Cell-size effect on the pullout resistance of square-shaped geocells embedded in gravel

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ABSTRACT: Geosynthetic reinforced soil retaining walls (GRS RWs) technology has been spread worldwide mainly due to higher seismic stability of this type of structures compared to the conventional unreinforced backfill retaining walls. GRS RWs typically use geogrids as backfill reinforcement material. In the present research, a new type of tensile reinforcement comprising of square-shaped geocell is presented. A mattress of square-shaped geocell is constituted by interconnected straight longitudinal and transversal members which are able to accommodate and confine larger soil particles within its cells unlike planar geogrids. In order to investigate the effects of the cell size of a geocell mattress on the overall pullout resistance of this material embedded in gravelly soils, a series of pullout tests were conducted. There is a value of S, 60 mm, leading to maximum peak pullout resistance and initial stiffness, when S of the geocell buried in Gravel No.1 increases. But when the geocell was buried in Gravel No.3, there is not such a value. The peak pullout resistance is increased when H_T increases. When D_{50} increases from 3.2 mm (Gravel No.1) to 7.5 mm (Gravel No.3), there is no significant effects on the peak pullout resistance.

Keywords: Square-shaped geocell, spacing, height, pullout resistance, initial stiffness

1 INTRODUCTION

Geosynthetic reinforced soil (GRS) structures exhibits higher seismic stability and cost effectiveness under high seismic demand in contrast to the conventional unreinforced structures (Tatsuoka et al., 2007, Munoz et al. 2012, Tatsuoka et al. 2012). GRS technology has been also applied to the Design Standard for Railway Soil-Retaining Structures in Japan for very important soil structures (e.g. high speed trains), i.e. the Rank I, important soil structures (e.g. urban trains), i.e. the Rank II, and the Rank III, other non-critical soil structures. Geogrids as planar tensile reinforcements are conventionally used to tensile-reinforce the backfill of GRS structures. Good interlocking between soil particles and geogrid ensures achieving higher pullout resistance (Tatsuoka et al., 2007). Other parameters such as the covering ratio, the surface roughness of the longitudinal members, and the thickness of transversal members of the grid are relevant to increase the pullout resistance (Nishikiori et al., 2007 and 2008). The soil-geogrid interaction provides an additional increase in the stiffness of the reinforced soil as result of interlocking of the soil particles within the aperture of the geogrid following induced friction and passive resistance of transversal members (Giroud, 2009). However, when good soil for backfilling (i.e. well-graded gravelly soil or well-graded sandy soil) in the vicinity of the construction site and good compaction methods are not unavailable it is difficult to construct a GRS structure to meet the required seismic performance of Rank I, II and III. Therefore, a three-dimensional geocell placed as reinforcement is proposed to be used in GRS structures on the premise that geocell can firstly accommodate a wide range of large soil particle of poor backfill within its cells and secondly, it may offer acceptable pullout strength to reinforce soils under high seismic stability in a similar manner that geogrid reinforcement.

A geocell is a three-dimensional soil confinement system widely used as base reinforcement subjected to vertical loads in foundation engineering when encountering soft soils. The typical geocell type consist of diamond-shaped cells. The influencing parameters of geocell on the foundation reinforcement performance such as geometry, geocell material, infilled soil, loading methods and others have been investigated via laboratory tests (Rea and Mitchell, 1978; Shimizu and Inui, 1990; Dash et al., 2001a, b). For instance, triaxial compression tests on a single geocell or multiple geocells (Bathurst and Karpurapu, 1993; Rajagopal et al., 1999; Mengelt et al, 2006).

Previous studies on the pullout resistance of geocells show that the conventional type of geocell (i.e. diamond-type) shows large deformability, low elastic modulus and low pullout resistance (Munoz et al., 2012). This is mainly due to the weak strength of the welding elements forming the diamond shape of the geocells are torn out with easy. In this view, to overcome the low strength of welding elements of the conventional geocell, a newly-developed square-shaped geocell having longitudinal and vertical elements arrange perpendicular to each other is proposed in this research as a new tensile reinforcement for GRS applications. In this regard, pullout experiments have been conducted previously (Han and Kiyota et al., 2012 and 2013a Han et al. 2013b and Mera et al. 2015, Haussner et al. 2016). However, different parameters on the pullout behavior of this new type of reinforcement such as the influence of the spacing between transversal members of geocell, the height of transversal members, the particle size of the backfill (i.e. the geocell size effect) and others have not been studied yet. In order to investigate the above, a series of pullout tests were conducted for geocells having different spacing and height of transversal members and different soil particle size.

