EFFECT OF BOLT CONNECTION OF SQUARE-SHAPED GEOCELL MODEL ON PULLOUT TEST RESULTS

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ABSTRACT: In order to investigate the effect of bolts that were used to connect geocell members in previous studies on the pullout resistance of the square-shaped geocell model, a series of pullout tests were carried out on the geocell models with and without bolts. Based on the results, it was found that the effect of bolt connection on the pullout resistance is more significant than that of transverse member. Therefore, for accurate investigation of the pullout behaviour of square-shaped geocell which is affected by both the backfill material characteristics and the size of geocell, this paper recommends that bolt connections should not be used to make geocell models for pullout test.

Key Words: square-shaped geocell, bolts, pullout resistance

INTRODUCTION

Because of high seismic stability, small deformability and cost effectiveness, Geosynthetic Reinforced Soil Retaining Walls (GRS-RWs) have been widely used (Tatsuoka et al., 2007). Geogrids are conventionally used as planar tensile reinforcements to tensile-reinforce the backfill of retaining walls (RWs). Tatsuoka et al. (2007) indicated that cohesionless soil is often required to ensure good interlocking between soil particles and geogrid to achieve high pullout resistance, when geogrids are used to tensile-reinforce the backfill of RWs. Nishikiori et al. (2007 and 2008) conducted a series of pullout tests and summarized that when the covering ratio and surface roughness of the longitudinal members, and the thickness of transverse members of the grid increases, the pullout resistance will increase. Palmeira et al. (1989) and Palmeira (2008) investigated the effect of particle size relative to the thickness of grid transversal members. The results showed that when the ratio between member thickness and soil particle size is over 12, the normalized bearing strength would be independent of soil particles. Brown et al. (2007) investigated the shape and bending stiffness of transversal members and found that a low bending stiffness would result in a progressive mobilization of bearing resistance and a low pullout resistance. Giroud (2009) pointed out that the soil-geogrid interaction mechanism can be summarized based on the increased soil stiffness which results from interlocking of the soil particles in the aperture of the geogrid and the pullout resistance which is induced by the friction and passive resistance of transversal members. However, when poorly graded materials which might contain large soil particles are used as backfill material because good quality backfill materials are not locally available, the interlocking effect between the geogrid and soil particles decreases, which in turn reduces the seismic stability of GRS-RWs.

Compared to the conventional reinforcement material, a newly-developed square-shaped geocell (Han et al. 2012 and 2013a) exhibits better pullout resistance. It is important to understand the effect of cell size of square-shaped geocell on the pullout resistance. Han et al. (2013b) and Mera et al. (2015) studied the influence of the height of transverse members of geocell and backfill soil particle size on pullout resistance, while Haussner et al. (2016) investigated the effect of spacing of transverse members of the geocell. However, the geocell models used by Haussner et al. (2016) was prepared with bolt connection which may affect the results of pullout test. In order to establish accurate pullout behaviour of the geocell having different cell-sizes, the effect of bolt-connection on the pullout resistance should be clarified.

TEST APPARATUS, MATERIALS AND PROCEDURES

Pullout Test Apparatus

The pullout test apparatus used in this study is shown in Fig.1, which mainly has a soil container, a motor, a load cell and linear variable differential transducers (LVDT). The inside dimension of soil container was 700 mm in length, 400 mm in width and 500 mm in height. The opening height of the front wall for pulling out the geocell model was 46.5mm. The geocell model was embedded in backfill soil inside the soil container and pulled out in plane-strain condition by using a motor with a constant displacement rate. Horizontal displacements of the geocell model at 60 mm (d_{60}), 180 mm (d_{180}) and 360 mm (d_{360}) from the face of the front wall were measured using LVDTs. The LVDTs were connected to the designated locations on the longitudinal member using inextensible stainless steel wires. The load cell was used to measure the pullout force, and a surcharge of 1kPa was applied by lead shots.

