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Analysis of the Soil Arch Effect of the Mechanical Rotary Bored Anti-slide Piles and Ultimate Arch Thickness Calculation

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Abstract

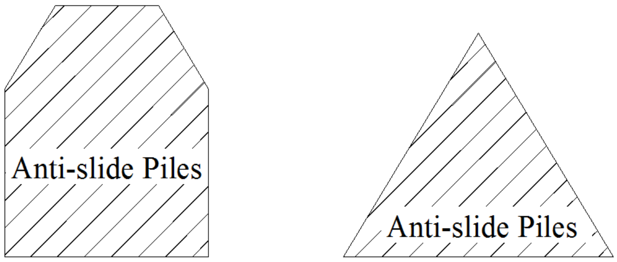
The soil arch effect is an important precondition to give full play to the supportive role of the anti-slide piles and other non-continuous supporting structures in a safe and economical manner and the study on the establishment and destruction modes of the soil arch effect of the anti-slide piles is of great significance to confirm the reasonable pile distance. Current researches on the soil arch effect of anti-slide piles mostly focus on artificial bored piles (rectangular pile), while studies on the mechanical bored anti-slide piles with round sections are relatively scarce. Meanwhile, there are more and more cases of application of the mechanical rotary bored anti-slide piles to engineering practice. It is obviously unreasonable to directly apply the rational pile spacing obtained based on the theory of rectangular anti-slide pile soil arch to the design and construction of mechanical rotary bored anti-slide piles. Therefore, taking advantage of the geometrical characteristics of the reasonable arch axis curve and the direction of the compressed fracture angle, this paper put forward the form of arching of the soil arch effect of the mechanical rotary bored anti-slide piles based on mechanical concept analysis, made analytical investigation into the failure theory of the soil arch effect of this kind of anti-slide pile and further verified the result using the numeral simulation software. Finally, the ultimate arch thickness under the influence of large landslide thrust is calculated, which provides an important reference for the determination of the reasonable pile spacing of the mechanical rotary bored anti-slide piles.

Key words

Soil arch effect, Mechanical rotary bored anti-slide piles, Circular cross section, Failure theory, Ultimate arch thickness.

1. Introduction

In the construction of mountainous roads and railways, due to the complex geological and terrain conditions, a large number of high-slope projects have been formed, so the anti-slide piles are applied more and more extensively. In order to reduce the project cost, if possible, the anti-slide pile often uses discontinuous structure, and no soil shield is set. The arching effect [1] formed by the strength of the soil itself transmits the residual thrust of the soil mass between the piles to the pile body to achieve the purpose of support. At present, there are many researches on the soil arch effect of artificial bored pile (rectangular pile), and systematic theories have also formed. As for the soil arch effect of the anti-slide piles with other section types other than rectangular ones, You Wenxing et al. studied the anti-slide pile with a special cross section as shown in Figure 1a. They put forward the theory of the part behind the pile and side pile serving as the arch springing support and made related analysis and certification [2]; Wang Peiyong et al. once considered the difference of the supporting and retaining effects of triangle anti-slide pile and rectangular anti-slide pile [3]. But in general, there are few studies on anti-slide piles with non-rectangular cross section. In particular, there is still no specific study on the soil arch effect of the anti-slide piles with round section form such as the mechanical rotary bored anti-slide piles. And with the continuous development of the slope control project, for mechanical rotary bored anti-slide pile, the pile hole boring is mainly completed by machine, and workers are not required to go down to the pile well, so this kind of pile is more secure from the perspective of construction. It will be widely used in the society which generally emphasizes engineering safety for the moment. The study on its soil arch effect is of great significance to the construction and design of this kind of anti-slide piles. The author thinks that the soil arch effect of the mechanical rotary bored anti-slide piles has similarities with those of the rectangular anti-slide piles. The soil arch of the two kinds of anti-slide piles is both spontaneously formed by the stress transfer and adjustment due to the uneven deformation of the soil body, which is the result of adjusting own shear strength to resist the exterior forces [4, 5]. There is no doubt that the soil arch axis of the mechanical rotary bored anti-slide pile is also an arch, but the supporting form and specific location of the soil arch remain to be discussed. Therefore, adopting the idea of engineering analogy, this paper first carries out qualitative analysis of the arching form of the mechanical rotary bored anti-slide piles based on the existing theories about the soil arch effect of the rectangular anti-slide piles, and then analyzes the destabilization failure mode of the soil arch and finally proves that the arching of the soil effect of mechanical rotary bored anti-slide piles is practical through back calculation and numerical modeling based on the ultimate failure theory.



