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SURCHARGE PILES IN SOFT CLAY FOUNDATIONS: ENGINEERING SOLUTIONS FOR MULTI-STORY STRUCTURES

(A case study-driven article focusing on overcoming challenges with weak subsoil)

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Abstract

Soft clay foundations are known for instability. Clay often sinks under heavy weights. Builders face many challenges in multi-story construction on such soil. This article looks at surcharge piles as a ground improvement method. Surcharge piles help to compress weak soil early. These piles increase the soil's shear strength. Post-construction sinking becomes less likely. This case study examines the construction of a tall apartment building on land previously used as farmland, showcasing the practical application of surcharge piles. It highlights challenges to soil variability, including uneven settlement across the site and environmental constraints that add complexity. The study provides an in-depth analysis of these issues. The article looks at new ideas like vertical drains to speed up consolidation, vacuum consolidation to lower environmental impacts, and real-time monitoring systems for better accuracy. Suggestions include using advanced soil testing and numerical modeling tools to improve surcharge designs and tackle uneven settlement risks. The study finds that surcharge piles, when used together with modern technologies and careful site management, offer an efficient and affordable way to stabilize soft clay foundations. This method helps keep multi-story buildings stable and durable over a long time.

Keywords – soft clay foundations, surcharge pile, ground improvements, soil consolidation, multi-story buildings, differential settlement, vertical drains, vacuum consolidation, geotechnical engineering, sustainable construction.

I. INTRODUCTION

Soft clay foundations, notorious for their instability and tendency to settle under heavy loads, pose a significant risk for multi-story buildings. The unique challenge of building tall structures on such weak grounds necessitates exploring innovative engineering solutions. Surcharge piles, a proven and highly effective method of stabilizing and strengthening the soil, are pivotal in mitigating the risk of settling and enhancing the foundation's stability [1].

The process of surcharging involves installing a large amount of soil on a building pad that helps the soft clay soil to compact and increase the shear strength of the foundation. Despite its advantages, specific challenges need to be considered and evaluated to determine the overall impact on the project. This article will examine key case studies to determine how surcharge piles will effectively improve ground and cost-effective solutions. We will also provide insights on challenges and limitations.

II. BACKGROUND

Surcharge mud piles began in early geotechnical practices, where engineers used them to improve the stability of soft and compressible soils. This approach has changed much over the years, and the evolution of geotechnical engineering technologies has significantly influenced its development.

The principle of preloading uses the idea of adding weight to soil to prepare it for construction. This approach started in the mid-1900s when people began understanding how soil settles. Karl Terzaghi, known as the "father of soil mechanics," really helped people learn about this. In 1925, he developed the Consolidation Theory. This theory demonstrated that applying weight to the soil pushes water out of the soil. Over time, this compression gradually reduces settlement, with the rate of settling slowing down progressively [2], [3].

While traditional methods like deep foundations are effective and provide adequate ground stabilization, they can be costly, and the project could not be economically viable. This article examines the effectiveness of a surcharge pile on a multi-story building whose ground condition was not suitable for handling the load of the building. In this case study, the developer wanted to build a multi-story apartment building that was previously used as a soybean farm. A significant portion of the site consists of cultivated farmland and, hence, was not strong enough to hold the weight of the building. After several discussions and geotechnical studies conducted on this site, it was determined that the ground conditions needed to be improved, and the use of a surcharge load to pre-compress the underlying soft soils might allow shallow footings to support greater loads or the use of higher capacity deep foundations such as driven pile foundations would be required.

III. PROBLEM STATEMENT

The construction of multi-story buildings on a soft clay foundation presents significant challenges, with the soil's instability and tendency to settle under heavy loads increasing the risk of uneven settling and structural instability. Ground improvement becomes a vital part of project planning. While traditional methods like deep foundations are effective, they often come with a hefty price tag, especially for large projects where cost is a significant concern. Surcharge piles, a tested and cost-effective method for soil strengthening, provide a promising solution by compacting soft soils to increase shear strength and reduce the risk of settling [5].

The usefulness of surcharge piles depends on specific site factors like soil type, load needs, and project limitations. This case study explores how building a multi-story apartment on farmland once used for growing soybeans presented unique challenges. The site's soil is too weak to hold the building's weight without significant ground changes. Surcharge piles presented a hopeful and affordable choice instead of deep foundations. However, their use needed a close study of design details, settling time, and overall effect on the project [6].

