Feasibility of total system for ground protection-power generation-construction waste material reusing

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ABSTRACT

In order to maintain the current standard of living without deteriorating the global environment, it is necessary to develop and spread the effective power generation methods using clean energy. Rational ground reinforcement is necessary to minimize the ground damage caused by frequent natural disasters such as earthquakes. It is important to actively reuse the construction waste material for reducing the economic cost of civil works. In this study, one of the useful tools for constructing and maintaining a recycling-oriented society is considered. First, a concept of the total system to perform both ground reinforcement and electric power generation using the recycled asphalt pavement material and newly prepared T-shaped unit is proposed. The T-shaped unit that is referred as a PG unit in this study mounts the electric circuit with Peltier device. A series of the field monitoring for electric power generation and the laboratory test for the mechanical properties of protected ground are conducted for discussing the feasibility of the proposed total system. The results of the field monitoring show that the newly prepared PG unit can generate the electric power by using the temperature on the ground surface. In the laboratory test, it is also confirmed that the bearing capacity of the ground can be improved by using recycled asphalt pavement material and PG unit waste. The both results of field monitoring and laboratory test imply that the proposed total system can be realized.

Keywords: ground protection, power generation, construction waste material reusing

1 INTRODUCTION

The 2018 Hokkaido Eastern Iburi Earthquake caused many damages to infrastructure facilities and houses due to ground disasters such as slope failure and liquefaction. At the same time, the electric power supply was cut off in a wide area of Hokkaido, which had inconvenient impact on people's lives. Both of the damage of infrastructure facilities or houses and the interruption of the energy supply necessary for usual life increase the damage at the natural disaster. It is important to improve the ground to minimize damages at natural disaster and to develop environmentally friendly electric energy supply method.

Reusing various resources is very important to maintain a sustainable social life. In the field of civil engineering, effectively reusing the construction waste material is beneficial for reducing costs of the civil engineering project. In this study, a concept of total system for ground protection - power generation – construction waste material reusing is proposed to contribute to the above from the viewpoint of geotechnical engineering.

Figure 1 illustrates the concept of total system for ground protection - power generation – construction waste material reusing. In this proposed total system, the ground surface is covered with the recycled asphalt pavement material (RAP), and T-shaped unit (PG unit) is inserted into the ground to reinforce and protect the ground. RAP has several engineering advantages (Yokohama & Sato, 2019). The advantages are as follows; Ground surface protection using RAP has been successful for a long time. The cyclic strength of sandy soil mixed with RAP is higher than that of the plain sandy soil. The bonding occurs between soil particles when the RAP specimen is compressed with a low confining pressure at the triaxial compression test. RAP is adopted as the test material in this study because these advantages are effective in realizing the suggested system shown in Figure 1.

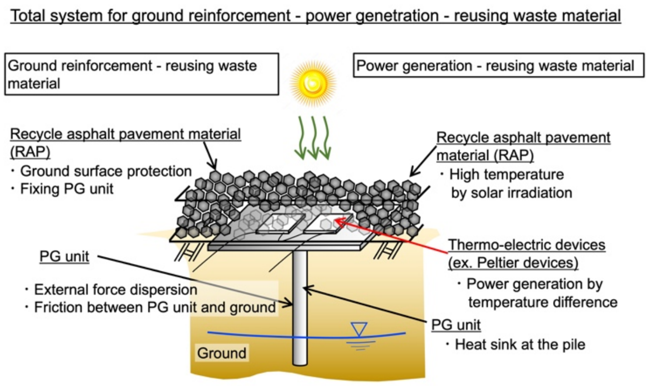

Fig. 1. Concept of total system for ground protection – power generation – construction waste material

In this study, the tool used for the proposed total system that realizes ground reinforcement and power generation is called PG unit. The PG unit has a shape in which plate and pile are connected. The PG unit is mainly composed of metal with high thermal conductivity. It is thought that ground reinforcement is realized by inserting the PG unit into the ground and exerting friction between the PG unit and the ground. On the other hand, the PG unit, which is a built-in Peltier element attempting to generate the electric power using the temperature difference between ground surface and underground. The recycled asphalt pavement material covering the ground surface is exposed to sunlight irradiation and plays a role in increasing the temperature difference on surface of the PG unit.

