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PILED RAFT FOUNDATION: STATE OF ART

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ABSTRACT

In engineering, a foundation is a crucial structural element that transfers load from a structure to the underlying soil. Foundation failure can have severe consequences, highlighting the need to understand and mitigate potential risks. To meet the growing demand for efficient and sustainable foundations, engineers are constantly exploring innovative designs that optimize material use while maintaining or enhancing load-bearing capacity. One such system that has gained popularity in recent decades is the piled raft foundation. This system offers a cost-effective and high-performance solution, particularly for challenging soil conditions. It is needed to highlight a general and broad information about this system including pros and cons, design criteria, soil-pile interaction as well as pile-raft interaction. So, this paper provides a comprehensive review of various design concepts for piled raft foundations, as proposed by different researchers. the load-sharing mechanism within these systems was explained as well. The study reveals that several factors influence the load-sharing ratio, and that the raft component plays a significant role in reducing total and differential settlement.

KEYWORDS

Piled raft, Load sharing mechanism, Settlement, Shallow foundation.

1. INTRODUCTION

Generally, foundations are classified as shallow or deep (Sari et al., 2021). Both types systems are designed to transfer vertical and lateral loads to the ground securely (Hirai, 2022). The choice of foundation type is influenced by factors such as soil conditions, water levels, building weight, cost, and material availability (Alsamia & Koch, 2023) as well as building height. The shallow foundation is suitable when the soil near the surface is strong enough to support the building's weight and load (Al-Recaby, 2021; Alsamia & Koch, 2023; Aouadj & Bouafia, 2022; Zhang & Xue, 2022). As the population increases and urban areas expand, there is a growing need to build skyscrapers and high-rise buildings (Kumar & Kumar, 2018). This structures are subjected to significant lateral load from wind, water, or earthquakes. Shallow foundations are typically inadequate for resisting these forces, making deep the preferred choice (Banerjee et al., 2022).

The increasing prevalence of skyscrapers and high-rise buildings created a demand for improved deep foundation systems that could lower foundation costs and increase reliability. Deep foundation systems have been developed over time, starting with bearing piles and skin friction piles, moving to a combination of these, and culminating in the pile-raft foundation, which is now commonly used (Solanki & Sorte, 2016). Piles are increasingly used below the shallow foundations to support the structural loads and reduce settlement as part of the continuous development of foundation engineering and construction (Siegel, 2011).

Raft foundations are a type of shallow foundation, which is the footing that covers the entire building footprint. They are used when the soil is loose or compressible, or when the combined area of all the footings in design is greater than half the building's overall size (Huang & Yu, 2017). When a raft foundation alone doesn't meet design requirements, incorporating piles can enhance its performance. This combination can be particularly effective in challenging soil conditions (Chandiwala & Vasanwala, 2023; Saleh & Abbas, 2021).

The exact origin of the piled raft concept is difficult to pinpoint, as it likely evolved over time and through the work of various engineers and researchers. However, the term "piled raft" seems to have gained widespread recognition and usage in the latter half of the 20th century. Where piled raft foundations have become a popular and cost-effective choice for supporting various structures. Since the concept of "settlement reducers" was introduced by (Burland et al., 1977) which located one pile beneath each shaft of structure, piled rafts have gained widespread recognition. Japan has been a pioneer in using piled raft foundations, with numerous applications dating back to the 1980s (Kitiyodom et al., 2011).

Piled raft foundations have been successfully implemented in various countries, including the foundation for the Burj Khalifa Fig. 1, the world's tallest building (Hamada et al., 2020). Beyond high-rise structures, this foundation system has also found application in marine environments (Deb & Pal, 2024), supporting structures such as wind turbines, oil storage tanks, and offshore platforms (Deb & Pal, 2022). The aim of this study is to review the design concepts for piled raft foundations, their advantages and disadvantages, and discuss the load-sharing mechanism and the factors that influence it.

