Construction Technology for Foundation Reinforcement with Cement-Soil Mixed Piles in Municipal Road Projects

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Keywords: Municipal road construction projects; Cement-soil mixed piles; Foundation reinforcement; Construction technology

Abstract: As a crucial component of urban transportation systems, municipal roads have their foundation treatment quality directly related to road service life and operational safety. Taking a municipal road project as an example, this paper details the application of cement-soil mixed piles in soft soil foundation reinforcement under complex geological conditions such as loose strata, high water content, and insufficient strength. Firstly, the basic principle of cement-soil mixed piles is expounded, emphasizing that they improve foundation bearing capacity and stability by forming a well-integrated and appropriately strong consolidated soil layer through physicochemical reactions between cement and soft soil. Subsequently, key technical points are systematically analyzed from four aspects: construction preparation, process flow, quality inspection, and construction precautions, providing a practical technical approach for high-quality construction in municipal road projects.

1. Introduction

Municipal roads play a pivotal role in urban transportation networks, with their construction quality directly influencing vehicle traffic efficiency, resident travel safety, and the stability of future urban development. During municipal road construction, foundation treatment is a critical aspect, as the stability of the foundation determines whether the road can maintain good performance over an extended period. Among the widely used foundation reinforcement techniques, the construction method of cement-soil mixed piles has gradually become common in municipal road projects due to its high construction efficiency and significant effects. With the accelerating pace of urbanization, the rational popularization and optimization of construction technology for enhancing foundations with cement-soil mixed piles hold profound significance for improving the quality of municipal road projects and ensuring their long-term safe operation.

2. Project Overview

A certain municipal road project has a total length of 998.7 m, with a standard red line width of 60 m. Preliminary geological surveys reveal that the site's soil layers primarily consist of interbedded marine and terrestrial deposits, rendering the soil loose and unstable. The surface is covered with plain fill soil, approximately 2.4–4.3 m thick, filled within the last three months, with relatively high water content, insufficient strength, and inadequate compaction. Some areas are replenished by groundwater, with widespread soft soil layers. Beneath the plain fill soil, there is mainly silty clay interbedded with silt, while deeper layers consist of clay interbedded with silt or silty sand. The stratigraphic structure is complex, with poor soil uniformity, interbedded silty sand and thin silt layers, and overall poor engineering geological conditions unsuitable as a qualified subgrade bearing layer. Without reinforcement, post-construction settlement, cracking, and even damage to the pavement are likely, severely affecting its safety and durability. Therefore, based on project (actual conditions) and technical feasibility analysis, the project ultimately decided to adopt cement-soil mixed pile construction technology for soft foundation reinforcement to enhance foundation bearing capacity, improve stability, and ensure the successful completion and long-term safe operation of the road project.

  DOI: 10.25236/icacel.2025.161

3. Principles of Foundation Reinforcement Technology with Cement-Soil Mixed Piles

3.1 Basic Concepts of Cement-Soil Mixed Piles

As a commonly used technology for soft soil foundation treatment, cement-soil mixed piles are particularly suitable for reinforcing saturated soft clay and are widely applied in civil engineering projects such as municipal road construction. The basic idea is to use cement as a solidifying agent, with the assistance of special mixing equipment, to inject cement slurry or cement powder into deep soft soil layers and thoroughly mix them, thereby producing physicochemical reactions with the soil. This transforms low-strength, poorly stable soft soil into a well-integrated, high-strength, and water-stable foundation layer.

In this technological system, the selection of cement is crucial. Ordinary Portland cement is typically chosen due to its excellent setting and hardening properties, enabling efficient chemical reactions with soft soil to form stable cement-soil piles. Meanwhile, different soil conditions significantly impact construction techniques and treatment effects. For instance, silty soils generally have high water content, high porosity, and low strength, requiring an increased cement content and improved mixing techniques during construction to ensure pile quality. However, for silt and sandy soils with coarser particles and high permeability, careful consideration must be given to slurry penetration and diffusion during operations to ensure uniform mixing.

Construction techniques are the core steps influencing the success of cement-soil mixed pile construction. During the operation of mixing machinery, rotating blades must fully combine cement and soil, enabling close bonding between the solidifying agent and soil particles to form a robust pile. Construction parameters such as mixing depth, rotational speed, and blade structure must be scientifically set according to specific engineering geological conditions. Accurately controlling construction techniques and ensuring uniform mixing are key to fully leveraging the reinforcement effects of cement-soil mixed piles[1].

