Study on Combined Toe-and-side Grouting Technology for Over-length Friction Piles

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Abstract: Combined toe-and-side grouting technology was employed to increase the bearing capacity of cast-in-situ bored piles. A field test was conducted to investigate the combined toe-and-side grouting technology for over-length friction piles. L-shaped injection pipe was used for pile-toe grouting and circular injection pipe was designed for pile-side grouting. The design and setting of the injection pipes was introduced in detail for reference. And, the construction process and the selection and computation of grouting pressure and volume were investigated. The grouting devices and grouting parameters was proposed for combined toe-and-side grouting on over-length friction piles. The principles and standards for grouting control were also summarized to provide a good reference for post-grouting construction of over-length friction piles.

Introduction

In large bridges, cast-in-situ bored piles usually make use of over-length friction piles of super large diameters with high bearing capacity, due to large upper loads. The cast-in-situ bored pile will inevitably result in such adverse effects as toe sediment and slurry cake, which can be effectively reduced by post-grouting, so as to improve the pile bearing capacity. In respect of grouting site, the post-grouting falls into three categories: pile-toe post-grouting, pile-side post-grouting and combined toe-and-side grouting [1]. Scholars have conducted numerous experimental and theoretical analyses on the grouting technology of cast-in-place piles, analyzed its economic benefit, and concluded that pile-toe and pile-side pressure grout injection in cast-in-situ bored piles can remarkably increase the bearing capacity, and produce significant technical and economic benefits [2]. Zhu Kui et al. [3] have analyzed load-carrying mechanism and technology of pile-toe grouting cast-in-situ bored piles based on engineering example, proposed matters needing attention in pile-toe grouting, and made technical-economic comparison. Yang Xinyan et al. [4] have argued that pile-toe post-grouting is an advanced construction technology which can effectively reduce the adverse effects of bottom sediment and slurry cake on the side of lower pile part, so as to improve cast-in-situ bored pile performance and save engineering cost. In recent years, pile-toe post-grouting has been widely studied and applied in cast-in-situ bored piles; however, for over-length friction piles, pile-toe post-grouting can only improve pile bearing capacity to a limited extent, so combined toe-and-side grouting is required. At present, there are few studies on combined toe-and-side grouting in over-length friction piles due to technical limits, and the setting of grouting pipes, grouting parameters, and technical control remain immature. This paper studies combined toe-and-side grouting for over-length friction piles based on field grouting experiment in a bridge pile foundation project.

Experiment profile

The experiment was carried out on the pile foundation project of Dongxiaojiang Bridge at Shaoxing. The Dongxiaojiang Bridge is located in a marine-deposition plain, where the surface layer is plastic silty clay, of local soft plastic, with a thickness of 1.0-2.2 m, under which is a marine-deposition

silty soil lay, with a thickness of 1.6-6.4 m; under that comes liquid-plastic sludge with a thickness of 8.0-16.0 m; under which is marine deposit silty clay with a thickness of 10.9-12.7m, and then comes plastic silty clay with a thickness of 1.3-7.1 m, and the bottom is alluvial silt, medium sand, and grit with cohesive soil layers, with a depth of 37.1-37.8 m. The piles in the approach regions of the Dongxiaojiang Bridge have a length of 60 m, a diameter of 1.5 m and a design allowed bearing capacity of 5800 kN. Three piles were selected for post-grouting experiment: grouting pipes were preset during binding of reinforcement cage, and the grouting started when the pile foundation strength reached 80% of the design one; two piles adopted combined toe-and-side grouting and one pile only adopted pile-toe post-grouting. Multiple tests were used to determine the setting of grouting pipes, selection of grouting devices, grouting parameters and standards for grouting quality control for combined toe-and-side grouting. Moreover, static test was performed to verify the increase in bearing capacity by grouting.

Equipment and technology for combined toe-and-side grouting

Pile-toe grouting pipe: For cast-in-situ bored pile with a large diameter (≧1.0m), three grouting pipes may be set evenly along the circumference. As the cast-in-situ bored piles in the project has a diameter of 1.5 m, three seamless steel tubes Φ32×3.0mm, the bottom of which were made into L-shaped, were arranged around the circumference for grouting. In the 600 m length of L-shaped grouting pipe, Φ6 mm grouting holes at a spacing of 50 mm were provided to the pipe toward the pile. To prevent the blocking of grouting holes during grouting of pile shaft concrete, the holes, before the pipes being laid down, were blocked with drawing pins and wrapped and sealed with cut bicycle tube and tape. The grouting pipes, after being connected and bound inside the spiral bars of the reinforcement cage were laid down with the reinforcement cage. The grouting pipes were connected by straight sleeve welding. The setting of pile-toe grouting pipes is shown in Fig. 1 and Fig. 2.

