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Assessment of Geogrid Application in Reduced-Scale Footing with Transparent Soil

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ABSTRACT: This study presents an experimental investigation into the application of geogrids for basal reinforcement of footings. To achieve this, a series of reduced-scale load tests were conducted on a transparent granular soil foundation. These tests involved the strategic placement of a single layer of geogrid at varying depths. In addition to the load tests, a suite of geotechnical characterization assessments and transparency quantification measurements were meticulously performed to gain insights into the complex behavior of the transparent soil medium. This comprehensive characterization provided valuable information regarding the soil's response to the geogrid reinforcement. Furthermore, the study included a detailed investigation of the geogrid material itself, with a focus on measuring its tensile strength properties. The results derived from this research effort not only contributed to determining the optimal depth for geogrid embedment, accounting for geometric constraints, but also unveiled the substantial influence of the geogrid positioning on the reinforcement strategy. These findings offer valuable insights into the practical implementation of geogrids for footing reinforcement, ultimately advancing our understanding of soil-engineering interactions and their implications for structural stability and safety.

KEYWORDS: Geogrids, Basal Reinforcement, Footings, Transparency Quantification.

RESUMO: Este estudo apresenta uma investigação experimental sobre a aplicação de geogrelhas para reforço basal de fundações. Para alcançar esse objetivo, uma série de testes de carga em escala reduzida foram conduzidos em uma fundação de solo granular transparente. Esses testes envolveram a colocação estratégica de uma única camada de geogrelha em profundidades variadas. Além dos testes de carga, uma série de avaliações de caracterização geotécnica e medidas de quantificação de transparência foram realizadas para obter entendimento sobre o comportamento complexo do meio de solo transparente. Essa caracterização abrangente forneceu informações relevantes sobre a resposta do solo ao reforço com geogrelha. Além disso, o estudo incluiu uma investigação sobre o próprio material da geogrelha, com foco na medição de suas propriedades de resistência à tração. Os resultados derivados deste esforço de pesquisa não apenas contribuíram para determinar a profundidade ideal para a incorporação da geogrelha, levando em consideração as condições geométricas, mas também revelaram a influência substancial da posição da geogrelha na estratégia de reforço. Essas descobertas oferecem uma melhor compreensão para a implementação prática de geogrelhas no reforço de fundações, avançando assim no entendimento das interações solo-engenharia e suas implicações para a estabilidade e segurança estrutural.

PALAVRAS-CHAVE: Geogrelhas, Reforço Basal, Sapatas, Quantificação da Transparência.

1 INTRODUCTION

Soils, as defined for engineering purposes, consist of loose or weakly bound mineral particles responsible for supporting foundations. The study of soil encompasses a wide range of variables and can be highly complex. Generally, soils tend to possess low tensile strength and undergo significant deformations when subjected to loading, particularly in shallow foundation scenarios. In such circumstances, the level of deformation induced by shallow foundations can be considerable, often necessitating the adoption of more robust solutions, such as deep foundations, which can substantially increase project costs (Ferreira & Zornberg, 2015).

The utilization of geogrids for basal reinforcement of footings has garnered considerable attention in geotechnical engineering owing to their potential to increase the stability and load-bearing capacity of soil foundations. Geogrids, typically composed of high-strength polymer materials, are distinguished by their capacity to distribute loads, and restrain soil movement, consequently enhancing the performance of shallow foundations under vertical and horizontal loading conditions. However, further studies in this regard are necessary to gain a deeper understanding of the geotechnical behavior of this solution.

In this context, various techniques have been employed to study basal reinforcement of footings, including numerical analyses and experimental studies, both in laboratory and field settings. In terms of laboratory studies, the use of transparent soils has emerged as a particularly intriguing investigative alternative, providing valuable insights into soil dynamics.

Transparent soils constitute a biphasic medium comprising solid particles immersed in a saturation fluid, both characterized by their transparency and compatible refractive indices (Iskander & Liu, 2010). One of the significant implications of this unique characteristic is that light beams passing through this medium follow a linear trajectory due to the equivalence of refractive indices, creating a homogeneous medium for light transmission. This phenomenon allows detailed visualization of relative movements among solid-phase particles, providing insight into their interactions and their interactions with other objects. Notable applications of transparent soils include analyzing soil-structure-geosynthetic interaction (Ezzein & Bathurst, 2011, 2014; Ferreira & Zornberg, 2015), investigating pile penetration in clayey and sandy soils (Ni et al., 2010; Hird et al., 2011; Stanier et al., 2014), and conducting centrifuge tests for foundation modeling (Song et al., 2009; Black, 2015).

