STUDY OF HURRICANE WAVES AROUND THE TAIWAN COAST

By

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ABSTRACT

The objective of this research is to study the prediction method of hurricane waves around this island, especially in the Taiwan Strait. The paper describes the prediction of hurricane waves used by Bretchneider's (1976) Method and finds out the predicted waves are different from measured waves, therefore the Bretchneider predicted model is modified by the authors and then the modified model is applied to predict waves again. It is found out that predicted waves match well with the measured waves. The results of the modified Bretchneider model are compared with those of the Ijima tracing method and find out the former is better than the latter.

The second part is to apply the modified model to predict the extreme value of wave heights and compute the worse hurricane wave condition of the surrounding sea area around island, within recent score year (1959-1978). The calculated sites are Chu-Wei, Nan-Liaw, Ta-Shih, Cheng-Kung, Pu-Tai, Tung-Kang, Nan-Wan as shown in Fig.1 and Shiau Liu-Chieu totally 8 stations. Then use the Gumbel Distribution TYPE 1 to predict the extreme wave height of each returned period.

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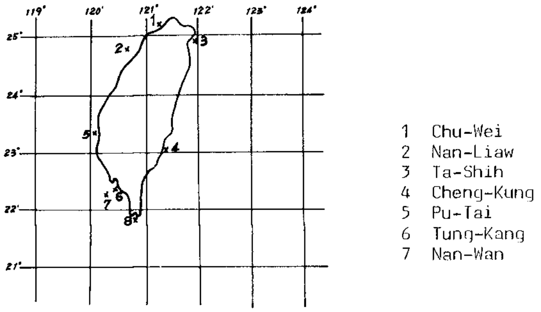

Fig.1 Location of Wave Calculation Sites

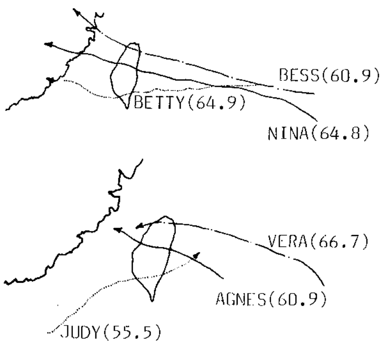

Fig.2a The pathes of six typhoons

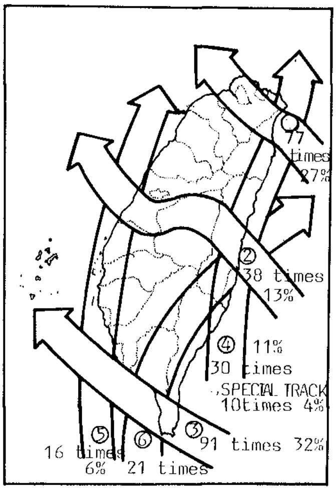

Fig.2b Statistics of Typhoon Track attacked this area

1. INTRODUCTION

"Typhoon" is the most severest atmosphere condition to natural damage when it is threatening the island of Taiwna, Republic of China. Because of the violent wind of typhoon, the induced wave height is stronger than that of the monsoon. Therefore, typhoon waves have to be considered as the design criteria of ocean and coastal engineering.

Usually there are several methods of typhoon wave prediction: (1) Tracing Method of Ijima (2) Graphic Method of Wilson (3) Numerical Calculation Method of Tang (4) Empirical Method of Bretschneider. The first three methods have good accuracy, but the calculation procedures are complicated. As for the Bretschneider empirical method, its calculation procedure and accuracy showed satisfactory results. In this paper, the authors calculated six typhoon waves in Kaohsiung, Taichung and other harbors of Taiwan by use of the empirical method. From the comparison of measured and calculated result, the empirical method have been added some modifications to fit for suitable use of the Taiwan areas.

The modified Bretschneider method is also applied to estimate the highest typhoon waves of Taiwan during the past 20 years. The statistical theory is used to get the possibly extreme waves of the recurrence interval of 100 years, 50 years,..., etc. This conclusion may provide a reference for the design of ocean structures.

