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Influence of Vertical Pressure on Raft's Lateral Load Contribution in Piled Raft Systems: A Numerical Investigation

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A B S T R A C T

This study investigates the influence of vertical pressure on the lateral load contribution of the raft in piled raft systems using numerical modeling. ABAQUS software was employed to simulate various configurations of piled raft foundations subjected to increasing vertical pressure. The analysis focused on examining the relationship between vertical pressure and the raft's lateral load contribution, with particular attention to the contact pressure between the soil and raft. The results reveal that as the vertical pressure increases, the lateral contribution of the raft also rises, primarily due to the increase in contact pressure between the raft and the surrounding soil. This study provides valuable insights into optimizing the design of piled raft foundations under combined vertical and lateral loads.

Keywords: Piled raft foundations, Vertical pressure, Lateral load contribution, Contact pressure, Numerical modelling, ABAQUS software

Introduction

Piled raft foundations are an innovative and efficient solution for supporting structures, particularly in scenarios where both vertical and lateral loads are substantial. They have been utilized to overcome the difficulties of constructing on soft soil profiles since very early times. Designing piles at the time was based on experience. The vertical behavior of piles has recently been the subject of increasingly extensive theoretical and experimental research due to its significance. Numerous approaches to its lateral and vertical design have been developed (Poulos and Davis, 1980). When both raft and piles take part in load sharing mechanism this form of foundation is known as a combined piled raft foundation or a raft that has been strengthened by the addition of piles. Lionardo Zeevaert observed the first application of such a raft and pile combination in Mexico. In Mexico City's extremely compressible volcanic soil buildings, he first used them in 1957 (Zeevaert, 1957). These systems utilize a combination of piles and a raft to share the loads, improving overall stability while optimizing the number of piles required. In recent years, significant research has been conducted to better understand the interaction between piles, rafts, and soil. One critical aspect of this interaction is the raft's contribution to lateral load resistance, which becomes more pronounced as contact pressure between the soil and the raft increases. Understanding this relationship is vital for designing foundations that efficiently withstand lateral forces, particularly in seismic or wind-prone regions.

A key parameter influencing the lateral contribution of the raft is the vertical pressure applied to the foundation system. Vertical pressure, which results from the superstructure's load, directly affects the contact pressure between the raft and the underlying soil. As the contact pressure increases, the raft engages more actively with the surrounding soil, enhancing its lateral load resistance. However, the extent to which vertical pressure influences this lateral contribution is not fully understood, necessitating a deeper investigation through numerical simulations and experimental studies.

This research aims to address this gap by performing a detailed numerical investigation of the raft's lateral contribution under varying levels of vertical pressure in piled raft systems. Using ABAQUS software, a finite element modeling approach was employed to simulate the behavior of piled raft foundations under combined vertical and lateral loads. The study focuses on the relationship between vertical pressure, soil-raft contact pressure, and the resulting lateral contribution of the raft, providing new insights into how vertical forces enhance the overall lateral stability of the foundation system.

The results of this study have important implications for the design and optimization of piled raft foundations. By quantifying the impact of vertical pressure on the raft's lateral load contribution, this research offers guidance for engineers to develop more efficient and resilient foundation designs, particularly for structures located in regions susceptible to high lateral forces. The findings also serve as a basis for future studies aimed at improving the performance of piled raft systems under complex loading conditions.

Importance and Objectives

This research holds significant importance in the field of foundation engineering, particularly as urban development leads to increasingly taller and heavier structures. The reliability and resilience of foundation systems are paramount, and piled raft foundations have emerged as an effective solution for such challenges. However, a comprehensive understanding of how these foundations behave under lateral loads, especially in conjunction with varying vertical pressures, remains inadequately addressed. By investigating the relationship between vertical pressure and the raft's lateral load contribution, this study aims to bridge a critical gap in existing literature, ultimately contributing to more informed design practices and enhanced structural safety.

