12TUNNEL 7: GEOLOGICAL & GEOTECHNICAL ASSESMENT

12.1Exploratory drillings

As per the requirement of scope of work outlined in the terms of reference, 12 bore holes were drilled with a cumulative length of 404m at different locations along the proposed alignment. Necessary care has been taken during drilling operations by deploying good quality diamond drill machines to obtain good core recovery to obtain RQD values. The locations of the boreholes were selected in such a way, so that these holes intersect the envisaged ground/ strata conditions at different depths. The location and details of boreholes drilled; total depth of drillings is shown in table below.

Chainage	BH	GL	FL	Depth
60778	BH-1	398.74	380.173	24.00
60828	BH-2	401.55	380.028	26.00
60878	BH-3	398.982	379.884	24.00
60928	BH-4	403.006	379.739	28.00
60978	BH-5	411.532	379.595	37.00
61028	BH-6	421.513	379.45	47.00
61078	BH-7	426.41	379.306	52.00
61128	BH-8	414.542	378.997	43.00
61178	BH-9	407.636	378.497	34.00
61228	BH-10	413.132	377.997	40.00
61278	BH-11	398.878	377.497	26.00
61308	BH-12	394.27	377.197	23.00

12.2TUNNEL-7 SRT

12.2.1Location:

Sr. No.	Chainage	Line	Spread	Location (T-07)		Length
				Start	End	In meter
1	60.778km to 61.308km	L1	S1 to S5	60.778km	61.308km	530

12.2.2 Seismic survey results and conclusion

Table 12.1: Summery of Tunnel-1 SRT test

Variation of maximum range of thicknesses below EGL (M)			Avg. V_p (m/sec)	Calculated V_s (m/sec)	Dynamic Young's Modulus (MPa)	Shear Modulus (MPa)
Layer	From	To				
Layer-I	0.50	3.00	700	327	466	172
Layer-II	3.00	4.50	2200	1132	7441	2819
Layer-III	4.50	25.00	3800	2101	28238	11031

Sample Calculation:

The Young's Modulus E is the uni-axial stress-strain ratio. Its dynamic value is expressed by the following equation:

$$E = \frac{\rho V_p^2 (1+\mu)(1-2\mu)}{1-\mu}$$

Where, E = Dynamic Young's Modulus in kN/m2

Vp = 700 m/sec

ρ = 1.6 gm/cc ≈ 1.60 kN.s2/m4 (mass density)

μ = 0.36

So, calculated E = 466480 kN/sqm ≈ 466 MPa

The Shear Modulus G is the stress-strain ratio for simple shear. Its dynamic value is obtained by the following:

$$G = \frac{E}{2(1+\mu)} = \rho V_s^2$$

So, Shear Modulus G comes out to be 171500 kN/sqm ≈ 172 MPa

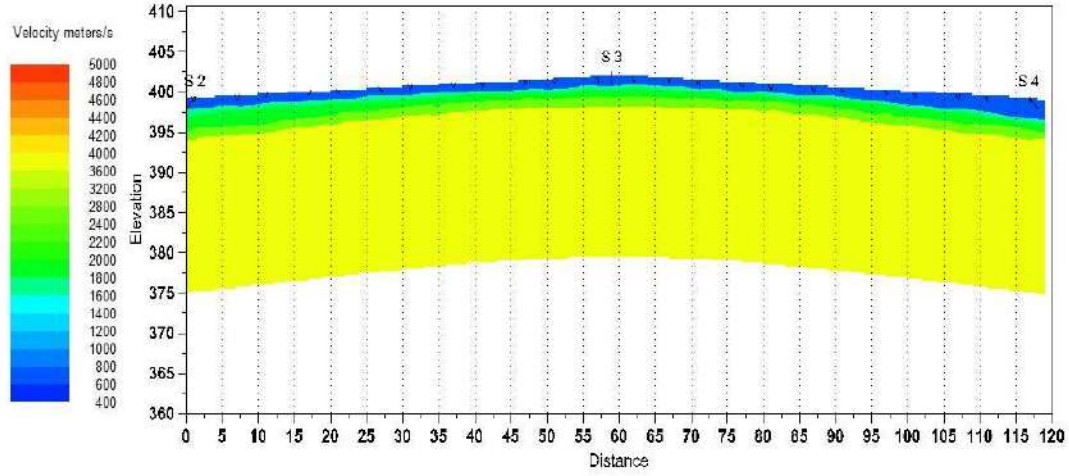
Again,

$G = \rho V_s^2$ giving Vs = √(G/ρ)