In this study, it is experimentally shown that the PG unit above mentioned can be one of the useful tools for realizing a total system for ground protection - power generation - construction waste material reusing. The series of laboratory tests is conducted to investigate the mechanical properties of the ground protected by recycled asphalt pavement material (RAP) and PG unit under monotonic or cyclic loading conditions. Field monitoring is also performed to investigate the possibility of power generation using PG unit. From these results, the feasibility and problems of the total system for ground protection – power generation - construction waste material reusing is discussed.

2 FIELD MONITORING FOR POWER GENERATION BY GROUND TEMPERATURE

Figure 2 shows the configuration of the PG unit developed for the power generation and the wiring of the mounted Peltier device. The PG unit consists of a box that collects the solar radiation heat, a plate on which thermo-electric elements are mounted, and a pile that fixes the PG unit to the ground. The electric circuit in which 10 sets of 3-ply Peltier elements were connected in series connection was created and mounted inside the plate of the PG unit. In order to facilitate the heat exhausting of PG unit, heat pipes were attached to the pile of PG unit. The temperature sensors were mounted on the surface and reverse side of the plate and pile tip of the PG unit.

Figure 3 explains the location and situation of field monitoring for the electric power generation by using the PG unit. The field monitoring was carried out at 4 locations. The PG units of [Oy] and [Sh] were installed in two places in Sapporo city, Japan. The PG unit of [Ur] was installed in Uryu-cho where is located at about 80 km north of Sapporo city. The PG unit of [Ok] was installed in Okushiri-cho where is located at 185 km southwest of Sapporo city. [Ok] and [Oy] were inserted up to the depth of 400 mm in the ground. These two PG units were directly contacted the ground. The ground water was not found at [Ok] and [Oy] points. For the PG unit of [Sh], the PG unit had the length of 3.0 m. This unit was inserted into the boring hole with the

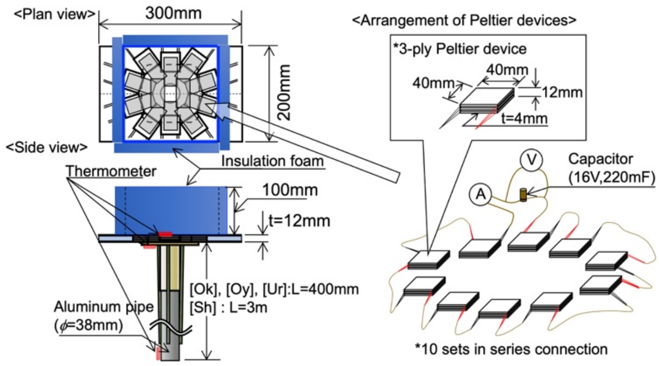

Fig. 2. Configuration of the PG unit for power generation

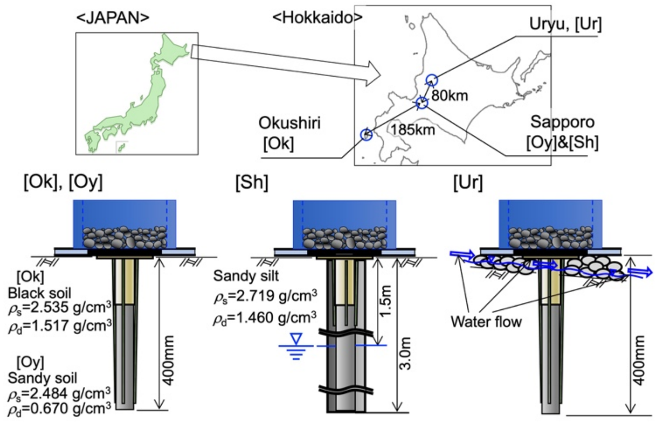

Fig. 3. Situation of the field monitoring for the power generation

length of 3 m. The groundwater level was seen at 1.5 m in deep. The borehole was covered with a polyvinyl chloride pipe. Below the 1.5 m in depth, the PG unit was in contact with the groundwater, but there is no direct contact between this PG unit and the surrounding ground. The PG unit of [Ur] that was set up in Uryu-cho was inserted up to a depth of 400 mm. In the [Ur] point, the water pumped from underground flows over the ground surface and cools the PG unit of [Ur].

