Tunnelling and Underground Space Technology 38 (2013) 348–356

Contents lists available at ScienceDirect

Tunnelling and Underground Space Technology

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

Time-dependent behavior of tunnel lining in weak rock mass based on displacement back analysis method

Mostafa Sharifzadeh [a,*], Abolfazl Tarifard [b], Mohammad Ali Moridi [a]

[a] Department of Mining Engineering, Western Australian School of Mines, Curtin University, Australia
[b] Department of Mining Engineering, Sahand University of Technology, Tabriz, Iran

ARTICLE INFO

Article history:
Received 27 August 2012
Received in revised form 5 July 2013
Accepted 10 July 2013
Available online 13 August 2013

Keywords:
Creep
Time-dependent
Burger-creep visco-plastic model (CVISC)
Finite difference method
Back analysis
Shibli tunnel

ABSTRACT

Weak rock mass behavior is an important and challenging consideration during construction and utilization of a tunnel. Tunnel surrounding ground deformation in weak rocks causes to gradual development of loading on the support system and threats the opening stability. In this research, time-dependent behavior of Shibli twin tunnels was investigated using laboratory testing, monitoring data, and finite difference numerical simulation approaches. The host rock of Shibli tunnels are mainly composed of gray to black Shale, Marl and calcareous Shale. Geological maps and reports demonstrate a heavily jointed condition in the host rock through two orogenic phases. The experiment was organized in following order to understand the behavior of the rock mass around the tunnels. At first, triaxial creep test were conducted on intact rock specimens. Then, the time-dependent behavior of the tunnel host rock was numerically simulated considering Burger-creep visco-plastic model (CVISC). Finally, displacement based direct back analysis using univariate optimization algorithm was applied. Also, the properties of the CVISC model and initial stress ratio were estimated. Numerical modeling was verified by its comparison with tunnel displacement monitoring results. The creep behavior of the rock mass was predicted during tunnel service life based on back analysis results. Results show that thrust force, bending moment, and the resulting axial stresses will gradually increase at the spring line of the final lining. After 55 years of tunnel utilization the compressive strengths of lining concrete will not be stable against the induced-stresses by thrust force and bending moment, thus the tunnel inspection and rehabilitation are recommended.

1. Introduction

Tunnel excavation in weak rock mass causes tunnel wall convergence and increases ground pressure on a support system. These variations are mainly due to the advance of the tunnel face and time-dependent behavior of the host weak rock mass. The time-dependent behavior of the rock mass is particularly common in tunnels excavated in soft rock, heavily sheared weak rock masses, or rock masses with high in situ stress (Zhu and Zhao, 2004; Guan et al., 2008). After a tunnel excavation and the installation of support system in such rock masses, the ground may gradually move as time passes. Additionally, the contact pressure may develop through time because of the time-dependent behavior of the weak rock mass. In extreme conditions, the large tunnel closures and the reduction of the tunnel cross section may occur (Pellet, 2009); or further reinforcement is needed during its service life (Guan et al., 2008). Therefore, the time-dependent features of rock mass should be taken into account in the long-term design and maintenance of tunnels excavated in the weak and the soft rock mass.

In order to describe the time-dependent deformation or creep in tunnels, various approaches have been established based on analytical (Goodman, 1989; Fahimifar et al., 2010; Nomikos et al., 2011), empirical (Sakurai, 1978; Sulem et al., 1987), and numerical methods (Boidy et al., 2002; Lian-guo et al., 2008; Guan et al., 2008; Pellet et al., 2009; Nadimi et al., 2010). This research presents a numerical simulation as one of the common methods to solve rock creep problems. It is well known that the rock properties, determined from laboratory tests; cannot be directly used for prediction of tunnel behavior for appropriate numerical simulations. Thus, it is essential to compare simulation results with obtained measurements from monitoring the tunnels over a long period (Boidy et al., 2002; Pellet, 2009).

Nowadays, back analysis as a helpful technique is used for determining the unknown geomechanical properties. The most back analysis techniques in the geotechnical engineering problems are stipulated the basis of methods which utilize the monitored data of stress, strain and displacement.

* Corresponding author. Address: Curtin University, Department of Mining Engineering, Western Australian School of mine, Locked Bag 30, Kalgoorlie 6433, Western Australia, Australia. Tel.: +98 (021) 6454 2952; fax: +98 (021) 6640 5846.
E-mail address: m.sharifzadeh@curtin.edu.au (M. Sharifzadeh).

0886-7798/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.tust.2013.07.014

This study evaluates the displacement considering direct back analysis of time-dependent behavior of Shibli tunnel using univariate optimization algorithm. General geology of the project region is strongly influenced by two orogenic phases, which have resulted in heavily jointed rock masses. The Shibli tunnels host rocks are mostly comprised of gray to black shale, marl and calcareous shale. This study also focuses on a specific section of the northern tunnel. Accident statistics show the third collapse in this section and some sections of the southern tunnel in the same zones so far (Sharifzadeh et al., 2012). For this purpose, several experimental creep tests were performed on rock around the tunnel. Then, monitoring results were precisely investigated to obtain a realistic creep model. Finally, long term behavior of tunnel stability was studied.

