



# Analysis of the Influence of Pile Foundation Setting on the Stability of Half Slope in High Fill Section

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**Abstract.** In order to effectively plan the supporting measures of slope pile foundation in high fill section, the finite element analysis model of anti-slide pile in a railway station slope was constructed by MIDAS GTS software. By changing the parameters of the pile, how these variables affect the bending moment, safety factor and horizontal displacement of the pile is analyzed. The results show that increasing the diameter of the pile and reducing the distance between the piles can effectively improve the safety factor.

**Keywords:** slope; anti-slide pile; safety factor

## 1 Introduction

A new railway is located in the transition zone between the Loess Plateau and the Qinghai-Tibet Plateau, and there are a large number of high fill projects. In particular, the station is densely filled with high fill and deep excavation. In order to overcome the difficulty of lacking natural plane site as the station site, the combined retaining structure of pile foundation and retaining structure has been applied in the design of the station site of the project. It is necessary to carry out research on the influence of the setting range and method of pile foundation on the slope stability of high fill section. It is of great engineering significance to provide valuable data and experience for similar engineering research, design and construction.

### 1.1 Overview of the Project

Typical work sites within the scope of the station are selected. The main strata are Quaternary Holocene alluvial sandy loess, fine breccia soil, and Upper Pleistocene aeolian sandy loess. Under the platform surface of this section, the vertical slope de

sign should be carried out by using the combined structure of pile foundation and retaining wall. The real picture of the slope is shown in Figure 1<sup>[1]</sup>.

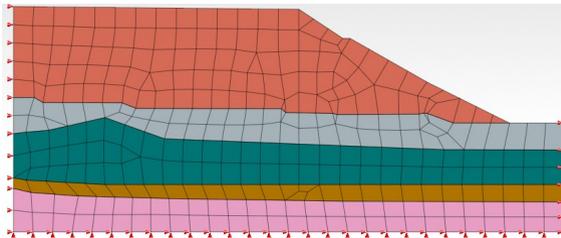


**Fig. 1.** Scene of slope

**1.2 Model Construction**

In order to study the influence of anti-slide pile on slope stability, the section of typical working point is selected to calculate the slope stability, and the two-dimensional analysis model of slope is established based on Midas GTS NX simulation software<sup>[2]</sup>. The finite element model is established as shown in Fig. 2.

The Mohr-Coulomb ( M-C ) constitutive model is used for the soil layer. Anti-slide pile adopts elastic model. The soil layer and foundation structure are simulated by 2D element, pile foundation and beam element. The numerical calculation parameters of each element are listed in Table 1.



**Fig. 2.** Slope finite element model diagram

**Table 1.** Soil material and physical parameter table of anti-slide pile

Rock-soil mass	Heavy ( kN/ m <sup>3</sup> )	Elastic modulus ( MPa )	Poisson ratio	Cohesion ( kPa )	Internal fric- tion angle ( ° )
Q <sub>4</sub> sandy loess	18.6	6	0.3	14	19
Q <sub>4</sub> fine breccia soil	19.6	17.5	0.3	15	32
Artificial fill	20	120	0.3	28	20
W <sub>2</sub> conglomerate	23	250	0.3	45	36
Slide-resistant pile	21	250	0.25		

## 2 The Influence of Pile Length on Slope Stability

Taking the pile length  $H$  equal to 40m, 35m, 30m and 35m as an example, the pile length calculated in the study is less than or greater than the actual design pile length within a certain range for comparative analysis, and the law of change is analyzed. The influence of pile position change on slope stability under certain conditions of pile length is analyzed, so as to study the range of influence of pile position setting on slope stability. The schematic diagram of anti-slide pile reinforcement is shown in Figure 3. The results are shown in Figure 4 [3-6].

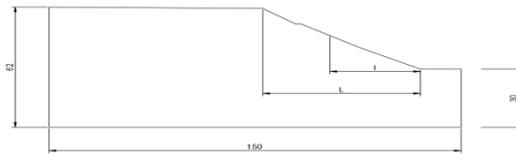


Fig. 3. Anti-slide pile reinforcement diagram

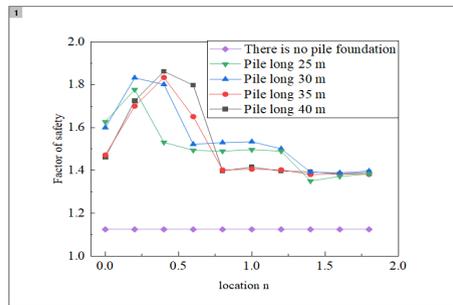


Fig. 4. Relationship between slope safety factor and pile length

From the perspective of improving the safety factor of the slope, with the increase of  $n$ , the safety factor increases first and then decreases. When the pile length changes, the longer pile length safety factor is larger when  $n$  is less than 0.8. When  $n$  is greater than 0.8, although the shorter pile length has a higher safety factor, the overall safety factor is still low.

