Effect of Coastal Sand Dune for Reduction of Tsunami Pressure on Seawall

Tetsuya Hiraishi
Disaster Prevention Research Institute, Kyoto University
Fushimi, Kyoto, Japan

Tetsuya Okutani and Sou Iwata
Graduate School of Engineering, Kyoto University
Saikyo, Kyoto, Japan

ABSTRACT

The estimation of tsunami height and arrival time is very important to design the coastal tsunami prevention and port protection facilities. The numerical simulation can be performed using not only simple topography conditions, but also complex topography. However, the numerical results in relatively complex areas may have errors in the calculation. Coastal dunes may exist at the front of the important structures like tidal walls. This paper discusses on the variation of tsunami force acting the tidal wall located behind the dune employing physical experiments.

KEY WORDS: Tsunami; coastal dune; model experiment, tsunami reproduction basin; wave force; seawall; movable bed experiment.

INTRODUCTION

Japanese coastal areas have high tsunami risk and the risk has been increasing year by year mainly due to the concentration of population and social property to urban areas usually located near coasts. Therefore, the prediction of future tsunami intensity and implementation of tsunami prevention technique are very important. The prediction with high accuracy needs the consideration with correct information of coastal geometry bordering sea. Natural coastal sand dunes may be effective to reduce the tsunami energy (Matuyama et al., 2012). Meanwhile the tsunami wave pressures acting on a vertical tide wall is estimated in Asakura formula (Asakura et al., 2000). Few papers concerns the tsunami pressures behind a relatively large sand dune. Figure 1 shows an example of coastal zone cross section. In the photograph, the wave incident direction is the right side and the center part becomes steep valley and the surface is scoured by wave action. The cross-section figures demonstrate that the coast has a hilly mound and the face is scoured by wave action. The scouring on the coastal hilly mound (dune) was generated in the 2011 Great East Japan Earthquake Tsunami (ex., Hiraishi et al., 2011). When a gigantic tsunami attacks, the tsunami wave may overflow the sand dune and reach to the coastal structures behind it. The tsunami wave pressure on the coastal dike located behind the dune may be varied by the existence of the dune compared with the case of no sand dune. The main purpose of this experiment is the prediction of the effect of the sand dune to reduce the tsunami wave pressure acting on the tidal wall. The effect of tsunami is very important to reserve the dune geometry in the target urban area. The experiment was carried out in the Tsunami Reproduction Basin in Kyoto University (Hiraishi el al.,2015).

Figure 2 shows the bird view figure of the basin. The model sand dune was installed at the edge of the slope with 1/10 inclination. In the following sessions, the second session expresses the experimental set-up and condition. The third session shows the experimental results and the forth discussion. The last session indicates the conclusions.

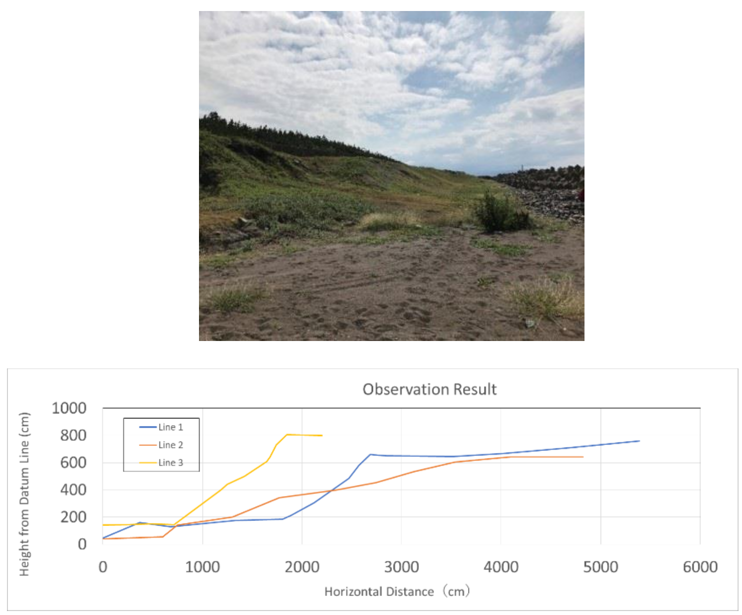


Figure 1 Cross section of sand dune (Joetsu Coast, Japan)

