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An integrated Approach for Rockmass Characterization and Support Requirement for Discharge Tunnel of Dewas-II Project, Udaipur District, Rajasthan

V.P. Sharma*

Abstract

The Akodara and Madri link tunnels of Dewas-II Project with a cumulative length of 12.3 km are under construction. The tunnels passes through monotonous flysh metasediments comprising mainly phyllite and schist with bands of quartzite, minor calcareous rocks along with meta volcanics represented by talc-chlorite/chlorite schist and ultramafic intrusive belonging to Aravalli Supergroup. The rocks are disposed as moderately plunging steeply inclined tight to isoclinally folded sequence. An attempt has been made to use an integrated approach utilizing the most widely accepted rock load classification of Terzaghi (1946), Rock Tunneling Quality Index ('Q') of Barton et al (1974) and Rock Mass Rating (RMR) of Bieniawski (1989) for determining the rock mass characteristics and tunnel support requirement.

The analysis of the geotechnical parameters and computed Q and RMR values reveal that the tunnelling media comprises rockmass of poor to fair category in general and very poor in about 20% to 30 % of the tunnel length, where weak shear zones are encountered. There are some crucial zones viz large solution cavities, thick shear zones and weathered rockmass of very poor category beneath local nalas. In about 50 % of the tunnel section, squeezing ground conditions has been anticipated based on Terzaghi's rock load theory. Support categories 1 to 4 (Grimstad and Barton, 2002) have been arrived at on the basis of 'Q' values for major part of the tunnel.

Introduction

Udaipur city, known as the 'City of Lakes', is one of the important tourist destination of India. The city boasts thriving mineral based industries. The growing consumption and dwindling trend of rain fall have rendered the lakes redundant in meeting the water demand of the city. To meet the ever increasing demand, a four stage inter basin water transfer scheme has been contemplated. The Dewas-II stage under construction, envisages construction of two dams and two tunnels comprising about 1 km long Madri link tunnel and 11.3 km long Akodara tunnel having 12.3 km cumulative length. Five shafts of 9 m dia are being opened to facilitate the tunneling operation; one in Madri link tunnel and four in Akodara tunnel. The size of the Madri link tunnel is 3.00 x 3.50 m with excavated height of 4.14 m and that of main Akodara tunnel is 5.75 x 5.75 m with excavated span of 6.10 m.

Geological set-up

The tunnel passes through monotonous flysh metasediments comprising mainly phyllite and schist with bands of quartzites, minor calcareous rocks along with completely altered meta volcanics represented by talc-chlorite/chlorite schist and ultrabasic intrusives belonging to Aravalli Supergroup. The rocks trends NNE-SSW with moderate to steep dip towards WVW. The rocks have under gone polyphase deformation and exhibit progressive increase in the grade of metamorphism from low green schist facies in the east to low amphibolites facies in the west forming moderately plunging, tight to isoclinally folded sequence (Gupta et al, 1997).

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*D-32, Siddharth Nagar, Malviya Nagar, Jaipur-302017
E-mail: vijay_ps59@yahoo.com

Preliminary geotechnical assessment of tunneling media

The trend of rocks is parallel to the tunnel alignment in Madri link tunnel (unfavorable disposition) and across the alignment in case of Akodara tunnel (favorable disposition) with moderate to steep dips in west south west direction. The phyllite display variation in composition with intercalatary quartzite bands along with minor impure calcareous bands. The intercalations of quartzite with phyllite are frequent and they are thicker in the western and central part of the tunnel (Chandra Madhav, 2006). As the composition of phyllite vary considerably and so are the strength and other geotechnical parameters accordingly. Besides the most pervasive S_1 foliation, the schistose rocks are beset with three sets of joints; sub vertical cross joint set and two oblique sets of joints. The concentration and attitude of these joints vary from place to place due to later phases of deformation. A number of shear zones, mostly thin with clay fillings, running parallel to the foliation in schistose rocks as well as cutting across it at different angles are the most important geotechnical features requiring attention.

The thickness of the overburden over tunnel (Fig-1) varies from 15 m to 415 m. About 50 % of the tunnel section falls in VII category (squeezing ground-moderate depth) of rock classes of Terzaghi's rock load theory. The ground water occurs in water table condition (5 m to 30 m depth) in joints, fissures and solution channels. As the maximum thickness of the overburden is about 400 m the height of water column tends to increase as the relief increases affecting the joint water reduction factor (Jw), which has an important role in rockmass characterization.

