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Back analysis of closure parameters of Panet equation and Burger's model of Babolak water tunnel conveyance

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ABSTRACT

Babolak water conveyance in north of Iran on Babolak river is under construction. Tunnel support consists of lattice girder, rock bolt, and shotcrete. According to application of classification systems RMR and Q, rock mass in the path of primitive part of the tunnel which is excavated in Marn is evaluated weak and very weak. In first part of the paper the Closure parameters of Panet equation associated with face advance and time effect of the tunnel in six different stations are determined using optimizing Levenberg–Marquardt and Trust-Region back analysis techniques on convergence instrumentation data. In second part of the paper, Burger's creep parameters are determined using instrumentation results in 0+603 station and Panet equation results in a back analysis performed utilizing FLAC3D. Predicted convergence results by the Panet equation are in good agreement with numerical analyses.

1. Introduction

During tunnel excavation convergence and support pressure increase in relation to time which is due to face advance and time-dependent properties of tunnel host rock. Different authors have reported different values of displacements due to time-dependent behaviors (50% [1] and more than 75% [2] of total displacements). In order to describe the time-dependent deformation or creep in tunnels, numerous analytical tools have been developed, which may be classified into three groups: closed-form or theoretical solutions [3,4], empirical approaches [2,5,6], and numerical methods [7,8]. Back analysis using numerical methods is widely used for determining the unknown geomechanical properties. Many papers have utilized back analysis in order to determine time-dependent properties of weak rocks [9–11].

This paper uses Panet equation to separate displacements due to face advance and time-dependent behavior in a water conveyance tunnel in Iran. Time-dependent properties of the tunnel host rock mass are determined through numerical analysis.

2. Geology and description of water conveyance tunnel

In order to provide a part of required water for Alborz dam storage, a cofferdam has been considered on 700 m distance on Babolak River. The cofferdam transmits Babolak River water to Babol River at Alborz main dam upstream using a diversion tunnel (Fig. 1). The diversion tunnel has 4.2 m width and northwest–southeast orientation with 2600 m long. Road header is used for tunnel excavation. Support system in Babolak water conveyance tunnel consists of shotcrete, wire mesh, steel net arch with 1 m spacing and grouted rock bolt. The most overburden depth in +1750 m distance from diversion tunnel inlet is 185 m [13].

Tunnel route host rock consists of sandstone, silty-Marn, sandy-Marn, Marn and Conglomerate in brown and red colors from Miocene epoch with Conglomerate interlayers [13]. Engineering geological studies consist of field observations, boreholes and laboratory tests on the samples collected from field. After discontinuity measurement in tunnel route, discontinuity orientations were processed by utilizing computer software, DIPS 5.1. The determined dominant discontinuity sets along the tunnel route are given in Table 1. Geological engineering features of discontinuities are presented in Table 2.

Tunnel route convergence at six stations is investigated. Three stations (0+550 m, 0+ 603 m and 0+638 m) are located in brown sandy Marn rock mass. Overburden depth in these stations is 70, 85 and 89 m, respectively. Three other stations (0+717 m,

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Fig. 1. Alborz dam and Babolak tunnel location [12].

Table 1
Dip and dip direction of discontinuities in tunnel route [13].

Discontinuities	Dip (°)	Dip direction (°)
Bedding	29	129
Discontinuity 1	26	116
Discontinuity 2	46	160
Discontinuity 3	51	300

Table 2
Discontinuities condition in tunnel route [13].

Discontinuities endurance	1–3 m
Opening	1–5 mm (surface parts) 0.1–1 mm (deep parts)
Filling (if exist)	5 mm
Roughness	Smooth
Weathering	Little to average
Water condition in discontinuities	Damp

0+732 m and 0+848 m) are located in green Marn rock mass with overburden depth 105 m, 107 m and 120 m, respectively.

Mechanical properties of two types of rock were obtained using common rock mechanics tests. Results are presented in Table 3.

3. Tunnel route evaluation using rock engineering classification systems

For considered Babolak tunnel route rock mass the following parameters were derived, RMR=38 (RQD: 8, strength of rock mass: 2, joint spacing: 10, joint condition: 8, ground water condition: 10, adjustment of rating: -2) [14], Q=0.19 (RQD: 35, J_n: 9, J_r: 1, J_w: 1, J_a: 2, SRF: 10, ESR: 1.6 and equivalent dimension: 2.7) [14].

GSI index is used for geological classification of rock mass, using the equation proposed by Hoek and Brown [16]:

$$\mathrm{GSI} = RMR'76 \tag{1}$$

To determine *RMR'76* according to RMR76 value, assuming rock mass to be dry, the ground water rating was set to 10. Also adjustment for Joint Orientation was set to 0. GSI value for Babolak water conveyance tunnel according to RMR is 38.

Table 3
Uniaxial compressive strength test results [14,15].

Test condition	Rock mass type	Compressive strength (MPa)	Elasticity module (GPa)
Saturated	Sandy Marn	7.5–15	5–7.29
Saturated	Marn mass and silty Marn	0.5–5	Less than 1

4. Determining mechanical parameters of rock mass using RocLab software

This software was designed in 2002 for determination of strength parameters of rock mass according to Hoek–Brown criterion. It can determine cohesion (C), internal friction angle (Φ), compressive (σ_{cm}) and tensile (σ_t) strength, deformation modulus (E_{cm}) along with Hoek–Brown criterion parameters [17]. Input parameters for software are compressive strength of intact rock (σ_{ci}=12 MPa), Geological Strength Index (GSI=38), Hoek–Brown parameter for intact rock (m_i=9) and disturbance factor (D=0), unit weight of rock (γ=0.022 MN/m^3) and tunnel overburden (85 m) [18] values in parenthesis are for present study.

Using RocLab following parameters were determined for host rock (sandy Marn) of Babolak water conveyance tunnel: C (MPa) =0.22, Φ (°) =35, σ_t (MPa) = −0.012, σ_{cm} (MPa) =1.6, E_{cm} (GPa) =1.7.

5. in situ stresses

Based on the results of in situ tests, many relations have been proposed to determine in situ stresses. San Goupta [19] proposed a relation based on stress measurement in hydraulic fracture test in Himalaya weak rocks for overburden less than 400 m:

$$\begin{cases} \sigma_H = 1.5 + 1.2\sigma_V \\ \sigma_h = 1 + 0.5\sigma_V \\ \sigma_V = \gamma Z \end{cases} \tag{2}$$

For 90 m overburden depth in Babolak tunnel and average rock density of 0.022 MN/m^3, ratio of horizontal to vertical stress from 1 to 1.95 would be obtained using Eq. (2). It is in agreement with convergence records since more convergence has been recorded in walls than roof of tunnel. Horizontal to vertical stress ratio of 1.5 has been considered for further calculation of Babolak tunnel.