Geological analysis of tunnel excavations in AA Flow from Deccan trap basalt

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Abstract

A D-shaped transportation tunnel with a height of 9 m and width 5.5 m using drilling and blasting technique is under construction near Gulbarga, in the state of Karnataka. It is being excavated in \`A\`Ā flows of Deccan trap basalt in which, a columnar jointed compact basalt (CJCB) from the dense and jointed core (DJC) portion of \`A\`Ā flow-1, occupying crown and walls, followed by ~ 4 m thick volcanic breccia (VB) of lower \`A\`Ā flow-2 occupying walls and invert has been observed. CJCB is impervious with high compressive strength and has vertical, persistent columnar joints whereas VB is weak, pervious, slaking with impersistent, random joints. Crown instability due to CJCB as well as wall, invert instability and over excavation in VB are important problems faced in the exposed portion of the tunnel. It is a sort of mixed face tunneling condition with high strength CJCB is underlain by low strength VB. After detailed investigation, lining of VB and spot bolting of CJCB has been suggested for the exposed length of the tunnel.

Key words: Deccan Trap Basalt, \`A\`Ā Flow, Tunnel

1. Introduction:

Decisive aspects of the feasibility of underground excavations are stability, designed shape, construction time and cost. These parameters are directly dependent on geological conditions. Underground excavations i.e. tunnels, powerhouses etc. carved in Deccan Trap Basalt (DTB) are also governed by these decisive factors (Gupte et al, 1980; Gupta et al., 2011; Jain et al., 2014, 2015, 2016). Basalts have high strength; low porosity and permeability, but variation in number, attitude, persistence etc. of cooling and other joints, differential degenerative/disintegrative weathering and as well as the relation of alignment with the morphological components of these basalt flows are important parameters responsible for the problems faced during tunnelling in this area. The main objective of this paper is to understand engineering behaviour of \`A\`Ā flows and their morphological components inside the tunnel and provide a reasonable solution to these problems. The Gulbarga tunnel case study has been discussed in the present work. The problems encountered during the excavation phase of this tunnel have been resolved integrating preliminary geological investigation data, geological mapping as well as rock mass characterization of the exposed portions. Studies include, correlation of preliminary geological investigation (Noble, 2012), engineering geological mapping of exposed portion of the tunnel (Joshi et al., 2014a; Joshi et al., 2014b) , stereo analysis of joints encountered at 3 m interval in the crown section, Rock Mass Characterization and provision of support system for exposed portion of the tunnel using Q System Handbook (NGI, 2015).

2. Geology of Deccan Trap Basalt (DTB):

The Deccan Trap Basalt (DTB) occupies western and central part of India (Figure 1). It is one of the remarkable Continental Flood Basalt (CFB) provinces in the world. DTB covers more than 500,000 km^2 area in western and central India. Presently, it occupies more than 85% area of State of Maharashtra and parts of Gujarat, Madhya Pradesh, Karnataka, and Andhra Pradesh. On the basis of lithology, stratigraphy of the Western DTB has been given by Godbole et al(1996) whereas Beane et al(1986), Jay et al(2008) have given on the basis of geochemical mapping. In the present work, scheme given by Godbole et al(1996) has been followed and is shown in Table-1.

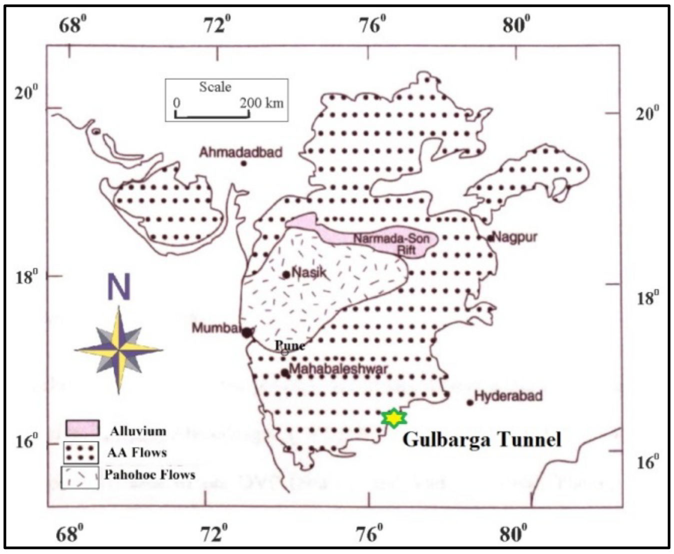

Figure 1 Geological map of Deccan Trap Basalt with Location of Tunnel (Deshmukh, 1988), (Reproduced with permission from Geological Society of India, Bengaluru)

2.1 Flow Morphology in DTB:

The lava flows of DTB are classified on the basis of their physical morphology, such as Pāhoehoe and `A`Ā lava flow. Pāhoehoe flow composed of three distinct flow units such as basal zone, lava core and lava crust(Self et al., 1998), whereas `A`Ā flow (Figure2) show brecciated top and bottom (formed due to rolling over of fragments during the process of movement of flow) and jointed dense core(Macdonald, 1953). The crust of `A`Ā has a variable thickness of 1 to 5 meter of rolled over fragments and is developed in the top (fragmentary top i.e. FT) as well as bottom portions of the lava flow (fragmentary bottom i.e. FB). The size of the fragments varies from few mm to few meters in diameter. The fragments which are forming a thin crust are commonly known as volcanic breccia (VB). Top of flow is generally marked with variable thickness VB and may have tachylitic bands etc. (Macdonald 1953), (Kshirsagar,1982). This zone has been referred as inter-flow horizons(Bodas et al, 2009). According to Lyle (2000), these `A`Ā flows show multitier columnar jointing and the orientation of these joints changes giving rise to fanning columns in the outcrop. These aphinitic columnar basalts are referred in the present work as columnar jointed compact basalt (CJCB). These columns also show hackly joints, followed by 1-2 m zone of platy joints. These platy joints are underlained by the fragmented bottom. The typical flow morphology is shown in the Figure 2. Recently, Sheth et al., (2011), (2017) have renamed flow top breccia as recycled breccia from few localities in DTB.

Table 1 Compilation of Stratigraphic Schemes for Deccan Volcanic Province as Lithostratigraphic Scheme Godbole et al (1996) and Chemostragraphic Scheme (Beane et al., 1986) for DTB

Lithostratigraphy Godbole et al (1996)		**Dominant Flow Type**	**Chemostratigraphy(Beane et al., 1986)**	
Subgroup	**Formation**		**Subgroup**	**Formation**
Wai	Mahabaleshwar (400 m)	′A′ā flows	**Wai**	Desur
				Panhala
				Mahabaleshwar
	Purandargad (525 m)	-- GPB -- ′A′ā flows		Ambenali
	Diveghat (375 m)	′A′ā flows		Poladpur
Lonavala	Karla (450 m)	Pahoehoe	**Lonavala**	Bushe
	Indrayani (250 m)	′A′ā flows		Khandala
Kalsubai	Ratangad (*with intercalated GPBs*) (1050 m)	-- GPB – ′A′ā flows -- GPB -- pahoehoe -- GPB -- Mixed -- GPB – pahoehoe	**Kalsubai**	-- 2 GPB Units -- Bhimashankar
				------ GPB ------ Thakurwadi
				------ GPB ------ Neral
				------ GPB ------ Igatpuri
	Salher(>350 m)	-- GPB -- pahoehoe		------ GPB ------ Jawhar

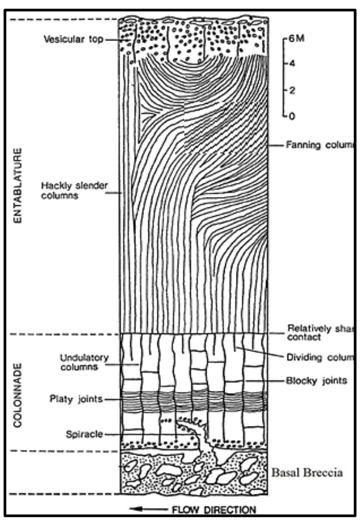

Figure 2 Typical Flow Morphology of `A`Ā flows, modified after Lyle (2000)

2.2 Geology of the Gulbarga Area:

The study area lies in the SE part of mainland DTB (Figure 1) showing laterite-capped hills above 610 ±10 m RL. These caps are underlain by a number of `A`Ā flows. Detail geomorphology and geology of the tunnel area has been discussed as follows.

2.2.1 Geomorphology of Gulbarga Area:

The area is characterized by gently undulating topography with broad valleys trending NE-SW. All minor streams originating from and south of the area join the south-easterly flowing Kagna River which in turn meets Bhīma River further south-east. The northerly stream forms a dendritic pattern and is a part of Manira River flowing in NW. The tunnel passes through a drainage divide of Kagna and Manira rivers. Physiographically, the area can be divided into two regions as northern and southern low lands with a Bidar plateau (with elevation 640 to 690 m) in between which is made up of laterite. The altitudes vary between 420 to 684 m above MSL. A terraced landscape with flat-topped hills been seen in the area. Average rainfall recorded is 550 to 650 mm in the area. The climate of the area is generally dry throughout the year.

