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Geotechnical Investigation and Monitoring of Underground Excavation of Tunnel-2 in Srisailam Left Bank Canal Tunnel Project (AMRP), Nalgonda District, Telangana, India

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Abstract

Construction stage geotechnical investigation for tunnels within rocks includes detailed engineering geological mapping of excavated strata and its subsequent rock mass classification for the purpose of selection and installation of suitable supports. Monitoring of ground deformations during excavation of rock tunnels serves as the principal means of verifying the design of tunnel supports and stability of the excavation. Geology of the area comprises of Archean gneissic complex with basic intrusives overlain unconformably by the Srisailam Quartzites. The contact of basic intrusives with granite reaches was expected to be fractured and sheared and identified as adverse geological conditions and may warrant instrumental monitoring. In this work, the underground excavation of Srisailam Left Bank Canal (SLBC) Tunnel2, excavated in the Archean gneisses and granites was mapped by face mapping and 3D geological logging on 1:250 scale during construction stage, for the entire length of 7121Mresulting in identification of Chainages 2776M, 3200M and 4170M for field monitoring. Field instrumentation comprising of MPBX/SPBX, Load cells were installed at the adverse locations. The ground deformations were found to have attained stability with the installation of primary supports comprising shotcrete 50MM thick and pattern rock bolts 4M long full grouted for Rock Mass Class III (Fair Rock), shotcrete 100MM thick and pattern rock bolts)/ Steel Ribs with back fill concrete for Rock Mass Class IV and V(Poor Rock and Very Poor Rock).

Keywords: Geological Investigation, Rock Mass Classification, Excavation Monitoring, Ground Deformation, Tunnels, Nalgonda District

Introduction

Nalgonda is one of the droughts affected and backward districts of Telangana State. People are mainly dependent on agriculture for their livelihood. The water available from dug wells and bore wells has the problem of excess fluoride. To overcome this problem and provide fresh water for drinking and agriculture, the Srisailam Left Bank Canal (SLBC) tunnel scheme was proposed under the Alimineti Madhava Reddy Project (AMRP) by the erstwhile Government of Andhra Pradesh and now Telangana.

The SLBC tunnel scheme consists of two water transfer tunnels, Tunnel-1 and Tunnel-2 with a balancing reservoir in between. A network of canals connects the tunnels with the balancing reservoir. Tunnel-1 has a length of 43.931 km and is being bored by two Tunnel Boring Machines (TBMs), while Tunnel-2 has a length of 7.121 km and was excavated by the Drill and Blast Method (DBM).

Raju M. (1989, 2008, 2009) investigated the geotechnical conditions along the tunnel alignment in the SLBC tunnel scheme in the AMRP. Raju K. (2009) made a geotechnical evaluation of the design parameters for use in the TBMs of the SLBC tunnel with the help of satellite imageries. Kuthe *et al.* (2021) developed a method for estimation of insitu rock block size using digital image analysis of rock faces. Liu *et al.* (2022) carried out primary support optimisation of shallow rock tunnels based on active support using field monitoring.

Scope of the Study

The present study is confined to Tunnel-2 (T2) using the layout plan of the alignment (Fig.1). The inlet of Tunnel-2 is located at 16°32'24"N, 78°56'58"E, near Teldevarpalli Village, while the outlet is at16°35'43"N, 78°58'24"E, near Neredigumma Village of Chandampeta Mandal, Nalgonda District of the Telangana State. The area under study falls in the Survey of India Topographic sheet no.56 L/14/SE. The tunnel has a finished diameter of 8.758M and modified horse shoe in shape.

As Tunnel-2 was excavated by the drill and blast method, construction stage geological mapping was done and the stability of the excavation had to be checked before casting in situ lining. As per design, the rock loads are to be carried by the primary supports

