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# Experimental Development of New Type Reinforced Soil Wall

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**ABSTRACT:** Our aim in this study is to develop a new type of reinforced soil walls as substitute for concrete ones. The structure that piles are inserted into reinforced soil wall body has been studied as the new type structure. In this development, a static-loading test, a dynamic centrifuge model test and an impact-loading test were carried out in order to confirm the practicability of the structure to actual diverse sites. In this paper, the details of the static and impact loading tests are introduced and the practicability of the structure is discussed.

**Keywords:** Reinforced Soil, Pile Foundation, Retaining Wall, Rock-fall Protection Structure

## 1. INTRODUCTION

The high ductility of soil structures reinforced by geogrid is well known, as is the possibility of building independent soil structures. The independent reinforced soil structure, which is referred to "Geo-wall" in this paper, has been applied to such diverse structures as rock-fall protection walls [1], mud and snow avalanche protection walls [2] and the suchlike. Fig. 1 shows an example of the application of Geo-wall to a rock-fall protection wall. Since Geo-wall can be built using existing soil at the construction site if it is compactable one, they are being used ever more frequently as one of economic and CO2 reducible structures.

Fig. 1. Application to a rockfall protection wall.

At present, however, the adoption of the spread foundation for Geo-walls makes the design too wide for application to narrow construction sites, such as beside mountainous road. If a narrow Geo-wall as like as RC structure with pile foundation is achieved, Geo-walls could be widely applied. And it can also be applied as substitute for concrete structures and contribute sustainable development.
Therefore, a new type reinforced soil wall with inserting piles into the Geo-wall body as shown in Fig. 2, which is referred to "Piled Geo-wall" in this paper, has been developed by authors. The application of piles to Geo-wall in order to improve lateral resistance is a completely new approach, since piles tend to be vertical bearing piles and are applied to soil fillings or as reinforcements to soil fillings on soft ground vertical pile [3]. In this novel approach, an assumption is made regarding the interaction between the pile and Geo-wall, as shown in Fig. 3. The high ductility of the Geo-wall was assumed to make it possible to transmit lateral force to the piles despite large relative displacement between the pile and Geo-wall. The validity of this assumption and practicability of Piled Geo-wall to actual diverse structure were confirmed through three experiments, a dynamic centrifuge model test [4]-[6], a static loading test and an impact-loading test.

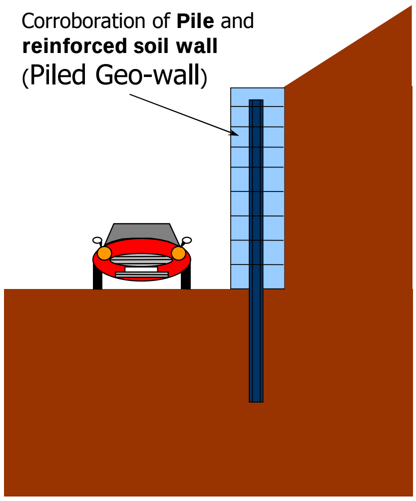



Fig. 2. An image of Piled Geo-wall.

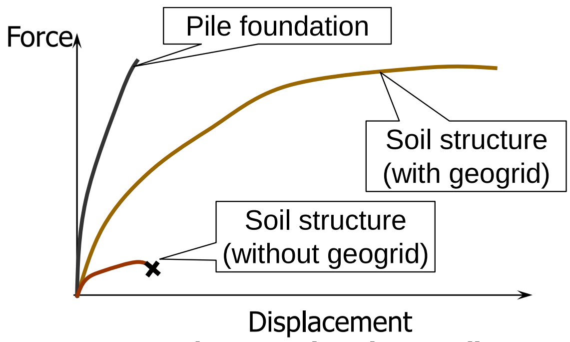



Fig. 3. Interaction between pile and Geo-wall.

In this paper, the details of the static and impact loading tests are introduced and the practicability of the Piled Geo-wall is discussed.

## 2. STATIC AND IMPACT LOADING TEST

### 2.1 Geo-walls for Experiments

Three full scale Geo-walls, normal Geo-wall (without pile), Piled Geo-wall-1 (PGW-1) and Piled Geo-wall-2 (PGW-2) were built on an actual field, and, at first, a static loading test was carried out with using the normal Geo-wall and PGW-1 and then an impact loading test was carried out with using all Geo-walls as shown in Fig. 4. Respective structural conditions, measurements and loading conditions are illustrated in each section of experiment. Fig. 5 shows the appearance of the Geo-walls.

