INFLUENCE OF PARTICLE SIZE AND GEOMETRY ON THE PULLOUT TESTS OF GEOCELL EMBEDDED IN SOIL

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ABSTRACT: To increase the pullout resistance and stiffness of geocells, pullout tests were carried out on different types of small scaled models of geocells with the backfill of Toyoura sand and gravelly soil under the surcharge of 1kPa.The influences of geometry of geocell and particle size of the backfill on pullout resistance and initial stiffness have been found. The test results indicated that the square-type geocells show higher initial stiffness and pullout resistance, but strain softening behavior, compared with the diamond-type geocells. For square-type geocells, the height and the shape of transverse ribs have an influence on the pullout resistance and initial stiffness. The test results also indicated that different types of geocells show different relationships between relative particle size of the backfill, pullout resistance and initial stiffness.

Key Words: geocell, particle size, pullout resistance

INTRODUCTION

Earth reinforcements by using geogrids, geocells, geotextiles and geomembrane have been widely applied to earth structures which have merits such as simple construction, cheap and environment-friendly filled material. Especially, for the last two decades, geosynthetic-reinforced soil retaining walls (GRS RWs) with a stage-constructed full-height rigid (FHR) facing have been constructed for railways, highways and other facilities and shown greater seismic resistance than conventional retaining wall structures (Tatsuoka et al., 2009).

The shaking table tests of integral bridge with a GRS-RW and a FHR facing (Nojiri et al., 2006) showed that higher tensile resistance of reinforcement layers at the back of the facing is crucial to the seismic stability. The tensile resistance is the minimum of the connection strength between the reinforcement and the facing, the tensile rupture strength of reinforcement and the pullout resistance of reinforcement (Nishikiori et al., 2007).

On the one hand, geogrids and geotextiles as planar reinforcements are commonly used to tensile-reinforce the backfill of earth structures. Pullout tests have been conducted to investigate the behavior of geogrids. Nishikiori et al. (2007) investigated various types of geogrid reinforcements including polymer grid, and rough phosphor bronze grid. Kuroda et al. (2012) investigated the influence of longitudinal and transverse members on pullout behavior of geogrids. Their results have shown that the pullout resistance largely depends on the surface friction of longitudinal members (shear resistance) and the thickness of transverse ribs (passive resistance).

On the other hand, geocell, a three-dimensional interconnected geosynthetic, can also be used as

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tensile reinforcement in the backfill of earth structures (Ling et al., 2009). The important benefit of geocell is to confine large particles in the three dimensional cells and respective cells have a large anchorage capacity when pull laterlly. Kiyota et al. (2009) conducted pullout tests with diamond-type geocells, which shows the strain hardening behavior in the load and displacement curve. Kuroda et al. (2012) examined the effect of particle size of backfill soil on the pullout resistance and stiffness of diamond-type geocells, which shows that pullout resistance becomes larger as the particle size becomes larger. However, the progressive deformations of geocells in the direction of pullout and a lower global stiffness have been found, compared with the pullout behavior of geogrids.

In order to increase the stiffness and pullout resistance of geocells, three square-type geocells (SG-1, SG-2, and SG-3) were tested in this study. The SG-1, SG-2, and SG-3 have different heights and shapes of transverse ribs which would cause the geometry effects of geocells during the pullout tests.

TEST APPARATUS, PROCEDURES AND MATERIALS

Pullout test apparatus

Figure 1 shows the schematic diagram of pullout test apparatus. The tests were carried out on plane-strain condition. The dimensions of sand box are 700mm (length) ×400mm (width) ×800mm (height). The pullout test apparatus was mainly made of steel except for longitudinal side walls, which were made of hard glass plates to reduce friction on the sidewalls. The front wall was composed of separate plates fixed on load cells for measuring the lateral force on the front wall. An opening of 30mm (height) was provided at the front wall for pulling out the model geocells. The tapes were used at the opening of the front wall to prevent the sands falling out during tests.