In this context, this study presents an experimental investigation focused on assessing the effectiveness of geogrids in basal reinforcement of footings. Specifically, a series of reduced-scale load tests were conducted on a transparent granular soil foundation, allowing for direct observation and analysis of soil-structure interactions. The utilization of transparent soil models offers a unique advantage by providing visual access to the underlying soil behavior, enabling a detailed examination of reinforcement mechanisms and load transfer mechanisms.

2 MATERIALS AND METHODS

The materials utilized in this research comprised transparent sandy soil and reduced-scale geogrids. The key properties of interest for the research are described subsequently, followed by detailed explanations of the 1-g reduced scale load tests.

2.1 Transparent Soil

The solid matrix utilized to produce the transparent sand in this research consisted of high purity fused quartz. The supplier reported that the fused quartz contained over 99.995% amorphous silica (SiO_2), with a refractive index of 1.4585 and a specific gravity of 2.2. Prior to use, the material underwent a cleaning process with isopropyl alcohol followed by grinding. Details of the quartz fragment processing are presented in Figure 1.

Particle size distribution was determined through sieving (NBR 7181, as in ABNT, 2016), with grains ranging from 2.36×10^{-3} m to 2.0×10^{-3} m diameter selected for subsequent tests. The scaling factor adopted in this research was equal to 10, resulting in quartz grain dimensions ranging from 2.36×10^{-2} m to 2×10^{-2} m in prototype dimensions.

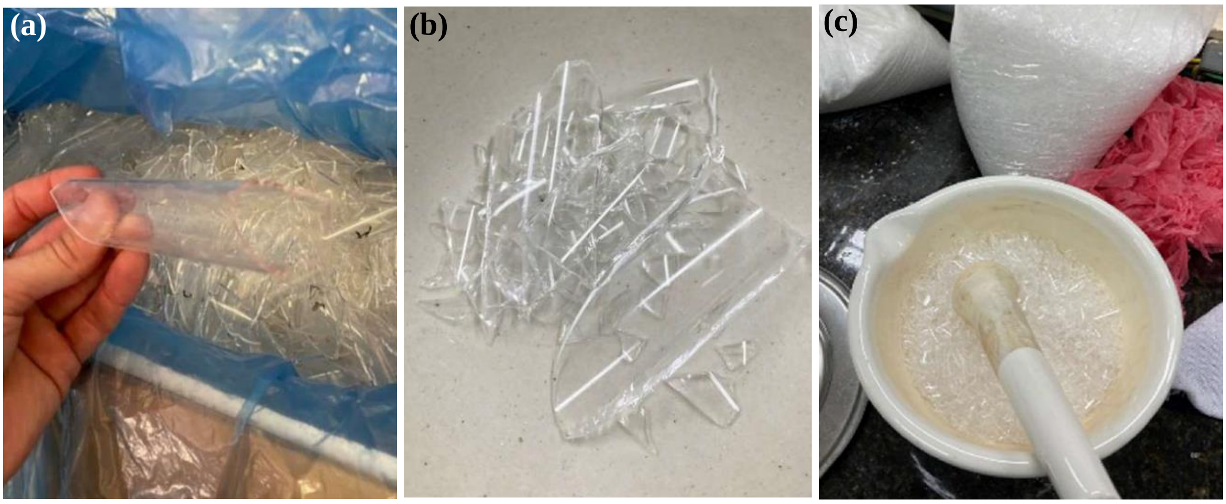


Figure 1. Preparation of transparent sand: (a) Quartz fragments prior to processing; (b) After cleaning with isopropyl alcohol; and (c) During the grinding process.

Sample saturation was achieved by mixing mineral oil and solvent (turpentine) in various concentrations. A digital refractometer measured the refractive indices of mineral oil (1.4746) and solvent (1.4287), while values for the mixtures are presented in Fig. 2(a). Transparency assessment was conducted using a benchtop turbidimeter, with results depicted in Fig. 2(b).