a b
a: anti-slide piles with special sections b: anti-slide piles with triangular section

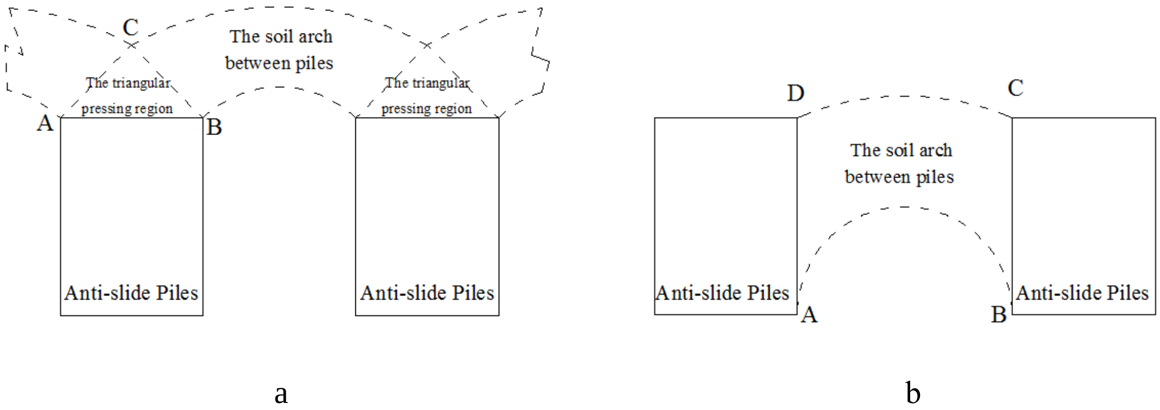
Fig.1. Sketch Map of Anti-slide Piles with Other Section Types

2. Qualitative Analysis of the Arching Form of Mechanical Rotary Bored Anti-slide Piles

In this paper, the qualitative analysis of the arching of mechanical rotary bored anti-slide piles can be carried out based on the existing theory about the soil arch effect of the rectangular anti-slide pile.

2.1 Brief Description of the Arching Form of the Rectangular Anti-slide Piles

There are two types of recognized arching forms for the soil arch effect of rectangular piles: The first type is shown in Figure 2a: the arch springing of the soil arch is located in the triangular pressing region behind the pile. This area is completely composed of squeezed soil, which plays the role of supporting the soil arch. The second type is shown in Figure 2b. The soil arch between piles are formed with the friction force between the pile side and the soil body. The two kinds of soil arch have been studied by many scholars, and many theories on the soil effect of the rectangular anti-slide piles have been concluded [6, 7]. Objectively, these two types of soil arch both exist, but the focus of the analysis and calculation of different engineering objects is different: for example, for the pit support pile, the soil arch behind the pile is more important, because the extrusion displacement of the soil between piles is strictly controlled. For the underground anti-slide piles used in the slope engineering, due to the continuity of the soil body surrounding the pile body, the impact of the second type of soil arch can't be neglected.

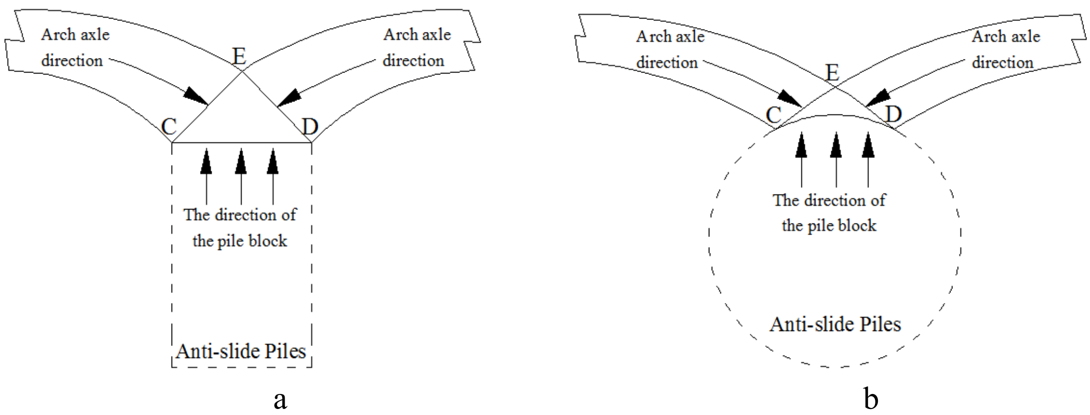


a: The first type of arching from   b: The second type of arching form

Fig. 2. Sketch Map of Two Types of Arching Forms of Rectangular Anti-slide Piles)

