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Research Article

Improvement of clay subgrade soil using geogrid and geocell reinforcement: An experimental investigation

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Abstract

The subgrade soil and its properties are crucial in designing pavement structures because they provide adequate support for the pavement. The subgrade must be capable of supporting the loads applied by the pavement structure without excessive deformation under adverse climatic and traffic conditions to extend the pavement's life. Not all soils possess the required characteristics, but some are suitable good-quality materials for pavement construction. Therefore, whenever soils cannot be replaced, many methods for modifying their performance as subgrade materials should be applied. Among those methods, reinforcement of subgrade soils has become a very common practice in recent years. There are many methods currently being used to reinforce soils, including the use of geogrids or geocells. In this research project, geogrids and geocells were used as soil reinforcement on three different types of geogrids and geocells to enhance the performance of clay subgrades. Samples of clay from Baghdad, Iraq, were measured for swelling potential and CBR with and without geogrids and geocells at various depths in a mold. Swelling and CBR of moist soils improved when geogrids or geocells were used to reinforce the soil, and both resulted in a maximum CBR when geogrids and geocells were placed at 0.3 of the height of the molded clay sample.

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1. Introduction

One of the most commonly used ground improvement techniques is soil reinforcement. The increasing use of soil reinforcement, especially in stabilizing subgrade soils for road pavements, can be attributed to several important factors, namely the wide range of materials available for use as geosynthetic reinforcements, ease of construction, cost-effectiveness, and time savings. According to [1, 2], the effectiveness of soil reinforcement is mainly dependent on the frictional resistance between the layers of reinforcements and surrounding soil. In addition, [3-5] shows that a number of studies have demonstrated the positive effect of different types of geosynthetic reinforcement material on the behavior of foundation systems. Furthermore, several researchers have investigated the use of geocells as a means of strengthening soils and have identified numerous advantages to their use [6-9].

In the 1970s, for the first time, the US Army Corps of Engineers improved geocell to reinforce cohesionless soil quickly [10]. Subsequently, researchers conducted numerous studies to investigate the behavior of geocell-reinforced soil. These studies entail the topics of the kinds of

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soil, the geometric shape, the material components of geocell, and the loading states to identify the influence of the different key parameters on the assessment of the performance and mechanisms of soil reinforcement. In the last few decades, there have been limited attempts to model geocell reinforcement simulations using three-dimensional analysis, and the research in this area often faces additional complications due to the challenges of accurately modeling real configurations. According to Giroud and Han [11], as well Huang [12], geosynthetics in flexible pavement design can improve the structural integrity of pavements through proper evaluation of geosynthetic materials and appropriate use of empirical methods to determine pavement design parameters. Huang [12] and IRC-37 provide empirical requirements for the modulus of the various layers of a flexible pavement in relation to the layer thickness and California Bearing Ratio (CBR) value. Huang [12] and IRC-37 provide empirical requirements for the modulus of the various layers of a flexible pavement in relation to the layer thickness and California Bearing Ratio (CBR) value.

According to Sireesh [13], geo cell mattresses can significantly increase the performance of clay subgrade with void by providing sufficient extension distance compared to the size of the void. Madhavi [14] compared the effectiveness of planar layer, geo cell, and randomly placed mesh material as soil reinforcement and found that geo cell is the most effective alternative to other reinforcing materials. Pokharel [15] studied the effect of various variables on the behavior of soil reinforced by a single layer of geocell under static load testing and found that the performance of a geocell-reinforced sand structure is influenced by the modulus elasticity of the geocell's structure. Dash [7] evaluated the effects of relative density on the performance of geocell reinforcement, and his findings indicate that soil needs to be compacted to higher levels of density to fully utilize the benefits of geocell reinforcement. Woven geotextiles were found to be superior to non-woven geotextiles by conducting experimental evaluations using California Bearing Ratio (CBR) tests on the geotextiles interfaced between an unbound gravel subbase and an unconsolidated clayey subgrade in an unpaved flexible pavement system, according to Rajkumar et al. [16]. Bindu et al. also [17] performed plate load tests on soft clay beds with coir Geocell mattresses at varying heights and discovered that the optimal height of the geocell in the chevron pattern with vertical strips at the joints equals the width of the loading plate. However, extending the height further did not have any significant effect on improving bearing capacity. Sahib et al. [18] investigated the effect of the soils' moisture contents and degree of compaction of clay subgrade soil on the interface shear strength with and without geogrid under four normal stresses equal to 25, 50, 75, and 100 kPa. Interface efficiency values greater than unity ($\eta > 0.7$) indicate that there is an efficient bond between the soil and the geosynthetic. This indicated that the interface strength between the soil and the reinforcement is greater than the shear strength of the soil. Jaafar et al. [19] performed an extensive experimental study on a specific clay subgrade soil with four different amounts of glass powder with and without geogrid, respectively. The study was aimed at investigating the resulting increase in the soil strength, as well as the development of a better bond at the interface between the treated subgrade and a Type B granular subbase layer reinforced with an SS2 Geogrid. The interaction coefficient (η) for all glass powder contents was above 1.0, indicating good performance and a strong bond of the geogrid reinforcement. The interaction coefficient increased uniformly with the increase of glass powder contents, which indicates the formation of stronger interface bond between the soil matrix and the geogrid which can be purposefully used in design for better structural stability and improved load transfer efficiency.

