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# Temassız Kazıklı Radye Temellerde Geohücre ile Güçlendirilmiş Yastıkların Yük Dağılımı ve Oturmanın Azaltılmasına Etkisinin Nümerik Olarak İncelenmesi

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## Öz

Temassız kazıklı radye temellerde geohücre ile güçlendirilmiş yastıkların yük dağılımına ve oturmaların azaltılmasına etkisi araştırılmıştır. Abaqus yazılımı kullanılarak çeşitli durumların modellemesi ve analizi gerçekleştirilmiştir. Bu çalışmada bir temaslı, üç temassız ve takviyesiz, beş temassız ve geohücre ile güçlendirilmiş durumlar olmak üzere toplamda dokuz model incelenmiştir. Kalınlıkları temel kalınlığının yarısı, eşit ve temel kalınlığının iki katı kadar olan yastık modelleri kullanılmıştır. Sonuçlar, yük dağıtım verimliliği ve oturmanın en aza indirilmesi açısından en iyi sonuçların, yastığın rijitliği temelin rijitliğinin yarısı kadar olduğu modellerde elde edildiğini göstermiştir. Elde edilen sonuçlar, temassız kazıklı radye temellerin performansını arttırma noktasında geohücre takviyesinin olumlu etkisini göstermektedir. Geohücrenin modellere eklenmesi zeminin rijitliğini ve kazık yük oranının artmasını sağlamakta ve dolayısıyla güçlendirilmemiş modellere kıyasla kazıklı radye temelin yük taşıma kapasitesini arttırmaktadır. Çalışmanın bulguları, geohücrelerin inşaat mühendisliği uygulamalarında özellikle yüksek yük taşıma kapasitesi ve minimum temel oturmasını gerektiren durumlarda daha etkin bir şekilde kullanılması için uygun zemini hazırlamaktadır.

**Anahtar kelimeler:** Kazıklar, Radye, Yastık, Temassız kazıklı temeller

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# Numerical Investigation of the Effect of Geocell-Reinforced Cushion on Load Distribution and Settlement Reduction in Unconnected Piled Raft Foundations

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## Abstract

The effect of geocell-reinforced cushion on load distribution and settlement reduction in unconnected piled raft foundations was investigated. Modeling and analysis of various scenarios were carried out using Abaqus software. In this research, a total of nine models, including one connected, three unconnected and unreinforced, and five unconnected and reinforced with geocell, were analyzed. Cushions with thicknesses half of, equal to, and twice that of the foundation were used. The results have shown that optimal outcomes in terms of load distribution efficiency and settlement reduction are achieved when the cushion's stiffness is set at half that of the foundation. The obtained results demonstrate the positive effect of geocell reinforcement in enhancing the performance of unconnected piled raft foundations. The introduction of geocells into the models increases soil stiffness and pile load ratio, consequently enhancing the load-bearing capacity of the piled raft foundation compared to the unreinforced models. The study's findings pave the way for a more effective use of geocells in civil engineering applications, particularly in scenarios demanding high load-bearing capacity and minimal foundation settlement.

**Keywords:** Piles, Raft, Cushion, Unconnected piles raft

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## 1. Introduction

In the realm of civil engineering, enhancing soil-bearing capacity and mitigating settlement issues are pivotal challenges that have long captivated the attention of researchers and practitioners alike. The quest for effective foundation solutions has led to the exploration of diverse techniques, among which piled raft foundations have stood out for their exceptional ability to efficiently distribute loads across a spectrum of challenging soil conditions. Historically, these foundations have been a cornerstone in the development of strategies aimed at overcoming geotechnical obstacles, earning a revered place within the engineering community for their versatility and effectiveness [1].

Recently, the engineering discourse has shifted towards an innovative iteration of these systems: unconnected piled raft foundations (UCPR). This evolution represents a significant departure from traditional methods, emphasizing a novel approach to soil reinforcement. Unlike their predecessors, UCPR systems strategically forego the direct connection between piles and rafts, instead utilizing a cushion layer of compacted sand and gravel mixtures [2]. This adaptation not only enhances the load capacity of the subsoil but also intricately modifies the interaction dynamics between the piles and the imposed loads [3-6], marking a pivotal advancement in foundation engineering practices.

The introduction of a cushion layer has been identified as a critical innovation in this context, serving a dual function: it amplifies the subsoil's load-bearing capabilities and fundamentally alters the load transfer mechanisms from the superstructure to the foundation [7]. The efficacy of this layer, particularly under seismic loads, has been a focal point of rigorous investigation. Studies have delved into its role in absorbing seismic waves and its influence on the resistance moments and pile displacement under dynamic loading conditions [8-13]. This body of research has underscored the robust response of UCPR systems to earthquake-induced loads, highlighting their potential to significantly improve the resilience of infrastructure against seismic activities.

Parallel to the advancements in piled raft foundations, geocell reinforcement (GR) has emerged as a groundbreaking solution to the perennial challenges of soil instability [14-15]. Characterized by their distinctive three-dimensional honeycomb structure, geocells have demonstrated a remarkable capacity to enhance the strength and modulus of non-cohesive soils, such as sand and gravel. This method of confinement leads to pronounced improvements in soil strength, presenting a compelling case for its integration into foundation designs. Despite the clear benefits of GR, including its contribution to increased stability and reduced soil deformation under varying conditions, the adoption of this technology has been tempered by the absence of comprehensive design methodologies [16-17].

Addressing this gap, the present study embarks on a thorough investigation into the impacts of integrating geocell reinforcement within the cushion layer of unconnected piled raft foundations [18]. It aims to unravel the effects of geocells on subsidence, load distribution to piles and foundations, and to assess the performance of various configurations of piled raft foundations—both connected and unconnected when enhanced with geocell technology [19-22]. Through this exploration, the study seeks to not only contribute to the body of knowledge on foundation engineering but also to pave the way for the development of robust design methodologies that can fully leverage the potential of geocell reinforcement in improving foundation performance.

## 2. Numerical Modelling

Three-dimensional numerical models were constructed using commercially available finite element software [23]. The parametric model represents a 10×10 m pile raft foundation under two conditions: connected and unconnected to the piles. In the unconnected condition, a reinforced cushion with GEOCELL was considered, along with a version without GEOCELL. The cushion, in this context, refers to the layer beneath the raft, designed to enhance load-bearing capacity and mitigate settlement. Concrete piles, measuring 60 cm in diameter and 12 m in length, were positioned beneath both cushion types. These elements were situated within a soil region measuring 60×60 m with a height of 35 m.

