Study on the reliability of the carrying capacity of static pressure pipe piles in Shenyang

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Abstract: On the basis of the previous work, combined with the test piles collected from Shenyang area, this paper makes a detailed study of the current standard single safety factor design pile base method to the probability limit state design pile base method. The main work is statistical analysis, calculation of reliability index, analysis of the main factors affecting the reliability index of static pressure pipe pile and the analysis of its sub-coefficient coefficients, the reliability of its carrying capacity analysis has made a useful exploration.

1 Introduction

In Our country, pile-based engineering as a part of geotechnical engineering is also an important field of reliability theory application, and static pressure pipe pile as a new pile type, so it also needs to be studied for reliability. However, since its research object is a collection of one or more minerals, the engineering properties of the rock depend to a large extent on its mineral composition. Soil is the product of rock weathering, and its performance index is much more variability than that of artificial material, so it is more difficult to apply the reliability method. However, with the application of reliability analysis method in geotechnical engineering, the realization of reliability design is the inevitable trend of the development of pile-based engineering in the future. At present, the pile-based specification is also in the transition stage from the fixed-value method to the approximate probability method, which requires a large number of systematic statistics.

2 Reliability Analysis of Static Pressure Pipe Pile

2.1 Determination of Bearing Capacity of Single Pile

In engineering, the foundation of pile foundation design is to determine the vertical ultimate bearing capacity of single pile. Whether the vertical ultimate bearing capacity of single pile can be determined correctly and reasonably is related to the safety and economy of the whole project. According to the *Technical Specification for Building Pile Foundation*, the common methods to determine the vertical ultimate bearing capacity of single

pile are static load test in situ, static penetration test, standard penetration test and empirical parameter estimation. Static load test method and empirical formula method are widely used, which are stipulated in national and regional codes.

2.2 Statistical Analysis of Trial-to-Account Ratio

Static load test is the most reliable method to obtain the ultimate bearing capacity of single pile. The static load test value is taken as the true value of ultimate bearing capacity, the influence of geometric size and soil quality is reflected by calculation parameters, and then the ratio of the bearing capacity of static load test to the bearing capacity calculated according to the code (hereinafter referred to as trial-calculation ratio) is used to determine the calculation. The variability of the standard value of the ultimate bearing capacity of a single pile is reflected by the statistical variability of the trial-to-test ratio because of the uncertainty of the calculation model. The calculation value of the vertical bearing capacity of single pile is calculated by the empirical formula recommended by the pile foundation code, so the reliability level of the bearing capacity parameter table of the empirical formula method can be indirectly reflected by comparing the reliability analysis with the trial design.

In this paper, 66 complete data of static pressure pipe pile vertical static load test are collected in Shenyang area. The pile diameter is 300 mm, 400 mm and 500 mm. The shortest pile length is 7.3 m and the longest is 21.0 m. The fitting test of probabilistic distribution of trial-and-error ratio is carried out by means of test method. Statistical hypothesis tests are carried out for normal distribution, lognormal distribution and extreme value type I distribution. The results show that the distribution test results are not rejected for normal distribution and lognormal distribution, and rejection occurs for extreme value type I distribution hypothesis.

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According to the asymmetry of frequency histogram and the minimum of statistics, it is reasonable to assume lognormal distribution.

2.3 Random variable of load λ_G and λ_Q statistical

In the process of calculating the reliability index of β vertical bearing capacity of single pile, in addition to the above resistance distribution, the comprehensive load effect distribution of pile top is also used, including the dead load effect G and live load effect Q acting on pile top.

In practical projects, the most common load combination is that only one variable load is involved in the combination, that is constant load G + office floor live load Q_O , constant load G + residential floor live load Q_R , and constant load G + wind load W_W .

2.4 Calculation of a reliable indicator of vertical carrying capacity of a single pile

The reliability index of single-pile vertical carrying capacity β can be calculated according to the limit state equation and the statistical parameters of each random variable established earlier. At present, the approximate methods of calculating reliability index mainly include the central point method, the calculation point method, the JC method and the Monte Carlo method. In this paper, the JC method recommended by the Joint Committee on Structural Safety in International Structures is used to calculate reliable indicators. When the load effect ratio ρ changes, so does the reliability index. However, the absolute value of the load effect ρ does not affect a certain value. In this paper, the three basic combinations and different values are calculated by using their own program, and it is found that when the safety factor is calculated, the total mean of the reliability index β is 3.89. That is to say, the current design method of the security reserve is relatively large, the most adverse situation in the table reliability index value is also greater than 3.2.