IV. METHODOLOGY

Based on his expertise, the geotechnical engineer's site inspection is a thorough and meticulous process determining the best course of action. Soil samples must be taken to assess the condition of the ground, and one method is to drill borings to a depth of 40 to 60 feet. A dilatometer sounding was performed to a depth of 80 feet to understand the soil's mechanical properties. This procedure provides a comprehensive understanding of the soil, including its stiffness, shear strength, and deformation characteristics.

With Standard Penetration Test (SPT) boring, it is determined that the initial 7-9 feet consists of very loose to loose density soil, underlying the Sandbridge formation soils encountered Norfolk formation soils consisting of layers of loose density Clayey Sand (SC) and very soft Clayey Silt (ML) extending to depth of 22 to 24.5 feet. Below this layer, a firm consistency of Clayey Silt (MH) and Silty Clay (CH), containing organic matter extending to a depth of 32 to 37 feet. Below Norfolk Formation soils, Yorktown Formation soils consist of Silty Fine Sand (SM) and Fine to Medium SAND (SO and SP-SM) layers to a depth of 32 to 42 feet. Underlying this layer, both Silty Sand (SM) and Clayey Silt (ML) contain marine shell fragments extending to a depth of 60 feet.

For structures with wall loads exceeding 4 kips per lineal foot (klf) or column loads more than 30-thousand-pound force (kips), there are risks of unacceptable total and/or differential settlements. To support these higher loads, using a surcharge load to pre-compress the underlying soft soils might allow shallow footings to support greater loads by limiting the proposed structures' post-construction settlements [1], [3].

Based on the results of the Dilatometer sounding, the Geotechnical Engineer recommended providing a soil modulus that can be used to estimate settlements of footing foundations bearing on the undisturbed natural soils. The data obtained from the Dilatometer and the condition of the soil studied through SPT boring determined that settlement estimates for column loads of 200 kips, 400 kips, and 600 kips that are 3.10 inches, 4.08 inches, and 4.66 inches, respectively, when supported on a footing proportioned for an allowable soil bearing of 2 ksf.

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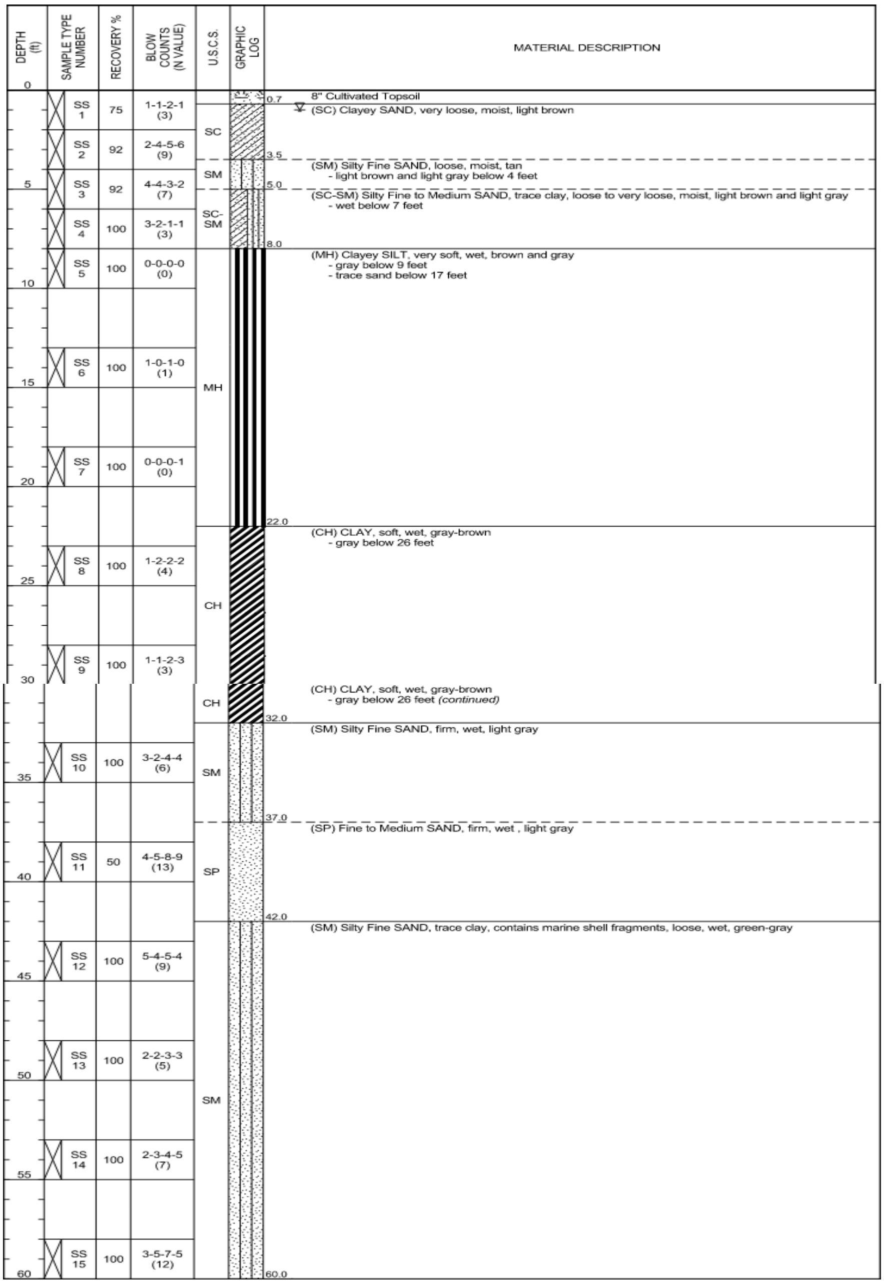