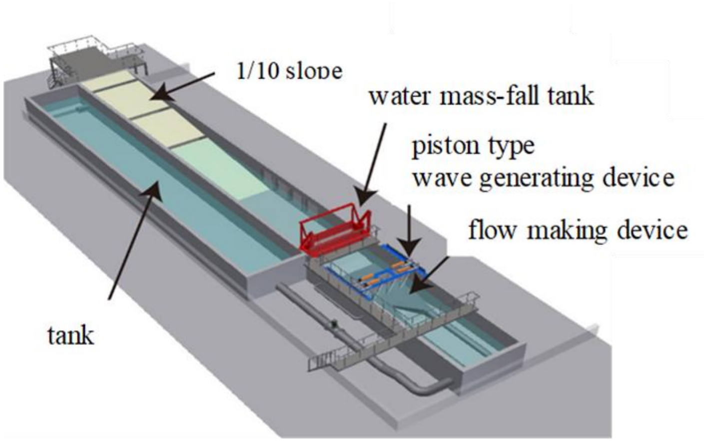


Figure 2 Bird view of Tsunami Reproduction Basin of Kyoto University

EXPERIMENTAL SET

Figure 3 shows the cross section of target coastal dune located at seaside of a seawall. The “unit” in the figure is “mm”. The height of seawall is 250mm and the length (in the transverse side) is 750mm. The diameter of sand composing the dune is 0.1 and 0.2mm for the case of movable bed-condition. For the comparison with case of slide face, the fixed dune which was covered in the wood plates was tested in the tsunami wave(soliton) and long waves.

The distance between the dune and tidal wall is varied in the model case. Two distance of 50 and 625mm is employed to indicate that the near-side wall and far-side one. The height of seawall is fixed to stop the over-topping by a normal-size tsunami. The normal-size tsunami corresponds to the design tsunami of seawall. The wave gages were equipped along the center line of wave channel.

Table 1 shows the experimental case. In the experiment, two type of waves were employed to compare the effect of wave period. One is the soliton wave and another is the long wave. The wave height was 12.5cm and it corresponded to about 10m as the scale was assumed to be 1/80. The distance (DIS) stood for that between the dune edge and seawall. DIS was varied from 80cm to 135cm in order to investigate the space effect behind the dune. The diameter was that of sand employed in the dune. “Try No.” indicates the trial number of the experiment with the same condition. At least five times, the same measurement was done in the experimental channel. The result in each case was calculated as the averaged value of the five times measurement data.

Figure 4 shows the elemental figure on the slip slope having the wave gages even on the 1/10 slopes. In this study wave profiles and velocity at WG-1 ～ WG-6 and V-6（Current meter) are employed for analysis. The sand dune is installed just behind the current meter V-6 and wave meter WG-6. The width of the dune model is 4m which is the same to the width of the basin. The model dune is divided into two part, one is the fixed bed and another the movable composed with real sand of the particle diameter 0.2 and 0.1mm. In the figure the brown part corresponds to the movable sandy part.

The wave pressure distribution on the tidal wall is measured by the pressure gages equipped on the straight line on the tidal wall line as shown in Figure 5. Asakura et al.(2000) already proposed the triangle distribution of tsunami wave pressure on a vertical wall in the run-up area. Their proposed distribution is a triangle distribution with a peak becoming the three times larger than maximum water level.

