Evaluation of Post-grouting Bearing Capacity of Cast-in-situ Bored Pile Based on Self-balance Method

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Abstract. When the site conditions are complex and the building structure is sensitive to settlement, post-grouting can be adopted for bored grouting pile to improve its bearing capacity, reduce settlement and improve the safety of pile foundation. In this paper, the ultimate bearing capacity of pile foundation is tested by self-balance method, and the ultimate bearing capacity of the two test piles is improved by 95% and 33.3% respectively. The post-grouting has a good impact on the formation with poor bearing capacity and denaturation index.

1. Introduction
Bored cast-in-place pile has been widely used in engineering because of its low cost and fast construction speed. When the bearing capacity and deformation indexes of the site are poor, in order to improve the bearing capacity of the rock pile foundation and reduce the settlement, the post-grouting process is often adopted to improve the safety of the pile foundation.

2. The test principle of Self-balance method
The Self-balance method uses a special loading device, the load box, which is embedded in the corresponding position in the pile together with the steel cage before the concrete is poured (the specific position depends on the different purposes of the test). The compression tube and other test equipment required are led from the pile to the ground and then pours concrete into piles. The pressure pump is loaded on the load box, and the load box generates forces in the upper and lower directions, and it is transmitted to the pile body. As the pile’s own weight and side resistance is counter-force, we will get the data equivalent to two static load tests: above the load box, we obtain the corresponding reaction series parameters of the upper part of the pile during reverse loading. In the lower part of the load box, we obtain the corresponding reaction parameters of the lower part of the pile during forward loading. Through the calculation and analysis of the relationship between the loading force and these parameters (displacement, etc.), we can not only obtain the bearing capacity of the pile foundation, but also obtain series of pile foundation engineering design data such as the limit side resistance parameter of each layer of rock and soil body and the ultimate tip resistance of the pile [1-3].
In the actual measurement, the ultimate bearing capacity of the upper pile of the load box $Q_U^+$ and the ultimate bearing capacity of the pile under the load box $Q_U^-$ are obtained. According to the literature [4], the ultimate bearing capacity of single pile is obtained:

$$Q_u = \frac{Q_{U+} - W}{\gamma} + Q_{U-}$$  \hspace{1cm} (1)

In the formula:
- $Q_U$: Vertical compressive ultimate bearing capacity of single pile (kN);
- $Q_{U+}$: Measured ultimate bearing capacity of piles on the upper part of the load box (kN);
- $Q_{U-}$: Measured ultimate bearing capacity of piles under the load box (kN);
- $W$: The weight of the upper pile of the load box;
- $\gamma$: The correction coefficient of the pile side resistance of the upper part of the load box is usually 0.75~1.0, for clay and silt, $\gamma=0.8$, for sand $\gamma=0.7$.

3. Test pile setting

The bearing capacity and deformation index of the argillaceous silt in the site are poor. In order to improve the bearing capacity of the rock pile foundation and reduce the differential settlement with the limestone foundation pile, the post-grouting treatment is applied to the shale siltstone foundation pile. The test carried out the bearing capacity comparison test of the two piles before and after grouting.

(1) Test pile No. 1

Two load boxes are arranged on the test pile No. 1, the upper load box is located at 9.2m below the ground, and the lower load box is located at the pile end.

Test sequence:

1. Load the lower load box after 14 days of pile formation, and the bearing capacity of the pile end was measured;
2. After 2 days (the load on the lower load box is removed), the upper load box can be tested. At this time, the lower load box is opened until the lower load capacity of the upper pile of the upper load box reaches the ultimate load capacity, and the lower load box is closed until the upper pile of the upper load box reaches the ultimate bearing capacity, and the pile end is grouted after the test;
3. After the grouting, the load box loading test is carried out for not less than 14 days. After 2 days (the load on the lower load box is removed), the upper load box is tested.

(2) Test pile No. 2

The test pile No. 2 is equipped with a load box for testing the limit value of single pile bearing capacity before and after grouting.

Test sequence:

1. After 14 days of pile formation, the ultimate bearing capacity of the single pile was measured and tested.
2. Loading test after not less than 14 days after grouting, the ultimate bearing capacity of the single pile after grouting was measured.

4. Test results before grouting

Test pile No. 1

Lower load box test situation:

When the lower load box of the test pile No. 1 was tested, the loading of the first two stages was normal. When the third stage load (2×2000 kN) was added, the displacement of the pile end dropped sharply and could not be stabilized and the loading was terminated. The loading curve is shown in Figure 1.

