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Parametric Analysis of An Empirical Correlation Predicting Support Pressure in Squeezing Ground

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ABSTRACT

Himalayan region is full of geological surprises when it comes to the underground construction activities due to fragile nature and frequent variations. The region is tectonically highly active and squeezing of rock mass around underground structures has been a major problem faced by geologists and engineers during the construction of many hydroelectric projects. It is because of this reason, the region has been a study centre for many research workers. The underground excavations have to be made structurally stable by installing appropriate support systems of appropriate stiffness at appropriate times. As the rock mass surrounding the excavation continues to deform, even after installation of the supporting system, it exerts large pressure on it. Therefore, it is essential to have a proper knowledge of the high support pressures exerted. Hence, an empirical correlation was developed by Dwivedi et al. (2014) for prediction of support pressure in squeezing ground condition. In the present study, an attempt has been made to analyse the influence of parameters involved in the aforementioned empirical correlation.

Keywords: Squeezing ground; Support pressure; Empirical correlation; Joint factor

1. INTRODUCTION

Stability is the major concern for underground constructions in weak rock masses due to the presence of discontinuities and high in-situ stress conditions. High in-situ stress or anisotropic stress condition causes rock bursting, squeezing or other stress-induced-stability problems (Selmer-Olsen and Broch, 1977). Stress-induced-stability problems in weak rock masses are characterized by squeezing. Thus, a combination of weak rock mass with high in-situ stress multiplies the squeezing problem. According to Barla (1995), squeezing around the tunnel opening may terminate by end of construction period or it may prolong for considerable amount of time, if adequate supports are not installed. According to Kovári (1998), squeezing is the phenomenon of large deformations that develops during tunnelling through weak rocks and if an attempt is made to arrest these deformations with the help of a lining or a support system, rock pressure builds up and may reach values beyond the structurally manageable range. The only feasible solution in highly squeezing ground condition is a flexible tunnel support system in combination with a certain amount of over-excavation in order to accommodate the deformations (Singh et al. 1992; Singh and Goel, 2006; Cantieni and Anagnostou, 2009).

Squeezing conditions may vary over short distances due to rock heterogeneity and variations in rock mass properties. Thus, in case of unreliable predictions of support pressure at the design stage, tunnel construction in squeezing ground becomes a herculean task claiming high cost and delay in time. However, if the support pressure can be reliably predicted using the governing parameters which can be easily assessed in the field, and accordingly appropriate stabilisation measures are implemented, then a good tunnelling rate can be achieved (Jethwa, 1981; Dube et al., 1986; Barla et al., 2011).

In the present study, an attempt has been made to analyse the parameters involved in the empirical correlation developed by Dwivedi et al. (2014) for assessment of support pressure in tunnels subjected to squeezing ground conditions. The joint factor (J_f), a measure of rock mass quality (Ramamurthy and Arora, 1994; Singh, 1997), allowable tunnel deformation, in-situ stresses (horizontal and vertical), support stiffness and radius of tunnel are the governing parameters involved in the correlation.

2. DATA COLLECTION

The correlation chosen for the study (Eq. 2) has been developed using data of 53 squeezing tunnel sections from 10 different tunnelling projects located in India and other countries (Table 1).

Table 1 - Tunnelling projects at a glance considered for data collection

Sl. No.	Name of Project	Place
1.	Chenani-Nashri Highway Tunnels, NH-1A	Jammu and Kashmir (J&K), India
2.	Udhampur-Katra Railway Tunnels	Udhampur, J&K, India
3.	Noonidih Colliery (Coal Mine)	Jharia Coal Fields, Jharkhand, India
4.	Giri-Bata Hydroelectric Project	Himachal Pradesh, India
5.	Nathpa Jhakri Hydroelectric Project	Himachal Pradesh, India
6.	Maneri Stage - 1 & II Hydroelectric Project	Uttarakhand, India
7.	Chhibro-Khodri Hydroelectric Project	Uttarakhand, India
8.	Loktak Hydroelectric Project	Imphal, Manipur, India
9.	Kaligandaki –A Hydroelectric Project	Syangi, Nepal
10.	Tala Hydroelectric Project	Chukha Dzongkhag, Bhutan

The geology of rock mass along the tunnels of above listed projects has already been discussed in the research work presented in Dwivedi et al. (2014).

3. SELECTION OF PARAMETERS

Following parameters have been considered for development of dimensionally correct empirical correlations for prediction of support pressure in squeezing and non-squeezing ground conditions:

i) Size of tunnel or tunnel radius, *a*

ii) In-situ stresses (vertical, σ_v and horizontal, σ_h)
iii) Support stiffness, K
iv) Uniaxial compressive strength of intact rock (σ_{ci})
v) Rock mass characteristics defined by joint factor, J_f, and
vi) Normalised tunnel deformation, d.