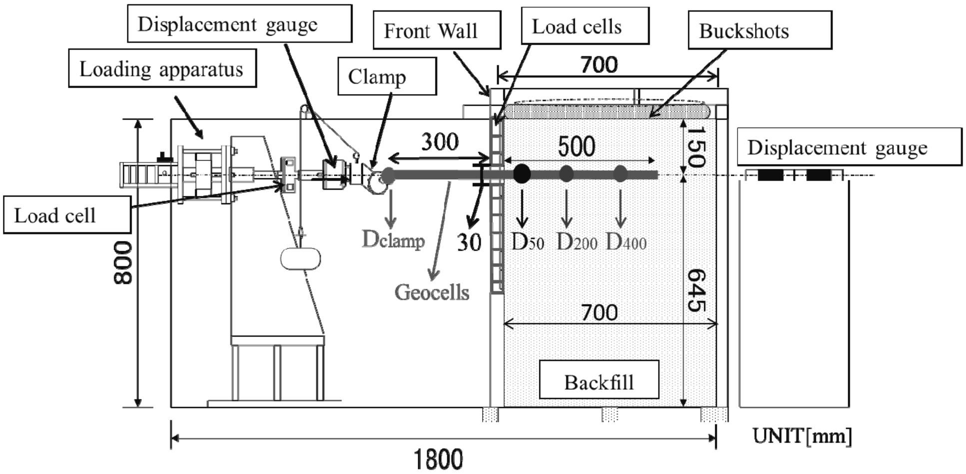


Figure 1. Schematic diagram of pullout test apparatus

Pullout test procedures

Dry Toyoura sand was poured into the sands box through three sieves in order to make the sand backfill homogeneous and the relative density (90%) was obtained by the fixed dropping height above the sands specimen. And then the geocells were embedded in the sand backfill. The pullout displacements of geocells (D_{clamp}) were measured using two displacement gauges at the clamping device and the displacements of the geocells away from the wall 50mm (D_{50}), 200mm (D_{200}), and 400mm (D_{400}) were also measured by three displacement gauges. The surcharge of 1kPa was applied by buckshots. The tests were conducted by pulling the geocell out at a constant speed of 5mm/min using a jack driven by a motor. The pullout force was measured using a load cell. As shown in Figure 2, the earth pressures on the front of the wall were measured by 13 load cells. All measurements and instruments used are shown in Table 1.

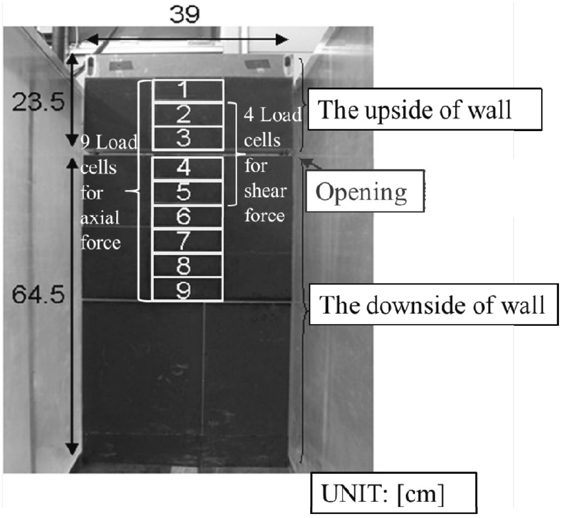


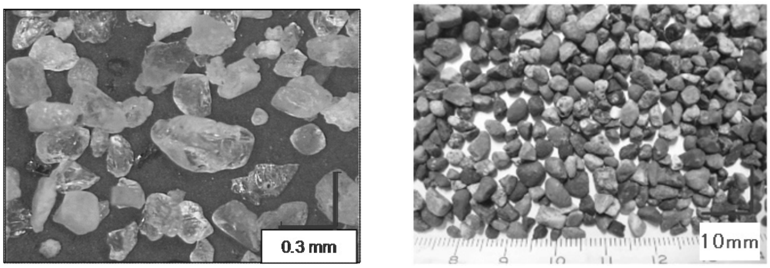
Figure 2. Load cells on the front wall

Table 1. Measurements and instruments

Mearsurment	Instrument	Number
Displacement at clamp	Displacement gauge	2
Geocell displacements	Displacement gauge	3
Pullout force	Load cell	1
Shear force on the wall	Load cells	4
Axial force on the wall	Load cells	9

Pullout test material

The soils used in this study were Toyoura sand and Gravel No.1. Figure 3 shows the particle size of Toyoura sands and Gravel No.1. The particle size of Toyoura sand is 0.1mm~0.2mm, and the relative density is 90%. The particle size of Gravel No.1 is 3mm~5mm.