2. BASIC THEORY

Typhoon Waves Calculation

The Bretschneider empirical method is modified from the practical application around Taiwan coastal areas. The procedures are as follow:

$$(1)\quad \frac{U_r}{U_R} = -\frac{1}{2}\frac{fR}{U_R}\frac{r}{R} + \sqrt{\left(1+\frac{fR}{U_R}\right)\frac{R}{r}\,e^{\left(1-\frac{R}{r}\right)} + \left(\frac{1}{2}\frac{fR}{U_R}\frac{r}{R}\right)^2}$$

$$(2)\quad U_R = K\sqrt{\Delta P} - 0.5fR \qquad \text{(Knots)}$$

$$(3)\quad U_{RS} = 0.865U_R$$

$$(4)\quad \Delta U = \frac{1}{2}V_F\cos(\theta+\beta)$$

$$(5)\quad U^*_{RS} = U_{RS} + \Delta U$$

$$(6)\quad H_R = K'\sqrt{R\Delta P}$$

$$(7)\quad H^*_R = H_R(1+\Delta U/U_{RS})^2$$

(8) $f_0^{-1}/U = 0.4\tanh[\ln(1+ \frac{40H_s}{U^2} / 1- \frac{40H_s}{U^2})^{0.5}]^{0.6}$

(9) $T_s = \sqrt[4]{\frac{4}{5}}\, f_0^{-1}$

where U_r, U_R: wind speeds at distance r and R from the typhoon center

f : the Coriolis parameter

ΔP : $P_N - P_0$

P_N, P_0: normal pressure and central pressure, inches of H_g

R : radius of maximum wind, for U_R

K : 67, when latitudes = 20°N - 25°N

U_{RS}: average wind speeds at radius R for the 10m reference plane above mean sea level (Knots)

V_F: actual forward speed of typhoon (Knots)

θ : angle between wind direction and forward direction of typhoon

β= 25°, incurvature angle of wind to tangent of isobars

H_R: wave height at radius R (ft)

K': a coefficient which can be obtained from the following polynomial (Liang 1978)

$$K' = 7.59-41.21(\frac{fR}{U_R})+160.51(\frac{fR}{U_R})^2-219.32(\frac{fR}{U_R})^3$$

H_R^*: wave height at radius R for a hurricane moving at a constant forward speed

T_s: wave period (sec)

3. EXTREME WAVES ESTIMATION

There are a number of methods used in various engineering practices which can be applied to the problem for obtaining design wave height. This paper used a method called "Gumbel Distribution Method". The theory is briefly described as follows:

$$P = \left(\frac{S'}{S+1} \right) 100 \qquad (\%)$$

where S : total number of occurrences on record

S': summation of occurrences, beginning with the highest value to any successive lower values until S'=S the following equations are used

$$P = \exp(-\exp(-y))$$

$$y = -\ln(-\ln p)$$

Gumbel's theory of extreme values shows that the plot (on extreme-value paper) of a series of observed extreme values of wave heights X should approximate to a straight line.

$$X = X_0 + my$$

where X_0: the modal value of the distribution
m : slope of dx/dy

Gumbel has provided a method of calculating X_0 and m.

$$m = \pi/\sqrt{6}/\sigma_x$$

$$X_0 = \overline{X} - 0.5772/m$$

where σ_x: standard deviation of X_i
$\overline{X}$: average value of X_i

the recurrence interval can be found from

$$I = 100\,\frac{Y}{SP}$$

Y: number of years of record

4. PRACTICAL CALCULATION AND MODIFICATION

Six typhoons are chosen for the case study of wave calculation. Comparisons of the theoretical calculated and the measured waves are made, because of the information of winds and waves are very complete. These typhoons are (1) Judy (May 1966) (2) Agnes (Sep. 1971) (3) Bess (Sep. 1971) (4) Nina (Aug. 1975) (5) Betty (Sep. 1975) (6) Vera (July 1977). The pathes of these typhoons are shown in Fig.2.

