Efficacy of Geosynthetic Reinforcement in Soil Proximate to Sinkhole-Formed Areas in The Kadapa Region: A Comprehensive Study

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Abstract. This presents a detailed investigation into the efficacy of geosynthetic reinforcement in soils collected from regions near sinkhole formations in the Kadapa region. Sinkholes substantially threaten infrastructure and human safety, necessitating innovative engineering solutions for stabilization and prevention. The study employs a multidisciplinary approach, combining geotechnical analyses, laboratory testing, and numerical simulations to assess the effectiveness of geosynthetic reinforcement in mitigating the risks associated with sinkhole-prone soils. Field investigations involve soil sampling from surrounding sinkholes, focusing on diverse geological conditions. Laboratory testing includes geotechnical analyses such as compaction, shear strength, and permeability, with and without geosynthetic reinforcement. The results of this research contribute to a nuanced understanding of how geosynthetic reinforcement influences the mechanical behaviour and stability of soils near sinkhole formations. The study aims to provide practical insights into the optimal design parameters for geosynthetic reinforcement in geologically sensitive areas, offering guidance for engineers and planners working on infrastructure projects. Ultimately, this research seeks to enhance the resilience of structures and landscapes in the Kadapa region and similar geological contexts, fostering sustainable development practices in sinkhole-prone areas. This study concludes that geosynthetic reinforcement presents a promising solution for mitigating the risks associated with sinkhole formation in the Kadapa region. Through a comprehensive investigation, it has been demonstrated that the implementation of geosynthetics effectively enhances the stability and load-bearing capacity of soil in proximity to sinkhole-prone areas. The findings underscore the importance of adopting geosynthetic solutions as a proactive measure to address the challenges posed by sinkhole occurrences. This study provides valuable insights for engineers, geologists, and policymakers in developing sustainable strategies for sinkhole hazard management and infrastructure resilience in the Kadapa region and beyond.

Keywords: Geosynthetics; Reinforcement; Sinkhole areas.

B. S. Babu et al. (eds.), *Proceedings of International Conference on Advanced Materials, Manufacturing and Sustainable Development (ICAMMSD-2024)*, Advances in Engineering Research 257,
https://doi.org/10.2991/978-94-6463-662-8_88

1. Introduction

Sinkhole formations pose significant geological hazards in the Kadapa Region, where the interaction of underlying geological features with surface processes leads to sudden collapses in the landscape. These sinkholes not only result in structural damage but also pose risks to human safety and infrastructure stability. Traditional methods of soil stabilization have often fallen short in effectively mitigating sinkhole formation and its associated impacts. Geosynthetic reinforcement presents a promising solution to address soil instability and mitigate sinkhole risks. Geosynthetics are engineered materials that offer unique properties for improving soil strength, enhancing drainage, and controlling erosion. However, their specific application and effectiveness in the context of sinkhole-prone areas in the Kadapa Region have not been extensively studied.

This study aims to investigate the efficacy of geosynthetic reinforcement techniques in stabilizing soil proximate to sinkhole-formed areas within the Kadapa Region. By conducting detailed geotechnical analyses, field assessments, and performance evaluations of geosynthetic materials, this study seeks to provide critical insights into the suitability and practical applications of geosynthetics for soil stabilization and sinkhole mitigation. The outcomes of this research endeavour will contribute to advancing our understanding of soil engineering practices tailored to sinkhole-prone regions, ultimately enhancing resilience against sinkhole hazards and supporting sustainable infrastructure development in the Kadapa Region

2 Literature Survey

The efficacy of geosynthetics in soil stabilization around sinkhole-prone areas was examined through various studies, highlighting key insights drawn from the literature.

2.1 Sinkhole Formation and Subsidence

A study **[1]** stated that sinkholes in limestone occurred as the rock dissolved, creating cavities. If the cavity ceiling was weak, it could collapse, leading to surface subsidence. **A research work [2]** noted that Florida Statutes defined sinkholes as landforms created by rapid soil subsidence due to groundwater dissolution of bedrock. They suggested that sinkholes could arise from both natural processes (karst terrain) and other factors, not exclusively limited to karst geology.

Author [3] described that rainwater containing carbon dioxide formed carbonic acid, which dissolved limestone and created subsurface flow systems contributing to sinkhole formation.

