PARAMETERS INFLUENCING THE PULLOUT RESISTANCE OF SQUARE SHAPE GEOCELL EMBEDDED IN SANDY AND GRAVELLY BACKFILLS

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ABSTRACT: In order to investigate the influence of the backfill particle size and spacing of a square shape geocell, a series of pullout tests were conducted varying the spacing between transverse members embedded in well compacted sandy and gravelly backfills under a 1 kPa surcharge. Based on the obtained results it was determined that the ratio between the spacing of the geocell and backfill particle size influence the governing pullout mechanism and therefore the total pullout resistance of the geocell. In this sense, when the difference between the spacing and particle size is very large, the pullout resistance of the square shape geocell is governed by the shear resistance along the shear bands at the top and bottom interfaces, which is independent of the spacing of the geocell. On the other hand, as the spacing is decreased, the pullout resistance of the geocell is rather governed by the anchorage capacity of the cells, where larger spacing of the transverse members result in higher pullout resistances due to a better accommodation of larger particles within each unitary cell and development of a higher passive resistance.

Key Words: square-shape geocell, particle size, spacing, pullout resistance

INTRODUCTION

Since its introduction two decades ago, the Geosynthetic Reinforced Retaining Walls (GRS-RW) with full-height rigid (FHR) facing have been widely used in Japan for important infrastructure and major rehabilitation projects due to its high seismic stability, small deformability and cost effectiveness (Tatsuoka et al., 2007). Different types of geogrids and geotextiles have been conventionally used as planar tensile reinforcements of retaining walls, embankments and other soil structures. The pullout resistance of a geogrid soil reinforced element largely depends on the interlocking degree between the geogrid and backfill material (Kuroda et al. 2012 and Nishikiori et al. 2007). In this sense, in order to achieve a satisfactory performance, high qualify backfill material such as sandy soils are required. However, in many cases, these conditions are not met due to local unavailability of the backfill material, potentially leading to a decrease in deformability and seismic resistance of the structure.

Ling et al. (2009) conducted a series of shaking table tests of a geocell-facing retaining wall, finding that geocells show higher seismic stability compared to the conventionally geogrid-reinforced soil retaining walls, suggesting that three dimensional reinforcements can successfully be implemented to build gravity walls and soil reinforcement.

Considering the advantage of geocells to confine larger particles and a higher anchorage capacity when laterally pulled, Kiyota (2009) and Kuroda (2012) conducted a series of pullout tests using conventional shape geocells (diamond shape) to investigate the possibility of implementing geocell

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soil reinforcement. The results suggested that despite the higher pullout force of the diamond shape geocell compared to several geogrids, its progressive deformation leads to a decrease in the overall stiffness. With this in mind, Han (2012, 2013) conducted a series of pullout tests with a newly developed type of geocell, namely the square shape geocell. Comparing the pullout test results to those of the diamond shape geocell and several commonly used geogrids, it was found that the square shape geocell shows the highest pullout resistance as well as a higher pre-peak stiffness.

Moreover, Han (2014) and Mera (2015) investigated the influence of the existing relation between the height of the transverse reinforcements and particle size of the backfill material on the pullout resistance of the square shape geocell. The results showed that as the particle size of the backfill material is increased, an increase in the height of the transverse members yields higher pullout resistance due to an increment in the anchorage capacity of the geocell. However, the authors reported that it seems that there exists an upper limit at which a further increase in the particle size-height ratio does not yield a higher pullout resistance, since the anchorage resistance becomes larger than the shear resistance, thereafter the pullout resistance being governed by the shear resistance of the backfill material and therefore independent of the height of the transverse members.

In this study, the influence of the combined effect of the backfill particle size and spacing of the transverse members on the pullout resistance of the square shape geocell is investigated. The series of pullout tests consist of two different types of square shape geocells with different spacing, embedded in three different types of well compacted backfill materials.

