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PREDICTION OF DESIGN WATER LEVEL DUE TO STORM SURGE AT THE SEOGWIPO COASTAL ZONE IN KOREA

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ABSTRACT: Seogwipo coastal region is known to develop coast tourist attractions and expand its harbor facilities, but this region is also more likely to get damaged by typhoons since it is affected by most of the typhoons coming into the Korean Peninsula. This study comprehended the characteristics of Jeju Island coastal areas by analyzing severe weather elements like a typhoon, and particularly reviewed design water levels by storm surge in Seogwipo Harbor. The design water level was calculated on the basis of frequency analysis results regarding extreme water levels, tidal residuals per hour and observed surges and numerical simulation-based surge heights in case of a typhoon attack, and this study also suggested problems that rapid climatic change aspects cannot be reflected recently. To solve such a problem, it is required to constantly maintain the related data and apply high-degree stormy surge numerical simulations-based plans to the present work.

Keywords: Design water level, storm surge, frequency analysis, seogwipo

INTRODUCTION

Most of the typhoons affecting the Korean Peninsula go through Jeju Island every year, leading to lots of damage, and especially Seogwipo coastal region is directly affected by open-sea typhoons since it is located in the southern area of Jeju Island, suffering greater surges than Jeju Harbor. Besides, Seogwipo coastal area is mostly surrounded by high-altitude coastal cliffs and bed rocks, but various kinds of tourist attractions and harbor facilities are being developed and expanded in this area. Thus, this study aims to comprehend the climatic change aspects of Jeju Island by comparing typical severe weather element, such as minimum air pressure, maximum wind speed and maximum instantaneous wind speed of typhoon with other Korean coastal areas’ and grasp the risk of surges as the size and strength of typhoons are more increasing recently.

After calculating the design water level of Seogwipo Harbor with Harbor and Fishing Port Design Standard (Ministry of Maritime Affairs and Fisheries, 2005) applied variously, this study reviewed and compared it with coastal facilities and coastal region altitudes in Seogwipo coastal area. Thus, the tidal data of Seogwipo Tide Station, NORI (National Oceanographic Research Institute) was analyzed to calculate the annual extreme water level, annual maximum tidal residual and maximum stormy surge height when a typhoon goes through this area.

In addition, by establishing and applying a system of stormy surge numerical simulations for Seogwipo coastal area, this study calculated the storm surge height of each typhoon. Then, this study determined the design water level by values provided by considering the maximum high water level into the results of extreme water level frequency analysis and surge height frequency analysis.

ANNUAL CHANGE OF SEVERE WEATHER ELEMENTS

As a kind of a tropical depression, typhoons usually occur in the southwestern region of the North Pacific Ocean, and when they are about to arrive in the Korean Peninsula, they go through the peak period, and while going through the land, they become weaker in strength and dissipate at last. Accordingly, right before its landing, a typhoon has the greatest force, but after landing, it normally becomes weaker to some degree (Ministry of Government Administration and Home Affairs, 2002). Compared to Japan geographically, the Korean Peninsula is less affected by typhoons, but since it is located on the way of typhoons moving northeastward, the Korean Peninsula gets directly affected by a couple of typhoons every year. According to the Typhoon White Book (KMA, 1986), when a typhoon is developed around an equatorial front, and moves northward and arrive at 32~40N, 120~138E, it is defined as a typhoon affecting the Korean Peninsula.

Prior to applying a stormy surge numerical simulation, this study examined annual climatic changes (between 1960 and 2008) from the data of air pressure

