Research on the Performances of Post Grouting Bored Cast-in-Situs Piles Based on the Self-Balanced Method

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Abstract: Post-Grouting Technology Can Increase the Bearing Capacity and Reduce the Settlement of Bored Cast-in-Place Piles. However, the Effect of Post-Grouting Technology on the Improvement of Piles Varies under Different Site Conditions. Therefore, in Order to Improve the Bearing Performances of Piles through the Post-Grouting Technology, the Static Load Test Should Be Carried out; Improvement Suggestions Should Be Put Forward. as a Method of Static Load Test, the Self-Balanced Method Has the Advantages of Saving the Time of Construction Compared with the Traditional Pile-Loading Method; the Test Piles Can Be Used as Engineering Piles after Grouting for the Test. in This Paper, through the Self-Balanced Test of the Post-Grouting Method, It is Concluded That Post-Grouting Has Obvious Effects on Improving the Ultimate Compression Bearing Capacity and Reducing the Settlement Volume.

1. Introduction

For high-rise buildings and infrastructure with poor foundation conditions or strict restrictions on bearing capacity and settlement, bored piles are required to meet the conditions of high bearing capacity and small settlement. Some scholars have applied the grouting technology to bored pile, thus forming post grouting technology. The post grouting method means to install the grouting pipe on the reinforcement frame of the pile body in advance, and inject the cement slurry into the pile bottom or the pile side through the grouting pipe after the construction of the bored pile body. It can not only compact the sediment at the pile end through high pressure, but also solidify the sediment through cement slurry, thus eliminating the adverse effect of sediments at the end of bored pile and improving the carrying capacity of the foundation at the pile end. At the same time, the cement slurry can fill pores in the mud cake on the side of the pile and strengthen the mud cake; it enhances the friction between the pile body and the bedrock soil layer, and improve the bearing capacity of the bored pile.

In order to understand the effect of post grouting technology on the bearing capacity of bored pile, and study the performance improvement of bored pile after the post grouting process, it is necessary to test the performance of the post grouting bored pile. Based on an actual construction project, this paper carries out a self-balanced test on post grouting bored piles. The project is located in the area of bedrock soil layer composed of plastic red clay and limestone.

2. Solutions to the Problem

Based on a practical project, this paper uses the self-balanced method to test the bored pile; it studies the mechanism and type of the post grouting technique as well as its effects on improving the bearing capacity of the bored pile.

The main contents are as follows.

Under the condition of cement slurry with a certain water-cement ratio, grouting pressure, specific load boxes and the fixed distance from load boxs to the pile end, the self-balanced tests are carried out for different piles respectively.

In order to achieve good comparative effect, six piles in the project are tested. Two of them are

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tested before grouting (E5-11 and E5-101); two are tested after grouting (E5-58 and E5-77), and the last two are tested before and after grouting (S-129 and E5-88).

By analyzing the Q-s curves, as well as diagrams of axial forces and friction resistance distributed on the pile body, the improvement of bearing capacity and settlement of bored piles after the post grouting process is studied.

3. Project Profile and the Self Balance Test Method

The proposed project is located in Kaiyang.

Table 1 Main Parameters Of Tested Piles in Area e

Number of the pile	E5-11	E5-101	E5-58	E5-77	S-129	E5-88
Diameter of the pile (mm)	1000	1200	1000	1200	1000	1200
Effective length of the pile (mm)	9.3	12.2	15.4	11.7	7.0	16.6
Number of the concrete label	C30	C30	C30	C30	C30	C30
Estimated ultimate bearing capacity (kN)	9420	13565	12246	17640	12246	17640
Maximum test load required (kN)	9420	13565	12246	17640	12246	17640
load grading (10 degree)	4750kN/ 10	6800kN/ 10	6150kN/ 10	8850kN/ 10	6150kN/ 10	8850kN/ 10
position of the load box	0.3m above the pile end	0.3m above the pile end	0.3m above the pile end	0.3m above the pile end	0.3m above the pile end	0.3m above the pile end
Test date before grouting	03.17	03.19	/	/	03.16	03.20
Test date after grouting	/	/	03.21	03.18	04.06	04.07
Date of pile-forming	01.26	01.27	01.26	01.27	01.28	01.27
note	engineer-ing pile	engineer-ing pile	engineer-ing pile	engineer-ing pile	engineer-ing pile	engineer-ing pile

According to the geotechnical investigation report of the site provided by the investigation unit, the main stratum distribution of the site within the pile length is as follows.

