Tunneling through adverse geological conditions in granitic terrain

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Abstract— Generally it is pre mind setup that granitic terrain is always suitable for tunneling media and requirement of detail feasibility studies are minimize accordingly. To facilitated irrigation and other utility en-route of seven draught prone Districts of Telangana State, Dr B R Ambedkar lift irrigation project is under construction. Twin tunnels 9.55 km length with 10 m finished dia are being constructed to lift water from SripadaYellampalli Reservoir to Medaram tank. Granitic rock with dominant intrusive zones of amphibolites/basic enclaves were observed in the studied tunnel length. Problematic zones categorized into fair, poor and very poor rock classes with occasional bands of good rock class based on rock tunneling quality index 'Q' between chainage 8.298 and 9.865 km. This zone observed dripping to flowing in nature, created difficulties for tunneling. Heavy steel ribs were erected for rock mass supports in poor and very poor tunnel reaches as per design drawing. These problematic zones are responsible for delaying the construction progress and created vulnerable situation for the tunneling work.

Modifications /changes in excavations plan was done, which was very much essential as per the site condition to achieve the targeted quantity of excavation within the time frame. Intelligently changes in excavations were planned based on the anticipated poor rock masses at ahead of tunnels reaches. Modification was based on the subsurface exploration data. In this paper emphasis are made on the requirement of detailed feasibility study along the tunnel alignment even the tunneling media is made up of granite.

Keywords—granitic terrain; twin tunnels; sripadayellampalli reservoir; medaram tank; rock tunneling quality index

1. INTRODUCTION

The Dr.BR Ambedkar (Pranahitha – Chevella-Sujala-Shravanthi) Lift Irrigation Scheme is being constructed to lift 160 (TMC) water from the Pranahitha River (EL +150 m) to the Chevella reservoir (EL +635 m). Pranahitha River is a tributary of Godavari River, which formed by the confluence of Wainganga and Wardha Rivers. The objectives of this scheme isto facilitate irrigation and other utility en-route for seven draughts prone Karimanagar, Khammam, Medak,

Nizamabad, Adilabad, Warangal and Ranga Reddy Districts of Telangana State.Package-6 of this scheme is being constructed to lift 146.24 TMC water from SripadaYellampalli reservoir to Medaram tank situated near DharmaramMandalin Karimnagar DistrictFig.1

The water need to be lifted from the tunnel bed level at RL+ 109 m to Medaram tank at its FRL +230 m. Twin tunnels 10 m finished dia and 9.55 km long are being constructed to supply the water with the design discharge of 535 cumecs. Twin tunnels will join the surge pool cavern, from where draft tube tunnels lead to the pump house cavern is being constructed. Underground cavernswere planned because it is safer construction, more economic and environmental friendly.

Water will be lifted from RL+ 109 m to the cistern located at ground level RL +241 m with the help of pumps and through pressure/delivery mains. Water from cistern (+241 m) to the Medaram tank (FRL +230 m) will move through gravity. To lift the huge amount of water during the monsoon high capacity of pumps (6 x 124.4 MW) will be installed in the pump house cavern.

Fig.1. General layout map of Dr B R Ambedkar (PCSS) package-06

II. GEOLOGY OF THE AREA

The regional lithological units belong to NW-SE trending Karimnagar Granulite Terrane (KGT), supracrustal rocks of Peninsular Gneissic Complex (PGC) of Archean age [1,2]. Basic enclaves of older metamorphics occur within PGC granites at places which are mainly represented by pyroxinite/amphibolite [3]. Dolerite dykes are also emplaced into the main litho units at places. Medium to coarse grained, grey to pinkish grey granites, migmatite, gneiss and charnokites intruded by dolerite dyke and basic enclaves of Karimnagar Granulite Belt are exposed in the area [4,5]. The general stratigraphic sequence of the study area is given in Table 1. The area is predominantly pediplain terrain dotted with inselberg, denudational and residual hillock developed over resistant granite rocks and small linear ridges of dolerite dykes [6].

TABLE I GENERALIZED STRATIGRAPHIC SEQUENCE [7].

