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Experimental Evaluation of Sandy Soil Reinforced with Synthetic Fiber for Bearing Capacity

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دراسة معملية لقدرة تحمل التربة الرملية المحسنة باستخدام الألياف الصناعية

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Abstract:
Many sites need to improve the soil before implementing the projects. There are many methods to improve the soil, but some methods have a negative impact on the environment, such as chemical improvement. At the same time, another one is as expensive as replacement soil. Therefore, it was searched for economical ways that are less harmful to the environment. One of the most effective and reasonably priced ways to enhance the characteristics of sandy soil, according to earlier research, is synthetic fiber. This paper's findings describe the usage of locally sandy soil to increase the stability and bearing capacity of woven jute cloth. The study is to promote the use of geotextile, which has emerged as a significant technique for improving soil in recent years. The investigation shows that bearing capacity factors have significantly improved.
This study examines the impact of the layer depth of woven jute geotextile on bearing capacity factors and stability using poorly graded sandy soil SP as defined by ASTM-USCS. Results showed a significant improvement when the jute textile layer is closer to the surface than the penetrating depths, indicating the possibility of obtaining good stability and high resistance. Also, a small distance between the two layers yielded better results than using a large distance.

Keywords: Sandy Soil, Synthetic Fiber, Woven Jute, Bearing Capacity, Settlement.

الملخص
تحتاج العديد من المواقع إلى تحسين التربة قبل البدء في تنفيذ المشاريع. هناك العديد من الطرق لتحسين التربة، ولكن بعض هذه الطرق يؤثر سلبًا على البيئة مثل التحسين الكيميائي. في الوقت نفسه، يعتبر البعض الآخر مكلفًا كاستبدال التربة. لذلك، تم البحث عن طرق اقتصادية وأقل ضرراً على البيئة. تعتبر الألياف الاصطناعية إحدى الطرق الأكثر فعالية والأقل تكلفة اقتصادياً كما أشارت إليها العديد من الدراسات السابقة. تقدم هذه الورقة نتائج الاختبارات المعملية على التربة الرملية المحلية من مدينة رأس لانوف والتي تم تحسين قدرتها على التحمل واستقرارها باستخدام الألياف الصناعية المنسوجة. حيث تهدف الدراسة إلى تشجيع استخدام الألياف الاصطناعية والتي أصبحت طريقة مهمة لتحسين التربة في السنوات الأخيرة. في هذا البحث تم استخدم رمل سيء التدرج حسب تصنيفه بالنظام الموحد ASTM-USCS لدراسة تأثير عمق طبقات الخيش

وعددها على قدرة تحمل التربة وهبوطها. وأظهرت النتائج تحسنًا كبيرًا عندما كانت طبقة النسيج أقرب إلى السطح وكذلك عندما كانت المسافة صغيرة في حال استخدام طبقتين.

الكلمات المفتاحية: تربة رملية، ألياف صناعية، خيش منسوج، قدرة التحمل، هبوط التربة.

Introduction

A building's foundation is its most critical component. Errors in its design or construction can lead to catastrophic structural failures. For this reason, a thorough evaluation of the construction site's conditions is essential, typically involving both on-site inspections and laboratory analysis. In regions with loose, sandy, or otherwise weak soil, measures must be taken to strengthen the ground to guarantee the safety and stability of any structure built upon it. The soil must be sufficiently solid and have a high enough load-bearing capacity to support the weight of the building and prevent it from sinking.

Various techniques and materials exist to achieve this soil improvement. Generally, when reinforcing soil, several key principles must be considered to avoid different modes of failure. First, if the initial layer of reinforcement is placed too deep, the ground above it can collapse because it behaves as an unsecured mass. This risk is mitigated by positioning this upper layer closer to the base of the foundation. Second, if the reinforced layers are spaced too far apart vertically, the soil between them can give way. Therefore, maintaining a careful vertical distance between these layers is crucial. Third, if the reinforcing elements are not strong or plentiful enough for a large reinforced area, the entire reinforced block can fail as a single unit, with the depth of this block determining how the collapse manifests. Finally, if the reinforced zone itself is made of two distinct soil types—a weaker layer under a stronger one—a collapse can occur within this composite zone Wayne et al. (1998) [1].