So, calculated Vs = 327.395 m/sec, say 327 m/sec

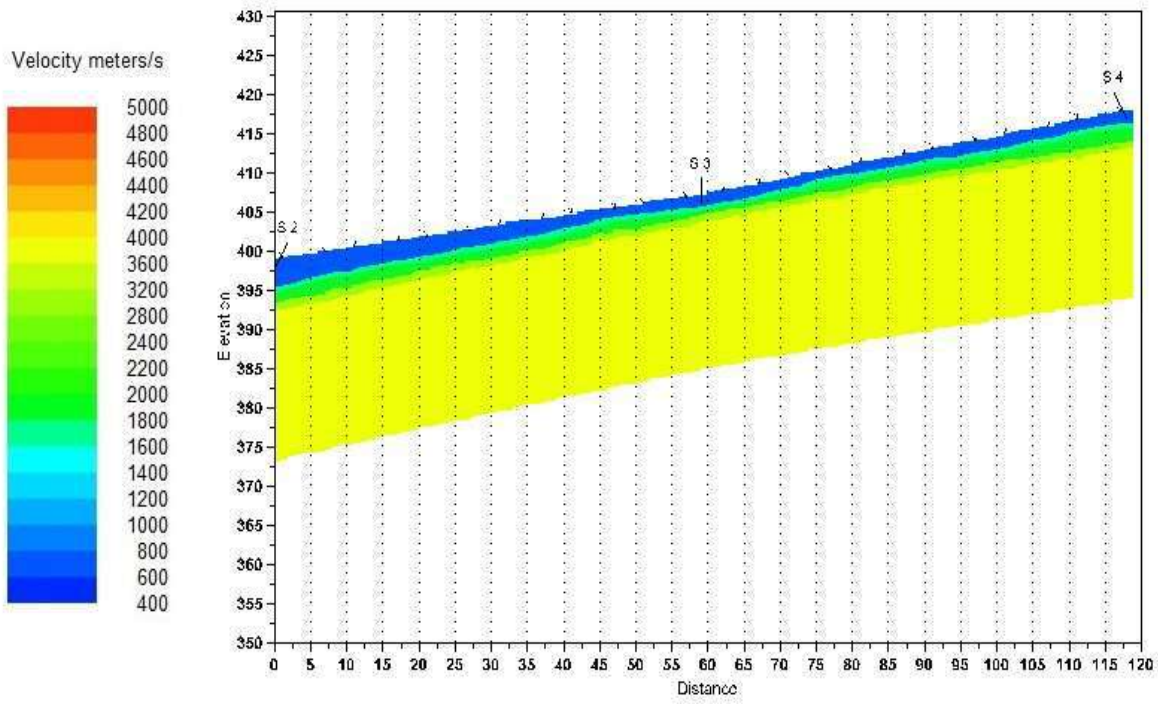
SEISMIC PROFILE(T07)

