Structural Stability: A Comprehensive Review of Pile Foundations in Construction

Fayaz Kaladi[1], Fei Wang[2] and Fatima Zahra Kherazi[3]

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Abstract

This article examines the essential business management expertise and analyses the piling process, where lengthy poles are driven into the ground to improve the safety and reliability of construction projects. Pile foundations, critical for supporting structures like homes and roads, come in different shapes, sizes, and materials depending on soil conditions. They play a vital role in various construction scenarios, dealing with issues such as uplift loads and external forces like wind and waves. This study will explore the suitability of pile foundations in different situations, including high groundwater tables, heavy superstructure loads, cost considerations, compressible shallow soil, scouring risk near water bodies, proximity to canals or drainage systems, poor soil conditions, and unmanageable water seepage. The article also discusses three types of pile foundations: Driven Pile Foundations, Cast-in-situ Pile Foundations, and Combined Pile Foundations, highlighting their materials, soil compaction processes, and limitations. It will also emphasize the principles of pile design and engineering practices in cold regions, stressing the need for a deeper understanding of various factors to predict pile behaviours accurately. Loading tests are used to uncover factors related to the bearing capacity of piles in cold regions. Frost heave, frost jacking, and the frozen soil–pile interface are also explored. Gathering reliable data from on-site monitoring or lab testing is crucial for analyzing the bearing capacity of piles in frozen ground and understanding the processes during freezing.

Keywords: Management Structural Stability, Business Review, Pile Foundation, Construction.

Introduction

Piling is a crucial construction process employed by contractors to enhance the safety and dependability of their projects. It involves driving long poles into the ground, typically made of timber, steel, or concrete. These piles' shape, size, and material vary based on soil conditions and project requirements (Fleming et al., 2008). Piling fortifies the ground to support heavy structures, such as homes, office complexes, roads, and other infrastructure.

Pile foundations, a widely used type of deep foundation, have a long history in geotechnical engineering. Piles are well-suited for providing structural support in areas with frost-prone soils that freeze deeply during certain seasons or in regions with much frozen ground (Zheng et al., 2020). Pile foundations can be installed with minimal disruption to frozen ground and can effectively shield structures from the effects of seasonal freezing, ground movement, and permafrost thaw (Chen et al., 2023).

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*[1] School of Civil Engineering and Mechanics, Jiangsu University, Zhenjiang, China.
Corresponding Author Email: fayaz.kaladi@gmail.com*
[2] School of Civil Engineering and Mechanics, Jiangsu University, Zhenjiang, China. Email: wangfei9107@ujs.edu.cn
[3] School of Management Sciences, Jiangsu University, Zhenjiang, China. Email: fayaz.kaladi@gmail.com

In this review article, we explore and discuss the critical aspects of pile foundations, such as their importance, versatility, suitability factors, types, and applications in cold climates. We also ensure that a comprehensive guide for practitioners is provided, as well as future research gaps and knowledge and environmental considerations. Piling is a crucial part of building for the safety and stability of structures. The most important points to note are that there are still some unanswered questions regarding frozen soil and the interface between frozen soil and piles, the value of interdisciplinary engineering and architectural collaboration in ensuring efficient foundation design and resolving construction challenges, and the impact of permits, regulations, and environmental factors on the viability of pile foundations in building projects.

Numerous variables, including the diameter, length, area of the piles, soil layers, and building techniques, might affect the foundation. Gathering enough samples that meet the exact prerequisites for statistical analysis is challenging. Thus, using the probability technique, the pile foundation's safety factor is calculated based on the statistics of the pile foundation bearing capability. Following is the limit state function of the pile foundation's bearing capacity. Where P is the pile foundation's bearing capacity, G is the dead load, Q is the living load, and K is the safety factor, we get $Z=P-K\ (G+Q)$.

Suitability of Pile Foundation

Engineers often use pile foundations to ensure the safety and stability of the ground before constructing anything on top of it (ICSMGE, 2005). This approach involves distributing the weight of a structure over a broader surface area, which is particularly important when dealing with taller buildings like skyscrapers (Ali & Moon, 2007; Sarkisian, 2016). Pile foundations become necessary in various construction scenarios, such as addressing uplift loads or handling external forces like wind and waves that could impact the structure's stability (Biriukova, 2020; Malhotra, 2009).

