ORIGINAL ARTICLE

Analysis of Causes of CFG Pile Necking in Saturated Soft Soil Layer and Its Control Measures

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Abstract: In recent years, composite foundation technology has been widely used in foundation treatment. Composite foundation theory has become an important research topic in the field of geotechnical engineering. CFG pile (Abbreviation of cement, fly ash, and gravel pile) in composite foundation is one of the commonly used technologies. It has advantages such as simple construction, reliable quality and low cost. When it is used in soft foundation treatment, it significantly improves the bearing capacity, reduces settlement, and turns waste (fly ash) to treasure, which benefits economic and social significantly. During construction, various defects in construction quality will affect the effect of soft foundation treatment. CFG pile necking is one of the more representative quality defects. This paper combined some project examples to analyze the causes of CFG pile necking and develop effective control measures for it which has a certain reference value towards the quality control of the technology.

Keywords: Saturated soft soil layer; CFG pile; Necking

Introduction

In recent years, the scale of capital construction increasingly expands. The circumstances in encountering poor foundation in civil engineering construction are growing. When natural foundation is unable to meet the requirements of the above building (structure), foundation has to be treated which formed an artificial foundation to ensure the safety of the building (structure) and it functions normally. The application of CFG pile in consolidating soft soil foundation is gradually applied in soft soil treatment. This paper will introduce this method with examples.

1.Application of CFG pile in saturated soft soil layer

1.1 CFG pile in composite foundation technology

CFG Pile is the abbreviation of cement fly-ash gravel pile. It is referred to high bond strength pile that is formed from cement, fly ash, gravel, sand or stone by mixing with water. CFG pile, together with soil between piles and cushion formed composite foundation. Because the strength and modulus of CFG pile body is larger than the strength of soil between piles, under the influence of loading, the stress on top of the piles is larger than the stress on the surface of soil between piles. Piles can transfer the bearing load to deeper soil layers and correspondingly reduce the bearing load in the soil between piles and this improves the bearing capacity of composite foundation, and reduces deformation. Together with unreinforced, utilization of industrial waste such as fly ash as admixture in pile making has greatly reduce

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the project cost. The CFG pile composite foundation technology possesses high bearing capacity, short construction period and low production cost especially the use of long spiral drill pipe in CFG pile construction technology. Pressure pump that used during CFG pile construction work has the advantages such as no mud, no noise pollution and do not need to carry out dewatering. It has been applied in many foundation treatment programs.

1.2 Main points of CFG piles composite foundation in saturated soft soil treatment

1.2.1 Effect of continuous driving on pile quality

In order to get an idea about the effect of continuously driving on pile quality, tests of continuous driving and staggered driving of pile have been done in the field. The outer diameter of the test pile is 40cm, and piles distance is 1.4m. During the process of continuous pile driving, when the adjacent test piles are driven, upwelling phenomenon is seen on the pile mixture of the pile which has already been driven while this phenomenon does not appear for the staggered driving pile test. Examination on excavated piles revealed that the CFG piles that have been driven continuously are squeezed and flattened, the pile diameter is relatively smaller. While the CFG pile diameter of staggered driving test is more regular and no phenomenon of neither squeezed nor flattened is seen, the diameter is about 39.5 cm with better quality. As we can see, project quality can be ensured if staggered driving measure is taken.

1.2.2 Effect of pile concrete slump and pipe drawing speed on pile quality

In place slump tests with slump 8–10cm and 2–4cm that have been done revealed that when the immersed tube filling pile with mixture of slump of 8–10cm is done, there is more laitance on top of the piles, which has thickness up to about 1m. When the immersed tube filling pile with mixture of slump of 2–4cm is done, there is lesser laitance on top of the piles, which is about 10cm thick. When slump degree is higher, there will be more slurry but also more diluted. Since vibration extubation causes the mixture to be compacted, it allows the laitance to fill up the pores and the excess laitance is brought to the top of the pile by vibration, which affects the pile quality. When the slump degree is small, the slurry is relatively lesser but thicker and it fills up the pore spaces between gravel and graded aggregate and thus there is less slurry on top of the pile, which is favorable to pile quality. From the ratio test, if slump degree is small, less water is required, the ratio of water-cement is also small, and it has high strength. Field test shows that the CFG pile mixture with slump degree of about 3cm is more appropriate for construction work. In addition, from the pipe drawing speed test in field shows that the extubation rate of not more than 1.5m/ min is more appropriate.

