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Study on countermeasures for liquefaction of individual houses and backfill of quay using SandwaveG

K. Okabayashi, F. Kawatake, Y. Tsuno & G. Hashimura
National Institute of Technology, Kochi College, Nankoku City, Kochi, Japan

ABSTRACT: In recent years, liquefaction damage has been widely reported in Japan due to occurrences of large-scale earthquakes. Even in Kochi Prefecture, it is an urgent task to implement liquefaction countermeasures in individual houses and coastal areas in preparation for the Nankai Trough Giant Earthquake. In this study, regarding the liquefaction countermeasures for individual houses, the effect of liquefaction countermeasures when the ground of the residential land was replaced with SandwaveG was examined. Furthermore, the effect of liquefaction countermeasures when the quay backfill soil was replaced with SandwaveG was also examined. This study was carried out using our university's dynamic centrifuge. As a result, it was confirmed that the countermeasure effect by using SandwaveG as a liquefaction countermeasure work for residential land and quay backfill soil was confirmed.

1 INTRODUCTION

In the 2011 Great East Japan Earthquake, liquefaction occurred in a wide range from the Tohoku region to the Kanto region, and concentrated in the reclaimed land in Tokyo and Chiba Prefecture and the Tone River basin. Most of the damage due to liquefaction were on the foundations of individual houses, and some reinforced concrete low-rise buildings were also damaged (Ministry of Land, Infrastructure, Transport and Tourism. (2011)).

In Japan, the Nankai Trough Giant Earthquake is expected to occur in the near future. Kochi Prefecture is surrounded by steep mountains, so it may not be possible to receive immediate rescue and assistance on land when the disaster happens. Therefore, in Kochi Prefecture, it is necessary to take measures against liquefaction in individual houses and coastal quays (Kochi Prefecture (2013)).

In this study, we will examine the effect of liquefaction countermeasures using SandwaveG. SandwaveG is recycled glass granulation sand that is made by dicing glass into a dice shape by a special crushing method, eliminating sharp edges and allowing safe use. Since it is a recycled material, it contributes to the effective use of resources and is an inexpensive and environmentally friendly material. The material characteristics of SandwaveG are that they have a lower density than sand, high water permeability, a wide range of optimum water content, and high liquefaction strength. In addition, it has a small swellimg ratio, so if it is applied to the foundations of individual houses sites, it will also prevent reliquefaction.

In this study, we conducted a basic experiment on the liquefaction occurrence condition on horizontal ground using SandwaveG. After implementation, applicability as a liquefaction countermeasure material for individual houses sites and applicability as a drainage material in the backfill part of the sheet pile quay will be examined.

As the research method, the dynamic centrifuge are used. The effect of the proposed method against liquefaction will be examined.

2 FEATURES OF SANDWAVEG

Currently, about 1.24 million tons of glass bottles are supplied to the market as products every year in Japan. As a glass bottle recycling system, there are cases where a glass bottle is used repeatedly and cases where it is crushed and reused as a raw material for a new glass bottle. However, 420,000 tons of glass bottles are discarded annually in landfills. Glass Sourcing Co., Ltd. has established a recycled glass granulation system with a processing capacity of 50 tons per hour. “Sandwave G” is recycled glass granulated sand in which glass bottles are granulated into dice by a special method to eliminate sharp corners (Glass Resourcing Co., Ltd. (2019)).

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The grain size distribution curve of SandwaveG is shown in Figure 1. SandwaveG has a particle size of 0.075 to 5 mm.

The compaction curve of SandwaveG is shown in Figure 2. As a compaction characteristic, no clear peak appears and the optimum water content ratio is wide, so construction management is easy and stable quality can be ensured.

Figure 3 shows the liquefaction strength test results at a void ratio of 0.671 (Dr = 35.8%).

Table 1 shows the physical properties of SandwaveG from the maximum density and minimum density test, the maximum density is $\rho_{t\ max}$ = 1.775 g/cm^3, and the minimum density is $\rho_{t\ min}$ = 1.376 g/cm^3.

The coefficient of permeability at a compaction degree of 90% is shown. In the compacted state, the coefficient of permeability is 1.3×10^{-4} m/s,so SandwaveG is as permeable as sand and gravel.

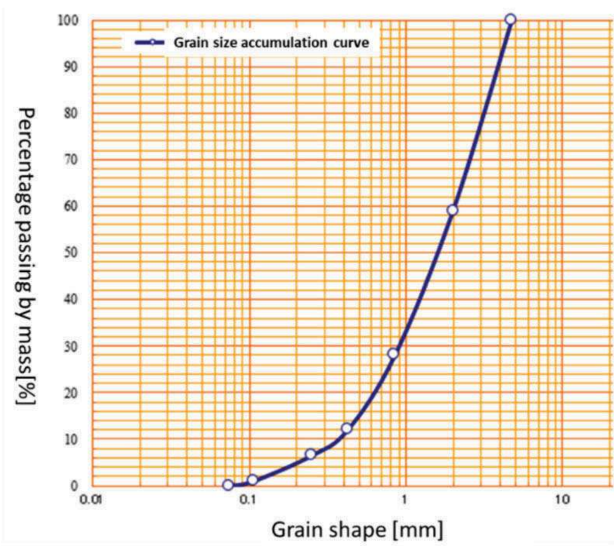

Figure 1. Grain size distribution of SandWaveG.