(a) (b)

Fig. 1. Burj Khalifa: (a) Foundation system raft shape with supported piles, (b) Burj Khalifa Skyline (El Gendy et al., 2018; Peirce, 2023)

2. DESIGN CONCEEPT

Piled raft foundations have gained significant popularity in recent decades. Engineers have widely recognized their unique features, which has prompted significant research efforts to use various approaches to comprehend these foundations' engineering behavior (Ahadi et al., 2024). Designing a piled raft foundation involves considering several key factors, as with any foundation system (Mohammed, 2013):

- Ultimate load capacity: The foundation must be able to withstand vertical, lateral, and moment loads.
- Maximum settlement: The overall settlement must be within acceptable limits.
- Differential settlement: Uneven settlement between different parts of the foundation should be minimized.
- Raft loads: The raft must be designed to handle the stresses and moments it will experience.
- Pile loads: The individual piles must be designed to withstand the loads they will carry.

3. ADVANTAGES OF PILED RAFT FOUNDTION

Piled raft foundations offer several advantages over traditional foundation systems:

- Increased load-carrying capacity: piled raft foundations have high load-carrying capacity due to the efficient load sharing between the piles and the raft (Deb & Pal, 2019).

- Reduce settlements: the raft foundation has been combined with piles to reduce settlements for rigid structures and to reduce both total and differential settlement for flexible structures (H. H. Ahmed & Al-Zaidee, 2020).
- Load redistribution: if one or more piles fail due to defects or adverse soil conditions, the raft can help redistribute the load to unaffected piles. This reduces the impact of individual pile failures on the overall foundation performance (Sinha & Hanna, 2017).
- Piled raft foundations offer a cost-effective and efficient solution, it requires fewer piles than traditional pile groups to achieve the same load-bearing capacity and settlement performance. Where the raft distributes loads more efficiently, enhancing the foundation's resilience by reducing the impact of potential pile failures (Ahadi et al., 2024). As demonstrated by (Jayarajan & Kouzer, 2020), a piled raft foundation offers significant cost savings (approximately 30-50%) compared to a traditional pile-only foundation while meeting the required strength and serviceability criteria. Where The piled raft foundation can be an intermediate option between raft foundation and pile foundation in terms of rigidity, settlement and cost (Deb & Pal, 2022).

4. DISADVANTAGES OF PILED RAFT FOUNDTION

While piled raft foundations offer several advantages, they also have some potential drawbacks:

- Complex behavior: piled raft foundations exhibit complex behavior due to the interaction between the raft and the piles that behave as a unit (Lee et al., 2014). This can make accurate design and analysis challenging.
- Limited research and data: there is a relative scarcity of research and data on the long-term behavior of piled raft foundations (Deb & Pal, 2019). This makes it challenging to accurately predict the foundation's performance.

5. MECHANISM OF PILED RAFT FOUNDATION

A piled raft foundation is a combined structure comprised of three elements: raft, piles and subsoil that supports the foundation system (Banerjee et al., 2022; Mali & Singh, 2018). The design of the piled raft foundation is depending on transferring the structure stresses to the soil by a load sharing mechanism between the raft and piles (D. Ahmed et al., 2022), resulting in complex interaction between the raft, piles and soil. Which is governed by the pile and raft geometry and soil condition (Hanna & Vakili, 2021). Fig. 2 shows the interactions in a piled raft foundation (Kaynia, 2021).

This complex behavior is not fully understood. There's a lack of comprehensive research and data on how these components interact factor and share loads (Deb & Pal, 2019).