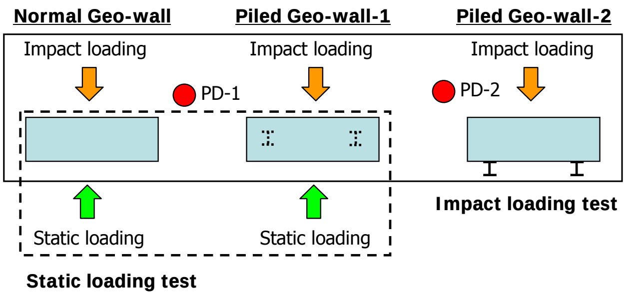



Fig. 4. Location of Geo-walls and respect experiments.

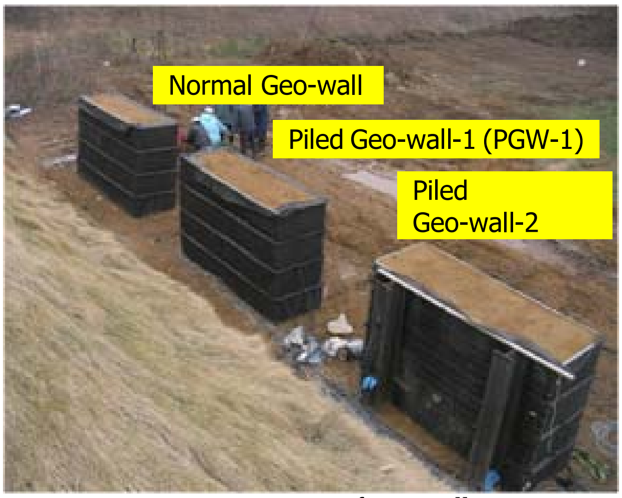



Fig. 5. Appearance of Geo-walls.

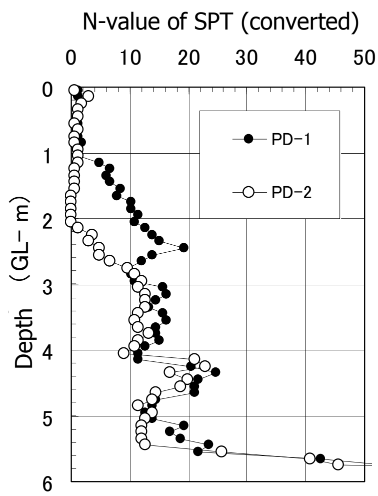


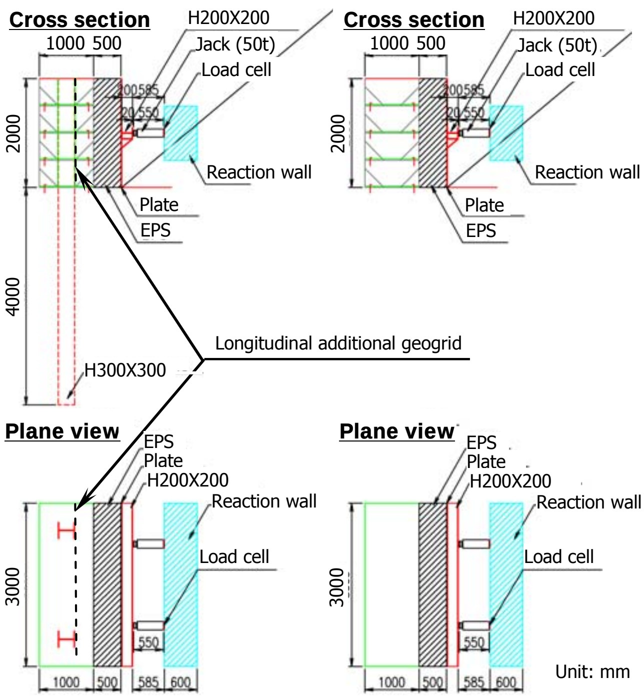

Fig. 6. Results of dynamic penetration tests.

### 2.2 Ground Condition

The foundation ground consists of three types of sandy silt, soft buried one, medium stiffness and stiffness ones. Fig. 6 shows the results of dynamic penetration test converted to N value of standard penetration test (SPT). The location of the borings, PD-1 and 2, is shown in Fig. 4. The thickness of the soft buried top soil is varied from the place of normal Geo-wall (PD-1) to Piled Geo-walls (PD-2).

