Research on the Ductility Design of Concrete Anti - Slide Piles for Building Slopes in Saline-Alkali Soil Areas of Lanzhou City

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Keywords: Saline Soil, Building Slope, Governance Project, Improved Concrete Anti-Slide Pile, Finite Element Analysis.

Abstract: This paper takes the newly built building slope in Lanzhou City, Northwest China as the engineering background. In order to ensure the stability of the saline - alkali soil slope, the durability of the treatment project, and the safety of the residential buildings on the top of the slope, improved concrete anti - slide piles are adopted to protect the slope based on traditional reinforced concrete. The finite - element calculation results show that, firstly, this method is one of the most effective ways to treat important saline - alkali soil building slopes. Secondly, (1) the supporting effect of the anti - slide piles prevents the potential slip surface from penetrating from the top to the bottom of the slope, and the horizontal displacement of the slope body is the largest; (2) compared with the maximum displacement of the slope supported by ordinary concrete anti - slide piles, the horizontal displacement of the slope supported by the improved anti - erosion concrete anti - slide piles is the smallest. The displacement of the former along the entire length of the pile is smaller than that of the latter, which is conducive to improving the stability of the slope. This method can provide a basis and experience for similar building slopes in the future.

1 INTRODUCTION

As the level of national infrastructure construction continues to improve and the transformation from traditional civil infrastructure to smart civil engineering is taking place, high - quality development has also ushered in a change towards new - quality productive forces. However, in transportation engineering construction, slope instability or the re - activation of old landslides are inevitable problems. Liu and Sun (2013), Ruan et al. (2005) believe that landslides are one of the common issues in engineering geological disaster management; Zhou (2004) argues that ground excavation and rainfall are common factors triggering landslides; Ying (2000) holds that anti - slide piles are the most effective protective engineering measures for landslides, especially large - scale ones; (Tang et al., 2013; Wang, 1999) consider that the Lijiawan landslide is a multi - layer and multi - level super - large landslide, which has seriously threatened the normal operation of the expressway and the personal and property safety of the toll station; Zhang (1996), Zhao et al., (2012) established a numerical model of the landslide using finite element software, analyzed the plastic zone, deformation mechanism and characteristics of the landslide, and compared them with the horizontal displacement and plastic zone nephograms of the slope after support to verify the treatment effect.

In this project, the excavation of the building slope has formed a slope with a maximum height of nearly 9 meters. The slope toe is almost vertical, and the stability of the slope is average. The slope may collapse at any time in case of rainfall or other adverse geological conditions. There is a residential building at the top of the slope, which is an important object to be protected. The slope is classified as a second - level slope. Due to the particularity of this project, factors such as the corrosiveness of saline - alkali soil in Lanzhou area to concrete structures are taken into account in the slope design and calculation. Therefore, it is necessary to improve the corrosion resistance of concrete anti - slide piles.

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Figure 1: Location of the project.

2 PROJECT OVERVIEW

2.1 Engineering Background

Bashangdi, Yatou Village, Bali Town, Qilihe District, Lanzhou City. It is adjacent to the village road on the east side, with the (Zone B) of the community to its north and high mountains to its west. The site was originally arable land (the area near the road on the east has been excavated down about 12 meters). The slopes to be protected are those on the north and west sides of a seven - storey residential building. This location is part of the Chuandong Fold Belt within the Sichuan Subsidence Fold Belt. Atmospheric precipitation and surface runoff in summer are the primary means of rainwater replenishment. The western region of China has the most extensive distribution of salt lakes. Notably, the salt lakes in the Hexi Corridor area possess extremely strong corrosiveness, and the content of SO42- is 4.2 times the maximum value stipulated in the current railway specifications, as depicted in Figure 1.

2.2 Topography and Geotechnical Composition

According to the results of on - site investigation, the geomorphic unit of this site is classified as the high terrace of Yatou Village on the south bank of the Yellow River. The original site had well - developed valleys with deep cuts. After artificial excavation, filling, leveling and transformation, the terrain is relatively flat. The new project site is located in Qilihe District, where mountains, ridges, terraces, plains, beaches and gullies crisscross. According to its geomorphic characteristics, it can be divided into the southern rocky mountain area, the central loess ridge area, and the northern river valley basin. The terrain of the proposed project area is relatively complex with large undulations. Among them, the slope to be reinforced in the project is the slope where Building No. 9 is located, and the elevation difference ranges from 1.5 to 15.1 meters. The terrain and geomorphology of the proposed slope have large undulations, and there are mainly two types of corresponding soil: (1) The soil in the project area is mainly loess - like silt; (2) In the main agricultural area of the project area, the surface is a vegetation soil layer.

