Experimental Study on Physical Model of Prestressed Anchorage Mechanism of Fractured Rock Slope

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Abstract. In view of some problems in the application of prestressed anchoring technology in broken rock slope, this study, combined with the prestressed anchoring project of K+276 broken rock slope of Chengdu-Chongqing Expressway (CCE), based on the field geological survey and key data monitoring, adopts physical model test to study the diffusion mode of prestressed anchor cable. The concrete influence of rock mass quality, anchor cable tensioning tonnage and other factors on the stress and deformation of broken rock slope is analyzed, and the application mechanism of prestressed anchorage technology in the reinforcement of broken rock slope is discussed.

key word: Prestressed anchorage; fractured rock slope; anchor pier center; group of anchor; compression deformation.

1. Introduction

At present, the prestressed anchor cable reinforcement technology has been widely applied in the field of rock slope reinforcement [1-3], and many experts and scholars have done a lot of research on this point. The research conclusions and application technologies are mainly for general rock slope with good integrity [4], and the research scope mainly includes prestressed anchorage mechanism [5], prestress loss of anchor cable [6], etc.

However, for the fractured rock slope, due to its characteristics of poor integrity and complex stress, there are few studies on this kind of slope [7,8]. In this paper, based on the prestressed anchoring project of K+276 fractured rock slope of Chengdu-Chongqing Expressway, the anchoring mechanism of this kind of slope is analyzed and studied by physical model test on the basis of field geological survey and key data monitoring.

2. Project Overview

This paper choose the Chengdu-Chongqing Expressway (CCE) K+276 and broken rock slope as the research object, and the slope is located in the town of Chongqing-Rongchang high peak area which is shown in Figure 1. The mountain natural slope keeps in 35 deg to 48 deg, and the slope is on the right side of the road, and on the other side of the highway is a large crop growing area, for which the sections in the study area are basically excavated sections and the largest excavation height is 122.5 m.

Rongchang District is located in the east Sichuan Parallel range-gorge area, which is a part of the fold belt of the east Sichuan arc group. The landform is along the comb fold in the east Sichuan parallel range-gorge area, which is a typical hilly landform. The structure is located in the northeast of Zhongxian syncline, with strata occurrence of 90°∠10°and faults passing through. Among them, two groups of fractures are mainly developed in the sandstone, and the exposed strata are mainly quaternary limestone and sandstone, which are affected by secondary faults and have poor integrity.

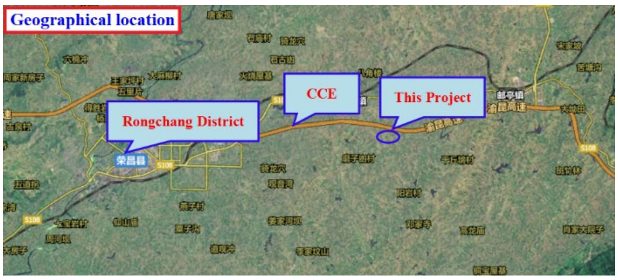

Figure 1. Project geographical location.

Due to the high degree of fragmentation of the rock stratum, the designer adopted the combination of a single anchor pier, an anchor pier and a frame beam to reinforce the broken rock slope. The anchoring structure situation is shown in Figure 2.

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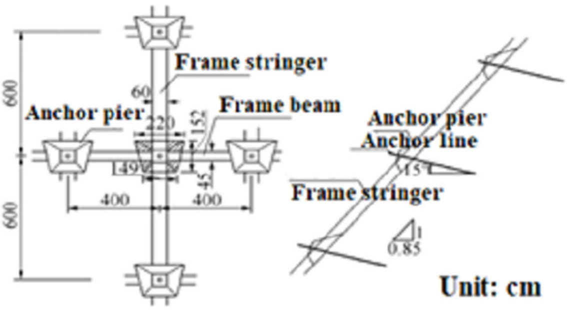

Figure 2. Broken rock slope anchoring structure on the CCE K+276.

3. Model Experiment Design

3.1 Model scale

This physical model was completed in Southwest Water Transportation Engineering Research Institute. Taking into account the requirements of model characteristics, site constraints, and the similarity principles, this model adopts a normal model with correspondingly equal plane scale and vertical scale [9], which is made according to the geotechnical engineering physical model, and the corresponding model scales are listed in Table 1.

Table 1. The scale value of this project model.

