Improving Bearing Capacity of Footings using Geocells - a Review

Jayamohan J, Aparna S, Aswathy Sasikumar

Abstract—Over the last two decades, the beneficial effects of using different geosynthetic reinforcing materials in foundations have received considerable attention. In general, the tensile strength of soil is poor and hence the soil often needs to be strengthened to improve stability, increase bearing capacity and reduce settlements and lateral deformation. The use of geosynthetics by providing three dimensional confinements to the soil in the form of geocells can significantly improve the soil performance and reduce costs in comparison with conventional designs. This paper reviews experimental tests and studies carried out by different researchers on geocell reinforced soil. Literatures indicated that the inclusion of geocell reinforcement in sand decreased settlements and leads to an economic design of the footings.

Keywords *— Bearing capacity, experimental tests, foundation, geocell reinforcement, improve stability, lateral deformation, reduce settlements*

1 INTRODUCTION

THE increase in demand for land space all over the world due to rapid urbanization has resulted in an increase in the need to construct on soft soil grounds, which were considered unsuitable for construction a couple of decades ago. The stability of structures on soft soil deposits is a challenging task due to high settlement and heaving tendency of soft soil. In such cases, ground improvement techniques are adopted to improve the load carrying capacity and to reduce the settlement of the soft foundation bed. The introduction of geosynthetics as reinforcement has significantly reduced the cost of ground improvement and simplified the construction procedure. Geocell reinforcement is a technique developed for soft soil reinforcement, which is being increasingly used for construction of roads and embankments.

2 GEOCELL

Geocell is a three dimensional, polymeric, honeycomb like structure of cells interconnected at the joints that provide effective confinement of the encapsulated soil against being pushed away from the region under loading. The filled cells being interconnected, the panel acts like a large mat that spreads the applied load over an extended area leading to an improvement in the overall performance as shown in figure 1.

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(a) (b)

Fig 1: a) Geocell b) Soil reinforced with geocell

New types geocell are made of a new polymer structure characterized by low temperature flexibility similar to high density polyethylene (HDPE) [22]. The base layer reinforced geocell mattress in road construction, acts as a rigid slab or a mattress for distribution the traffic load vertically on a broader subgrade. Therefore, the vertical force applied to the subgrade gets decreased and the capacity increases [16]. Figure 2 shows the typical configurations of geocell reinforcing elements.

The concept of lateral confinement by cellular structures dates back to 1970s where the United States Army Corps of Engineers developed this idea for providing lateral confinement to soil to improve the bearing capacity of poorly graded sand [26]. The predecessors of present geocells were sand grids made up of paper soaked in phenolic water resistant resins. Later metallic geocells, especially those made of aluminum were chosen because of strength requirements, but they proved unfeasible because of handling difficulty and high cost. Geocells have also been made using geogrid sheets jointed by bodkin joints [5]. At present, high density polyethylene (HDPE) is the most

ISSN 2229-5518

common polymer used to make geocells by welding extruded HDPE strips together to form honey combs. Geocells come in different shapes and sizes with variations in the type of material used, the aspect ratio and the height and thickness of the cells. The geocell reinforcement arrests the lateral spreading of the infill soil and creates a stiffened mat to support the foundation thereby giving rise to higher load-carrying capacity.

