論文の内容の要旨

論文題目　　Development of a New Type of Geocell as Tensile Reinforcement for GRS RWs
（補強土擁壁の引張り補強材としての活用に向けた新型ジオセルの開発）

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In the last two decades, in Japan, more than 150 km of geosynthetic-reinforced soil retaining walls (GRS RWs) with a stage-constructed full-height rigid (FHR) facing have been constructed for railways, highways and other infrastructures. This is due mainly to their greater seismic resistance compared to conventional type of RWs. To achieve a high seismic stability of GRS RWs, high tensile resistance of the reinforcement layer at the back of the facing wall is crucial. Geogrid is commonly used as planar tensile reinforcement of the backfill of RWs, embankments and other earth-structures. However, GRS RWs with geogrid reinforcement may encounter the following potential problems: In Japan, geogrid reinforcement requires the use of high-quality backfill materials (i.e. well-compacted sandy soils) to ensure good interlocking of soil particles within the aperture of the geogrid. Nevertheless, in reality, locally abundant and economic soil materials, which may be poorly-graded or include large particles, are often used as the backfill materials. This results in a decrease in its deformability, since the bond stress along the interface between the geogrid and the backfill becomes lower than the shear strength of the backfill to a larger extent with an increase in the backfill soil particle size; What's more, for other GRS structures such as a GRS integral bridge, due to the presence of heavy girder structure, large earthquake-induced inertial force may be activated, which requires the reinforcement to provide a higher pullout resistance. In order to alleviate these problems and improve the overall seismic performance of GRS structures, traditional type geocells (i.e. diamond-shaped geocells) have been firstly introduced and tested. However, their performance was found to be not adequate in the case of very severe earthquakes. Therefore, in this thesis, a new type of geocell, namely square-shaped geocell, was developed. Essentially, it consists of square-shaped cells constituted of a series of straight longitudinal members with transversal walls at separated locations.

In this study, the tensile strength of the newly-developed square-shaped geocell was evaluated by pullout tests comparing to the traditional diamond-shaped geocell and commercial geogrids embedded in gravelly soils with different particle size (i.e. Gravel No. 1, D_{50}=3.2 mm, Gravel No. 3, D_{50}=7.5 mm and Gravel No. 5, D_{50}=14.2 mm). It was found that the square-shaped geocell shows a less pronounced progressive deformation, higher pullout peak resistance and higher pre-peak stiffness than diamond-shaped geocell when using as backfill soils Gravel No.1 and Gravel No.3. This can be attributed to the effect of the in-plane geometry of the new geocell. In fact, the presence of straight longitudinal members in the square-shaped geocell reduces the progressive deformation of the cells compared with diamond-shaped geocell when subjected to a pullout force, which enhances the pre-peak stiffness and the pullout peak resistance of the geocell. In addition, comparison between square-shaped geocell and commercial geogrids revealed that the peak and the residual pullout resistances of the square-shaped geocell increase and become higher than those of the commercial geogrids with an increase in backfill soil particle size from Gravel No.1 to Gravel No.3. Such a behavior confirms the advantageous use of the square-shaped geocell over the commercial geogrid due to more efficient confinement of larger soil particles in the cells resulting in a larger anchorage capacity of the cells.

The combined effects of geocell height and particle size of backfill soil on the interface mechanism between the geocell and the adjacent backfill soil was also investigated. In general, it was observed that the pullout resistance increases with an increase in the transversal member height of the square-shaped geocell. However, there exists an upper limit of the pullout resistance that is reached when the height of the transversal member exceeds certain values and such threshold increases with an increase in the backfill particle size. A conceptualized pullout interaction mechanism was proposed based on the pullout test results. The pullout resistance is equal to the smaller value between: (i) the shear resistance within the shear bands along the upper and bottom faces of a geocell, which is independent of the height of the geocell members; and (ii) the anchorage resistance induced by passive pressure developing inside the cells, which increases with an increase in the height of the geocell members. Therefore, as the height of the geocell increases, the total pullout resistance approaches to the anchorage resistance and increases with an increase in the height of the geocell. However, when the geocell height reaches a certain limit value, the pullout resistance is given by the shear resistance and, thus, it does not increase with a further increase in the height of geocell. Both shear resistance and anchorage resistance, and therefore the pullout resistance, increase with an increase in backfill particle size.

