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The Application of Soft Foundation Treatment of Cement-soil Mixing Pile in Zhangzhuang Pumping Station

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Abstract. The text introduces the process of comparison and selection of foundation treatment scheme, combining with example of foundation treatment in Zhangzhuang pumping station, and elaborates the detailed design steps and calculation way of cement-soil mixing pile,the economy benefits is very significant through settlement check, composite static load test, static load test of single pile, the bearing capacity of composite foundation meets the design demand.

Keywords: foundation treatment; Cement-soil Mixing Pile; bearing capacity.

1. Project Introduction

The project of Zhangzhuang pumping station is located in Qianxian county Puyang City Henan Province, on the Yellow River embankment of south part of Huangzha, the lower reaches of Jindi River, east to Yellow River, south to Bei Zhangzhuang Village Wuba country Qiantai County, and it is the key project of water logging control, removing alkali in the Delta of lower reaches of Jindi River, and also the only pumping project the flood of Jindi River goes into Yellow River when the Huanghe is backwatering. In order to arrive the requirement of flood discharge, the pumping station should be expanded, and after demonstration, the pumping station was built with drainage capacity 40m3/s, and the length is 22.90m, the width is 12.00m, the height is 25.93m, and it is located right side of old pumping station.

2. Engineering geology

According to the survey report provided by geological specialty, the stratum of pumping station is fourth new tongchong, flood deposit（Q4al+pl）, the layer thickness more than 22.0m, and it can be classified four layers: The first layer is brown silty clay, the thickness is around 3.0-3.5m, humidity, and it is malleable, there is 0.5m the plough layer on the surface. The second layer is mucky clay, gray-gray black, humid, soft plastic, smooth section, the thickness around 10.0m, the third layer is gravelly clay, greyish white, gray black to gray-green, humid, soft plastic, gravel,the content is around 10%-30%, the particle size is around 0.5-1.0cm, the ingredient of mother rock is mainly sandstone and dolomite, the sandy content is rather high in some part, and the thickness is around 3.0-4.0m. The fourth layer is gravel layer, light gray, and the particle size is around 1.0-4.0cm, including muddy, the content is around 10%-15%.

The location of pumping station is flat and open, no landslide, no collapse, no structural fracture zone and other bad geological processes, its geological structure is simple, the hydrogeological conditions is easy, and it is pore water in loose rocks, with depth of water around 0.2-0.3m;the crack degree of earthquake is Ⅷ, and it is near earthquake area; the types of building site is two level (medium complicated site).

According to the building design and calculation of level elevation of pumping station, new pumping station is located in the layer of muddy clay.It is soft plastic shape, and the bearing capacity is low, and nature foundation is difficult to meet bearing layer of building, and the foundation must be treated in the building site. The physical mechanics indicator of pumping station see the table 1, table 2.

Table 1 The table of recommended values of physical mechanics of pumping station

Layer Number	Lithology	Allowable carrying capacity [R] kPa	Compression modulus Es MPa	Shearing strength		permeability coefficient	Recommended slope ratio	Remarks
				Internal friction angle (ϕ -degree)	Cohesion C (kPa)	K cm/s	temporary	
Q4al+pl Q4al+PL	silty clay		4 ∫ 5	10 ∫ 13	6 ∫ 9	4.5×10-6 ∫ 5.0×10-5	1:1.25 ∫ 1:1.5	It was recommended the temporary support measure should be taken when the side slope was digged.
	Muddy clay	80 ∫ 90	2 ∫ 3	2 ∫ 5	5 ∫ 7	3.0×10-6 ∫ 5.0×10-6	1:1.5 ∫ 1:1.75	

Table 2 The table of recommended values of physical mechanics of pumping station (cement soil mixed piles)

Stratum code	Main lithology	Natural gravity (kN/m^3)	The characteristic value of pile side friction resistance (kPa)	The extreme resistance characteristic value (kPa)
Q_4^{al}	muddy clay	18.5	12~14	
	Gravelly clay	19.9	35~40	
	Gravel layer			210~220

3. The comparison and selection of foundation treatment plan

According the engineering geological condition and nature, the foundation treatment method of Zhangzhuang pumping station has cement soil mixed piles or high pressure jet grouting pile. Both of them are belong to chemical reinforcement methods of soft foundation, but there are some difference on working principle, construction technology, pile forming machinery, bearing capacity of single pile and etc.

The cement-soil mixing method is using cement and other material as curing agent, making the soft soil and curing agent (slurry or powder) forced mixed in the deep place of foundation through mixing machine, and the soft soil was made into cement stabilized soil with integration, water stability and some strength, and improve the strength of foundation and increase deformation modulus.

