SHAKING TABLE TESTS OF SQUARE-SHAPED GEOCELL REINFORCED SOIL RETAINING WALLS WITH DIFFERENT BACKFILL COMPACTION DEGREES

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ABSTRACT: In order to investigate the influence of the backfill compaction degree on the seismic resistance of square-shaped geocell RS-RWs, a series of 1-g shaking table model tests were conducted on square-shaped geocell RS-RWs with poorly compacted and well compacted Silica Sand backfills. Additionally, as to compare the seismic resistance of the square-shaped geocell RS-RWs with that of conventional RWs, additional shaking table tests were conducted on conventional geogrid RS-RWs and T-shape RWs. The residual deformation of the RW, response acceleration of the wall facing and backfill, and shear formation were investigated at each stage to study the seismic performance of the RWs. It was determined that the square-shaped geocell RS-RWs with a well compacted backfill significantly outperforms the conventional geogrid RS-RWs and T-shape RWs, showing a higher ductile behavior and smaller wall deformation. Moreover, it was also determined that although a lower backfill compaction degree increases the wall facing deformation, the square-shaped geocell RS-RWs with a low compacted backfill shows a similar or even better seismic performance to that of geogrid RS-RWs with well compacted materials.

Key Words: square-shape geocell, seismic performance, backfill compaction degree, ductile behavior

INTRODUCTION

Geosynthetic-reinforced soil (GRS) structures have been widely implemented in the past decades around the world for constructing important earth retaining structures, such as embankments, retaining walls, abutments and slope stabilization, mainly due to its advantages in costs, construction time, and structural stability (Tatsuoka 1997a, Tatsuoka et al. 2007). The main features and advantages of the GRS RWs with a FHR facing derive from its stage construction, which is simple, fast and allows a rigid connection between the rigid facing and the backfill. The seismic stability of GRS-RWs have been recorded and validated widely based on case histories after major earthquakes. Tatsuoka et al. (1996) reported that conventional GRS-RWs with a FHR facing suffered limited residual deformation after the Hyogo-ken Nambu Earthquake, confirming the high seismic performance of the GRS-RWs. Similarly, Nishimura et al. (1996) also reported that conventional GRS-RWs under seismic sintensity larger than 6 (JMA) suffered no threatening structural damage, keeping the integrity of the structure during and after the earthquake. The seismic performance of GRS-RWs has been also investigated

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extensively by laboratory experimental model tests. Koseki et al. (1998) and Watanabe et al. (2003) conducted a series of shaking table model tests to qualitatively analyze the seismic behavior of GRS-RWs, reporting that the predominant failure mode of GRS-RWs was overturning and that the GRS-RWs with a FHR facing show a more ductile behavior compared to traditional gravity-type RWs.

Different types of geogrids and geotextiles have been conventionally used as tensile reinforcements of retaining walls, embankments and other soil structures. The high pullout resistance of geogrids can be attributed to the interlocking degree between the geogrid and surrounding backfill material (Kuroda et al., 2012; Nishikiori et al., 2007), the longitudinal members providing the tensile resistance, while the transverse members mobilize the passive resistance. Lopes et al. (1999) and Haussner et al. (2016) reported that an adequate soil particle size – geogrid aperture is necessary to mobilize a good geogrid – soil interlocking to achieve a higher pullout resistance.

A new type of tensile reinforcement, namely the square-shaped geocell, was introduced by Han (2014), showing that the square-shaped geocell can not only confine larger particles but has a higher peak pullout resistance than both conventional geogrids and diamond-shaped geocells. However, the influence of the backfill compaction degree has not yet been studied, a parameter that in of great importance for traditional GRS-RWs.

In this sense, this study aims to investigate the influence of the backfill compaction degree on the seismic performance of square-shaped geocell RS-RWs. For this purpose, square-shaped geocell with a transverse spacing of 120 mm were implemented as tensile reinforcements and embedded in Silica Sand No.7 compaction degrees between 89% and 100% and subjected to seismic motions in 100 gal increments until failure. For practical reasons, the square-shaped geocell will be addressed as "geocell" in this paper.

