Pile Foundation Design and Analysis of Teaching Building in A High School

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Abstract. The foundation design should adhere to the principles of adapting measures to local conditions, using local materials, protecting the environment and saving resources. Based on the geotechnical engineering survey data, the design should be carried out by comprehensively considering the factors such as structure type, material situation and construction conditions. The pile foundation design is adopted in this project, which includes the determination of pile end bearing layer and pile length, the determination of vertical bearing capacity of single pile, the calculation of pile number and pile layout form, the checking calculation of pile foundation bearing capacity and settlement, the design and checking calculation of pile body structure, the design and checking calculation of pile cap. Until all requirements of the specification are met.

1. INTRODUCTION
The design object is the No.1 teaching building of Huaiyang No.1 High School, which is located on the east side of Xi Huang Avenue. The No.1 teaching building covers an area of 80 square meters, a construction area of 4,320 square meters and a maximum height of 19.2 meters. According to the engineering geological survey report, the lithology of the soil layers is shown in Table 1, in which the first soil layer is miscellaneous fill with thickness of about 0.9 meters and followed by silty clay, silty soil, silty sand, silty soil, and silty sand.

\[ q_{pa} \] is the characteristic value of pile tip resistance, \( q_{sia} \) is the characteristic value of pile side resistance, \( l_i \) is the thickness of soil layer. The engineering geological properties are shown in Table 2, in which the \( f_{ak} \) is the Characteristic value of foundation bearing capacity, \( E_s \) is compression modulus, \( \varphi \) is internal friction angle, \( C \) is cohesion, \( q_c \) is soil cone resistance, \( q_c \) is pile side friction, \( k \) is permeability coefficient, \( \gamma \) is gravity density, \( e \) is porosity ratio.
2. PILE FOUNDATION DESIGN AND CHECK
Bored pile foundation is chosen based on the following factors including safety, economy, short construction period, environmental protection and so on. For bored pile foundation, the construction period is relatively short, the cost is high and the environmental impact is small; while for manual digging pile foundation, the construction period is long, the depth of bearing layer should not be too deep, and the site environment is difficult to deal with because there are many residents in the place where the building is located. Thus, bored pile foundation was used for its mature construction technology and the effective quality assurance[3].

Specially, the structural form of the teaching building is frame structure and the plane layout of frictional piles is shown in Figure 1, in which the middle column load is 2050 KN, the side column load is 1810 KN, and the Angle column load is 800 KN. The load acting on the pile bottom is: \( F_k = 2050 \text{KN} \), \( M_x = 60 \text{kN} \cdot \text{m} \), \( M_y = 200 \text{kN} \cdot \text{m} \).

Table 1 Occurrence of soil layer

| No. | Soil layer        | \( l_i \) (m) | Elevation (m) | Buried depth (m) | \( q_{sia} \) (kN) | \( q_{pa} \) (kN) |
|-----|-------------------|---------------|---------------|------------------|-------------------|------------------|
| 1   | Miscellaneous fill| 0.9           | 99.39         | 0.9              | 20                | —                |
| 2   | Silty clay        | 1.7           | 99.13         | 2.6              | 50                | —                |
| 3   | Silty soil        | 0.9           | 96.86         | 3.5              | 60                | —                |
| 4   | Silty clay        | 3.9           | 92.68         | 7.4              | 50                | —                |
| 5   | Silty sand        | 19.3          | 73.43         | 26.8             | 45                | 650              |
| 6   | Silty soil        | 4.2           | 69.23         | 31               | —                 | —                |
| 7   | Silty sand        | 4.2           | 65.03         | 35.2             | —                 | —                |

Table 2 Engineering geological properties of soil layer

| Soil layer      | \( f_{as} \) (kPa) | \( E_s \) (MPa) | \( \phi \) (°) | \( q_c \) (MPa) | \( f_k \) (kPa) | \( k \) (cm/s) | \( \gamma \) (kN/m³) | \( e \) |
|-----------------|--------------------|-----------------|---------------|-----------------|----------------|---------------|-----------------|-------|
| Miscellaneous   | —                  | —               | —             | —               | —              | —             | 19.8            | 0.662 |
| Silty clay      | 95                 | 3.8             | 14.0          | 16.6            | 0.7            | 30            | 8.1-7           | 20.1  | 0.675 |
| Silty soil      | 140                | 9.5             | 15.2          | 13.2            | 2.4            | 38            | 5.6-6           | 20.0  | 0.655 |
| Silty clay      | 95                 | 3.8             | 13.2          | 16.2            | 0.7            | 25            | 8.1-7           | 20.1  | 0.675 |
| Silty sand      | 220                | 19.5            | 35            | 0               | 14.5           | 140           | 7.8-4           | 19.6  | 0.750 |

Figure 1: Foundation plan

2.1. Pile end bearing layer and pile length
The pile end bearing layer is the silty sand layer, the pile length is 9.4 m, and the dept of the pile entering into the bearing layer is 3.4 m. The cross section of the pile is 300×300 mm, the height of pile top extending into the pile cap is 100 mm, and the buried depth of pile cap is 1.5 m. C30 concrete and HRB335 steel bars was chose to ensure the pile cap strength.

