Composite foundations with post-grouting piles

Fondations mixtes avec des pieux de post-injection

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ABSTRACT: Composite foundation with post-grouting piles is a new type foundation strengthening technique. The construction practice in recent years has shown that it is a safe and reliable measure with lower cost, especially suitable for foundation treatment of middle and high buildings. This paper presents a brief introduction of the composite foundation with post-grouting piles for Shao Yao Ju residential building in Beijing, China, as an example.

1 INTRODUCTION

In case of composite foundation, the soil between piles will bears a part of the load of upper structure beside which is beared by the piles. So the number of piles may reduced and the cost becomes lower. In China, a lot of engineering foundation have adopted this type of foundation treatment technique.

A new type of composite foundation with post-grouting piles has been developed in order to improve the stress condition and the function of composite foundation. It is characterized by follows:

1.1 The strength of pile materiel is more than 15 MPa. With this high strength rigid piles, the pile-soil stress ratio can be easy to regulate by increasing the pile length and the pile skin friction. Thus enhance the bearing capacity of composite foundation effectively.

1.2 After the piles were installed in the foundation, grout is injected into the interface of the piles and surrounding soils under pressure. The pile skin friction can be increased by more than 30%-50% after the grout is set completely.

1.3 The natural soil stratum under the base plate of building foundation needs to be treated with compacting grouting beside the round pile grouting. This procedure may increase the density of subsoil, cause the skin friction of upper and lower layers become homogeneous and improve the bond betwwen base plate and subsoil. so the piles and the subsoil will support the loads together at the beginning.

1.4 The relatively weak subsoil will be consolidated to some extent by set grouts penetrated into the soil layers with both fracturing and permeation mechanisms during the grouting processes.

2 CONSTRUCTION PROCEDURES

The construction procedures of composite foundation with post grouting piles mainly include drilling, piling, round pile grouting and subsoil compacting grouting.

2.1 Drilling

Bore-holes may be drilled from ground surface or from the bottom of foundation pit according to the site condition. The slurry method for drilling should be adopted when ground water is presented, while drilling without drilling liquid by using earth auger can be accepted when no ground water is appeared.

The parameters of bore-holes, such as diameter, spacing, number and depth can be calculated by design requirement, geological condition and the character of post-grouting.

2.2 Piling

When the bore holes were drilled, the pile will be formed by displacement of the drilling slurry by grout or by pouring concrete according to the actual condition. The former method is used for the holes filled with slurry. A stand pipe is insert to the bottom of the hole at first, then the high strength grout is injected into the bore-hole through the pipe under pressure to force out the drilling slurry. For the holes without slurry, use the latter method. It just to pour the concrete into the hole directly.

A steel tube should be placed inside the holes before piling for post grouting purpose.

2.3 Round pile grouting

After the strength of pile material reachs to a certain value inject a special grout with high concentration, high strength, high stability and high fluidity into the bottom of holes through the preinstalled tube. When grout spread upward along the lateral sides of pile, some remains at the interface between the pile and soil to form a shell of set grout, and some penetrates into the soil stratum between piles to form a lot of set grout veins, as shown in Figure.1.

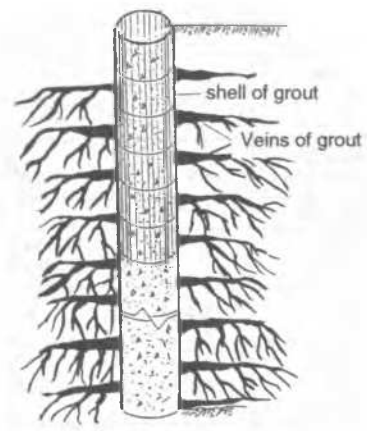

Figure 1. Scheme of completed post-grouting pile

2.4 Compacting grouting

A serise of grout tubes are preinstalled in the base plate during pouring process after piling and grouting round the piles. When the strength of concrete reaches to a certain extend, inject the grout with high concentration, high strength, high stability and high fluidity into the soil under the base plate through these tubes. This procedure may be carried out at the same time with the construction of upper structure. But the grouting pressure should be controlled strictly to prevent the unpermissible deformation of base plate.

3 A PRACTICAL CASE, SHAO YAO JU RESIDENTIAL BUILDING

3.1 Characteristics of the project

The Shao Yao Ju project involes two residential buildings with 24 stories over ground and 2 stories under ground. The construction area of each building is about 20000m², and the area of base plate of each building is 870m². The design load is 380kPa.

The sequence of soil layers from surface is: artificaial random fill, sandy clay, silty clay, sandy silt and middle-fine sand. These soil layers not satisfied to bear the design load, especially the upper artifitial random fill with a thickness of 2.8-13.2m comprising with stone, garbage and humus. It is unfavorable for the structure if it has not treated. In original design, a pile foundation alternative was adopted for thses buildings. The construction cost was varied between R.M.B. 4.5-5 million yuen according to the variations of design parameters. The alternative of composite foundation with post grouting piles has solved the problem successfully and has reduced the cost to R.M.B. 2.4 million yuen.