Figure 4 (a) to (d) show the voltage V, electric current A, and temperature difference of the PG unit ΔT obtained at [Ok], [Oy], [Sh] and [Ur]. The temperature difference ΔT is defined as the difference of temperatures between at the surface and reverse side of the plate of the PG unit. From the results at [Ok], [Oy], [Sh] and [Ur], it is recognized that the phase differences between voltage V or electric current A and temperature difference ΔT are not seen. The behavior of the voltage V or the electric current A seem to be similar the behavior of the temperature difference ΔT.

Figure 5 (a) to (d) show the voltage V – temperature difference ΔT relation and the electric current A – temperature difference ΔT relation obtained from [Ok], [Oy], [Sh] and [Ur]. From these four cases, it can be seen that the relationship between the voltage or the electric current and the temperature difference is approximately proportional. From the results at [Oy] and [Sh], it can be seen that the proportional

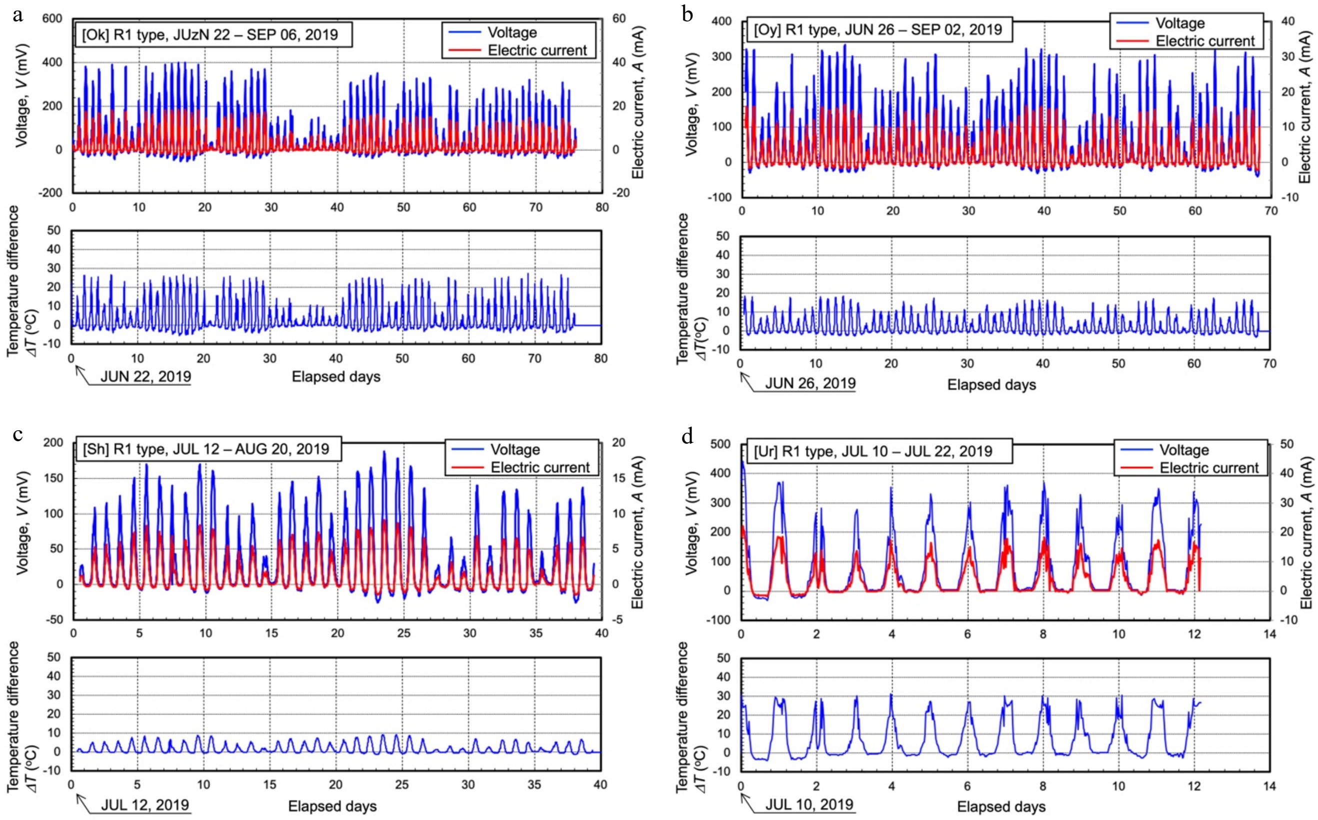

Fig. 4. The voltage, electric current and temperature difference of PG unit. (a) [Ok], (b) [Oy], (c) [Sh], (d) [Ur].