The main objective of this study is to improve the properties of clay subgrade soil by reinforcing the soil with geocell and geogrid through an experimental program that includes testing more than 150 samples of soil using the California Bearing Ratio test in soaked and unsoaked conditions and comparing the results of soil reinforcement with different types of geogrids and geocells, as well as showing their placement inside the CBR mold, unlike previous studies that examined geogrids or geocells separately or only theoretical studies that did not focus on lab test results.

2. Materials and Methodology

2.1 Origin and Characteristics of Geocell

Geocells (also referred to as Cellular Confinement Systems) are polymeric panels that are produced using either high-density polyethylene (HDPE), polyester, or other polymers in three-dimensional formats via an expandable manufacturing process. While expanding these panels into their desired shape during manufacturing, they become interconnected strips that create flexible three-dimensional cellular limbs, thus holding fill material(s) in place after compacting them as well as preventing their mass movement due to the tensile reinforcement that these systems provide. Geocell systems improve the structural and functional performance of soils and aggregate fill(s), while also providing a free-draining environment for maintaining fill in place. Other applications include: Ground stabilization; erosion prevention; retaining walls or "grade dams"; protection against slope failure or channel erosion; and landfills (for restaurants/sand) where geocells may be used together (with other technologies) to create an underground landfill space. The geocell used in this study is manufactured by Tensar Company and is known for its high polymer durability, which refers to the ability of the geocell's polymer matrix to maintain mechanical performance over its service life under environmental and mechanical stresses. The details and properties of geocell are shown in figure 1 and table 1 respectively.

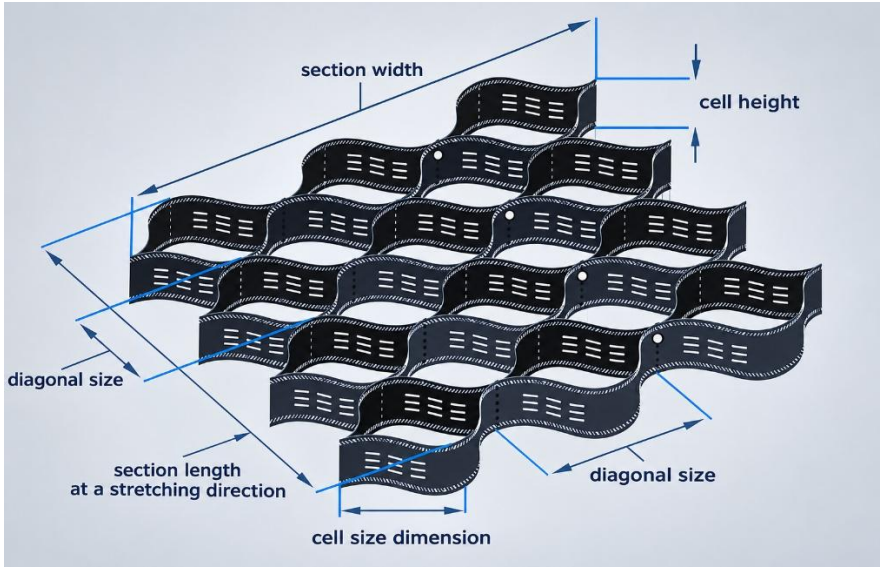


Fig. 1. Details of geocell

Table 1. Properties of geocell

Properties of geocell	Values
Polymer	Polyvinyl Chloride
Number of cells (m^2)	260
Mass per unit area (gm/cm^2)	0.033
Diagonal size (along width) (mm)	55
Diagonal size (along length) (mm)	60
Strip thickness (micron)	250
Open area (%)	15
Cell depth (cm)	4
Thickness (mm)	1.5
Modulus of elasticity (MPa)	235
Coupling stiffness (N/m^3)	$2.4*10^6$
Poisson ratio	0.45
Junction efficiency (%)	95