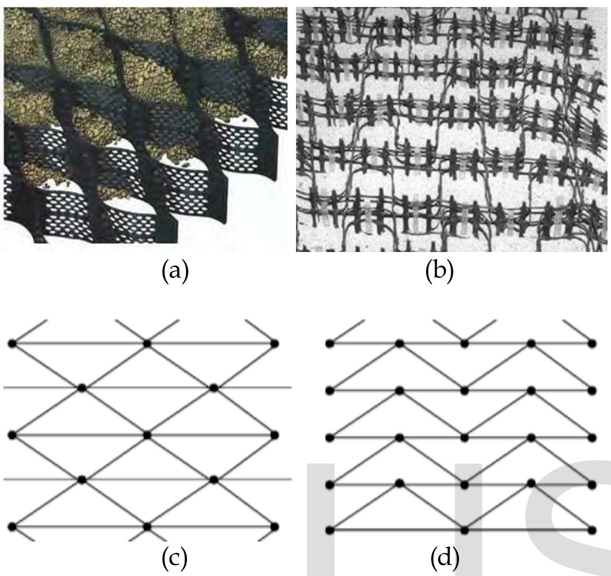

Fig 2: The typical configurations of geocell reinforcement elements.
a) Perforated geocell [1]
b) Handmade geocell [7]
c) Handmade geocell diamond pattern [7]
d) Handmade geocell chevron pattern [7]

The numerical analysis of geocell reinforced soils requires truly three dimensional simulations because of all round confinement of soil by geocell pockets. Numerical simulations have shown that geocell confinement effectively increases stiffness and strength while reducing vertical settlement and lateral spreading. Due to the complex geometry of geocells, it would be preferable to work with equivalent two dimensional models that can represent the three dimensional nature of the geocell reinforcement.

3 Reinforcement Mechanisms

When compared with the unreinforced base, geocell reinforced base can provide lateral and vertical confinement, tensioned membrane effect and wider stress distribution. According to Giroud and Noiray (1981) [10] lateral confinement, increased bearing capacity and tensioned membrane effect was identified as the major reinforcement mechanisms geotextile reinforcement. Dash et al. (2004) [7] demonstrated the advantages of the geocell as compared with other planar and randomly distributed mesh elements. The confinement by the geocell created a better composite material, redistributed the footing load over a wider area and reduced the settlement. As shown in Figure 3 due to the three-dimensional structure the geocell can provide lateral confinement to soil particles within the geocell. The geocell provides vertical confinement in two ways:
1) the friction between the infill material and the geocell wall and
2) the geocell reinforced base acts as a mattress to restrain the soil from moving upward outside the loading area.
The tensioned membrane effect is referred to as the tension developed in the curved geocell reinforced mattress to resist the vertical load ([4]; [7]; [28]). Due to the height of the geocell, the geocell-reinforced mattress more likely provides a beam or plate effect than tensioned membrane effect. The confinement of the geocell increases the stiffness of the reinforced base thus having a wider stress distribution than the unreinforced base. Zhou and Wen (2008) [28] indicated that the geocell reinforced base can provide bending resistance, tensile strength, and shear strength and intercept the failure planes from the subgrade. Understanding of these mechanisms originated from cyclic plate load tests, but later research was focused on these mechanisms under cyclic loading.

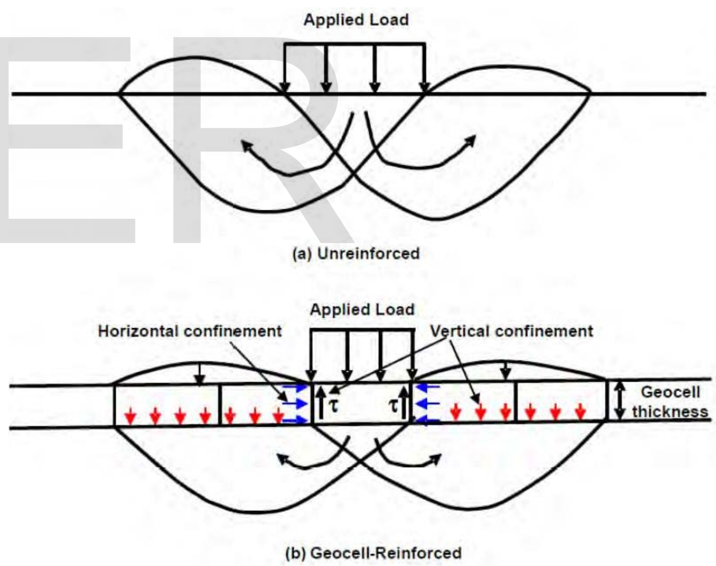

Fig 3: Unreinforced and geocell-reinforced soil behaviour [22]