2.2 Types and Causes of Sinkholes

- **Author [2] and [4]** stated sinkholes as surface depressions due to the dissolution of near-surface bedrock.
- **Author [5]** notified sinkholes into three primary types: collapse, subsidence, and solution sinkholes. They also noted that factors such as soil piping, unrelated to karst, could induce sinkholes.

- **A study [6]** extended the classification to include six types of sinkholes: solution, collapse, dropout, buried, caprock, and suffosion, emphasizing the complexity of sinkhole formation.

2.3 Role and Mechanism of Geosynthetics

- **Author [7]** discussed geosynthetics' design, selection, and application for soil stabilization, focusing on their utility in strengthening embankments, steep slopes, and retaining walls. Failures in geosynthetic applications were often attributed to construction flaws rather than material issues.
- **A study [8]** examined geosynthetics in a two-layered soil setup to improve load-bearing capacity in unpaved roads. Using geogrids and geotextiles as reinforcement layers, they observed improved performance under various conditions.

2.4 Geosynthetics in Sinkhole Investigations and Mitigation

- **Author [9] and [10]** proposed combining techniques such as aerial photography, geophysical studies, and borings for sinkhole investigations. They emphasized the importance of tailoring approaches to specific site conditions.
- **Author [11]** presented a simulation of geosynthetic-reinforced embankments over weak soil in Algeria using PLAXIS software. Their study highlighted the role of geosynthetics in enhancing stability in regions with high compressibility and low bearing capacity, providing insights into geosynthetics' performance under varied environmental conditions.

These studies collectively showcased the mechanisms of sinkhole formation, the role of geosynthetics in soil reinforcement, and methods for utilizing geosynthetics to mitigate risks in sinkhole-prone areas. This review established a foundation for exploring geosynthetics’ efficacy in stabilizing soils in such regions.

2.5 Sinkhole Formation in Kadapa Region

The Kadapa region in Andhra Pradesh, India is geologically susceptible to sinkholes due to its karst topography, where limestone and other soluble rocks dominate the subsurface. Over time, the dissolution of these rocks by acidic groundwater has led to the formation of underground cavities. When these cavities reach a critical size or when surface loads change, they may collapse, creating sinkholes.

In Kadapa, sinkholes are typically triggered by natural processes, such as heavy rainfall and groundwater movement, and by human activities, including extensive mining and quarrying. The region has seen several instances of infrastructure damage, including road collapses and threats to agricultural land, highlighting the need for soil stabilization and mitigation strategies. Given these challenges, geosynthetic reinforcement has emerged as a potential solution to improve soil stability around sinkhole-affected areas, protecting infrastructure and enhancing the resilience of the land.

Fig.1. Geographical 2D View of Sinkhole

Fig 2. Geographical 3D View of Sinkhole

2.6 Sample Collection Point

Strategic points within Buggaletipalle Village are selected for soil sample collection. These points are chosen based on variations in geological features, potential sinkhole risk areas, and other relevant factors identified during the initial survey.

