Using the Improved Central Pressure Method to Forecast Damage Caused by Typhoons

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***Abstract*—The purpose is to forecast the number of damaged maritime structures at each coastal region for each pass of typhoons from the central pressure of typhoon. Using data on the damage of maritime structures caused by 74 typhoons during previous 25 years from 1980 to 2004, vulnerability of 4 coastal regions along the coastline of Kumamoto Prefecture in the west of Kyushu Island of Japan is estimated for 13 groups of typhoon with different paths. It is possible to forecast the number of damage cases and the sensitivity of coastal regions by giving the path and the central pressure of the typhoon at a latitude of 30°N. The conclusion shows that the improved Central Pressure (CP) method can be used to estimate the damage level of maritime structures that will occur along the coast before a typhoon strikes. The forecasting method reported here will be used for the purpose of coastal zone management in disasters prevention works. Further, it is useful for information of storm warning and evacuation for fishermen, offices and crew.**

***Index Terms*—central pressure, vulnerability, sensitivity, smoothed damage cases.**

I. Introduction

This paper deals with the number of damage cases of the maritime structures caused by typhoons in the harbors and the coastal areas along the coasts in Kumamoto Prefecture in the Kyushu Island of Japan (Fig. 1 and Fig. 2). The damage of structures means breaching of dikes, cracking of seawalls, overturning of breakwaters, shift of breakwaters, removal of rubble from groins etc.

The number of damage cases is the sum of the cases of damage of structures in each region for each typhoon. If the seawall is damaged at two points along the coastline, it is counted as two damage cases. In Kumamoto Prefecture, the coasts face open and closed seas. The open sea is East China Sea. The closed seas are Ariake and Yatsushiro Seas. In this paper, we divided the coastline into 4 coasts (Fig. 2). All typhoons had passed through an area delineated by a latitude of 30° and 35°N and a longitude of 127° 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.

A statistical analysis is done on the number of damage cases of the maritime structures in harbors and coastal areas, the path and scale of the typhoons. Based on the analysis, a forecasting method is proposed for the damage in each coast caused by typhoon.

The author already proposed a relationship between the maximum wind speed near the typhoon center at a latitude of 30°N and the number of damage cases. This method was so called MWS (Maximum Wind Speed) method. This Method was used to forecast the damage level by giving the path and the maximum wind speed of the typhoon based on 43 typhoons during 15 years from 1980 until 1994 at a latitude of 30°N (Hashimura, 2002). The result of this analysis does not show a high accuracy.

To improve this situation, the central pressure of typhoon as a new parameter was introduced (Hashimura, 2006). Considering the effect of waves with storm surge on the maritime structure damage, the central pressure of typhoon is important parameter. The central pressure is closely relation with the maximum wind speed of typhoon. A relation between the central pressure of typhoon and the damage length of maritime structures is examined. This method is so called CP (Central Pressure) method. The result of this analysis is already presented (Hashimura, 2006).