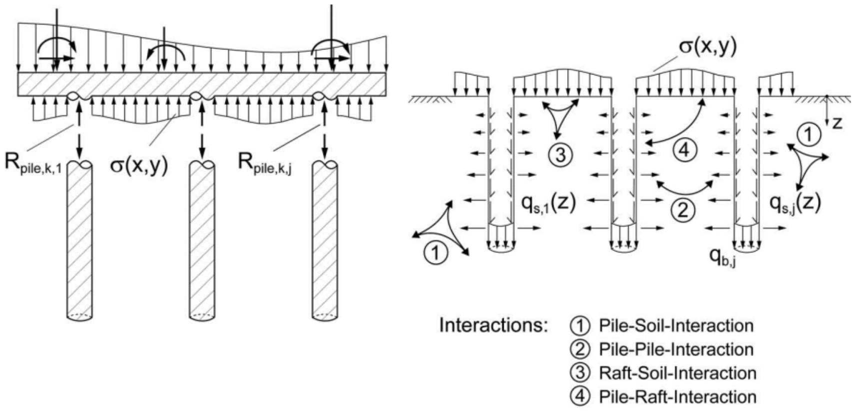

Fig. 2. Bearing behavior and interactions of combined pile-raft foundation system (Katzenbach & Choudhury, 2013; Kaynia, 2021)

The load sharing ratio α_p is a critical parameter in piled raft foundation design. It quantifies the ratio of the total load carried by the piles relative to the entire foundation system (Lee et al., 2015). Mathematically, it can be expressed as (Kumar & Kumar, 2018):

$$\alpha_p = \frac{Q_p}{Q_{pr}} = 1 - \frac{Q_r}{Q_{pr}} \quad (1)$$

The load-sharing mechanism between piles and the raft is non-linear, meaning the relationship is not a simple proportion (Hanna & Vakili, 2021). Traditional piled raft design assumes that piles carry the entire structural load, there are no carry sharing from the raft (Mohammed, 2013). On the other hand, if the load is supposed to be carried by piles only, the piled raft foundation design would become overly conservative and may be uneconomical (Dongyu and Junhwan, 2015; Park, Park and Lee, 2016). However, if the load carrying capacity of rafts is considered without a thorough understanding of the interaction effects, the design might not be sufficiently conservative (Park & Lee, 2015).

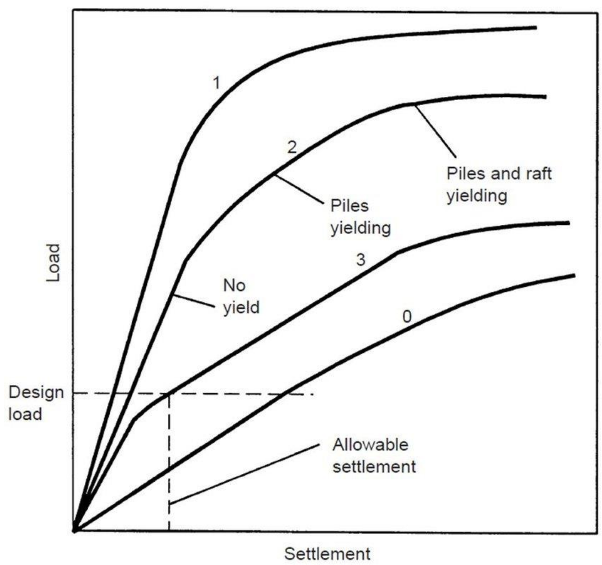

Fig. 3. load-settlement relationships of different approach of foundation system (Solanki & Sorte, 2016)

Fig. 3 (Solanki & Sorte, 2016) illustrates different approaches to pile design, where:

- Curve 0: A raft foundation alone leads to excessive settlement at the design load.
- Curve 1: The traditional approach considers all loads to be carried by piles. Using longer piles in deep soil can create twisting moments and be uneconomical.
- Curve 2: A lower safety factor with fewer piles allows the raft to carry more load.
- Curve 3: Strategic pile placement can act as "settlement reducers," allowing for acceptable settlement while maintaining economy.

The raft's contribution can be significant, as demonstrated by both numerical calculations and field monitoring of pile foundations, (Watcharasawe et al., 2021) studied load-sharing behavior in a pile foundation constructed on soft clay based on monitoring results of a high-rise building project in Bangkok. They found that the raft foundation despite being designed using a conventional approach that neglected its load-carrying capacity, shared 10-20% of the total load. This indicates that rafts can contribute to the overall load-carrying capacity of pile foundations, even in soft soil conditi+ons.

