Forecasting Damage Length of Maritime Structures Caused by Typhoons Based on Improved EWE Method

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Abstract—**The aim is to forecast the damage length of damaged maritime structures at each coast for each pass of a typhoon of the equivalent wave energy of a typhoon at a latitude of 30°N using the so-called equivalent wave energy (EWE) method, which has been improved. EWE of typhoons is defined based on the maximum wind speed and the duration of wind blowing of the typhoon. Using the data on the damage length of maritime structures by typhoons and the path and the equivalent wave energy of typhoons, the vulnerability of coastal regions along the coastline of Japan for 13 groups of typhoon with different paths is estimated. The improved EWE method has been upgraded in comparison with EWE method and it will be used to estimate the damage length of damaged maritime structures that will occur along the coast at a latitude of 30° N before a typhoon strikes. The forecasting method reported here will be used for the purpose of coastal zone management in disaster prevention works. Further, it provides useful for information of storm warning and evacuation of residents along coastlines.**

Index Terms—**Equivalent wave energy method, damage length, typhoon vulnerability.**

I. Introduction

This paper deals with the damage of maritime structures caused by the typhoons in the harbors and coastal areas along the coasts in Kumamoto prefecture on Kyushu Island of Japan (Fig. 1 and Fig. 2). The damage of structures means the breaching of dikes, cracking of seawalls, overturning of break waters, shift of breakwaters, removal of rubble from groins, etc. The damage length is defined as a summation of the alongshore length of the parts of structures damaged by a typhoon.

In Kumamoto Prefecture the coasts face closed and open sea areas. The closed sea areas are the Ariake and Yatsushiro Seas. The open sea area is the East China Sea. In this paper, we divided the coastline into 4 coastal regions. Each coastal region has different topographical characteristics (Fig. 2). The coasts facing the closed sea areas are the Ariake east (Ar. E.), Yatsushiro east (Yt. E.) and Yatsushiro west (Yt. W.) coasts. The coast facing the open sea area is the Amakusa west (Ak. W.) coast.

Typhoons which pass through Kyushu Island have many tracks. All typhoons dealt with in this paper had passed an area delineated by a latitude of 30°N and 35°N and a longitude of 127°E and 132°E (Fig. 3) in the past 25 years from 1980 to 2004. The number of typhoons passing through the delineated area is 74.

The author already examined a relationship between the maximum wind speed near the center of a typhoon at alatitude of 30°N and the damage length caused by typhoon [1], [2]. This method was previously called the MWS method. This method is used to forecast the damage length by giving the path and the maximum wind speed of the typhoon based on 43 typhoons over 15 years from 1980 until 1994 at a latitude of 30°N. The magnitude method was introduced as a new step of the MWS method [3], [4]. The magnitude method is defined based on the maximum wind speed and the size of typhoon. After that, the equivalent wave energy (EWE) method was introduced as a new step of the magnitude method [5]. The equivalent wave energy method is defined based on the maximum wind speed and the duration of wind blowing of a typhoon.

Furthermore, the author proposed an improved MWS method and an improved magnitude method that are calculated based on 74 typhoons over 25 years from 1980 until 2004 [6]-[8].

Additionally, in this paper, an improved Equivalent Wave Energy (iEWE) method, which is calculated based on 74 typhoons, is proposed for forecasting the damage length caused by a coming typhoon in each coast. The vulnerability and the damage length of maritime structures at each coast for the historical path of a typhoon, which is shown in Fig. 4, are estimated.

II. 13 Groups of Typhoon

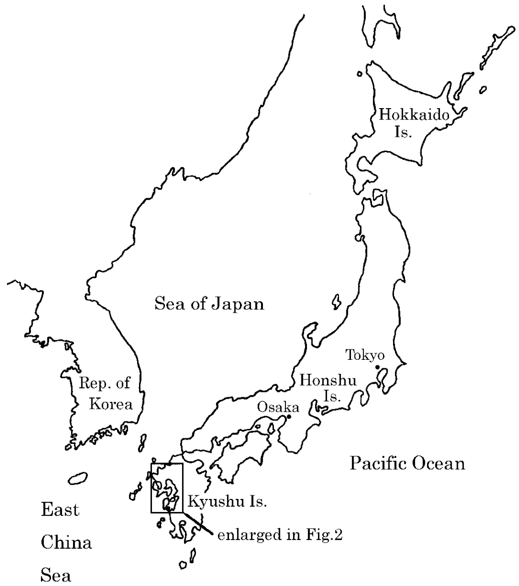

Fig. 1. Location of Kyushu Island of Japan.