There are a few parameters should be determined more carefully because of their significant influence on calculated result. They are discussed individually as follows:

(1) R

R can be determined from the empirical formula of Graham and Nunn (1959)

$$R=28.52\tanh[0.0873(|LAT|-28^\circ)]+12.22\exp(-\Delta P/33.86)+0.2V_F+37.22$$

where R: radius of maximum wind (Km)
LAT: latitude of typhoon center
ΔP: $1013.2-P_0$ (mb)

(2) ΔP

ΔP can be determined from the formula of Wang (1978)

$$\Delta P = P_N - P_0 = 1000 + \frac{(1000-P_0)}{10} - P_0$$

(3) U_R

Bretschneider applies the equation $U_R=K\sqrt{\Delta P}-0.5fR$ in his method to calculate the maximum wind speed U_R. The result of calculation is not always coincident with typhoon record of the Central Weather Bureau. So we use the typhoon record instead of the equation of Bretschneider.

From the above procedures, the waves can be calculated and compared with measured data as shown in Table 1.

Table 1 Comparison of predicted and measured waves of six typhoons

day/hour (LMT)		$H_{1/3}$ (m) prediction	$H_{1/3}$ (m) measurement	$T_{1/3}$ (sec) prediction	$T_{1/3}$ (sec) measurement
Typhoon: Betty		Sep. 1975		Site Depth: 28m	
22	8	4.8	5.1	8.5	12.5
	10	5.3	5.5	9.0	12.0
	12	6.2	6.2	9.6	11.8
	14	6.7	6.0	10.1	11.9
	16	7.2	6.3	10.5	10.9
	18	6.6	7.0	10.0	11.6
	20	5.8	6.4	9.4	11.0
	22	5.0	5.0	8.8	10.1

day/hour (LMT)		$H_{1/3}$ (m) prediction	measurement	$T_{1/3}$ (sec) prediction	measurement
Typhoon: Agnes		Sep. 1971		Site Depth: 19m	
18	16	3.4	4.4	7.1	8.3
	18	3.8	4.8	7.6	8.4
	20	4.3	4.6	8.1	10.1
	22	4.7	3.9	8.5	8.6
19	00	5.0	5.0	8.5	9.8
	02	3.8	4.0	7.5	9.2
	04	4.4	3.6	8.0	10.1
	06	4.5	2.8	8.2	8.6
Typhoon: Judy		May 1966		Site Depth: 12m	
30	08	3.8	2.8	7.7	9.6
	10	4.0	5.0	7.8	11.3
	12	4.1	5.4	7.9	10.8
	14	4.1	5.5	7.8	10.9
	16	5.1	5.9	8.5	9.7
	18	6.8	5.7	10.1	10.6
	20	6.4	4.9	9.8	9.5
	22	4.9	2.5	8.5	8.0
Typhoon: Nina		Aug. 1975		Site Depth: 28m	
3	06	5.3	5.3	8.8	12.3
	08	6.7	5.4	9.9	11.7
	10	7.8	6.1	10.7	11.8
	12	7.4	7.8	10.5	11.7
	14	5.0	5.8	8.6	9.3
	16	4.1	4.0	8.0	8.2
	18	3.4	3.2	7.7	9.2

day/hour(LMT)		$H_{1/3}$(m) prediction	$H_{1/3}$(m) measurement	$T_{1/3}$(sec) prediction	$T_{1/3}$(sec) measurement
Typhoon: Vera July 1977 Site Depth: 38m					
31	06	12.9(ft)	11.4(ft)	7.4	9.3
	08	15.6	12.2	8.2	8.3
	10	19.9	12.6	9.4	8.0
	12	23.8	14.7	10.2	9.2
	14	28.1	22.1	11.1	10.4
	16	33.4	29.6	12.0	12.1
	17	36.0	40.9	12.3	14.0
	18	34.5	26.9	12.0	10.7
Typhoon: Bess Sep. 1971 Site Depth: 19m					
22	16	3.8	3.0	7.5	6.4
	18	4.5	3.6	8.1	7.6
	20	5.1	3.8	8.7	8.1
	22	5.4	3.9	8.9	8.5
23	00	5.7	4.2	9.2	8.9
	02	5.8	4.6	9.3	9.1
	04	5.6	4.2	9.1	8.3
	06	5.3	3.7	9.0	7.8

