In-Situ Test Research of Restraint Reinforced Cement-Soil Pile

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***Abstract*—Restraint reinforced cement-soil pile is a pile in which the ordinary cement-soil pile is installed and wrapped with geogrid and carbon fiber cloth on its outside. This paper studies the load-bearing mechanism and construction technology of new restraint reinforced cement-soil pile at first; it has carried out indoor unconfined compressive strength comparative test through on-site coring combined with construction, finding out the strength of restraint reinforced cement-soil pile could be increased by 15%-20%, and its construction technology and the strength of construction pile could meet the design requirements. The comparative study on the static load test of ordinary cement pile and restraint reinforced cement pile of same diameter and length was conducted, and it turned out the ultimate load-bearing capacity of restraint reinforced cement-soil pile under the same condition could be improved by 10% to 15%, and its settlement value was less than ordinary cement-soil pile under the same load.**

***Index Terms*—restraint reinforced, cement-soil pile, core drilling, static load test**

I. Introduction

The vertical tubular restraint reinforced cement mixing pile is a new type of pile which installs traditional cement-soil mixing pile with vertical tubular restraints to enhance the compressive strength of cement-soil pile (Ref. [1]-[6]). It has been applied in the ground treatment of some highways in Sichuan Province, and has achieved good reinforcement effects. But no further research has been conducted on the relevant design and calculation theory, construction technology, quality control and reinforcement effect evaluation, which becomes the bottlenecks affecting and limiting the further promotion of restraint reinforced cement-soil pile based composite foundation. Many factors can influence the quality of restraint reinforced cement-soil pile, including geological condition, pile diameter, pile length, geogrid, and the construction technology (Ref. [7]-[11]). In terms of the strength of pile, pile diameter, the bearing capacity of soils between the piles, the change of the strength of soils between the piles, the friction resistance between piles and soils, settlement deformation, no mature parameters have been obtained so far, so it is necessary to carry out related theoretical test and research on construction technology, explore the reinforcement mechanism and construction technology of restraint reinforced cement-soil pile based composite foundation, to obtain further understanding and knowledge of restraint reinforced cement-soil pile based composite foundation, and improve its performance, so as to better develop the technology (Ref. [12]-[16]). With the advantages of fast construction speed and low cost, ordinary cement-soil piles are widely applied in engineering practices, of which the ultimate bearing capacity is mainly controlled by the strength of its pile shaft. For the restraint reinforced cement-soil pile, geogrid and carbon fiber cloth are set up in the periphery of the ordinary cement-soil pile to improve the strength of pile shaft. This paper first introduces the load-bearing mechanism and construction technology of new restraint reinforced cement-soil pile; and carries out indoor unconfined compressive strength contrast test through on-site coring based on construction and in-situ static load test.

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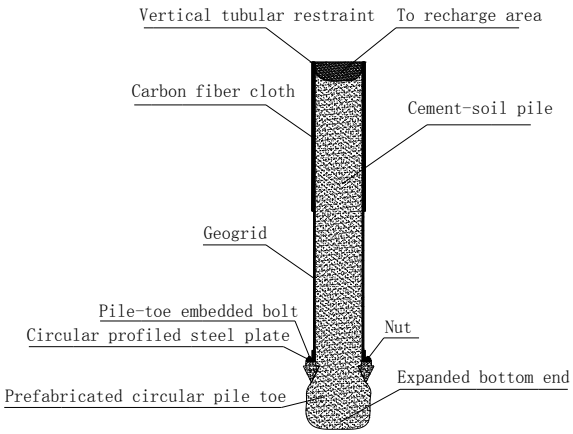

Figure 1. Structure of restraint reinforced cement-soil pile.

II. Load-Bearing Mechanism of Restraint Reinforced Cement-Soil Pile

The restraint reinforced cement-soil pile technology enhances the strength of its pile shaft through the "confining effect" of vertical tubular restraints, to further improve single pile ultimate bearing capacity. The pile shaft of restraint reinforced cement-soil is similar to that of traditional cement-soil mixing pile. Its structure is shown in Fig. 1, and its load-bearing mechanism is as follows: the axial force of the upper part of pile shaft is relatively large, and decreases downwardly along with pile shaft, so geogrids are installed from the top to bottom as restraints, and carbon fiber cloth is fixed on the outside

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of the geogrids from the top to the middle part of pile shaft; the restraint is connected with the tip of prefabricated circular pile, the bottom end of cement mixing pile is expanded, and a recharge area is formed on the top of pile by supplementing cement paste; due to the restriction force by the lateral cylindrical restraints, the compressive strength of pile shaft can be effectively improved, and its bearing capacity is significantly increased. Compared with the traditional cement-soil mixing pile, the restraint reinforced cement-soil pile has a better bearing capacity.