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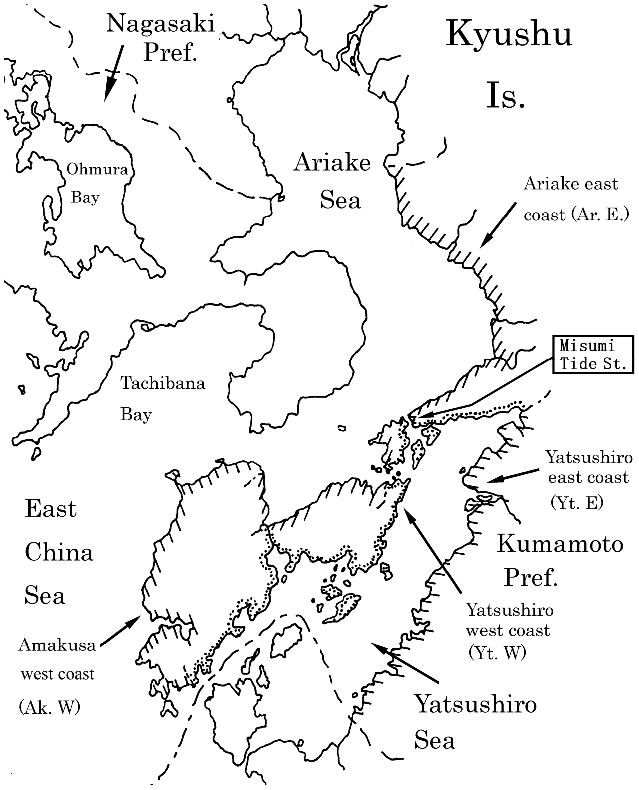

Fig. 2. The 4 coastal regions located in Kumamoto Prefecture.

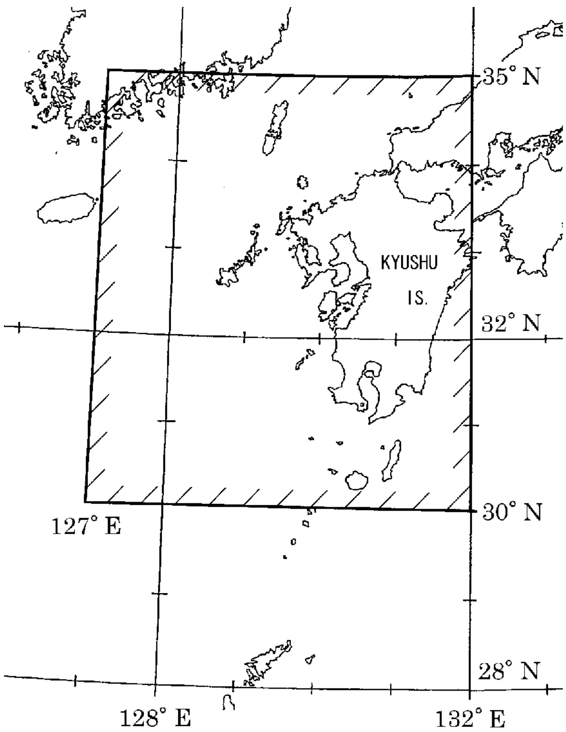

Fig. 3. Delineated area including Kyushu Island

The 74 typhoons, which passed through an area delineated by a latitude of 30°N and 35°N and a longitude of 127°E and 132°E (Fig. 3), between 1980 and 2004 are analyzed. The above mentioned delineated area was determined judging from the possibility of damage of the maritime structures along the coasts in Kumamoto Prefecture.

The typhoons between 1980 and 2004 were divided into 13 groups based on their paths (Fig. 4). The circled numbers in Fig. 4 indicates 13 storm paths for the 74 typhoons. The typhoons which did not follow any of these 13 groups are neglected.

In this paper, the author estimates the damage length of maritime structures on the coasts from the equivalent wave energy of a typhoon at a latitude of 30°N. The typhoon of each path has a different direction of movement and the east longitude of the position at a latitude of 30°N. The reason why 30 degrees north latitude is selected is that the direction of movement of a typhoon is roughly fixed and the scale of the typhoon becomes stable there.

