Field test research for optimization design under condition of complex Soil Stratum

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Abstract. It is highly important to choose suitable of the foundation in underground engineering. With the engineering, the foundation is made of gravelly soil, which distributed discontinuity and had bad uniformity. Drilling method, dynamic sounding method and deep plate loading test were applied, combined with previous investigation results, geotechnical parameters were defined and optimization designed. Upon the result of field tests, some control measures were made to improve the condition of foundation .District control measures were suggested to be made. The silt clay layer④under the basement of 1# building's east A- area, pile pier was suggested to be set up, the pier's bottom should be set in cement gravel⑤strata, and should made of C15 plain concrete, raft foundation should also be applied. In other areas, soil upon cement gravel⑤strata were suggested to be dig out, and replaced with rubble concrete to the level of foundations bottom, also should applied raft foundation. Foundation strength and deformation were up to the mustard according to the result of numerical simulation. The optimization design not only supplied the technical demand well, but also reduced a lot of construction schedule and save cost. This study supplied some theory and technical guides to closely engineering.

1. Introduction

With the improvement of the economy level and scientific technology in China, underground space projects are developing quickly. Fully considering the structural reliability of underground space, easy construction, economic rationality and other factors, foundation scheme optimization choose become a important problem in the engineering. At present, most of the foundation scheme is diversification and integration in the project [1-2].

In view of the foundation scheme selection and optimization, scholars at home and foreign carried on the thorough research and engineering practice [3-5].Zhou feng et al [6] has carried on the numerical analysis, which based on the analysis of the experimental results of natural foundation with variable stiffness cushion working characteristic. Zhao Ming-hua et al [7] based on the similarity theory, designed and completed a large geotechnical reinforced cushion, sand well, medium material pile and flexible pile of nine groups of model test of composite foundation, which were analyzed in reinforcement effect. Liu Jin-li et al [8], in considering the upper structure, raft, the interaction of pile and soil, and the characteristics of the work, the variable stiffness leveling design was put forward. Gong Xiao-nan [9] putted forward the idea of composite foundation in the generalized composite foundation theory problems and settlement control design. Chen Long-zhu et al [10], made finite element analysis about reinforced concrete raft of the variable stiffness composite foundation treatment. Zhang hua et al [11], on soil cement mixing composite foundation reinforcement scheme optimization of finite element analysis also got similar results.

2. Building structure and formation characteristics

2.1 Requirements of building structure

A section of 1# building in a project, which is shear wall structure and safety class II, has 32 layers on the ground floor, column spacing 3 m, and the plane size 73.7 m × 16.5 m. The building has 3 basements, and base elevation is 40.00 m. Base load of the building is 450 KN/m^2,and the base reaction force is 480kPa of standard combination, which is 440kPa of quasi-permanent combination. The elevation of underground garage foundation is 39.5 m, which mostly in the ③ layer of silty clay and $③_1$ layer of gravel soil, partial in the ⑤ layer of cemented gravel layer, and $③_1$ layer of gravel soil has complexity and inhomogeneity. In order to make a more stable foundation evenly, reducing uneven settlement, foundation program optimization need to be done.

2.2 Distribution of gravel soil layer

According to geotechnical investigation report shows that gravel soil layer is described as: gray, wet, medium density, limestone rock, content of 40%~60%, φ1~5 cm, greater than 10 cm of the largest, poor roundness, hypo-edge angle and mild round. Partial calcareous conglomerates cemented thin, hard, and partial lens-shaped profile. The thickness is 0.90~11.60 m, average 4.40 m.

Analysis of existing reports and coring site shows (Figure1) that gravel soil has the characteristics of relatively poor uniformity, distribution not continuous and so on.

Fig. 1 Field coring test

3. Field test for optimal design of foundation.

In order to further clarify physical and mechanical parameters of the $③_1$ layer soil under 1# floor, field test was needed. For the characteristics of distribution of gravelly soil, adopted drilling exploration, static cone, bearing capacity test to optimal design the plan which using layer soil as foundation bearing layer. In-situ test, included 3 drilling exploration, 4 heavy dynamic sounding test and 3 bearing capacity.

3.1 Field exploration experiment

Based the arrangement, combined with the site conditions, arranged 3 drilling hole , depths were 19.0 m,15.0 m and 15.0 m, using XY-100 hydraulic robot rotary drill, above the ground water table drilling without water, under the ground water table hole wall of anchor is sustained by slurry, diameter of the hole must greater than 110 mm.