Table 1 Experimental case

Dune Type	Case	Wave Height (cm)	Wave Type	Distance (DIS) (cm)	Diame -ter (mm)	Try No.
Solid	Case-I	12.5	Soliton	137.5	0.2	5
Solid	Case-II	12.5	Soliton	80	0.2	5
Solid	Case-III	12.5	Long wave	137.5	0.2	5
Solid	Case-IV	12.5	Long wave	80	0.2	5
Remov	Case-V	12.5	Soliton	137.5	0.2	5
Remov	Case-VI	12.5	Soliton	80	0.2	5
Remov	Case-VII	12.5	Long wave	137.5	0.1	5
Remov	Case-VIII	12.5	Long wave	137.5	0.2	5
Remov	Case-IX	12.5	Long wave	80	0.2	5

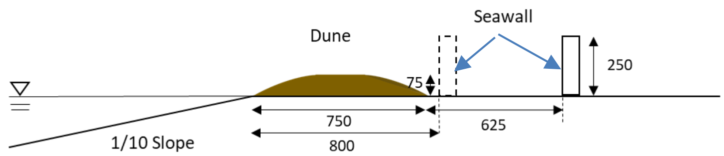


Figure 3 Cross section of dune and tidal wall model

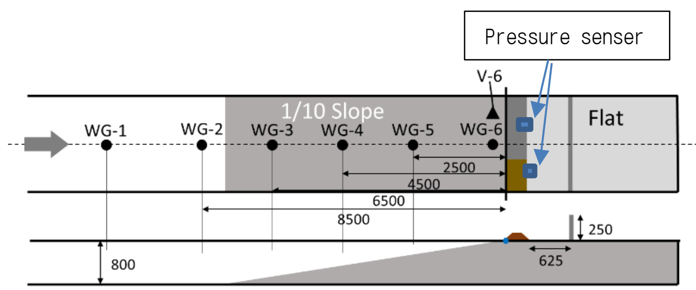


Figure 4 Implementation of wave gage and dune model

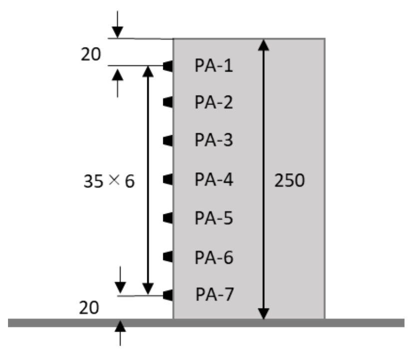


Figure 5 Model tidal wall and point of pressure gage

Figure 6 shows the tsunami wave profile observed in the offshore large experimental buoy station. The buoy is operated as one of the networks of NOWPHAS system (NOWPHAS, 2021) The location of the buoy is near to the epicenter of the 2011 Great East Japan Earthquake. Real tsunami profile shows the first peaks of Tohoku Great-Earthquake Tsunami. At the first, a large wave with peaky profile is coming, and after that small peaks continue and the lowest tsunami (negative wave) is following. Meanwhile, the generation system in the basin is applied to reproduce the solitary wave and the tidal current as shown in Figure 7.

The soliton wave is generated by the piston-mode operation. In the operation, the wave paddle was set back at the first time and pushed to the forward to make a single solitary wave. The tide in the channel was reproduced in a pump system. The pump can generate the flow at the maximum of 1.0m/s in the basin. The combination of solitary wave generation and tidal current reproduction at the same time makes the reproduction of tsunami wave with long period.

