WAVE CHARACTERISTICS CAUSING COASTAL DAMAGE AROUND THE TYPHOON STORM ZONE: ANALYSIS AT OSATO COAST FOR TYPHOON NO. 19, 2019

Kosuke Nakagawa, Tokushima University, nakagawa@kisocon.co.jp
Ryoichi Yamanaka, Tokushima University, ryoichi_yamanaka@tokushima-u.ac.jp
Hironori Okegawa, Kiso Kensetsu Consultant, okegawa@kisocon.co.jp
Yasunori Kozuki, Tokushima University, kozuki@tokushima-u.ac.jp

INTRODUCTION

The Osato Coast is located on the southeastern part of Tokushima Prefecture, and is a natural coastline of sand and gravel with a total length of approximately 4 km facing the Pacific Ocean. An artificial pine forest located behind the coastline is used for disaster prevention and recreation (Fig. 1).

Typhoon No. 19, which passed through eastern Japan from October 12 to 13, 2019, caused river flooding and strong wind damage in various parts of Japan. On the Osato Coast, waves caused inundation damage to pine forests and large-scale beach deformation. This is the largest damage recorded in history, and the pine forest in the inundation area died. The objective of this study is to evaluate the wave characteristics and damage generation process during the damage.

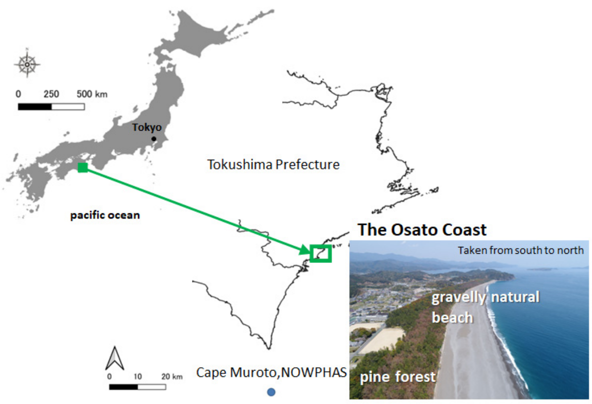

Figure 1 - Location map

WAVE CHARACTERISTICS OF TYPHOON NO. 19 IN 2019

WAVE CONDITIONS AND CHARACTERISTICS

We summarized the wave data from the Nationwide Ocean Wave information network for Ports and HArbourS (NOWPHAS) Cape Muroto that was gathered by NOWPHAS managed by the Ports and Harbours Bureau of the Ministry of Land, Infrastructure, Transport and Tourism of Japan (Fig. 2). Wave observation values showed that "swell waves" with a period of at least 8 s and waveform gradient of less than 0.025 continued for at least three days from around midnight on October 10, reaching a peak of a significant wave height of 10.84 m and period of 17.2 s at midnight on October 12.

Based on past observation data from NOWPHAS Cape Muroto (seven years from 2015 to 2021), we extracted the maximum values of "swell waves" in each year, specifically the annual maximum wave height and annual maximum period, and compared the values over time. Fig. 3 shows a scatter plot of the significant wave height and significant period. "Swell waves" occurred every year, but those in Typhoon No. 19 were an exceptional combination of wave height and period. Furthermore, they can be considered unique waves that simultaneously satisfied the factors of increasing the wave overtopping rate, etc., together with the duration of "swell waves."

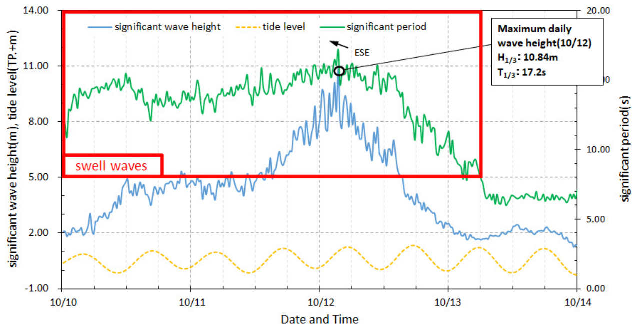

Figure 2 - Typhoon No. 19 wave observations (from Cape Muroto, NOWPHAS)

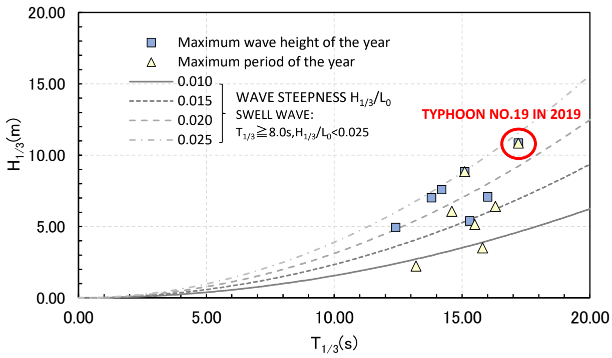

Figure 3 - Comparison of swell waves over time (from Cape Muroto, NOWPHAS)

OSATO COAST WAVE ESTIMATION AND DAMAGE OCCURRENCE PROCESS

WAVE ESTIMATION OFF OSATO COAST

The wave estimation involved calculations based on the energy balance equation, which is one of the refraction and shallow water calculation methods for multidirectional irregular waves. However, the energy balance equation used in this analysis included the diffraction term introduced by Mase and others (Mase et al., 1999). Table 1 lists the wave conditions. The values for the offshore waves were set on a trial basis to match the observed values at the daily maximum wave height (October 12) in the abovementioned wave data.