(a) (b)

Figure 3. Pictures of particles: (a) Toyoura sand; (b) Gravel No. 1

Three types of model geocells are shown in Figure 4. The model geocells reinforcement is 500mm (length) ×350mm (width) ×25mm (longitudinal height), having 8 cells in longitudinal direction and 7 cells in transverse direction. The model geocells were made of polyethylene terephthalate (PET) covered with PVC materials for protection, having square aperture opening size of 60mm (length) ×50mm (width), longitudinal height of 25mm(1/6 of the practical projects), thickness of 1mm, ultimate tensile strength of 56kN/m, and 20% strain at ultimate tensile strength.

As can be seen from Figure 4, the square-type-1 geocells (SG-1) were prepared with full height of transverse ribs (25mm), the square-type-2 geocells (SG-2) were made with half height (12.5mm) of transverse ribs of SG-1, and the square-type-3 geocells (SG-3) were fabricated with half height of rotated transverse ribs of SG-1. The testing cases are summarized in Table 2.

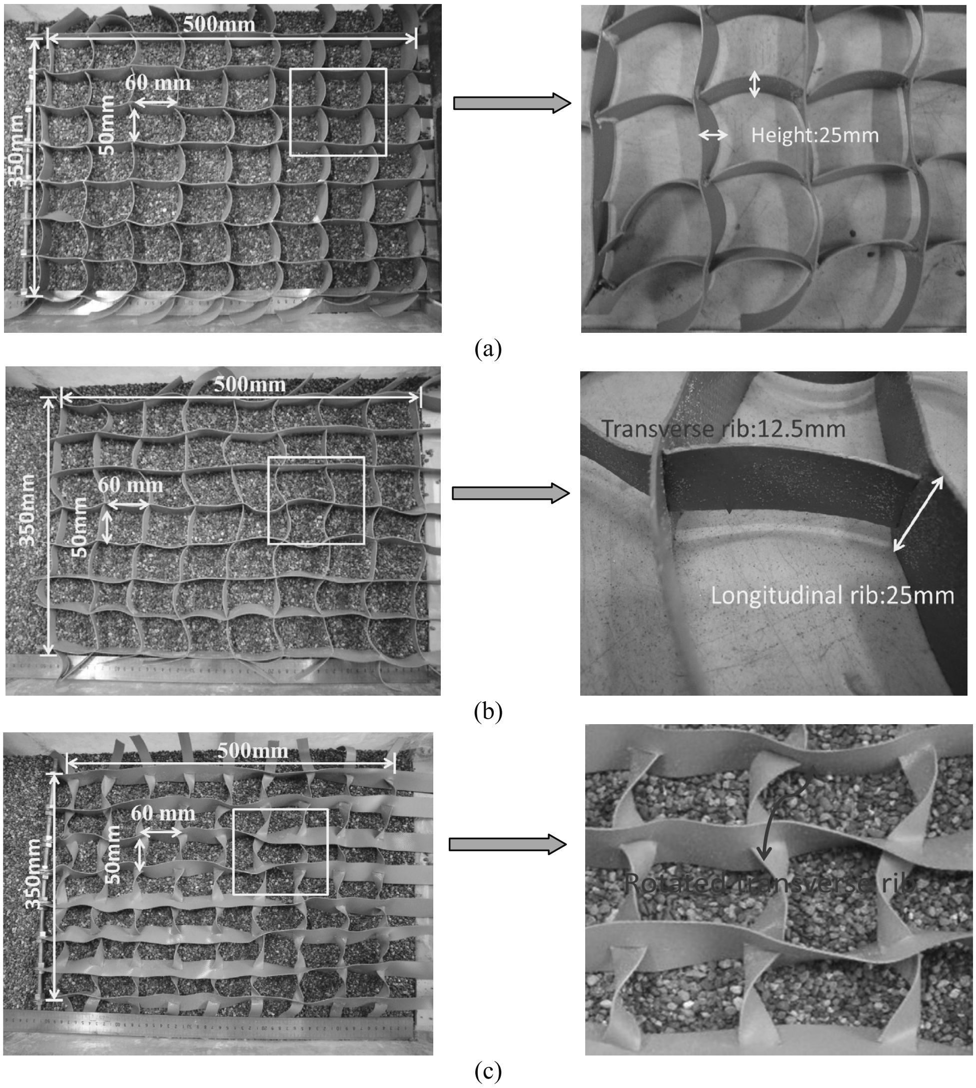


Figure 4. Geometry characteristics of square-type geocells: (a) SG-1; (b) SG-2; (3) SG-3

Table 2. Tests cases

Test cases	Types of geocells	Material of backfill
Test-1	SG-1	Gravel No.1
Test-2	SG-2	Gravel No.1
Test-3	SG-3	Gravel No.1
Test-4	SG-3	Toyoura sand

RESULTS AND DISCUSSION

Effects of geometry of geocell

