Effect of geocell shape and filling material characteristics on bearing capacity geocell reinforced soils

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ABSTRACT

In this study, series of experimental test were conducted on geocell type of reinforcements for its implementation to improve the strength of soft ground. The ground for test pit has less tensile strength than normal ground, which causes problems like subsidence of ground or weakening of bearing capacity. From the series of large soil box with geocell experiment varying filling materials and geocell shapes, the effect of geocell shape and filling material characteristics on bearing capacity of geocell reinforced soil layers was evaluated. Based on the result, reinforcement of bearing capacity and stress distribution effect of the sub-ground according to increase of loading was analyzed under the conditions including height, width, and shape of geocell, and types of filling materials. Evaluation of bearing capacity based on a large soil box test suggested that the ultimate bearing capacity with the maximum reinforcement increases by four to eight times in comparison with natural ground, and the largest ultimate bearing capacity is given in geocell shape of 1:1.2 (width: height) which is filled with sand, and to be 1:0.8 (width: height) when filled with sedimentary clay. Also, the maximum earth pressure in reinforced ground decreases 50% up to 60% in comparison with unreinforced ground because of dispersion of lower stress.

Keywords: honeycomb geocell, bearing capacity, reinforced ground, shallow foundation, stress distribution effect

1 INTRODUCTION

Soft grounds for low-landfilled sites cause several problems included ground subsidence, sliding of slope, and settlement of foundation because their tensile strength is weaker than that of ordinary grounds. When soil is overstressed, it can cause excessive subsidence or shear failure of soil. Therefore, geotechnical and structural engineers who design foundation evaluate bearing capacity of soil and, for extremely soft ground, apply techniques to reinforce the bearing capacity. Among different techniques to reinforce a soft ground, geotextile reinforcement confines horizontal movement and creates friction by installing continuous board-type or belt-type element.

Especially, geocell which is developed by geotextile for protection and stabilization applications increases tensile strength and improves bearing capacity of soft ground. Geocell is used to reinforce an embankment, sub-base, foundation, retaining wall, and subsoil below roads because it has a roll to maximize a shearing strength and bearing capacity in soft ground. It has been studied to understand reinforcement mechanism of geocell with one or multiple cells. Tri-axial compression test and large scale bearing capacity test have been applied in the geocell reinforced layer which is installed on a clay and sand material to confirm the efficiency of bearing capacity with reinforcement.

Many studies were conducted on various construction methods to resolve these problems. Army R.D. (1981) proposed a bearing capacity formula for ground with surface load and high density, in terms of bearing capacity of continuous foundation of various restraint systems. Also, Rajagopal (1999) conducted a static load test of 1-cell geocell, in which 260mm × 185mm geocell was transformed into 235mm × 200mm after the test. Dash (2007) conducted a test on a geocell-reinforced sand ground with the width of the reinforced layer, width and height of geocell, and height of cover soil as variables, for its behavior when loaded with line load. Zhou et al. (2008) pointed out that geocell-reinforced ground can suffer bending-resistance, tensile strength, shearing strength, and prevent plane failure of the lower ground. Pokharel (2010) found that the binding force between cells limits movement of soil particles increases longitudinal binding force.

This study aimed to analyze ground reinforcement efficiency and behavior characteristics with geocell shapes and filling materials. The effect on bearing capacity of geocell was evaluated through the test of large soil box.
2 LABORATORY MODEL TEST

2.1 Characteristics of soil material

To evaluate the influence of geocells on the load bearing capacity of soil, the laboratory model tests were carried out in a test box with four types of specimen like sand, clay, weathered granite soil, and aggregate material. USCS of each filling material was ML, SP, GP, and SW; clay is used as lower ground and filling materials, while weathered soil, aggregate, and sand were used only as filling materials. Physical properties of soil specimen were represented as in Table 1 according to USCS.