3.2 Reinforcement Technology with Cement Mixed Piles

During the treatment of saturated soft soil foundations, the construction technology of cement mixed piles is a frequently used reinforcement method. Its core idea is to use lime or cement as a solidifying agent, directly operating on deep foundation layers with the assistance of special mixing machinery to thoroughly mix the solidifying agent with soft soil. Through this process, chemical and physical reactions occur between the soft soil and solidifying agent, transforming the originally soft and insufficiently bearing soil layer into reinforced soil with high strength, good integrity, and favorable water stability. In terms of structural characteristics, cement mixed piles belong to the category of composite piles, with compressive strength, lateral pressure resistance, and overall stiffness between flexible and rigid piles. Due to the rigidity limitations of the pile itself, deformation issues may arise when vertical loads exceed a certain range. Therefore, flexible composite foundation forms have gradually emerged in engineering practice to further improve bearing performance and adapt to complex geological conditions.

4. Construction Techniques

4.1 Construction Preparation

(1) Before construction begins, thorough preparation of relevant technical data is essential, including main parameters such as pile top elevation, pile length and reinforcement depth, pile layout drawings, and mix proportions. The pile layout is typically square, with pile spacing controlled at 1.3 m in roadbed sections and approximately 1.6 m in green belt areas. Construction pile length is 15 m, with an effective pile length of 14.5 m, and a required cement content of no less than 18%.

(2) Prior to formal operation at the construction site, site leveling must be completed. Simultaneously, thorough surveys of underground pipelines are necessary, clearing obstacles within a buried depth of 2 m and reinforcing soft soil areas to enable smooth pile layout by construction

equipment. Subsequently, equipment layout, transmission pipelines, and power lines should be scientifically planned according to specifications to ensure orderly overall construction.

(3) The cement slurry mixing system, including mixing devices, storage units, and conveying equipment, should be pre-installed and debugged. Its reasonable layout and process connection are conducive to improving construction efficiency.

(4) All cement mixed pile construction must strictly adhere to design plans. During construction, test standards should be strictly followed to scientifically detect and control pile strength and uniformity, ensuring quality compliance.

(5) From the perspective of raw materials, uniformly use qualified products. Meanwhile, construction personnel should undergo systematic safety training and detailed technical disclosures to strengthen their awareness of norms and operational capabilities, providing reliable guarantees for project quality and construction safety[2].

4.2 Construction Techniques

In this project, a two-spray four-mix wet method was adopted, with a complete process flow including: surveying and setting out → drill positioning → equipment inspection → cement slurry mixing → initial descent with slurry spraying and mixing → pile body elevation and mixing → secondary descent with slurry spraying and mixing → further elevation and mixing → pile body formation → equipment relocation.

(1) Surveying and Setting Out. Before construction, re-examine measurement control points provided by the owner and accurately set out and position each pile according to design drawings. Each pile must be individually identified and signed off before proceeding to the next step.

(2) Drill Positioning. The drill bit center must be strictly aligned with the designed pile position to ensure the vertical stability of the pile machine, preventing inclined or offset piles that could affect foundation bearing capacity. Before formal operation, a comprehensive test of the drill and other construction equipment should be conducted to ensure their operational status.

(3) Cement Slurry Mixing. Prior to drill descent operations, slurry should be prepared in advance, selecting P·O42.5 ordinary Portland cement with a cement content of 18% (equivalent to 79 kg per linear meter) and strictly controlling the water-cement ratio at 0.55 during preparation. When the injection radius exceeds the range, storage devices should be installed at suitable locations to ensure continuous slurry supply.

(4) Descent with Slurry Spraying and Mixing. After the motor is started, the mixer will gradually descend along the pile frame direction, using an ammeter to ensure that the descent speed does not exceed 1.2 m/min while adjusting the slurry spray volume according to design standards. During descent, continuous mixing should be maintained while ensuring the drill rod remains vertical.

(5) Elevation and Mixing. Upon reaching the predetermined elevation, immediate elevation and mixing operations should be initiated, controlling the speed at 0.8 m/min to ensure uniform mixing of cement and soil within the pile body.

(6) Process Repetition. After the initial elevation, descend again for slurry spraying and mixing, repeating the elevation and mixing operations for a total of four cycles. When mixing reaches the designed pile stopping elevation, a qualified pile body can be formed.