### 2.3 Static Loading Test

A static loading test was carried out in order to confirm the practicability of Piled Geo-wall to earth retaining wall. In this test, two full scale Geo-walls, PGW-1 and normal Geo-wall (without pile), were adopted. Fig. 7 shows the structural summary of the test. Two jacks set at 1.0m in height give static horizontal load. And the horizontal load is carried as distributed pressure through an EPS of 0.5m in thickness, a steel plate of 0.12m in thickness and H steel (H200 x 200 x 8 x 12).




(a) PGW-1 (b) Normal Geo-wall

Fig. 7. Structural summary of static loading test.

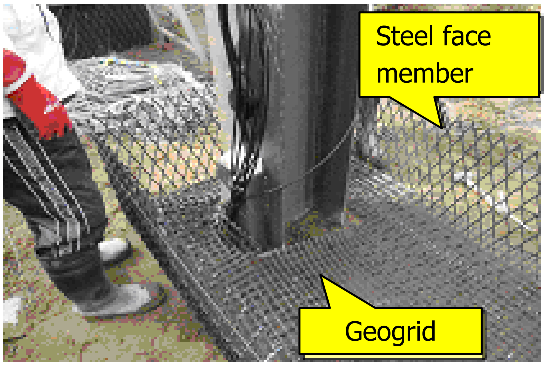
The procedure of Geo-walls' building is as follows;

**Pile installing (Piled Geo-wall only):** H steel piles (H-300x300x10x15) of 6.0m in length are installed in 4.0m into the ground.

**Setting of steel face member and installing of geogrid at each layer:** steel face members were set on the both side of Geo-wall and a geogrid was installed at one layer. In the construction of Piled Geo-wall, a geogrid with holes located in the piles was installed through the piles, as shown in Fig.8. Fig. 9 shows the tensile stiffness of the geogrid.

**Installing of longitudinal additional geogrid at each layer (Piled Geo-wall only):** the additional geogrid was installed on the loading side of piles, as shown in Fig. 10, in order to transmit the load to the piles from the Geo-wall body smoothly.

The executions of each layer, 0.5m in thickness, were repeated until that the Geo-walls, 2.0m in height, were completed.




Fug. 8. Installing of steel face member and geogrid.

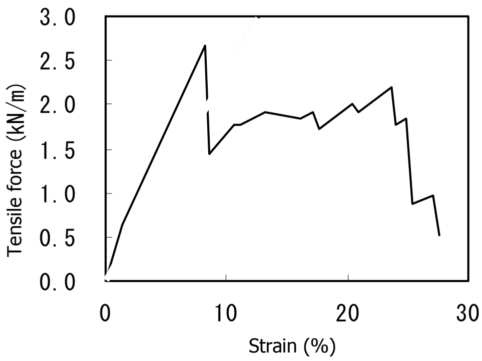



Fig. 9. Tensile stiffness of geogrid.

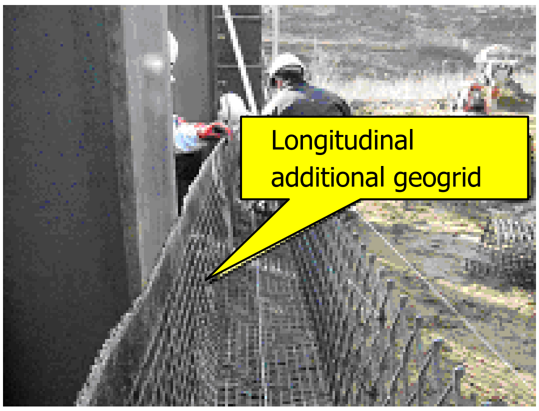
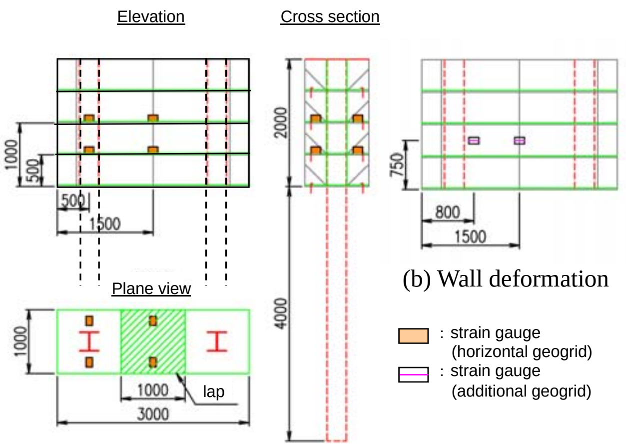