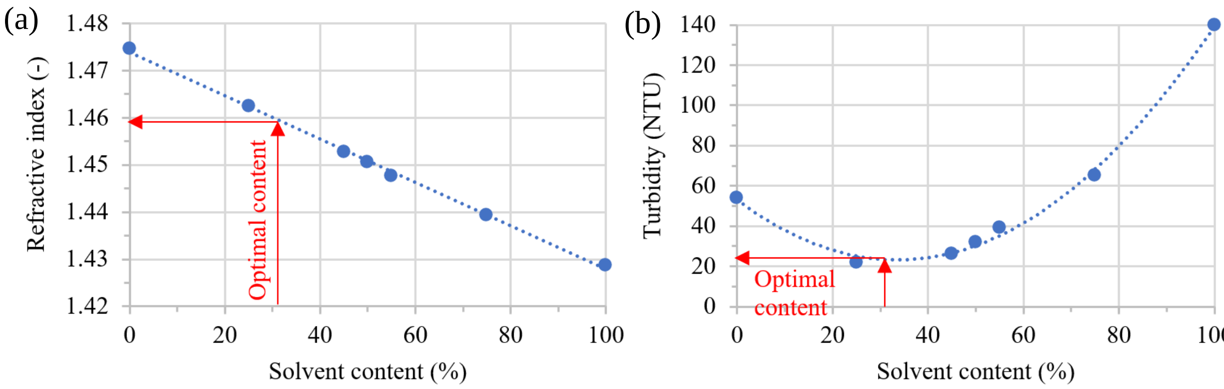


Figure 2. Mixtures of mineral oil and solvent (Pierozan et al., 2023): (a) Refractive indices; and (b) Turbidity.

Based on the data in Figure 2, the optimal mixture ratio for transparency was determined to be 69.2% mineral oil and 30.8% solvent. This ratio closely approximates the refractive index of fused quartz (1.4585) and coincides with the minimum turbidity determined for the mixture.

The minimum and maximum void ratios of the crushed fused quartz were determined according to technical standards, yielding values of 0.46 (NBR 16843, as in ABNT, 2020a) and 0.76 (NBR 16840, as in ABNT, 2020b), respectively.

2.2 Geogrid

Given the need to simulate a real geogrid on a reduced scale, a polyester screen with a nominal opening of 0.002 m was used, commonly employed as waterproofing reinforcement in the construction industry. This implies that, considering the scaling factor of 10 adopted in this research, the prototype-scale geogrid has dimensions of 2×10^{-2} m, which is typical of commercially available geogrids.

To better understand the stress-strain behavior of geogrids, an EMIC universal testing machine was utilized [Fig. 3(a)]. On the side of the equipment, there is a suitable grip available for sample fixation, as indicated in Fig. 3(b). The uniaxial tensile tests (NBR ISO 10319, as in ABNT, 2013) were conducted at a constant speed of 1.667×10^{-5} m/s, with loadings measured using a 5 kN load cell connected to a data acquisition system. A total of 5 samples were tested.

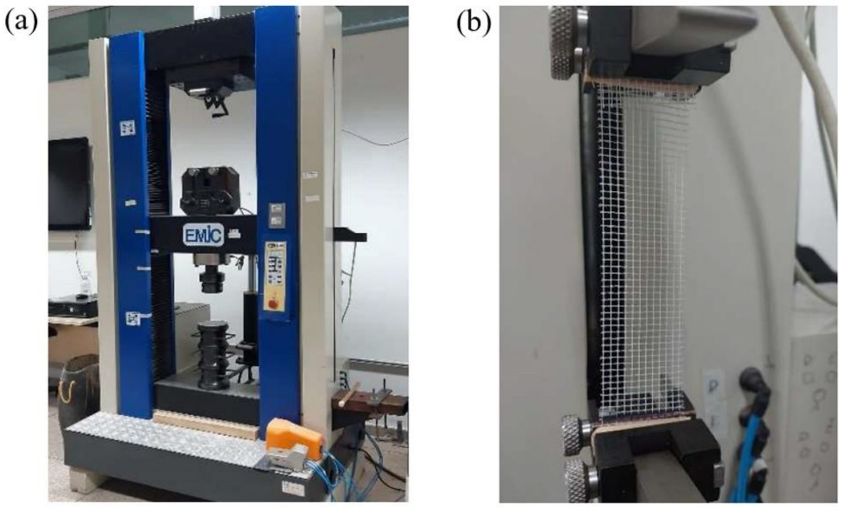


Figure 3. Uniaxial tensile tests of the reduced-scale geogrid: (a) EMIC universal testing machine; and (b) Sample during the test.