Quartz/ pegmatitic veins (acid intrusive)	Peninsular Complex	Gneissic
Granodiorite		
Biotite granite gneiss/ tonalite	High Grade Supracrustals	
Amphibolites/ pyroxene granulite		
Banded magnetite quartzite/ quartzite /schist		

III. GEOLOGICAL MAPPING AND ASSESSMENT OF ROCK SUPPORT

Evaluation of right main tunnel (RMT) and left main tunnel (LMT) based on 3D geological mapping was done between chainages 8.298 and 9.865 km for cumulative length of 2.959 km. This was done to suggest suitable measure for rock support and tunnel stability. The assessment of 'Q' [8,9] for the encountered rock mass was done. Based on rock

tunneling quality index 'Q' rock mass was categorized into fair, poor and very poor rock mass with occasional bands of good rock (Fig. 5 and 6). ISRM [10] classification was used for the characterization of rock mass into different weathering grade. Critical faces were mapped on 1:100 scale for giving necessary required rock support input and further excavation methodology.

The rock mass in RMT and LMT are intersected by four joints sets with random joint Table II and III respectively. Basic enclaves generally recharge with water and whenever excavation was done in such type of tunnel media, stability problems were encountered. Basic-enclaves, grey granite and garnetiferous granulite in the form of zones are the rock types encountered in the excavated reaches. The rock mass in RMT are falling under good (4.78%), fair (78.90%), poor (14.39%) and very poor (1.91%), rock classes. In the LMT rock mass categorized into good (9.33%), fair (75.57%) and poor (15.08%). rock class. Support categories for the different rock mass class is given in Table IV.

Fig.2. Metabasic enclaves exposed at chainage 9.100 km in LMT

TABLE II JOINT SETS MAPPED IN RIGHT MAIN TUNNEL DOWNSTREAM

Joint Set	Dip direction/ Dip Amount	Spacing (cm)	Persistence (m)	Roughness*	Aperture (mm)	Infilling	Ground Water	Remark
J1	325-005/40-65	16-60	>20	R/I/P, SP	Tight to 1	Non softening material	Dr	Prominent joint
J2	070-085/60-75	20-60	5-15	R/I/P, SP	Tight to 1	Non softening material	Dripping/flo wing	Prominent joint
J3	245-250/30-40	20-100	>20	R/I/P, SP	Tight to 2	Non softening material	Dry	Prominent joint
J4	160-190/35-50	30-100	>20	R/I/P, S/U, SP	Tight to 1	Non softening material	Dry	Prominent joint
J5	235-260/35-40	-	-	R/I/P, S/U, SP	Tight to 1	-	Dry	Random

*R/I/P- rough irregular planar, S/U-slickenside to smooth undulating, S/P- smooth planar

TABLE III JOINT SETS MAPPED IN LEFT MAIN TUNNEL DOWNSTREAM

Joint Set	Dip direction/ Dip Amount	Spacing (cm)	Persistence (m)	Roughness*	Aperture (mm)	Infilling	Ground Water	Remark
J1	330-355/40-65	15-60	>20	R/I/P, SP	Tight to 1	Non softening material	Dry	Prominent joint
J2	070-090/45-70	20-60	5-15	R/I/P, SP	Tight to 1	-	Dripping/flo wing	Prominent joint
J3	230-260/40-75	20-100	>20	R/I/P, SP	Tight to 2	Non softening material	Dry	Prominent joint
J4	155-200/40-65	15-60	>20	R/I/P, S/U, SP	Tight to 1	Non softening material	Dry	Prominent joint
J5	170-190/30-40	-	-	R/I/P, S/U, SP	Tight to 2	-	Dry	Random

*R/I/P- rough irregular planar, S/U-slickenside to smooth undulating, S/P- smooth planar

TABLE IV SUPPORT CATEGORIES FOR THE DIFFERENT ROCK MASS CLASS

Rock Class	Tunneling Quality Index 'Q'	Support System	Remark
Very Good	$Q > 40$	Spot rock bolt only	Type of rock bolt HYSD Bars of Grade Fe 415 with cement and resin capsule grouted and tensioned type.
Good	$10 < Q \leq 40$	4.5 m long, 4.5 m spacing, 25 mm dia rock bolt	
Fair	$4 < Q \leq 10$	3 & 5 m long, 1.5 m spacing at crown, 25 mm dia rock bolt, 50 mm thickness SFRS at crown and 25 mm at sides	
Poor	$1 < Q \leq 4$ (2-4)	ISMB 200 @1000 mm c/c	The support system is designed for $Q = 2.29$ and $J_r = 2.0$.
		ISMB 300 @1900 mm c/c	
Poor	$1 < Q \leq 4$ (2-4)	ISMB 200 @500 mm c/c	The support system is designed for $Q = 2.29$ and $J_r = 1.0$.
		ISMB 300 @950 mm c/c	
Poor	$1 < Q \leq 4$ (1-2)	ISMB 200 @400 mm c/c	The support system is designed for $Q = 1.38$ and $J_r = 1.0$.
		ISMB 300 @800 mm c/c	
Very Poor	$0.1 < Q \leq 1$	ISMB 200 @300 mm c/c	The support system is designed for $Q = 0.77$ and $J_r = 1.0$.
		ISMB 300 @ 650 mm c/c	