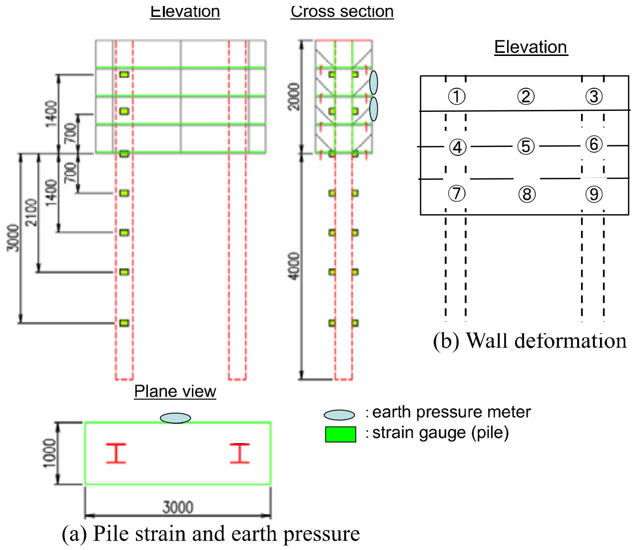

Fig. 10. Installing of longitudinal additional geogrid.




(a) Pile strain and earth pressure

Fig. 11. Measurements of strain in geogrids.

The measurements of strains of geogrids, additional longitudinal geogrids and a pile, earth pressure of the Geo-walls at the loading side, deformation of the Geo-walls and jack pressures were planned. Fig. 11 and 12 show the summary of measurements.




(a) Pile strain and earth pressure

Fig. 12. Measurements of strain of pile, earth pressure and deformation of Geo-wall.

Fig. 13 shows the relationship between falling moment and displacement of centre top of the Geo-walls (No.2 of Fig. 12(b)). Where, in order to compare with the active earth pressures loaded to retaining walls with different height, vertical axis is presented by falling moment. According to the results, high resistance characteristics of the Piled Geo-wall can be confirmed from the viewpoint of that the proof strength of Piled Geo-wall is still increasing even if corresponding earth pressure of retaining wall of 4.0m in height is loaded. Against the Piled Geo-wall, because of soft bearing foundation shown in Figure 6, the normal Geo-wall indicated the tendency of falling by corresponding earth pressure of retaining wall of 2.0m in height. Namely, in case of adoption of normal Geo-wall in this site, too wide Geo-wall has to be designed.

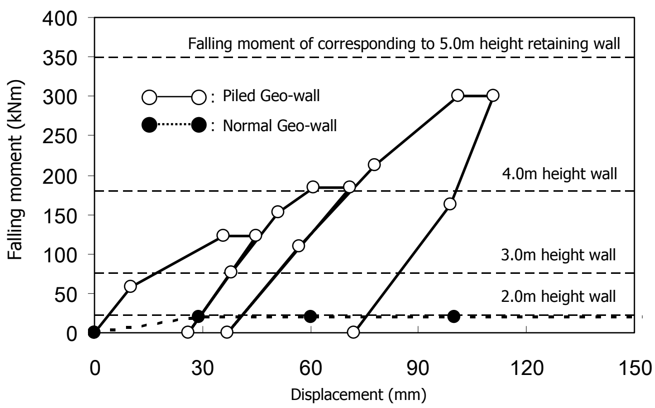
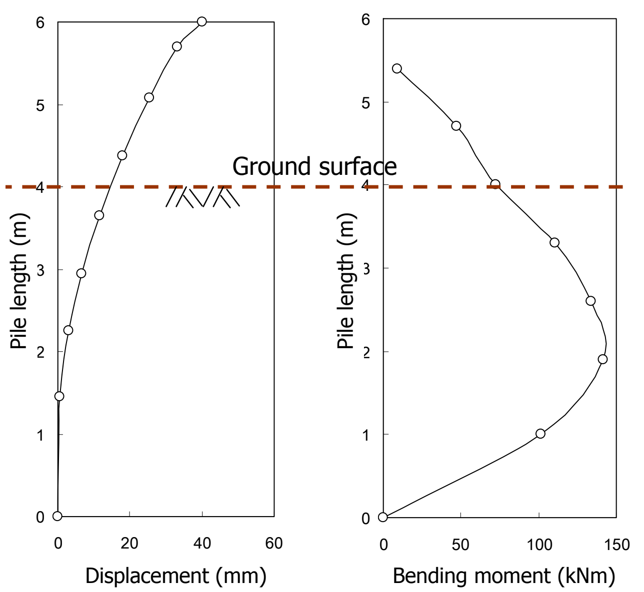