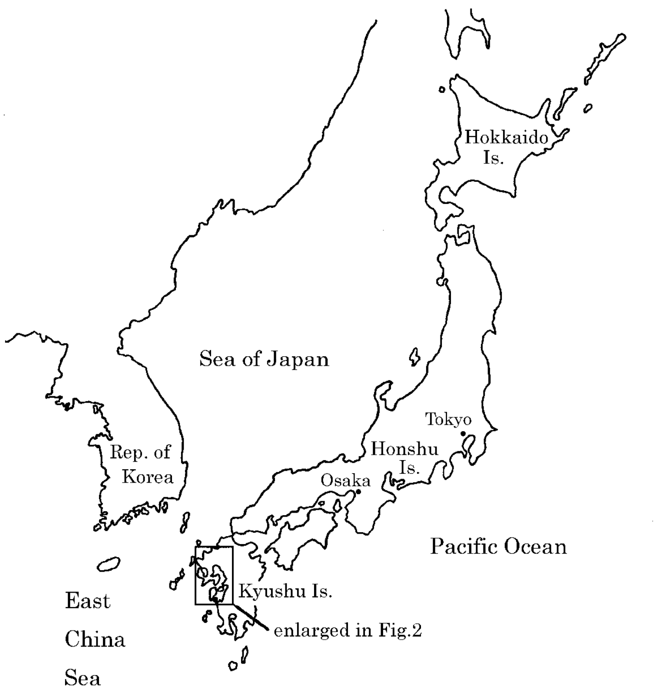

Fig. 1 Location of the Kyushu Island of Japan

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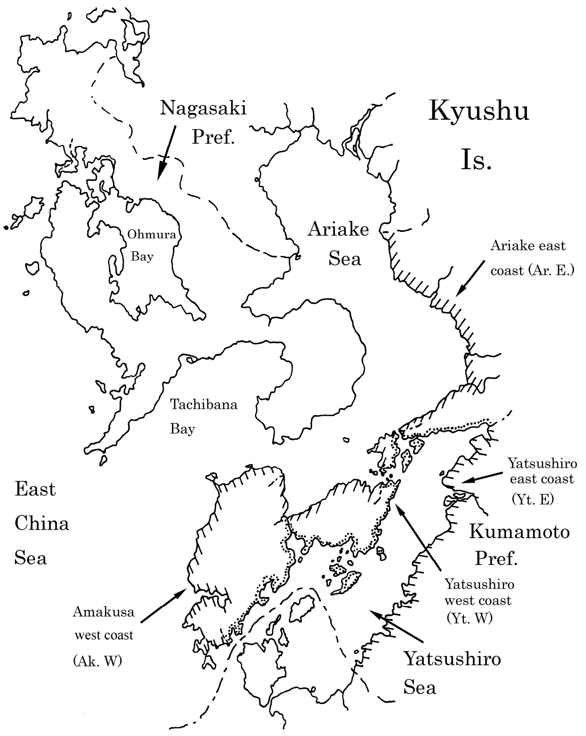

Fig. 2 the 4 coastal regions located in Kumamoto Prefecture

Furthermore, to improve the MWS method (Hashimura, 2002) more high accuracy, the author proposed an improved MWS method which is calculated based on 74 typhoons during 25 years from 1980 until 2004 (Hashimura, 2008) .

In this paper, an improved CP method which is calculated based on 74 typhoons mentioned above is proposed for forecasting the number of damage cases caused by a coming typhoon in each coast. The sensitivity and the number of damage cases at each coast for each path of typhoon are estimated.

II. 13 Groups of Typhoon

The 74 typhoons, which passed through an area delineated by a latitude of 30° and 35°N and a longitude of 127° and 132°E (Fig. 3), between 1980 to 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 variation of wind speeds and wind directions by the typhoon which goes up northward is shown in Fig. 4. The A, B, C, and D points show the situations of typhoon, and a, b, c and d shows the wind directions and wind speeds at P station. The b shows the maximum wind speed and wind direction at P station when typhoon is on B situation. The example of the distribution of wave heights and wave directions on the open sea in the storm area of typhoon are shown in Figs. 5(a) and (b). Fig. 5 shows the distribution of waves caused by typhoon with the speed of movement of 40 km/h and the central pressure 960 hPa, and 970 hpa (Hashimura, 1993).

The Yatsushiro and Ariake Seas are the closed sea and extend north and south. Typhoon 8513 proceeded from the south northward off of Kyushu and took a northerly course near the western part of the Yatsushiro and Ariake Seas shown in Fig. 6 (Hashimura, 1993). The whole area of the Yatsushiro and Ariake Seas was within the dangerous semi circle, that is, the first and fourth quadrants of the low pressure area. The wind directions of maximum wind speeds on the vicinity of the Yatsushiro and Ariake Seas (Fig. 2) agree with the wind direction of maximum wind speed of b shown in Fig. 4. Therefore, the wave height distribution and wave directions in the Yatsushiro and Ariake Seas are equivalent to the waves in Figs. 5 (a) and (b).

