Study on Reinforcement Effect of Anti-sliding Piles on Qinhuai River Slope

Zhangh Huan

Tongji University, Shanghai, China

email: 18217280830@163.com

Abstract. This paper summarizes the necessity and the reinforcement methods of slope stability, and introduces the application of strength reduction method in slope stability calculation. Combined with the Qinhuai River slope improvement project in Nanjing, the strength reduction method is used to analyze the impact of anti-slide piles on the Qinhuai River. The influence of the stability of the embankment slope, the calculation shows that the anti-slide pile effectively improves the stability of the Qinhuai River slope and can provide experience for various slope improvement projects.

Keywords: Embankment slope; Anti-sliding pile; Strength reduction method

1 Introduction

Slopes can be divided into natural slopes and excavated slopes according to their genetic state, and soil slopes, rock slopes and composite slopes according to their materials. The Qinhuai River is divided into the outer Qinhuai River, the inner Qinhuai River and the Qinhuai New River. According to the genetic cause, the Qinhuai New River is formed by artificial excavation, and according to the material, it is basically a soil slope. After years of development, the Qinhuai River has developed into an urban inland river, with a large number of residential areas distributed along the river, and it is an important place for residents to relax and entertain. Due to the influence of multiple factors such as steep slope, water level rise and fall, heavy rainfall during flood season, and ship waves, in recent years, the slope of the Qinhuai River has experienced serious initialization of water level changes, steep slope foot, seepage and flooding, and local collapse. The instability of embankment slopes will not only pose a huge threat to the lives and properties of coastal residents. Therefore, it is of great significance to study the stability of Qinhuai River slopes, ensure the safety of regional flood control, maintain the orderly living environment of residents, and protect people's lives and property.

D. Li et al. (eds.), *Proceedings of the 2023 9th International Conference on Architectural, Civil and Hydraulic Engineering (ICACHE 2023)*, Advances in Engineering Research 228,
https://doi.org/10.2991/978-94-6463-336-8_77

2 Slope stability analysis theory and reinforcement method

At present, the commonly used slope stability calculation methods[1]-[3] mainly include limit equilibrium method and numerical analysis method. Slope instability control methods mainly include laying anti-sliding piles, concrete retaining wall engineering, slope remediation and anti-seepage treatment, anchoring technology, etc.

3 Slope stability calculation of a renovation project in Qinhuai River

3.1 Slope instability criterion

The instability of Qinhuai River slope is generally manifested by the collapse of the slope along the weak surface and the sudden change of lateral displacement. At present, the criteria for judging the instability and failure of the slope in the numerical analysis of slope stability [4]usually include: whether the finite element calculation converges, whether the plastic zone penetrates, and whether the characteristic points in the slope mutate.

3.2 Calculation of slope stability before and after anti-sliding pile reinforcement

The strength reduction method[5]-[6] was first proposed by Zienkiewicz (1975), and the concept of strength reduction coefficient was proposed, which is the ratio of the maximum shear strength that the soil can provide to the actual shear stress generated by the external load on the soil when the external load remains unchanged. The essence of using the strength reduction method to calculate the stability of the slope in Abaqus is to gradually reduce the c and φ values of the soil, resulting in the inability to match the soil stress and strength, and the stress that the soil cannot bear is transferred to the surrounding soil, resulting in damage. In Abaqus, the shear strength parameters of the soil can be changed with the field variable (taken as the strength reduction coefficient F_{sr}) to achieve strength reduction. According to the reduced strength parameters, the finite element analysis is carried out until the slope reaches the critical failure state. The ratio of the strength index at the time of failure to the original strength index of the soil is the safety factor F_{sr} of the slope. The reduced strength parameters can be expressed as:

$$c_m = c/F_{sr} \tag{1}$$

$$\varphi_m = \arctan(\tan\varphi/F_{sr}) \tag{2}$$

The typical engineering section is shown in the figure 1. Among them, the anti-sliding piles are drilled piles with a diameter of 800mm, with a pile length of 25m and a pile spacing of 1.5m. The driving position is 9.9m away from the top of the slope. The slope slope is 1:3.