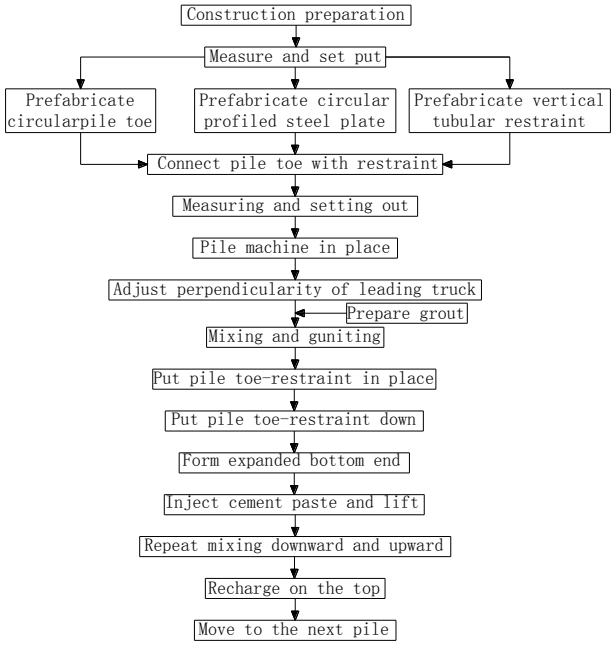

Figure 2. Flowchart of restraint reinforced cement-soil pile construction.

III. Study on the Construction Technology of Restraint Reinforced Cement-Soil Pile

The construction technology processes of the restraint reinforced cement-soil pile are as follows: following the design drawings, connect cylindrical restraints with prefabricated circular pile toe through circular profiled steel plate, and use mixing pile machine with a hinged compression bar to carry out routine mixing and guniting of ordinary cement-soil pile after piling trial and determining parameters; the first guniting volume is controlled to 80% of that of cement mixing pile; then take pile toe-restraints into place, turn on mixing pile machine, use the compression bar to prop up against the inside of prefabricated circular pile toe, drill stem will lead compression bar to press prefabricated circular pile toe-vertical tubular restraints slowly going down into soils; when the prefabricated circular pile toe subsides to specified level, rotate mixing blades to expand the bottom end of pile; when the expanded bottom end is formed, turn on the mortar pump to press cement paste into foundation, inject cement paste while rotating, and elevate the mixing machining at the speed strictly designed and determined in advance, then inject the rest cement paste, and continuously inject cement paste till it reaches the ground. After the completion of the construction of cement mixing pile, supplement some cement paste at the top of pile to form a recharge area on the top. The construction process diagram of restraint reinforced cement-soil pile is shown in Fig. 2.

IV. Field Experimental Study on Restraint Reinforced Cement-Soil Pile

In general, the application of the reinforcement treatment method of restraint reinforced cement-soil pile soft foundation in highway engineering is still in the research and application stage, the design of the restraint reinforced cement-soil pile lacks of mature theory, and the construction experience is very little. In order to facilitate the development of such soft foundation treatment technology, optimize the existing design method, construction technology and test method of restraint reinforced cement-soil pile, a series of field test researches on the restraint reinforced cement-soil piles of a certain project under construction have been conducted, mainly including the following two aspects: the inspection on core-drilling of restraint reinforced cement-soil pile and the strength of samples; research on the load test of restraint reinforced cement-soil pile.

A. Geological Outline of the Testing Area

Test area, located in the alluvial plain on the south bank of Qiantang River, has flat and open terrain, covered by many ponds and rivers. The first layer of the surface is sludge, the second layer is mucky soil, which is in brown color, and in plastic-flow status, mixed with thin layers of silt; the third layer is clay, in brown or grey color and in plastic-flow status, mixed with thin layers of silt, containing humus, shells pieces can be found occasional; the fourth layer is fine sand, in brown color, dense and saturated. The specific physical and mechanical indexes of the soils of test area are shown in Table I.

TABLE I. Physico-Mechanical Indexes of Measured Soil Layers

Soil layer number	Name of soil layer	Soil layer thickness /m	Natural unit weight /(kN m^{-3})	Compression modulus E_S/MPa	C' /kPa	φ' / °
①	Sludge	1.2	15.73	1.87	3.45	1.81
②	Oozy soft clay	8.08	17.69	2.83	6.88	4.86
③	Clay	12.12	18.66	8.90	18	20
④	Fine sand	5.27	19.00	13.5	0	30

B. Coring Test and Indoor Experimental Study on Restraint Reinforced Cement-Soil Pile

The diameters of the restraint reinforced cement-soil piles for test were 500mm, 600mm and 700mm respectively, the designed pile length was 13m, 425# ordinary Portland cement was added with a percentage of 20%, water and cement ratio was 0.5, SJB-1 deep mixer was used in the forming of piles, and guniting method adopted blade guniting. The drilling-core of the above-mentioned restraint reinforced cement-soil piles with

different diameters are shown in Fig. 3, the strength value of the drilled core from each restraint reinforced cement-soil pile 28d was 0.61 to 0.88 MPa.

Figure 3. Drilled cores from restraint reinforced cement-soil pile.

Further, unconfined compressive strength test was conducted in laboratory, the results show that the strength of restraint reinforced cement-soil pile with a diameter of 500mm was increased by 20% compared with the traditional cement-soil pile, that of the restraint reinforced one with a diameter of 600mm by 17%, and that of the restraint reinforced one with a diameter of 700mm by 15%. The specific test comparative data are shown in Table II. The test proved the restraint reinforced cement-soil pile technology significantly enhances the strength of its pile shaft through the "confining effect" of vertical tubular restraints.

