

A backfill construction technology for ultra-deep and ultra-narrow foundation trenches with high-early-strength soil cement

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Abstract. As the self-weight of superstructures becomes increasingly large, higher requirements are set for the foundation. Therefore, foundation pits become increasingly deep and foundation trenches are narrower, which puts forward stricter requirements for the backfill quality of foundation trenches. Based on a transportation hub project in the south square of a railway station, this study analyzed difficulties in backfilling deep foundation pits and ultra-deep and ultra-narrow foundation trenches and proposed to use high-early-strength soil cement as backfill materials of the above foundation trenches. Moreover, the preparation process of high-early-strength soil cement and supporting equipment were studied and key technologies for backfill construction were elaborated in detail. This can provide engineering practices and technical reference for similar projects.

Keywords: Deep foundation pit, foundation trench, high-early-strength soil cement, backfill, preparation.

1. Introduction

At present, foundation pits have been increasingly deep and foundation trenches become increasingly narrow. For some deep foundation pits, the width of foundation trenches is smaller than 1 m. The backfill materials and methods for foundation trenches are crucial to the overall stability of buildings, normal utilization of pipelines and safety of the foundation. At present, the commonly used method for backfilling foundation trenches in projects is use of lime soil (the ratio of lime to soil is 2:8) that is compacted by layers. The disadvantages of this method are that the compaction equipment is needed for layered compaction, while manual compaction, rather than large compacting machines, can only be used for narrow foundation trenches, resulting in low construction efficiency and delayed construction schedule. Furthermore, after compaction, the bearing capacity of lime soil is not high, so this method is not suitable for special buildings requiring a certain bearing capacity. In addition, lime soil is not waterproof, so a lot of water is retained in foundation trenches, which poses great additional pressures on the basement walls. The underground structures of buildings need special waterproof treatment, which increases the overall cost of buildings.

Against the background of a transportation hub project in the south square of a railway station, high-early-strength soil cement and supporting equipment that could significantly improve the bearing capacity and waterproof performance of backfill soil in foundation trenches were developed. The backfill process of high-early-strength soil cement in deep foundation pits and ultra-deep and ultra-narrow foundation trenches was proposed, which solved difficulties of low backfill efficiency, low bearing capacity and inferior waterproof performance of traditional lime soil. By combining with field application and summary, the backfill construction technology for deep foundation pits and ultra-deep and ultra-narrow foundation trenches with high-early-strength soil cement was developed. This is able to provide engineering practices and technical reference for similar projects.

2. Overview and difficulties of the project

2.1. Project overview

The transportation hub project in the south square of the railway station is located in the south of the station in a city and mainly includes underground structures, such as south and north underground parking lots and reservation project for rail transit. The underground structures are designed into two floors and three in local areas. The total construction area is about $1.4 \times 10^5 \text{ m}^2$, and the foundation pits are 10~23 m in depth. The foundation pits are supported by composite soil nailing walls and pile anchors, and the foundation trenches are narrow, as shown in Fig. 1.



Figure 1. Space of the foundation trench

2.2. Difficulties of the project

(1) Earthwork of $3.5 \times 10^4 \text{ m}^3$ needs to be backfilled for the south underground parking lot. The narrow working face of the foundation trench is 1.5 m in width, so it is impossible to construct with large-scale machines and the efficiency of manual layered compaction is low. Moreover, the backfill construction should be completed in the node construction period of 60 days according to instruction of owners, so the construction period is short.

(2) Ramp bridges are distributed on both sides of the underground parking lot and pile foundation and cast-in-place supports are in the backfill range of foundation trenches. High backfill quality is required to meet the requirements for pile foundation construction and bearing capacity of supports in later period.

(3) The construction area is detected to have a high groundwater level, so the waterproof project of the main part is the key and difficulty of the whole project. Rigid waterproofing with reinforced concrete needs to be implemented according to the requirements of the waterproof system. The waterproof rolls should be used for the second waterproofing layer, while the backfill soil is utilized as the third waterproofing layer. The permeability resistance of backfill soil directly affects the quality of the waterproof system.

3. Process principle

In view of characteristics, such as short construction period, and high requirements for bearing capacity and permeability resistance in the backfilling of foundation trenches in the south underground parking lot, this study put forward high-early-strength soil cement as backfill materials of ultra-deep and ultra-narrow foundation trenches.