Figure 1: Typical section of an SPT boring record of the subsurface conditions encountered

At this site, surcharging appears to be a viable solution for supporting column loads of up to 400 kips. To achieve the necessary degree of soil consolidation, the Engineer recommends applying a surcharge consisting of at least 12 feet of additional fill above the planned finished grade across the entire building area. The surcharge fill should extend at least 5 feet beyond the perimeter of the building footprint to ensure uniform consolidation. Based on the analysis, it is estimated that the total settlement of the building area due to the surcharge will range around 3 inches. The surcharge fill should be rolled or compacted during placement to enhance stability and minimize the risk of erosion or saturation. This approach is expected to prepare the foundation for the proposed structural loads effectively.

V. IMPLEMENTATION

The implementation of a surcharge load involves a step-by-step process. This process ensures that weak soil beneath the construction site settles properly, achieving the required strength and stability for safe construction. This method is carefully executed and monitored to ensure the consolidation of the ground surface meets project requirements.

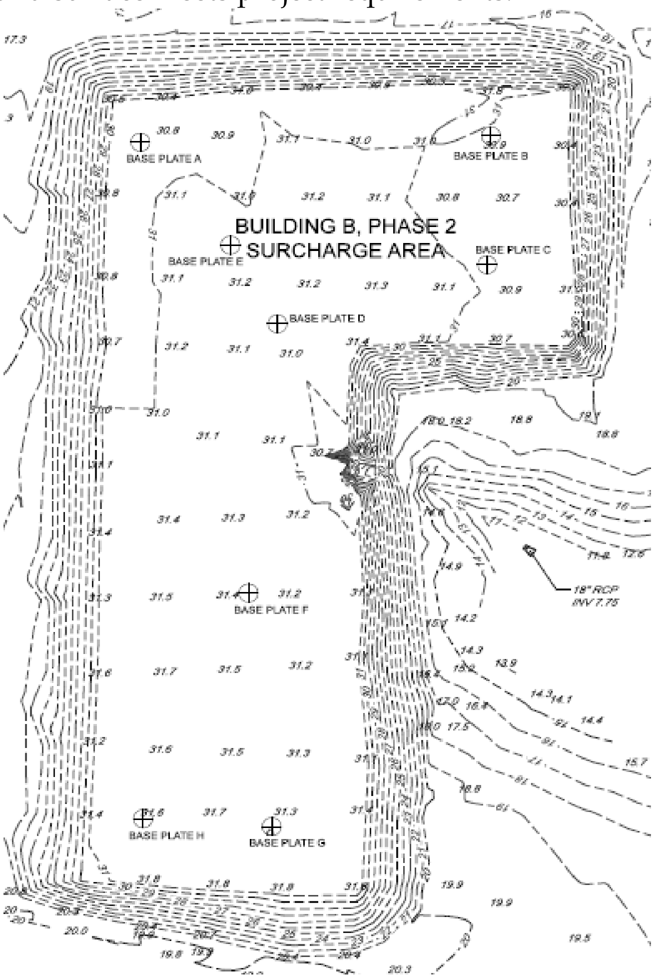

Figure 2: Plan view of surveyed surcharge sitting over a building footprint

- Before placing the surcharge load, the site should be cleared of plants, vegetation, and topsoil from the site, and the ground should be leveled. Sound drainage systems help water escape and shrink the time for ground settling, such as vertical drains or sand drains [5].
- A temporary load of select fill is placed over the construction area. The Geotech engineer recommended that the fill height be 12 feet. In most cases, the surcharge extends beyond the building footprint to ensure uniform soil consolidation, and in this scenario, the surcharge slope was 1:2 (Horizontal: Vertical).
- The surcharge material gets pressed down tightly. This stops erosion and keeps water from soaking in. Stability stays safe during this time. Workers usually use rolling or light

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compaction methods. These methods mainly apply in places where water might gather [4]. Slopes are hydro-seeded to control erosion, and a silt fence is installed at the perimeter of the surcharge.

- During the consolidation period, experts check the soil using settlement plates, piezometers, and inclinometers. Settlement plates observe vertical movement. Piezometers look at the drop in pore water pressure. Inclinometers watch for side-to-side soil movement. These tools offer real-time information to review consolidation progress. Adjustments are reconsidered if necessary [3].