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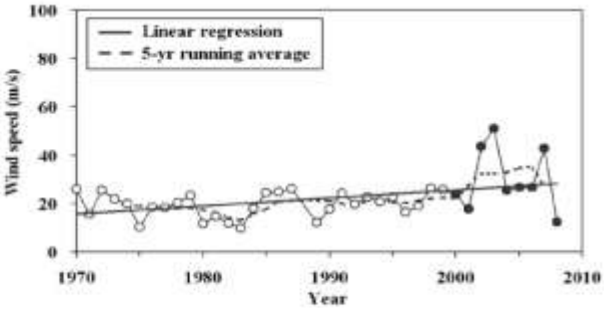
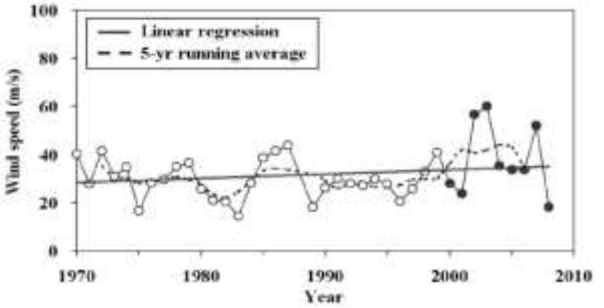
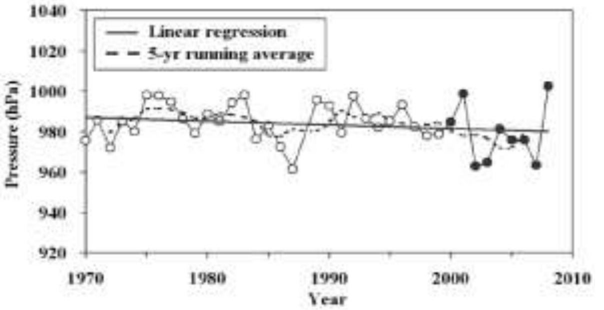
and wind, which are typical meterological elements related to typhoon activities. By reviewing data regarding the maximum wind speed, maximum instantaneous wind speed and minimum air pressure observed by 22 weather stations located in coastal points, this study suggested the annual change rate of each coastal area and the total change during the period of data. It shows that the maximum wind speed in Jeju coastal area is greatly increasing, compared to other coastal areas, and the maximum instantaneous wind speed is all increasing similarly in Jeju coastal area, the west coast and the south coast of Korea. However, the minimum air pressure is found to greatly decrease in the south coast and Jeju coastal area.



(a) Maximum wind speed



(b) Maximum instantaneous wind speed



(c) Minimum air pressure

Fig. 1 Wind speed and air pressure in Jeju

Fig. 1 shows annual changes and mean values of typhoon movement in the meterological data of Jeju coastal area.

Considering the fact that most of the typhoons greatly damaging the Korean Peninsula had a path from Jeju coastal area to the south coast, this study found out that the strength of typhoons is constantly increasing, especially to the Korean Peninsula. As mentioned by lots of other researches published recently, one of the main causes for increasing typhoon activity and strength all over the world can be found in the sea surface temperature rise caused by climatic change.

Analysis of Tidal Elevation Data

For basic data of the design water level of Seogwipo Harbor, this study analyzed the one hour-interval tidal elevation data provided by Seogwipo Tide Station of NORI (1985 to 2010).

Table 1 Annual maximum high water level

Year	H. W. L		Year	H. W. L	
	extreme	1hr		extreme	1hr
1985	316	314	1998	333	328
1986	317	314	1999	330	328
1987	328	328	2000	339	339
1988	322	320	2001	347	346
1989	329	328	2002	339	337
1990	330	328	2003	335	333
1991	325	324	2004	345	345
1992	325	324	2005	326	326
1993	327	327	2006	333	333
1994	326	324	2007	331	330
1995	325	322	2008	328	327
1996	327	325	2009	340	339
1997	338	338	2010	347	345

Table 1 shows annual maximum high water level values in Seogwipo, extracted from the extreme water level and one hour-interval water level data provided by the homepage of NORI. This study also carried out a harmonic analysis of annual tidal elevation data, through which created predicted tidal levels of a relevant year. Then, through their differences, this study calculated tidal residuals as shown in Table 2.

This study separated the maximum tidal residual of a relevant year from the maximum surge height by the influence of a typhoon in the relevant year, while considering that there was no maximum surge height in the periods (1988, 1990, 2008 and 2009) when the Korean Peninsula was not directly affected by a typhoon. The results obtained by analyzing the tidal elevation data was used as basic data to calculate the design water level of Seogwipo Harbor, which would be described in the latter part of this study.