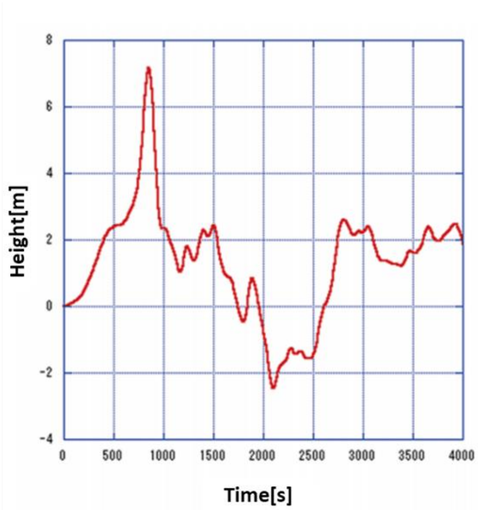


Figure 6 Tsunami wave profile obtained in an offshore buoy system

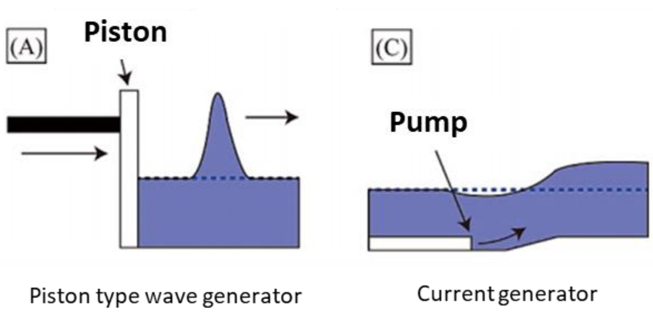


Figure 7 Generation mechanism of solitary wave and current

EXPERIMENTAL RESULT

Figure 8 shows the observed profile of tsunami waves at WG-1 and WG-6, and V-6. Observed tsunami profile is quite well reproducing one in the solitary wave at WG-1. The profile is transformed in shallower area mainly due to wave breaking and it is deformed in WG-6. The velocity profile at V-6 has a single peak and that is very sharp. A small peak at t=12.5s is due to the reflection wave. In this case, only the piston mode is employed for generation.

Figure 9 shows the combination wave profile. The combination tsunami wave is generated in the superposition of solitary wave, uniform current and several sinusoidal currents with different amplitude and period. The profile becomes the positive part of long wave like WG-1. The profile shows a slight twisting point at t=15s. That point becomes remarkable in WG-6 profile. The steep increasing of water level before t=20s in WG-6 corresponds to the soliton wave part of composed long wave. After steep increasing, the high-water level is kept. Even at WG-5, the long wave part is well kept in the profile and is much deferent from that in Figure 8. The profile at V-6 has the flat part more than 5s. The time is much longer than the case shown in Figure 8. In this case, the both systems of piston and current generator are employed to reproduced the tsunami wave.

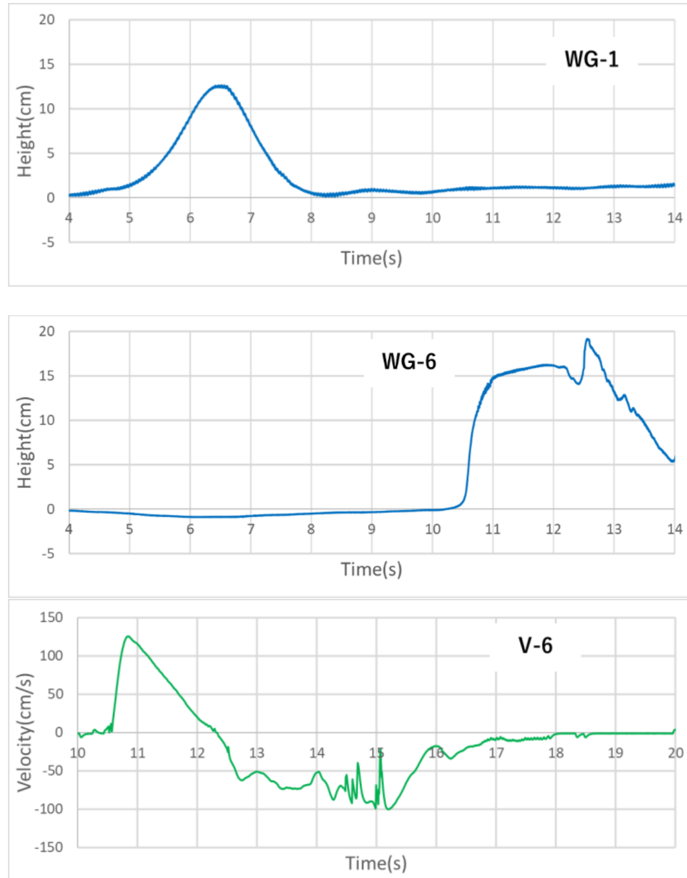
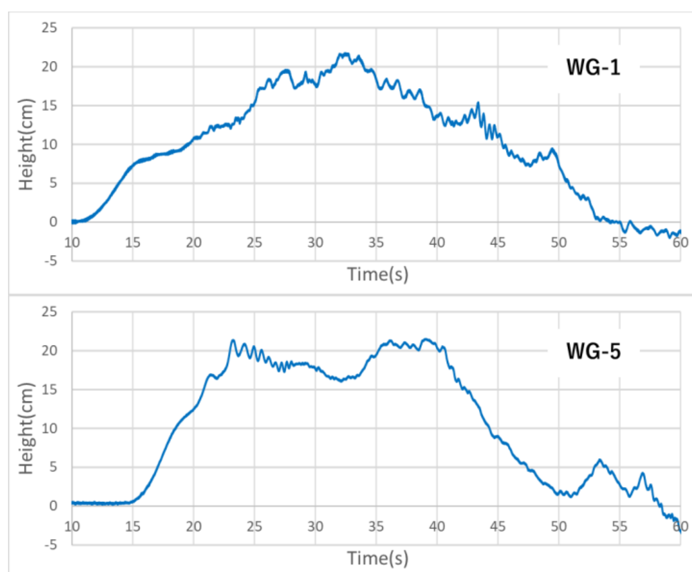