T07L1S1



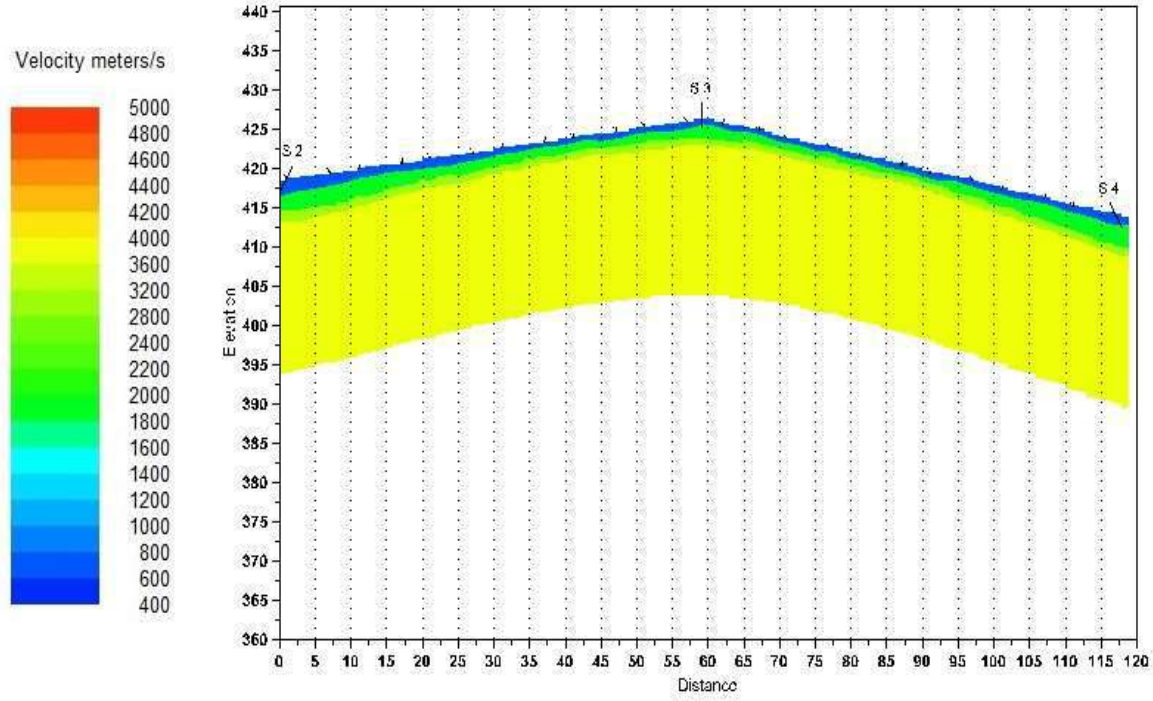
Shot point depth computation

T07L1S2



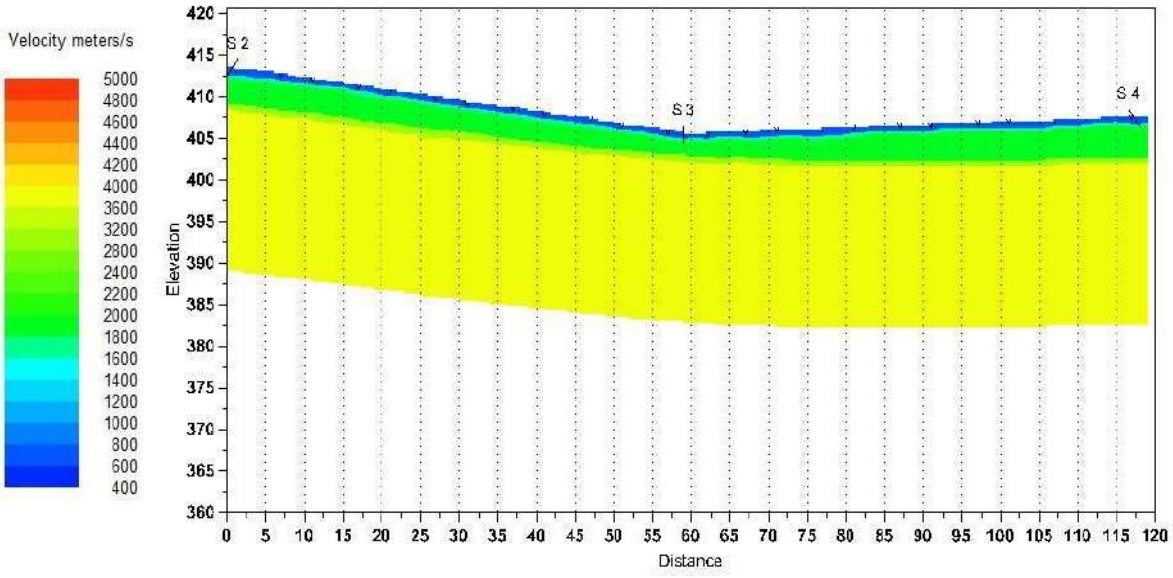
Shot point depth computation

T07L1S3



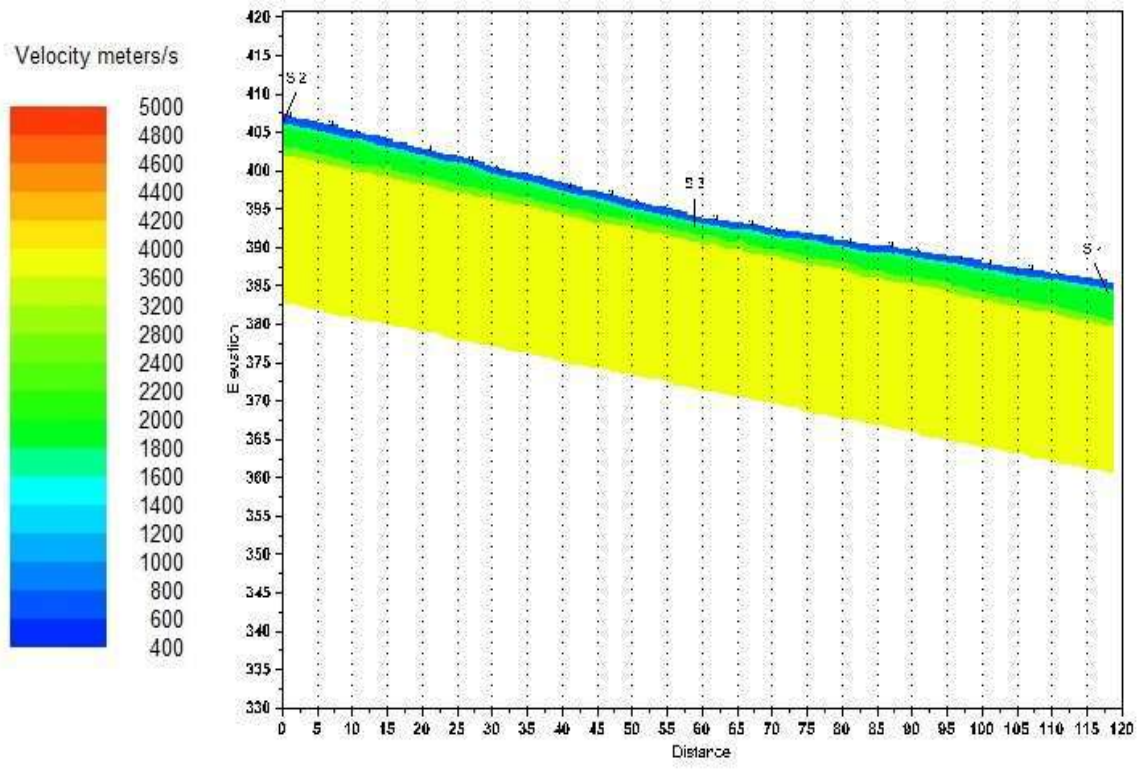
Shot point depth computation

T07L1S4



