Engineering Geology 242 (2018) 1–11

Contents lists available at ScienceDirect

Engineering Geology

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

# *In situ* observation and evaluation of zonal disintegration affected by existing fractures in deep hard rock tunneling

Xia-Ting Feng[a,b,*], Hao-Sen Guo[a], Cheng-Xiang Yang[a], Shao-Jun Li[b]

[a] Key Laboratory of Ministry of Education on Safe Mining of Deep Metal Mines, Northeastern University, Shenyang 110819, China
[b] State Key Laboratory of Geomechanics and Geotechnical Engineering, Chinese Academy of Sciences, Institute of Rock and Soil Mechanics, Wuhan 430071, China

A R T I C L E I N F O

*Keywords:*
Zonal disintegration
*In-situ* observation
Digital borehole televiewer
Deep hard rock
RMIBT

A B S T R A C T

Zonal disintegration refers to the phenomenon whereby fractured zones and intact zones appear alternately in surrounding hard rocks under high stress conditions. In this study, zonal disintegration within hard surrounding rocks of deep tunnels at the China Jinping Underground Laboratory Phase II (CJPL-II) was observed by using a digital borehole televiewer in pre-drilled boreholes. The results revealed that fractured zones within intact high-strength marbles were small and exhibited a higher degree of fracturing, whereas fractured zones within low-strength, low-integrity, marbles showed fewer, yet larger fractures. An evaluation method based on rock mass integrity index using digital borehole televiewer data (RMIBT) has been proposed for the analysis of zonal disintegration process in the deep hard rocks surrounding the tunnels. By using the method we were able to quantify the initiation and evolution of fractures during zonal disintegration. The formation mechanism of the second and third fractured zones induced by the existing fractures was further investigated using numerical analysis. The data provide an insight into the evolution of failures in, and a basis for support design and stability control of, deep engineering works in hard rock.

## 1. Introduction

Rockmass fractured zones refer to the zones where macrofissure initiation, fracture extension, and rock blocks fall due to excavation (Feng and Hudson, 2011; Walton et al., 2015). Zonal disintegration is a special engineering geological phenomenon occurring in fractured zones under high-stress conditions in deep hard rock: it refers to the alternating appearance of fractured and intact zones in surrounding rocks in both of two sidewalls and in front of the tunnel face during the excavation of deep tunnels in hard rock (Fan et al., 2016; Roy et al., 2017). Deep hard rocks are mainly characterised by cracking of surrounding rocks during excavation which induces the formation and evolution of zonal disintegration in rocks (Wu et al., 2009; Carlà et al., 2017). Cracking of surrounding rocks provides precursory information as to hazards such as rock spalling and large deformation of deep hard rock tunnels and caverns (Liu et al., 2017; Erarslan, 2016; Lei et al., 2017; Sirdesai et al., 2017). Therefore, the *in-situ* observation and quantitative evaluation of zonal disintegration in deep hard rocks is important for optimisation of support design and engineering stability control.

Zonal disintegration was first seen, in real-time, in a deep gold mine in Witwatersrand, South Africa in 1980 (Adams and Jager, 1980). By using ultrasonic testing, Shemyakin et al. (1986) observed zonal disintegration in multiple ore bodies such as the sulphide ore of the Norilsk minefield. They believed that the quantity of zonal disintegration is related to the burial depth and rock strength. By analysing observed data of acoustic wave velocity, strain, and amount of drilling cuttings, the zonal disintegration is correlated with burial depth and rock parameters (Tan et al., 2010). With the application of a borehole camera exploration device, Tan et al. (2012) observed zonal disintegration in different ore beds in Xinwen Mine and concluded that blasting action and stress unloading are the main factors inducing zonal disintegration. By simulating the formation of zonal disintegration in surrounding rocks of deep roadways using an analog simulation, the peaks and valleys of the strain and displacement in surrounding rocks are distributed as a wave-form (Zhang et al., 2017). The possibility of inducing discrete fractures was studied using slowly unloading P-waves (Zhu et al., 2014). For the *in situ* observation of fractured zones, different approaches have different precisions: the precision of acoustic testing is 0.8 m from a signal projector to a receiver (Li et al., 2012), while that of a borehole camera exploration device is the recording error, about 0.5 m, caused by different probe pushing velocities. Consequently, different test methods with different precisions yield distinct measurement results of fractured zones. The formation mechanism of zonal

* Corresponding author at: Key Laboratory of Ministry of Education on Safe Mining of Deep Metal Mines, Northeastern University, Shenyang 110819, China.
*E-mail address:* xtfeng@whrsm.ac.cn (X.-T. Feng).

https://doi.org/10.1016/j.enggeo.2018.05.019
Received 2 January 2018; Received in revised form 14 May 2018; Accepted 15 May 2018
Available online 17 May 2018
0013-7952/ 

disintegration needs to be further understood. It is not clear as to the extent, or mechanism of influence, of the existing fractures on the formation of the zonal disintegration. Moreover, no evaluation index has been established for fractured zones. As fractured zones of varying fracture extents exert different influences on a project, the extent of fracturing should be used as an important index. All these make accurate *in-situ* observation and quantitative evaluation difficult.