Figure 8 Wave and current profile of solitary wave
(Piston type wave generator is employed)



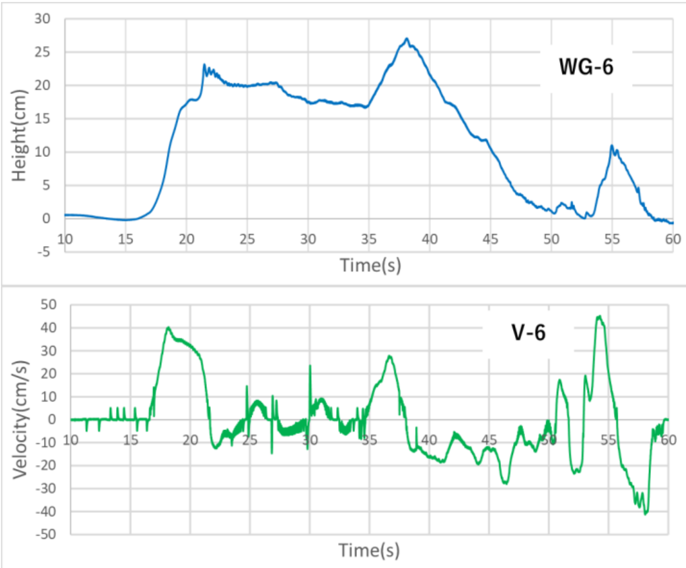


Figure 9 Wave and current profile of long wave
(Piston type wave maker and Current generator are employed)

Figure 10 shows the example of vertical distribution of observed wave pressure distribution. The total wave force is calculated by the integration of the wave pressures. The symbol Δh_1 is the height of the bottom senser from the sea bed. The symbol Δh_2 is the interval of each pressure senser.

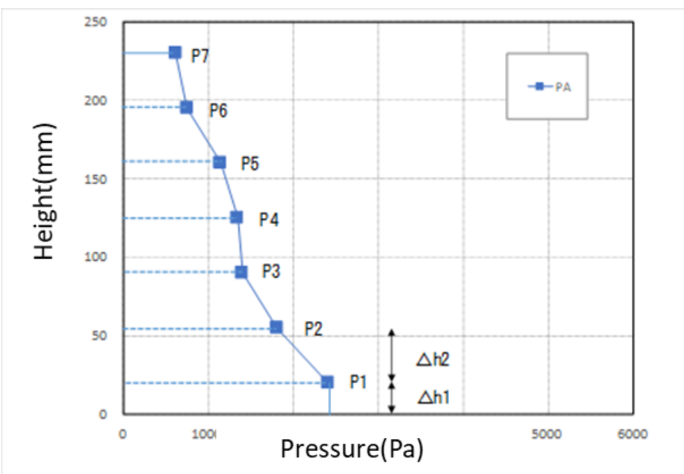


Figure 10 Distribution of wave pressure

Figure 11 shows the time series of observed wave force at the movable sand dune (PA: blue) and the fixed (PB: red) bed case. The case is Case-I in Table 1. The force peak appears 0.2s behind when the wave peak appears. The peak values of movable and fixed bed's look the same but the second peak value about 12,3s is different. The reason of difference is seemed the influence of reflection waves.