Table 1. Characteristics of soils.

| Soil type            | Aggregate | Weathered granite soil | Sand | Clay |
|----------------------|-----------|------------------------|------|------|
| \[W_n\] (%)         | 2.3       | 25.2                   | -    | 27.8 |
| \[G_s\]             | 2.63      | 2.67                   | 2.61 | 2.71 |
| \[\gamma_d(max)\] (kN/m^3) | 20.9  | 20.1                   | 16.8 | 16.8 |
| \[W_{optimum}\] (%) | -         | 11.1                   | -    | 17.9 |
| LL(%)                | N.P-      | 2.0                    | N.P  | 36.1 |
| PI(%)                | N.P      | 8.2                    | N.P  | 8.2  |
| Finer. 200 (%)       | 0         | 2.3                    | 0    | 76.8 |
| USCS                 | GP        | SP                     | SW   | ML   |

2.2 Large-scaled model test using geocell

A large soil box in which reaction beam of 1400mm in length, 1000mm in width, and 1400mm in height, was used to create natural ground and geocell reinforced ground. After compacting 700mm of clay, the upper reinforced ground was made under different conditions. Layer compaction of 200mm, 200mm, 200mm, and 100mm in depth was performed on a natural ground composed of slit clay, so that it is as close to the compaction condition of 85% of the maximum dry unit weight as possible. Also, a field density test was conducted to ensure equal compaction conditions for each test and recompose lower ground before creating the reinforcement layer.

Six earth pressure gauges within the natural ground were installed right below the upper load plate at 300mm, 375mm, 450mm, and 600mm in depth. Especially, pressure gauges at 375mm in depth were moved laterally by 200mm and 400mm to examine decrease of earth pressure from the central point. The conditions of soil box for the loading test are shown in Fig. 1.

3 BEHAVIOR BY CYCLIC LOADING

The plate bearing tests for evaluation of bearing capacity was tested on the top of the natural ground without geocell. This result was compared with a bearing capacity on the reinforced ground with P.P mat. Several laboratory model tests were conducted, 1 type of non-reinforced condition and 4 types of reinforced ground condition with honeycomb geocell.

A cyclic plate loading was applied to evaluate bearing capacity of the model ground that was prepared with the conditions. The loading test was also conducted to measure the earth pressure dispersion by loading. The test procedure was tabulated in Table 2.

Fig. 1. Device of large-scaled test for bearing capacity.
Table 2. Series of bearing capacity test under the various test conditions.

| Test | Reinforce condition       | Using geocell size(W×H) (mm) | Dr (%) |
|------|---------------------------|------------------------------|--------|
| 1-a  | Non-reinforced            | -                            | 85%    |
| 1-b  | Geocell + Weathered soil  | 300×120                      | 85%    |
|      |                            | 300×180                      |        |
|      |                            | 200×240                      |        |
| 1-c  | Geocell + Aggregate       | 300×240                      | 85%    |
|      |                            | 400×240                      |        |
| 2-a  | Geocell + Sand            | 300×240                      | 85%    |
| 2-b  | Geocell + Clay            | 300×240                      |        |

Log P - S graph of settlement with loads was shown in Fig. 2. Non-reinforced ground shows rapid changing and yielding at 70 kPa, while ground reinforced by geocell shows sudden settlement and is failed under the loads between 430 kPa ~ 470 kPa.

![Log P - S graph of settlement with loads](image)

Fig. 2. Bearing capacity by non-reinforced and reinforced soils with geocell.

The allowable bearing capacity and yield load of a natural ground were calculated to examine the reinforcement effect of soft ground based on geocell system. In natural ground, when the sediment clay is used for filling an extremely soft ground whose ultimate bearing capacity is 69.34 kPa, the ultimate bearing capacity increases up to 430% in comparison with the natural ground. When aggregate is used for filling, the strength is 845% in the case of 300mm × 240mm geocell. When aggregate with large diameters is used for filling, 300mm × 240mm geocell shows the largest bearing capacity. In the case of filling materials with large particle size were filled in the geocell with small size width, the geocell was interfered by the filling material during compaction and the reinforcement efficiency was decreased because large and small particles were not mixed sufficiently and density was changed within the unit cell.

