Analysis on Application Effect of Prestressed Anchor Cable in Large Span Tunnel

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Abstract: Safety is the top priority during the construction process, the construction risk increases sharply with the increase of section size. Bifurcated tunnel structure is adopted in the entrance portal section of Bibanpo tunnel. The span of transition section reaches 25.79m (type A) and 22.11mm (type B). To ensure safety, a new support method of pre-stressed anchor was used. during the construction, we monitored the structure stress of primary support, and the tension stress of pre-stressed anchor cable, and we get that: the pre-stressed anchor cable can support quickly, prevent plastic zone from deepening, decrease the load of primary support structure, especially the load of shaped steel. Through engineering practice, it can be concluded that pre-stressed anchor is an effective active support method. The successful application experience in Bibanpo tunnel is of great significance for similar projects.

1. Introduction
Chinese high-speed railway has been booming for the decade. By the end of 2017, high-speed railway operating kilometrage has reached 25 thousand kilometres, an increase of 13.6% compared with 2016. The development focus of high-speed railway has been converted from the eastern plain area to the western hilly and mountain area where bridges and tunnels take a large proportion in high-speed railway line. For example, bridges and tunnels account for more than 90% in Guangxi section in Guiyang-Guangzhou high-speed railway and Jiangxi and Fujian section in Hefei-Fuzhou high-speed railway. With the rapid development of high-speed railway construction, the proportion of high-speed railway tunnel construction has increased significantly; high-speed railway has large cross-section, long tunnel, geological conditions and the complexity of construction environment [1-3].

Tunnel structure is comprehensively influenced by horizontal and vertical section index as well as topographical and geological conditions. In regions with precipitous mountains and gorges, and in chicken-claw-like regions having ridges and valleys, bridges and tunnels connect end to end. As for long tunnel in those regions, the length of development line cannot meet the requirements of conventional single tunnel with single line as high-speed railway has large turning radius and incapability in bypassing and avoiding. As a result, bifurcated tunnel become a useful way to solve those problems. The bifurcated tunnel can adapt to the changeable geological conditions. Its structural form has the characteristics of multi-scale and multi type. It has the characteristics of large-span double arch tunnel and small clear distance tunnel[4-6].

The transition section of the bifurcated tunnel is of great cross-section and high construction risk. According to investigation, large span tunnels are widely used in hydropower plants and underground oil and gas reservoirs, maximum excavation span reaches more than 50m, but its span height ratio is
small, rock conditions are good. Many scholars have done a lot of research on the mechanical properties of the surrounding rock of the hydropower station, and Meng Guoqing and other scholars have done a lot of research on the typical rock mechanical problems. Wang Hui et al. Analyzed the mechanical parameters and deformation law of surrounding rock through deformation monitoring and numerical simulation. Li Zhipeng et al. Analyzed the deformation and failure characteristics of surrounding rock during the construction of monkey underground powerhouse cavern group[7-9]. In terms of high-speed railway tunnel, relying on the large-span excavation of Badaling tunnel of the Great Wall, there have been many studies[10, 11], but it is a multi-span structure form, which is different from Bibanpo tunnel. Due to the particularity of the section form and geological conditions of the project, the existing achievements are difficult to be directly applied, so targeted research is needed. Through on-site monitoring, we analyzed surrounding rock deformation, pre-stressed anchor cable tension, shaped steel strain, as well as contact stress between primary support and secondary lining. The analyses proved that those new methods could speed up construction, prevent surrounding rock collapse, and reduce secondary lining eccentric pressure.

New Method of Design and Construction.

1.1. Engineering Background
Bibanpo tunnel is located in the transition zone of Yunnan-Kweichow Plateau, the tunnel has a maximum buried depth of 750m and is the longest tunnel and control project for the Shanghai-Kunming passenger line. Bifurcated tunnel structure is adopted in the entrance portal section of the tunnel. The span of transition section reaches 25.79m (type A) and 22.11mm (type B), which are of great potential for construction safety.

![Fig.1 Location of Bibanpo tunnel and Geological section of bifurcation structure.](image)

1.2. Pre-stressed Anchor Cable Support
To ensure safety, we put forward an optimized process of excavating and breaking through one side of the tunnel first and drilling back through the other side in consideration of the large excavation area and long construction period. We presented reinforced support system of pre-stressed anchor cable in view of problems including surrounding rocks with no secondary lining, unstable structure and unbalanced load releasing.