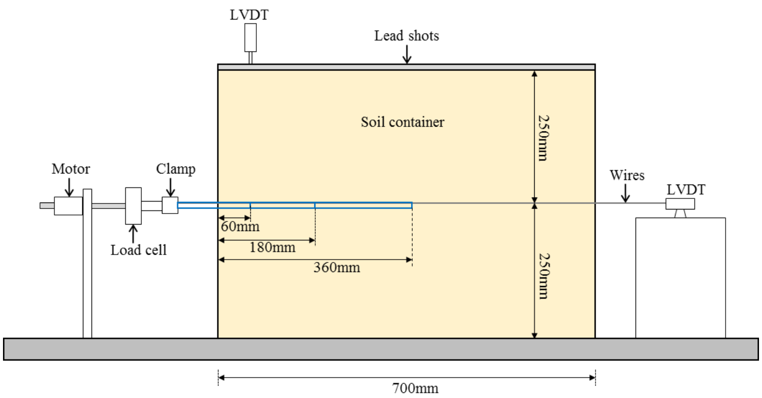


Fig. 1. Schematic diagram of pullout test apparatus

Soil Material and Tested Reinforcements

In this study, gravel No. 3 (D_{50}=7.5 mm) was used as the backfill material. Square-shaped geocell model used in the previous study (Haussner et al., 2016) is shown in Fig. 2. The geocell model reinforcement is 360 mm (length) ×350 mm (width). The heights of the transverse and longitudinal members are 25 mm and 45 mm respectively. The spacing (S) between transverse members vary from 30 to 360 mm. The spacing between longitudinal members is 50mm, so there are seven cells in the transverse direction. The geocell members were made of polypropylene (PP). And bolts were used to connect the transverse and longitudinal members during preparation of geocell models. The geocell models with S= 30 mm, 180 mm and 360 mm are shown in Fig. 2 (a), (b) and (c) respectively. Figure 2 (c) shows the geocell model buried in the Gravel No.3 backfill.

This study conducted a series of pullout tests to investigate the effect of the bolt connection. The bolts used for the connection are shown in Fig. 3. For the geocell model with S= 360 mm, there were 12 bolts in one longitudinal member. The location and the length of screws and bolt heads installed in the longitudinal members are shown in Fig. 3 (b) and (c). In total, there were 96 bolts for the geocell model with S= 360 mm which consisted of eight longitudinal members. This paper denotes this model as LTB (Fig. 4 (a)). Figure 4 (b) shows a geocell model without bolts, which has the same structure as LTB, denoted as LT. In order to investigate the effect of bolt connection on the friction between the soil and geocell member, a model with 96 bolts and without a backward transverse member, denoted as LB (Fig. 4 (c)), was subjected to pullout test. In addition, a model without bolts which has the same structure as LB was also prepared (denoted as L, shown in Fig. 4 (d)).

Pullout Test Procedures

The backfill soil was prepared in the pullout box with ten layers and each layer was compacted to the target density. When the preparation of the first five layers was finished, the geocell model was laid on the backfill soil and then the front end was fixed to the clamp. The last five layers were then placed on the geocell model. The vertical displacement of the backfill surface was measured with an LVDT at a distance of 60 mm (V_{60}) from the front wall. The geocell model was pulled out at a constant rate of 5mm/min using a precision jack driven by a motor. The test cases are summarized in Table 1.

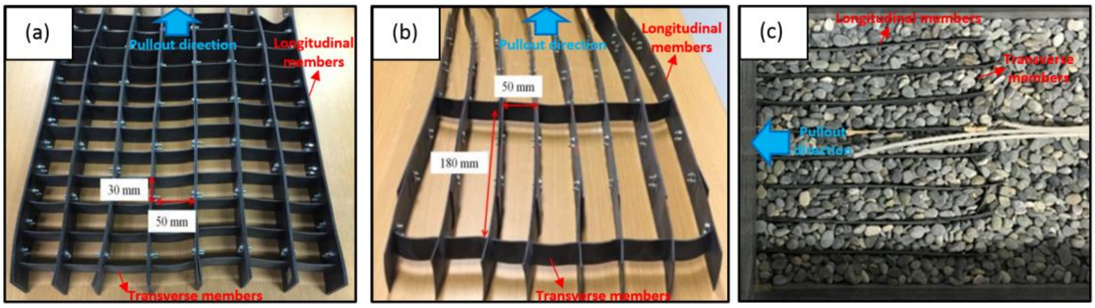


Fig. 2. Some square-shaped geocell models: (a) S=30 mm, (b) S=180mm,
(c) S=360 mm (After Haussner et al., 2016)