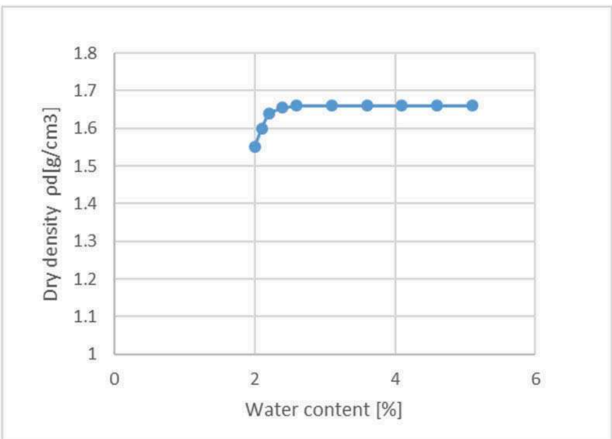

Figure 2. Compaction curve of SandWaveG.

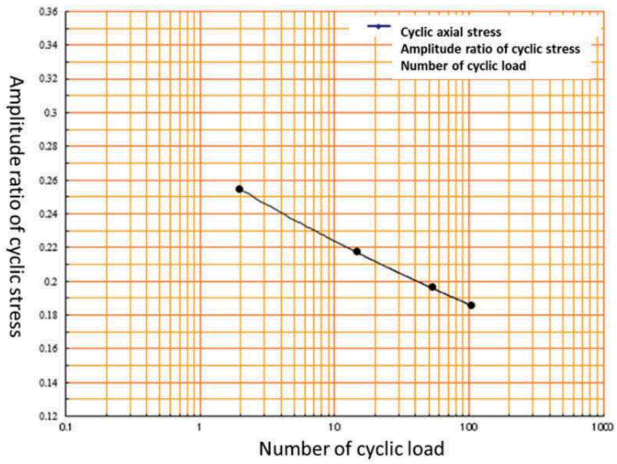

Figure 3. Liquefaction resistance curve of SandwaveG.

Table 1. Physical properties of SandwaveG.

Item	Symbol	Unit	Value
Density	ρs	g/cm^3	2.501
Maximum density	ρtmax	g/cm^3	1.775
Minimum density	ρtmin	g/cm^3	1.376
Maximum dry density		g/cm^3	1.660
Optimum water content	wopt	%	2.6
Coefficient of pemeability (Dr=50%)	k	m/s	2.27×10^{-4}
Swelling ratio		%	0.0013

3 EXPERIMENTAL METHOD

3.1 *Experimental case*

In this study, four models were used as study cases. Case1 is a horizontal ground model of Toyoura sand, Case2 is a horizontal ground model of SandwaveG, Case3 is a residential land model of Toyoura sand and Case4 is a residential land model of SandwaveG.

Figure 4 shows a horizontal ground full-scale model. The dimensions are full-scale. For the ground layer, Toyoura sand and SandwaveG with Dr = 50% were used. The Underwater drop method was used to prepare the ground.

Figure 5 shows a residential ground full-scale model. The structure was a two-story RC building, and the load on the residential land was 31.4 kN/m^2. The size of the residential land model was 1/40 of the actual size, and the bottom area was 13×12 cm^2. According to the law of similarity, Toyoura sand was placed in the stainless-steel case so that the total weight was 0.994 kg. The ground layer used was Toyoura sand and SandwaveG with Dr = 50%. The preparation used the Underwater drop method.

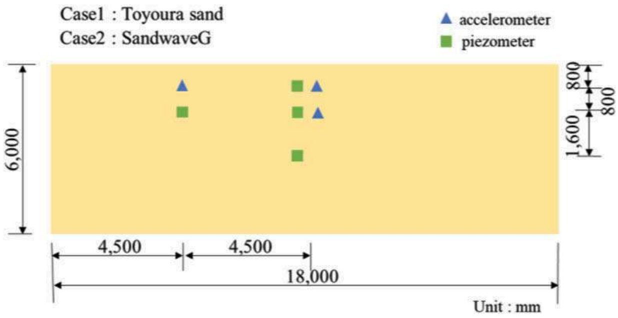

Figure 4. Full-scale model of horizontal ground.

