Reliability Study on Anchor Anti-slide Pile

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ABSTRACT

The commonly used approaches in the analysis and design of anchor anti-slide pile are deterministic. The average values of the input parameters are usually considered and the uncertainties of the different parameters are taken into account via a global factor of safety which is essentially a “factor of ignorance.” Because of the Complexity of anchor anti-slide pile and interaction of structure and soils and rocks as well as the variability of parameters of soils and rocks, there are differences between definite analysis and practical engineering of this structure system. A reliability based approach for the analysis of anchor anti-slide pile is more rational since it enables one to consider the inherent uncertainty of each input parameter. A reliability analysis of anchor anti-slide pile is presented based on the structural mechanics calculation which is an effective method to calculate anchor anti-slid pile. Mathematical simulation is conducted using Monte Carlo method, which is not sensitive to dimension, based on calculation method. Through verifying of an engineering case, the authors work made contribution to the transition of designing method of anti-slid pile with anchored rod from definition to reliability.

KEYWORDS: anchor pile; structural mechanics; reliability analysis; Monte Carlo simulation

INTRODUCTION

It is an effective engineering method to use anchor anti-slide piles to strengthen slope and to treat landslide. By installing the anchor rod at the top or other position of anti-slide pile, which supplies the tension for anti-pile, the distribution of external and internal forces of anti-pile becomes more rational, therefore the section of the anti-pile is decreased, and the cost of the project is reduced gradually. In other countries, such researches mainly focus on coastal engineering and embankment engineering, considering the pile as passive pile in soft clay. Tschebotarioff (1973) calculated the internal force of pile based on the assumption of the triangular distribution of earth pressure on pile. Brandy (1996) analyzed the interaction of pile and soil using three-dimension finite element method. The result of this analysis is accord with that of centrifugal test .Stewart grouped the researches aboard into pressure method, deformation method and finite element method. In china, anchor anti-pile is extensively used in strengthening slope and treating landslide. Many researchers devoted themselves to theory research. Zhang Youliang *et al.* (2002) studied the mechanics of interaction of pile and soil, Dei Zihang (2002) deduced the different thrust and distribution function of soil resistance. He also proposed the finite difference method and analyzed the internal force of pile shaft. Yang Youfan (2002, 2003) studied "*m*-*k*" and "*k*-*k*" of the finite difference method used calculation the internal forces of anti-pile. Liu Xiaoli and Zhou Depei (2002) suggested the approach for determination pre-stressed value of anchor line and dynamic design method. Zhang Jinkui (2002) analyzed the behavior of anti-pile under load and effects of strengthening using the calculating results of finite element method. Many achievements have been made in studying on anchor anti-pile. However, the present theory research is focused on deterministic analysis. It has no specification about anchor anti-slide pile in different design codes, much less reliability of it. The design of anchor anti-slide piles depended on experiences of designers who make calculation by selecting varies parameters and safety factors. Therefore, the reliability study on anchor anti-slide pile system becomes one of concerned research subjects. The internal forces and deformation of single pile with singly anchored rod were calculated in this paper. Based on the calculation, the reliability of the system was analyzed.

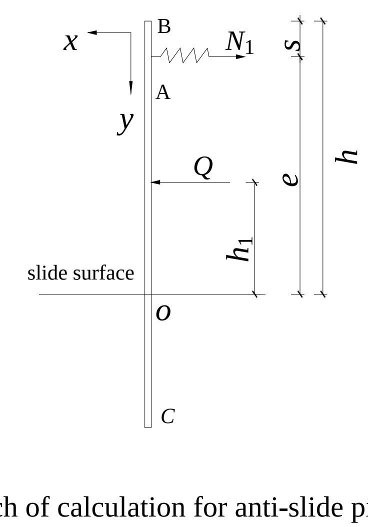

Figure 1: Sketch of calculation for anti-slide pile with anchored rob

Q=slide thrust; *s*=the distance between the point A and B; *e*=the distance between slide surface and anchor point; *h*=pile length above slide surface; h_1=the distance from acted point of slide thrust to slide plane.