In case of a flexible support system, rock mass and support system continue to deform together after installation of the support system and hence support pressure decreases. Therefore, radial deformation of tunnel (%) has been considered as one of the governing parameters. This parameter has been determined as follows with the help of collected data of radius and radial deformation of tunnel:

$$d = \frac{u}{a} * 100\% \tag{1}$$

where d represents the normalised radial tunnel deformation (%), u, the radial tunnel deformation (m), and a is the radius of the tunnel (m).

4. CORRELATION FOR SUPPORT PRESSURE IN SQUEEZING GROUND

It is a general understanding that the support pressure should increase with increase in in-situ stresses and it should decrease with increase in the value of allowed tunnel deformation. Also, the competent rock mass will exert small support pressure and hence a low value of J_f will result in a lower value of support pressure. Using this analogy, the correlation suggested by Dwivedi et al. (2014) was developed. Several trials were conducted to arrive at the dimensionally correct correlation between the observed support pressure and other parameters including joint factor (Eq. 2) with correlation factor of 0.92. The corresponding plot is presented in Fig. 1. In this figure, ratio ($10P_{obs}/\sigma_v$) has been plotted against $[J_f^{\,3}\sigma_h^{0.1}/\{10^7\sigma_{ci}^{\,0.1}(d^{0.2}+J_f/1434)\}]$ to develop the correlation represented by Eq. 2.

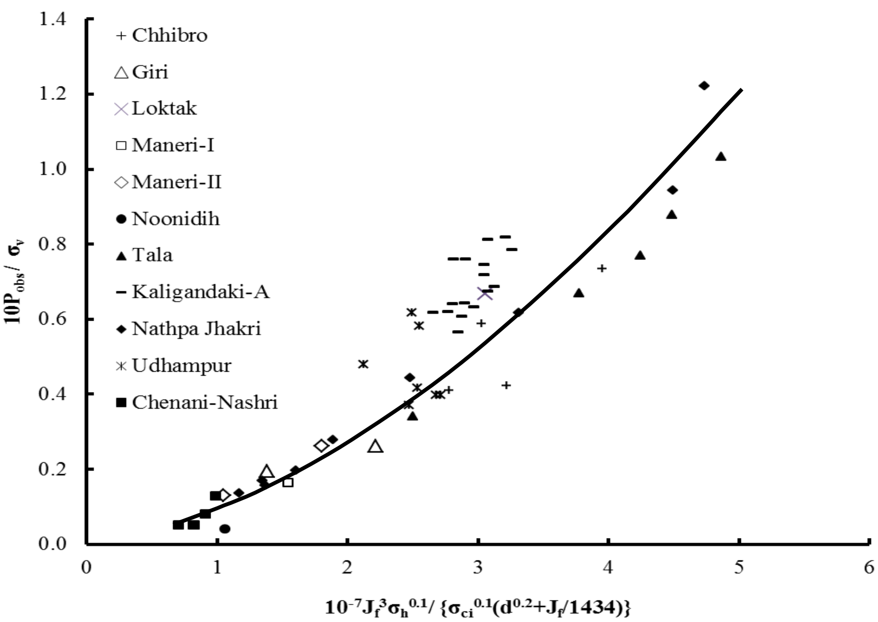

Fig. 1 - Plot of $[10P_{obs}/\sigma_v]$ versus $[10^{-7}J_f^3\sigma_h^{0.1}/\{\sigma_{ci}^{0.1}(d^{0.2}+J_f/1434)\}]$ for squeezing grounds

$$P_s = 9.23*10^{-3}\sigma_v\left(\frac{J_f{}^3\sigma_h{}^{0.1}}{10^7\sigma_{ci}{}^{0.1}\left(d^{0.2}+\frac{J_f}{1434}\right)}\right)^{1.7} \qquad (R^2=0.92) \qquad (2)$$

where

P_s = predicted short-term vertical support pressure, MPa,
J_f = joint factor after excavation of tunnels,
σ_v = vertical in-situ stress (0.027*H),* MPa,
σ_{ci} = uniaxial compressive strength of intact rock, MPa
σ_h = horizontal in-situ stress, MPa,
d = radial tunnel deformation (%), and
H = tunnel depth or overburden above the tunnel crown, m.

The dimensionally correct correlation represented by Eq. 2 and involving joint factor (J_f) exhibits significance for zero value of tunnel deformation and it predicts support pressure, when the supports are installed without any delay on substituting tunnel deformation, $d = 0$.