TEST APPARATUS, PROCEDURES AND MATERIALS

Pullout Test Apparatus

The pullout test apparatus showed in figure 1 was newly developed at the Institute of Industrial Science, the University of Tokyo. The pullout tests were conducted under plain strain conditions, were the reinforcements were embedded in a backfill in the soil container. The pullout test apparatus consists of the soil container and a loading system. The dimensions of the soil container are 700 mm in length, 400 mm in width and 500 mm in height. The opening size on the front wall was kept constant at 45 mm. In order to prevent the soil of coming out when the pullout force is applied, cloth was used as a sealing agent. Moreover, lead shots were placed directly on top of the soil to simulate a 1kPa surcharge.

The pullout test loading system is controlled by a motor, which provides a constant pullout rate of 5 mm/min. In order to measure the generated pullout forces, a 49 kN load cell was attached to the pullout loading system, with a clamp connecting the load cell and the square shape geocell. Moreover, in order to measure the horizontal displacements of the square shape geocell and vertical displacement of the backfill, LVDTs were used at different positions, with a sampling time of three seconds.

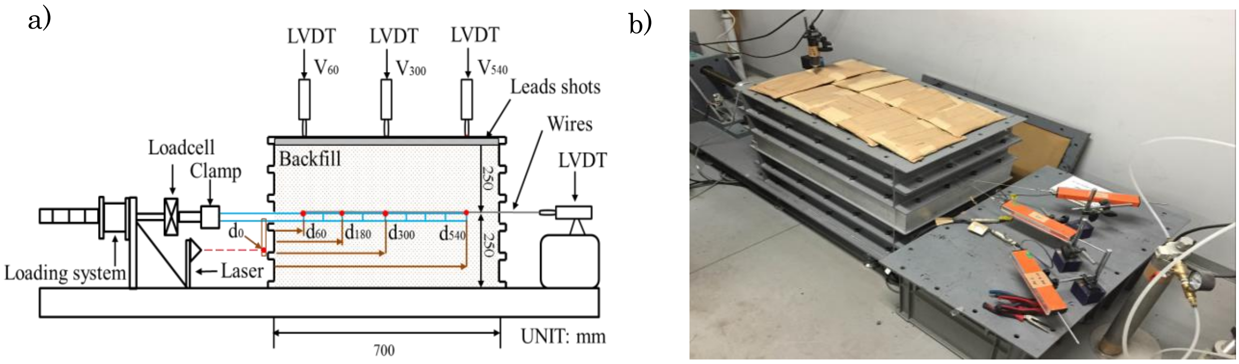


Figure 1. Pullout test apparatus, (a) Schematic diagram, (b) Final setting before testing

Pullout test procedures

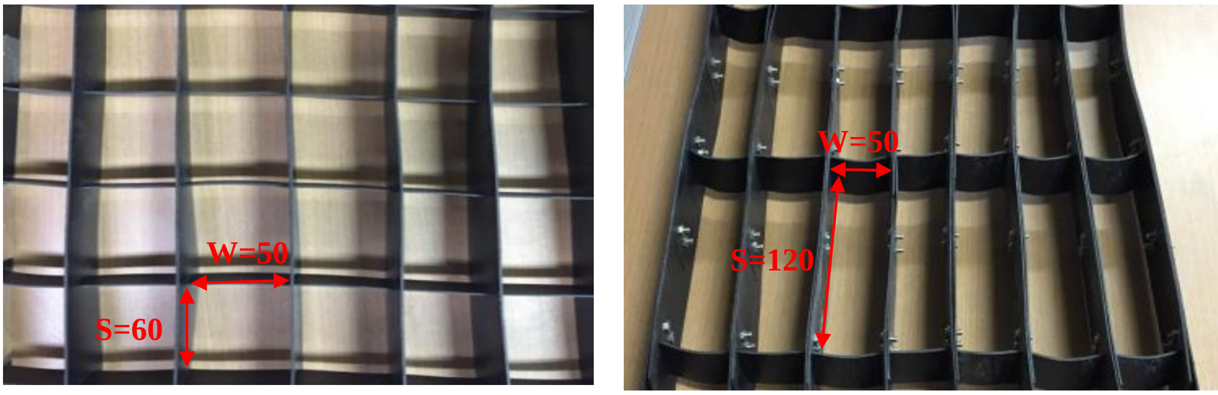
In order to achieve a well compacted backfill (D_c>95%), manual compaction was done in 50 mm intervals, 10 layers in total. The square shape geocell under consideration was placed in the soil container and then firmly fixed to the clamp, followed by sealing the aperture with cloth in order to prevent the backfill material of coming out when applying the lateral pullout. Moreover, in order to track the horizontal displacement of the square shape geocell, stainless inextensible wires were installed at distances of 60 mm (d_{60}), 180 mm (d_{180}) and 360 mm (d_{360}) from the front wall and connected to Linear Variable Displacement Transducers (LVDT). The wires were protected by stiff tubes in order to avoid the contact between the wires and the soil. All LVDTs were fixed to a steel plate behind the soil container. Additionally, an LVDT was installed at the top of the soil container at a distance of 60 mm from the front to measure the dilatancy of the backfill. Finally, a 1kPa surcharge was applied on the top of the backfill by buck shot bags, letting the backfill to settle and /or dilate freely. The pullout force was measured by a load cell attached to the clamp connecting the geocell, at a constant rate of 5 mm/s. The pullout force, horizontal displacements at d_{60}, d_{180} and d_{360} and vertical displacement at V_{60} were recorded in three seconds intervals by a data logger.