The performance of reinforced sand foundations was explored by Laman et al. (2007) [2] through both physical and numerical modeling. Their analysis of ring foundations indicated that incorporating geogrid reinforcement could improve ultimate bearing capacity by a factor of three. The study determined that the most effective setup involved four geogrid layers with a width of 3D placed at a depth of 0.3D. These experimental outcomes were corroborated by finite element analysis conducted in Plaxis using a hardening soil model, affirming the value of geogrids for foundation strengthening.

Complementing this work, Altalhe et al. (2012) [3] investigated strip foundations on reinforced slopes. Through an extensive series of 117 lab tests, the impact of geotextile reinforcement variables was quantified. The data showed that bearing capacity multipliers increased with the number of layers, reaching values up to 8 for a three-layer system. A key finding was that optimal performance was achieved when the vertical spacing between geotextile layers was set at 0.3B.

Noorzad et al. (2013) [4] conducted a finite element analysis using Plaxis software to model the interaction of twin strip footings on geotextile-reinforced soft clay. Their investigation focused on key parameters such as reinforcement depth, layer count and spacing, tensile stiffness, and the clearance between the footings. The findings confirmed that geotextile inclusion markedly increases bearing capacity while reducing settlement. Peak performance was achieved with specific configurations: a top layer depth of 0.2-0.3 times the footing width (B) and a footing separation of around 2B. Furthermore, the research indicated that exceeding a certain stiffness threshold for the reinforcement offers minimal additional benefit, establishing an optimal number of layers (Nopt) beyond which the returns diminish.

In a related 2014 study, Kazi et al. [5] explored the performance of an embedded strip footing on sand reinforced with multiple layers of woven geotextile, combining laboratory tests with PLAXIS 2D simulations. They determined that adding more geotextile layers consistently enhanced bearing capacity. A significant discovery was that using reinforcements with wraparound ends substantially outperformed straight-edge sheets, offering superior confinement and settlement control. The optimal number of layers for maximum benefit was found to be between two and four, varying with the footing's embedment depth. The numerical model showed strong agreement with experimental results at lower settlement values.

Oria et al. (2017) [6] investigated a technique to improve the geotextile-sand interface by treating it with cement. Laboratory tests on sand reinforced with a single geotextile layer of varying lengths demonstrated that cement treatment strengthened the soil-reinforcement interaction, boosting bearing capacity by 6–17%. This effect was most pronounced for shorter reinforcement lengths. The treatment also reduced the required length of geotextile by approximately 40% to achieve a target bearing capacity. These experimental outcomes were validated by complementary numerical modeling.

Altalhe et al. (2018) [7] performed 21 plate load tests to analyze strip footing behavior on sand slopes reinforced with shredded polystyrene. Variables included polystyrene content (5%, 10%, 15% by weight), reinforced layer depth (1B and 2B), and sand density (60%, 70%, 85%). The results indicated that incorporating polystyrene shreds increases the bearing capacity ratio (BCR) and reduces settlement, with effectiveness growing alongside reinforcement content and soil density. This approach presents a method to enhance sandy slope properties while repurposing waste material.

Aria et al. (2019) [8] evaluated the efficacy of the wraparound geotextile technique using PLAXIS-3D simulations. The study analyzed the impact of lap length and reinforcement width across three soil densities (50%, 70%, 90%). The wraparound method increased bearing capacity by up to 120% over unreinforced soil and by about 45% over standard reinforcement without wrapped ends. This technique enhances shear strength mobilization and minimizes horizontal displacement, proving advantageous for construction sites with limited space. A regression model was developed to predict the BCR based on lap length and width, showing little influence from soil density.

A 2020 review by Guo et al. [9] synthesized developments in geosynthetic-reinforced soil (GRS) foundations. It examined the mechanisms—such as lateral restraint, tensioned membrane effect, and stress dispersion—by which geogrids and geotextiles improve bearing capacity and reduce settlement. The review encompassed experimental model tests, numerical methods (FEM, FDM, DEM), and analytical models for predicting ultimate capacity. It also highlighted research gaps, including a need for understanding dynamic behavior, reinforcement-soil interaction, and failure mechanisms, advocating for more large-scale field testing and unified analytical models.