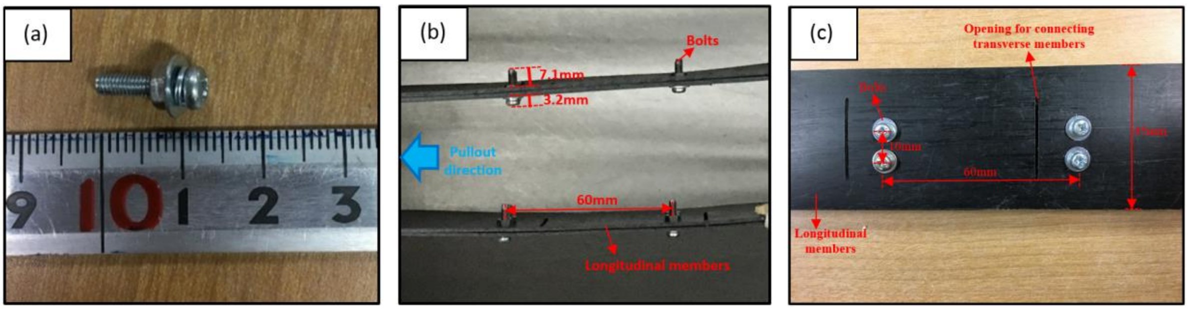
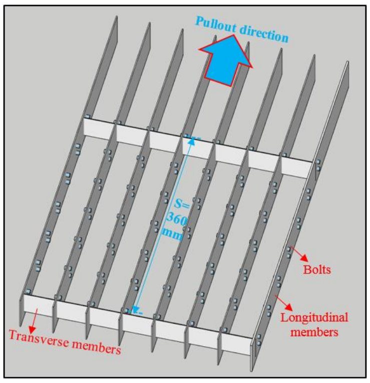
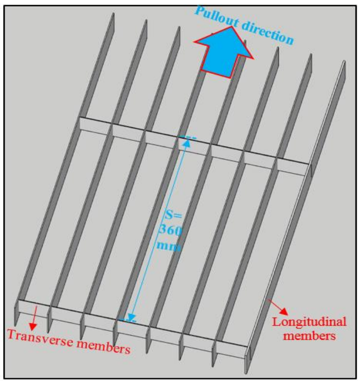


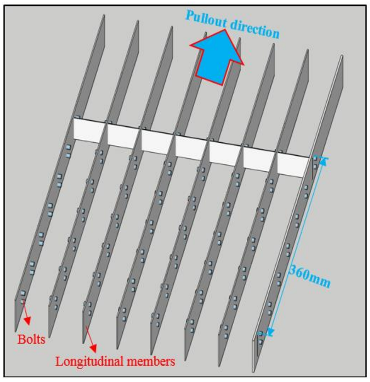
Fig. 3. Bolts used in this study: (a) before being installed, (b) installed in geocell models (S=360 mm), top view, (c) installed in geocell models (S=360 mm), front view