- The surcharge load stays in position until the soil reaches the needed level of consolidation. This process could last weeks or months. Factors such as soil permeability and load intensity affect the duration. Vertical drains sometimes speed up this process. They let water flow out faster [5]. The engineer has anticipated that the surcharge should be placed for a minimum of 12 weeks to achieve maximum compaction, but this depends on the monitoring readings taken after the surcharge is placed.
- After the Engineer determines that the settlement has stopped by observing the settling readings, the surcharge material is removed from the ground. The site becomes ready for building construction. The foundation remains stable, securely supporting the planned structure with minimal post-construction settlement.

VI. RESULTS AND FINDINGS

The settlement data indicates that the surcharging process has been moderately effective in achieving soil consolidation across the monitored area, with an average settlement of 3.6 inches. However, significant variations in settlement were observed at different points, raising concerns about differential settlement. For instance, Point C experienced the highest cumulative settlement of 9.2 inches, suggesting weak soil conditions or high compressibility at this location. In contrast, Point D displayed an unfavorable settlement of -2.7 inches, which could indicate soil rebound due to unloading, localized anomalies in soil behavior, or potential errors during the measurement process. The remaining points showed moderate settlement values, ranging between 1.7 and 8.0 inches. These variations highlight potential challenges in ensuring uniform consolidation, which is critical for the stability of the planned structure.

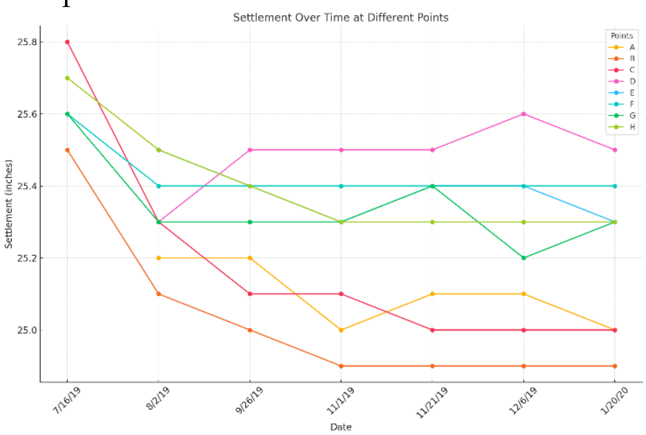

Figure 3: Graphical representation of settlement summary

Differential settlement, as observed in this data, may result from variability in soil composition, uneven surcharge load distribution, or differences in initial soil moisture content and compaction. While the extension of the surcharge load beyond the building footprint likely helped minimize differential settlement, the observed inconsistencies suggest the need for additional investigation. Supplementary testing, such as cone penetration tests or piezometer data, could provide further insights into soil behavior at critical points like C and D [5].