Fig. 4 shows the significant wave height distribution map as the calculation result. It was estimated that a significant wave height of at least 10 m occurred off the Osato Coast. This is similar to the observed value from the NOWPHAS Cape Muroto, and the wave characteristics are regarded as similar.

Table 1 - Calculation conditions (energy balance equation)

Item		parameter
input wave (Offshore wave)	condition	Typhoon 19, 2019 Maximum daily wave height October 12, 3:20
	wave direction※1	N112.5°
	wave height Ho(m)	10.91
	period To(s)	17.2
	wavelength Lo(m)	461.5
off Cape Muroto, NOWPHAS	significant wave height (m)	10.84
	significant period (s)	17.2
	wave direction※1	N112.5°
H_o/L_o		0.023
S_{max}		25
Number of directional divisions Δα=4.0°		45
Frequency division number		10
Tide level（T.P. m）		1.00

※1 clockwise angle from north

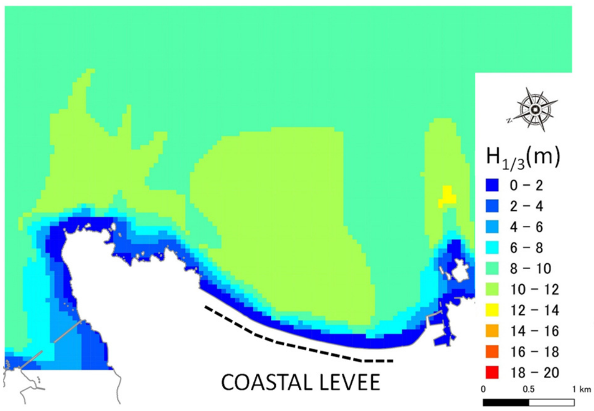

Figure 4 - Distribution map of significant wave height

EVALUATION OF DAMAGE GENERATION PROCESS

We evaluated the inundation damage from the perspectives of wave backflow and runup using the surveyed cross-sectional views before and after the typhoon (Fig. 5).

a) Backflow: Survey points nos. 7, 12, and 17, which had major inundation damage, exhibited deposition on the landward side of the backshore berm position prior to the typhoon. Moreover, at some locations, such as no. 7, the sedimentation exceeded the crest height of the coastal embankment. It A linear correlation between sedimentation height and backflow height has already been established (Udo et al., 2006) and in this case, the backflow height due to the long-period waves reached a maximum position in the sedimentation area, which may have contributed to the inundation of the hinterlands. Meanwhile, at the coastal start and end points (survey points nos. 0 and 22), where there were few inundated areas, the backshore berms were eroded due to the action of the long-period waves, but there was almost no change in the topography of the offshore beach. This shows that the sediment moved to the center of the coastline. Unlike the former, inundation due to the backflow was avoided by lowering the backshore and foreshore.

b) Wave runup: This was calculated using the modified virtual gradient method (Nakamura et al., 1972) for the topography before and after the typhoon (Table 2). At nos. 7, 12, and 17, the waves overtopped the embankment in the topography both before and after the typhoon. At nos. 0 and 22, the waves did not overtop the topography before the typhoon; however, at no. 0, the waves overtopped the topography after the typhoon, which was consistent with the range of inundation distribution.

CONCLUSION

The waves that hit the Osato Coast due to Typhoon No. 19 were the largest “swell waves” ever observed in history in terms of the scale of wave height and period. Furthermore, the waves were considered unique as they simultaneously fulfilled the elements of increasing wave overtopping rate along with the duration of “swell waves.” These long-period waves caused large-scale beach deformation. However, it can be inferred that the inundation damage was mainly caused by backflow at points where sediment movement contributed to sedimentation, and inundation damage was caused by overtopping waves at points where sediment movement contributed to erosion.

The damage caused by “swell waves” has been increasing in recent years (Takashima et al., 2015) and the frequency of “swell waves,” coastal disasters, and beach deformation is expected to increase due to changes in typhoon paths and increased intensity, which are considered to be the effects of global warming (Kashima et al., 2009). Here, sandy beaches on the coastline prevent hinterland inundation and overtopping as they are integrated with the embankment, providing an important facility for coastal disaster prevention. In the future, we will use sophisticated numerical models to evaluate and elucidate the mechanism of large-scale beach deformation that is caused by current waves, and use it to improve regional disaster prevention and the survival of pine forests.