Based on the uniaxial tensile tests conducted with samples of the reduced-scale geogrid, average secant stiffness values were determined to be 0.41 kN/m, 0.83 kN/m, and 1.37 kN/m at axial deformations of 2%, 5%, and 10%, respectively.

2.3 1-g Reduced Scale Load Tests

Before assembling the essay, the quartz grain drop height was calibrated using the sand rain technique to achieve a homogeneous material in terms of relative density. For this purpose, the material was poured from various heights, and the resulting relative compactness was determined for each height. These values were then used to construct the calibration curve presented in Figure 4.

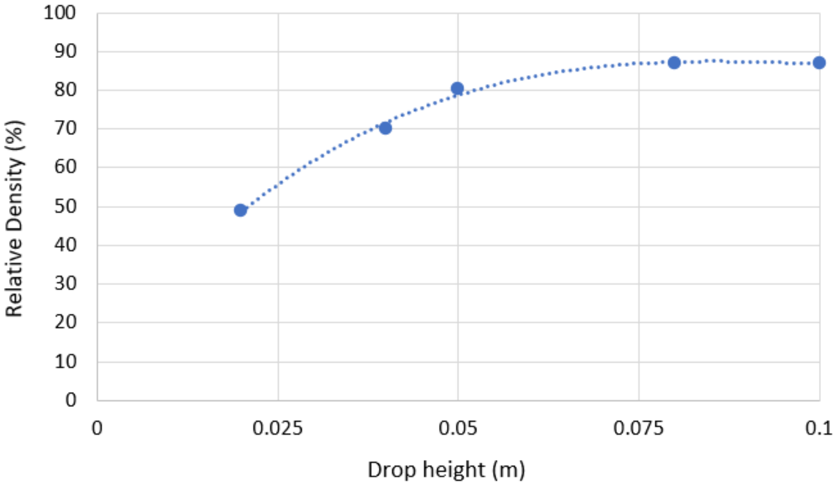


Figure 4. Calibration curve of quartz grain drop height.

Based on the results presented in Figure 4, a drop height of 0.05 m was adopted for the quartz grains, resulting in a relative compactness of approximately 80%. The material placement was carried out in stages, with enough material poured in each stage to fill a 0.01 m height inside the acrylic cube (Figure 5), followed by the saturation fluid being evenly spread. This procedure was necessary to prevent the incorporation of air bubbles.

Regarding strength parameters, Nelsen (2018) found friction angles of fused quartz grains to be 45° and 44° for dry and saturated conditions, respectively. Given the similarities between the materials used in both studies, these values were adopted in the present work.

Figure 5 displays an image of the acrylic cube used for the reduced-scale (1-g) experiments, indicating the internal dimensions of the cube with sides of 0.15 m, the base dimensions of the square footing (0.04 m x 0.04 m), and the height of quartz used in the experiments, which was 0.1 m. The geogrid used in the experiments had dimensions of 0.1 m x 0.1 m and was centrally positioned below the footing, with distances between the base of the footing and the geogrid set at 0 m, 0.01 m, 0.02 m, 0.03 m, and 0.04 m. Each test was conducted with only one layer of reinforcement.

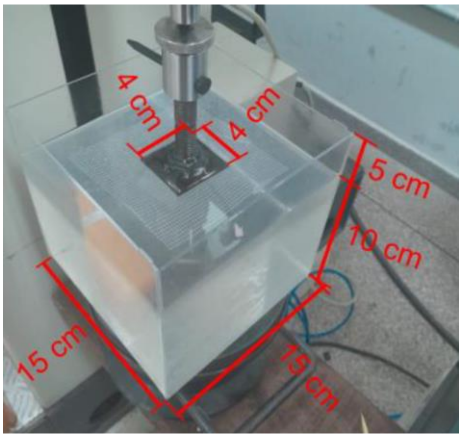


Figure 5. Physical model of a shallow foundation reinforced with geogrids.

