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A study of excavation sequence and contour blasting method for underground powerhouses of hydropower stations

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ABSTRACT

The choice of a reasonable excavation sequence and contour blasting method is one of the key techniques for the construction of underground powerhouses. Firstly, the excavation sequences and contour blasting methods commonly adopted for main large-scale underground powerhouse under construction or completed in PR China is introduced and analyzed. Secondly, on the basis of an analysis of the propagation of cracks driven by explosion gases during contour blasting, and taking into account the combined effects of initial in situ stress of surrounding rock mass and the explosion pressure of adjacent blast boreholes, the process of propagation of crack formed along excavation contour under action of laterally high in situ stress is analyzed and demonstrated. The results show that the in situ stress of surrounding rock mass is one of the main factors affecting the crack propagation for contour blasting, and when the in situ stress is higher than 10–12 MPa, it is improper to adopt an excavation sequence of pre-split first followed by the main rock mass excavation, alternatively, the excavation sequence with middle cut blasting carried out first, followed by pre-split or smoothing blasting is recommended.

1. Introduction

China is very rich in hydropower resource, its totally developable hydropower capacity amounts to 542,000 MW, which takes first rank in the world. But most of hydropower resources are distributed in the rivers of western mountain areas, such as Jinshajiang River, Yalongjiang River, Daduhe River, Lacangjiang River, Wujiang River, Hongshuihe River and the upper reaches of the Yellow River, as well as Nujiang River and Brahmaputra River (Wu, 2007). High dams built after the 1990s in China basically adopted underground powerhouse design, such as Ertan, Longtan, Xiaowan, Xiluodu, Laxiwa, Nuozhadu, Pubugou, Shuibuya and Xiangjiaba. In order to fully utilize the water resources during the flooding season, an underground powerhouse is also arranged in the right bank at Three Gorges Project which has a capacity of 4200 MW. The distribution diagram of major large-scale underground powerhouses is shown in Fig. 1.

Currently, the method of drilling and blasting layer by layer is still the dominant excavation method for large underground powerhouses and the height adopted for a typical layer in most projects is 8–10 m. The diagram for the excavation procedures of the underground powerhouse at Xiluodu Hydropower Station is shown in Fig. 2. The excavation of main underground powerhouses is divided mainly into three parts, i.e., the excavation of arch roofs (I), layer containing rock-anchored beams (III) and high walls (II, IV–XI) (Li et al., 2008).

The worldwide practice of the excavation of large-scale underground powerhouses shows that, a reasonable excavation sequence and the contour blasting method has a direct effect on the excavation quality, construction schedule and excavation economy (Chandra et al., 2010; Mandal et al., 2008; Chen et al., 2007; Venkatesh et al., 2005; Cai et al., 2003; Mendez, 1993; Wallis, 1984; Hamel and Nixon, 1978).

In this paper, by comparing and analyzing the excavation sequences comprehensively, contour blasting methods and the excavation results of main large-scale underground powerhouses under construction or completed in the western mountainous areas in China, and combining this with the calculation of the dynamic crack propagation during contour blasting, the authors try to put forward some guidelines to select the excavation sequences and blasting methods for underground powerhouse under different rock types and in situ stress level conditions.

2. Investigation on the excavation sequences and contour blasting methods adopted in large-scale underground powerhouse in China

For excavation of the arch roof layer of large-scale underground powerhouses built or being built since 1990s, drilling and blasting

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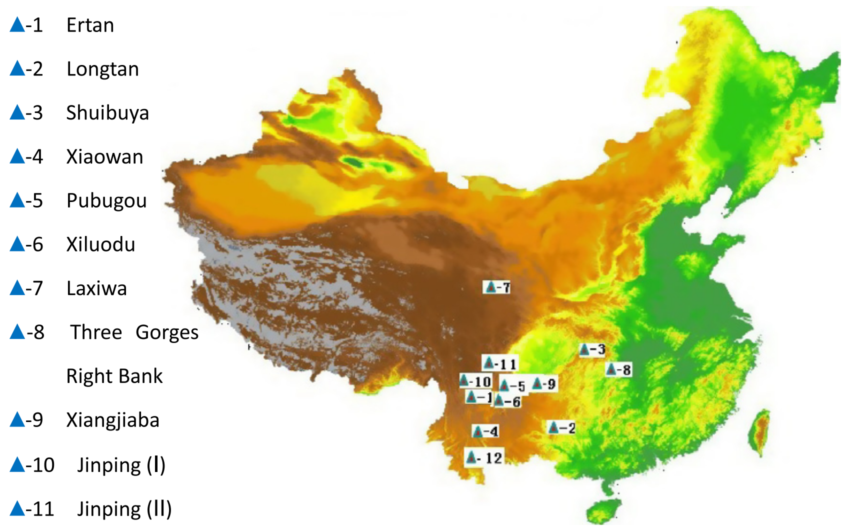

Fig. 1. Distribution of major large-scale underground powerhouses under building or completed in China.