2.3 Meteorological and Hydrological Conditions

Lanzhou has a continental climate in the middle temperate zone, characterized by large temperature differences, low precipitation, and a mild climate. It is located in the transition zone between the monsoon and non - monsoon climate regions, with a typical temperate semi - arid climate. The average altitude of the urban area is about 1520 meters, and the annual average temperature is around 10℃. Surrounded by mountains to the north and south, the climate is dry with abundant sunshine, and both the annual and daily temperature differences are relatively large. The winter is long and relatively cold, with little rain and snow; spring and summer are short, with relatively high temperatures but no intense heat; autumn is short, with a rapid temperature drop. The maximum rainfall in Lanzhou over the years is 564.9mm, and the annual average precipitation is 327mm. The annual average

Table 1: Soil parameters.

name	Characteristic value of foundation bearing capacity fak(KPa)	Poisson's ratio v	Serious γ(kN/m³)		cohesive strength c(kPa)	Friction angle φ(°)
			Natural working condition	Saturation condition		
Loess silt	120	0.28	16.0	17.0	20	26
Round gravel soil	260	0.24	19.0	20.0	22	29
C30 anti-slide pile	name	Poisson's ratio v	Elastic modulus E(GPa)	Serious γ(kN/m³)	Design strength (MPa)	Preparation strength (MPa)
	control group	0.20	30.0	23.0	30.0	
	Experimental group	0.19	32.7	23.1		38.2

temperature is 10.3℃, the average annual sunshine hours are 2446 hours, and the frost - free period is more than 180 days.

The maximum rainfall of 564.9mm in Lanzhou over the years has a significant impact on the steep slope on the south side of this project. Protective measures should be taken for the southern part of the slope protection area. This site is located in an arid region (aridity index K⩾1.5), and the foundation will be in a weakly permeable layer with a water content greater than 20%. The average temperature in the site area in January is less than - 4.0℃, which belongs to the frozen area, and the freezing depth of the site is about 1.05 meters. According to the test results of on - site samples sent to the laboratory and referring to the evaluation criteria for the corrosiveness of site soil in China's geotechnical code [1] "Code for Geotechnical Investigation" (GB50021 - 2001), it is determined that the soluble salts precipitated from the site soil have slight corrosiveness to the concrete structure and slight corrosiveness to the steel bars in the reinforced concrete structure.

3 FINITE ELEMENT ANALYSIS AND CALCULATION OF SLOPE STABILITY AND ANTI-SLIDE PILE

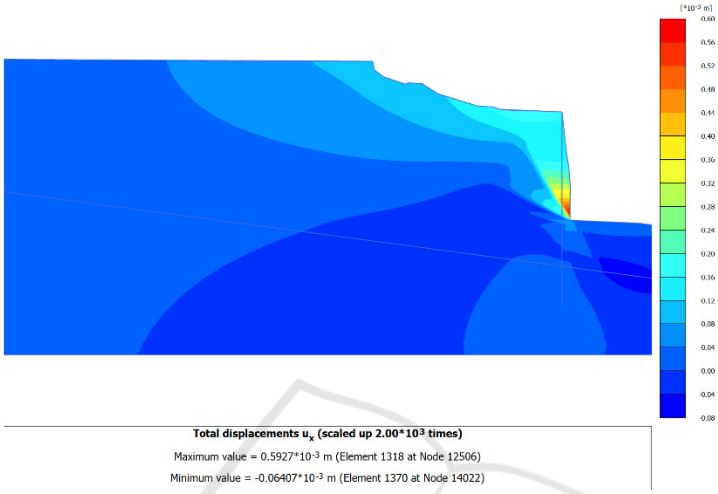
3.1 Geotechnical Parameters

Based on the on - site survey and drilling to obtain core samples of rock and soil, the shear strength parameters of the rock and soil were obtained through laboratory tests. The rock and soil parameters are shown in Table 1.