2.2 Qualitative Analysis of the Arching Form of Mechanical Rotary Bored Anti-slide Piles

Under the action of the landslide thrust, the soil body behind the mechanical rotary bored anti-slide pile will be firstly blocked by the anti-slide pile, and some of the soil will remains behind the pile and suffers compressional deformation. Therefore, during the process of shaping of the soil arch effect of the mechanical rotary bored anti-slide pile, a triangle press-bearing region similar to the first type of arching form of the rectangular anti-slide will possibly form in this region, which is shown in the CDE zone in Figure 3b. CD stands for the pile soil contact surface in the press-bearing region. Figure 3a is the sketch map of the triangle pressure-bearing zone of the rectangular anti-slide pile.



a: rectangular anti-slide pile   b: mechanical rotary bored anti-slide pile

Fig.3. Sketch Map of the Triangular Pressure-bearing Zone of Two Types of Anti-slide Piles

Due to the pressure sensitivity of the geomaterials, there is small possibility of shear failure in the interior of the soil body in the pressure-bearing area of the two kinds of anti-slide piles under the squeezing action of the symmetric axis force, while there is great possibility of shear failure on the surface of the pressure-bearing area. Compared with the rectangular pile, when the axle load of the soil arch is large, the shear failure might occur to the soil body on the surfaces of DE and CE in the pressure-bearing zone. Since the pile body has a hook face, there is possibility of shear failure of the soil body on the pile soil contact surface CD. Since the soil surface of the rectangular anti-slide pile is horizontal, under the action of the symmetric arch axis force, there is no shear stress on the CD surface in theory. So relatively speaking, the pressure-bearing region behind the pile in the first type of arching form is less stable than that of the rectangular anti-slide pile. Under relatively large force of landslide thrust, the area that can stably serves as the supporting arch springing is limited in this region, and the bearing capacity is weak accordingly. Therefore, the possibility that soil arch effect occurs only in the first type of arching form is small for mechanical rotary bored anti-slide pile. Furthermore, under most circumstances, the soil body surrounding the pile body is all continuous and exposed pile body is seldom seen. Therefore, there must be great friction force between the pile body and the soil body during the process of blocking and there is great possibility of the occurrence of soil arch between the piles in the second type of arching form similar to the rectangular anti-slide pile.

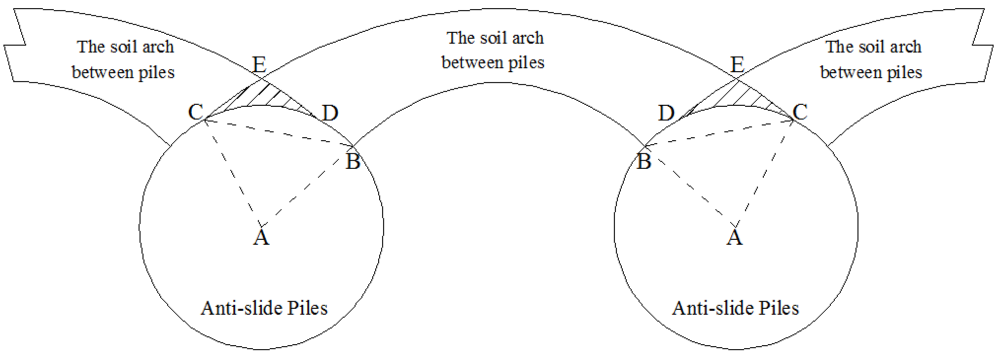


Fig.4. Sketch Map of the Arching Form of Mechanical Rotary Bored Anti-slide Pile

To sum up, the soil arch effect of the mechanical rotary bored anti-slide pile is likely to have the above two types of arching forms. And because of the continuity of the surface of the pile body, there is no demarcation point between the right angle and corner, so these two kinds of soil arches actually roll up into one. The effect is shown in Figure 4. An analogous triangle pressure-bearing area similar to the first type of soil arch of the rectangular pile was produced behind the mechanical rotary bored anti-slide pile, i.e. CDE part in the picture, which is smaller than that of the same-size rectangular anti-slide pile. At the same time, a majority of the arch springing directly supports the body of the mechanical rotary bored anti-slide pile, i.e. the position where section BD is located. At this moment, the whole BDEC area can be viewed as the pressure-bearing area of the arch springing, which contains the extruded soil CED and partial pile body BCD. The whole BE surface constitutes the pressure-bearing face of the soil arch springing.