Upper load box test situation:

When the upper load box of the test pile No. 1 was tested, the loading of the first five stages was normal. When the sixth stage load (2×3500 kN) was added, both the upward and downward
displacements showed a steep drop, and the downward displacement could not be stabilized, and the loading was terminated. The loading curve is shown in Figure 2.

Test pile No. 2
When the test pile No. 2 was tested, the loading of the first four stages was normal. When the load of the fifth stage (2×6000 kN) was added, the downward displacement showed a steep drop and could not be stabilized, and the loading was terminated. The loading curve is shown in Figure 3.

![Figure 1. Loading curve of lower load box on test pile No.1](image1)

![Figure 2. Loading curve of upper load box on test pile No.1](image2)

![Figure 3. Loading curve of test pile No.2](image3)
5. Test results after grouting

Lower load box test situation:

When the lower load box of the test pile was grouted, the first 6 stages of loading were normal. When the 7th stage load (2×5200 kN) was added, the pile end displacement showed a steep drop, which could not be stabilized and the loading was terminated.

Upper load box test situation:

When the lower load box of the test pile No. 1 was tested, the loading conditions of the first 8 stages were normal. When the load of the 9th stage (2×6500 kN) was added, the upward and downward displacements could not be stabilized and the loading was terminated. The loading curve is shown in Figure 5.

![Figure 4. Loading curve of lower load box on test pile No. 1](image)

![Figure 5. Loading curve of upper load box on test pile No. 1](image)

Test pile 2

When the test pile No. 2 was tested after grouting, the loading of the first five stages was normal. When the load of the sixth stage (2×9100 kN) was added, the downward displacement showed a steep drop, and the upward and downward displacements could not be stabilized, and the loading was terminated. The loading curve is shown in Figure 6.
6. Analysis of the results of the comparison test

6.1 Ultimate bearing capacity

According to the test results before and after grouting, according to the literature [4], the ultimate bearing capacity of piles before and after grouting in Table 1 are obtained.

Table 1 Comparison of ultimate bearing capacity of piles before and after grouting

| Pile number | Number 1 | Number 2 |
|-------------|----------|----------|
| Before grouting /kN | 6333 | 10555 |
| After grouting /kN | 12350 | 16467 |

6.2 Pile side resistance and tip resistance

According to the test results, the side resistance and tip resistance values before and after grouting are shown in Table 2.

Table 2 Test side resistance and end resistance value of No.1 test pile

| Status         | Average side resistance of pile side /kPa | Ultimate end resistance /kPa |
|----------------|------------------------------------------|------------------------------|
| Before grouting | 409                                      | 1327                         |
| After grouting  | 700                                      | 4025                         |

The ultimate bearing capacity of No.1 test pile before grouting is 6333kN, and the ultimate bearing capacity after grouting is 12350kN;

The ultimate bearing capacity of No. 2 test pile before grouting is 10555kN, and the ultimate bearing capacity after grouting is 16467kN;

6.3 Analysis of Mechanism of Post-grouting to Improve Bearing Capacity of Pile Foundation

The post-grouting of the pile is to inject the cement slurry into the soil by pressure to reinforce the pile. The slurry is squeezed into the soil under pressure to consolidate the soil. Moreover, after the slurry entering the void in the soil, it coheres and solidifies, and acts as a reinforcement and cementation. It can strengthen the sediment at the bottom of the hole and increase the bearing capacity of the pile end. After grouting, there is also a certain reinforcement effect on the mud skin of the pile side, which improves the side friction resistance of the pile.

7. Conclusion

The bearing capacity tests of the two test piles were carried out by self-balancing method, and post-grouting was carried out to compare the bearing capacity, tip resistance and side friction. The results show that the ultimate bearing capacity of No.1 test pile before grouting is 6333kN, the ultimate bearing capacity after grouting is increased by 95%; the ultimate bearing capacity of No. 2 test pile
before grouting is 12350kN, and the ultimate bearing capacity after grouting is increased by 33.3%. It shows that after grouting, the effect of the pile with poor bearing capacity is obvious, and the ultimate bearing capacity is improved much.

Acknowledgments
This work is supported by Guizhou Science and Technology Support Project ([2018]2833), Science and technology research and development project of CSCEC(CSCEC-2016-Z-25). They are gratefully acknowledged.

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