11 Mar 1998, 4:30 pm - 6:30 pm

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Proceedings: Fourth International Conference on Case Histories in Geotechnical Engineering, St. Louis, Missouri, March 9–12, 1998.

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Paper No. 6.08

ABSTRACT

A criterion for identifying the squeezing potential of tunnel is proposed. Tunneling conditions, classified as slightly or non-squeezing, moderately squeezing and highly squeezing, were identified by relating the strength-stress (σ_{cm}/P_o) ratio to the development of plastic zone extent and the amount of tunnel closure. Actual case histories of tunneling in Taiwan show that this criterion predicts the tunnel performance quite well. This enables the identification of tunneling conditionsexpected which require special considerations in support design and excavation - support procedures.

KEYWORDS

Squeezing ground, rock mass strength, in-situ stress, strength-stress ratio, plastic zone, tunnel closure.

INTRODUCTION

Tunneling in squeezing ground is characterized by the occurrence of large rock deformation and/or by high rock pressure on support works. This phenomenon can occur gradually after the completion of tunnel or dramatically during construction causing instability in the extreme case. In many instances, the tunnel deformation or rock pressure on support works is so large that it requires the remining of the intruding rock mass and replacing the damaged support works. The remedial measures are very difficult and expensive to carry out (Photo 1). It is often the major cause of delay in construction schedule and cost over-run in tunneling project. Therefore, identification of squeezing condition is the first step in making appropriate support design and adopting suitable construction procedures in tunneling project.

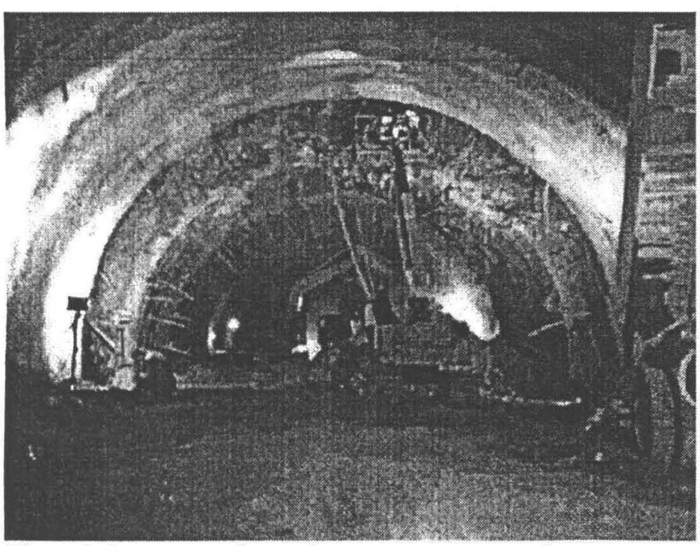

Photo 1 Remining of tunnel in squeezing ground

Many definitions or mechanisms of the time-dependent behavior of rock have been suggested. According to the phenomenological definition of squeezing rock adopted by the Commission on Squeezing Rocks in Tunnels, ISRM, "Squeezing of rock is the time-dependent large deformation, which occurs around the tunnel, and is essentially associated with creep caused by exceeding a limiting shear stress. Deformation may terminate during construction or continue over a long time period." This definition of squeezing adopted is different from swelling caused by volume expansion of rock mass due to the absorption of moisture, which can also cause time-dependent displacement around tunnel. However, it is recognized that in some cases squeezing may be associated with swelling.

PREVIOUS STUDIES ON SQUEEZING CONDITIONS

The identification of squeezing conditions is very important in the design and construction of tunnels. Various methods or criteria have been proposed. Empirical classification systems have been used for identifying the squeezing conditions, such as Terzaghi's classification and Q-system. More recently, Grimstad and Barton (1993) have updated the Q-system to identify the behavior of squeezing rock in terms of plastic flow under the influence of high rock pressure. Other methods for quantifying the squeezing potential of rocks have been proposed by various researchers. Jethwa et al (1984) define various degrees of squeezing on the basis of $\sigma_{cm}/\gamma H$ ratio where σ_{cm} is the uniaxial compressive strength of rock mass, γ is unit weight and H is overburden depth. Aydan et al (1991) proposed that rock would exhibit squeezing behavior when $\sigma_{cm}/\gamma H$ ratio is less then 2.0. However, the uniaxial compressive strength of intact core is used for σ_{cm}. Consideration is also given to the tangential strain at the tunnel perimeter. Tangential strain greater than 1% would be needed for squeezing to occur. Singh et al (1992) suggested that squeezing may occur where the depth of tunnel is greater than 350 $Q^{1/3}$ with rock mass uniaxial compressive strength σ_{cm} estimated as being equal to $0.7\gamma Q^{1/3}$. This would correspond to a tunnel radial strain greater than 1% and a plastic radius around the opening equals to 5 times the tunnel radius (Barla, 1994).