3. Analysis of Failure Theory of the Soil Arch Effect of Mechanical Rotary Bored Anti-slide Pile

Relevant researches point out that the soil arch effect of the anti-slide pile is formed by the soil body after exerting its own shear strength, so there is upper limit for its bearing capacity. When the landslide thrust behind the pile exceeds the upper limit, the soil arch will be damaged, and the soil arch effect will lose efficacy. Thus, the retaining effect of the anti-slide pile will be greatly affected [8][9]. Therefore, the study of the failure mode and pressure-bearing limit of the soil arch effect of the anti-slide piles are of great significance to the construction and design of anti-slide piles.

3.1 Relationship of the Failure of Arch Springing Pressure-bearing Area and the Overall Unstability of the Soil Arch

In the above analysis, it has been mentioned that the soil body behind the mechanical rotary bored anti-slide pile and the pile side constitute together the arch springing pressure-bearing area. Relevant researches point out that the arch axis of the soil arch effect of the anti-slide pile is a reasonable arch axis curve [10, 11], which is shown as the imaginary line HF in Figure 5. The imaginary line BC indicates that this soil arch is located in the end section of the arch curve. The principal stress of the arch axis shall be perpendicular to this section which is an important stress analysis surface. Jiang Liangwei and Huang Runqiu pointed out when stress failure occurs to the arch springing, the key of the failure is that the proportional relationship of the shearing strength and the normal stress has exceeded the strength allowing condition. The judgement on the soil arch intensity can be simplified as the analysis of the axial compressive stress σ of the arch ring. The arch springing is the place where the axial compressive stress is maximum and the failure of soil arch is most likely to occur [12]. Therefore, the analysis of the overall unstability of the soil arch effect of the mechanical rotary bored anti-slide pile can be transformed into the analysis of the stability of the arch springing pressure bearing area. Once shear failure occurs to the arching springing, the whole soil arch can't continuously play its role.

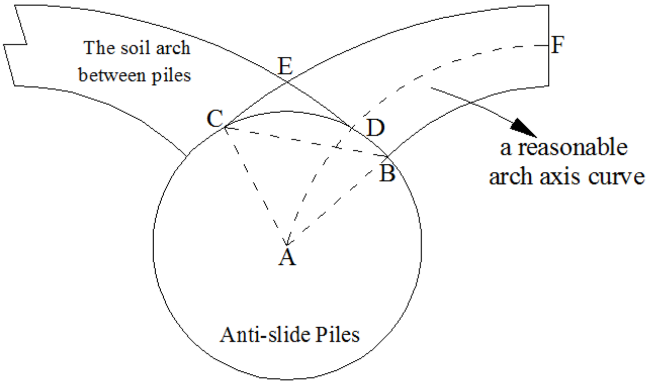


Fig.5. Sketch Map of Soil Arch Effect of the Mechanical Rotary Bored Anti-slide Pile

3.2 The Proposition of the First Breakdown Point of the Arch Springing Pressure-bearing Area

Within the whole soil arch range, the arch springing pressure-bearing area bears the largest uniaxial stress. The arch springing pressure-bearing area can be further divided into CDE and BCD two parts in Figure 5 as per the difference of pressure-bearing objects. As mentioned earlier, both regions are less likely to be damaged from the interior. Compared with the landslide thrust, the intensity of the anti-slide pile materials is very high, and because of the pressure-sensitivity of the geotechnical materials, the shear strength of the soil mass in the compressional area will enhance a lot accordingly under the confining pressure effect. Therefore, in the whole arch springing pressure-bearing area, the soil mass at the surface of this region is most vulnerable to shear damage, i.e. Faces BE and CE in Figure 5.