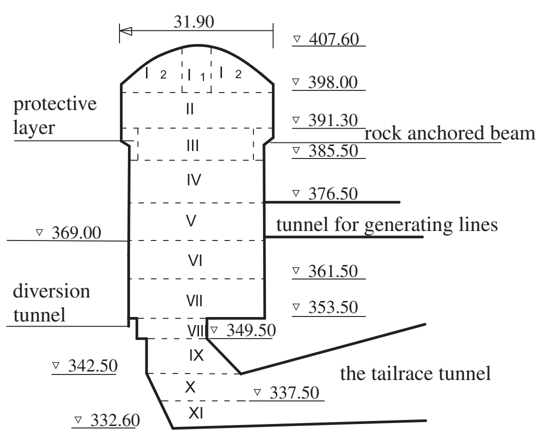

Fig. 2. The diagram for the excavation sequence of underground powerhouse at Xiluodu hydropower station.

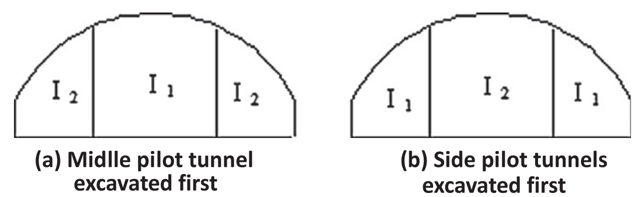

Fig. 3. Excavation sequences of arch roof layer of underground powerhouse.

method, with a borehole diameter of 42–50 mm and a hole depth of 3.0–3.5 m, is adopted without exception in China. For the excavation of the layers below the arch roof layer, to speed up construction speed, the deep-hole bench blasting method is always employed, which generally adopts a borehole diameter of 70–90 mm and a layer height of 8–10 m.

Detailed information of the excavation sequence and contour blasting methods adopted in main large-scale underground powerhouse completed or under construction over the past 20 years in China is introduced as follows (Zhu et al., 1997; Li et al., 2005; Ren and Zeng, 2008; Miao et al., 2007; Chen et al., 2008; Bai et al., 2007; Yin and Yang, 2009; Zeng et al., 2005; Liu et al., 2009; Zhang, 2008; Yin and Chen, 2007).

2.1. Arch roof layer

Two common excavation sequences adopted for the excavation of the arch roof layer is shown in Fig. 3. Except for Longtan Hydropower Station, the arch roof excavation sequences (ARES) adopted in all the other projects were that, middle pilot tunnel was advanced ahead first, and followed by enlarged excavation of both sides, which is shown in Fig. 3a and referred to as ARES-I in the following paragraphs. At Longtan Hydropower Station, two sides pilot tunnels were excavated first, followed by the excavation of the middle pillar, which is shown in Fig. 3b and this kind of excavation sequence is referred to as ARES-II in the following paragraphs. The practice at Longtan Hydropower Station shows that, ARES-I tends to cause a large displacement of the arch roof layer, thus this kind excavation sequence is rarely used in other following projects. On the excavation periphery, smooth blasting is adopted in all projects.

2.2. Layer containing rock-anchored beam

For the excavation of the layer containing the rock-anchored beam in underground powerhouses, all of the 12 projects investigated arrange a lateral protective or buffering layer AGFEB before the final contour of anchored beam, as can be seen in Fig. 4. On the slant excavation contour CDE, smooth blasting is commonly employed. For vertical contour EF, which belongs to a part of the high wall of underground powerhouses, either the smoothing or pre-split blasting method could be adopted in practice.

Most projects adopt a *rock-anchored beam* excavation sequence(ABES) as follows (defined as ABES-I): pre-split blasting is carried out first on the outside edge AG of the protective layer AGFEB (III2

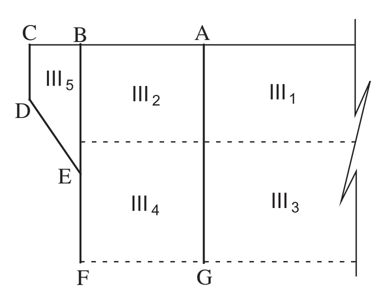

Fig. 4. The excavation sequence of layer containing rock-anchored beam.