The results of Test-4 for the pullout resistance against displacements of different locations along the model geocells are shown in Figure 5. When the pullout load is applied, the force is transmitted from the front to the end of the geocells in the soil. This shows the extensibility of geocells when it being pulled out from the soil. However, the relationship between pullout resistance (T) and local displacement of 50mm behind the wall (D_{50}) overestimates the initial stiffness of geocell during the process of pullout without considering the deformation of geocells at the front of the location of 50mm. However, the relationship of T-D_{clamp} underestimates the initial stiffness of geocells since the clamp displacement includes the deformations of geocells in the air.

In order to evaluate the displacement of geocells (D_0), as shown in Figure 5, the strain between the clamp and the location of 50mm behind the wall can be obtained. Therefore, D_0 can be calculated by interpolation method.

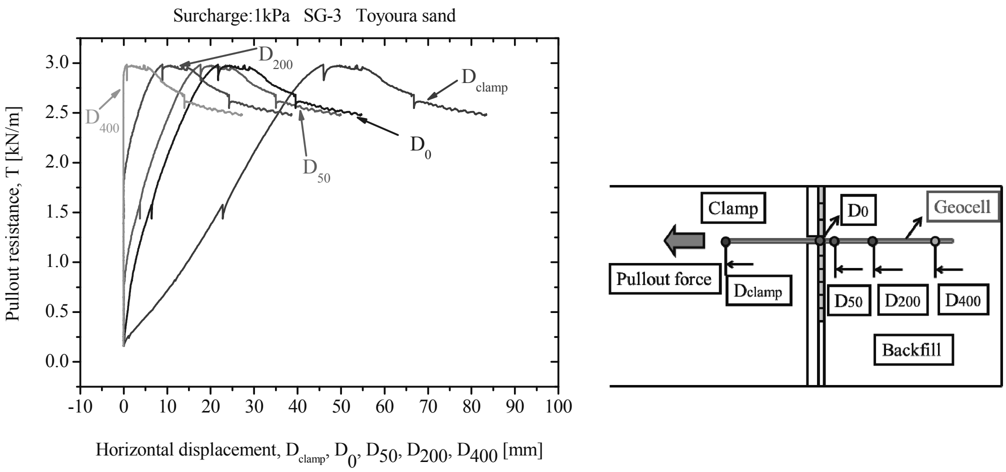


Figure 5. Pullout resistance against displacements of different locations along geocell of Test-4 and schematic diagram of the displacements measured along the geocell

Figure 6 shows the pullout resistance (T) against the displacement of geocell (D_0) for square-type geocells (SG-1, SG-2, and SG-3) and diamond-type geocells (DG) (Kuroda, 2012) with the same height of SG-1, which were conducted on the same test condition. The difference of the pullout resistance and initial stiffness are mainly due to the geometry of the geocells.