Chung and Cascante (2006) [6] using footing width as B have identified that a zone between .3B and .5B maximize the benefits of soil reinforcement. They noticed that the accommodation of reinforcements within one footing width below the foundation can lead to an increase in bearing capacity ratio (BCR) and the low strain stiffness of the reinforced system. This increase is due to the transferring of the foundation loading to deeper soil layers as well as a reduction in stresses and strains underneath the foundation. Mosallanezhad et al. (2007) [21] dealt with the influence of a new generation of reinforcement (named as grid anchor) on the increase of the square foundation bearing capacity. It was found that the critical value of u/B, h/B and b/B were equal to 0.25, 0.25 and 4.5 respectively. They also showed that BCR for this system was greater than ordinary geogrid. Latha et al. (2009) [15] showed that within the soil reinforcement system the shear modulus of soil increases with the number of layers in depth under cyclic loading. The geometry of the test configuration for geocell-reinforced foundation bed [3] is shown in figure 4.

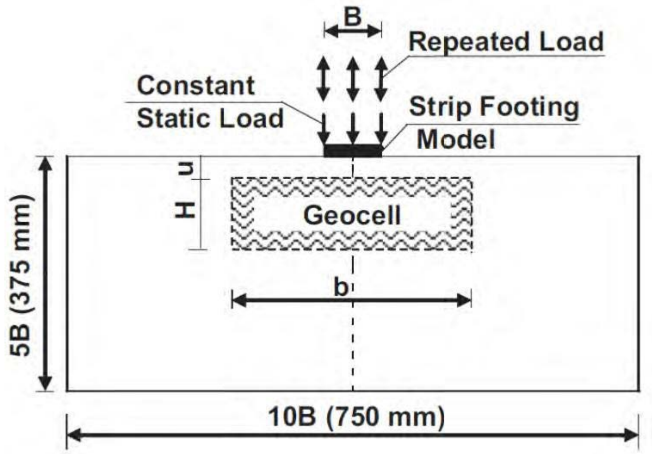

Fig 4: Geometry of the geocell- reinforced foundation bed [3]

Han et al. (2008) [11] investigated the load transfer mechanism between infill and geocell by carrying out both experimental and numerical studies on the behaviour of geocell reinforced sand under a vertical load. The studies showed that geocells could increase the bearing capacity and elastic modulus of the reinforced sand by providing confinement for the infill material. Boushehrian et al. (2011) [2] studied experimentally and numerically the effect of the depth of the reinforcement layer (u), spacing between reinforcements (h) and reinforcement stiffness on the bearing capacity of circular and ring foundations of sand.

4 Stability of Geocell Reinforced Soil

The geocell confinement system not only increases the load-bearing capacity of the soil but also substantially reduces the settlement. This is achieved by the confinement of the failure wedges which would be developed in an unreinforced soil from laterally and outward displacement. The lateral movement and shear failure are resisted by both the tensile hoop strength of the cell walls and the passive resistance of the full adjacent cells. In addition, the frictional interlock between the infill material and the cell walls allows the load to be distributed or shared with adjacent cells. At large settlement the tensile strength of the geocell walls becomes important.

Garidel and Morel (1986) [9] conducted punching tests using a rigid circular plate on geocells in silty subsoils. They carried out both small and large displacement tests and found that, for large displacements, there was vertical shearing of sand and the deformed shape of fill material was almost the same as subgrade material. Khay and Perrier (1990) [13] investigated the suitability and mechanical behaviour of geocells in granular subgrade material. Geocells used had a/b (a = geocell size and b = geocell height) ratio of 0.5 with varying b of 10, 15 and 20 cm. The geocell structure showed considerable trafficability enhancement. The settlement of the geocell structure was markedly low, indicating the slab effect of such structures. Kazerani and Jamnejad (1987) [12] carried out some tests on geocell-reinforced soft subgrade material which was simulated by using blocks of medium-density polystyrene. Poorly graded and well-graded soils were used separately as a base soil. Both cyclic load and static load were applied. A considerable improvement in the mechanical properties of the poorly graded granular fills was found by preventing the degradation of the fill particles. Bathurst et al., (1998) [1] implied that, in laboratory studies, a three-dimensional geocell proved about five times stiffer in bending than the same weight of two-dimensional sheets of similar grid materials with sand placed on top to the same depth as the geocell.