2.2. Vertical bearing capacity characteristic value of single pile
1) The characteristic value of vertical bearing capacity of single pile is calculated by the following
formula\(^2\),

\[ R_a = q_{pa}A_p + u_p \sum q_{sia}l_i = 502KN \]  

where, \( R_a \) is the characteristic value of vertical bearing capacity of single pile, kN; \( A_p \) is the cross section area of pile bottom, \( m^2 \); \( u_p \) is the perimeter length of pile, m; \( q_{pa} \), \( q_{sia} \), \( l_i \) are shown in Table 1.

2) The characteristic value of vertical bearing capacity of composite foundation piles calculated by the following formula,

\[ S_a = \sqrt{A/n} = 1.34, S_a/d = 4.47, B_c/l = 1, \]

\[ A_c = \left( A - nA_{ps} \right)/n = 1.33m^2 \]  

where, \( A_c \) is the calculated net area of the base pile; \( A_{ps} \) is the section area of pile; \( S_a \) is the pile center distance; \( A \) is the calculation area of the cap; \( B_c \) is the width of the cap

\[ R = R_a + \eta_c f_{ak} A_c = 502 + 0.06 \times 110 \times 1.33 = 511KN \]  

where, \( \eta_c \) is the cap effect coefficient; \( f_{ak} \) is the thickness-weighted average characteristic value of bearing capacity of each soil layer within the width range of 1/2 of the cap bottom (≤5m).

Number of foundation piles and pile layout

Number of piles \( n \) is determined by the following way,

\[ n > f_k/R_a = 2050/502 = 4.08 \]  

thus, 5 piles is chosen. The pile spacing \( S \) is 0.9 m, the pile cap height is 1 m, the buried depth of pile cap is 1.5 m, the thickness of the reinforcement protection layer is 70 mm, and the height of the pile top inserting into the cap is 100mm. Therefore, the effective height of the pile cap is

\[ h_0 = 1.0 - 0.07 = 0.93m \]

Average weight of the cap and soil \( \gamma_{GK} = 20KN/m^3 \), then, the standard weight value of the cap and its upper soil

\[ G_k = \gamma_{GK} bld = 20 \times 3.0 \times 3.0 \times 1.5 = 270KN \]  

2.3. Design and check of pile side resistance

The side length of the bored pile is 300 mm, the concrete strength grade of the bored pile is C25, and HRB335 steel bars are selected. The reinforcement ratio of the pile shaft structure is no less than 0.2% - 0.65%, thus 6 root Φ 10 HRB335 steel bar with cross section area of 471 mm\(^2\) is chosen to meet the requirements. The protective concrete layer of the main reinforcement is 70 mm.

\[ N \leq \varphi_e f_c A_{ps} = 6692KN \]  

where, \( \varphi_e \) is frictional coefficient, \( \varphi_e=0.8 \); \( f_c \) is the Uniaxial compressive strength of concrete. Thus the pile side resistance meets the requirement of bearing capacity because the pile bearing capacity of 6692KN is greater than its load of 2050KN.

2.4. Design and check of pile shaft

The vertical force of a single pile tip \( Q_k \) is

\[ Q_k = \frac{F_k + G_k}{n} = \frac{2050+270}{5} = 464KN \]  

where, \( n \) is the number of piles in pile foundation. The vertical force of a single pile tip \( Q_k \) is 464 kN, and which is lower than the characteristic value of vertical bearing capacity of foundation pile \( R \) of 511 kN, therefore, the bearing capacity of the pile meets the requirement.

2.5. Design and check of the pile cap

The reinforcement of the pile cap adopts HRB335 steel bars with tensile strength \( f_y \) of 300N/mm\(^2\) and with reinforcement area arranged along the X-axis of 3307mm\(^2\), and 9 root Φ 20 steel bar with cross section area of 3421mm\(^2\)is chosend as shown in Figure 2. The same reinforcement form is alsochosed along the Y axis and the X axis. The calculated results show that the pile cap meets the requirements of shearing, punching and bending resistance. Besides, according to the soil properties and building height, the maximum settlement amount is allowed to be 200 mm. The layered summation method was used to
calculate the settlement of the pile foundation, and the calculated final settlement was 100.63 mm, which meets the settlement requirements.

![Diagram of pile cap design](image)

3. CONCLUSION
Building foundation design is very important for the safety of the building. In this paper, pile foundation design is carried out for No. 1 teaching building of Huaiyang No. 1 High School. The project covers an area of 800 square meters and a maximum building height of 19.2 meters. The soil layers do not meet the required bearing capacity under their natural condition. According to the scale, the structural characteristics and the geotechnical engineering characteristics of the teaching building, combined with the design principles of "safety, economy, construction period and environmental protection" and the local engineering situation, bored pile scheme was adopted. The pile specifications, the vertical bearing capacity of a single pile, the number of piles and the plane layout of the piles are designed based on the "Code for Design of Building Foundation" and other theories[4][5]. Then, the bearing capacity and the settlement calculation of pile foundation, the pile structure and the pile bearing capacity of the piles themselves, and the anti-punching, anti-shearing and anti-bending strength of pile foundation cap were checked and they were then considered to meet the requirements. As a result, the designed pile foundation can bear the upper load pressure and ensure the safety of the teaching building.

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