Numerical and Experimental Analysis of Load-Sharing Behaviour in Piled-Raft Foundations

Thesis submitted in partial fulfillment for the Award of the Degree of

Doctor of Philosophy

by

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Chapter 6

Conclusions and Future Scope

6.1 Introduction

In recent years, the analysis of piled raft foundations has garnered significant attention in structural and geotechnical engineering research due to its potential advantages in minimizing settlement and improving stability. The concept of a pile raft foundation involves a highly intricate and sophisticated system. The three-dimensional stress distribution in piled raft foundation necessitates a comprehensive understanding and analysis to ensure the foundation's stability and performance over various soil conditions.

The review of existing literature conducted in this study provides an in-depth understanding of advancements in analysing piled raft foundations. A meticulous examination of existing scholarly works highlighted the evolving significance of piled raft foundations in addressing settlement issues and enhancing stability. Various studies explored the complex mechanics of load distribution, stress propagation, and deformation behaviour within this foundation system. The review showcased diverse methodologies employed, ranging from analytical models and numerical simulations to experimental investigations, underscoring the multidisciplinary approach to studying piled raft foundations. Additionally, the literature review unveiled the impact of key parameters, such as geometric configurations, soil properties, and loading conditions, on the performance of these foundations. Insights gained from previous research informed the experimental and numerical approaches undertaken in this study, ultimately contributing to a broader understanding of piled raft foundation behaviour. The literature review also identified gaps and avenues for further research, reinforcing the significance of the present study's findings and paving the way for future advancements in the geotechnical and structural engineering field.

This thesis presents a comprehensive investigation into the behaviour of piled raft foundations under various loading and soil conditions, employing numerical simulations using finite element (FE) software and small-scale experimental methods. The present study used the advanced capabilities of ABAQUS software to analyse the behaviour of piled raft foundations extensively. The outcomes of these simulations have led to several observations, which are sequentially summarized in the subsequent section. The findings of this study demonstrate that piled raft foundations can serve as a viable alternative to conventional foundation systems in soil conditions where concerns regarding differential settlements and instability arise. Moreover, the analysis highlights that key parameters, including geometrical and soil parameters, significantly impact the performance of piled raft foundations. By carefully considering and optimizing these parameters, the effectiveness and efficiency of piled raft foundation designs can be enhanced.

Also, this study conducted a comprehensive exploration of small-scale model tests to understand the behaviour of piled raft foundations. The significance of piled raft foundations in mitigating settlement issues and improving load distribution has been widely recognized in geotechnical engineering. Through an intricate interplay of soil, piles, and raft, these foundations offer an innovative solution for various construction scenarios. The primary objective of this research was to enhance the comprehension of the performance of piled raft foundations through systematic small-scale model testing.

The experimental investigations undertaken in this study provided valuable insights into the behaviour of piled raft foundations under controlled conditions. The results of the small-scale model tests revealed a multifaceted interplay of forces and deformations within the piled raft system. Observations related to settlement patterns with variations in parameters were systematically documented. Additionally, the load-sharing mechanisms between the individual piles and the raft were elucidated, shedding light on how these components collaborate to distribute applied loads effectively. Notably, the findings obtained from the small-scale model tests not only corroborated existing theoretical frameworks but also provided a platform for developing analytical models.

The insights gained from these experiments offer practitioners and researchers a clearer perspective on the particulars of load distribution, settlement mitigation, and overall stability within these foundation systems. Moving forward, the findings and methodologies established in this study pave the way for further research, encouraging the exploration of larger-scale tests, numerical simulations, and field validation studies to continually enhance the design and performance assessment of piled raft foundations. Furthermore, the subsequent section outlines suggestions for future research endeavours.

6.2 Conclusions

The conclusion of our current research effort provides us with a collection of insightful findings that illuminate the complexities and real-world implications of piled raft foundation systems. Presented below are the key conclusions that have emerged from this investigation:

- Piled raft foundations are particularly effective in stabilizing weak soils with limited load-bearing capacities, offering enhanced control over settlement compared to conventional piles and shallow foundations. This advantage is invaluable for ensuring stability and minimizing settlement issues in challenging soil conditions.
- The behaviour of piled raft foundations depends on various factors, including the geometry of foundation elements, soil characteristics, loading conditions, and installation methods. These parameters collectively determine load distribution, settlement, and response to external forces, underscoring the need for a comprehensive understanding of their interplay to ensure effective design

and predictive performance.