In comparison, the lowest resolution of digital borehole cameras can reach 0.2 mm in the monitoring of fractured zones (Li et al., 2013), which is higher than that for fissures observed using ordinary acoustic wave testing and borehole camera exploration devices under the same conditions. So, digital borehole cameras can more accurately depict the initiation and evolution of a fractured zone upon excavation. As the evaluation method for rock mass integrity based on borehole televiewer data (RMIBT) can quantify rock integrity (Guo et al., 2017), the research proposed an evaluation index based on RMIBT for zonal disintegration degree (RMIBT-Z) in deep hard rock. By using the index to the China Jinping Underground Laboratory Phase II (CJPL-II) project, the authors observed the initiation and evolution of single fractured zones and zonal disintegration in hard rocks surrounding deep tunnels. Furthermore, the range of the rupture zone and degree of fracturing were quantified. In this way, the initiation and evolution characteristics of fractured zones and zonal disintegration in rocks of different lithologies and structures in CJPL-II were obtained. Furthermore, the research compared the obtained single fractured zones and zonal disintegration with excavation damaged zones (EDZs) detected using acoustic wave testing and discussed the mechanism of formation of zonal disintegration in deep rock.

## 2. *In situ* observation scheme at CJPL-II

### 2.1. Engineering background

The CJPL-II is composed of four experimental caverns, each of which is 130 m long and contains two 65-m-long laboratories. It has the overall pattern of eight laboratories, plus a small rock size laboratory, with an overburden depth of about 2400 m (Fig. 1). From the west to the east, there are 1#, 2#, 3#, and 4# experimental caverns, the axes of which are all parallel to auxiliary tunnels of the project and the azimuth of the axes is N58°W. The 1–8# labs have gateway-like excavation

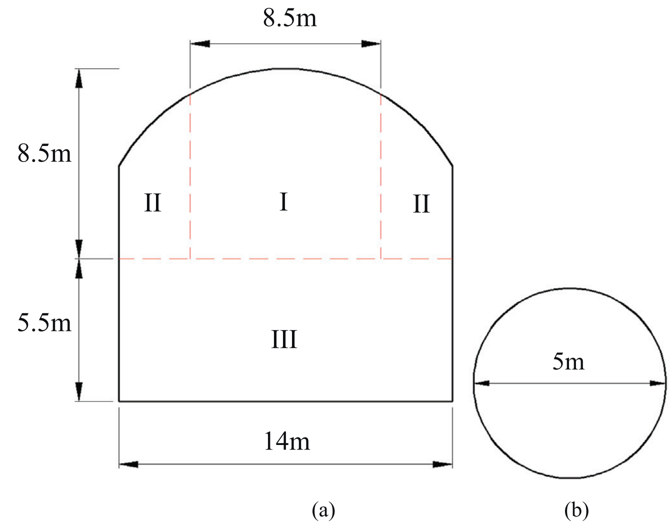


**Fig. 2.** Cross-sections and excavation stages at CJPL-II. (a) Cross-section of the 1#~8# Labs. (b) Cross-section of the 9-1# Lab.

sections measuring 14 m × 14 m. They were excavated by using the drilling and blasting method in three steps: excavation of pilot tunnels in the upper layer (Step I), the expanding excavation of the upper layer (Step II), and the excavation of the bottom layer (Step III). While the 9-1# lab is a cavern having a round excavation section, with a diameter of 5 m, was constructed through full face excavation (Fig. 2).

The site of CJPL-II is located in the anticlinal region whose axis runs nearly north to south. The axis of the 2# traffic tunnel is located at the anticline core which outcrops at chainage 0 + 2 m of the 4# Lab. The 1#, 2#, and 3# Labs are situated at the northwestern limb while 4#~8# Labs were located at the southeastern limb of the anticline. As to the occurrence characteristics of strata, from the core to the western limb of the anticline, the strata are near-SN~NNE trended and inclined to the NW in the northwestern limb while to the SE in the southeastern limb. 3# and 4# laboratories have two developed fault zones: One has the axis direction of N10–20°W, and the other has the axis direction of N25–35°W. Both zones have SW dip direction and a dip of 70–80°. The types of the faults are difficult to determine based on their exposed

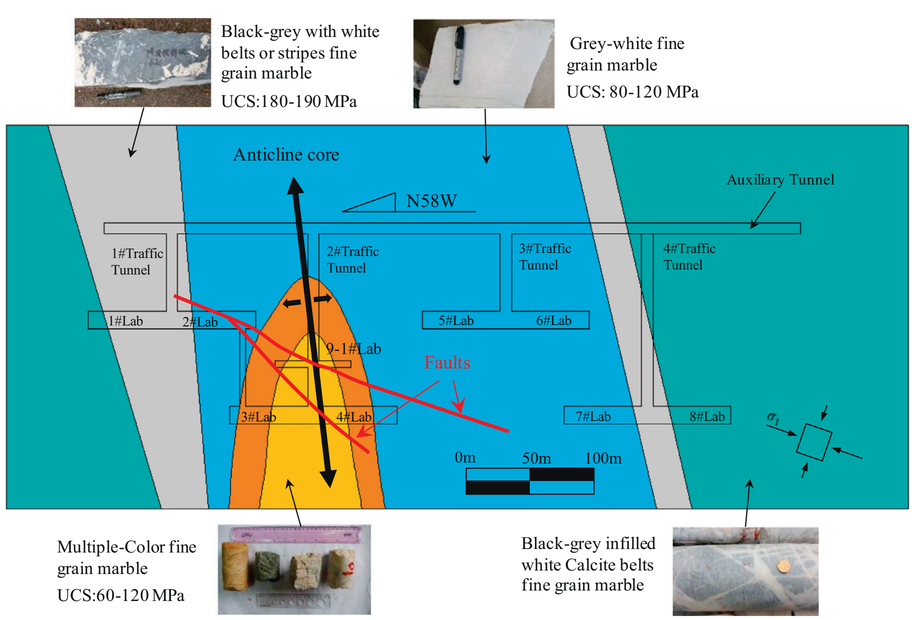


**Fig. 1.** Distribution of geological conditions at CJPL-II. (modified from Feng et al., 2016).