Pile-side grouting pipes: The grouting sections were arranged at a spacing of 10 m, 8 m from the top and 12m from the bottom: circular grouting pipes were mounted at 8 m, 18 m, 28 m, 38 m, and 48 m, outside the spiral bars of the reinforcement cage. The circular grouting pipes were made by bending Φ32 steel tube, and connected with vertical grouting pipes though elbow connection. A row of Φ6 mm grouting holes, at a spacing of 200 mm and open outward against the pile circumference, were drilled on the circular grouting pipes, and blocked with drawing pins and wrapped with cut bicycle tube. The setting of pile-side grouting pipes is shown in Fig. 1 and Fig. 3.

BW-150 mud pump or other plunger-type mud pumps with a pressure higher than 10 MPa were selected. The steel wire armored high pressure rubber hose with a pressure resistance over 10 MPa was used as the ground surface delivery hose. The post-grouting construction was carried out following the process flow diagram shown in Fig. 4.

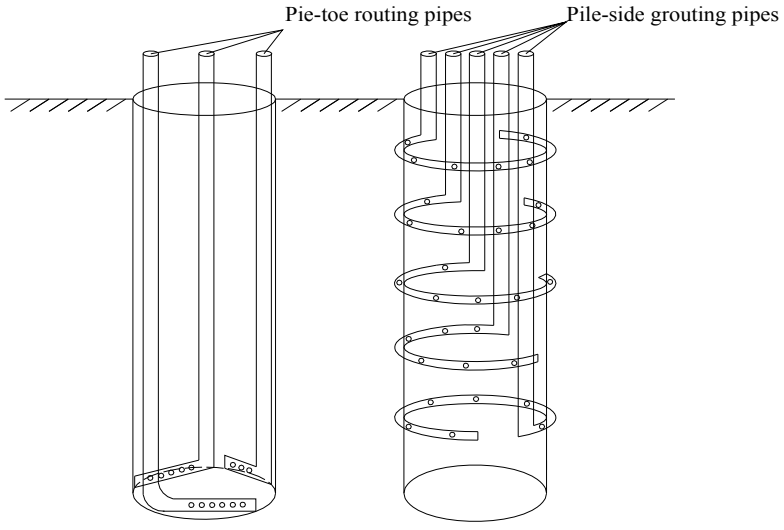

Fig. 1 Setting of pile-toe and pile-side grouting pipes

Fig. 2 Setting of pile-toe grouting pipes

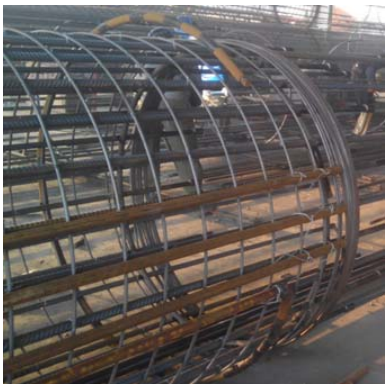

Fig. 3 Setting of pile-side grouting pipes

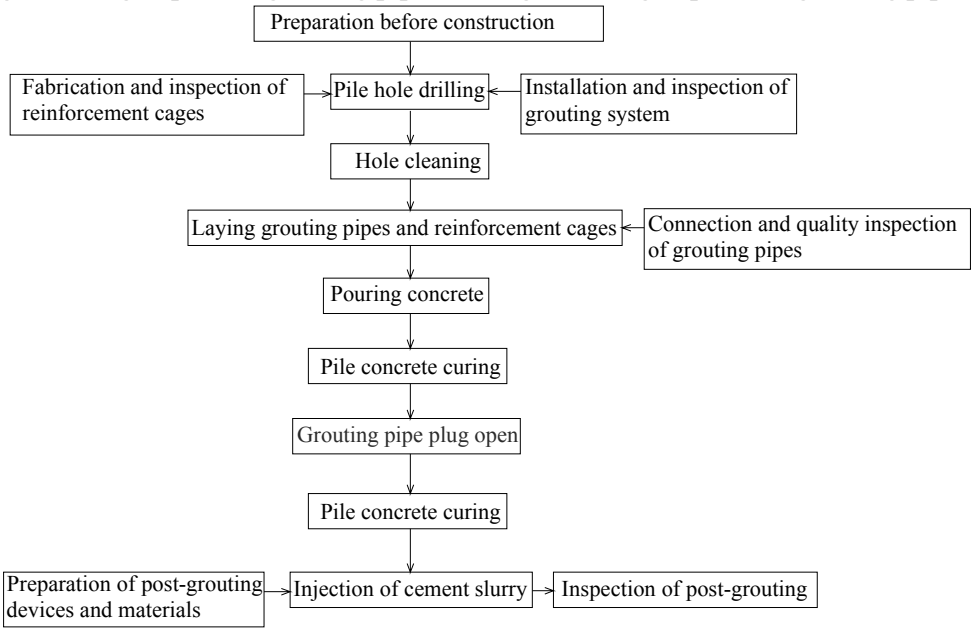

Fig. 4 Construction process for post-grouting

Process control for combined toe-and-side grouting

Post-grouting is an assistant measure to improve cast-in-situ pile quality, and its result depends on a number of factors such as grouting devices, grouting method, soil property, grouting process, parameters and control standards. Therefore, the process control of combined toe-and-side grouting involves various factors, and following control standards have been determined through testing.