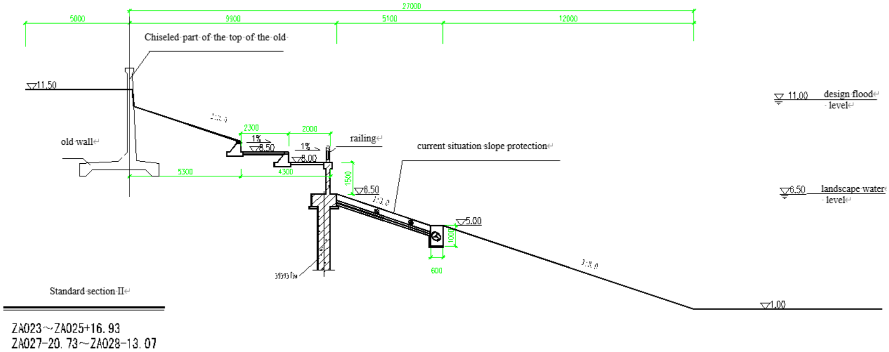

Fig. 1. Design section of Qingliangmen Bridge~ Shuiximen Bridge section

The soil parameters used are as follows.

Table 1. of Soil Parameter Values

Geotechnical number	Geotechnical name	Cq(kPa)	Φq(°)
1	Plain fill (silty clay)	35.9	11.6
4	Silty clay	7.7	15.0
5	Silt	0.0	16.8
5-1	Silty clay	20.1	7.5
5-2	Silty silty clay	0.7	3.8
6	Silty clay	52.7	13.6
6-1	Silt	12.1	22.0
6-3	Silty clay	18.7	9.7
8	Residual soil	42.0	15.4
9-1	Sandstone	24.4	10.1

Calculate the stability in the initial state without taking any anti-skid measures.

The finite element calculation model of this section is established by ABAQUS, as shown in the figure 2. A total of 6430 nodes and 5301 eight-node isoparametric elements.

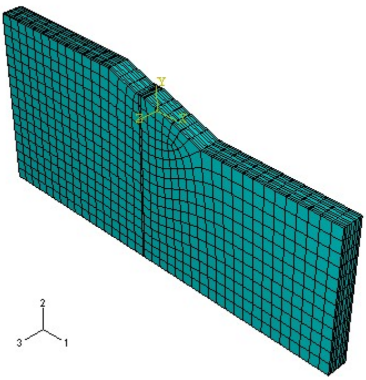

Fig. 2. Three-dimensional finite element mesh for slope stability analysis

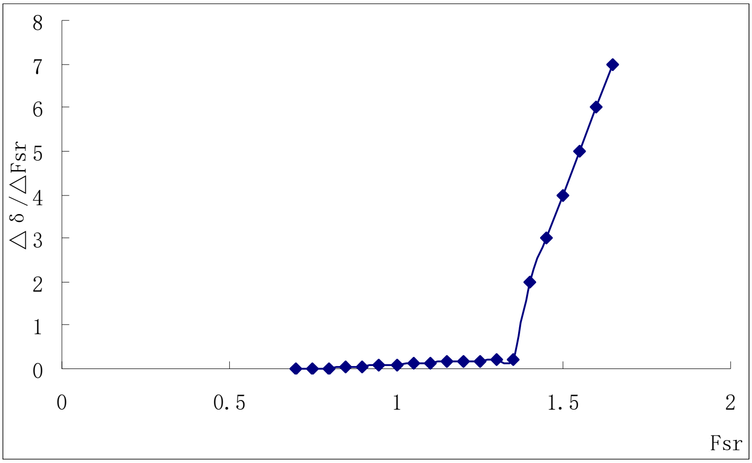

Fig. 3. The relationship curve between $\Delta\delta/\Delta F_{sr}$ and the strength reduction coefficient F_{sr}