TABLE II. CONTRAST OF UNCONFINED COMPRESSIVE STRENGTH OF INDOOR CORE SAMPLE

Pile diameter (mm)	Unconfined compressive strength (kN)	
	Traditional soil cement pile	Restraint reinforced cement-soil pile
500	151.13	180.64
600	218.74	256.12
700	306.85	352.06

C. *Research on the Static Load Test of Restraint Reinforced Cement-Soil Pile*

Single pile bearing capacity is an important indicator to evaluate the treatment effect of new pile foundation. In order to study the treatment effect of soft foundation by restraint reinforced cement-soil pile and its bearing mechanism, static load test was carried out on the restraint reinforced cement-soil piles of a project. The comparative Q-s curve diagrams between the restraint reinforced cement-soil pile and traditional cement-soil pile with a length of 13m and pile diameters of 500mm, 600mm and 700mm respectively are shown in Fig. 4 to Fig. 6. The test results show that the single pile bearing capacity of restraint reinforced cement-soil pile was improved significantly compared to traditional cement-soil pile, and the smaller the pile diameter was, the more significant the "restraint effect" was, the greater the single pile bearing capacity increased, and correspondingly, the smaller the decreased magnitude of the post-construction settlement was.

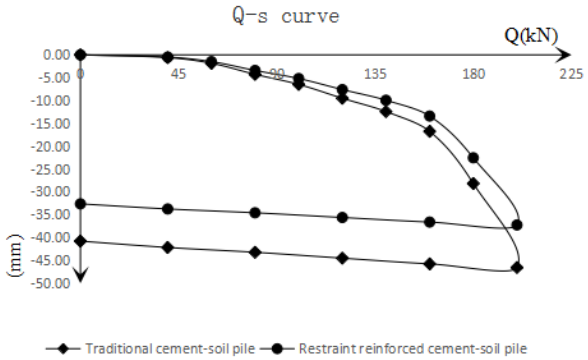

Figure 4. Restraint reinforced cement-soil pile Q-s curve of static load test (pile length of 13m, pile diameter of 500mm).

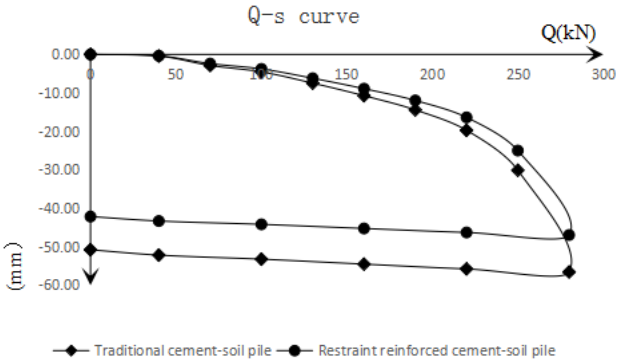

Figure 5. Restraint reinforced cement-soil pile Q-s curve of static load test (pile length of 13m, pile diameter of 600mm).

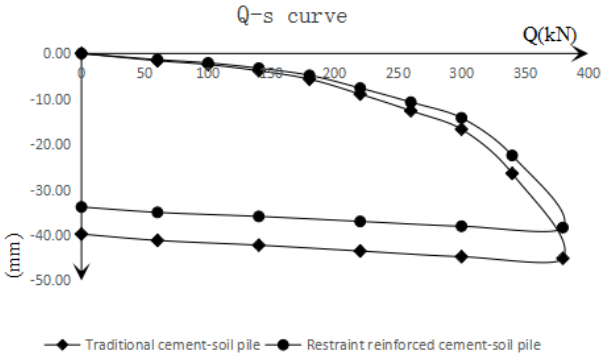

Figure 6. Restraint reinforced cement-soil pile Q-s curve of static load test (pile length of 13m, pile diameter of 700mm).

V. CONCLUSION

This paper carries out indoor unconfined compressive strength contrast test and on-site static load test combined with construction based on the introduction of load-bearing mechanism and construction technology of new restraint reinforced cement-soil pile, and the major conclusions are as follows:

(1) Through on-site coring and static load test, it has been proved that the construction pile shaft of new restraint reinforced cement-soil pile could meet the design requirements in terms of compressive strength and ultimate bearing capacity.

(2) The unconfined compressive strength of core samples from the piles which were installed with geogrids and carbon fiber cloth is 15% to 20% higher than that of ordinary core samples, and the increased compressive strength value of core samples wrapped by carbon fiber cloth is greater than that of geogrids.

(3) According to the static load test comparative study on ordinary cement-soil pile and restraint reinforced cement-soil pile with the same length and diameter, the ultimate bearing capacity of the restraint reinforced cement-soil pile is increased by 10% to 15% under the same working conditions, the increase ratio of the ultimate bearing capacity of small-diameter pile is greater than that of large-diameter pile; the settlement value of the restraint reinforced cement-soil pile is less than ordinary cement-soil pile under the same load.

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