2 TEST APPARATUS AND MATERIALS

2.1 *Pullout test apparatus*

A schematic diagram of pullout test apparatus is shown in Figure 1. The geocell models were embedded two types of gravelly soils inside a steel container. The container is 700 mm in length, 400 mm in width and 500 mm in height. The geocell models were pulled out under plane-strain condition following a constant displacement rate which was controlled by a motor and in-built computer. The opening height of the front wall for pulling out the geocell model was adjusted in order to avoid any undesirable additional friction due to the opening contacting the geocell ribs. A surcharge of 1kPa was applied by lead shots placed on the crest of the backfill.

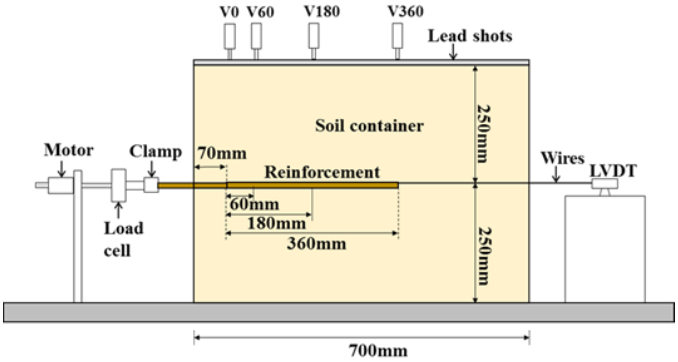


Figure 1. Schematic diagram of Pullout test apparatus

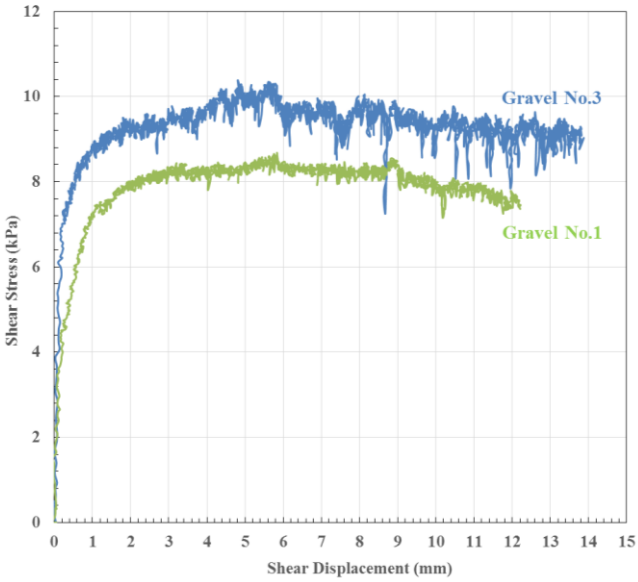
Typically, this surcharge represents the load imposed by the pavement in actual structures factor-reduced in the testing model. A scaled model by a factor of 1/10 was used in the experiments.

2.2 *Gravelly soils and square-shaped geocells*

Two types of gravelly soils were used as the backfill material in the experiments presented herein, i.e. Gravel No. 1 and Gravel No. 3. Figure 2 shows the grain size of this soils and the results of direct shear test carried out under the normal stress 5 kPa. Table 1 shows physical and mechanical properties of the gravels including grain size (D_{50}), coefficient of uniformity (U_C), minimum and maximum density and internal friction angle, respectively. The square-shaped geocell consists of polyethylene (PE) ribs having its longitudinal and transversal members arranged perpendicularly to each other. The dimension of the geocell is 360 mm in length and 350 mm in width as shown in Figure 3. Six different arrangement of the square-shaped geocell were used in the experiment as summarized in Table 2. The geocell models were scaled down by a factor of 1/10 in regard to its prototype.