Fig 3. Soil samples collection from the Sinkhole

Fig 4. Geotagged location of the sinkhole-formed area

3 Methodology

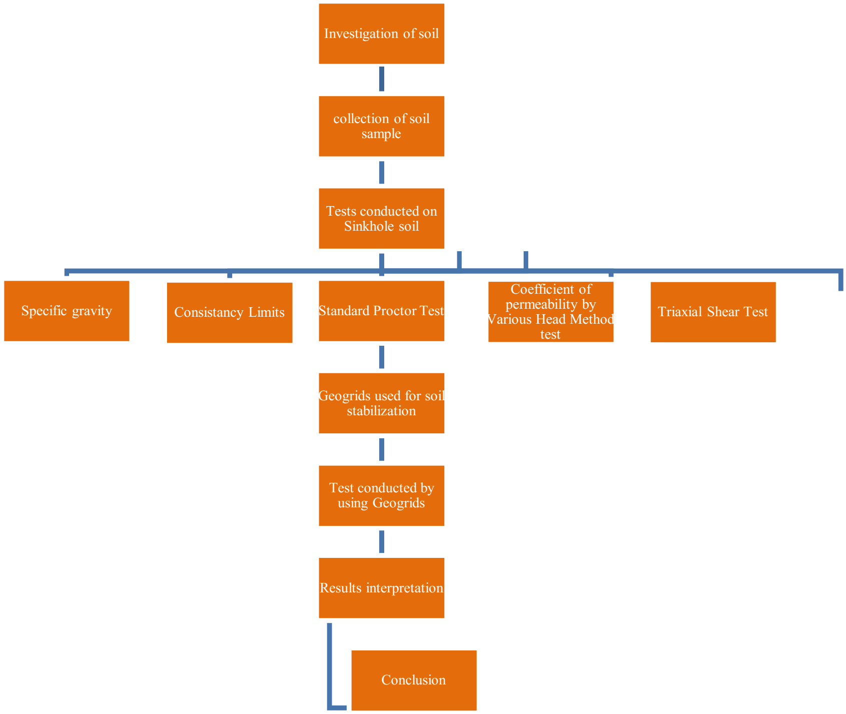

Fig. 5. Methodology of the experimental approach

4 Results and Discussions

The comprehensive laboratory test results before and after the implementation of geogrids provide valuable insights into the effectiveness of geosynthetic reinforcement in improving soil stability within sinkhole-prone areas like the Kadapa region.
Moisture Content: The moisture content of 10.66% observed in sinkhole soil represents the amount of water present in the soil relative to its dry weight, expressed as a percentage. This measurement plays a crucial role in understanding the soil's physical properties and behavior, particularly in the context of soil compaction and stability.
Specific Gravity: The specific gravity of 2.43 for sinkhole soil indicates the density of the soil particles relative to the density of water. It is a fundamental property used to characterize the composition and compactness of soil materials.

Consistency Limits

Liquid Limit (LL)

The liquid limit (LL) of soil is the moisture content at which the soil transitions from a plastic state to a liquid state under specific testing conditions. It is determined using the Casagrande method and is expressed as a percentage of the dry soil weight. Soil collected from the sink-hole area has a liquid limit of 15.5%.

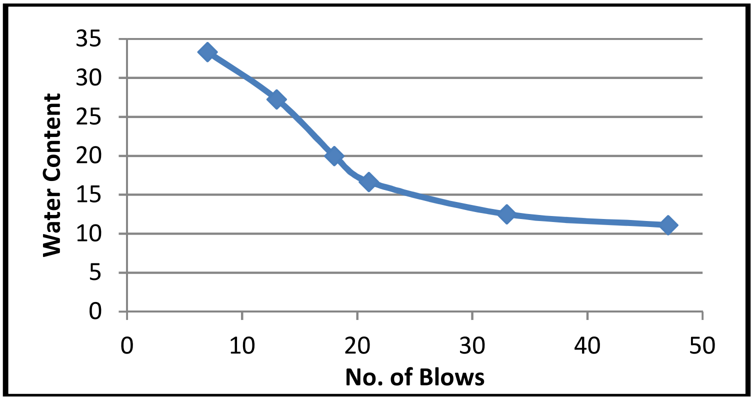

Fig. 6. Liquid Limit curve

Plastic Limit:

The plastic limit (PL) is the moisture content at which the soil just begins to crumble when rolled into threads of specific diameter. A plastic limit of 14.28% suggests that the soil contains a significant amount of clay and exhibits cohesive properties. Soils with higher plastic limits tend to undergo more significant volume changes with changes in moisture content.

Grain size Analysis: The coefficient of uniformity (Cu) is a measure of the particle size distribution of soil aggregates. It is calculated as the ratio of the sieve size that allows 60% of the soil particles (by weight) to pass (D60) to the sieve size that allows 10% of the particles (by weight) to pass (D10). In this case, a Cu value of 2.75 indicates a relatively wide range of particle sizes within the soil sample.