Table 2 Maximun tidal residual and Storm surge height

Year	Tidal residual		Year	Tidal residual	
	annual	typhoon		annual	typhoon
1985	50.8	50.8	1998	48.3	32.2
1986	67.3	67.3	1999	48.2	48.2
1987	59.3	56.0	2000	38.0	37.6
1988	30.7	-	2001	49.5	17.1
1989	37.9	29.4	2002	88.8	88.8
1990	34.3	-	2003	38.3	38.3
1991	52.0	52.0	2004	45.9	38.3
1992	24.2	17.8	2005	47.2	47.2
1993	42.0	42.0	2006	41.6	41.6
1994	42.8	42.8	2007	40.5	40.5
1995	32.2	32.2	2008	28.1	-
1996	33.2	24.7	2009	45.6	-
1997	49.7	46.7	2010	24.1	24.1

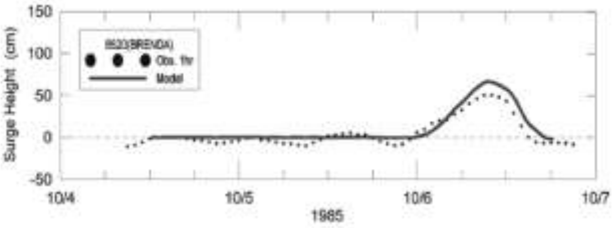
CALCULATION OF SURGE HEIGHTS OF MAIN TYPHOONS

To reflect surge heights obtained through the results of numerical simulations for each typhoon in the past on the design water level, this study established a system of numerical simulations by using HD module of Mike21 Model for Seogwipo coastal area. The broad-area matrix was set up for East China Sea including Korea, Japan and Taiwan to sufficiently reflect the reappearance of typhoon development and progressing paths, and detailed bands were established to reflect influences of coastal lines and water depth change. Fig. 2 shows calculation domains. The lattice spacing of Area-1 is 32,400m, and by reducing the lattice size by 1/3, this study established Area-5 in a lattice interval of 400m.

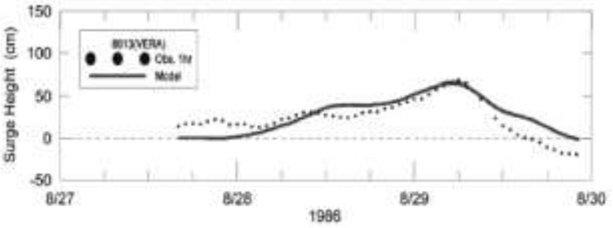
The data about water depth and coastal lines of calculation domains was based on digital charts, digital maps and water depth measurement data released by NORI. To verify the numerical model, this study selected 3 main typhoons causing great surges in Seogwipo Harbor in the past and compared them with the time-series observed surge heights as shown in Fig. 5. As a result, it was found that the typical path of typhoons causing great surges in Seogwipo Harbor was mainly led to landing the south coast of Korea like Typhoon Rusa, or passing through the Straits of Korea.

Suggesting values calculated by the results of observed surge heights during main typhoon influential periods and numerical simulations, Table 3 shows surge heights by the top 22 typhoons as equally as the number of maximum surges per year as shown in Table 3. The maximum surge height in Seogwipo was observed as 88.8cm during the Typhoon Rusa (0215) attack in 2002, and surge heights over 50cm were observed in Typhoon Vera (8613) and Typhoon Brenda (8520).

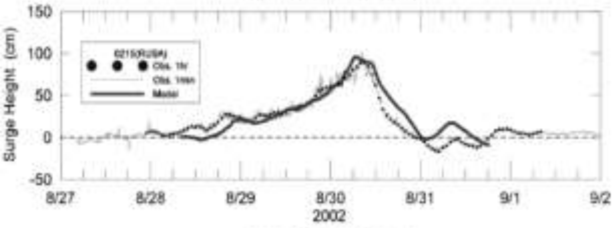
Fig. 2 Calculation domains



(a) 8520(BRENDA)



(b) 8613(VERA)



(c) 0215(RUSA)