When  $n = 0$  and  $n = 1$  ( i.e., the pile position is located at the foot and top of the slope ), the safety factor of different pile lengths does not change much. When the anti-slide pile is set at  $n = 0.2-0.6$  ( the pile position is located in the middle and lower part of the slope ), the safety factor of the slope is greatly improved. And when  $n$  is greater than 1.4, the safety factor is further reduced, indicating that the pile foundation is set outside the 20 m range of the slope top edge, which does not affect the stability of the slope.

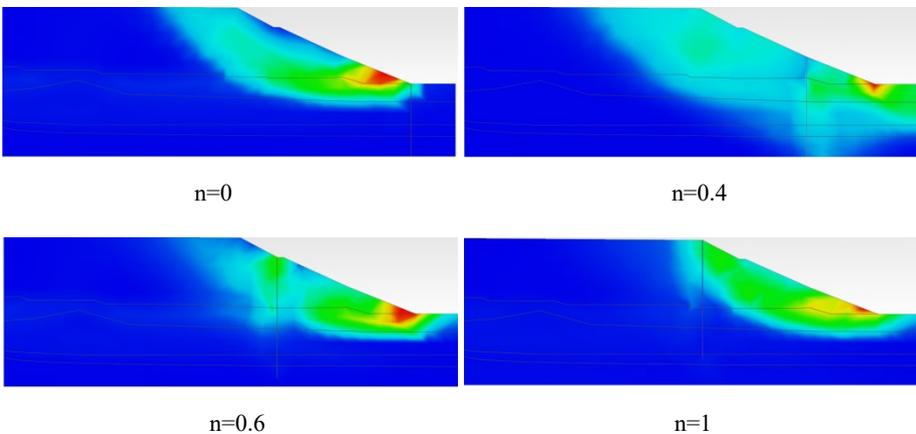
When the pile length is lengthened, the safety factor is further improved, which is because the anti-sliding ability of the pile foundation is mainly composed of two parts : the bearing capacity of the pile end and the friction resistance of the pile side. With the increase of pile length, the pile side friction resistance increases, and the

anti-sliding force also increases, thus improving the bearing capacity of the pile foundation. In addition, long piles can penetrate deeper into more stable soil layers and improve the stability of pile foundations. However, it will also increase the cost of the project, and the design of pile length should be optimized in the actual design of the project.

As shown in Fig. 5, the potential critical sliding surface of the slope is one of the key indicators for evaluating the stability of the slope, which can directly reflect the stability of the slope. Taking the pile length of 40 meters as an example, the influence of anti-slide pile position on slope stability is discussed by comparing and analyzing the sliding surface morphology under different pile position conditions.

When  $n = 1$  or  $n = 0$ , the anti-slide pile is located at the top or foot of the slope, forming a through sliding surface, and the soil inside the slope may slide continuously, resulting in slope instability. In these two cases, the calculated slope safety factor is relatively small, indicating that the anti-slide pile has a limited effect on improving slope stability. However, when  $n = 0.4$  or  $n = 0.6$ , that is, when the anti-slide pile is located in the middle of the slope, the sliding surface is effectively divided into upper and lower parts by the anti-slide pile, forming a non-through sliding surface. The existence of the anti-slide pile prevents the development of the sliding surface and increases the anti-slide force of the soil. At this time, the slope safety factor has been significantly improved compared with the safety factor of other pile positions.

The results show that the anti-slide pile can play its anti-slide role more effectively and improve the overall stability of the slope when it is located in the slope. Reasonable selection of pile position can effectively improve the safety factor of slope and prevent the occurrence of slope instability accidents.