The predicted wave height has good accuracy as shown in Table 1, but the predicted wave period is always greater than the measured data. So we use the wave period modification coefficient G

$$G = \text{average value of } \frac{\text{measured wave period}}{\text{predicted wave period}} = 1.2$$

Comparisons between two Wave Model with measured values are shown in Fig. 3.

5. ESTIMATION OF EXTREME WAVES

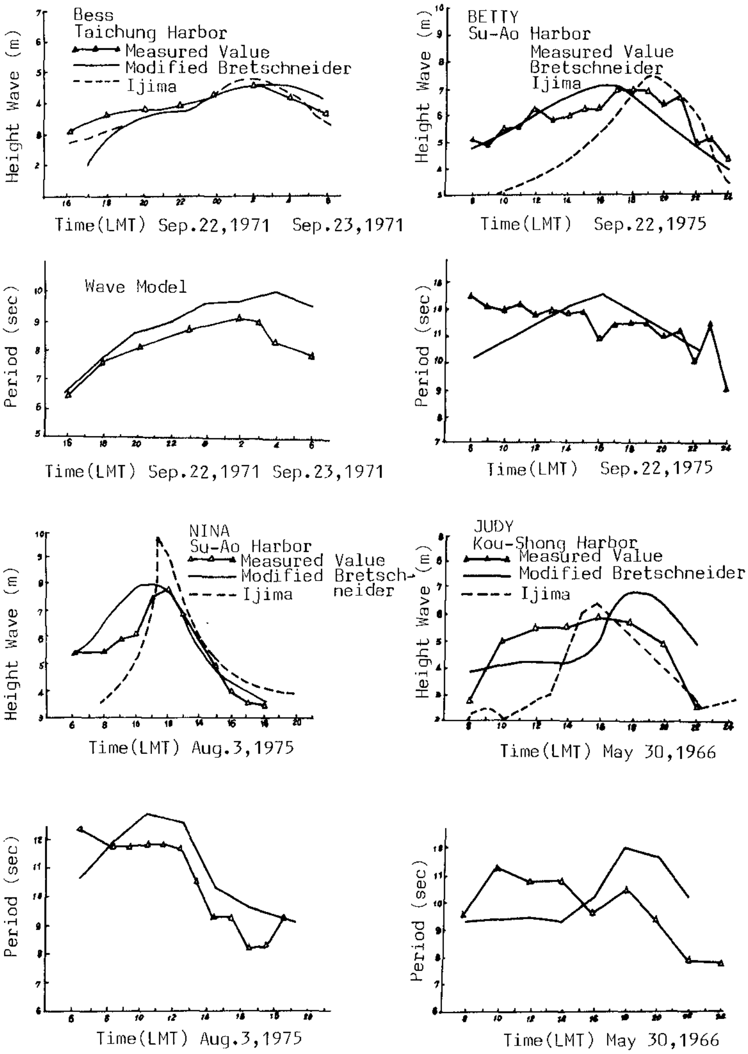

Fig.3 Comparison between Two Hurricane Wave Model

We select eight sites for the estimation of extreme waves. The sites are shown in Fig.1.

The calculation procedures are shown in the following:

(1) Select all typhoons from 1959 to 1978 (20 years) that influenced the coastal areas of Taiwan. Decide their best tracks and other information.

(2) Apply the modified Bretschneider method to calculate $H_{1/3}$ and H_{max} caused by these typhoons at the eight sites.

(3) If $H_{1/3} > 4$m, $H_{max} > 8$m, and typhoon passing within 3 degress of the estimation site, then it can be used to estimate the extreme waves.

(4) Apply the Gumbel distribution method to calculate the extreme waves.

From the above procedures, the extreme waves of eight sites can be obtained and enlisted in Table 2.