2.2.2 Geology of Tunnel:

The tunnel passes through 2 different `A`Ā lava flows separated by volcanic breccia of variable thickness. At the Northern portal, this tunnel is passing through a junction of two lava flows. Crown of the tunnel forms a part of dense and jointed core portion (CJCB) of an `A`Ā flow -2 and invert is in the volcanic breccia of a top of `A`Ā flow -1(Table: 2). According to Godbole et al (1996), these flows forms a part of Mahabaleshwar Formation. Figure 3 show the geological map of the tunnel area showing three different flows, and Figure 4 show the cross section along an alignment of the tunnel. Tunnel lies about 100 km south of seismically active Killari (Latur District, Maharashtra) area. However, seismicity has not been recorded in the immediate vicinity of the project. According to IS:1893(Part-1), (2002), Gulbarga – Bidar area lies on the border of Seismic Region II and III indicating moderate seismic risk

Table 2 Lithostratigraphy of the Gulbarga tunnel

Formation	Unit	Zone of the flow	Lithology	Thickness in m	RL in m
Mahabaleshwar	`A`Ā flow -2	Dense and Jointed Core	Columnar Jointed Compact Basalt (CJCB)	5—7	584 to 575
	`A`Ā flow -1	Interflow Horizon	Volcanic Breccia (VB)/ FTB (FTB)	1—5	575 to 570

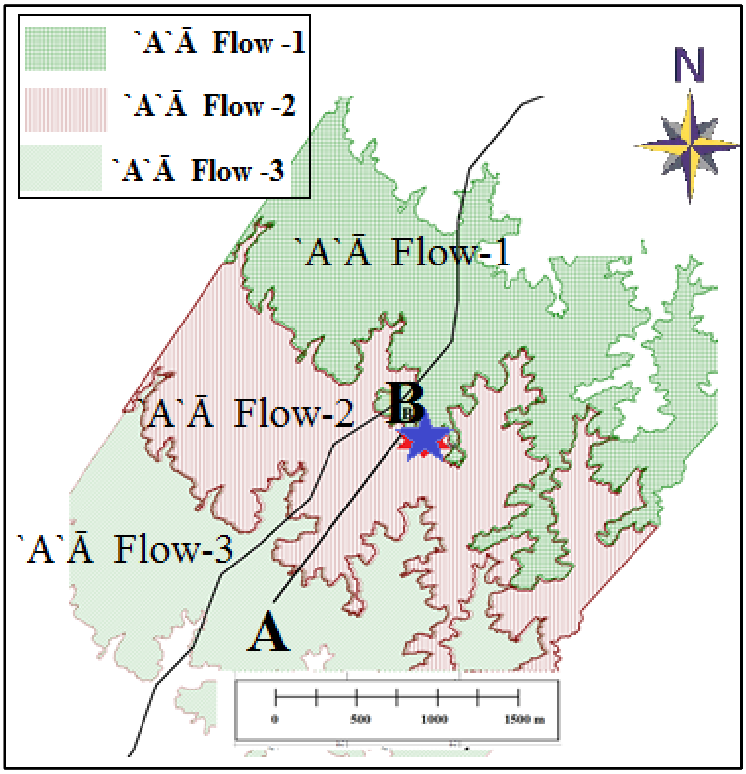

Figure 3 Geological Map of Gulbarga Tunnel Area

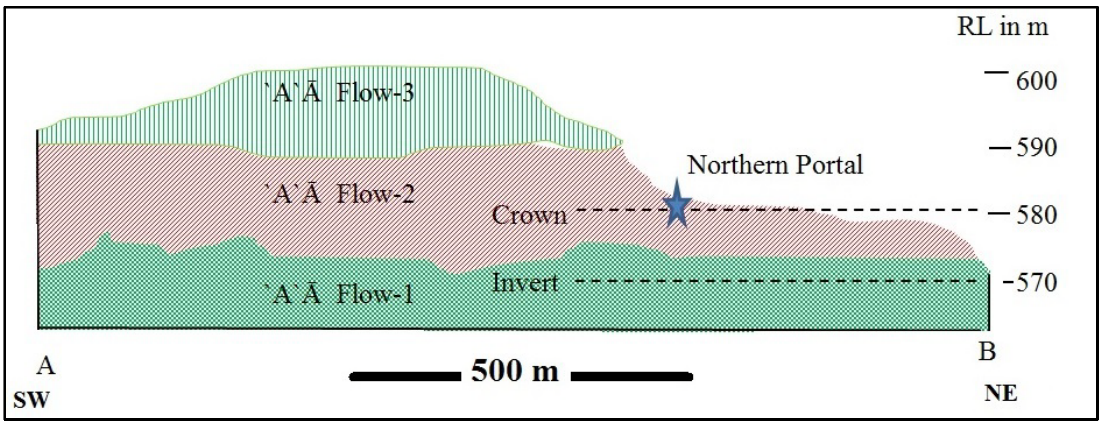

Figure 4 Cross Section along A-B of Gulbarga Tunnel Area

3. Engineering Geologic Factors Influencing Engineering Structures:

The occurrence of thick and weak deteriorating volcanic breccia in the wall and invert is causing wall collapses and excessive excavation in the invert leading to variation in pay line is an important engineering geological problem faced during the excavation. Another problem faced is due to fanned columnar joints from the dense and jointed core (CJCB) along the length of the tunnel leading to portal and roof collapses. To resolve these engineering geological problems, a systematic study which included evaluation of preliminary geological investigation data, high-resolution geological mapping of the exposed portion of the tunnel and application of rock mass characterisation method to provide the supports has been carried out. This methodology is based on the guidelines for Deccan Basalt Flow Mapping, (Bodas et al, 2009), and evaluation of support systems in the tunnel using Q method (NGI, 2015). Along with this, guidelines given by relevant IS codes have been followed e.g. IS:7422(Part-II), (2004),- to describe rocks in the field, IS:4464(2004)- to describe weathering and Uniaxial Compressive Strength (UCS) in kg/cm^2 in field conditions and IS:11315(Part-1-10) to evaluate various joint parameters as well as IS:13365(Part-2), (1996) and IS:13365(Part-1), (1998) to evaluate Rock Mass Rating (RMR) and Q system respectively, have been used to evaluate field parameters.

3.1 Preliminary Geological Investigation:

Noble (2012) have drilled 9 boreholes along the alignment of the tunnel. Out of these 9 boreholes, BH-4 and BH-5, which are at Ch. 58560 and 58730 m respectively, are considered for evaluation for present work. Figure 5 shows correlation for BH-4 and BH-5 along the alignment using the data collected during the borehole investigation (Noble, 2012). In BH-4, from 594 to 591 m RL, the black cotton soil is recorded. It is followed by thick, jointed fresh compact basalt (CJCB). This compact basalt followed by volcanic breccia from 572.6 to 568 m RL. Below 568 till the end of the borehole 4, i.e. up to 562.9 m CJCB is present. In BH-5, from 600 m RL to 599 m RL, the black cotton soil is present. It is followed by thick, jointed fresh compact basalt (CJCB) up to 569 m RL. Volcanic Breccia (VB) is present from 569 to 566 m RL and followed by compact basalt (CJCB) up to 562 m RL where BH-5 is terminated. The joints in CJCB are either vertical / steeply inclined cutting the core at more than 60°. In VB natural joints are not recorded in BH-5. All joints recorded in VB in BH-5 indicate that these are mechanical joints. In BH-4 core recovery is very low in VB. All pieces are loose and but do not show any natural joints.

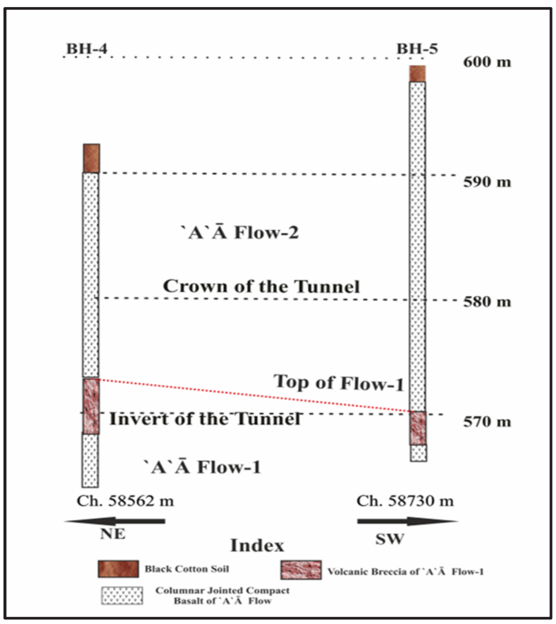

Figure 5 Correlation between BH-4 and BH-5 along the alignment of the Gulbarga Tunnel, Based on Noble (2012)

3.2 Analysis of Laboratory Results:

Table: 3 (a) and (b) shows morphology, lithology evaluated by the authors and laboratory tests carried out by Noble Geostruct, Mumbai in 2012. For various laboratory tests, (Fig 6 a-f) data from BH-4 and 5 has been considered whereas for deformation modulus and water permeability tests data for BH-3, 5, 6 and 7 have been considered. Based on this data, Figs: 6 (a) to (f) were plotted showing variations in parameters measured in Laboratory for samples collected during the investigation.