ESTABLISHMENT OF SQUEEZING CONDITIONS

Most of the recent criteria proposed relate the phenomenon to the strength-stress ratio of rock mass. In this paper, the results of numerical analyses on a circular unsupported tunnel were used to develop the relationship between the potential of plastic radius and tunnel closure versus the $\sigma_{cm}/\gamma H$ ratio. Actual case histories of tunnels were used to relate the tunnel performance with the numerical results obtained.

The rock mass is assumed to behave as an elasto-perfectly plastic material, and the onset of plastic failure is defined by the Mohr-Coulomb criterion. In order to estimate the cohesive strength (c) and friction angle (ϕ) for rock mass, the generalized Hoek-Brown criterion was used.

$$\sigma_1 = \sigma_3 + \sigma_c \left(m_b \frac{\sigma_3}{\sigma_c} + s\right)^a$$

Where σ_1 and σ_3 are the maximum and minimum principal stresses; σ_c is the uniaxial compressive strength of intact core; m_b, s and a are the constants for the rock mass and are related to the RMR value (Hoek et al, 1995). Having estimated the parameters for the criterion, values for c and ϕ can be calculated for an appropriate range of stress interested. The uniaxial compressive strength of rock mass can then be estimated as

$$\sigma_{cm} = 2c\cos\phi / (1 - \sin\phi)$$

The deformation modulus of rock mass was estimated by using an empirical relationship compiled by Chern et al (1997), instead of using the formula suggested by Serafim and Pereira (1983) which is more suitable for very hard rocks. In this approach the modulus of rock mass was obtained by factoring down the elastic modulus of intact core according to the quality of rock mass described by RMR value.

Several types of rock with core strength of 25, 50 and 100MPa were used in the analyses in order to study the applicability of criterion for different types of rock. Tunnels with various rock types, rock mass qualities and overburden depths were used for the parametric studies. To establish the behavioral trend, dimensionless plots from the results of parametric studies were used. Dimensionless plastic zone extent (R_p/R) and tunnel closure (δ/R) were related to the ratio of rock mass strength to in-situ stress (σ_{cm}/P_o). The results are shown in Fig. 1a and 1b.

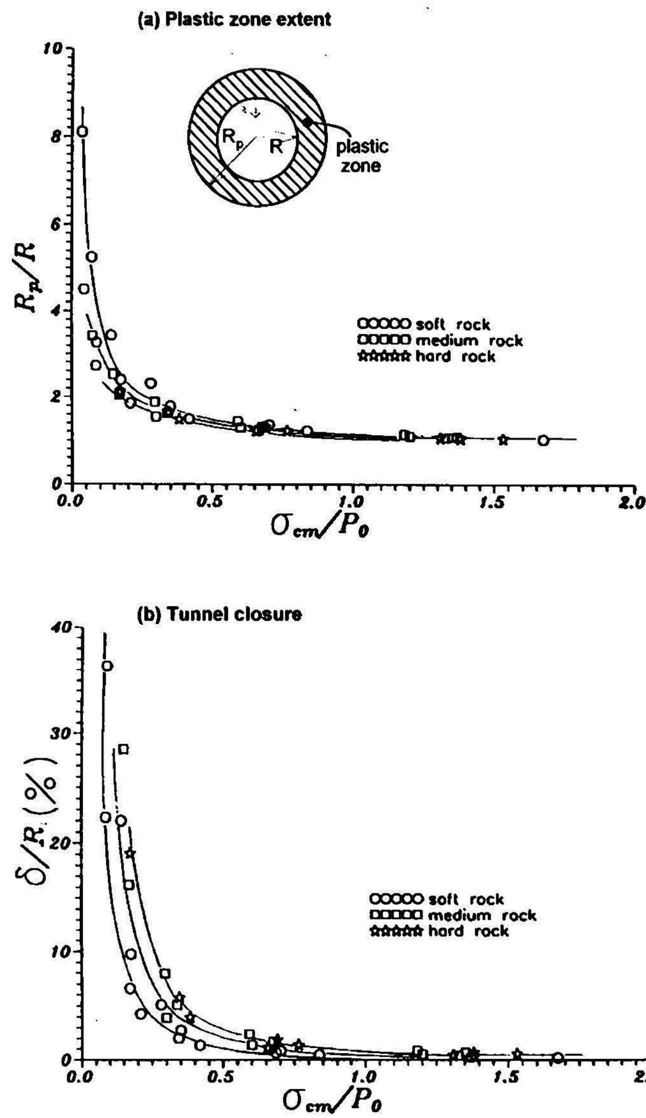

Fig. 1 Results of plastic zone extent and tunnel closure of unsupported tunnel by numerical analysis