3.2 Design Parameter

As above-mentioned, composite foundation with post-grouting piles includes piling, round pile grouting and compaction grouting under the base plate. Since there are about 3 meters thick of artificial random fill leaved under the base plate, which has to strenghen by pressure grouting. The main design problems are how to determine pile diameter, pile spacing, pile length, allowable skin friction(after pile grouting), allowable pile capaciaty , pile material strength, strength of set grout, maximum grouting pressure, grouting depth in artificial random fill, etc. Table 1 lists the parameters adopted for this project.

Table 1 The design parameters of foundation treatment measures for Sao Yao Ju project

parameter	unit	value
diameter of friction piles	mm	300
spacing between piles	m	1.6
pile length	m	14
allowable skin friction of pile(after round pile grouting)	kPa	40-45
allowable pile capacity (after round pile grouting)	kN	560
strength of pile material	MPa	15-20
grouting depth in the random fill	cm	30-50 cm thicker than it's thickness
maximum pressure of round pile grouting	MPa	1-1.5
maximum pressure of compaction grouting under base plate	MPa	0.5-0.7
maximum pressure of grouting for randon fill	MPa	0.7-1.0

3.3 Bore holes arrangement

The bore holes with a diameter of 300 mm are arranged as equilateral triangle with 1.6m hole spacing and row spacing, see Figure.2.

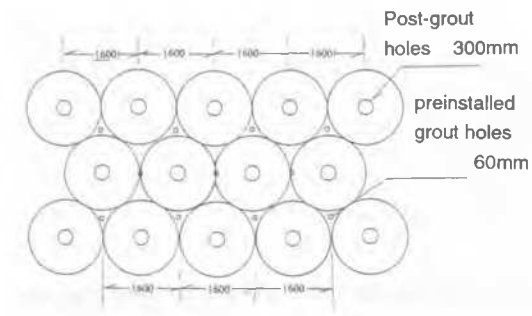

Figure. 2 The arrangement of post-grouting piles and preinstalled grout holes

3.4 Drilling

Percussion drilling was employed because there are some stone blocks and garbage in the artificial random fills. Water is accepted as the drilling liquid for boring the clay layer, but for the silt, fine sand and random fill, slurry was used during drilling. The waste slurry was collected to the slurry pond in situ at first, then was pumped to a certain place with mud pump. After drained and dried up , it was transferred to the waste collect yard.

3.5 Piling

After the bore hole reached the predetermined level, insert two steel tubes into the bore hole filled with slurry. One with an open end for displacement grouting sinks to a level about 20cm above the bottom. Another one for round pile grouting sinks to the bottom and is pushed into the subsoil about 15cm to form an end blockage in order to prevent the grout entering this tube during displacement grouting. Then inject a special grout with high concentration, high strength, high stability and high fluidity into the hole by using grout pump to displace the drilling slurry wholely. After that, push out this tube and thus formed a high strength pile with a 2" steel bube inside, as shown in Figure.3.

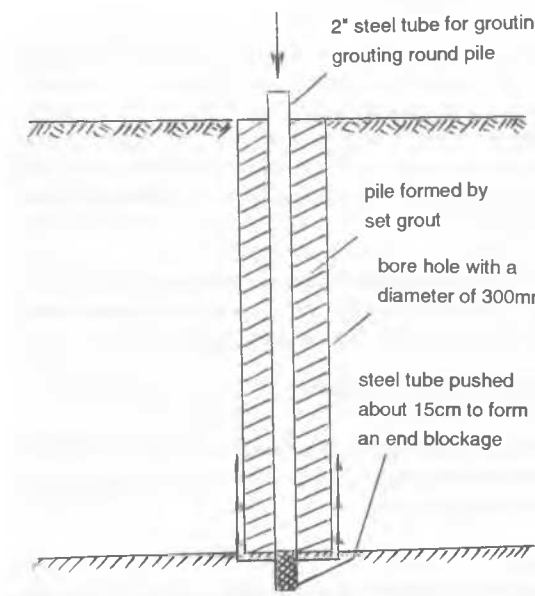

Figure 3 The friction pile formed by displacement grouting

3.6 Round pile grouting

When the pile strength reaches to 30%-40% of design strength, start round pile grouting through the preinstalled tube. It needs a higher pressure to push out the end blockage first. After the grout goes through, lower the pressure quickly to grouting with low pressure and low flow. In the grouting process, if a higher pressure is needed, both presure increment and rising speed can not be too large for avoiding the concentrated seepage along the pile and the grout get up to the ground surface too quick.

3.7 Compaction grouting

Owing to the foundation deformation caused by the compression of subsoils in the construction process, fissures or voids may exist between the base plate and cushion and between the cushion and subsoil. The soil stratum may be distubed during excavation of the foundation pit. These defects may induce foundation settlement in early stage. After the structure is established, a more unfavorable consequence may happen in long term under the effect of some factors(such as ground water, etc.). So this hidden danger has to be eliminated before it happens by the way of compaction grouting.