2.2 Geogrid

Linear polymer-based Geogrids are defined as open planar structures formed through an interconnected network of tensile elements joined together at their points of intersection to establish a stable unit [20]. When manufactured, extruded geogrids fall into two categories based on their manufacturing processes, which use directional stretching of the polymer sheet to classify them into the respective type of load support. Uniaxial geogrids, for example, are produced by applying longitudinal (or axial) stretch to the polymer sheet, producing much greater tensile strength in this direction than in the transverse direction. Conversely, Biaxial geogrids are created through both a longitudinal and a transverse stretch of the polymer sheet, resulting in relatively equal levels of tensile performance in both longitudinal and transverse orientations. Finally, Triaxial geogrids are created to provide strength in multiple directions with close to equal resistance (approximately 360 degrees) to soil; they are considered to be the best type of Geogrid due to their high-performance characteristics [21]. Figure 2 shows the principal characteristics of the different types of geogrids noted above. In addition, Table 2 provides examples of the physical and mechanical characteristics for each geogrid type as provided by their respective suppliers. Durability of geogrids depends on polymer type, structural design, and service environment. The standard for uniaxial, biaxial and triaxial geogrids offers excellent long-term tensile strength, satisfactory UV resistance, and chemical stability, making it suitable for outdoor, high-load, and long-term reinforcement. The geogrid used in this study was manufactured by Tensar Company. The junction efficiency of geogrid and geocell is very necessary to prevent stress concentration, reduces vertical movement and shares weight across adjacent elements.

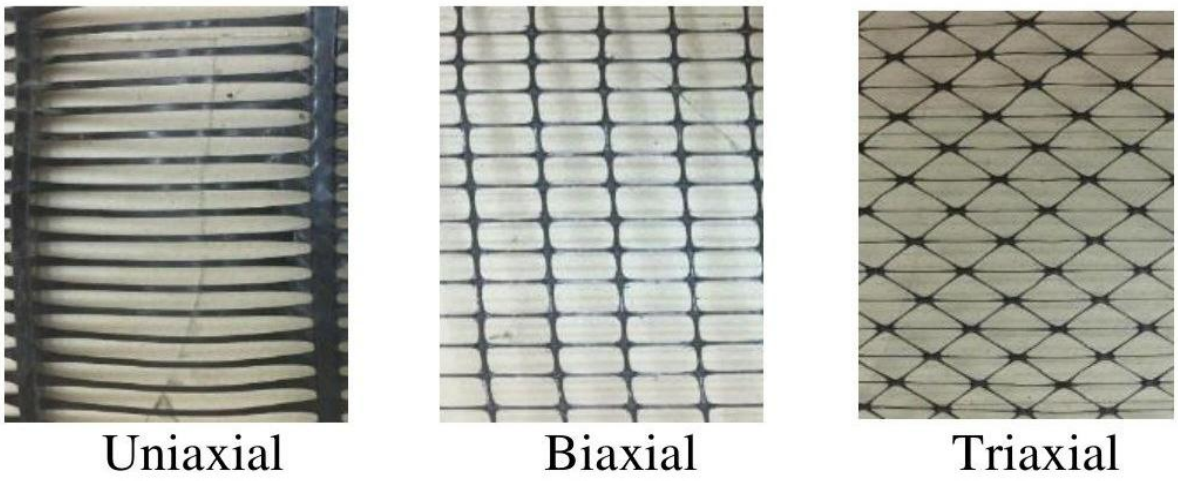


Fig. 2. Types of geogrid materials

Table 2. Engineering properties of geogrid

Property	Uniaxial	Biaxial	Triaxial
Tensile strength at 5%strain (kN/m)	32	28	
Maximum tensile strength(kN/m)	60	40	
Flexural stiffness (gm-cm)	9500000	750000	
Efficiency %		93	93
Thickness (mm)		1.27	1.6
Rib pitch (mm)		33	60
Width (mm)		25	1.2
Young modulus (Gpa)	20	15	12
Junction Efficiency %	90	93	93

2.3 Clay Subgrade Soil

The clay sample used for the study came from Baghdad, Iraq. A method was used to reduce any chance of contamination around the sample from other particles (e.g., farming materials that have accumulated due to surface conditions). A layer of topsoil was removed, and a set of soil samples

were then taken at random depths starting at least 1 m below the surface of the ground. The basic properties of this clay material are summarized in Table 3, while its compaction properties determined by the standard Proctor test are shown graphically in Figure 3, and the grain size distribution of soil is shown in Figure 4.