The load tests were conducted using the same universal testing machine as previously indicated. The rate of load application was set to 1.667×10^{-5} m/s, and the load monitoring was carried out automatically with the assistance of a load cell with a capacity of 5 kN and a data acquisition system connected to it.

3 RESULTS AND DISCUSSION

In Figure 6, the results of the 1-g reduced scale load tests are presented in terms of stresses at the base of the footing versus vertical displacements.

Based on the results presented in Figure 6, it can be observed that the unreinforced solution, designated as unreinforced quartz, exhibited the lowest resistance values, as expected. However, when a layer of geogrid was included immediately below the footing (referred to as embedding equal to 0 m), there was a slight increase in resistance; nevertheless, the values approached those measured for the unreinforced quartz. On the other hand, considering an embedding equal to 0.01 m resulted in a significant increase in the measured stresses, indicating this as the most favorable geometry in terms of resistance. Similarly, embedding equal to 0.02 m also showed high resistance values, although lower than those observed with an embedding of 0.01 m. Likewise, embedding equal to 0.03 m resulted in lower values than those measured with an embedding of 0.02 m, and embedding of 0.04 m exhibited even lower values compared to embedding of 0.03 m. It is worth noting that in the case of embedding equal to 0.04 m, the stress values approached those measured in the case of unreinforced quartz and zero embedding.

Considering that the footing has a lateral dimension equal to B, with this value being equal to 0.04 m, and that the embeddings of 0.01 m, 0.02 m, 0.03 m, and 0.04 m correspond to B/4, B/2, (3×B)/4, and B, respectively, it can be concluded that the geometry that best favored the mobilization of resistance by the geogrid was that corresponding to B/4, making it the most economical solution. On the other hand, considering an embedding with a value equal to B resulted in a very small increase in resistance, approaching the situation where there is no reinforcement, making it not an economically and technically advantageous solution. Furthermore, it is important to note that increasing the depth of installation of the geogrid incurs costs and greater construction difficulties, highlighting the importance of adopting the most economical configuration.

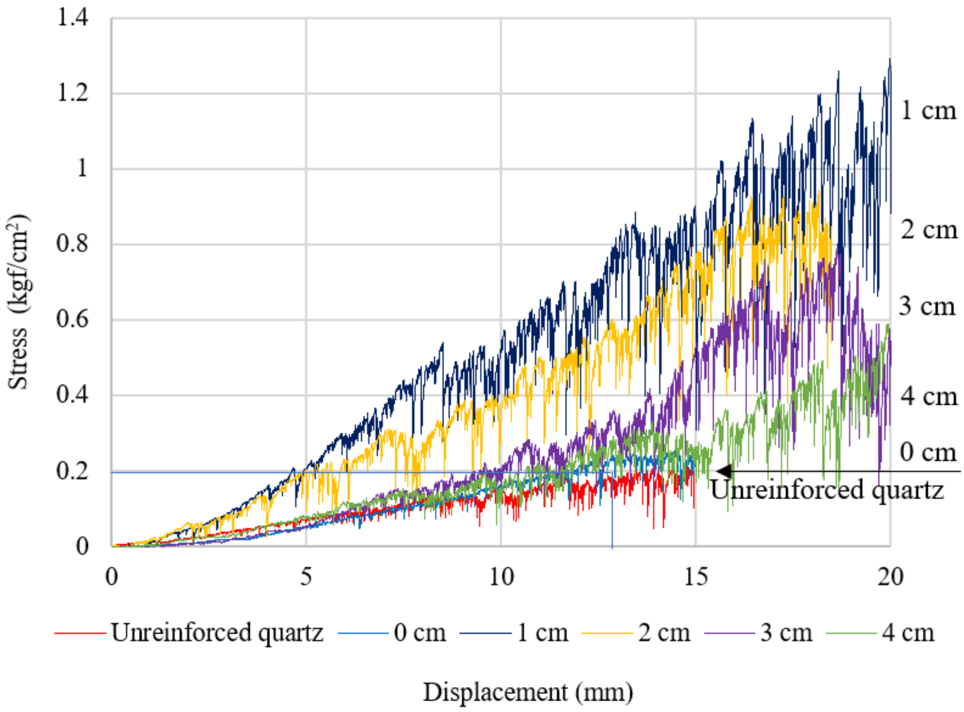
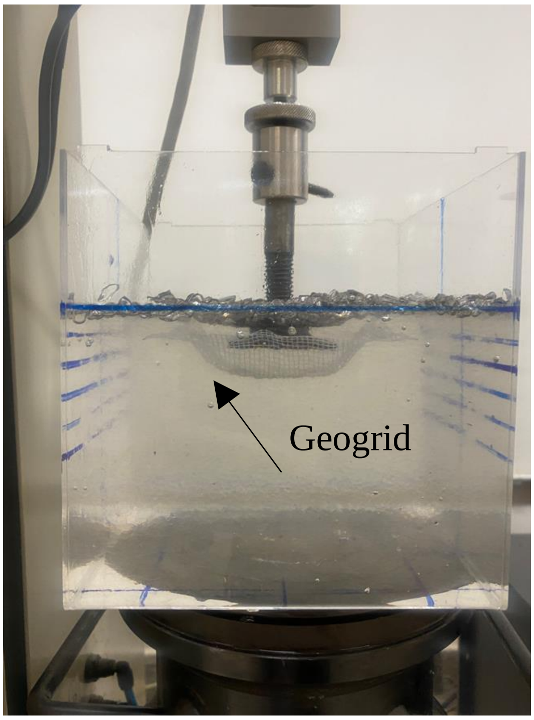


