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Review Paper

A Review of Studies on Geocell-reinforced Foundations

Chowdhury Swaraj*and Suman Shakti
Department of Civil Engineering, NIT Rourkela, Rourkela, INDIA

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Abstract

Recent surge in the urbanization has led to a massive growth of infrastructure around the world. This has led to construction in soil mass considered otherwise unsuitable for construction. Ground improvement is an essential condition to build any civil engineering structure in these type of soil as they are found to have low bearing capacity and uneven settlement among other drawbacks. Geosynthetics are being widely used for the last two decades as soil reinforcement to improve the quality of soil owing to their ease of operation and overall cost. Geocell is the most advanced form of geosynthetics. Geocell is a three dimensional, polymeric, honeycomb like structure of cells interconnected at joints. The soil particles can be trapped inside these cells providing an overall confinement to the soil layer and improves it properties regarding support of civil engineering structures. Several researchers have shown the efficiency of geocell in improvement of bearing capacity of foundation when the soil is reinforced with geocell. The present paper is a review of the experimental techniques adopted to assess the performance of geocell as a foundation reinforcement material and validates its use for further by the practicing engineers as a soil improvement medium.

Keywords: Soft soil, foundations, geosynthetic, geocell, geocell-reinforced foundation.

Introduction

Recent decades have experienced a massive rise in demand for land owing to rapid industrialization and urbanization and hence subsequent rise in infrastructure building. However, the amount of land space on which construction can be done as it is limited, thus, engineers have moved on to construct on land masses that were considered unsuitable for construction earlier. It is a risk to construct over such land due to high compressibility, uneven settlement and low bearing capacity. Several types of ground improvement techniques involving stabilizing or reinforcing the soil are used to increase the bearing capacity and make these type of soils suitable for construction[1-2]. Among the various techniques available for ground improvement, soil reinforcing has been emphasized by many researchers as an effective method[3-9]. Historically, mankind has been using reinforcing techniques for a long time in the by making clay walls reinforced with bamboo or reed but the interest in the area was mainly generated in the modern times by the work of Vidal[10]. In the recent decades, geosynthetics have been adopted by engineers the world as a soil reinforcing technique due to their ease of construction and cost efficiency. Geocell is the latest development in the field of geosynthetics and its benefits have been highlighted by several researchers[11-18]. Geocell is three dimensional, polymeric, honeycomb like cell structure created by welding high intensity thermoplastic sheet (figure 1). Geocells are easier to work with as they can be folded for transportation purposes and stretch themselves when filled with concrete or stone. They also provide a lateral confinement to the fill thus providing strength. Due to the above mentioned ease of workability and serviceability, geocells are widely used in geotechnical engineering for various applications by reinforcing soft soil strata and stabilizing slopes and embankments[19]. A geocell confines the soil particles within its pockets which prevents the lateral spreading of soil which allows the soil layer to behave as a stiif mattress and hence the load is distributed over a larger area[3]. This study is a review of some of the recent experimental and numerical findings related to works on geocell-reinforced foundations.

Figure-1
A typical geocell[15]

Experimental studies

Krishnaswamy et al. applied uniform surcharge pressure on laboratory scale model of geocell-reinforced embankments supported over soft clay foundations. Geocell of different thickness were placed above the soft soil foundation and embankments were made above this layer of geocell[20]. They concluded that providing a geocell base improved the performance of the embankment in term of the maximum surcharge load and the deformations. The properties of the geocell like its tensile strength and aspect ratio had a profound influence on the overall functioning of the geocell. The optimum value of aspect ratio was found to be 0.5.

Dash et al. through model tests in laboratory to study the bearing capacity of strip footing based on geocell-reinforced sand[21]. They varied several parameters like cell size, material, tensile strength and height and width of the geocell for sand of different relative densities. Figure-2 and figure-3 respectively show the plot of bearing pressure vs settlement for different height and width of the geocell. It can be seen from figure-2 and figure-3 that pressure-settlement behavior is almost linear for a settlement up to 50% of the foundation width and load up to eight times the bearing capacity of foundation that is not reinforced. The optimum height and width of the geocell was determined to be 2 and 4 times respectively the width of the footing. They also concluded that cell size and orientation has a considerable effect on the performance of geocells. Dash et al. measured the functioning of geocell-reinforced strip footing in sand when planar reinforcement is added along with geocells[11]. They found that the placement of a planar geogridunderneath the geocell mattress increased the bearing capacity of footing and stabilized it against rotation. However, this effect was not so profound for large height of geocellmatress and an optimum value of 2 times the width of the foundation was achieved.