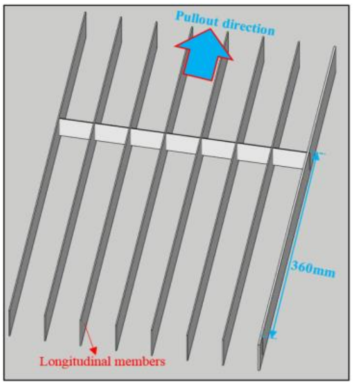
(a) LTB model



(b) LT model



(c) LB model



(d) L model

Fig. 4. Reinforcements: (a) LTB model, (b) LT model, (c) LB model, (d) L model

Table 1. Pullout test cases of LTB, LB, LT and L buried in Gravel No.3 backfill

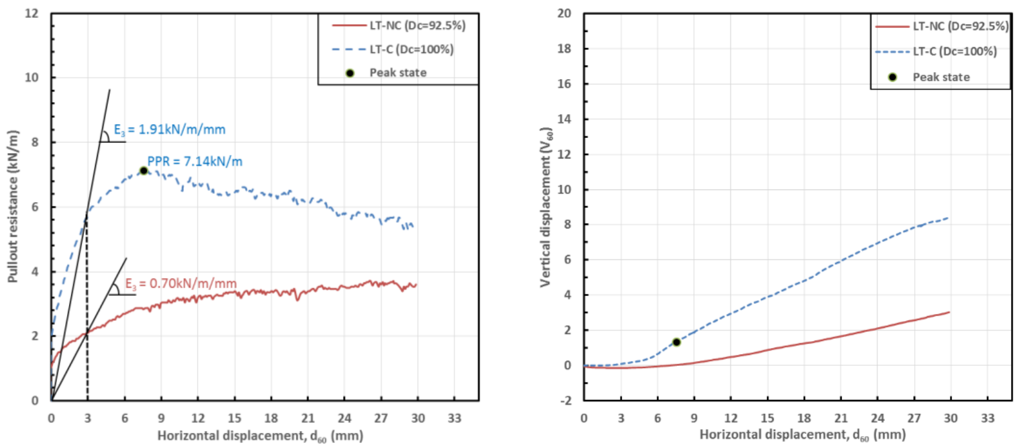
Test	Number of reinforcements			D_C (%)
	Longitudinal members	Backward transverse embers	Bolts	
LTB-NC	8	1	96	92.5
LTB-C				100
LT-NC	8	1	0	92.5
LT-C				100
LB-NC	8	0	96	92.5
LB-C				100
L-NC	8	0	0	92.5
L-C				100

RESULTS AND DISCUSSION

Typical Pullout Behavior of Square-shaped Geocell

The typical pullout test result of the square-shaped geocell, LT model, embedded in Gravel No.3 is presented in Fig. 5. The relationship between pullout resistance and horizontal displacement (d_{60}) is plotted in Fig. 5(a), and the relationship between vertical displacement (V_{60}) at the backfill surface and horizontal displacement (d_{60}) is plotted in Fig. 5(b).

The results show that there is a high maximum pullout resistance (PPR) due to dilatancy of soil in high compacted condition (Test LT-C), and then the resistance decreases to a residual state as the pullout displacement increases. For the backfill soil with low degree of compaction (Test LT-NC), the pullout resistance increases gradually as pullout continues, and there is no peak state. It is evident from the result that a higher degree of compaction of backfill soil results in a larger pullout resistance and initial stiffness (E_3) with lager dilatancy of the backfill. Initial stiffness (E_3) is secant modulus defined as the ratio of the pullout resistance to the horizontal displacement at d_{60}= 3 mm, as illustrated in Fig. 5(a).

