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Evaluation of mechanical properties of shale and schist - based on back calculations and monitoring at the Uri-project, Himalya, India.

Auswertung der mechanischen Eigenschaften von Schiefer und Schyst-ausgehend von Nachrechnungen und Kontrollmessungen am Uri-Projekt, Himalaya, Indien"

Évaluation des propriétés mècaniques de pierre d´ argile fluable et de schistes-basée sur des calculs antérieurs et des observations achevées sur le Projet Uri, Himalaya, Inde.

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ABSTRACT: In the paper, today's knowledge regarding prediction of the rock mass properties from rock mass classification systems is evaluated. The paper illustrates a case where back calculation of convergence measurements has been used for estimating rock mass properties. The work is based on observations made at the Uri project, in Kashmir, India. The result is compared with estimates which are based on commonly used classification systems. The result shows that convergence measurement in a tunnel gives the only reliable prediction of the rock mass properties.

RÉSUMÉ: Les connaissances actulles concernant les prévisions des propriétés d'une masse rocheuses en s'appuyant sur la classification des masses rocheuses sont exposées dans cet article. Ce dernier présente une étude oú des calculs antérieurs basés sur des mesures de convergence ont permis d'estimer les propriétés rocheuses. Ce travail fut achevé à l'aide d'observations effectuées sur un chantier au Cachemire en Inde, le Projet Uri. Les résultats sont comparés aux prévisions obtenues selon les systèmes de classification classiques. Ces résultats montrent que seules les mesures de convergences faites dans un tunnel apportent une prévision valable des propriétés de la masse rocheuse.

ZUSAMMENFASSUNG: Diese Arbeit ist eine Auswertung der heutigen Kentnis wie man die Eigenschaften einer Steinmasse durch Klassifisierung voraussieht. Hier wird ein Fall beschrieben wo man die Eigenschaften einer Steinmasse durch Nachrechnungen der Konvergierung in einem Tunneln geschätzt hat. Die Arbeit gründet sich auf Beobachtungen und Erfahrungen bei dem Uri Project , in Kashmir, India. Das Ergebnis wird mit anderen Ergebnissen verglichen, die sich auf bewährten Klassifisierungssystemen gründen. Es wird gezeigt,daβ das Messen von Konvergierungen die einzige Methode für eine zuverlässige Voraussage des Benehmens einer Steinmassse ist.

1 INTRODUCTION

Rock mass classification systems are today used to estimate rock mass properties of a rock mass. Such properties are used as input parameters for predictions of the rock mass behaviour. In this paper some existing classification system are evaluated regarding their possibility to predict rock mass properties. The evaluation is limited to one case study and the results must therefore be considered as indications only and not as general statements.

The field studies for the work presented here was carried out at the Uri project which is a 480 MW Project is situated in the State of Jammu and Kashmir in north-western India. The power plant is supplied with water from the Jhelum River which has its springs in Kashmir and flows through the Kashmir Valley into Pakistan, where it becomes a tributary of the Indus River. The project is designed as a run-of-the-river scheme. The water is diverted from the river and lead from the head regulator and desilting basins into an 11-km long headrace tunnel and two 210-m high pressure shafts. After passing through the four turbines in the machinery hall the water is lead through the draft tubes and the 2-km long tailrace tunnel back into the river. The headrace and tailrace tunnels are of horseshoe shape with a diameter of 9 m.

2 GEOLOGY ALONG TAILRACE

The tailrace tunnel intersects the Panjal thrust, which is one of the major thrust zones in this part of the Himalayas. The tunnel runs from Panjal Volcanics, a competent basaltic rock in which the power station is located, through a thrust zone, ending in red shale at the outlet side. At the upstream end of the tailrace tunnel, after about 30 m of Panjal volcanics, a 290-m wide strata consisting of a mixture of sheared and crushed mica, talc, chlorite and graphite schists and phyllites with some limestone bands was encountered. A notable amount of clayey gouge was also present. The strength of the rocks in this major thrust zone was very low and their engineering properties poor.