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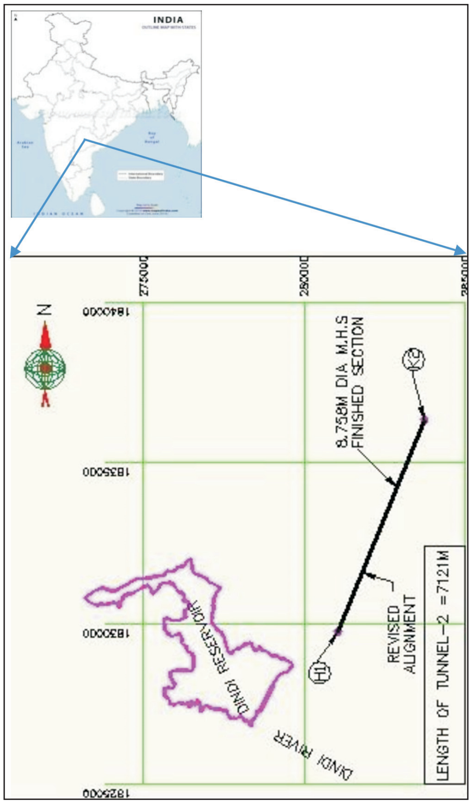

Fig. 1. Layout Plan of Tunnel T2

depending on the class of rock. The primary lining or supports consisted of rock bolts, shotcrete and steel ribs with backfill concrete at few reaches depending on the class of rock mass. Subsequently, the tunnel was monitored using instrumentation, which comprised of MPBX (Multi Point Borehole Extensometer), SPBX (Single point Borehole extensometer) and load cells.

Geology of the Study Area and Tunnel 'T2'

The study area constitutes the Archaean basement comprising of granites and granite gneisses overlain unconformably by the Srisailam Quartzites occurring on the flat-topped hills of Chandampeta Mandal.These quartzites constitute the uppermost stage of the Krishna Series in the Cuddapah Super Group and rest unconformably on the Archaean basement (Sen and Narsimha Rao, 1967). Rajurkar and Ramalingaswami (1975) divided the Cuddapah succession into three groups, namely, lower Cuddapah Group, Nallamalai Group and Kurnool Group. The Srisailam Quartzites is included under the Cumbum slate subgroup of the Nallamalai Group. Meijerink *et al.* (1984) also proposed a three-fold division of the succession and included the Srisailam Formation under the Bairenkonda subgroup. The Nallamalai fold belt (NFB) forms a tectonic boundary with the other rock groups and was excluded from the lithostratigraphic succession (Patranabis-Deb *et al.*, 2012). The NFB is separated from the Cuddapah Basin by the easterly dipping Rudravaram thrust (Das and Chakraborty, 2019). The lithostratigraphic divisions of the Cuddapah System proposed by Nagaraja Rao *et al.* (1987) have been adopted in this work (Table 1).

The predominant rock formations along the alignment of Tunnel2 are granites with occasional basic intrusives. The Tunnel (T2) was excavated only in the Archean formation consisting of granites and, in some reaches, basic intrusives as shown in the geological section prepared based on mapping done during the construction stage of the project before concrete lining (Fig.2 a-d).

Joints and Discontinuities

Four sets of joints (J1 to J4) intersect the rock mass (Table 2) with the fourth set (J4) intersecting only in the low cover reaches up to Chainage700M. Joint sets are moderate to widely spaced with sets J1 and J2 having high to medium persistence and J3 having low persistence. Other discontinuities of importance are six shear zones between the chainages 2770M to 2827M, 3200M to 3220M, 3490M to 3560M, 4160M to 4190M, 4470M to 4480M and 5440M to 5470M. These shear zones have N-S and E-W strike and dip at $265^{\circ}/70^{\circ}$, $340^{\circ}/80^{\circ}$, $340^{\circ}/85^{\circ}$, $275^{\circ}/80^{\circ}$-85°, $177^{\circ}/17^{\circ}$ and are oblique to the tunnel alignment which is at N22°E -S22°W direction. The shear zones have resulted in over break cavity formation of 0.5M to 0.7M

Table 1: Stratigraphy of Cuddapah Supergroup (Nagaraja Rao *et al.*, 1987)