3.2.1 Variation of RQD Percentage: The plot of RQD% Vs Depth is given in Fig 6 (a). In BH-4, from 590 to 575 m RL, RQD % varies from 57 to 81% i.e. fair to good quality rock with maximum 8 joints per running meter (IS:4464, 2004) within the borehole. This depth of the borehole is drilled in CJCB. In VB in BH-4, value of RQD% has been reported between 0 to 35% indicating more than 15 joints per running meter are present in the borehole. In BH-5, RQD% varies with depth from 0 to 96 %. In the CJCB section, RQD% varies from 20-96% indicating poor to excellent quality of rock (IS:4464, 2004) whereas in VB, RQD% varies from 66 to 96% indicating good to excellent quality rock with number of joints per running meter less than 8.

3.2.2 Variation of Uniaxial Compressive Strength in kg/cm^2: In CJCB, UCS varies from 1254 to 2509 kg/cm^2 indicating strong to very strong rock in both the boreholes. Sample tested from BH-4, for VB shows UCS from 78 to 157 kg/cm^2 i.e. weak to moderately weak rock. (IS:4464, 2004). In BH-5, UCS values for VB vary from 314 to 392 implying a moderately strong rock. The plot of UCS in kg/cm^2 Vs Depth is shown in Fig 6 (b).

3.2.3 Variation of Slake Durability: Fig 6(c) shows plot of slake durability percentage Vs depth in m. CJCB samples show slaking % up to 12% whereas VB samples show variation as high as 41% in BH-4 and BH-5. According to IS:10050, (1981) CJCB shows very low slaking and VB shows medium slaking.

3.2.4 Variation of Point Load Index (MPa): Point load strength in BH-4 shows variation from 2.14 to 9 MPa for CJCB and for VB it is 0.18 to 0.71 MPa. In BH-5, for CJCB, the value of point load index varies in between 8 to 10 and for VB, it is between 1.4 to 1.8 MPa (IS:8764, 2008). Fig 6 (d) shows the plot of Point Load Index in MPa Vs Depth in m.

3.2.5 Variation in Deformation Modulus Values in MPa: Fig 6(e) shows the plot of Deformation Modulus Versus Depth in BH-3, 5, 6 and 7 boreholes. Deformation modulus test was carried for 14 samples. Modulus of deformation (IS:9221, 2001) has been found to be varying for VB and CJCB. For CJCB, values are in the range of 6000 to 10000 MPa and for VB values are in the range of 10 to 2000 MPa. Fig 6(e) shows plot of Deformation Modulus Versus Depth in these boreholes.

3.2.6 Variation in Permeability Values: 17 Pressure meter tests were carried out in BH-3, 5, 6 and 7(IS:5529 (Part-2), 2006). These tests show permeability in the range of 4 to 8 lugeon in the tunnel section. Fig 6(f) shows the plot of pressure meter tests for these boreholes.

Table 3(a) Details of BH-4 including Flow morphology, Laboratory tests (Noble, 2012)

Depth in RL m*	Flow**	Morphological Unit of the Basalt Flow**	Lithology**	RQD %*	Piece No.*	Density (g/cc)*	Water Absorption (%)*	Porosity (%)*	Slake Durability (%)*	UCS(kg/cm2)*
594.06	--	--	soil	0	--	--	--	--	--	--
591.46	\`A\`Ā Flow-2	DJC	CJCB	0	--	--	--	--	--	--
590.56				61	--	--	--	--	--	--
589.06				87	--	--	--	--	--	--
587.56				79	40	2.81	0.2	0.71	--	1568
586.06				85	--	--	--	--	--	--
584.56				71	46	2.84	0.26	0.7	--	1725
					47	2.89	0.19	0.69	8	1960
583.06				77	53	2.82	0.19	0.7	--	1647
					54	2.79	0.18	0.71	15	1411
581.56				78	61	2.86	0.21	0.69	--	1803
					65	2.8	0.26	0.71	--	1568
					66	2.77	0.19	0.72	17	1490
					67	2.91	0.2	0.34	--	2117
					69	2.75	0.3	1.08	--	1254
580.06				71	71	2.74	0.21	1.08	--	1411
					73	2.8	0.24	1.06	29	1647
					75	2.83	0.29	0.7	--	1725
578.56				57	79	2.85	0.26	1.04	--	1882
					85	2.91	0.13	0.68	--	2039
577.06				85	89	2.8	0.18	0.71	31	1568
					93	2.76	0.13	1.08	--	1490
575.56				73	101	2.92	0.28	0.68	--	2039
574.06				39	103	2.77	0.21	1.07	--	1490
					111	2.33	0.37	1.49	--	135
					112	2.31	0.99	1.28	--	120
572.56	\`A\`Ā Flow-1	FT	VB	10	121	2.07	1.92	1.43	--	78
571.06				10	124	2.17	1.81	1.81	--	157
					125	2.17	1.85	1.36	--	157
569.56				0	--	--	--	--	--	--
568.56		DJC	CJCB	46	146	2.01	1.99	1.47	--	39
567.06				30	149	2.64	0.67	1.12	49	549
565.56				65	166	2.63	0.71	0.75	--	627
					168	2.61	0.59	0.76	--	549
					170	2.65	0.57	1.12	--	470
					172	2.62	0.51	1.13	38	627
564.06				63	179	2.64	0.66	0.75	--	706

Table 3(b) Details of BH-5 including Flow morphology, Laboratory tests (Noble, 2012)

Depth in RL meter From*	Flow**	Morphological Unit of the Basalt Flow**	Lithology**	RQD %*	Piece No.*	Density (g/cc)*	Water Absorption (%)*	Porosity (%)*	Slake Durability (%)*	UCS(kg/cm2)*
594.06	--	--	soil	0	--	--	--	--	--	--
591.46	\`A\`Ā Flow-2	DJC	CJCB	0	--	--	--	--	--	--
590.56				61	--	--	--	--	--	--
589.06				87	--	--	--	--	--	--
587.56				79	40	2.81	0.2	0.71	--	1568
586.06				85	--	--	--	--	--	--
584.56				71	46	2.84	0.26	0.7	--	1725
					47	2.89	0.19	0.69	8	1960
583.06				77	53	2.82	0.19	0.7	--	1647
					54	2.79	0.18	0.71	15	1411
581.56				78	61	2.86	0.21	0.69	--	1803
					65	2.8	0.26	0.71	--	1568
					66	2.77	0.19	0.72	17	1490
					67	2.91	0.2	0.34	--	2117
					69	2.75	0.3	1.08	--	1254
580.06				71	71	2.74	0.21	1.08	--	1411
					73	2.8	0.24	1.06	29	1647
					75	2.83	0.29	0.7	--	1725
578.56				57	79	2.85	0.26	1.04	--	1882
					85	2.91	0.13	0.68	--	2039
577.06				85	89	2.8	0.18	0.71	31	1568
					93	2.76	0.13	1.08	--	1490
575.56				73	101	2.92	0.28	0.68	--	2039
574.06				39	103	2.77	0.21	1.07	--	1490
					111	2.33	0.37	1.49	--	135
					112	2.31	0.99	1.28	--	120
572.56	\`A\`Ā Flow-1	FT	VB	10	121	2.07	1.92	1.43	--	78
571.06				10	124	2.17	1.81	1.81	--	157
					125	2.17	1.85	1.36	--	157
569.56				0	--	--	--	--	--	--
568.56		DJC	CJCB	46	146	2.01	1.99	1.47	--	39
567.06				30	149	2.64	0.67	1.12	49	549
565.56				65	166	2.63	0.71	0.75	--	627
					168	2.61	0.59	0.76	--	549
					170	2.65	0.57	1.12	--	470
					172	2.62	0.51	1.13	38	627
564.06				63	179	2.64	0.66	0.75	--	706