The primary objective of this research is to quantitatively assess how variations in vertical pressure influence the lateral load contribution of the raft in piled raft systems. Utilizing advanced numerical modeling with ABAQUS, this study seeks to simulate real-world conditions and analyze the resultant contact pressures between the raft and the surrounding soil. By establishing a clear correlation between vertical pressure and lateral contribution, the findings aim to provide empirical data that can guide engineers and designers in optimizing the performance of piled raft foundations across diverse soil types and loading scenarios.

Furthermore, this research aspires to contribute to the broader field of geotechnical engineering by enhancing the understanding of soil-structure interaction mechanisms. The insights derived from this study are expected to inform the development of guidelines and best practices for the design of piled raft foundations, ultimately leading to safer and more efficient structures. Additionally, the findings may serve as a foundation for future investigations into more complex loading conditions, such as seismic and dynamic loads, thereby expanding the applicability of this research in addressing real-world engineering challenges.

Literature Review

Piles have been utilized to overcome the difficulties of constructing on soft soil profiles since very early times. Designing piles at the time was based on experience. The vertical behavior of piles has recently been the subject of increasingly extensive theoretical and experimental research due to its significance. Since then, numerous approaches to its lateral and vertical design have been developed (Poulos and Davis, 1980).

This form of foundation is known as a combined piled raft foundation or a raft that has been strengthened by the addition of piles. Lionardo Zeevaert observed the first application of such a raft and pile combination in Mexico. In Mexico City's extremely compressible volcanic soil buildings, he first used them in 1957 (Zeevaert, 1957).

Traditional pile raft designs presume that the applied lateral load will solely be resisted by piles, which leads to more piles with extended lengths.

The behavior and design of piled raft foundations are complicated due to the intricate interactions between the soil and the structure, as well as among different structural components. Rafts can be utilized to mitigate differential settlement and ensure a more uniform distribution of loads across all piles, as suggested by Burland (1995). On the other hand, piles can serve as means to reduce settlement and alleviate stress, as highlighted by Mandolini et al. (2013).

Various studies and methods have been proposed for vertical analysis, including the trilinear settling curve introduced by Poulos (2001). this theory states that the combined stiffness of the piled raft system will follow the trilinear settlement curve until the pile capacity is fully utilized at load P1. Beyond point P1, the stiffness of the raft alone will be effective until the piled raft system reaches its maximum capacity, referred to as Pu. At this stage, the load settlement curve levels off, as depicted in the figure.

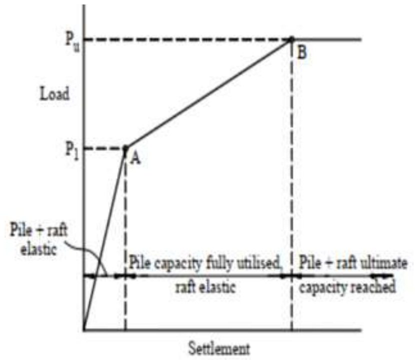

Fig 1 - Tri-linear load settlement curve for piled raft (Poulos, 2001)

"Winkler model for Piled raft (WMPR)" is another technique proposed by Jamil and Ahmad (2019) for determining bending moments in a raft of a piled raft system. The piled raft is supported using this technique on a bed of Winkler springs and pile springs placed at the appropriate locations. When estimating the stiffness of rafts and piles, interaction factors between piles and rafts are taken into account.

Small-scale pile raft models that were subjected to horizontal loading were centrifuge tested by Horikoshi et al. in 2003. In this work, the behaviour of a piled raft with a rigid pile raft connection at the top was predicted using centrifuge testing at 50g. In this research investigation, the author projected that with relatively small lateral deformations, the frictional resistance between the raft and the earth becomes fully mobilised.