From a symmetrical point of view, it is enough to just study the stress condition of the soil body on the BE face. As the arch springing pressure-bearing face, BE face is not perpendicular to the arch axis and the stress on the surface is uneven. The point B, as a point on BE face, is also at the end section BC of the arch axis, so it bears the largest stress on the whole BE face. It has been pointed out earlier that the judgement on the soil arch intensity can be transformed to the analysis of the axial compressive stress σ of the arch ring [12]. Therefore, the shear failure is most likely to occur to point B in the whole soil arch pressure-bearing surface, because:

1) The surface BC where point B is located bears the largest uniaxial stress and point B also belongs to the potential failure surface BE.

2) The included angle between the tangential direction of point B at the pile body surface and the major stress surface BC is the largest. Since the whole BE surface is the soil-pile interface, the direction of the shearing strength borne by the points at the surface of the pile body is consistent with the tangential direction of all points. It can be seen from the Mohr's Circle in Figure 6 that when the soil body suffers ultimate failure, the included angle between the shearing strength and the main stress surface is just 45°+½*Φ* (*Φ* is the internal friction angle of the soil mass) . Before this angle is reached, the larger the included angle between the tangential direction of a point in the arc and the major stress acting surface BC, the more likely shear damage will occur. Therefore, point B can be viewed as the first breakdown point to study the failure of the whole arch springing pressure-bearing area.

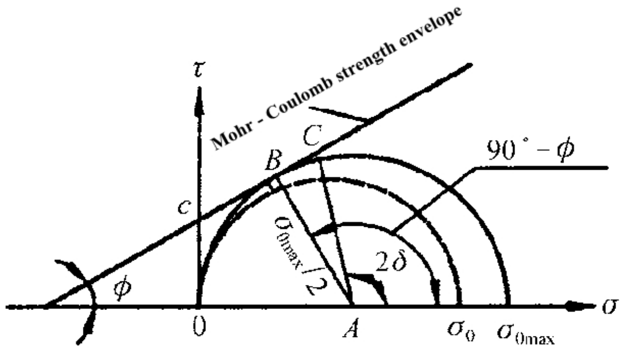


Fig.6. Unidirectional Pressed Mohr's Circle and Strength Criterion

4. Calculation of the Ultimate Thickness of the Arch in the Soil Arch Effect of Mechanical Rotary Bored Anti-slide Pile

Under the action of landslide thrust, the arch thickness in the soil arch effect of the anti-slide pile is directly affected by the size of the landslide thrust behind the pile, demonstrating the carrying capacity of the soil arch. Under normal conditions, the bearing capacity of the natural soil arch is certainly limited, thus corresponding to only one ultimate arch thickness. The determination of the ultimate arch thickness helps to study the ultimate slip resistance capacity of the anti-slide pile and other discontinuous retaining structure under the condition that the slab-pile wall is not set.

As mentioned before, point B is thought to be the point where the shear failure occurs the earliest in the arch springing area and is called the first failure point. It can be seen from the stress condition of the point that: when the landslide thrust behind the pile is small, or even far smaller than the maximum support capacity of the soil body to spontaneously form the soil arch between piles, point B is in a steady state of bearing unidirectional pressure. The stress condition of this point meets the following condition:

$$\theta < 45^\circ + \frac{\phi}{2} \tag{1}$$

$$\sigma_0 < \sigma_{0\max} \tag{2}$$

In the formula, θ is the included angle between the arc tangential direction of point B and the major stress surface. Φ is the internal frictional angle of the soil body; σ_0 is the stress exerted on the major stress surface BC at the end of the soil arch; σ_{0max} is the ultimate principal stress of the shear failure of soil body.

When the landslide thrust behind the post became larger, the stress σ_0 on the surface of BC is close to the ultimate stress σ_{0max}. And the included angle between the acting surface and the tangential direction of the failure point B is close to the limit angle $45°+½\Phi$.When the landslide thrust reaches the limit, and shear damage occurs to this point coincidently, the stress condition of point B shall satisfy:

$$\theta = 45^\circ + \frac{\phi}{2};\quad \sigma_0 = \sigma_{0\max} \tag{3}$$

$$\angle ABC = 45^\circ - \frac{\phi}{2} \tag{4}$$

$$AB = AC = r \quad so \quad \angle ACB = \angle ABC = 45^\circ - \frac{\phi}{2} \tag{5}$$

$$BC = 2r\cos\angle ABC = 2r\sin\frac{\phi}{2} \tag{6}$$

$$\angle BAC = 90^\circ + \phi \tag{7}$$

where r refers to the radius of the mechanical rotary bored anti-slide pile; θ is the included angle between the arc tangential direction of Point B and the major stress surface; Φ refers to the internal friction angle of the soil body; σ_0 is the stress exerted on the major stress surface BC at the end of the soil arch; σ_{0max} is the ultimate principal stress of the shear failure of soil body.

