Analytical and Empirical Research on Squeezing Potential in Beheshtabah Water Transport Tunnel in IRAN

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ABSTRACT

The survey of squeezing potential and time dependent convergence is the first step of tunnel design. Lining failure and section deformation of tunnel under overloading and finally time dependent creep, are the effects of this phenomenon. So this phenomenon can cause more cost, delay in implementing the project and damage to concrete liner in tunnel advancing. Beheshtabad water transfer tunnel, with 1070 million cubic meters annual transfer ratio has been planned to solve water shortage problems in agriculture and industry in central plateau of IRAN. This tunnel with about 67 kilometers length and 6 meters diameter will be largest water transfer tunnel in IRAN. As for more zones of this tunnel included limy stone with high overburden, dangers of squeezing must be considered. In this paper at first with geological sampling, geophysics studies and boreholes, tunnel has been zoned then with the use of various criteria squeezing potential has been evaluated.

Keywords: Central Plateau of IRAN, Beheshtabad tunnel, Squeezing potential, Convergence.

1 INTRODUCTION

Squeezing or time-dependent convergence of tunnel excavation is a one of the problems in the poor rock conditions and high overburden. The magnitude of tunnel convergence, the rate of deformation and the extent of yielding zone around the tunnel depend on the geological and geotechnical Conditions. The in-situ state of stress is related to the rock mass strength, the groundwater flow, pore pressure and also the rock mass properties. Tunneling in high squeezing potential, will be cause often major delays in construction schedules and cost overruns. So, choosing an appropriate excavation method and timely support system, play a major role in controlling this phenomenon. Zayandehrood River is the only permanent river in the Central Plateau of Iran. Water demand in this area is constantly growing Due to population growth, focusing on key industries, withdraw ground water tables and reduce its quality. So, Beheshtabad tunnel, with transporting 1070 millions of cube meter of water per year to Iran central plateau, in order to eliminate the shortages in parts of drinking water, industry and agriculture is considered. This plan consist of a one dam with 184 meters height and water transport tunnel with the length of about 65 km and 6 meters diameter, that would be the longest water transport tunnel in IRAN. In this article, the length of the tunnel has been partitioned into sections using interpreted geological, geophysical studies and borehole data. After evaluating squeezing potential with alternative analytical and experimental methods for each section, the results of the different methods are compared with each other.

2 EMPIRICAL APPROACHES

The empirical approaches are essentially based on classification schemes. Two of these approaches are mentioned below, in order to illustrate the uncertainty that still exists on the subject, notwithstanding its importance in tunneling practice.

2.1 Singh et al. (1992) approach

This method is based on the results of 39 case histories, by collecting data on rock mass quality, *Q*, overburden and height, has been proposed. Squeezing potential is predictable with using equation (1) and table 1 (Singh et al. (1992)).

$$H=350Q^{1/3} \quad (1)$$

Table 1: Classification of squeezing behavior according to Singh et al. (1992)

type of behavior	*H*
squeezing conditions	$>350Q^{1/3}$
non squeezing conditions	$<350Q^{1/3}$

2.2 Goel et al. (1995) approach

A simple empirical approach developed by Goel et al. (1995) is based on the rock mass number *N*, defined as stress-free *Q* as follows:

$$N = (Q)_{SRF = 1} \qquad (2)$$

This is used to avoid the problems and uncertainties in obtaining the correct rating of parameter SRF in Barton et al. (1974) Q. Considering the tunnel depth H, the tunnel span or diameter *B*, and the rock mass number *N* from 99 tunnel sections, Goel et al. (1995) have plotted the available data on a log-log diagram (Figure 2) between *N* and $H{\times}B^{0.1}$.

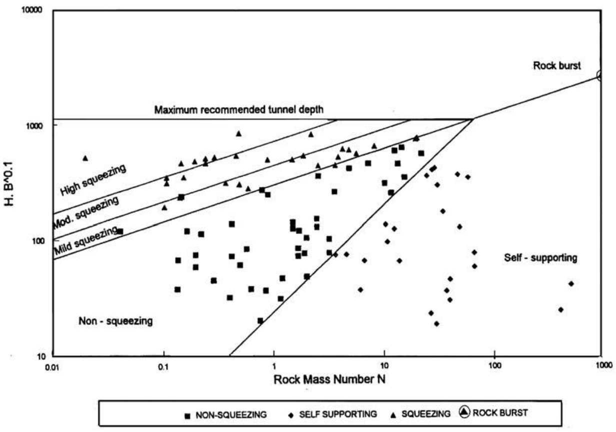

Figure1. Goel et al. (1995), (2000) approach for predicting squeezing conditions

3 SEMI-IMPIRICAL APPROACHE

The common starting point of all these methods for quantifying the squeezing potential of rock is the use of the "competency factor", which is defined as the ratio of uniaxial compressive strength σ_c/σ_{cm} of rock/rock mass to overburden stress γH. Two of such methods are briefly discussed in the following.