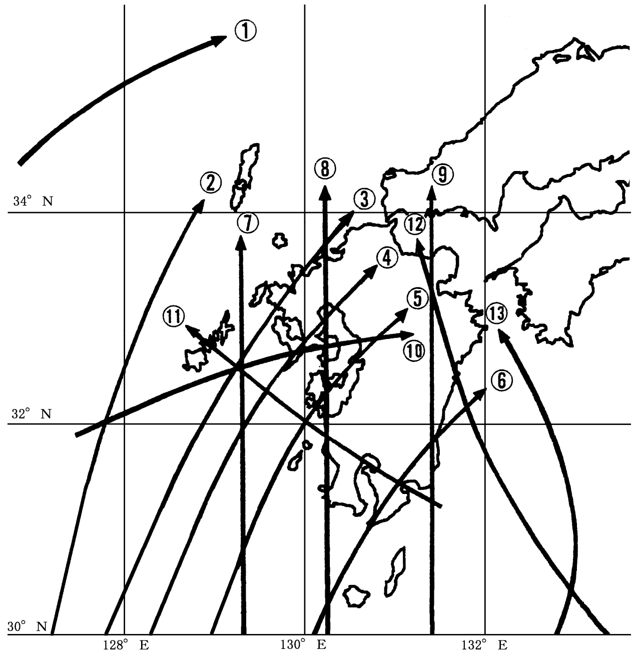

Fig. 4. Historical typhoon paths.

III. Equivalent Wave Energy

Considering the effect of waves on the maritime structure damage, not only the wave height, H, but also the wave period, T, is important [9]. The maximum wind speed and the duration of strong winds are closely related to the typhoon's energy and its transfer. Wind waves gain their energy from the typhoon energy, and the wave height and period increase in the process of the typhoon energy transfer.

In this paper, the damage length of maritime structures on the coasts and the harbors is estimated based on the equivalent wave energy of a typhoon. The equivalent wave energy is defined as H^2T^2. It is determined based on the duration time of the wind blowing and the maximum wind speed near the center of a typhoon. To determine the wind speed and its duration, different areas are specified for each path (Table I). The areas were determined considering the effectiveness of waves on the maritime structures along the coasts in Kumamoto Prefecture.

By observing the maximum wind speed $V_{max,\,i}$ in a typhoon at time t_i and the maximum wind speed $V_{max,\,i+1}$ at time t_{i+1} ($=t_i+\Delta t$), the average maximum wind speed $V_{max,\,ave}$ is defined by (1)

$$V_{max,\,ave} = [\, \Sigma\ \{(V_{max,\,i+1}+V_{max,\,i})/2\} \times (t_{i+1}-t_i)]/\ \Sigma\ (t_{i+1}-t_i) \qquad (1)$$

The maximum wind speed near the center of a typhoon at a standard observatory time is periodically observed every one, three or six hours by the Japan Meteorological Agency (JMA). The time t_1 is adjusted at the observatory time when the typhoon passes through at a latitude of 30°N. t_n is the time when the typhoon passes out from the specified area (Table 1) for each typhoon path. The duration, t, is determined by t_n-t_1.

Next, the significant wave height, $H_{1/3}$, and period, $T_{1/3}$, are determined from the wave forecasting curves based on the SMB method by using the duration, t, and average maximum wind speed, $V_{max, ave}$, calculated by (1). The equivalent wave energy, E, is calculated as $H_{1/3}^2T_{1/3}^2$, the equi-value lines of which are shown in the wave forecasting curves based on the SMB method.

TABLE I: SPECIFIED AREA TO ESTIMATE EQUIVALENT WAVE ENERGY

Typh. P.	Latitude and Longitude
1	between 30ºN and 35ºN and to the west of 130ºE
2	to the north of 30ºN and to the west of 130ºE
3	to the north of 30ºN and to the west of 131ºE
4	to the north of 30ºN and to the west of 131ºE
5	to the north of 30ºN and to the west of 132ºE
6	to the north of 30ºN and to the west of 133ºE
7	between 30ºN and 34ºN
8	between 30ºN and 34ºN
9	between 30ºN and 34ºN
10	to the north of 30ºN and to the west of 131ºE
11	to the north of 30ºN and to the west of 127ºE
12	between 30ºN and 34ºN
13	between 30ºN and 34ºN

IV. ESTIMATION OF THE SMOOTHED DAMAGE LENGTH USING THE EWE METHOD

The damage length for each coast is defined as a summation of the damage length of part of the maritime structures damaged by each typhoon on the coast. Smoothed damage length is further defined as in (2).

$$L_s = (L_d / L_t) \times 100 \quad (2)$$

where L_s is the smoothed damage length, L_d is the damage length by each typhoon for the coast and L_t is the total damage length by all typhoons for this particular coast. The smoothed damage length indicates the contribution to the total damage length for the coast by each typhoon.