Shot point depth computation

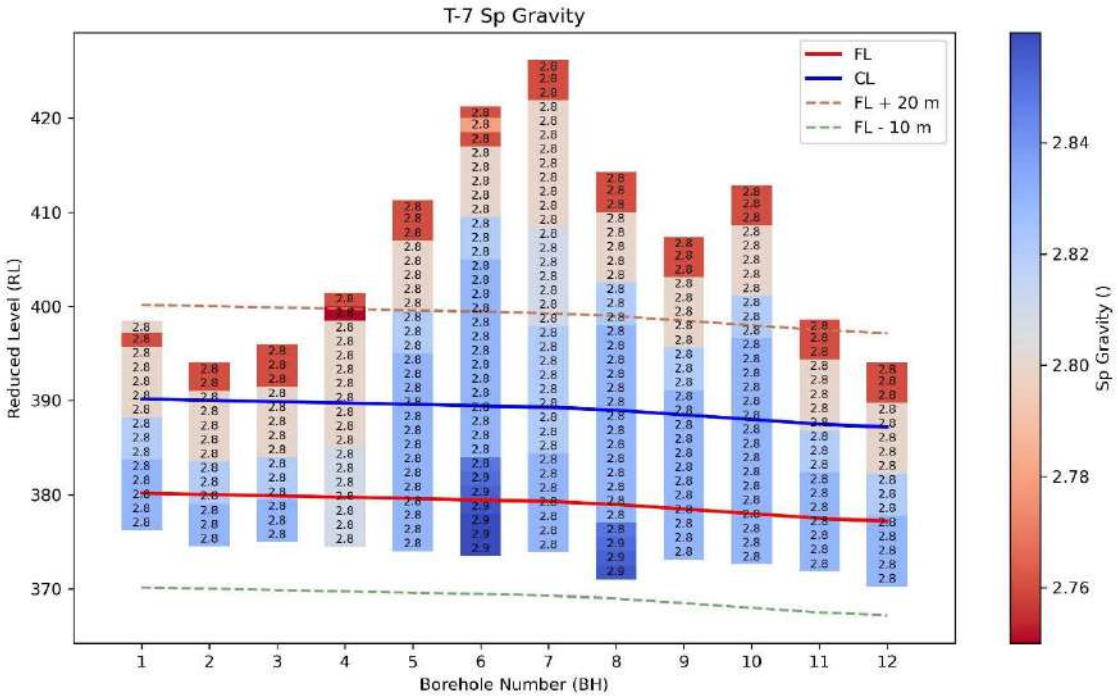
T07L1S5



Shot point depth computation

12.3Assessment of the engineering properties of rock sample:

12.3.1Specific Gravity



12.3.1.1 Mean and Standard deviation Specific Gravity