3.1 Jethwa et al. (1984) approach

As mentioned above the degree of squeezing is defined by Jethwa et al. (1984), on the basis of the equation (3) and Table 2 below:

$$N_c = \sigma_{cm}/P_0 = \sigma_{cm}/\gamma H \qquad (3)$$

Where:
σ_{cm} = rock mass uniaxial compressive strength;
P_0 = in situ stress;
γ = rock mass unit weight;
H = tunnel depth below surface.

Table 2: Classification of squeezing behavior according to Jethwa et al. (1984)

type of behavior	N_C
highly squeezing	0.4
moderately squeezing	0.4-0.8
mildly squeezing	0.8-2
non squeezing	>2

3.2 Aydan et al. (1993) approach

Aydan et al. (1993), based on the experience with tunnels in Japan, proposed to relate the strength of the intact rock σ_{ci} to the overburden pressure γH by the same relation as (3), by implying that the uniaxial compressive strength of the intact rock σ_{ci} and of the rock mass σ_{cm} are the same. The fundamental concept of the method is based on the analogy between the stress-strain response of rock in laboratory testing and tangential stress-strain response around tunnels. As illustrated in Figure 2, five distinct states of the specimen during loading are experienced, at low confining stress σ_3 (i.e. $\sigma_3 \leq 0.1\sigma_{ci}$) The following relations are defined which give the normalized strain levels η_P, η_s and η_f.

$$\eta_P=\varepsilon_P/\varepsilon_e=2\sigma_{ci}^{-0.17},\ \eta_s=\varepsilon_s/\varepsilon_e=3\sigma_{ci}^{-0.25},\ \eta_f=\varepsilon_f/\varepsilon_e=5\sigma_{ci}^{-0.32} \quad (4)$$

Where ε_P, ε_s and ε_f are the strain values shown in Figure 2, as ε_e is the elastic strain limit.

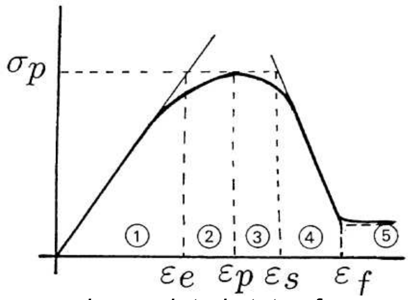

Figure2. Idealized stress-strain curve and associated states for squeezing rocks (Aydan et al., 1993)

Based on a closed form analytical solution, which has been developed for computing the strain level ε_θ^a around a circular tunnel in a hydrostatic stress field, the five different degree of squeezing are defined as shown in Table 3. In this table ε_θ^a is the tangential strain around a circular tunnel in a hydrostatic stress field (Aydan et al., 1993), whereas ε_θ^e is the elastic strain limit for the rock mass.

Table 3: Classification of squeezing behavior according to Aydan et al. (1993)

Squeezing degree	Theoretical expression
non-squeezing	$\varepsilon_\theta^a/\varepsilon_\theta^e \leq 1$
light-squeezing	$1 \leq \varepsilon_\theta^a/\varepsilon_\theta^e \leq \eta_P$
fair-squeezing	$\eta_P \leq \varepsilon_\theta^a/\varepsilon_\theta^e \leq \eta_s$
heavy-squeezing	$\eta_s \leq \varepsilon_\theta^a/\varepsilon_\theta^e \leq \eta_f$
very heavy squeezing	$\varepsilon_\theta^a/\varepsilon_\theta^e \geq \eta_f$

4 ANALYTICAL-THEORETICAL APPROACHES

4.1 Barla and International Society of Rock Mechanics (ISRM) approaches

The squeezing potential in these methods can be expected in accordance with Table 4 by considering the values of tangential stress (σ_θ), uniaxial compressive strength (σ_{cm}) and the maximum stress (σ_1).

Table 4: Classification of squeezing behavior according to Barla and ISRM approaches

Squeezing degree	Evaluation Method	
	(σ_{cm}/σ_1) Barla	($\sigma_\theta/\sigma_{cm}$) ISRM
non-squeezing	>1	<1
light-squeezing	1-0.4	1-2
fair-squeezing	0.4-0.2	2-4
heavy-squeezing	0.2>	>4

5 EVALUATION OF SQUEEZING POTENTIAL IN BEHESHTABAD WATER TRANSPORT TUNNEL

A result of the asses squeezing potential for zone of the tunnel which occurrence of this phenomenon with using different criteria, has been shown in the Figure 3. To study the Different criteria results, percentage of each category of squeeze zones that study subjects are calculated and are shown in Table 5.