IV. ANTICIPATED ADVERSE GEOLOGY BASED ON BORE HOLES DATA

In view of adverse geological condition encountered in RMT and LMT between 8.292 and 9.000 km tunnel reaches, investigations stage bore holes log data of balanced tunnels length drilled at 9.200, 9.350, 9.450, 9.600, 9.770 km were reviewed. After study of bore holes data it was observed that at chainage 9.200 and 9.450 km rock quality designation (RQD) value was reported nil. RQD values of chainages 9.350, 9.600 and 9.778 km were ranges between 10% and 40% indicating that excavation must be done carefully. As per subsurface data problematic zones were anticipated between 9.200 and 9.900 km tunnels reaches, where tunneling work will be delayed and man and machinery may not be utilized properly. Planning was made for avoid any delay and proper utilization of man and machineries. Probing map was prepared based on bore holes data for the chainage between 9.100 and 9.910 km. It was decided that probe holes, controlled blasting and immediate sealing shotcrete, spot bolts followed by design rock support will be done at earliest as possible in these anticipated tunnel reaches

Fig.3. Graphical representation of Q map between 10.600 and 9.965 km of RMT

V. MODIFICATION OF EXCAVATION PLAN BASED ON ANTICIPATED GEOLOGY

Based on subsurface data information it was decided that excavation should be done towards upstream side from new

proposed adit-3 in view of anticipated adverse geology between chainage 9.200 and 9.900 km. Based on detailed study, excavation plan was modified towards upstream in view of likely excavation progress delay for twin tunnels. Modification plan for excavation was suggested for chainage 10.500 to 9.915 km upstream and 10.500 to 10.600 km downstream tunnel reaches from the new proposed adit-3.

As per bore hole data of chainage 10.675 km, anticipated geology was good/favorable rock media. A 565 m long multipurpose adit-3 was excavated to reach at the twin tunnels at 10.500 km and to enter in surge pool area. Adit-3 was excavated in the good to very good tunnel media except at the few locations where fair rock class was mapped in the form of weathered/alterd and closely spaced joints in the form of bands. Graphical representation of 'Q' of 10.600 and 9.965 km reach is given in (Fig.3) -. Rock tunnel media intersected with one plus random to maximum two plus random joint sets and where rock tunneling quality index 'Q' ranges between 10.24 and 98.5. RQD values ranges from 82.0 to 98.5%. Excavation of twin tunnels were restarted from chainage 10.500 (junction) towards upstream i.e. 9.915 km and from 10.500 towards 10.600 km for excavation of twin tunnels and for surge pool entry. Excavation was completed within specified time frame as given by project management. Machinery and man power were utilized properly. Further excavation was done for entry in surge pool which was done with this modified excavation plan.

VI. TUNNELING CHALLENGES AND METHODOLOGY APPLIED IN ADVERSE TUNNEL REACHES

During the excavation of advance right main tunnel (RMT) over break at chainage 8.452 km was recorded where seepage and metabasic were met during tunneling. Sudden over break after taken a blast at chainage 8.452 km which was finally reached upto 6.0 m length x 5 m (width) x 7 m (height) with seepage 160 liter/minute was recorded. Temporary and permanent rock support as soon as possible were completed and after crossing this cavity reach precautions were taken during further tunneling. Probe holes were done for critical/doubtful reaches. Fore polling was done after every 2 blasts and ensuring the overlapping in the critical poor/very poor tunnel reaches. When this problem encountered in right main tunnel (RMT), left main tunnel (LMT) was excavated

upto 8.260 km and problem was anticipated well in advanced in LMT and precautions were taken.

Inview of poor and very poor rock mass encountered in RMT it was decided that precautions should be taken from chainage 8.268 km with controlled blasting. After reaching at chainage 8.283 km, three probe holes of 50 mm dia. and 12 m long were drilled and rock types were examined. Change in colour of backflow water (greenish black) and sudden change in penetration rate were observed at 8.0 m depth from face. During the drilling of right side probe hole, sudden gap was observed by Boomer operator. In view of changed in the colour of back flow water and penetration rate, forepoling with iron rod having 25 dia. and 5.5 m length at the crown level with 30 cm spacing up to the spring level was done. Some time the spacing of forepolling was slightly reduced in very critical tunnel reaches. At chainage 8.288 km, basic enclaves with dripping condition was recorded and tunneling quality index 'Q' encountered at the tunnel reach fall under poor rock class.

