Engineering Geology 137–138 (2012) 85–96

Contents lists available at SciVerse ScienceDirect

Engineering Geology

journal homepage: www.elsevier.com/locate/enggeo

In situ monitoring of rockburst nucleation and evolution in the deeply buried tunnels of Jinping II hydropower station

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ARTICLE INFO

Article history:
Received 12 January 2012
Received in revised form 12 March 2012
Accepted 18 March 2012
Available online 28 March 2012

Keywords:
In situ monitoring
Deeply buried tunnel
Rockburst
Nucleation and evolution
Jinping II hydropower station

ABSTRACT

Rockbursts occurred frequently during the excavation of several parallel tunnels in the Jinping II hydropower station under a maximum overburden of 2525 m over an average length of 17.5 km. In order to investigate the nucleation and evolution mechanism of rockbursts, a comprehensive monitoring campaign consisting of a digital borehole camera, cross-hole acoustic apparatus, and sliding micrometer was undertaken for *in situ* measurements in two specially excavated test tunnels *B* and *F*. This paper presents the comprehensive monitoring methods applied, and results of numerical analysis applied to a typical rockburst that fortuitously occurred during the testing period. Precursory characteristics preceding rockbursts are: (a) abundant crack initiation, propagation and coalescence, (b) deformation of surrounding rock mass involving an accelerated deformation stage, quiescence stage and reaccelerated deformation stage, and (c) decrease of the characteristic elastic wave velocity of the rock mass. The nucleation and evolution of rockbursts discussed consist of four stages: a) stress adjustment, b) energy accumulation, c) crack initiation, propagation and coalescence, and d) fractured rock collapse and ejection. The results provide a direct case history to assist the prediction and support of rockburst disasters, and contribute to field excavation of deeply buried tunnels.

1. Introduction

Rockbursts are a serious hazard which may occur during the excavation of deeply buried tunnels. The Jinping II hydropower station on the Great Jinping River Bend of Yalong River takes advantage of a 310 m natural head from the Jinping I scheme. Water is diverted by a sluice dam to headrace tunnels for power generation, as shown in Fig. 1. It has the largest water tunnels for a hydraulic power station and is one of the most outstanding tunneling projects in the world. There are seven parallel high pressure tunnels with maximum overburden up to 2525 m, mostly excavated in marble (Wu et al., 2010; Zhang et al., 2011a). The two auxiliary tunnels were completed on August 8, 2008, while one water drainage tunnel and the other four headrace tunnels with the diameter of 12.4 to 13.0 m are still being excavated at the bench. Rockbursts have occurred frequently during tunnel excavation under high geostress conditions. Approximate statistics on the burial depth of 1500–2000 m and over 2000 m collected from the two auxiliary parallel tunnels indicate that 15.6% and 31% of excavated tunnel length has been affected by rockbursts, respectively (Zhang et al., 2009a).

There has much research into nucleation and evolution of rockbursts, including laboratory tests, microseismic monitoring and numerical analysis. Gane et al. (1946) reported the early work on rockbursts in South African gold mines. Cook et al (1966) summarized rockburst research and presented a significant improvement of the understanding of the rockburst mechanism through laboratory experiments. Based on true triaxial laboratory tests, He et al. (2010) and Gong et al. (2012) pointed out that rock slabbing precedes the occurrence of rockbursts. Research on failure modes and changes of damaged zone of rock samples based on true triaxial tests (Cheon et al., 2006), dynamic disturbance tests (Huang et al., 2001; Zhang et al., 2009b) and physical model tests (Lu et al., 2008) indicates intensive cracking occurs before rockbursts. *In situ* microseismic monitoring tests (Tang and Kaiser, 1998; Abdul-Wahed et al., 2006; Stiros and Kontogianni, 2009; Chen et al., 2011; Xu et al., 2011) revealed that the energy release and microseismic events tended to increase for most of the monitored rockbursts. In addition, numerical simulations have been conducted to investigate the evolution process of stress, energy and fractures (Mueller, 1991; Tang and Kaiser, 1998; Sun et al., 2007; Józef and Janusz, 2009; Jiang et al., 2010). In most cases, there is a lot of precursory information about fractures, deformation, stress adjustment and energy accumulation and release before the occurrence of rockbursts. Gu et al. (2002) stated that the formation process of rockbursts can be divided into three stages: extension cleavage cracking, rupturing into rock slabs, and ejecting of rock blocks. He et al. (2007) suggest that the occurrence process of rock bursts may be divided into vertical slabbing, vertical buckling and

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doi:10.1016/j.enggeo.2012.03.010