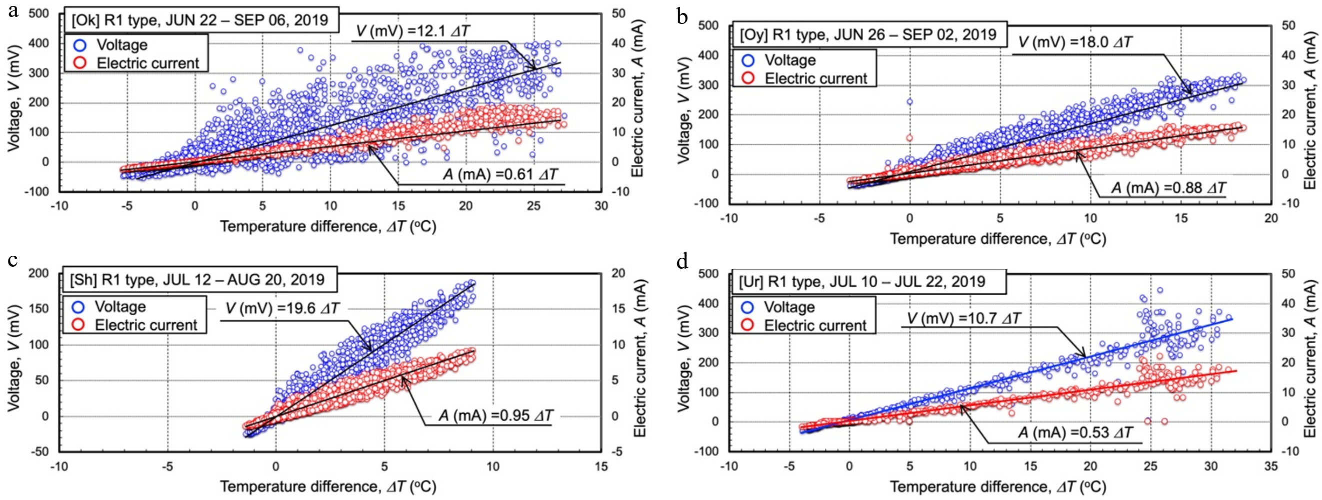

Fig. 5. The relations between the temperature difference and the voltage or the electric current. (a) [Ok], (b) [Oy], (c) [Sh], (d) [Ur].

coefficients of V - ΔT relation and A - ΔT relation are near 20 and 1.0, respectively. On the other hand, it is also found that the proportional coefficients of V - ΔT relation and A - ΔT relation are near 10 and 0.5, respectively from the results at [Ok] and [Ur].

Next, the range of the temperature difference ΔT is focused on. From Figure 5 (c), the temperature difference ΔT is -1.4 to 9.1, and the range of the temperature difference is narrower than the other results. PG unit at [Sh] is in contact with the groundwater, but the length of the pile of PG unit is the longest of all. It is considered that the long pile such as [Sh] makes the exhaust heat of PG unit difficult. This situation seems one of the reasons why the range of the temperature difference is narrowed. On the other hand, the results at [Ur] shows the wide range of the temperature difference among all. The pile of PG unit can be cooled by the water, so it is expected that the large temperature difference is secured.