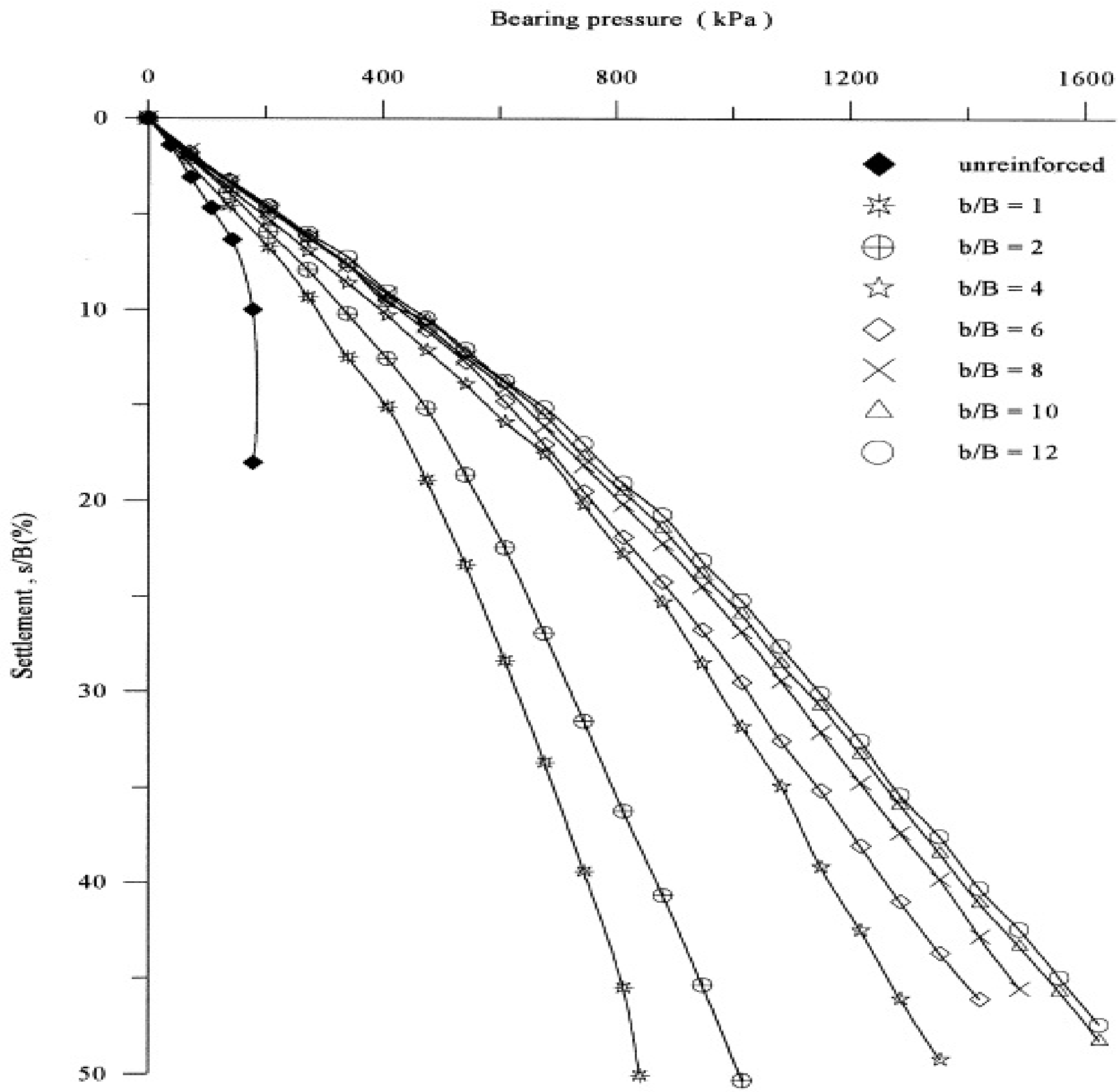


Figure-2
Plot showing the bearing pressure corresponding to different value of settlement for different widths of geocell mattress[21]