5 Laboratory Tests onducted On Geocell Reinforced Soil

Researchers ([1]; [2]; [4]; [7]; [8]; [11]; [15]; [17]; [24]; [25]; [27]) mentioned the load spreading action of the reinforced layer and a subsequent reduction in the vertical stress in the layer underlying the geocell layer. They showed that there is an increased performance on the footing over a buried geocell layer even with the geocell mattress width equal to the width of the footing. The geocell mattress transfers the footing load to a deeper depth through the geocell layer. An increase in the bearing capacity of the geocell mattress with an increase in the ratio of cell height to cell width was observed by [17] and [23]. Dash *et al.* (2001) [8] found that the load carrying capacity of the foundation bed increased with a rise in the cell height to diameter ratio, up to a ratio of 1.67, beyond which further improvements were marginal. The optimum ratio reported by [23] was around 2.25. Krishnaswamy *et al.* (2000) [14] reported an optimum ratio of about 1 for geocell supported embankments constructed over soft clays. Several researchers have found an improvement in the load bearing capacity of foundation with an increase in the mattress thickness, up to a geocell height of twice the width of the footing.

Sitharam and Sireesh (2012) [24] found out that better performance of the footing can be obtained if the depth of placement of cellular mattress is 0.05D from the base of the footing in the case of sand beds. The optimum width of the cellular mattress was found to be around (b/D = 5.0) in sand and at 40% footing settlement values, 30% improvement is observed in load carrying capacity in the case of reinforced sand beds. Moghaddas et al., (2010) [19] explained with laboratory tests that with an increase in the number of planar reinforcement layers, the height of geocell reinforcement and the reinforcement width, the bearing pressure of the foundation bed increases and the footing settlement decreases. They proposed that the optimum depth for the topmost layer of planar reinforcement is u/B=0.35 while the depth to the top of the geocell should be approximately u/B=0.1. For bearing capacity greater than 200% and reductions in settlement by 75% can be achieved with the application of geocell reinforcement, where as planar reinforcement arrangements can only deliver 150% and 64% for these two quantities, respectively. The geocell reinforcement also reduces the magnitude of the final settlement.

Boushehrian et al., (2012) [3] conducted large-scale tests and the result shows that by using grid-anchors together with geocells, the amount of permanent settlement decreases to 30%, as compared with the unreinforced condition. The number of loading cycles reaching the constant dimensionless settlement value decreases to 31%, compared with the unreinforced condition. He also mentioned that the value of the mobilized shear stress ratio for geocell supported footings is only 0.35–0.5 unlike the unreinforced footing where it reaches 1. Dash et al. (2001) [8] through their studies concluded that Chevron pattern for the formation of geocells is more beneficial than the geocells in diamond pattern. The optimum width of the geocell layer was found out to be around 4 times the footing width and to obtain maximum benefit, the top of geocell mattress should be u/B=0.1 from the bottom of the footing. The optimum aspect ratio of geocell pockets for supporting strip footings was found to be around 1.67.