considering 1D zone of influence of each borehole:

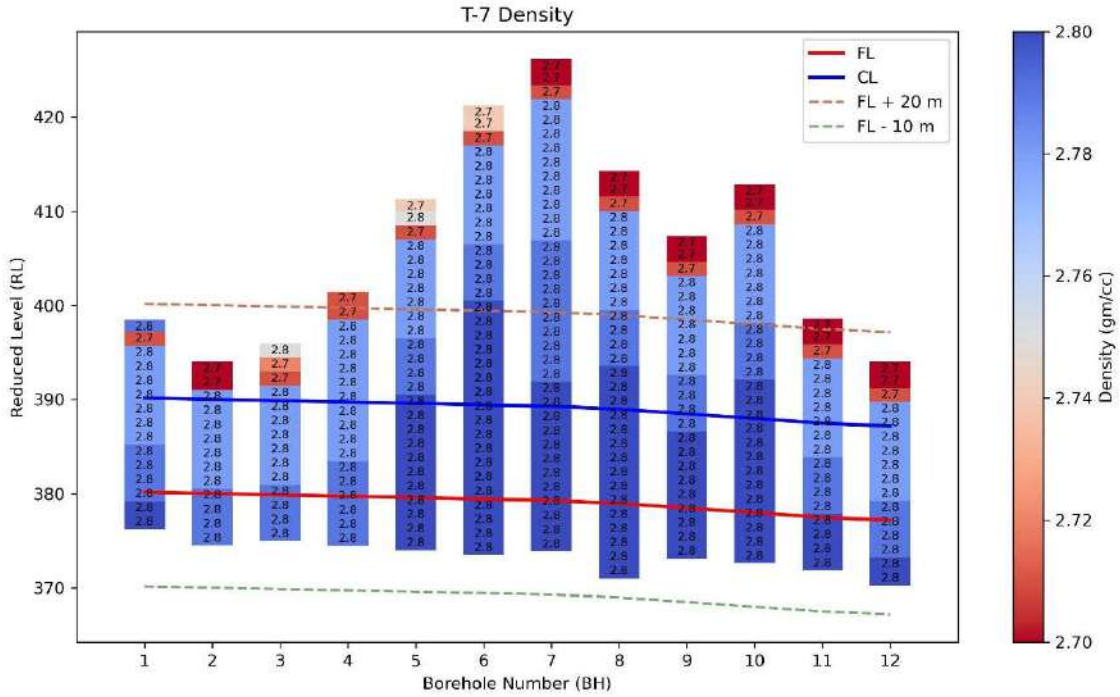
BH No.	Chainage	Mean	Std
BH01	60778	2.82	0.010
BH02	60828	2.82	0.014
BH03	60878	2.82	0.014
BH04	60928	2.81	0.005
BH05	60978	2.83	0.000
BH06	61028	2.85	0.013