The high pressure jet grouting is using the rig with grouting pipe to predetermined location of solum, and the reinforcement slurry was injected from the spray nozzle with 20Mpa high pressure to impact the solum, and the soil particle in the solum was mixed with the slurry with the impact force, centrifugal force, gravity. After the slurry solidified, the cylinder was formed in the soil.Besides, the slurry squeezed the soil around the pile, and making compaction effect.

As per the real condition of this project, the comparison and selection was made for two schemes from the degree of foundation reinforcement, construction technology, quality control, engineering cost and etc., and the result can be seen table 3.

Table 3 The comparison and selection table of foundation treatment scheme

Projects	Program 1: cement-soil mixing pile	Program 2: High pressure jet grouting

Foundation reinforcement strength	Under same water-cement ratio, pile length, pile diameter, soil condition, it is inferior to program 2.	High strength of foundation reinforcement
Construction technology	Easy construction, huge pile forming machinery, and fast pile-forming, high efficiency, low construction noise, non-pollution, no vibration	Easy construction,portable equipment, low construction noise, low vibration
Quality Control	Easy to control	Easy to control
Project unit price	54 yuan/meter	700 yuan/meter
Advantages	Low cost	High strength of foundation reinforcement
Disadvantage	Under the same conditions, the strength of foundation reinforcement is inferior to Program 2	High cost
Conclusion	recommended	Not recommended

Through above general comparison, considering the new built pumping station with small base stress, the foundation strength is not too high,the program 1 can meet the requirement of foundation bearing capacity and transformation, and the effect of saving engineering investment is obvious, so the cement soil mixed piles was choosed as foundation treatment way.

4. Scheme design

The normal design step of cement soil mixed piles: 1) The maximum base stress was calculated according to the pump station, and set the eigenvalue of bearing capacity of composite foundation after the foundation treatment. 2) The piles diameter,piles length and pile spacing was set initially according to the relevant survey report of site engineering geology and considering the construction condition and machinery. 3) Calculate the eigenvalue of bearing capacity of single pile. 4) Calculate the eigenvalue of bearing capacity of composite foundation. 5) Deformation calculation. 6) Determine the various control indicators of cement soil mixed piles according to the real demand of the projects.

4.1 Preliminary Plan

The project proposed to use the mixing pile with diameter 0.6m, and the pile length 10.5-13.3m, stretch into the sand and gravel layer not less 1.0m. The strengthening agent used 42.5 common portland cement, cement content is 15%, cement paste water-cement ratio is 0.6. area replacement rate is around 20%,proposed pile spacing 1.2m,equilateral triangle arrangement. The bearing capacity of treated formed composite foundation not less 160kpa.

4.2 Calculate the eigenvalue of the bearing capacity of a single pile

According to the regulation of 7.3.3 in JGJ79-2012 “the handling technical specification of building foundation”,the eigenvalue of bearing capacity of single pile should be determined by static load test on site. It can be estimated by formula 1, and it should be meet the requirement of formula 2 ,and the carrying capacity of single pile is not less the one provided by resistance of soil around pile and pile tip soil, and take the minimum of both of them.

$$R_a = u_p \sum_{i=1}^{n} q_{si} l_{pi} + \alpha_p q_p A_p \qquad (1)$$

$$R_a = \eta f_{cu} A_p \quad (2)$$

Among of them, R_a is the eigenvalue of carrying capacity of vertical single pile, kN; f_{cu} is is the average value of 90d cube strength indoor reinforced soil test block same as cement soil ratio of mixing piles, and the cube with side length 70.7mm under standard curing conditions, kPa; η is strength reduction factor of single pile, and the dry method can be 0.2-0.25, the humidity method can be 0.25; A_p is the sectional area, m2 ; u_p is the pile's perimeter, m; n is the number of soil layers in the range of pile length; q_{si} is the eigenvalue of lateral resistance the i layer in pile perimeter; l_{pi} is the thickness of i layer soil in the range of pile perimeter, m; α_p is the resistance coefficient exertion of pile tips, and the cement mixed pile is 0.4-0.6; q_p is the eigenvalue of carrying capacity of untreated pile tip foundation.

According to formula (1), it is calculated that R_a = 250.0kN.