1.2.3 Single pile and composite foundation test results on site

Table 1 Single Pile and Composite Foundation Test Results on Site

Test no	CFGP1 (Single Pile)	CFGP2 (Single Pile)	CFGP3 (Single Pile)	CFGP4 (Single Pile)	CFGP5 (Single Pile)	CFGP6 (Single Pile)
Standard Load Bearing Capacity (KPa)	555	558	560	310	320	315

2. Introduction of project examples

2.1 Case overview

The case describes the Xinxiang Binhu Town 12# floor project which is located in intersection of Weihe road and Yanshan Road in Xinxiang Plain New Area Binhu Town. 1.35m below the top of the pile of this project is silty clay with load bearing capacity of Fak85KPa, the foundation design is soft foundation treated CFG pile construction site. CFG pile is the high bond strength pile which is formed by mixing from cement, fly ash, gravel, stone and water. It formed composite foundation together with the soil between piles and gravel cushion. According to the requirements of design, the pile diameter of the CFG in the said area is 0.4m, pile length of 16m, pile spacing of 1.4m, and piles distribution is arranged in square. CFG is required to be driven not less than 1.0m into the bearing stratum. The CFG pile cement used is 42.5 grade Portland cement; fly ash used are II, III and above level fly ash; the ratio of the weight of pile material used is cement: fly ash: chips: gravel=1:1.530:3.529:8.855. The compressive strength is designed to be R28≥20MPa. Once the CFG pile construction work is done, sand cushion is laid on top of the pile to form composite foundation. The pile load bearing capacity is not less than 550kN, while the composite foundation has load bearing capacity of not less than 300kPa.

2.2 Engineering geology features

Field exploration, in-situ static sounding and laboratory soil test results, combined with the nearby project site experience, sum up that the soil of this site is mainly made up of Quaternary Holocene to Pleistocene silt, silty clay and fine and medium sand. The specific characteristics of each soil layers are described as follows:

1) 1st layer: Silt (Q4al)

Yellowish brown, slightly wet, slightly dense. Dull reaction, low dry strength, low toughness. Occasionally shell fragments of snail can be seen, sandy. Partly with interlayered with thin silty clay. The layer is widely spread in the region. Thickness of 0.50-4.20m, with average thickness of 2.09m; 0.50-4.20m depth of bottom layer, with average depth of 2.09m.

2) 2nd layer: Silty Clay (Q4al)

Greyish brown to yellowish grey, soft plastic to plastic. Tangent plane is slight smooth, medium dry strength, and moderate toughness. Contain black ferromanganese spots. 0.40-3.5m thick with average thickness of 1.58m; 2.60-4.20m depth of bottom layer with average depth of 3.35m.

3) 3rd layer: Silt (Q4al)

Yellowish brown, slight wet, medium dense. Dull reaction, low dry strength and low toughness. Occasionally shell fragments of snail can be seen, stronger sand feeling. Partly interlayered with thin silty clay and this layer is widely spread in this region. 0.90-4.30m thick, with average thickness of 1.99m; 4.40-8.40m depth of bottom layer with average depth of 5.37m.

4) 4th layer: Silty Clay (Q4al)

Yellowish brown to yellowish grey, plastic. Tangent plane is smooth, medium dry strength and moderate toughness. Contain black ferromanganese spots. Partly interlayered with thin silty clay, and this layer is widely spread in the region. 1.00-4.00m thick, with average thickness of 2.07m; depth of bottom layer is 6.00-11.00m, with average depth of 7.45m.

5) 5th layer: Silt (Q4al)

Yellowish brown to yellowish grey, wet and medium dense. Dull reaction, medium seismic response, low dry strength, low toughness. Occasionally shell fragments of snail can be seen, sand feeling is slightly stronger. This layer is present partly in this region. 0.50-2.20m thick with average thickness of 1.15m; depth of bottom layer is 7.50-10.20m with average depth of 8.41m.

6) 6th layer: Fine Sand (Q4 al+pl)

Yellowish brown to yellowish grey, saturated, medium dense. Composed mainly by quartz and feldspar, contains small number of dark minerals. Partly interlayered with thin silt, and widely distributed in the region. 2.80-5.50m thick, with average thickness of 4.26m; depth of bottom layer of 11.00-14.50m, with average depth of 12.21m.

7) 7th layer: Fine Sand (Q4 al+pl)

Yellowish grey, saturated, dense. Composed mainly by quartz and feldspar, contains small number of dark minerals.

This layer is commonly distributed in the region. Partly interlayered with thin silt layer, 5.50-7.50m thick with average thickness of 6.67m; depth of bottom layer of 18.00-21.50m, with average thickness of 18.88m.

3.The analysis of the causes of CFG pile necking in saturated soft soil layer and its control measures