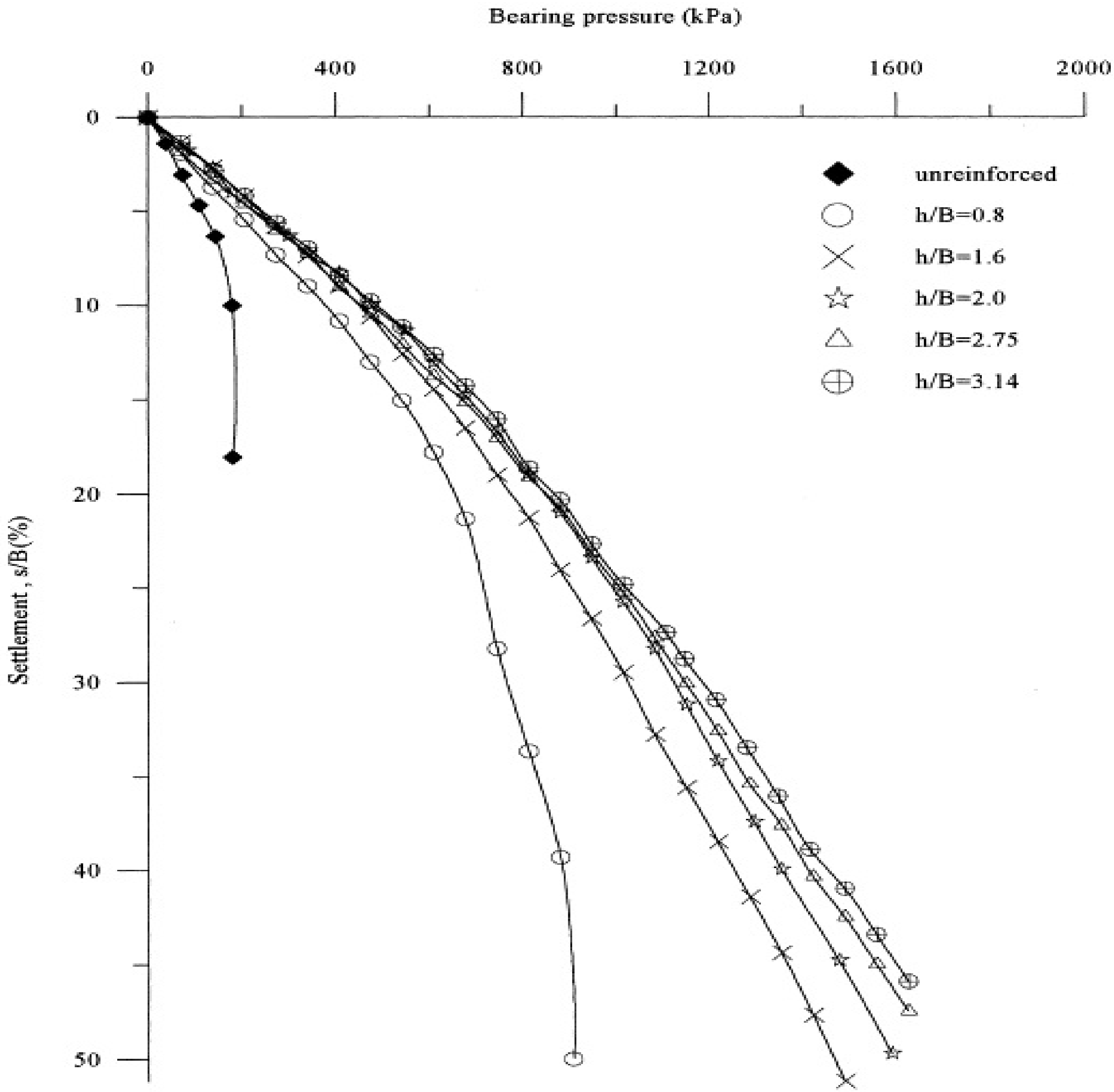
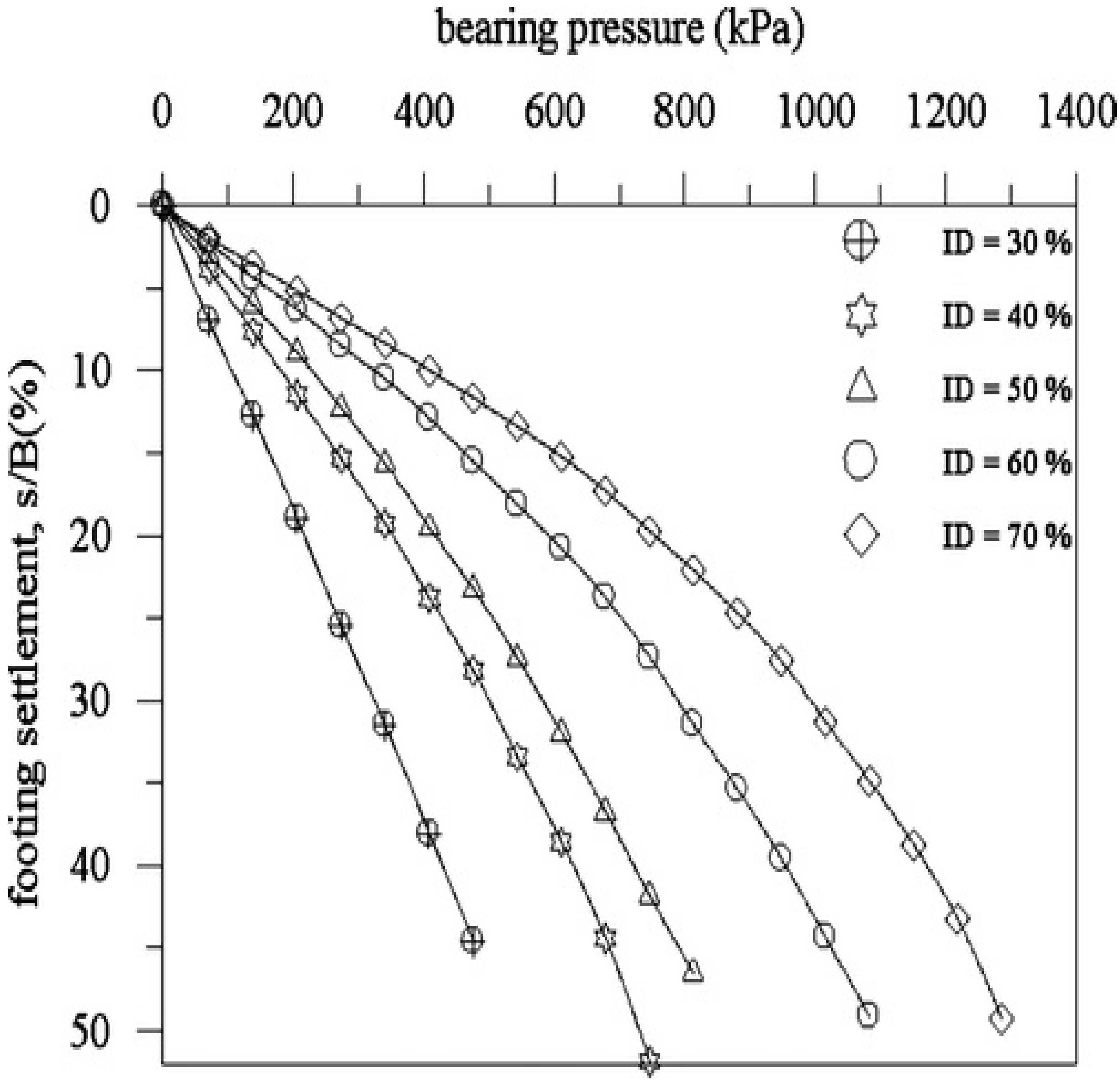