Acknowledgment

This work was supported by JSPS KAKENHI Grant Numbers 18K04659 and 22K04335.

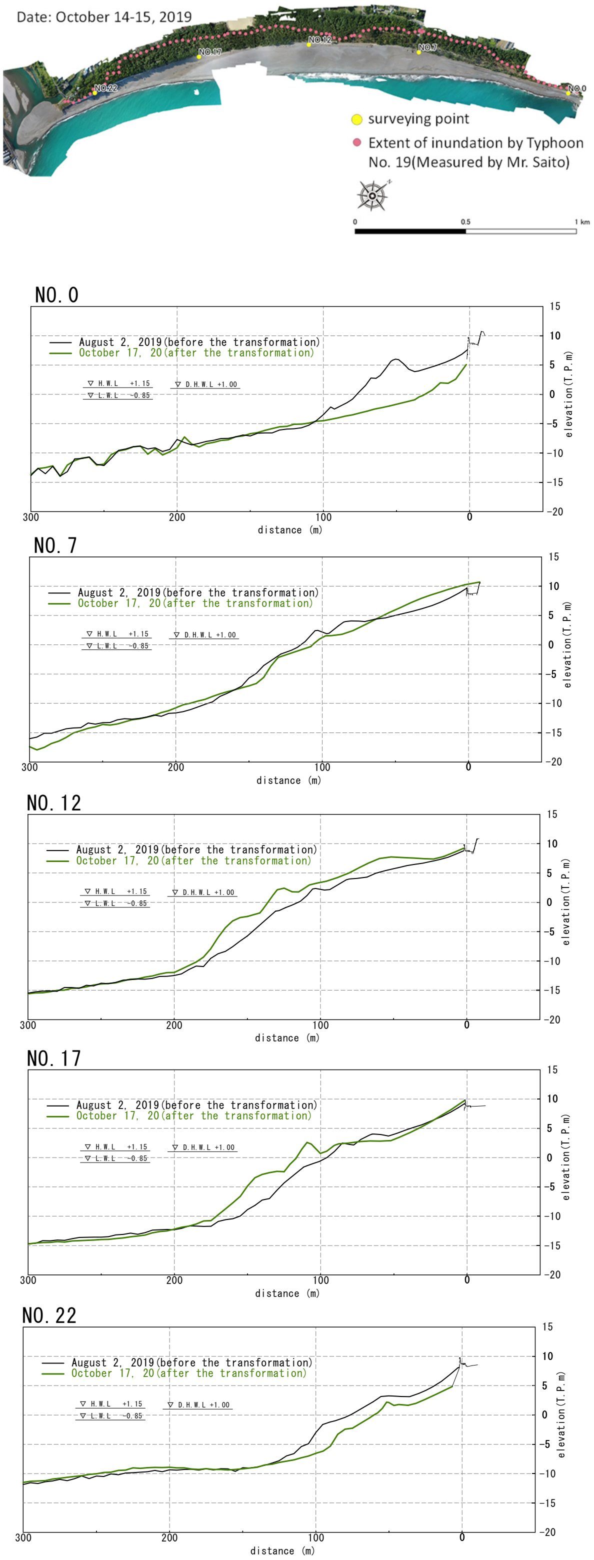

Figure 5 - Inundation distributions and beach cross sections before and after Typhoon No. 19

Table 2 - Calculation results of wave runup

Point	No.22	No.17	No.12	No.7	No.0
Levee Height (TP m)	9.8m	9.86m	9.87m	9.76m	9.74m
before the transformation	9.3m	10m	10m	10m	9.7m
after the transformation	9.4m	10m	9.82m	10m	10.8m

REFERENCES

Hajime Mase, Tomotsuka Takayama, Shoji Kunitomi, Toyoaki Mishima (1999): Multi-directional spectral wave transformation model including diffraction effect, Proceedings of JSCE, No. 628, II-48, pp. 177-187.

Keiko Udo, Yoshiaki Kuriyama (2006): Effects of waves on the backshore deformation process, Proceedings of Coastal Engineering, JSCE, no. 53, pp. 546-550.

Mitsuru Nakamura, Yasuo Sasaki, Jyoji Yamada (1972): Study on wave launching heights in a double cross-section, 19th Proceedings of Coastal Engineering, JSCE, pp. 309-312.

Hiroshi Takashima, Yukitomo Tsubokaw, Toshio Endo, Yasuhiro Takahashi, Yoshihiro Utsunomiya, Eriko Matsufuji (2015): Evaluation method of offshore design wave considering long period swell, Proceedings of JSCE, series B2 (coastal engineering), vol. 71, no. 2, pp. 91-96.

Hiroaki Kashima, Katsuya Hirayama, Tetsuya Hiraishi, Katsuyoshi Shimizu (2009): Estimation of encounter timing of swell by using nationwide wave observation system (NOWPHAS), Technical note of the Port and Airport Research Institute, no. 1191.