Group	Formation	Thickness(m)	Lithology
Kurnool Group	Nandyal Shale	50±100	Shale
	Koilkuntla Limestone	15±50	Limestone
	Paniam Quartzite	10±35	Quartzite
	Owk Shale	10±15	Shale (ocherous)
	Narji Limestone	100±200	Limestone
	Banganapalle Quartzite	10±50	Conglomerate, Quartzite
		~Unconformity~	
Srisailam Quartzites		300	Quartzites and shale
		~Unconformity~	
Nallamalai Group	Cumbum: phyllite,slate,quartzite, dolomite		
	Cumbum (Pullampet) formation	2000	
	Bairenkonda (Nagari) Quartzite	1500±4000	Nagari: conglomerate, quartzites and shales with intrusives
		Angular unconformity	
Chitravati Group	Gandikota Quartzite	300	
	Tadpatri Formation	4600	Shale, ash fall tuffs, quartzite, dolomite with intrusives
	Pulivendla Quarzite	1±75	Conglomerate and quartzite
		Disconformity	
Papaghni Group	Vempalli Formation	1900	Stromatolitic dolomite, dolomitic mudstone,chert,breccia and quartzite with basic flows and intrusives
	Gulcheru Quartzites	28±210	Conglomerate, arkose,quartzite and shale
		Nonconformity	
		Archean Gneissic Complex	

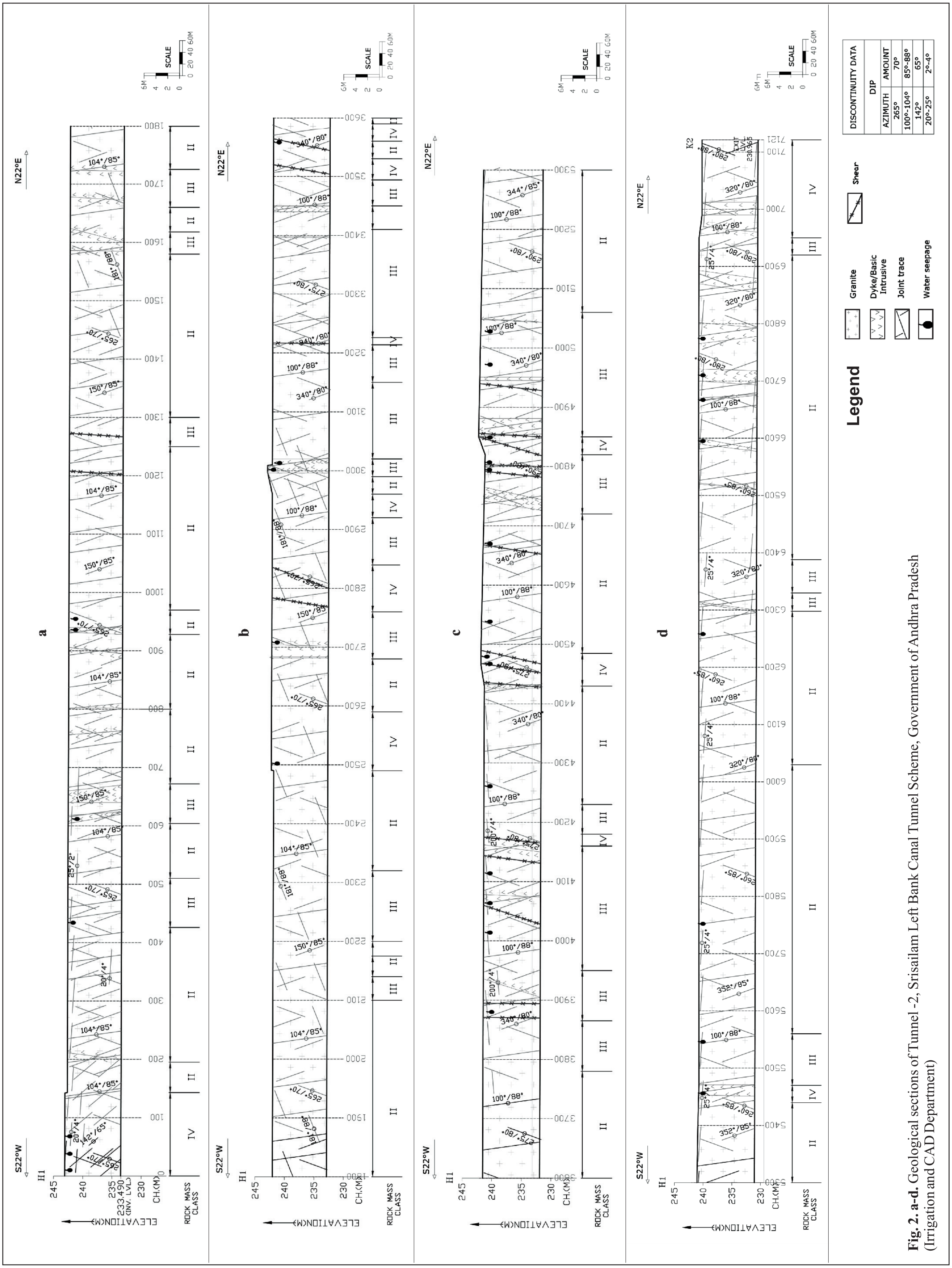

Fig. 2. a-d. Geological sections of Tunnel -2, Srisailam Left Bank Canal Tunnel Scheme, Government of Andhra Pradesh (Irrigation and CAD Department)