Soil cement, made by mixing, vibrating and curing mixtures composed of soil as main aggregate, Portland cement as cementitious materials and water as reaction medium, is a kind of hard materials with special engineering characteristics.[1-5] Due to mechanisms of backfilling and consolidating soil particles with admixtures, the high-early-strength soil cement has permeability resistance. It can not only avoid damages of groundwater to the high-early-strength soil cement, but also be closely

combined with the foundation structure to ensure that groundwater will not seepage along the interface between the structure and backfill soil to damage the structure. Moreover, it is of high economic efficiency. The high-early-strength soil cement has characteristics of self-compaction, with no need of compaction, which solves problems of low efficiency and long construction period of manual compaction of narrow foundation trenches, that is, the construction period is shortened and the strength requirements are met. The materials are also environmentally friendly. During the construction, the centralized mixing is adopted, and the materials are liquid in in-situ casting, so they do not lead to dust pollution and are environmentally friendly, satisfying the current environmental protection requirements.

4. Construction process and key points of operation

4.1 Construction process

The backfill process for deep foundation pits and ultra-deep and ultra-narrow foundation trenches with high-early-strength soil cement is demonstrated in Fig. 2.

4.2 Key points of operation

4.2.1 Test of the mixing ratio of high-early-strength soil cement.

(1) Theoretical mixing ratio

① Calculation of the mixing ratio

a. The reference value of the mixing ratio of admixtures can be determined according to the construction experience and the performance indexes of high-early-strength soil cement. The mixing ratio of admixtures should be 7~25%, and the mixing amount a should be calculated according to the following formula.

$$a = \frac{\text{mass of admixtures}}{\text{wet mass of soil } (1-w)} \times 100\%$$

b. The water-cement ratio in admixture slurry should be determined by observing the plasticity of trial mixtures of high-early-strength soil cement, and ensuring the pumping conditions to be met during construction.

② Trial of the mixing ratio

a. The mixing ratio is trialed based on the calculated mixing ratio. The amounts of various materials in the calculated mixing ratio should be adjusted through trials till the performance of high-early-strength soil cement meets design and construction requirements.

b. The strength test of the mixing ratio for trial mixing should satisfy the following requirements.

(2) Field test

① Test equipment and material preparation

a. Weighing equipment

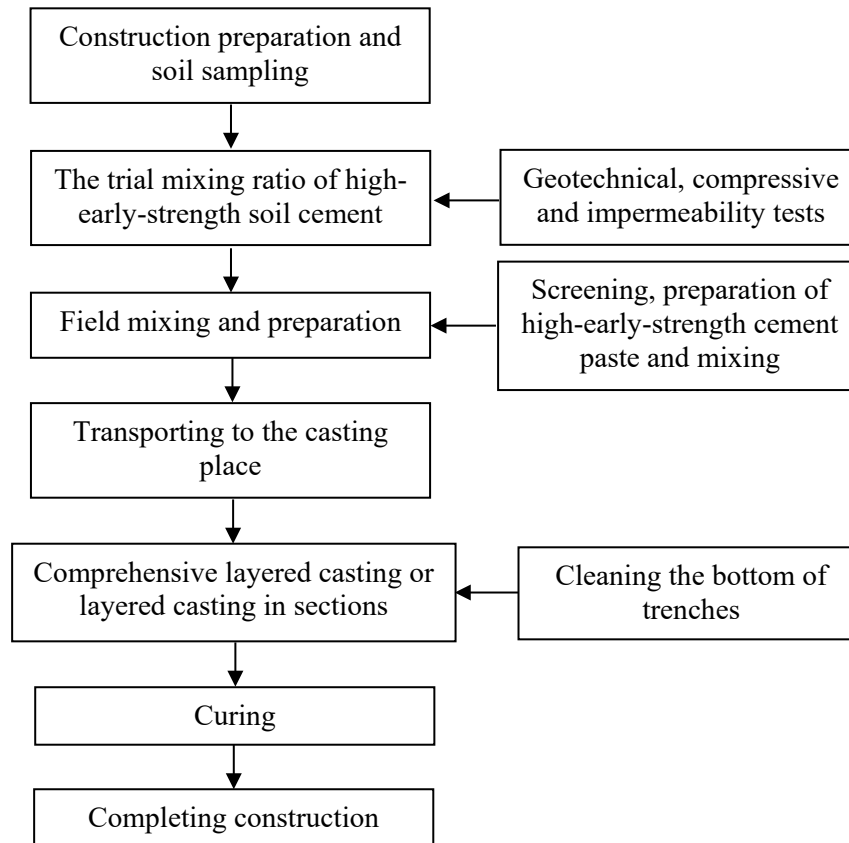


Figure 2. Construction process

A platform balance was used for weighing bulk materials such as soil samples and cement and an electronic balance was used to weigh admixtures.

b. Mixing equipment

A single horizontal shaft forced mixer (for trials of the mixing ratio of soil cement) and a drum-type forced mixer (for off-site verification of the mixing ratio of soil cement) were utilized.

c. Detection tools

Test molds and a slump cone were adopted.

d. Materials

P.042.5 ordinary Portland cement (Sunnysy Group), class II fly ash (Nanding Thermal Power Plant, Shandong Province, China), admixtures (binder was used to promote early hardening of soil), groundwater and plain soil (soil from foundation pits) were used.