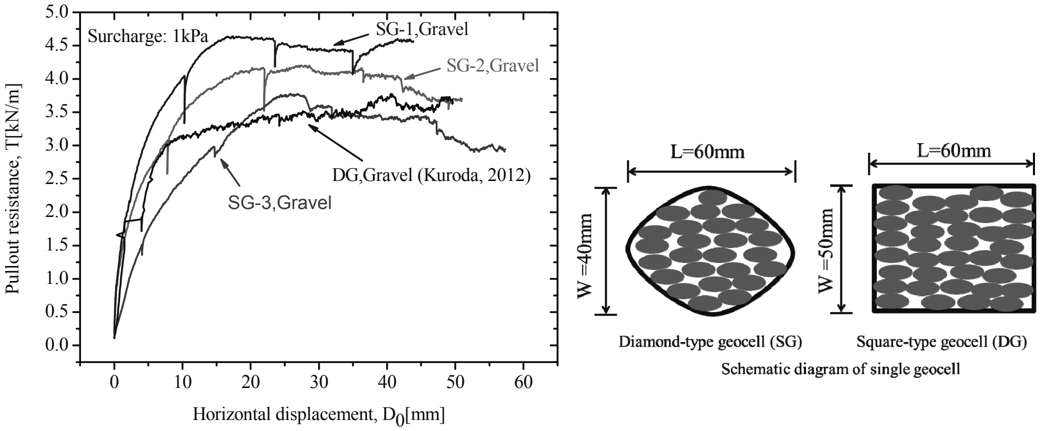


Figure 6. Relationship between pullout resistances against displacements for various types of geocells and schematic diagram of single geocell

For square-type geocells (SG-1, SG-2, and SG-3), the strain-softening behavior is apparent; and for diamond type geocells (DG), the strain-hardening behavior is apparent. It is found that DG reaches its yield pullout resistance at smaller displacement of 8mm, whereas SG-1, SG-2, SG-3 need larger pullout displacement to mobilize the peak pullout resistance.

It also can be seen that SG-1 not only has a higher pullout resistance and initial stiffness than DG, but also has a higher residual pullout resistance.

Among the square-type geocells SG-1, SG-2, SG-3, the pullout resistance and initial stiffness of SG-1 is higher than that of SG-2 and SG-3. This is due to the difference of transverse ribs. As can be seen from Figure 4, the height of transvers ribs in SG-2 is half of that in SG-1. As a result of the rotation of the transverse ribs in SG-3, the height of transvers ribs in SG-3 may be no more than half of that in SG-1. According to the mechanism of pullout resistance of reinforcement embedded in the backfill (Kiyota et al., 2009), when the particle size of backfill soil with respect to the height of geocell reaches a certain level, the anchorage force induced by passive pressure would determine the total pullout resistance, as a result, the pullout resistance would decrease as the decrease of the height of geocell.

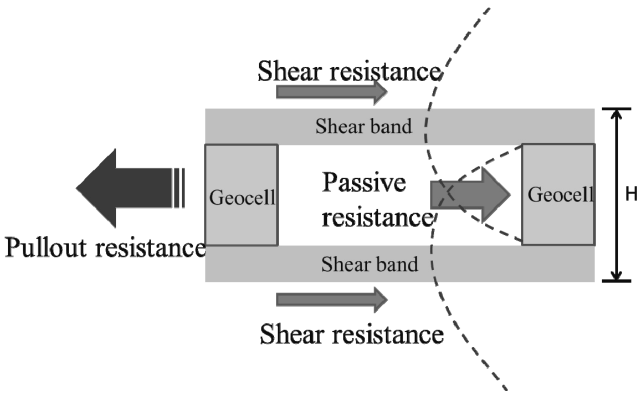


Figure 7. Mechanism of pullout resistance of reinforcement embedded in the backfill

Earth pressure on the wall

Figure 8 compares the results of earth pressure on the wall, when the geocells (DG, SG-1, SG-2, and SG-3) were pulled out from soil. As shown in Figure 8, the earth pressure induced by diamond-type geocells (DG) is higher than that by square-type geocells (SG-1, SG-2, and SG-3), which indicates that the excess confining pressure around DG induced by the mobilization of the geocells is higher than that of SG.

