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Physical modeling of deformation failure mechanism of surrounding rocks for the deep-buried tunnel in soft rock strata during the excavation

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ABSTRACT

A physical modeling experiment was carried out to study deformation mechanism of tunnel excavated in the deep-buried soft rock strata. During the process of excavation, an infrared camera and a full-field strain measurement system were employed to obtain the thermal response and deformation of surrounding rock. Meanwhile, strain rosettes were used to measuring the strain of surrounding rocks, which were installed with a circular layout pattern in the surrounding rocks. Deformation failure mechanism of surrounding rocks was investigated by synthetic analysis of the infrared images, experimental pictures, and displacement field images. A numerical model was implemented to compare the displacement results of the physical model. The results showed that driving footage produced an effect on the deformation of surrounding rock, the bedding plane had an inevitable influence on the deformation of surrounding rock during the excavation processes and temperature variations of surrounding rock can reflect the behavior change of surrounding rock.

1. Introduction

Many underground constructions, such as tunnels for civil engineering projects and mining excavations, have to be constructed in stratified rock masses. Stratified rock masses produced an inevitable effect on the stability of tunnels (Zhang et al., 2012). With increasing of the mining depth, the deformation failure mechanism of tunnels excavated in stratified rock masses became more complex. Therefore, studies on the deformation failure mechanism of deep-buried roadway will be helpful to reduce excavation related engineering problems.

Many scholars have studied the stability, deformation and mechanical behavior of surrounding rock during the excavations process using varied methods including numerical simulation, laboratory experiments, and in-situ tests. Because in-situ tests are limited both in time and costs (He, 2011), the physical model test and numerical simulation are the two more powerful methods to do some research on the stability and failure of the geotechnical engineering structure (Lin et al., 2015a, 2015b). In the aspect of the model test, plenty of research have been conducted. The change of stresses during the excavation was studied by tests (Terzaghi, 1954; Murayama, 1968). Goodman and Shi (1985) put forward the key block theory to predicate the stability of rock blocks during the tunnel excavations. Jeon et al. (2004) studied the effect of fault and weak plane on the stability of tunnel during the excavation process by small-scale model tests. Wu et al. (2004) researched the mechanical behavior of rock masses during the construction using discontinuous deformation analysis. Lee et al. (2008) studied the failure mechanism of tunnel faces by the scaled model test. He et al. (2009, 2010a, 2010b, 2011) did a lot of work to research the failure mechanisms of the tunnel excavated in the inclined stratified rock masses in deep coal mines by the physical model test. Zhu et al. (2010) studied the stability of an underground cavern group by the large-scale three-dimensional (3-D) geomechanical model tests and numerical simulations. Zhu et al. (2011) conducted a mode test to research the failure mechanism of caverns under high stress. Gong et al. (2013a, 2013b, 2015a, 2015b) analyzed the infrared thermography of failure process during the excavation process by the model test. Huang et al. (2013) researched the influence of weak interlayer on the failure pattern of rock mass around tunnel by numerical simulation and physical model test. Lin et al. (2015a) investigated the failure behavior and instability of the "large, deep, long and in-group" tunnels constructed in the Jinping II hydropower station by the model test. Lin et al. (2015b) carried out a geomechanical model test to study the cracking, stability and reinforcement of the slope. Li et al. (2015) researched the deformation of surrounding rocks and failure mechanisms of deep roadways by the physical model test. Yang et al. (2015) used numerical simulation and physical model test to research the mechanical behavior of jointed rock mass adjacent to an underground excavation. Liu et al. (2003) assessed and analyzed the stability of the Three-Gorges dam

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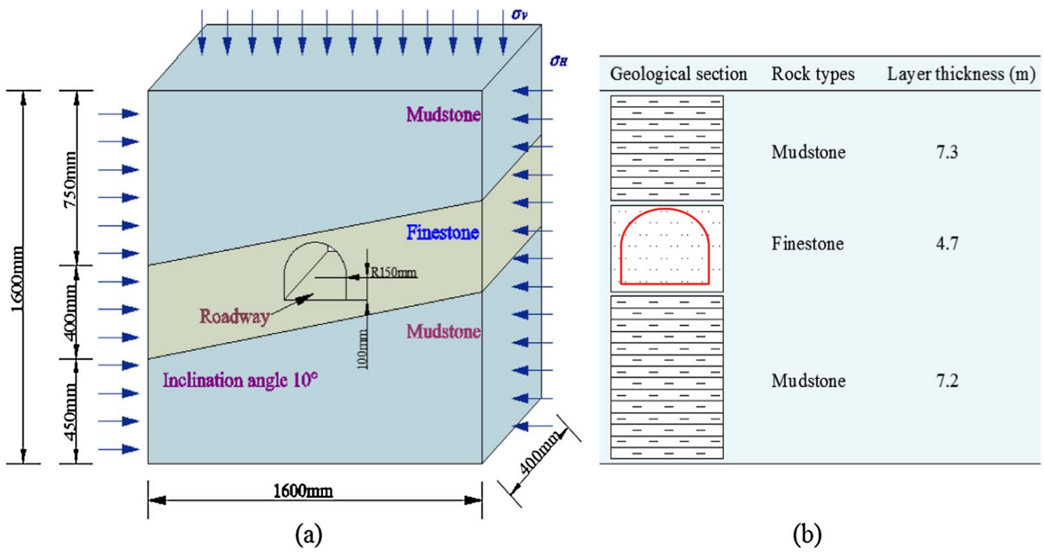