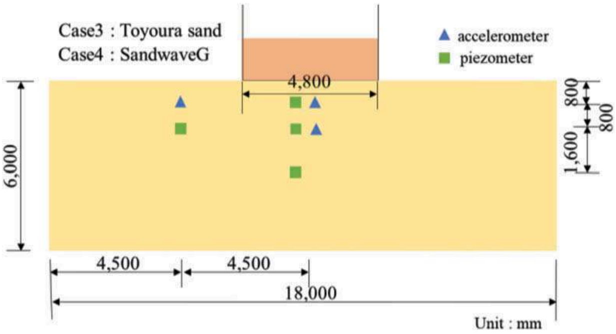

Figure 5. Full-scale model of residential land.

3.2 *Seismic wave*

The acceleration required to generate liquefaction in the experimental soil layer was calculated by the simple judgment method of the Road Bridge Specification (Japan Road Association (2012)). Figure 6 shows the input seismic wave.

In the centrifugal model test, the acceleration was set to 40 times and the period was set to 1/40 with respect to the actual seismic wave according to the similarity rule.

3.3 *Apparatus and model*

Liquefaction experiments were carried out using a centrifuge of Kochi National College of Technology. Figure 7 shows the centrifuge. Experiments were carried out in a centrifugal force field of 40 g.

Figure 8 shows an experimental model of the residential land model Case4.The model dimensions were scaled to 1/40 of the actual dimensions. Seismic accelerometers and piezometers were installed at 20 mm, 40 mm and 80 mm depth from the ground surface. Targets were placed at 56.25 mm intervals to see the deformation. In the experiment of Case1, the top targets were placed at 20 mm depth.

Figure 9 shows a photograph of a horizontal ground model with SandwaveG before the experiment. The base layer and the liquefaction layer were

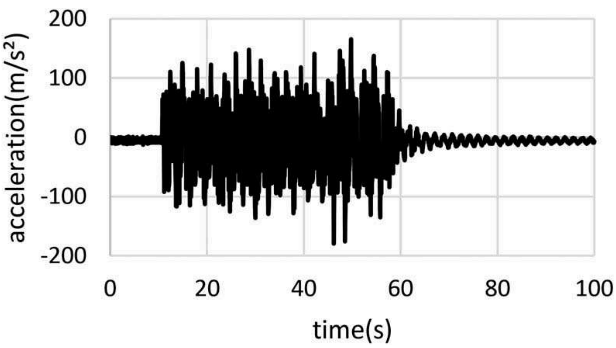

Figure 6. Input seismic wave.

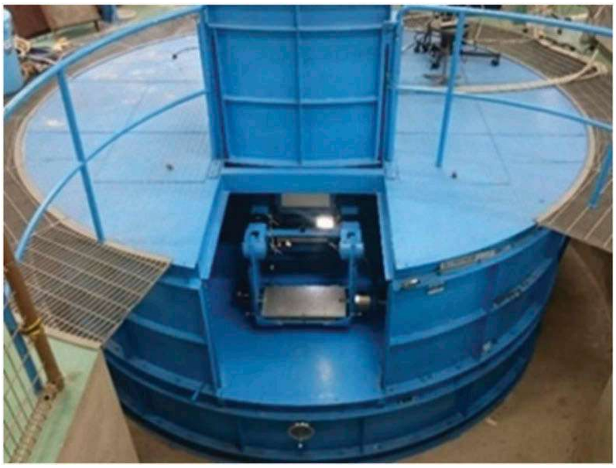

Figure 7. Equipment for dynamic centrifuge.

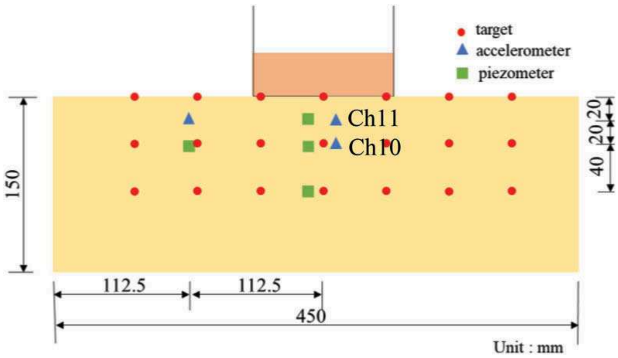

Figure 8. Experimental model.