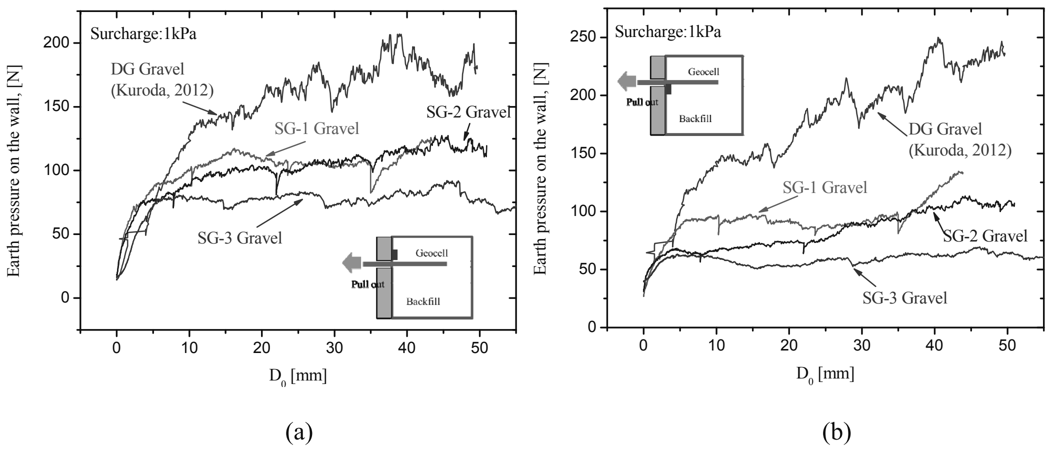


Figure 8. Earth pressure on the front wall: (a) on the upside of opening (load cell No.3); (b) on the downside of opening (load cell No.4)

A general interpretation of these results suggests that diamond-type geocells deform larger than square geocells on tensile force. In other words, the soils in the diamond cells may be pushed out much more easily than that in the square-type geocells, which could result in higher excess confining pressure. Meanwhile, the diamond-type geocells and more surrounding soils moved together to increase the earth pressure on the wall.

The earth pressure caused by SG-2 and SG-3 is lower than that by SG-1. There is a possibility that the decreased height of the transverse ribs in SG-2 and SG-3 would reduce the confining effect, thereby reducing the earth pressure.

Effects of particle size of backfill

Figure 9 shows the particle size effect on initial stiffness and pullout resistance. For SG-3 and DG, the initial stiffness increases and pullout resistance increase by 27% as the backfill material changed from Toyoura sand to gravel.

The particle size effect can be represented by the value of A/D (from Figure 6, A: average size of single cell, A= (L+W)/2; D: average diameter of soil particles) and H/D (H: the height of geocells; D: average diameter of soil particles).

Figure 10 summarizes pullout test results of diamond-type geocells (Kuroda et al. 2012) under surcharge of 1kPa, which show the particle size effect (A/D and H/D) on pullout resistance (and initial stiffness). As can be seen, for diamond-type geocells, the pullout resistance increases as the value of A/D (and H/D) decreases and reaches its maximum value (7.0kN/m) when A/D is 3.5 (and H/D is1.6). Yet, the initial stiffness rises to its peak value (2.41MPa) when A/D is 5.4 (and H/D is 3), and then the initial stiffness falls to 1.56MPa when A/D is 3.5 (and H/D is1.6).