Downstream of this fault zone, schistose meta-volcanics with strata of schists were encountered. Several minor faults, some of them quite healed, were also encountered. After about 860 m the rock changed to partly graphitic schists over a length of 200 m. A massive marble bank and the Panjal thrust concluded this series of strata. Further downstream the rock mass consists entirely of red and green Eocene shales. The shale was in general well consolidated but thinly bedded. The bedding plane consisted in part of a high content of non-swelling but unconsolidated clays (Fig. 1)

In the zones consisting of graphitic, crushed mica schists as well as in the upstream part of the shale, the rock cover reaches 400-500 m. The relatively large overburden in combination with the poor properties of the rock mass resulted in a troublesome squeezing. This part of the tunnel was excavated by multiple drift, a divided heading and a bench was used for the excavation.

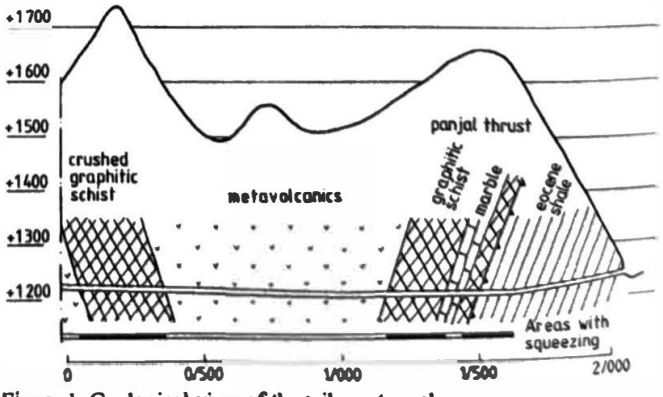

Figure 1 Geological view of the tailrace tunnel.

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3 BACK CALCULATION, METHOD STATEMENT

As an integrated part of the excavation system, measurements of the convergence was carried out. Most measurements was carried out as horizontal convergence measurements. Some of the measurement points was installed close to the face as a part of the excavation procedure in both the weak and heavily crushed grafitc schists as well as in the more competent Panjal vulcanics In the following, a method is shown of how the convergence measurements can be used to analytically estimate the rock mass properties of the rock mass that is encountered. Special attention is given to the influence of installed rock support on the measurements and how that influence can be accounted for. The measurements from the Uri project are evaluated and the results are compared to what could be expected from well known classification systems.

The estimation of the elastic-plastic properties of the rock mass can be performed by back calculations, i. e. comparisons between the measured and calculated development of deformation that is associated with tunnel face advances. The following is a short description of the methods for calculating the deformations.

The deformation close to the tunnel face (see figure *) is the result of a complex redistribution of tresses in the vicinity of the face and this has been intensively studied in the past decades, e. g. Lombardi (1974, 1979), Panet (1982), Lee (1990) and etc. The radial displacement associated with the tunnel advance for an unsupported circular tunnel can be determined by the following expression (Chang, 1994), which is adapted from Panet (1982):

$$\frac{u(x)}{u_\infty} = 1 - \left(1 - \frac{u_0}{u_\infty}\right)\left(1 + 1.19\frac{x}{r_{p\infty}}\right)^{-2}$$

where u(x), u_∞ and u_o is respectively the displacement at distance x from the face; the ultimate displacement far away from the face and the displacement at the face; $r_{p\infty}$ is the radius of the plastic zone far away from the face. Studies show that a value of 30% for the ratio u_∞/u_o is a good approximation for engineering purposes (Chang, 1994). The plastic radius $r_{p\infty}$ for a rock mass with residual strength can be obtained by (Stille, 1984)

$$\frac{r_{p\infty}}{r_i} = \left(\frac{\frac{2}{1+k}(p_o + a) - a + a_r}{a_r}\right)^{\frac{1}{k-1}}$$

where p_o is the inital pressure; ϕ is the friction angle of the rock mass; c is the cohesion of the rock mass; ϕ_r is the residual friction angle of the rock mass; c_r is the residual cohesion of the rock mass; r_i is the radius of the tunnel; $k = \tan^2(45 + \phi/2)$; $a = c/\tan\phi$; $k_r = \tan^2(45 + \phi_r/2)$ and $a_r = c/\tan\phi_r$.