Rock falling from left crown portion in LMT between chainage 9.060.5 and 9.071 km was observed from already rock supported area. Rock falling was due to joints combination where ribs were erected in view of sitegeological conditions (Fig.7). Contact of metabasic enclaves with granite in the form of poor rock encountered at chainage 9.865 km reach which was excavated through adit-3 in the metabasics media with closely spaced joint in the form of crushed/loose formation where immediate sealing shotcrete followed by riberection upto 5 m area was completed. Face was packed with sand bags upto crown portion to avoid overbreak and sudden collapse. Sometime overbreak due to joint orientation was also observed in the some reaches where critical situation was faced for support and further excavation (Fig.4).

Fig.4. Contact zone between grey granite and metabasics enclaves at 9.865 km of LMT

Dripping to flowing condition was also recorded in various tunnel reaches where rock mass was found moderately to highly weathered and rock mass generally observed poor and rib were erected. Drainage holes were provided in the tunnel reach where seepage was encountered > 2 liters/minute.

For the critical/doubtful tunnel reaches probe holes were done and if any change in backflow water and change in

penetration rate observed during the drilling fore polling at the crown level was done to avoid any overbreak/sudden collapse. Fore polling were done with length of 3.5 to 5.0 m with 25 mm dia. rod for this purpose. In all the critical tunnel reaches immediate sealing shotcrete followed by spot bolt, pattern rock bolts & shotcrete and rib were erected.

Fig.5. Graphical representation of Q map between 8.298 and 9.690 km of LMT

Fig.6. Graphical representation of Q map between 8.298 and 9.865 km of RMT

Fig.7. Rock falling between chainage 9.060.5 and 9.071 km of LMT

Additional/longer rock bolts and shotcrete 50-100 mm thickness were done for the potential/wedge forming areas due

to joint sets and continuity of joints at the different tunnel reaches in twin tunnels.

VII. CONCLUSION

Granitic terrain is generally advisable tunneling media where chances of geological surprises and requirement of heavy rock support are less in comparison of Himalayan terrain. Sometimes due to this philosophy, during detailed investigation study for tunnel alignment only geomorphologic doubtful and contact zones of different geological formations are generally consideration for subsurface study. For this project about 3.146 km twin tunnels alignment was not properly investigated due to the above mentioned philosophy. In these reaches bore holes were drill at the rock ledge (middle rock mass) of the twin tunnels. Projecting Q-values for the similar chainages in various locations were not matching with the actual values. Tunnel progress was delayed due to adverse geological condition during tunneling work. Advance modification planning was done otherwise it would have more fiscal losses. All these type of things can be avoided through proper Detailed Project Report stage investigations.

Granitic terrain is mostly good tunneling media but the intrusive/adverse geological conditions make it problematic where underground excavation and support system is time taking process. Adverse geological probability increased with respect of tunnel length. In such type of longer tunnels more subsurface data needs to be interpreted for the selection of safe tunneling alignment. Tunnel alignment needs to be decided based on subsurface data rather than based on rock type. Tunnel diameter can be minimized and number of tunnels can be increased as per the site geological conditions.

As per site geological condition additional support in view of joint sets can be provided to avoid overbreak and smooth tunneling work. Software based wedge analysis also helpful study in view of deep effect of joint combination on the rock mass.

Necessary modification on excavation plan and support design is required if some doubtful/adverse geological features are anticipate in ahead tunnel reaches in the rock mass. Twin tunnels were supported with heavy steel ribs for the encountered rock class based on tunneling quality index 'Q' for poor and very poor rock tunnel reaches.

Overbreaks due to combination of joints was recorded. In general poor and very poor rock chainages are very difficult to anticipate without probe hole techniques but in this project site based on joint nature/orientation, 25 m in advanced rock mass was anticipated.

Between chainage 8.298 and 9.865 km in RMT and 8.298 and 9.690 km in LMT rock class falls in very poor 1.01%, poor 14.71%, fair 77.34% and good rock 6.92 %. Terrain does not give the actual idea about the rock mass conditions. With the help of subsurface exploration rock mass can be categorized in a better way. Planning for bore holes should be done on the tunnel alignment. For twin tunnels it can not be on the rock ledge, but should be for both the tunnels. Proper investigations can save crores of rupees and time. For this project advance planning for the modification in excavation

plan was done. Timely supporting of adverse geological reaches with some delay was done but without loss or injury of manpower and machinery.

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