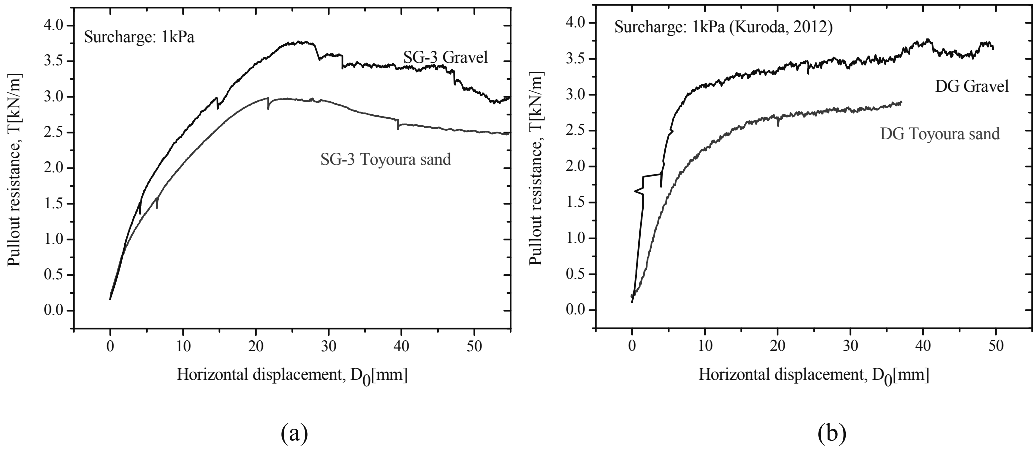


Figure 9. Relationship between pullout resistance and displacements of geocells in different backfill: (a) SG-3; (b) DG

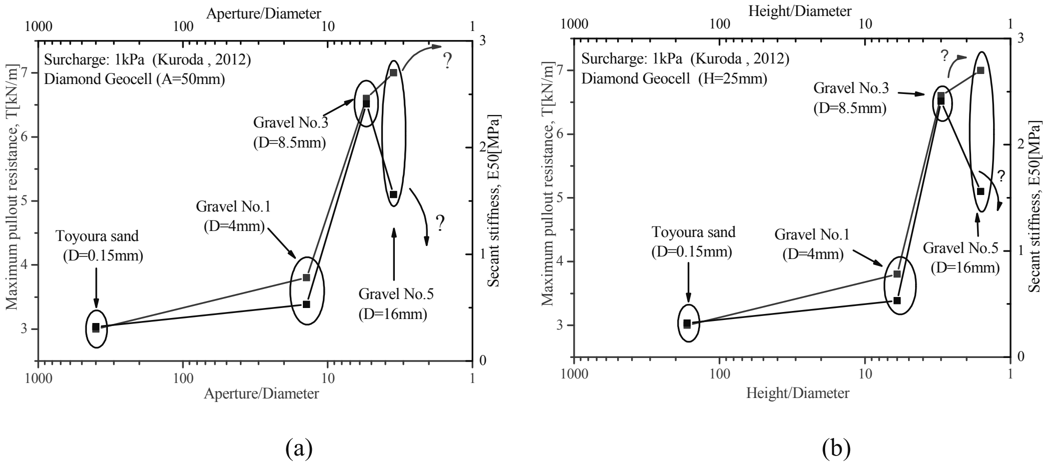
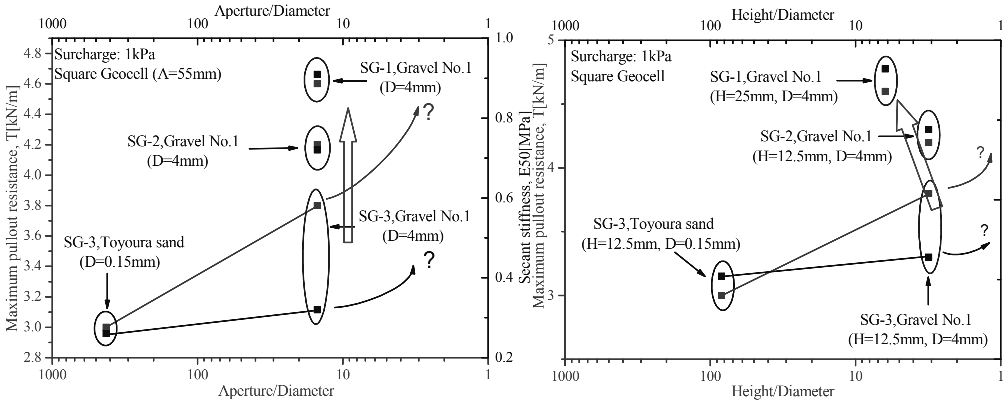


Figure 10. For diamond-type geocells: (a) Relationship between A/D and pullout resistance (and initial stiffness); (b) Relationship between H/D and pullout resistance (and initial stiffness)

Figure 11 compares the particle size effect on square-type geocells (SG-1, SG-2, and SG-3). From Figure 11 (a), for the same A/D, the difference of geometry and height of the square-type geocell will influence the pullout resistance and initial stiffness. From Figure 11 (b), as the height of geocell increases, the pullout resistance and initial stiffness increase. However, more tests are needed, for example, the backfill with larger particles, to describe the relationship between A/D (and H/D) and pullout resistance and initial stiffness.