6. LOAD SHARING BEHAVIOR

The need for efficient foundation systems in urban environments with increasing structural loads has driven researchers to extensively study the combined behavior of piles and rafts in piled raft foundation systems, with a focus on load-sharing ratio and overall performance. Table1 provides an overview of earlier research on load-sharing behavior in piled raft foundation.

Table 1. Overview of earlier research on load-sharing behavior.

Reference	Title of Research	Work Methodology	Conclusion
(Butterfield & Banerjee, 1971)	The Problem of Pile Group–Pile Cap Interaction.	The study used Mindlin equation to model the load-displacement behavior and load distribution between piles and the cap.	The pile caps contribute between 20% and 60% of the total load, depending on the group size and, being higher for the larger groups at larger spacing's.
(de Sanctis & Mandolini, 2006)	Bearing Capacity of Piled Rafts on Soft Clay Soils.	The study examines the role of the raft in piled raft foundations on soft clay soils using experimental data and 3D finite element analysis with ABAQUS.	The piles typically carry most of the load at failure, with their capacity remaining relatively constant compared to their performance as a standalone group. The raft's load share is generally less than the piles, varying depending on factors like pile layout and raft geometry.

Reference	Title of Research	Work Methodology	Conclusion
(Lee et al., 2015)	Estimation of Load-Sharing Ratios for Piled Rafts in Sands that Includes Interaction Effects.	The study analyzes the load-sharing behavior of piled rafts in sandy soils, considering pile–raft interaction effects. Using 3D finite element analysis in PLAXIS 3D, it examines factors like pile spacing, raft size, and sand density.	The piles tend to carry more of the initial load, but the raft's contribution increases as settlement progresses. Wider pile spacing results in a greater load share for the piles, while the load-sharing ratio between piles and the raft decreases non-linearly as settlement progresses.
(Mali & Singh, 2020)	3D Numerical Modelling of Large Piled-Raft Foundation on Clayey Soils for Different Loadings and Pile-Raft Configurations.	The study analyze the behavior of piled raft foundations under various conditions using a 3D finite element model. The model considered the interactions between piles, rafts, and soil.	Wider pile spacing reduces average settlement and enhances load-sharing, while closer spacing minimizes differential settlement. Different load patterns affect settlement and load distribution.
(Hanna & Vakili, 2021)	Load sharing mechanism of non-displacement piled-raft foundation in sand.	The study conducted an experimental investigation using a prototype model of a piled-raft foundation in sand. The focus was on understanding how pile spacing and settlement influence the load-sharing mechanism between the piles and the raft.	The raft's share of the load increases with the overall settlement of the foundation. For pile spacing less than or equal to 3 times the pile diameter, piles carry most of the load. However, As pile spacing increases, the raft's share of the load increases. The magnitude and distribution of loads on the foundation can influence load-sharing behavior.
(Ahadi et al., 2024)	Investigation of load sharing mechanism of Piled Raft Foundations in sandy soils.	The study developed a 3D finite element model using PLAXIS 3D Foundation software to analyze the impact of critical parameters (pile length, soil friction angle, and raft thickness) on load-sharing behavior in piled raft foundations and validated it through centrifuge testing.	longer piles generally lead to increased load-sharing by the piles, and a higher soil friction angle (up to 30 degrees) can also increase the load carried by the piles Fig.4. The raft thickness had a relatively minor impact on load-sharing in this study Fig.5.

7. SUMMERY

Piled raft foundations play a crucial role in construction because they offer a versatile and effective solution for challenging soil conditions and distribute heavy structural loads, ensuring stability and minimizing settlement, especially in situations where conventional foundation systems are inadequate. This makes them a critical tool in modern geotechnical engineering. They are used in a variety of construction projects, including high-rise buildings, bridges, and other large-scale structures.