During the running period, the water level in front of the slope is ∇5.50m, and the stable groundwater level behind the slope is ∇8.0m. The water level difference between the front and the back of the slope is considered, and the seepage before and after the slope is not considered[7]. When calculating the initial position, take Fs = 0.6, that is, the shear strength of the soil is enlarged to avoid the damage of the slope at the beginning of the calculation. Then increase the strength reduction coefficient linearly, and the initial increment step is set to 0.1, and the finite element method analysis is carried out. According to the shear strength displacement field in the strength reduction analysis step, the change trend of the displacement increment of the characteristic point with the strength reduction coefficient is analyzed. According to the ratio of the horizontal displacement increment of the characteristic point to the increment of the strength reduction coefficient $\Delta\delta/F_{sr}$, and the strength reduction coefficient F_{sr} data, draw the relationship curve between $\Delta\delta/F_{sr}$ and F_{sr}, and then judge the stability safety factor of the slope according to the curve.

It can be seen from Figure 3 that before F_{sr} increases from 0.6 to 1.32, the $\Delta\delta/\Delta F_{sr}$ value increases slowly with the increase of F_{sr}, the horizontal displacement of the top point of the slope increases slightly with the decrease of the shear strength, and the slope is in a stable state; when F_{sr} reaches 1.32, the $\Delta\delta/\Delta F_{sr}$ value of the feature point increases sharply with the increase of F_{sr}, indicating that the horizontal displacement of the feature point has a sudden change.

After the F_{sr} reaches 1.32, the shear strain increment of the slope soil penetrates from the foot of the slope to the top of the slope, and is distributed in a band shape. The soil is close to the limit state. The slope may begin to slide along the surface, that is, the safety factor of the slope is 1.32, and the surface is the corresponding most dangerous potential sliding surface. According to the finite element calculation results, the drawn slope displacement contour is shown in Figure 4. It can be seen that the position of the sliding arc when the slope is about to become unstable. Figure 5 shows the direction of displacement of each node. Figure 6 shows taking out a section as the direction of node displacement of the study plane.