For practical use of the PG unit, it is important to widen the range of temperature difference and increase the proportional coefficient between the electric output and the temperature difference of the PG unit. It is also necessary to select the arrangement and type of Peltier elements inside the PG unit, and to improve the cooling method of the PG unit.

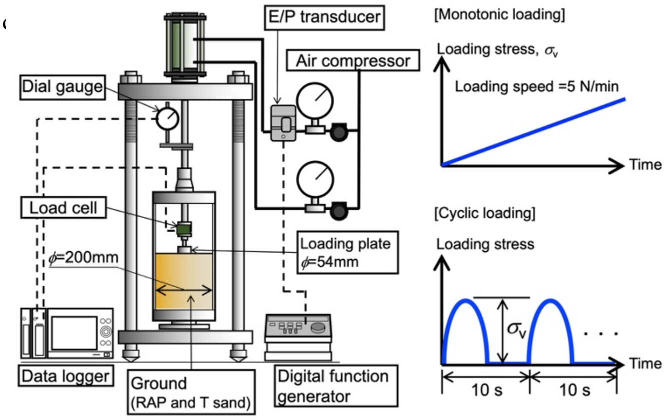

Fig. 6. Test apparatus and loading method.

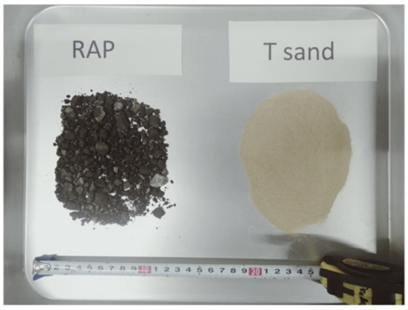

Fig. 7. The external view of RAP and T sand.

3 MECHANICAL PROPERTIES OF THE GROUND PROTECTED BY RAP AND PG UNIT

The series of laboratory tests were conducted to investigate the mechanical properties of the ground protected by recycled asphalt waste and PG unit. Figure 6 is a schematic figure of the test apparatus and the loading method. The test apparatus mainly consists of an acrylic cylindrical cell with inner diameter of 200 mm, an actuator, a loading frame, and some measuring devices. The actuator is a pneumatic cylinder with a loading rod. A loading plate with a diameter of 54 mm is connected to the tip of the loading rod. An electric signal was transmitted from the function generator to the electro-pneumatic converter to control the operation of the actuator. The external force was applied on the ground surface to perform the loading tests. The loading force and vertical displacement were measured by the load cell and dial gauge. In this study, the monotonic loading test and the cyclic loading test were performed. In the monotonic loading test, the vertical force acting on the loading plate increased by 5 N per minute. In the cyclic loading test, the compressive force was applied to the ground surface. The period of cyclic loading is 10 seconds.

In this study, recycled asphalt pavement material (RAP) and sand are prepared for testing materials. RAP is the recycled aggregate produced from deteriorated asphalt pavement. RAP is sampled in Sapporo city on August 2014 (Yokohama and Sato, 2019). Toyoura sand (T sand) is also adapted for the testing material.

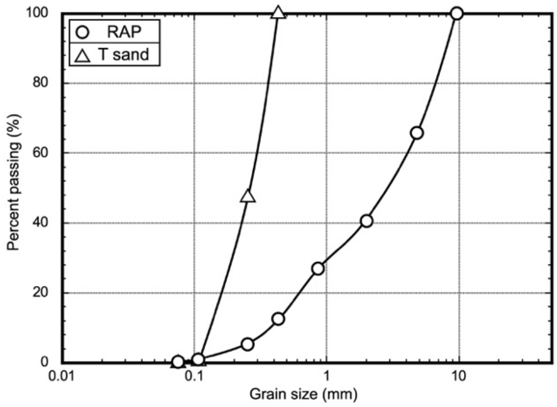

Fig. 8. Grain size distributions of RAP and T sand.

Table. 1. Index properties of RAP and T sand.