Pullout test materials

Silica Sand No.7 (D_{50} = 0.25 mm), Gravel No.1 (D_{50} = 3.2 mm) and Gravel No.5 (D_{50} = 14.2 mm) were used as poorly graded sandy and gravelly backfill materials (Fig.2). The square space geocell was 360 mm in length x 350 mm in width. The height of the transverse and longitudinal members was kept constant at 25 mm and 45 mm respectively, while the spacing between adjacent transverse members was 60 mm and 120 mm for each type of square shape geocell. Both types of square shape geocell were made of polypropylene, same material used for commercial geogrids (Fig. 3).

(a) (b) (c)

Figure 2. Soil Materials: (a) Silica Sand No.7, (b) Gravel No.1, (c) Gravel No.5



(a) (b)

Figure 3. Square shape geocell (a) Spacing S=60 mm (b) Spacing S=120 mm

Table 1. Test Cases

Geocell	Height (mm)	Spacing (mm)	Backfill Material
SG-1			Silica Sand No.7
SG-1		60	Gravel No.1
SG-1	25		Gravel No.5
SG-2			Silica Sand No.7
SG-2		120	Gravel No.1
SG-2			Gravel No.5

RESULTS AND DISCUSSION

Effect of particle size (D_{50}) on the pullout force

The existing relationship between the particle size (D_{50}) and spacing (S) was investigated by varying the spacing (S) between transverse member of the geocell, while keeping its height constant at 25 mm, and increasing the particle size of the backfill material.

From figures 4a and 4b it can be noted, that for both types of geocell embedded in Silica Sand No.7, Gravel No.1 and Gravel No.5 (SG-1 and SG-2), as the particle size of the backfill material increases, the peak pullout resistance also notoriously increases, with a decrease in the strain softening rate after the peak state. It is also important to note that a larger spacing (S=120 mm) yields higher peak pullout resistance compared to that of a smaller spacing (S=60mm).

a) b)