Fig. 14 shows the maximum response distribution of pile. According to the results, it can be confirmed that the horizontal load is transmitted to the pile and the pile contributes for improving the lateral resistance of the narrow Geo-wall.




(a) Displacement (b) Bending moment

Fig. 14. Maximum response distribution of pile.

Fig. 15 shows the relationship between horizontal load and strain occurring in longitudinal additional geogrid. According to the results, the strain occurring in the geogrid of the pile side is larger than the center one and the strain depends on the intensity of the horizontal load, thus the geogrid is considered to sufficiently function for transmitting of lateral force to piles from Geo-wall body.

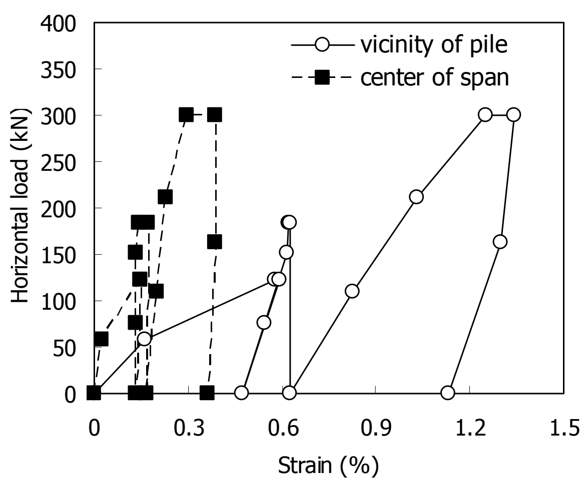



Fig. 15. Strain occurring in additional geogrid.

Fig. 16 shows the responses of the pile and the Geo-wall body at the point of pile top (No.1 of Figure 12(b)). According to the results, large relative displacement of the pile and Geo-wall is occurred though, the lateral force is transmitted to the pile from the Geo-wall and the lateral resistance of the Geo-wall was improved as abovementioned. Namely, the validity of the assumption established previously, “Geo-wall with high ductility can transmit lateral force to piles despite large relative displacement between the pile and Geo-wall as shown Fig. 3”, could be confirmed.

## 2.4 Impact-Loading Test

An impact-loading test was carried out in order to confirm the practicability of Piled Geo-wall to rockfall protection

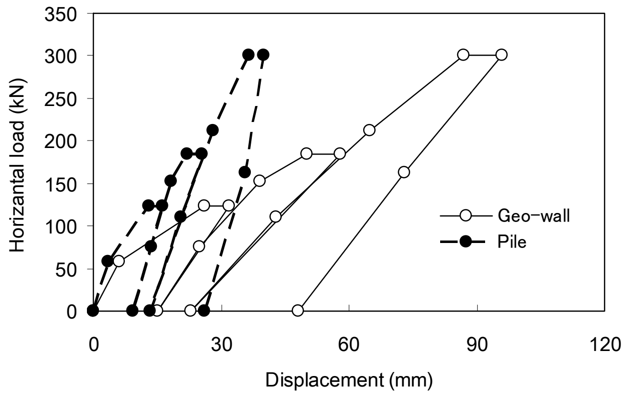



Fig. 16. Response of pile and Geo-wall body.

walls. In this test, three actual scale models, the two models of the normal Geo-wall and PGW-1, which are adopted in the static loading test, and a new one (PGW-2) were adopted, as shown in Fig. 4. The piles of PGW-2 are installed at outside of Geo-wall as shown in Fig. 17, are adopted.