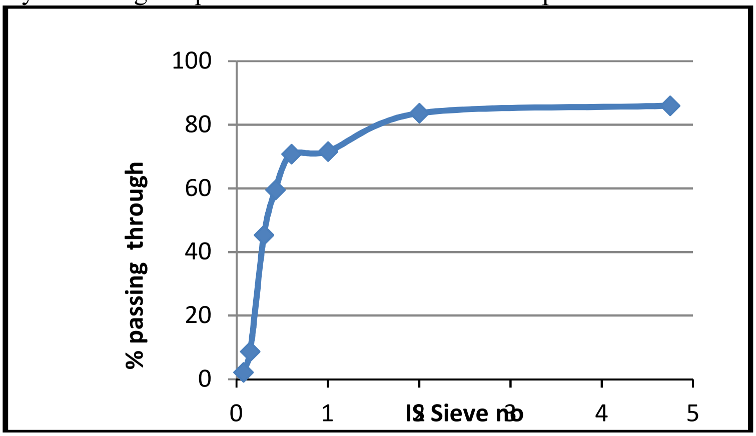

Fig. 7. Grain size distribution curve

Standard Proctor's Compaction test: The optimum moisture content (OMC) is the moisture content at which the soil can be compacted to achieve its maximum dry density (MDD) under specified compaction conditions. In this case, an OMC of 15% indicates the moisture content required to achieve the highest level of soil compaction.

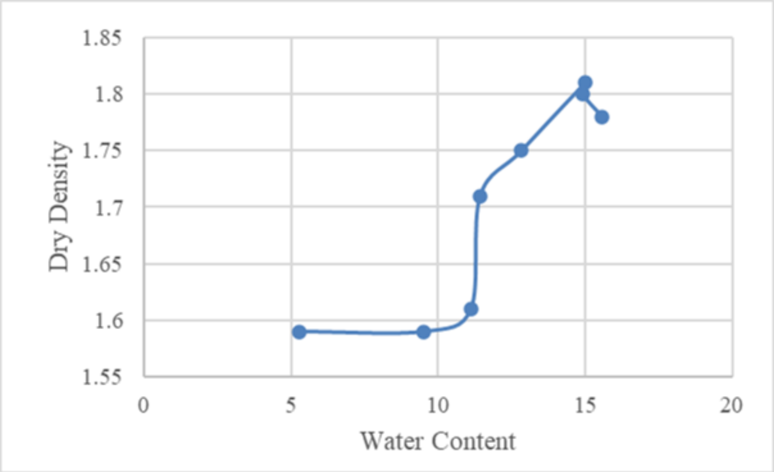

Fig. 8. Compaction curve before using Geogrids

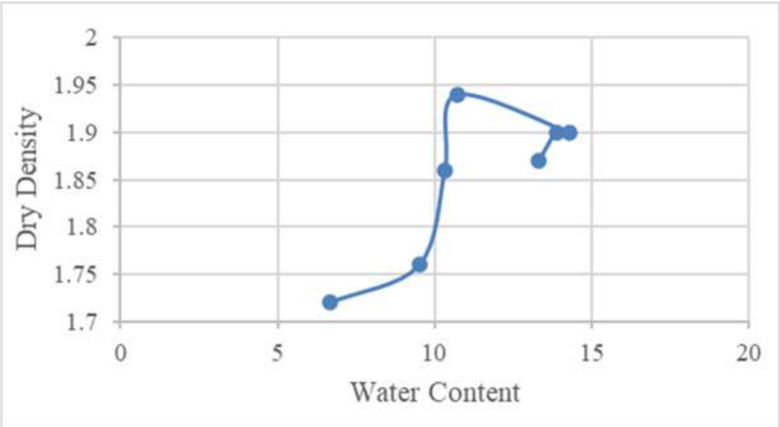

Fig. 9. Compaction curve after using geogrid in three layers

Permeability Test: The permeability coefficient (k) of 0.000207 cm/sec, as determined from the coefficient of permeability test, indicates that the sinkhole soil exhibits relatively low permeability. Permeability refers to the ability of a porous material, such as soil, to allow fluids (typically water) to pass through it under a hydraulic gradient.
Triaxial Shear Test: Triaxial test is conducted on soil samples to assess their mechanical properties under different stress conditions, providing valuable data for geotechnical engineering analysis and design. The test involves subjecting a cylindrical soil specimen to controlled axial and radial stresses while measuring deformation and stress responses. Triaxial Shear Test results showed a significant increase in soil cohesion,

from 0.14 kg/cm² to 0.77 kg/cm², while the angle of internal friction (Phi) remained relatively stable (from 33.4° to 33.3°.