The smoothed damage length is expected to increase rapidly with the increase of maximum wind speed (Hashimura, 2003). To express this trend, a relation between them was given by (3).

$$L_s = \exp [\{(V_{max} - \mathrm{m}) \ln 10 \} / 10] \quad (3)$$

where V_{max} is the maximum wind speed near the center of a typhoon, and L_s is the smoothed damage length. The value of m was selected to be equal to the minimum values of maximum wind speed in m/s 17, 25, 29, 33, 37, 41 and 44.

Fig. 5 shows a relation of the maximum wind speed near the center and the equivalent wave energy of 74 typhoons. Applying regression analysis to Fig. 5, we get

$$V_{max} = 10.36\, E^{0.123} \quad (4)$$

Substituting (4) into (3) yields:

$$Z = \exp [\{(10.36\, E^{0.123} - \mathrm{m}) \ln 10\}/10] \quad (5)$$

The horizontal axis, E, in Fig. 6 shows the equivalent wave energy of a typhoon. The vertical axis shows the smoothed damage length. The smoothed damage length by each typhoon at each coast is plotted with different symbols for different coasts. The lines a~g in Fig. 6 are expressed by (5) with m values from 44 to 17 respectively. The figures shown along the horizontal and vertical axes are the numbers of six areas (from 1 to 6) divided by the lines b~f.

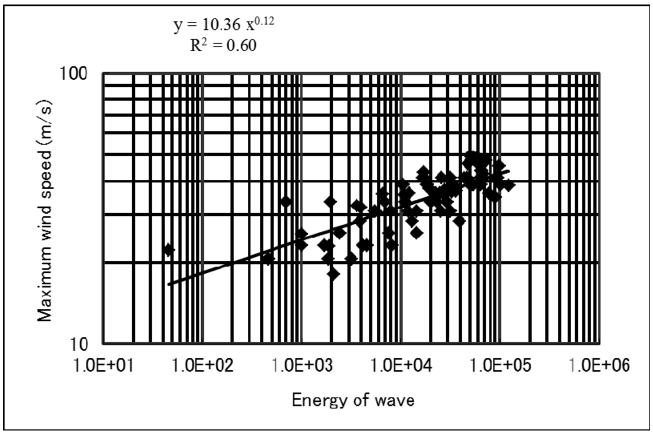

Fig. 5. Equivalent wave energy of typhoons and maximum wind speeds.

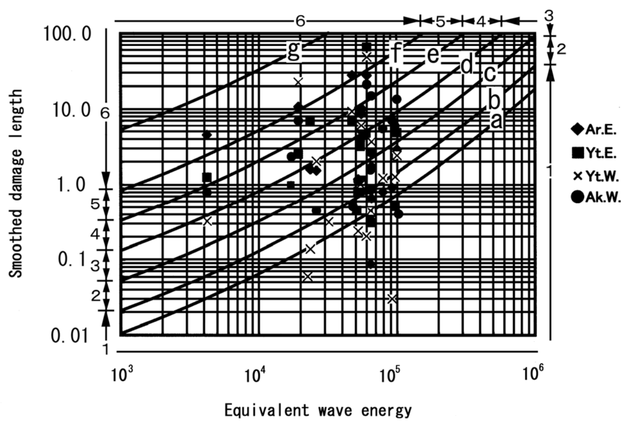

Fig. 6. Equivalent wave energy and smoothed damage length.

V. SENSITIVITY AT FOUR COASTS AND ESTIMATION OF DAMAGE LENGTH

The first row of the third to sixth and the ninth to twelfth column in Table II indicates 4 coasts in Fig. 2 with their abbreviations. The order of typhoons in the same path depends on firstly the maximum wind velocity near the center of a typhoon at a latitude of 30°N, and secondly on the depth of the central pressure. Table 2 shows the No. of the area in which the plotted point is located for each typhoon in each path. When no damage occurs, the No. is not shown. The larger the No., the relatively larger damage occurs for the same equivalent wave energy. We call the number in Table II the "sensitivity value" of each coast for each typhoon. The sensitivity value indicates the vulnerability of each coast for each typhoon. It should be noticed that the typhoon indicating the maximum smoothed damage length at the coast does not always have the maximum sensitivity value.

