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Study of Geocell Foundation

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ABSTRACT: The geocell foundation system, an innovative soil reinforcement technique, has gained prominence in geotechnical engineering due to its ability to enhance soil strength and stability. This cellular confinement system consists of interconnected, honeycomb-like cells made of high-density polyethylene (HDPE), which distribute loads effectively and reduce settlement. Geocells improve bearing capacity, mitigate soil erosion, and provide cost-effective solutions for weak soil conditions. This study investigates the behavior of geocell-reinforced foundations under static and dynamic loads, focusing on parameters such as cell geometry, material properties, and infill type. Experimental and numerical results demonstrate significant improvements in performance, highlighting geocell foundations as a sustainable alternative for various infrastructure applications.

KEYWORDS: Geocell Foundation, High Density Polyethylene, Geotechnical Engineering

I. INTRODUCTION

The geocell, with its intricate three-dimensional honeycomb-like structure crafted from interconnected synthetic strips, serves as a robust solution for reinforcing foundations. Within this structure, soil experiences heightened lateral stresses, effectively limiting the movement of soil particles and enhancing shear strength [1]. The confinement provided by adjacent cells further bolsters resistance against external loads passively, aided by the geocell's high hoop strength, which restricts lateral expansion fig. 1. Such structural integrity, often established through methods like extrusion or adhesion, significantly mitigates the intrusion of base materials into soft soil foundations, thereby fortifying weakened substrates and minimizing settlement occurrences. Consequently, the bearing capacity of geocell-reinforced foundations is intricately linked to factors like cell wall tensile strength, cell opening size, and joint characteristics [2, 3].

The modern form of geocells came into existence since 1980s. Unlike planar textiles and grids, geocells, which are three-dimensional networks of cells filled with a choice of soil, provide added benefits such as all-round confinement through hoop stresses developed in the cells and a beam effect resulting from their stiff-mat configuration.

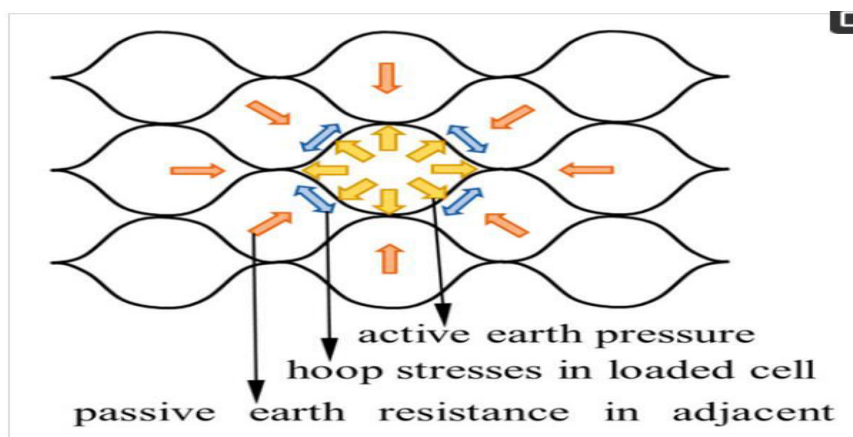


Figure 1: Force distribution in the geocell

Geocells, by virtue of their shape and depth, provide greater load-bearing capacity and reduce lateral deformations in soils confined by them under static and cyclic loading scenarios. The inclusion of geocells in various structures has additional benefits such as stability improvement, climate resilience, higher resistance to cyclic loads, erosion control, basal support, and savings in time and cost [4][8]. Because of these merits, geocells are extensively used in pavements, slopes, foundations, embankments, and reinforced earth (RE) walls. Recently, geocells have also found application in heavy-duty highways and high-speed trains [4, 5].

II. GEOCELL CONFIGURATION

The concept of cellular confinement systems, commonly known as geocells, originated in the 1970s when engineers sought innovative methods to stabilize loose or weak soils. The earliest development of geocells can be traced to research by the U.S. Army Corps of Engineers, who explored soil stabilization techniques for military roads and airstrips, particularly in soft and challenging terrains. The goal was to create a lightweight, portable system that could enhance soil stability under heavy loads.

