CHAPTER THIRTY EIGHT

A Typhoon Wave Hindcasting Technique

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ABSTRACT

The typhoon wave forecasting technique proposed by C.L. Bretschneider (1) is a good simple method. However, the measured maximum wave height at Nan-Wan Bay (at southern tip of Taiwan) of Ida typhoon is about twice of the hindcasted maximum wave height. In general, the hindcasted maximum typhoon wave height arrives earlier than the measured data for Bretschneider's method as well as the other methods, such as Tang's and Ijima's methods. And as the typhoon is approaching the station, the hindcasted wave heights are smaller than the measured ones. On the contrary, as the typhoon is leaving the station, the hindcasted wave heights are greater than the measured heights. In order to improve these defects, the typhoon swell proposed by Liang (7) is superimposed upon the typhoon wind wave according to the energy conservation principle. The modified wave period is calculated by the energy-weighted method.

In this paper 8 typhoons are as examples to show that the new method has amended the above-mentioned defects.

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1. INTRODUCTION

There are approximately 4 typhoon wave hindcasting techniques :(1) Wilson's graphical method (2) Tang's numerical technique. (3) Ijima's tracing method, and (4) Bretschneider's empirical method. Liang (3) has used Tang's method to hindcast typhoon wave at South Taiwan strait of Typhoon Elsie (Oct., 1975). The result is that the hindcasted peak wave arrived 7 hours ahead of the measured data. And the hindcasted peak wave height is 2 meters less than the measured one. However, Tang's method is proved to be quite good for typhoon wave on shoaling beaches.

Tsai (10) has used Ijima's tracing method to hindcast waves of typhoons Nina (Aug.,1975), Betty (Sept., 1975), Bess (Sept., 1971) and Judy (May, 1966). The results show that in the approaching period the measured wave heights are much higher than those of hindcasted wave heights, and vice versa for the leaving period. However, the hindcasted peak wave heights are close to the measured ones. Therefore, Ijima's method can be used to determine the design wave.

Bretschneider's empirical method is very simple. Liang & Lin (4) have used it to hindcast waves of Typhoon Vera (July, 1977). It was found that in the initial stage the hindcasted wave heights are higher than the measured data and the hindcasted peak wave height is close to the measured one. The former result may be due to the sheltering effect of the land. However, Liang has hindcasted wave of Typhoon Ida (July, 1980). The measured wave heights are much higher than the hindcasted data (Fig. 7). The reason is that Typhoon Ida's center did not pass through the wave station at Nan-Wan (at the southern tip of Taiwan) as Typhoon Vera did. Therefore, more typhoon swell energy overlapped on the typhoon wind wave for the latter case.

Hou, Kou & Tzeng (2) have modified Bretschneider's method by reducing the R value (radius of maximum wind speed) and found that the hindcasted peak wave heights are close to the measured ones. But, if the variation of the typhoon track changes greatly, the hindcasted data do not match the measured data, such as for Typhoon Judy (Fig. 1).

This paper is going to use Bretschneider's method to calculate typhoon wind wave and Liang's typhoon swell method to estimate typhoon swell. Then, by the energy superposition principle and wave energy weighting method, the typhoon wave height and wave period are estimated.

2. THEORY

A simple introduction of Bretschneider's method and Liang's method is as follows:

(A) Typhoon wind wave hindcasting method (for area within the radius 10R)

(1) Typhoon wind field

$$\frac{Ur}{U_R} = -\frac{1}{2}\frac{fR}{U_R}\frac{r}{R} + [(1+\frac{fR}{U_R})\frac{R}{r}e^{(1-\frac{R}{r})} + (\frac{1}{2}\frac{fR}{U_R}\frac{r}{R})^2]^{\frac{1}{2}} \tag{1}$$

in which,

r	radius of typhoon measured from typhoon center.
R	radius of maximum wind speed.
f	Coriolis force coefficients.
Ur, U_R	Geostrophic wind speed at radius r or R.