5. PARAMETRIC STUDY

Variation in values of short-term support pressure predicted by the dimensionally correct empirical correlation developed in the present study (Eq. 2) with various influencing parameters has been studied by carrying out following parametric study. It should be remembered that short-term support pressures are likely to be more than say 0.2MPa in the squeezing ground conditions.

5.1 Influence of Tunnel Depth, *H*

An attention was made to consider 3 values of J_f, namely 300, 350 and 400 and values of support pressure were predicted on basis of Eq. 2 for different values of H and the variation has been potted in Fig. 2. Figure 2 shows that support pressure increases with increase in depth of overburden rock mass for the values of J_f between 300 and 400. The slope of the curve increases with value of J_f. For example, slope (dy/dx) of the curves for J_f = 300, 350 and 400 are $2.2*10^{-4}x$, $3.3*10^{-4}x$ and $5.5*10^{-4}x$ respectively, where x denotes the values on x-axis i.e. tunnel depth (Fig. 2). Slope of the curve for J_f = 400 is the highest indicating that tunnel attracts higher support pressure at faster rate with tunnel depth in the presence of weaker rock mass. It is obvious that H should be sufficiently high to cause squeezing to take place. This is also evident from the empirical correlations developed by Singh et al. (1992) and Goel (1994) for prediction of ground conditions.

5.2 Influence of Tunnel Radius, a

The influence of the size of tunnel on short-term support pressure has been studied in the form of variation of support pressure with radius of the tunnel and has been plotted in Fig. 3, which suggests that support pressure increases only marginally with increase in tunnel radius. However, support pressure increases for tunnels excavated at large depth. It is interesting that the short-term support pressure is inferred to be nearly independent of the size of opening in the medium overburden. The Q system is also based on the same assumption.

5.3 Influence of Joint Factor, J_f

Figure 4 shows the effect of joint factor, J_f on tunnel short-term support pressure. It is clear that tunnel support pressure increases significantly with increase in joint factor, J_f. In other words, tunnel support pressure is highly influenced with quality of rock mass and it increases exponentially, if the rock mass quality deteriorates, i.e., for high values of joint factor. In addition to this, support pressure increases for tunnels having larger radius. This effect can be clearly seen in Fig. 4, where curve for 8 m radius tunnel has a steeper slope as compared to that for tunnel having radius of 4 m. It is observed in practice that J_f increases for broken rock mass depending upon the degree of squeezing and in-situ stress than undisturbed rock mass.