In 1975, the Corps collaborated with Presto Products Company, leading to the invention of the first modern geocell system made from high-density polyethylene (HDPE). This material proved ideal due to its flexibility, durability, and resistance to environmental degradation. Early geocells were initially used in military applications, such as stabilizing soft sands in desert environments to support heavy military vehicles.

The reinforcement efficiency of geocells is mainly governed by the geocell configuration, geocell material properties, and soil properties. This section presents a detailed discussion on the evolution of geocells with variations in the parameters grouped under these three categories. Various studies that dealt with the variation in geocell geometry and configuration are reviewed, and the individual and combined effects of these parameters are discussed in light of the published papers. The geocell configuration mainly pertains to the shape, size, quantity, and location of geocells. The various factors that define the configuration are the height (H), overall width (b), pocket shape, and pocket opening size (d), which is the diameter of the equivalent circle, the pattern of arrangement in the case of geocells made of geogrids, embedment depth (u), and the number of geocell layers, as depicted in Figure 2. Since geocells improve strength through friction and interlocking, their height, width, and pocket size play a pivotal role in their reinforcing action. The number of geocell layers (N) becomes an important parameter only at higher levels of external loads applied on weak soils.

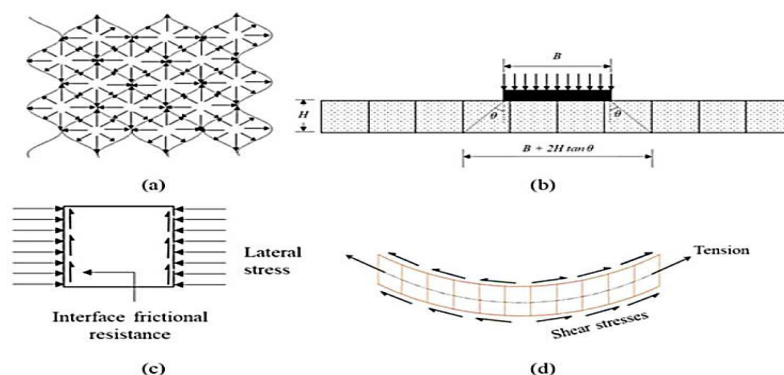


Figure 2: Mechanisms of geocell reinforcement: (a) confinement effect (plan view); (b) stress dispersion effect (sectional elevation); (c) lateral resistance effect on a single geocell (front view); (d) membrane effect (sectional elevation).

III. GEOSYNTHETIC REINFORCEMENT FOR LOAD SUPPORT

Planar geosynthetics have been used as soil reinforcement for many years; three-dimensional geocells are comparatively new. Geocell reinforcement usually utilizes geotextile for separation. Geogrid improves the stiffness of the reinforced soil by interlocking, lateral restraint and tension membrane; it reduces the applied stress on the soft soil and increases the bearing capacity while decreasing settlement. The performance of geogrid depends on aperture size

and shape, material stiffness at junctions, and shape and stiffness of ribs. Ever since the U.S. Army Corps of Engineers used geocell for reinforcing beach sand in the 1970s, numerous research programs, experiments and monitored applications have been carried out to further understand the geocell-reinforcement mechanisms. Vertical and lateral confinement, wider stress distribution and beam/slab effect are identified as the main reinforcement mechanism of geocell. Higher tensile stiffness, strength and creep resistance of geocell material provide the reinforced base with improved bearing capacity, higher modulus and extended design life. High-strength NPA geocell reinforcement also improves the creep resistance of the reinforced structure, which is a very important factor in the repetitive loading conditions, as it significantly reduces the initial deformation and rate of creep of the reinforced material.

A design method using NPA geocell reinforcement for unpaved roads was developed by modifying the Giroud and Han (2004) method for planar reinforcement for rut criteria. This method has already been employed to design unpaved roads in various projects and has been verified. Design using NPA geocells has been successfully employed in paved and unpaved roads and other geocell-reinforced, load-bearing earthen structures.

The authors have encountered several cases where a hybrid design with geogrid and geocells make the project structurally sound and economically feasible. It recommended a high-strength geocell and geogrid hybrid design as an alternative to ground improvement in soft soil that could improve the bearing capacity of the foundation by four to five times. They reported reduction in maintenance cycles and cost, showing the efficacy of the hybrid geosynthetic solution by use of biaxial geogrid and NPA geocells.