**Fig. 5.** The most dangerous sliding surface of anti-slide piles at different positions

In order to further study the influence of the change of pile length on the safety factor and the force of the pile body, the pile is arranged in the middle of the slope, that is,  $n = 0.5$ , and the internal force diagram of different pile lengths is calculated respectively when the pile diameter is 1.2 meters and the pile spacing is 4 meters. Figure 6

shows the curve of the maximum bending moment of the pile with depth under four different pile lengths. The curve in the diagram reflects the variation of the maximum bending moment of the pile with the depth, and also reflects the influence of the pile length on the slope stability and the stress state of the pile.

The results in the figure show that with the increase of pile length, the maximum bending moment of pile body shows an upward trend. This shows that when the pile length increases, the soil lateral pressure and shear force borne by the pile body also increase, resulting in an increase in the bending moment inside the pile body. At the same time, the increase of pile length also brings the improvement of slope safety factor. In general, it can be concluded that the better the reinforcement effect of anti-slide pile, the greater the maximum bending moment of pile body. The change of pile bending moment generally shows a trend of ' first decrease, then increase and then decrease '.

It is generally believed that the monitoring results of pile top displacement are important parameters for analyzing the deformation of anti-slide piles. Figure 6 By comparing the simulation results of different pile lengths, the displacement of the top of the anti-slide pile is studied. The horizontal displacement of the pile is the largest at the top of the pile, and gradually decreases with the increase of depth, forming a curve similar to a parabola. When the pile length is short, the horizontal displacement of the pile is about 10 mm. This is because shorter piles do not penetrate deeper into more stable soil layers, so their ability to resist horizontal loads is weak. When the pile length is less than 35 meters, the horizontal displacement of the pile decreases with the increase of the pile length. This is because longer piles can penetrate deeper into deeper soil layers, which have better soil properties, thereby increasing the lateral resistance of the pile. However, after the pile length exceeds 35 meters, the effect of increasing the pile length on reducing the horizontal displacement of the pile will no longer be significant.

In general, it is recommended that the pile length of 35 meters is set in the middle and lower part of the slope.

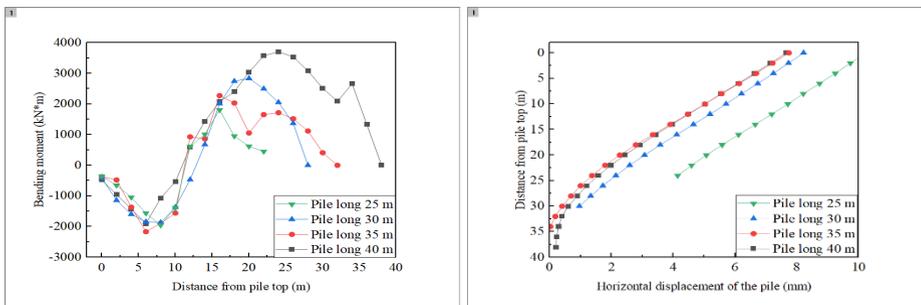


Fig. 6. Bending moment and pile displacement diagram of different pile length

### 3 Effect of Pile Diameter on Slope Stability

The matching of pile diameter and pile length is also an important factor affecting slope stability [7]. In a certain range, increasing the pile length can improve the stability of the slope, but if the pile diameter is too small, even if the pile length increases, its bearing capacity and friction resistance may not be enough to resist the sliding force of the slope. In order to analyze the influence of pile diameter and pile spacing on the effect of slope reinforcement. It is assumed that the pile length is 40 m, the pile spacing is 4 m, and the pile diameter is 0.8m, 1.0m, 1.2m, 1.4m respectively. The relationship between the shear force, bending moment, pile displacement and the pile diameter is shown in Figures 7 and 8.

