TYPE DOOR RIGID FRAME-PILE ARCH SYSTEM CHARACTERISTICS AND DISASTER PREVENTION APPLICATION IN THERMODYNAMICS

by

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The construction of mountain roads often promotes the occurrence of landslides, and poses a serious threat to the safety of driving and the geological environment. This paper introduces a new type of road landslide area anti-sliding structure based on thermal factors. The type door rigid frame-pile arch system, it is mainly composed of three parts: the gate type anti-slide pile, the reinforced concrete arch plate, and the mouth shaped guard pier. Its characteristics are: door-type anti-slide pile role is to resist the landslide thrust and the main road as a support structure; reinforced concrete arch between the plate as the door-type anti-slide pile and pile retaining force transmission member, active play arch structure compression high strength, can change the mechanical properties of stress paths, so that the lateral landslide sliding force to reduce; shaped mouth guard pier to control the deformation and solid slope, and enhance the overall stability of the system. The FLAC3D simulation results show that the stress distribution of arch plate is more uniform, with the increase of the sliding force, the stress in the arch foot and the lower part of the arch plate increases rapidly, which accords with the principle of soil arching. At the same time, the contact beam gradually works, The landslide thrust is transmitted to the front row of piles. The stress of the rear row of piles increases more than that of the front row of piles. The stress of the upper part of the beam increases more than that of the lower part of the beam. The overall trend is more and more gentle.

Key words: *type door rigid frame-pile arch system, soil arch effec, landslide, stress analysis, door type anti-slide pile, arch plate, thermal*

Introduction

Guizhou Province is located on the plateau slope where the Yunnan-Guizhou Plateau transitions to the low mountains and hills in the east. It is also an intensely karstic plateau mountain that emerges between the Sichuan Basin and the hills of Guangxi [1]. It is the only province in the country with no plains, and accounts for mountains and hills. The province has a total area of more than 90%, with a large area of soluble rock exposed, diversified lithology of the formation, fragile geological environment, and severe human engineering activities, resulting in a large number of geological disasters, and it is characterized by suddenness and concealment. By the end of 2014, the province had identified 12261 potential geological hazards (including 6429 landslides), which is the province with the highest geological disasters in China [2].

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Landslide is a common geologic disaster with great destructive and damage surface, which poses a serious threat to people's economic property and life security and even causes disaster. In recent years, in the Western Expressway and railway construction in China, the cost of slope treatment is 30-50% of the total cost, so the reasonable design and effective management of the slope will directly affect the state investment in infrastructure and safe operation [3]. Therefore, many scholars and engineering experts at home and abroad have made a great deal of research on landslide disaster and control, which has reached a higher theoretical level and gained rich practical experience.

Anti-sliding piles are commonly used to control landslides. They mainly use the anchoring function of stable strata and mobilize a certain range of rock and soil masses to resist the sliding force of landslides. Piles and soils play a significant role. The engineering practice shows that it has outstanding advantages such as strong anti-sliding ability, small number of completion, flexible pile position, simple construction, and ability to further verify geological conditions. Can be set in the landslide body is the most conducive to anti-slip site, can be used alone, can also be used in conjunction with other structures, so widely used, has become the main measures for landslide control [4-6].

Gate-type anti-sliding piles, also known as door (frame) anti-slide piles, belong to the type of frame-type anti-slide piles and are a relatively new type of slope support structure developed from Europe and the USA in the 1950. Two rows of anti-slide piles are arranged at the front and the back of the landslide, and they are connected by a beam to form a spatial anti-sliding structure with a beam-column combination. In [7-12], engineering examples, model tests, theoretical calculations, and numerical simulation studies have shown that gate-type anti-sliding piles are relatively rigid. Under the action of tie beams, the front and rear rows of piles jointly assume the landslide thrust and the Earth pressure around the pile effectively reduces the horizontal displacement of the pile, so that more landslide thrust is transmitted to the stable (anchor section) below the sliding surface through the axial force, so the gate type anti-slide pile limits the deformation of the slope. The overall stability of the anti-sliding structure is significantly better than double-row piles without tie beams, which can resist greater landslide thrust and can save investment. Gate-type anti-slide piles have a short history of development, there are few relevant studies, and the structural stress mechanism is complex, and the slope stress distribution is not clear, so the calculation theory, a reasonable structural form, pile-soil interaction, landslide thrust and piles. The transfer and distribution of earth pressure must be further studied.