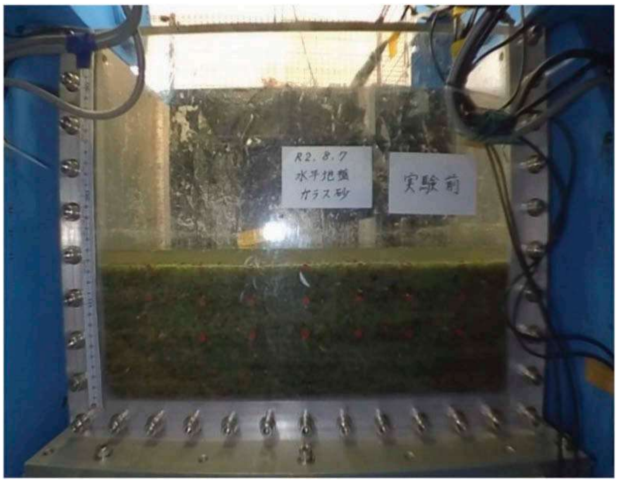

Figure 9. Model of horizontal ground with SandwaveG (Before experiment).

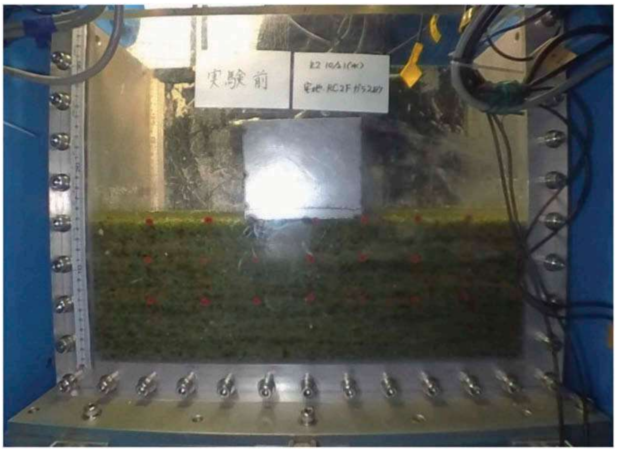

Figure 10. Model of residential land with SandwaveG (Before experiment).

saturated with a methyl cellulose solution having a viscosity 40 times that of water.

Figure 10 shows a photograph of experimental model of the residential land model Case4.

4 EXPERIMENTAL RESULTS

4.1 *Settlement of the ground*

Figure 11 shows the subsidence diagram of Case1 (Toyoura sand of horizontal ground). The settlement is calculated from the amount of movement of the target before and after the experiment. The maximum amounts of subsidence are about 20 mm at the upper part (20 mm from the ground surface), about 15 mm at the middle part (40 mm from the ground surface), and about 5 mm at the lower part (80 mm from the ground surface). It can be seen that the deeper the depth, the smaller the amount of subsidence.

Figure 12 shows the subsidence diagram of Case2 (horizontal ground with SandwaveG).

It can be seen that the amounts of subsidence are smaller than Case1 and the maximum amounts are about 15 mm at the upper part (ground surface) and about 2 to 5 mm at the middle part and the lower part.

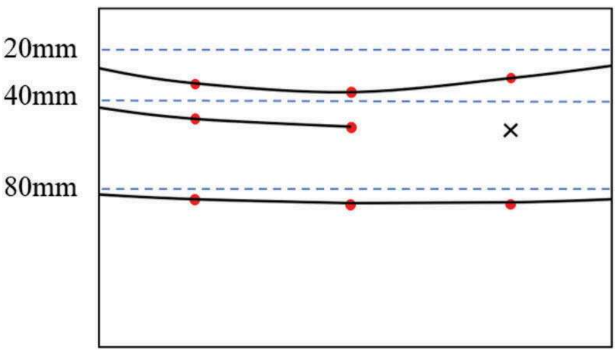

Figure 11. Settlement in Case1 (After experiment).

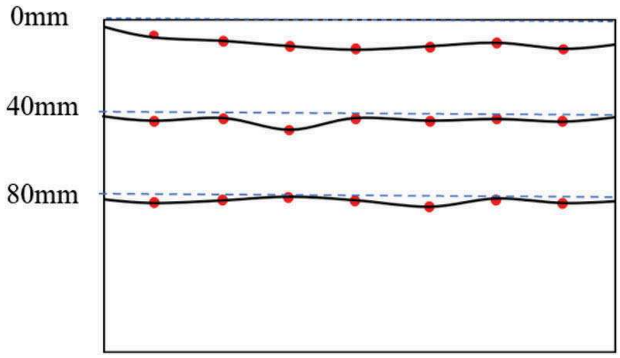

Figure 12. Settlement in Case2 (After experiment).

Figure 13 shows a photograph of the residential land model Case4 after the experiment.

Figure 14 shows the subsidence of Case3 (Toyoura sand of residential ground). The maximum amounts of subsidence are about 15 mm at the upper part (ground surface) and about 2 to 5 mm at the middle part and the lower part.

Figure 15 shows the subsidence of Case4 (SndwaveG of residential ground). The maximum amounts of

Figure 13. Model of residential ground with SandwaveG (After experiment).