Design adjustments may be required to mitigate risks. Measures such as installing vertical drains to expedite consolidation, redistributing surcharge loads, or using geotextiles to stabilize weaker zones could address significant settlement variations. Additionally, after the surcharge removal, reinforcing weaker areas, particularly Point C, with deeper foundations or improved soil treatments may be necessary to prevent post-construction settlement. Addressing these issues will enhance the uniformity of soil consolidation, ensuring the stability and long-term performance of the planned structure [4].

Table 1: Settlement summary of a building surcharge

Settlement Summary								
Date	A	B	C	D	E	F	G	H
7/16/19		25.5	25.8			25.6	25.6	25.7
8/2/19	25.2	25.1	25.3	25.3	25.5	25.4	25.3	25.5
9/26/19	25.2	25.0	25.1	25.5	25.4	25.4	25.3	25.4
11/1/19	25.0	24.9	25.1	25.5	25.3	25.4	25.3	25.3
11/21/19	25.1	24.9	25.0	25.5	25.4	25.4	25.4	25.3
12/6/19	25.1	24.9	25.0	25.6	25.4	25.4	25.2	25.3
1/20/20	25.0	24.9	25.0	25.5	25.3	25.4	25.3	25.3
Delta in Inches	2.4	8.0	9.2	-2.7	1.7	2.0	3.9	4.4
Average Settlement In Inches			3.6					

VII. DISCUSSION

The findings of this study demonstrate that the use of surcharge piles effectively stabilized the weak clay soil, achieving an average settlement of 3.6 inches across the monitored area. However, significant variations were observed, with Point C showing the highest settlement of 9.2 inches, suggesting localized weak soil conditions or higher compressibility. Conversely, Point D experienced a rebound of -2.7 inches, potentially indicating soil behavior anomalies or the effect of unloading. These results align with Terzaghi's Consolidation Theory, which highlights that applying a surcharge accelerates soil consolidation by expelling pore water [3]. However, the observed variability emphasizes the need for site-specific adaptations and supplemental measures [4].

The practical results of these findings are essential. Surcharge piles provide a cheaper option than deep foundations. These piles are especially useful for stabilizing soft clay foundations in tall building projects. The uneven settlement shows the need for more ground improvement actions. Workers should install vertical drains to speed up consolidation. Geotextiles might be used for local reinforcement. This helps soil behave uniformly. Uniform behavior of the soil is very important [5]. This study works well but admits some limits. Advanced soil tests, like cone penetration or triaxial tests, are missing. These tests give more profound insights into what lies below the surface. The monitoring period fits this study but might miss long-term settlement changes. More research and study are likely necessary.

Future research needs to look at how surcharge-treated soil behaves over time when under dynamic loads like heavy traffic or earthquakes. Engineers should use advanced numerical modeling tools such as PLAXIS to get better predictions of settlement. PLAXIS might also help create better surcharge pile designs for different types of soil [7]. This study shows the importance of thoughtful planning, close observation, and changes to suit specific sites. These actions keep structures stable and long-lasting, especially on weak, soft soils. Focusing on land conditions is crucial to ensure the stability and security of structures.

VIII. CHALLENGES AND LIMITATIONS

Using surcharge piles to improve ground conditions helps but brings challenges and limits. A big challenge is the different settlement levels across the area. For example, Point C had the highest level of settlement at 9.2 inches. In contrast, Point D showed a rebound of -2.7 inches. These numbers show that soil behavior varies in different spots. This inconsistent settling can be risky. Dangerous differential settlement may affect how stable and long-lasting structures are [9]. Uneven ground sinking worries many in soft clay areas. These soils often squish down unevenly. Such clay compresses and easily lets water move through.

One problem with surcharging is the long time needed for soil to settle, which may delay project timelines. Using vertical drains probably speeds up this process by shortening the path for water to escape, but putting them in place increases the project’s cost and complexity. These drains can reduce the time required, but they also introduce additional challenges [10]. The monitoring systems used need constant watching. These systems, like settlement plates and piezometers, ask for technical skills to understand real-time data well. Poor handling of these tools leads to wrong judgments of soil consolidation. This mistake raises the risk of problems with settlement after construction [1].