*: Carried out by(Noble, 2012) **:Reported by the authors

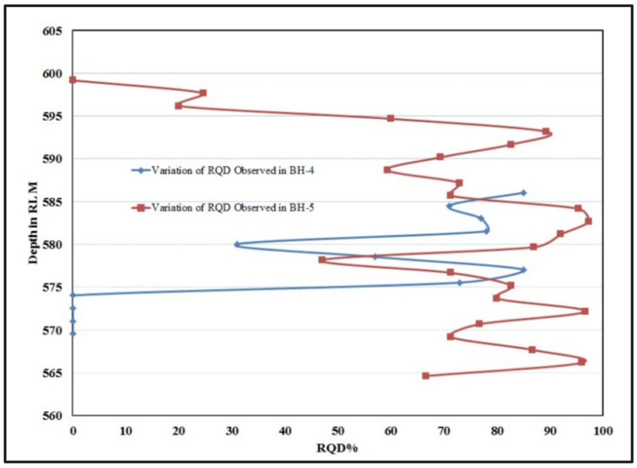

Figure 6 (a) Variation in RQD percentage for BH-4 and 5

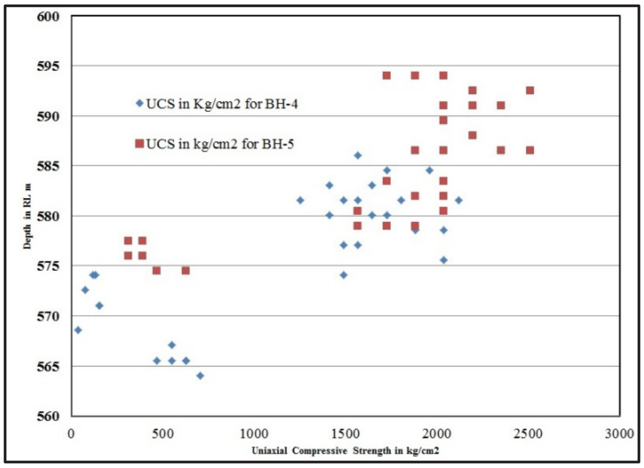

Figure 7 (b) Uniaxial Compressive Strength (UCS) in kg/cm^2 for BH-4 and 5 Samples

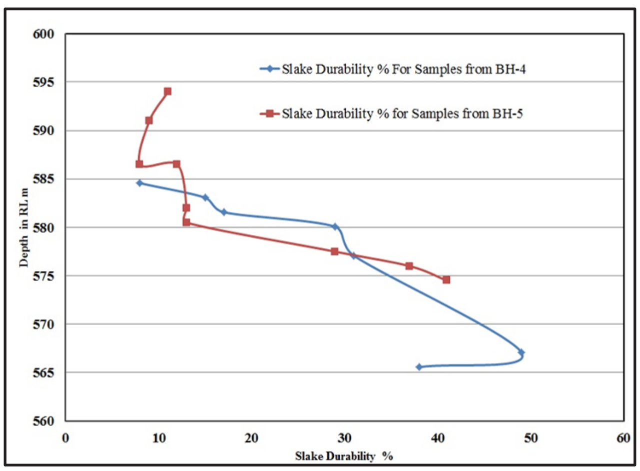

Figure 8 (c) Slake Durability Test for BH-4 and 5 Samples

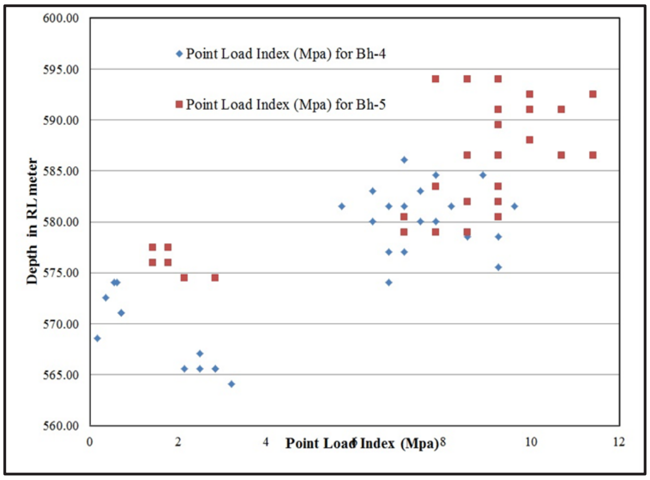

Figure 9 (d) Point Load Index (MPa) Test for BH-4 and 5 Samples

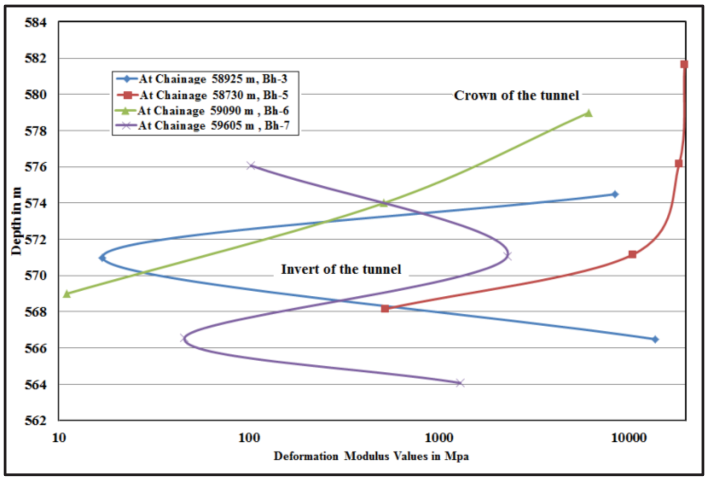

Figure 10 (e) Deformation Modulus (MPa) Test for BH-3, 5, 6 and 7 Samples

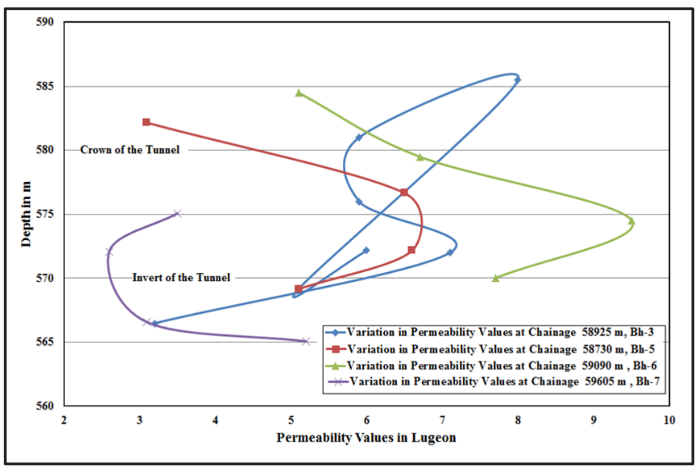

Figure 11 (f) Permeability Test for BH-3, 5, 6 and 7

3.3 Geological Mapping of Tunnel:

A tunnel log sheet was prepared to generate geological map of the tunnel with a grid of 20 cm X 20 cm, including left and right wall as well as the crown. This grid was chosen to give due weightage to changing pattern of joint orientation (as evident from Figure 7 and 8). This mapping included recognition of various zones of the flow (FT/ Central dense/FB), lithology, weathering condition of rock, information relevant to joints such as orientation, spacing, sets, persistence, weathering and ground water inflow. Photographs of exposures at 20m interval are given in Fig. 8 and 9. Figure 8(a-f) shows exposures along the left wall and Figure 9(a-f) shows exposures along crown of the tunnel. The detail geological map has been prepared using this method and is presented here in the Figure.

At the Northern portal, exposure of CJCB followed by VB has been observed. This CJCB is forming the dense core middle lower portion of an `A`Ā flow -2 and VB belong to the top fragmented (FT) portion of the `A`Ā flow -1. (Table: 2). CJCB is jointed with persistent joints along the portal face of the tunnel and shows 80°/110°, 85°/230° and 70°/310° as three joint. VB section present in the lower half of the portal does not show any persistent joint and it appears to be of low strength or fragile with pronounced weathering observed in the hand specimen. The exposed face of the tunnel is dry without any seepage. Fig. 7(a) shows the front view of a Northern portal with various levels and rock type encountered at these levels. Fig. 7(b) shows the occurrence of CJCB and VB at Left-hand wall and Fig. 7(c) shows CJCB and VB at Right-hand wall of the portal

Figure 8 (a-f) shows exposures along the left wall and Figure 9 (a-f) shows exposures along the crown of the tunnel. Dense, jointed core (DJC), and Fragmented Top (FT), are two important morphologies of `A`Ā flow observed in the tunnel. Rock in DJC is identified as columnar jointed compact basalt (CJCB) and the one from FT is volcanic breccia (VB). DJC exhibits sub-vertical columnar joints and few random joints with varying attitude. CJCB occupies part of the walls and crown i.e. from 574 m to 570 m and VB from 574 (Wall) to 570 m (invert). This is in conformity with results of BH-4. CJCB is greyish black in colour and aphinitic in nature with absence of vesicles and jointed (78°/110°, 25°/35°, 72°/230° and 30°/325°). Thin section prepared for selected sample from this rock shows (Figure 11 (a-d)) glomeroporphyritic texture with fresh unaltered plagioclase laths, pyroxene crystals and isotropic iron oxide grains are abundant. Overall rock is fresh. (IS:4464, 2004) and shows slight alteration along the joint walls. Intersecting joints are also seen (Figure 9(a), (b), (c), (d)). Prominent joints show medium persistence i.e. up to 10m, rough,-planar, and free of any clay coating and have an aperture ≤1 mm. The spacing of the joints is 400- 600 mm. Occasional zeolitization observed along joint planes but these surfaces are fresh in condition (IS:4464, 2004). The joints observed in the tunnel portion in CJCB exhibit a typical columnar arrangement and have irregular polygonal shape. Centre to center distance of polygon varies from 300 mm to 500 mm. These polygons show a median along 5°/N40°. The lower portion of CJCB shows platy joints, 4-6 in numbers with 100 to 150 mm spacing, along with the sub-vertical columns. Due to change in the attitude of columnar joints and presence of additional few random joints, irregular blocks in the crown section (Figure 9 (a-f).) are developed.

