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The Use of Geogrids in the Reinforcement of Weak Foundation Soils: A Remedial Strategy for Improving Ground Stability

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Abstract: **This paper presents a value-added approach to improving ground stability and mitigating foundation failures using geogrids as a reinforcement material in weak foundation soils. The primary focus of this research was to evaluate geogrids as an effective and sustainable solution for enhancing the load-bearing capacity and structural reliability of foundations constructed on weak or problematic soils. The reinforcement system using geogrids was designed to increase the shear strength of soil and reduce settlement by integrating geosynthetic materials within the soil mass. This paper aims to develop a comprehensive understanding of the behavior of geogrid-reinforced soil systems with the sole goal of promoting their application, both in new construction and foundation remediation projects. This research began by reviewing various remediation systems or strategies used in combating foundation failure, that is, their effectiveness, efficiency, and limitations. It further discussed the use of geosynthetics, particularly geogrids, as a remedy for foundation reinforcement. Characteristics, mechanical properties, efficiency, and their wide range of applications was critically analyzed to gauge their suitability as a reinforcement material. Furthermore, the research focused on identifying the limitations and practical deployment challenges of geogrid-reinforced foundations. To achieve this, the study analysed experimental evaluations to assess the degree of improvement achieved by geogrid reinforcement. This study ultimately provides an assessment of the feasibility, efficiency and potential for geogrids as a remedial method for addressing foundation failures in weak soils.**

Keywords: **geogrids, geosynthetics, foundation reinforcement, weak soils, ground improvement, structural remediation.**

I. INTRODUCTION

Soil stability plays a fundamental role in structural engineering, as it directly influences the safety and longevity of constructed facilities. The capacity of soil to maintain its cohesion and resist disintegration under external forces—such as water, wind, or mechanical loading—is essential in assessing its suitability for supporting structural loads. Stable soil demonstrates increased resistance to erosion and enhanced infiltration capacity, contributing to improved geotechnical performance and overall soil health (Zhang et al., 2018). The portion of a structure that interfaces with the ground—typically through its foundation—is known as the footing. The ability of the underlying soil to sustain structural loads without undergoing excessive deformation or failure is crucial in preventing issues such as differential settlement, tilting, or collapse (Abusharar et al., 2016). Therefore, a comprehensive evaluation of soil properties, including shear strength and bearing capacity, is imperative prior to any construction activity. In cases where the soil is found to be weak, mitigation strategies such as soil stabilization, reinforcement, or the use of deep foundations may be necessary to ensure structural integrity (Indraratna et al., 2017). The main objective of this paper is to attest that geogrid are sustainable for use as reinforcement for clayey soils since they increase the soil's bearing capacity rapidly.

Several strategies can be implemented to counteract such problematic soils. Some of these strategies include:

1. Underpinning

This is a method of strengthening a foundation system that has experienced either a sudden increase in water table level, soils with little bearing capacity that have caused considerable levels of settlement or any other kind of distress, such as degraded timber piles as a result of corrosion (Das, 2016). This technique typically involves extending the foundation to a deeper, more stable soil strata or redistributing the structural load over a larger area by broadening the footing or foundation so as to enhance its stability and performance (Coduto, 2011). Although underpinning is a reliable method for restoring structural stability, it often presents a major drawback in the form of considerable disruption to ongoing activities and building occupants throughout the construction phase (Tomlinson et. al, 2014)

2. Foam jacking (Polyurethane Injection)

Polyurethane foam injection is a versatile and effective solution that involves pumping polyurethane into the problematic regions. High-density polyurethane foam is used in emergency cases. This method is a preferred choice for raising the level of highways and residential concrete structures. While being waterproof and long-lasting, this method provides for proper stabilization together with precise levelling. This however, is a temporary solution and unsuitable for heavy structures.

3. Carbon Fibre Reinforcement

Carbon fibre is a composite material (polymer matrix, carbon reinforcement) consisting of thin, strong crystalline filaments of carbon, essentially carbon atoms bonded together in long chains (DragonPlate, 2025). Carbon fibre strips are applied to foundation walls to provide additional strength and prevent cracking and bowing. They are highly efficient, quick and non-disruptive. Only suitable for minor structural issues and does not address underlying soil problems.

