In-Situ Study to Assess the Quality of Pre-drilled Embedded Geotextile Gravel Grouting Pile

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***Abstract* — This paper introduces pre-drilled embedded geotextile gravel grouting pile, a new method of foundation treatment, about its bearing mechanism, construction process and characteristics, and demonstrates the results of: i) in-situ small-strain test, ii) drilling core field test, and iii) static load test based on support construction. Our main conclusions are: i) compared with traditional gravel grouting pile, the pre-drilled technique, with construction quality easy to control and more reliable quality of pile forming, can effectively overcome the defects related to pile body and avoid mud pollution under appropriate conditions; ii) the results of small-strain test and drilling core test show that the pile formed with the process has complete pile body, strong pile bonding and even aggregate to meet design strength, its pile body has a higher concrete strength than the pile formed with traditional process; iii) the data of static load test indicate that the pile formed with the process exhibits load-bearing property of rigid pile, with ultimate bearing capacity about 10-15% higher than traditional gravel grouting pile to reach design requirements.**

Keywords - pre-drilling; embedded geotextile; gravel grouting pile; small-strain test; drilling core; static load test.

I. INTRODUCTION

A great deal of research has been conducted on composite foundation treatment technology at home and abroad [1-6]. Pre-drilling embedded geotextile gravel grouting pile is a new method of soft foundation treatment and adopts grouting technique on the basis of gravel pile [7-11]. The technique has already been applied in foundation treatment for some highways in Zhejiang province and achieved good effect. But without in-depth research on its relevant design and calculation theory, construction process, quality control or evaluation for reinforcement effect, it is difficult to further promote pre-drilling embedded geotextile gravel grouting pile composite foundation. There are a lot of factors which may influence the quality of pre-drilling embedded geotextile gravel grouting pile including geological conditions, diameter and length of the pile, slurry, aggregate and construction technology. Specific methods to determine various design parameters such as pile strength, pile diameter, the effect of bearing capacity of pile earth, intensity fluctuation of pile earth, friction resistance between pile and soil as well as settlement have not yet been elucidated. So it is necessary to research related theory tests and construction technology and to explore reinforcement mechanism and construction process of pre-drilling embedded geotextile gravel grouting pile composite foundation to further understand it, improve its performance and develop the technology better.

This article introduced bearing mechanism, construction process and technical characteristics of pre-drilling embedded geotextile gravel grouting pile that is a new technical way of foundation treatment. Besides, in-situ small-strain test, drilling core field test and static load test on the basis of support construction are performed.

II. RESEARCH ON BEARING MECHANISM OF PRE-DRILLING EMBEDDED GEOTEXTILE GRAVEL GROUTING PILE

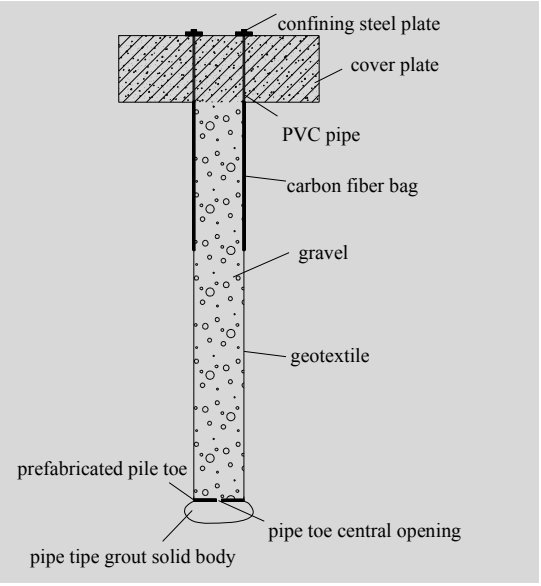


Figure 1. Pre-drilling embedded geotextile gravel grouting pile structure.

Geotextile bags in pre-drilling embedded geotextile gravel grouting pile can prevent gravel from being polluted by mud and provide more appropriate conditions for drilling pile dry. The pile constructed with geotextile gravel grouting pile technique is similar to plain concrete rigid pile with wide application. Its structure is shown in Figure 1. Load-bearing mechanism is as follows: slurry cements gravel into a pile as well as compacts, cements and

consolidates clay around the pile and eluvial soil (clay) to improve pile side resistance and pile tip resistance. So the problems of neck-narrowing, ballooning and hole collapse can be effectively solved. The process is simpler and load effect is better than pile-side post-grouting and pile-end post-grouting technology.