DISCUSSION

Here the wave pressure distribution was picked up when the maximum force appears. Figure 12 shows such the distribution of tsunami wave pressure on seawall in case of fixed bed and movable bed. The total force is almost equal but the both has the difference locally. In the lower part of the distribution, the pressure of movable bed becomes larger than that of fixed bed. The soliton wave energy is slightly reduced by the friction on the sandy dune and dune-transformation. Meanwhile the difference between the movable and fixed dune become remarkable in case of long wave.

Figure 13 shows the wave pressure distribution for the case of DIS=80.0cm. For almost all depth, the pressure in fixed dune becomes larger than the movable one. The reason why the long wave caused such a difficult works is the continuous flow action on the sandy layer. The uni-directional current may cause the deformation of sandy dune and large friction on it. Such disturbance due to sandy dune induces the reduction of tsunami force indicated in Figure 13.

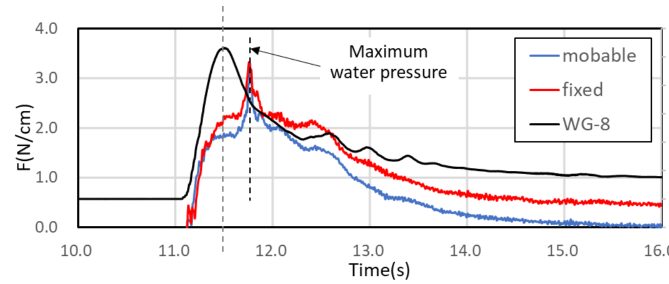


Figure 11 Comparison time-dependent profile of wave force in case of movable and fixed bed (Case I)

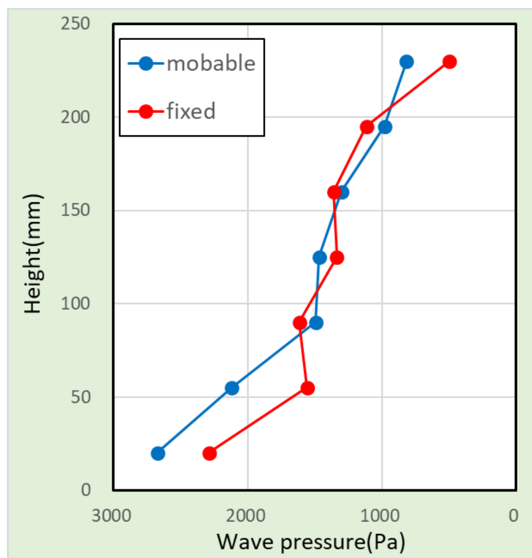


Figure 12 Comparison of wave pressure distribution of movable and fixed beds
(Comparison with Case II and Case VI)

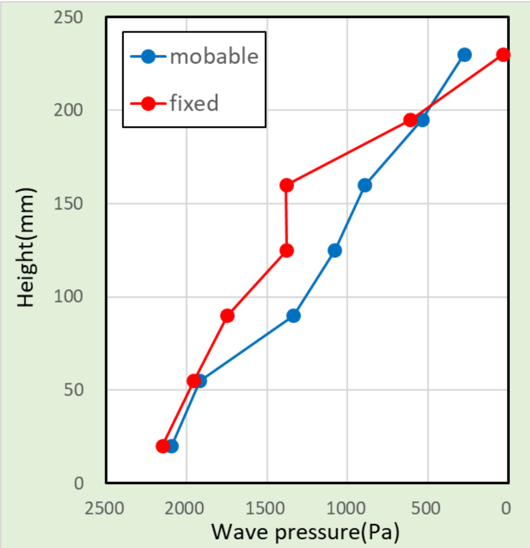


Figure 13 Comparison of wave pressure in removable and fixed dune for long wave
(Comparison with Case IV and Case IX)

In this session, we would like to compare the case with tidal barrier and the experimental case without sand dune in the power generation area. Figure 14 shows the situation of the case for seawall and without sand dune. The other condition like distance from the wave paddle is the same.