2. Study area

The Shibli twin tunnels are part of Tabriz–Zanjan freeway which connects the city of Tabriz to Bostanabad country (Fig. 1). The Shibli tunnels with a total length of 4533 m (northern tunnel: 2244 m and southern tunnel: 2289 m) were constructed to remove heavy traffic. The purpose of these tunnels will be the reduction of the driving casualties' statistic in the old Shibli stepped road. Tunnel cross sections are both horse shoe shaped with 14 m width and 11 m height. The distance between axes of the two adjacent tunnels is approximately 60 m apart.

The tunnels are located in the outermost northern–west part of central Iran geological formation. The host rocks of the Shibli tunnels are mostly composed of gray to black Shale, Marl and calcareous Shale. This formation has been exchanged to heavily jointed rock masses after two orogenic phases (Fig. 2). According to the engineering geological investigations, rock mass rating (RMR) was inferred from the surface and underground mapping. In case, the host rocks were divided into three geotechnical units including A, B and C units at construction stage. Block A assigned to the most competent part of the host rock containing calcareous and Sandy Shale and Limestone. Block B, which belongs to the fair class of RMR index, consists of black to gray Shale and jointed Limestone. Lastly, the crushed black Shale and Marl constitute the rocks of block C. A heavily jointed rock masses located in block C cause the most complicated situation especially where there is a combination of high water inflows and severely tectonized zones. The rock mass quality was determined using rock mass classification systems such as RMR, Q and GSI. It has been argued that application of RMR was not appropriate for incompetent combinations of the ground i.e. RMR < (30–40). Hence, GSI was used instead to rate the poor rock masses within the tunnel route. Detailed information of rock mass rating is presented in Fig. 2. Additionally, Table 1 illustrates the characteristics of four predominant joint sets inferred from surface mapping and subsurface investigation (Aradan Construction Co., 2009).

The Shibli tunnels were constructed with top heading and benching method. The temporary support system in block C consists of grouted rock bolt with 6 m length, steel rib with 0.5 m spacing, and 25 cm thickness of shotcrete were installed after each excavation sequence. The final lining was installed approximately 13 months after top heading excavation. Typical cross-section of the tunnel is schematically illustrated in Fig. 3, and the properties of temporary support system and final lining listed in Table 2 (Aradan Construction Co., 2009).

Tunnels deformations were monitored by instrumentation. Several instrumentations such as convergence pints and multi-point bore hole extensometers (MPBX) were installed at different instrumentation stations during excavation along tunnels. Following a top heading excavation, three convergence measurement points were installed for tunnel convergence monitoring. This array was increased up to five point convergence measurements after bench excavation. In addition, three point borehole extensometers were installed and monitored at the complete monitoring stations, Fig. 3b.

3. Triaxial creep tests on Shale specimens

Triaxial creep tests were conducted on specimens taken from the tunnel host rocks in order to evaluate their time-dependent behavior at laboratory scale (Fig. 4). Multi-step loading modes on a single sample adopted for performing creep tests, because a single-step loading mode on several samples usually requires more rock samples. In this case, the heterogeneity of rock samples may cause scatter in experimental results. The results of triaxial creep tests on three specimens of Shale are illustrated in Fig. 5.

During the creep tests and the creep phases of the triaxial tests, most of the samples under deviatoric loading exhibit time-dependent strains. It has been shown that the time-dependent behavior of Shales cannot be neglected and should be taken in to account for the assessment of the tunnel behavior in its service life.

4. Time-dependent numerical modeling

In order to conduct time-dependent numerical modeling, the finite difference code FLAC has been used (Itasca Consulting Group,

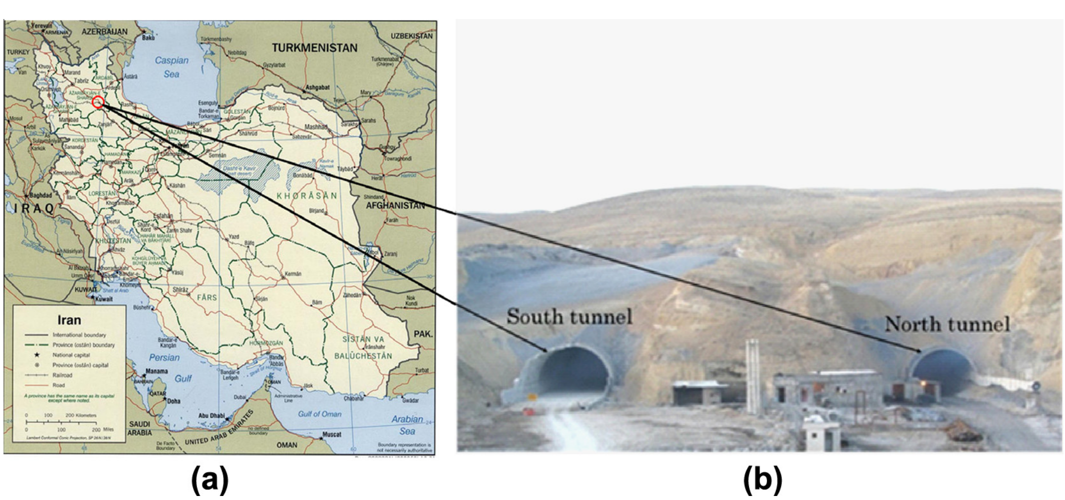

Fig. 1. (a) Location of Shibli twin tunnels in Iran map and (b) the photo of Shibli twin tunnels site.