In addition, the effect of spacing between transversal members on pullout resistance was investigated. It was found that when the pullout resistance of the geocell is determined by the shear resistance within the shear bands along the upper and bottom faces of the geocell, the spacing between transversal members has little influence on the pullout resistance, which means that reducing the number of transversal members is possible for cost effectiveness.

Although the pre-peak pullout stiffness of the geocell model (made of softer material, with scale factor of 1/10) was found to be lower than that of the commercial geogrid (made of stiffer material), this drawback could be minimized by preloading, which reduces the slackness of the transversal members. The pre-peak stiffness may increase not only by good initial test setting-up, but also by using stiffer longitudinal and transversal members to reduce the progressive development of tensile forces in the pullout direction of the geocell.

The seismic performance of GRS RW using square-shaped geocell (geocell-RS RW) backfilled with sand was evaluated comparing to traditional non-reinforced T-shape RW and geogrid-RS RW (with geogrid^M reinforcements having relative larger aperture size) by shaking table model tests. In addition, shaking table model tests on non-reinforced T-shape RW, geogrid-RS RW (with geogrid^M reinforcements having relative larger aperture size and geogrid^C reinforcements having relative smaller aperture size) and geocell-RS RW backfilled with gravel were also conducted to check if geocell-RS RW has or does not have a higher seismic stability than geogrid-RS RW in the backfill with larger particles.

The seismic performance of geocell-RS RW was found as follows:

1) Based on the evaluation of residual overturning angle and sliding displacement of the wall, geocell-RS RW shows more ductile behavior than geogrid-RS RW and non-reinforced T-shape RW when backfilled with sand. This trend becomes more pronounced when backfilled with gravel under higher base acceleration.

2) From the analysis of settlements of the backfill soil, geocell-RS RW shows better performance than geogrid-RS RW and non-reinforced T-shape RW by restricting settlements under higher base acceleration.

3) From the evaluation of response accelerations of the wall and the backfill soil, in the case of sand backfill, the response amplification of geocell-RW is similar with geogrid-RS RW. While in the case of gravel backfill, geocell-RS RW shows a smaller amplification response than geogrid-RS RW under higher base acceleration. This suggests that geocell-RS RW has a higher seismic stability than geogrid-RS RW under higher base acceleration (i.e. from 468 gal to 844 gal) especially if embedded in gravels having larger particles.

4) The threshold acceleration was defined as the amplitude of the base acceleration in the active state when the residual lateral displacement of the facing wall at the position of the top of the wall reaches 5% of the total wall height. Based on this concept, it was found that at the threshold state the threshold acceleration of geocell-RS RW is higher than that of geogrid-RS RW in both backfill of sand and gravel, indicating that geocell-RS RW exhibits a higher seismic stability than geogrid-RS RW. It was also noted that, as the backfill soil changes from sand to gravel, the threshold acceleration of geocell-RS RW almost keeps steady, while the threshold acceleration of geogrid-RS RW decreases, indicating a decrease in the seismic stability of geogrid-RS RW.

5) The dynamic behavior of geocell-RS RW was analyzed as a damped single-degree-of-freedom system. It was found that when backfilled with sand, although geogrid-RS RW and geocell-RS RW may show some unstable dynamic behavior, both clearly exhibits higher dynamic strength, dynamic ductility and damping capacity at failure than non-reinforced T-shape RW. Alternatively, when backfilled with gravel, geocell-RS RW clearly shows higher dynamic strength, dynamic ductility and damping capacity at failure than geogrid-RS RW.

The analysis of shaking table model tests of geocell-RS RW and geogrid-RS RW demonstrated that the geocell has an substantial benefit to confine larger soil particles comparing to geogrid, which induces a higher anchorage resistance and/or higher shear resistance at the top and bottom interfaces between geocell and the adjacent backfill than geogrid, therefore increasing the seismic performance of GRS RW, especially in the case of very severe earthquakes.