IV. PROJECT AND HYBRID DESIGN

The compressor station had two pads adjacent to each other. Pad A was constructed earlier in the summer and the pad under consideration is Pad B. Pad A had faced several challenges due to soft soil at the surface. The construction of Pad B was planned for summer of 2016 but was delayed as the existing soil on-site was found to be of very poor strength. There were uneven and differential settlements under previously placed wooden mats and the existing silty clay soil was not suitable to support the expected loads. After removal of the mats, the equipment and trucks were stuck on the clay surface; the depressions right under the truck tires were as deep as 35.4 inches (900 mm). To avoid the difficulties faced earlier, the owner decided to look for an alternative solution for Pad B.

The footprint of Pad B under consideration was about 291,000 square feet (27,000 m²). Geotechnical investigation supplied by the owner had recommended 2 psi (15 kPa) as the characteristic undrained shear strength (S_u) of the soft silty clay subgrade. The seasonal water table was found to be close to the existing subgrade in the southern side of the pad. The project needed solutions to support a 237-ton (215-tonne) crane and loads from trailers carrying 154-ton (140-tonne) loads, with individual axle loads not exceeding local highway limits.



Figure 3: Stretched NPA geocell and gravel infilling in process

A 51-inch (1,300-mm) thick planar geosynthetic-reinforced granular structure was conventionally designed with three layers of nonwoven geotextile (grab tensile strength 160 pounds [712 N]) and triaxial geogrid to build the pad. This solution would have required 31.5 inches (800 mm) of existing soft soil excavation and 51 inches (1,300 mm) of reinforced crushed gravel fill. Once excavated, the material would need to be hauled off-site and replaced with imported material. All these activities would have contributed to a huge increase in the project cost and the extraction of a lot of virgin crushed gravel aggregate that would have made it impossible to meet the project deadline. Thus, an innovative design with a hybrid geosynthetics solution was presented that not only was sustainable in terms of cost and environmental indicators but also would enable winter construction.

V. APPLICATION

1. Soil Stabilization

- Reinforces weak or loose soils to provide a stable foundation for construction.
- Used in soft clay, silt, and sandy soils to improve load distribution.

2. Road and Pavement Construction

- Provides a stable base layer for highways, rural roads, and unpaved roads.
- Reduces the thickness of the pavement layers and improves durability.

3. Railway Track Beds

- Improves load distribution beneath rail tracks.
- Reduces maintenance costs by minimizing differential settlement.

4. Slope Protection

- Prevents soil erosion on embankments, slopes, and riverbanks.
- Ensures stability of steep slopes by confining soil and vegetation.

5. Retaining Structures

- Acts as reinforcement for retaining walls and abutments.
- Resists lateral earth pressures effectively.

6. Foundation Improvement

- Enhances the bearing capacity of shallow and deep foundations.
- Reduces settlement under static and dynamic loading conditions.

7. Flood Control and Coastal Protection

- Used in levees, dikes, and breakwaters for erosion resistance.
- Reinforces riverbanks and shorelines against wave action.

8. Temporary Access Roads

- Provides stability for construction site access roads, especially in remote or marshy areas.

9. Landfill and Waste Containment

- Reinforces base layers in landfills to prevent leakage and settlement.

10. Airport Runways and Aprons

- Supports load distribution for heavy aircraft, reducing damage to runway surfaces.

VI. CONCLUSION

The geocell foundation system has proven to be an effective and sustainable solution for enhancing soil stability and load-bearing capacity, particularly in weak or problematic soils. By confining infill material within its cellular structure, geocells distribute loads more uniformly, reduce settlement, and improve overall foundation performance. This system also offers environmental and economic benefits, including reduced material usage, faster construction times, and adaptability to various site conditions. Experimental and numerical analyses confirm its applicability in diverse infrastructure projects, such as roadways, embankments, and retaining walls. With its ability to address geotechnical challenges while promoting sustainability, the geocell foundation system is poised for broader adoption in modern engineering practices.

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