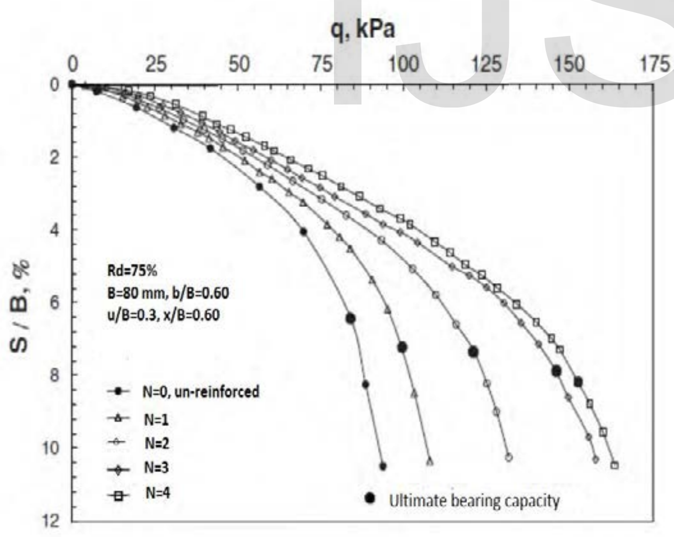

Figure 5: Variation of (q) with (S/B) for different number of layers [2]

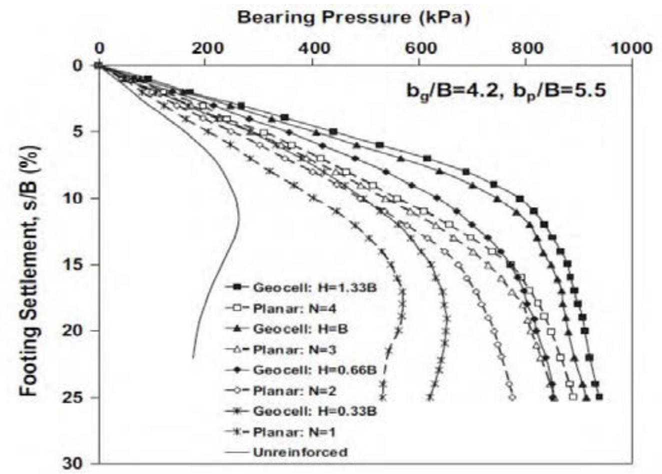

Figure 6: Variation of bearing pressure with settlement for the geocell and planar reinforcement with long width (bg/B = 4.2 & bp/B = 5.5) [2]

Figure 5 shows the variety of (q) with (S/B) for different number of layer geocell [3]. Figure 6 shows the variation of bearing pressure with settlement for the geocell and planar reinforcement with long width [2].

6 Conclusion

Experimental study results obtained by previous researchers on reinforced soil with synthetic material can be concluded as follows:

- The presence of geogrid in the soil makes the relationship between the settlement and applied pressure of the reinforced soil almost linear until the reaching to the failure stage.
- The reinforcement reduces the magnitude of the final settlement.
- The reinforcement's efficiency in reducing the maximum footing settlement decreased as the height and width of geocell were increased.
- In case of sand beds, the increased performance of the footing is observed to increase in footing settlement.
- The better performance of the footing can be obtained if the depth of placement of cellular mattress is 0.05B from the base of the footing in the case of sand beds.
- The optimum width of the cellular mattress is around (b/B = 5.0) in the sand.
- The optimum depth of planar reinforcement is (u/B) = 0.35 and for 3D geotextile it is (u/B) = 0.1.
- With increase in the number of planar reinforcement layers, the height of geocell reinforcement and the reinforcement width, the bearing pressure of the foundation bed increases and the footing settlement decreases.

- For bearing capacity greater than 200% and reductions in settlement by 75% can be achieved with the application of geocell reinforcement, where as planar reinforcement arrangements can only deliver 150% and 64% for these two quantities, respectively.
- With the provision of a geocell layer, indicating that the geocell mattress transmits the footing load to a deeper depth, thereby bringing about a higher load carrying capacity.
- The value of the mobilized shear stress ratio for geocell supported footings is only 0.35–0.5 unlike the unreinforced footing where it reaches 1.
- The cumulative settlement increased with the number of load cycles with a gradually decreasing rate.
- For the same number of load cycles, the cyclic load induced settlement increases with increasing initial monotonic load.
- The displacement per load cycle increases with decreasing the load frequency.

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