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Geocells for Transportation Geotechnical Applications

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Abstract. Since their inception in early 70's, geocells have found numerous applications in civil engineering. One of the most important applications of geocells, which has created considerable impact in the field of reinforced soil structures is their usage in various transportation geotechnical applications. Geocells are successfully being used for the reinforcement of road embankments, unpaved roads and creation of flexible retaining walls. This paper demonstrates the beneficial effects of geocells in all these applications through laboratory model studies. Embankments were built on soft clay with the support of a geocell layer, withstanding higher loads with lesser settlements. Geocell reinforcement in unpaved roads has significantly improved the cyclic load bearing capacity and resilient modulus, improving the traffic benefit ratio and reducing the rutting. Geocell walls built with low cost polymers could sustain severe earthquake conditions, without undergoing failure.

Keywords: geocell, embankments, unpaved roads, retaining walls, reinforced soil

1 Introduction

The primary application of Geocells, when they were conceptualized and implemented in 1970, was providing immediate support for the movement of heavy military vehicles over soft roads [1,2]. Over the years, geocells have found many other applications like foundation reinforcement, erosion control, slope protection, channel protection, flood walls and blast protection. However, the use of geocells in various transportation related applications including roads, embankments and retaining walls, remains well ahead among all other applications. Today, geocells are being extensively used across the world, to construct low maintenance roads in difficult ground conditions. Many case studies are available in literature, demonstrating the successful performance of geocells in protecting the roads and other components of transportation infrastructure against adverse weather conditions, earthquakes and floods.

Pokharel et al. [3] discussed the field size pilot studies on geocell reinforced unpaved road sections built in Northern Alberta and British Columbia. These roads are geographically located in places prone to cold winters and extreme freeze and thaw conditions. An excellent case study of building a geocell flood wall in a short time to protect the city of Smithland, Kentucky from flood was reported by Geocell Systems Inc.[4]. Another case study of a 15 m tall geocell retaining wall built in Istanbul to resist seismic loads was illustrated by PRS Geotechnologies [5]. The geocells were made of low tensile strength

Gali Madhavi Latha

uniaxial geogrids but provided high strength, flexibility and resistance to extreme earthquake motions. Another case study of rehabilitation of damaged roads due to heavy rainfall in Hangal of North Karnataka using geocells is documented by Bagli [6]. Geocells provided a long-term solution to the problems of reflective cracking, rutting and mud-pumping, which were a constant hurdle to the movement of vehicles during every monsoon season.

Several earlier researchers have presented the beneficial effects of geocell reinforcement for transportation applications through laboratory model tests. The beam effect and all-round confinement effect of geocells were conceptually explained by Han et al. [7]. Bathurst et al. [8] and Rajagopal et al. [9] quantified the all-round confinement effect of geocells through large scale laboratory triaxial tests. Krishnaswamy et al. [10] showed that geocell confinement can drastically reduce the vertical settlements and heave of embankments built on soft clay layers. Benefits of geocell reinforcement in reducing cyclic deformations in soils was investigated by Latha et al. [11], Nair and Latha [12] and Latha and Manju [13]. Thakur et al. [14] showed that the all-round confinement effect of geocells is capable of reducing creep deformations in recycled asphalt pavements. Leshchinsky [15] presented results from simulated load tests on models of railroad ballast embankments, showing that geocells are effective in controlling the permanent deformations and degradation of ballast to slow down the deterioration of the embankment geometry under heavy duty rail traffic movement. Saride and Rayabrapu [16] discussed different methods of design of pavements reinforced with geocells, in the light of laboratory model pavement studies on geocell reinforced granular bases.

This paper presents some important laboratory and small-scale field simulations on geocell reinforced embankments, road sections and retaining walls, carried out over a period of 25 years.

2 Geocell Supported Embankments

Embankments to support road and rail-road traffic movement are essential components of transportation network. In countries like India, where diverse soil conditions pose many challenges for the construction and maintenance of these embankments, supporting these embankments on a strong geo-cellular network is a sustainable solution. Since geocells are tri-planar, they confine the infill soil in both lateral and vertical directions, thus providing a strong mat like foundation to the embankment. Apart from transferring their tensile stiffness to loadbearing capacity of soils, geocells also contain the soils, allowing for the re-orientation of shear planes and reducing the load on the foundation soil. The pressure bulb, which usually extends to deeper soils, is widened and limits itself to shallow depths of the soil layers due to the beam effect of geocells, thus allowing constructions on weaker soils. Most importantly, the benefits of geocell are immediate and hence the disturbance to traffic movement during the construction phase is minimal. Additional supporting system for compactors and trucks carrying construction materials are also not needed since geocells provide full-support for the vehicular traffic, as soon as they are expanded in the field and filled with the infill material. Figure 1 illustrates a geocell supported embankment constructed over a soft clay foundation bed.