Another morphology is that of fragmented top (FT) with lithology as volcanic breccia. It has various angular –subangular fragments of various sizes, caught up in the lava matrix. These rocks have suffered degenerative/disintegrative weathering which has reduced their strength. (Figure 6b). In the Borehole studies, from 574 m to 568 m, volcanic breccia was encountered and has low UCS and high slaking. Thin section petrography of selected samples (MRG_VB_1 and 2) from VB show (Figure 11(a-d)), decomposed plagioclase feldspar phenocrysts with dissolution pits in abundance indicating weathering grade III to IV (IS:4464, (2004)). More than 50% of the plagioclase grain is observed to be altered.

3.4 Stereoplot of Joints observed in the crown

In the exposed section, total 328 joints were recorded. These joints are plotted on the stereo net for every running meter for the exposed section and their representative plots (Every 10 m) are presented. Direction 70°/N230° is observed to be prominent from portal to 58550 m as observed in Fig. 13 (a-e). From 58570 to 58612 the joint 74°/N107° becomes prominent which is seen in Fig. 13(f to i). This has helped to understand the behaviour of joints and their influence on tunnel alignment. At portal (Figure 13-a), an unfavorable wedge has been formed due to the intersection of more than three different joints and tunnel alignment. Along the alignment, an intersection of joints, forming a wedge at 58528 (Figure 13-a), 58560 (Figure 13-e), 58570 (Figure 13-f), 58574, 58580 (Figure 13-g), 58592 (Figure 13-h), 58595, 58610 m (Figure 13-j), leading to instability in the crown of the tunnel.

3.5 Rock Mass Characterization (RMC) of Exposed Portion of Tunnel:

RMC is an important aspect of any rock type as it gives some understanding to the end user. Parameters such as RQD%, joint parameters, UCS in kg/cm^2 are important from the evaluation point of view. In the present work, UCS values measured from BH-4 and BH-5 are taken as representative values, joint parameters were evaluated using various methods suggested by (IS:11315(Part-1-10), 1995). For every meter, RQD% has been determined for CJCB and VB separately. Along with this, the average spacing of joints is 200-600 mm indicating average RQD% value ranges between 90 to 95% in the entire CJCB. For VB, RQD % is considered as around 60%. Even though, VB is relatively joint free with very few occasional and impersistent joints, since, NGI(2015), suggests that for softer rocks such as VB, RQD value should be reasonably low.

3.5.1 Evaluation of RMR and Q value

To understand the stability of the portal and suitable measures, RMR and Q values were evaluated as per the procedures are given in IS (IS:13365(Part-1), 1998; IS:13365(Part-2), 1996) as well as Q method handbook (NGI, 2015). CJCB and VB show sufficient thickness from 58528 to 58573 m chainages, hence, these rocks are evaluated separately. Table 4(a) and 4(b) summarizes field observations and evaluation of RMR and Q value for VB section (walls). Table 4(c) and 4(d) specifies field observation and evaluation of RMR and Q value for CJCB (walls and crown). VB is not exposed from CH. 58573 to 58612.

For VB, Value of RMR is 32 i.e. Class IV POOR ROCK for all locations and Q value varies between 2- 4 indicating poor to fair rock and For CJCB, value of RMR ranges from 67-72 i.e. Class I: Good to Very Good rock. The unsupported stand up time calculated using the chart provided in the RMR system, for present tunnel is about 1 year. Q is high around 22 with De is >3 and ESR is 1.0 for portals and 1.3 for tunnel section.

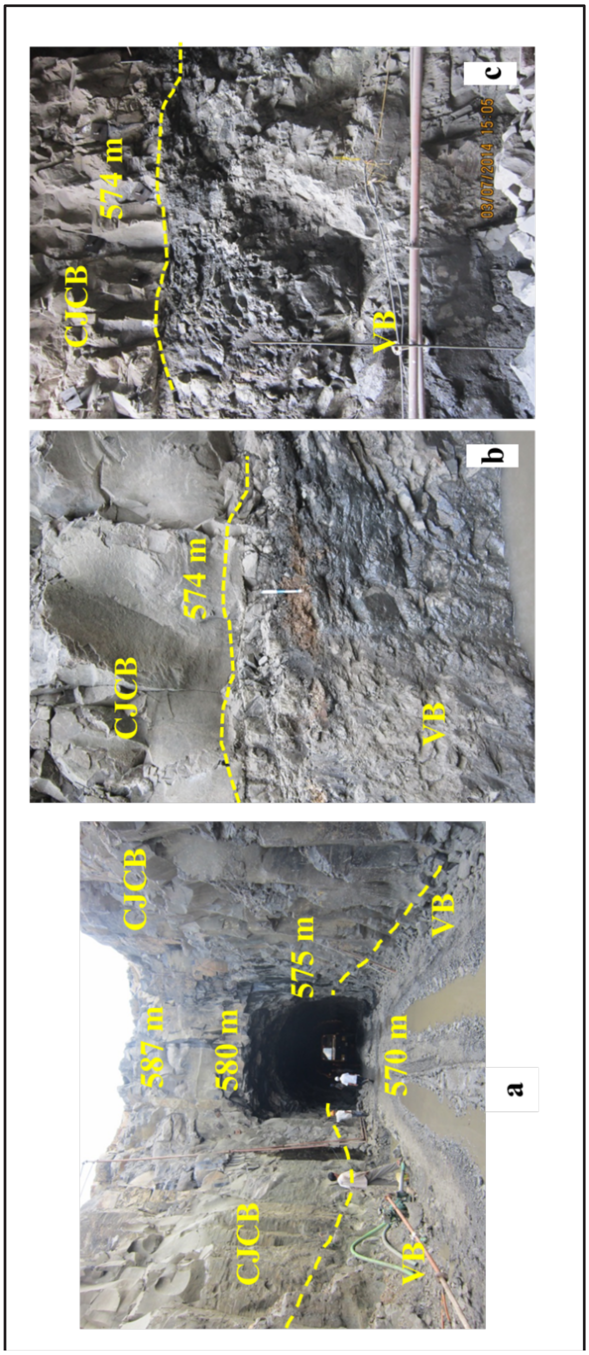

Figure 12 Northern Portal showing exposures of CJCB and VB, (a): Front View, (b) Left-hand wall, (c) Right-hand wall exposures