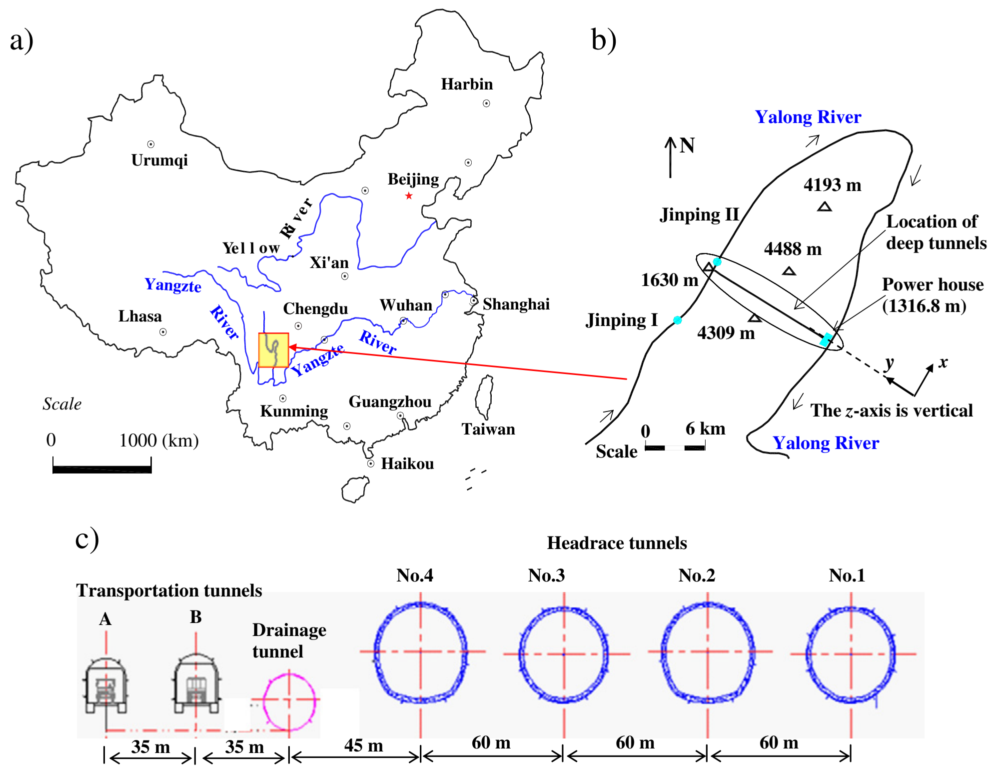

Fig. 1. Location and plan of the Jinping II hydropower station: (a) Location of the Jinping project in China, (b) Layoutof the Jinping hydropower project across the Yalong River, (c) Configuration of seven tunnels.

rockburst damage. However, rockbursts are an extremely complex phenomena influenced by multiple factors such as geological conditions, groundwater, rock lithology and tunnel excavation process. How to obtain direct and comprehensive field characteristics of rockbursts during the nucleation and evolution process in very deep open excavations remains an unresolved problem.

Several specialized test tunnels to the south of a pre-excavated tunnel of auxiliary tunnel *A* were excavated for *in situ* monitoring of rockbursts under the support of Ertan Hydropower Development Company, LTD. Comprehensive monitoring facilities were adopted to study the initiation and evolution characteristics of rockburst during tunnel excavation, such as digital borehole camera, cross-hole acoustic apparatus and the use of sliding micrometer. Fortunately, a typical rockburst occurred close to a monitored tunnel section and permitted us to collect the significant information about crack initiation and propagation, surrounding rock mass displacement, and changes in elastic wave transmission properties of the rock mass, as presented in this paper.

2. Geological conditions

The Jinping II hydropower station is located at the eastern foothills of the Qinghai–Tibet Plateau in an area influenced by the collision of the Eurasian plate and the Indian Ocean plate. The principal strata

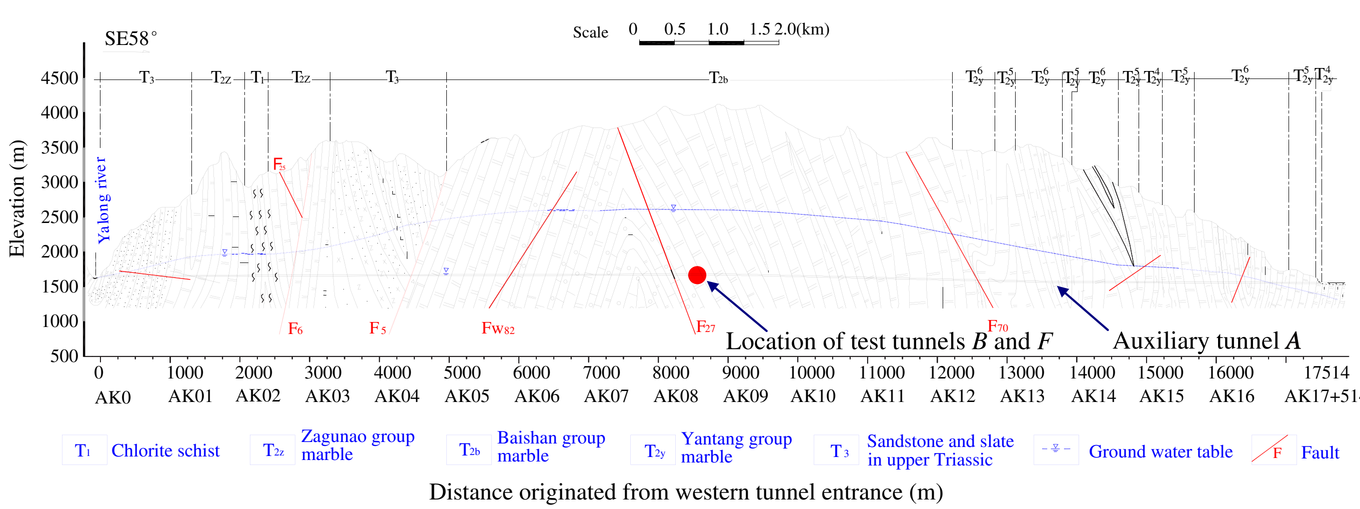

Fig. 2. Geological profile of auxiliary tunnel A and the location of test tunnels, with designed monitoring log positions.