4. Deep Cement Mixing (DCM)

Deep Cement Mixing (DCM) is a ground improvement technique used for foundations, where cement is mixed with soil in situ to create columns of soil-cement mixture, enhancing soil strength and stability. This method is particularly effective in improving soft soils and can be used to create a foundation base or enhance an existing foundation. Disadvantages include high material and equipment costs, and it needs precise quality control.

5. Aggregate Piers (Vibro Stone Columns)

This technique involves inserting crushed stone columns into the ground using a vibrating tool. The stone columns increase the load-bearing capacity and drainage of the soil, reducing the potential for settlement and liquefaction. It provides fast installation and is equally suitable for large areas. Despite all these, it is less effective in clayey soils, and vibration may affect the structural integrity of buildings nearby.

These strategies, despite the limitations, have proved successful, effective, and environmentally friendly. These techniques are designed to either improve the load-bearing capacity of the ground or redistribute structural loads to a more competent soil stratum. Their effectiveness lies in their ability to adapt to a variety of soil conditions and structural demands. For instance, underpinning provides deep foundational support ideal for high-load structures, while methods like foam jacking offer efficient, non-invasive solutions for lighter or shallow foundations. Additionally, techniques such as jet grouting and deep soil mixing are particularly effective in improving subgrade strength in soft or saturated soils, although it is more technically complex and environmentally unfriendly.

In terms of overall performance, these methods not only restore stability but also prolong the lifespan of existing structures without the need for complete reconstruction. The selection of the appropriate method depends on a balance of factors, including site conditions, environmental sensitivity, load requirements, and cost-effectiveness. When correctly chosen and implemented, modern foundation remediation methods are highly reliable, offering structural safety and sustainability.

INFLUENCE OF SOIL VARIABILITY ON GEOGRID USE

Geogrids have been used for reinforcement and have proved efficient over time. They have been in use since 1978 (Koerner, 2005). Geogrid reinforcement has been extensively studied in the context of granular soils due to their favourable drainage characteristics and mechanical interlocking with the grid apertures. Numerous laboratory and field experiments have demonstrated that the integration of geogrids into granular subbases significantly improves load distribution, reduces settlement, and enhances overall bearing capacity. For instance, Giroud and Han (2004) developed analytical models for geosynthetic-reinforced unpaved roads using granular materials, showing substantial improvement in performance and cost savings. Similarly, Naeini (2008) conducted model tests on granular soils and found that geogrid reinforcement increased the ultimate bearing capacity by up to 80% compared to unreinforced conditions. These studies highlight the effectiveness of geogrids in granular soil systems, where particle interlock and friction play critical roles in the reinforcement mechanism.

Sandy soils have also been widely used in experimental studies on geogrid reinforcement, given their cohesionless nature and predictable behaviour under load. Research by Dash et al. (2007) examined the improvement in bearing capacity of strip footings on geogrid-reinforced sand and found that the reinforcement's effectiveness depends significantly on its placement depth and the number of geogrid layers. Another study by Moghaddas (2010) evaluated the behaviour of a circular footing on reinforced sand, confirming that geogrids can reduce surface deformation and increase stability under cyclic loading conditions. These findings reinforce the importance of understanding the interaction between geogrids and sandy soils, where uplift resistance and stress dispersion are key benefits of reinforcement.

This research will therefore explore clayey soil behaviour, while reinforced with geogrids and when unreinforced. This comparison will assist in knowing the effectiveness of geogrids as a reinforcement material and document the implications of their use, together with their limitations. The findings, can later be advanced to determine the cost-benefit analysis of geogrids compared with the, above discussed, traditional methods and their long-time performance in clayey soil (their design life, negative life-time effects of its use etc.)

II. METHODOLOGY

A. *RELATED THEORY*

The triaxial test, which will be used for this experiment, is a common experiment (ASTM,2011) particularly advantageous because it closely replicates in-situ stress conditions and enables the determination of critical soil properties, including cohesion, friction angle, and pore water pressure response. Unlike simpler strength tests, such as the unconfined compression test, the triaxial shear test allows for precise control over drainage conditions, making it suitable for evaluating both cohesive and granular soils under different loading scenarios.

The test can be conducted in three primary variations: Consolidated Drained (CD)test, Consolidated Undrained (CU) test, and Unconsolidated Undrained (UU) test. The CD test allows full drainage throughout, the CU test permits consolidation but restricts drainage during shearing, while the UU test does not allow consolidation or drainage. Each variation is selected based on the soil type and the engineering application being considered. Among these, the CU test is widely preferred for assessing saturated soils that may experience rapid loading conditions, as it simulates real-world scenarios such as sudden foundation loading.