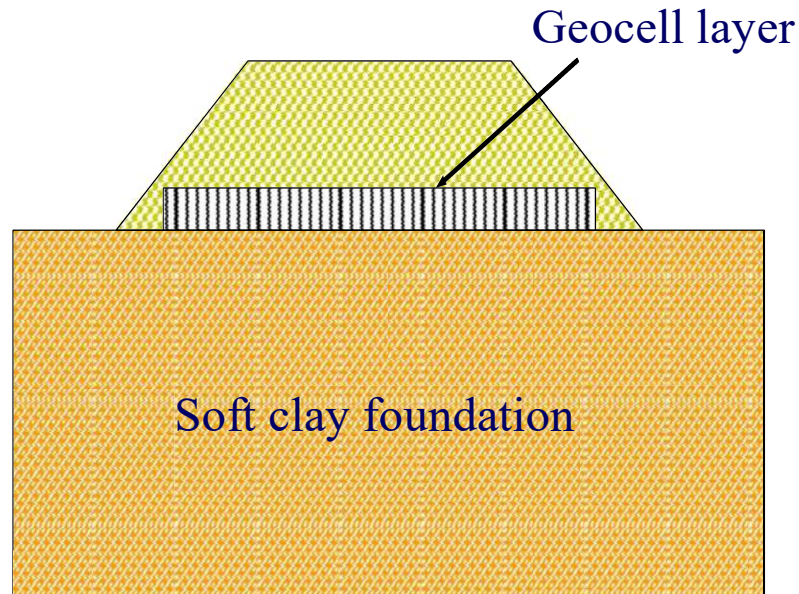


Fig. 1. Schematic diagram of a geocell-supported embankment

To understand the benefits of geocell reinforcement in embankments over soft soil beds, laboratory plate load tests were carried out. A soft clay bed of 0.4 m depth was created by mixing a lot of water with clay and consolidating it for a week by applying a uniform surcharge of 10 kPa. At the end, the shear strength and CBR properties of the clay bed were measured by taking undisturbed samples from the prepared test bed. The unit weight of the test bed was 17 kN/m^3 , CBR value in soaked condition was 0.5% and the undrained cohesion was 20 kPa. Uniaxial and biaxial geogrids and geonets were used in different model tests to fabricate the tri-planar honey-comb shaped geocells. Clayey sand was filled in geocells and carefully compacted to a unit weight of 17 kN/m^3 .

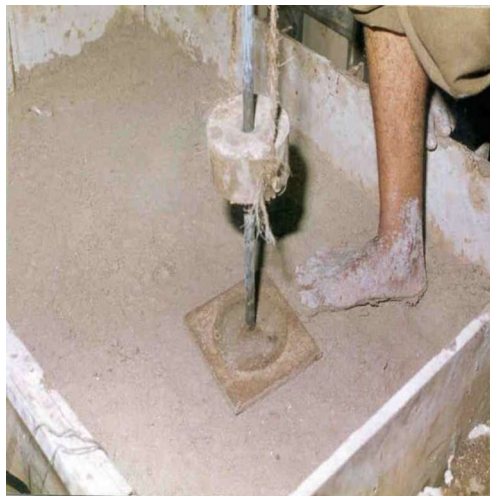
Symmetric half models of soil embankments of base length 1.8 m, width 0.8 m and height 0.6 m were built on top of the geocell layer using clayey sand to a unit weight of 19 kN/m^3 . Plate load tests were conducted on the model embankments and settlements of the embankment, deformations of the slope and heave of the soil layer adjacent to the embankment were measured using dial gauges. Figure 2 shows the sequence of the model construction and testing.



(a)



(b)



(c)



(d)

Fig. 2. Sequence of embankment model construction and testing
a) Mixing of soft clay b) Filling of geocells c) Compacting the embankment
d) Test set-up

Results from the load tests on model embankments proved that geocells provided at the base of the embankment are effective in controlling the vertical and lateral deformations of the embankment. Variation of vertical deformations with different aspect ratios of geocell layer created using single-plane biaxial geogrid is shown in Fig. 3. The position of dial gauges are marked with V in Fig. 4. As seen from the figure, inclusion of the geocell layer has significantly reduced the settlements of the embankment and also controlled the heave of the soil adjacent to the embankment. Aspect ratio, which is the ratio of height to diameter of the geocell is an important factor that governs the deformations in the embankment. The optimum value of aspect ratio for the test configurations and materials used in these model tests was found to be unity. The geocell supported embankment with the cell aspect ratio of unity has settled three times less compared to an identical embankment constructed on the soft clay layer, without the geocell layer.