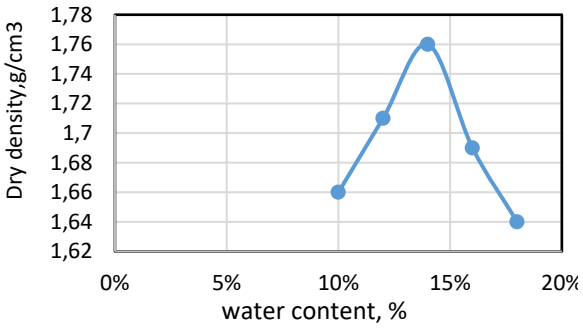


Fig. 3. The soil compaction curve for clay

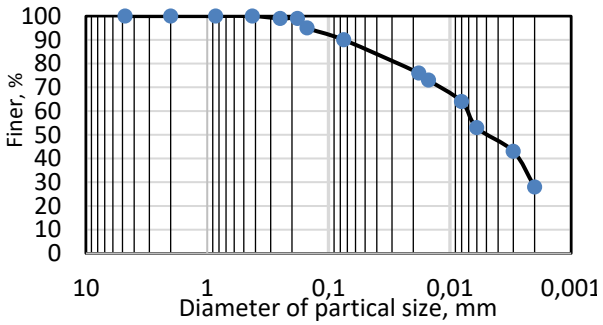


Fig. 4. Grain-size distribution curve of the clay

Table 3. Properties of clay soil type

Characteristics	Results	Specification requirement
Max. dry density (gm/cm^3)	1.76	AASHTO T99 – 95
Optimum moisture content (%)	14.1	AASHTO T99 – 95
Liquid limit (%)	42.3	AASHTO T89 – 96
Plastic limit (%)	29.2	AASHTO T90 – 96
Plasticity index (%)	13.1	
Specific gravity	2.68	

3. Methodology

3.1 California Bearing Ratio (CBR) Test

Soil samples with geocell mixed in along with a variety of geogrids were tested using the CBR standard method according to ASTM D1883-21 [22]. Geocells & geogrids were inserted at positions of 0.1 H, 0.2 H, 0.3 H, 0.4 H, 0.5 H, and 0.6 H, where H is the total height of 175 mm from the top of the CBR 186 mold, and then subsequently their associated CBR values were obtained. These same soil samples were also tested to obtain optimum moisture content (OMC) and maximum dry density (MDD) information by the compaction test. The CBR apparatus consisted of an outer cylinder mold 175 mm in height and an inner diameter of 150 mm and included a bottom plate, collar, and a load frame containing a 50 mm diameter cylinder plunger. The load applied to the soil sample being tested was applied at a rate of 1.25 mm/min until the depth of the penetration reached either 2.5 mm or 5.0 mm prior to marking both CBR values as well as recording the final reading from the dial gauge after completion of the soaking duration as a basis for determining the swelling value for that particular sample. Three specimens are tested for each case at a controlled laboratory temperature of about 20 °C ± 2 °C.

3.2 CBR Test Procedure

Detail CBR test procedure is described below.

3.2.1 Specimen Preparation

- The soil sample is saturated to the optimum moisture content.
- The soil is compacted in five layers within a 5-liter cylindrical mold, with a specified number of blows (56 blows) applied to each layer using a standard rammer (4.9kg).
- The top surface of mold is flattened and leveled with the help of a straight edge.
- The weight of the mold with compacted soil is used to determine dry density.

3.2.2 Soaking (Optional for Soaked CBR)

- The soil sample is loaded with surcharge weights and perforated swell plates to simulate the actual loading of the pavement.
- The complete mold assembly is then placed in a water tank for a period of 96 hours (4 days) to simulate the worst-case field moisture conditions.
- The mold is removed and the swell is measured using a dial gauge.

3.2.3 Penetration Test

- The soil specimen is loaded with surcharge weights (usually 2.5 kg).
- A standard metal piston with a diameter of 50 mm is placed in the center of the soil surface with a small initial seating load (about 4 kg).
- The load and penetration dial gauges are zeroed.
- The compressive load is applied on the plunger at a constant rate of 1.25 mm/min.
- The load values are taken at the following penetration intervals: 0.5, 1.0, 1.5, 2.0, 2.5, 4.0, 5.0, 7.5, 10.0 and 12.5 mm.

4. Results and Discussions

Laboratory tests were performed using soaked and unsoaked clay subgrade soil with and without geogrid and geocell reinforced at either 2.5 mm (depth) or 5.0 mm (depth) beneath the surface. Geocell and geogrid were installed at 0.1H, 0.2H, 0.3H, 0.4H, 0.5H, and 0.6H from the bottom of the test mold when conducting the tests. The relationship between the penetration and load for the soaked and unsoaked clay subgrade soil without reinforcement are shown in figure 5. Three samples were tested for each case and the statistical analysis (standard deviation and mean) is performed to draw the relationship between the location of reinforcement (geogrid and geocell) and the CBR value based on the mean value as shown in the figures below. Where the CBR values of the soaked and unsoaked clay subgrade soil with both geocell and geogrid are shown in Figures 6 and 7, respectively. The peak CBR values for the clay subgrade soil so tested are shown in Table 4 to explain the statistical analysis.