In a complementary study, Chen et al. (2021) [10] employed experimental and numerical methods to study geogrid-reinforced foundations. Laboratory model tests on strip footings involved observing displacement and failure patterns digitally for sand reinforced with geogrids of different lengths and layer numbers. The research showed that more and longer reinforcement layers improved foundation bearing capacity and stiffness. Failure propagated progressively from the bottom layer upward, a process accurately captured by FLAC 2D simulations. The reinforcement mechanism was attributed to more uniform stress distribution and restricted soil movement.

Recent geotechnical research has validated the efficacy of geosynthetic reinforcement in enhancing soil performance for foundation support. Ateş and Şadoğlu (2024) performed plane-strain laboratory tests on dense sand to analyze a strip footing supported by wrap-around geotextile layers. Their study, which utilized Shukla's reinforcement technique, involved varying the number of geotextile layers, their depth of placement, and their wrap length. The most favorable outcomes were observed using three reinforcement layers placed at a depth of 0.3 times the footing width (B) with a wrap length of 2B. This configuration achieved a bearing-capacity ratio above three and reduced settlement by 78% compared to unreinforced sand. Analysis via particle-image velocimetry revealed a combined failure mechanism, integrating punching shear within the reinforced zone with a broader general shear failure beneath it.

Finally, Nasery et al. (2025) evaluated the protection of buried uPVC pipes from rock-fall impacts using geogrid-reinforced sand cushions. Combining physical impact tests with numerical modeling, they determined that a 0.3 m reinforced sand overlay significantly reduced peak pipe strain by 42% and vertical displacement by 78%. Furthermore, increasing the soil cover height diminished pipe deflection by an additional 16%. Their parametric analysis concluded that geogrid stiffness and layer thickness are more critical than tensile strength, identifying an optimal design with specific aperture size and spacing.

Inspired by these findings on improved bearing capacity and reduced settlement, this study investigates the application of reinforced soil foundations, specifically within the Libyan context. A common challenge for construction in Libya is the prevalence of soils with low load-bearing strength. This research aims to address this by exploring efficient techniques and optimal geotextile selection to ameliorate soil properties. The potential of woven jute geotextile to enhance the engineering characteristics of sandy soil from Ras-lanuf City is examined through a series of laboratory experiments designed to quantify improvements in bearing capacity.

Concept of Reinforcement

A common and economical approach to strengthening weak subsoil is partial-depth replacement with an engineered fill. This fill consists of soil amended with manufactured fibers of a specific width. These fibers act as reinforcement, significantly increasing the soil's bearing capacity while simultaneously reducing settlement. The design calculations for this method, including bearing capacity, often rely on established principles like Terzaghi's equation.

$$q_u = 1.3CN_c + qN_q + 0.4\gamma B$$

Previous research has determined the value of the coefficient that expresses the increase in soil bearing capacity, as shown in the following equation.

$$\text{Bearing capacity ratio (BCR)} = \frac{Bearing capacity of renforced soil}{Bearing capacity of unrenforced soil} = \frac{q_r}{q_o}$$

The calculation of this coefficient incorporated multiple factors, such as the quantity of geotextile layers and their individual placement depths.

Materials Used

Soil

For the present study, samples of fine golden sand were collected from Ras Lanuf city in Libya to evaluate the bearing capacity of reinforced sandy soil beneath footings. The sampling process, conducted in autumn, involved retrieving material from various depths between 10 cm and 50 cm below the ground surface (Figure 1). Analysis of the soil's particle size distribution, shown in Figure 2, led to its classification as a poorly graded sand. Finally, Table 1 details the engineering properties of this sand, as determined by ASTM testing methods.