TEST APPARATUS, PROCEDURES AND MATERIALS

Shaking Table Apparatus and GRS RW Model

A shaking table apparatus located at the Earthquake Resistant Structures Research Center of the Institute of Industrial Science, University of Tokyo was used in this study. A soil container (1800 mm x 875 mm x 400 mm) was implemented to model the GRS RS-RWs, as shown in Figure 1. The square-shaped geocell RS-RWs and geogrid RS-RWs were constructed using a full height rigid facing, considering a scale factor of 1/10. The facing wall is 500 mm in height, 395 mm in width and 30 mm in thickness, made of duralumin. In order to achieve a rough surface between the wall facing and the adjacent subsoil, sand paper # 150 was glued at the bottom of the wall. Additionally, to avoid any backfill material from leaking out between the container and wall facing, a sponge tape was adhered along the container – wall contour and sealed with grease. For comparison purposes, the results of this investigation are compared to a series of T-shape RW, implemented by Han (2014).

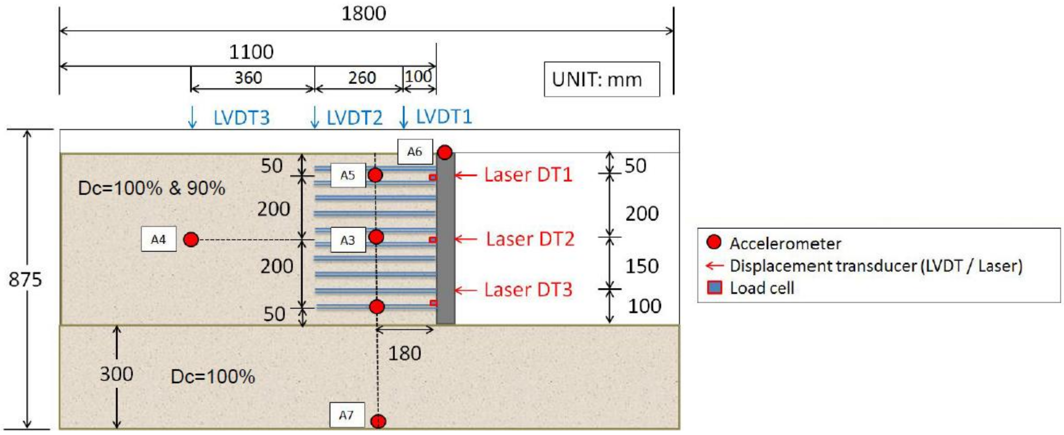

Figure 1. Schematic diagram of GRS RW model

Backfill and Reinforcement Materials

Silica Sand No.7 (Figure 2) was used as backfill and subsoil materials. The compaction degree of the subsoil layer (300 mm) was kept at 100%, while the compaction degree of the backfill was varied between 89% for a poorly compacted backfill and 100% for a well compacted backfill. In the case of poorly compacted backfill materials, the lowest compaction degree was achieved by gently filling in the backfill. On the other hand, manual tamping method was used to achieve a well compacted backfill. Moreover, in order to have visual contact of the backfill deformation, colored backfill material was placed at 10 cm intervals on the acrylic transparent glass. Additionally, for the same purpose, pointers were attached to the acrylic glass with grease and spaced at 5 cm intervals horizontally and vertically from each other.

Figure 2. Silica Sand No.7 backfill material

Square-shaped geocells reinforcements with a transverse spacing of 120 mm, and a transverse and longitudinal height of 35 mm and 30 mm respectively (Figure 3a), were used for the geocell RS-RWs. The square-shaped geocells were made of polyethylene (PE) strip members. As geogrid reinforcements, TSG 700 geogrids, a polyester fiber grid with an acrylic resin coating with an aperture size of 7 mm x 7 mm (Figure 3b), were used for geogrid the geogrid RS-RWs. A total of ten reinforcement layers 360 mm in length and 350 mm in width were firmly mechanically attached to the wall facing in 50 mm vertical intervals. A surcharge of 1 kPa was applied by lead shots on top of the backfill. For comparison purposes, the results of the current study are compared to the results of Han (2014), who used a self-made geogrid made of phosphor – bronze thin narrow strips (0.2 mm thick x 3 mm wide) and transverse mild steel bars (0.5 mm in diameter), as show in Figure 3c.