Soil arching effect is a kind of physical phenomenon widely existed in the field of tunnel, slope and earth dam, and it is a kind of spatial effect of the uneven movement of soil body. The soil arching effect between piles can be regarded as a kind of stress migration phenomenon caused by the interaction of pile and soil, that is, *strong first and then arch*. How to use the principle of soil arching effect, to optimize the supporting structure and reduce the engineering quantity, so as to achieve the ideal control effect, is a problem that many scholars and engineering practitioners care about. The soil arch between anti-slide piles is caused by uneven deformation of soil between piles and soil, and the shear strength of soils is exerted the soil structure is formed with the anti-slide pile as the arch foot, which makes the stress deflection the transverse distribution, and concentrates on the anti-slide pile body, thus achieving the anti-slide effect [13]. The formation of soil arch is the process of stress redistribution and self strength adjustment, it has been proved by Terzaghi *et al.* [14], Ladanyi and Hoyaux [15], Hand [16] in the foundation and pile soil, and it is pointed out that the shear strength and the s*upporting arch foot* are the key factors for the formation and stability of soil arching.

Its main characteristics are that the reinforced concrete arch slab is used to replace the soil arch, which actively exerts the mechanical properties of the structural arch with high compressive strength and can change the stress path. At the same time, the internal force and deformation of the pile body can be automatically adjusted with the cross beam of the portal anti-slide pile. The structure has strong flexural and overturning resistance, and resists the landslide thrust through the joint action of pile and arch.

Type door rigid frame-pile arch system

Structure introduction

The portal-rigid structure-pile arch system is inspired by the soil arching effect and is a new type of composite structural support system developed on the basis of gate-type anti-slide piles, fig. 1 . It is currently on both sides. Slope project successfully implemented. The system is mainly composed of three parts: modified door-type anti-slide piles (abbreviated as *gate structure*), reinforced concrete arch plates (abbreviated as *arch plates*), and square-shaped protection pylons (abbreviated as *mouth plinths*). The type door rigid frame-pile arch system is shown as fig. 1.

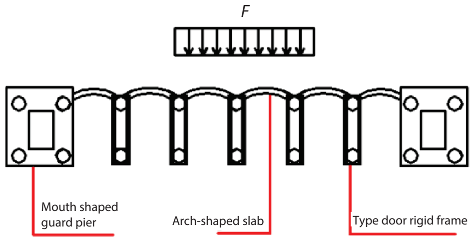

Figure 1. Schematic diagram of type door rigid frame-pile arch system

The design concept of this anti-sliding system is to use the arch structure with the characteristics of small bending moment, large axial force, and uniform stress distribution. The thrust, f, acting on the back of the arch is divided along the arch plate into vertical and horizontal force components (the direction of the stress is deflected.) A part of the vertical component force, f_1, is transmitted to the anchorage section rock mass through the anti-sliding pile in the form of axial force, and the other part is transmitted to the rock mass around the pile. The lateral force f_2 is transmitted due to the adjacent two arches. The lateral force is in the opposite direction and the structure is the same. Therefore, the lateral forces cancel each other out as the forces in the pile, fig. 2, that is, the thrust (earth pressure) of the landslide is reduced, so that the reduction in the amount of supporting work can be achieved. Good deformation control effect.

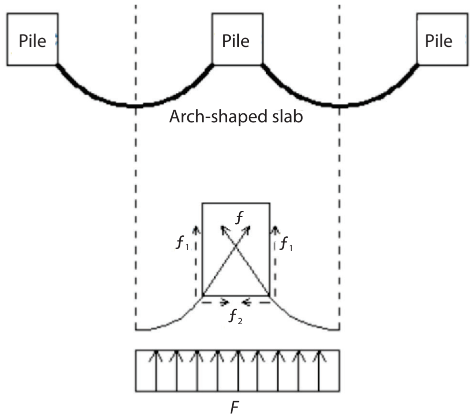

Figure 2. Pile and arch stress diagram

Numerical analysis

The establishment of a model

The FLAC3-D was used for modelling and analysis. Assuming that the roadbed of mountain roads was filled, the force of the portal frame and the arch plate was studied. Based on the corre-

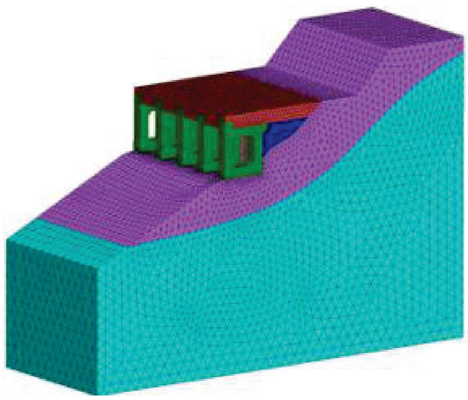

Figure 3. Calculation model and division of finite elements (*for color image see journal web site*)

sponding engineering geological conditions of a road fill slope, and combined with other similar projects to do comprehensive analogy, the modelling range of the 3-D numerical analysis model is determined: $X = 89.9$~145.9 m, $Y = 9.3$~28.7 m, Z = 90.2~128.3 m, fig. 3.