Structural Mechanics Calculation Method

Fig.1 shows the sketch of calculation for anti-slide pile with anchored rob. When the deformation between pile and anchored rod is compatible, the tension of the anchored rod is N_1.

$$N_1 = \frac{b_1}{\left(a_1 + \frac{l_1}{E_g A_1}\right)} \tag{1}$$

Where, a_1 and b_1 are calculation parameters. l_1 is the length of anchor rod, E_g is the cross section of anchor rod, A_1 is elastic modulus of anchor rod.

The calculation of the part of loaded anti-pile is performed depended on the formula for calculating beam in structural mechanics, which is comparably simple. The anchored part of anti-pile is calculated based on Winkler foundation model, using the following formula (Eq. 2).

$$\left.\begin{array}{c}
x_y = x_o\varphi_1 + \frac{\varphi_o}{\beta}\varphi_2 + \frac{M_o}{\beta^2 EI}\varphi_3 + \frac{Q_o}{\beta^3 EI}\varphi_4 \\
\varphi_y = \beta\left(-4x_o\varphi_4 + \frac{\varphi_o}{\beta}\varphi_1 + \frac{M_o}{\beta^2 EI}\varphi_2 + \frac{Q_o}{\beta^3 EI}\varphi_3\right) \\
\frac{M_y}{\beta^2 EI} = -4x_o\varphi_3 - \frac{4\varphi_o}{\beta}\varphi_4 + \frac{M_o}{\beta^2 EI}\varphi_1 + \frac{Q_o}{\beta^3 EI}\varphi_2 \\
\frac{Q_y}{\beta^3 EI} = -4x_o\varphi_2 - \frac{4\varphi_o}{\beta}\varphi_3 - \frac{4M_o}{\beta^2 EI}\varphi_4 + \frac{Q_o}{\beta^3 EI}\varphi_1 \\
\sigma_y = Kx_y
\end{array}\right\} \tag{2}$$

RELIABILITY ANALYSIS OF ANTI-PILE WITH ANCHORED ROD SYSTEM

Reliability Calculation

Depending on the value of function $Z = R - S$, structures are distinguished into three states: reliable state, when $Z = R - S > 0$, limit state, when $Z = R - S = 0$ and failure state, when $Z = R - S < 0$. Generally, The basic variable, X_i, which is used describe structure is random, thus, the reliability of structure can be expressed with probability when the structure is in reliable, which is described with P_s

$$P_s = P(Z > 0) \tag{3}$$

It is assumed that *R* is the resistance force random variable and *S* is load effective random variable. $f_R(r)$ and $f_S(s)$ are probability density function for R and S respectively, $F_R(r)$ and $F_S(s)$ are probability distribution function accordingly. *R* and *S* are independent, then the reliable probability is following.

$$P_s = P(Z > 0) = \int_0^\infty f_s(s)\left[\int_0^\infty f_R(R) d_R\right] d_s \tag{4}$$

The reliability of structure also can be measure with the failure probability of structure p_f, which represents the probability that the structure cannot perform the intended function.

$$P_f = P(Z < 0) = \iint_{r<<} f_R(r) f_S(s) d_r d_s$$
$$= \int_0^\infty \left[\int_0^s f_R(r) d_r\right] f_s(s) d_s = \int_0^\infty F_R(s) f_s(s) d_s \tag{5}$$

or

$$P_f = P(Z < 0) = \int_0^\infty \left[\int_0^\infty f_s(s) d_s\right] f_R(r) d_r$$
$$= \int_0^\infty [1 - F_s(r)] f_R(r) d_r \tag{6}$$

The reliability and failure for structure are not compatible case, that is p_s and p_f are complementary, therefore $P_s + P_f = 1$.