By Graham and Nunn, an empirical formula for maximum wind speed radius is as follows:

$$R' = \{28.52 \tanh[0.0873(\phi - 28)] + 12.22 \exp[(p_o - 1013.2)/33.86] + 0.2 V_F \times 1.852 + 37.22\} / 1.852 \quad \text{(N.M.)} \tag{2}$$

in which,

ϕ	latitude
p_o	typhoon center atmospheric pressure in mb
V_F	typhoon moving speed in knots

Here, R is modified by the following equation

$$R = R' - [(U_R - 100)/6 + 6] \tag{3}$$

where

$$U_R = K\sqrt{\Delta p} - 0.5\, fR \tag{4}$$

$$K = -\phi/7.5 + 70 \tag{5}$$

after Liaw (8), typhoon center atmospheric anomaly in inches of mercury column is as follows:

$$\Delta p = \frac{1}{33.86}\left[1000 + \frac{(1000 - p_o)}{10} - p_o\right] \tag{6}$$

The mean (10 minute) sea surface wind speed at 10 meter height at radius R is as follows:

$$U_{RS} = 0.865\, U_R \tag{7}$$

for moving typhoon

$$U_{RSS} = U_{RS} + \frac{1}{2} V_F \cos\theta \tag{8}$$

in which,

θ	angle between the line connecting typhoon center and wave station and the direction of typhoon motion

Similarly, we have

$$U_{rs} = 0.865\, Ur \tag{9}$$

$$Urss = Urs + \frac{1}{2} \; VF \cos\theta \tag{10}$$

(2) Estimation of wave height and wave period

For stationary typhoon, the wave height at radius R is

$$H_R = K'\sqrt{R \cdot \Delta p} \quad (ft) \tag{11}$$

K' is a function of $\frac{fR}{U_R}$ and can be approximated by the equation:

$$K' = 7.59 - 41.21 \left(\frac{fR}{U_R}\right) + 160.51 \left(\frac{fR}{U_R}\right)^2 - 219.32 \left(\frac{fR}{U_R}\right)^3 \tag{12}$$

$$\frac{T_o}{U_{RS}} = 0.4 \tanh\left\{ \ln \left(\frac{1 + \frac{40\,H_R}{U_{RS}^2}}{1 - \frac{40\,H_R}{U_{RS}^2}} \right)^{0.5} \right\}^{0.6} \tag{13}$$

$$T_R = (4/5)^{\frac{1}{4}}\, T_o \tag{14}$$

T_R is the wave period at radius R.

Hr is the wave height at radius r, Hr/H_R is a function of r/R and fR/H_R (1). Tr is the wave period at radius r.

$$\frac{T_o}{U_{rs}} = 0.4 \tanh\left\{ \ln \left(\frac{1 + \frac{40Hr}{Urs^2}}{1 - \frac{40Hr}{Urs^2}} \right)^{0.5} \right\}^{0.6} \tag{15}$$

$$Tr = (4/5)^{\frac{1}{4}}\, T_o \tag{16}$$

For moving typhoon,

$$H_{RS} = H_R \left(1 + \frac{\frac{1}{2} V_F \cos\theta}{U_{RS}}\right)^2 \tag{17}$$

$$Hrs = Hr \left(1 + \frac{\frac{1}{2} V_F \cos\theta}{Urs}\right)^2 \tag{18}$$

(B) Typhoon swell estimation (for radius r greater than 10R)
After Liang (7), the swell height is as follows:

$$Hs = C\, H_{RS} \frac{R}{\sqrt{DD}} \quad \text{(Meter)} \tag{19}$$

DD distance between typhoon center and station in N.M.
C a constant, about 0.11

The swell period is as follows:

$$Ts = C' T_{RS} \tag{20}$$

C' is always greater than 1 and empirically equal to

$$C' = 0.0021 \left(\frac{DD \cdot T_{RS}}{R \cdot U_{RSS}}\right)^2 + 0.0021 \left(\frac{DD \cdot T_{RS}}{R \cdot U_{RSS}}\right) + 1.21 \tag{21}$$

The time lag for the swell to arrive the station is:

$$T_{lag} = \frac{DD}{1.516 \times T_s} \quad \text{(hours)} \tag{22}$$

As the typhoon moves to the station, T_{lag} decreases; and as the typhoon moves away from the station, T_{lag} increases. By using the principle of energy flux conservation, a swell wave height correction coefficient λ is obtained (7).

$$\lambda = \left(\frac{T_D}{T_D'}\right)^{\frac{1}{2}} \tag{23}$$

in which

T_D Duration of swell if the typhoon were stationary

T_D' The real duration

The swell wave height is then as follows,

$$Hs' = \lambda Hs \tag{24}$$

By the principle of energy conservation, the typhoon wave can be estimated as follows:

$$H_{1/3} = (H's^2 + Hw^2)^{\frac{1}{2}} \quad \text{(meter)} \tag{24}$$

$$T_{1/3} = \frac{H's^2 Ts + Hw^2 Trs}{H's^2 + Hw^2} \quad \text{(sec)} \tag{25}$$

where

$$Hw = 0.3048 \; Hrs \quad \text{(meter)} \tag{26}$$

3. COMPARISONS OF HINDCASTED AND MEASURED DATA.

In the paper 8 typhoons are used to check the different models by the measured wave data. The typhoons and the wave stations are shown in Table I.