III. RESEARCH ON CONSTRUCTION PROCESS OF PRE-DRILLING EMBEDDED GEOTEXTILE GRAVEL GROUTING PILE

A. Construction Method

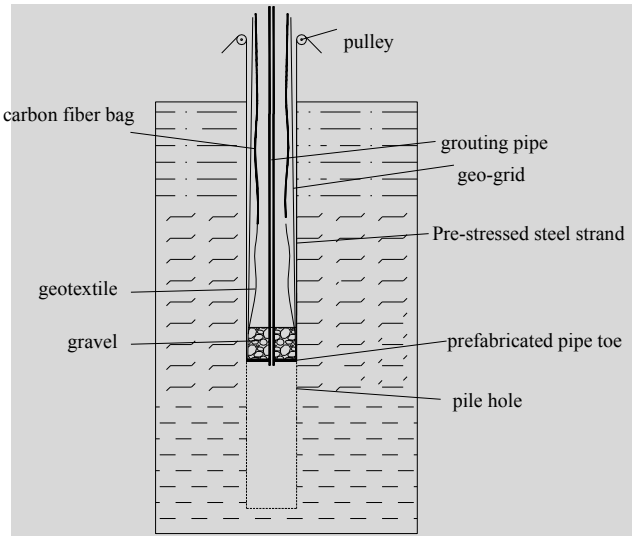


Figure 2. Pre-drilling embedded geotextile gravel grouting pile construction method

As shown in Figure 2 and Figure 3, pre-drilling embedded geotextile gravel grouting pile is constructed with the following method: in accordance with design requirements, firstly use a drill for drilling pile dry or drilling for slurry retaining wall, lift precast pile tip with two or three pre-stressed steel strands and put it into pile hole at a certain depth, while geotextile bags and grids (according to the needs) are fixed on pile tip outwards in turn, then pour gravel into geotextile bags to the height of 0.5-0.8 meters, let pile tip and gravel fall to the bottom of pile hole under the gravity and fill gravel into the bags while pile tip sinks, take measures to vibrate and compact the gravel filled, after gravel is poured to the designed elevation of pile top, inject grout under pressure through a reserved grouting tube to eluvial soil (clay) and gravel at the bottom of pile tip to form pile end slurry solid and gravel grouting pile, finally pour (or grout gravel to form) a cover plate simultaneously. Steel strands can be pulled out and reused or be reserved in the foundation to apply pre-stress on pile body and cover plate after pile body and cover plate meet design strength requirements. Anchorage is arranged on the upper of cover plate. In order to ensure the integrity of upper pile body and pile quality as well as improve bearing capacity of pile top, carbon fiber bags can be placed at 3-5 meters of upper pile body.

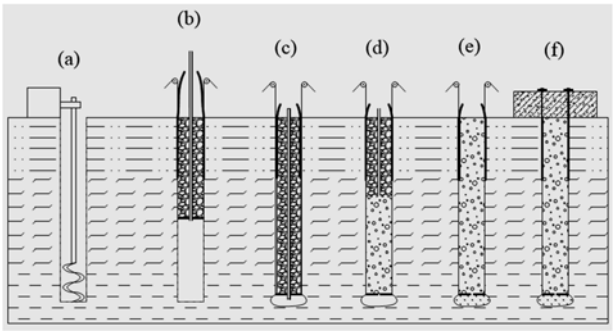
B. Technical Characteristics

1) Drilling pile dry and drilling for slurry retaining wall can reduce compaction effect in conventional pile foundation construction, with stable and reliable quality of drilling.

2) External geotextile bags can ensure that gravel will not mix with soil dust or mud to improve the strength of gravel grouting body.

3) During the construction in formation, in which it is not easy for drilling, gravel is filled, vibrated and compacted into the bags to guarantee pile diameter and to increase ultimate pile perimeter resistance.

4) Construction of pre-drilling embedded geotextile gravel grouting pile is simple and fast with obvious economic benefit.



(a) drilling; (b) precast pile tip and pour gravel;(c) grouting under steel plate; (d) pile body grouting; (e) gravel grouting pile body; (f) construct cover plate

Figure 3. Pre-drilling embedded geotextile gravel grouting pile construction process.