Literature Review

This article explores the concept of piling in the everyday environment area and permafrost zones, its applications, and different piling methods. We also provide an overview of common pile types. If you are considering a career in the construction industry, understanding the fundamentals of piling is essential. Pile foundations are utilized in various construction scenarios. They are particularly suitable in the following situations:

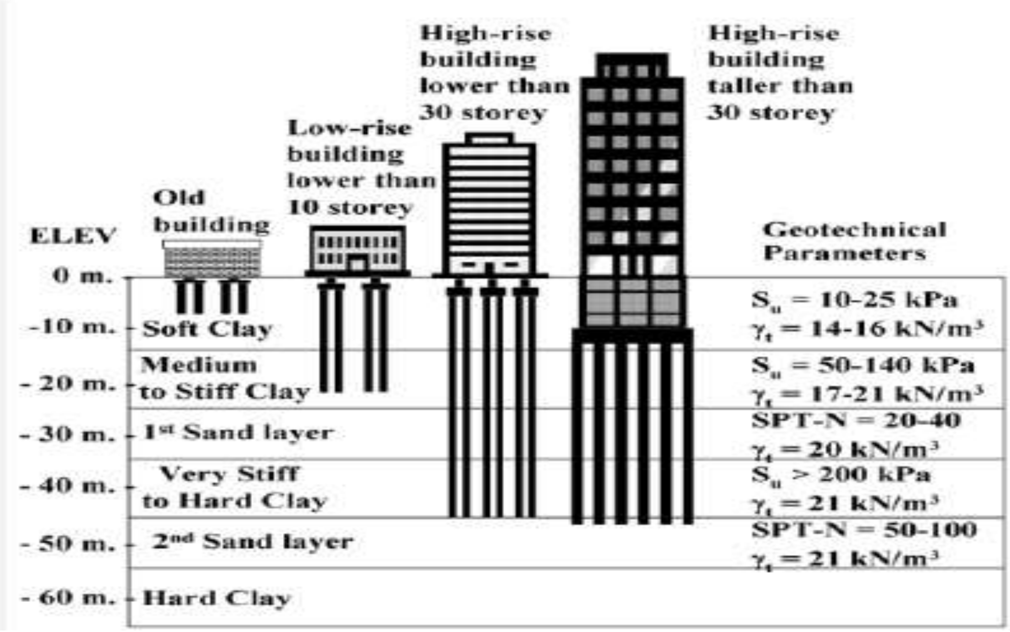
High Groundwater Table

When the groundwater table is close to the surface, traditional foundations may not be viable due to the risk of water infiltrating the foundation. Pile foundations provide a solution by extending deep into stable soil or bedrock (Beichmann & Van Lohuizen, 1980; Gutiérrez et al., 2014; Spence et al., 2021).

Figure 1: Heavy Superstructure Loads

For structures that carry substantial loads, such as large buildings or bridges, additional support is often required. Pile foundations are effective in distributing this weight to deeper, more stable layers of soil or rock (Reese et al., 2005; Whitaker, 2013).