(a) Gravel No.1

(b) Gravel No.3



(c) Direct shear test results

Figure 2. Gravelly soil used in the experiments

Table 1. Gravelly soil physical and mechanical characteristics

	Soil	D_{50} (mm)	U_C	Minimum Density (g/cm_3)	Maximum Density (g/cm_3)	Internal friction angle (°)
1	Gravel No.1	3.2	1.36	1.55	1.73	37
2	Gravel No.3	7.5	1.28	1.60	1.784	53

Table 2. Square-shaped geocell reinforcement used

	Longitudinal members			Transversal members		
	Number	Spacing (mm)	Height (mm)	Number	Spacing (mm)	Height (mm)
1	8	50	18.75	4	120	12.5
2	8	50	37.5	13	30	25
3	8	50	37.5	7	60	25
4	8	50	37.5	4	120	25
5	8	50	37.5	3	180	25
6	8	50	60	4	120	40

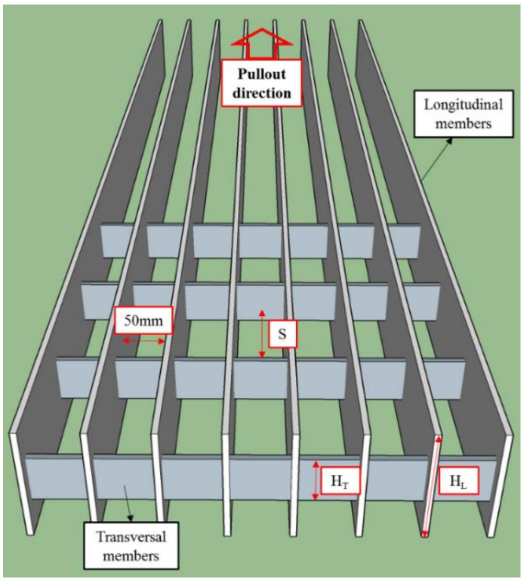


Figure 3. Schematic diagram of square-shaped geocell reinforcement: S is the spacing between transversal members; H_T is the height of transversal members; H_L is the height of longitudinal members; $H_L=1.5H_T$.

2.3 *Pullout test*

The gravelly soil was poured into the soil container by ten layers and each layer was compacted to achieve a target density (i.e. compaction degree Dc of 100% on average). After placing five layers of backfill in the steel container, the geocell model was placed on and its front end was fixed to a rigid clamp. Five additional layers of gravelly soil were placed to fill the steel container.

Wire-type LVDTs to measure the local horizontal displacements of the geocell model at four different locations in the horizontal axis corresponding to D_0, D_{60}, D_{180} and D_{360} were arranged along the middle axis of the geocell. See Figure 1. The Wire-type LVDT at D_0 is located 70 mm from the front wall of the steel container and its position coincides with the first transversal member. In order to minimize the influence of frictional characteristics of front wall, if any, teflon panels were glued to the front wall. The vertical displacements of the backfill at the surface were measured by LVDTs placed vertically at distances D_0, D_{60}, D_{180} and D_{360}. A load cell connected with a clamp was used to measure the pullout force. The geocell model was pulled out at a constant rate of 2.5 mm/min. Table 3 summarizes the test cases conducted in this study.

Table 3. Square-shaped geocell reinforcement used in test cases

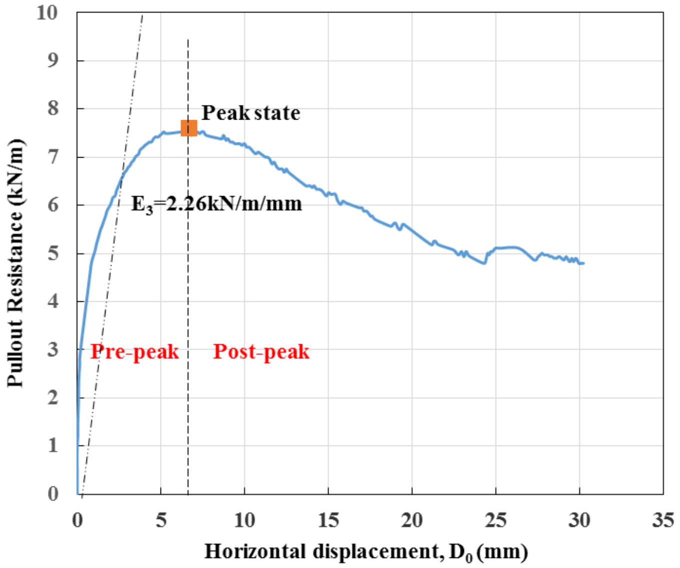
Case	Soil backfill		Transversal members				Objectives		
	Materials	Compaction degree (Dc/%)	S (mm)	S/D_{50}	H_T (mm)	H_T/D_{50}			
1	Gravel No.3	100%	30	4	25	3.3	a		c
2			60	8			a		c
3			120	16			a		c
4			180	24			a		c
5	Gravel No.1	100%	30	9.4	25	7.8	a		c
6			60	18.8			a		c
7			120	37.5			a	b	c
8			180	56.3			a		c
9			120	37.5	12.5	3.9		b	
10			120	37.5	40	12.5		b	

a) Evaluate the effect of spacing of transversal members on the pullout behavior
b) Evaluate the effect of height of transversal members on the pullout behavior
c) Evaluate the effect of grain size on the pullout behavior