Environmental concerns pose a significant limitation, as placing and compacting large volumes of surcharge fill can lead to runoff and erosion, particularly in areas with inadequate drainage systems. Implementing erosion control measures and adhering to environmental regulations are necessary steps, but they can increase the project's overall cost and add complexity to the process [8]. Additionally, the rebound noticed at Point D shows the need for more soil testing. Tests like cone penetration or vane shear help understand how the soil behaves in specific spots. These tests guide better surcharge design.

Surcharge piles offer a more affordable option compared to deep foundations. These challenges show the importance of studying the site, testing the soil thoroughly, and watching closely. Future projects may use advanced geotechnical software. This software probably predicts how soil behaves. It helps improve surcharge details and solve site problems [11].

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IX. RECOMMENDATIONS

Engineers face various challenges when using surcharge piles in soft clay foundations. They must address these issues with several valuable recommendations. A thorough geotechnical investigation is crucial, helping find soil differences and likely weak spots. Engineers need to identify these variations. Advanced testing methods like cone penetration tests (CPT) and pressure meter tests offer detailed insights. Such tests show how soil behaves, helping engineers design surcharge loads more precisely [12]. Additionally, including vertical drains in the surcharge process speeds up soil consolidation. These drains cut project times, especially in areas with low-permeability soils. They often come with extra costs. However, vertical drains significantly increase the efficiency of the surcharging. For big projects, they are genuinely worth the investment [13].

New techniques, like vacuum consolidation, sometimes replace old surcharge methods. Vacuum consolidation applies negative pressure to compress the soil. This method works quickly and helps the environment. Traditional surcharge strategies require a lot of fill material, but vacuum consolidation does not. This significantly reduces runoff and erosion while supporting sustainability goals [14]. Another good solution uses electro-osmosis. An electric current pushes water out of soil pores. This method works well in fine-grained soils like clay. Traditional methods might be slower in these types of soils [15].

Digital tools, like real-time monitoring systems, should be used to increase accuracy and speed during the surcharging process. Smart sensors inside piezometers and settlement plates offer constant information about soil actions. This enables engineers to respond quickly and effectively, reducing dangers and ensuring risk minimization remains a top priority [16]. Using advanced numerical modeling tools like FLAC or ABAQUS helps simulate complex interactions between soil and structures. These tools optimize surcharge designs [17].

Incorporating these advanced techniques and technologies helps projects reach better outcomes with less harm to the environment, increased efficiency, and improved safety. Traditional surcharge piles still serve as an effective method. However, using innovative solutions and modern monitoring tools greatly enhances their application in complex geotechnical conditions.

X. CONCLUSION

The study shows that surcharge piles effectively stabilize soft clay foundations for tall buildings. Heavy loads on the soil press it down. This method settles the ground. An average drop of 3.6 inches occurred over the site. However, Large differences in settlement appeared, especially at Points C and D. This shows the need for studying each location closely and making changes. These results agree with earlier studies. They show how preloading reduces problems after building and helps keep foundations stable [9].

Surcharge piles are effective but come with challenges. The settlement process often requires significant time, and uneven ground settling can pose serious problems for structural stability. Environmental concerns, such as runoff and erosion, add to the complexity. Advanced methods can address these issues effectively. Vertical drains accelerate the settling process by providing quicker drainage paths, while vacuum consolidation minimizes environmental impact, making it a crucial technique for sustainable ground improvement [14]. Using digital tools like innovative monitoring systems and software like FLAC or ABAQUS optimizes surcharge design. These tools help with effective risk management during the consolidation process [17].

Future studies need to study how surcharge-treated soil performs over a long time when under dynamic loading conditions like heavy traffic or earthquakes. Scientists should use modern soil testing methods, such as cone penetration tests and electro-osmosis techniques. These tests help in understanding soil behavior. They probably also improve surcharge applications [15]. Overall, designers must approach projects thoughtfully, adapting designs to the unique conditions of each site. Incorporating new technologies is essential, as innovative tools significantly enhance reliability and efficiency. This is especially critical in challenging geotechnical locations, where site-specific solutions play a pivotal role in ensuring success.

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