TABLE II-I: SENSITIVITY VALUE OF COASTAL REGIONS FOR EWE OF TYPHOONS

Typh. No.	P. No.	Ar. E.	Yt. E.	Yt. W.	Ak. W.
T0314	1				
T8520	1				
T8118	1	1		1	3
T8705	1				
T8613	1				
T9711	1				
T0014	1				
T0415	1				
T9809	1				
T9429	1				
T8605	1				
T9007	1				
T8712	2	2	1	3	5
T9109	2	2	1	1	3
T8410	2	1		2	3
T0306	2				
T0006	2				
T9119	3	4	2	4	4
T0418	3	6	4	4	
T8105	3				
T9918	4	5	6	6	5
T9117	4	3		3	2
T9708	4				
T9210	5			1	
T9612	5	4	3	2	3
T9019	6		1		
T9313	6	2	3	1	
T8019	6				1
T0416	6	1			1
T0423	6				4
T0310	6				
T0406	6				
T9719	6	2	2	1	2
T9020	6				
T8922	6				
T8506	6				
T9514	6				

Roughly speaking, the coasts facing the closed sea areas from the number shown in Table II are easily damaged by typhoons in paths No. 3, 4, 8 and 11, and the coast facing the open sea are easily damaged by typhoons in paths No. 4 and 8.

Table III shows the maximum sensitivity value for each path in each coast. This table indicates an index of vulnerability of each coast for each typhoon path. The damage length induced by a coming typhoon at a coast can be estimated as follows:

The path is determined based on Fig. 4 when the typhoon passes through at latitude of 30°N. The maximum sensitivity value for this path is determined at each coast based on Table III. The maximum and minimum values of the smoothed damage length are determined in Fig. 6 by giving the equivalent wave energy and the maximum sensitivity value. The maximum and minimum damage length by this typhoon at this coast is forecasted by substituting the maximum and minimum values of smoothed damage length and the total damage length by all 74 typhoons at this coast in (2).

TABLE II-II: SENSITIVITY VALUE OF COASTAL REGIONS FOR EWE OF TYPHOONS

Typh. No.	P. No.	Ar. E.	Yt. E.	Yt. W.	Ak. W.
T0421	6	3	5	1	
T0207	6				
T0404	6				
T9021	6				
T9810	6				
T8917	6				
T8608	6				
T0204	6				
T9307	7	1			3
T9503	7				
T9306	7				
T8513	8	6	4	6	5
T9606	9				
T8213	9				
T8013	9			1	
T8219	9				
T8906	9				
T9305	9				
T8310	10	2	3	2	4
T8911	11	1		1	2
T0215	11				1
T8407	11				
T9414	11				
T8508	11				
T9112	11				
T0209	11				
T9905	11				
T8110	11	6	5	3	4
T0211	11				
T9908	11				
T9113	11				
T0410	12				
T9211	12				
T9407	13				
T0304	13				
T9209	13				
T8512	exclude				

TABLE III: MAXIMUM SENSITIVITY VALUES OF EWE FOR EACH REGION

Path No.	1	2	3	4	5	6	7
Ar. E. (Closed)	1	2	6	5	4	3	1
Yt. E. (Closed)	0	1	4	6	3	5	0
Yt. W. (Closed)	1	3	4	6	2	1	0
Ak. W. (Open)	3	5	4	5	3	4	3

Path No.	8	9	10	11	12	13
Ar. E. (Closed)	6	0	2	6	0	0
Yt. E. (Closed)	4	0	3	5	0	0
Yt. W. (Closed)	6	1	2	3	0	0
Ak. W. (Open)	5	0	4	4	0	0

VI. Conclusions

The damage length of maritime structures on 4 coasts in the west of Kyushu Island in Japan by typhoons from 1980 to 2004 is analyzed.

The equivalent wave energy of a typhoon is defined and calculated for 74 typhoons attacking these coasts during this period. The vulnerability of the 4 coasts for 13 groups of typhoon with different paths is estimated as sensitivity. This sensitivity value can be used to forecast the damage level at each coast by a coming typhoon. The improved Equivalent Wave Energy (iEWE) method shows high accuracy compared with the current Equivalent Wave Energy (EWE) method.

The improved maximum wind speed method is the easiest way of predicting the vulnerability of a coast with a certain degree of accuracy. The improved Magnitude method is a forecasting method that can take account of the effects of storm surges. Although this method can be expected to improve the accuracy of prediction, it should be considered that the degree of ease of use decreases with improving accuracy. The improved Equivalent Wave Energy (iEWE) method delivers the highest accuracy of these three methods, because it considers the maximum wind speed and the duration of a typhoon. However, the problem remains that the method is quite difficult to use.

This paper shows that the degree of risk and influence of coasts due to typhoon can be estimated by the iEWE method before a typhoon strikes.

Further study including other factors of typhoon is needed for high quality forecasting.

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