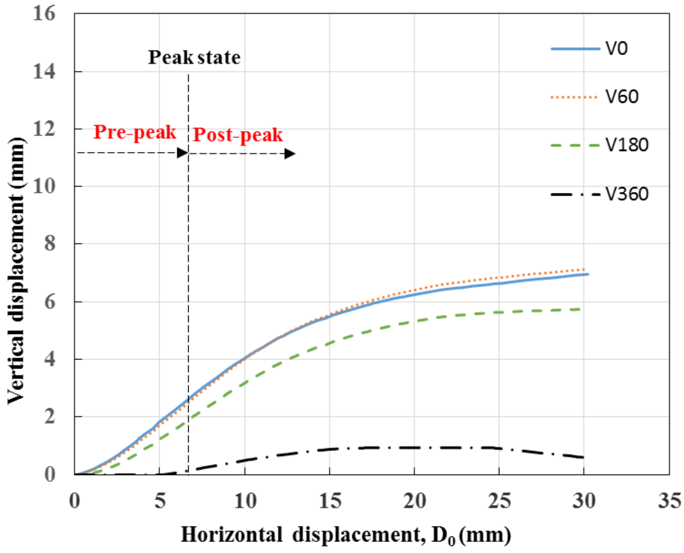
3 RESULTS AND DISCUSSION

3.1 *Typical pullout-deformation curves*

Figure 4a shows the typical pullout test results of the square-shaped geocell embedded in Gravel No.1 (D_{50}= 3.2 mm) for S= 60 mm and H_T= 25 mm. The relationship between pullout resistance and horizontal displacement (D_0) is shown in Figure 4a. Figure 4b shows the relationship between vertical displacement V_0 and horizontal displacement (D_0). Initial stiffness (E_3) is the secant modulus defined as the ratio of the pullout resistance to the horizontal displacement at D_0= 3 mm.



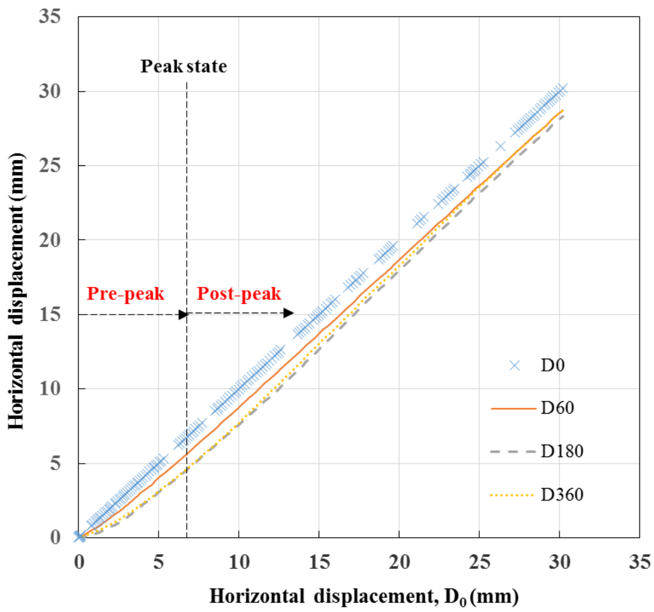
(a) Pullout resistance against horizontal displacement