Parameter selection

Anti-sliding piles, arch plates, and moderately weathered rocks have been modeled using isotropic elastic models and the Moore Coulomb plasticity model has been adopted above the weathered top surface. Physical and mechanical parameters are shown in tab. 1.

Table 1. Physical and mechanical parameter values

Rock type	Weight [kNm^{-3}]	Elastic modulus [GPa]	Poisson's ratio	Cohesion [MPa]	Internal friction angle [°]	Tensile strength [MP]
Filling	23.00	0.02	0.35	0.04	17.90	–
Strong weathered layer	24.00	9.17	0.28	0.50	22.50	0.15
Bedrock (medium weathering)	26.00	15.00	0.18	1.20	38.90	1.00
Concrete	25.00	25.50	0.17	2.00	40.00	1.50

Calculation results analysis

The surface load of the anti-sliding structure adopts a method of increazing the degree of filling to analyze the girder frame structure and the stress of the arch plate. The arch of the stress (normal density), type door rigid frame of the stress (normal density) and the arch and type door rigid frame of the stress (1.5 times the density) are shown as figs. 4(a), 4(b), 5, respectively.

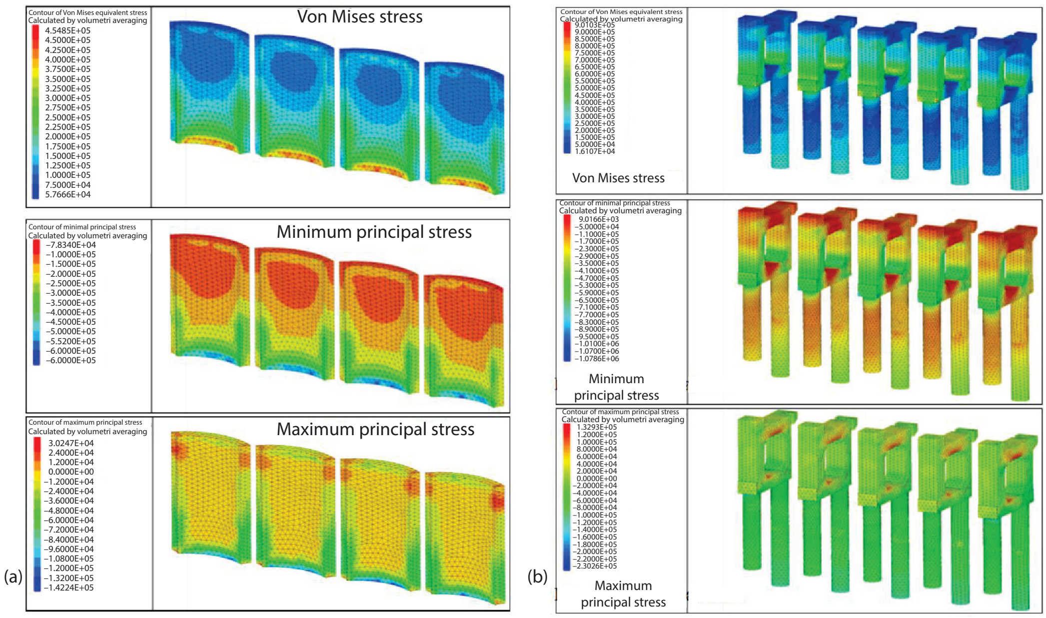

Figure 4. (a) The arch of the stress diagram (normal density), (b) type door rigid frame of the stress diagram (normal density)