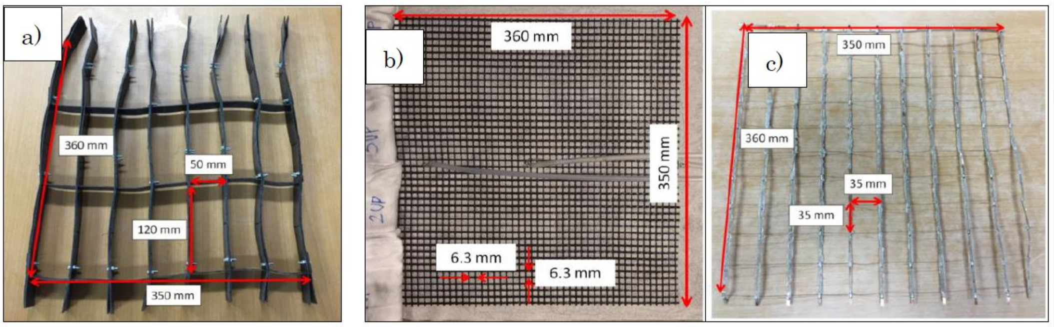

Figure 3. (a) Square-shaped geocell, (b) TSG 700 Geogrid, c) Phosphor bronze georid

Instrumentation

In order to analyze the residual deformation of the wall facing, LDTs were used to measure the lateral displacement at three different locations along the center line of the wall facing. Moreover, the backfill settlement at three different positions was measured using LVDTs. Finally, the response acceleration of the subsoil, backfill and wall facing was measured using accelerometers embedded in the subsoil, backfill and at the top of the wall facing. The retaining walls were subjected 100 gal sinusoidal waive increments, with a predominant frequency of 5 Hz, until complete failure of the wall occurred. Figure 1 shows the details of the different instrumentations.

TEST RESULTS AND DISCUSSION

Figure 4 shows the failure state of the T-shape RW, both geogrid RS-RWs and the geocell RS-RW with a well compacted backfill (Dc=100%). Figure 4e the failure state of a geocell RS-RW will a poorly compacted backfill material (Dc=90%). The results suggest that the predominant failure mode of the geogrid and geocell RS-RWs is wall-sliding with a small degree of overturning of the wall facing. On the contrary, the predominant failure mode of the T-shape RW was overturning with a small component of base sliding. Both geogrid RS-RWs and geocell RS-RW show a ductile behavior, accumulating its backfill and wall facing deformation gradually. On the contrary, the T-shape RW showed a brittle behavior, accumulating large deformation very sudden and rapidly at until complete failure at 488 gal. Interestingly, the TSG 700 geogrid RS-RW showed considerably smaller wall facing and backfill deformation than the Phosphor-bronze geogrid RS-RW, failing at 846 gal and 790 gal, respectively. On the other hand, the geocell RS-RW with a well compacted backfill material showed a remarkably high seismic stability even at a base acceleration of 943 gal, showing reduced wall facing and backfill deformation. Lastly, the geocell RS-RW with a low compacted backfill (Dc=90%), although it shows a considerably larger deformation than the geocell reinforcement embedded in a well compacted backfill material, it shows a similar settlement and wall facing deformation to that of the geogrid RS-RWs with a well compacted backfill, failing at a base acceleration of 781 gal.

