Journal of Rock Mechanics and Geotechnical Engineering 8 (2016) 640–650

Contents lists available at ScienceDirect

Journal of Rock Mechanics and Geotechnical Engineering

journal homepage: www.rockgeotech.org

Full length article

Engineering rock mechanics practices in the underground powerhouse at Jinping I hydropower station

Aiqing Wu [a,*], Jimin Wang [b], Zhong Zhou [c], Shuling Huang [a], Xiuli Ding [a], Zhihong Dong [a], Yuting Zhang [a]

[a] Key laboratory of Geotechnical Mechanics and Engineering of the Ministry of Water Resources, Yangtze River Scientific Research Institute, Wuhan, 430010, China
[b] Yalong River Hydropower Development Company, Ltd., Chengdu, 610051, China
[c] HydroChina Chengdu Engineering Corporation, Ltd., Chengdu, 610072, China

ARTICLE INFO

Article history:
Received 4 January 2016
Received in revised form
7 April 2016
Accepted 12 May 2016
Available online 18 June 2016

Keywords:
Underground powerhouse
High geo-stress
Rock mechanics
Rock mass stability
Engineering practice

ABSTRACT

Based on the analyses of data obtained from the underground powerhouse at Jinping I hydropower station, a comprehensive review of engineering rock mechanics practice in the underground powerhouse is first conducted. The distribution of strata, lithology, and initial geo-stress, the excavation process and corresponding rock mass support measures, the deformation and failure characteristics of the surrounding rock mass, the stress characteristics of anchorage structures in the cavern complex, and numerical simulations of surrounding rock mass stability and anchor support performance are presented. The results indicate that the underground powerhouse of Jinping I hydropower station is characterized by high to extremely high geo-stresses during rock excavation. Excessive surrounding rock mass deformation and high stress of anchorage structures, surrounding rock mass unloading damage, and local cracking failure of surrounding rock masses, etc., are mainly caused by rock mass excavation. Deformations of surrounding rock masses and stresses in anchorage structures here are larger than those found elsewhere: 20% of extensometers in the main powerhouse record more than 50 mm with the maximum at around 250 mm observed in the downstream sidewall of the transformer hall. There are about 25% of the anchor bolts having recorded stresses of more than 200 MPa. Jinping I hydropower plant is the first to have an underground powerhouse construction conducted in host rocks under extremely high geo-stress conditions, with the ratio of rock mass strength to geo-stress of less than 2.0. The results can provide a reference to underground powerhouse construction in similar geological conditions.

1. Introduction

Jinping I hydropower station involves cascaded development of the hydropower resources on the Yalong River. The major structures consist of a concrete double-curvature arch dam and an underground powerhouse. The water diversion and power generation system is placed on the right bank of the dam site. Six generators, each composed of one unit with a capacity of 600 MW, are placed underground.

The underground cavern complex on the right bank is composed of water intake tunnels, underground powerhouse, bus bar openings, main transformer hall, surge chambers, and tailrace tunnels, etc. (Fig. 1). Three major caverns (powerhouse, main transformer hall, and surge chambers) are parallel to one another. The rock cover over the cavern ranges from 160 m to 420 m and the distance from the valley slope to the cavern is about 120 m (Fig. 2). The orientation of the longitudinal axis of powerhouse is N65°W. The scale of the underground cavern complex is significantly large. For the powerhouse, the excavation height is 68.8 m and its length is 276.99 m, with a span of 25.6 m under the crane beam elevation and 28.9 m above that. The dimensions of the main transformer hall are 197.1 m × 19.3 m × 32.7 m (length × width × height). The design of water diversion and power generation system adopts the concept that every three generators correspond to one surge chamber and one tailrace tunnel. Two surge chambers are cylindrical on their sidewalls and spherical on their top arch. On the right is the No. 1 surge chamber which is 80.5 m high with

* Corresponding author. Tel.: +86 137 0711 9362.
E-mail address: wuaiqing@vip.sina.com (A. Wu).
Peer review under responsibility of Institute of Rock and Soil Mechanics, Chinese Academy of Sciences.