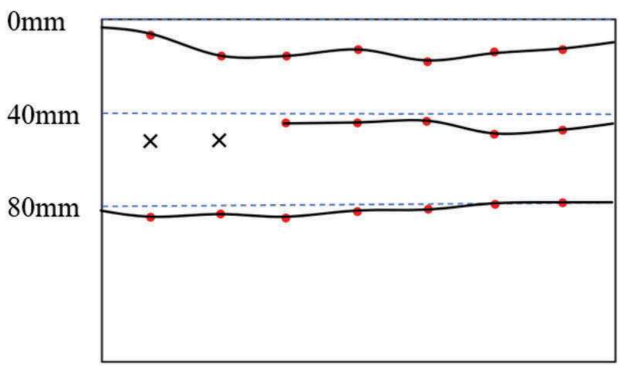

Figure 14. Settlement in Case3 (After experiment).

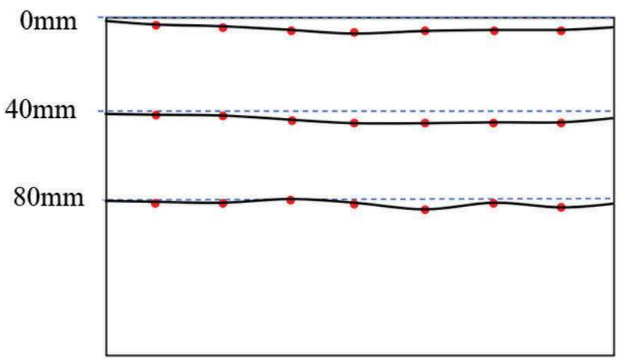

Figure 15. Settlement in Case4 (After experiment).

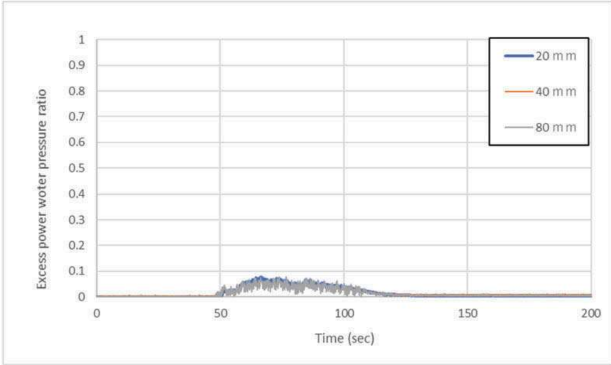

Figure 17. Excess pore water pressure ratio in Case4.

subsidence are about 5 mm at the upper part and about 2 to 4 mm at the middle part and the lower part.

In other words, it can be seen that the amount of subsidence on the ground surface of SandwaveG is smaller than that of Toyoura sand.

4.2 *Excess power water pressure ratio*

Figure 16 shows the measured values of excess pore water pressure ratio in Case3 with Toyoura sand. The excess pore water pressure ratio is almost the same at three locations due to the input of seismic motion. In the upper part (20 mm), the value of excess pore water pressure ratio rises from 0.4 to 0.5, and in the middle and lower parts (40 mm and 80 mm), it rises from 0.4 to 0.6, and then disappears.

Figure 17 shows the measured values of excess pore water pressure ratio in Case4 with SandwaveG. The excess pore water pressure ratio is almost the same at three locations due to the input of seismic motion. The value of excess pore water pressure ratio rises to about 0.08 and then disappears.

Figure 18 shows the measured values of the acceleration in Experimental Case3. The input seismic waves and the measured acceleration in the middle (40 mm) and upper (20 mm) are shown. The measured values are almost the same as the input seismic motion, but due to the rise in pore water pressure, the ground is slightly attenuated due to the liquid state.