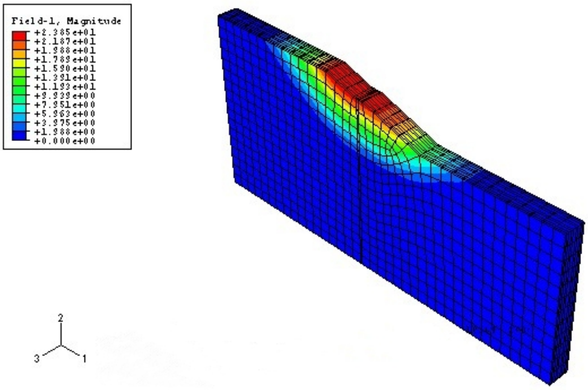

Fig. 4. Displacement contour diagram

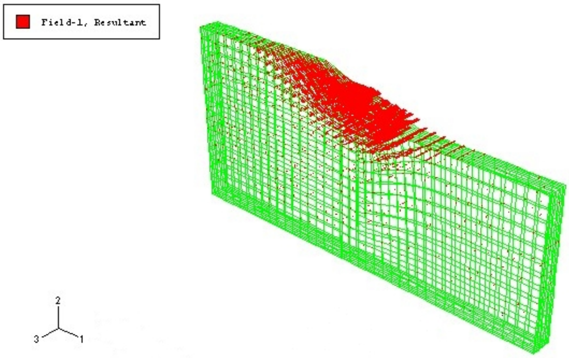

Fig. 5. Displacement vector diagram

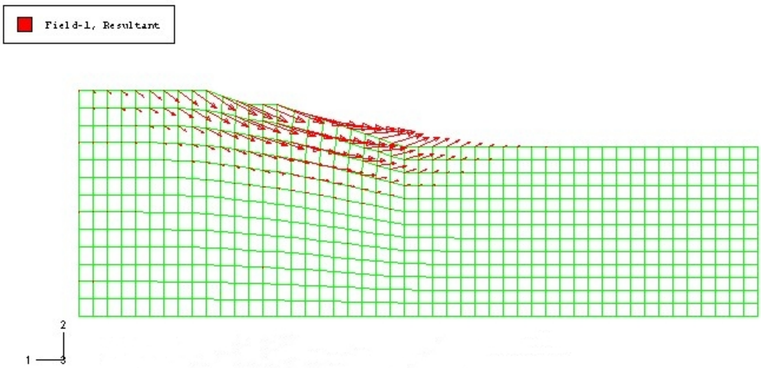

Fig. 6. Displacement vector planarization diagram

After setting up anti-sliding piles, the relationship curve between $\triangle\delta/\triangle F_{sr}$ and the strength reduction coefficient F_{sr} can be obtained as shown in Figure 7, which shows that the stability of the soil on the upper part of the anti-sliding pile has been greatly improved, but it cannot be determined that the stability coefficient of the slope is 2.3. As can be seen from the picture of slope damage, after setting up anti-sliding piles, the soil damage is mainly the soil after the anti-sliding piles. Therefore, it is necessary to draw the relationship curve between the surface displacement of the soil after the anti-sliding piles and the strength reduction coefficient, as shown in Figure 8~ Figure 9. It can be seen from this that after setting up anti-sliding piles, the stability of the slope is determined by the soil behind the anti-sliding piles. At this time, the stability of the entire slope is very high, and the local soil stability coefficient is 1.8.

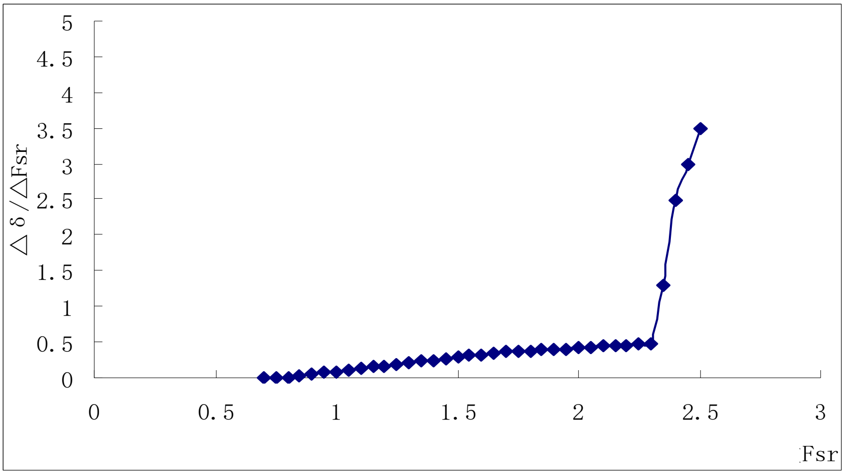

Fig. 7. The relationship curve between $\triangle\delta/\triangle F_{sr}$ and F_{sr} of anti-sliding piles is set up

