EXPERIMENTAL STUDY OF THE EFFECT OF VEGETATION ON WAVE OVERTOPPING UNDER STRONG WINDS

Yudai Aoki, Niigata University, f22e023k@mail.cc.niigata-u.ac.jp
Kosuke Sasaki, Niigata University, t20a049a@mail.cc.niigata-u.ac.jp
Ryota Nakamura, Niigata University, r-nakamura@eng.niigata-u.ac.jp
Kunihiko Ishibashi, Niigata University, isibasik@eng.niigata-u.ac.jp
Katsuhiro Yamamoto, Niigata University, yamaka@eng.niigata-u.ac.jp

INTRODUCTION

Coastal structures at ports and coastlines in Japan are usually built with concrete. These grey infrastructures can increase the concentrations of greenhouse gases and lead to the global warming. In recent years, a changing climate as a result of global warming potentially leads to unexpected coastal hazards. For example, on 9th September 2019, one of the most severe typhoon Faxai made landfall in Japan's Kanto region, causing widespread and severe damage. On Fukuura coast located on the western side of Tokyo Bay, the typhoon Faxai caused the collapse of seawalls due to high waves and flooding to the hinterland due to overtopping waves. Therefore, in recent years, new disaster management measures in coastal areas have been required in addition to grey infrastructure, and green infrastructure become alternatives. For instance, mangroves have the potential to attenuate wave intensity due to their shape characteristics (Quartel et al., 2007). In addition, Dong et al. (2020) show the effect of placing vegetation in front of seawalls in an experiment under windless conditions. Their result shows higher vegetation density could lead to lower the wave overtopping discharge. However, there are few studies that have examined the effects of vegetation on wave overtopping during storms (Vuik et al., 2016). Therefore, in this study, we focused on studying wave overtopping under strong winds against vertical seawalls, investigated the effects of vegetation on wave overtopping rate, and verified the effectiveness of green infrastructure.

METHODOLOGY

In this study, a hydraulic model experiment was conducted to investigate the effects of vegetation on wave overtopping under strong winds. The experiments at a scale of 1/40 were conducted in the hydrodynamics laboratory at Niigata University, Japan. The lab setting assumed the vertical seawalls of Fukuura coast. Figure 1 shows a schematic of the experimental setup in this study. A two-dimensional wave flume (length 10 m, height 0.8 m, and width 0.4 m) equipped with a wind fan and an air duct on top was used for the experiments. The vertical seawall used in the experiments was the similar to that at Fukuura coast. The water depth was fixed at 0.35 m. Three wind speeds U were used: 0 m/s (no wind), 7.24 m/s (middle wind), and 10.21 m/s (high wind). Two patterns of vegetation density, sparse and dense, were used. The vegetation was placed in front of the vertical seawall. Regular waves were generated by a flap-type wave maker behind the air duct with periods ranging from approximately 1.0 to 1.9 seconds. The overtopping water was captured in a plastic tray placed behind the vertical seawall.

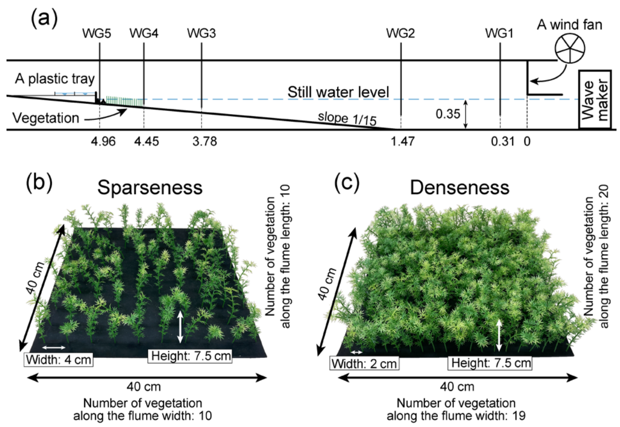

Figure 1 - (a) Schematic of experimental setup applied in this study. (b) Sparse vegetation used in the experiments. (c) Dense vegetation used in the experiments.