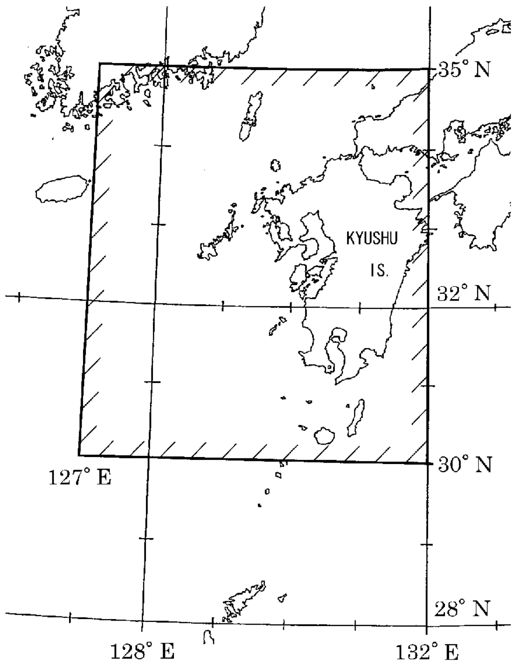

Fig. 3 Surrounded area including Kyushu Island

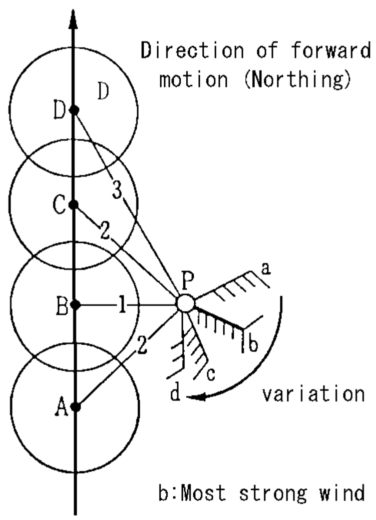

Fig. 4 Model case of variation of wind direction and wind speed at each situation of typhoon (Otsuka, et al. 1986)

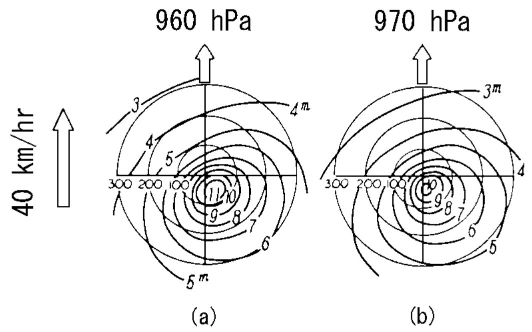

Fig. 5 Distribution of wave height in the storm area of typhoon by Unoki method (Sakurai, et al.1987)