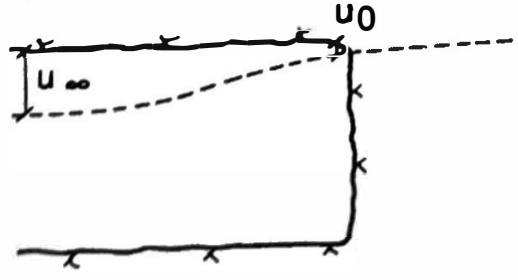

Figure 2 Schiss showing deformation development associated with tunnel face advances

For a supported tunnel, the function u(x) can be determined by the self similarity principle (SSP) (Nguyen-Minh et al, 1992) as shown in Figure **.

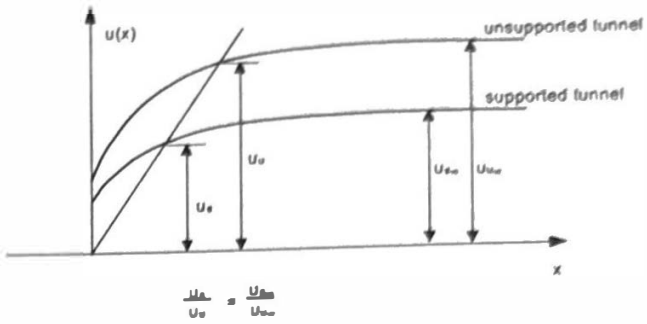

Figure 3 Self similarity principle (SSP) for determination of supported deformation

By using the concept of Ground Reaction Curve (GRC), the above method for calculating the deformation development associated with tunnel face advances can be integrated as shown in Figure 4 (Chang, 1994).

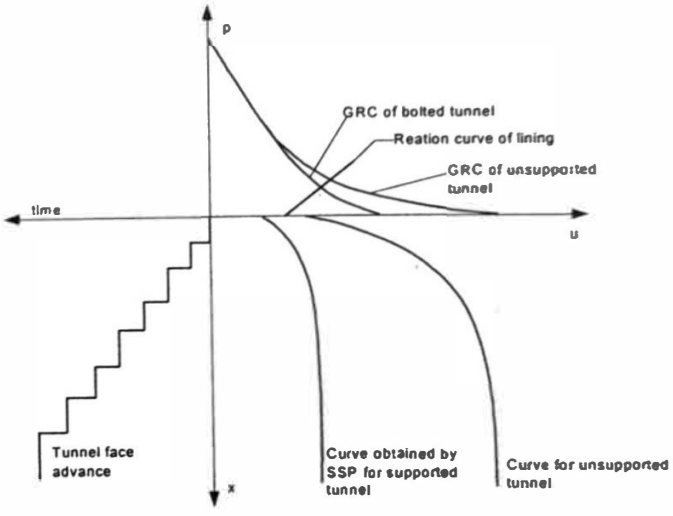

Figure 4 Integrated method for calculating the deformation development associated with tunnel face advances (Chang, 1994)

For calculating the ground reaction curves for unsupported respectively bolted tunnels, the analytical solutions by Stille (1983, 1984) can be used.
By adjusting the input parameters, the estimation of the rock properties is achieved by matching the calculated curves of supported deformation development to the measured values.

4 EVALUATION OF PROPERTIES

In order to evaluated the properties of the rock mass, convergence measurements were carried out close to the face. This was done in the crushed graphitic schist as well as in the panjal Volcanic. Measurement was carried out in the volcanics in the adits to the power station and in the tailrace tunnel. The general quality corresponds to RMR=50 in both the locations but in the adit to the power house the tunnel got excavated perpendicular to the foliation whereas the orientation of the tailrace tunnel is parallel to the foliation. The crushed graphitic shist was weak and its quality corresponds to a RMR-rating of 8-12.