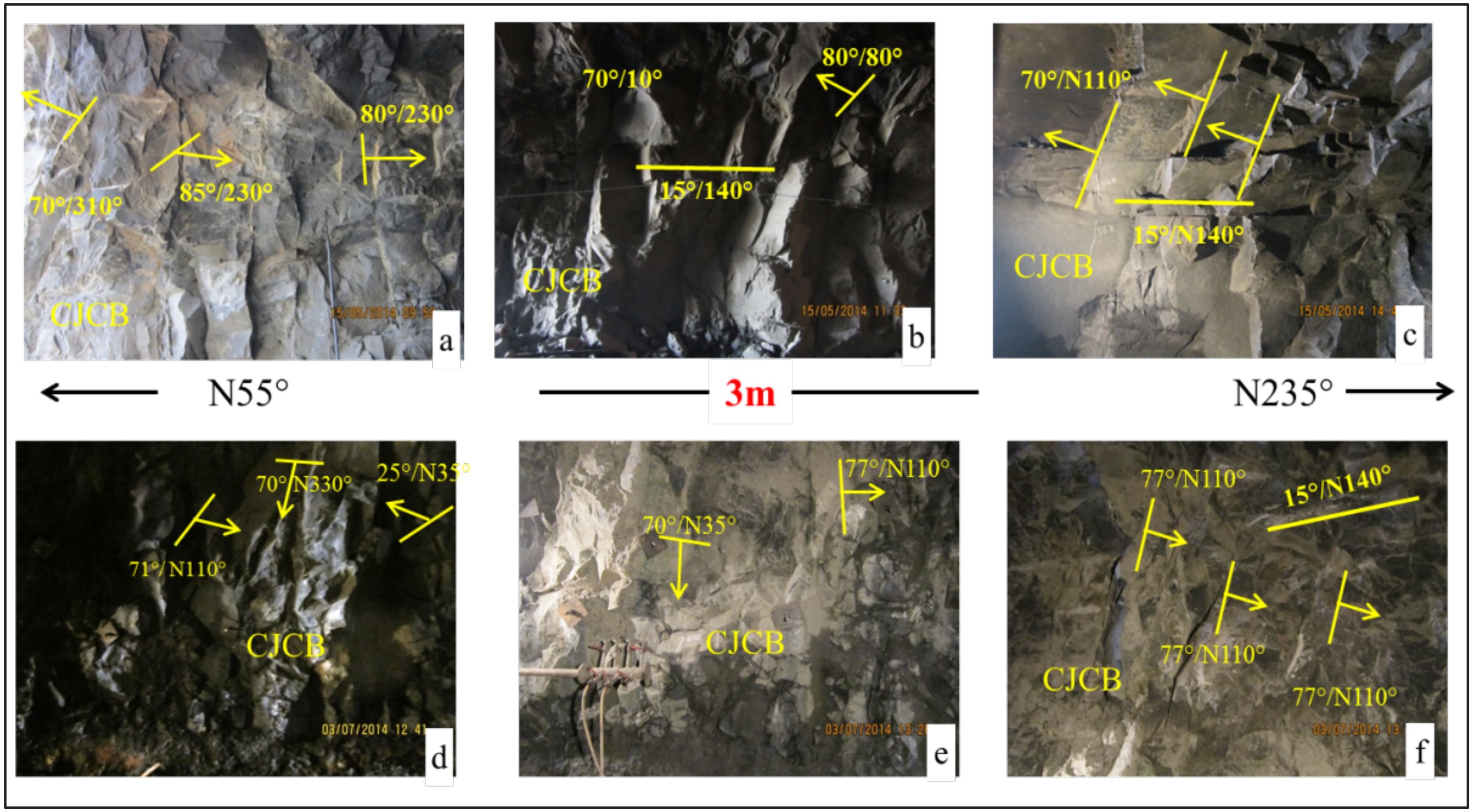

Figure 13 Exposures along left-hand wall of Tunnel, (a) Ch. 58528m (Northern Portal), (b) Ch.58550 m, (c)58570 m, (d)58590 m, (e) Ch. 58600 m, (f) 58612 m

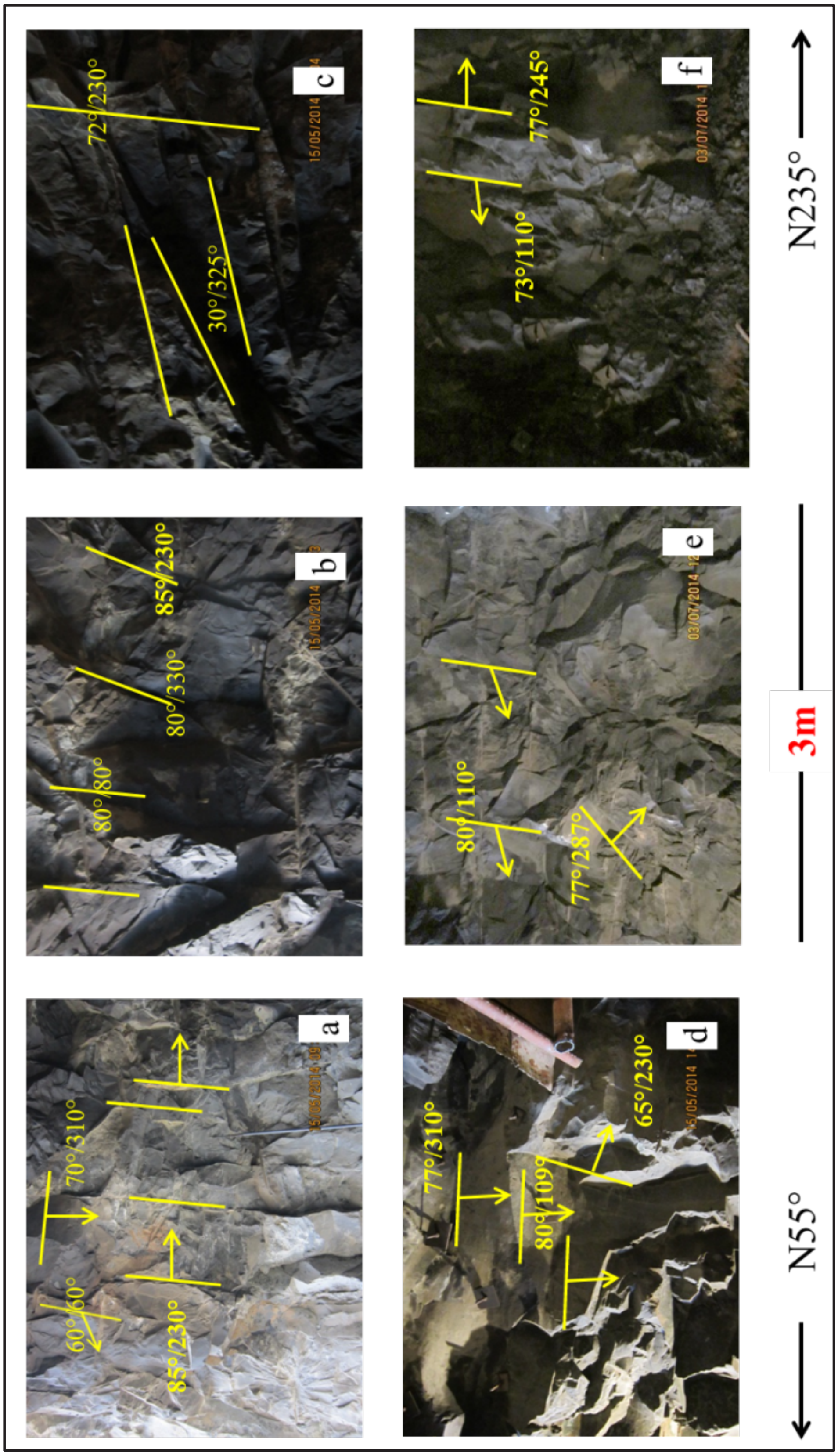

Figure 14 Exposures on the crown of Tunnel, (a) Ch. 58528m (Northern Portal), (b) Ch.58550 m, (c)58570 m, (d)58590 m, (e) Ch. 58600 m, (f) 58612 m