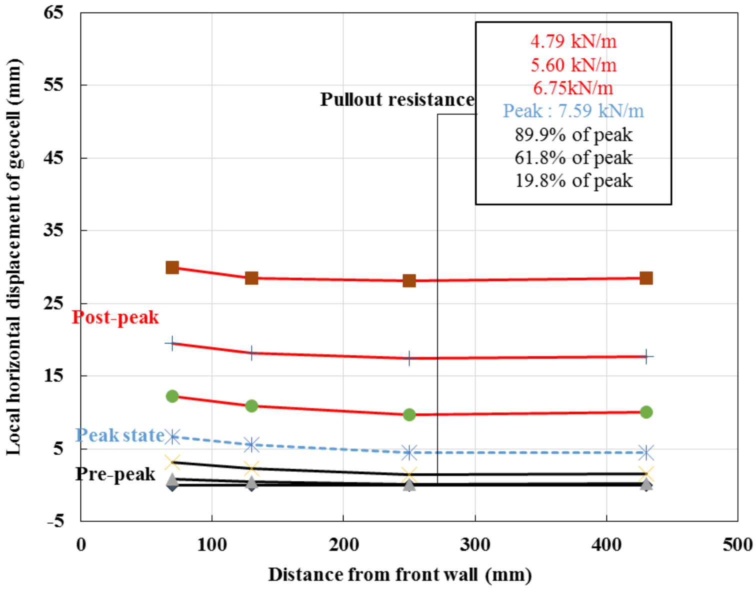
(b) Vertical displacement against horizontal displacement

Figure 4. Typical pullout test results of the square-shaped geocell

Figure 5 shows the variation of the stress-deformation characteristics of square-shaped geocell subjected to a pullout force. During the pre-peak phase, the tensile force of geocell is progressively transferred to the adjacent backfill along the geocell from the front end to the rear end. It could be associated with the growth in the local tensile strain with growing pullout force at larger rates closer to the front end. The force transferred via shear resistance at the interface between the geocell and adjacent soil particles and passive resistance within the geocell along the transversal members. When the force is applied, it is the front end of the geocell which initially deforms, then gradually followed by the other parts and finally the whole model work together during the post-peak phase. It means that the entire geocell model is pulled out without the change of tensile strain distribution.



(a) Horizontal displacement against D_0



(b) Local horizontal displacement along geocell at different pullout force

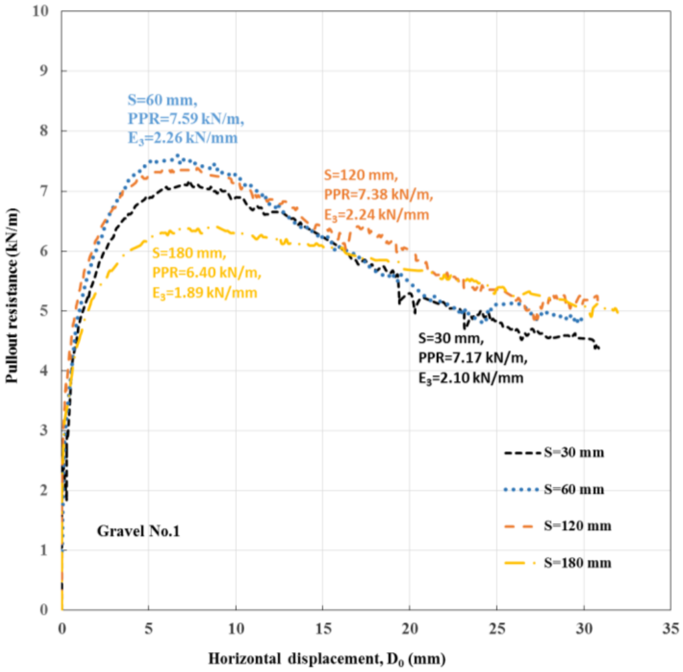
Figure 5. The stress-deformation characteristics of square-shaped geocell