The tunnel excavated in vulcanics was unsupported close to the face whereas the tunnel excavated in graphitic shist was supported by 25cm of sprayed reinforced concrete at the face. The back calculation of the rock mass properties for the tunnel excavated in volcanic can therefore be carried out in accordance with equation __ whereas the graphical method illustrated in figure __ must be used in order to evaluate the measurements carried out in graphitic shist.

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Since the graphitic shist is heavily supported it is of importance that the properties of the rock support is accurately accounted for. In order to correctly estimate the horizontal stiffness of the shotcrete, a numerical simulation was carried out in the finite difference code FLAC. This study is reported in Brantmark (1998) and concludes in that the horizontal stiffness is as low as 7 kPa/mm.

The result from the back calculations are shown in table 1 and they are graphically shown in figures 5 and 6. From these graphs several observations can be made: A good match between computed and measured development of deformation was obtained in all cases. In the case of graphitic schist, a significant part of the potential deformation was restrained by the installed support. This strong influence from the support makes it difficult to evaluate the properties accurately since the "true" behaviour of the rock mass itself to a great extent is hidden by the support. The resulting properties of the panjal vulcanics is therefore more reliable than the properties of the grafitic schist.

Further, the assumed amount of deformation that takes place ahead of the face affects the results significant. The more deformation that is assumed to develop ahead of the face the lower properties will be assumed to the rock mass.

Table 1 Back calculated properties of the rock mass

Back analysed values			
	Volcanics		Graphitic
	TRT. 1/975 parllel foliation	perpendicular to the foliation	Schist
Young's mod. (GPa)	5	12	2
Cohesion (MPa)	1	1	200
Angle of frict.	30	30	23
Strength σcm (MPa)	3.5	3.5	600
Poisson's ratio	0.25	0.25	0.25
Dilatancy	20	20	5

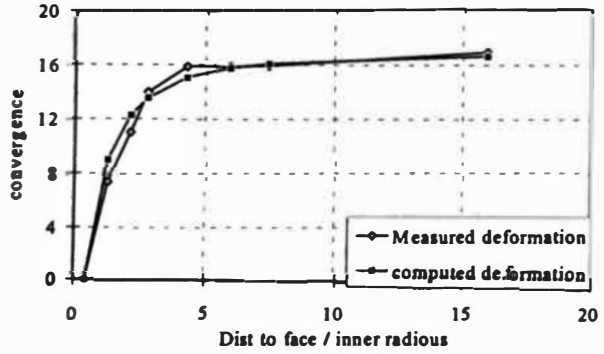

Figure 5 Computed development of deformation in volcanic, section 1075, parallel to the foliation, E = 5 GPa, ϕ = 30°, C = 1000 kPa. RMR ≈ 50, GSI ≈ 60

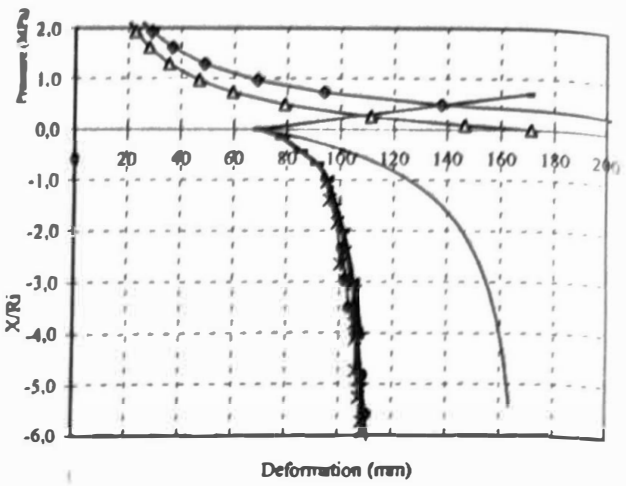

Figure6 Result of back calculations of properties of the rock mass in sections 0/293-0/310. Ground reaction curve is shown for bolted and unbolted rock mass. Development of deformation is shown for bolted tunnel and fully supported tunnel. Response curve for shotcrete corresponds to 7kPa/mm.