IV. IN-SITU TEST RESEARCH OF PREDRILLING EMBEDDED GEOTEXTILE GRAVEL GROUTING PILE

Overall, it is still in the stage of research how to apply geotextile gravel grouting pile soft foundation reinforcement method to highway engineering. There is no mature theory for the design of geotextile gravel grouting pile and fewer construction experience. To promote the development of this soft foundation treatment technology as well as optimize the existing design method, construction skills and test method of geotextile gravel grouting pile, we conducted a series of field test research on pre-drilling embedded geotextile gravel grouting pile in some engineering, which mainly includes the following aspects: study on (1) small-strain test of geotextile gravel grouting pile; (2) drilling core test of geotextile gravel grouting pile; and (3) load test of geotextile gravel grouting pile composite foundation.

A. Geological Conditions at Test Section

Geological situations near test site can be summarized as follows: the surface layer (1) is filling soil, which consists mainly of miscellaneous fill, grain filling and

planting soil; (2) layers of silty clay, yellow-brown, saturated, plastic to hard plastic state, mixed yellow spots, uneven mixing sand with mica and plant roots, medium-compression layer; (3) silt clay, gray or dark gray, saturated, plastic flow state, with mica and a small amount of humic, high water content and high compressibility, (4) silty clay: gray or green gray, saturated, generally plastic flow state to soft plastic state, a lot of mixing sand with mica, medium compressibility, stratigraphically steady, discontinuous distribution; (5) fine sand, gray and more dense. Its specific physico-mechanical parameters are shown in Table 1.

TABLE I. PHYSICO-MECHANICAL INDEXES OF SOIL LAYERS AT TEST SECTION

layer	thickness /m	natural water content w/%	natural densiity (kN·m3)	void ratio e	liquidity index IL	Compression modulus ES/MPa	C' /kPa	φ' / °
①	1.2							
②	3.0	45.0	17.4	1.260	0.79	2.77	21.6	7.2
③	8.7	50.2	16.5	1.494	1.17	1.81	7.0	2.5
④	1.8	30.8	18.9	1.125	1.36	3.58	13.4	13.2
⑤	5.5	25.0	19.6	0.702		8.27	36.1	18.9

B. Small-Strain Test of Geotextile Gravel Grouting Pile

The test was performed with PDI dynamic testing instrument and accelerometer as signal acquisition sensor. In order to make the test more representative, every pile was tested many times with various firing mechanism and different firing and receiving distances to select correct firing and receiving measure. The results of small-strain test of geotextile gravel grouting pile with the length of 28 meters, the diameter of 500 millimeters and the ratio of length to diameter of 56 are shown in Figure 4.

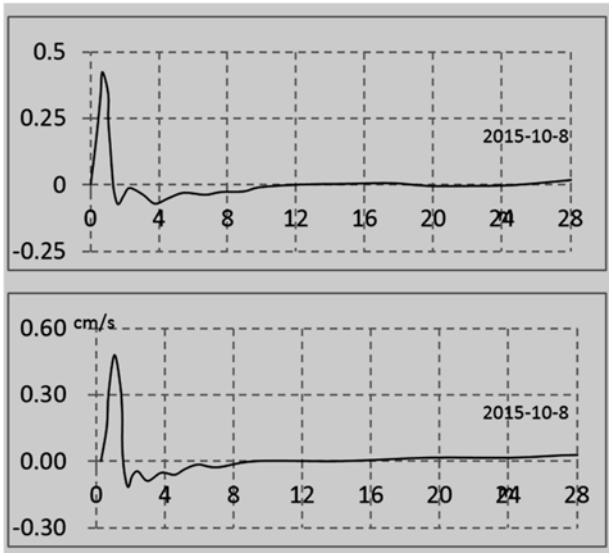


Figure 4. Pre-drilling embedded geotextile gravel grouting pile typical wave picture of small-strain test

The results of small-strain test demonstrated good effect. Average wave velocity were about 3200 m/s. Except very few piles with slight neck-narrowing at 2 meters of the upper, body quality of the rest was good and the reflection from pile bottom was obvious. The test results prove that, on the basis of appropriate firing and receiving mechanism, it is feasible to use small-strain dynamic test technology to test construction quality of slurry solid gravel pile and the results can well reflect construction quality of slurry solid gravel pile.