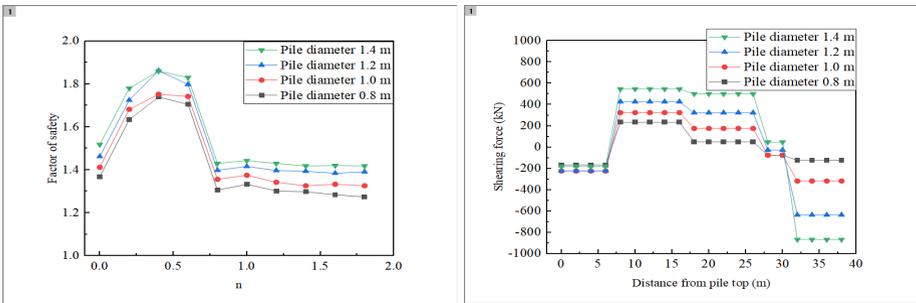


Fig. 7. Safety factor and shear diagram under different pile diameters

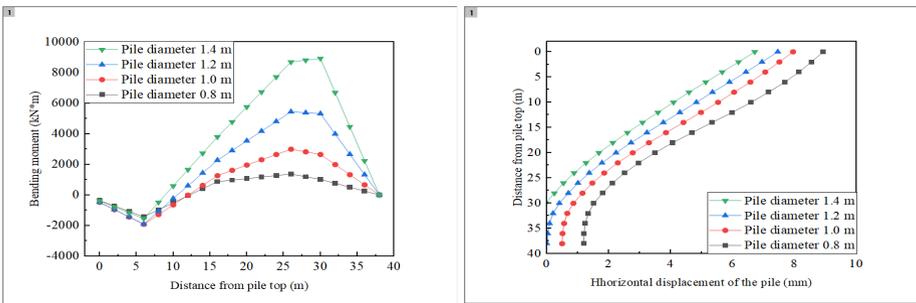


Fig. 8. Bending moment and pile displacement diagram under different pile diameter

It can be seen from Fig.7 that when the pile diameter gradually increases from 0.8 meters to 1.2 meters, the safety factor of the slope shows a steady upward trend. When the pile diameter is 1.2 meters and  $n = 0.4$  ( the pile position is located in the middle and lower part of the slope ), the slope safety factor reaches a peak of 1.86, which indicates that the pile diameter plays an important role in improving the slope stability. This is because the increase of pile diameter leads to the increase of pile cross-sectional area and pile stiffness, so that the pile can withstand greater lateral earth pressure. With the increase of pile diameter, the pile body can more effectively disperse and bear the lateral force from the soil, thus improving the stability of the

slope. At the same time, the increase of the stiffness of the pile body makes the anti-deformation ability of the pile body significantly improved when it is subjected to lateral earth pressure. The enhancement of this anti-deformation ability helps to reduce the deformation of the slope. However, when the pile diameter is further increased to 1.4 meters, the change of safety factor is not obvious. This shows that the improvement of the safety factor of the slope by the pile diameter is not unlimited, but there is an optimal range. Beyond this range, the effect of increasing the pile diameter on improving the safety factor of the slope will no longer be significant, because the increase in economy and construction difficulty becomes uneconomical [ 8, 9].

With the increase of pile diameter, the contact area between pile and soil also increases, which means that the friction resistance between pile and soil is enhanced, thus improving the stability of slope. It can be seen from Figure 8. With the increase of pile diameter, the bending moment of pile body increases gradually. Excessive bending moment may cause the pile material to reach its strength limit, resulting in damage. This kind of damage will not only reduce the bearing capacity of the pile, but may have an adverse effect on the stability of the slope.

Figure 8 shows the relationship between the pile diameter and the horizontal displacement of the pile. With the increase of pile diameter, the horizontal displacement of pile body decreases gradually. When the pile diameter is 0.8 meters, the maximum horizontal displacement of the pile body reaches 9.2mm, and when the pile diameter increases to 1.4 meters, the maximum horizontal displacement decreases to 6.3mm. This change rule shows that increasing the pile diameter can effectively control the horizontal displacement of the pile body, thereby reducing the deformation of the slope and improving its stability.

In summary, it is recommended that the pile diameter of this project be 1.2 meters [ 10,11 ].

### 4 Effect of Pile Spacing on Slope Stability

The fixed pile length is 40m, the pile diameter is 1.2m, and the pile spacing is 2m, 4m, 6m and 8m respectively for analysis and assumption. The relationship between shear force, bending moment, pile displacement and pile spacing is shown in Figs. 9 and 10 [ 12 ].