A series of injecting tubes is placed in the base plate during the process of pouring concrete for compaction grouting purpose (see Figure 2).Drilling and grouting is carried out through the placed injecting tubes when the base plate reaches enough strength. The fissures and voids are filled with grout thus strengthen the bond of base plate and the bearing layer, so the stress can be transmit more reliable. The soft soil can also be densified during grouting process. The suituation of grout tube installation is shown in Photo 1.

Photo 1 The situation of installation of grout bubes

3.8 Grouting the random fill

Grouting of the artificial random fill is carried out at 2-3 days after compaction grouting is completed watiting for the grout consolidation. Drilling and grouting also go through the placed tubes that has mentioned above. Dry boring and grout with high concentration, high strength, high stability and high fluidity are adopted. The results demonstrate that the grout take of soil stratum exceed the theoretical value that calculates with porosity.

3.9 Loading test of composite foundation

Two set of lading test were carried out in situ to examine the conformability of theoretical and actual condition. One of the test is located in the place with random fill, and another is located in the place without random fill. The area of every test composite foundation is 1.6 × 1.6=2.56 m² involoving one post-grouting pile. The allowabe pile capacity is 560kN as mentioned in Table 1. The parameters of the loading test are as follows:

1. Design load applied to each test area P:
   $P = F_1 \cdot q$
   F_1 - test area, 2.56m²;
   q-design load of building, 380 KPa;
   ∴ P=2.56 × 380=973 KN
2. Theoratical bearing capacify of this test area of composite foundation R:
   $R = Bp + Bs\ (F_1 - F_p)$
   Bp - allowable pile capacify, 560 kN
   Bs - allowable bearing capacify of soils betwwen piles, 170 kPa
   Fp - cross sectional area of each pile, 0.07m²
   ∴ R = 560 + 170 (2.56 - 0.07) = 980 kN
3. Total load used in loading test Q equals to 2.2 times the theoretical bearing capacity R:
   $Q = 2.2 \cdot R = 2.2 \times 980 = 2200$ kN

The test results are shown in Figure 4.

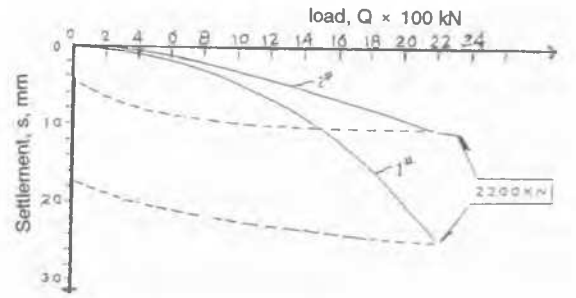

Figure 4 The results of loading test dealing with composite foundation

The curve 1# represents the composite foundation with random fill and the curve 2# represents that without random fill. It is clear from the curves that the settlements of both test sites are less than 5mm under the design load. In the case of two times design load the biggest settlement of the site with random fill is not exceed 16mm and in the site without random fill is abot 8mm.

3.10 Settlement observation of the buildings

6 settlement observation points are arranged in each building after complettion of the grouting work to monitoring the settlement of buildings (see Figure. 5). In Figure 5, A,B,C are the number of bench mark, 1-6 and 1' -6' are the settlement observation points.

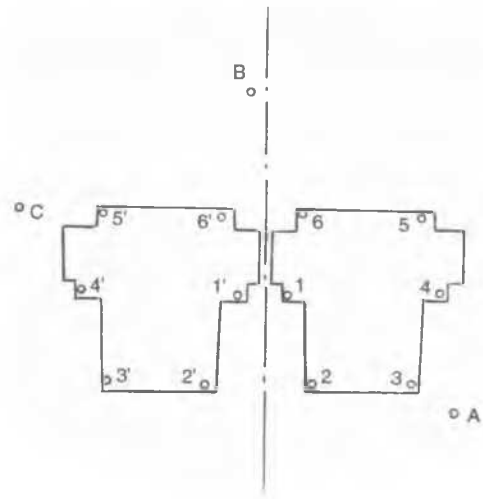

Figure 5. the arrangement of observation point

The results of observation are as follows:
1. The settlement nearly equals to zero when the building is risen to 3-5 storeys.
2. Total settlements are not exceed 2.0mm when the building goes to 10 storeys. It equals to 40% of design load.
3. Total settlement varied betwwen 6-11 mm when the building goes to75%-95% of design load.

4. CONCLUSION

Owing to the adoption of composite foundation with post grouting pile alternative, obvious technical and economic benefit have been got in the construction of two high buildings located in Shao Yao Ju, Beijing. Both the results of loading test in situ and the settlement observation data demonstrate that the settlement and diferental settlement are far less than the allowable values specified in the operating standard. Reasons account for the good results mainly are as follows:
1. The strength of pile material is high enough, so that the deformation of the piles are relatively small.
2. Round pile grouting increases the skin friction of piles and the pile-soil stress ratio in a large extent.
3. Round pile grouting also improves the strength and density of the soil between piles in various extent.
4. Compaction grouting under base plate increases the density of subsoil and improves the pile-soil friction and the normal stress distribution in the upper part.
Now, the technologies for composite foundation with post-grouting piles are extended to other similar projects.

References

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