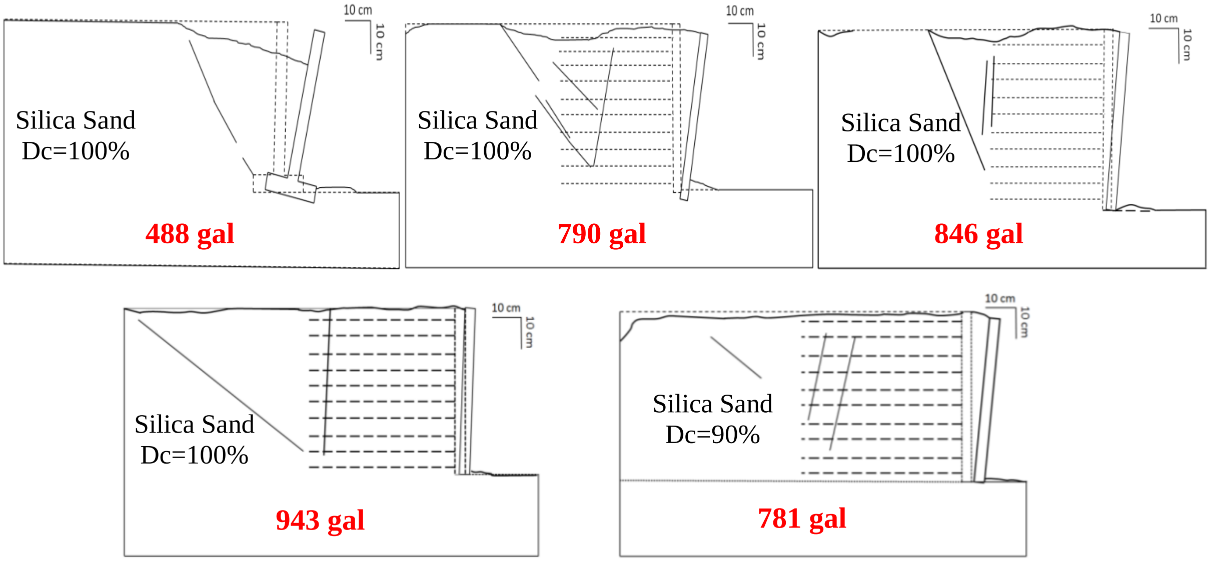

Figure 4. (a) T-shape RW, (b) Phosphor-bronze geogrid RS- RW, (c) TGS 700 geogrid RS-RW, (d) geocell RS-RW (Dc=100%), (e) geocell RS-RW (Dc=90%)

The residual deformation of the backfill and wall facing is analyzed based on the wall facing overturning angle (θ), wall bottom displacement (d_s) and backfill settlement (S/H) as a function of the base acceleration (α_b), plotted in Figures 6 and 7. Due to the high rigidity of the wall facing, the displacement at the top and bottom of the wall can be obtained by linear extrapolation of the horizontal displacements recorded at 10 cm, 25 cm and 45 cm from the bottom of the wall (Figure 1). Similarly, the overturning angle at the top of the wall is obtained using the displacement reading from the top and bottom of the wall facing. The backfill settlement was measured immediately behind the reinforced area (36 cm behind the wall facing) and well behind on the unreinforced area of the backfill (72 cm behind the wall facing).

Figure 5a presents the overturning angle after each shaking stage until complete failure of the RW. From this figure it can be noted that until a base acceleration of about 250 gal, all five types of retaining walls showed a limited overturning angle. However, as the acceleration increased, the overturning angle of the T-shape RW started to accumulate very rapidly. In the case of the geogrid and geocell RS-RWs, the residual overturning angle of the wall accumulated more progressively, showing a more ductile behavior. Out of all the retaining walls under consideration, the geocell RS-RW with a well compacted backfill shows the smallest wall overturning angle even at large base accelerations. This behavior is attributed to the larger pullout resistance of the geocell embedded in a well compacted sandy backfill, which more efficiently restrains the tilting of the wall facing.

Moreover, the results show that the geocell RS-RW with a poorly compacted backfill initially shows similar overturning angles to that of the TSG 700 geogrid RS-RW with a well compacted backfill material. However, as the seismic acceleration increases, the geocell RS-RW with a loose backfill out performs both types of geogrid RS RW, possibly due to an increment on the pullout resistance of the bottom reinforcements due to densification of the backfill and higher post-post pullout resistance of the geocell.