Figure-3
Plot showing the bearing pressure corresponding to different value of settlement for different heights of geocell mattress[21]

Dash et al. also studied circular footing supported on geocell-reinforced sand and found that geocell improved the bearing capacity of the footing and reduced its surface heaving[3]. They concluded that the geocell enables the load to be redistributed uniformly over a broader area. According to another study on strip footings that were supported on geocell-reinforced sand, it was found that the reinforcement effect of geocell is maximum below the footing and much smaller in the end portions of the footing[22]. The end portions contribute by getting strength from the soil which is derived by mobilizing soil passive resistance and frictional resistance between geogrid-soil interfaces. The strain behavior in the geocell also indicated that a geocell mattress behaves like a subgrade supported composite beam under the footing load. An observation of the displacement patterns in the subgrade soil of the model foundation showed that geocell crossed the potential failure planes in soil below the foundation.

To study the effect of relative density of soil on the functioning of geocell-reinforced sand foundations, Dashused load tests on sand beds, both with and without geocell reinforcements[23]. After carrying out tests for relative densities of 30% to 70%, he concluded that the geocell reinforcement in sand foundations is effective for a large range of relative density. He presented a graph of foundation settlement vs the bearing pressure for soil of different relative density (Figure 4). It can be seen from figure-4 that the settlement is same at a higher bearing pressure for soil of higher relative density, so it is advisable to compact foundation soil to higher density for obtaining better results from geocell reinforcement.



Figure–4
Plot showing the bearing pressure corresponding to different value of settlement for foundation reinforced with geocellat different relative densities[23].

