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Dam foundation excavation techniques in China: A review

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ABSTRACT

A protective layer (PL) is commonly reserved above foundation surface to protect the underlying rock mass during dam foundation excavation. In China, the PL of dam foundation is conventionally subdivided into two or three thin layers and excavated with the shallow-hole blasting method, even by pneumatic pick method in case of soft rock mass. The aforementioned layered excavation of the PL delays the construction of the whole project. After nearly 30-year practices, several safe and efficient methods for the PL excavation of dam foundation are gradually developed. They include shallow-hole bench blasting with cushion material (SBC) at the bottom of the hole, and horizontal smooth blasting (HSB). The PL is even cancelled on the condition that horizontal pre-split technique is employed during dam foundation excavation. This paper introduces the aforementioned two PL excavation methods (shallow-hole blasting and bench blasting) and horizontal pre-split technique of dam foundation without protective layer (HPP). The basic principles of blasting method, blasting geometry, charge structure, drill-and-blast parameters of typical projects are examined. Meanwhile, the merits and limitations of each method are compared. Engineering practices in China show that HSB is basically the optimal method for dam foundation PL excavation in terms of foundation damage control and rapid construction. Some new problems for dam foundation PL excavation arising, such as strong unloading and relaxation phenomenon that encountered in the gorge region of southwest China, are needed to be addressed; and the corresponding countermeasures are discussed as well.

1. Introduction

With the rapid development of economy, a sharp increasing demand for electricity is required in China in the last three decades. As a result, many large-scale hydropower projects have been completed or are under construction in China (Jia et al., 2010), as shown in Table 1. Construction of hydropower projects often involves large-scale and high-intensity excavation, whilst drill-and-blast method is still the main method for rock dam foundation excavation. The dam foundation surface serves as the bearing surface, and it should be noted that water pressure is acting on the bedrock where the weak interfaces between the dam and the bedrock are observed. Therefore, the stabilities of the reservoir-dam system and the bedrock are critically important during dam foundation excavation by blasting. In the process of dam foundation excavation, weathered and other weak rocks need to be fragmented by blasting and removed. Meanwhile, blasting-induced damage should be strictly controlled, especially in the regions in the vicinity of the designed excavation contours such as the foundation surface. Hence, close attention has been paid to blasting techniques which are employed on dam foundation surface.

Generally, the following four steps are taken during dam foundation excavation, i.e. (1) removing the loose rock mass before excavation, (2) excavating the main rock body at a certain distance above the planned foundation level, (3) excavating reserved rock mass near the planned foundation level, and (4) cleaning the foundation (Murphy et al., 1976; Novozhilov and Oganesyan, 1978; Mgalobelov, 2000; Kühnel, 2004).

In Europe and USA, the main rock body at a certain distance above the planned foundation level is usually excavated by loosening blasting method combined with controlled perimeter blasting techniques, such as pre-splitting, cushion blasting or smooth blasting. The selection of specific blasting method and thickness of the reserved rock mass are generally left to the contractor. The reserved rock mass near the planned foundation level is usually excavated by shallow-hole blasting or prying with hydraulic excavator.

In the former Soviet Union, during the dam foundation excavation process, a protective layer (PL) above the designed foundation

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Table 1
Statistics of dam construction in China.

Year	Number of dams		Proportion all over the world (%)	
	Dam height >30 m	Dam height >100 m	Dam height >30 m	Dam height >100 m
1973	1644	14	25	3.5
1988	3768	33	41	7.2
2005	4839	129	37.8	15
2008	5191	142	–	–

surface must be reserved. The main body of the rock mass is excavated by bench blasting, and the PL will be excavated by the controlled perimeter blasting. In China, this former Soviet Union's method was adopted in dam foundation excavation before 1980s. Typical dam foundation excavation method is shown in Fig. 1.

The thickness of the PL is determined associated with the geometry of blasting-induced damage zone (BDZ). The BDZ is generally defined as the rock zone beyond the excavation boundary where the physical, mechanical and hydraulic properties of the rock mass have been significantly affected due to blasting excavation (Cai and Kaiser, 2005; Blümling et al., 2007; Malmgren et al., 2007; Wu et al., 2009; Bastante et al., 2012). The larger the BDZ is, the thicker the PL is. In gorge regions with high in situ stress, rapid excavation of rock mass will lead to a quick release of in situ stress that induces an excessive deformation and a bigger excavation-induced damage zone (EDZ) during dam foundation excavation (Li et al., 2010; Duan et al., 2011; Chen et al., 2012).