RESULTS AND DISCUSSION

Figure 2 shows the relationship between the wave overtopping rate and wave steepness of incident wave. The black solid line shows the general allowable wave overtopping rate in Japan, which is set for areas where houses and public facilities are densely located behind seawalls and serious damage from wave overtopping is especially expected. The black dashed line shows the general allowable wave overtopping rate in Japan, which is set for areas where there are no houses behind seawalls. Inagaki et al. (2023) conducted a wave overtopping experiment in the same laboratory under the same experimental conditions as this study without the presence of vegetation. They reported that the maximum wave overtopping rate without vegetation in front of the vertical seawall was 0.4, which is well above the allowable overtopping rate of 0.02. In this study, the experiment was conducted with vegetation in front of the vertical seawall, and the maximum overtopping rate was approximately 0.019, which is below the allowable overtopping rate of 0.02. Therefore, vegetation reduces the overtopping rate, confirming the effectiveness of placing vegetation in front of vertical seawalls. The result also shows that the overtopping rate was smaller under a higher density of vegetation case than under a lower density of vegetation case. These tendencies were not affected by the wave steepness and wind speed. This indicates that more vegetation could reduce the overtopping rate.

Figure 3 shows the relationship between wave height before breaking and wave overtopping rate. The wave overtopping rate tended to increase as the wave height before breaking increased, and the wave overtopping rate decreased when the density of vegetation was higher than when it was lower. This suggests that wave overtopping

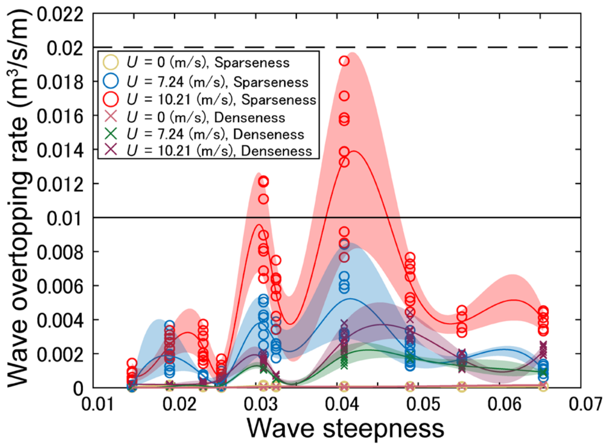

Figure 2 - Relationship between wave overtopping (in real scale) and wave steepness. Solid lines are spline curves (cubic polynomial interpolation) of the mean wave overtopping rates for each case, representing the interpolated mean values. The shaded areas are bounded by spline curves of the maximum and minimum wave overtopping rates for each case. The black solid and black dashed lines are the general allowable overtopping rates of seawalls in Japan.

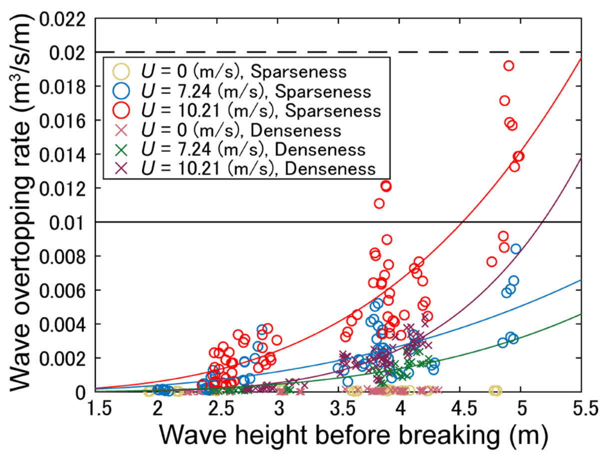

Figure 3 - Overtopping rate (in real scale) arranged by wave height before breaking (in real scale), wind speed, vegetation density (sparseness, denseness). Solid lines are approximate curves for each case by power law.