3 Partial coefficient of total resistance of hydrostatic pile

3.1 The partial coefficient of total resistance is obtained from the limit state equation

When the partial coefficient method is used to design pile foundation, the total safety coefficient is decomposed into two partial coefficients of load and resistance. Pile top load is composed of dead load and live load, and the variation coefficient of them is different, so different partial coefficient is multiplied by corresponding load standard value respectively. According to JC method, the limit state equation is converted into the limit state practical design expression at the design check P^* point, and then, on the premise of the given standard values, a component coefficient is selected to minimize the overall error between the designed component's reliability index and the specified target reliability index. Since the coordinate of the check point satisfies the limit state equation, equation (1) can be written as:

$$G^* + Q^* = R^* \quad (1)$$

The G^* 、 Q^* 、 R^* in the formula are the design checking point values of dead load, live load and resistance respectively. So:

$$\begin{cases} \gamma_G = G^*/G_K \\ \gamma_Q = Q^*/Q_K \\ \gamma_R = R_K/R^* \end{cases} \quad (2)$$

The equation (2) is the definition of the partial coefficient in the design of probability limit state of pile foundation.

Among them, according to Chinese *Uniform standard for the design of architectural structure reliability*, unite take: $\gamma_G = 1.2$, $\gamma_Q = 1.4$, then the average value of structural resistance μ_R can be obtained from the limit state equation, then calculate the standard value of resistance R_K^* according to the statistical parameters μ_R/R_K , thus the component coefficient of resistance γ_R is determined.

3.2 Calculation of component coefficient of resistance

In view of three load combination forms and ten different load effect ratios, the partial coefficients of pile foundation resistance are calculated, and the target reliability index is taken as the total mean value obtained from the previous analysis $\beta = 3.89$, the average coefficient of ultimate bearing capacity of single pile $K_R = \mu_{\lambda R} = 1.080$, the coefficient of variation $\delta_R = 0.0247$, $\gamma_G = 1.2$, $\gamma_Q = 1.4$, the calculation results of γ_R are shown in Table 1 below:

Table 1. The calculation results of component coefficient of resistance γ_R ($\beta = 3.89$)

Combination	ρ									
	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50

$G + Q_o$	1.445	1.386	1.358	1.326	1.309	1.285	1.280	1.271	1.268	1.263
$G + Q_R$	1.482	1.453	1.417	1.387	1.358	1.332	1.329	1.318	1.309	1.302
$G + W_w$	1.524	1.496	1.449	1.423	1.495	1.468	1.457	1.442	1.428	1.421

From Table 1, it can be seen that when the load effect combination is certain, the form of load combination has a certain influence on the resistance partial coefficient, that is $\gamma_{G+Q_o} < \gamma_{G+Q_R} < \gamma_{G+W_w}$, but the influence is very little.

For each load combination and each load effect ratio, we can calculate different $R_{K_i}^*$ and S_i . Then generation into the formulain, the optimum resistance component coefficient in the design expression can be obtained $\gamma_R = 1.4126$, when the difference between the designed pile foundation and the target reliability index is the smallest.

4 Conclusion

In this paper, the complete pile test data of 66 static pressure pipe pile vertical static load tests collected in Shenyang area are presented, on the basis of JC method, the overall reliability level of pile foundation design in current foundation code is calculated by using "calibration method", and the rough corresponding relationship between the total safety factor and the corresponding average reliability index is given as follows: When $K = 2$, $\beta = 3.89$; it is concluded that the magnitude of reliability index β is affected by the variability of basic variables in the limit state equation, probability distribution of λ_R , total safety factor K , load combination form and the effect of load effect ratio ρ . For example, when K is a fixed value, the influence of different load combinations on reliability index is as

follows: $\beta_{G+Q_o} > \beta_{G+Q_R} > \beta_{G+W_w}$; moreover according to the combination of different working conditions, the average value is taken as the recommended value of the target reliability under the corresponding working conditions, the corresponding optimum resistance partial coefficients $\gamma_R = 1.4126$ are obtained.

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