Table I

Typhoon	Time	Wave Station	Water Depth
Judy	May, 1966	Kaoshiung Harbor	12 m
Agnes	Sept., 1971	Taichung Harbor	19 m
Bess	Sept., 1971	Taichung Harbor	19 m
Nina	Aug., 1975	Su-Ao Harbor	28 m
Betty	Sept., 1975	Su-Ao Harbor	28 m
Elsie	Oct., 1975	South Taiwan Strait	104 m
Vera	July, 1977	Keelung Harbor	38 m
Ida	July, 1980	Nan-Wan Bay	16 m

Because the wave stations are not at deep sea (expect Elsie Typhoon), shoaling effect is considered. The measured data and hindcasted data of the above eight Typhoons are shown in Fig 1 - Fig 8.

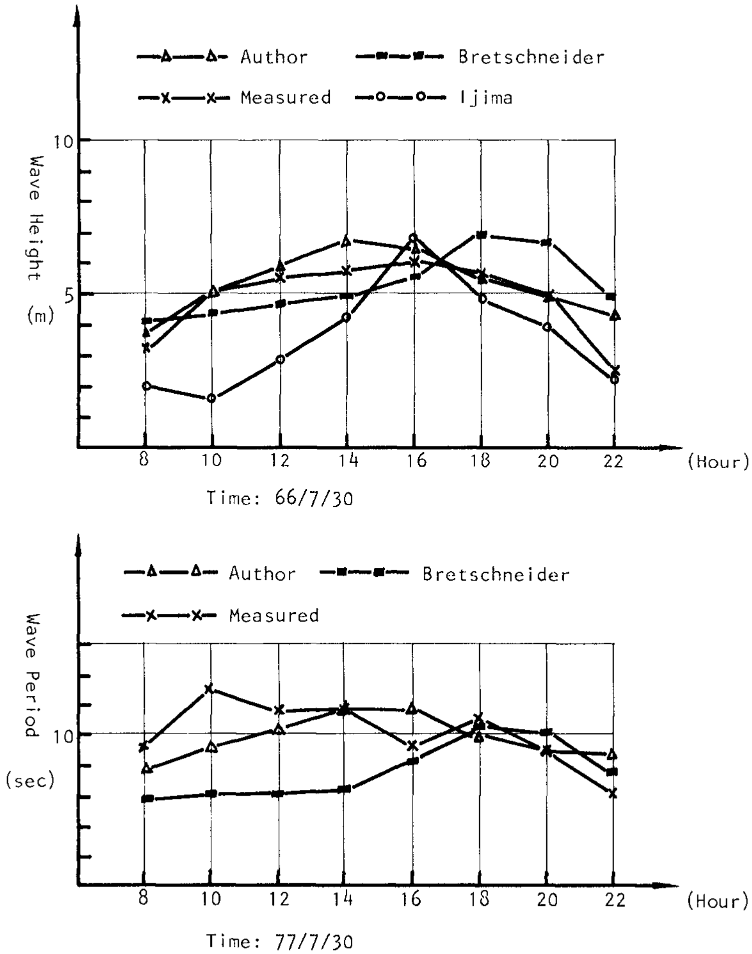


Fig 1 Judy Typhoon

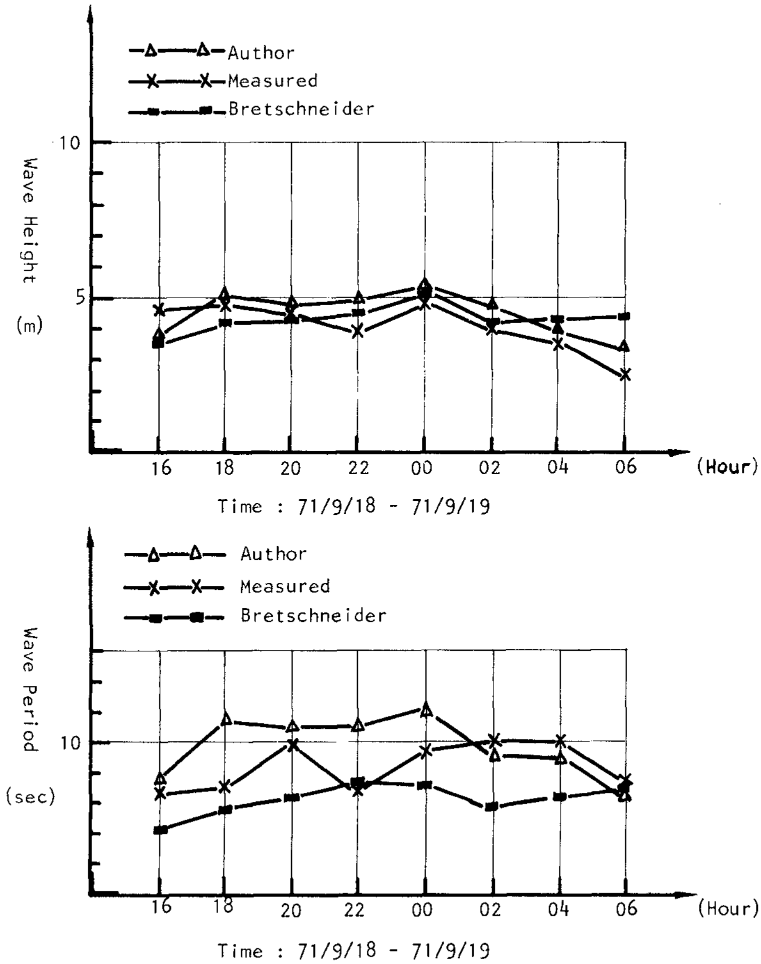


Fig 2 Agnes Typhoon

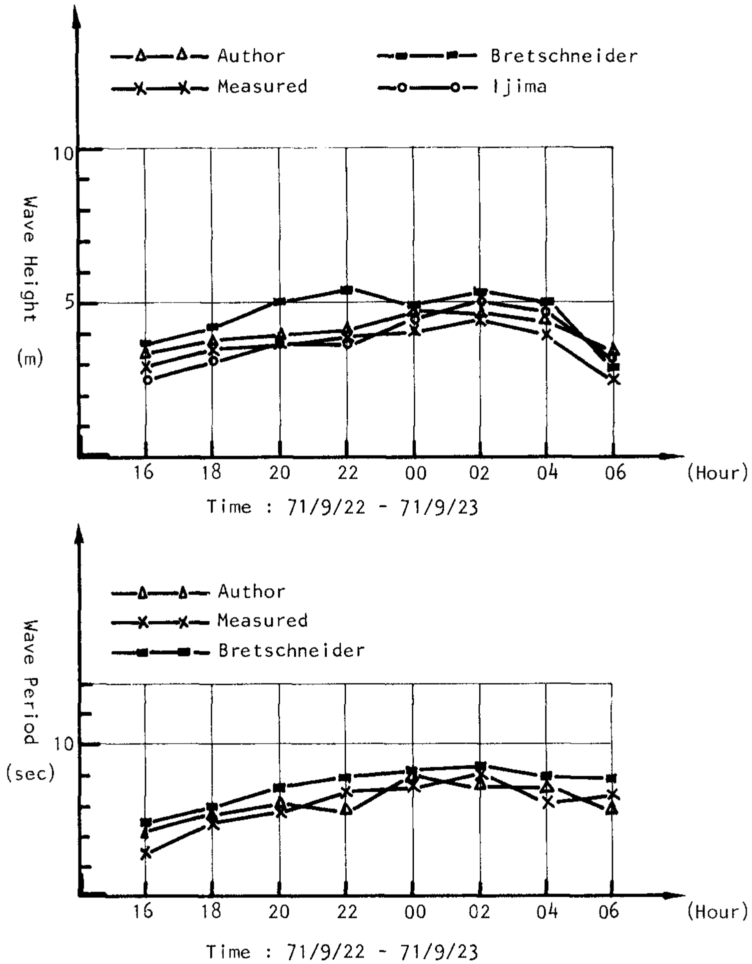
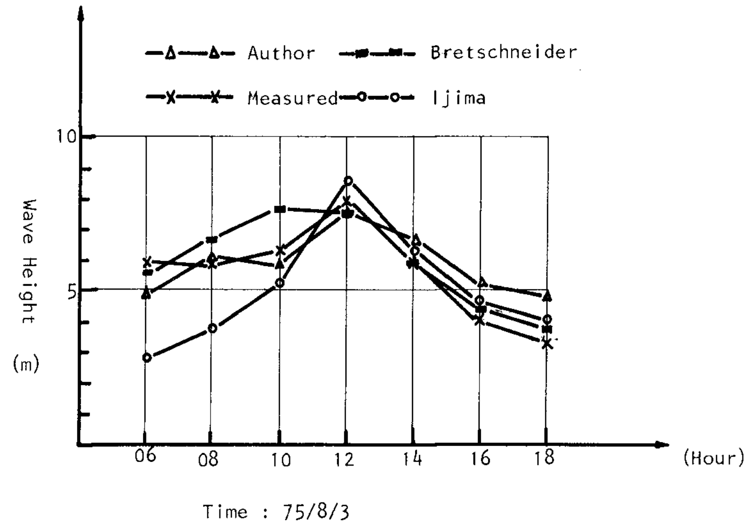