Table 2: Joint data of the study area (Notation: Rg-Rough,Tg-Tight)

Joint Set	Chai-nage (From)	Chai-Nage (To)	Dip azimuth	Dip amount	Spacing (MM)	Persis-tence (M)	Rough ness	Aper ture (MM)	Fill-ing
J1	0	7121	265°-280°	70°-85°	600-1000	10-20	Rg	Tg	NIL
J2	0	7121	100°-104°	85°-88°	5000	3-10	Rg	Tg	NIL
J3	0	2800	142°	65°	700-1500	<3	Rg	Tg	NIL
J4	0	700	20-25	2° - 4°	5000	10-20	Rg	Tg	NIL

between 4470M to 4480Mand characterised by seepage conditions. There are a few minor joints of random orientation which are non-persistent.

Methodology

Construction stage geological mapping was done during tunnel excavation and the quantitative description (IS11315) and classification of rock mass (IS 13365) was carried out as per Q-system (Barton *et al.*, 1974). To monitor the stability of excavation, instruments were installed at TunnelT2 (IS13414, 1992) in compliance with the Geological Survey of India (GSI) report for carrying out monitoring (Prasad and Meshram, 2010).

Field Instrumentation Observations

The plan of field instrumentation was identified during construction stage geological mapping (Fig.3; Table 3).

As 76% of tunnel was excavated in Good Rock, 18% in Fair Rock and the remaining 6% only in Poor rock (Prasad and Meshram, 2010) with no roof fall or collapse in the tunnel except only over break cavities and accordingly the instrumentation reaches were identified and the observations were made using instrumentation (Fig. 4-6).

Results and Discussion

Rock Mass Classification

Based on the construction stage Geological mapping and quantitative classification of rock masses an L-section drawing of Tunnel 2 was prepared (Fig. 2. a-d) and the quantitative classification was carried out (Table 4).

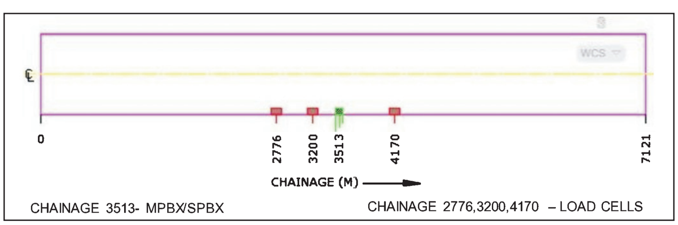

Fig. 3. Plan of Instrumentaion Tunnel T2

Table 3: Location of field instruments in Tunnel T2

SN	Chainage(m)	Instrument
1	3513	MPBX (Multi point borehole extensometer)/ SPBX (Single point borehole extensometer)
2	2776	Load cell
3	3200	
4	4170	