Chapter 3

- Through an extensive 3D finite element analysis using ABAQUS, this study has yielded critical insights into piled raft foundations on sandy soil. Increasing pile length significantly enhances load-bearing capacity and stiffness while simultaneously reducing settlement (Figure 3.13). Notably, extending pile length from $10m$ to $20m$ resulted in a substantial 60% increase in load-bearing capacity.

- In comparison to a reference diameter of $0.25m$, the load-bearing capacity consistently improved with each successive $0.25m$ increment, showing significant enhancements of approximately 83%, 200%, and 315%, respectively. Similarly, increasing the number of piles significantly improved load distribution and enhanced load-bearing capacities in piled rafts. The considered case showed an increase of approximately 6.6%, 26.67%, and 70.67%, respectively, in bearing capacity at a 40mm settlement for configurations with 4, 12, and 16 piles (Figures 3.14, 3.18).

- Raft thickness plays a substantial role, enhancing load-carrying capacity and stiffness while initially experiencing self-weight-induced settlement (Figure 3.19). In the present study, a 200% load capacity increase was observed as raft thickness progressed from $0.25m$ to $1.5m$.

- The analysis highlights the significant impact of soil characteristics on piled raft foundation behaviour, wherein an increase in soil elastic modulus results in greater stiffness and enhanced load capacity. Specifically, transitioning from an elastic modulus of $15MPa$ to $50MPa$ typically leads to higher foundation load capacity, with observed percentage increases ranging from 16% to 4.3% for every $5MPa$ increase (Figure 3.16).

- Elevated friction angles enhance both skin friction and end-bearing capacity, resulting in increased load-bearing capacity and decreased settlements in load-settlement curves. For instance, an increase in the friction angle value from 25° to 30° resulted in a 10% load capacity increase, followed by rises of 16.5% and 21.5% at 35° and 40°, respectively, demonstrating diminishing percentage improvements of 10%, 5.5%, and 4.4%, respectively. Moreover, the Poisson's ratio exerted a minimal influence on the load-bearing capacity, resulting in a modest increase of only 1.5% to 2.5% within the range of Poisson ratio values from 0.2 to 0.4 (Figures 3.15, 3.17).

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- Piled rafts surpass the combined capabilities of individual raft and pile foundations due to complex interaction mechanisms. This superiority arises from the complex interplay between soil and foundation elements, highlighting the potential for optimized load-bearing performance in foundation systems.

- Load distribution plays a crucial role, characterized by nonlinear changes in the load-sharing ratio relative to settlement. As settlement increases, the raft assumes a larger portion of the load, showcasing its adaptive response to changing circumstances.

- In the considered study, with 9 piles of 360mm length, load resistance reached 13.8kN for sand and 10.6kN for clay, compared to 3.6kN for unpiled rafts, indicating an increase of approximately 280% and 200%, respectively. The corresponding variation in pile length from unpiled raft to 160mm, 160mm to 260mm, and 260mm to 360mm showed an increase of 72%, 136%, and 283% for the sand case, whereas 92%, 150%, and 192% for the clay case. Thus, the experimental study confirmed that longer piles in piled-rafts significantly increase the bearing capacity.

- Even with just a few piles, the load-bearing capacity of the foundation significantly improves, especially with more piles. In both sand and clay scenarios, raft capacity against a $40mm$ reference settlement remained around $3.6kN$, but increased to $4.5kN$, $8kN$, $10kN$, and $14kN$ for 1, 4, 5, and 9 piles in sand, and to $5.2kN$, $7.9kN$, $8.8kN$, and $10.2kN$ for the same respective pile numbers in clay.

- With an increasing number of piles, there is a notable rise in the load improvement ratio (LIR). However, it was observed that the LIR was more significant during the initial phases but decreased as settlement values increased, indicating the mobilization and contribution of piles following the initial loading stages (Figure 4.17).
- In most instances, piled rafts exhibited similar load-sharing patterns over clay and sand soils. However, a notable difference was observed: over sand, the raft contributed a more substantial portion of the load compared to its role over clay, accounting for approximately 90% when the number of piles was lower. Nonetheless, this proportion decreased as the number of piles increased. Conversely, in clayey soil, the presence of piles exerted a more significant influence on load sharing, resulting in an enhanced contribution from the raft as settlement occurred (Figures 4.18 and 4.19).

Chapter 5

- Simplified settlement-based predictive models are developed in the present study to assess the interaction factors in sand and clay. It was observed that the interaction factors, including pile-pile interaction factor, raft-pile interaction factor, and pile-raft interaction factor, exhibit a range of values rather than a singular constant value.
- In sandy soil, the pile-pile interaction factor (α_{pp}) begins relatively high, gradually decreasing, while in clay, it undergoes more modest variations with changes in settlement, offering critical insights into the response of pile groups under increasing load conditions. Specifically, as shown in Figures 5.3, 5.4, 5.3b, and 5.4b, the α_{pp} value decreases with increasing raft settlement. In sand, it declines from close to unity to 0.65 at a settlement of 0.20, while in clay, it only slightly changes from 0.69 to 0.62.