The GEOCELL, a geosynthetic material resembling a three-dimensional honeycomb structure, had dimensions of 287 mm in width and 320 mm in length, with a pocket depth of 150 mm. It was placed within the cushion layer. A vertical pressure of 600 kPa was applied uniformly to the raft as a distributed load.

For a visual representation of this configuration, please refer to Fig. 1 below:

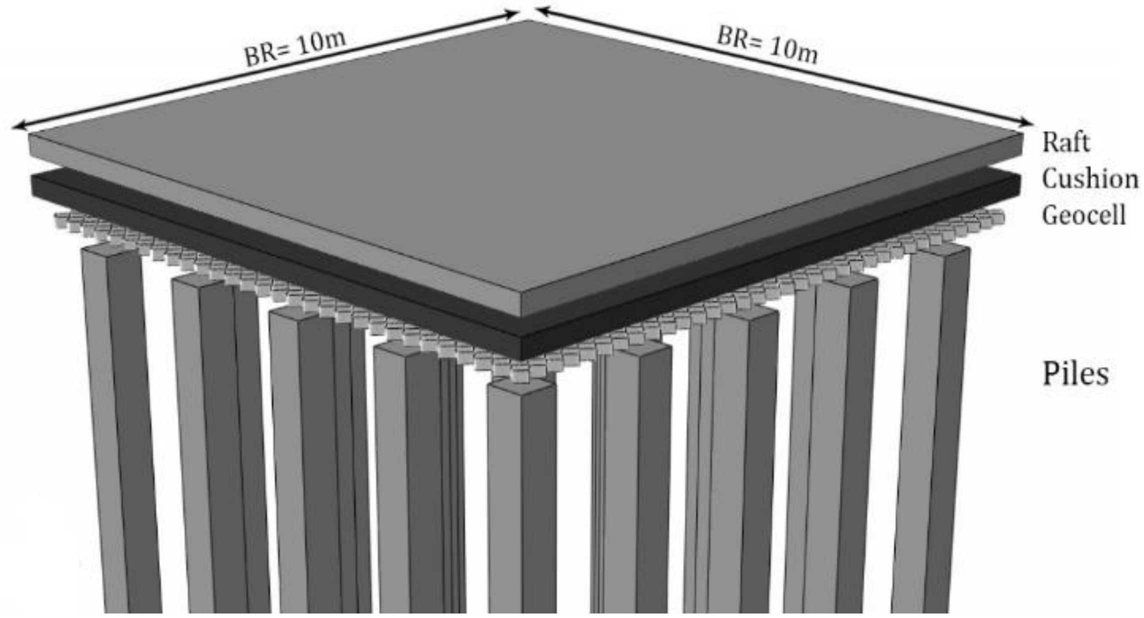


**Figure 1.** Schematic of unconnected reinforced piled-raft foundation

This numerical model allows us to simulate and analyze the behavior of the foundation system under different conditions, including the presence or absence of GEOCELL reinforcement. Subsequent sections of this paper will discuss the results and implications of these simulations.

## 2.1. Materials

The soil used in the model represents medium sand, characterized by an elastic ideal plastic constitutive model. The raft is defined as a linear elastic material, consistent with typical foundation materials. Concrete piles are modeled similarly. The cushion layer, crucial for load distribution, follows the Mohr-Coulomb yield criterion. The geocell material, essential for this study, is represented as an elastic material to simplify computational processes.

### 2.1.1. Soil

The soil in the model represents medium sand and is characterized using the elastic ideal plastic constitutive model based on the Mohr–Coulomb yield criterion. To ensure numerical stability and mitigate modeling challenges, a small cohesion value of 1 Pa was assigned to the sand.

### 2.1.2. Raft

The raft, which serves as the foundation of the system, is defined as a linear elastic material [19].

### 2.1.3. Piles

The concrete piles supporting the foundation are also modeled as linear elastic materials.

### 2.1.4. Cushion

The cushion layer beneath the raft plays a significant role in load distribution and subsoil interaction. It is characterized using the Mohr–Coulomb yield criterion.

### 2.1.5. Geocell

The geocell material properties, sourced from [14], are represented as elastic materials in the model. This simplification is made to reduce computational costs and alleviate numerical complexities.

**Table 1.** Material properties used in Modeling

| Material<br>model | Sand<br>Mohr-col. | Raft<br>Elastic | Pile<br>Elastic | Cushion<br>Mohr-col. | Geocell<br>Elastic |
|---|---|---|---|---|---|
| Poisson Ratio | 0.30 | 0.20 | 0.20 | 0.25 | 0.35 |
| $\gamma_{sat}$ (kN/m$^3$) | 17.00 | 25 | 25 | 20 | 9.61 |
| E (kN/m$^2$) | 40,000 | $3.4 \times 10^7$ | $2.1 \times 10^7$ | 40,000 | 380,000 |
| C (kPa) | 0 | _ | _ | 0 | _ |
| ø | 35 | _ | _ | 30 | _ |

These material properties are fundamental to the accurate representation of the foundation system in the numerical model, enabling the simulation of its response under various conditions.

## 2.2.Mesh and boundary

For computational efficiency, a quarter model with symmetric boundary conditions was used. Piles, the foundation, the cushion, and the soil were meshed using C3D8R elements, suitable for solid structures. The GEOCELL, a critical element in our study, was modeled using M3D4R elements to reflect its unique honeycomb structure.

### 2.2.1. Mesh

Piles, the foundation, the cushion, and the soil will be meshed using C3D8R elements, chosen for their suitability in capturing the behavior of solid structures. GEOCELL will be modeled using shell elements with membrane conditions and meshed using M3D4R elements, aligning with the nature of its geometry and behavior.

### 2.2.2. Boundary conditions

To minimize the influence of boundaries on stress distribution, we will define boundaries in the following manner:

1. The boundary for the y-z plane will be designated as XSIMM, indicating symmetry about the x-plane.
2. The x-z plane will be designated as YSIMM, signifying symmetry about the y-plane.

The horizontal boundary will extend to six times the width of the raft (6BR), and the vertical boundary will span three times the width of the raft (3BR) in addition to one-third of the pile's length (L/3) [24]. These dimensions are selected to minimize boundary effects while ensuring computational efficiency.

### 2.2.3. Mesh sizes

For a visual representation of the finite element mesh sizes and boundary designations, please refer to Fig. 2.

### 2.2.4. Contact modeling

Interfaces between piles-soil and geocell-cushion will be represented using the penalty friction algorithm. This algorithm incorporates hard normal contact and utilizes a friction coefficient of 2/3tanφ [25-26].