Zhou and Wen, by conducting tests on geocell-reinforcedsand cushion over foundation of soft cohesive soil taken from the Qin-shen Railway established a decrease in the settlement of underlying soft soil[13]. They also noticed an increase of 3000% and a decrease of 44% in the subgrade reaction coefficient, K_{30} , and the deformation respectively.

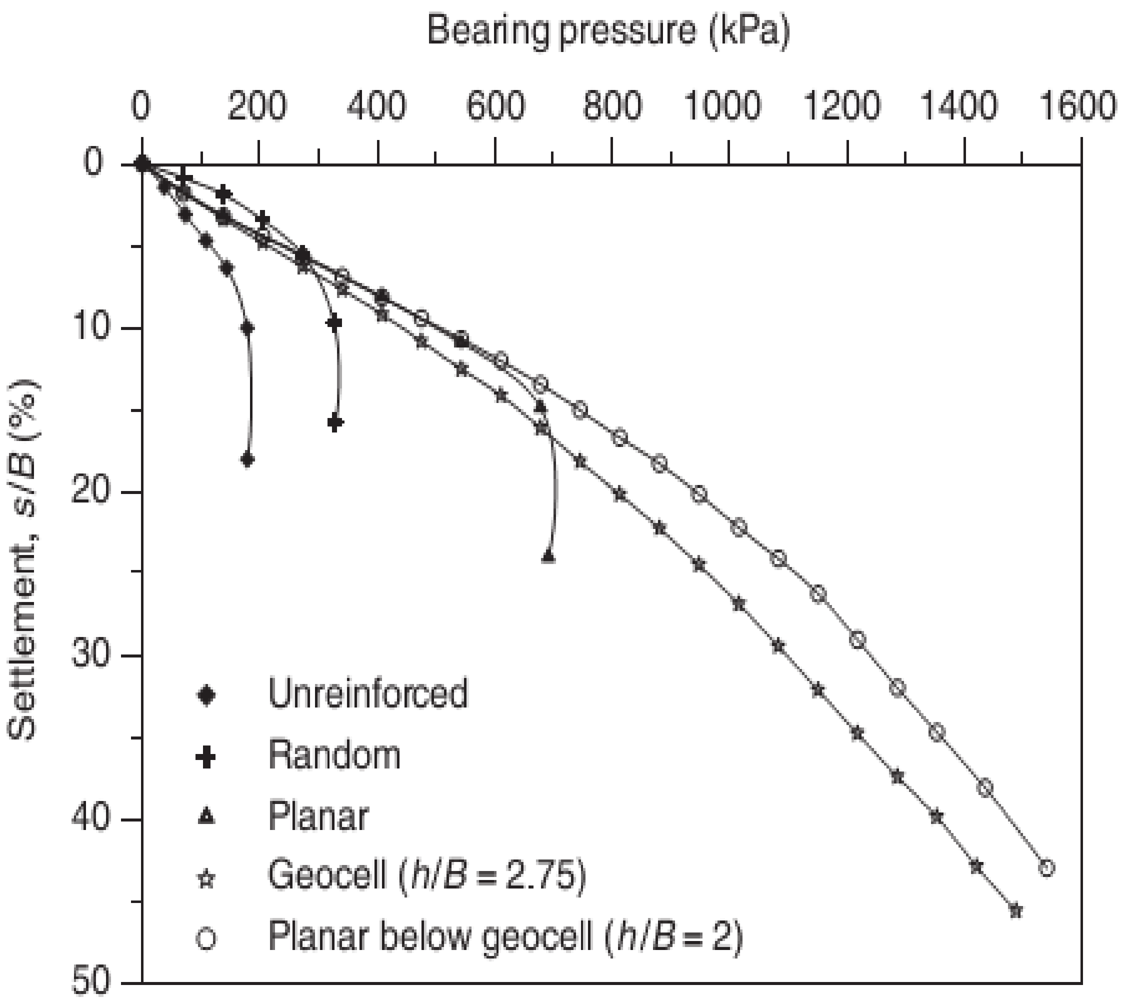
Dash used a number of model tests to find out the effects of materials used in geocell on the load carrying mechanisms of geocell-reinforced sand foundations and concluded that if materials having high strength are used to make geocells and the geocell has smaller apertures in orthogonal directions, it gives higher compressibility and bearing capacity to geocell-reinforced foundation[24].