Plastic red clay:

Characteristic value of bearing capacity: f_{ak}=170kPa; average load-bearing: γ = 17.9kN/m³; internal friction angle: φ_k=4.7°; cohesion: C_k=27.7kPa; compression modulus: Es=4.33MPa

Moderately weathered limestone:

Characteristic value of bearing capacity: f_{ak}=5000kPa; characteristic value of pile end bearing capacity: q_{pa}=5000kPa; average load-bearing: γ=24.55kN/m³

4. Test Results

The tables of displacement of E5-11, E5-101, E5-58, E5-77, S-129 and E5-88 under all levels of load, the Q-s curves of downward displacement of the load box, the U-δ curve of upward displacement of the load box and the U-δ curve of the pile top obtained from the pile foundation self-balanced test are as follows.

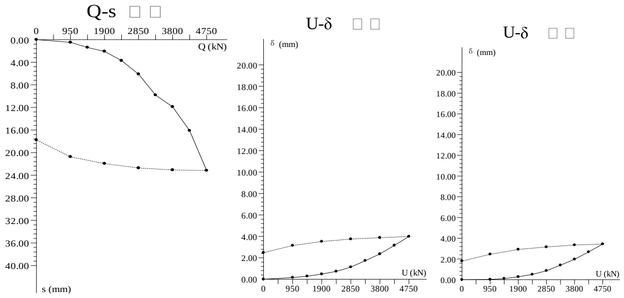

Fig.1 Diagrams of the Downward and Upward Displacement At the Load Box and the Displacement of the Pile Top of E5-11

The effective length of E5-11 bored pile is 9.3m. The loading of the load box is graded based on the estimated load value of 4750 kN; the loading grade is divided into 10 levels, with the load value of 475kN for each grade. The load of the first grade is two times of the load level (namely 950kN). When the test pile is loaded to the 10th grade of 4750 kN, the Q-s curve of downward displacement of the lower part of pile changes slowly; the U-δ curve of the upward displacement of the upper part of pile changes slowly. The displacement of upper and lower parts of the pile is relatively stable. As the designed maximum loading value has been reached, after negotiation, it is decided to terminate the loading and start the unloading. The maximum load of 4750kN is taken as the final loading value. The maximum downward displacement is 23.18mm; the residual displacement after unloading is 17.76mm; the rebound rate is 23.4%. The maximum upward displacement is 3.99mm; the residual displacement after unloading is 2.49mm; the rebound rate is 37.6%.

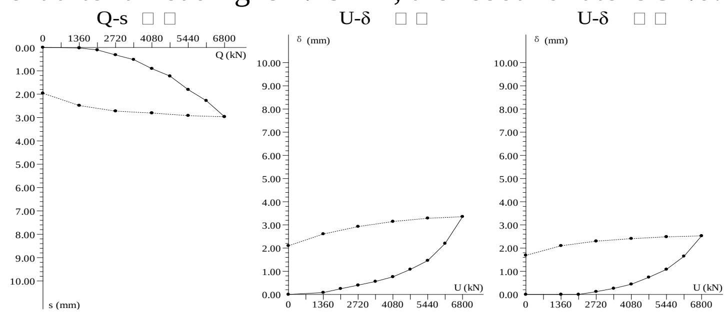

Fig.2 Diagrams of the Downward and Upward Displacement At the Load Box and the Displacement of the Pile Top of E5-101

The effective length of E5-101 bored pile is 12.2m. The loading of the load box is graded based on the estimated load value of 6800kN; the loading grade is divided into 10 levels, with the load value of 680kN for each level. The load of the first grade is two times of the load level (namely 1360kN). When the test pile is loaded to the 10th grade of 6800kN, the Q-s curve of downward displacement of the lower part of the pile changes slowly; the U-δ curve of the upward displacement of the upper part of the pile changes slowly. The displacement of upper and lower parts of the pile are relatively stable. As the designed maximum loading value has been reached, after negotiation, it is decided to terminate the loading and start the unloading. The maximum load of 6800kN is taken as the final loading value. The maximum downward displacement is 2.97mm; the residual displacement after unloading is 1.96mm mm; the rebound rate is 34.0%. The maximum upward displacement is 3.36mm; the residual displacement after unloading is 2.10mm; the rebound rate is 37.5%.