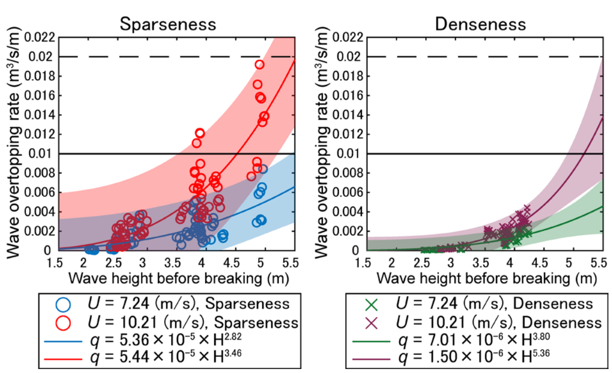

Figure 4 - Relationship between wave overtopping rate and wave height before breaking. Solid lines are approximate curves for each case by power law. The shaded areas show the 99% prediction intervals for overtopping rate in each case.

rate is related to wave energy before breaking, and wave energy decreases as the waves pass through the vegetation. Therefore, the wave overtopping rate can be smaller under the high-density vegetation case than under the low-density vegetation case.

Figure 4 shows the equation for the relationship between wave height before breaking and overtopping rate, and the 99% prediction interval derived from the results of this study. The results indicate that when the wind speed is 10.21 m/s and vegetation density is low, wave heights exceeding 5 m before breaking may cause the overtopping rate to exceed the allowable overtopping rate of 0.02. On the other hand, when the vegetation density is high, the overtopping rate may slightly exceed the allowable overtopping rate of 0.02 at wave height exceeding 5.5 m. At a wind speed of 7.24 m/s, in the case of low-density vegetation case, the overtopping rate may exceed the allowable overtopping rate of 0.01 when the wave height before breaking exceeds 5.5 m, however, in the case of high-density vegetation case, the overtopping rate is less than the allowable overtopping rate of 0.01. These results show that in the case of high-density vegetation case, the wave overtopping rate rarely exceeds the allowable wave overtopping rate up to a wave height of 5.5 m before breaking, even when wind speed increases. These results indicate that vegetation can be an effective measure to reduce the wave overtopping rate.

CONCLUSIONS

In this study, we conducted experiments on wave overtopping under strong winds by installing vegetation on the front face of the vertical seawall. As a result, the wave overtopping rate tended to increase as the wave height (wave energy) before breaking was higher, and the wave overtopping rate decreased when the vegetation density was higher. This suggests that the wave overtopping rate is reduced at higher vegetation density than at lower density, mainly because the wave energy can be reduced at higher vegetation density. Therefore, the results of this study indicate that green infrastructure can be effective in reducing wave overtopping rate. The results of this study suggest that it is expected that green infrastructure will be used as an alternative coastal disaster management measure in addition to conventional grey infrastructure.

REFERENCES

Dong, Abolfathi, Salauddin, Tan, Pearson (2020): Enhancing climate resilience of vertical seawall with retrofitting - A physical modelling study. Applied Ocean Research, 103, Article 102331.

Inagaki, Shibayama, Ishibashi, Nakamura, Esteban (2023): EXPERIMENTAL INVESTIGATIONS INTO THE EFFECT OF STRONG WINDS ON WAVE OVERTOPPING AT A VERTICAL SEAWALL. Coastal Engineering Proceedings, (37), structures.26.

Quartel, Kroon, Augustinus, Van Santen, Tri (2007): Wave attenuation in coastal mangroves in the Red River Delta, Vietnam. Journal of Asian Earth Sciences, 29(4), 576-584.

Vuik, Jonkman, Borsje, Suzuki (2016): Nature-based flood protection: The efficiency of vegetated foreshores for reducing wave loads on coastal dikes. Coastal Engineering, 116, 42-56.