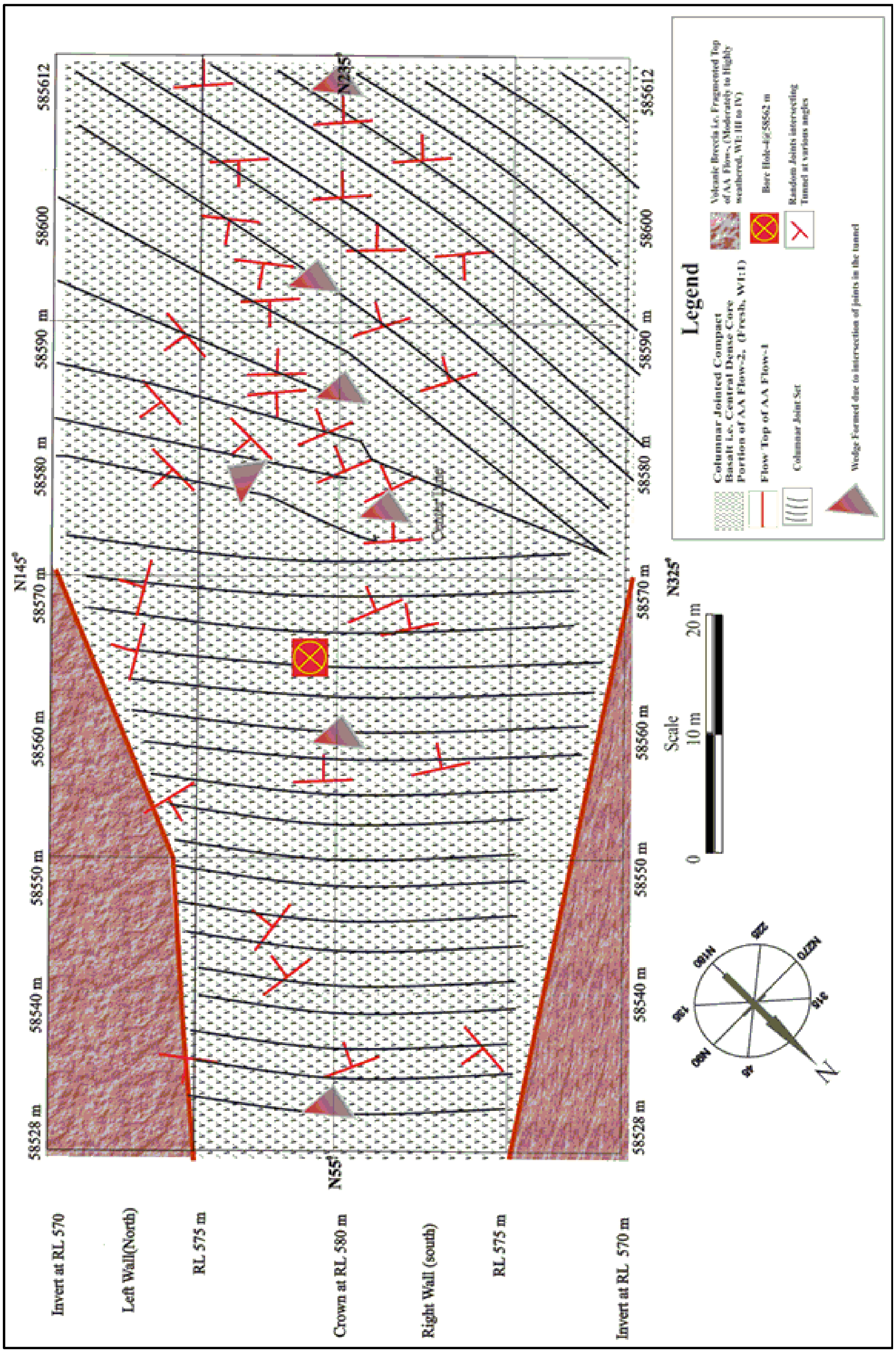

Figure 15 Geological Map of Marguthi Tunnel

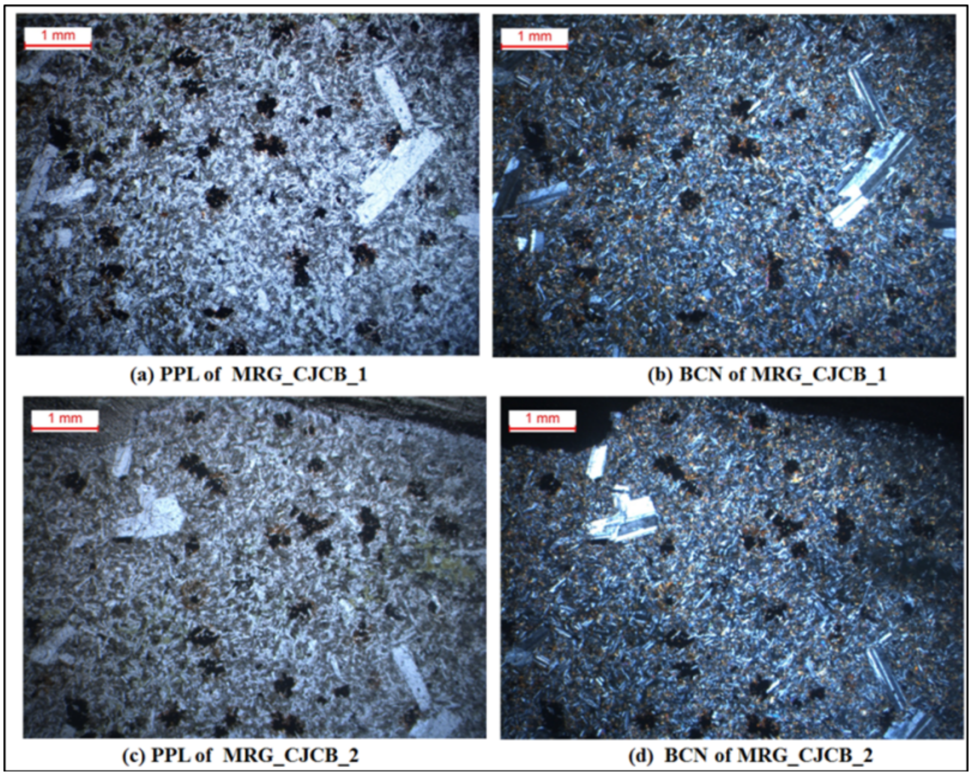

Figure 11 (a-d) Thin Sections of Representative Samples of CJCB

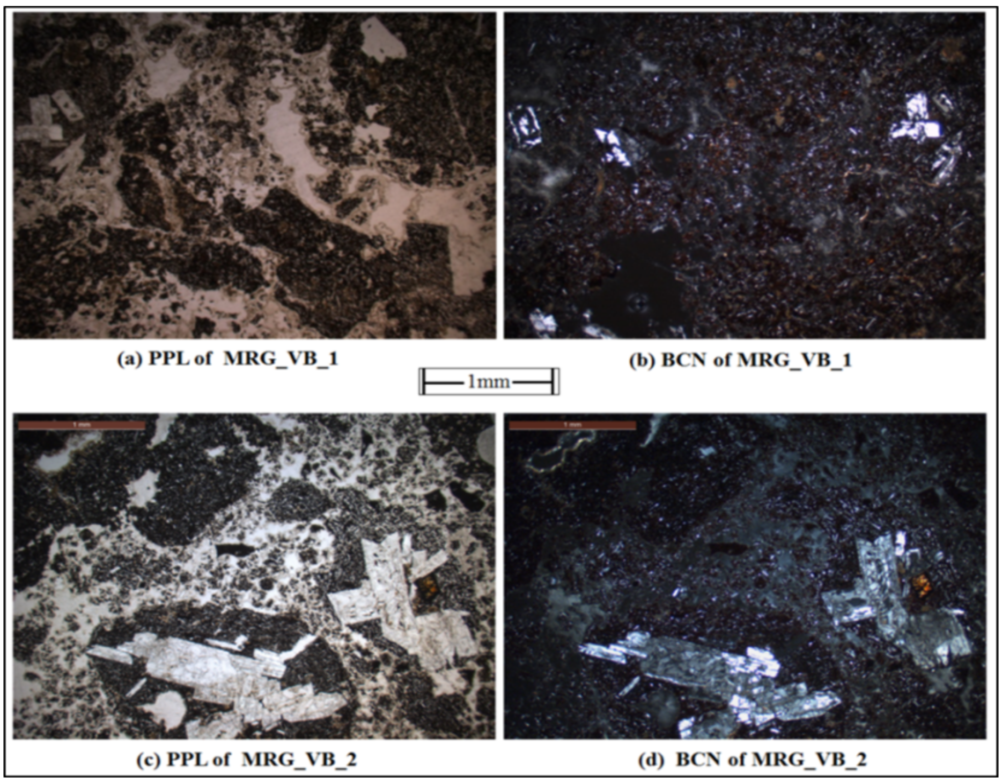

Figure 12(a-d) Thin Sections of Representative Samples of Volcanic Breccia

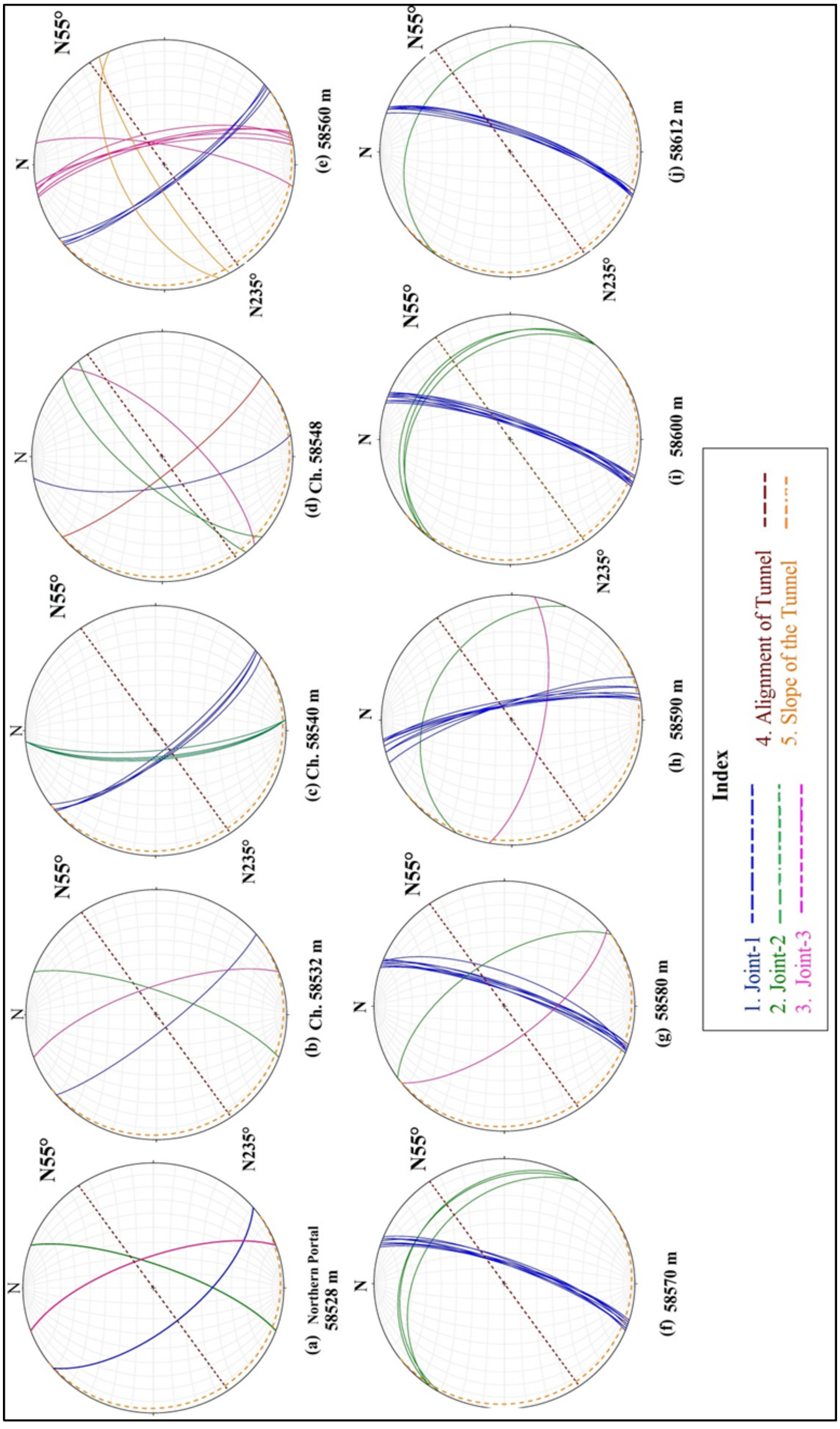

Figure 13 (a-j) Stereoplots for Gulbarga Tunnel

4.0 Analysis of Results and Discussion

A portion of tunnel occurring in CJCB shows moderate occurrence of joints. CJCB is fresh in condition with columnar joints and Weathering Grade-I (as per IS:4464, (2004). Columnar, random, persistent joints lead to the development of irregular blocks of CJCB. These irregular blocks in the crown at various chainages make it unstable. VB has a good thickness inside the tunnel which is moderately weathered (Grade: III-IV) weak and deteriorating.