Plane scale λ_L	Vertical scale λ_H	Stress scale λ_γ	Roughness scale λ_n
80	80	9.67	1.73

3.2 Main test measuring instruments and simulation materials

Considering the similarity of simulations, the fine sand was used as the medium material in this experiment; the oak wood with better stiffness was used to make sash beams; the XHX-3XX vibrating wire bar stress meter was used to monitor the stress of steel bars and anchors in concrete structures , as well as the internal force of the anchor cable, in which the reinforcement stress gauge is installed by binding, welding or threaded connection.

4. Analysis of Experimental Results

According to the simulation model established in this paper, three kinds of anchoring methods are adopted, including the single anchor cable consolidation, anchor cable and the sash beam joint consolidation, and group anchor consolidation. Then, the study focused on analyzing the influence of tension force on the compression deformation of the slope under various anchoring forms.

4.1 Analysis of anchorage test of the single anchor cable

4.1.1 Slope stress and deformation distribution.

Under the tension of a single anchor cable, a compressive stress concentration area with a range of about 4m is formed near the center of the anchor pier along the slope trend, and the additional stress is basically axisymmetric along the center of the anchor pier, shown in Figure 3. Along the depth direction of the anchor cable, a compressive stress concentration area with a range of about 8m is formed, and its additional stress gradually decreases to 0 with the increase of the distance from the slope surface in Figure 4. Comparing Figure 3 and Figure 4, it can be seen that under the same tension, the additional stress along the slope is greater than such one along the depth direction of the anchor cable.

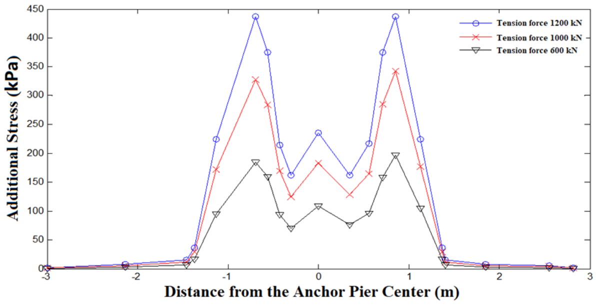

Figure 3. Variation of the additional stress with different tension forces along the slope.

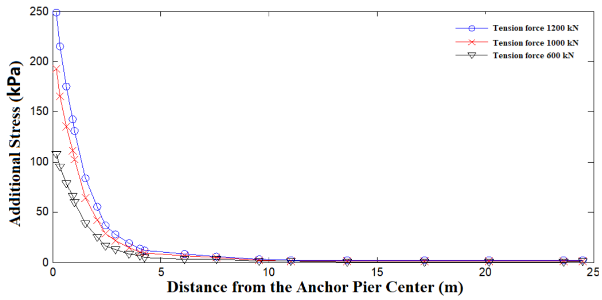

Figure 4. Variation of the additional stress with different tension forces along the depth direction.

4.1.2 Additional stress concentration features on slope.

According to the analysis of on-site measurement results, the main concentration area of the additional stress on the slope is below the anchor pier, and along the vertical axis of the slope, the additional stress gradually diffuses and attenuates with the increase of the depth of soil penetration. At the same time, by observing the distribution of additional stress at each depth, it can be seen that the distribution of additional stress in each layer of soil is a typical downward parabola, in which the peak value is at the center of the anchor cable, and when the depth reaches 10 m, the additional stress basically tends to zero. In the horizontal direction, the additional stress on the soil layers with different depths also decreases with the increase of the distance from the center of the anchor cable. It can be seen from this that the additional stress on the slope of the soil at the bottom of the anchor pier is the largest, and it gradually spreads and attenuates along the horizontal and vertical directions, which is shown in Figure 5. The reinforcement effect of the prestressed anchor-cable frame beam system in strengthening the broken rock slope is not affected by the thickness of the loose layer.

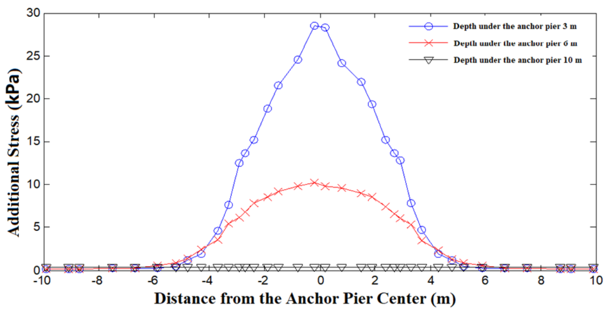

Figure 5. Variation of the additional stress with different depths.