Figure 5b shows the residual wall sliding against base acceleration. It can be observed that all five retaining walls show little wall sliding up to a base acceleration of 300 gal. In the case of the T-shape RW, the wall sliding displacement accumulates slower than the overturning before complete failure, confirming the failure mode by overturning. On the other hand, the geogrid and geocell RS-RWs show small wall bottom displacements up to 600 gal. The geocell RS-RW with a well compacted backfill remarkably show very little sliding even at large seismic motions. This is attributed to the high pullout resistance of the geocell embedded in well compacted backfills, more efficiently restraining the sliding of the wall. Moreover, geocell RS-RW with a low compacted backfill material accumulates larger sliding deformation than both types of geogrid RS RWs as the base acceleration increases. This behavior can be attributed to the difference in compaction degree between the subsoil and the backfill, which creates a weak plane with a smaller shear resistance along the subsoil – backfill interface.

Furthermore, Figure 6 shows the backfill settlements measured at a distance of 36 cm and 72 cm from the wall facing. Prior to a base acceleration of 300 gal, no evident settlement took place for any of the retaining walls. Beyond 300 gal, the settlement for the T-shape RW accumulates rapidly due to its brittle behavior and predominant overturning failure mode. It is also evident that the smaller residual overturning angle and wall bottom displacement of the geocell RS-RW with a well compacted backfill material result in small backfill settlements. On the other hand, the geocell RS-RW with a poorly compacted backfill material show large settlement mainly due to the densification of the loose backfill and larger wall facing residual deformation.