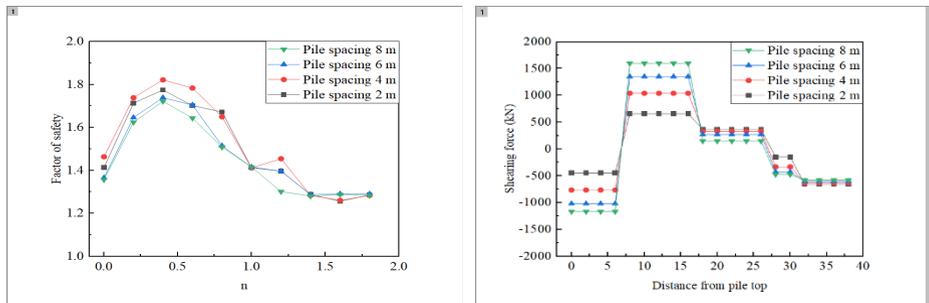


Fig. 9. Safety factor and shear curve under different pile spacing

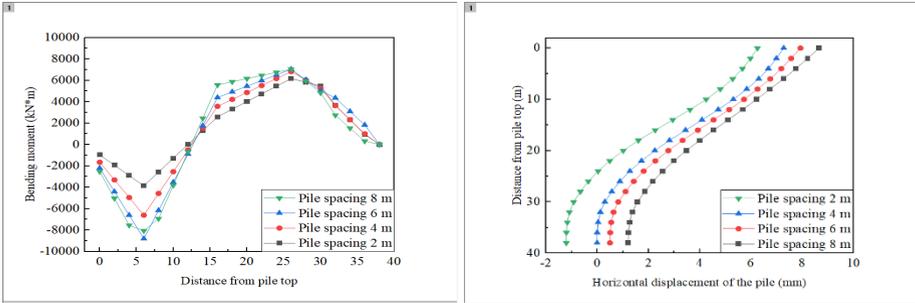


Fig. 10. Bending moment and pile displacement diagram under different pile spacing

It can be seen from Fig.9 that the slope safety factor shows a decreasing trend with the increase of pile spacing. The reason is that the smaller pile spacing means that the soil is supported by more piles, which provides a stronger anchoring effect and improves the overall stability. The reduction of pile spacing makes the stress distribution in the soil more uniform, and the load is shared by more piles, which is very important to maintain the stability of the slope. If the pile spacing is too large, the anchoring effect between the pile and the soil may be significantly weakened, and the risk of soil failure may be increased [13,14].

Figure 10 is the bending moment diagram of the pile body corresponding to different pile spacing after the anti-slide pile reinforces the slope. With the increase of pile spacing, the soil pressure between piles shared by each anti-slide pile also increases, resulting in a gradual increase in the bending moment of the pile [15,16].

Figure 10 shows the change of horizontal displacement of pile body under different pile spacing. With the increase of pile spacing, the horizontal displacement of the pile body also increases, the maximum displacement reaches 8.76 mm, and the minimum displacement is 6.12 mm. This result shows that the increase of pile spacing will not only lead to the decrease of slope stability, but also cause greater displacement of pile body, which may have a negative impact on the overall stability of slope.

When considering the influence of pile spacing on slope stability, the economic problem must also be considered. Although reducing the pile spacing can improve the stability of the slope, it will also increase the number of piles, thereby increasing the cost of the project. Therefore, the choice of pile spacing needs to ensure that the expected reinforcement effect can be achieved without causing unnecessary waste of resources.

In general, it is recommended that the pile spacing of this project is 4 meters.

## 5 Conclusion

In this paper, the main influencing factors of slope stability under the combined structure of pile foundation and retaining structure are studied by finite element simulation. It is recommended that the pile position should be set in the middle and lower part of

the slope. The pile length is 35 meters, the pile diameter is 1.2 meters, and the pile spacing is 4 meters. The following main conclusions are drawn :

(1) The influence of pile position on slope stability : When the anti-slide pile is located in the middle and lower part of the slope, the safety factor is significantly improved. When the pile foundation is located at the top of the slope after 20 meters, the anti-sliding effect is poor. Setting anti-slide piles in the middle of the slope can effectively divide the sliding surface and improve the stability of the slope.

(2) The influence of pile length and slope stability : For the unstable slope, increasing the pile length is helpful to improve the stability of the slope within a certain range. With the increase of pile length, the maximum bending moment value of pile body shows an upward trend. The longer the pile length, the more likely the pile body is to be destroyed. The horizontal displacement of pile body is the largest at the top of pile, which decreases with the increase of depth.

(3) The increase of pile diameter can significantly improve the safety factor of the slope within a certain range. However, the increase of pile diameter is also accompanied by the increase of bending moment, and excessive bending moment may lead to pile damage. In addition, the increase of pile diameter is also beneficial to control the horizontal displacement of pile body, which helps to reduce the deformation of slope.

(4) The reasonable selection of pile spacing is very important for the reinforcement effect of slope. Smaller pile spacing can provide better anchoring effect and improve the safety factor of the slope. However, too small pile spacing will lead to an increase in project costs.

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