On other hand, piled raft foundations involve complex interactions between piles, the raft, and soil, making their design and analysis more challenging than simpler foundations. Their design relies on distributing structural stresses through load-sharing between the raft and piles.

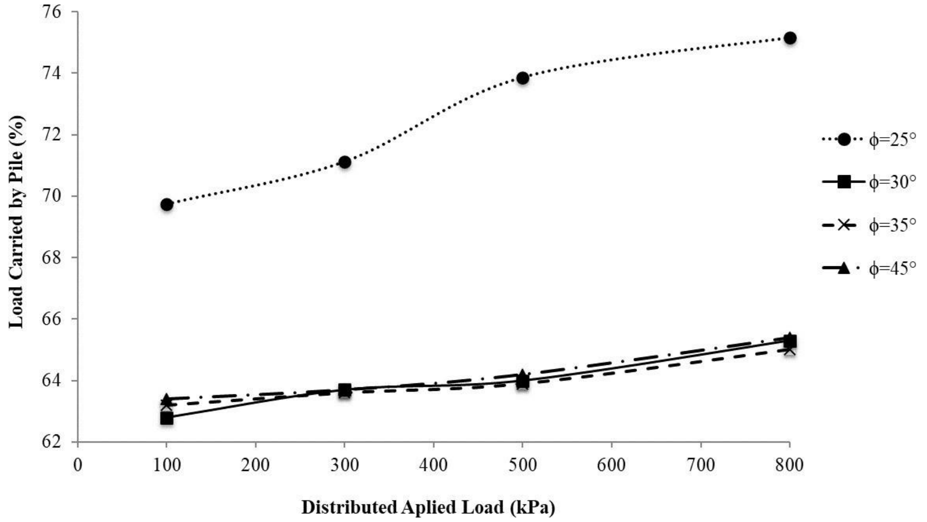

Fig. 4. Load carried by pile versus distributed applied load in the various angles of internal friction of the soil for a raft foundation supported by a single pile (Ahadi et al., 2024)

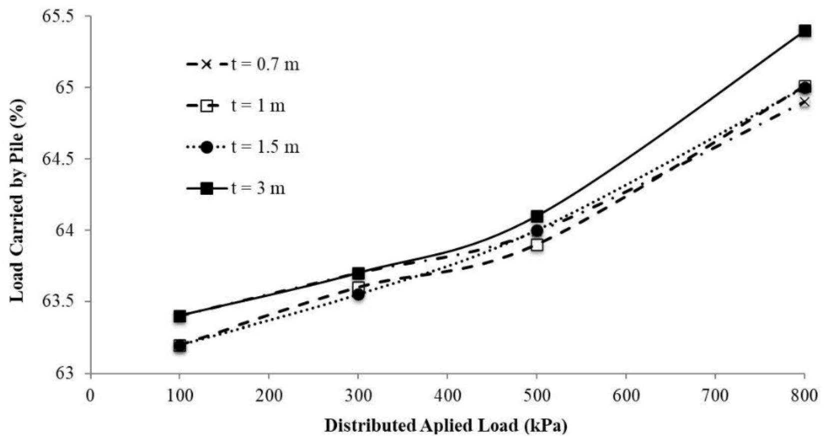

Fig. 5. Load carried by pile versus distributed applied load in the various raft thickness for a raft foundation supported by a single pile (Ahadi et al., 2024)

According to studies, several factors affect the load-sharing between piles and the raft, as follows:

- The load-sharing ratio decreases non-linearly with increasing settlement.
- The proportion of load carried by piles increases with wider pile spacing.
- Load-sharing behavior is affected by pile arrangement and the magnitude and distribution of loads.
- The type of soil significantly affects the foundation's behavior. A higher soil friction angle (up to 30 degrees) can also increase the load carried by the piles.