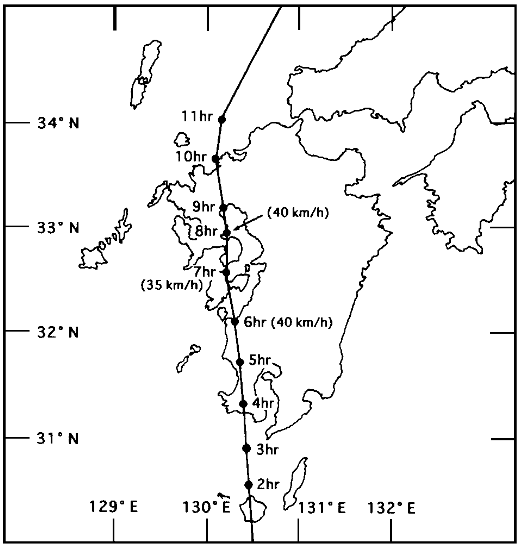

Fig. 5 Hourly positions of Typhoon 8513 on August 31st, 1985

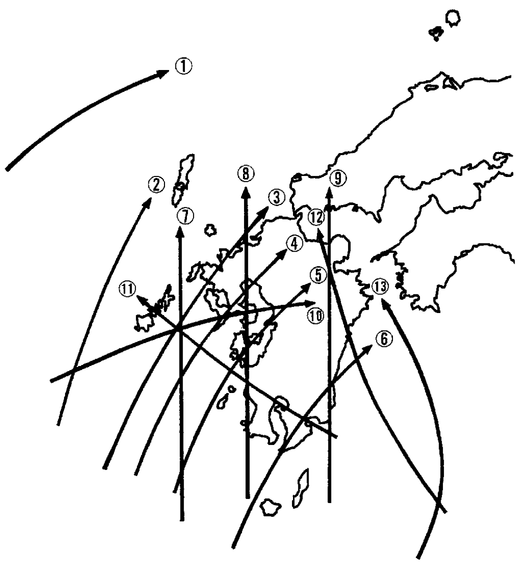

Fig. 7 Historical typhoon paths

In the north hemisphere, the wind in the right area of typhoon in the direction of movement is stronger than in the left area. The direction of the strong wind is from between ENE and SE. Therefore, a coast facing the sea rightwards near the center of the typhoon in the right area of typhoon is largely affected by high waves coming SE. Damage is amplified by the combination of storm surge and swells with high waves at the time of the high sea level.

The 74 typhoons between 1980 and 2004 are divided into 13 groups based on their paths (Fig. 7 and Table 1). The circled number in Fig. 7 is each number for 13 groups. The typhoons which did not follow any of these 13 groups are neglected. In this paper, it is tried to estimate the damage of maritime structures at the coasts from the central pressure of typhoon. The central pressure of typhoon is obtained from the data observed periodically at a latitude of 30° N by Japan Meteorological Agency (JMA). The reasons why a latitude of 30° N is selected is that the direction of movement of typhoon is roughly fixed and the scale becomes stable there. Table 1 shows the 13 categories based on the direction of movement and the longitude of the position of the typhoons for each path at a latitude of 30° N. D is measured clockwise from north.

TABLE 1. THE 13 CATEGORIES BASED ON THE DIRECTION OF MOVEMENT AND LONGITUDE OF THE TYPHOON'S LOCATION FOR THE TYPHOONS THAT OCCURRED AT A LATITUDE OF 30° N

Path	Direction (D)	Longitude (L)
1	0.0°< D≦ 22.5°	123.2°< L≦ 125.5°
2	0.0°< D≦ 22.5°	126.3°< L≦ 127.2°
3	D = 22.5°	125.2°< L≦ 127.6°
4	D = 22.5°	L≦ 128.3°
5	D = 0.0°	L≦ 129.3°
6	22.5°< D≦ 67.5°	128.5°< L≦ 132.0°
7	D＝ 0.0°	128.9°< L≦ 129.1°
8	D＝ 0.0°	L≦ 130.4°
9	-22.5°< D≦ 22.5°	130.2°< L≦ 131.5°
10	D = 45.0°	L≦ 124.0°
11	-67.5°< D≦ -22.5°	129.4°< L≦ 136.6°
12	D = -45.0°	L≦ 133.4°
13	D = 22.5°	132.4°< L≦ 133.5°

III. SMOOTHED NUMBER OF DAMAGE CASES FOR EACH COAST

Smoothed number of damage cases is defined as in (1):

$$Y = (N / T) \times 100 \qquad (1)$$

where Y is the smoothed number of damage cases, N is the number of damage cases caused by each typhoon for each coast, and T is the total number of damage cases by all typhoons for this particular coast. The smoothed number of damage cases indicates the contribution to the total damage cases for the coast by each typhoon.

Table 2 shows the calculated smoothed number of damage cases. The second and eight columns (Path No.) indicate the path No. as determined based on Fig. 7. The typhoons are ordered based on 1) the path No., 2) the maximum wind speed near the typhoon center, and 3) the central pressure at a latitude of 30° N. The first line of the third to sixth and the ninth to twelfth columns indicates 4 coasts shown in Fig. 2 with their abbreviations. The bottom line of the eighth to eleventh columns indicates the total number of damage cases, T shown in (1), by all typhoons for each particular coast.

At all coasts facing open and closed seas, Typhoon 9918 in path No. 4 induced the largest damage. Therefore, Typhoon 9918 in path No. 4 induced enormous damage at the coasts in Kumamoto Prefecture. At Ariake east coast facing the closed sea, Typhoon 9918 in Path No. 4 induced the largest damage. The second largest damage is induced by Typhoon 0418 in path No. 3. At Yatsushiro east coast facing the closed sea, Typhoon 9918 in path No.4 induced the largest damage. The second largest damage is induced by Typhoon 0418 in path No. 3. At Yatsushiro west coast facing the closed sea, Typhoon 9918 in path No. 4 induced the largest damage. The second largest damage is induced by Typhoon 8513 in path No. 8. At Amakusa west coast facing the open sea, Typhoon 9918 in path No. 4 induced the largest damage. The second largest damage is induced by Typhoon 8712 in path No. 2.