B. CONSOLIDATED UNDRAINED (CU) TEST

The Consolidated Undrained (CU) is performed in two primary stages: consolidation and shearing. In the consolidation phase, the soil specimen is subjected to an all-around confining pressure while allowing drainage, ensuring that excess pore water dissipates, and the soil reaches equilibrium under the applied stress. This step mimics the long-term natural consolidation process in soil deposits.

In the shearing phase, axial stress is applied while drainage is restricted. This simulates real-world conditions where saturated soils experience rapid loading, such as during earthquakes, foundation loading, or embankment construction. By measuring both the total and effective stresses during shearing, engineers can derive critical soil parameters such as the effective cohesion (c') and effective angle of internal friction (ϕ').

C. COLLECTION OF SAMPLES

The soil sample was collected from a depth of 1 meter in pits (2 No.) excavated at the test site, that is, the University of Eldoret. This depth was chosen to ensure that the sample was representative of the subsoil conditions. The extracted soil was carefully handled to maintain its natural moisture content and structure. It was then transported to the laboratory for further preparations before testing.

By use of ASTM standards: D4767 – “Consolidated-Undrained Triaxial Compression Test on Cohesive Soil”

D. APPARATUS

- Triaxial compression device (electrically driven strain-controlled device)
- Triaxial cell
- Pestle.
- Specimen mould (Membrane Stretcher).
- Rubber membrane (70mm diameter, 140mm depth)
- Membrane stretcher
- Ruler binding strips
- Two Porous stones/plates.

PROCEDURE

1. The weight, diameter, density, and moisture content of the samples of the dry soil needed for preparation of three soil samples of 70mm diameter and 140mm height were determined.
2. Specified amount of water was added to the dry soil and mixed thoroughly. Some of the soil was reserved for moisture content determination. (Care was taken to ensure the soil was plastic and not liquid)
3. Three soil samples were prepared by packing in the following process:
   a) 70mm diameter membranes were taken and fit smoothly into the cylindrical moulds, folding the ends of the membrane over the ends of the stretcher.
   b) The samples were then inserted into the membrane and consolidated using a pestle and the lower plate attached using rubber bands. Three samples were prepared containing plain soil and three containing soil reinforced with geogrids.
   c) The samples were then removed from the membrane stretcher, ready for testing.
4. The lower plate and upper porous plates were then attached to the base of the triaxial cell care being taken to ensure no damage the soil specimen
5. The load bar was then brought into contact with the load piston.
6. A pre-determined chamber pressure was then applied for the lateral pressure σ3. The test was stopped when the sample reached maximum strain which is 20%
7. After the sample failed, the machine was shut off and reversed to release the chamber pressure and remove the load piston.
8. The specimen was then removed, and its final moisture content obtained.
9. Three samples were tested by repeating steps 4 to 7 at different confining pressures.
10. The same procedure was used for samples (3 No.) containing two layers of geogrids.
11. Two graphs were plotted for each confining pressure after the necessary calculation by the machine's software after which,
    a) A graph of deviator stress **(Δσ)** versus axial strain ε was plotted in MS Excel. The maximum deviator stress was then used to calculate the maximum value of the major principal stress, $\boldsymbol{\sigma 1 = \Delta\sigma max + \sigma 3}$
    b) Mohr's circle using values of σ1 and σ3 as abscissa and shear stress as ordinate was also plotted.
12. From Mohr's circle, a curve tangent to each circle was drawn, and the slope of the tangent and the y-intercept were determined. The slope of the tangent gave the angle of internal friction, and the y-intercept the value of the soil cohesion, c.

