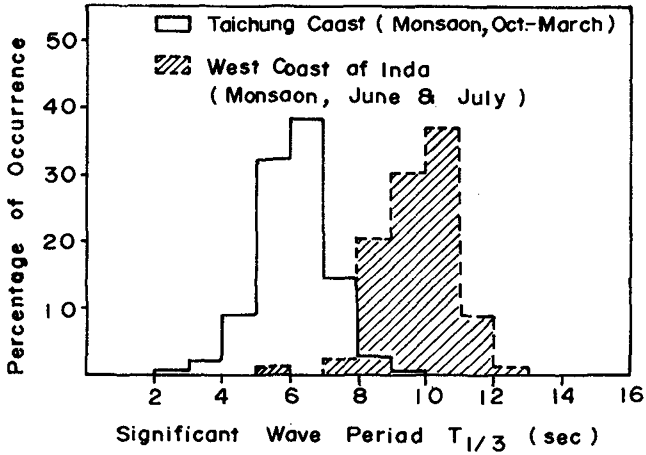

Fig. 25 Comparison of Wave Period Distribution.

Table I. Manthly Carrelatian Caefficient between Wave Height and Wind Speed

Month / year	Jan.	Feb.	March	April	May.	June
1973	—	—	0.61	0.70	—	—
1974	0.60	0.83	0.84	0.68	—	0.56
1975	0.78	0.84	0.88	0.87	0.59	0.80

Month / year	July	Aug.	Sep.	Oct.	Nav.	Dec.
1973	—	—	0.66	0.91	—	0.83
1974	0.77	0.52	0.74	0.84	0.63	0.75
1975	0.96	0.76	0.39	0.95	—	—

Table 2. Carrelation Coefficient between typhoon Wind and Wave Height.

Typhoon Name	Ora.	Betty	Bess	Agnes	Nina	Nadine	Gloria
Carrelation Coefficient	0.46	0.32	0.68	0.48	0.85	0.36	0.34

Table 3. Ratio of Hmax to $H_{1/3}$ for Typhaon Waves.

Typhoon Name	Ora.	Betty	Bess	Agnes	Nina	Nadine	Glaria
Mean	1.562	1.497	1.507	1.517	1.654	1.630	1.707
Standard Deviation	0.131	0.177	0.155	0.208	0.223	0.283	0.240

Table 4. Significant Wave Height in Meter for Various Return Interval (yr.)

Return Interval	1	5	10	25	50	100	Remark
Taichung Coast West Coast of Taiwan	5.0	6.0	6.4	7.1	7.4	7.8	Strait Wave
North & East Caast of Taiwan	9.8	11.9	12.8	14.2	15.0	16.0	Open Ocean Wave