This can Justification by the skin friction in the piled raft foundation system. The skin friction influenced by pile-soil-pile interaction and lateral earth pressures induced by the raft and pile base failure zone (Phung et al., 2010). Pile-soil-pile interaction occurs within pile groups due to the significant overlap of stresses transmitted to the surrounding soil (Pham, 2016). This phenomenon, known as the group effect, is quantified by the group efficiency factor (Pratama et al., 2023). So, the increasing the distance between piles reduces negative pile group effects, allows for a better distribution of the load between the piles and the raft, and improves the overall efficiency of the foundation system.

Furthermore, the presence of the raft increases lateral earth pressures against the piles while causing soil settlement beneath it, reducing relative displacement near the raft (Phung et al., 2010). Which leads to decreases the load-sharing ratio during the progress of the settlement process.

8. CONCLUSIONS

- Piled raft foundations provide a versatile and efficient solution for challenging soil conditions and substantial structural loads. By integrating the advantages of both raft and pile foundations, they can support heavier loads than either system individually.
- The interaction between piles, raft and soil in piled raft foundation makes the design and analysis process more complex than traditional foundations.
- The exact load-sharing ratio between piles and the raft can vary depending on several factors, including: pile spacing and arrangement, settlement, loading conditions, length of pile, and soil friction angle.
- In a piled raft system, both the piles and the raft share the structural load, however, the raft's load share in a piled raft foundation is typically less than that of the piles.

9. REFERENCES

Ahadi, A., Ghavami, S., & Ardakani, A. (2024). Investigation of load sharing mechanism of Piled Raft Foundations in sandy soils (A. Ahadi & S. Ghavami (eds.)).

Ahmed, D., Taib, S. N. L. B., Ayadat, T., & Hasan, A. (2022). Numerical Analysis of the Carrying Capacity of a Piled Raft Foundation in Soft Clayey Soils. Civil Engineering Journal (Iran), 8(4), 622–636. https://doi.org/10.28991/CEJ-2022-08-04-01

Ahmed, H. H., & Al-Zaidee, S. R. (2020). Three-Dimensional Explicit Finite Element Simulation of Piled-Raft Foundation. Journal of Engineering, 26(3), 127–144. https://doi.org/10.31026/j.eng.2020.03.11

Al-Recaby, M. (2021). Assessing the Increase in Bearing Capacity of Bored Piles in Sandy Soil Using Expansive Additives. Kufa Journal of Engineering, 10(1), 12–28. https://doi.org/10.30572/2018/kje/100102

Alsamia, S., & Koch, E. (2023). Evaluation the Behavior of Pullout Force and Displacement for a Single Pile: Experimental Validation With Plaxis 3D. In Kufa Journal of Engineering (Vol. 14, Issue 2, pp. 105–116). https://doi.org/10.30572/2018/KJE/140207

Aouadj, A., & Bouafia, A. (2022). CPT-based method using hybrid artificial neural network and mathematical model to predict the load-settlement behaviour of shallow foundations. In Geomechanics and Geoengineering (Vol. 17, Issue 1, pp. 321–333). https://doi.org/10.1080/17486025.2020.1755459

Banerjee, R., Bandyopadhyay, S., Sengupta, A., & Reddy, G. R. (2022). Settlement behaviour of a pile raft subjected to vertical loadings in multilayered soil. Geomechanics and Geoengineering, 17(1), 282–296. https://doi.org/10.1080/17486025.2020.1739754

Burland, J., Broms, B., & Mello, V. (1977). Behaviour of foundations and structures.

Butterfield, R., & Banerjee, P. K. (1971). the Problem of Pile Group-Pile. In Géotechnique (Issue 2, pp. 135–142).