These plots show that rather narrow band of scattering in results were formed inspite of different rock types used. The results show that when the σ_{cm}/P_o rato is high, very limited plastic zone in the rock mass around the tunnel and very small tunnel closure are expected. The plastic zone thickness and tunnel closure increase with decreasing σ_{cm}/P_o ratio. They increase rapidly when the σ_{cm}/P_o ratio is less than 0.25. Practical experiences suggest that once this stage is reached, squeezing condition is expected to occur. This will be further examined by using the results of actual tunneling case histories in Taiwan. From the results of these studies, three types of tunnel response are categorized as follows:

$\sigma_{cm}/P_o \geq 0.5$ slightly or non-squeezing
$0.5 > \sigma_{cm}/P_o \geq 0.25$ moderately squeezing
$\sigma_{cm}/P_o < 0.25$ highly squeezing

These criteria are very similar to those obtained by Jethwa et al (1984). However, it was rather different from those suggested by Aydan et al (1991), in which squeezing condition is expected when the $\sigma_c/\gamma H$ ratio is less than 2.0. The difference could be due to the use of intact core strength σ_c in the criteria instead of using the rock mass strength. Intuitively, intact rock strength is not a reliable indicator to the tunnel behavior, unless the jointing in rock mass is very wide and does not influence the strength of rock mass significantly.

EXAMINATION OF CRITERIA BY USING ACTUAL CASE HISTORIES

Several tunnel case histories in Taiwan constructed in recent years which developed various behavior ranging from very stable to highly squeezing conditions were used to examine the criteria established. These case histories include tunnels of various sizes and shapes excavated in rock formation of various geological ages, rock types, rock mass qualities and overburden depths. These case histories are summarized in Table 1. The results of these case histories plotted on the R_p/R vs σ_{cm}/P_o relationship are also shown in Fig. 2. It may be seen that for tunnel with σ_{cm}/P_o value over 0.5, i.e., classified as slightly or non-squeezing ground, all tunnels are in stable condition. These cases include the Nan-hua diversion tunnel (1), Maan headrace tunnel (2), New Tieulun headrace tunnel (5), Mucha tunnel (8) and Pengshan tunnel (10). For tunnels with σ_{cm}/P_o value in the range of 0.25 to 0.5, i.e., classified as moderately squeezing ground, local support damages have been observed. These cases include the Maan headrace tunnel (3) and New Tienlun headrace tunnel (6). For tunnels with σ_{cm}/P_o less than 0.25, i.e., classified as highly squeezing ground, excessive tunnel deformation, extensive support damage or even collapse of tunnel have been reported. These cases include Maan adit A (4), New Tienlun headrace tunnel fault zone (7), Mucha tunnel fault zone (9) and Pinglin tunnel D&B section (11). Therefore, the tunnel performance correlates quite well with the squeezing conditions proposed from the performance of actual tunnel case histories in Taiwan.

CONCLUSIONS

A criterion for identifying the squeezing potential of tunnel is presented. From the limited case histories of tunnel behavior in Taiwan, the criterion proposed appears to correlate quite well with the performance of tunnel during construction. From the practical experiences gained, it appears that for ground condition with slightly or non-squeezing potential the recommendations by the empirical rock classification systems widely used, such as Q and RMR, give conservative support design. On the other hand, for highly squeezing ground, detailed investigation on the tunnel behavior shall be conducted to examine the appropriateness of empirical support design and the special excavation-support procedures or ground improvement required.