BH07	61078	2.83	0.005
BH08	61128	2.84	0.011
BH09	61178	2.83	0.000
BH10	61228	2.83	0.000
BH11	61278	2.83	0.005
BH12	61308	2.82	0.013

12.3.1.2 Recommended Specific Gravity considering 1D zone of influence:

Chainage	**Statistical / Reduction Method** **(Sp = μ - σ across boreholes within ±10 m of FL and CL)**	**Reference Standards / Guidelines**
60780 to 61180	2.81	IS 13030:1991; IS 1124:1974
61180 to 61320	2.81	

12.3.2 Dry Density



12.3.2.1 Mean and Standard Deviation in Density considering 1D zone of influence of each borehole:

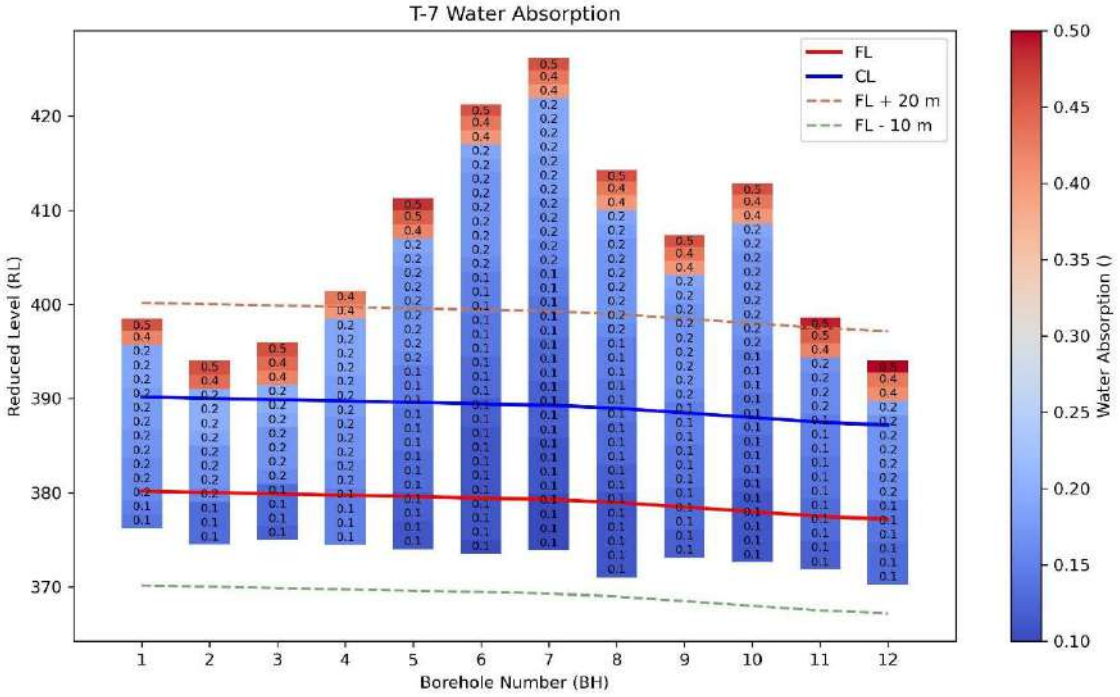
BH No.	Chainage	Mean	Std
BH01	60778	2.79	0.008
BH02	60828	2.78	0.005
BH03	60878	2.78	0.005
BH04	60928	2.79	0.005
BH05	60978	2.80	0.000
BH06	61028	2.80	0.000