The above equations show that: When the ultimate failure occurs to the soil arch effect of the mechanical rotary bored anti-slide piles, the arch thickness of the soil arch is a constant value, which equals to $2r\sin\frac{1}{2}\Phi$. Meanwhile, when the soil arch between the piles is to suffer ultimate failure, the corresponding central angle $\angle BAC$ is definitely larger than 90°. So the soil arches whose arch springings are at both sides of the same pile will definitely form a confluence area, which is similar to the triangle compression zone in the first type of arching form of the rectangular anti-slide pile. At the same time, partial arch springings directly support the pile body.

To sum up, the arching form of the soil arch of mechanical rotary bored anti-slide pile put forward after qualitative analysis corresponds to reality.

5. Numerical Simulation Verification

When numerical simulation is carried out to the soil arch effect, the soil arch effect can be simplified as a two-dimensional question to be resolved [13-15]. By adopting the soil engineering finite element software Plaxis 8.2, this paper simplifies the soil arch effect to a two-dimensional problem to carry out numerical simulation, and uses the results to verify the conclusions in this paper about the arching form of the mechanical rotary bored anti-slide pile. Take the underground soil layer of unit thickness as the analysis object, and add one even load p in the horizontal direction to simulate the landslide thrust. Use different sizes of p to simulate different sizes of landslide thrust. The simulation principle is shown in Figure 7. Assume that (1) the displacement direction of the simulated soil layer of unit thickness is limited to the horizontal direction; (2) the section of the pile body is a circle whose radius is 3m; (3) the soil layer is composed of sand; Elasticity modulus=13,000kN/m², Poisson's ratio v=0.3, internal friction angle Φ= 32°, dilatancy angle=0° and there is even load.

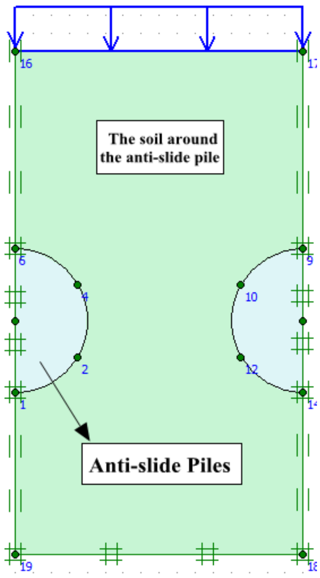


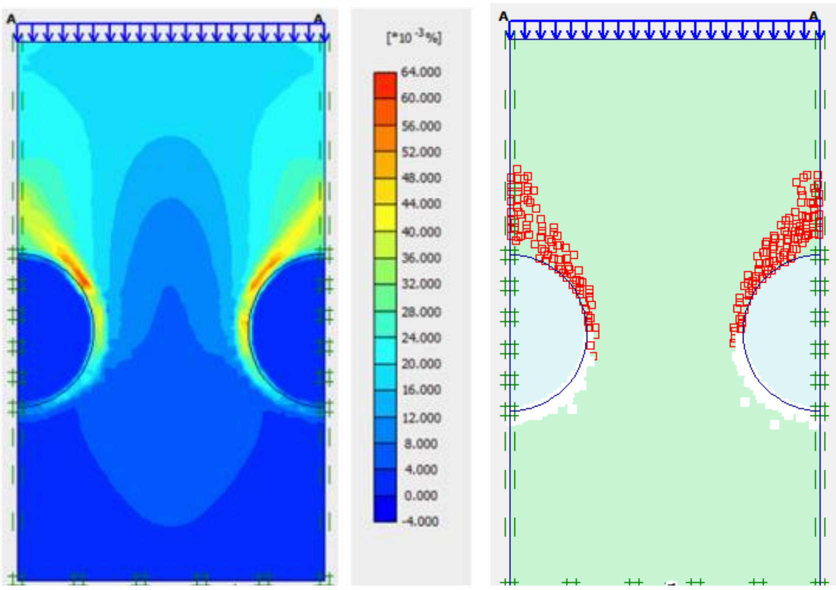
Fig.7. Sketch Map of Plaxis Numerical Modeling