Fig. 3 Simulated storm surge heights

Table 3 Storm surge height (cm) at Seogwipo

No.	Typhoon	Storm surge height(cm)	
		Obs.	Cal.
8508	KIT	40.4	35.5
8520	BRENDA	50.8	66.3
8613	VERA	67.3	65.5
8705	THELMA	56.0	71.1
8712	DINAH	41.0	46.9
9109	CAITLIN	37.1	51.8
9112	GLADYS	52.0	52.7
9307	ROBYN	42.0	38.2
9414	ELLIE	42.8	47.6
9429	SETH	34.6	59.9
9719	OLIWA	46.7	47.0
9905	NEIL	36.4	35.5
9907	OLGA	48.2	49.5
0014	SAOMAI	37.6	39.2
0215	RUSA	88.8	95.5
0314	MAEMI	38.3	52.7
0418	SONGDA	38.3	50.3
0514	NABI	47.2	49.2
0603	EWINIAR	41.6	43.0
0610	WUKONG	32.3	38.1
0613	SHANSHAN	36.0	61.7
0711	NARI	40.5	44.3

Application of Virtual Typhoon Numerical Simulations

In this study, a method of grasping the characteristics of tidal waves with a linearized virtual typhoon simulation (Park Seon-joong et al., 2009) was equally applied to Seogwipo coastal area. A linearized typhoon path was created with information about the strength of Typhoon Maemi, and by moving it from side to side, this study combined 10 paths and 5 attack angles to examine change in surge height for various virtual linearized paths.

Fig. 4 shows a graph about attack angles generating the maximum surge height of each path, and a path with the highest surge was marked with a thick solid line. Here, Virtual Typhoon T1 to T10 were provided to move a path from side to side in an interval of 0.5 degree from the center of Seogwipo, and a1 to a5 showed attack angles increasing by 10 degrees between 45 and 85 degrees from the northern part (90 degree). In case that Typhoon Maemi is actually linearized, it corresponds to T4_a4 marked with a dotted line, and its surge height is 51cm. On the other hand, a virtual typhoon having most effect on Seogwipo was one with its path along T3_a1, and its surge height was calculated as 88cm.

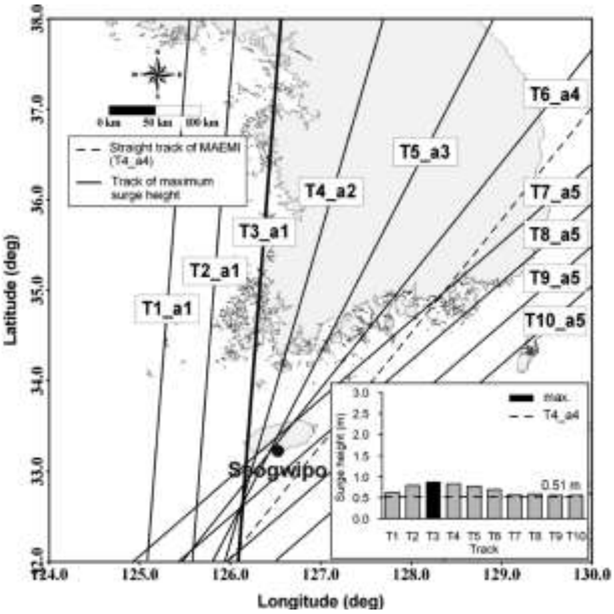


Fig. 4 Virtual typhoon track

In case of Seogwipo coastal area, the maximum surge height likely to occur as the typhoon strength is reinforced was found to be 93 to 100cm in the condition of 50 years’ frequency and 107 to 114cm in the condition of 100 years’ frequency.

Calculation of the Design Water Level of Seogwipo Coastal Area by Storm Surges

To calculate the design water level by stormy surge, methods suggested by Harbor and Fishing Port Standard can be largely divided into three kinds. These three different methods were divided by highest high water levels, water level with a surplus of these water levels, tidal water levels of certain reappearance year (ex.: 50 years’ reappearance period) and water levels in combination of approximately highest high water levels and surge heights. Particularly, this study calculated the design water level for 50 years’ reappearance period through basic data about approximately extreme high water levels, annual extreme high water levels, annual maximum tidal residuals and maximum surge height during typhoon attacks.