3.2 *Effects of spacing (S)*

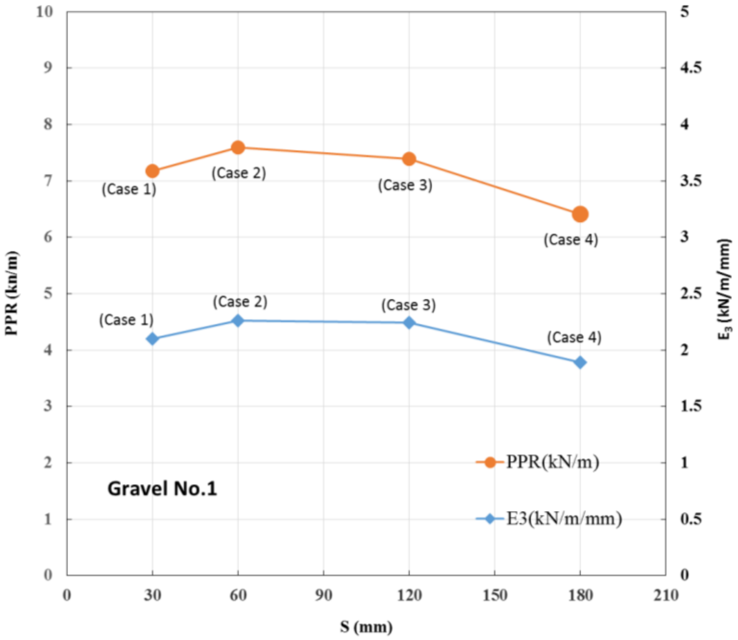
3.2.1 *Geocell buried in Gravel No.1*

Figure 6 shows the pullout behaviors of square-shaped geocell with different spacing (S=30 mm, 60 mm, 120 and 180 mm) between transversal members embedded in Gravel No.1. There is optimum value of S, 60 mm, resulting to the maximum peak pullout resistance (PPR) and initial stiffness (E_3).

Soil particles are confined by transversal members. When the geocell is pulled out, soil particles have a tendency to move to the upward and downward direction. Because of this, normal pressure will be acted on the shear interface between geocell model and surrounding soil, which contributes to the pullout resistance. When S= 180 mm, confinement effect of transversal members is limited and confinement effect on some soil particles far from the transversal member may could be neglected, and it is expected no increment on pullout resistance when S increases. The displacement of soil particles is also restricted when S decreases to 120 mm. But more particles are confined in the per unit length, so larger pullout resistance were measured compared to S =180 mm. When S is 60 mm, the failure wedge before the transversal member may fully develop. More soil particles have a tendency to move to the upward and downward direction, resulting more normal pressure acted on the shear interface and higher pullout resistance. When S is 30 mm, the pullout resistance is smaller than S= 60mm, may be due to the low mobilization of shear strength and low friction between soil particles that allows relative displacement. Although confinement of soil particles grew due to small S.



(a) Pullout resistance against horizontal displacement

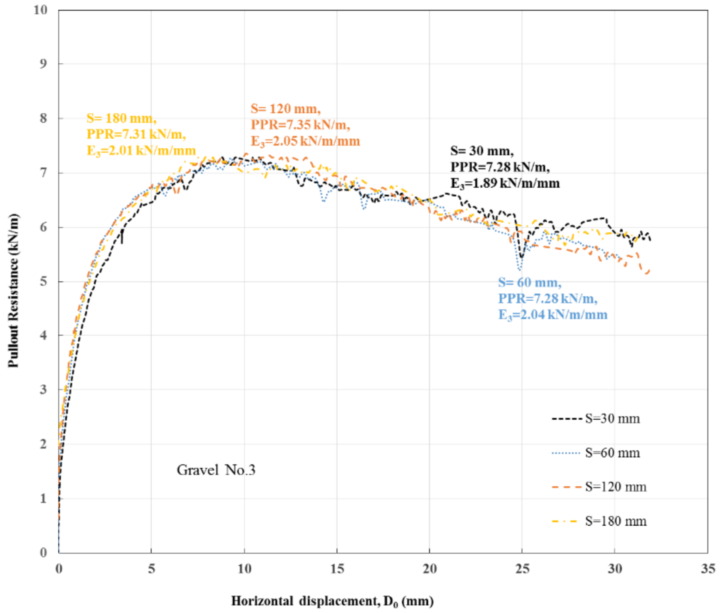


(b) Peak Pullout resistance (PPR) and initial stiffness (E_3) against S
(See cases 1 to 4 in Table 3)
Figure 6. Pullout behaviors of square-shaped geocell with different S buried in Gravel No.1

