Multiple Compound Foundation Bearing Characteristics

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Abstract. To study the bearing characteristics of composite foundation with long rigid piles and short flexible piles, the light dynamic penetration and the static loading test are used base on comprehensive testing and analysis of soft soil characteristics, and combining with the treatment design parameters of soft soil with long rigid piles and short flexible piles. The results show that it is feasible that using rigid piles with 400mm diameter and 15m length and flexible piles with 550mm diameter and 6m length to deal with soft soil mainly composed of flow plastic muddy clay. The composite foundation bearing capacity can reach 100kPa, which meet the needs of the corresponding project.

Introduction

Soft soil has the characteristics of high natural water content, high compressibility and low bearing capacity, which cannot meet the requirements of the natural foundation. So it needs to be handled to improve its load-bearing. When using a variety of methods to jointly deal with the same soft ground, it has become a multi-composite foundation, such as long and short piles composite foundation, rigid and flexible pile composite foundation[1]. In fact, as early as the 1990s, people had the design idea of composite foundation and have made some research results. In 2001, Shi Xuguang was studied the performance of composite foundation with rigid-flexible composite piles by 3D elastic analysis[2]. In 2003, Guo Xinshen and Gong Xiaonan analyzed the performance of long-short pile composite foundation and explored the design method of long-short pile composite foundation and explored the design calculation method of long and short pile composite foundation by using the finite element method[3]. In 2004, Shang Xinsheng discusses the working mechanism of multi-component composite foundation and its optimization design techniques[4]. In 2005, Lin Wenqiang and Xia Xuyang studied the stress-sharing of soft soil pile with rigid-flexible-pile composite foundation by testing[5]. In 2012, Kong Dezhi and Lei Yanjie studied the relationship between load and settlement of rigid-flexible long-short pile composite foundation by model test[6]. However, most of the above research focuses on model tests or numerical simulation analysis, which does not involve the practical engineering applications of the length of rigid-flexible composite foundation. We rely on the Long-rigid piles and short-flexible piles are used to comprehensively treat soft-soil foundation projects of Ningbo Beilun port warehouse to test the composite foundation performance, which provide reference and reference for similar practical projects.

Engineering geological conditions

Ningbo Beilun port warehouse locate in northeast coastal region Beilun District, Ningbo City, Zhejiang Province. Project site is a coastal seaside plain. The ground level of the site is generally 1.76 ~ 3.78m.

Site stratum structure

Site strata from top to bottom are as follows:

①-1 Plain fill, it made of gravel and clay, the gravel particles are different sizes. The structure of the soil is loose. The soil is uneven, which distribution local area in engineering site. The thickness is 0.4-1.5m.

①-2 Silty clay, it is plastic state and its compressibility is medium compression to high compression. The soil is uneven, which distribution all engineering site. The thickness is 0.6-2.1m.

② Muddy clay, it is flow plastic state and its compressibility is high compression. The soil is uneven, which distribution all engineering site. The thickness is 11.6-17.4m.

③ Silty clay, it is soft plastic to plastic state and its compressibility is medium compression. The soil is uneven, which distribution all engineering site. The thickness is 8.1-25.1m.

④ Silty clay, it is soft plastic state and its compressibility is medium compression. The soil is uneven, which misses in local area. The thickness is 3.0-14.1m.

⑤ Silty clay, it is flow plastic state and its compressibility is medium compression to low compression. The soil is uneven, which distribution all engineering site. There is a gravel in the soil, The thickness is more than 7.0m.

Physical and mechanical properties

The main physical and mechanical properties of each stratum in the site as shown in table 1.

Table 1 Statistical table of physical and mechanical properties

Stratum	Statistical indicators	Water content ω_0 (%)	Porosity ratio e	Cohesion C (kPa)	Internal friction angle Φ (°)	Compression modulus E_{s1-2}
Silty clay ①-2	Range value	24.6-42.0	0.692-1.177	16.1-38.8	12.3-17.1	2.91-6.80
	average value	31.0	0.869	26.8	14.6	4.83
	Number of samples	53	53	50	50	53
Muddy clay ②	Range value	36.6-63.3	1.027-1.748	8.0-16.4	7.0-12.9	1.72-4.00
	average value	45.9	1.283	11.6	9.1	2.51
	Number of samples	261	261	242	242	187
Silty clay ③	Range value	21.0-40.6	0.598-1.121	17.3-58.0	12.6-19.9	3.95-8.88
	average value	29.3	0.821	31.6	15.6	5.53
	Number of samples	312	312	312	312	128
Silty clay ④	Range value	22.7-45.1	0.664-1.276	15.9-42.6	12.2-20.7	3.28-8.76
	average value	30.8	0.865	27.0	15.8	5.46
	Number of samples	103	103	99	99	103
Silty clay ⑤	Range value	21.4-43.9	0.611-1.257	21.0-57.4	13.7-18.7	3.80-16.60
	average value	28.6	0.805	40.6	17.2	7.95
	Number of samples	182	182	167	167	182