In addition, the experimental data also show that under the anchoring state of a single anchor cable, the additional stress and compressive deformation of the surface slope are large, meanwhile the bearing capacity of the surface layer is required to be high, as well as the reinforcement effect of the broken rock slope is poor.

4.2 Anchorage test analysis

To solve the huge additional stress and compressive deformation of the surface layer under the anchoring state of a single anchor cable, the commonly employed way for the anchoring is used the anchor cables and sash beams together. Thus, the additional stress is dispersed by sash longitudinal beams, in which the stress state level of the surface layer is reduced.

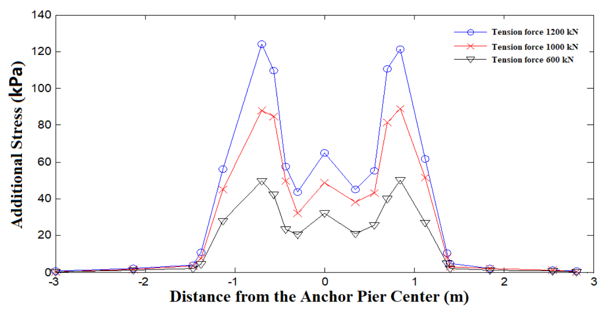

Figure 6. Variations of the additional stress under the joint action.

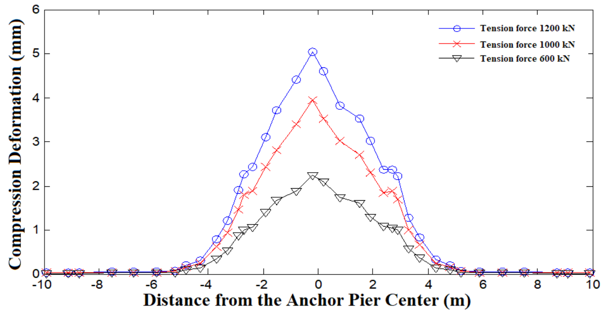

Figure 7. Variations of the compression deformation under the joint action.

The variations of the additional stress and the compression deformation, along the slope and under the joint action of the beam and the anchor pier, are plotted in Figure 6 and Figure 7, respectively. The results show that after using the anchor cable and the sash beam to be anchored together, the sash beam bears about 60% of the tension force of the anchor cable, of which the beam shares about 26% of the tension force of the anchor cable. According to the analysis of Figure 2, it can be seen that under the action of different tension forces, the influence range under the frame beam is basically the same, which is about ±5 m. Furthermore, to change the influence range of the beam, the main measures are to change the stiffness and span of the beam by the theory of elastic foundation beam.

4.3 Experimental analysis of group anchor action

The group anchor action refers to the combination of multiple anchor cables and transverse and vertical beams, and the deformation of the slope is restrained by the combined action of the frame beam anchor system and the tension force of the anchor cables. The arrangement of group anchors is shown in Figure 8.

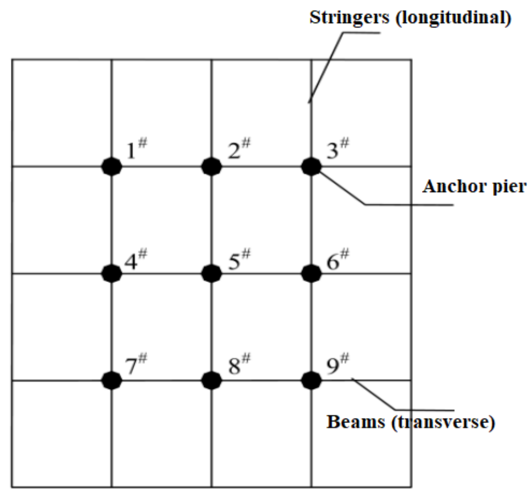

Figure 8. Group anchor scheme.

4.3.1 Additional stress distribution with group anchors.

Taking the center of the 5# anchor pier as the origin, taking the transverse direction as X axis and the vertical direction as Y axis, the additional stress distribution of the slope under the action of the group anchors is listed in Table 2.

Table 2. Additional stress distribution with group anchors (Unit: m).