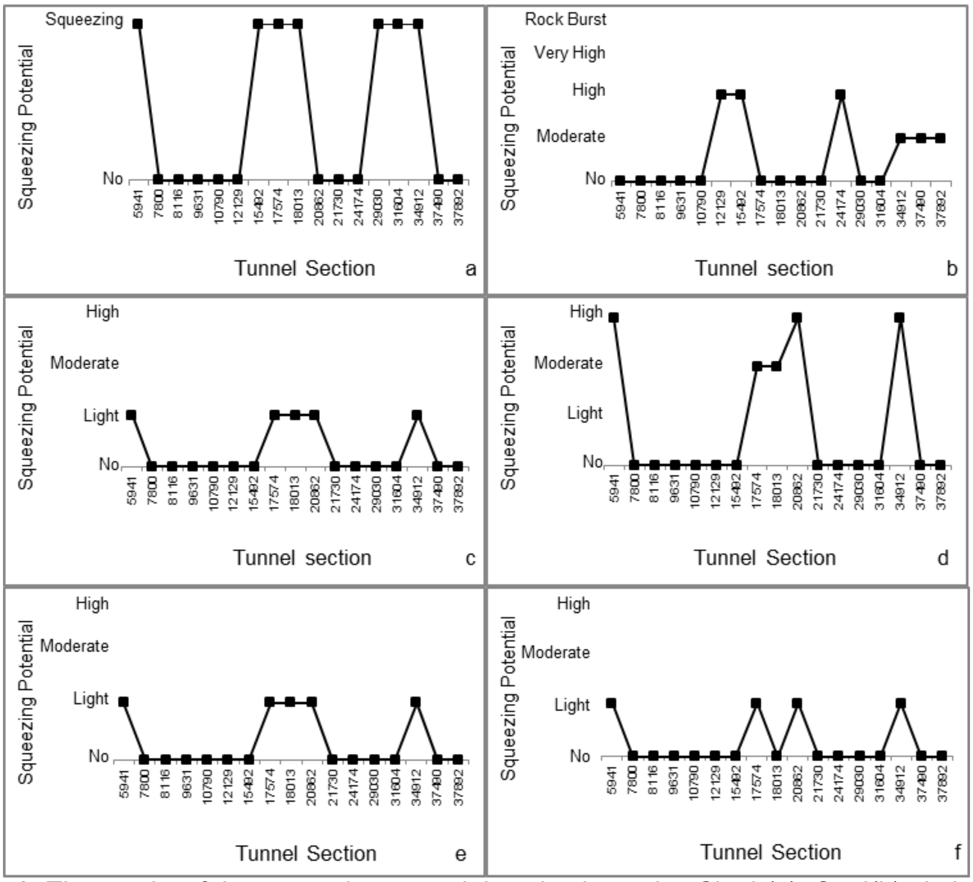

Figure3. The results of the squeezing potential evaluation using Singh(a), Goal(b), Jethwa(c), Aydan(d), Barla(e) and ISRM(f) criteria.

Table 5: The results of the squeezing potential in Beheshtabad water transport tunnel

Evaluation criteria	percentage of tunnel sections In each squeezing conditions				
	very heavy-squeezing	heavy-squeezing	fair-squeezing	light-squeezing	non-squeezing
Singh	0	0	0	39	61
Goal	0	17	17	0	66
Jethwa	0	0	0	28	72
Aydan	0	17	11	0	72
Barla	0	0	0	22	78
ISRM	0	0	0	28	72

6 DISCUSSION AND CUNCLUTION

In this paper, squeezing potential studied in Beheshtabad water transport tunnel in IRAN using deferent criteria. The results showed that, empirical and analytical methods are almost accommodating with each other. According to Singh, Jethwa, Barla and ISRM approaches, a great number of tunnel sections fall into non-squeezing potential category. Aydan and Goal criteria, similar to the recently mentioned approaches, have been predicted moderate to heavy squeezing potential for a small percentage of sections. Based on our researches, the results showed that, 71, 20, 5 and 4 percent of total panels are in none, light, moderate and heavy squeezing conditions, respectively. Thus, the rock masses in this tunnel path are in none to light squeezing potential. In very poor squeezing conditions, use of heavy support and monitoring the displacements of roof and bottom of tunnel and in moderate to high squeezing conditions, use of flexible support is essential.

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