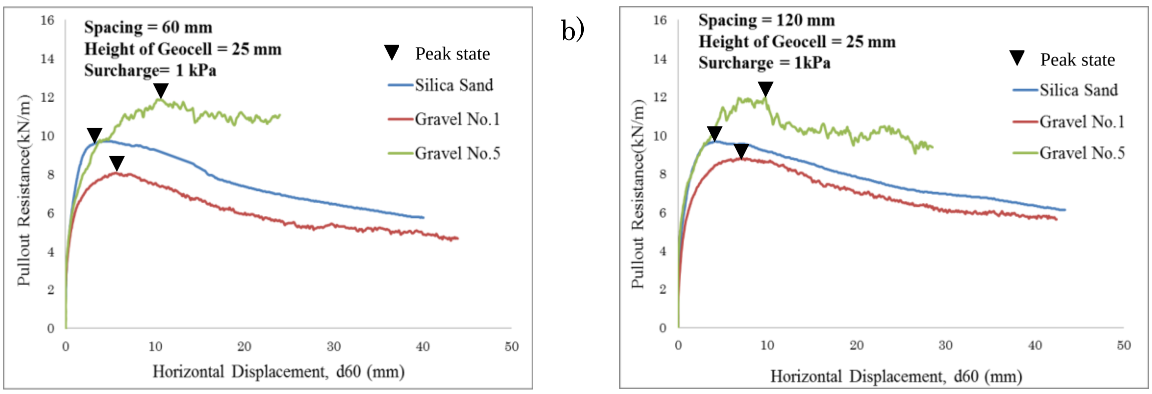


Figure 4. Relationship between horizontal displacement (d_{60}) and pullout resistance (a) Spacing S=60 mm, (b) Spacing S=120 mm

a) b)

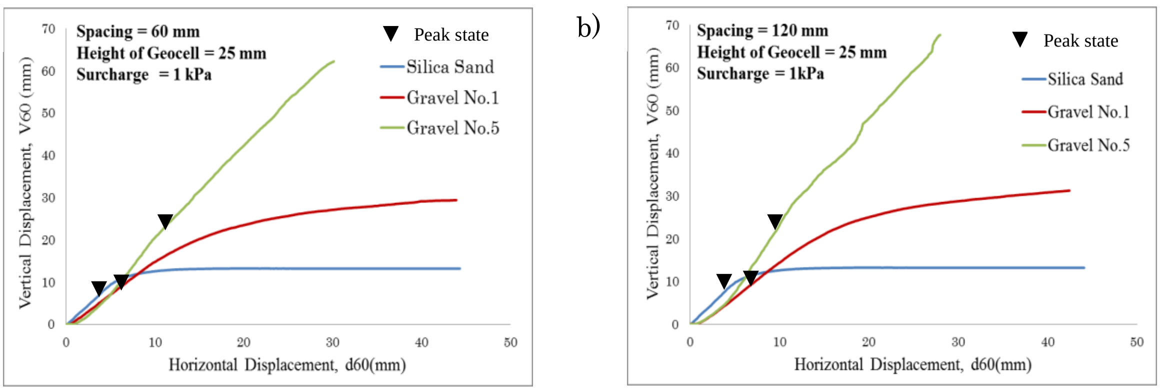


Figure 5. Relationship between horizontal displacement (d_{60}) and vertical displacement (V_{60}) (a) Spacing S=60 mm, (b) Spacing S=120 mm

Figure 5 shows the effect of an increase in the backfill particle size on the dilatancy rate for both types of geocell, SG-1 and SG-2. Both types of geocells show similar dilatancy rate behaviors, where at large horizontal displacements, larger particle sizes lead to a higher dilatancy rate. It is important to note that larger particle size materials show a more rapid increase in the dilatancy rate which is more notoriously observed in the post-peak region approaching to a residual state. In an opposite way, in the pre-peak region, the larger particles material show a smaller dilatancy rate, being considerably smaller than that of the smaller particle size backfill material. This behavior can be attributed to a lower pre-peak stiffness of the geocell reinforcement embedded in larger particle backfill materials. Moreover, the slower strain-softening rate in larger particle backfills leads to a gradual increase in the dilatancy rate which results in thicker shear bands adjacent to the geocell, leading to an increase in the confining pressure in each unitary cell, translating into a larger pullout resistance, especially at larger horizontal displacements.

Combined effect of particle size (D_{50}) and spacing (S)

Figures 6a and 6b compare both types of geocells (SG-1 and SG-2) embedded in Silica Sand No.7, Gravel No.1 and Gravel No.5. From figure 6a it can be noted that the peak pullout force for both types of geocells embedded in Silica Sand are the same with a similar strain softening rate in the post-peak region. Contrary, when embedded in Gravel No.1 and Gravel No.5, with the increase in the particle size and spacing between transverse members, it yields higher peak-pullout forces and slower strain softening. Moreover, figure 6b compares the relationship between the vertical displacement (V_{60}) and horizontal displacement (d_{60}). From these results it can be observed that the dilatancy rate for geocells with a spacing of 60 mm and 120 mm embedded in Silica Sand are identical. This behavior indicates that the total pullout resistance is governed by the shear resistance along the developed shear bands, and therefore independent on the size of the geocell. On the other hand, an increase in the particle size and spacing (S), leads to a higher dilatancy rate resulting in a higher pullout capacity. The change from no influence of the spacing to an increasing influence of it on the pullout resistance indicates that the governing mechanism of the total pullout force is directly influenced by the spacing and the particle size. In this context, the pullout resistance of larger particle sizes is rather governed by the anchorage resistance developed in each unitary cell, which has not yet become larger than the resistance of the shear bands. Moreover, larger spacings allow a higher passive resistance to be developed within the geocell, which at the same time can better allocate larger soil particles.