TABLE 2. SMOOTHED NUMBER OF DAMAGE CASES

T. No.	Path No.	Ar. E.	Yt. E.	Yt. W.	Ak. W.	T. No.	Path No.	Ar. E.	Yt. E.	Yt. W.	Ak. W.
T0314	1					T0421	6	1.63	6.86	0.33	
T8520	1					T0207	6				
T8118	1	0.81		0.33	8.50	T0404	6				
T8705	1					T9021	6				
T8613	1					T9810	6				
T9711	1					T8917	6				
T0014	1					T8608	6				
T0415	1					T0204	6				
T9809	1					T9307	7	1.63			1.31
T9429	1					T9503	7				
T8605	1					T9306	7				
T9007	1					T8513	8	10.57	9.80	22.15	9.80
T8712	2	5.69	0.98	8.14	13.07	T9606	9				
T9109	2	2.44	1.96	2.28	7.84	T8213	9				
T8410	2	4.88		3.58	6.54	T8013	9			0.33	
T0306	2					T8219	9				
T0006	2					T8906	9				
T9119	3	5.69	4.90	6.51	6.54	T9305	9				
T0418	3	17.89	15.69	15.96	3.92	T8310	10	7.32	5.88	5.54	11.76
T8105	3					T8911	11	0.81		0.98	1.31
T9918	4	29.27	31.37	28.34	15.69	T0215	11				0.65
T9117	4	1.63		1.30	0.65	T8407	11				
T9708	4					T9414	11				
T9210	5			0.65		T8508	11				
T9612	5	3.25	2.94	2.28	5.23	T9112	11				
T9019	6		2.94			T0209	11				
T9313	6	1.63	9.80	0.33		T9905	11				
T8019	6				1.31	T8110	11	1.63	1.96	0.65	0.65
T0416	6	1.63			1.96	T0211	11				
T0423	6				1.31	T9908	11				
T0310	6					T9113	11				
T0406	6					T0410	12				
T9719	6	1.63	4.90	0.33	1.96	T9211	12				
T9020	6					T9407	13				
T8922	6					T0304	13				
T8506	6					T9209	13				
T9514	6					Total number		123	102	307	153

In any case, large damage occurred at the coasts near the center of typhoon in the right side in the direction of typhoon movement. This result suggests a close relation between the number of damage cases and the distribution of wind speed in the typhoon.

IV. THE RELATIOSHIP BETWEEN THE CENTRAL PRESSURE OF TYPHOON AND THE SMOOTHED NUMBER OF DAMAGE CASES

The smoothed number of damage cases is expected to increase rapidly with an increase in the maximum wind speed (Hashimura, 2002 and 2007). This trend can be expressed by (2) (Hashimura, 2008):

$$Y = \exp\left[\{(V - m)\ln 8\} / 10\right] \qquad (2)$$

where Y is the smoothed number of damage cases, and V is the maximum wind speed near the center of typhoon at a latitude of 30° N. Based on the classification of JMA, the values of m for first 7 ranks are 44, 41, 37, 33, 29, 25 and 17 m/s respectively for the lines a, b, c, d, e, f and g (Fig. 8).

From the relation of the maximum wind speed near the center and the central pressure of 74 typhoons at a latitude of 30˚ N, Y in (2) can expressed by (3).

$$Y = \exp\left[\{(-2.932\times 10^{-3} P^2 + 5.209518\,P - 2262.334518 - m)\ln 8\}/10\right] \qquad (3)$$

where P is the central pressure of typhoon.