Chandiwala, A., & Vasanwala, S. (2023). Experimental Study of Lateral Loading on Piled Raft Foundations on Sandy Soil. International Journal of Engineering, 36(1), 28–34. https://doi.org/10.5829/IJE.2023.36.01A.04

de Sanctis, L., & Mandolini, A. (2006). Bearing Capacity of Piled Rafts on Soft Clay Soils. Journal of Geotechnical and Geoenvironmental Engineering, 132(12), 1600–1610. https://doi.org/10.1061/(ASCE)1090-0241(2006)132:12(1600)

Deb, P., & Pal, S. (2024). Evolution of Piled Raft Foundation at Static Loading Condition and Application of Numerical Modelling: A State-of-the-Art Review. Archives of Computational Methods in Engineering. https://doi.org/10.1007/s11831-024-10172-w

Deb, P., & Pal, S. K. (2019). Analysis of Load Sharing Response and Prediction of Interaction Behaviour in Piled Raft Foundation. In Arabian Journal for Science and Engineering (Vol. 44, Issue 10, pp. 8527–8543). https://doi.org/10.1007/s13369-019-03936-1

Deb, P., & Pal, S. K. (2022). Structural and geotechnical aspects of piled raft foundation through numerical analysis. Marine Georesources & Geotechnology, 40(7), 823–846. https://doi.org/10.1080/1064119X.2021.1943083

Dongyu, P., & Junhwan, L. (2015). Comparative Analysis of Various Interaction Effects for Piled Rafts in Sands Using Centrifuge Tests. Journal of Geotechnical and Geoenvironmental Engineering, 141(1), 4014082. https://doi.org/10.1061/(ASCE)GT.1943-5606.0001183

El Gendy, O., El Gendy, A., & El Gendy, O. (2018). Analysis of Piled raft of Burj Khalifa in Dubai by the program ELPLA. GEOTEC Software Inc., Canada, 3–23.

Hamada, J., Yamashita, K., & Nakane, K. (2020). Settlement behavior of piled raft foundation supporting residential building adjacent to tall pile foundation building (P. Duc Long & N. T. Dung (eds.); pp. 27–32). Springer Singapore. https://doi.org/10.1007/978-981-15-2184-3_2

Hanna, A. M., & Vakili, R. (2021). Load-sharing mechanism of non-displacement piled-raft foundation in sand. In Proceedings of the Institution of Civil Engineers: Ground Improvement (Vol. 174, Issue 2, pp. 105–115). https://doi.org/10.1680/jgrim.17.00072

Hirai, H. (2022). Failure surface for shallow foundations in sand using a classical bearing capacity. Soils and Foundations, 62(2), 101125. https://doi.org/https://doi.org/10.1016/j.sandf.2022.101125

Huang, A.-B., & Yu, H.-S. (2017). Shallow foundations. In Foundation Engineering Analysis and Design (pp. 189–240). CRC Press. https://doi.org/10.1201/9781351255400-4

Jayarajan, P., & Kouzer, K. M. (2020). Combined Piled Raft Foundation (CPRF) System for Polymerization Loop Reactor Structure BT - Construction in Geotechnical Engineering (M. Latha Gali & P. Raghuveer Rao (eds.); pp. 185–202). Springer Singapore.

Katzenbach, R., & Choudhury, D. (2013). ISSMGE Combined Pile-Raft Foundation Guideline.

Kaynia, A. M. (2021). Analysis of Pile Foundations Subject to Static and Dynamic Loading. CRC Press. https://doi.org/10.1201/9780429354281

Kitiyodom, P., Matsumoto, T., & Sonoda, R. (2011). Approximate Numerical Analysis of a Large Piled Raft Foundation. Soils and Foundations, 51(1), 1–10. https://doi.org/10.3208/sandf.51.1

Kumar, V., & Kumar, A. (2018). An experimental study to analyse the behaviour of piled-raft foundation model under the application of vertical load. Innovative Infrastructure Solutions, 3(1), 35. https://doi.org/10.1007/s41062-018-0141-8

Lee, J., Park, D., & Choi, K. (2014). Analysis of load sharing behavior for piled rafts using normalized load response model. In Computers and Geotechnics (Vol. 57, pp. 65–74). https://doi.org/10.1016/j.compgeo.2014.01.003

Lee, J., Park, D., Park, D., & Park, K. (2015). Estimation of load-sharing ratios for piled rafts in sands that includes interaction effects. Computers and Geotechnics, 63, 306–314. https://doi.org/10.1016/j.compgeo.2014.10.014