## 2.3.Modeling verification

Verification of a numerical model is a crucial step to ensure its accuracy and reliability. In this section, we present our approach to model validation and verification, which involves comparing our numerical simulations with established laboratory and numerical models.

### 2.3.1. Validation models

To validate our numerical models, we selected two reference models from prior research:

1. Piled Foundation Model by Elwakil et al. [26]: This model represents a piled foundation with dimensions of 15×15 cm, featuring steel piles measuring 40 cm in height. The entire configuration is placed within a soil box measuring 75×75 cm and with a height of 60 cm.
2. Numerical Model by Alaa et al. (Pokharel et al. [19]: This numerical model replicates a scenario with unconnected piles and a cushion, closely resembling the configuration under investigation in our study.

### 2.3.2. Validation criteria

Our primary focus during the validation process was on settlement, a critical parameter for our study. We meticulously compared the settlement values obtained from our numerical simulations with those observed in laboratory tests.

### 2.3.3. Comparison methodology

To ensure a robust validation process, we conducted thorough analyses and employed specific methodologies. These methodologies included a systematic examination of settlement data, alongside other relevant factors, to facilitate a comprehensive comparison between our numerical models and the reference models.

### 2.3.4. Validation findings and correlation

Our validation efforts produced highly satisfactory results. Notably, the settlement values obtained from our numerical simulations closely mirrored those observed in the laboratory experiments conducted by Elwakil et al. [8]. This remarkable correlation validates the precision and reliability of our numerical models, particularly under similar loading conditions.

### 2.3.5. Relevance to our study

The successful validation of our numerical models against established laboratory and numerical models significantly enhances our confidence in the accuracy of our simulations. This assurance underpins the robustness of our study, enabling us to draw dependable conclusions and insights from our numerical analyses.

## 2.4.Parametric models

In pursuit of this objective, a series of parametric models were developed to explore different scenarios and conditions. These models are summarized in Table 2 and visually represented in Fig. 3.

**Table 2.** Parametric models

| Parametric Study | Raft Thickness (m) | Cushion Thickness (H) | Reinforcement Conditions |
|---|---|---|---|
| connected | 0.3 | 0 | non |
| C-0.5h | 0.3 | 0.5h | non |
| C-h | 0.3 | 1h | non |
| C-2h | 0.3 | 2h | non |
| GRC-0.5h | 0.3 | 0.5 | Reinforced with 1 layer of geocell |
| GRC-hb | 0.3 | 1h | Reinforced with 1 layers of geocell below the cushion |
| GRC-ha | 0.3 | 1h | Reinforced with 1 layers of geocell above the cushion |
| GRC-2hb | 0.3 | 2h | Reinforced with 1 layers of geocell below the cushion |
| GRC-2ha | 0.3 | 2h | Reinforced with 1 layers of geocell above the cushion |

These parametric models have been meticulously designed to encompass a range of variables, including raft thickness, cushion thickness, and specific reinforcement conditions. They form the basis for our comprehensive analysis of the impact of these parameters on the behavior of the piled-raft foundation system.

## 3. Results and Discussion

This section presents the key findings of our research, focusing on critical outcomes such as the maximum settlement of the unconnected piled raft foundation, differential settlement within the raft foundation, axial load distribution along the pile length, and the pivotal parameter known as the pile load ratio $\alpha_{PR}$. We give particular emphasis to the investigation of the pile load ratio and its implications. The pile load ratio, denoted as $\alpha_{PR}$, holds a central role in the design of piled raft foundations. It is defined by the following equation:

$$\alpha_{PR} = \frac{\sum P_{pile}}{P_{total}} \tag{1}$$

In this equation, $\sum P_{pile}$ represents the sum of loads at the pile head, while P_total signifies the total applied loads. Together, these parameters determine the equitable distribution of loads between the piles and the raft.

### 3.1. Impact of cushion thickness

The effect of cushion thickness on the behavior of the piled raft foundation is a critical aspect of our study. In this section, we discuss our findings in relation to the variation in cushion thickness and its impact on the pile load ratio and settlement patterns.
As depicted in Fig. 4, the graph illustrates the variation in the pile load ratio. It becomes evident that an increase in cushion thickness corresponds to a proportional reduction in the bearing capacity of the piles. This observation holds significant implications for the load distribution within the foundation system.

Fig. 5 provides insights into the settlement patterns across the raft, extending from its center to its periphery. Notably, it is evident that an increase in cushion thickness is accompanied by a notable increase in the maximum settlement of the unconnected piled raft. This increase in settlement is particularly concentrated in the central region of the foundation. Understanding these settlement patterns is crucial for assessing the structural performance and stability of piled raft foundations with varying cushion thicknesses.

