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Model tests on retaining walls with modified geocells

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ABSTRACT: Geocells, 3D cellular inclusions infilled with granular sands, have gained extensive popularity in earth retaining structures over the years. Although geocells have undergone several geometric evolutions to achieve their current versatile shape, configuration, and texture, the fundamental engineered design- comprising interconnected cells and infill soil- has remained unchanged. Recently, the authors proposed a structural modification to geocells in the form of a geocell anchor cage (GAC), where each geocell has a central anchor pin, and these pins are connected to a basal grid to form a cage-like system. The inclusion of GACs beneath the geocell mattress significantly enhanced the load carrying capacity and reduced deformations in geocell reinforced sand beds. While the benefits of GACs in geocell reinforced foundations are well established, the present study investigates their application in geocell retaining earth (RE) walls. Geocell walls, geocell-grid walls, and geocell-GAC walls were physically modelled in this study. The performance of these walls was evaluated in terms of displacements, pressure within the cell pockets, and strain in the cell pockets at different elevations. The inclusion of GACs beneath the geocell mattress increased the surcharge capacity of the geocell wall by 1.7 times and that of the geocell-grid wall by 1.2 times. At all elevations, the geocell-GAC wall exhibited the least lateral deformations, followed by the geocell-grid wall and then the geocell wall. Thus, the inclusion of GACs beneath the geocell enhances the performance of the conventional geocell RE walls with minimal additional cost.

KEYWORDS: Geocells, anchor cages, retaining walls, model tests.

1 INTRODUCTION

Geocells retaining earth (RE) walls have gained significant popularity in recent years due to their extensive application in the transportation infrastructure. In such walls, a three-dimensional network of geocells with infill soil forms the retaining portion, effectively resisting the lateral pressure developed in the backfill by overlying loads. The use of geocells in retaining structures was first investigated by Bathurst & Crowe (1994), who replaced the conventional concrete retaining structure with geocell systems and observed excellent wall support with minimal deformations. Since then, several researchers have explored geocell reinforced earth (RE) walls to quantify the effects of various parameters such as slope angle, loading area, reinforcement extension into the backfill, wall type, and geometric properties of geocells (Chen & Chiu 2009; Chen et al. 2013; Song et al. 2017; Song et al. 2018). Though plenty of studies have been conducted on geocell RE walls with geocells of different configurations, materials, and connectors, their fundamental structure remained the same, with an interconnected network of cells and infill soil.

Recently, the authors introduced an engineered modification to geocells in the form of an anchor cage system, in which each geocell has an anchor pin at its center, and these pins are connected to a basal grid to form the cage-like structure (Latha et al. 2024). Authors have conducted extensive plate load tests on various sand beds to quantify the effectiveness of GAC inclusions below the geocell mattress. The bearing capacity of a sand bed reinforced with a geocell mattress of width three times the footing width and a GAC underlain is comparable to that of a sand bed reinforced with a geocell mattress of width four times the footing width. Incorporating GACs below the geocell mattress improved the reduction in settlement of the geocell bed from 30% to 58% and reduction in heave from 166% to 202%. While the benefits of GACs in geocell reinforced foundations are well established, the current paper investigates their application in earth retaining structures. In this study, RE wall model tests were conducted on the geocell wall, the geocell-grid wall, and the geocell-GAC wall to quantify the effectiveness of GAC inclusions within the geocell mattress relative to the conventional reinforcements such as geocells and geocell-grid combinations.

2 RETAINING WALL MODEL TESTS

Model tests on geocell wall, geocell-grid wall, and geocell-GAC wall were conducted in a tank of dimensions 1.5 m × 0.4 m × 1 m. The base dimensions of the RE walls were 1 m in length and 0.4 m in width, with an overall height of 0.6 m. All walls were constructed at a slope angle of 76°. In the geocell RE wall, the retaining portion consists of a geocell mattress with a pocket size of 100 mm and a height of 100 mm, extending to a total length of 300 mm laterally. GACs were placed below the geocell mattress in the retaining portion in geocell-GAC walls, as shown in Figure 1. In GACs, the pins are of 10 mm diameter, and they run throughout the entire height of the geocells. The pins have a helical texture with a sharpened end. The grid to which the pins are attached has a rib depth of 2 mm and a rib width of 3.4 mm. In addition to these tests, the grid-alone tests were also conducted, where the grid without pins was placed below the geocell mattress, forming the geocell-grid walls. In all the tests, locally available river sand (poorly graded) was used as both infill and backfill and manually compacted to achieve a relative density of 70%. The properties of the sand used in the current study are provided in Table 1. A fully constructed geocell GAC wall model is shown in Figure 2.