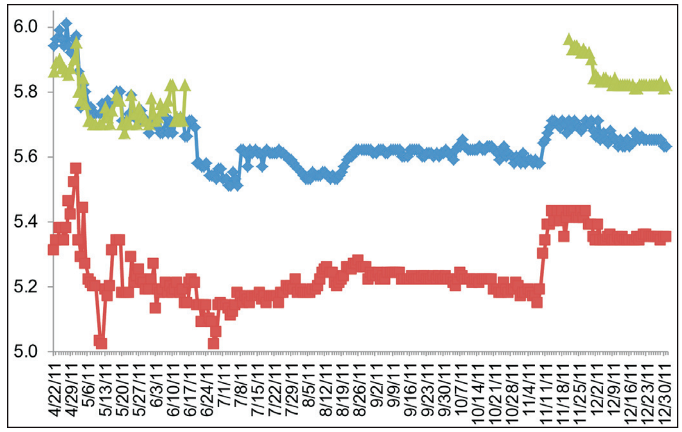

Fig. 4. Variation of Average Load in Tunnel T2

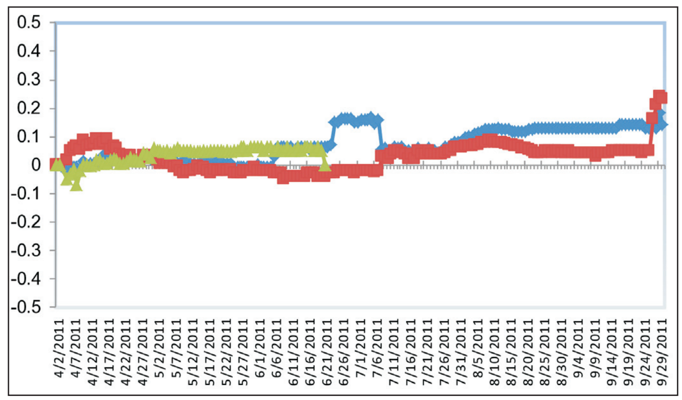

Fig. 5. Displacement of MPBX at Chainage in Tunnel T2

The quantitative classification showed that most part (76%) of the tunnel was excavated in rock mass Class II (Good rock), with the remaining part comprising of Class III (Fair rock) and Class IV (Poor rock) constituting 18% and 6%, respectively. The primary support consisted of spot bolting 4M long fully grouted for Class II (Good Rock), shotcrete 50MM thickness and staggered pattern rock bolts 4M and 4.5M long fully grouted for Rock Mass Class III (Fair Rock) and shotcrete 100MM thick and pattern rock bolts / Steel Ribs with back fill concrete for Rock Mass Class IV (Poor Rock).