Also, the economical benefits of geocells can be seen from Fig. 4, where the cells were filled with the native clay material instead of clayey sand. Even with a clay infill, significant improvement in the performance in terms of reduction in lateral deformation can be seen. The embankment built directly on the soft clay bed has moved laterally by about 6 mm under a surcharge pressure of 50 kPa. However, the embankment supported on clay-filled geocell layer has deformed only by about 0.6 mm. The embankment supported on clayey-sand-filled geocells has not undergone any lateral deformations under 50 kPa.

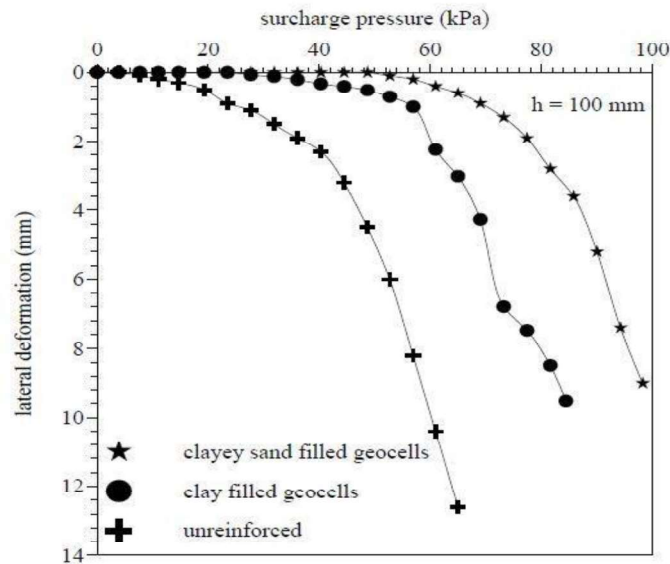


Fig. 3. Variation of lateral deformations with geocell infill material

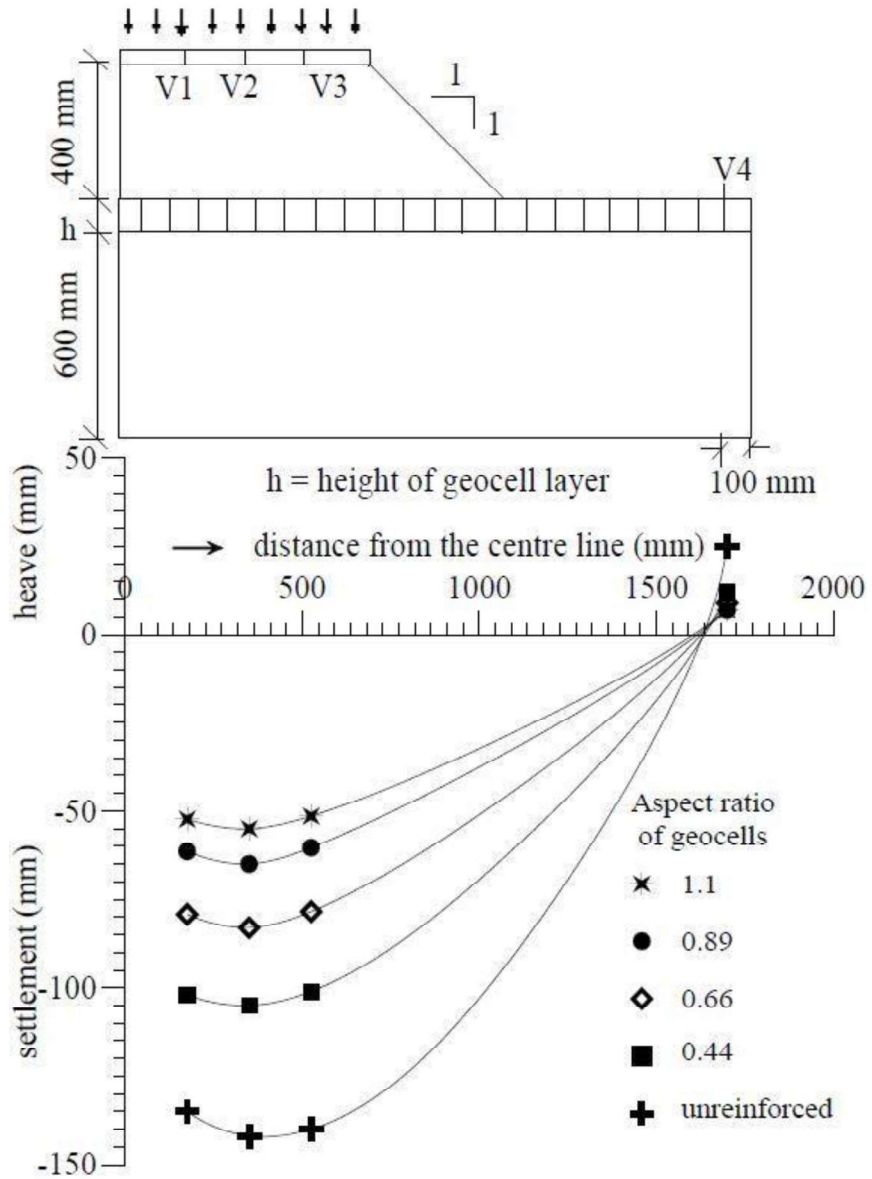


Fig. 4. Variation of embankment settlements with geocell reinforcement of different aspect ratios