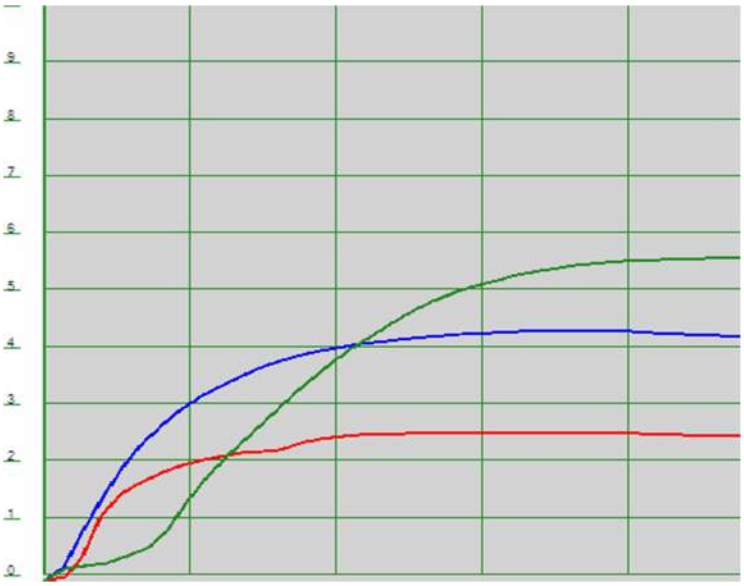

Fig. 10. Deviatoric Stress(kg/cm^2) vs Axial Strain (%) before using geogrid

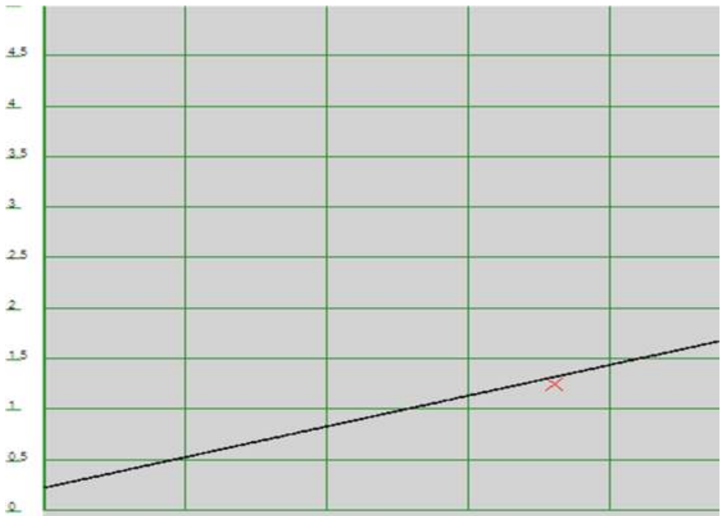

Fig. 11. Mean stress vs Shear stress [a = 0.22 kg/cm^2, alpha=31.3^o] before using geogrid

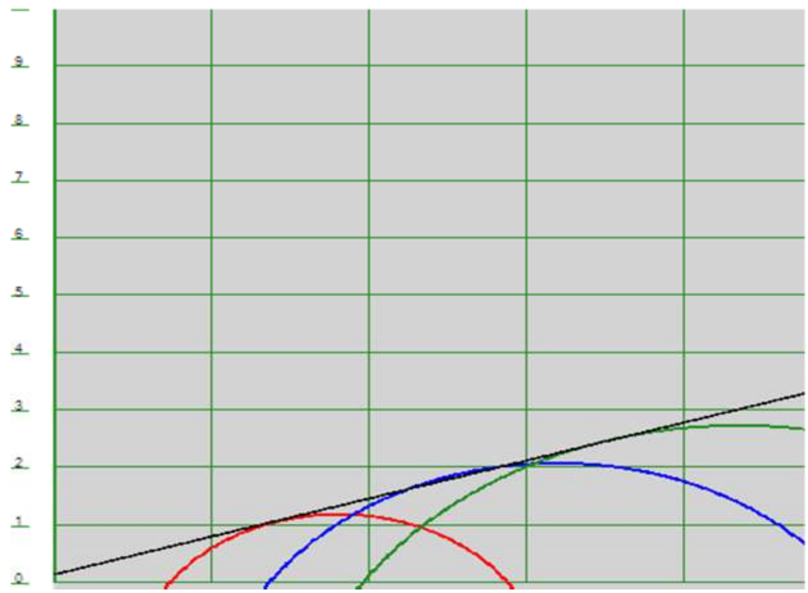

Fig. 12. Shear Stress (kg/cm^2) vs Normal Stress (kg/cm^2) [c=0.14kg/cm^2, Phi=33.4^o] before using geogrid