http://dx.doi.org/10.1016/j.jrmge.2016.05.001

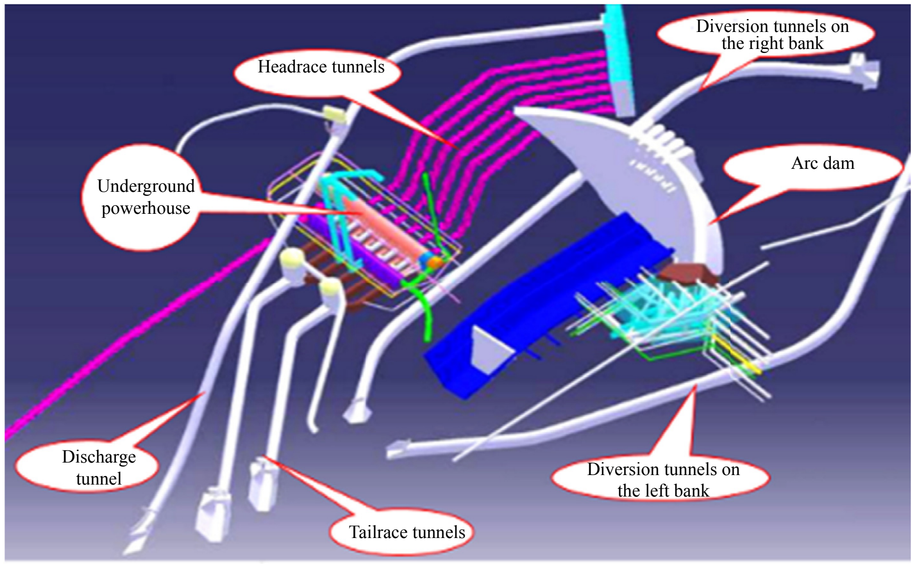

Fig. 1. Layout of major works of Jinping I hydropower station.

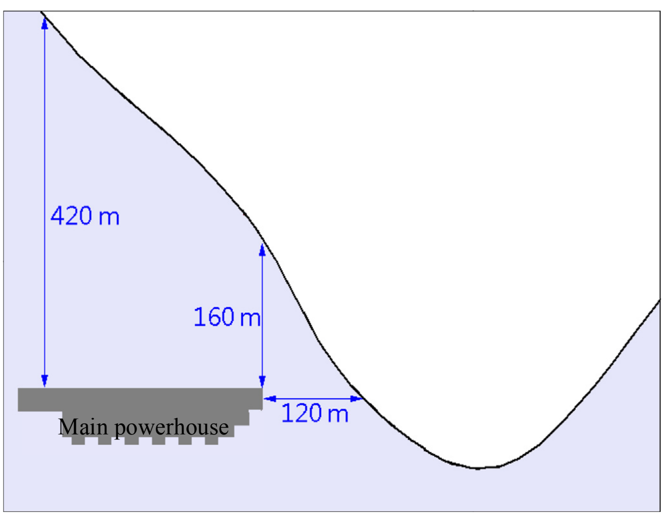

Fig. 2. Rock cover over the cavern and distance from the valley slope to the cavern location.

diameters of 41 m and 38 m on its upper and lower parts, respectively. On the left is the No. 2 surge chamber which is 79.5 m in height with diameters of 37 m and 35 m on its upper and lower parts, respectively.

The flow direction of Yalong River at the dam site is NE25°. The river is roughly straight with a narrow cross-section. The underground powerhouse is located 350 m downstream of the dam axis with a vertical overburden depth of 180–350 m and a horizontal overburden depth of 110–300 m. According to geo-stress measurements, the maximum principal stress ranges from 19 MPa to 35.7 MPa with a NW-NWW orientation. Its tensor points downward to the outward direction of the slope and also intersects the river flow direction at a large angle. The outcrop strata of the underground powerhouse region are mainly composed of marbles of the Zagunao formation of Middle and Upper Triassic Series. The uniaxial compressive strength of saturated rocks is less than 75 MPa. Using the initial geo-stress measurement data and rock strength testing results, the ratio of rock mass strength to geo-stress for the rock around the underground powerhouse is determined from 1.5 to 3. Thus the geo-stress condition can be classified as a high to extremely high geo-stress condition.

Geological structures, such as faults f13, f14, f18, and lamprophyre dike X, are observed within underground powerhouse region. The presence of the faults not only lowers the integrity of the surrounding rock mass, but also plays a decisive role in the deformation and stability of rocks around the powerhouse.

The excavation of the underground powerhouse at Jinping I hydropower station started in January 2007. It took four years to complete the excavation of underground cavern complex and the excavation of the surge chambers was completed in December 2010. Among all the underground powerhouses, Jinping I hydropower station is the first one built under extremely high geo-stress condition with a span of 30 m, where the ratio of rock mass strength to geo-stress is the lowest. Due to the site-specific geological conditions and high geo-stress distribution, complex rock mechanics problems related to construction are challenging issues that should be addressed (Wang, 2003; Qian, 2004; Gong et al., 2010; Wu et al., 2010a; Wu and Zhu, 2014). Monitoring data show that the maximum deformation measured in the surrounding rock mass reaches 250 mm and the depth of the unloading relaxation area exceeds 15 m. In this case, multiple rock failure modes are observed around the underground powerhouse.

In view of the rock mechanics problems in Jinping I hydropower station, many studies have been conducted, such as geological conditions, project layout (Zhou and Tang, 2009; Huang et al., 2014), excavation and rock mass support (Duan et al., 2009; Wang et al., 2013), stability analysis and evaluation (Wang et al., 2007; Li et al., 2009; Wu et al., 2010b; Huang et al., 2011; Lu et al., 2012), deformation and failure mechanism (Chen et al., 2010; Liu et al., 2010; Lu et al., 2010; Wei et al., 2010; Xie and Sun, 2010; Yi et al., 2010; Zhou et al., 2012), and time effect of surrounding rock mass deformation (Chen et al., 2011; Li et al., 2014). Based on the experiences obtained from underground powerhouse construction over the past decade (Wu et al., 2011), the present paper tries to analyze the rock mass stability and supporting measures needed according to the site-specific geological conditions and mechanical properties of rocks obtained at an earlier stage. The data obtained from a geological