3 Geocell Faced Retaining Walls

Transportation geotechnical applications have retaining walls to serve functions like gradient change, slope protection and elevated corridors. Most of the gravity retaining walls are being replaced with reinforced soil walls, to provide flexibility and resistance to seismic loads. Geocell walls provide attractive and economical solutions for such scenarios, given the ease of their construction and their geometrically stable configuration. Unlike other types of mechanically stabilized soil retaining walls, geocell walls do not require any facing. The key design principle of a geocell retaining wall is to counteract the cyclic vehicular loads, wind loads and seismic loads through the additional friction and resisting moment generated at the base of the wall. Since geocell walls are built by stacking the layers of geocells, the entire width of the geocell layer acts as the reinforced fill and the driving forces from the weight of the retained backfill are counteracted by the gravitational forces exerted by the reinforced fill. The failure wedge shifts to much deeper into the fill, increasing the shear resistance under active and passive pressure conditions. The stacked geocells themselves act as the facing of the wall and if an offset is provided between different layers, grass and other bio-stabilizing plants can be grown in cell pockets, which will further contribute to the stability of the wall. The porous walls of the geocells restrict the development of pore pressures inside the fill, thus reducing the danger of wall collapse and liquefaction. These walls are extremely stable against seismic loads since the design provides flexibility and makes the entire structure ductile, allowing displacement adjustments between the layers, unlike full-height rigid faced walls or gravity walls. Fig. 5 shows the schematic diagram of a commonly adopted geocell wall.

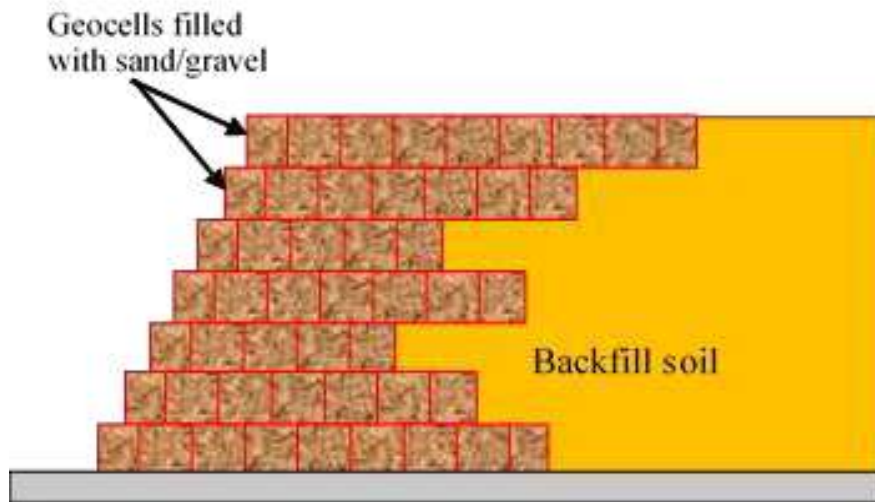


Fig. 5. Schematic diagram of a typical geocell faced retaining wall

Gali Madhavi Latha

One of the important advantages of geocell walls is their resistance to earthquake shaking that comes from the wider facia, which is effective in resisting both sliding and overturning of the wall. To understand the response of geocell faced walls to earthquake shaking, geocell faced walls constructed in a laminar shear box were tested on a uni-directional shaking table.

Low strength geonets were used to create the geocell facing. The sequence of steps followed for the construction of a geocell faced wall inside the laminar shear box mounted on the uni-directional shaking table is shown in Fig. 6. Initially the geocell layer of 100 mm height and 100 mm diameter is expanded to the required width of the box (0.5 m) and filled with aggregate of average size 10 mm and compacted. Backfill sand is then filled to the height of the geocell layer and compacted. Then the next layer of geocells is placed above the first layer with an offset of 50 mm and filled with aggregates and compacted. This step is followed by the backfill sand filling up to the second layer. These steps are repeated till the full height of the geocell faced wall (0.6 m) is reached.