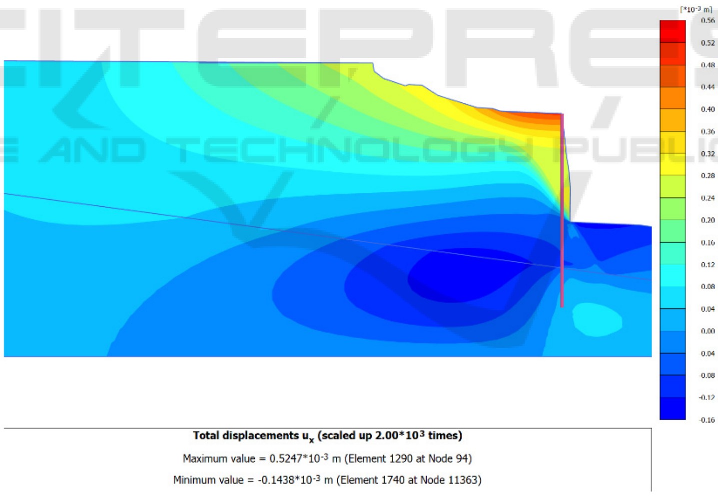
3.2 Calculation of Anti-Slide Pile

Since the maximum height of this slope is 9 meters, the two - dimensional finite element software Plaxis 2D for geotechnical engineering deformation and stability analysis is adopted. It can simulate the nonlinearity of soil and rock, and the elastoplastic constitutive model is the Mohr - Coulomb model. The anti - slide piles are modeled as linear elastic non - porous structures. Wang et al., (2019) added 5.305% slag micro - powder and 0.014% polycarboxylate high - performance water - reducing agent to the concrete according to the mass ratio. This not only improves the strength of the concrete but also enhances its impermeability and the flexural capacity of the anti - slide piles. The calculation formula for the preparation strength of concrete is calculated according to $f = f.k + t\sigma$. In the formula, f is the preparation strength of concrete (MPa); f is the strength standard value of concrete at the designed age (MPa); t is the probability coefficient, and the design strength guarantee rate is 95%.

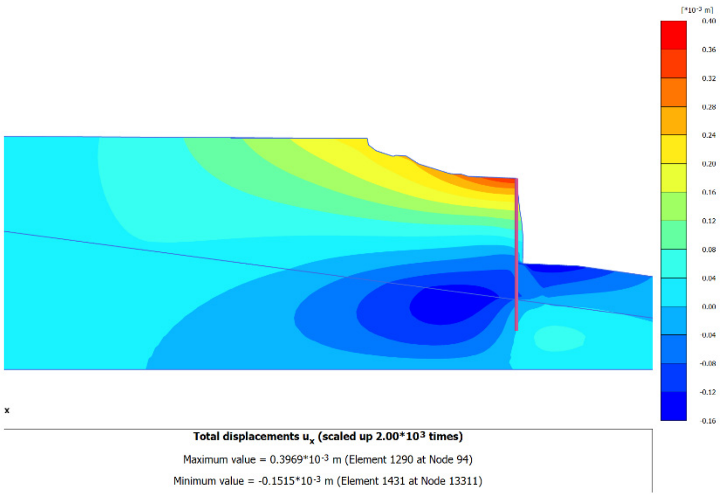
In the finite element model, the Embedded pile element model is used for anti - slide piles. The embedded beam unit (embedded beam) is employed to simulate the mechanical and engineering properties of the piles, which can analyze the deformation, internal force of the piles and the pile - soil interaction. The diameter of the piles is 0.3 meters, and the center - to - center spacing of the piles is 1.5 meters. Non - large - diameter piles can ensure rapid convergence under certain accuracy conditions. The Mohr - Coulomb elastic - ideal plastic model (MC) constitutive model for the soil can well simulate the mechanical behavior of this kind of soil. A total of 2453 elements and 20720 nodes are divided, as depicted in Figure 2. In order to determine whether plasticity occurs in a calculation, a function of stress and strain is introduced here as the yield function. The ideal plastic model is a constitutive model with a fixed yield surface. The two parameters of the plastic model are the friction angle φ and the cohesion c. These yield functions can jointly represent a hexagonal pyramid in the principal stress space.



