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Construction Technology of Irrigation Pile in the Rock-Soluble Development Area

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Abstract: In the Shenzhen region, where strong karst development is widely distributed, karst caves pose significant difficulties and risks to pile foundation construction. This paper, based on the Yanba Expressway Municipalization Reconstruction Project and referencing previous engineering experiences, proposes the application of sleeve valve pipe grouting technology for pre-treatment of small- to medium-sized and bead-shaped karst caves. Specific implementation measures and construction precautions are presented. Practical results demonstrate that the pre-treated karst cave areas achieved stable soil conditions, providing favorable prerequisites for subsequent pile foundation construction. The method proves convenient and feasible in operation, substantially reducing safety and quality risks during construction. This successful practice offers valuable experience for similar projects.

Keywords: Strongly developed karst; Karst cave; Sleeve valve pipe grouting; Pile foundation construction

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1. Introduction

The Dapeng area of Shenzhen is affected by two sets of fault zones: the “Lianhuashan Major Fault” in the northeast direction and the “Shenzhen-Wuhua Subordinate Fault” in the northwest direction, which have a significant impact on the geological conditions of Shenzhen. The cutting effect of the fault zones causes limestone and marble to be crushed and fractured. Under the action of flowing water from surface water, river water, artificial rainfall, and reservoirs, the carbonate components in the limestone undergo intense dissolution and erosion, laying a geological foundation for karst development. As construction projects in Shenzhen advance into karst-developed areas, karst-related issues pose a series of challenges to pile foundation construction. If not properly addressed, problems such as hole collapse, grout leakage, drill pipe jamming or dropping, and excessive concrete pouring are likely to occur. Combining engineering practice, this paper adopts sleeve valve pipe grouting technology for the pre-treatment of small-to-medium-sized karst caves (with a height of 4–10 meters) and bead-shaped karst caves to ensure the smooth progress of subsequent pile foundation construction, thereby providing references and

experience for engineering construction in karst-developed areas of Shenzhen [1].

2. Project overview

The Phase I Project of Yanba Expressway Municipalization Reconstruction is located in Yantian District and Dapeng New District of Shenzhen. Limestone was exposed through drilling in the Kuiyong Interchange section (K16+750.00 ～ K18+900.00) of the project's covered route. Detailed geological exploration revealed that the cave and fissure rate reached 68.2%, indicating that the karst in the site is strongly developed. Karst caves are mainly distributed in the upper part of the bedrock, with highly random development scale and distribution, and a high possibility of connectivity. The dissolved (soil) caves are mainly closed and open-type karst caves. The filling status of the karst caves includes fully filled, semi-filled, and empty. The fillings of the karst caves are soft plastic gravel-containing silty clay in a suspended state. The development scale and connectivity of the karst caves have a significant impact on the construction of bridge pile foundations. Corresponding treatment measures must be taken to ensure the safety of pile foundation construction.

3. Karst cave treatment principles and technical schemes

Based on engineering examples, fully considering the principles of a reasonable scheme, structural safety, easy construction operation, low engineering cost, and maintaining the water environment, reasonable treatment measures are adopted according to the height, size of different karst caves, and their filling conditions. There are mainly three treatment methods for karst caves in this project [2]:

(1) Rubble-clay backfilling method: It is used for single-layer karst caves with a height of less than 4 m. This hole-forming method is economical, fast, and convenient.

(2) Pre-treatment by sleeve valve pipe grouting: It is suitable for single-layer karst caves or bead-shaped karst caves with a small volume and a height of 4–10 m. It can simultaneously consolidate the soil around the pile foundations of the same bearing platform to achieve the purpose of consolidating multiple piles at one time. Meanwhile, it is supplemented by the rubble-clay backfilling method.

(3) Steel casing follow-up embedding method: It is suitable for pile foundations in karst caves with a single karst cave larger than 10 m, large volume, and fillings in fluid plastic state, semi-filled state, fully filled state, bead-shaped cavities, or semi-filled karst caves. The cost is relatively high, and the construction requirements are strict.

This paper mainly introduces the pre-treatment technology of karst caves at pile foundations by the sleeve valve pipe grouting method.

4. Process principle and characteristics of the sleeve valve pipe grouting method

4.1. Process principle

The sleeve valve pipe grouting method was first proposed by the French company Soletanche in the 1950s, also known as the Soletanche method [3]. It began to be widely used in China in the late 1980s. In the sleeve valve pipe grouting method, the grouting pipe is inserted into the borehole first, and then a sealing material is filled in the gap between the outer wall of the pipe and the borehole wall to prevent the grout from flowing back or spreading randomly. A high-pressure pump is used to inject grout into the cavity of the karst cave and the gaps in

the soil layer. Taking advantage of the grout's characteristic of rapid solidification, the method achieves the goal of blocking the connected channels of karst. At the same time, the grout and soil interact and consolidate to form a cement-solidified body, which improves the soil strength, reinforces the soil in the karst cave area to enhance overall stability, and ensures the smooth progress of subsequent construction.