C. Drilling Core Test of Geotextile Gravel Grouting Pile

Through drilling core, we can not only directly determine the cementation of pile body concrete, whether cement and sand-gravel aggregate is mixed evenly and whether there is any quality problem on pile body such as infiltrated mud, hollow, segregation and broken pile, but also check pile length and the thickness of sediment at pile bottom as well as know pile (end-bearing pile) bearing layer lithology. Compression test for concrete core samples was done to measure concrete strength of pile body.

Drilling core of a geotextile gravel grouting pile is shown in Figure 5. The results show that the pile was consolidated well above 15 meters to be a column with uniform aggregate and complete cross section; pile consolidation was fair at 15-20 meters to be a column with incomplete section on some pile segments; But below 20 meters, due to mechanical vibration in drilling process which is not easy to control and more aggregate in slurry solid gravel pile body, neither pile consolidation was ideal nor complete pile core was taken out, but only short column pile body and a large number of gravel aggregate.

Figure 5. Pre-drilling embedded geotextile gravel grouting pile drilling core.

D. Static Load Test of Geotextile Gravel Grouting Pile Composite Foundation

Bearing capacity of composite foundation is an important evaluation indicator for its reinforcement effect. For further study on the effect of geotextile gravel grouting pile to treat soft soil foundation and bearing mechanism of composite foundation, static load test of geotextile gravel grouting pile and composite foundation in a certain project was carried out. Q-s curve of a geotextile gravel grouting pile with the length of 28 meters and the diameter of 600 millimeters changes

slowly. Its ultimate bearing capacity is 800kN. The settlement under each stage load indicates a relatively long period of stability; Q-s curve of a geotextile gravel grouting pile with the length of 28 meters and the diameter of 500 millimeters falls fast. Its ultimate bearing capacity is 720kN. The settlement under the last stage load is accelerated; Q-s curves of the two piles are shown in Figure 6. Composite foundation of the three geotextile gravel grouting piles had a bearing plate with the area of 7.29m2, max load of 1610kN, accumulated maximal settlement of 410 millimeters, residual settlement of 398 millimeters and bearing capacity of 199kPa. Its P-s curve changes slowly, as shown in Figure 7.

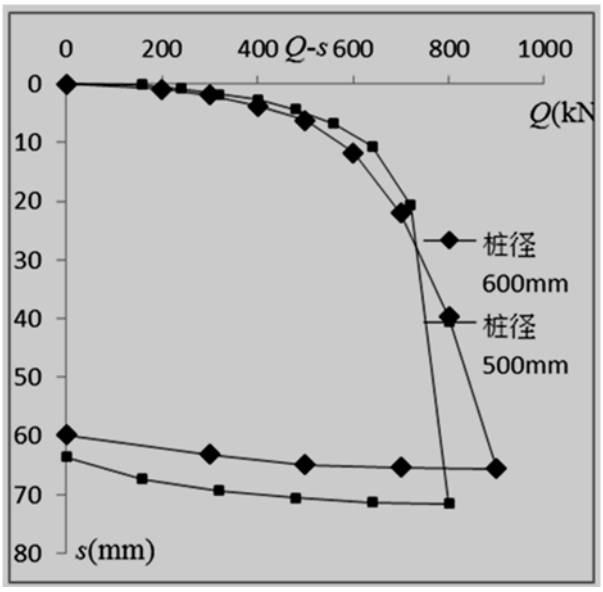


Figure 6. Pre-drilling embedded geotextile gravel grouting pile Q-s curve of static load test (pile length of 28m).

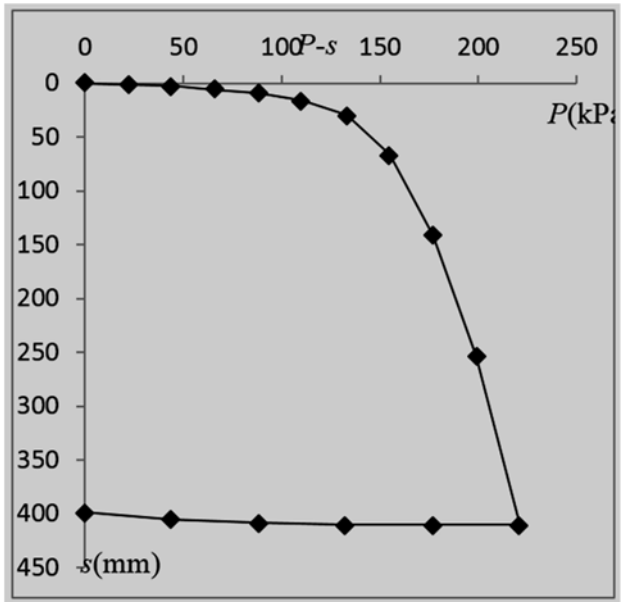


Figure 7. Pre-drilling embedded geotextile gravel grouting pile composite foundation P-s curve of static load test (pile length of 28m, pile diameter of 500mm).