Reliability analysis of anti-pile with anchored rod system

According to the working behaviour of loaded anti-slide pile with anchored rod, it is considered as series system of anchored rod and anti-slide pile. There are three cases for this system failure: anchored rod failure, anti-slide pile failure and the system failure caused bearing capacity of foundation soil. Therefore, the possible failure models are ① drawing of anchored rod; ② failure of OA segment of anti-slide pile; ③failure of AB segment of anti-slide pile; ④ failure of OC segment of anti-slide pile. After the failure model of the system is determined, the reliability of it is calculated.

USING MONTE CARLO METHOD TO SIMULATE THE RELIABILITY ANALYSIS OF ANTI-PILE WITH ANCHORED ROD SYSTEM

Selection of random variable

The selected random variable directly affects the quality of calculation or design of the system. There are many parameters in the system of anti-slide with anchored rod. These parameters include anchor rod parameters such as anchored rod length, anchored rod section dimension, anchored segment length, quantity of anchor bar, elastic modulus of anchor bar and, parameters for anti-slide pile, physical and mechanical indexes of rocks and soils as well as interaction parameters between pile and anchor rod. If consider all of parameters as random variables, the amount of calculation is very large. In addition, because of the limit of statistical analysis information at present, it is impossible to consider all of parameters as random variables. Viewed from this point, when analyzing the reliability of anchor anti-slide pile system, take those that have mainly effect on the reliability of the system as random variable while take another as certain value. The forging treatment for selecting random variable is practical and reasonable. In this paper, slide thrust force, axially compressive strength of concrete, shear strength of anchor rod, rock and soil at surrounding are random variable, the resultant parameters are certain value.

Establish limit state equation

(1) limit state equation of anchor rod

$$Z_1 = T_u - N_1 = \pi D L_e \tau - \frac{b_1}{\left(a_1 + \frac{l_1}{E_g A_1}\right)} = 0 \tag{7}$$

Where ultimate resistance to uplift of anchor rod $T_u = \pi D L_e \tau$ (2003)

(2) Loaded segment of anti-slide pile OA:

$$Z_2 = \alpha_{s\max} f_{cm} b h_0^2 - \frac{8N_1^2}{Q} + N_1 s = 0 \tag{8}$$

(3) Loaded segment of anti-slide pile AB:

$$Z_3 = \alpha_{s\max} \alpha_1 f_{cm} b h_0^2 - \frac{Qs^2}{2h} = 0 \tag{9}$$

(4) anchored segment of anti-slide pile OC:

$$Z_4 = M_{\mu\max} - M_{y_0} = \alpha_{s\max} f_{cm} b h_0^2 - M_{y_0} = 0 \tag{10}$$

where, M_{y_0} =moment of anchored segment of anti-slide pile, at this time $y = y_0$.

Monte Carlo calculation procedure

The procedure of Monte Carlo simulation is as following:

(1) Determine the four possible failure models of anchor anti-slide pile system.

(2) Produce random number for each random variable of anchor anti-slide pile system using computer. Load effect and resistance value obtained from these random value are applied to compute performance function Z_j through limit state equation. The positive or negative of performance function is judged. There are four failure cases (Z_1, Z_2, Z_3, Z_4). When any of these performance functions is negative, The anchor anti-slide pile can be considered failure. Generally, Sampling is in turn form one to four performance function. When any of performance function is less than zero, sampling is stopped. The corresponding failure model with performance function is the actual one.

(3) Repeat steps (1) and (2), record the number of failures.

(4) The failure probability of the system is obtained by dividing the total samples by actual failure samples. Assumed n times sampling have been held, *m* represents the number of failure, then

$$P_f = \frac{m}{n} \tag{11}$$

COMPUTION OF ENGINEERING EXAMPLE

General introduction of project

In this paper, The BiaoTa hill landslide is taken as engineering example. This landslide having clearing boundary, consists of new and old one, the latter is 85 meters from north to south and 95 meters from east to west, situated on the west of BiaoTa hill of Yan'an city, in china. The main sliding direction is NW65 degree. The elevation of back wall of landslide is 1040 meters, the elevation of shear exit is 94 meters. The elevation difference is 66 meters. The rear edge of steep wall which north wall height is range from 2.5 meters to 4 meters, south wall is 1 meter to 2 meters, is range from 1 meter to 3 meters. The degree of slip mass is 45 to 50, thus reducing a concave slop with three steep walls. It is the typical topography for slide slope. The new landslip is 53 meters from north to south and 59 meters from east to west, located in middle of the old one. The elevation of back wall of landslide is 1025 meters and the elevation of shear exit is 76 meters.