(Lhr, 2015)

III. RESULTS AND DISCUSSION

1. *PLAIN SOIL SAMPLES*

Diameter of Sample= 70mm

Length of Sample, Lo= 140mm

Original area of Sample, A_o =3848.45 mm^2

Volume of the Sample, V =0.53878 m^3

Table 1: Plain soil samples

SOIL SAMPLE	WEIGHT(g)
S1	1002
S2	973
S3	970

Table 2: Results from the triaxial test machine for plain soils

TEST NO.	CHAMBER PRESSURE	DEVIATOR STRESS	MAJOR PRINCIPLE STRESS	RADIUS	AVERAGE
S1	150	77	227	38.5	188.5
S2	200	89	289	44.5	244.5
S3	250	99	349	49.5	299.5

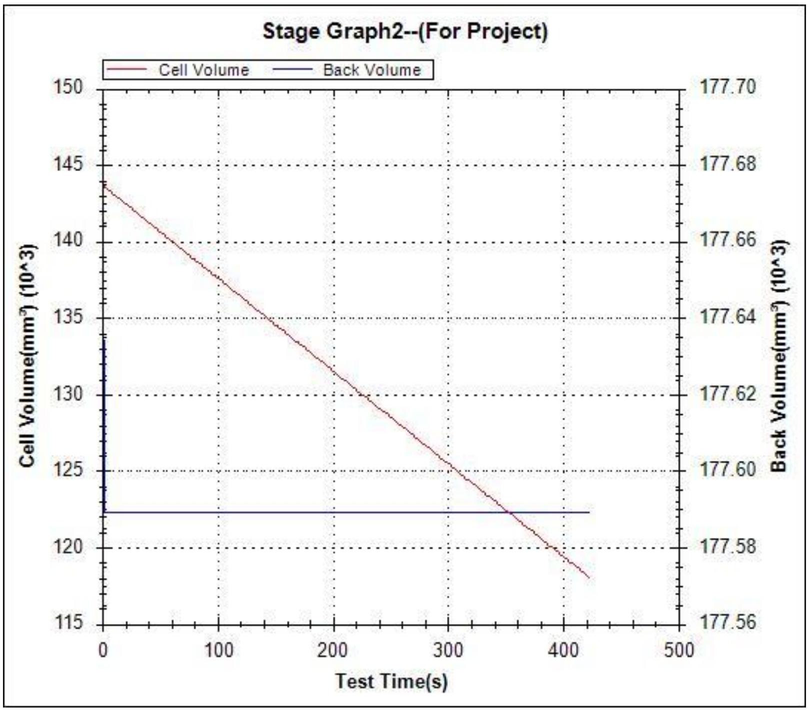

Figure 1: Soil sample 2 cell volume against back volume

2. Geogrid reinforced soil samples

Diameter of Sample= 70mm

Length of Sample, L_o= 140mm

Original area of Sample, A_o =3848.45 mm^2

Volume of the Sample, V =0.53878 m^3

Table 3: Soil samples with Geogrid

SAMPLE	WEIGHT(g)
G1	992
G2	1009
G3	1004

Table 4: Results from the triaxial testing machine for soils with geogrids

TEST NO.	CHAMBER PRESSURE	DEVIATOR STRESS	MAJOR PRINCIPAL STRESS	RADIUS	AVERAGE
G1	150	69	219	34.5	184.5
G2	200	132	280	40	240
G3	250	92	342	46	296