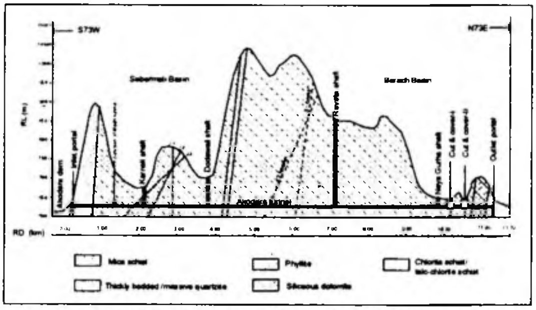

Fig. 1: Longitudinal section of Akodara tunnel, Dewas-II project

Methodology of rock mass characterization

The dominant rock types exposed along the tunnel alignment are chlorite schist (CS), phyllite (PH), thickly bedded/massive quartzite (TMQ), schistose quartzite (SQ) and siliceous dolomite (SD). These rocks have been classified into five categories based on the geotechnical parameters observed on the surface as well as 3D logging of some part of the tunnel. The categories are-

1. Weathered rock with low inter block coherency
2. Fresh rock with one plus one random sets of joint
3. Fresh rock with two plus one random sets of joints
4. Fresh rock with shears having <10cm thickness and
5. Fresh rock with shears having >10cm thickness

The first category of rockmass is confined to the portal areas and the tunnel sections crossing local nalas on the surface. The most widely accepted Rock Tunneling Quality Index ('Q') of Barton et al (1974), Rock Mass Rating (RMR) of Bieniawski (1989) for all five categories have been calculated. The ranges of 'Q' and RMR values and modulus of deformation and support pressure for all the five rock types are given in Table-1.

According to the Terzaghi's (1946) rock load classification the strata can be classified as hard and stratified/schistose rock in major part of the tunnel and the rock load for this type of strata (0 to 0.5 B) will vary from nil to maximum 8.1 tonnes/m^2. Singh et al, 1995 have recommended 0.04 to 0.07 MPa vertical support pressure (p_v) and nil side support

Table 1:

Rock type	'Q'	RMR (Observed)	Modulus of deformation (E_d) * GPa (Average)	Support pressure (MPa)			
				$p_{v\,(el)}$** Non squeezing conditions	$p_{v(sq)}$ ** Squeezing conditions		
				H-150 m	H-150 m	H-250m	H-400 m
CS	0.03-0.88	20 - 60	5.25	0.23	0.09	0.13	0.21
PH	0.03-1.03	21 - 62	5.62	0.20	0.10	0.14	0.24
TMQ	0.22-10.7	31 - 84	16.05	0.09	0.34	0.86	2.92
SQ/PQ	0.05-8.00	23 - 70	11.23	0.16	0.24	0.56	1.71
SD	0.22-1.56	25 - 70	10.23	0.11	0.19	0.36	0.82

pressure (p_h) for such category. In squeezing ground conditions, which are likely to be encountered in central part of the tunnel with thickness of the overburden >150 m the vertical pressure ranges between 0.3 to 0.6 Mpa. The (p_v) is also computed from correlation equations of Goel et al., 1995a and Singh et al., 1997 using Rock Mass Number (N) and depth of tunnel (H). The $p_{v(el)}$ calculated for non squeezing ground condition lies between 0.09 MPa for most competent rock (TMQ) and 0.23 MPa for the weakest rock (CS). The corresponding values for 400 m overburden for squeezing ground conditions ($p_{v(sq)}$) are 2.92 MPa and 0.21 MPa respectively for mild to moderate squeezing conditions. The analysis of these values shows an inverse relation between 'N' (Rock Mass Number) and support pressure in non squeezing ground conditions and direct relation in squeezing ground conditions.

All four 9 m dia shafts are being sunk through phyllite. The rock mass quality of walls (Q_w) computed for shafts for different categories of rock mass vary from 0.08 to 1.83. The average Q_w value (0.79) may be considered as quite safe for designing the support requirement. The self supporting dia of the shaft in this rock mass computed from ESR (Excavation Support Ratio) and Q_w is 6.36 m (Barton et al (1974). The long term support pressure calculated from the equation (Singh et al, 1992) ranges between 0.18 MPa for rock with thick shear zones to 0.49 MPa for fresh rock with few joints.

In order to check the authenticity of the geotechnical data collected the RMR values for all the categories have been calculated using Rutledge and Priston's (1978) equation also, which has given highest correlation coefficient of 0.81 amongst five different equations as evaluated by Goel et al., 1995b. The observed RMR plotted against calculated values (Fig-2) shows very good positive correlation with 0.92 as coefficient of correlation.

The 3D logging of about 1100 m tunnel section of Akodara tunnel and about 300 m section of Madri tunnel revealed some crucial zones requiring special attention during tunnelling.