According to the *Construction Technical Specifications on Rock Foundation Excavating Engineering of Hydraulic Structures in China* (DLT5389-2007), the thickness of the PL in the vicinity of the horizontal foundation surface should be determined by in situ blasting test. If an in situ blasting test is difficult to perform, a thickness of 25–40 times the cartridge diameter D of the last layer for bench blasting is proposed, as shown in Table 2. The thickness of dam foundation PL of some newly constructed large-scale projects (Luo and Shen, 2003; Bao and Wan, 2006; Zhao et al., 2008; Guan and Yuan, 2009) is listed in Table 3.

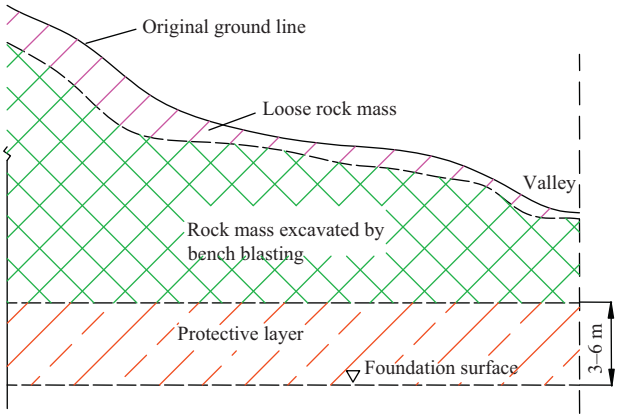

Fig. 1. Typical dam foundation excavation method in China.

Table 2
PL thickness H proposed in technical specifications by National Development and Reform Commission of People's Republic of China (2007).

Intact and hard	Relatively intact/hard	Jointed and soft
25D	30D	40D

2. Layered excavation of dam foundation protective layer

The layered blasting excavation of the PL has been employed in China for several decades since 1960s. In the current technical standard DLT5389-2007, the conventional layered blasting excavation is still suggested as a reliable method for dam foundation PL excavation. The 3-layer PL excavation should be considered, and the excavation of each layer is strictly controlled. Typical procedure of layered blasting excavation of PL is shown in Fig. 2.

(1) The first layer

Shallow-hole bench blasting should be adopted. After the excavation of the first layer, the remaining thickness of the PL should be not less than 1.5 m. Cartridge diameter should be less than 40 mm.

(2) The second layer

For the second layer, the single-hole blasting method should be adopted. After the excavation of the second layer, for intact/hard or relatively intact/hard rock mass, the remaining thickness should be not less than 0.5 m; for jointed/soft rock mass, the remaining thickness should be not less than 0.7 m. The angle between the drilling hole and the horizontal foundation surface should be not less than 60°. Cartridge diameter should be less than 32 mm.

(3) The third layer

For intact/hard or relatively intact/hard rock mass, the drilling hole should not go through the horizontal foundation surface; for jointed/soft rock mass, the bottom of drilling hole should be 0.2 m above the horizontal foundation surface, and the final 0.2 m of rock mass should be excavated by prying. The provisions for angle of the drilling hole and cartridge diameter

Table 3
Thickness of dam foundation PL of some newly constructed large-size projects (Luo and Shen, 2003; Bao and Wan, 2006; Zhao et al., 2008; Guan and Yuan, 2009).

Project	Thickness of PL (m)	Lithology of dam area
Xiluodu	5.5	Breccia lava/basalt
Jinping I	5	Sandy slate/marble
Laxiwa	3	Metamorphic rock/intrusive granite
Longtan	3	Sandstone/siltstone/argillite

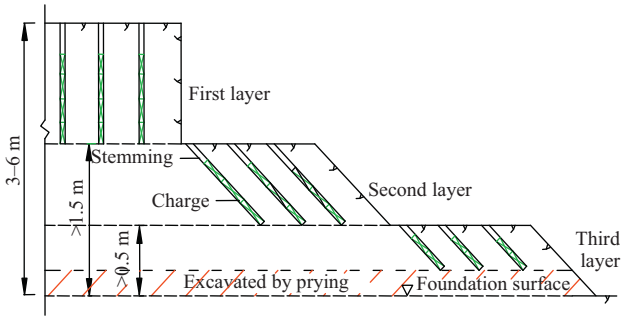

Fig. 2. Typical procedure of layered blasting excavation of PL.