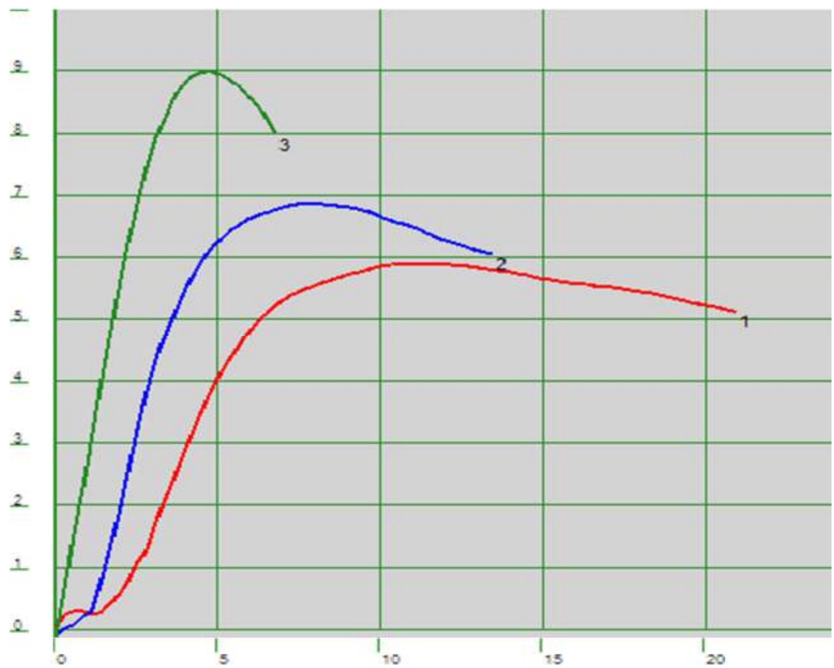

Fig. 13. Deviatoric Stress (kg/cm2) vs Axial Strain (%) after using geogrid

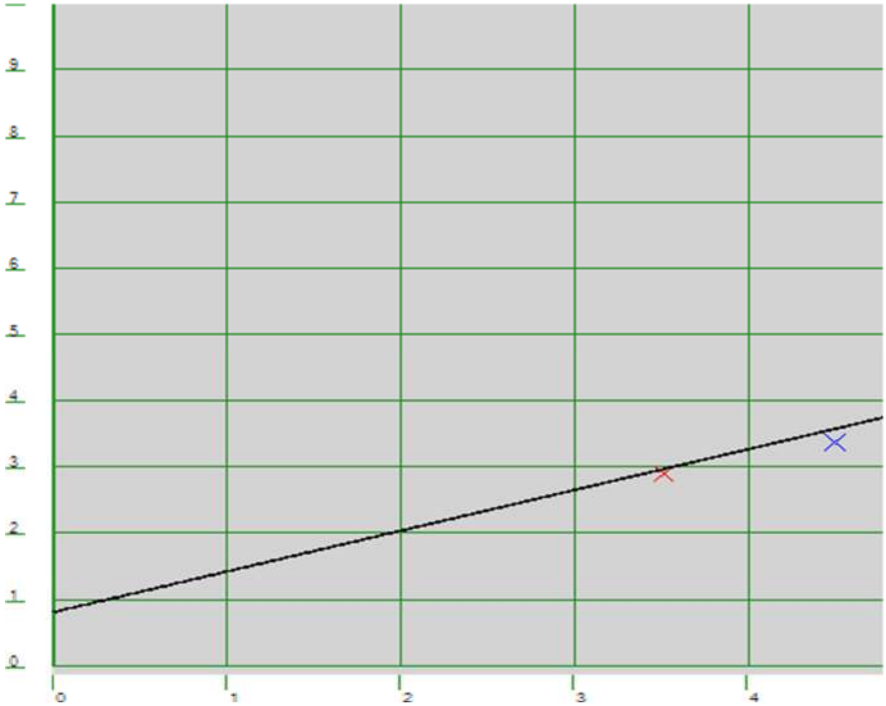

Fig. 14. Mean stress vs Shear stress [a = 0.81kg/cm^2, alpha = 31.5^o] after using geogrid