Fig. 1. Stratum distribution. (a) Stratum distribution in geological model and (b) rock profile.

Table 1
Physical and mechanical parameters for the real rocks.

Rock types	Unit weight (kg/m^3)	UCS (MPa)	Young's modulus (GPa)	Poisson's ratio
Firestone	2320	15.5	3.7	0.18
Mudstone	1900	7.6	2.8	0.30

foundation, China by modeling test. Zhang et al. (2016) took new measurement techniques to study the deformation of the underground cavern group in large-scale 3D geomechanical model test. Chen et al. (2016) employed numerical simulation and model test to research the stability of brick-lined tunnels. Sun et al. (2017a, 2017b) studied the effect of horizontal stress on the failure mechanisms of the deep-buried roadway by the physical model test. Liu et al. (2017) used model test and simulation to research the distribution law of unsymmetrical loading tunnel in bedding rock mass.

Previous research paid more attention to the deformation failure mechanism and stability of tunnels after the tunnel was excavated completely, few studies on the deformation failure of deep-buried tunnels during the whole excavation processes. However, for the deep-buried tunnel, the study of excavation processes is useful to provide some theoretical guidance to reduce the tunnel's deformation. In the

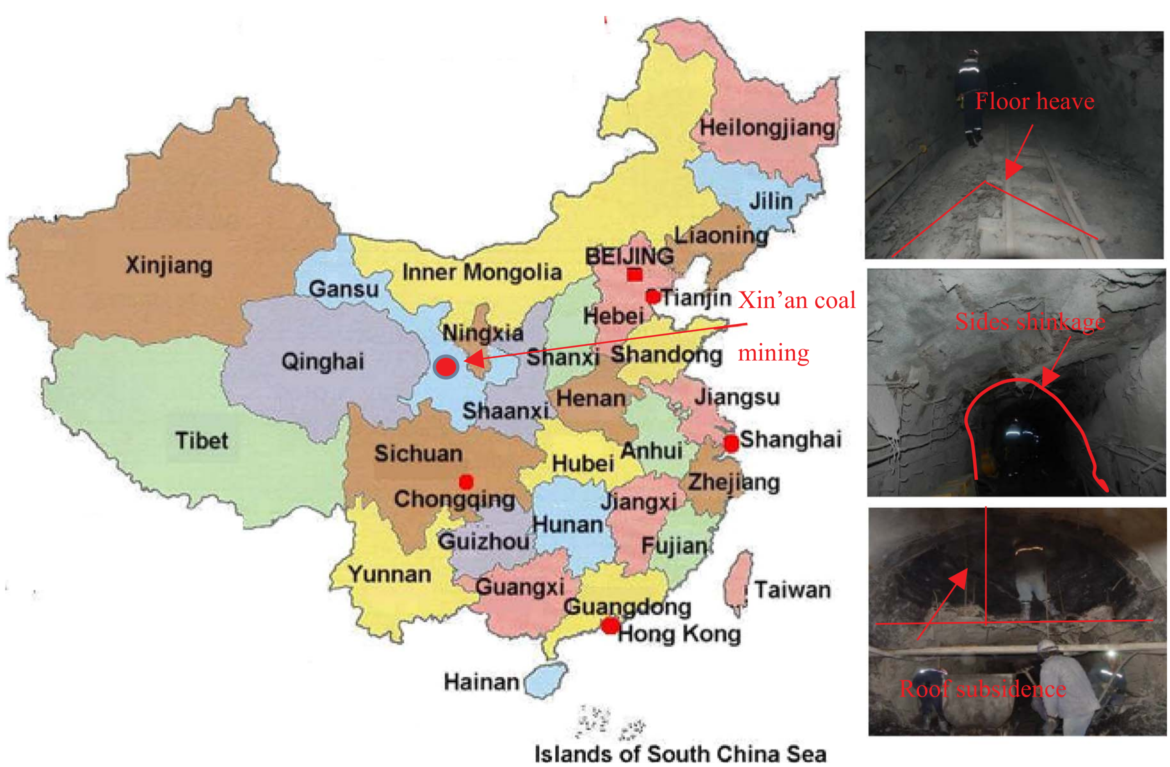

Fig. 2. Deformation failure of roadway.