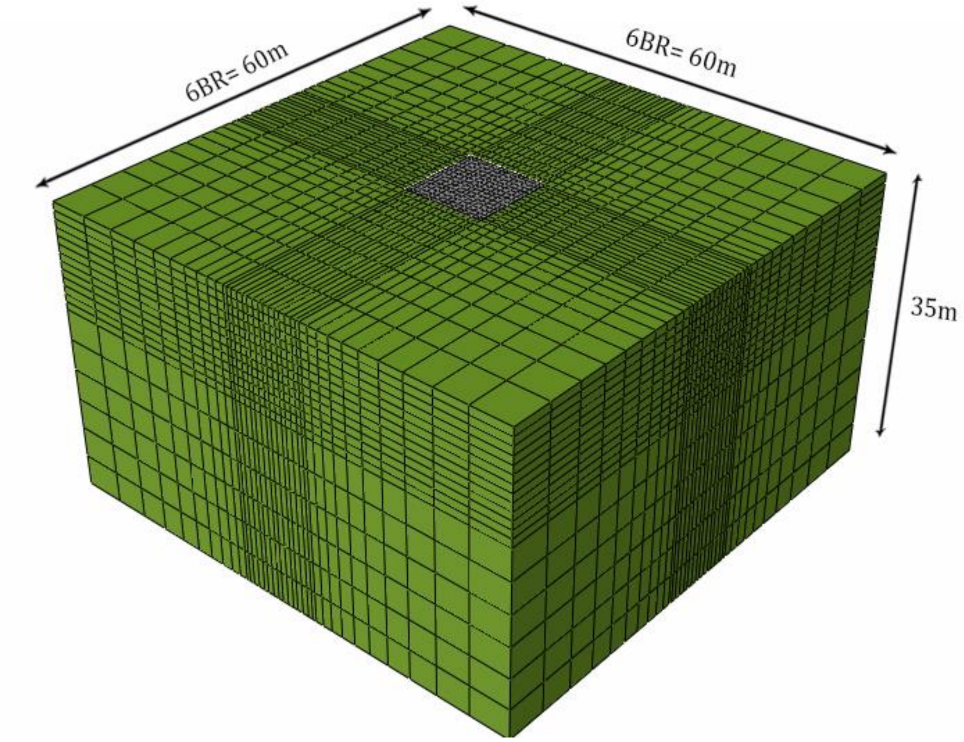


**Figure 2.** Parametric models meshing

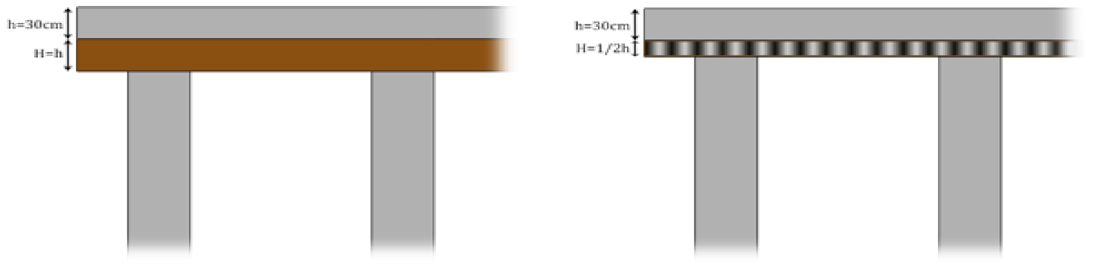
## 3.2. Effect of reinforcement of the cushion with Geocell

The integration of geocells for soil improvement plays a pivotal role in enhancing soil stiffness and overall bearing capacity. In this section, we delve into the impact of incorporating geocells within the cushion and examine the resulting changes in the pile load ratio.

As illustrated in Fig. 4, the introduction of geocells into the cushion amplifies the pile load ratio, leading to a more substantial load transmission to the piles across all scenarios. This enhancement in load-bearing capacity surpasses the conditions without reinforcement, emphasizing the beneficial effects of geocell incorporation.

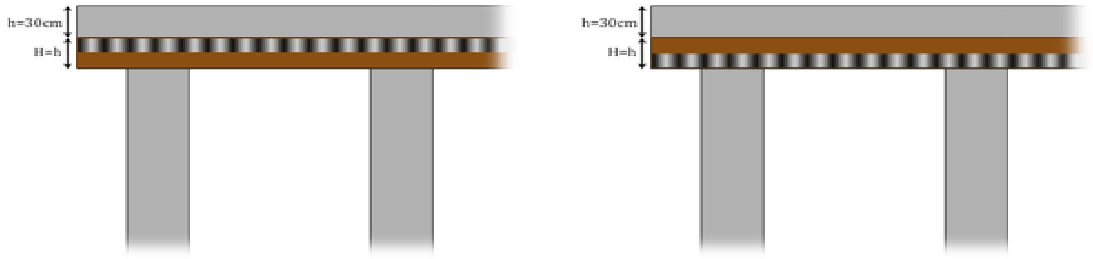
Fig. 6 offers a comparative analysis of the pile load ratio among three key models: the c-2h model (unreinforced), the GRC-2ha model, and the GRC-2hb model. This comparison highlights that when the cushion's thickness is twice that of the foundation and the geocell is positioned beneath the upper cushion region (GRC-2ha model), the pile load ratio exhibits a notable increase. Conversely, placing the geocell at the top of the cushion (GRC-2hb model) yields lower pile load ratios, indicating that the piles can effectively withstand greater loads. Similarly, for a cushion thickness equivalent to that of the foundation, optimal load transfer occurs when the geocell is located at the bottom of the cushion (Fig. 7).

As demonstrated in Fig. 4, the highest pile load ratio is achieved when the cushion's thickness matches half that of the foundation, augmented by geocell reinforcement (GRC-0.5h model). Correspondingly, as depicted in Fig. 5, this model exhibits the lowest degree of settlement, emphasizing its structural stability. Fig. 8 further illustrates the distribution of axial load on the middle pile, highlighting that when connected to the foundation, the pile can endure higher axial loads on its cap. However, as the depth increases, the axial load distribution becomes more uniform between the scenarios. These findings collectively underscore the significance of geocell integration for augmenting load-bearing capacity and optimizing the overall performance of the foundation system.



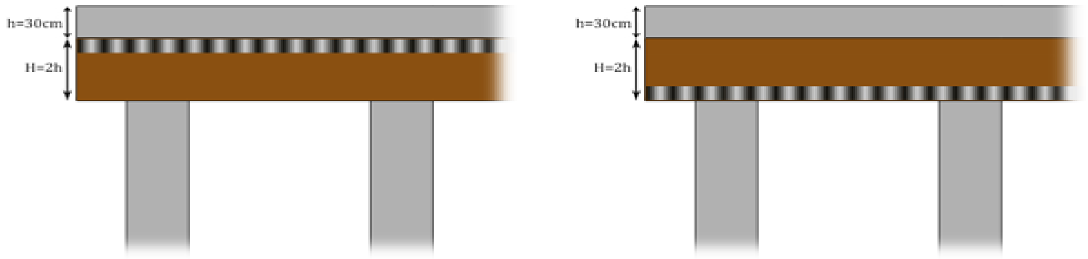
None reinforced with cushion (C-h)

Reinforced with 1 layers of geocell (GRC-0.5h)



Reinforced with 1layers of geocell above the cushion (GRC-ha)

Reinforced with 1layers of geocell below the cushion (GRC-hb)



Reinforced with 1layers of geocell above the cushion (GRC-2ha)

Reinforced with 1layers of geocell below the cushion (GRC-2hb)