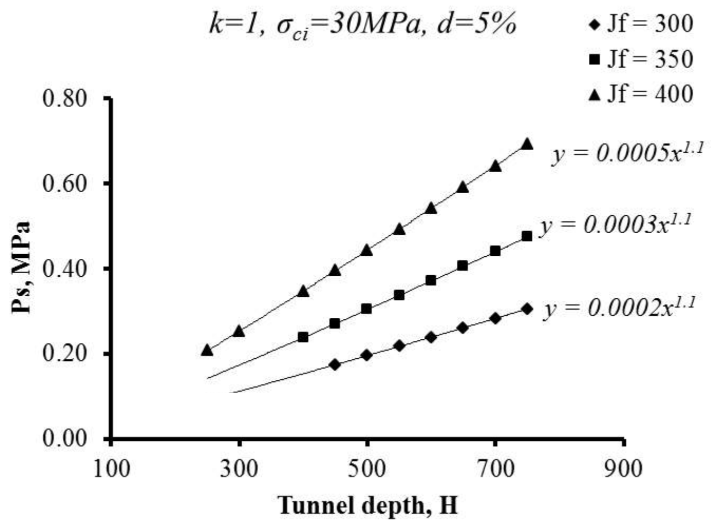

Fig. 2 - Variation in tunnel support pressure with tunnel depth

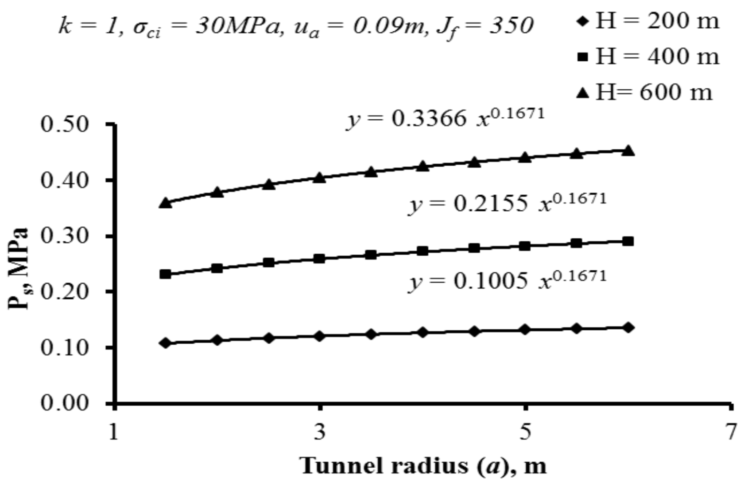

Fig. 3 - Variation in tunnel support pressure with tunnel radius

5.4 Influence of Tunnel Closure, d

Values of tunnel support pressure have been plotted with the values of allowable tunnel deformation in Fig. 5. The plot suggests that support pressure decreases on increasing allowable limit of tunnel deformation. This is because induced stresses around a tunnel opening are released when tunnel deformation is allowed leading to reduced support pressure. Yet one should not allow tunnel closure beyond 5%, otherwise support pressure will increase with rapid loosening of rock mass resulting in increase of J_f.

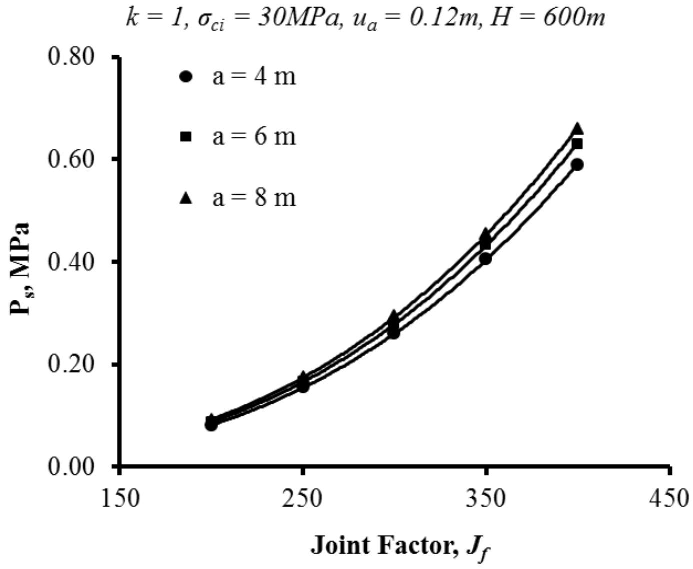

Fig. 4 - Variation in tunnel Support Pressure with Joint Factor

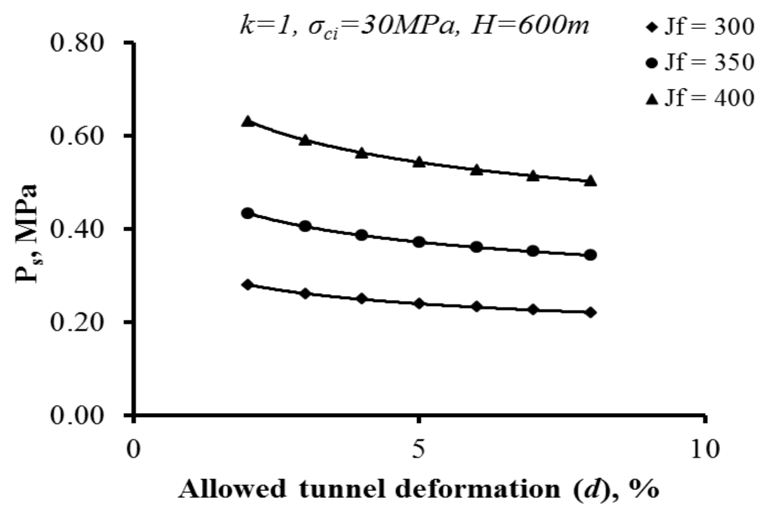

Fig. 5 - Variation of tunnel support pressure with tunnel deformation

5.5 Influence of Horizontal In-situ Stress, σ_h

Plot in Fig. 6 indicates that for a given value of J_f, support pressure is marginally affected due to increasing horizontal in-situ stress. However, tunnel support pressure increases with horizontal in-situ stress for higher J_f values. The severity increases with reduction in the quality of rock mass or an increase in J_f value.

5.6 Influence of Uniaxial Compressive Strength, σ_{ci}

Figure 7 shows the variation of tunnel support pressure with uniaxial compressive strength of intact rock. The plot indicates that tunnel support pressure decreases only marginally with increase in σ_{ci} values. The variation is plotted for three different values of J_f. All the curves show that support pressure is unaffected beyond σ_{ci} = 40 MPa. It can therefore be inferred that for rock masses exhibiting, J_f << 250, the influence of σ_{ci} values on tunnel support pressure will be absent, as expected.