Deb and Pal (2019) used ABAQUS to conduct a numerical investigation of piled rafts in their research. They evaluated the lateral capacity response of a 3x3, 4x4, and 5x5 pile structure with varying s/d ratios in clay soil underlain by sand. When the load is applied on the piled raft, the initial loads are mostly taken by the piles. Once the piles are mobilized, then the additional loads are sustained by the raft present in the piled raft. The proportion of load carried by the piles increases with the number of piles, spacing among the piles and the width of the raft, but it reduces with the increase in the thickness of the raft and the thickness of the silty-clay soil layer.

Methodology

For this study, a soil box was designed to replicate the real-world behavior of a piled raft foundation system subjected to vertical and lateral loads. The dimensions of the soil box were carefully selected to minimize boundary effects and ensure an accurate representation of soil-structure interaction. The box measured 1.2m x 0.9m, providing sufficient space around the piles and raft to avoid any influence from the boundaries on the foundation behavior. The depth of the soil box was designed to accommodate the full length of the piles while allowing for an adequate depth of soil below the raft. These dimensions ensured that the model captured the critical aspects of the foundation's behavior without being computationally excessive.

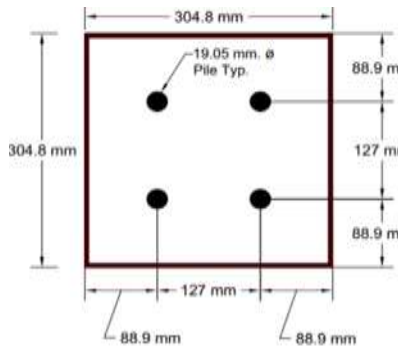

Fig 2 - Plan view of Pile Raft system

The numerical analysis was conducted using ABAQUS, a finite element analysis (FEA) software, well-suited for simulating complex soil-structure interactions. ABAQUS/CAE was employed to model the geometry of the soil box, raft, and piles, ensuring that all structural elements were accurately represented. The interaction between the soil and foundation components was modeled using surface-to-surface contact algorithms available in the ABAQUS standard module. This contact modeling allowed for the simulation of friction and the transfer of forces between the soil and the raft, which is critical for assessing the lateral load contribution of the raft under varying vertical pressures.

The soil was modeled as an elasto-plastic material, using the Mohr-Coulomb failure criterion to simulate realistic soil behavior under load. This material model was chosen because it captures the nonlinear stress-strain relationship of soil, particularly under high-pressure conditions. The mesh for the soil box and foundation system was generated with finer elements around the piles and raft to ensure accuracy in the critical zones, while coarser elements were used in areas farther from the foundation to reduce computational demand. The ABAQUS/Explicit module was used for solving the dynamic interaction between the soil and the foundation, providing insights into how vertical pressure influences the raft's lateral load contribution.

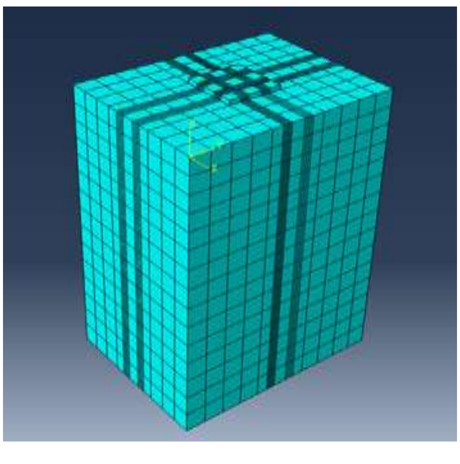

Fig 3 - ABAQUS model

A parametric study was conducted to investigate the effects of varying vertical pressures on the lateral contribution of the raft. Different vertical load scenarios were applied incrementally to the top of the raft, and the resulting lateral displacements and forces were monitored. ABAQUS's post-processing tools were used to extract data on the contact pressures between the raft and the soil, as well as the lateral load distribution. These results provided a clear understanding of how the vertical pressure influences the lateral resistance of the raft, contributing to the overall load-bearing capacity of the foundation system.

