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Rock mechanical problems and optimization for the long and deep diversion tunnels at Jinping II hydropower station

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Abstract: According to site-specific environments such as high water pressures, high in-situ stresses and strong rockbursts, the design scheme of the long and deep diversion tunnels at Jinping II hydropower station was optimized to ensure construction safety. New drainage tunnels were considered. Furthermore, lining structures and grouting pressures were modified during the excavation of tunnels. The construction scheme was updated dynamically based on the complex geological conditions. For instances, the diversion tunnels were first excavated by drilling and blasting method at the first stage of construction, and then by the combination method of tunnel boring machine (TBM) and drilling and blasting, and finally by drilling and blasting method. Through optimized scheme and updated construction scheme, the excavation of diversion tunnel #1 was successfully completed in June, 2011. This paper summarizes the key issues in rock mechanics associated with the construction of the long and deep diversion tunnels at Jinping II hydropower station. The experiences of design and construction obtained from this project could provide reference to similar projects.

Key words: Jinping II hydropower station; diversion tunnels; optimized design; construction method; grouting

1 Introduction

Jinping II hydropower station is located on the Yalong River, at the junction of Muli, Yanyuan and Mianning counties, Liangshan Yi Autonomous Prefecture, Sichuan Province. It is an important hydropower station along the Yalong River, with a total installed capacity of 4 800 MW. Electricity is generated through four 16.67 km-long diversion tunnels, which cut the 150 km-long river bend.

The project consists of 7 deep parallel tunnels, i.e. 4 diversion tunnels, 2 auxiliary tunnels, and 1 drainage tunnel. From south to north, there are auxiliary tunnels A and B, drainage tunnel, diversion tunnels #4, #3, #2 and #1. The auxiliary tunnels A and B with a diameter of approximately 6 m were excavated by drilling and blasting method, and were completed in August, 2008. The drainage tunnel with a diameter of 7.2 m was excavated by tunnel boring machine (TBM) from east to west and later by drilling and blasting method from west to east. Four diversion tunnels were excavated from the two ends at the same time. The diversion tunnels #1 and #3 with a diameter of 12.4 m, were excavated by TBM, while the horseshoe-shaped diversion tunnels #2 and #4 with a diameter of 13 m were excavated by drilling and blasting method. The diameters of the diversion tunnels at Jinping II hydropower station are larger than those of Qinling tunnel and Sierra tunnel, which are 8.8 and 5.8 m, respectively. To ensure that the generators in the diversion tunnel #1 will be in operation in time, the diversion tunnel #1 should be excavated firstly, followed by the diversion tunnels #2, #3 and #4 [1, 2].

The axes of diversion tunnels at Jinping II hydropower station are almost orthogonal to the ridge line of Jinping Mountain. The overburden depth of diversion tunnels is basically over 2 000 m, with the maximum of 2 552 m (greater than that of Simplon tunnel, the maximum of 2 135 m), and it is very close to that of diversion tunnel at Sierra hydropower station in French (the maximum of 2 619 m) [1]. For the purpose of timely water drainage during construction, the working face of drainage tunnel should be ahead of those of diversion tunnels.

Restricted by the complex topography, it is impossible to properly arrange adits, inclined and