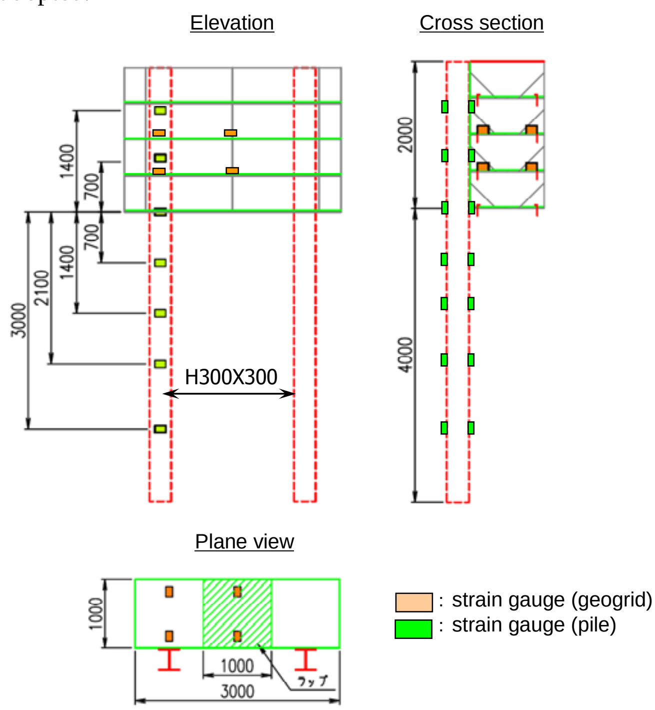



Fig. 17. Structural condition and measurements of PGW-2.

PGW-2 was adopted to confirm the best position of pile installing in case of impact loading, because there considered a possibility that keeping wide energy absorption extent is better than receive the rockfall energy at the center of Geo-wall body as PGW-1. In addition, the loading direction of static and loading tests are different, thus longitudinal additional geogrid of PGW-1 was installed on both sides of the Pile previously. In PGW-2, the additional geogrid was not installed. In this impact test, the impact of 100kJ was loaded to respective Geo-walls as shown in Fig. 18. Fig. 19 to 21 show the respective test results.

According to the results, against the collapse of normal Geo-wall, both Piled Geo-walls could receive the impact energy. Namely, the effectiveness of application of piles to improve lateral resistance of Geo-wall could be confirmed.

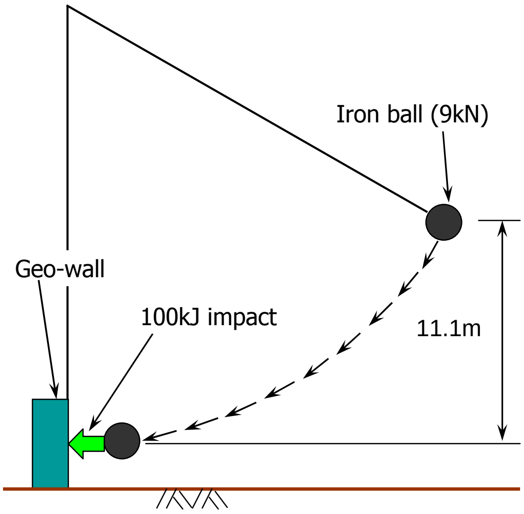



Fig. 18. Impact-loading test.

Note, however, that the deformation of the back side of the Geo-wall (protecting side, road side for instance), one of PGW-2 (piled installed at outside of the Geo-wall) is smaller than one of PGW-1 (piles installed at center of the Geo-wall). Since this result, the possibility that the best position of pile installing is outside of the Geo-wall in impact loading case can be considered. Meanwhile, from Fig. 22 showing responses of piles of the PGW-1 and 2, it is also considered that the resistance of the piles of PGW-1 seems to be smaller than ones of PGW-2. With respect to the result, following reasons can be considered.
- There might be a void in front of resistance surface of the piles of PGW-1 before the impact-loading test because of the static loading test implementation.
- In the foundation ground that the piles of PGW-2 were installed, the soft buried soil is comparatively thin, because the piles of PGW-2 were installed at the position closed to vicinity hill of 0.65m.
The best position of pile installing in case of impact loading has to be studied again with considering abovementioned phenomenon in the near future.

Fig. 19. Normal Geo-wall.