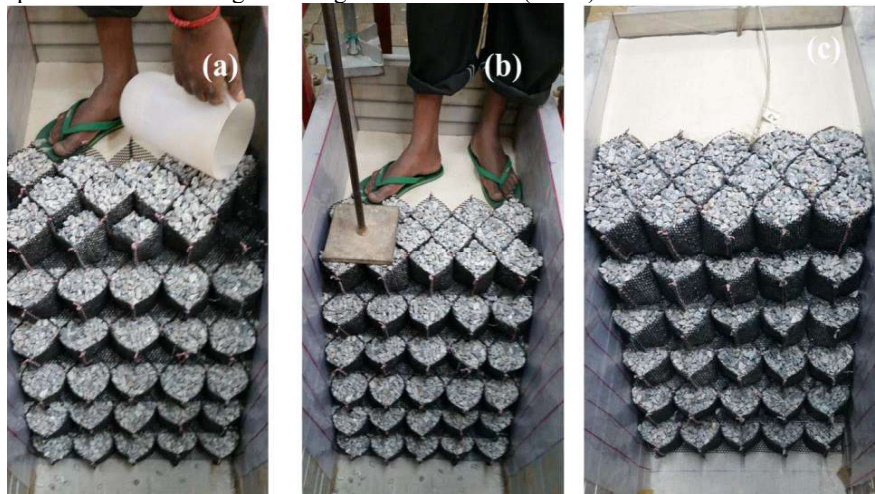
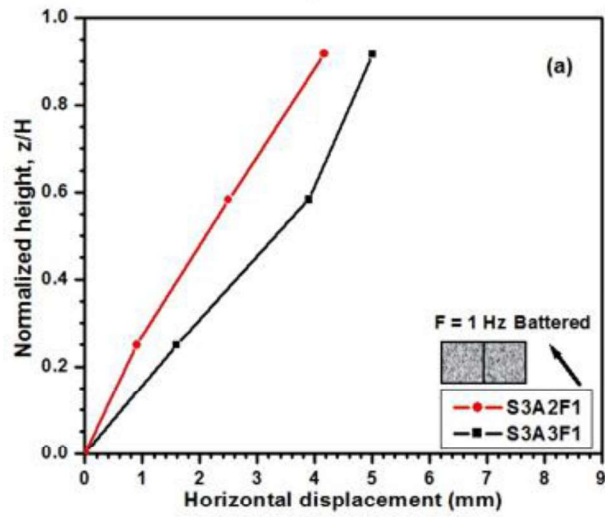
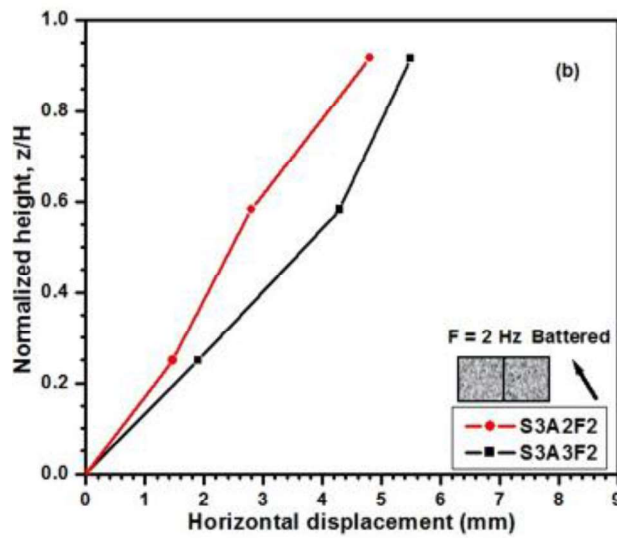


Fig. 6. Construction of Geocell faced retaining wall a) Filling aggregate in cells b) Compacting infill c) Finished wall

Displacements of the model walls were continuously monitored using ultrasonic displacement transducers, which can measure 20 displacement values within each second, with an accuracy of 1micrometer. Also, these transducers are not in contact with the models and hence they remain undisturbed during the model testing. The model walls were shaken with different amplitudes and frequencies of shaking. It was observed that the geocell faced walls stayed intact even after severe shaking conditions. For example, Fig. ??? shows the results from a set of simulated shaking studies, where the models were shaken to a frequency of 1 Hz, changing the amplitude of shaking between 0.2g and 0.3g in tests S3A2F1 and S3A3F1, respectively. These values of acceleration amplitude represent moderate and severe seismic conditions.