Table 2 Extreme Waves of Eight Sites

Site 1: Chu-Wei 25.1°N 121.2°E 30m depth					
$H_{1/3} = 1.600y + 5.928$ $H_{max} = 2.768y + 10.86$					
I(year)	100	50	30	20	10
$H_{1/3}$ (m)	14.3	13.2	12.3	11.7	10.5
H_{max}(m)	25.1	23.1	21.7	20.6	18.6

Site 2: Nan-Liaw 24.8°N 120.7°E 65m depth					
$H_{1/3} = 1.458y + 5.927$ $H_{max} = 2.548y + 10.713$					
I(year)	100	50	30	20	10
$H_{1/3}$ (m)	13.5	12.4	11.7	11.1	10.1
H_{max}(m)	23.8	22.0	20.7	19.7	17.9

Site 3: Ta-Shih 24.95°N 121.9°E 30m depth					
$H_{1/3} = 1.794y + 6.446$ $H_{max} = 3.104y + 11.674$					
I(year)	100	50	30	20	10
$H_{1/3}$ (m) H_{max}(m)	15.8 27.7	14.5 25.5	13.6 23.9	12.9 22.7	11.6 20.5

Site 4: Cheng-Kung 23.1°N 121.4°E 30m depth					
$H_{1/3} = 1.412y + 5.423$ $H_{max} = 2.381y + 10.369$					
I(year)	100	50	30	20	10
$H_{1/3}$ (m) H_{max}(m)	12.9 22.5	11.9 20.9	11.2 19.6	10.6 18.7	9.6 17.0

Site 5: Pu-Tai 23.4°N 120.1°E 30m depth					
$H_{1/3} = 1.329y + 5.126$ $H_{max} = 2.209y + 10.013$					
I(year)	100	50	30	20	10
$H_{1/3}$ (m) H_{max}(m)	11.7 20.4	10.8 18.8	10.1 17.7	9.5 16.8	8.6 15.2

Site 6: Tung-Kang 22.5°N 120.4°E 30m depth					
$H_{1/3} = 1.252y + 5.345$ $H_{max} = 2.174y + 9.878$					
I(year)	100	50	30	20	10
$H_{1/3}$ (m) H_{max}(m)	11.5 20.6	10.7 18.9	10.0 17.7	9.5 16.8	8.6 15.3

Site 7: Shiau Liu-Chieu 22.4°N 120.4°E 30m depth					
$H_{1/3} = 1.269y + 5.30$ $H_{max} = 2.2y + 9.696$					
I(year)	100	50	30	20	10
$H_{1/3}$ (m) H_{max} (m)	11.7 20.6	10.8 19.0	10.1 17.9	9.6 17.0	8.7 15.4

Site 8: Nan-Wan 21.9°N 120.8°E 30m depth					
$H_{1/3} = 1.172y + 5.386$ $H_{max} = 2.001Y + 9.939$					
I(year)	100	50	30	20	10
$H_{1/3}$ (m) H_{max} (m)	11.3 19.9	10.5 18.5	9.9 17.5	9.4 16.6	8.6 15.2

6. CONCLUSION

(1) The modified empirical method has pretty good accuracy in maximum hurricane wave height prediction. Therefore, it is very suitable for coastal areas of Taiwan.

(2) The extreme wave heights $H_{1/3}$ of 100 years recurrence interval at the eight sites are ranked by order: 15.8m, 14.3m, 13.5m, 12.9m, 11.7m, 11.7m, 11.5m, 11.3m. This result may be considered as design criterias of the ocean and coastal engineering at these sites.

(3) Bretschneider (1973) had used the ship observed data and typhoon information of past 10 years (1961-1970) to estimate the waves of Taiwan offshore areas. The result of his estimation was 16m ($H_{1/3}$ of 100 years recurrence interval), a little greater than the result of this paper. The reason of this small deviation may be the site depth - Bretschneider's estimation was in the deep sea, this paper's estimation was in the coastal sea.

7. REFERENCES

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