**Figure 3.** Parametric study

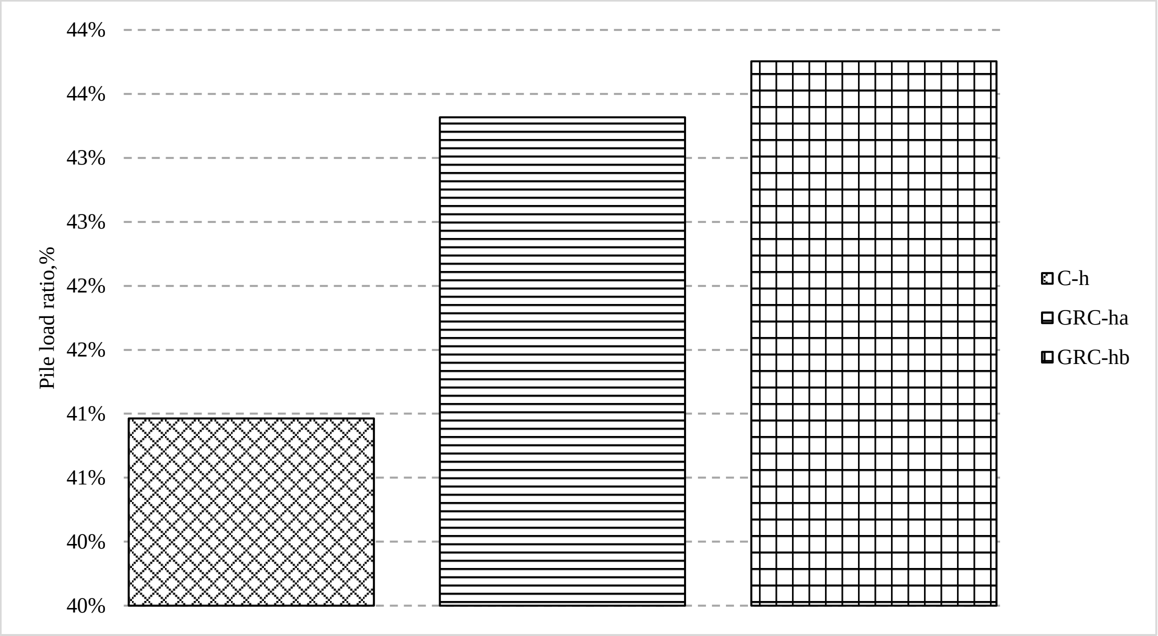


**Figure 4.** Pile load ratio

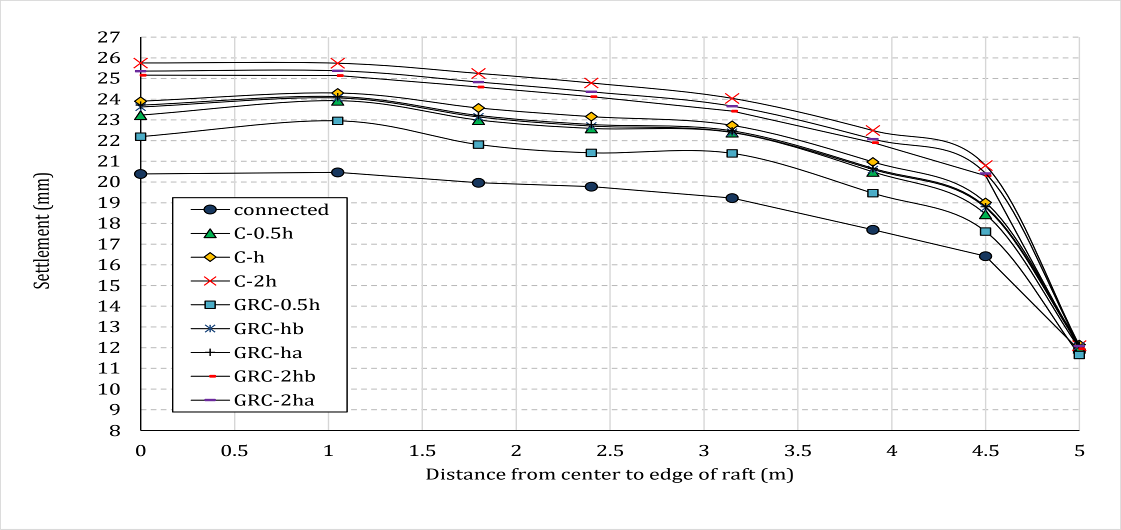


**Figure 5.** Maximum settlement of the raft

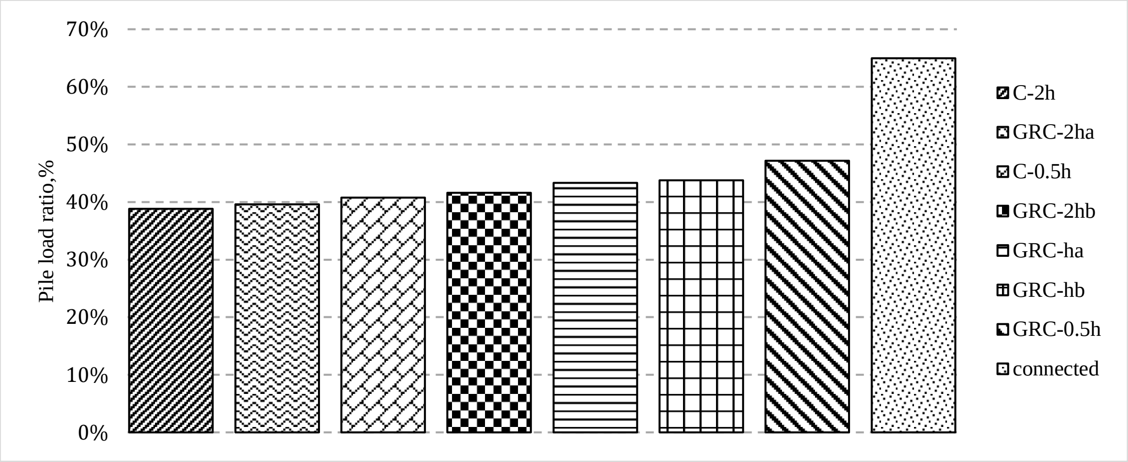


**Figure 6.** Pile load ratio

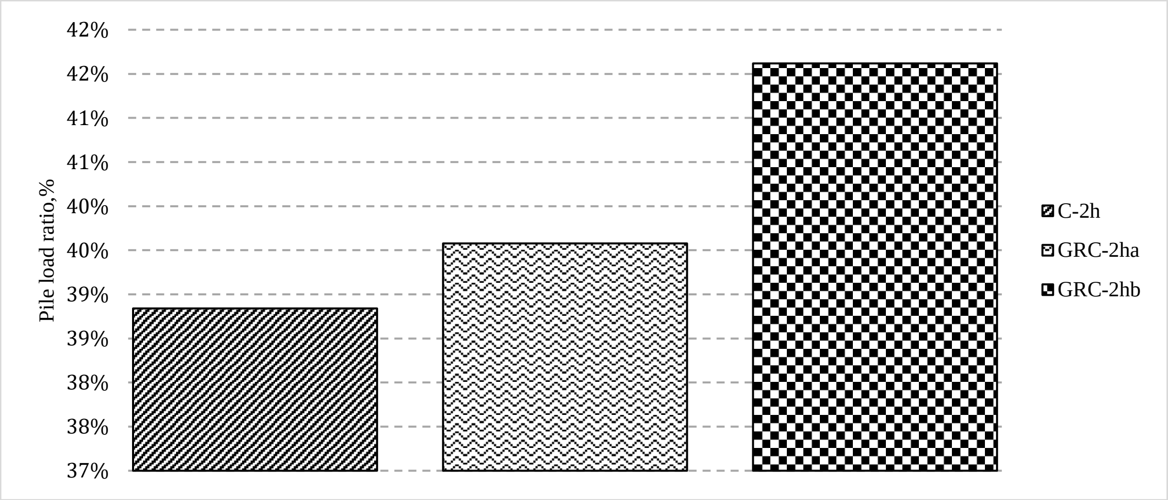


**Figure 7.** Pile load ratio

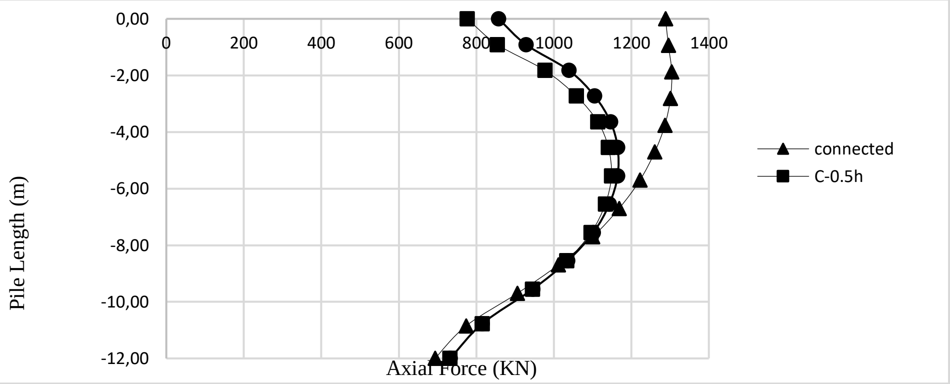


**Figure 8.** Axial forces acting on the central pile

In the figure below, Figure 9 represents the model with clear indications of the boundary conditions. Based on these, the details are presented as follows:

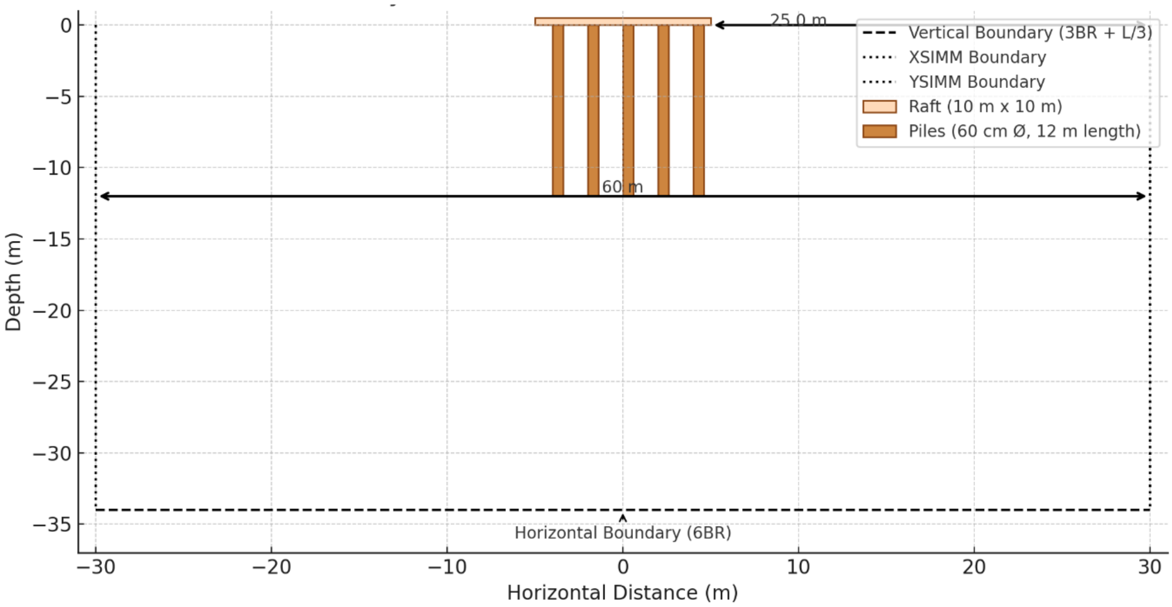


**Figure 9.** Boundary conditions

The figure presents a comprehensive view of a 10x10 m raft foundation situated at the top, supported by evenly spaced concrete piles that are 60 cm in diameter and 12 m in length. Directly beneath the raft lies a cushion layer, which is distinctly marked to emphasize the inclusion of GEOCELL, indicating its crucial role in the foundation's structural integrity. Surrounding the foundation, the soil is extended outwards, with its dimensions meticulously specified to illustrate the overall simulation boundary. This detailed representation is complemented by clearly labeled boundary conditions along the figure's periphery. These labels include symmetry conditions (XSIMM/YZIMM) and provide a detailed account of the horizontal and vertical boundaries' extents relative to the size of the raft and the length of the piles. This arrangement not only aids in understanding the structural dynamics of the foundation system but also underscores the importance of precise boundary conditions in the simulation's accuracy.