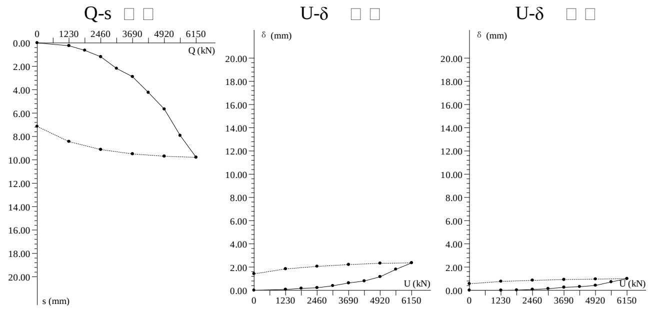

Fig.3 Diagrams of the Downward and Upward Displacement At the Load Box and the Displacement of the Pile Top of E5-58

The effective length of E5-58 bored pile is 15.4m. The loading of the load box is graded based on the estimated load value of 6150kN; the loading grade is divided into 10 levels, with the load value of 615kN for each level. The load of the first grade is two times of the load level (namely 1230kN). When the test pile is loaded to the 10th grade of 6150kN, the Q-s curve of downward displacement of the lower part of the pile changes slowly; the s-lgt curve is straight-forward. the U-δ curve of the upward displacement of the upper part of the pile changes slowly; the δ-lgt curve is straight-forward. The displacement of upper and lower parts of the pile are relatively stable. As the designed maximum loading value has been reached, after negotiation, it is decided to terminate the loading and start the unloading. The maximum load of 6150kN is taken as the final loading value. The maximum downward displacement is 9.79mm; the residual displacement after unloading is 7.15mm; the rebound rate is 27.0%. The maximum upward displacement is 2.37mm; the residual displacement after unloading is 1.42mm; the rebound rate is 40.1%.

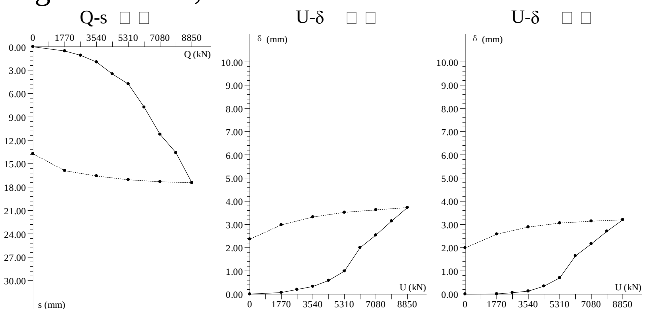

Fig.4 Diagrams of the Downward and Upward Displacement At the Load Box and the Displacement of the Pile Top of E5-77

The effective length of E5-77 bored pile is 11.7m. The loading of the load box is graded based on the estimated load value of 8850kN; the loading grade is divided into 10 levels, with the load value of 885kN for each level. The load of the first grade is two times of the load level (namely 1770kN). When the test pile is loaded to the 10th grade of 8850kN, the Q-s curve of downward displacement of the lower part of the pile changes slowly; the s-lgt curve is straight-forward. The U-δ curve of the upward displacement of the upper part of the pile changes slowly; the δ-lgt curve is straight-forward. The displacement of upper and lower parts of the pile are relatively stable. As the designed maximum loading value has been reached, after negotiation, it is decided to terminate the loading and start the unloading. The maximum load of 8850kN is taken as the final loading value. The maximum downward displacement is 17.45mm; the residual displacement after unloading is 13.72mm; the rebound rate is 21.4%. The maximum upward displacement is 3.73mm; the residual displacement after unloading is 2.37mm; the rebound rate is 36.5%.