3.1Construction situation

3.1.1Construction method

(1).Pile tip and pile pipe setting: According to the pile centre of construction stakeout, prefabricated steel pile tip is firstly set up. Pile frame installation must be horizontal, pile pipe should be connected to pile tip vertically, both on the same axis, and then adjust the immersed tube to be perpendicular to the ground, vertical deviation shall not be more than 1%.
(2).Immersed tube: During the vibration process of immerse tube, eccentric shall be avoided and always check if the prefabricated steel pile tip is damaged, whether the pile pipe has offset or inclined. If the mentioned situation occurred, it should be corrected immediately. No water or mud is allowed to enter into the pile pipe. If water or mud enters the pile pipe, 1.5m thick of sealing concrete shall be poured before immersing the pile.
(3).Determine the pile buried depth: Immersing tube by staggered driving in alternate row; determine the changes in geological formations according to the immersing speed and current changes during the process. When the immersed tube reached the standard bearing stratum elevation or design elevation, the final pile embedded depth is determined according to the geological formation changes that have been determined during tube immersing.
(4).Pouring concrete: Concrete shall be poured as much as possible every time when concrete is poured into pile tube. When long pile tube is used to drive shorter pile, concrete can fill up the tube at once; while driven a long pile, the first concrete poured shall fill up the pile pipe. The height of first extubation shall be controlled in the required limit to accommodate the amount of concrete to pour during the second concrete pouring. The tube shall not be pulling too high. During the extubation process, plumb checking should be done to check the declining level in concrete surface inside the tube.
(5).Extubation: Start the motor, leaving vibration for 5 to 10s, then start extubation, with extubation rate of 1.2 to 1.5m/min (extubation rate is referred to linear velocity, not the average speed), and every 1m of pulling up, vibrate for 5s. When the immersed tube is pulled up 2m above the ground, vibration shall be slow down to 10s. If low bearing capacity silty clay is encountered, extubation rate shall be slow down. If concrete quantity is insufficient, concrete shall be packing from air during the extubation process to ensure the pile top elevation meet the design requirements. After piling, the pile top elevation shall be considered for protected pile length.

3.1.2. Pile test analysis

For this project, the number of CFG pile for testing is determined to be 6, and 1.4m spacing arrangement. 28 days after the pile constructed test is completed, single pile static load bearing test and low strain dynamic test are done onto parts of the tested piles. The pile tests show that the main quality defect in pile is necking, and this is a phenomenon of incomplete pile, occurred mainly in the second and fourth layer of silty clay which has lower load bearing capacity. These two types of soil layer have common features such as saturated, plastic flow state and they are typical saturated soft soil layer.

3.2 Analysis of the causes of necking

3.2.1 The construction sequence is inappropriate in saturated soft soil piling. During continuous pile driving, the new driven squeezing the piles that have been driven will causing the piles that have been driven to be squeezed into oval or irregular shape, resulting in necking.

3.2.2. The control of the rate of extubation is not strict, which is too fast. In saturated soft soil, since extubation is too fast, the concrete is unable to fill up the pile hole on time before the soft soil occupying the pile hole, resulting in necking.

3.2.3. The control in concrete ratio is not stick, resulting in excessive water loss in concrete, causing blockage during pouring process; and operator failed but blindly remove the tube after blockage, causing the soft soil back silting and occupying the pile hole, and resulting in necking.

3.2.4. The concrete slump is too high, causing the failure in resisting the back silting pressure effectively during concrete pouring process, and pile hole is occupied by back silting soft soil, resulting in necking.

3.3 Analysis of control measures

3.3.1. Based on the actual project situation, to establish a reasonable and feasible driving order. The order shall follow from long pile to shorter pile and from middle to both sides, driven staggered in each and alternate row. The construction order from surrounding to center shall be prohibited. The time interval between driving a new pile with the nearby piles that have been driven shall not be shorter than the concrete setting time.

3.3.2. Control the extubation rate strictly; the extubation rate shall be 1.2 to 1.5m/min. The silty clay in this project is thicker, when the nozzle is pulled up to the saturated soft soil layer, the extubation rate shall be slow down to 0.8 to 1.0m/min to ensure that the concrete can fill up the pile hole, to prevent extrusion caused by back silting pressure.

3.3.3. The concrete used in CFG pile is commercial concrete. The stone chips and gravel were stacked in the mixing station where moisture content of the aggregate is greatly affected by outer influences. Therefore, there must be full time test personnel to test the changes in aggregate moisture content, and adjust the ratio of construction mixture timely, to ensure the accuracy in concrete mixture ratio.

3.3.4 On-site construction workers shall conduct test on the slump before pouring concrete, to ensure that the slump in the range of 30 to 50mm. Concrete with substandard slump shall not be used, and shall be return to mixing station.

3.3.5. Control the vibration time strictly, to ensure 5s of vibration in every 1m of pulling. When immersed tube is pulled up to 2m above the ground, vibration shall slow down to half which is 10s. Vibration shall not be too long.

CFG pile necking is a type of more representative quality problem. After necking, cross sectional area of pile is decreasing, and this reduce the load bearing capacity of a single pile, and thereby reducing the overall load bearing capacity of composite foundation, causing the efficiency in soft foundation treatment. However, these quality problems are manageable, as long as reasonable control measures are taken and the control measures are strictly implemented, CFG necking problem can be greatly reduced and controlled under an allowable range. During the inspection process, the formulated control measures from the strict pile test of this project passed the inspection test 100%, proving that control measures are effective and feasible. This paper discussed the analysis of CFG necking effect on the project in the 12# floor building in Lot C Xinxiang BinHu Town, and introduced the related control measures, which can be used as a reference for relevant project.

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