(7) Equipment Cleaning. If construction is interrupted or paused for more than three hours, water must be immediately introduced into the slurry mixing system, the mortar pump opened to flush the pipelines, and residual soft soil within the mixing head cleaned to prevent equipment blockage and ensure smooth subsequent construction[3].

4.3 Construction Quality Inspection

To effectively ensure the construction quality of cement mixed piles, strict control over original data and on-site records throughout the construction process is necessary, comprehensively evaluating pile quality using various detection methods. Firstly, during the pile excavation and inspection stage, a random selection of completed piles should be made according to design requirements, focusing on inspecting the uniformity, integrity, and mixing state of cement slurry and soft soil after bonding to determine if they meet specification requirements. Meanwhile, drilling and coring should be conducted to visually reflect the internal structure of the pile body and check if the mixing depth and pile length meet design standards. Combined with indoor test block strength tests, comparisons and analyses of coring samples and test results can infer the bearing capacity of the composite foundation, ensuring it meets design bearing requirements. In addition, in-situ testing methods such as lightweight dynamic penetration and standard penetration tests should be adopted to monitor pile strength and uniformity in real-time, further confirming pile quality[4].

During the construction of soft soil foundation reinforcement, monitoring lateral displacement and settlement is also an indispensable aspect, with specific detection measures including:

(1) Three days after pile formation, excavate shallow pile heads to a depth of 50 cm below the gray surface; adopt visual evaluation for uniform mixing degree and actual measurement for pile diameter, with a sampling inspection ratio of no less than 1/20 of the total number of piles.

(2) On the 10th day after pile formation, conduct N10 tests using a lightweight dynamic penetration device to verify pile length and pile body uniformity, with a test quantity requirement of 1/100 of the total number of piles.

(3) On the 28th day after pile formation, clean the pile tops and conduct drilling and coring as well as mechanical tests. The coring rate should exceed 85%, and pile position detection should be random and uniform, with a sampling frequency of 0.5% of the total number of piles. The unconfined compressive strength of the pile body should preferably be greater than 0.6 MPa; for foundation bearing capacity tests, the green belt area should meet 80 kPa, and the roadbed section should meet 100 kPa.

5. Construction Precautions

(1) Strict control over pile diameter and pile length is essential.

Before drill operation, the length of the mixing pile should be precisely set to avoid construction depths exceeding design standards. While ensuring the drill bit is intact, the diameter and mixing state of the formed mixing pile should be regularly verified. If wear exceeds 10 mm, immediate replacement is necessary to prevent impacts on pile body quality and overall stability.

(2) Maintaining verticality during pile body construction is crucial.

During operation, the angle between the construction platform and the ground and the levelness of the lifting device should be repeatedly calculated. Each pile position should be rechecked at least twice, and personnel should be arranged to supervise and record the entire operation process. The allowable verticality deviation should not exceed 1 degree. A plumb bob should be used to monitor the drill rod in real-time during construction, and immediate corrections should be made upon detecting deviations to prevent reduced bearing capacity due to inclination.

(3) Strict guarantees for the forming quality of pile ends, pile bodies, and pile tops are necessary.

During the initial drill lifting, approximately 1 minute should be spent at the pile bottom for end grinding. During drill lifting, residual slurry should be evenly sprayed into the pile body, and approximately 30 seconds should be spent at the pile top for head grinding. Construction should proceed pile by pile without interruption in slurry spraying. If slurry spraying is interrupted due to power outages or equipment failures, the stopping depth should be detailed recorded, with resumption of spraying within 12 hours and an overlap section of no less than 100 cm; if construction is suspended for more than 12 hours, pile replenishment operations are required.

6. Conclusion

Cement-soil mixed piles represent an efficient technology for soft soil foundation treatment, demonstrating significant advantages in municipal road construction. They not only resolve issues such as insufficient bearing capacity and low deformation modulus in soft soil layers but also ensure overall foundation stability and long-term road operational safety through reasonable process control and strict quality inspection. Practice has proven that the scientific promotion and optimization of cement-soil mixed pile construction techniques can not only enhance the quality of municipal road projects but also reduce later maintenance costs and avoid safety hazards. Against the backdrop of accelerating urbanization, the application value and promotional significance of this technology will become increasingly prominent, providing solid support for the sustainable development of urban transportation infrastructure.

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