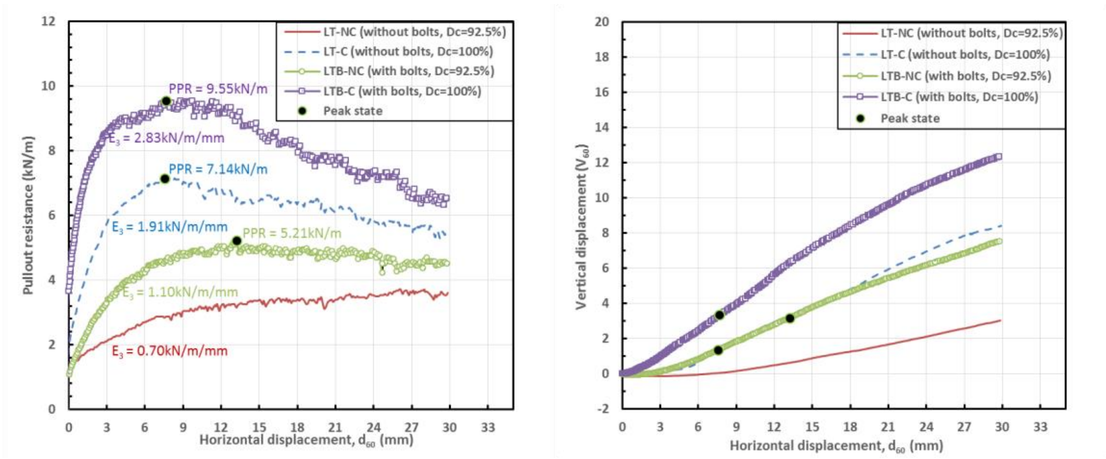


(a) Pullout resistance-d_{60} relation (b) V_{60}-d_{60} relation

Fig. 5. Typical pullout behaviours of square-shaped geocell

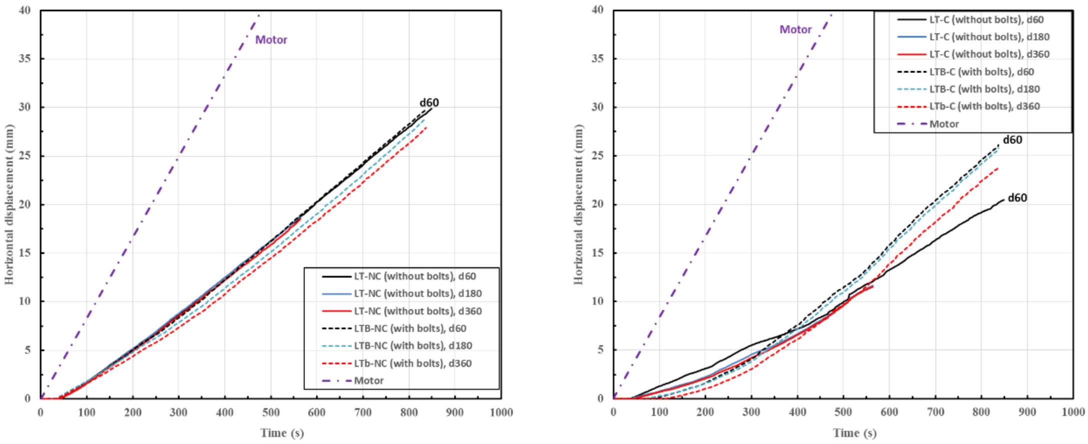
Effect of Bolts on the Pullout Behavior of Square-shaped Geocell

Figure 6 shows the relationships between pullout resistance, d_{60}, and V_{60}. It is evident from the results that the presence of bolts results in larger pullout resistance and initial stiffness in both low compacted soil backfill (Test LT-NC and LTB-NC) and high compacted soil backfill (Test LT-C and LTB-C). The bolts also result in more significant dilatancy of the backfill for LTB-NC (LTB-C) than LT-NC (LT-C). Figures 7 (a) and (b) show the change in horizontal deformation with time during the pullout test. Since the effect of bolt connection on the deformation characteristics of geocell seems to be insignificant, the large pullout resistance of LTB may be attributed to a large friction at the side surface of longitudinal members caused by the bolt connection. In fact, as shown in Fig. 8, the pullout



(a) Pullout resistance-d_{60} relation (b) V_{60}-d_{60} relation

Fig. 6. Pullout behaviours of square-shaped geocell



(a) Results in low compacted backfill (b) Results in high compacted backfill

Fig. 7. Horizontal displacement versus elapsed time

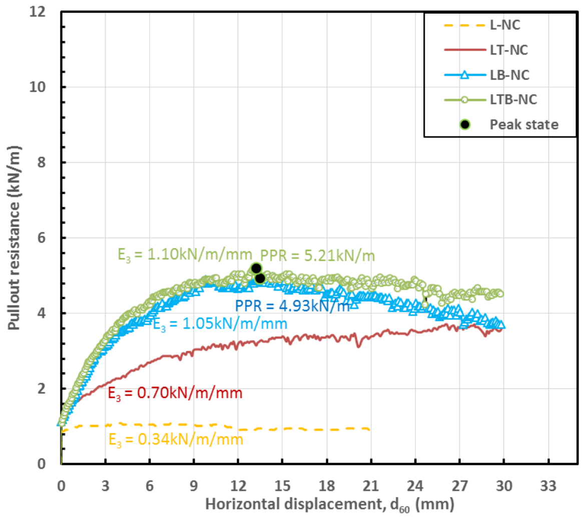


Fig. 8. Pullout behaviours of square-shaped geocell

resistance of LB model is much larger than that of L model, and is at the same level as LTB model. The results indicate that the effect of bolt connection is more significant than that of transverse member, and it should be excluded in order to investigate the effects size of square shaped geocell on pullout resistance.

CONCLUSIONS

A series of pullout tests were carried out to investigate the effect of bolts on the pullout behaviour of square-shaped geocell. The main conclusions could be summarized as follows:

(1) Bolts used for connecting geocell members result in a larger pullout resistance and initial stiffness in backfill soil of both low and high degree of compaction.

(2) There is a significant effect of bolt-connection on the pullout resistance of square-shaped geocell. For accurate investigation of the pullout resistance, it is recommended not to use bolt connection to make geocell model for the pullout test.

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