3.2 In-situ severe cone dynamic penetration test

Weight of the heavy hammer was 63.5 kg and falling distances was 76 cm, diameter of the drill pipe was 42 mm, experiments in detritus soil, cleared the hole before test, severe cone dynamic penetration test in one hole each time, recorded the blow counts N63.5 each time when injected 10 cm among continuously injection 50 cm.(figure 2)

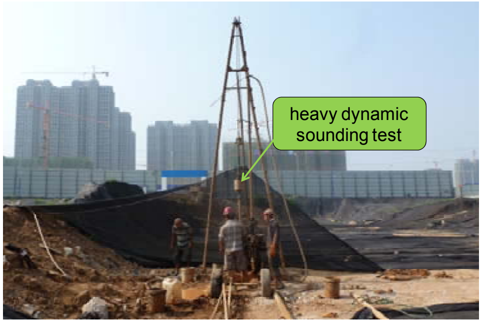

Fig. 2 Severe cone dynamic penetration test

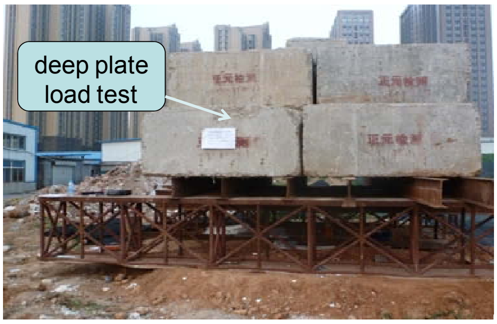

Fig. 3 Deep plate load test

3.3 In-situ deep plate load test

Adopted bearing plate whose diameters was 800 mm, the top of test pit was 1000 mm and bottom was 900 mm, should avoid disturbed the bottom soil, maintain its structure and natural water content, lay sand cushion not exceeding 20 mm under the bearing plate, multi-stage loading gave by reaction frame providing counterforce, measured displacement and loads(figure 3).3 in-situ SZ1,SZ2 and SZ3 deep plate load test was implemented, depths were 6.5 m、7.0 m、7.5 m.

4. Optimization design of foundation

4.1 Analysis of the field test results

During field investigation, there were 3 drilling holes, and 4 group heavy dynamic penetration tests and 3 group deep plate load tests had been performed on this site from 07.01.2014 to 07.28.2014, for almost a month. The stratigraphic distribution of the drilling holes and results of the heavy dynamic penetration tests were summarized (Table 1). P-S curves of deep plate loading tests of SZ1, SZ2, SZ3 were gained (Fig 4).

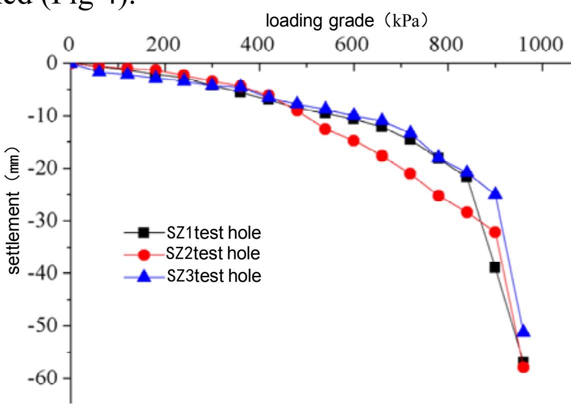

Fig. 4 The P-S curve of in-situ deep plate load test

Table 1 Stratigraphic distribution of the drilling holes and results of the heavy dynamic penetration tests

	Strata thickness（m）			Results of the heavy dynamic penetration test (deep – N_{120})		
	BZ1	BZ2	BZ3	BZ1	BZ2	BZ3
① Miscellaneous fill	-	2.30	2.50	-	-	-
② Loessial silty clay	4.00	4.40	1.00	-	-	-
③ Silty clay	3.20	1.20	1.90	-	-	-
$③_1$ Gravel soil	-	1.30	5.10	-	9.00—26	8.10—11 9.10—13 10.00—15
④ Silty clay	-	4.20	3.00	-	-	-
⑤ Cemented gravel	5.40	1.60	1.50	-	-	-
$⑤_1$ Gravel soil	3.40		-	-	-	-
⑥ Completely weathered diorite	3.0		-	-	-	-

According to the field test results, the measured bearing capacity characteristic values for the 3 group deep plat load tests in ③$_1$ gravel soil are 437.5kPa, 420kPa and 420kPa respectively. Because the rang of bearing capacity characteristic values is less than 30% of its average, the bearing capacity characteristic measured value is 425.8kPa in A-step of Building 1#.