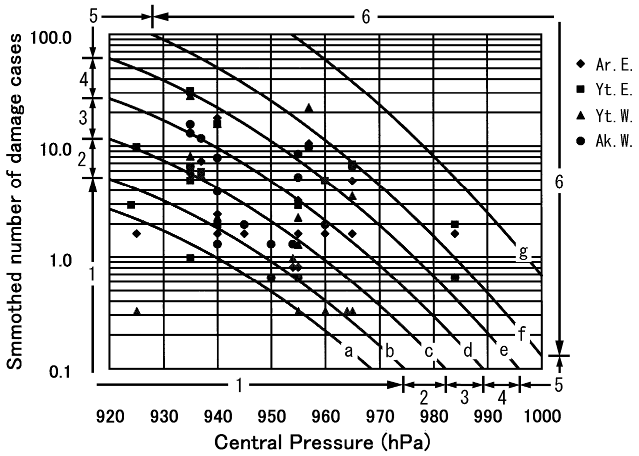

Fig. 8 Central pressure and smoothed number of damage cases

The horizontal axis in Fig. 8 shows the central pressure of typhoon at a latitude of 30° N. The vertical axis shows the smoothed number of damage cases. The symbols represent the different coasts. The lines a to g in Fig. 8 show the theoretical values predicted using (3), with the values of m varying from 44 to 17. The numerical values, 1 to 6, shown outside of figure, denote the six areas delineated by the lines b to f.

V. VULNERABILITY AT 4 COASTS AND ESTIMATION OF NMMBER OF DAMAGE CASES

Table 3 shows the number of areas in which the plotted point is located. When no damage occurs, the number is not shown. The number given in Table 3 is termed the “sensitivity value” for central pressure of typhoon based on the number of damage cases. The sensitivity value indicates the vulnerability of the coast to the individual typhoon. It should be noticed that a typhoon with the largest smoothed number of damage cases at the coast does not always has the largest sensitivity value. If the numbers 5 and 6 mean to be easily damaged, the following facts are clear:

1) Ariake east coast is easily damaged by the typhoons in paths No. 2, 8 and 11, but is not weak for the typhoons in paths No. 9, 12 and 13.
2) Yatsushiro east coast is easily damaged by the typhoons in paths No. 4, 6, 8 and 11, but is not weak for the typhoons in paths No. 1, 7, 9, 12, and 13.
3) Yatsushiro west coast is easily damaged by the typhoons in paths No. 2, 8 and 11, but is not weak for the typhoons in paths No. 7, 12 and 13

TABLE 3. SENSITIVITY VALUES OF SMOOTHED NUMBER OF DAMAGE CASES FOR CENTRAL PRESSURE

T. No.	Path No.	Ar. E.	Yt. E.	Yt. W.	Ak. W.	T. No.	Path No.	Ar. E.	Yt. E.	Yt. W.	Ak. W.
T0314	1					T0421	6	4	5	2	
T8520	1					T0207	6				
T8118	1	2		1	5	T0404	6				
T8705	1					T9021	6				
T8613	1					T9810	6				
T9711	1					T8917	6				
T0014	1					T8608	6				
T0415	1					T0204	6				
T9809	1					T9307	7	1			1
T9429	1					T9503	7				
T8605	1					T9306	7				
T9007	1					T8513	8	5	5	6	5
T8712	2	3	1	3	4	T9606	9				
T9109	2	2	2	2	3	T8213	9				
T8410	2	5		5	5	T8013	9			2	
T0306	2					T8219	9				
T0006	2					T8906	9				
T9119	3	3	2	3	3	T9305	9				
T0418	3	4	4	4	2	T8310	10	3	3	3	4
T8105	3					T8911	11	2		2	2
T9918	4	4	5	4	4	T0215	11				1
T9117	4	3		2	2	T8407	11				
T9708	4					T9414	11				
T9210	5			1		T8508	11				
T9612	5	3	3	3	4	T9112	11				
T9019	6		1			T0209	11				
T9313	6	1	3	1		T9905	11				
T8019	6				2	T8110	11	6	6	5	5
T0416	6	2			2	T0211	11				
T0423	6				2	T9908	11				
T0310	6					T9113	11				
T0406	6					T0410	12				
T9719	6	3	4	1	3	T9211	12				
T9020	6					T9407	13				
T8922	6					T0304	13				
T8506	6					T9209	13				
T9514	6					T8512	exclude				

4) Amakusa west coast, which faces the open sea, is also easily damaged by the typhoons in paths No. 1, 2, 8 and 11, but is not weak for the typhoons in paths No. 9, 12 and 13.