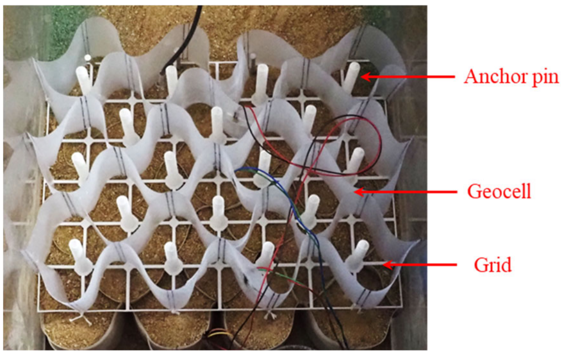

Figure 1. Photograph of the geocell anchor cage (GAC) placed below the geocell mattress.

Since GAC is a novel technique, the grids and pins were fabricated using 3D printing technology through a fused deposition modelling 3D printer. Polylactic acid was used to fabricate GACs. The 3D printed grid showed an ultimate tensile strength of 15 kN/m in both orthogonal directions. To avoid scaling issues, low strength 3D printed geocells are used in the current study (Krishna & Latha 2024). For the fabrication of geocells, polypropylene sheets of 0.4 mm thickness were printed first and then ultrasonically welded to form honeycomb shaped cells. All the welds are 5 mm in thickness. The 3D printed geocells were found to have a cell wall strength of 2.9 kN/m, junction shear strength of 3.2 kN/m, and junction peel strength of 2.2 kN/m.

Table 1. Properties of sand used in the current study

Parameter	Value	Unit
Specific gravity	2.61	-
Effective particle size	0.32	-
Coefficient of curvature	0.88	-
Coefficient of uniformity	3.31	-
Maximum unit weight	17.22	kN/m^3
Minimum unit weight	14.82	kN/m^3

Figure 2. Photograph of the geocell-GAC retaining wall model

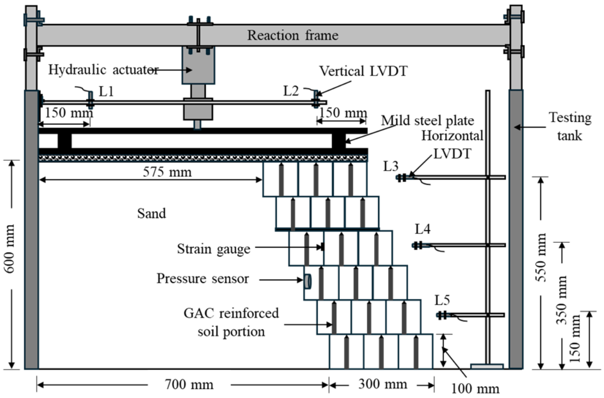

Figure 3. Schematic view of the geocell-GAC retaining wall model test setup.

The schematic diagram of the model setup for the geocell-GAC wall with complete instrumentation is provided in Figure 3. Load was applied throughout the crest of the wall using a hydraulic jack of 150 kN capacity. Vertical and lateral deformations at different locations of the RE wall were measured using non-contact type LVDTs. Pressure sensors and strain gauges were attached to the geocell wall to measure the pressure and strain mobilised along the geocell wall. All walls were loaded until the surcharge pressure remained constant over time.

3 RESULTS AND DISCUSSIONS

The vertical settlement versus surcharge capacity of different walls is provided in Figure 4. The inclusion of GACs below the geocell mattress significantly increased the surcharge capacity of the geocell wall and the geocell-grid wall. The surcharge capacity of geocell, geocell-grid, and geocell-GAC are 50.3 kPa, 60.7 kPa, and 82.3 kPa, respectively. The inclusion of GACs below the geocells improved the surcharge capacity of the conventional geocell wall by 64% and that of the geocell-grid walls by 35%.

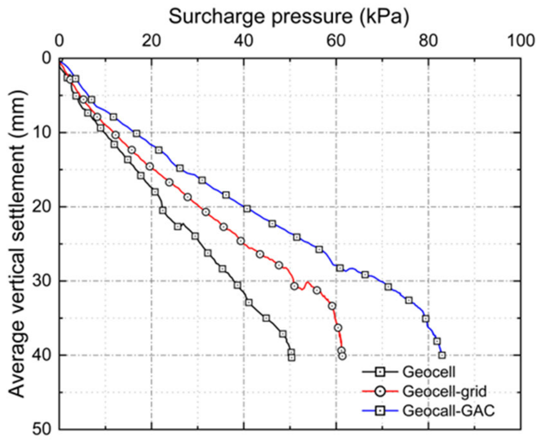

Figure 4. Pressure-settlement response of different model retaining walls

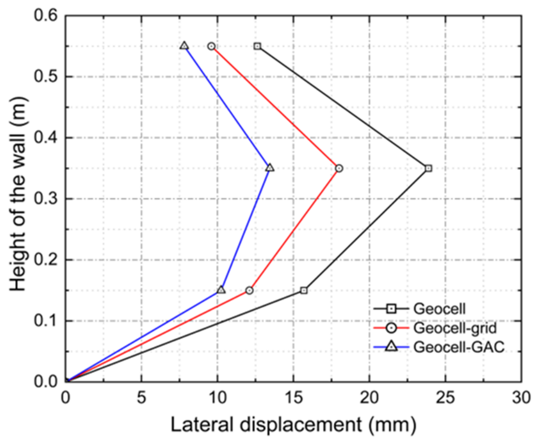

Figure 5. Variation in lateral displacement along the height of different walls under a surcharge pressure of 50 kPa.