1) Grouting devices

The grouting devices include grouting pipes and grouting valves. In general, steel tubes, bound or welded on the stiffening rib of the reinforcement cage are used for grouting pipes. The grouting valve should be able to bear a certain hydrostatic pressure and has the function of cut-off. For pile-toe grouting, the tubular one-way grouting valve, but not grouting preloading box, grouting bag and V-shaped grouting pipe of complicated structure, was used for open-type grouting; for pile-side grouting, the flexible grouting pipe valve on the pile-soil interface, but not sleeve valve pipe in the pile shaft, was used for lossless shaft grouting. The grouting equipment features simple installation, low cost and high reliability, and can apply to taper and flat base holes formed by different drilling tools.

The number of pile-toe grouting pipes, determined according to the pile diameter, should not be less than 2 and should be 3 for piles of a diameter larger than 1.2 m, to guarantee the evenness of grout diffusion and reliability of post-grouting. For the piles with a length larger than 15 m and requiring high increase in bearing capacity, combined toe-and-side grouting should be used. The spacing for side grouting sections should be determined according to the soil layer property, pile length, and requirement on bearing capacity increase, to be 6-12 m in general.

2) Grouting parameters

The key grouting parameters associated with post-grouting quality include grouting water cement ratio, end grouting pressure, grouting flow and grouting volume. Too large water cement ratio results in loss of grout and low efficiency of post-grouting, and too small water cement ratio leads to increase in grouting resistance and reduce grouting availability. Therefore, the water cement ratio should be determined according to soil layer types, degree of soil compaction, and whether the soil is saturated. The water cement ratio should be 0.45-0.65 for saturated soil, 0.7-0.9 for unsaturated soil and 0.5-0.6 for loose gravelly soil and gravel.

The end grouting pressure for pile-toe grouting should be determined according to soil property and depth of grouting points, to be 3~10 MPa for decomposed rock, unsaturated cohesive soil and silty soil, and 1.2-4 MPa for saturated soils,low for soft soil and high for compact cohesive soil. The grouting pressure for pile-side grouting is about 1/2 that of pile-toe grouting.

To facilitate grout diffusion and guarantee grouting result, the grouting flow should be controlled, less than 75 L/min usually. The optimal grouting volume is a crucial factor to ensure that the increase in pile bearing capacity meets the requirement, and over-grouting will lead to unnecessary consumption; therefore, the grouting volume should be determined by trial grouting. In preliminary design, the pile diameter, length, properties of soils at pile toe and side, increase of single pile bearing capacity and whether multiple grouting is required, should be considered: an estimate can be made as shown in Formula(1) [5]:

$$G_c = \alpha_p d + \alpha_s \mathrm{nd} \quad (1)$$

where: G_c is grouting volume, represented by the cement mass; α_p and α_s are the empirical coefficients for grouting volume at pile toe and pile side, respectively, α_p=1.5-1.8, α_s=0.5-0.7, higher values for pebble, gravel and medium-coarse sand; n is the number of pile-side grouting sections; d is the design pile diameter, m.

The general control principle of grouting: the double control of grouting volume and pressure was used, dominated by grouting volume (cement consumption). Grouting sequence: The combined toe-and-side grouting in saturated soils should be performed in a sequence of pile-side first and pile-toe second; for unsaturated soils, pile-toe grouting first and pile-side second; for multi-section pile-side grouting, from top to bottom; the interval between pile-side grouting and pile-toe grouting should not be less than 2 h; The grouting of one pile in the study is shown in Table 1.

Table 1 Grouting parameters of experimental pile

Pile	Pile length/m	Pile diameter/mm	Initial grouting pressure/MPa	Stable grouting pressure/MPa	End grouting pressure/MPa	Grouting volume/t
Pile-side	60	1500	1.2	1	1.5	4.5
Pile-toe			2.2	2	2.5	2.7

Conclusions

Combined toe-and-side grouting experiment was conducted on over-length friction piles. Field test was employed to investigate the combined toe-and-side grouting technology. The setting of grouting pipes, the selection of grouting devices, the construction process, as well as the control standards for grouting pressure and volume, are summarized based on the experiment, and it is concluded that:

(1) Over-length friction piles should adopt combined toe-and-side grouting: 2-3 L-shaped grouting pipes are used as pile-toe grouting pipes according to the pile diameter, and a number of circular grouting pipes as required are used for pile-side grouting pipes. The grouting holes on the grouting pipes should be sealed before grouting.

(2) During grouting, pile-side grouting first, and pile-toe grouting second; and multi-section pile-side grouting should be processed from top to bottom, and the grouting pressure should not exceed the allowed grouting pressure.

(3) Double control of grouting volume and pressure should be implemented: the pile-side and pile-toe post-grouting quality should be first controlled according to grouting volume, which should be computed according to the experimental formula and determined by field test.

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