	ρ_s (g/cm^3)	ρ_{dmax} (g/cm^3)	ρ_{dmin} (g/cm^3)
Recycled asphalt pavement material (RAP)	2.366	1.607	1.412
Toyoura sand (T sand)	2.649	1.636	1.344

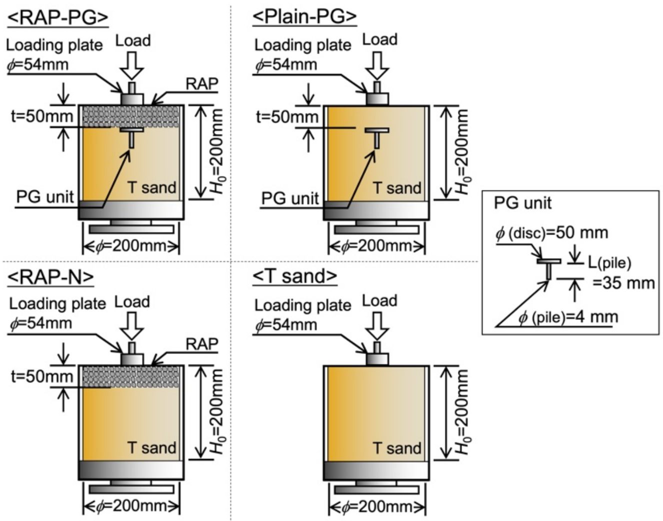

Fig. 9. The ground conditions in the laboratory tests.

From this figure, it is found that RAP is a lumpy black particle and T sand is a fine sand particle. The grain size distribution and the list of index properties of the test samples are shown in Figure 8 and Table 1, respectively.

Figure 9 shows the ground conditions in the testing. T sand was deposited in the acrylic cylindrical cell by the multiple sieve pluviation method (Miura and Toki, 1982) to prepare the testing ground. When laying RAP material, RAP was gently spread on the surface of the T sand ground using a scoop. In the case of the RAP-PG, RAP was laid and a PG unit was inserted into the T sand ground. In the RAP-N case, RAP was laid on the surface of T sand and PG unit was not inserted.

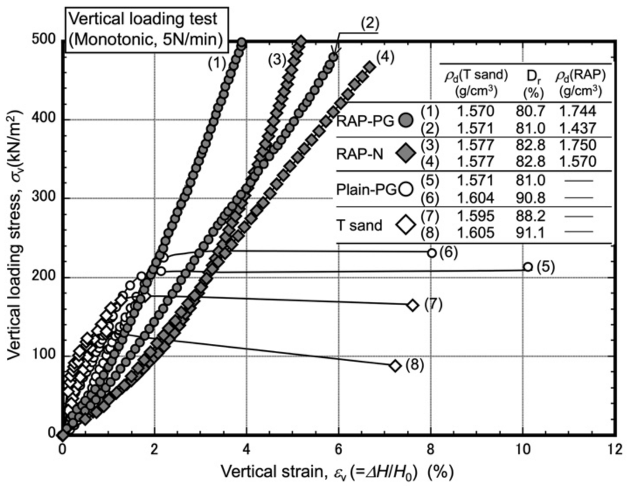

Fig. 10. The relation between the loading stress and vertical strain at the monotonic loading.

Plain-PG shows the case that the PG unit was inserted without RAP laying on the ground surface. Finally, the case without RAP layer and PG unit is expressed as T sand. In each case, the thickness of the RAP layer and the insertion depth of the PG unit were 50 mm.

Figure 10 shows the relationship between loading stress σ_v and vertical strain ε_v obtained from the monotonic loading test. σ_v is the external force divided by the area of the loading plate. ε_v is the settlement of the loading plate normalized to the thickness of the testing ground. From this figure, it can be seen that the shape of the stress-strain curve of the Plain-PG case is similar to that of T sand case and the vertical stress of Plain-PG is higher than that of T sand. Although the initial gradient of the σ_v – ε_v curves are small, the loading stresses σ_v in RAP-PG and RAP-N are higher than the vertical stress of Plain-PG at the end of the testing. These results indicate that covering the ground surface with RAP layer has helped to improve the bearing capacity of the ground. In addition, the results also show that the vertical stress is somewhat higher when the PG unit is inserted than in the case without the PG unit. It can be seen that the presence of the PG unit also plays a role in increasing the bearing capacity.