Figure 15 shows the comparison of the total maximum force acting on the tidal wall. In the vertical graph, the blue corresponds to the no dune case, red movable and gray fixed dune model case. The case without dune generates the larger integrated pressure than the movable and fixed dune case.

Figure 16 shows the comparison of the maximum wave force in case of long waves. In case of long wave, the influence of reflection wave is so large and the maximum force in the wave appears at the case of fixed dune. When the distance (DIS) between the sand dune and seawall becomes -137.5cm, the difference is small and the value of the case without dune is smaller than the case with dune. The reason of the difference is that the horizontal flow route becomes narrow on the dune and the velocity is amplified at the top of the dune. The tsunami wave force becomes larger in the cases with dune and the movable dune is smaller than the fixed dune by the dune deformation.

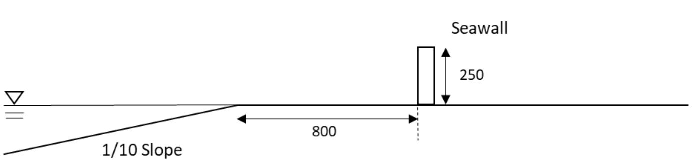


Figure 14 Cross section of case without dune

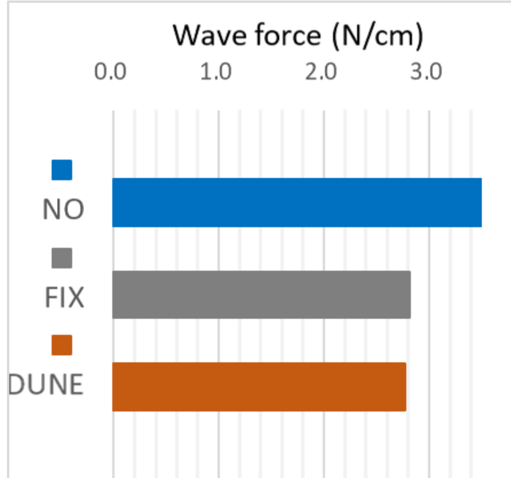


Figure 15 Comparison of wave force on solitary wave acting on the movable, fixed and flat beds

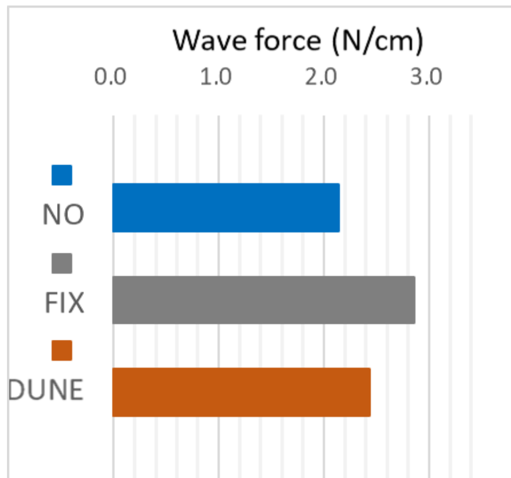


Figure 16 Comparison of wave force in long wave acting on seawall for case of (DIS=137.5cm)

CONCLUSIONS

In this paper, we conducted a series of experiments on the variation of wave pressure distribution and wave force acting on the vertical seawall behind coastal dune. The generated waves were 1) solitary wave and 2) long wave. In case of 1), the wave pressure becomes similar in fixed and movable dune cases. In case of 2), the wave pressure becomes smaller in the movable dune case than fixed dune mainly because of the deformation of the dune by long waves.

In the comparison with the case without dune, the tsunami wave pressures become smaller in the dune existence for the soliton wave. Meanwhile, in the case of long period wave, the wave pressures in the case with dune becomes larger than the case without dune. The reason seems that the fast flow on the dune makes the high pressures on the seawall. The movable dune is better as the dune type. When the dune is composed of movable sand, the wave force became smaller than in fixed dune case for 2) long waves.

The results obtained in this study is applied to the design of seawall located behind the coastal dune.

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