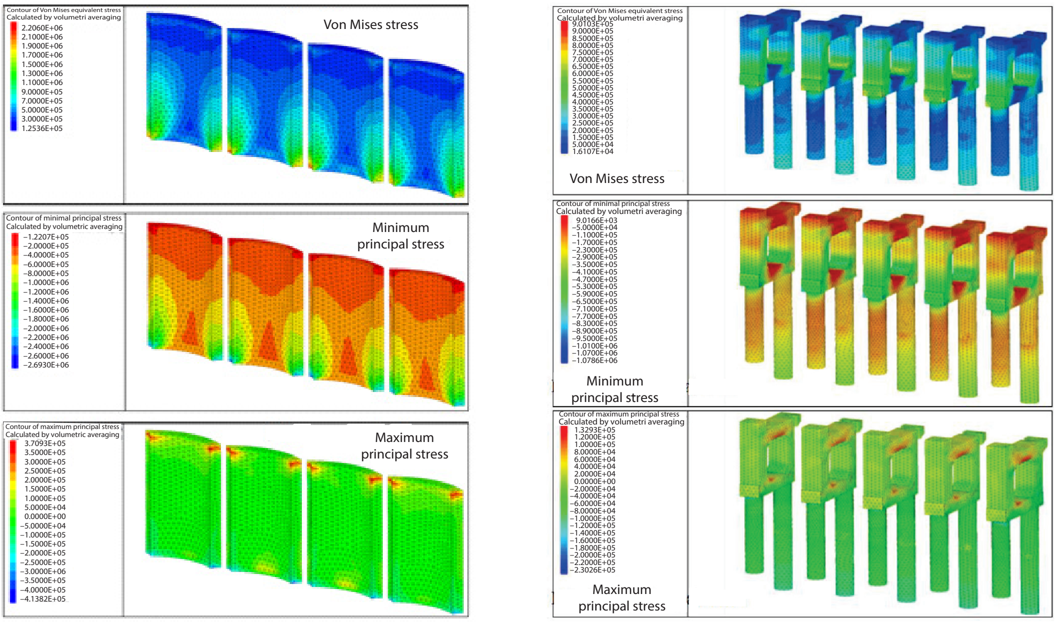

Figure 5. The arch and type door rigid frame of the stress diagram (1.5 times the density)

From the previously mentioned stress cloud diagram, it can be seen that the overall stress distribution of the arch plate is relatively uniform. With the increase of the sliding force, the stress of the arch foot and the dome increases rapidly. The position of the dome is mainly subjected to compressive stress, but in upper and lower parts of the arch a certain range of tensile stress concentration occurs at the dome position, and the arch position is mainly subjected to tensile stress, and the maximum tensile stress occurs at the bottom of the arch. This is because the arch position is not only affected by active earth pressure, but also affected by due to the large lateral rock pressure, the strength of the joint between the arch and the anti-slide pile and the strength of the lower part of the arch should be strengthened. As the glide force gradually increases, the girder gradually exerts its effect, transmitting the thrust of the landslide to the front row of piles, and the increase in the stress of the rear row of piles is greater than that of the front row of piles. For the front row of piles, the outside of the upper part of the pile and the inside of the middle part of the pile are mainly subjected to tensile stress, and the rest of the pile is mainly subjected to compressive stress. For the rear row of piles, the inside of the middle and upper part of the pile and the pile. The outside of the lower part is mainly subjected to tensile stress, and the rest parts are mainly subjected to compressive stress. The maximum compressive stress appears in the middle position of the rear row of piles. Therefore, it may be considered to reduce the elastic modulus of the front row of piles, that is, the concrete marking, in order to achieve better The economic benefits.

Example analysis

Project introduction

The left side of a road is adjacent to Chishui River. During the construction process, landslides were triggered. The sliding surface is located in argillaceous sandstone, and the depth of the sliding surface is about 5-8 m.

Governance solutions

In order to eliminate the hidden dangers of landslides and ensure road safety, a half-bridge structure system consisting of a door-type rigid frame-pile arch system and a laneway panel (sidewalk panel) is used to support and share the road.

Type door rigid frame

The span of the portal frame structure is 5 m, and the length of the unearthed part is controlled by the elevation of the road surface. The front and rear rows of anti-sliding piles have a diameter of 1.2 m, the middle to middle pile spacing is 4.5 m, and the anti-sliding pile body uses C_{30} concrete.

Arch plate

The unearthed part of the pile length is connected by an arch plate, and the connection between the arch plate and the column is a trouser-type connection in which the arch legs are arranged, and the arch feet and the column are cast at the same time. The arch axis is a circular curve with a radius of 3.92 m and a thickness of 0.5 m.

Figure 6. Completed photo

Mouth shaped guard pier

The mouth shaped guard pier is composed of a platform, a pier, a column, a cap beam, and a prime plate. The size of it is 6.75 m × 5.84 m, the hollow size is 3.3 m × 2.1 m, and the cap beam size is 3.3 m × 1 m × 0.4 m.

Effect of governance

The type door rigid frame-pile arch system system utilizes its structural advantages and the resistance of the rock and soil around the pile, effectively strengthening and improving the mechanical properties of the structure, and saving over 30 million investment compared with the original pile foundation joist. Effectively curb the further development of landslides and shorten the construction period. The roads have been completed and open to traffic for three years. During the construction and operation period, the rivers encountered multiple floods in fifty years.

Conclusions

This paper describes for the first time a new type of retaining structure used for landslide control: the basic composition and working principle of the portal-rigid structure-pile arch system. The FLAC3-D finite element software is used to investigate the force, and the following conclusions are drawn.

- The system can be applied to semi-excavated and semi-filled roadbed, and can be used as a supporting structure of roads and a structure to resist landslides.
- The FLAC3-D simulation results show that with the increase of the sliding force, the tensile stress of the arch foot and the lower part of the arch plate increases rapidly, so the strength of the joint between the arch plate and the anti-slide pile and the strength of the lower part of the arch plate should be strengthened.

- The structure system effectively strengthens and improves the mechanical properties of the structure and consolidates the stability of the slope. Compared with the traditional anti-sliding structure, it has low cost, strong stability and good anti-sliding effect. It can be popularized in landslide control and road engineering in mountainous areas.

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