It is important to note that the higher dilatancy rate of larger particles in the post-peak region compared to that of smaller particle size material can be attributed to a development of thicker shear bands at the interfaces between the geocell and backfill.

a)

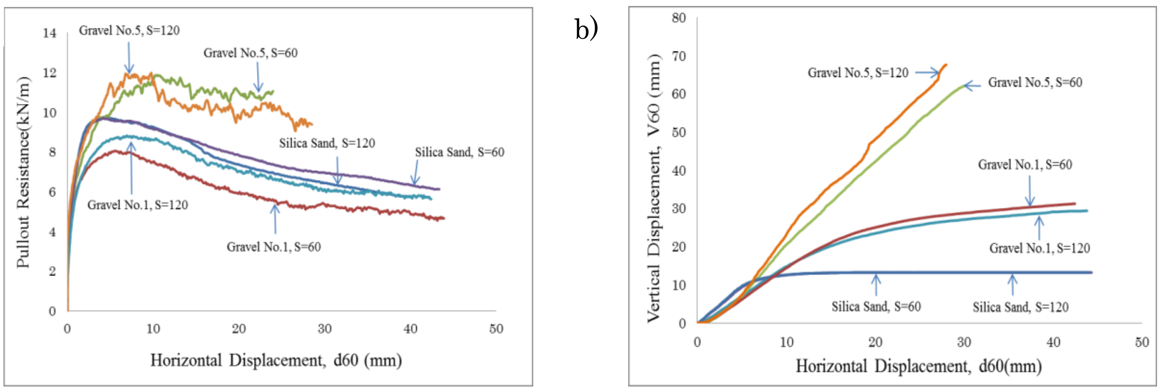


Figure 6. Comparison of pullout behavior of SG-1 and SG-2, (a) Relation between horizontal displacement (d_{60}) and pullout resistance, (b) Relation between horizontal displacement (d_{60}) and vertical displacement (V_{60})

Table 2. Peak Pullout Resistance varying spacing (S) and particle size (D_{50})

Height (mm)	Spacing (mm)	Particle Size (D_{50})	Peak Pullout resistance (kPa)
25	60	0.25	9.7
		3.2	8.82
		14.2	11.86
	120	0.25	9.7
		3.2	8.02
		14.2	11.96