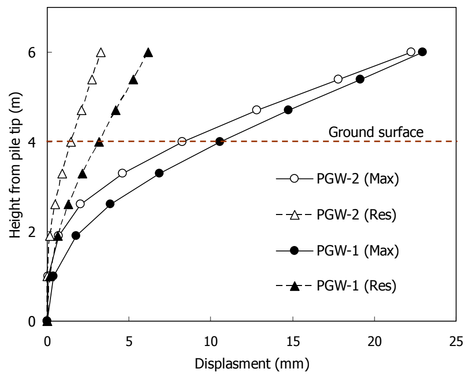
Fig. 23 shows transition of strain occurring in the longitudinal additional geogrid and the pile of PGW-1. According to the results, from the viewpoints of the strain occurring in the geogrid and the timing of occurrence of the strain between the geogrid and the pile, effect of the geogrid to transmit the lateral forces to the piles from Geo-wall could also be confirmed in the impact-loading test.

(a) Loading side

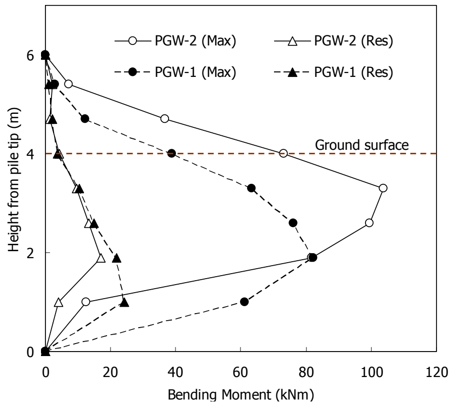
(b) Back side (protecting side)
Fig. 20. Piled Geo-wall-1 (PGW-1)

(a) Loading side

(b) Back side (protecting side)
Fig. 21. Piled Geo-wall-2 (PGW-2)

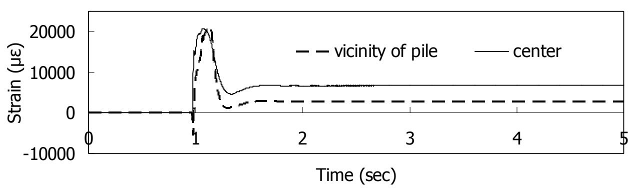



(a) Displacement

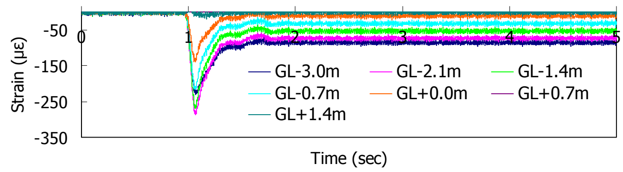



(b) Bending moment

Fig. 22. Response of piles of PGW-1 and 2.




(a) Additional geogrid




(b) Pile

Fig. 23. Strain of additional geogrid and pile of PGW-1.

## 3. CONCLUSION AND DISCUSSION ON PRACTICABILITY OF PILED GEO-WALL

**Application of piles to Geo-wall:** The effectiveness of application of piles to Geo-wall in order to improve lateral resistance of Geo-wall was confirmed from all the tests carried out in this study.

**Unification of piles and Geo-wall body:** Geo-wall with high ductility can transmit lateral forces to piles despite large relative displacement between the pile and Geo-wall. And adoption of longitudinal additional geogrid is effectiveness to achieve the unification of piles and Geo-wall body. Note, however, that the effect of the relative displacement to the internal quality of the Geo-wall body has to be studied.

**Application to retaining walls:** High resistance characteristics against static load and dynamic earth pressure could be confirmed from the static loading test as well as the previous carried out dynamic centrifuge model test [4]-[6]. Therefore, application of Piled Geo-wall to retaining walls is sufficiently possible for all ones depending on the tolerable deformation of the Piled Geo-wall and the embankment sustained by Piled Geo-wall.

**Application to rockfall protection walls:** High performance of Piled Geo-wall to receive rockfall could be confirmed from the impact loading test. Hence, application of Piled Geo-wall to rockfall protection walls would be possible if it is similar target rockfall with the experiment carried out in this study. Further experiments to determine the best position of the pile installing and to study the design for appropriate size of Piled Geo-wall depending on the intensity of rockfall energy are necessary before the widely application.

**Design code for the application:** Studies on the design method based on numerical simulations of the test results are conducting by authors. Although needed further experiments and studies to solve several issues are remained as abovementioned, a valuable design code for widely use of Piled Geo-wall would be published in the near future.

**Expectation of Piled Geo-wall to sustainable development:** Piled Geo-wall has possibility to be used as alternative structure of concrete ones with similar size. Therefore, if the development of Piled Geo-wall is achieved, it can be expected that the Piled Geo-wall contribute to sustainable development from the viewpoint of reducible structure of $CO_2$.

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