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Longitudinal deformation profile of a tunnel in weak rock mass by using the back analysis method

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ABSTRACT

Analysis of the rock mass deformation behavior is a very important aspect of the safety assessment for tunnel construction in weak rock mass. In this paper, the deformation characteristics of a soft rock mass tunnel using three beaches construction method were investigated, which include the crown settlement and horizontal displacement and have 9 sections with 3 different construction schemes. The optimized construction schemes by decreasing the beaches length and changing the geologist of primary support were proposed. Then, applying the displacement back analysis method to calculate the rock mass parameters, double parameters were analyzed by using the golden section method. Results show that the tunnel deformations were affected by the elastic modulus E and the lateral pressure coefficient λ of rock mass, and the change of E has greater influence than λ on the tunnel deformation. The change of λ has greater influence on the crown settlement than that on the horizontal displacement. Furthermore, the regularity and characteristics of longitudinal deformation profile (LDP) in a weak rock mass tunnel was studied by utilizing the Fast Lagrangian Analysis of Continua (FLAC), and the LDP of the three long-beach construction scheme and the three short-beach construction scheme were compared. The results show that the complete displacements of tunnel under the three short-beach construction scheme condition by decreasing the lengths of the middle and lower benches are smaller than that under the three short-beach construction scheme condition, however the pre-deformation of the tunnel deformation under this two construction scheme conditions is nearly the same. The extrusion deformation at the tunnel face of the three short-beach construction scheme is larger than that of the three long-beach construction scheme. Therefore, increasing the area of the core soil is a feasible measure to control the extrusion deformation on the tunnel face. Finally, the tunnel optimized construction scheme was verified benefit the tunnel stability. The measures of decreasing the length of middle and lower bench and closing the invert early and immediately will benefit the tunnel stability.

1. Introduction

By the end of 2015, 14006 highway tunnels with a total length of approximately 12,684 km have been constructed for operation in China. Recently, the construction speed of highway tunnels has exceeded 1000 km annually. China has been at the forefront of tunnel construction in terms of quantity, scale, and difficulty. Many tunnels are constructed in the weak rock mass, thereby resulting in complex engineering problems which are encountered by Chinese engineers. The most common engineering problems in tunnelling include large deformation, considerable clearance limit, and collapsing. The tunnel deformation behavior in weak rock mass is complex, therefore, the aforementioned engineering problems have occurred in various local and overseas tunnel constructions, such as the Tauern tunnel in Austria, Enasan tunnel in Japan, Jia Zhuqing tunnel of the Nanning to Kunming railway in China, and Wu Shaoling tunnel in Gansu province (China). These engineering problems could affect the speed and safety of construction, as well as cause the construction to go out of control, costly failure, and casualties. Therefore, studying the deformation behavior of tunnels in weak rock mass is significant in resolving the engineering problems.

During tunnel excavations, the deformation of the rock mass caused by the unloading of itself will vary with time. In the past few decades, the radial shape of the displacements around the tunnel face has been estimated. In the mid-1970s, numerical methods were used to analyze the displacement around the tunnel face, thereby obtaining valuable

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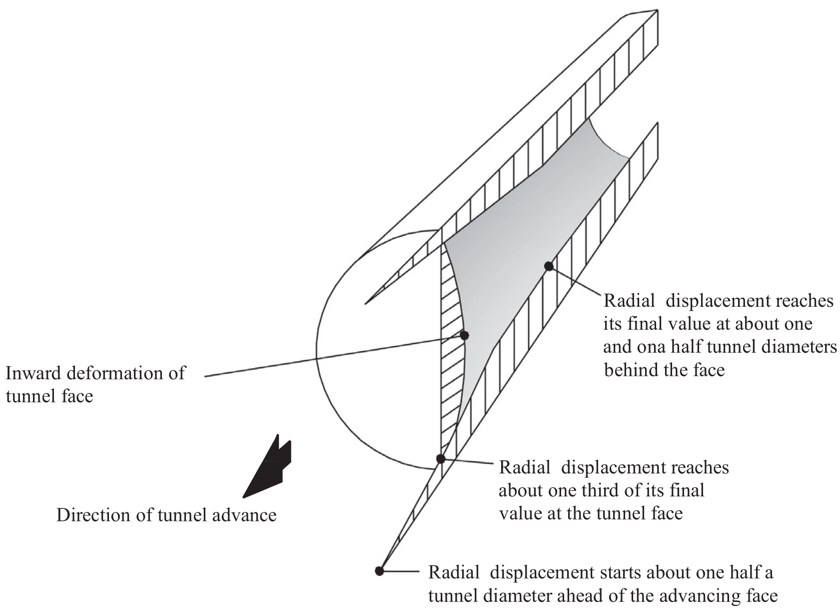

Fig. 1. The deformation pattern in the rock mass that surrounds an advancing tunnel.

information on the stability of the tunnel (Ranken and Ghaboussi, 1975; Hocking, 1976). From the 1980s, monitoring measurement has been extensively used to assess the response of the rock mass based on the field measurements of the rock mass deformation using special instruments (e.g., tap extensometer and precision level) (Sakurai and Takeuchi, 1983; Gioda and Sakurai, 2010). The measured results can reflect the behavior of the rock mass and supporting structures, as well as evaluate the stability of the tunnel structures (Lai et al., 2016b; Luo et al., 2016, 2017a, 2017b; Schubert et al., 2002). However, the measured displacement of the rock mass is only a part of the complete deformation.