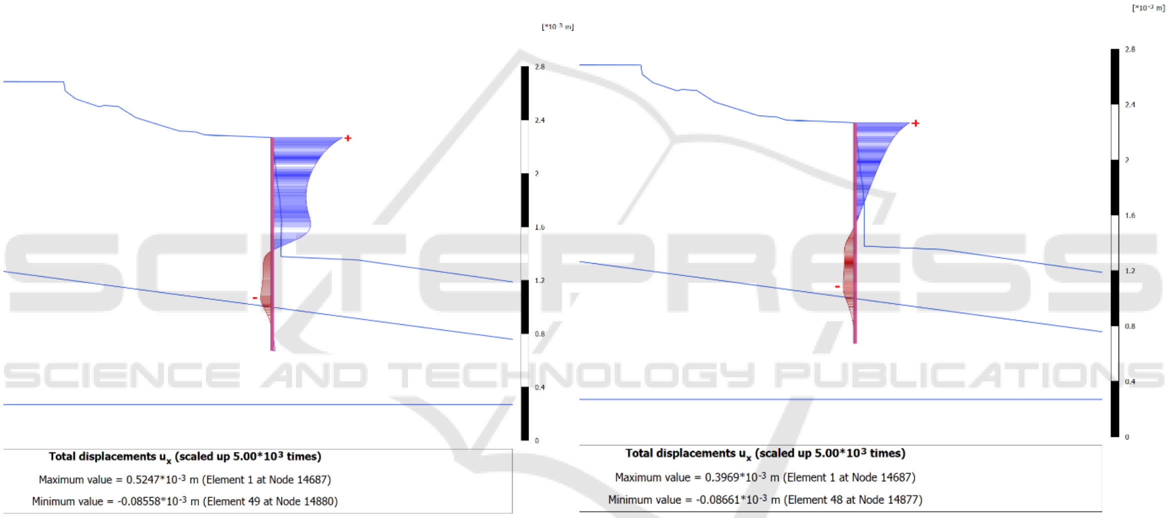
(a) Horizontal displacement of unsupported slope (mm)



(b) Horizontal displacement of ordinary concrete anti-slide pile (mm)



(c) Horizontal displacement of improved anti-erosion concrete anti-slide pile (mm)



(d) Horizontal displacement of ordinary concrete anti-slide pile and improved anti-erosion concrete anti-slide pile (mm)

Figure 2: The calculation result.

4 CONCLUSION

To ensure the stability of a 9 - meter - high building slope, based on the on - site geotechnical sample testing and slope stability calculations, the main conclusions are as follows:

(1) Through on - site inspection and core - sampling of geotechnical specimens, the corrosivity of salt ions in the rock and soil, as well as geotechnical parameters, were analyzed. The soluble salts in the rock and soil have a slight corrosive effect on the concrete structure.

(2) By calculating the stability coefficient of the 9 - meter - high building slope, it was found that the slope stability is insufficient, especially under rainfall or seismic conditions, where the stability further decreases. Through comparative analysis of the slope's stability, horizontal displacement of the slope body, and the horizontal displacement variation along the entire length of the anti - slide piles under natural conditions, ordinary anti - slide pile retaining conditions, and sulfate - resistant formulated concrete anti - slide pile conditions, the horizontal displacement of the slope follows the order: U1x (natural slope) > U2x (ordinary concrete anti - slide pile) > U3x (improved anti - erosion concrete anti - slide pile). Under natural conditions, there is a potential through - going slip surface from the top to

the bottom of the slope. The maximum water - level displacement is 0.59 mm. The maximum displacement of the slope supported by ordinary anti - slide piles is 0.52 mm, and the maximum displacement of the slope supported by the improved anti - erosion concrete anti - slide piles is 0.40 mm. The maximum displacement of the pile body is at the pile top, and the displacement of the top of the ordinary anti - slide pile is greater than that of the improved anti - erosion concrete anti - slide pile.

(3) Considering the weak corrosivity of the saline - alkali soil to concrete and the long - term durability of anti - slide piles in the building slope, measures such as increasing the thickness of the concrete protective layer and adding slag micro - powder to the mixture can improve the compactness and impermeability of the concrete. By comparing and analyzing the changes in the mechanical properties of the anti - slide piles before and after improvement, it was found that these measures can also save certain costs. These technical measures can provide some reference experience for similar projects in the future.

AUTHOR CONTRIBUTION

Xiaosen Li, Shanzhi Fan, Haihong Zhang,: conceptualization, methodology, data curation, writing-original draft preparation. Xingrong Liang, Wenjing Zhang: visualization, investigation, resources, project administration, supervision, funding acquisition. Shanzhi Fan: review & editing.

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DATA AVAILABILITY

The data used to support the findings of this study are available from the corresponding author upon request.

CONFLICTS OF INTEREST

We declare that we do not have any commercial or associative interest that represents a conflict of interest in connection with the work submitted.

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