(a)



(b)

Fig. 7. Facing deformations of a geocell wall with different frequencies of shaking
a) 0.3g, 1 Hz frequency b) 0.3g, 2 Hz frequency

Gali Madhavi Latha

Deformation of geocell faced walls at different elevations at two different seismic amplitudes are shown in Fig. 7a. For a moderate seismic shaking of 0.2g amplitude, the wall deformed by a maximum amount of 4.2 mm and for severe seismic shaking of 0.3g amplitude, the wall deformation was 5 mm. for an acceleration amplitude of 0.2g, the deformation at the top of the retaining wall was found to be 4.2 mm, whereas for an acceleration amplitude of 0.3g, the horizontal displacement was 5 mm . Another set of model tests were carried out at a shaking frequency of 2 Hz and the deformations corresponding to 0.2g and 0.3g acceleration amplitudes from tests S3A2F2 and S3A3F2, respectively, are presented in Fig. 7b. This situation corresponds to much severe shaking of the wall and for this condition, the wall displaced by a maximum about of 4.8 mm at an amplitude of 0.2g and 5.5 mm at an amplitude of 0.3g. and for a frequency of 2 Hz, as shown in Fig.5.15b, the values were 4.8 mm and 5.5 mm, respectively. However, the wall did not fail even under such severe seismic shaking conditions, proving that the geocell faced walls have extremely high resistance to earthquake shaking.

4 Geocell Reinforced Unpaved Roads

Geocells perform multiple functions when used to reinforce unpaved roads. Apart from providing tensile and shear resistance to the road, their network can act as a separator between the soft subgrade and sub-base/base courses, limiting the mud-pumping and layer mixing. By providing a layer of geocells in the road section, the thickness of the aggregate layer can be significantly reduced with additional advantage of increased strength and resilience. Being a porous inclusion, geocells also allow free drainage between the layers and restrict the development of excess pore water pressures within the road sections.

To understand the beneficial effects of geocells in unpaved roads, laboratory plate load tests were carried out on model sections with geocell reinforcement. In a steel test tank, a clay subgrade is created using low plastic clay by compacting it to a unit weight of 18 kN/m³ at its optimum moisture content of 15%. Under these conditions, the CBR value of the subgrade clay is 19%. Repeated load type plate-load tests were carried out on the model road sections built using aggregate of average size 10 mm above the clay layer. Commercial geocells with honeycomb shape and porous walls, supplied by Strata geosystems were used to reinforce the aggregate base layer. Height of the geocell layer was varied in different model tests, starting from 25 mm to 150 mm, in increments of 25 mm. The test sections have square dimensions of 0.75 m sides in plan and 0.62 m height. Fig. 8 shows the schematic representation of the model test set-up.

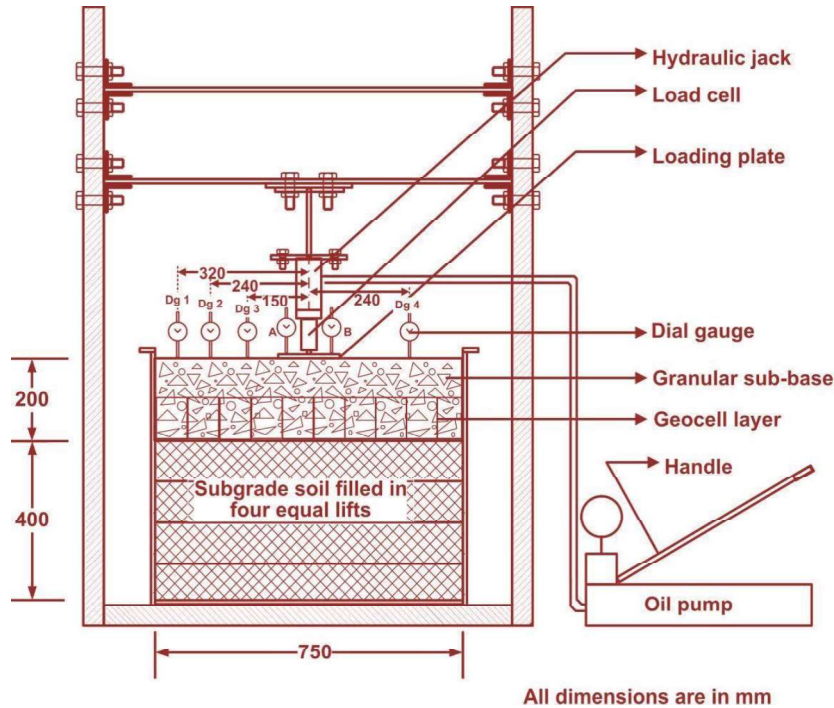


Fig. 8. Schematic diagram of the model set-up for repeated load tests on unpaved roads

Reduction in the vertical deformations of the road sections with the inclusion of geocell layers of different heights is shown in Fig. 9. The plot shows diminishing benefits beyond a cell height of 75 mm, suggesting possible buckling that can happen in cell walls with further increase in height. The maximum reduction in vertical deformations was observed to be about 70%. In the repeated load testing, vertical deformations are categorized into elastic and plastic settlements. Plastic settlements are detrimental to the performance of the roads since they represent the fraction of settlements that will be permanent, unlike elastic settlements.