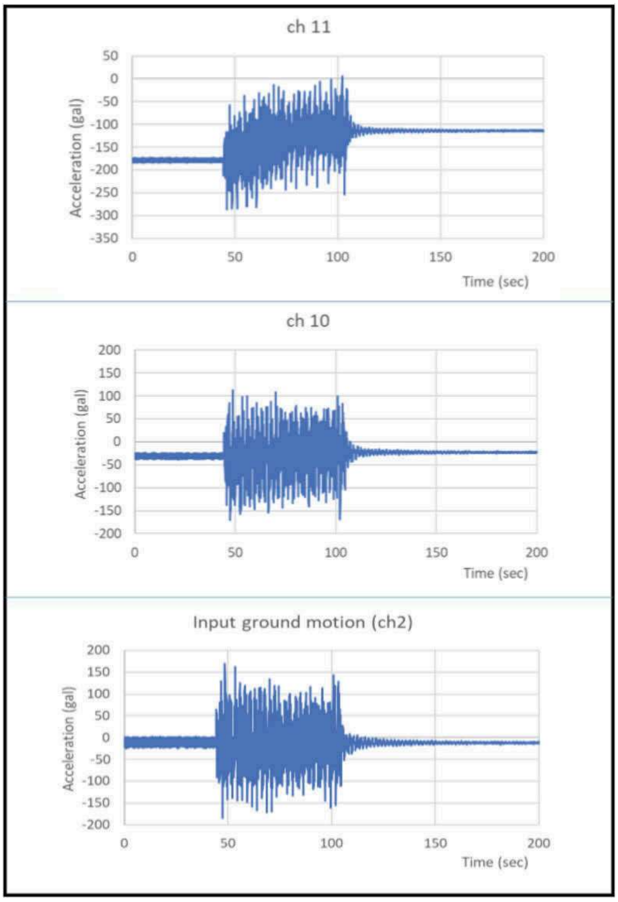

Figure 18. Acceleration in Case3.

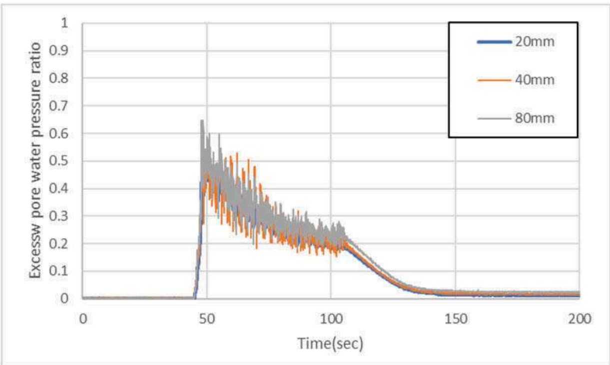

Figure 16. Excess pore water pressure ratio in Case3.

Figure 19 also shows the measured values of the acceleration in Experimental Case4. The measured values are almost the same as the input seismic wave, but the pore water pressure hardly rises, and the acceleration is slightly amplified as it approaches the ground surface.

Figure 20 shows the acceleration response spectra of the seismic waves of Ch10 and Ch11 in Experimental Case3. In Ch10, seismic waves are predominant with a period of 0.80 seconds and 2.39 seconds.

Even in Ch11, seismic waves are predominant at 0.78 seconds and 2.39 seconds, which is almost the same period as Ch10. The maximum acceleration is

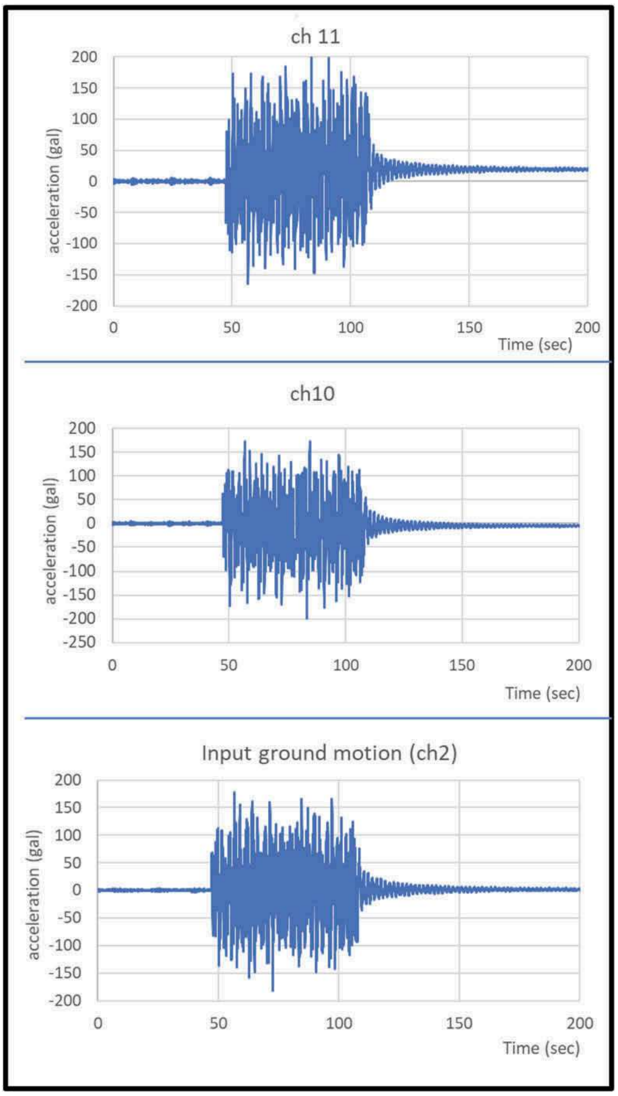

Figure 19. Acceleration in Case4.

888 gal for Ch10 and 779 gal for Ch11, which is a slight decrease in Ch11. This is considered to be the effect of liquefaction.