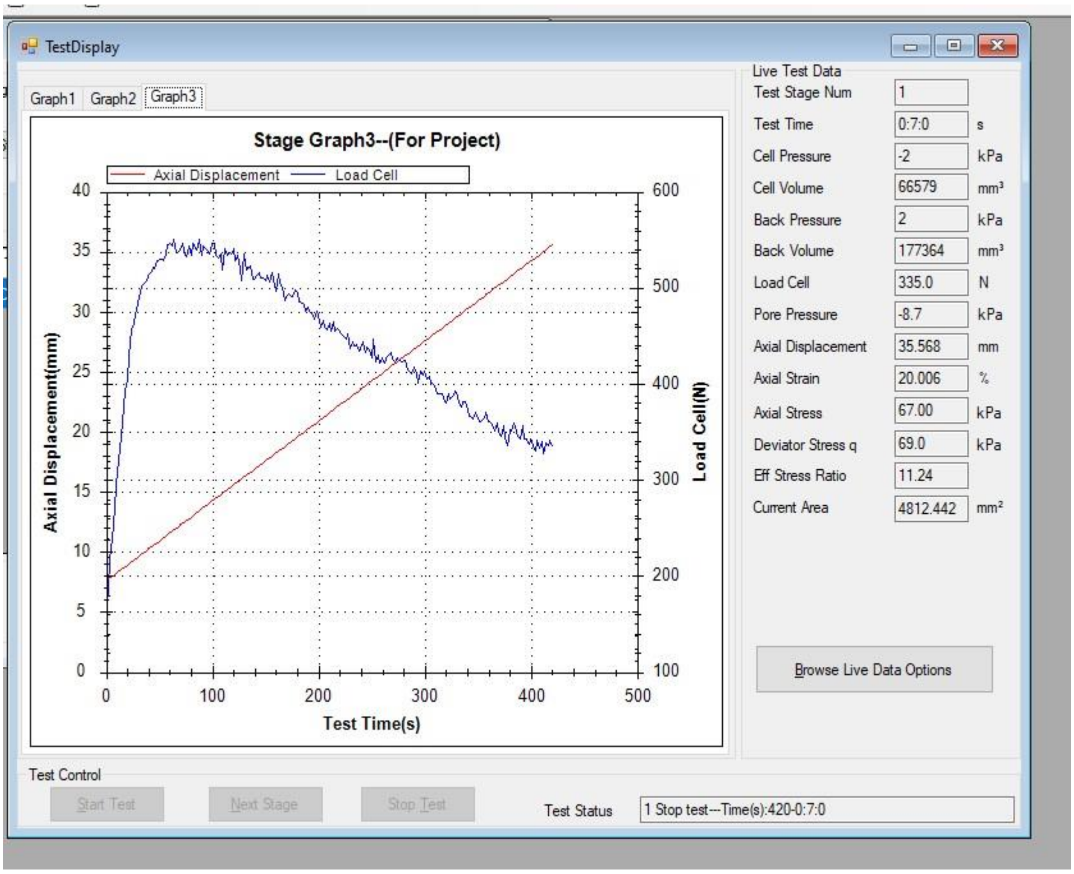

Figure 2: Geogrid's soil sample showing displacement against load cell and data obtained from the test

From the above results, the Mohr Circle was plotted to determine the properties of the soil such as cohesion and angle of friction. This promoted the determination of the bearing capacity for both the reinforced and unreinforced soil. Both these parameters were obtained in graphs plotted using Microsoft Excel sheets. Using the formula, $\boldsymbol{\tau = c + \sigma \tan(\phi)}$