Lateral deformations at different locations of the RE wall under a surcharge pressure of 50 kPa are shown in Figure 5. At all elevations, the inclusion of GACs beneath the geocells significantly reduces the lateral deformations compared to both the conventional geocell wall and the geocell-grid wall. Under the applied loading, all walls exhibited bulging in the upper half, aligning well with findings from previous studies on geocell walls under similar loading conditions (Chen & Chiu

2009; Shiwani et al. 2024). The percentage reduction in lateral displacement of the geocell-GAC wall for a surcharge pressure of 50 kPa relative to the geocell wall at 0.15 m, 0.35 m, and 0.55 m from the base of the wall is 34.7%, 43.7%, and 38.1%, respectively. The inclusion of GACs within the geocells proves to be more effective in regions where lateral deformations in the geocell wall are more pronounced, particularly in the upper half where lower confinement results in greater lateral wall movement. In the lower portion, where higher overburden pressure produces greater confinement, the stiffer sand–geocell composite itself resists deformations, thus limiting the improvement of GAC addition.

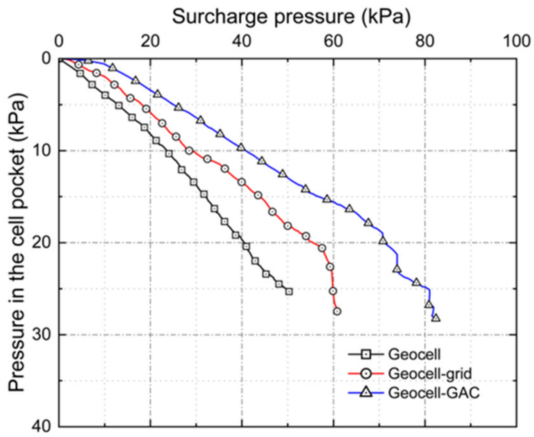

Figure 6. Pressure developed inside the geocell pockets of different retaining walls.

The variations in pressure developed inside the cell pocket and strain mobilised in the geocell wall under increasing surcharge pressure for different wall configurations are shown in Figure 6 and Figure 7, respectively. The lowest pressures and strains are mobilised in the cell wall of the geocell-GAC wall, followed by the geocell grid wall, and the greatest in the geocell wall. At 50 kPa surcharge pressure, the pressure developed in the cell pockets of the geocell-GAC wall is 47% lower than that in the geocell wall, and 27.5% lower than the geocell-grid wall. These lower pressures indicate a redistribution of stresses among the geocells, pins, and basal grid within the cell pockets of geocell-GAC walls. Similarly, the strain mobilised in the cell wall of geocell-GAC wall at 50 kPa was 47% lower than that in the geocell wall and 28% lower than geocell-grid wall. These lower strain values suggest enhanced long-term durability of geocell-GAC walls and reduced susceptibility to creep deformations.

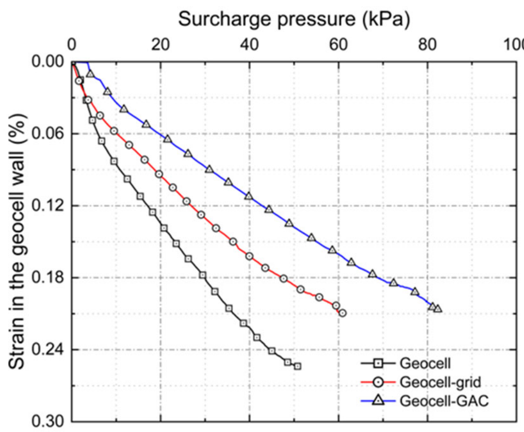

Figure 7. Strain mobilised in the geocell wall of different retaining walls.

The quantity of reinforcements used for different RE walls is shown in Table 2. The Geocell-GAC wall achieved a 70% increase in the surcharge capacity compared to the conventional geocell wall, with only a 10% increase in the reinforcement material used. Similar trends are observed in the percentage reduction of lateral displacement, pressure inside the cell pocket, and strain mobilised in the geocell wall, where the performance improvements significantly outweigh the marginal increase in material usage. Thus, the inclusion of GACs below the geocell mattress enables them to support heavier loads at minimal additional costs and also promotes sustainable construction through reduced raw material usage, lower carbon footprint, and improved long-term durability of the RE walls.