Figure 21 shows the acceleration response spectra of the seismic waves of Ch10 and Ch11 in Experimental Case4. In Ch10, seismic waves are predominant in periods of 0.78 seconds and 12.54 seconds, with maximum accelerations of 1168.2 gal and 864.5 gal, respectively. In Ch11, the seismic wave is 1173.0 gal in 0.80 seconds and 869.9 gal in 2.56 seconds, which is predominant in almost the same period as Ch10. Both the period and the maximum acceleration values have changed little. This is considered to be due to liquefaction has not occurred.

5 APPLICATION TO QUAY BACKFILL SOIL

There was a phenomenon that the excess pore water pressure ratio increases near the wall of the quay compared to the untreated quay (Tokuhisa (2016)). It is necessary to dissipate the excess pore water pressure in the vicinity of the quay wall to prevent liquefaction.

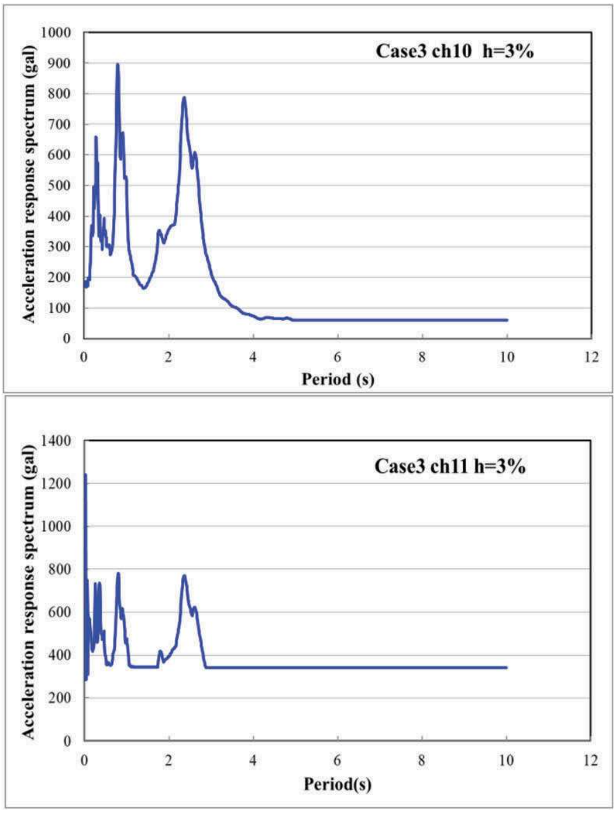

Figure 20. Acceleration response spectrum of Case3.

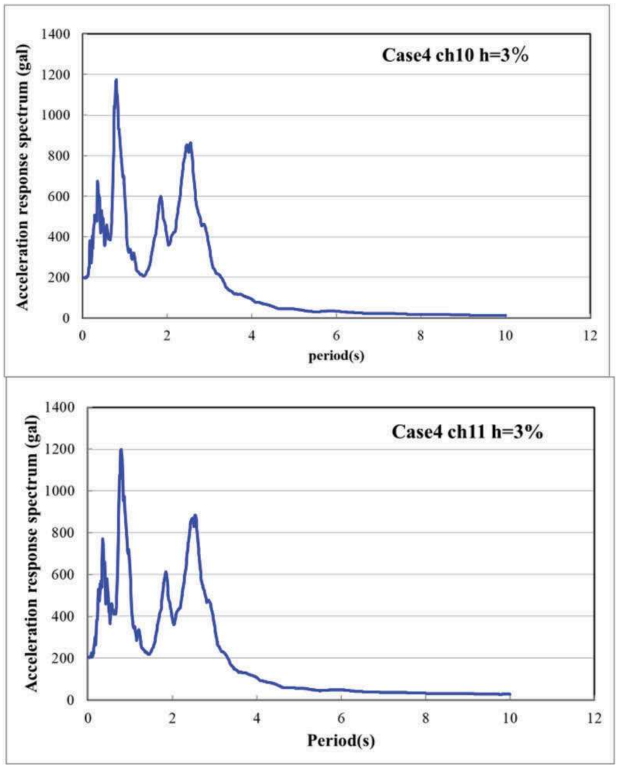

Figure 21. Acceleration response spectrum of Case4.

Figure 22 shows the application of SandwaveG to the Sand bag of the full-scale model quay. The Sand bags were piled up with SandwaveG in a highly permeable Non-woven. The permeability steel sheet pile is a steel sheet pile that was made holes at regular intervals so that water is drained from the holes.

In this case, a 1mm thick stainless-steel plate was used as the steel sheet pile. And the stainless-steel plate made 2 mm diameter holes was used as the permeability steel sheet pile. The holes were placed at intervals 25 mm in length and 12.5 mm in width. And the 2 sheet piles were connected by 1 mm diameter wires.

Figure 23 shows the excess pore water pressure ratio when there is no drainage measure in the backfill of the quay. The excess pore water pressure ratio is larger toward the top and rises to 0.7, 0.3, and 0.1.