② Test process

Step 1: The samples were weighed according to the optimized mixing ratio.

Step 2: Admixtures were firstly mixed with water to form admixture slurry. Then, materials were fed into the mixing equipment in an order of water, admixtures, soil, fly ash and cement. The mixture was stirred for the set time of 120 s.

Step 3: Two groups of test blocks were taken to test the slump. The relevant data were recorded.

Step 4: The backfill environment and equipment were simulated to backfill the foundation pits.

Step 5: The test blocks setting for 12 h under the same conditions were detected.



Figure 3. Retention of test blocks

4.2.2 Field mixing and preparation of high-early-strength soil cement

A complete set of equipment for preparing high-early-strength soil cement was used for field mixing of backfill materials. By using the set of equipment, the high-early-strength soil cement with a large slump can be quickly, evenly and sufficiently mixed according to various compositions, different mixing ratios and specific conditions of different construction sites. It is characterized by stable quality, low costs and simple process.

The set of equipment comprises a feeder, a pulp-making device, mixers and a transporting device.

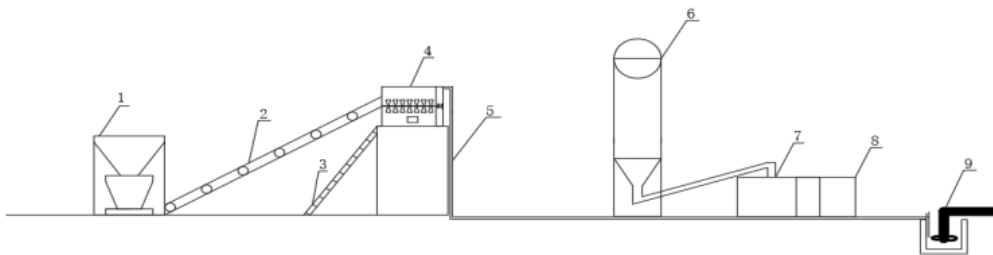


Figure 4. Schematic diagram of the set of equipment for preparing high-early-strength soil cement

In the figure, 1, 2, 3, 4, 5, 6, 7, 8 and 9 represent a screening and batching machine for plain soil, a conveyer belt for plain soil, an inspection ladder, a mixer for soil cement, a transporting pipe for slurry, a tank for preparing high-early-strength cement, a tank for mixing cement slurry, an operating room for the cement tank and a mixer, respectively.

4.2.3 Transportation and casting of high-early-strength soil cement

After mixing, the high-early-strength soil cement was transported from the mixing station to in-situ casting place by using a tank truck.



Figure 5. Transportation of high-early-strength soil cement

By combining layered casting in sections and comprehensive layered casting, the foundation trenches were backfilled.



Figure 6. Flowing state during casting and hardening states after casting

5. Conclusions

(1) After fully mixing the binder, cement and soil with water, physical and mechanical properties of soil are significantly improved through the physical and chemical reaction between compositions and soil. The strength, water stability and long-term volume stability of the materials meet the engineering requirements.

(2) The equipment for preparing high-early-strength soil cement is composed of the feeder, the pulp-making device, mixers and the transporting device. The equipment is able to quickly, evenly and fully mix the high-early-strength soil cement with a large slump with various compositions, different mixing ratios and specific conditions of construction sites. It is shown to have characteristics, such as stable quality, low costs and simple process.

(3) By using a tank truck, the high-early-strength soil cement is transported from the mixing station to the in-situ casting place. By combining the layered casting in sections with comprehensive layered casting, the foundation trenches are backfilled, which ensures continuity and quality of construction.

(4) The use of high-early-strength soil cement as backfill materials of deep foundation pits and ultra-deep and ultra-narrow foundation trenches saves the amount of lime soil and avoids dust pollution. This also accelerates backfill progress of foundation pits and ultra-deep and ultra-narrow foundation trenches. Compared with the construction with traditional lime soil, the backfill period for the foundation trenches in the south underground parking lot is shortened from 90 days to 60 days. This saves labors, machines per team and management costs.

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