Table 4. The peak CBR values for all test

Reinforcement	Condition	CBR penetration	Mean CBR (%)	SD	CV (%)	95% CI
Soil only	Soaked	2.5 mm	1.683	0.067	3.96	1.518–1.849
Soil only	Soaked	5.0 mm	2.220	0.082	3.69	2.017–2.423
Soil only	Unsoaked	2.5 mm	2.573	0.132	5.13	2.245–2.901
Soil only	Unsoaked	5.0 mm	3.143	0.150	4.77	2.771–3.515
Uniaxial	Soaked	2.5 mm	3.220	0.121	3.77	2.919–3.521
Uniaxial	Soaked	5.0 mm	3.927	0.132	3.36	3.599–4.255
Uniaxial	Unsoaked	2.5 mm	4.320	0.062	1.45	4.165–4.475
Uniaxial	Unsoaked	5.0 mm	5.023	0.117	2.32	4.733–5.313
Biaxial	Soaked	2.5 mm	5.487	0.091	1.65	5.261–5.712
Biaxial	Soaked	5.0 mm	6.393	0.110	1.72	6.120–6.667
Biaxial	Unsoaked	2.5 mm	6.523	0.087	1.34	6.306–6.740
Biaxial	Unsoaked	5.0 mm	10.067	0.133	1.32	9.736–10.397
Triaxial	Soaked	2.5 mm	7.447	0.050	0.68	7.322–7.572
Triaxial	Soaked	5.0 mm	9.183	0.106	1.15	8.920–9.447
Triaxial	Unsoaked	2.5 mm	9.393	0.080	0.85	9.194–9.593
Triaxial	Unsoaked	5.0 mm	22.383	0.275	1.23	21.699–23.067
Geocell	Soaked	2.5 mm	8.857	0.240	2.71	8.260–9.453
Geocell	Soaked	5.0 mm	11.467	0.331	2.89	10.644–12.290
Geocell	Unsoaked	2.5 mm	12.577	0.415	3.30	11.545–13.609
Geocell	Unsoaked	5.0 mm	25.443	0.596	2.34	23.962–26.924