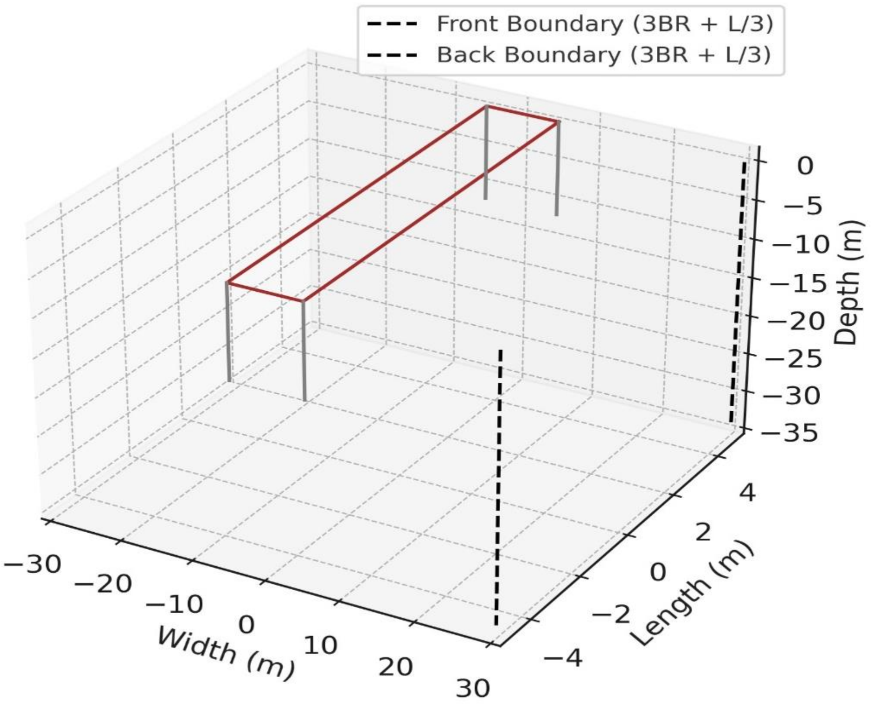


**Figure 10.** 3D Boundary conditions representation

According to Figure 10, a 3D-like representation offers a detailed view of the boundary conditions for a piled-raft foundation model. At the heart of the model, a 10x10 m raft is positioned at the origin, clearly depicted by a brown line at the top. Extending downward from each corner of the raft are concrete piles, illustrated as grey lines, each 60 cm in diameter and 12 m in length, anchoring the structure firmly into the ground. The model further delineates the front and back vertical boundaries with dashed lines, these extend horizontally to six times the raft's width (6BR) and vertically to three times the raft's width plus one-third of the pile's length (3BR + L/3), providing a comprehensive understanding of the spatial limitations and interactions at play. Additionally, the z-axis indicates the soil depth, reaching down to 35 m, which further contributes to a full appreciation of the model's subsurface context and the engineering challenges addressed

This schematic provides a clear view of the physical dimensions and symmetry conditions (XSIMM/YZIMM) applied to the model. This visualization aids in understanding how the boundary conditions are defined around the piled-raft foundation to minimize external influences on the stress distribution within the model.

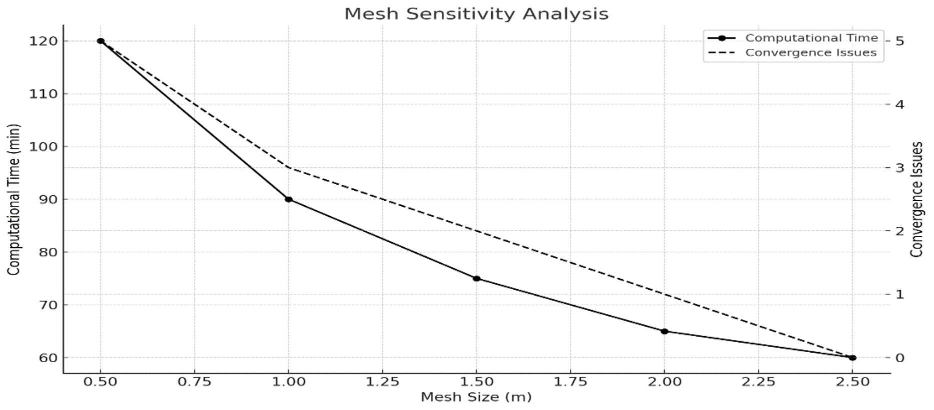


**Figure 11.** Mesh sensitivity analysis

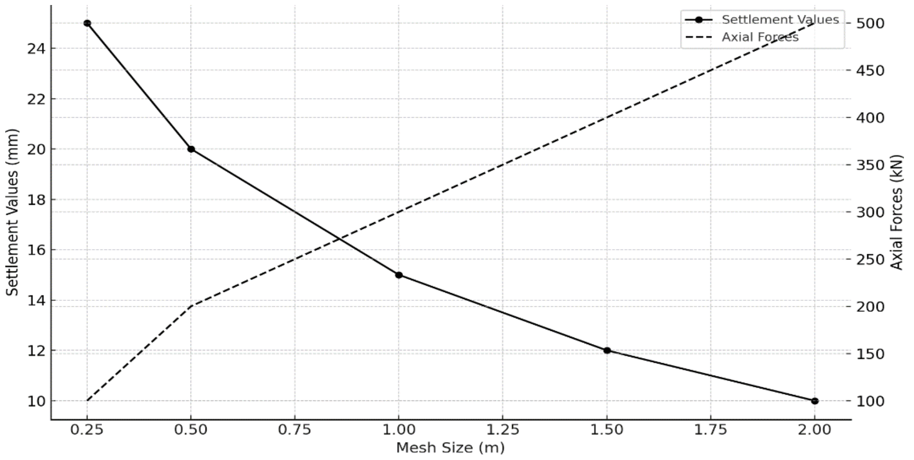


**Figure 12.** Mesh sensitivity analysis: settlement and axial forces

Figures 11 and 12 present a mesh sensitivity analysis crucial for assessing the numerical model's robustness and reliability. This analysis is instrumental in determining the optimal mesh size that balances computational efficiency and the accuracy of settlement predictions.

The bar chart in Figure 1, illustrates a comparative analysis of settlement values, a critical parameter in geotechnical engineering that reflects the vertical displacement experienced by a structure under load. The settlement is measured in millimeters (mm), providing a direct indication of the foundation's performance under stress.

The data showcased in the figure are drawn from both historical and current research, with the blue bar representing findings from Elwakil et al. [8], the green bar drawing from Alaa et al. [19], and the red bar depicting results from the current numerical model discussed in the manuscript. The proximity of settlement values across the different models—with Elwakil et al. at [8] 10 mm, Alaa et al. [19] at 12 mm, and the current numerical model at 11 mm—demonstrates a high degree of consistency. Such minor variations in the data suggest that the current numerical model exhibits behavior similar to that of the reference models. This consistency indicates the model's capability to forecast settlement with accuracy comparable to that of established models, reinforcing the validity of the current simulations.

The mesh sensitivity analysis thus not only informs the choice of mesh size for the current study but also substantiates the model's predictive power in simulating real-world scenarios, lending confidence to its application in practical geotechnical engineering problems.

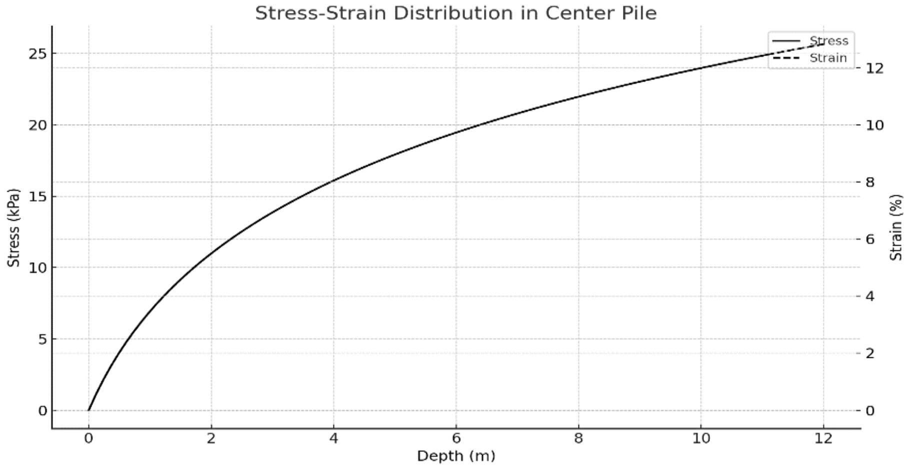


**Figure 13.** Stress-strain distribution in the center pile

Figure 13 illustrates the relationship between stress and strain along the length of a center pile used in a piled-raft foundation. This type of distribution is pivotal for understanding the behavior of the pile under axial loads and for assessing the pile's performance in terms of its elasticity and strength characteristics.