For the benefit of road service and maintenance, plastic settlements should be less. Comparison of plastic settlements accumulated in unreinforced road section and different geocell reinforced road sections are shown in Fig. 10. While the plastic settlement in unreinforced road section is about 110 mm at the end of 100 cycles of load, geocell reinforced section with 75 mm cell height could bring down the plastic settlements to less than 50 mm. Reduction in stiffness of the geocell with increase in height is a factor that should be considered in the design since geocells with height beyond 75 mm have shown comparatively lesser benefits.

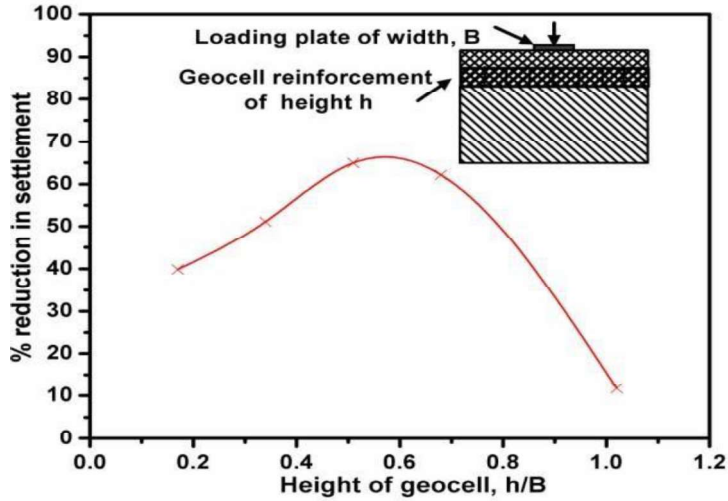


Fig. 9. Performance of geocell layer in reducing settlements in roads

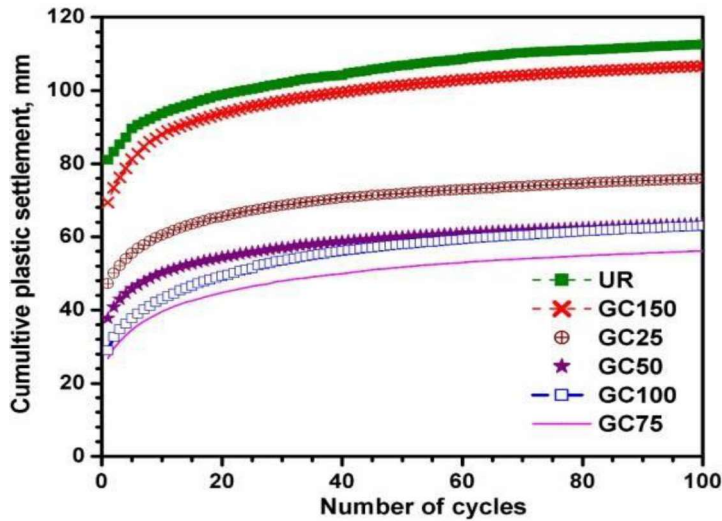


Fig. 10. Plastic settlements of road sections with geocell reinforcement

To demonstrate the effectiveness of geocells for unpaved roads in a field set-up, small scale field tests were carried out on the Indian Institute of Science campus. An unpaved road section of 2 m length and 1 m width was chosen for these tests. The natural sandy soil subgrade of the campus has a CBR value of around 20%. The native soil was ploughed to a depth of 0.5 m and mixed with excessive amount of water and left for a day after mixing. The CBR value of the prepared test bed was measured as 1%. Aggregate of

average size of 12 mm was used as the base course. Geocells were formed using a planar biaxial geogrid having ultimate tensile strength of 40 kN/m. Height and pocket size of the geocell layer were kept as 100 mm, which means that the aspect ratio of geocells was unity. The formation of a single geocell layer of 2 m² plan area consumed a planar geogrid of 5.85m² area. A geotextile layer having ultimate tensile strength of 55 kN/m was used as a basal layer for the geocells. In a different series of tests, only the planar geotextile and only the planar biaxial geogrid were used as reinforcement, instead of geocells. The cell pockets were filled with aggregate to a unit weight of 13 kN/m³. Prepared subgrade with geocell layer above the basal layer is shown in Fig. 11.