The cyclic mechanical behavior of the protected ground is examined. Figure 11 (a) and 11 (b) show the relationship between the amplitude of the vertical stress σ_v obtained from the cyclic vertical loading test and the number of loading cycles N_c that the vertical strain reaches 2% or 3%. From these figures, it can be seen that at the same N_c, the value of the σ_v in RAP-PG is higher than the that in Plain-PG and T sand. The σ_v – N_c relation at Plain-PG are very similar to that at T sand. The experimental facts express that the RAP layer has helped to improve the cyclic mechanical behavior on the ground. Figure 12 (a) and (b) show the vertical displacement of the ground surface after the cyclic vertical loading test with RAP-PG and Plain-PG, respectively. The results of RAP-PG (Figure 12 (a))

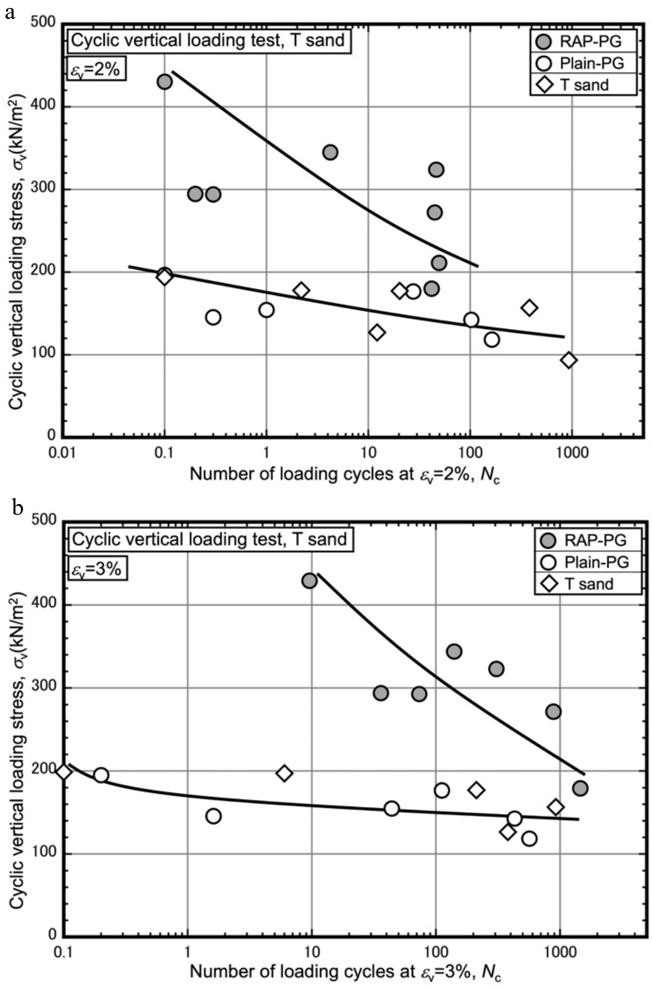

Fig. 11. Relationship between the vertical stress and number of loading cycles at the cyclic vertical loading test. (a) N_c at ε_v=2%, (b) N_c at ε_v=3%

were obtained at σ_v=323.8 kN/m^2 and N_c =1607. This figure shows that the RAP layer beneath the loading plate was compressed and the bulge of the RAP layer around the loading plate reached about 2 mm. On the other hand, the results of Plain-PG (Figure 12 (b)) were obtained at σ_v=194.8 kN/m^2 and N_c =23.6. From this figure, it can be seen that the T sand under the loading plate was compressed and the ground around the loading plate rises above about 8 mm. It is also seen that the depth of PG unit has moved down about 5 mm from the initial state. The difference between the two observations expresses that the RAP layer on the ground surface can be helpful to improve the cyclic mechanical properties and to suppress the deformation of the ground subjected to cyclic loading.