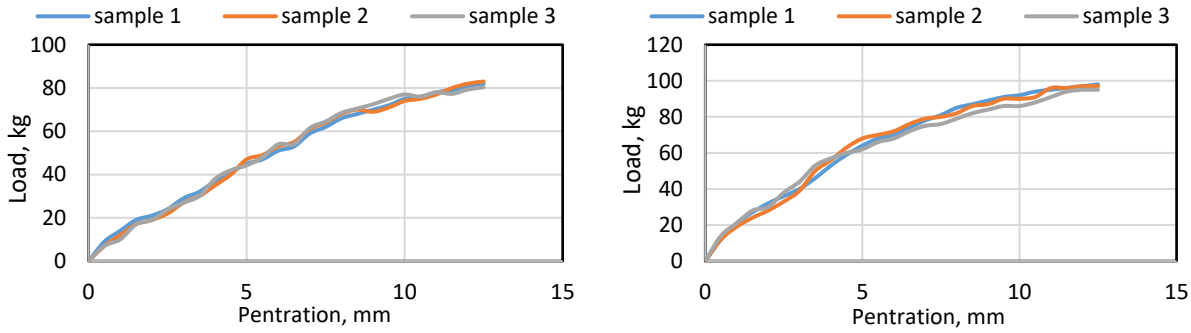


Fig. 5. The CBR values for clay subgrade soil without reinforcement

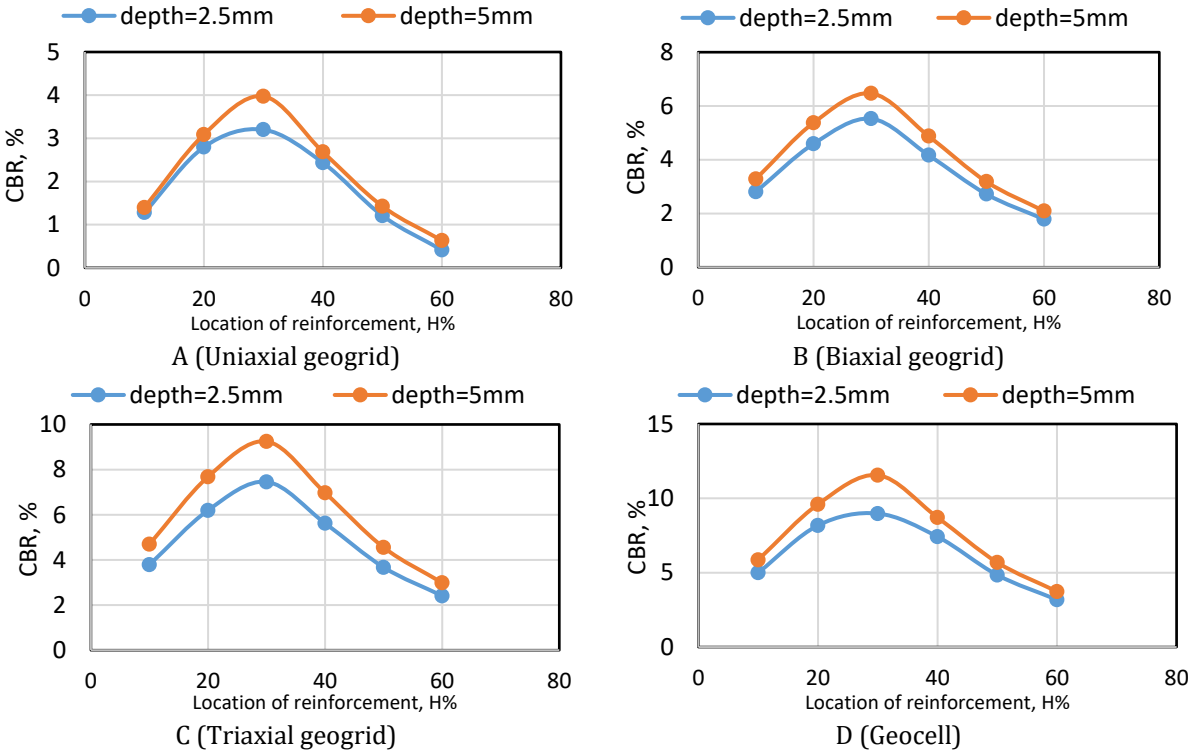


Fig. 6. The CBR values for subgrade soil with geogrid and geocell at different depth (soaking state)

The value of California Bearing Ratio (CBR) for sub-grade clay soil, treated with three different forms of geogrid and geocell, has seen an increase in number: 91%, 226%, 342%, and 426%, respectively, in saturating (soaking) states compared to untreated soil. The use of a geogrid and a geocell improves soil by increasing lateral confinement, enhancing the overall stiffness of the pavement, and increasing bearing capacity, while also reducing both lateral and vertical deflection. Thus, the treatment of soil with geogrids, geocells, or other types of engineered materials leads to improved performance of the road [23-25].

Biaxial geogrids provide tensile strength along longitudinal and transverse directions, while uniaxial provide tensile strength in one direction. By contrast, a triaxial geogrid transfers stresses through its triangular aperture configuration, allowing aggregate particles to interlock from multiple angles. It provides better uniform confinement, increased structural stiffness, and better resistance to permanent deformation under loading. Triaxial geogrids spread the loads over a larger area, which reduces the settlement and improves the performance of clay subgrade soil by increasing the particle interlock, rutting, and keeping a more stable pavement structure. This data explains the results of the CBR test, which shows that the clay subgrade soil reinforced by triaxial geogrid is better resistant compared to the biaxial and uniaxial geogrid.

