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Micropiled Post-Tensioned Raft Foundation System as a Sustainable, Innovative and Cost- Effective Solution: Case Studies in Saudi Arabia and the GCC Region

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ABSTRACT

Micropiles, initially conceived for underpinning and strengthening existing structures, have evolved into foundational elements for the construction of new superstructures and substructures. Although micropiles possess a lower load-bearing capacity relative to conventional piles, thereby elevating the cost-to-force ratio, the advent of the Combined Micropiled Raft Foundation (CMPRF) system offers a synergistic approach where the load is distributed between the micropiles and the raft foundation. This integration enhances structural efficiency and cost-effectiveness. Particularly in the Gulf Cooperation Council (GCC) regions, including coastal areas like Jizan on the Red Sea and Bahrain on the Arabian Gulf, the deployment of such foundational systems remains largely novel. Given this context, a detailed examination of the foundation's behavior under various stress conditions—including static, dynamic, and seismic influences—is imperative to ensure structural integrity and optimal performance. This paper presents two pioneering case studies within the GCC: the AMAS project, which features the world's largest micropiled post-tensioned raft foundations in Bahrain, and a significant warehouse foundation project in Jizan. These case studies highlight the employment of advanced methodologies and technologies such as Interferometric Synthetic Aperture Radar (InSAR) remote sensing, on-site monitoring, three-dimensional Finite Element Analysis (FEA), performance- based design, coupled soil-structure interaction (SSI) analysis, and the integration of automation, Artificial Intelligence (AI), and Machine Learning (ML). Results from these projects indicate successful implementation with a marked reduction in carbon footprint by over 75% and significant cost savings, underscoring the CMPRF system's viability and effectiveness.

1. SUMMARY:

This paper investigates the innovative deployment of Combined Micropiled Raft Foundations (CMPRF) in geotechnically challenging regions within Saudi Arabia and Bahrain, focusing on the advanced integration of micropiles with post-tensioned raft foundations. Traditionally, micropiles have been utilized for underpinning or reinforcement purposes (Cadden et al., 2004; Han et al., 2006), but recent developments have extended their use as primary load-bearing elements in combination with raft foundations. The CMPRF system effectively addresses the inherent load-bearing limitations of standalone micropiles by distributing loads between the micropiles and a raft (Alnuaim et al., 2016; Borthakur and Das, 2021; Elsawwaf et al., 2022; Hamzah M. B. Al-Hashemi, 2021; Hwang et al., 2017; Kempfert and Böhm, 2006; Wang et al., 2021).

Post-tensioning in raft foundations is a critical development in modern foundation engineering, offering enhanced structural performance and material efficiency. Post-tensioning involves the application of a pre-stressing force to the reinforcement steel within the concrete raft after the concrete has gained sufficient strength. This technique induces a compressive stress, which counteracts the tensile stresses generated by external loads, thereby improving the raft's load-carrying capacity and reducing the likelihood of cracking.

The advantages of integrating post-tensioning with micropiled raft foundations are manifold. Firstly, it allows for thinner raft sections and smaller footprints, essential in urban areas or regions with limited space. Secondly, the pre-stress introduced by post-tensioning helps to control differential settlements even under variable load conditions, thereby enhancing the overall durability and longevity of the structure. Furthermore, post-tensioned rafts distribute loads more uniformly across the foundation, reducing the stress on individual micropiles and ensuring a balanced load transfer to the underlying soil (Aalami, 2015; Souza, 2014).

In the context of the GCC, where seismic activity and challenging soil conditions prevail, the CMPRF system's resilience and adaptability are particularly beneficial. The case studies highlighted in this paper—the world's largest micropiled post-tensioned raft foundation for the AMAS project in Bahrain, and a similar implementation for a warehouse in Jizan—exemplify the practical application and effectiveness of this technology. Both projects utilized advanced design and monitoring technologies, including Interferometric Synthetic Aperture Radar (InSAR), Finite Element Analysis (FEA), and AI- driven data analytics, to optimize the design and ensure performance reliability under dynamic conditions (Chanda et al., 2023; Patil et al., 2022). The results demonstrated not only structural efficacy but also significant environmental benefits, with a reduction in carbon footprint exceeding 75%, showcasing the CMPRF system's potential as a sustainable and efficient solution for complex geotechnical challenges.

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