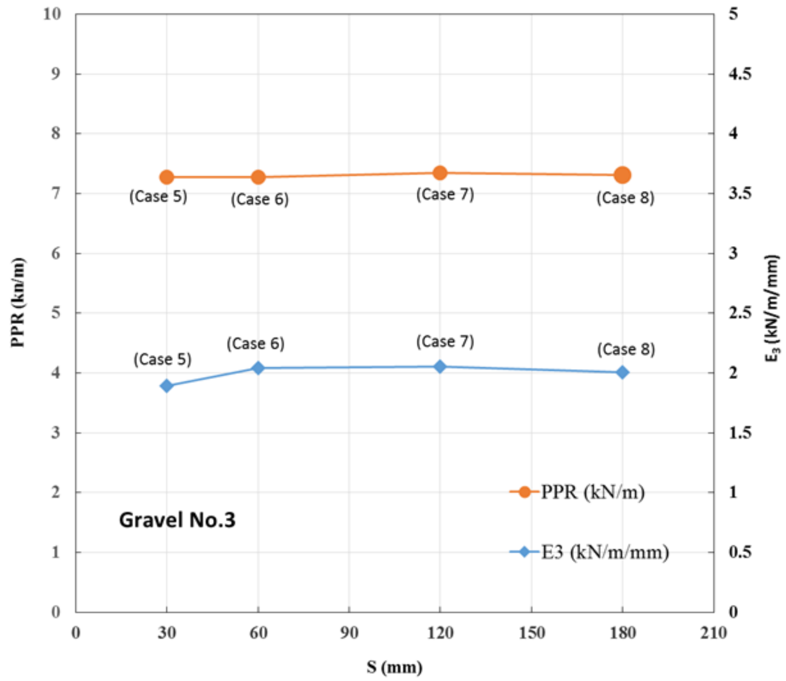
3.2.2 *Geocell buried in Gravel No.3*

Figure 7 shows the pullout behaviors of square-shaped geocell with different spacing (S=30, 60, 120 and 180 mm) embedded in Gravel No.3. It was found that the PPR and E_3 of all cases are almost same.

Compared with S= 120 mm, there is no decrease on the pullout resistance when S increases to 180 mm. When S= 60 and120 mm, it is expected a larger confinement and more normal force acted on shear interface that may contribute to larger pullout resistance. When S= 30 mm, large soil displacement will be restrained, preventing the formation of a failure wedge. They are not observed like in the case of Gravel No.1, it could be attributed to the large grain size that on the large internal friction angle of the soil particles induced a better confinement of the soil particles, which reduced the effect of S.



(a) Pullout resistance against horizontal displacement



(b) Peak Pullout resistance (PPR) and initial stiffness (E_3) against S

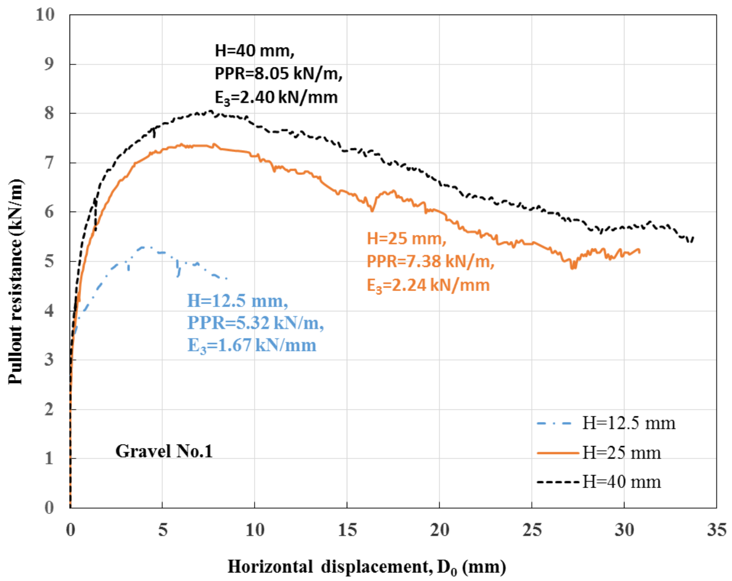
(See cases 5 to 8 in Table 3)

Figure 7. Pullout behaviors of square-shaped geocell with different S buried in Gravel No.3