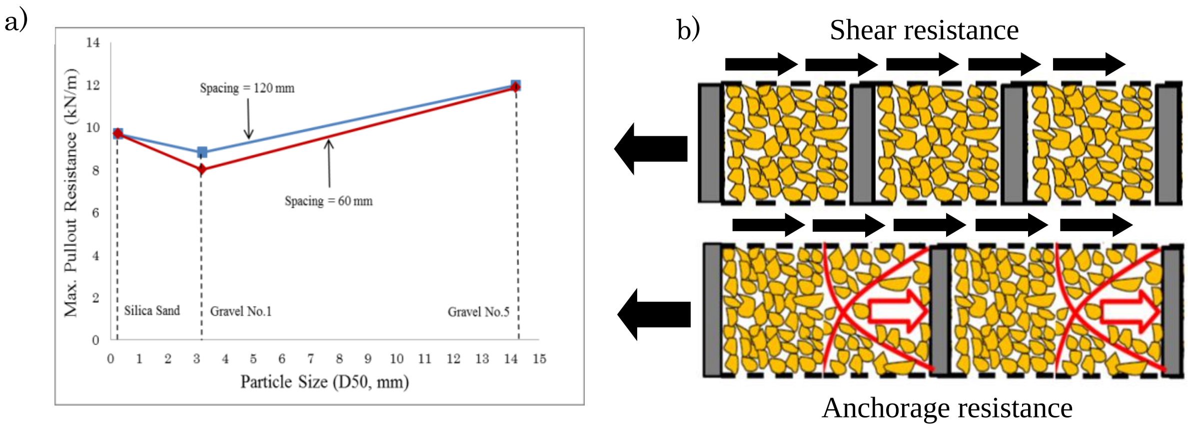


Figure 7. (a) Pullout resistance relative to particle size, (b) Schematic pullout mechanisms of the square shape geocell

Table 2 summarizes the peak pullout resistance with varying spacing (S) and soil particle size (D_{50}). From figure 7, it can be noted that the 120 mm spacing geocell embedded in Gravel No.5 exhibits the largest pullout resistance (11.97 kN/m). Interestingly, the 60 mm spacing geocell embedded in the same backfill material shows a slightly smaller pullout resistance (11.86 kN/m). Moreover, as the difference between the spacing and particle size ratio increases, there is a significant drop in the maximum pullout resistance for both types of geocells (i.e SG-1, SG-2). However, as the ratio is further increased, the maximum pullout resistance rather increases again to a higher value to that of the previous material.

This behavior can be attributed to the different governing pullout mechanism depending on the magnitude of the spacing – particle size ratio. In this sense, the pullout resistance will be governed by the shear resistance of the shear bands adjacent to the geocell when the difference between the particle size and spacing is considerably large. On the other hand, as this difference is decreased, the total pullout resistance is rather controlled by the anchorage resistance developed in the geocell. However, if the spacing is too small relative to the particle size, just a few soil particles will be allocated in each geocell, leading to an underperformance of the geocell, which might be the case for the S=60 mm and S=120 mm geocell embedded in Gravel No.5. Moreover, it is important to note that the smaller pullout resistance of the geocell embedded in Gravel No.1 compared to that embedded in Silica Sand No.7 is possibly because the developed anchorage resistance is still smaller than the shear resistance of the shear bands of the Silica Sand No.7 backfill material. Furthermore, the higher pullout resistance of a larger square shape geocell embedded in larger particles is possibly attributed to the better confinement of larger particles within each unitary cell leading to a larger development of passive resistance, resulting therefore in a higher pullout resistance.

CONCLUSIONS

Two types of square shape geocell with varying spacing of the transverse members were embedded in well compacted sandy and gravelly backfill materials and subjected to a series of pullout tests on small scaled models. The obtained results give important insights on the influence on the combined effects of the spacing and particle size of the backfill material on the pullout performance of the geocell. The findings are summarized as follows:

1. Increasing the particle size and spacing of the geocell yields a higher total pullout resistance of the square shape geocell due to a better accommodation of soil particles and a larger development of the passive resistance within the cells.
2. The total pullout mechanism of the square shape geocell depends on the difference between the backfill material particle size and spacing of the transverse members of the geocell. As the particle size of the backfill material becomes significantly small compared to the spacing, the total pullout resistance of the square shape geocell is governed by the shear resistance developed on top and bottom of the geocell. On the other hand, as the difference between the soil particle size and the spacing of the geocell becomes smaller, the total pullout resistance is rather governed by the anchorage resistance of the square shape geocell.
3. There seems to be an upper limit to which an extra increase in the spacing of the geocell does not have an influence on the total pullout capacity of the geocell due to being governed by the shear resistance of the shear bands developed at the upper and lower interfaces between the adjacent soil and geocell, which is independent of the geocell dimensions. Moreover, it is apparent that there exists a lower limit at which a further decrease in size of the spacing of the geocell will impede a good accommodation of the soil particles, leading to an under performance on the pullout resistance of the geocell.

In order to narrow down an optimal range of spacing and particle size, further pullout tests are needed using additional spacing sizes (i.e S=30 mm, S=90 mm, and S=180 mm) embedded in a given backfill material with an average particle size between those of Gravel No.1 (3.2 mm) and Gravel No.5 (14.2 mm).

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