Figure 24 shows a case where a Sand bag with a SandwaveG is installed on the back of the quay and a permeable sheet pile is used. The excess pore water pressure ratio rose to about 0.4 at the top of Ch15, but was suppressed to 0.2 or less at Ch16 and 17.

A Sand bag with a SandwaveG was installed on the back of the quay. By using a permeable sheet pile as the sheet pile, it is possible to prevent the increase in the excess pore water pressure ratio in the backfill soil. It was confirmed that it has the effect of preventing liquefaction.

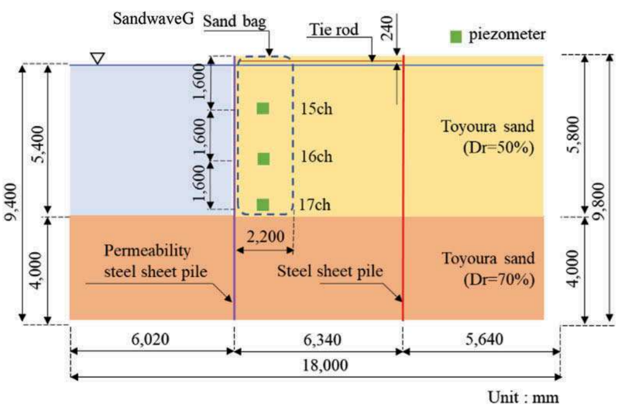

Figure 22. Application of SandwaveG to the Sand bag of the full-scale model quay.

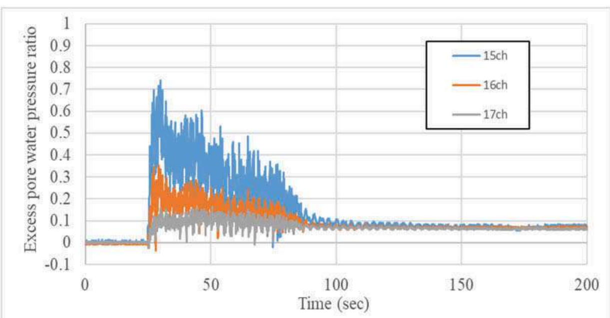

Figure 23. Excess pore water pressure ratio (no drainage measure).

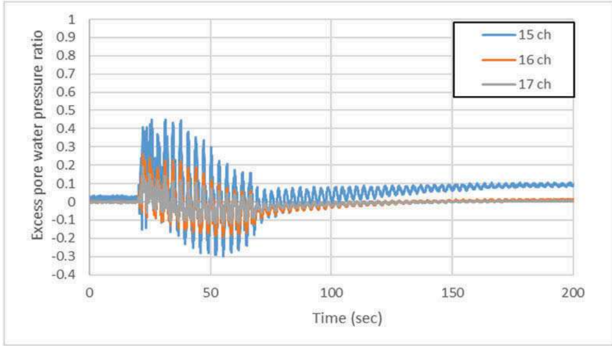

Figure 24. Excess pore water pressure ratio (Sand bag with SandwaveG).

6 CONCLUSION

From this research, we conducted a study to use SandwaveG as a countermeasure method for liquefaction, and the following items were clarified.

By using SandwaveG for residential ground

(1) Resistance to liquefaction increases.
(2) The amount of subsidence can be suppressed by increasing the liquefaction resistance during an earthquake.
(3) It is possible to prevent an increase in excess pore water pressure.
(4) Seismic waves increase slightly but hardly change.

By applying SandwaveG to quay backfill soil

(1) Liquefaction suppression effect can be expected.

REFERENCES

Glass Resourcing Co., Ltd. 2019. *Recycled glass granulated sand "SandwaveG" technical data*: 1–16

Japan Road Association 2012. *Specifications for highway briges PartV: seismic design. (in Japanese)*

Kochi City. 2015. Kochi City New Government Building Construction Office. *Kochi City New Government Building Implementation Design [Summary Version]*.: 17

Kochi Prefecture 2013. Kochi Prefecture Crisis Management Department Nankai Trough Giant Earthquake Countermeasures Division Public materials. *[Kochi version] Calculation results of damage estimation due to Nankai Trough Giant Earthquake (Drawing collection)*: 20–31

Ministry of Land, Infrastructure, Transport and Tourism. 2011. Materials provided by the River Department, Tohoku Regional Development Bureau, Ministry of Land, Infrastructure, Transport, and Tourism. *Damage and restoration status of river and coastal facilities in the Great East Japan Earthquake*: 2–46

Tokuhisa, K 2016. Thesis Research Reports, ADVANCE COURSE KOCHI NATIONAL COLLEGE OF TECHNOLOGY, 15th. *A study on the liquefaction countermeasures of wharf considering the Nankai Trough Giant Earthquake*: 12