Characteristic value of random variable

Characteristic value of random variable of this project indicates in table 1.

Table1: Characteristic value of variable

item		mean value	standard deviation	coefficient of variation
sandstone	*c* (MPa))	5.0	0.77	0.156
	φ(°)	40.2	0.59	0.015
silty clay	*c* (MPa)	18	18.77	0.47
	φ(°)	28.1	5.92	0.47
Compressive strength of reinforced concrete	f_c(MPa)	30	4.2	0.14

Engineering design

The space between piles center is 6m; the cross section of pile is 2m×1.5m; pile shaft concrete mark number is C30, elastic modulus of anti-pile, E, is 3.0×10^7 kN/m^2, its compressive strength is 16.5 N/mm^2. Ground coefficient of the sandstone below slide surface, *K* is=3.0×10^5 kN/m^3, which is constant with depth. The length of pile is 22m, which is 16m above the bed rock, 6m below bed rock.

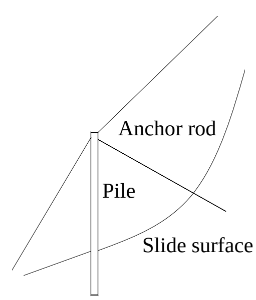

Figure 2: Plan of anti-slide pile anchored to rock

The anchor line installed at the top of the pile, each pile is anchored with one anchor line, the distance between pile and anchor line is 1m, the angle between anchor rod with horizontal surface is 30° the modulus of elasticity is 1.9×10^8 kN/m^2, the length of free section is 30m, achored section length is 10m, as Fig. 2 shows.

Calculation of reliability

Computation program is prepared using Visual Basic language. The reliability of foregoing design is calculated. The result is indicated in Table 2.

Table 2: Results of reliability calculations

	Sampling variables average value		Safety probability	The number of calculation
Z_1	m_τ	1276.66	0.999999	7812500
	m_Q	5795.25		
Z_2	m_{fcm}	47344.11	0.999996	7812500
	m_Q	5897.294		
Z_3	m_{fcm}	47346	0.999993	7812500
	m_Q	5892.3461		
Z_4	m_{fcm}	47343.94	0.999987	7812500
	m_Q	5897.513		
Calculation time			19 min	

CONCLUSION

A reliability analysis of anchor anti-slide pile is presented based on the structural mechanics calculation which is an effective method to calculate anchor anti-slid pile. Mathematical simulation is conducted using Monte Carlo method, which is not sensitive to dimension. The calculated results is verified through an engineering case. The main conclusions of this paper can be summarized as follows:

(1) The paper applied the structural mechanics calculation method of anchor rod-anti-slide system. This method takes the compatible deformation between anti-slide with anchored rod and soils and rocks into consideration, therefore it is more reasonable than other method in the theories of structural calculation of anti-slide with anchored rod.

(2) The minimized reliability parameter β of the son system in anchor rod-anti-slide pile system with design variables preliminary selected is up to 4.2, which completely satisfy the objective reliability need for a structure which importance level is the first and failure type is brittle described in the building code.

(3) Theoretical research on reliability of anti-slide pile with anchored rod is preliminary, there are many work required to improve(for example, analyzing the law for design parameters). Thus, the calculation and analysis in the paper can check the preliminary design.

(4) The equilibrium should attain between reliability and economy for engineering project, therefore, on the premise of determined objective reliability index, the optimum design is made by setting variables, and thus, the design both economy and rational can be got. This is the job want to do next.

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