BH07	61078	2.80	0.000
BH08	61128	2.80	0.000
BH09	61178	2.80	0.003
BH10	61228	2.80	0.000
BH11	61278	2.79	0.008
BH12	61308	2.79	0.008

12.3.2.2 Recommended Density considering 1D zone of influence:

Chainage	**Statistical / Reduction Method** **(d = μ - σ across boreholes within ±10 m of FL and CL)**	**Reference Standards / Guidelines**
60780 to 61180	2.79	IS 13063:1991
61180 to 61320	2.78	

12.3.3 Water absorption Test



12.3.3.1 Mean and Standard Deviation in Water Absorption Value considering 1D zone of influence:

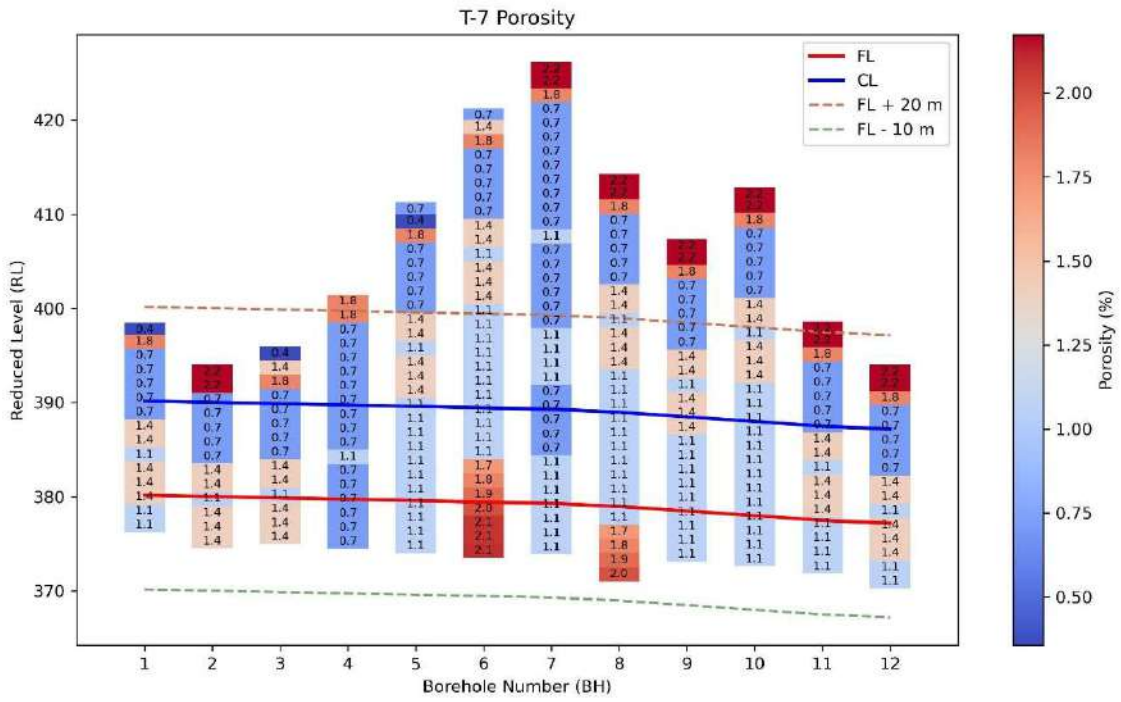
BH No.	Chainage	Mean	Std
BH01	60778	0.16	0.013
BH02	60828	0.17	0.028
BH03	60878	0.16	0.028
BH04	60928	0.16	0.011
BH05	60978	0.13	0.012
BH06	61028	0.11	0.005
BH07	61078	0.11	0.008