Y \ X	-12.5	-10	-7.5	-5	-2.5	0	2.5	5	7.5	10	12.5
-12.5	91.5	108.9	99.1	68.8	93.7	125.7	86.2	80.0	93.8	119.8	89.8
-10	122.9	91.9	97.4	105.0	136.0	128.4	137.9	133.0	124.5	100.9	106.0
-7.5	68.9	114.2	93.7	80.7	76.3	111.8	72.1	83.2	73.0	129.5	77.4
-5	49.8	132.5	49.9	45.5	44.0	87.1	42.5	42.2	49.4	122.1	46.4
-2.5	90.8	123.0	102.1	74.7	68.4	124.8	87.2	101.5	81.0	116.7	71.2
0	93.5	103.9	128.2	107.4	95.5	133.7	101.0	110.9	137.3	122.6	139.5
2.5	68.8	106.0	70.7	70.6	100.2	99.2	89.6	78.6	88.8	97.9	67.1
5	46.1	109.9	42.2	49.9	45.2	107.5	49.4	46.2	47.8	138.8	45.5
7.5	86.3	125.5	87.7	104.2	90.6	126.9	86.9	89.7	89.8	117.8	74.3
10	115.5	138.3	124.5	95.2	111.8	91.3	89.8	106.1	123.5	94.9	141.1
12.5	72.0	141.0	90.2	86.1	86.9	121.4	82.8	99.0	67.2	125.1	96.7

According to the data in Table 2, the compressive stress action area of each anchor cable takes the center of the anchor cable as the center of the circle and gradually spreads, and the combined action of multiple prestressed anchor cables forms a complete anchoring action zone. Its characteristics are reflected in any point on the slope, and its additional stress mainly depends on the distance from the nearest anchor pier. Further statistics of more monitoring points show that the anchoring action zone formed by the anchor group can be approximated as a rectangular area as a whole, and it is distributed in a parabolic state from a single axis perspective.

4.3.2 Superposition effect of the number of anchor cables.

For broken rock slopes, the most important factors for anchoring measures are the loss of anchor cable prestress and the anchoring force acting on the slope, for which the compression deformation at the center of the 5# anchor pier under different numbers of anchor cables is shown in Figure 9.

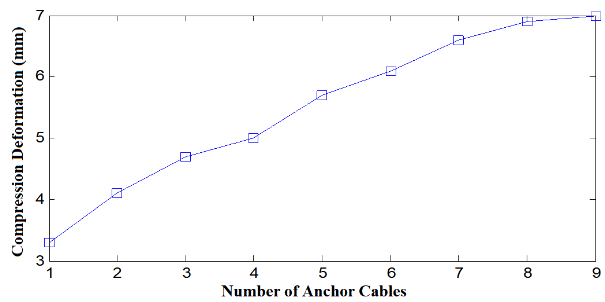

Figure 9. Compression deformation of 5 # anchor pier center with different number of anchor cable.

According to the analysis in Figure 9, the prestress and compression deformation of the broken rock slope are not linear with the increase of the number of tension anchor cables. When the number of tension anchor cables is in small quantity, the prestress level of the slope is low, in which the compression deformation and prestress loss are also light. As the number of tension anchor cables increases, the deformation of the slope increases, and the degree of prestress loss is also more serious.

5. Conclusion

This study takes the prestressed anchoring project of K+276 broken rock slope of Chengdu-Chongqing Expressway as the research object. On the basis of on-site geological investigation and monitoring of key data, the physical model test was used to study the prestressed anchoring mechanism by three methods, including the single anchor cable anchoring, the anchor cable and sash beam anchoring, and the group anchor acting. The following conclusions were drawn:

① In the single anchor cable anchoring test, a compressive stress concentration area is formed below the center of the anchor pier, with an influence radius of about 4m, and the center of the anchor pier is taken as the starting point, and it decays and spreads along the horizontal and vertical directions.

② In the co-anchoring test of the anchor cable and the sash beam, the sash beam shared about 60% of the additional stress on the slope surface, which effectively improved the stress condition of the slope, avoided stress concentration, and had a good effect.

③ In the group anchoring test, the frame beam anchorage system and the tension force of the anchor cable work together to form an anchoring action zone superimposed by several small compressive stress concentration areas, for which it can be approximated as a rectangular area as a whole, and it is distributed in a parabolic state from a single axial perspective.

Acknowledgments

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