From the facts mentioned above, roughly speaking, the coasts facing the closed sea are easily damaged by the typhoons in paths No. 8 and 11, and the coast facing the open sea are easily damaged by the typhoons in paths No. 2, 8 and 11.

Table 4 shows the maximum sensitivity value for each path at the individual coasts. This table indicates the vulnerability index for an individual typhoon path at each coast.

TABLE 4. MAXIMUM SENSITIVITY VALUES FOR THE SMOOTHED NUMBER OF DAMAGE CASES

	Path No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Ar. E.	**Closed**	2	5	4	4	3	4	1	5	0	3	6	0	0
Yt. E.	**Closed**	0	2	4	5	3	5	0	5	0	3	6	0	0
Yt. W.	**Closed**	1	5	4	4	3	2	0	6	2	3	5	0	0
Ak. W.	**Open**	5	5	3	4	4	3	1	5	0	4	5	0	0

The total number of damage cases induced by a coming typhoon for a coast can be estimated as follows:

The path is determined based on the Fig. 7 and Table 1 from the track of typhoon, which is forecasted by the JMA, near a latitude of 30° N. The central pressure at a latitude of 30° N is calculated based on the data which is obtained from JMA. Then the maximum sensitivity value of central pressure is determined from the path and the coast based on Table 4.

The smoothed number of damage cases is determined in Fig. 8 by giving the central pressure and the maximum sensitivity value. The total number of damage cases by a typhoon for a coast is forecasted by substituting the value of smoothed number and the total number of damage cases by all 74 typhoons for the same coast in (1).

This result shows a better close relationship between the number of damage cases and the central pressure of typhoon.

VI. THE APPLICATION OF THE PATH NO.8 TO TYPHOON 9918

The longitude of the typhoon's position at a latitude of 30° N was 128.3° E. The direction of progress was 22.5° clockwise from north. Therefore, Typhoon 9918 can be classified as a No. 4 Typhoon based on the classification in Table 1.

The application of path No. 8 to Typhoon 9918 is discussed as follows:

The central pressure of Typhoon 9918 is 935 hPa at a latitude of 30° N. Based on Table 4, the maximum sensitivity value along the western coast of Yatsushiro Sea for Typhoon 9918 in path No. 8 is 6. From Fig. 8, it can be seen that region 6 is located above and right area of line f. Thus, the smoothed number of damage cases, Y, is obtained from (3) for a sensitivity value of 6 and a central pressure of 935 hPa. The minimum smoothed number of damage cases, Y, is 68.6, which was obtained by substituting m=25 for line f. Therefore, the range for the smoothed number of damage cases along the western coast of Yatsushiro Sea for Typhoon 9918 lies above 68.6. The total number of damage cases along the western coast of Yatsushiro Sea during the last 25 years was N=307. The number of damage cases for Typhoon 9918 is estimated to be 68.6% of 307, that is, 210. This estimated minimum number of damage cases is quite large compared with the actual number (N=68) caused by Typhoon 8513 in path No. 8. It is shown that the typhoon in path No. 8 conditions suffer extremely large damage along the western coast of Yatsushiro Sea. The reason is that the central pressure 935 hPa for Typhoon 9918 is deep compared with the 957 hPa for Typhoon 8513.

VII. CONCLUSIONS

Vulnerability and damage of maritime structures along 4 coasts facing the open and closed seas in the west of Kyushu Island of Japan are discussed for 13 paths of typhoon.

The following conclusions can be discussed:

1) The large damage occurs at the coasts near the center of typhoon in the right side in the direction of typhoon movement.
2) The vulnerability of 4 coasts facing the open and closed seas for each path of typhoon is numerically shown by using a concept of sensitivity of central pressure.
3) The vulnerability index for an individual typhoon path at each coast is closely related to typhoon passage.
4) The improved CP Method can estimate the number of damage cases of maritime structures that will occur along the coast before a typhoon strikes.
5) The estimation of damage level by using the improved CP Method shows a high accuracy more than the CP

Method.

6) This forecasting method will be used for the purpose of coastal zone management in disasters prevention works.

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