Figure 13 illustrates the mechanism for improving the bearing capacity of the ground with both the RAP layer and the PG unit. The mechanism seems to be as follows. First, the RAP layer subjected to the external force is compressed and plays the role as a cushion. This is because RAP material has a high compressibility (Wen et al., 2010, Soleimanbeigi et al., 2014 and Yokohama et al, 2019). The PG unit inserted

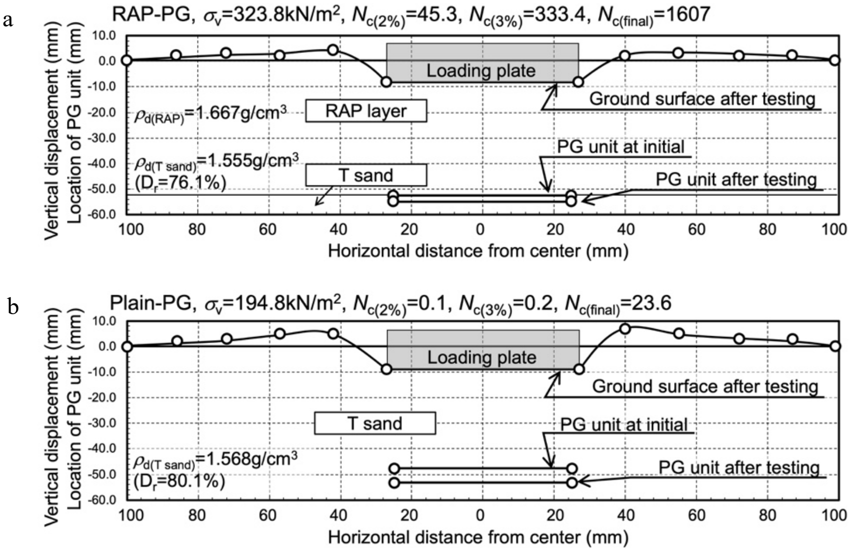

Fig. 12. The deformation behavior at the cyclic vertical loading tests. (a) RAP-PG case, (b) Plain-PG case.

in the ground supports the RAP layer and enhances the bearing capacity of the ground by friction between the PG unit and the ground. The RAP layer around the range of the external force is holding down the ground surface. For these reasons, the ground is protected, and the bearing capacity of the ground increases.

4 CONCLUSIONS

In order to suggest the engineering utilization method of construction waste material, one concept of the total system of ground reinforcement, power generation and waste material reuse was presented. The feasibility of the present total system is discussed by the series of the field monitoring and the laboratory testing. The mainly conclusions were obtained as follows,

1. From field monitoring on the power generation, it was found that the electric power can be generated by using the temperature of the ground surface. Inserting the PG unit that mounts the Peltier devices and covering the ground surface with RAP make the power generation possible. In this method, the maximum values of the output voltage and electric current were about 400 mV and 20 mA, respectively.
2. From laboratory tests, it was shown that the bearing capacity of the ground protected by RAP and PG unit under monotonic or cyclic loading conditions was higher than that of the ground without any protection. It is considered that the high compressibility of the RAP and the friction between the PG unit and the ground contributed to the improvement of the ground bearing capacity.

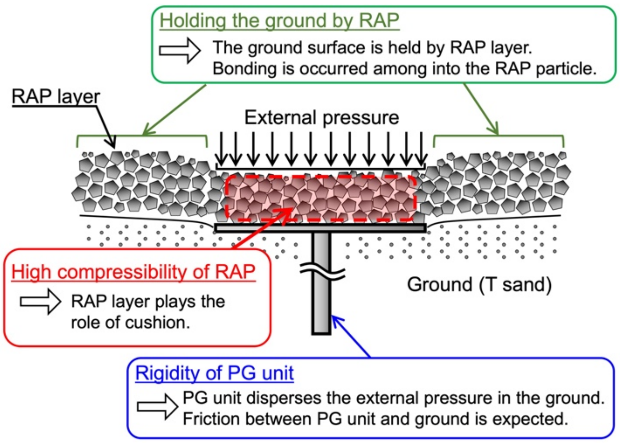

Fig. 13. The mechanism of the ground strength improvement by RAP and PG unit.

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