4.2. Process characteristics

(1) Simple operation: Drilling and pipe lowering are carried out according to the measured and positioned control points. Thanks to the effect of the sealing material and the control of the double-plug grouting core pipe, operations such as fixed-point, quantitative, intermittent, or repeated grouting can be realized.

(2) Strong operability: The grout stop system adopts a double-plug grout stop system for bidirectional sealing (upper and lower). One set of plugs includes a ring of grouting holes, which reduces the possibility of grout overflow and leakage. The grout stop system can move up and down in the pipe, enabling repeated grouting in a specific area or easy switching of grouting sections to achieve segmented grouting. In addition, according to the geological characteristics of different soil layers, it is convenient to change the grout with different mix ratios and adjust the grouting pressure.

(3) Economic and environmental protection: The grouting work platform occupies a small area, saving land use. By controlling the appropriate grouting pressure, targeted treatment of a specific area can be achieved, reducing the consumption of cement grout. At the same time, the sleeve valve pipe can be reused, which fully saves the construction cost while achieving the expected treatment effect.

5. Construction technology of the sleeve valve pipe grouting method

The construction process of sleeve valve pipe grouting generally consists of the following steps: leveling the construction site → delivering materials and equipment to the site → setting out and positioning → drilling → installing and embedding sleeve valve pipes → injecting casing material → grouting into karst caves → quality inspection.

5.1. Drilling

Boundary exploration holes shall be drilled. For small karst caves with a maximum projected side length of less than 5 m (revealed by geophysical exploration), boundary exploration holes may be omitted, and grouting holes can be drilled directly. For karst caves with a maximum side length of more than 5 m, a circle of boundary exploration holes shall be set along the contour line of the karst cave. If a karst cave is detected, drilling shall be conducted 2 m outward from the detected position until no karst cave is found, so as to determine the actual contour line of the karst cave. In this project, for the treatment of karst caves under pile foundations, grouting holes shall first be drilled 1 m around the pile foundations according to the detection results. Other grouting holes shall be arranged in a quincunx pattern with a hole spacing of 2 m × 2 m. Different drilling tools shall be used according to different geological conditions. The layout of grouting holes for a single pile foundation is shown in **Figure 1**. With the pile foundation as the center, four grouting holes shall be arranged at a spacing of 1 m in the first layer, and the second and third layers shall be arranged in a quincunx pattern at a spacing of 2 m. The layout of grouting holes for a single bearing platform is shown in **Figure 2**. It is superimposed based on the layout principle of grouting holes for a single pile foundation. The first layer shall be arranged at a spacing of 1m, and the second and

third layers shall be arranged in a quincunx pattern at a spacing of 2 m.

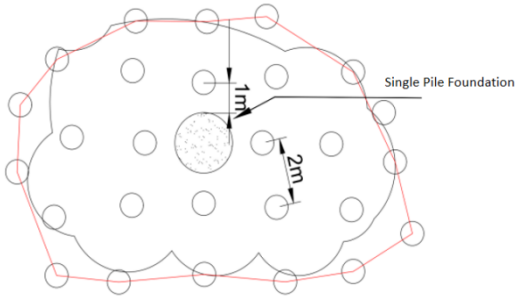

Figure 1. Schematic diagram of grouting for a single pile foundation

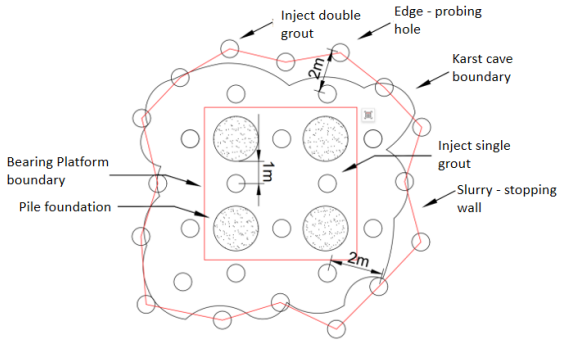

Figure 2. Schematic diagram of grouting for a single bearing platform

5.2. Lowering of sleeve valve pipes

Both solid pipes and perforated pipes are used as grouting pipes. According to the core drilling survey results, solid pipes are used for grouting above the top plate of the karst cave, while perforated pipes are used for grouting in the cavity of the karst cave. To ensure the grouting effect, a bottom plug must be installed at the bottom of the grouting pipe; after the installation of the grouting pipe is completed, a rubber cover shall be added at the pipe orifice for protection. The orifice of the grouting pipe shall be 10–20 cm above the ground, and the pipe shall be lowered to a position 30–50 cm below the bottom of the karst cave. After the lowering of the grouting pipe is finished, fill the pipe with clean water to check its airtightness.