COMPARISON WITH EXISTING CLASSIFICATION SYSTEMS

The rock mass properties can be estimated based on various rock mass classification systems. In this evaluation the following relations has been used to correlate the RMR-value and the corresponding Q, RMi, RMS and GSI value to the Mohr-Coloumb rock mass properties.

In order to determine the rock mass quality based on the RMR rating, the correlation proposed by Serafim and Pererira (___) was used. This correlation was simply presented in a table, and not related to the rating by any equations. Aydan et al. (1997) suggested the following relations related to the RMR-rating:

$$\sigma_{cm} = 0.0016 \cdot RMR^{2.5}$$

$$E_m = 80\sigma_{cm}^{1.4}$$

Grimstad and Barton (1993) suggests that the following relation is used to evaluate the modulus of elasticity for a rock mass with Q>1.

$$E_{mass} = 25 \cdot \log_{10} Q$$

Barton and Singh ( ) suggests that the rock mass strength is related to the Q-value by the following formulation.

$$\sigma_{cm} = 18.2Q^{3/4}$$

Stille et al. (1982) propose an alternative toe the RMR-rating which was named RMS. RMS was linked to rock mass properties through a table in the same way as the RMR rating, but the resulting properties was generally stronger.

Relation between GSI and Mohr-Coloumb properties are proposed by Hoek and Brown (1997).

The strength of the rock mass based on the RMi value is based on Palmström (1995, 1996). For the computations jR=1,5 and 3, jA=1, jL=0,75, Vb=0,2 and σ_c=150 MPa has been used.

All these relations concludes in the following table 2,3 which can be compared with the computed properties in table 1:

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Table 2 Computed properties for Volcanic rock, RMR=50

	Based on RMR	Q Grimstad Barton	Based on RMS/ Stille	Based on GSI	Based on RMR Aydan	RMi Palm-ström
Young's mod. (GPa)	10	7	2.5	10 - 17	8.6	
Cohesion (MPa)	0.25	-	1.3	6.9-7.9	-	
Angle of frict.	30		35	36-39	-	
Strength σcm(MPa)	0.9	23	5	28-36	28	30-130
Poisson's ratio	-	-	-	-	-	
Dilatancy	-	-	-	-	-	

Table 3: Computed properties for graphitic schist, RMR 8-12

	Based on RMR	Q based on Barton	Based on RMS/ Stille	Based on GSI	RMR based on Aydan
Young's mod. (GPa)	0.9-1.3	-	0.4-0.75	0.4-0.6	0.03
Cohesion (kPa)	<100	-	200	120-280	-
Angle of frict.	<15	-	15	12-19	-
Strength σcm (MPa)	<0.3	5.6	0.5	0.30.8	0.5
Poisson's ratio	-	-	-	-	-
Dilatancy	-	-	-	-	-

5 CONCLUSIONS

In this paper a case is illustrated were measurements on a construction site in the Himalayas has been used for back calculation of rock mass properties. The result is then compared with what could have been expected from commonly used relations between rock mass classification and properties. By comparing table 1 with table 2 and 3 it can be concluded that none of the classification systems could be used to fully predict the rock mass properties that was experienced in this case. This case supports therefore the opinion that an accurate predictions of a rock mass behaviour must be based on in-situ measurements in a reasonably sized test tunnel.

From table 2 and 3 it can further be concluded that newer relations between rock mass classification systems and rock mass properties tends to predict higher strength and larger stiffness than the older relations.

The dilatancy (volume expansion) is a significant factor in many formulations for computing the development of deformation in a tunnel. It is therefore worth noticing that no attempts has been made to relate this parameter to any of the classification systems.