- In sandy soil, the pile-raft interaction factor (α_{pr}) initially declines to 0.68 at a relative settlement of 0.10 due to pile capacity mobilization and reduced pressure near the piles in the soil-raft contact zone. Subsequently, as pile load capacity fully engages, the α_{pr} value rises. Conversely, in clay, it decreases to 1.05 due to pile mobilization, rises to 1.30 due to clay confinement between piles, but eventually decreases as cohesive behavior near the raft reaches a threshold. These trends are illustrated in Figures 5.5 and 5.6.
- The α_{rp} value consistently exceeds unity in sandy soil, indicating an enhanced pile capacity due to improved shaft resistance. Similarly, in clay soil, the α_{rp} value increases under the applied load following initial soil reorganization, but it remains below unity, suggesting a comparatively milder effect compared to sandy soil. Specifically, in sand, the α_{rp} value rises from 1.5 onwards, while in clay, it increases from 0.2 to 0.9. These trends are illustrated in Figures 5.7 and 5.8.

6.3 Potential avenues for future research

The research on piled raft foundations has seen significant advancements in recent years; however, several areas still need further exploration. Here are some potential areas of future research on piled raft foundation:

- Development of Accurate Numerical Models: Creating more precise and efficient numerical models is crucial for analyzing piled raft foundations. These models should consider intricate interactions between the raft, piles, and soil, allowing for a deeper understanding of how these components interact and influence the foundation's behaviour. This could lead to improved design and performance predictions.
- Long-Term Behavior Under Cyclic Loading: Investigating how piled raft foundations respond to long-term cyclic loading scenarios, like earthquakes or wind loads, is essential. Understanding how these dynamic forces impact

the foundation's stability, settlement, and overall performance over time can guide design choices to ensure safety and durability.

- Behavior in Problematic Soil Conditions: Piled rafts' behaviour in challenging soil conditions, such as collapsible and expansive soils, presents an important study area. Exploring how these unique soil properties interact with the foundation system will help optimize design approaches, considering factors like settlement control, load-bearing capacity, and long-term stability.

- Performance Under Dynamic Loading: Analyzing how piled rafts react to dynamic loading conditions, such as machine vibrations, is critical in various applications like industrial facilities or bridges. Understanding how the foundation responds to these dynamic forces ensures the structure's integrity and prevents potential vibrations-related issues.

- Alternative Material Exploration: Investigating the feasibility of using alternative construction materials, like recycled materials, for piled raft foundations has environmental and cost implications. This study could assess how such materials affect the foundation's performance, load-bearing capacity, and overall sustainability, potentially offering innovative solutions in construction practices.

- Emphasis on Total Settlement vs. Differential Settlement Models: Current studies on piled rafts tend to concentrate on overall or total settlement, often overlooking differential settlement, which refers to differential movements between different parts of the foundation. By focusing more on differential settlement models, researchers can gain insights into how non-uniform settling might affect the performance of the foundation and surrounding structures, especially in uneven or complex soil conditions.

- Research Opportunities for Varied Conditions: Opportunities for further research lie in exploring the behaviour of piled rafts in diverse scenarios. This includes studying how the foundation reacts when subjected to eccentric or inclined loading and when placed in stratified soil conditions where different soil layers have varying properties. Investigating the effects of the water table and examining the long-term behaviour of load sharing can provide a comprehensive understanding of the foundation's performance in various real-world situations.

- Complexity of Numerical Models vs Simplified Analytical Models: While advanced 3D numerical models have been developed to capture the intricate behaviour of piled rafts, there's a lack of simplified analytical models and standardized guidelines. This absence hinders the adoption of new design approaches and techniques. Developing simplified yet accurate analytical models and codified guidelines can bridge the gap between complex numerical simulations and traditional design methods, making advanced analyses more accessible and applicable in practical engineering design.

- Furthermore, there is a need for more field monitoring and testing to validate the performance of piled raft foundation in real-world applications. With continued research in these areas, piled raft foundation systems can become even more reliable and efficient, providing a sustainable and economical solution for various construction projects.

In conclusion, these points outline key research areas for advancing our understanding of piled raft foundations. Exploring accurate modelling, long-term behaviour, challenging soil conditions, dynamic loading, and innovative materials will contribute to safer, more efficient, and environmentally conscious foundation design and construction practices.