Interpretation of Load Cell Data

Load cells were installed at the three locations of Chainages

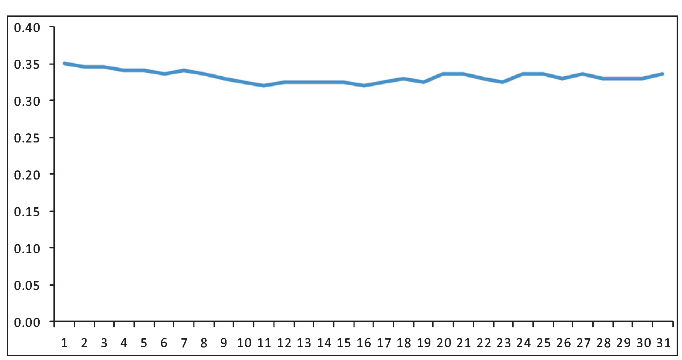

Fig. 6. Displacement of SPBX anchor at Chainage in Tunnel T2

Table 4: Quantitative Classification of Rock Masses in Tunnel T2

Chainage (M)	RQD	JN	RQD / JN	JR	JA	JR/JA	JW	SRF	JW /SRF	Q-Value	JV	Rock Mass Class	Rock Category
5	75	18	4.17	1	1	1	0.66	2.5	0.26	1	12	IV	Poor
135	80	9	8.89	1	1	1	1	2.5	0.40	4	11	IV	Poor
197	77.5	9	8.61	1.5	1	1.5	1	1.5	0.67	9	11	III	Fair
211	72.5	10.5	6.90	1.5	1	1.5	1	1.5	0.67	7	13	III	Fair
250	65	10.5	6.19	1.5	1	1.5	1	1	1.00	9	15	III	Fair
427	72.5	9	8.06	1	1	1	1	1	1.00	8	13	III	Fair
499	70	9	7.78	1	1	1	1	1	1.00	8	14	III	Fair
526	77.5	9	8.61	1	1	1	1	1	1.00	9	11	III	Fair
665	65	9	7.22	1	1	1	1	1	1.00	7	15	III	Fair
2720	57.5	9	6.39	1.5	1	1.5	1	1	1.00	10	17	III	Fair
2778	47.5	15	3.17	1.5	1	1.5	1	1	1.00	5	20	III	Fair
2827	47.5	10.5	4.52	1	1	1	1	1	1.00	5	20	III	Fair
2849	70	10.5	6.67	1.5	1	1.5	1	1	1.00	10	14	II	Good
2918	67.5	10.5	6.43	1.5	1	1.5	1	1	1.00	10	14	III	Fair
2972	62.5	9	6.94	1.5	1	1.5	1	1.25	0.80	8	16	III	Fair
2998	55	12	4.58	1	1	1	0.66	1	0.66	3	18	IV	Poor
3385	57.5	9	6.39	1.5	1	1.5	1	1	1.00	10	17	III	Fair
3396	52.5	9	5.83	1.5	1	1.5	1	1	1.00	9	19	III	Fair
3519	72.5	12	6.04	1.5	1	1.5	1	1	1.00	9	13	III	Fair
3536	67.5	10.5	6.43	1.5	1	1.5	1	1	1.00	10	14	III	Fair
4014	67.5	10.5	6.43	1.5	1	1.5	1	1	1.00	10	14	III	Fair
4024	60	9	6.67	1	1	1	1	1	1.00	7	17	III	Fair
4039	60	9	6.67	1	1	1	1	2.5	0.40	3	17	IV	Poor
4075	62.5	9	6.94	1	1	1	1	1	1.00	7	16	III	Fair
4093	67.5	9	7.50	1	1	1	1	1	1.00	8	14	III	Fair
4114	67.5	6	11.25	1	1	1	1	1	1.00	11	17	IV	Good
4178	60	9	6.67	1	1	1	1	2.5	0.40	3	17	IV	Poor
4276	65	9	7.22	1.5	1	1.5	1	1.25	0.80	9	15	III	Fair
4441	67.5	10.5	6.43	1.5	1	1.5	1	1	1.00	10	14	III	Fair
4468	67.5	6	11.25	1.5	1	1.5	0.66	1.5	0.44	7	14	III	Fair
4472	60	9	6.67	1.5	1	1.5	0.5	1.5	0.33	3	17	IV	Poor
4476	60	9	6.67	1.5	1	1.5	0.5	1.5	0.33	3	17	IV	Poor
4479	57.5	6	9.58	1.5	1	1.5	0.5	1	0.50	7	17	III	Fair
4734	70	9	7.78	1	1	1	1	1.25	0.80	6	14	III	Fair
5229	75	9	8.33	1.5	1	1.5	1	1.5	0.67	8	12	III	Fair
5460	60	12	5.00	1	1	1	1	1.25	0.80	4	17	III	Fair
5463	60	15	4.00	1	1	1	0.66	1.5	0.44	2	17	IV	Poor
5475	75	9	8.33	1	1	1	1	1	1.00	8	12	III	Fair
5766	82.5	6	13.75	1.5	1	1.5	1	2	0.50	10	10	III	Fair
5928	82.5	4	20.63	1	1	1	1	2.5	0.40	8	10	III	Fair
5941	80	4	20.00	1	1	1	1	2.5	0.40	8	11	III	Fair
6059	87.5	6	14.58	1	1	1	1	1.5	0.67	10	8	III	Fair
6161	82.5	9	9.17	1	1	1	1	1	1.00	9	10	III	Good
6194	75	9	8.33	1	1	1	1	1	1.00	8	12	III	Fair
6541	77.5	9	8.61	1.5	1	1.5	1	1.5	0.67	9	11	III	Fair
6588	70	10.5	6.67	1	1	1	1	1.25	0.80	5	14	III	Fair
6596	65	12	5.42	1	1	1	1	1.25	0.80	4	15	III	Fair
6644	77.5	12	6.46	1.5	1	1.5	1	1.25	0.80	8	11	III	Fair
6667	80	10.5	7.62	1.5	1	1.5	1	2	0.50	6	11	III	Fair
6694	70	12	5.83	2	1	2	1	2.5	0.40	5	14	III	Fair
6730	70	12	5.83	2	1	2	1	2	0.50	6	14	III	Fair
6775	90	9	10.00	1.5	1	1.5	1	2.5	0.40	6	8	III	Fair
6801	75	10.5	7.14	1.5	1	1.5	1	2.5	0.40	4	12	III	Fair
6840	65	13.5	4.81	2	1	2	1	2	0.50	5	15	III	Fair
6848	77.5	13.5	5.74	1.5	1	1.5	1	1	1.00	9	11	III	Fair
6853	77.5	13.5	5.74	1.5	1	1.5	1	1	1.00	9	11	III	Fair
6867	72.5	13.5	5.37	2	1	2	1	2.5	0.40	4	13	III	Fair
6873	75	10.5	7.14	2	1	2	1	2.5	0.40	6	12	III	Fair
6877	75	10.5	7.14	2	1	2	1	2.5	0.40	6	12	III	Fair
6888	77.5	10.5	7.38	1.5	1	1.5	1	2.5	0.40	4	11	III	Fair
6891	77.5	10.5	7.38	1.5	1	1.5	1	2.5	0.40	4	11	III	Fair
6897	80	9	8.89	1.5	1	1.5	1	2.5	0.40	5	11	III	Fair
6903	87.5	9	9.72	1.5	1	1.5	1	2	0.50	7	8	III	Fair
6914	90	9	10.00	1.5	1	1.5	1	2.5	0.40	6	8	III	Fair
6967	82.5	10.5	7.86	1.5	1	1.5	1	1.25	0.80	9	10	III	Fair
6971	82.5	10.5	7.86	1.5	1	1.5	1	1.25	0.80	9	10	III	Fair
6991	67.5	12	5.63	1.5	1	1.5	1	1	1.00	8	14	III	Fair
6998	55	10.5	5.24	2	1	2	1	2.5	0.40	4	18	III	Fair
7004	60	9	6.67	2	1	2	1	2.5	0.40	5	17	III	Fair
7010	57.5	10.5	5.48	2	1	2	1	2.5	0.40	4	17	III	Fair
7013	67.5	9	7.50	2	1	2	1	2.5	0.40	6	14	III	Fair
7022	87.5	10.5	8.33	1.5	2	0.75	1	1	1.00	6	8	III	Fair
7034	72.5	9	8.06	1.5	2	0.75	1	1	1.00	6	13	III	Fair
7041	87.5	9	9.72	1.5	1	1.5	1	1	1.00	15	8	II	Good
7121	90	9	10.00	1.5	1	1.5	1	1	1.00	15	8	II	Good