V. CONCLUSIONS

This paper introduced bearing mechanism, construction process and technical features of pre-drilling embedded geotextile gravel grouting pile that is a new technical way of foundation treatment. We also performed in-situ small-strain test, drilling core field test and static load test on the basis of support construction. And this article concludes as follows:

1) Through field tests, construction process of pre-drilling embedded geotextile gravel grouting pile is optimized to realize, compared with traditional gravel grouting pile, construction quality easy to control and more reliable quality of pile to effectively overcome the defects related to pile body and avoid mud pollution under appropriate conditions.

2) The results of small-strain test and drilling core test show that the pile formed with the process has complete pile body, strong pile bonding and even aggregate to conform design strength. Its pile body has a higher concrete strength than the pile formed with traditional process.

3) The data of static load test indicate that the pile formed with the process has load-bearing property of rigid pile with ultimate bearing capacity about 10-15% higher than traditional gravel grouting pile to reach design requirements.

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REFERENCES

[1] Asnoka, T. Kodaka, and M. Nozu, “Improvement of Deep Soft Clay with Sand”, Science Press, Beijing, China, 1993.

[2] M.Enoki, N.Yagi, R.Yatabe and E.Echimoto, “Shearing Characteristic of Composite Ground and Its Application to Stability Analysis”, Deep Foundation Improvement: Design, Construction and Testing, ASTM, 1991.

[3] CHEN Zhi-fang, “Experimental Analysis on Load-bearing Capacity and Optimization on Sparse Piles Composite Foundation with PTC “, Hohai University, 2005.

[4] CHI Yue-jun, SONG Er-xiang, CHEN Zhao-yuan, “Analysis of Bearing Performance of Rigid Pile Composite Foundation under Vertical Loads “, Engineering Mechanics, Vol. 20, No. 4, pp. 9-14, 2003.

[5] CHI Yue-jun, SONG Er-xiang, “Experimental Study on Stress Distribution of Composite Foundation with Rigid Piles”, Rock and Soil Mechanics, Vol. 24,No. 3, pp. 339-343, 2003.

[6] LIU Han-long, HAO Xiao-yuan, FEI Kang, CHEN Yong-hui, “Field Pour Concrete Thin Wall Cased Pile Technology and Its Application (II): Application and In-situ Test”, Rock and Soil Mechanics, Vol. 24, No. 3, pp. 372-375, 2003.

[7] CHEN Yong-hui, Wang Xin-quan, SHI Rong, CHEN Bing, YAO Cheng, “Bearing behaviors of crushed stone grouting piles”,

Chinese Journal of Geotechnical Engineering, Vol. 31, No. 6, pp. 871-878, 2009.

[8] MA Chongwu, MU Qingsong, MA Junwei, HUA Tuo, "Testing Research on Load Transfer Models of Single and Multiple Gravel Piles", Chinese Journal of Rock Mechanics and Engineering, Vol. 27, No. S1, pp. 3116-3121, 2008.

[9] ZHOU Cui-ying, MU Chun-mei, "Analysis on Effective Radius of Gravel Piles Reinforcement in Soft Soil Foundations Based on Microstructure", Chinese Journal of Geotechnical Engineering, Vol. 27, No.7, pp. 755-758, 2005.

[10] CAO Wen-gui, YANG Ze-hua, "Method for Analyzing Settlement of Reinforced-gravel-pile Composite Ground under Flexible Foundation", Chinese Journal of Geotechnical Engineering, Vol. 34, No. 11, pp. 1997-2003, 2012.

[11] ZHANG Li-rong, TANG Jing-hua, RONG Lei, "Construction Technology of Vibrating Sinking-pipe Bag Piles", Construction Technology, Vol. 41, No. 368, pp. 5-8, 2012.