4.3 Calculate the bearing capacity of composite foundations

According to the regulation 7.1.5 JGJ79-2012 in "the handling technical specification of building foundation", the eigenvalue of carrying capacity of composite foundation should be determined by static load test of composite foundation or using reinforcement static load test and the eigenvalue of carrying capacity of surrounding solid, when it is proposed initially, it can be calculated predictably as per formula (3) .

$$f_{spk} = \lambda m \frac{R_a}{A_P} + \beta(1-m) f_{sk} \quad (3)$$

Among them, it f_{spk} is the eigenvalue of the bearing capacity of the composite foundation, kPa; λ is the coefficient of exertion of bearing capacity of a single pile; m is the area replacement rate; β is the coefficient of exertion of soil bearing capacity between piles; f_{sk} is the eigenvalue of soil bearing capacity between piles after treatment, kPa.

According to formula (3), it can be calculated that f_{spk} =212.8 kPa > 160 kPa. Thus, it can be determined that the foundation treatment design can meet the requirement of the carrying capacity of composite foundation not less 160kpa.

4.4 Deformation calculation

The deformation of mixing pile composite foundation includes compression deformation of composite solid layer S1 and the compression deformation of untreated solid layer under the end of pile S2 , the former can be 10-30mm as per load, pile length, the pile strength and etc, and the compression modulus deformation value in this project S1 =30mm.The deformation of untreated soil layer under pile tip will calculate with layer summation method, according to the clause 5.3.5 GB50007-2011 in "the handling technical specification of building foundation", it is calculated by the design software of Lizhengyan foundation, and it is S2 =60.98m, the total settlement S2=S1+S2=91mm. According to the regulation of 5.3.4 in"the handling technical specification of building foundation", the allowable settlement of building foundation is 200mm, because it conforms to the regulation requirement.

4.5 Determine control indicators of cement-soil mixing piles

The indoor proportioning test of treatment foundation should be made before the construction. The various control indicators of mixing piles should be tested as per initial proposed treatment program. The curing agent, additive and its content, the strength parameters of cemented soil in different age, different ratio.

The strength of cemented soil f_{cu90} is the average value of 90d cube strength indoor reinforced soil test block same as cement soil ratio of mixing piles, and the cube with side length 70.7mm under standard curing conditions. It is important data of onsite testing and quality inspection of cement mixing piles. This project makes back-calculation Ra =184.2kN as per the formula (3), assumed f_{cu90}=160kPa, and as per formula (2), back-calculation f_{cu90}=2.6MPa. According to the real demand of foundation carrying capacity, the main control indicator of cement soil mixed piles in the construction of composite foundation was clarified as follows:

(1) The strength grade of ordinary portland cement is 42.5.

(2) The cement content is not less than 15%.

(3) Water-ash ratio 0.5 to 0.6.

(4) The eigenvalue of the vertical bearing capacity of a single pile R_a = 184.2kN.

(5) The eigenvalue of composite foundation bearing capacity f_{spk} = 160 kPa.

(6) f_{cu90} Not less than 2.60MPa.

$$f_{cu90} = （2.37\sim3.73） f_{cu7}$$
$$f_{cu90} = （1.73\sim2.82） f_{cu14}$$
$$f_{cu90} = （1.43\sim1.80） f_{cu28}$$

f_{cu7} f_{cu14} f_{cu28} f_{cu90} in above formula is the compressive strength of cement soil in the age of 7d, 14d,28d,90d. The detailed cement content,water-cement ratio and etc.are determined by indoor ratio test and process test piles.

5. Quality inspection

The cement mixing foundation piles of new built pumping station was formed after 28 days later, the carrying capacity testing of composite foundation was made by professional engineering testing agency, including the static load test of composite foundation and single pile. Form the static load test of composite foundation, the design value of carrying capacity of cement mixing pile composite foundation is f_{spk} =160kPa, the loading capacity should be not less two times of eigenvalue of carrying capacity of composite foundation in the design requirement, it is f_{spk} =320kPa， the carrying capacity of composite foundation of three piles was tested as 329 kPa on site， it is conformed to the design requirement.It can be known from the testing report of compressive static load of vertical single pile, the design value of carrying capacity vertically of cement soil mixed piles is R_a = 184.2kN,the load capacity should be not less 2 times of the eigenvalue of carrying capacity of single pile, it is 368.4kN, the carrying capacity of vertical foundation of single pile is 371 kPa， it is more than design request, and the total settlement is not more than 40mm,and it conforms to the specification requirement.

6. Conclusion

It is proved through the practice that the cement mixed piles was used to treat the soft foundation in the project of pumping station, and it not only conforms to the requirement for carrying capacity, settlement deformation, but also the construction is easy, and cost economy, and it is one foundation treatment method worth promoting.

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