2776M, 3200M and 4170M, due to the rock mass class being Poor (Class IV) to Fair (Class III)as Q-value was low, between 3 to 8. Load cells showed the following trend.

Chainage 2776M

At this location, the average load was between 5.6 and 6.0 tons for two months. This shows that the load levels are constant with time (SAND 95-1675, 1995).

Chainage 4170M

At this location also, the average load was between 5.6 and 6.0 tons for two months indicating that the load levels are constant with time (SAND95-1675, 1995).

Chainage 3200M

At this location, the average load was between 5.0 and 5.6 tons for two months. This again shows that the load levels are constant with time (SAND 95-1675, 1995).

Interpretation of MPBX Data

7-M anchor showed nearly stable displacement values of <0.05MM over a period of about two months with initial negative displacement signifying movement of rock into the excavation.10-M anchor showed nearly stable displacement values of ~0.06MM over a period of about two months. 4-M anchor showed a positive displacement of ~0.16MM over a period of nearly 55 days. The closure rates are significantly low (SAND 95-1675, 1995).

Interpretation of SPBX Data

Single Point Borehole Extensometer anchor showed a displacement of 0.32 to 0.35 MM over a period of one month indicating significantly low closure rates (SAND 95-1675, 1995).

Conclusions

Geological mapping along alignment indicated a fault intersection at Chainage 4.2KM and stream crossing at Chainage 5.4KM along a fault along with four fracture zones between Chainages 2690 to 3250M. Geological adversities identified were Chainage 2770 M to 2827M with Q-value between 5 to 6, Chainages 3200M to 3220M, 3490M to 3560M, 4160M to 4190M with Q-value of 3, Chainage 4472M to 4477M with Q-value between 3 to 7 and Chainage 5440M to 5470M with Q-value of 2.

The primary supports installed in these zones were shotcrete 100 MM thick and pattern rock bolts 4M long fully grouted with the exception of Chainage 5440M to 5470M were Steel Ribs with backfill concrete was provided. The other adverse zones were instrumentally monitored for displacement and closure of the tunnel.

The instrumentation data showed that the tunnel closure was significantly low, indicating the absence of any significant ground deformation. The excavation had become stable with the already provided primary supports.

Authors' Contributions

Ramakrishna, D. : Investigation, Conceptualization, Methodology, Writing - Original Draft, Formal Analysis. **Rajeshwara Rao, N.:** Supervision, Reviewing and Editing

Conflict of Interest

The authors declare that they have no conflict of interest.

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