Fig. 11. Geocell layer prepared at the site

A cover layer of 50 mm thickness is created above the geocell layer to facilitate smooth movement of vehicles by mixing the native soil with 10% water by weight. After the cover layer is finished, the road section is subjected to moving vehicular loading. A Honda Activa two-wheeler motor vehicle of 100 kg weight was used for this test. The weight of the rider was 55 kg. The vehicle was driven along the central line of the road section at a uniform speed of 20 kmph. This exercise was repeated 250 times and each time, the vehicle was allowed to move on the test bed at the same speed in the forward direction only, simulating on-way traffic. The entire road section was divided into equal area grids and the displacements were measured at the grid junctions at Sections 1, 2 and 3 as shown in Fig. 12 after every 50 passes of the vehicle. These displacements were used to calculate the rut depths. The rut depths were measured at marked grid points after every 20 passes until 250 passes were completed.

As observed from the rut depth measurements along the three transverse sections of the road shown in Fig.12, geocell layer is very effective in controlling the rut depth. Unreinforced road section (UR) developed deeper ruts and the vehicle started skidding on it within 20 passes of the vehicle. However, the road section with geocell reinforcement

(GC5.85) developed less deeper ruts and the vehicle passage was smooth till 250 passes. Between geotextile (GT) and geogrid (BG), geotextile performed better since the function of separation controlled the mixing of softer subgrade soil into the aggregate.

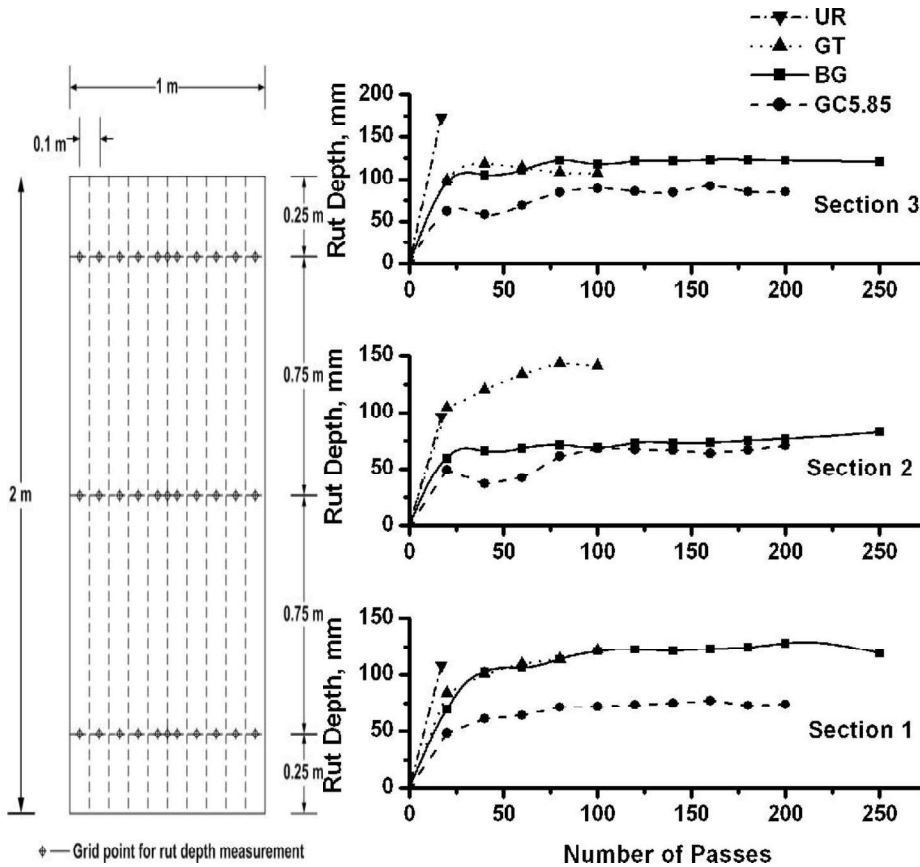


Fig. 12. Effectiveness of geocell layer in controlling the rut depths in unpaved roads

5 Summary and Conclusions

Beneficial effects of geocells in various transportation geotechnical applications are highlighted in this paper through various laboratory model experiments and small-scale field studies. Road embankments constructed on soft clay foundations supported on a geocell layer, retaining walls built with geocell facing and unpaved roads stabilized with

a geocell layer were tested under static, cyclic and seismic shaking conditions. These studies brought out the advantages of using geocells for reinforcing soils for various transportation engineering applications. With the support from the geocell layer, embankments settled less and the slope deformations were completely arrested. Under repeated loading conditions, the geocell reinforced unpaved road sections showed lesser plastic settlements and higher load bearing capacity compared to unreinforced road sections. Field tests with soft subgrades stabilized with geocell layer showed that the rut depth decreased substantially with the geocell reinforcement. Geocell reinforced road sections could sustain many vehicle passes without failure. Seismic load studies on geocell faced walls highlighted their effectiveness under most severe earthquake conditions.

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Gali Madhavi Latha

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