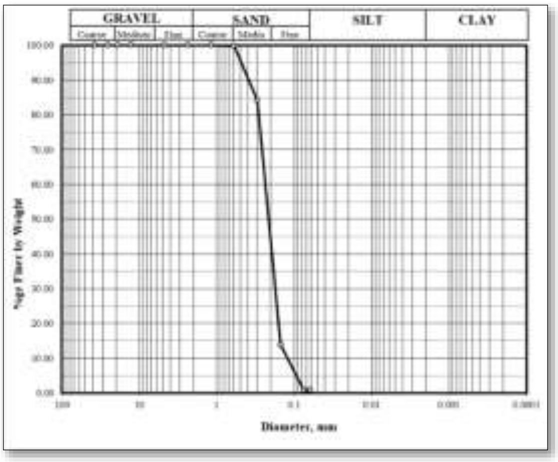


Figure 1: Soil Sample. **Figure 2:** The Particle Size Distribution.

Table 1: properties of sandy soil.

SN.	Test	Test Designation	Value
1	Unified Classification	ASTM-D2487	SP
2	CU		2.3
3	Cc		1.1
4	Specific Gravity	ASTMD-854-58	2.6
5	Relative Density	ASTMD-4254	60%
7	Dry Density	ASTMD-2216-71	1.7 g/cm^3
8	Water Content	ASTM-C-128	1.17%
9	Absorption Rate	ASTMD-2434	1.83g/cm3
10	Permeability	ASTMD-2434	1.609×10^{-3} cm/sec
11	Cohesion	ASTMD-3080	5 kN/m^2
12	Friction Angle	ASTMD-3080	38.6^o

Reinforced Material

The geotextile shown in Figure 3 is used. A manufactured material called woven jute geotextile is available in local markets at an economical cost. Therefore, the mechanical properties of the jute textile were studied, as shown in Table 2.

Figure 3: Reinforced Material**.**

Table 2: Properties of Geotextile

SN.	Test	Test Designation	Value
1	Density (mass per unit)	ASTMD-1556	284.6 g/m^2
2	Elongation	ASTMD-3039-76	3.5%
3	Elasticity Modulus		20.4 kg/cm^2
4	Textile Porosity	ASTMD-737	1mm

Test Methodology

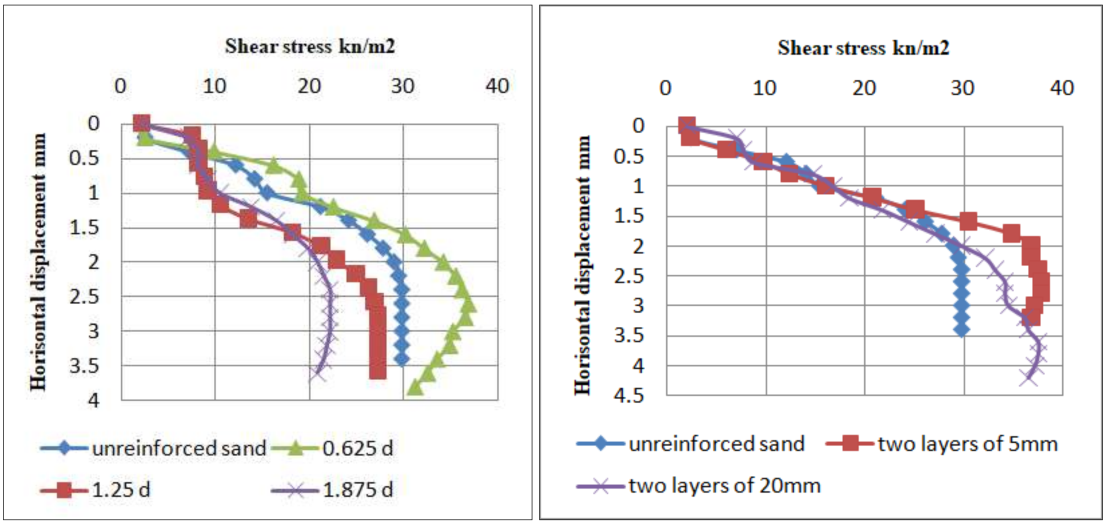
A direct shear apparatus, following the ASTM-D3080 standard, was employed to establish the bearing capacity factors of unreinforced soil. Normal loads of 2 kg, 4 kg, and 8 kg were applied to samples maintained at a dry density of 1.7 g/cm³ and a relative density of 60%. Subsequently, reinforcement strips were positioned at varying depths, expressed as a percentage of the shear box's total depth (d). The investigation also included tests on two-layer reinforcement configurations with vertical spacing's of 5 mm and 20 mm.