Moghaddas Tafreshi and Dawson studied the application of cyclic loads to geocell-reinforced sand foundations and found that the application of geocelldecreased the settlement under cyclic loading[25]. The optimum value for depth and width of the geocell was found to be 0.1 and 3.2 times the footing width respectively. The optimum value of depth for cyclic loading is in confirmation with the value under static loading, i.e., 0.05-0.1[12,26]. It was also found that geocell reduced the plastic deformation under repeated loading. The reduction was found to be more the percentage of reinforcement present was more and when the rate of loading was faster.

Dash and Bora studied the effects of both stone column and geocell in improvement of soft clay foundations[27]. They found that the maximum increment in bearing capacity due to stone column and geocell alone was 3.7 fold and 7.8 fold respectively. When used in combination with adequate spacing and depth, stone column and geocell showed as much as 10.2 fold increment in the bearing capacity of soil. They suggested that the optimum length and spacing of stone column that can be used are 5 and 2.5 times the diameter respectively. The maximum height of geocell that can be adopted was found to be equal to the depth of the foundation. Height of geocell more than the depth of foundation showed only marginal increase in the bearing capacity. This study provides a solution for cases where large height geocell or long stone columns are practically difficult. In these cases, a combination of shallow height geocell and medium length stone column can be effectively used.

To study the confinining effects of geocells, Chen et al. reinforced sand samples with geocells and conducted triaxial test on these samples[19]. Geocells having different shape, size and number of cells per unit of area were used to reinforce the sand samples. They found that the apparent cohesion developed in the sample depends on the shape, size and number of cells. But, the size of the cell was found to be the most influencing factor. They also noticed that the reinforcing effect was more profound at lower confining pressures as compaed to higher confining stress.

Dash et al. put strip loading on different sand beds reinforced with geocell, planar and randomly distributed mesh elements to compare the performance of different types of soil reinforcement[28]. Figure 5 shows a plot of bearing pressure vs settlement for various types of reinforcement. It can be seen that the geocell is most effective technique for reinforcement of soil. This finding can be attributed to the cellular structure of geocells which allows soils to be confined within the cells more effectively than other types of reinforcement.



Figure–5
Plot showing the bearing pressure corresponding to different value of settlement for foundation reinforced with different kinds of geocell[28]

Numerical studies

Limited information was found in the literature regarding numerical studies to assess the functioning of geocell regarding bearing capacity of reinforced foundation. Two such studies were done by Sitharam and Hegdeand Zhang et al.where they provided equations to calculate the bearing capacity offoundation on soft soil having a geocell layer at the base of embankment[29, 30].Sitharam and Hegdeproposed an analytical model to calculate the bearing capacity of foundation on clay in which has a combination of geocell and geogrid has been used as reinforcement[29]. They superimposed the values of bearing capacity due to "lateral resistance effect", "vertical stress dispersion effect" and "membrane effect" to reach to a final value of bearing capacity. The results from the analytical model and experimental investigation were found to be in agreement with each other. Zhang et al. presented an equation to calculate the bearing capacity of a soft subgrade soil which contains a geocell layer at the base of the embankment[30]. They included both the "vertical stress dispersion effect" and "membrane effect" of the geocell in calculation of the overall bearing capacity. The results from the obtained equation were also compared with experimental results and the two values were found to be in close conformity.

Conclusion

A review of the literature on geocell-reinforced foundations establishes the utility of geocell as an important method for ground improvement. The following conclusion can be made regarding behavior of geocells in foundations: i. Inclusion of geocell as reinforcement increase the bearing capacity of the foundation over soft soil. ii. Geocells made out of materials of higher strength and having smaller aperture in orthogonal direction show better improvement in performance. iii. The improvement in properties of the foundation is more if both the geocell and geogrid are used together as compared to the case when only geocellis used. iv. A combination of stone column and geocell improves the bearing capacity of foundation more than the use of geocell alone. v. The effects of geocell are more pronounced when the foundation soil is in dense state.

Scope for future work

Previous literature suggests that a lot of experimental work has been done regarding geocell-reinforced foundations both in sand and soft clay. The effect of different aspects of geocell like its thickness, tensile stiffness, cell size and shape and material of the geocell on the bearing capacity of foundations has been studied. Experiments to study the effect of geocell in combination with other reinforcement techniques like stone column and geogrid has also been carried out. Most of these studies however, are limited to laboratory scale model tests and appropriate dimensional analysis needs to be applied to these results for making them suitable for field applications. Also, numerical studies in this field are limited. More numerical studies can be done to develop analytical equations which can be used by the practicing geotechnical engineers in the field without any scaling for the real applications.

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