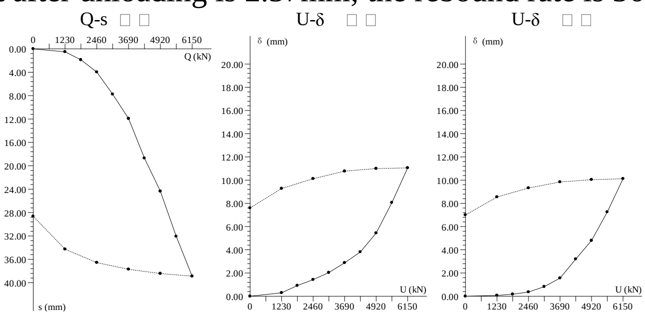

Fig.5 Diagrams of the Downward and Upward Displacement At the Load Box and the Displacement of the Pile Top of s-129 Before Grouting

Before grouting, the effective length of S-129 vertical bored pile is 7.0m. The loading of the load box is graded based on the estimated load value of 6150kN; the loading grade is divided into 10 levels, with the load value of 615kN for each level. The load of the first grade is two times of the load level (i.e. 1230kN). When the test pile is loaded to the 10th grade of 6150kN, the cumulative downward displacement of the lower pile is 38.89mm; the upward displacement of the upper pile is relatively stable. As the designed maximum loading value has been reached, after negotiation, it is decided to terminate the loading and start the unloading. The maximum load of 6150kN is taken as the final loading value. The maximum downward displacement is 38.89mm; the residual displacement after unloading is 28.64mm; the rebound rate is 26.4%. The maximum upward displacement is 11.06mm; the residual displacement after unloading is 7.60mm; the rebound rate is 31.3%.

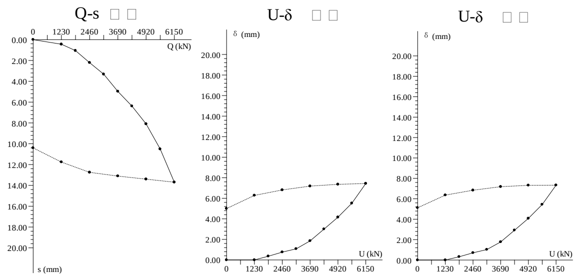

Fig.6 Diagrams of the Downward and Upward Displacement At the Load Box and the Displacement of the Pile Top of s-129after Grouting

After grouting, the effective length of S-129 vertical bored pile is 7.0m. The loading of the load box is graded based on the estimated load value of 6150kN; the loading grade is divided into 10 levels, with the load value of 615kN for each level. The load of the first grade is two times of the load level (i.e. 1230kN). When the test pile is loaded to the 10th grade of 6150kN, the Q-s curve of downward displacement of the lower part of the pile changes slowly; the s-lgt curve is straight-forward. The U-δ curve of the upward displacement of the upper part of the pile changes slowly; the δ-lgt curve is straight-forward. As the designed maximum loading value has been reached, after negotiation, it is decided to terminate the loading and start the unloading. The maximum load of 6150kN is taken as the final loading value. The maximum downward displacement is 13.70mm; the residual displacement after unloading is 10.40mm; the rebound rate is 24.1%. The maximum upward displacement is 7.45mm; the residual displacement after unloading is 5.00mm; the rebound rate is 32.9%.

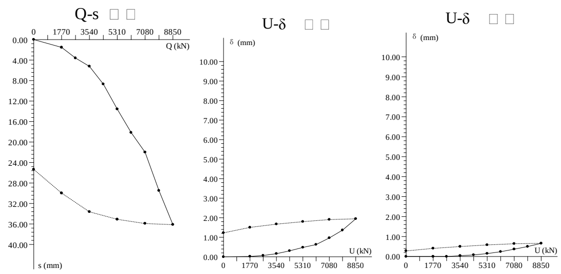

Fig.7 Diagrams of the Downward and Upward Displacement At the Load Box and the Displacement of the Pile Top of E5-88 Before Grouting

Before grouting, the effective length of E5-88 bored pile is 16.6m. The loading of the load box is graded based on the estimated load value of 8850kN; the loading grade is divided into 10 levels, with the load value of 885kN for each level. The load of the first grade is two times of the load level (i.e. 1770kN). When the test pile is loaded to the 10th grade of 8850kN, the cumulative downward displacement of the lower pile is 36.14mm; the upward displacement of the upper pile is relatively stable. As the designed maximum loading value has been reached, after negotiation, it is decided to terminate the loading and start the unloading. The maximum load of 8850kN is taken as the final loading value. The maximum downward displacement is 36.14mm; the residual displacement after unloading is 25.37mm; the rebound rate is 29.8%. The maximum upward displacement is 1.95mm; the residual displacement after unloading is 1.23mm; the rebound rate is 36.9%.