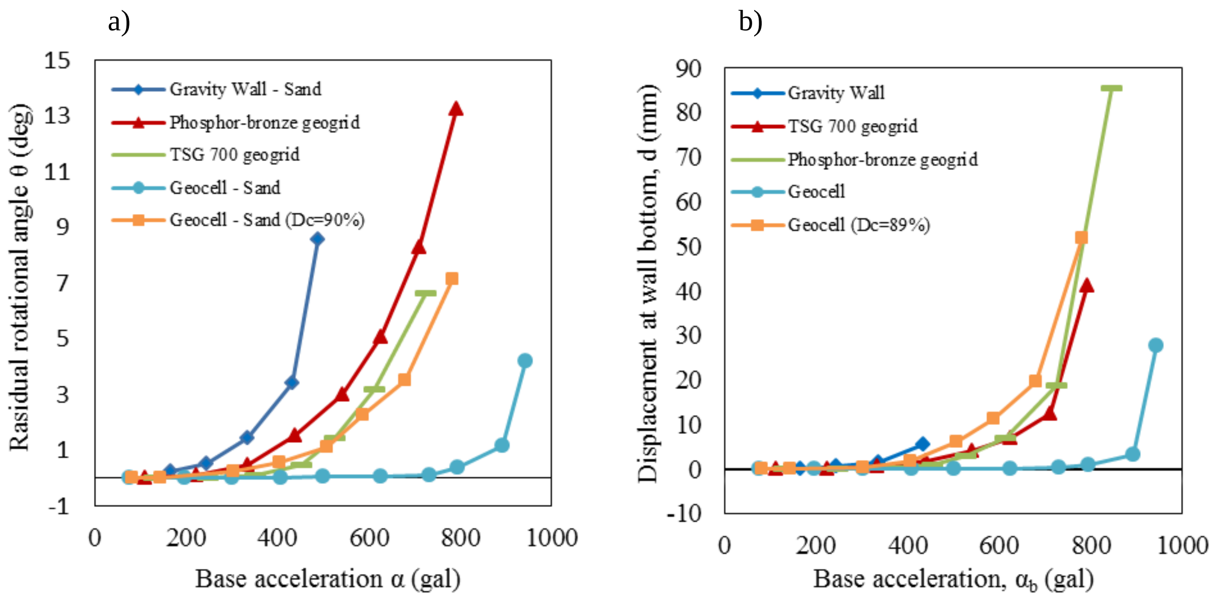

Figure 5, (a) Residual rotational angle, (b) Wall bottom displacement

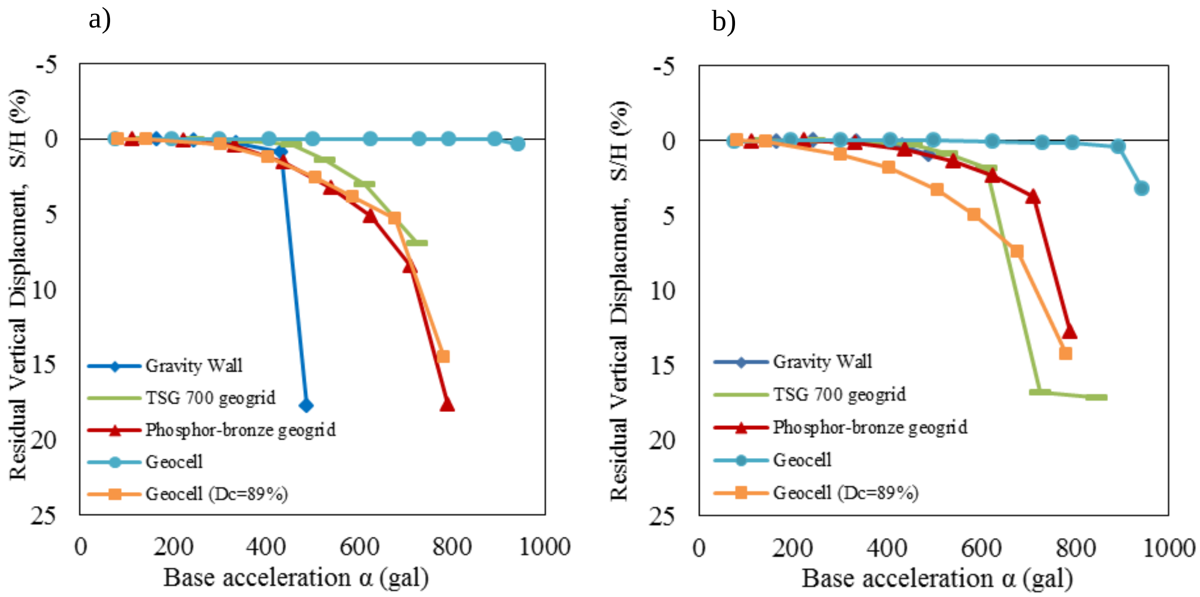

Figure 6, Backfill settlement at (a) 36 cm, (b) 72 cm

CONCLUSIONS

The seismic resistance of square-shaped geocells RS-RWs with well compacted and poorly compacted sandy backfill materials was compared to that of a T-shape RW and two geogrid RS-RWs in order to investigate the influence of the compaction degree on the seismic resistance of square-shaped geocell RS-RWs. Based on the results obtained, it was determined the following;

1. The predominant failure mode for the square-shaped geocell and geogrid RS-RWs is sliding with a small component of overturning (similar to Koseki et al. 1998 and Watanabe et al. 2003) regardless of the compaction degree.
2. The square-shaped geocell RS-RW with a well compacted backfill shows the highest seismic resistance than the other RWs, attributed to the large pullout resistance of the geocell embedded in a well compacted backfill, more efficiently restraining the overturning and base sliding of the wall facing.
3. Low backfill compaction increases the wall sliding and overturning of the wall at low seismic motions, yielding similar values to those of the geogrid RS-RWs. This behavior can be attributed to the lower initial stiffness of the geocell when embedded in poorly compacted backfills.
4. Square shaped geocells RS-RWs with a low compacted backfill material show smaller wall facing residual deformation than conventional geogrid RS-RW at larger base acceleration. This behavior can be attributed to the larger post-peak pullout resistance of the square shaped geocells.
5. An adequate soil particle size – geogrid aperture size increases the seismic performance of the geogrid RS-RWs due to an increment in the pullout resistance associated to a better interlocking effect between the geogrid and backfill material.

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