4 RESULT OF EARTH PRESSURE WITH REINFORCED CONDITION

To analyze behavior characteristics according to load of geocell filled with sand and clay which realizes reinforcement based on equivalent cohesion, a reinforced ground was formed on the top and clay ground on the bottom where earth pressure gauges were installed in different depths and distances from the loading plate. The variations of earth pressure according to load, depth, and distance were measured.

The measurement locations of earth pressure were expressed as multiples of the width of the loading plate, showing increase rate of each measured earth pressure, increase rate according to Boussinesq’s solution, and the decrease rate of earth pressure of non-reinforced ground. The reductions of ratio of vertical stress for fill material were tabulated in Table 3.

Table 3. Reduction ratio of vertical stress for fill materials.

| Filling material | Stress (kPa) | Location of pressure gauge | Reduction ratio (%) [(b-a)/b]*100 |
|------------------|-------------|----------------------------|-----------------------------------|
|                  | 60          | 2B (P1)                    | 69.5                             |
|                  |             | 2.5B (P2)                  | 59.9                             |
| Sand             | 240         | 3B (P3)                    | 64                               |
|                  |             | 4B (P4)                    | 74.5                             |
|                  | 480         | 2B (P1)                    | 65.1                             |
|                  |             | 2.5B (P2)                  | 50.8                             |
|                  |             | 3B (P3)                    | 55.7                             |
|                  |             | 4B (P4)                    | 58.1                             |
| Clay             | 60          | 2B (P1)                    | 30.4                             |
|                  |             | 2.5B (P2)                  | 58.9                             |
|                  |             | 3B (P3)                    | 61.7                             |
|                  |             | 4B (P4)                    | 62                               |
|                  | 240         | 2B (P1)                    | 36.7                             |
|                  |             | 2.5B (P2)                  | 58.8                             |
|                  |             | 3B (P3)                    | 55.2                             |
|                  |             | 4B (P4)                    | 48.3                             |
|                  | 480         | 2B (P1)                    | 37.9                             |
|                  |             | 2.5B (P2)                  | 50.2                             |
|                  |             | 3B (P3)                    | 43.3                             |
|                  |             | 4B (P4)                    | 30.6                             |

Ref. : 'a' is vertical stress which was measured in each location; 'b' is Boussinesq’s stress in each location.
Vertical stress with reinforced soil was compared with non-reinforced soil. The soil type was filled with sand and clay. The comparison of vertical stress is shown in Fig. 3. The measurement locations of the earth pressure were expressed as multiples of the width of the loading plate.

Earth pressure of geocell ground shows significantly lower values than that of the non-reinforced ground. This confirms the mattress behavior of geocell, which reinforces ground by dispersing vertical earth pressure based on the reinforced layer. The strength of earth pressure, when consistent load is applied, decreases by 60% in case of sand filling, and 30% to 40% in case of clay filling, in comparison with non-reinforcement. This explains efficient load distribution mechanism of geocell, and through the geocell system effect, the applied load is distributed to a larger area than that of without reinforcement case.

From the series of large soil box with geocell experiment varying filling materials and geocell shapes, the effect of geocell shape and filling material characteristics on bearing capacity of geocell reinforced soil layers was evaluated. The soil profiles and loading conditions of the experiments in the large soil box were constructed under well controlled environment to ensure the repeatability.

For each test, the measured stress distributions under the geocell reinforced soil layer were compared with those in boussinesq’s solution. The angle of stress distribution under the geocell reinforced soils is being increased approximately more 15%, and the earth pressure is also reduced about 50 ~ 60% comparing with unreinforced soil.

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