4.2 Deformation modulus and foundation modulus

The deformation modulus of soil should be calculated according to the initial straight line segment of P-S curve and the elastic theory of homogeneous isotropic semi infinite elastic medium. The deformation modulus of the deep plate load tests can be calculated from the following formula:

$$E_0 = \omega \frac{pd}{s} \qquad (1)$$

The foundation modulus can be obtained by the Slope of straight line segment in P-S curve, according to the following formula:

$$K_v = \frac{p}{s} \qquad (2)$$

According to the field test results, the deformation modulus and the foundation modulus of the ③$_1$ gravel soil are 21.69MPa and 61.62×10^6Pa/m respectively.

4.3 Analysis of soft substratum

When there is soft substratum in the range of soil stressed zone，according to Code for design of building foundation(GB50007—2011)Article 5.2.7 calculation formula：

$$p_z + p_{cz} \le f_{az} \qquad (3)$$

To rectangular foundation:

$$p_z = \frac{lb(p_k - p_c)}{(b + 2z\tan\theta)(l + 2z\tan\theta)} \qquad (4)$$

$$p_{cz} = \gamma_0 d + \gamma z \qquad (5)$$

$$f_{az} = f_{ak} + \eta_d \gamma_m (d - 0.5) \qquad (6)$$

According to the investigation report，Using the data of Drilling 10# to calculate：

l=75.10m，b=17.90m，p_k=510kPa，p_c=60kPa，z=40-30=10m，z/b=10/17.9=0.559，E_{s1}/E_{s2}=50/30=1.667，θ=21.3

$$p_z + p_{cz} = 480.6kPa \qquad f_{az} = f_{ak} + \eta_d \gamma_m (d - 0.5) = 867\ kPa$$

By the calculation analysis shows that soft substratum meet the requirements.

4.4 Foundation bearing capacity calculation

When the width of the rectangular foundation of the proposed building is more than 3 m，or embedment depth is greater than 0.5 m， the characteristic value of sub grade bearing capacity determined through the load test or other in-situ test, experience and other methods，need to be adopted under type fixed：

$$f_a = f_{ak} + \eta_b \gamma (b - 3) + \eta_d \gamma_w (d - 0.5) \qquad (7)$$

The type of symbol with the formula 1.

By the calculation:

$$f_a = f_{ak} + \eta_b \gamma (b - 3) + \eta_d \gamma_w (d - 0.5)$$
$$= 999.50(kPa)$$

The requirements of the base reaction (standard forming) is 480kPa. So the foundation bearing capacity satisfy the design requirements.

4.5 settlement calculation

According to Technical code for tall building raft foundations and box foundations(JGJ 6-2011)Settlement calculation formula is as follows.

$$s = p_k b \eta \sum_{i=1}^{n} \frac{\delta_i - \delta_{i-1}}{E_{0i}} \qquad (8)$$

The suitable formula for settlement calculation depth z_n is as follows.

$$z_n = (z_m + \xi b)\beta \quad (9)$$

Table 2 The calculation of foundation settlement

number of holes	soil layer	settlement（mm）
10	③$_1$gravel soillayer ⑤unconsolidated gravel bed	74.77
13	cyclopean concrete by changing and filling ⑤unconsolidated gravel bed	51.59
19	cyclopean concrete by changing and filling ⑤unconsolidated gravel bed	40.41
22	cyclopean concrete by changing and filling ⑤unconsolidated gravel bed	47.67

Through calculating that z_n is 7.6 m and settlements is 40.41~74.77 mm. They all meet the requirements.

5. Summary

（1）Due to distributed discontinuity and had bad uniformity, drilling method, dynamic sounding method and deep plate loading test were applied, combined with previous investigation results, geotechnical parameters were defined and optimization designed.

（2）Under the analysis of field test results, the foundation weak layer meet the requirements, but as a foundation bearing layer for gravel soils need for processing. Upon the result of field tests, some control measures were made to improve the condition of foundation .District control measures were suggested to be made.

（3）The silt clay layer④ under the basement of 1# buildings east A- area, pile pier was suggested to be set up, the piers bottom should be set in cement gravel⑤ strata, and should made of C15 plain concrete, raft foundation should also be applied. In other areas, soil upon cement gravel⑤ strata were suggested to be dig out, and replaced with rubble concrete to the level of foundations bottom, also should applied raft foundation.

（4） The optimization design take comprehensive test means not only supplied the technical demand well, but also reduced a lot of construction schedule and save cost. This study supplied some theory and technical guides to closely engineering.

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