Result and Discussion

The study evaluated three reinforcement depths within the shear box: the first in the upper half (0.625d), the second at the central axis (1.25d), and the third in the lower half (1.875d). For two-layer systems, spacings of 5 mm and 20 mm were compared. The complete dataset is provided in Table 3, with the findings for the 8 kg normal load presented graphically in Figures 4a and 4b.

Table 3: Improvement Ratio of Bearing Capacity with Varying Depth and Number of Reinforcement Layers.

SN.	Description of Reinforcement Layer Location	Reinforcement Layer Depth as a Ratio of Box Depth	Bearing Capacity Ratio (BCR)
1	Soil without reinforcement	-----	1
2	Reinforcement layer in the middle of the upper part of the box	0.625d	1.69
3	Reinforcement layer in the middle of the box	1.25d	1.394
4	Reinforcement layer in the middle of the lower part of the box	1.875d	1.199
5	Two reinforcement layers spaced 5mm.	-----	2.42
6	Two reinforcement layers spaced 20mm.	-----	1.393

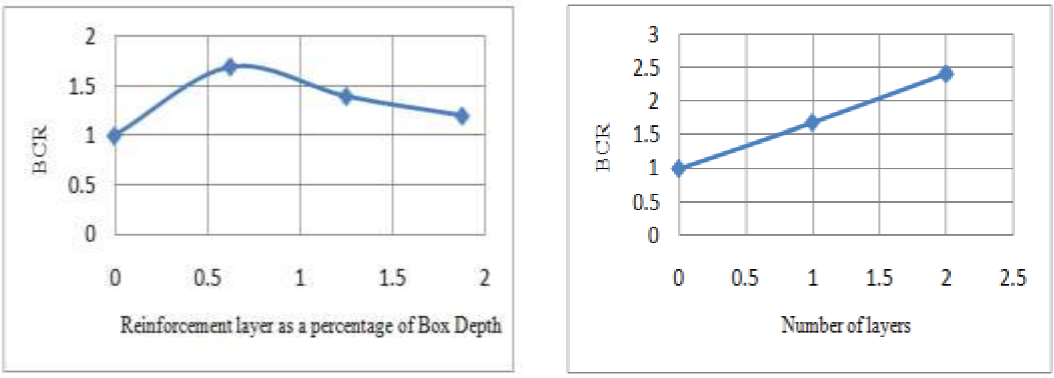


a- The Result at Different Depths **b-** The Result of Two L layers

Figure 4: The Relation between Shear Stress and Horizontal Displacement**.**

The positioning of woven jute layers directly alters the shear stress distribution within the soil. Placing a layer near the surface induces a localized increase in shear stress, concurrently causing a decrease in other regions. The study also noted that the peak stress zones of two adjacent layers were proximate to each other.

As illustrated in Figures 4-a and 4-b, the bearing capacity ratio (BCR) peaks when the reinforcement is installed at a depth of 0.625d beneath the foundation box. This optimal placement suggests that shallow reinforcement significantly improves the system's performance compared to unreinforced soil. A subsequent increase in the number of geotextile layers also leads to a higher BCR. This outcome corroborates research by Binquet and Lee (1975) and Enas B. Altalhe (2018), despite differences in their reinforcement methodologies.



a-Effect of Layer Depth on B.C.R **b-** Effect of Number of Layers on B.C.R

Figure 5: The Effect of Layer Depth and Number on BCR.

Conclusion

Key findings from direct shear tests on synthetically reinforced SP. soil:

- **Optimal Depth:** The first reinforcement layer is most effective at a depth of 0.625d, increasing bearing capacity by up to 1.69%. Exceeding this depth causes the layer to act as a rigid base, forcing a failure plane to develop above it.
- **Multiple Layers:** Increasing the number of reinforcement layers further improves the soil's bearing capacity and reduces settlement.
- **Layer Spacing:** A close vertical spacing between layers is critical; too much distance can compromise the structure and lead to collapse.

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