Where, τ = Shear strength

c = Soil cohesion

ϕ = Angle of internal fiction

σ = Normal stress on the critical plane

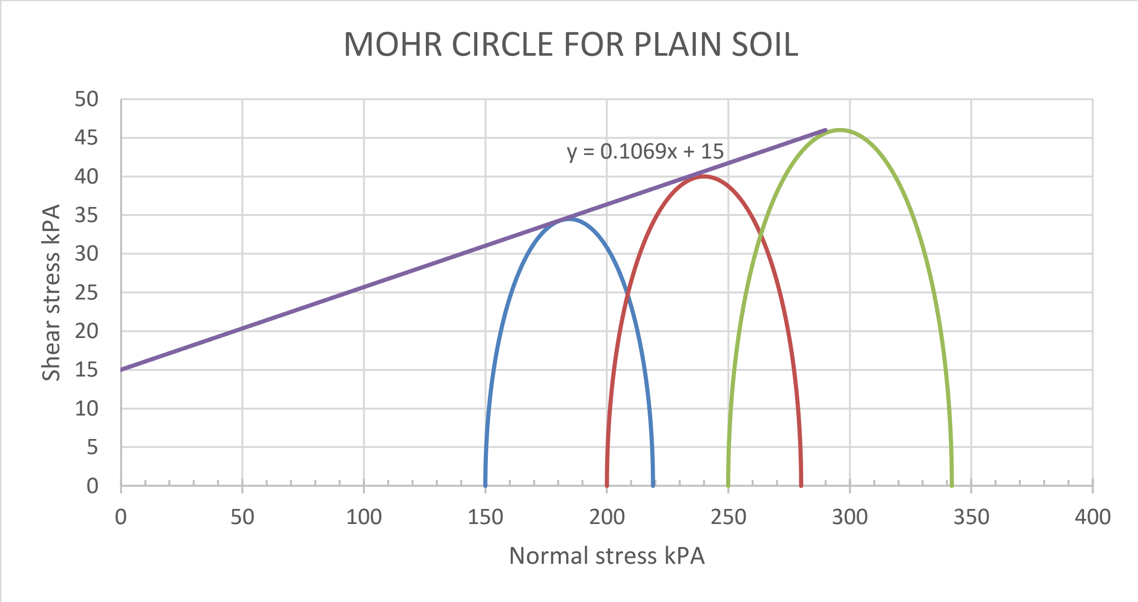

Figure 3: Mohr's circle for soil sample

Cohesion for soil sample S1, S2 and S3 from *figure 1*= 15

Angle of Friction=tan $^{-1}$ (0.1069) =6.101^{0}

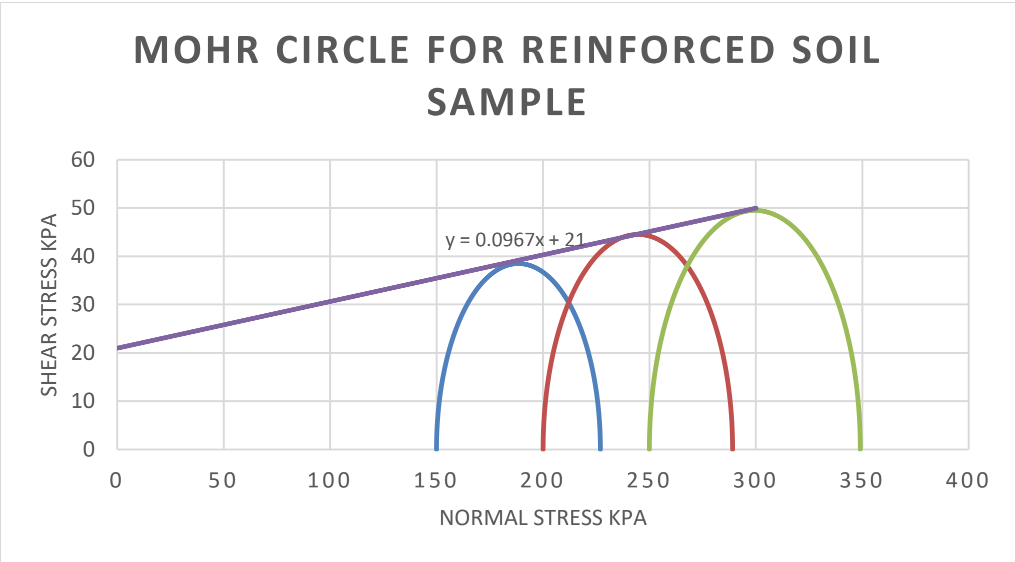

Figure 4: Mohr's circle for geogrid reinforced soil

Cohesion for soil sample G1, G2 and G3 from *figure 4*= 21

Angle of Friction=tan $^{-1}$ (0.0967) =5.523^{0}

For a square footing of 1500mm, the Terzaghi formula can be applied

$q_{ult}=1.3c \cdot N_c+\gamma \cdot D \cdot N_q+0.4 \cdot \gamma \cdot B \cdot N_\gamma$

Where, q_{ult}: is the ultimate bearing capacity.

c: cohesion of the soil.

γ: unit weight of the soil. =18 Kn/M (for moist clayey soils)

D: depth of the foundation. =1m

B: width of the footing =1500mm

N_c, N_q, and N_γ: are bearing capacity factors dependent on the soil's angle of internal friction (φ)

For $5.523^{0,}$ Nc=6.8, Nq=1.1 and Ny=0.18

6.101^{0}, Nc=7.2, Nq=1.13 and Ny=0.20

Therefor the ultimate bearing capacity for Reinforced soil is

= (1.3*21*6.8) +(18*1*1.1) +(0.4*18*1.5*0.18)

=**164.54KPa**

while the bearing capacity for plain unreinforced soil is

= (1.3*21*7.2) +(18*1*1.13) +(0.4*18*1.5*0.20)

=**130.5KPa**

Increase in Bearing capacity is therefore

= ((164.54-130.5)/(164.54))*100%

= **26.1%**

From the above results, it is ascertained that in reinforces soil with 26.1% more shear strength is observed leading to a higher ultimate bearing capacity. With this in mind, geogrids can be applied in soil reinforcement.

Depending on the interaction between the soil particles and the geogrid a decrease in friction angle is realized. As illustrated in the current analysis, the Mohr-Coulomb envelope for the geogrid-reinforced sample shows a friction angle of approximately 5.52°, slightly lower than that of the unreinforced sample with a friction angle of 6.10°. This behaviour is supported by findings from Kim (2014) which demonstrate that particle size and gradation affect the interlocking efficiency with geogrids. In cases where fine particles dominate or poor interlock exists, the reinforcement may reduce the effectiveness of friction mobilization, leading to a lower apparent friction angle.