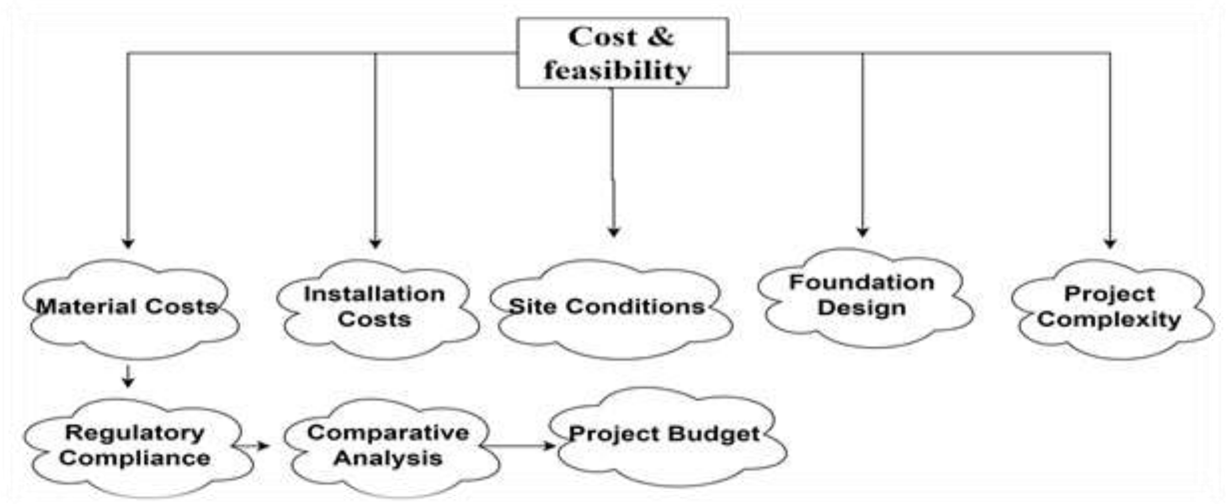
Figure 2: Cost and Feasibility



In cases where alternative foundation types are cost-prohibitive or not technically feasible, pile foundations offer a practical and economical solution. Cost and feasibility considerations are integral when evaluating pile foundation use in construction projects. The materials such as steel, concrete, or timber contribute to the overall cost. The installation of piles can involve specialized equipment and skilled labour, adding to installation costs (Barksdale et al., 1983; Holm & Schaufelberger, 2021; Sloan & Cotrell, n.d.). Conducting a thorough geotechnical investigation to understand soil properties is essential. Additional measures, like soil improvement, may be necessary in cases where poor soil conditions exist. Foundation design tailored to specific site conditions contributes to cost-effectiveness and feasibility (Whitaker, 2013; Whitman, 2000). The complexity of the overall construction project influences the feasibility of using pile foundations (de Moel et al., 2010; ICSMGE, 2005). In situations where the construction site poses challenges, such as proximity to water bodies, high groundwater tables, or environmental considerations, the feasibility of using pile foundations may be influenced by regulatory requirements, and any necessary permits or approvals should be factored into the overall project timeline and budget (Meju, 2000). A comparative analysis between pile foundations and alternative foundation types is essential for assessing feasibility.

In some cases, pile foundations offer load-bearing capacity and stability advantages, justifying the associated costs. The budget for the construction project is a decisive factor. Ensuring that the costs associated with pile foundations align with the project budget is crucial. Cost overruns can have significant implications for the overall financial feasibility of the project (Poulos, 2001; Tann et al., 2023; Wang et al., 2018; Zhang & Wang, 2016).

Figure 3: Compressible Shallow Soil



When the upper layers of soil are soft and compressible, pile foundations can reach deeper, load-bearing strata, ensuring the stability of the structure. Understanding how easily shallow soil can be compressed is crucial when planning and designing structures. If the soil near the surface compresses too much, it can cause problems with the building's structure and stability. Engineers use different methods, like preloading and consolidation, to handle this compressible shallow soil. These techniques help reduce settlement and make sure that structures built on or in these soil layers stay stable (Al-Shamrani & Dhowian, 1997; Bowa & Gong, 2021; Feng et al., 2017; Hussein, 2022; Kaynia, 2021; Acosta et al., 2019; Poulos, 2016; Reese et al., 2005).

Figure 4: Scouring Risk

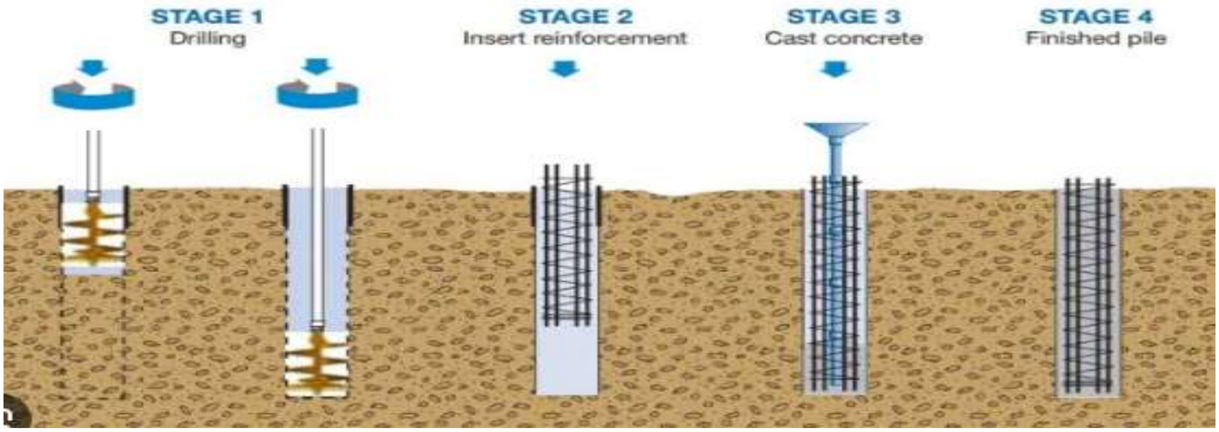
Structures located near riverbeds or shorelines may be vulnerable to soil erosion scouring (Abam et al., 2023; Galay, 1983). Pile foundations provide stability and prevent erosion-related issues. It's important to recognize that the conditions unique to a site play a significant role in assessing the risk of scouring. Scouring happens when water flow around foundation piles erodes the nearby soil, potentially compromising the stability of the foundation. Typically, a detailed site investigation and analysis are carried out during the design phase of a foundation project to address this risk thoroughly (Amini & Memari, 2020; Clayton, 2009; Di Pietro & Mahajan, 2022; Field et al., 2012; Zou et al., 2007).