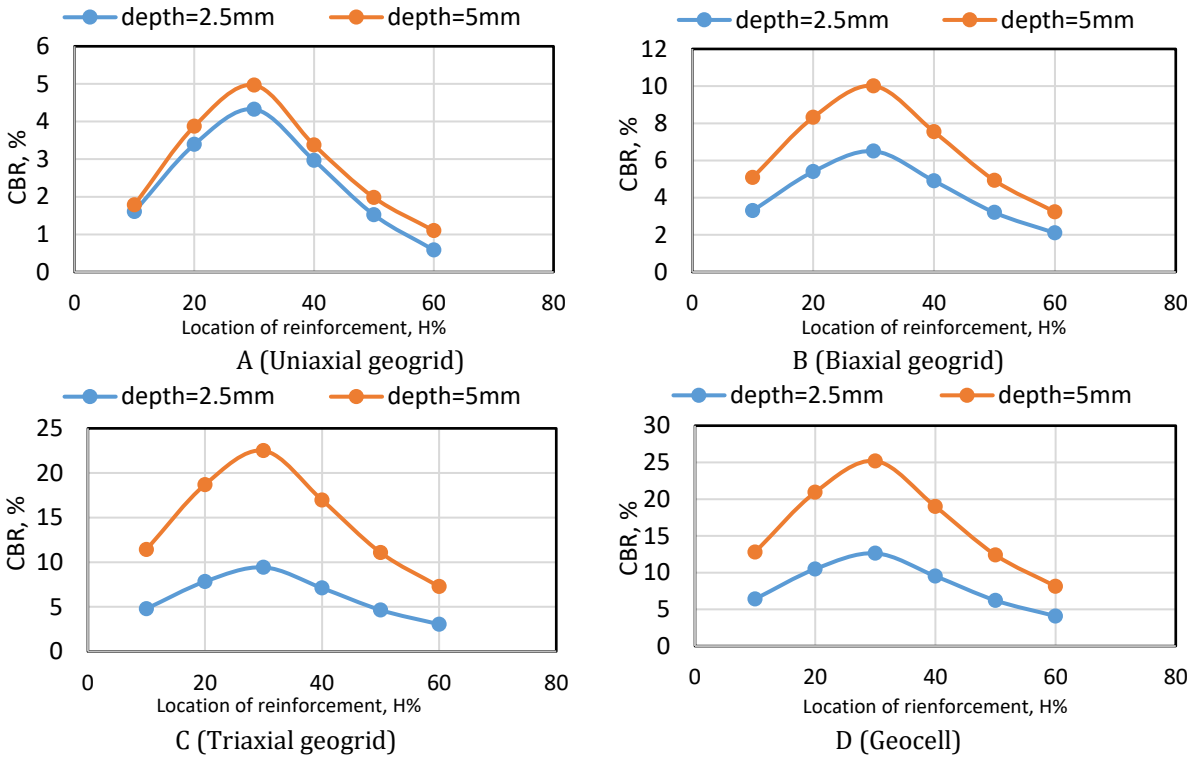


Fig. 7. The CBR values for subgrade soil with geogrid and geocell at different depth (unsoaked state)

The CBR value of geogrids treated for unsoaked and boiled conditions has been tested, and the improvements to the CBR value have been measured for uniaxial, biaxial, and triaxial geogrids. The greatest improvement to the CBR value is 22.38% for the unsoaked condition at a depth of 5 mm and produced when the triaxial geogrid has been placed at 0.3H, as shown by [11]. Gopichand et al. (2016) mentioned that the triaxial geogrid at 0.5H is near the pressure bulb, which helps the geogrid be placed within the pressure bulb and results in a 12% improvement in the CBR value. However, very little improvement is observed when the geogrid is placed at 0.6H since it is far away from the pressure bulb. Similar to how the CBR value of a treated geocell during dry and wet conditions was measured, the method also provides us with a direct measurement of improvement in CBR values over time within both conditions. The peak CBR value of the treated reinforcement was obtained when it was positioned at a depth of 0.3H, yielding a CBR improvement percentage equal to 25.4%. The measured improvement in the CBR value decreased with an increase in the depth of the geocell inside the soil mold.

The highest magnitude of compressive and lateral spreading stresses occurs directly beneath the load near the surface and gradually fans out and dissipates with depth [26]. Unreinforced soil under a surface load tends to undergo lateral displacement and shear failure along curved slip lines that trace the outer boundaries of high-stress zones inside the pressure bulb; therefore, the optimum location for a geogrid and geocell layer is found within the upper third of the mold at a depth of 0.3H. This placement aligns with the zone of maximum shear and high confining stress dictated by the soil's pressure bulb. This high confinement occurs inside this effective zone of the stress bulb, causing soil particles to interlock tightly with the geogrid apertures, creating a stiff composite layer that restrains lateral movement [11, 27]. When moving away from the zone of maximum shear and high confining stress dictated by the soil's pressure bulb, whether by increasing or decreasing the depth of reinforcement (0.2H and 0.4H), this change reduces the improvement of clay soil.

From the above results, the findings indicate that geocell-treated clay subgrade soil performs better than geogrid-treated soil. The performance of clay subgrade soil treated with geocell is better than that of soil treated with geogrid. This difference is attributed to the structure of geocell and geogrid as well as the nature of load transfer through soil. Geogrid features a two-dimensional mesh, whereas geocell has a three-dimensional honeycomb cellular structure; this design allows geogrid

to distribute loads horizontally across a wider area, while geocell distributes loads within a confined vertical and horizontal system, which crushes and strengthens the soil through tensile reinforcement and interlocking in the case of geogrid and by cellular confinement of infill material in the case of geocell, as well as the thickness of geocell encloses a larger volume of infill materials causing increasing the aggregate interlock and apparent cohesion and decreasing in the vertical stress transmitted down to weak subgrade clay soil.

Figure 5 provides a depiction of the swelling values of clay subgrade soils treated with geogrids and geocells. The swelling ratio of subgrade clay soils treated with uniaxial (8.3%), biaxial (4.4%), and triaxial (2.7%) geogrids, as well as geocells (2.2%), is lower than that of untreated subgrade clay soils (11.5%). This agreed with previous studies by Sahib et al. [28] and Jaafar et al. [29]. A geocell restricts volumetric expansion in unstable soils primarily through three-dimensional cellular confinement, which generates high hoop strength in the cell walls and passive resistance from neighboring cells to prevent lateral and outward soil movement. When confined soil absorbs moisture and tries to swell, it exerts an outward lateral push on the flexible but rigid high-density polyethylene (HDPE) cell walls. Lateral thrust is transferred to circumferential hoop tension by the interlinked pockets, which counter expansion, while internal swelling pressure is developed by individual cells. The surrounding empty or stable cells act as structural buttresses and provide passive resistance and lock the infill material in place. Close compaction of the infill (clay) in a constrained boundary increases the total shear resistance of the composite mattress, such that any small volumetric change is either diverted vertically or dissipated safely within the matrix limits. The degree of swelling reduction is directly proportional to the lateral confinement provided by the geocell; increased lateral confinement limits the outward horizontal expansion of expansive soil. Since clay particles require lateral expansion before vertical heave can occur, the limitation of lateral movement forces the soil to absorb swelling internally, which substantially reduces overall surface heave and swelling pressure [30, 31].