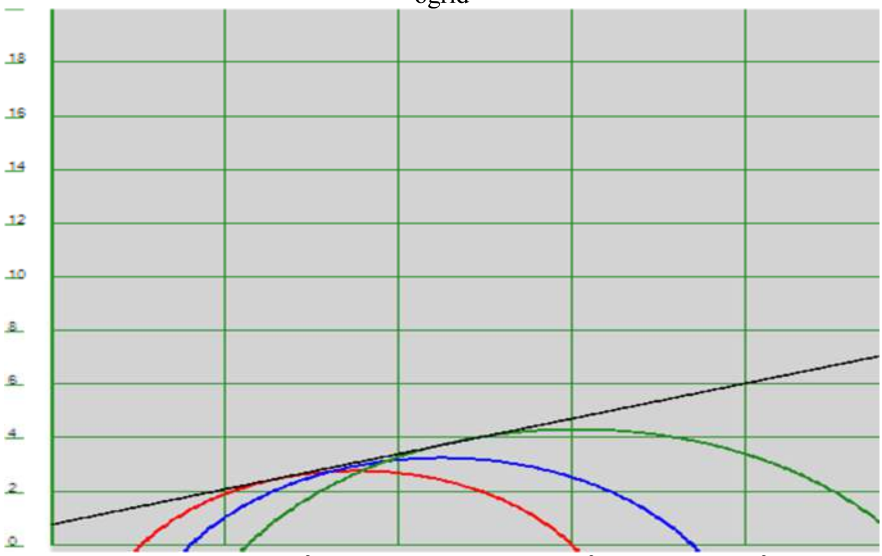

Fig. 15. Shear Stress(kg/cm^2) vs Normal Stress (kg/cm^2) [c=0.77kg/cm^2, Phi=33.3^o] after using geogrid

5. Conclusions

1. **Improved Soil Compaction**:
    - The Standard Proctor Compaction Test results showed a decrease in Optimum Moisture Content (OMC) from 15% to 10.71% and an increase in Maximum Dry Density (MDD) from 1.81 g/cc to 1.94 g/cc after geogrid reinforcement.
    - This increase in MDD indicates enhanced soil compactability and load-bearing capacity, demonstrating that geogrids can effectively stabilize the soil against settling and deformation.
2. **Reduced Soil Permeability**:
    - The Coefficient of Permeability decreased from 0.000207 cm/sec to 0.00012 cm/sec with the addition of geogrids.
    - This reduction in permeability suggests that geogrids restrict water flow through the soil, minimizing erosion, saturation, and loss of soil strength. This is beneficial for areas prone to water-induced soil instability.
3. **Enhanced Shear Strength**:
    - Triaxial Shear Test results showed a significant increase in soil cohesion, from 0.14 kg/cm^2 to 0.77 kg/cm^2, while the angle of internal friction (Phi) remained relatively stable (from 33.4° to 33.3°).
    - The higher cohesion value indicates improved shear strength, which enhances soil stability and its ability to support structural loads without significant deformation.
4. **Overall Impact of Geogrid Reinforcement**:
    - Geogrid implementation led to substantial improvements in soil characteristics, including better compaction, lower permeability, and greater shear strength. These changes are critical for ensuring the stability and resilience of civil engineering structures built on reinforced soil.
5. **Practical Implications for Sustainable Infrastructure**:]
    - Geogrids play a crucial role in optimizing soil properties, enabling more sustainable and resilient infrastructure development. The tailored reinforcement approach provided by geosynthetics offers a reliable strategy for soil stabilization in diverse environmental and geological settings, ultimately enhancing project longevity and reducing maintenance needs.

In conclusion, the findings confirm that geogrid reinforcement significantly improves the stability, load-bearing capacity, and durability of soils in construction applications, making it a valuable solution for civil engineering projects in sinkhole-prone or unstable regions.

Acknowledgments. Authors are thankful to the Management and Principal of G. Pulla Reddy Engineering College (A), Kurnool, for their constant support and encouragement for completing this research work.

Disclosure of Interests. No conflict of Interest among authors of this paper.

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