Figure 5: Structural integrity near hydro geoglogical site and poor soil condition

Proximity to Canals or Drainage Systems: When construction is near canals or deep drainage systems, pile foundations help maintain the structural integrity and prevent damage caused by shifting or eroding soil, because when working with pile foundations in close proximity to canals or drainage systems, a thorough grasp of the hydro geological and environmental conditions at the site is essential (Elam & Björdal, 2020; Heibaum, 2014; Jones & Jefferson, 2012; Lin, 2010). This awareness guides the foundation design, ensuring the incorporation of measures to tackle potential issues linked to the presence of water nearby (Dakhan et al., 2020; Jha et al., 2012; Mirani et al., 2021; Shah et al., 2021).

Poor Soil Conditions: In areas with poor soil quality, where excavation for traditional foundations is unfeasible or impractical, pile foundations can be installed without extensive soil removal (ICSMGE, 2005; Tatum et al., 1989; Thorburn & Littlejohn, 1992). Handling challenging soil conditions requires a good understanding of the specific soil features at the construction site (Akyildiz & Stuntebeck, 2006; Doran & Parkin, 1994; Schoenholtz et al., 2000). Pile foundations, known for their ability to reach stable soil layers and evenly distribute loads, are a common solution to address the difficulties posed by poor soil conditions in construction projects (Feld & Carper, 1996; Lazorenko et al., 2019).

Figure 6: Unmanageable Water Seepage



When it is challenging to keep foundation, trenches dry through pumping or other methods, pile foundations offer a solution by bypassing the need for dewatering. Pile foundations, with their ability to reach stable soil or bedrock below challenging surface conditions, ensure the safety and stability of structures in these diverse situations. Prior to commencing construction, engineers undertake a comprehensive site assessment. This evaluation encompasses various aspects, including soil composition, climate conditions, and other pertinent factors. Engineers also collaborate closely with architects to gain insights into the scale and specifications of upcoming infrastructure projects (Junejo et al., 2020, 2022; Junejo & Muhammad, 2018; Sohu et al., 2023). Armed with this critical information, they can anticipate and address potential construction challenges, primarily focusing on selecting the most appropriate piling method.

The overarching objective in this preparatory phase is to identify a piling type that meets the immediate project requirements and enhances the durability and structural soundness of the foundational support beneath the structure. By making informed decisions based on these assessments, engineers lay the groundwork for the long-term success and resilience of the construction project.