Hydrogeological conditions

The site groundwater is mainly pore water, which mainly present in Plain fill (①-1) and Silty clay (① -2). The remaining of stratums are relative aquifers, which permeability is poor. The water content is poor. The water volume of the weak confined water under relative aquifers is not large. The dynamic change of water level is not obvious. The soil thickness above the weak confined water is large. The weak confined water has less impact on the project.

The site groundwater depth is 0.40-1.20m, which altitude elevation is 1.81- -2.40m. The main supply sources of site pore water are atmospheric precipitation and nearby surface water. The groundwater level during the wet period is higher and the groundwater level during the dry season is lower. The groundwater level change range is 0.50-1.00m.

Natural foundation bearing capacity

The bearing capacity of each stratum in the site, the stratum friction eigenvalues around pile (q_{sa}) and the stratum bearing capacity at the pile end (q_{pa}) as shown in table 2.

Table 2 The bearing capacity of each stratum

Stratum	Bearing capacity	Prefabricated concrete pipe pile		Drilling piles		Cement and soil mixing pile	Uplift factor
	f_{ak} kPa	q_{sia} kPa	q_{pa} kPa	q_{sia} kPa	q_{pa} kPa	f kPa	λ_i
Silty clay ①-2	60	6		5		12	0.65
Muddy clay ②	30	4		3		7	0.50
Silty clay ③	80	8	200	7	150	22	0.65
Silty clay ④	70	7	150	6	120		0.65
Silty clay ⑤	90	9	220	8	160		0.70

Multiple compound foundations of long rigid piles and short flexible piles

The processing area is the planned warehouse area. Warehouse estimated maximum load is approximately 400kN/column, which requires that the composite foundation bearing capacity (f_{spk}) after reinforcement in the warehouse area is more than 100kPa. The maximum ground load is 50kN/m², which allowable settlement is less than 30mm. In order to achieve the above capacity and settlement requirements, long rigid piles and short flexible piles are used to deal with the soft ground of the site. Details are as follows:

The long rigid piles are 400mm diameter prestressed concrete pipe pile, which length is 15m. The pile spacing is 3600mm (N-S) ×3400mm (E-W).The short flexible piles are cement and soil mixing piles, which length is 6m with 550mm diameter. The pile spacing is 1800mm (N-S) ×1700mm (E-W), which will be cancelled If it overlaps with the position of the long pile. The cement content of the short flexible piles is not less than 15%.

Composite foundation bearing capacity inspect

Light Cone Penetration Test

The light cone penetration test are implemented at 27 points (avoid rigid piles) in composite foundation which after being processed for 3 days. The results of the lightweight penetration test are shown in Table 3.

The lightweight penetration test results corresponding to the bearing capacity of the foundation can be calculated using formula (1).

$$R= （0.8×N_{10}-2）×9.8 \qquad\qquad (1)$$

R- the bearing capacity of the foundation, N_{10}-hammer number of light cone penetration test. The calculation results are shown in Table 3.

Table 3 Light penetrating test results correspond to foundation bearing capacity（kPa）

Depth (m)	0.0-0.3	0.5-0.8	1.0-1.3	1.5-1.8	2.0-2.3	2.5-2.8	3.0-3.3	3.5-3.8
N_{10}	18	18	19	19	20	20	22	25
Bearing capacity	122	122	129	129	137	137	153	176