5.0 Conclusion

VB and CJCB- the two rock types encountered in the Gulbarga tunnel, show dissimilar properties such as low to high RQD percentage, weak to very strong UCS, and low to medium slaking. These varying properties imply variation in rock mass characterization of flow units for exposures in flow top i.e. VB as well as dense, jointed core i.e. CJCB. Formation of irregular, unstable, polygonal blocks in the crown, wedge due to varying attitude of CJCB as prominent engineering geological problem have arisen due to columnar joints. Due to deteriorating VB at invert and wall, pay line variation has been another problem in the tunnel.

5.1 Recommendations:

Engineering geological studies of the exposed and excavated portions of the tunnel emphasized the importance of classifying basalt rock types according to their flow morphology. The treatment recommended varies with the exposed zone of the flow. Accordingly, following measures are recommended:

a) As the strength of VB varies with time, it is recommended that invert portion exposed should be covered with appropriate cover such as plain cement concrete immediately upon excavation. This would avoid such problem in the future. In case of walls, as per RMR and Q charts recommendations for poor rock, shotcrete with 20-30 mm thickness need to be applied.
b) The support suggested for Good rock i.e. CJCB with RMR = 61–80, Full face, 1.0–1.5 m advance and complete support 20 m from face required. Locally, bolts in crown 3 m long, spaced 2.5 m, with occasional wire mesh. 50 mm in crown where required need to applied. While evaluating with Q, the support category number is 1 for the entire tunnel section in CJCB and the support suggested is **spot bolting, untensioned, grouted.** At portal, as Jn=8, Q value reduces to 13.50 and block size reduces to 11.50, with support category as 3 with Systematic Bolting with Fiber reinforced sprayed concrete with 5-6 cm thickness.

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Table 4(a) Rock Mass Rating (RMR) calculated for Volcanic Breccia (VB) Portion in the tunnel (IS:13365(Part-1), 1998)

Tunnel Direction		55°(58528 m chainage) to 235°(58573.0 m chainage)																	Crown @ RL 579 m			Invert @ RL 571 m
Sr. No	Chai-nage in m	R. L. in m for VB		Thick ness avail-able for rating in m	UCS Rating	RQD	Rating for Discontinuity Parameters									Relation of Dis-continuity orientation with tunnel	Rating adjust-ment	RMR	RMR Class	Rock Condi-tion
		From	To				P	S	A	R	I	W	GW	Dip	Dip Dir					
1	58528.20	575.10	571.00	4.1	4	8	2	1	1	2	2	2	10	80	N265	Favourable	0	32	IV	POOR ROCK
2	58548.00	574.20	571.00	3.2	4	8	2	1	1	2	2	2	10	80	N265	Favourable	0	32	IV	POOR ROCK
3	58558.00	572.00	571.00	1	4	8	2	1	1	2	2	2	10	80	N265	Favourable	0	32	IV	POOR ROCK
4	58568.00	571.50	571.00	0.5	4	8	2	1	1	2	2	2	10	80	N230	Favourable	0	32	IV	POOR ROCK
5	58573.00	571.50	571.00	0.5	4	8	2	1	1	2	2	2	10	80	N230	Favourable	0	32	IV	POOR ROCK

Table 4(b) Q calculation for Volcanic Breccia in the tunnel (IS:13365(Part-2), 1996; NGI, 2015)

Sr. No.	Chainage in m	R. L. in m for (VB)		Thickness available for rating in m	RQD	Jn	Jr	Ja	Jw	SRF	Q	Quality of Rock	Support Category	Support
		From	To											
1	58528.2	575.1	571	4.1	50	6*	4	4	1	5	2	Poor	1	Unsupported with spot bolting with bolt length 1.6 to 2.0 m. 2-3 cm shotcrete
2	58548	574.2	571	3.2	60	3	4	4	1	5	4	Fair	1	
3	58558	572	571	1	60	3	4	4	1	5	4	Fair	Not Required due to less thickness	
4	58568	571.5	571	0.5	60	3	4	4	1	5	4	Fair		
5	58571	571.5	571	0.5	60	3	4	4	1	5	4	Fair		

***: For Jn at Portal = JnX2 as Jn=3 for portal it becomes Jn=6 (NGI, 2013), **: Conversion of Q for wall support for rock mass of intermediate quality, Q value obtained should be multiplied by 2.5.**

Table 4(c) Rock Mass Rating (RMR) calculated for Columnar Jointed Fresh Compact Aphinitic Basalt in the tunnel (IS:13365(Part-1), 1998)

Sr. No	Chai-nage in m	R. L. in m for (CJCB)		Thic kness m	UCS	RQD	Rating for Discontinuity Parameters*									Relation of Discontinuity with tunnel	Rat-ing ad-just ment	RMR	RMR Class	Rock Condition
		From	To				P	S	A	R	I	W	GW	Dip	Dip Dir					
1	58528	580.00	575.1	4.90	13	17	8	2	5	5	6	6	10	80^0	N230^0	Favourable	0	72	II	Good to Very Good
2	58548	580.00	574.20	5.80	13	17	8	2	5	5	6	6	10	70^0	N310^0	Favourable	-2	70	II	Good to Very Good
3	58558	580.00	572.00	8.00	13	17	8	2	5	5	6	6	10	60^0	N335^0	Favourable	-2	70	II	Good to Very Good
4	58568	580.00	571.50	8.50	13	17	8	2	5	5	6	6	10	80^0	N110^0	Unfavourable	-5	67	II	Good
5	58573	580.00	571.5	8.50	13	17	8	2	5	5	6	6	10	30^0	N325^0	Unfavourable	-5	67	II	Good
6	58582	580.00	570	10	13	17	8	2	5	5	6	6	10	80^0	N110^0	Favourable	-2	70	**II**	Good to Very Good
7	58591	580.00	570	10	13	17	8	2	5	5	6	6	10	80^0	N110^0	Favourable	-2	70	**II**	Good to Very Good
8	58601	580.00	570	10	13	17	8	2	5	5	6	6	10	80^0	N110^0	Favourable	-2	70	**II**	Good to Very Good
9	58609	580.00	570	10	13	17	8	2	5	5	6	6	10	25^0	N35^0	**Unfavourable**	**-5**	67	**II**	Good to Very Good
10	58612	580.00	570	10	13	17	8	2	5	5	6	6	10	80^0	N110^0	Favourable	-2	70	**II**	Good to Very Good

***P: persistence, S: spacing, A: aperture, R: roughness, I; infillings, W: weathering, GW: ground water**

Table 4(d) Q calculation for Columnar Jointed Fresh Compact Aphinitic Basalt in the tunnel (IS:13365(Part-2), 1996; NGI, 2015)

Sr. No.	Chainage in m	R. L. in m for (CJCB)		Thickness m	RQD	Jn	Jr	Ja	Jw	SRF	Q	Support Category	Support Recommen-dations
		From	To										
1	58528	580.00	575.1	4.90	90	8#	1.5	0.75	1	2.5	4.50	3	Systematic bolting with a length of 2.4 m and at 2.0 m spacing with fibre reinforced sprayed concrete 5-6 cm thickness.
2	58548	580.00	574.20	5.80	90	4	1.5	0.75	1	2.5	18		
3	58558	580.00	572.00	8.00	90	4	1.5	0.75	1	2.5	18		
4	58568	580.00	571.50	8.50	90	4	1.5	0.75	1	2.5	18		
5	58573	580.00	571.50	8.50	90	4	1.5	0.75	1	2.5	18		
6	58582	580.00	570.00	10	90	4	1.5	0.75	1	2.5	18		
7	58591	580.00	570.00	10	90	4	1.5	0.75	1	2.5	18		
8	58601	580.00	570.00	10	90	4	1.5	0.75	1	2.5	18		
9	58609	580.00	570.00	10	90	4	1.5	0.75	1	2.5	18		
10	58612	580.00	570.00	10	90	4	1.5	0.75	1	2.5	18		

#: For Jn at Portal = JnX2 as Jn=4 for columnar basalt, for portal section in CB it becomes Jn=8, ## For Columnar Jointed Basalt Jn=4 , (NGI, 2015)

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