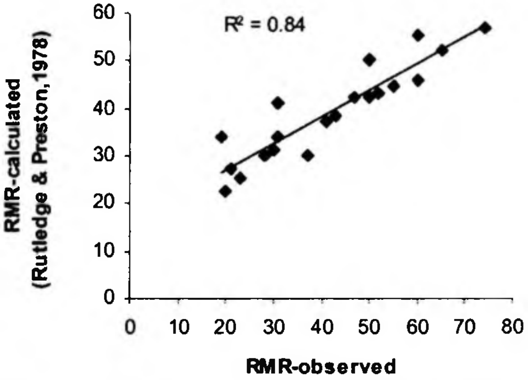

Fig. 2: Critical zones requiring special attention

Weathered rockmass below local ephemeral nalas

A vertically disposed moderately weathered fine grained ultrmafic intrusive body reported from outlet portal of Akodara tunnel having a width of about 4 m runs for about 50 m at acute angle with the tunnel axis. In this zone, regular fall of rock mass had been observed and hence steel rib support had to be provided at closure interval with lagging in about 90 m tunnel section. A nala flowing along the trend of the body is responsible for deterioration of rockmass. Similar instances of rockmass deterioration below two ephemeral nalas have also been reported in Madri link tunnel at two places, where the fresh rock cover is insufficient. At one place, the failure was along a steeply dipping thin shear zone, running at an acute angle with the tunnel axis, filled with clay gouge and fragmentary material. Another major failure occurred along about 1 m thick moderately dipping shear zone in the left wall of the tunnel for 10 m length. The fractured and highly weathered material had slided with heavy outburst of water into the tunnel leaving a 5 m high chimney. Such situation could have been averted had the expert's advise been taken at appropriate time. Grouting of the rockmass in the nala portion prior to tunneling in these crucial zones could have improvised the strength of the rockmass.

Cavities in siliceous dolomite

One large irregular cavity on each sidewall in the vicinity of outlet portion of Akodara tunnel has been observed (Fig.3). The cavity was formed due to sudden outburst of water, trapped under pressure in solution cavities of siliceous dolomite. Probe holes before further advancement of the tunnel would have prognosticated the situation and arrangements could have been made to release the water pressure by drill holes. To locate such cavities and loosened rockmass, geophysical investigation using reflection seismic sounding should have been carried out in calcareous rocks.

Fig. 3: Clay coated cross joints parallel to the tunnel alignment

Clay coated sub vertical cross joints parallel to the tunnel alignment in Akodara tunnel are also a feature to be given proper attention. Incidences of falling tabular chunks have been noticed at some places. Proper rock bolting of these overhung rockmass well in time is essential to avoid occurrence of any such accident. These joints to some extent also affect the excavated profile of the tunnel causing over breaks in the sections having predominance of such joints.

Support requirement in general

The surface observations and synthesis of the data generated during 3D logging of some portions of both the tunnels reveal that the rock mass quality in the tunnel varies from place to place but within certain limits i.e. poor to fair in general for most of the part and very poor in about 20% to 30 % of the tunnel length, where weak shear zones are encountered. The support categories on the basis of 'Q' values and equivalent dimension (De) of the tunnel are 1 to 4 (After Grimstad and Barton, 1993) for major part of the tunnel and accordingly rock bolting and shotcreting with/without wire mesh will be required as temporary support. Beside this steel rib support at all the portals and in the crucial zones having cavities and major shear zones due to very poor rock mass condition is warranted as permanent support. About 20% to 30% of the tunnel section may be left unsupported owing to higher 'Q' values. No permanent support is required in major part of the tunnel as the entire length of the tunnel is to be lined with 30 mm concrete with nominal reinforcement. The reinforcement has to be increased in squeezing conditions with installation of heavier permanent support based on anticipated/observed support pressure in the central part of the tunnel. The instrumentation of the tunnel openings is strongly recommended for the portion with over 100 m overburden in order to assess the degree of squeezing conditions.

In Madri link tunnel systematic rock bolting in the crown portion throughout the length of the tunnel besides shotcreting of loose fragmentary overhung rockmass is the support requirement in general. Steel rib support with backfilling and lagging is the desired support in crucial zones. All the portals also require steel rib support at least in initial 5-10 m section as the 'Q' values are drastically reduced. Instead of using steel rib support steel fiber reinforced shotcreting (SFRS) is strongly recommended which is a more faster and economic substitute.

The shafts as such do not have much problem. Only the portions with down dipping joints require systematic rock bolting. In the remaining 3/4th portion, spot bolting of the overhung rock mass along with shotcreting of the shear zones and loose rock mass with/without wire mesh will serve the purpose of safety.

Conclusions and recommendations

The rock mass characterization of the tunneling media of the tunnels of Dewas-II project is attempted using the most widely accepted Q and RMR methods. Lithologically five rock types viz CS, PH, TMQ, SQ/PQ and SD constitute the tunneling media. Each rock type has been further classified into five categories of rock mass on the basis of various geotechnical parameters. About 50% of the tunnel section, squeezing ground condition is anticipated. The support categories arrived at on the basis of Q values are between 1 and 4 for major part of the tunnel and accordingly support requirements have been suggested. Special attention should be given to crucial zones viz solution cavities, weathered rock mass beneath surface nalas and clay coated sub vertical cross joints for the safety of the tunnel as well as the tunnelling crew. Instrumentation of the tunnel for the portion with over 100 m overburden and using SFRS with rock bolting instead of conventional steel rib support is strongly recommended.

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