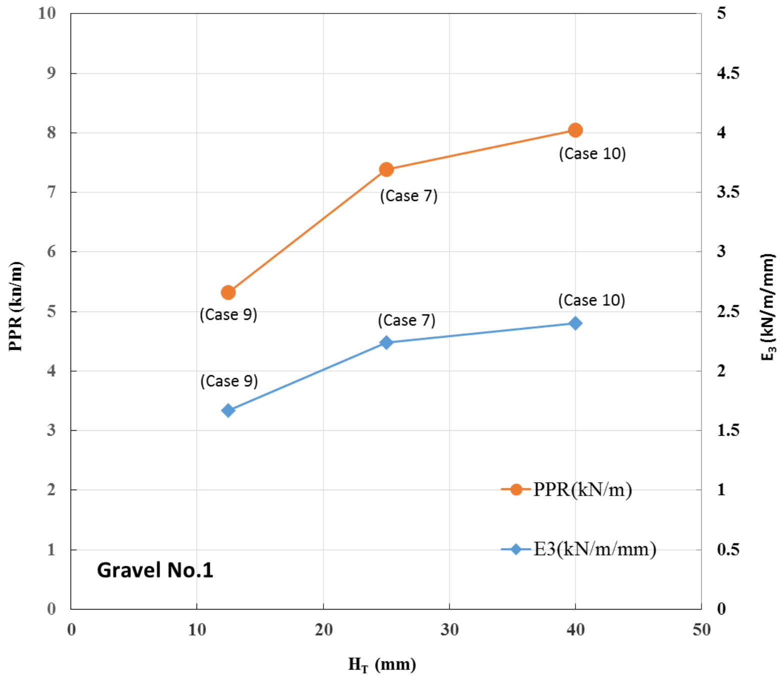
3.3 *Effect of height of transversal members (H_T)*

The effect of height of transversal members (H_T) was investigated by using the square-shaped geocell with different H_T but with same S buried in Gravel No.1, shown in Figure 8. It is clear that the peak pullout resistance (PPR) increases about 39% when H_T increases from 12.5 mm to 25 mm. When H_T increases from 25 mm to 40 mm, PPR grows about 9%. E3, the increase is in similar extent.

Reason for this could be when H_T increases from 12.5 mm to 25 mm, more soil particles will be confined, resulting in larger normal force in the shear interface and larger peak pullout resistance.



(a) Pullout resistance against horizontal displacement



(b) Peak Pullout resistance (PPR) and initial stiffness (E_3) against H_T

(See cases 7, 9 and 10 in Table 3)

Figure 8. Pullout behaviors of square-shaped geocell with different H_T

3.4 *Effect of grain size (D_{50})*

The effect of grain size was shown in Figure 9. There is no significant effects of D_{50} on PPR. When D_{50} increases, the PPR decreases about 4% for S= 60 mm, and the PPR increases about 14% for S= 180 mm. For S=30 and 120 mm, the PPR values are almost constant.

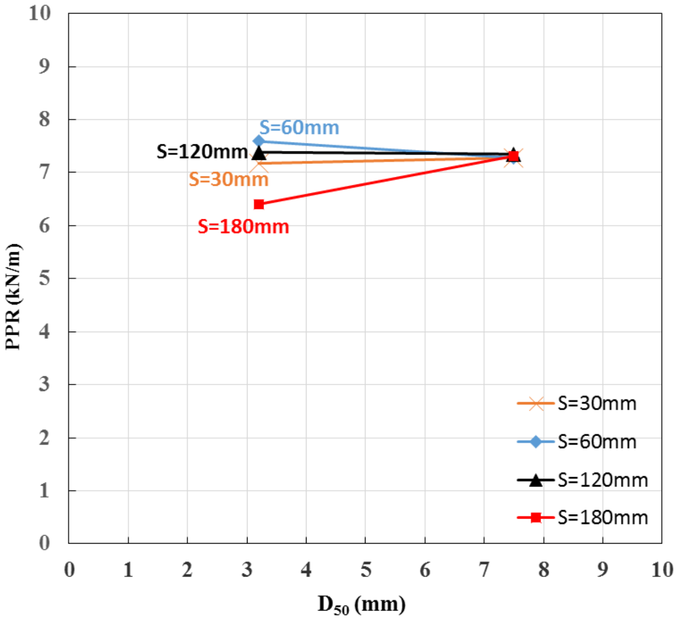


Figure 9. Peak Pullout resistance (PPR) of square-shaped geocell model with different S against D_{50}

4 CONCLUSIONS

A series of pullout tests were performed to investigate cell-size effect on the results of pullout tests of square-shaped geocell buried in gravels. The main conclusions can be summarized as follows. There is a value of S, 60 mm, leading to maximum peak pullout resistance (i.e. 7.59 kN/m) when the geocell is buried in Gravel No.1. When the geocell with different S buried in Gravel No.3, there is not a value of S which could result in a maximum peak pullout resistance. It is not observed in the case of Gravel No.1, this could be attributed to larger grain size gravel has larger internal friction angle (ϕ= 37º to 53º) induced a higher confinement of the soil particles. The PPR is increased when H_T increases. When D_{50} increases from 3.2 mm (Gravel No.1) to 7.5 mm (Gravel No.3), there is no significant effects on PPR.

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