Static load test

The static load test are implemented at 4 points (avoid rigid piles) in composite foundation which after being processed for 30 days. The square load plate is 1m×1m. The test grading loading is 20 kPa. The first stage load is 40 kPa and the last stage load is 200 kPa.
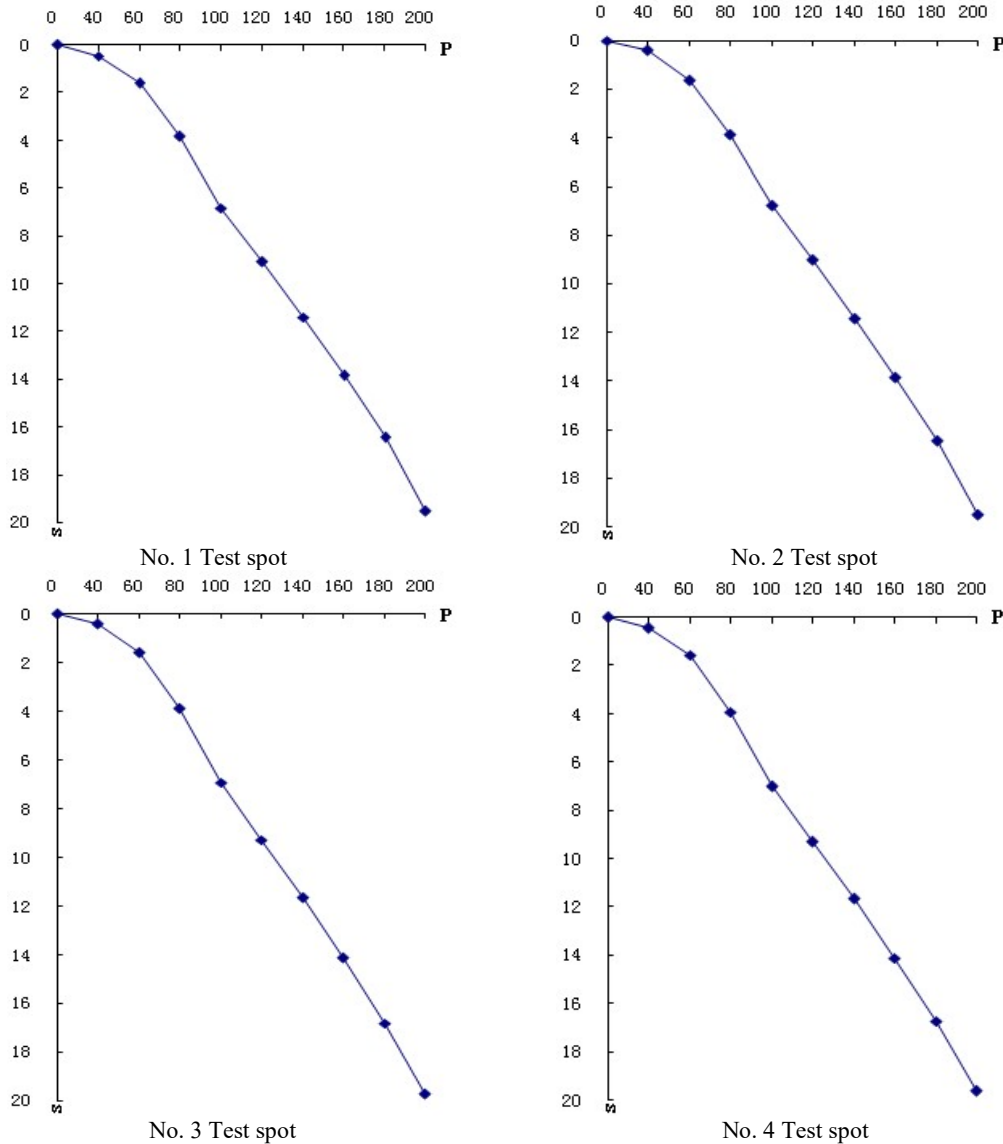
The results of the static load test are shown as figure 1.

No. 1 Test spot

No. 2 Test spot

No. 3 Test spot

No. 4 Test spot

Fig. 1 Composite ground static load test results

Conclusions

(1) It is feasible for using long- rigid and short-flexible piles to deal with soft ground composed mainly of muddy clays with plastic flow state and silty clays with soft plastics and plastics state.
(2) The long piles are rigid piles with 400mm diameter, which length is 15m. The pile spacing is 3600mm (N-S) ×3400mm (E-W).The short piles are flexible piles with cement and soil mixing piles, which length is 6m with 550mm diameter. The pile spacing is 1800mm (N-S) ×1700mm (E-W)
(3) The hammer number of light cone penetration test is 18 to 25, which corresponding bearing capacity is 120 Kpa to 170 Kpa
(4)The static load test results show that the bearing capacity is about 110 Kpa, which is basically consistent with light cone penetration test results. It meets the requirements of the corresponding project

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