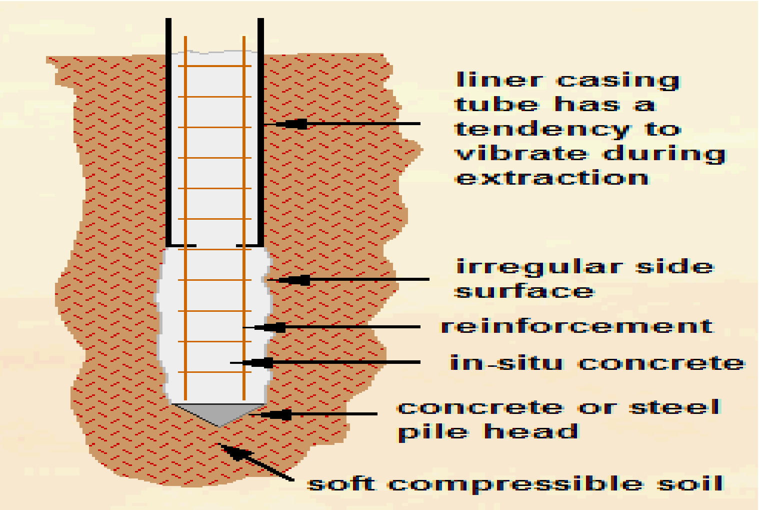
Driven Pile Foundations

The materials primarily employed for creating piles in the driven pile foundation method are concrete, steel, and timber. Concrete piles are produced in advance, and contractors acquire prefabricated steel and timber piles for direct insertion into the soil using a piling hammer. In granular soils, these piles displace an equivalent volume of soil, promoting soil consolidation. This compaction process enhances soil density and, consequently, its load-bearing capacity. The length of compaction piles primarily relies on the relative density before and after the compaction process, along with the necessary depth of compaction (Dakhan et al., 2021; Iqbal et al., 2023; Naveed et al., 2023; Sohu et al., 2019, 2022). Typically, compaction piles are shorter than the other piles. Notably, this construction approach must be better-suited for saturated silty soils with inadequate drainage capabilities. Excess water hampers soil compaction during pile installation, counterproductively reducing the soil's load-bearing capability.

Cast-in-situ Pile Foundations

Materials Used: Cast-in-situ foundations utilize concrete piles instead of transporting precast piles to the construction site. Workers bore holes into the ground, inserted steel reinforcements, and filled the cavity with concrete. This method provides flexibility in adjusting the foundation's depth according to the project's requirements and permits using smaller-diameter piles compared to those in driven pile foundations. The technique involves compacting concrete into place using a hammer while simultaneously removing the casing, ensuring a solid bond with the soil. Novelty is the main element in recognizing the tools, techniques and quality of research (Akhtar et al., 2023; Hongyun et al., 2023; Sohu et al., 2020; Sohu et al., 2020). Exercise caution is essential to prevent excessive concrete ramming or too swift withdrawal of the casing. Pulling out the liner tube may elevate the upper part of the in-situ concrete, leading to a void or necking in the upper segment of the pile. This can be averted through meticulous concrete quality control and gradual extraction of the casing. Employing driven cast in-situ concrete piles can offer a cost-effective solution, especially in sand, loose gravels, soft silts, and clays, particularly when many piles are needed.