5.3. Injection of casing material

To prevent grout backflow during the grouting process, casing material must be filled between the wall of the sleeve valve pipe and the soil layer, and the filling depth shall reach the bottom of the sleeve valve pipe. Grouting for the grout stop section shall be carried out 1–2 m away from the hole orifice to avoid grout overflow during grouting. During the initial grouting, the liquid level may drop, so it is necessary to inject the grout stop material repeatedly. After the injection of the casing material is completed, the grouting operation can only be carried out after waiting for at least 24 hours to allow the material to reach the required strength. The mix ratio of the casing material (by mass) is bentonite:cement:water = 2:1:9, and the mix ratio of the grout stop material (by mass) is water:cement = 1:1 [4].

5.4. Grouting

After the casing material reaches the required strength, a water injection test shall be conducted: clean water is injected into the grouting pipe and pressurized to achieve loop opening, with the loop opening pressure adopted in this project being 0.3 MPa to 0.5 MPa. A successful loop opening is indicated by a sudden drop in pressure accompanied by a sharp increase in water injection volume during the pressurization process, during which the grout absorption capacity of the stratum and the smoothness of the grouting pipe shall also be evaluated. For the holes around the karst cave in this project, double grouting is adopted, with the water-cement ratio of the cement grout being 1:1 (cement:water), the Baume degree of water glass being 30–40 Be, and the volume ratio of cement grout to water glass being 1:(0.5–0.8); the mix ratio must be determined through on-site proportioning tests to control the setting time of the double grout within 45–60 seconds, with the pressure set at 0.3–0.8 MPa, 3–4 grouting cycles, and an interval of 6–10 hours between each cycle. The central area of the karst cave is filled with single grout, with a water-cement ratio of (1–1.4):1 (water:cement), a grouting pressure of 0.5–1.0 MPa, three grouting cycles, and an interval of 6–10 hours between each cycle [5].

The grouting process shall follow the sequence of "treating large caves first and small ones later, and grouting from the outside to the inside." The grouting equipment and process are shown in **Figure 3**. Segmentally retreating grouting from bottom to top is performed using the front-section perforated pipe. The grouting length per segment is controlled at approximately 0.3–0.5 m, and the retreating section shall be removed promptly when the retreat length exceeds one section. The grouting speed at the top and bottom of the karst cave is controlled at 20–50 L/min, and 30–70 L/min for other parts. The final grouting pressure for peripheral holes is 0.6–0.8 MPa, and 0.8–1.0 MPa for central holes. Grouting can be stopped when the pressure is stabilized for no less than 10 minutes, and the grouting speed should not exceed 1/4 of the initial grouting speed.

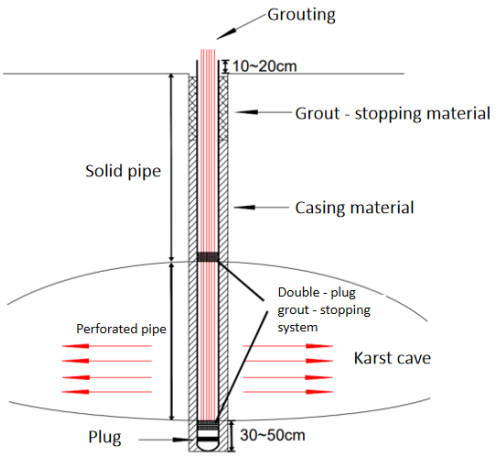

Figure 3. Schematic diagram of sleeve valve pipe grouting

6. Precautions during construction

When dealing with large-volume karst caves or highly connected bead-shaped karst caves where grouting is difficult to complete, measures can be taken appropriately, such as increasing the concentration of cement grout, adopting intermittent grouting, adding accelerators, or switching to double-grout grouting. If necessary, material-

feeding holes can be drilled to fill the caves with C15 plain concrete or M10 cement mortar [6,7].

Grouting shall be carried out continuously. If grouting needs to be interrupted due to special circumstances, it shall be resumed in a timely manner; otherwise, the sleeve valve pipes shall be cleaned immediately to ensure unobstructed flow inside. When resuming grouting, if the grouting speed is close to that before the interruption, the original grout mix ratio shall be used to continue grouting; if the grouting speed is significantly lower than that before the interruption, the concentration of the grout shall be increased step by step [8].

During grouting, if the returned grout becomes thicker, fresh grout with the same mix ratio shall be replaced promptly to continue pouring [9]. If grout leakage or overflow occurs, joint sealing treatment shall be conducted immediately. Comprehensive measures shall be adopted, such as plugging with double grout, appropriately reducing the grouting speed and pressure, adjusting the grout concentration, and extending the grouting interval [10].

7. Conclusion

To summarize, the pre-treatment of small-to-medium-sized karst caves (with a height of 4–10 m) and bead-shaped karst caves at pile foundation construction sites using sleeve valve pipe grouting with double grout can effectively prevent safety risks such as hole collapse and ground subsidence during construction. Meanwhile, it significantly improves the quality of hole formation. This technology can provide technical experience for pile foundation construction in similar areas with strongly developed karst in Shenzhen. The promotion of this technology will bring substantial benefits in terms of construction progress, quality, and safety, and thus holds certain guiding significance.

Disclosure statement

The authors declare no conflict of interest.

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