Fig 3 Bess Typhoon



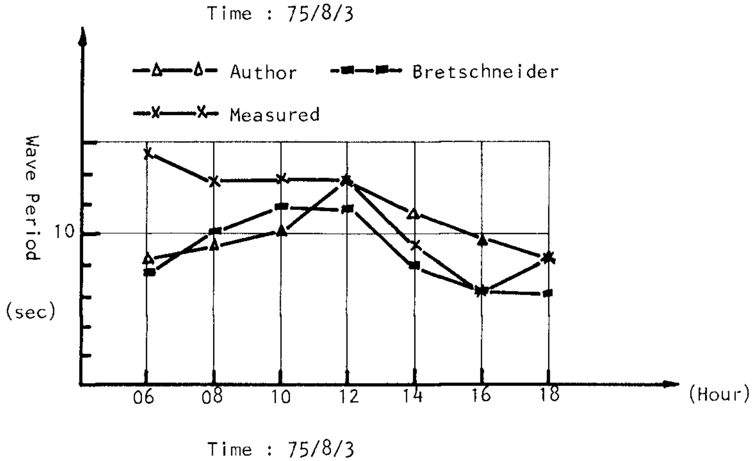


Fig 4 Nina Typhoon

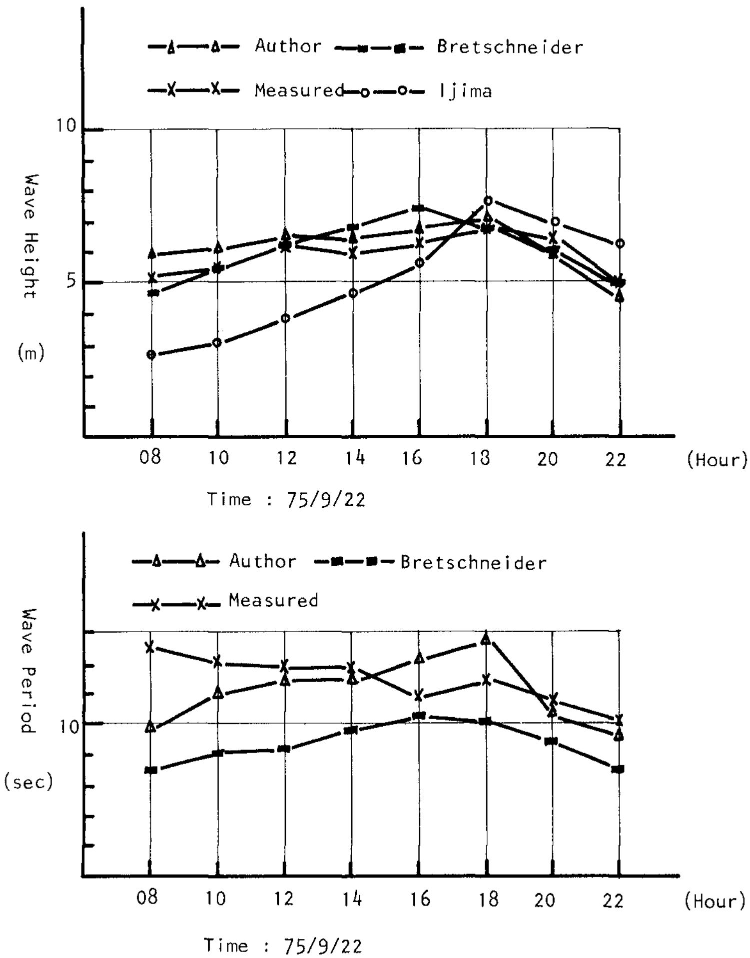


Fig 5 Betty Typhoon

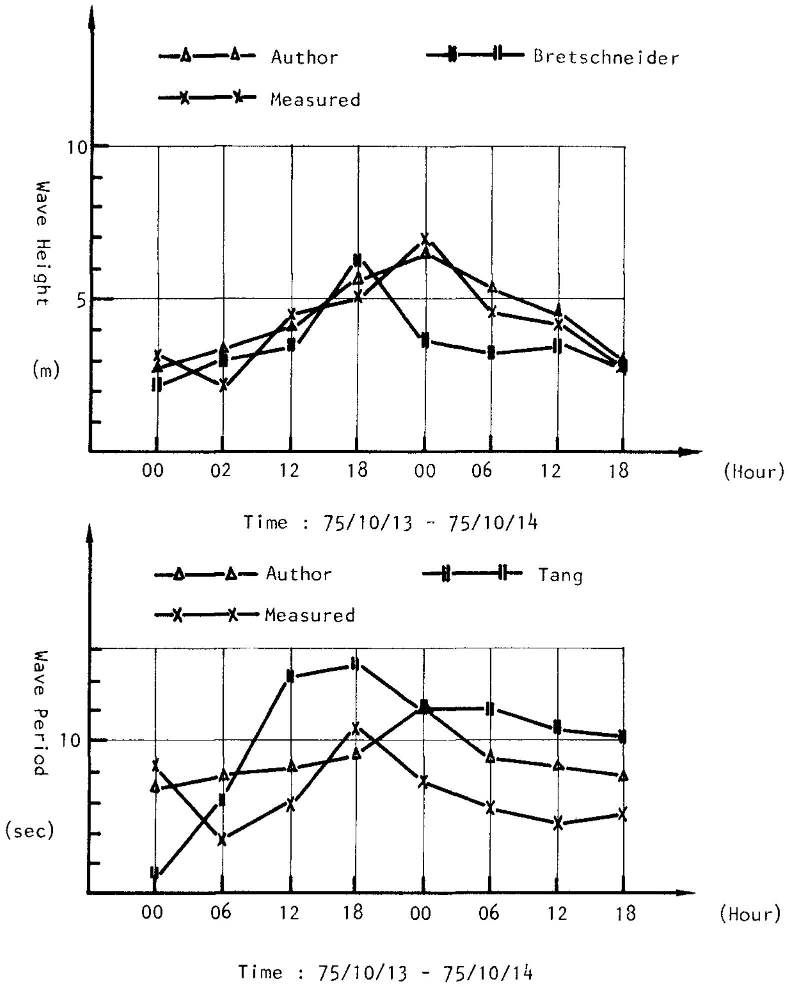


Fig 6 Elsie Typhoon

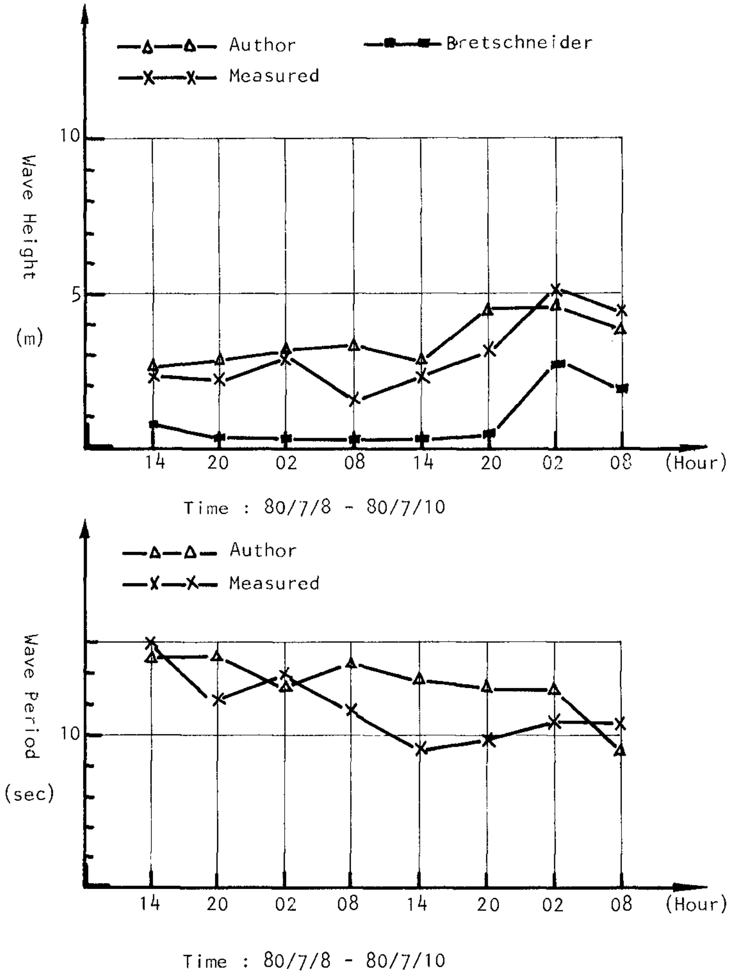
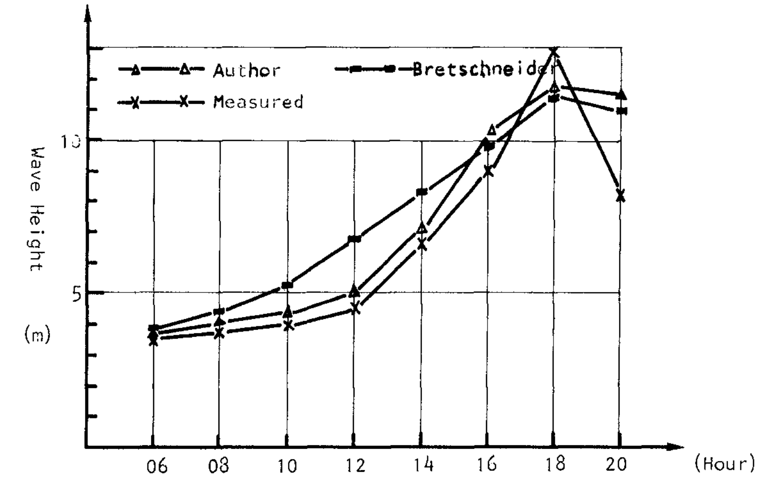
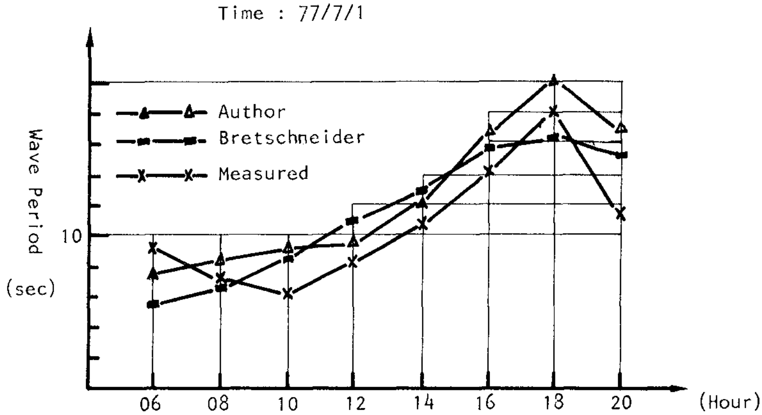


Fig 7 Ida Typhoon



Time : 77/7/1



Time : 77/7/1

4. CONCLUSIONS

This paper proposes a new typhoon wave hindcasting method which has improved several defects of the other models. Basically, this method is based on Bretschneider's method and Liang's typhoon swell method. Which is also partially originates from Bretschneider's method. Hence, it is sure that, (1) Bretschneider's method is a good typhoon wave predication method. (2) The effect of swell has not been considered in Bretschneider's method. Finally, there are two other things which should be further studied. One is R value (radius of maximum wind speed). Another is the wave period. However, the method proposed in this paper can be used in the wave climate prediction.

5. REFERENCE

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