Mali, S., & Singh, B. (2018). Behavior of large piled-raft foundation on clay soil. Ocean Engineering, 149, 205–216. https://doi.org/10.1016/j.oceaneng.2017.12.029

Mali, S., & Singh, B. (2020). 3D Numerical Modeling of Large Piled-Raft Foundation on Clayey Soils for Different Loadings and Pile-Raft Configurations. Studia Geotechnica et Mechanica, 42(1), 1–17. https://doi.org/10.2478/sgem-2019-0026

Mohammed, Y. (2013). Bearing Capacity of Pile Group and Piled Raft Foundations on Sandy Soil (Vol. 17, Issue 2, p. 33).

Park, D., & Lee, J. (2015). Comparative Analysis of Various Interaction Effects for Piled Rafts in Sands Using Centrifuge Tests. Journal of Geotechnical and Geoenvironmental Engineering, 141(1). https://doi.org/10.1061/(ASCE)GT.1943-5606.0001183

Park, D., Park, D., & Lee, J. (2016). Analyzing load response and load sharing behavior of piled rafts installed with driven piles in sands. In Computers and Geotechnics (Vol. 78, pp. 62–71). https://doi.org/10.1016/j.compgeo.2016.05.008

Peirce, K. (2023). Structural design considerations for super-tall buttressed core structure - the Burj Khalifa (pp. 42–54).

Pham, T. (2016). A Simplified Formular For Analysis Group Efficiency of Piles in Granular Soil. International Journal of Scientific and Engineering Research, 7, 15–21.

Phung, L., President, V., & Vietnam, V. (2010). Piled Raft—A Cost-Effective Foundation Method for High-Rises. Geotechnical Engineering Journal of the SEAGS & AGSSEA, 41.

Pratama, I. T., Widjaja, B., & Budianto, K. A. (2023). Numerical study on pile group efficiency for piles embedded in cohesive and cohesionless soils. In E3S Web of Conferences (Vol. 429). https://doi.org/10.1051/e3sconf/202342904003

Saleh, W. A., & Abbas, J. M. (2021). Influence of lateral cyclic loading on the piled-raft foundation embedded in layered soil. IOP Conference Series: Materials Science and Engineering, 1076(1), 012087. https://doi.org/10.1088/1757-899X/1076/1/012087

Sari, O. L., Saputra, A. A. I., Subhakti, A., Putri, A. P., & Khala, C. C. S. (2021). The influence in selection of pile type and foundation piling method. IOP Conference Series: Materials Science and Engineering, 1087(1), 012033. https://doi.org/10.1088/1757-899X/1087/1/012033

Siegel, T. C. (2011). Simplified Settlement Model for a Shallow Foundation on Composite Ground with Rigid Piles. DFI Journal - The Journal of the Deep Foundations Institute, 5(1), 68–72. https://doi.org/10.1179/dfi.2011.006

Sinha, A., & Hanna, A. M. (2017). 3D Numerical Model for Piled Raft Foundation. International Journal of Geomechanics, 17(2), 78–84. https://ascelibrary.org/doi/10.1061/%28ASCE%29GM.1943-5622.0000674

Solanki, R., & Sorte, S. (2016). A Review on Pile-Raft Foundation. In International Journal of Civil Engineering Research (Vol. 7, Issue 1, pp. 51–58). http://www.ripublication.com

Watcharasawe, K., Jongpradist, P., Kitiyodom, P., & Matsumoto, T. (2021). Measurements and analysis of load sharing between piles and raft in a pile foundation in clay (pp. 559–572). https://doi.org/https://doi.org/10.12989/gae.2021.24.6.559

Zhang, R., & Xue, X. (2022). Determining ultimate bearing capacity of shallow foundations by using multi expression programming (MEP). Engineering Applications of Artificial Intelligence, 115, 105255. https://doi.org/10.1016/j.engappai.2022.105255