(a) (b)

Figure 11. For square-type geocells: (a) Relationship between A/D and pullout resistance (and initial stiffness); (b) Relationship between H/D and pullout resistance (and initial stiffness)

CONCLUSIONS

The pullout tests of different types of model geocells were conducted by considering the geometry effects and particle size effects (A/D, and H/D) on pullout resistance and initial stiffness. The main conclusions from this study are as follows:

1. The pullout characteristics are affected by geometry of geocells.

Square-type geocells show strain softening behavior, while diamond-type geocells show strain hardening behavior under the surcharge of 1kPa.

Square-type geocells have higher initial stiffness and pullout resistance than diamond-type geocells with the same aperture and the backfill of Gravel No.1 under the surcharge of 1kPa. And also, for square-type geocells embedded in the Gravel No.1 backfill, as the height of transverse ribs decreases, the pullout resistance and initial stiffness decrease.

2. The pullout characteristics are affected by particle size effect.

The value of A/D (and H/D) can represent particle size effect. For diamond-type geocells, as the value of A/D (and H/D) decreases, the pullout resistance increases. Yet, there is an optimum value of A/D (and H/D) on the stiffness. However, different types of geocells may show different relationships between A/D (and H/D) and pullout resistance (and initial stiffness). Therefore, more tests are needed, for example, the backfill with larger particles, to describe the relationship between A/D (and H/D) and pullout resistance (and initial stiffness) for different types of geocells.

In addition, the pullout behavior of different types of geocells may be different under larger surcharge, since other factors, for instance, the connection between cells, may govern the ultimate pullout resistance. Therefore, the tests should also be conducted under larger surcharge in the future.

REFERENCES

Kiyota, T., Soma, R., Munoz, H., Kuroda, T., Ohta, J., Harata, M., and Tatsuoka, F. (2009). “Pullout behaviour of geo-cell placed as reinforcement in backfill.” *Geosynthetics Engineering Journal* 24(0), 75-82. (In Japanese).

Kuroda, T., (2012). " Evaluation of static and seismic stability of bridges with reinforced backfill and integrated structural (New type and Rehabilitated type bridges) by model tests." Master thesis, Department of civil engineering, Tokyo University of Science. (In Japanese).

Ling, H.I., Leshchinsky, D.,Wang, J.P., Mohri, and Y., Rosen, A. (2009). Seismic response of geocell retaining walls: experimental studies. *ASCE Journal of Geotechnical and Geoenvironmental Engineering* 135, 515-524.

Nishikiori, H., Aizawa, H., Soma, R., Sonda, Y., Hirakawa, D., and Tatsuoka, F. (2007). "Pull-out resistance of various types of reinforcement embedded in sand." *Geosynthetics Engineering Journal* 22, 97-102. (In Japanese).

Nishikiori, H., Soma, R., Aizawa, H., Hirakawa, D., and Tatsuoka, F. (2008). "Evaluation of various factors to pull-out resistance of various types of reinforcement embedded in sand." *Geosynthetics Engineering Journal* 23, 23-30. (In Japanese).

Nojiri, M., Aizawa, H., Hirakawa, D., Nishikiori, H., Sasada, M., Tatsuoka, F., Watanabe, and K., Tateyama, M. (2006) "Evaluation of dynamic failure modes of various bridge types by shaking table tests." *Geosynthetics engineering journal* 21, 159-166. (In Japanese).

Tatsuoka, F., Koseki, J., and Tateyama, M. (2009). "Seismic behaviour of geosynthetic-reinforced structures: Lessons from recent earthquakes and from recent earthquakes and design approaches." *The 12th Italian Conference on Geosynthetics, Italy.*