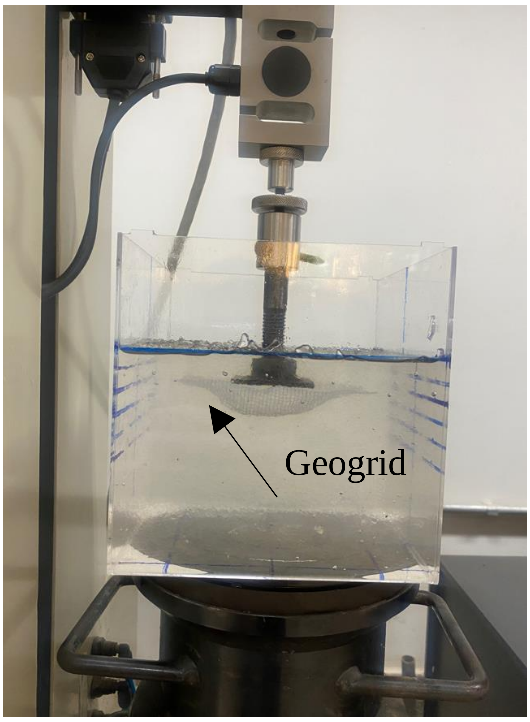
Figure 6. Stresses measured at the base of the footing in relation to the vertical displacements of the footing, considering the unreinforced quartz and depths of geogrid embedding equal to 0 m, 0.01 m, 0.02 m, 0.03 m, and 0.04 m.

To complement the presented results, Figure 7 depicts the geogrid configurations for vertical displacements of 0.015 m.

(a)



(b)