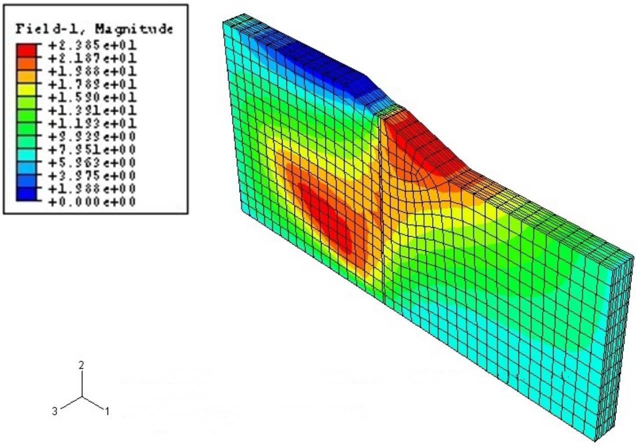

Fig. 8. Displacement contour diagram after setting up anti-sliding piles

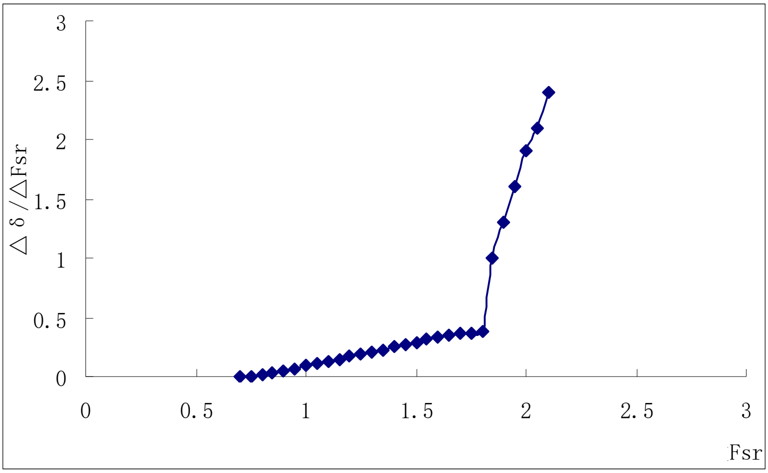

Fig. 9. The relationship curve between $\Delta\delta/\Delta F_{sr}$ and strength reduction coefficient F_{sr} after pile

Based on the calculation results of the above strength reduction method, it can be concluded that the stability safety factor of the typical section of the slope from Qingliangmen Bridge to Shuiximen Bridge is 1.32 before setting up anti-sliding piles. After setting up anti-sliding piles, the overall safety factor is increased to 2.3, and the local soil safety factor behind the anti-sliding piles is 1.8. In general, anti-sliding piles greatly increase the stability factor of the slope, which can effectively prevent the occurrence of landslide accidents.

4 Conclusion

According to the strength reduction method and the three-dimensional finite element analysis method, the stability calculation of the Qinhuai River slope before and after reinforcement is carried out, and the reinforcement effect of anti-sliding piles is evaluated. The following conclusions can be drawn through the above work:

1) The application of the finite element strength reduction method in the calculation of slope stability is reviewed. The sudden change of the horizontal displacement of the slope vertex is used as the criterion for judging the failure of the slope, and the position of the sliding surface is determined by the shear strain increment diagram.

2) Relying on the renovation project of a slope of Qinhuai River in Nanjing City, the finite element analysis strength reduction method is used to calculate the safety and stability coefficient of the representative section. Before reinforcement, the Qinhuai River slope had a stability coefficient of 1.32 due to its gentle slope, and the overall stability coefficient of the reinforced slope was 2.3, and the local (the soil behind the pile) was 1.8, which could meet the higher stability requirements. In general, the installation of anti-sliding piles effectively improves the anti-sliding ability of the Qinhuai slope.

References

1. Zheng Yingren, Zhao Shangyi, Zhang Luyu. Slope stability analysis by finite element strength reduction method [J]. China Engineering Science, 2002, 4 (10): 57-61.
2. Yang H. Huang, Bao Chenggang et al. Analysis of Soil Slope Stability [M]. Tsinghua University Press, 1988, 1-8.
3. Wang Jianfeng, Zhang Xiaoling. Slope reinforcement treatment technology for water conservancy and hydropower projects [J]. Urban Building Space, 2023, 30 (S1): 445-446.
4. Chen Linjing, Sun Ruixuan, Luo Yiming. Numerical simulation analysis of overall stability of pit-in-pit based on strength reduction method [J]. Urban Geology, 2023, 18 (03): 67-75.
5. Zienkiewicz O.C. Finite Element Method [M]. Beijing: Science Press, 1985.
6. DUNCAN J M. State of the art: limit equilibrium and finite element analysis of slopes[J]. Journal of Geotechnical Engineering, 1996, 122(7):577–596.
7. Xu Weiya, Xiao Wu. Research on slope failure criterion based on strength reduction and severity increase [J]. Geotechnical Mechanics, 2007 (03): 505-511. DOI: 10.16285/2007.03.014.