Figure 7: Combined Pile Foundations



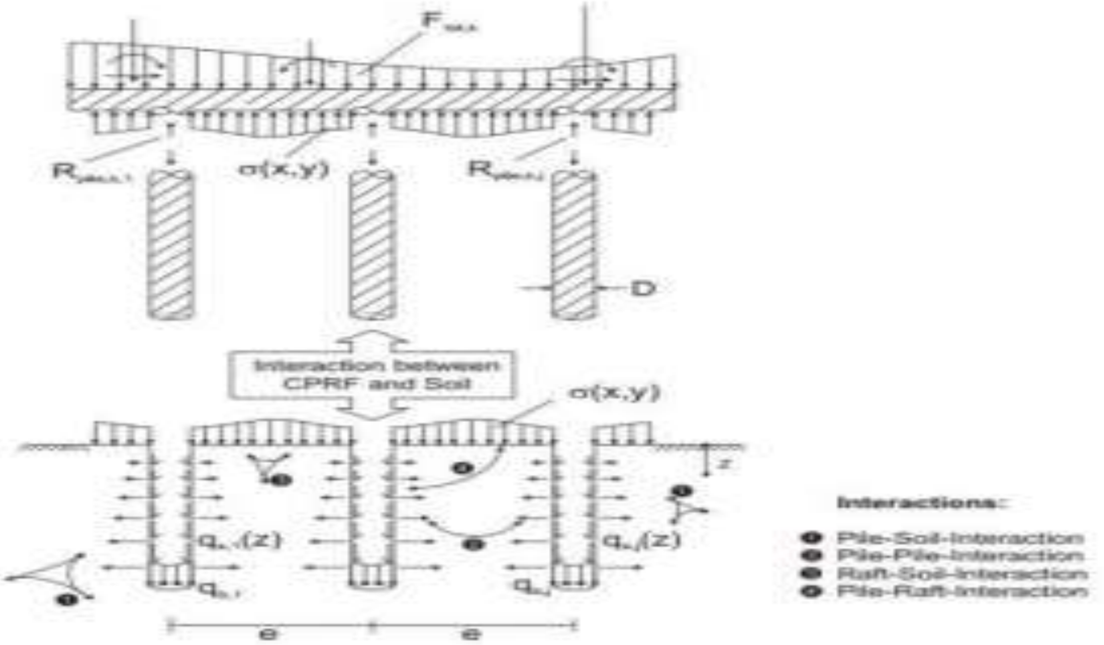
Methodology Description

A literature review creates the framework for the conversation by providing an overview of the body of knowledge. It gives readers a roadmap for navigating through essential points related to pile foundations and the suitability of pile foundations in different scenarios. It helps them understand the specific characteristics, materials, and applications. It also discusses the bearing capacity of piles in frozen soil, covering factors like freeze bond strength and end bearing capacity. All these things help readers understand the current state of the field and the gaps that the article aims to address.

This literature review presents an overview of the pilling foundation, with the author's goal of acknowledging the existing body of knowledge in the field while emphasizing the need to expand upon it, resulting in complete comprehension of this subject matter. With all the above knowledge provided, if any projects are going to start in those types of areas where these challenges may occur during the work, it should be kept in mind that before starting work, take careful consideration of the environmental and geological conditions of the areas before involving the architecture for designing.

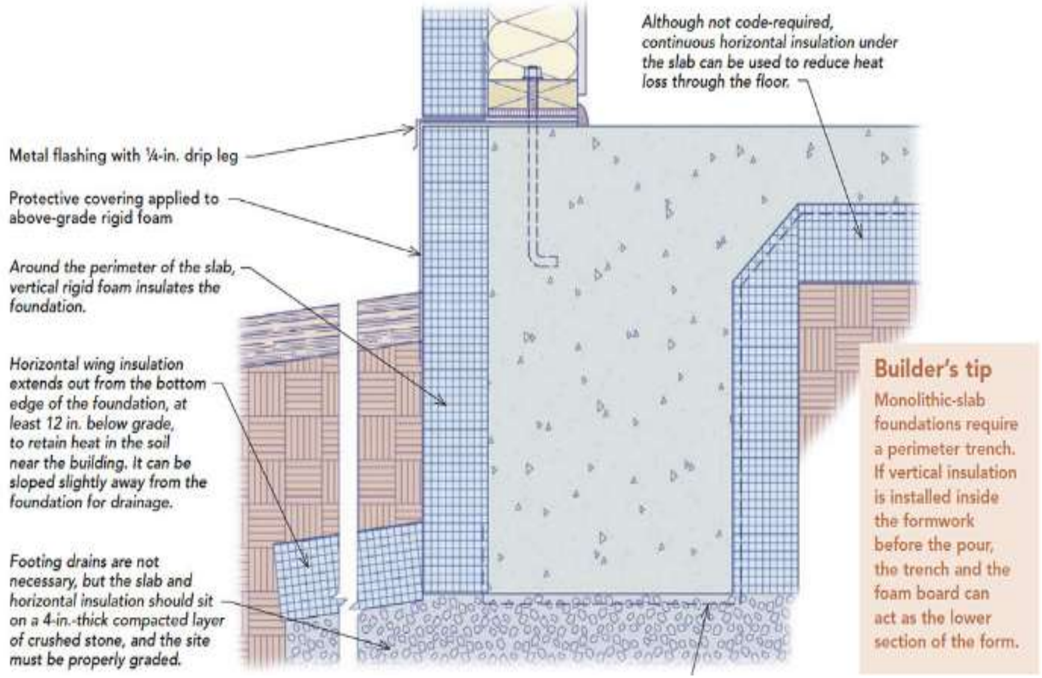
Combined pile foundations blend the driven pile foundation elements and cast-in-situ pile foundation processes, amalgamating their respective advantages. The CPRF (Combined Pile Raft Foundation) system comprises three key bearing elements: piles, a raft, and the subsoil. These pile approaches aim to minimize a structure's overall settlement and differential settlement to within acceptable limits in the most economical manner. This is achieved by considering the piles' and raft's contributions to the foundation system. Initially, workers insert a steel shell with the same diameter as the pile into the ground. Subsequently, they pour concrete into the shell to secure the foundation. This method is commonly employed when piling over water, effectively harnessing the strengths of both techniques.