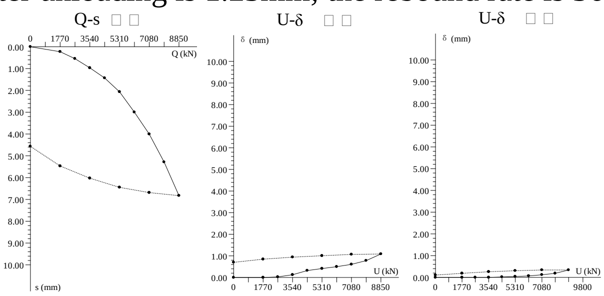

Fig.8 Diagrams of the Downward and Upward Displacement At the Load Box and the Displacement of the Pile Top of E5-88 after Grouting

After grouting, the effective length of E5-88 bored pile is 16.6m. The loading of the load box is graded based on the estimated load value of 8850kN; the loading grade is divided into 10 levels, with the load value of 885kN for each level. The load of the first grade is two times of the load level (i.e. 1770kN). When the test pile is loaded to the 10th grade of 8850kN, the Q-s curve of downward displacement of the lower part of the pile changes slowly; the s-lgt curve is straight-forward. The U-δ curve of the upward displacement of the upper part of the pile changes slowly; the δ-lgt curve is straight-forward. As the designed maximum loading value has been reached, after negotiation, it is decided to terminate the loading and start the unloading. The maximum load of 8850kN is taken as the final loading value. The maximum downward displacement is 6.83mm; the residual displacement after unloading is 4.57mm; the rebound rate is 33.1%. The maximum upward displacement is 1.09mm; the residual displacement after unloading is 0.70mm; the rebound rate is 35.8%.

5. Conclusion

On the basis of previous studies, based on the pile testing project in E area, this paper uses the self-balanced method to test the bored piles. It studies the mechanism and type of post grouting technique as well as its effects on improving the bearing capacity of the bored pile. The following conclusions are drawn.

First, according to the analysis and calculation of the measured data, the ultimate vertical compressive bearing capacity of each engineering pile can meet the design requirements; grouting at the bottom of pile can obviously improve the ultimate compressive bearing capacity.

Second, in the test, the displacement of the test pile at the pile end after grouting is smaller than that before grouting. Except for pile end compaction, grouting at the pile bottom also has obvious effects. Grouting at the bottom of pile can play a certain role in reducing the differential settlement among piles. Under the same loading level, the displacement of pile end is reduced by 75.49%, 73.6%, 64.77% and 81.1%.

Third, for the moderately weathered limestone, the ultimate end resistance of pile foundation rock and the ultimate side resistance of rock are significantly increased after post grouting at the pile end and the pile side.

Fourth, in the process of the self-balanced loading test, when the pile is subjected to vertical load, the upper part of pile moves upward; the soil on the pile side produces reverse friction on the pile body. The lower part of pile moves downward under the pressure of load box, and subjects to the reverse friction force exerted by the soil. The load can be transmitted to the bedrock and soil through the interaction between the pile body and the rock and soil on the side of the pile. The axial force in the pile increases with the decreasing distance from the load box. With the increasing load exerted by the load box, the interaction force between the pile and the bedrock soil increases until the contact surface is destroyed. After post-grouting, the condition of contact between the pile body and the pile side soil is improved; the friction resistance of the pile side soil to the pile body is enhanced.

Due to the limited ability, time and energy, there are still many shortcomings and deficiencies in the research on the self-balanced test of post grouting bored piles. Further studies can be carried out in many aspects. Following perspectives are recommended.

First, in this paper, only the pile end with limestone is studied. Other rock and soil layers at the pile end can be further researched.

Second, the theories and empirical calculation formulas of displacement and settlement of bored piles with post grouting at the pile end can be further improved.

Third, through the exploratory test on the typical soil layer in Guizhou, the more accurate and representative value of γ (the correction factor for the conversion of lateral upward resistance of the part of pile above the load box into downward resistance) can be obtained.

Acknowledgement

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