On the premise that if a wanted reliability can be secured with any extreme value distribution function used, any problems basically won’t take place during the process of analysis (Jeong Shin-taek et al., 2008), this study applied GEV (Generalized Extreme Value), Gumbel and Weibull distribution functions that are usually and widely used for extreme value distribution analysis. As a method to estimate parameters, this study used Moment Method, Maximum Likelihood Method and Probability Weighted Moment Method, and for the goodness-of-fit test, this study applied χ 2-test, Kolmogorov-Smirnov test, Cramervon Mises test and PPCC (Probability Plot Correlation Coefficient) test.

Table 4 Design water level at Seogwipo

	case	Design water level(cm)
1	High water level (NORI)	347.0
2	High water level (extreme)	355.3
3	High water level (1hr-tidal data)	355.7
4	Tidal residual (annual Max.) + App.H.H.W	79.7+303.2 = 382.9
5	Storm surge height (annual Max.) + App.H.H.W	84.8+303.2 = 388.0
6	Storm surge height (Obs., 50yr) + App.H.H.W	82.2+303.2 = 385.4
7	Storm surge height (Cal., 50yr) + App.H.H.W	97.4+303.2 = 400.6
8	Virtual typhoon Storm surge height (Cal., 50yr) + App.H.H.W	100.2+303.2 = 403.4

Table 4 is about the design water level of Seogwipo coastal area, provided by using the extreme high water levels and surge heights of 50 years’ frequency, shown as a range of DL(+) 347~403 cm. In case that the design water level of Seogwipo is calculated with the results of stormy surgy numerical simulation reflected from a conservative point of view, it seem appropriate to calculate it as about 400cm, which is a value about 15cm higher than 385cm, the design water level of Seogwipo Harbor suggested by Ministry of Maritime Affairs and Fisheries (2010).

Since the altitude of harbor facilities in Seogwipo Harbor is established as DL(+) 400 to 800cm (Choi Byeong-ho et al., 2004), it was analyzed to be safe for the design water level calculated by this study. However, since the frequency analysis conducted by this study for future statistical predictions is based on the premise that the present climate of the earth should not change in statistical features for the next 50 or 100 years’ period, it fails to reflect the effect of recent various climatic changes, such as stronger typhoon attacks.

As mentioned earlier, changes in severe weather elements of a typhoon are rapidly reinforced, so it seems quite difficult to determine right and safe altitudes of coastal and harbor facilities with the present methods of calculating design water levels. Since this matter corresponds to almost all the harbor and coastal areas in Korea as well as Seogwipo Harbor, it is required to constantly carry out a DB management of necessary data, such as altitudes of facilities in addition to data about tidal observation. At the same time, it is needed to seek plans that can be applied to the present work system through technical supplements for various stormy surge numerical simulation application plans.

CONCLUSION

By analyzing annual changes in the data of air pressure and wind speed that are typical meterological elements of a typhoon, this study came to discover that the extreme values of maximum wind speed, maximum instantaneous wind speed and minimum air pressure in Jeju coastal area occurred 21 times, 7 times and 10 times respectively in the 2000s, which shows a great rise, compared to other coastal areas.

For an examination of the design water level of Seogwipo coastal area by stormy surge, this study applied methods based on Harbor and Fishing Port Standard, and by analyzing surge heights during typhoon attacks, based on highest high water levels, tidal residuals per hour and surge heights during typhoon attacks by the results of observation and stormy surge numerical simulations, this study calculated the design water level.

Through this study, the design water level of Seogwipo coastal area was predicted as about 400cm, which shows the present harbor facilities in Seogwipo Harbor are safe. Nevertheless, out of all the 8 kinds of methods applied to calculate the design water level, 7 ones contain a statistical feature that the climate won’t change for the next 50 years, except one method applying virtual typhoons over 400cm of design water level, so they fail to reflect recent rapidly-changing climatic aspects and the effect of typhoon strength reinforced. Accordingly, by applying stormy surge numerical simulations whose validity is verified in various ways to the present work system, in addition to the method of this study calculating a design water level with virtual typhoons applied, it is necessary to seek plans that can be used to calculate design water levels by stormy surge and reflect various natural disaster-prevention programs and projects.

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