Despite this, the cohesion of the reinforced sample increases (from 15 kPa to 21 kPa in this case), contributing to an overall enhancement in shear strength. This increase in cohesion is attributed to the mechanical confinement effect induced by the geogrid, which bridges across potential failure surfaces, effectively restraining soil displacement. The study by Jie Liu (Jie Liu, 2014) verifies that pull-out resistance and interface bonding between geogrid and soil significantly contribute to higher cohesion-like behaviour. Thus, the presence of reinforcement can result in increased overall shear strength through enhanced confinement and apparent cohesion, even if the friction angle does not increase or slightly declines.

IV. CONCLUSION

This paper confirms that geogrids, as a reinforcement material for clayey soils, are effective despite the properties of clayey soils, as proven by the experiments conducted. After carrying out the said experiments, it is proven that geogrids not only provide adequate reinforcement, but they are also an effective way of strengthening weak clayey soils.

In conclusion, the use of this cost-effective reinforcement method is feasible and practicable for use in structural engineering and can efficiently be included as one of the foundation remediation strategies for weak or problematic soils.

REFERENCES

[1] Abusharar, S. W., El Sawwaf, M., & Youssef, S. (2016). Bearing capacity of shallow footings on geogrid-reinforced sand overlying natural clay. Soils and Foundations, 56(5), 912–923

[2] ASTM,. (2011). Standard Test Method for Consolidated Undrained Triaxial Compression Test for Cohesive soils, D4767 − 11. ASTM International.

[3] Coduto, D. ,. (2011). Geotechnical Engineering: Principles and Practices(2nd Edition ed.). Pearson.

[4] Das, B. M. (2016). Principles of Foundation Engineering (8th ed.). Cengage Learning.

[5] Dash, S. &. (2007). Bearing Capacity of strip footings supported on geocell-reinforced sand. Geotextiles and Geomembranes, 267-274.

[6] DragonPlate. (2025). Retrieved May 2025, from Alfred and Associates Inc.: https://dragonplate.com

[7] Giroud, J. ,. (2004). Design Method for geogrid-reinforced unpaved roads.1.Development of design method. Journal of Geotechnical and Geoenvironmental Engineering., 775-786.

[8] Jie Liu, J. P. (2014). Experimental study on the interface characteristics of geogrid-reinforced gravelly soil based on pull-out tests. Springer Nature.

[9] Kim, D. (2014). Effects of Particle Size on the Shear Behavior of Coarse Grained Soils Reinforced with Geogrid. MDPI.

[10] Koerner, R. (2005). Designing with Geosynthetics (5th ed.). Pearson Prentice Hall.

[11] Lhr, S. G. (2015). Determination of shear strength parameters of a given soil sample using the triaxial compression test. Seismic Group UET Lhr.

[12] Moghaddas Tafreshi, S. &. (2010). A Comparison of static and cyclic loading responses of foundations on geocell-reinforced sand. Geotextiles and Geomembranes, 434-447.

[13] Naeini, S. &. (2008). The Effects of geogrid reinforcement on bearing capacity of granular soils. International Journal of Civil Engineering, 267-274.

[14] Nataraj, M. S., & McManis, K. L. (1997). Strength and deformation properties of soils reinforced with fibrillated fibers. Geosynthetics International, 4(1), 65–79.

[15] Palmeira, E. M. (2009). Soil–geosynthetic interaction: Modelling and analysis. Geotextiles and Geomembranes, 27(5), 368–390.

[16] Shukla, S. K. (2017). Fundamentals of geosynthetic engineering (2nd ed.). CRC Press.

[17] Tang, C., Shi, B., Gao, W., Chen, F., & Cai, Y. (2007). Strength and mechanical behavior of short polypropylene fiber reinforced and cement stabilized clayey soil. Geotextiles and Geomembranes, 25(3), 194–202.

[18] Tomlinson, M. J., & Woodward, J. (2014). Foundation design and construction (7th ed.). CRC Press.

[19] Zhang, R., Chen, Q., & Zhang, X. (2018). Influence of soil structure and aggregate stability on infiltration characteristics in a sandy loam soil. Geoderma, 318, 32–39.