The results of numerical simulation are shown in Fig. 8, in which Figs. 8a and 8b represent the cloud picture of the shear stress and the sketch map of the plasticity point of the soil around the anti-slide pile, respectively. It can be seen from the cloud diagram of the shear stress that the maximum shear stress surface of the soil shows a clear trend from the pile side to the place behind the pile, but the internal shear stress of partial soil behind the pile is not large, indicating the possibility of internal shear failure is small under the action of the symmetry axis force action. But the shear stress on the surface of the region is very large, reflecting the shear failure is prone to occur to the surface of the press-bearing area of the arch springing. Jiang Liangwei, Huang Runqiu et al. proposed that for rectangular anti-slide pile, the anti-slide piles are set as a single row, and the continuously symmetrical soil arch is formed. In partial area behind the same pile body, the soil arches at the neighboring two sides form a triangle pressure-bearing area in this area. At this moment, the two waists of the triangle are the failure surfaces most unfavorable to the arch springing. The soil body in the arch ring cuts out towards the free face when being damaged. This conclusions conform to the numerical simulation results, suggesting that a triangle press-bearing region of the mechanical rotary bored anti-slide pile, which is similar to the first type of arching form of the rectangular anti-slide, has really formed.

In the schematic diagram of the plasticity dot: red dot refers to the plasticity point of the soil body, and the white part represents the tensile cut-off point. Except for a large number of plasticity points on the surface of the triangle pressure-bearing area, the plasticity points have spread from the place behind the pile to the position near the middle of the side face of the pile body, which is obviously not in the range of the triangular pressure-bearing area, indicating that in addition to providing support to the analogous triangle soil body behind the pile, the arch springing of the soil arch also supports the pile directly, so that stretching truncation does not occur to partial soil body on the surface of the pile under the axial pressure, but there is a possibility of shear failure.

Indicating that the arch arch in addition to supporting the pile after the triangular soil, but also directly supported on the pile body, resulting in axial pressure on the surface of the pile part of the soil did not occur tensile truncation, but there is the possibility of shear damage.

To sum up, for the soil arch effect of the mechanical rotary bored anti-slide pile, the two waists of its triangle pressure-bearing area and partial edge of the pile body together constitute the danger boundary of the arch springing of the soil arch, i.e. the position of the pressure bearing surface of the arch springing which was put forward previously. This boundary is the place where the soil arch stress is the most centralized. The corresponding shear strength is large and the shear failure surface is long, demonstrating a clear trend.



a b

a:Cloud Picture of Shear Stress b:Sketch Map of Plasticity Point

Fig.8. Sketch Map of Numerical Simulation Results

Conclusions

Combining the existing theories on the soil arch effect of the rectangular anti-slide pile, this paper makes qualitative analysis of the arching form and failure theory of the soil arch effect of mechanical rotary bored anti-slide piles. Later, calculation and numerical simulation were carried out to the analysis results and the results prove to be authentic. The conclusions are drawn as follows:

1) The forming of the soil arch effect of the mechanical rotary bored anti-slide pile relies simultaneously on the shear strength of the soil itself and the size of the pile-soil friction force, i.e. the soil arch behind the pile and the soil arch between the piles formed by the pile-soil friction force exist simultaneously, which are similar to the two kinds of soil arches of rectangular anti-slide pile. Different from the two kinds of soil arches of rectangular anti-slide pile, which exist independently from each other, there is only one complete soil arch for the mechanical rotary bored anti-slide pile because of the surface continuity of the soil body. The arch springing of this soil arch is co-supported by the analogous triangle pressure-bearing soil body behind the pile and local pile body.

2) The instability of the soil arch effect of the mechanical rotary bored anti-slide pile starts from the failure and instability of the arch springing, and the failure of the arch springing starts from the first failure point on the pressure-bearing surface of the arch springing. When the landslide thrust behind the pile is relatively small, and neither the stress size of the first failure point nor the included angle between the tangential direction of this point and the major stress surface achieves the extent to arouse shear failure to the soil body, the whole soil arch is secure and stable; when the landslide thrust behind the pile is relatively large, and ultimate failure occurs to the soil arch, both the stress size of the first failure point and the included angle between the tangential direction of this point and the major stress surface achieve the extent to arouse shear failure to the soil body, i.e. $\sigma_0=\sigma_{0max}$, $\theta=45°+½\Phi$. At this time, the arch thickness of the soil arch is a constant value, which equals to $2r\sin½\Phi$.