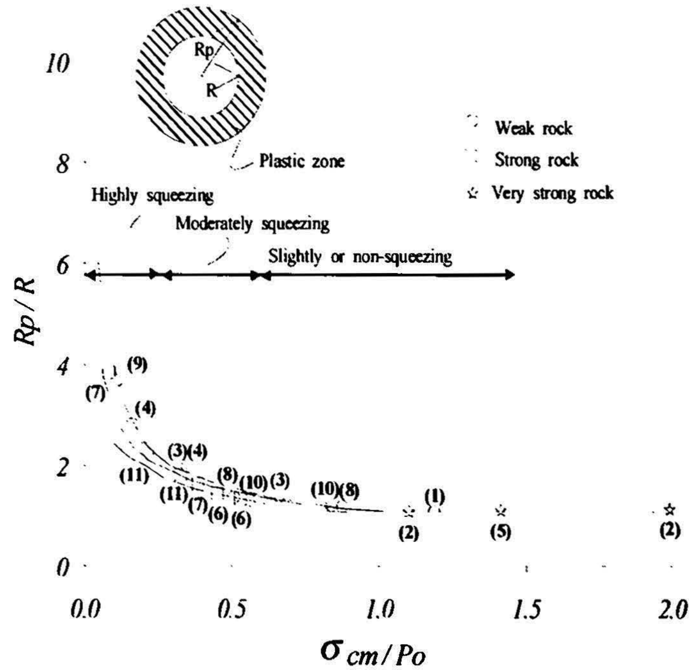

Fig.2 Examination of criteria by using actual case histories

REFERENCES

Aydan, O., T. Akagi and T. kawamoto [1991]. "The squeezing potential of rocks around tunnel: theory and prediction." *Rock Mechanics and Rock Engineering*, pp. 137-163.

Barla, G. [1995]. "Squeezing rocks in tunnels." ISRM News Journal, Vol. 2, No. 3 & 4, pp.44~49.

Chern, J. C., Y. L. Chang, C. W. Yu and K. R. Lee [1997]. "Empirical relationship between rock mass deformability and rock mass quality." Sinotech Engineering Research Foundation Report (in preparation).

Grimstad, E. and N. Barton [1993]. "Updating of the Q-system for NMT." Int. Symp. on Sprayed Concrete, Norway.

Hoek, E., P. K. Kaiser and W. F. Bawden [1995]. "*Support of underground excavations in hard rock.*" Mining Research, Canada.

Jethwa, J. L., B. Singh and B. Singh [1984]. "Estimation of ultimate rock pressure for tunnelings under squeezing rock conditions. A new approach." ISRM Symp. Design and Performance of Underground Excavation. Cambridge, UK.

Serafim, J. L. and J. P. Pereira [1983]. "Considerations of the geomechanics classification of Bieniawski." Proc. Int. Symp. Eng. Geol. Underground Constr., LNEC, Lisbon, Vol. 1, pp.33-42.

Singh, B., J. L. Jethwa, A. R. Dube and B. Singh [1992]. "correlation between observed support pressure and rock mass quality." Tunnelling and Underground Space Technology. 7(1).

Table 1 Tunnel case histories developed various behavior

Tunnel Cases	Rock Type/ Geo. Epoch	Typical Overburden (m)	RMR	σ_c (Mpa)	σ_{cm} (Mpa)	σ_{cm}/P_o	Squeezing Catagory	Tunnel Perfermance Observed
(1) Nanhua Diversion Tunnel	SS, ST/Pl	80	65	15	2.4	1.18	slight~non. squeezing	stable
(2) Maan H. R. Tunnel	SSQ/O1	300	40~60	100	8.2~15	1.1~2.0	slight~non. squeezing	stable
(3) Maan H. R. Tunnel	SH/M	200	30~55	30	1.6~3.3	0.33~0.66	moderately squeezing	local delayed shotcrete damage
(4) Maan Tunnel Adit A	SS/SH/M	200	17~34	25	0.7~1.6	0.14~0.33	highly~mod. squeezing	severe support damage
(5) New Tienlun H. R. Tunnel	SSQ/O1	500	50~70	150	17.6~34.8	1.41~2.78	slight~non. squeezing	stable
(6) New Tienlun H. R. Tunnel	Arg/O1	500	40~50	70	5.4~6.7	0.43~0.54	moderately squeezing	local shotcrete damage
(7) New Tienlun H. R. Tunnel (FZ)	SS/O1	400	5~30	50	0.7~3.0	0.07~0.38	highly~mod. squeezing	tunnel collapse to excessive tunnle deformation
(8) Mucha Tunnel	SS/M	110	30~50	25	1.4~2.4	0.49~0.87	sight~non. squeezing	stable
(9) Mucha Tunnel (FZ)	SS/SH/M	120	20	10	0.28	0.09	highly squeezing	excessive tunnel def. up to 1.20m in roof settlement
(10) Pengshan Tunnel	SS/M	140	40~55	25	1.9~3.0	0.55~0.86	slight~non. squeezing	stable
(11) Pinglin (D&B) Tunnel	Arg/O1	200	10~20	50	0.9~1.6	0.19~0.32	highly squeezing	excessive tunnel def. with ext. support damage

Note: Pl: Pleistocene O1: Oligocene M:Miocene FZ: Fault Zone