Table 2. Quantity of reinforcements used for different retaining walls.

Wall type	Material used (cm^2)
Geocell	33912
Geocell-grid	36528
Geocell-GAC	37093

3.1 *Reinforcing mechanisms in the geocell-GAC retaining wall*

The inclusion of GACs below the geocell mattress provides an additional confinement effect to the geocells. In addition to the confining stress mobilised at the sand-geocell interface, the sand-pin interface generates an additional shear stress, thus increasing the overall confinement within the geocell pockets. Also, the basal grid to which the anchor pins are attached provides an additional basal confinement and basal stability to the geocell mattress. In geocell-GAC RE walls, the additional stability provided by the pins and the basal grid improves the stiffness of the sand-geocell composite, facilitating a redistribution of stresses within the cell pockets. This results in higher surcharge capacity and reduced deformations in geocell-GAC walls compared to the conventional geocell wall.

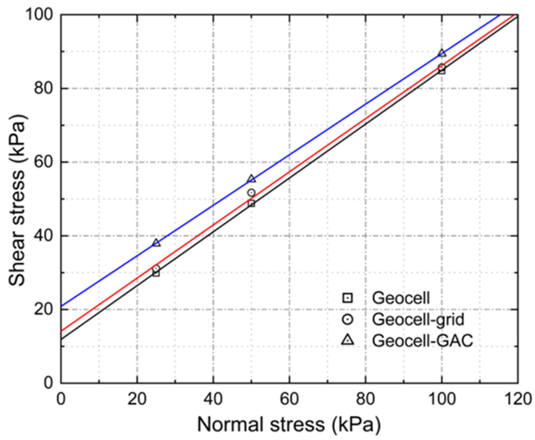

Figure 8. Interface shear response of different retaining walls.

In geocell RE walls, a stable configuration requires preventing the internal sliding between the individual geocell layers within the retaining portion (Bathurst & Crowe 1994). This stability relies on the shear resistance developed between the successive sand filled geocell layers within the retaining portion to counteract the lateral pressures from the backfill. To evaluate whether the inclusion of GACs improves this layer-to-layer resistance, interface shear tests were conducted for three configurations: geocell–geocell, geocell–grid, and geocell–GAC under normal stresses of 25, 50, and 100 kPa at a strain rate of 1.25 mm/min. In geocell-geocell tests, sand filled geocells were placed in the upper and lower shear boxes to replicate the in-wall conditions for geocell RE walls. For geocell-grid walls, the grid without pins was placed above the sand filled geocells (geocell-grid tests) in the lower shear box. In geocell-GAC tests, GAC was placed below the sand filled geocells in both boxes for in-wall conditions of geocell-GAC walls.

Mohr-Coulomb linear envelopes of different interface tests are plotted in Figure 8, indicating the highest shear strength mobilisation at the geocell-GAC interface, followed by the geocell-grid interface and then the geocell-geocell interface. The apparent cohesion mobilised at the geocell-GAC is about 1.2 times greater than the geocell-grid interface and 1.8 times greater than the geocell-geocell interface. These results confirm that the inclusion of GACs below the geocell mattress improves the shear strength of the conventional geocell RE walls, thus enabling them to withstand greater loads with reduced deformations.

4 CONCLUSIONS

The current study explores the application of geocell anchor cages (GACs) below the geocell mattress in the retaining wall systems. Geocell walls, geocell-grid walls, and geocell-GAC walls were physically modelled to quantify the effectiveness of placing GACs beneath the geocell mattress compared to the conventional reinforcements such as geocells and geocell-grid combinations. The following conclusions are drawn from the current study.

1. The inclusion of GACs below the geocell mattress improves the surcharge capacity and reduces the deformation of the conventional geocell retaining walls.
2. The pressure developed in the cell pocket and the strain mobilised on the geocell wall were reduced with the inclusion of GACs below the geocell mattress, indicating a redistribution of stresses by anchor pins and basal grid within the cell pockets.
3. In geocell-GAC walls, the anchor pins provide an additional confinement to the geocells, and the grid to which the pins are connected provides basal stability and confinement to the geocell mattress, thus enhancing the stiffness of the conventional geocell retaining walls. Also, the anchor cages below the geocell mattress improve the layer-to-layer shear resistance of sand filled geocell layers, preventing the possibility of internal sliding in geocell retaining walls.
4. Compared to the conventional geocell walls, with a 10% increase in reinforcements, the geocell-GAC walls achieved a significant increase in surcharge capacity and a decrease in deformations with minimal additional costs.

5 ACKNOWLEDGEMENTS

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