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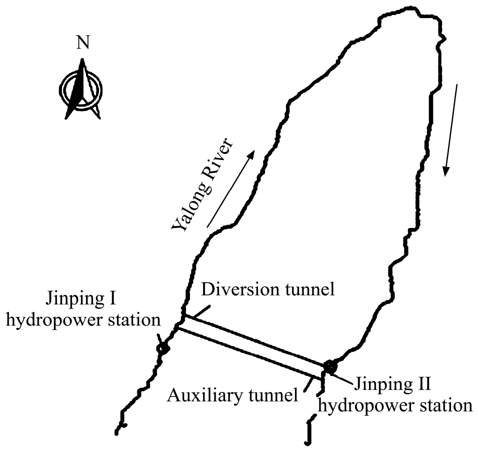
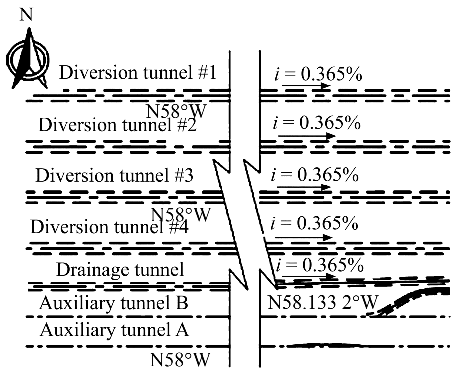
vertical shafts to assist in the excavation of diversion tunnels. The design and excavation of the diversion tunnels are key issues for the construction of Jinping II hydropower station. The complex hydrogeological conditions, i.e. the high water pressure, stable water supply, and high in-situ stress over 70 MPa, made the tunnel construction and structure design difficult. The diversion tunnels at Jinping II hydropower station are the largest and the most complicated underground projects so far in the world.

The design scheme has been modified and optimized several times, and the construction method and layout have been revised during the tunnel excavation. The location and layout of the diversion tunnels at Jinping II hydropower station are shown in Fig.1, where *i* represents the base slope of the tunnels.



(a) The location.



(b) The layout.

Fig.1 Location and layout of the diversion tunnels at Jinping II hydropower station.

2 Description of geological conditions

2.1 Topography

Jinping Mountain lies in nearly NS direction in the river bend of the Yalong River, where the gullies are deep and steep. Most mountain peaks are over 4 000 m, with the highest of 4 488 m (Santangshan peak). The largest altitude difference is over 3 000 m. The mountain ridges are in SN direction, with an unsymmetrical topography, i.e. wide in east and narrow in west. At mountain foot and the gully, collapsed debris and avalanche debris cone are frequently observed. Alluvial cone can also be observed at the gully mouth. Irregular topography with deep gullies and steep slopes are the basic features in this area.

Most of the prime lateral gullies (level-1) are nearly orthogonal to the Yalong River. These gullies are deeply cut in a form of high and steep slopes, and perennial runoff is observed. Gullies of Mofanggou, Nanmugou, Dashuigou, Mosagou, Meizipinggou, etc., are located in the east, and gullies of Lufanggou, Yangfanggou, Jiefanggou, Pusiluogou, Niuquanping-gou, Mianshagou, Luoshuidonggou, etc., are located in the west. There are also some prime gullies (level-2) that are lack of runoff sometimes, so most level-2 gullies keep dry. Waterfall can be observed sometimes in these gullies.

Carbonate rocks commonly exist in this area. Because of intensive regional metamorphism and sharply crust rise, karst landform is not fully developed. Mountains composed of carbonate rocks are very sharp and steep while mountains composed of clastic rock are thick and flat. There are significant differences between these two kinds of mountains.

2.2 Engineering geological settings

The most common strata exposed in the project area are Devonian-Jurassic strata of neritic-littoral facies and sea-land alternate phase. Triassic stratum covers over 90% of the project area, 70%–80% of which is composed of carbonate rocks.

The rocks along the diversion tunnels are mainly composed of marble, limestone, sandstone and slate of upper and middle Triassic system. The geological profile along the diversion tunnels is shown in Fig.2. It can be seen from Fig.2 that, from east to west, Yantang group (T_{2y}), Baishan group (T_{2b}), the upper Triassic system (T_3), Zagunao group (T_{2z}), and the lower Triassic system (T_1) are distributed along the diversion tunnels in sequence, and they can be described as follows:

(1) Group T_{2y} is mainly observed in Dashuigou gully and Laozhuangzi anticlinal core, which is mainly composed of marble and argillaceous limestone.

(2) T_{2b} marble is mainly observed in the middle area, which forms the main body of Jinping Mountains. It has a stable lithofacies, dense structure and pure