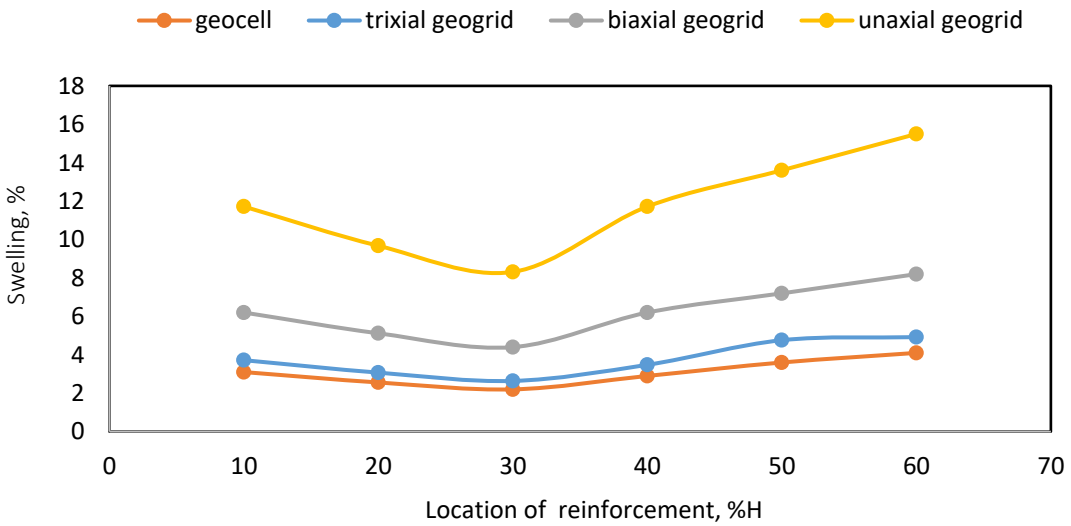


Fig. 8. The swelling values for subgrade soil with geogrid and geocell at different depth

Designers will be able to decrease the necessary amount of pavement layer thickness because of the increased (and decreased) swelling values of the subgrade. This will cause a significant decrease in initial construction costs. The increase (or decrease) in the CBR value will also limit the possibility of damage to the pavement due to maintenance expenses, and this change will increase the lifespan and improve the performance of the pavement [19, 32]. The sustainability of geosynthetics increasingly influences their selection in construction projects. Geocells and geogrids provide the means for sustainable construction by: aggregate reduction, minimal excavation, reduced transportation emissions, and extended infrastructure life. Geocells generally provide higher aggregate reductions in weak-soil applications. Contemporary products are increasingly produced with recycled polymers and advanced material technologies, further enhancing sustainability performance.

5. Conclusions

The subgrade soil is reinforced with three types of geogrids (uniaxial, biaxial, and triaxial) and geocell and tested in CBR tests at soaked and unsoaked cases. The geocell reinforcement provides better performance compared to geogrid as well as that the clay subgrade soil reinforced by triaxial geogrid is better resistant compared to the biaxial and uniaxial geogrid. The major conclusions obtained from the study are

- The use of geogrid and geocell reinforcements for clay subgrade soil has resulted in an improved California Bearing Ratio (CBR%) and reduced soil swelling compared to unreinforced soil, indicating that weak soil can be utilized for pavement activities when these materials are applied.
- The maximum amount of CBR obtained from using geogrid and geocell would be at (0.3H).
- The swelling of subgrade clay differs depending on which type of geosynthetic material was used to treat the clay. The swelling ratio for a given amount of clay using a uniaxial geogrid, a biaxial geogrid, a triaxial geogrid, and a geocell was 8.3%, 4.4%, 2.7%, and 2.2%, respectively.
- All tested clay materials exhibited higher unsoaked CBR values than soaked CBR values regardless of whether or not the geosynthetic material was present.
- The CBR value for subgrade clay soil treated with three different types of geogrids increased by 91%, 226%, and 342%, respectively, in the soaked condition when compared to untreated clay soil. The performance of geocell reinforcement exceeds that of the greater performance of geogrids. The maximum CBR for geocell at 0.3H was 25.44%, and for untreated CBR it is 3.14%.

The search results obtained are based on using geogrid and geocell as reinforcement of clay subgrade soil by assessing the CBR% and swelling of soil at the soaked and unsoaked states. According to the research findings, it is recommended to use geogrid and geocell for clayey soil improvement to reduce costs and raw materials used in pavement structure and support sustainable development. The samples are tested in the lab, while the field evaluation is not covered by the study.

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