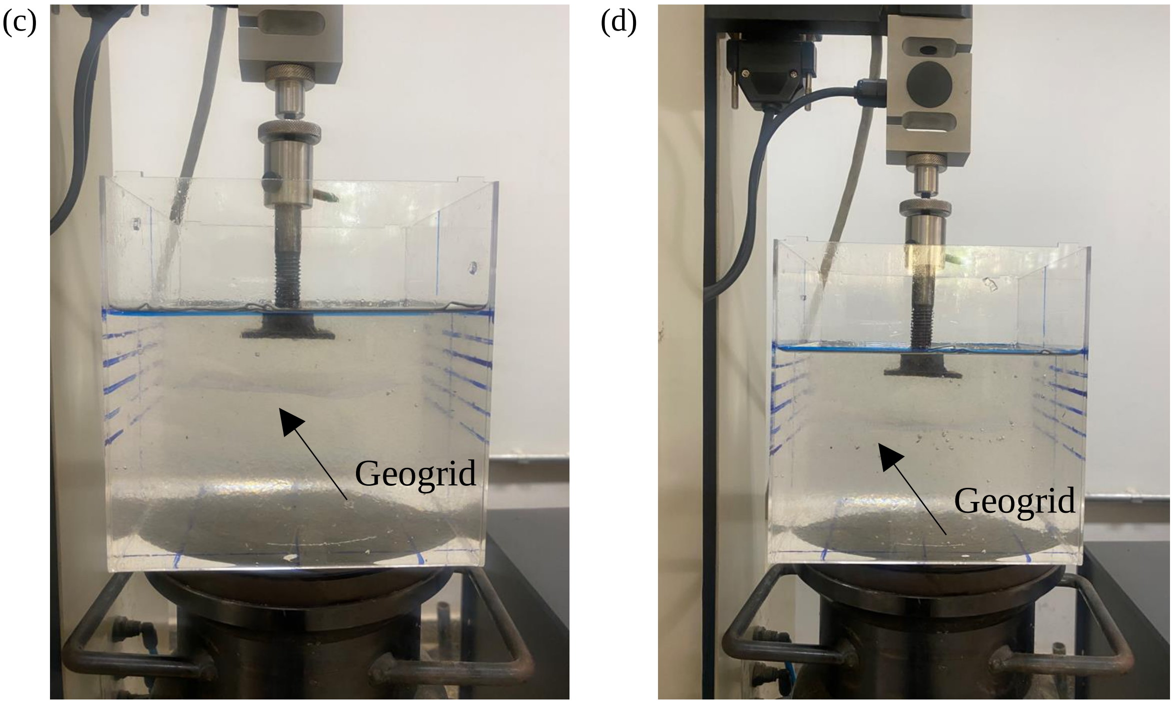


Figure 7. Geogrid configuration for a footing displacement of 0.015 m, considering embedment of: (a) 0.01 m; (b) 0.02 m; (c) 0.03 m; and (d) 0.04 m.

Based on Figure 6, as previously shown, it is evident that the embedding equal to 0.01 m was the one that most effectively favored the reinforcement element's solicitation. This factor carries significant technical implications as it can facilitate the use of geogrids as basal reinforcement for shallow foundations, especially when considering an embedding corresponding to B/4, where B is the width of the footing base. Additional studies should be conducted to assess the influence of different geometries and materials with varying strength parameters, as well as the influence of test scale.

4 CONCLUSIONS

This study investigated the behavior of shallow foundations reinforced with geogrids in transparent soil, using a reduced-scale (1-g) methodology. The research provided relevant insights into the properties and effectiveness of using geogrids to enhance the resistance of shallow foundations, considering different reinforcement embedment depths. Based on the obtained results, the following conclusions can be highlighted:

- The transparent sand produced from high purity fused quartz exhibited suitable optical properties, with a refractive index close to that of quartz (1.4585) and a specific gravity of 2.2. These characteristics allowed for accurate assessment of the interaction between the soil and the geogrid.
- The polyester geogrid used, with a nominal aperture of 0.002 m, proved to be an effective representation of commercially available geogrids in real scale, exhibiting average secant stiffness values of 0.41 kN/m, 0.83 kN/m, and 1.37 kN/m for axial strains of 2%, 5%, and 10%, respectively.
- The reduced-scale tests revealed that the foundation resistance increased with the inclusion of the geogrid. The maximum resistance was achieved with the geogrid positioned at a depth of 0.01 m (B/4), where B is the width of the foundation base.
- Greater embedment depths than 0.01 m resulted in progressive reductions in resistance, with the embedment at 0.04 m showing values close to those of the unreinforced foundation.
- The geogrid configuration with an embedment depth of 0.01 m was the most effective in mobilizing resistance, indicating that using an embedment depth equivalent to B/4 is the most economical and technically advantageous solution.
- The results suggest that the inclusion of geogrids as basal reinforcement can be an efficient strategy to enhance the resistance of shallow foundations, especially when adopting embedment depths corresponding to B/4.

In summary, the research confirms the effectiveness of geogrids in improving the resistance of shallow foundations in transparent soil, emphasizing the importance of optimizing embedment depth to maximize economic and technical benefits. These findings have the potential to guide foundation engineering practices, promoting more efficient and cost-effective solutions for construction projects. Further studies are recommended to explore the influence of different embedment geometries and materials with varying strength parameters, as well as the influence of test scale.

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