During the construction, we monitored and measured surrounding rock displacement and structure stress of primary support to prevent instability and collapse of surrounding rock and support structure. We also monitored and measured pre-stressed anchor cable tension, contact stress between primary support and secondary lining and structure stress of secondary lining to research the positive effects of pre-stressed anchor cable on tunnel stability and secondary lining.
2. Monitoring and Measuring Scheme
During the excavation of A-type section, we adopted total station to monitor and measure the displacement of vault and side wall; earthen pressure cell to monitor the contact stress between primary support and surrounding rock, as well as that between primary support and secondary lining; surface strain gauge to monitor shaped steel strain; concrete strain gauge to monitor the concrete strain of primary support and secondary lining. The arrangement of those apparatuses is shown in Fig.2. In the early stage of construction, we did not set geotechnical monitoring instrument as we did not pay attention to the risk of excavating the left side of A-type section first. Realizing the specialness and safety of excavating A-type section, we set geotechnical monitoring instrument before excavating the right pilot tunnel.

3. Results and Discussion
3.1. Pre-stressed Anchor Cable
We arranged three anchor cable dynamometers on the right side of A-type section, and three vibration wires in every dynamometer. The No.3 dynamometer was broken during tension process and the results of the No.2 and No.1 dynamometer are shown in Fig.3. After tension process, anchor cable stress became stable and would not change within three days. After the left pilot tunnel was finished, the pre-stressed anchor cable on hence can support quickly, prevent plastic zone from deepening, reduce the range of surrounding rock loose, decrease the load of primary support and keep the left pilot safe and stable for a long time. Arranging anchor cable dynamometers on the right side of A-type section not only keep the rock stable, but control the range of surrounding rock loose, prevent unbalanced load of secondary lining and reduce operation diseases.
3.2. Steel Stress Development

We adopted five stairs to excavate the right pilot tunnel to reduce the negative effects of excavation on lining structure and rock pillar. During the excavation (0-30d), the contact stress between surrounding rock and primary support structure, shaped steel strain and concrete strain increased as the right pilot tunnel was excavated. After the excavation was done, the increase of stress and strain slowed down. Fourteen days after the excavation was finished, the pre-stress anchor cables were arranged and started to tension. Seven days after the tension finished, with the influence of anchor cable tensile stress, the contact stress between primary support and surrounding rock near the anchor cable increased dramatically while shaped steel strain plummeted. Affected by excavation of invert, the surrounding rock loose range further expanded, the contact stress between primary support and surrounding rock increased. Shaped steel strain and concrete strain kept stable with the support of pre-stressed anchor cable. The changes of contact stress, shaped steel strain and concrete strain are shown in Fig.4.

![Graph showing developing trend of anchoring force on the right side of A-type section.](image)

Fig. 3 The developing trend of anchoring force on the right side of A-type section.

(a) contact stress between primary support and surrounding rock
(b) shaped steel strain
3.3. Shaped Steel Stress Distribution

The strain distribution of shaped steel and shotcrete are shown in Fig.5. On the right side of A-typed section, shaped steel stress were similar to shotcrete stress. The vault strain was relatively small, about $1.5 \times 10^{-4}$, yet arch wall strain was large, about $3.0 \times 10^{-4}$. From vault to arch wall, the strain constantly increased. The shaped steel strain of side wall was small while that of shotcrete was large because invert excavation weakened the bearing ability of shaped steel at side wall, and shotcrete started to bear the load.

Through the analysis of stress and strain of primary support, we could conclude that pre-stressed anchor cable can rapidly decrease the load of primary support structure, especially the load of shaped steel, and ensure the safety and stability of surrounding rock during excavation.

4. Conclusion

The paper takes Bibanpo tunnel in Shanghai-Kunming high-speed railway as an example, explains the design origin, project procedure, support structure, monitoring and measuring methods and result analysis of the bifurcation section. Combining the successful construction experience of bifurcation section of Bibanpo tunnel, we draw into the following conclusions.

Through monitoring and measuring, we get the changes of pre-stressed anchor cable, shaped steel stress and contact stress between the primary support and secondary lining during the construction of large-span section in Bibanpo tunnel. The results prove that pre-stressed anchor cable can control surrounding rock stress release, reduce the structure stress of primary support and decrease secondary lining eccentric pressure.
Acknowledgements
This work is financially supported by National Key Research and Development Program of China (2017YFC08060010, 2017YFC08060003), National Natural Science Foundation of China (41601574), Special Project of Scientific and Technological Innovation for Social Undertakings and People's Livelihood Guarantee of Chongqing, China (cstc2017shmsA30010).

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