Figure 8: Design and regulations for pile foundations in cold regions



In permafrost terrain, designing piles involves meeting two essential criteria. Firstly, there must be a sufficient margin of safety to guard against significant failures. Secondly, the settlement should be kept within an acceptable limit throughout the structure's design life. To establish appropriate design parameters, one can rely on either a substantial number of pile-loading tests or theoretical solutions, provided that the creep and physical properties of the frozen ground are well-known. Several factors, including the temperature profile, external loading, salinity, and grain size of the soil, can influence the interaction between a pile and frozen soil. However, due to certain aspects of frozen soil remaining unclear, gaining a deeper understanding that considers a combination of various factors is encouraged to accurately predict pile behaviors. The principles of pile design and engineering practices in cold regions have been succinctly summarized, with key parameters clarified for comprehensive guidance.

Figure 9: Bearing Capacity of Pile Foundation



Although not code-required, continuous horizontal insulation under the slab can be used to reduce heat loss through the floor.

Metal flashing with ¼-in. drip leg

Protective covering applied to above-grade rigid foam

Around the perimeter of the slab, vertical rigid foam insulates the foundation.

Horizontal wing insulation extends out from the bottom edge of the foundation, at least 12 in. below grade, to retain heat in the soil near the building. It can be sloped slightly away from the foundation for drainage.

Footing drains are not necessary, but the slab and horizontal insulation should sit on a 4-in.-thick compacted layer of crushed stone, and the site must be properly graded.

Builder's tip

Monolithic-slab foundations require a perimeter trench. If vertical insulation is installed inside the formwork before the pour, the trench and the foam board can act as the lower section of the form.

The bearing capacity of piles in frozen soil relies on the long-term and freeze bond strength at the pile–frozen soil interface and the end bearing capacity. This calculation appropriately combines these two mechanisms' contributions, determined through short- or long-term creep tests. Researchers commonly use semi-empirical, empirical, numerical, and analytical methods to calculate a pile's bearing capacity.

In winter, when the temperature drops and reaches frost-susceptible soil, substantial frost heave is likely to occur if enough water is present. Consequently, the frozen ground may force a deep foundation upwards due to the surrounding soil's upward movement.

It is essential to gather reliable data from in-situ monitoring or laboratory testing to analyse the bearing capacity of piles in frozen ground. This data not only aids in quantifying parameters used in numerical approaches but also plays a crucial role in understanding the frozen soil–pile interface. Currently, the mechanism at the interface is not fully comprehended, necessitating a more sophisticated theoretical explanation. Physicochemical processes occurring during freezing can be implicated in the theoretical framework for understanding this interface.

Discussion and Conclusion

In conclusion, this article delves into the critical role of piling in construction, emphasizing the significance of pile foundations in ensuring the safety and stability of diverse structures. From supporting homes and roads to addressing challenges like uplift loads and environmental forces, pile foundations prove indispensable in various construction scenarios. The exploration of the suitability of pile foundations in different situations, ranging from high groundwater tables to poor soil conditions, underscores their versatility and importance in the context of cold regions; the article sheds light on the unique considerations involved in designing pile foundations. Safety margins, settlement limits, and the intricate interplay between piles and frozen ground are crucial aspects that demand careful attention. The principles of pile design and engineering practices in cold climates are highlighted, emphasizing the need for a nuanced understanding of various factors to predict pile behaviours accurately.

Recommendations

It is underlined how crucial it is to comprehend soil composition, climate, and other factors to choose the ideal piling technique. Consider the advantages and disadvantages of composite pile foundations, driven pile foundations, and cast-in-situ pile foundations regarding the project, the cost of the materials, and their overall complexity. Make sure the approach selected satisfies the project's requirements and budget by contrasting pile foundations with alternative options. This will ensure the longevity of buildings in cold climates and provide essential information for accurate forecasting.

Examining phenomena like frost heave, frost jacking, and the frozen soil–pile interface adds depth to our understanding of challenges specific to cold regions. The reliance on loading tests and the importance of gathering reliable data through on-site monitoring or laboratory testing are essential in analyzing the bearing capacity of piles in frozen ground. In essence, this article serves as a comprehensive guide, appealing to practitioners and those considering a career in the construction industry. Unraveling the intricacies of piling provides valuable insights that contribute to the long-term success, resilience, and safety of construction projects.

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