3) The specific location of the first failure point is very important. As long as the location is figured out, the specific position and the size of corresponding bearing capacity of the soil arch of the mechanical rotary bored anti-slide pile at the ultimate state can be inferred based on the ultimate arch thickness and the degree of the central angle of the soil arch. And combining the size of the actual landslide thrust, the reasonable pile distance can be figured out. Although the algorithm of the specific location of the first failure point is not given in this paper, the concept of stable analysis around this point was put forward and relevant theories can further develop. This paper is of great significance to the study of the reasonable pile distance for mechanical rotary bored anti-slide pile.

References

1. Z.S. Wu, L.M. Zhang, Studies on the mechanism of arching action in loess, 1995, Journal of Chengdu University of Science and Technology, vol. 83, no. 2, pp. 15-19.
2. X.Wen, X.J. Pei, Y.P. Liu, Stress characteristics and soil arch effect analysis of anti-sliding piles with special cross-section, 2013, Journal of Engineering Geology, vol. 21, no. 5, pp. 797-803.
3. P.Y. Wang, T. Dong, X.D. Li, Comparative analysis of anti-sliding performances between two kinds of piles based on soil arch theory, 2016, Journal of Logistical Engineering University, vol. 32, no. 6, pp. 22-28.
4. M. Yang, L.K. Yao, G.J. Wang, Study of centrifuge model tests and numerical simulation on soil arching in space of piles, 2008, Rock and Soil Mechanics, vol. 29, no. 3, pp. 817-822.
5. H.L. Jia, C.H. Wang, J.H. Li, Discussion on some issues in theory of soil arch, 2003, Journal of Southwest Jiaotong University, vol. 38, no. 4, pp. 398-402.
6. Y.H. Zhou, D.P. Zhou, J. Feng, Geometrically mechanical characters of soil arch between two adjacent laterally loaded piles and determination of suitable pile spacing, 2006, Rock and Soil Mechanics, vol. 27, no. 3, pp. 455-462.
7. D.P. Zhou, S.G. Xiao, et al, Discussion on rational spacing between adjacent anti-slide piles in some cutting slope projects, 2004, Chinese Journal of Geotechnical Engineering, vol. 26, no. 1, pp. 132-135.
8. J.X. Zhang, F.Q. Chen, H.Y. Jian, Numerical analysis of soil arching effects in passive piles, 2004, Rock and Soil Mechanics, vol. 25, no. 2, pp. 174-178.
9. S.Q. Peng, J. Zhou, L. Fan, et al., Research on earth pressure of rigid retaining wall considering soil arching, 2008, Rock and Soil Mechanics, vol. 29, no. 10, pp. 2701-2707.
10. C.H. Wang, Y.B. Chen, et al., Soil arch mechanical character and suitable space between one another anti-sliding pile, 2001, Journal of Mountain Science, vol. 19, no. 6, pp. 556-559.
11. Q.K. Wang, Discussion on the soil arching effect and the critical spacing between adjacent anti-slide piles, 2005, Journal of Wuhan University of Technology, vol. 27, no. 8, pp. 64-67.
12. L.G. Jiang, R.Q. Huang, Z.X. Jiang, Analysis of soil arching effect between adjacent piles and their spacing in cohesive soils, 2006, Rock and Soil Mechanics, vol. 27, no. 3, pp. 445-450.
13. A.M. Han, J.H. Xiao, G.X. Mei, Plane FEA of soil arching effects m echanism in passive piles, 2005, Journal of Nanjing University of Technology, vol. 27, no. 3, pp. 89-92.
14. Z.C. Li, M. Yang, Soil arching effect on passive piles and 3-D numerical analysis, 2006, China Civil Engineering Journa, vol. 39, no. 3, pp. 114-117.

15. X.D. Ju, W.J. Feng, J.M. Zhu, Research on affecting scope of soil arch behind anti-slide piles, 2006, J. of China Three Gorges U niv. (Natural Sciences), vol. 28, no. 3, pp. 197-200.