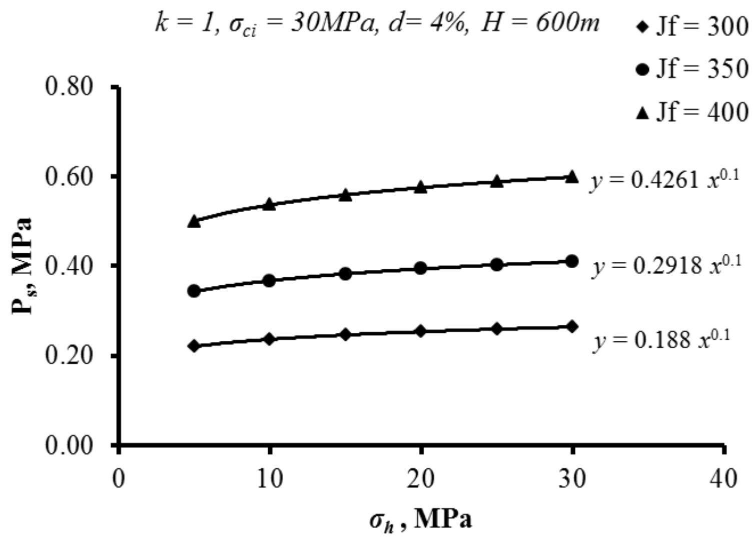

Fig. 6 - Variation of tunnel support pressure with σ_h

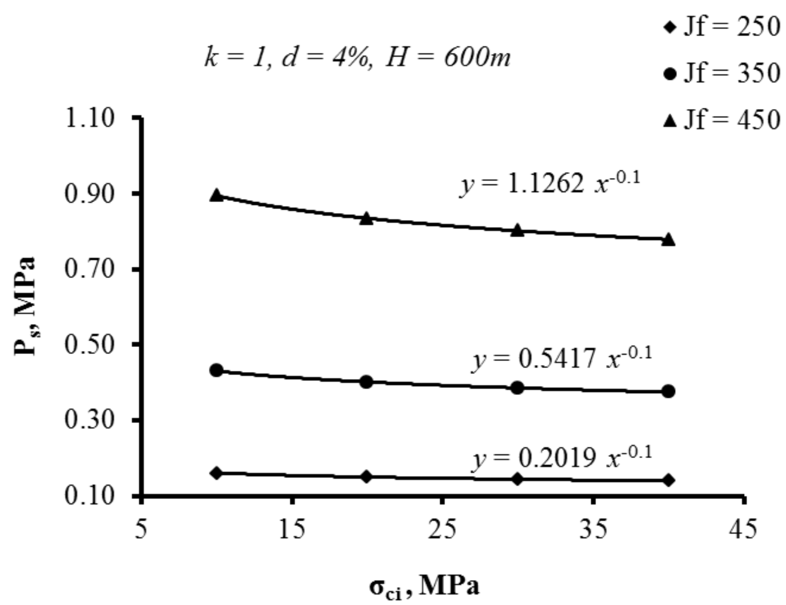

Fig. 7 - Variation of tunnel support pressure with σ_{ci}

6. LIMITATIONS OF STUDY

- The dimensionally correct empirical correlation (Eq. 2) discussed in the paper is valid for tunnels excavated in squeezing ground conditions by drill and blast method only (where convergence of unsupported tunnels is usually more than 1% of its size).
- In the analysis, equivalent tunnel radius, a has been taken in to consideration, which is computed using expression: $a = (A/\pi)^{0.5}$ for non-circular openings, where A is cross-sectional area of tunnel.

- Effects of construction methodology, rate of advance during tunnelling and the time of installation of secondary lining have not been considered in the analysis. The latter is accounted for indirectly to some extent by the time-dependent tunnel deformation (*d*).
- Time after excavation has not been considered as a parameter in the correlation.

7. CONCLUDING REMARKS

The joint factor is found to be successful in squeezing ground condition, in spite of its simplicity. The joint factor takes into account the anisotropy of the rock mass which is found to influence the squeezing ground conditions significantly. So the proposed correlation for short-term support pressure is reliable and shall be valid globally in squeezing ground conditions.

No significant influence of tunnel size on short-term support pressure was observed for tunnel depth lower than 600 m in squeezing ground condition. In addition to this, uniaxial compressive strength of intact rock (σ_{ci}) has been found to have a marginal influence on support pressure in weak rocks (σ_{ci} < 20 MPa at higher tunnel depth), whereas the influence was observed to be nearly absent for σ_{ci} > 40.MPa.

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