Complete deformation includes those before, during, and after the tunnel excavation. Hoek (1998) used a three-dimensional finite element method (FEM) to analyze the rock mass deformation that surrounds a circular tunnel advancing through a weak rock mass, thereby showing a deformation pattern in the rock mass that surrounds an advancing tunnel (Fig. 1). Carranza-Torres and Fairhurst (2000) established a longitudinal deformation profile (LDP) to analyze and graph the radial displacements along the axis of the tunnel in sections located ahead and behind the tunnel face (Fig. 2). With respect to distance from the tunnel face, LDP includes three components: (1) Y_1, pre-deformation, (2) Y_2, loss displacement, which cannot be measured before the installation of the monitoring instrument, and (3) Y_3, measured displacement.

LDP for a tunnel is important to determine the appropriate timing

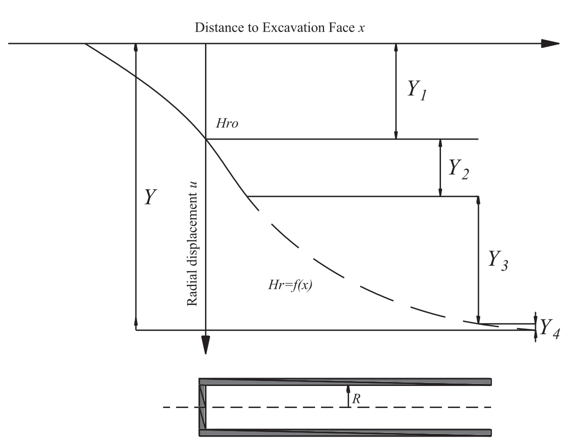

Fig. 2. The radial displacements along the axis of the tunnel in sections located ahead and behind the tunnel face.

for the installation of support or to optimize the installation of support with specific displacement capacity (Song et al., 2016). Two methods are used to obtain LDP, namely, field measurement and numerical simulation. Dr. Zhao (2010) introduced the rock mass deformation of Gui Pu tunnel in Japan, and the space distribution characteristics of a tunnel crown settlement was tested by setting an approximately 50 m-horizontal monitoring tube above the crown of the tunnel surface along the longitudinal of the tunnel. Moreover, Chinese scholars (Zhao, 2010; Li et al., 2014) obtained the data of ground settlement in shallow tunnels. The field measurement data indicated that the pre-deformation Y_1 was located in the crown and ground of the tunnels. Many attempts were used to measure LDP in the field, however, the results were incomplete because the monitoring measurement is difficult to obtain, particularly in deeply buried tunnels. By contrast, numerical simulation is extensively used with the development of computer technology. Numerical simulation includes finite element method (FEM), finite difference method and discrete element method (Jiao et al., 2005). However, the material parameters of the ground are difficult to determine in a numerical simulation. The material properties are affected by the inhomogeneous nature of the soil mass or rock mass, and the influence of complicated geological factors (Liang et al., 2003).

The back analysis method was first introduced to obtain the actual material parameters during tunnel construction in 1980s (Cividini et al., 1981). Back analysis is an effective indirect technique that uses displacements (Sakurai and Takeuchi, 1983; Gioda and Sakurai, 2010), strains (Sakurai et al., 2010), stresses (Kaiser et al., 1990), or acoustic emission information (Cai et al., 2007) to obtain the material parameters. Moreover, back analysis has been extensively used in underground engineering and has become increasingly popular in solving engineering problems (Yeh and Yoon, 1981; Cividini et al., 1983; Okabe et al., 1998; Li et al., 2001; Lee et al., 2006; Feng et al., 2006; Vardakos et al., 2007; Hudson and Feng, 2007; Guan et al., 2009). Levenber–Marquardt, Gauss–Newton, Bayesian, Powell, Rosenbork, and genetic algorithms have been proposed to obtain the optimal values of the parameters from the measured displacements (Deng and Lee, 2001; Huang et al., 2009; Lai et al., 2016a; Ren et al., 2005; Miranda et al., 2011; Yang et al., 2010; Yu et al., 2007). However, problems remain unresolved. For example, searching for the estimated parameter values is difficult in a large and considerably multimodal space (Khamesi et al., 2015).

This study based on a weak rock mass tunnel in the Mingyazi tunnel in Shaanxi Province of China to measure the tunnel displacement in