Results and Discussion

The results of the numerical analysis are presented and discussed in detail, focusing on the relationship between vertical load and the lateral load contribution of the raft in a piled raft system. Using ABAQUS, a series of simulations were conducted to evaluate the effect of varying vertical loads on the lateral behavior of the foundation. The analysis considered key factors such as contact pressure at the raft-soil interface and the interaction between the piles and the raft. The findings reveal important insights into how increasing vertical pressure enhances the lateral contribution of the raft, improving the overall performance of the piled raft system. These results are further supported by graphical representations and observations from the numerical simulations.

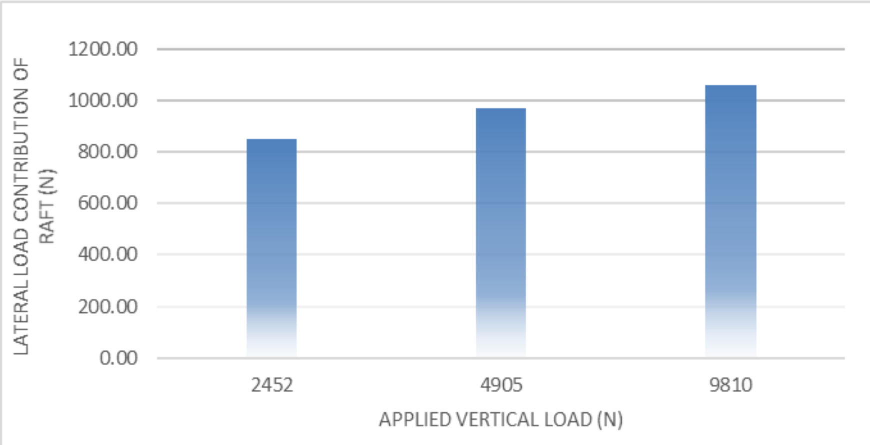

Fig 4 - Effect of Applied Vertical Load on Lateral Load Contribution in Piled Raft System

The graph illustrates the relationship between applied vertical load and the corresponding lateral load contribution in a piled raft system using four piles. As shown, an increase in vertical load leads to a proportional increase in the lateral load contribution of the raft. Specifically, the lateral load contribution rises from approximately 850 N at a vertical load of 2452 N, to nearly 1050 N when the vertical load is increased to 9810 N. This trend highlights how the raft's lateral resistance becomes more significant as the vertical pressure on the raft increases.

The increase in lateral load contribution can be attributed to the increasing contact pressure between the raft and the surrounding soil. As vertical loads are applied, the contact pressure at the interface between the raft and the soil intensifies, leading to enhanced frictional resistance. This frictional interaction plays a crucial role in improving the raft's ability to resist lateral loads. Essentially, as the contact pressure increases, the soil and raft work together more effectively to counteract lateral displacements, thereby contributing to the system's overall lateral stability.

Furthermore, the four piles in this system also benefit from the increased contact pressure, though the primary focus here is the raft's contribution. The piles provide vertical load support, but the raft plays an active role in resisting lateral loads. With increasing vertical load, the enhanced soil-raft contact strengthens this contribution. The findings suggest that optimizing the vertical load on the raft can significantly enhance its lateral load contribution, thereby reducing the reliance on piles for lateral stability and making the foundation system more efficient.

Conclusion

- The numerical analysis demonstrated that increasing vertical load significantly enhances the lateral load contribution of the raft in a piled raft system. This relationship is primarily due to the increased contact pressure between the raft and the soil.
- As vertical pressure increases, the frictional resistance at the soil-raft interface strengthens, contributing to the raft's ability to resist lateral loads more effectively, reducing the reliance on piles for lateral stability.
- The findings indicate that optimizing the applied vertical load can lead to more efficient foundation designs, where the raft plays a crucial role in both vertical and lateral load resistance.

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