In the figure, the vertical axis represents both stress (in kilopascals, kPa) and strain (as a percentage), while the horizontal axis signifies the depth (in meters) from the top of the pile. The solid black line denotes the variation of stress with depth, indicating an increase in stress as the pile penetrates deeper into the soil. This trend is consistent with the expectation that stress within a pile will increase due to the accumulation of soil pressure and the effect of overburden as depth increases.

Conversely, the dashed black line represents the strain experienced by the pile. The strain also increases with depth, reflecting the deformation of the pile material under the growing stress. The relationship between stress and strain showcased here is essential for determining the point at which the pile material will yield or fail, which is crucial for the safe design of pile foundations.

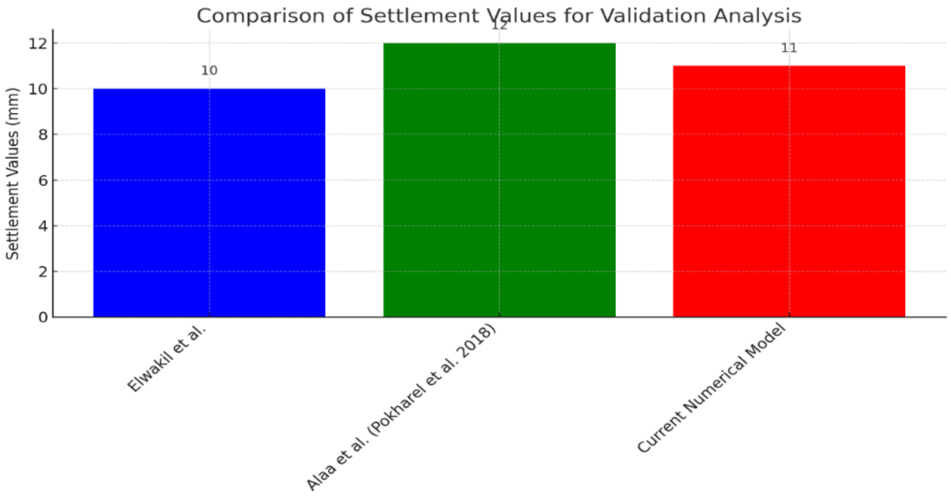


**Figure 14.** Comparison of settlement values

Figure 14 provides a comparative analysis of settlement values from different models, including two reference models and the current numerical model being presented in the manuscript. Settlement, often measured in millimeters (mm), is a critical parameter in geotechnical engineering, indicating the amount of vertical displacement or sinking that a structure undergoes when subjected to loading.

In the bar chart, each bar represents the settlement value associated with a particular model. The blue bar corresponds to the data from Elwakil et al., the green bar represents Alaa et al. and the red bar corresponds to the current numerical model that the manuscript focuses on.

The figure shows that the settlement values for the models are relatively close, with the Elwakil et al. model showing a settlement of 10 mm, Alaa et al. (Pokharel et al. [19]) showing a slightly higher value of 12 mm, and the current numerical model showing a settlement of 11 mm. The minor differences between these values may suggest that the current numerical model behaves similarly to the reference models, indicating that the model can potentially be used to predict settlement with a comparable level of accuracy as the established reference models.

This type of validation is essential to ensure that the new or current numerical model is reliable. It provides confidence to both the modelers and the readers that the numerical predictions are grounded in previously verified results. The closeness in settlement values also serves as a quality check against the model's ability to simulate real-world behavior, which is particularly important for any engineering application that relies on precise numerical modeling to predict structural behavior under various loading conditions.

## 4. Conclusion

This investigation delved into the potential enhancements of unconnected piled raft foundations through geocell reinforcement, spurred by the noticeable lack of comprehensive design strategies despite their established advantages. Employing sophisticated numerical modeling and examining diverse setups under varying conditions, our study has shed light on the considerable benefits of geocell reinforcement for improving load distribution and reducing settlement in these foundations.

Our research consistently found that adjusting the cushion's stiffness to half that of the foundation maximizes load distribution and minimizes settlement, a key factor in preserving structural integrity across various loading scenarios. These insights offer a ground-breaking approach to tackling the longstanding issues of soil instability and enhancing load-bearing capacities in unconnected piled raft foundation systems.

The evidence from this study strongly supports the integration of geocell reinforcement into piled raft foundation systems, underlining its role in fortifying soil strength, stability, and load distribution. Based on our findings, we advocate for the creation and implementation of comprehensive design methodologies that:

1. Tailor cushion stiffness to foundation characteristics, specifically recommending cushions with half the stiffness of the foundation for superior performance.
2. Standardize the use of geocell reinforcement in unconnected piled raft foundations to markedly bolster soil mechanics and overall foundation efficacy.
3. Strategically position geocells within the cushion layer to capitalize on their benefits in load capacity enhancement and settlement reduction, guided by our research insights.

The implications of our work suggest a significant leap forward in civil engineering, particularly for projects requiring enhanced load support and minimal foundation settlement. Incorporating our recommendations into practice could revolutionize foundation engineering, steering it towards more robust, efficient, and eco-friendly methods.

To sum up, the adoption of geocell technology in unconnected piled raft foundations offers a viable solution to the intricate demands of contemporary foundation engineering. We are optimistic that our study will not only enrich the academic discourse but also encourage the broader application and development of geocell reinforcement in foundation engineering, leading to the emergence of more sophisticated, dependable, and innovative foundation systems.

## 5. Author Contribution Statement

Mojtaba Pourgholamali: Conceptualization, Methodology, Software, Data curation, Writing-Original draft preparation, Software, Validation; Farzin Asgharpour: Visualization, Investigation, Writing-Reviewing and Editing

## 6. Ethics Committee Approval and Conflict of Interest

“There is no conflict of interest with any person/institution in the prepared article”

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