BH08	61128	0.12	0.011
BH09	61178	0.14	0.011
BH10	61228	0.12	0.012
BH11	61278	0.14	0.011
BH12	61308	0.15	0.017

12.3.3.2 Recommended Water Absorption Value considering 1D zone of influence:

Chainage	**Statistical / Reduction Method** **(A= μ + σ across boreholes within ±10 m of FL and CL)**	**Reference Standards / Guidelines**
60780 to 61180	0.16	IS 13063:1991; IS 2386 (Part 3):1963
61180 to 61320	0.15	

12.3.4 Porosity



12.3.4.1 Mean And Standard Deviation in Porosity considering 1D zone of influence in each Borehole:

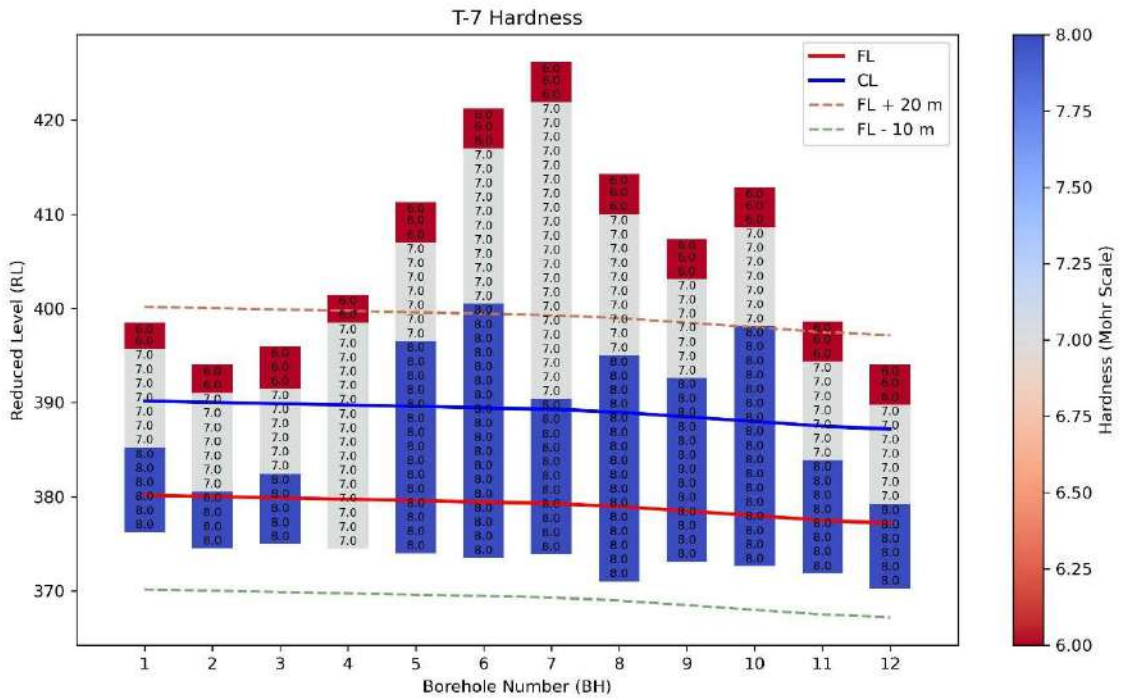
BH No.	Chainage	Mean	Std
BH01	60778	1.22	0.256
BH02	60828	1.10	0.349
BH03	60878	1.10	0.349
BH04	60928	0.75	0.112
BH05	60978	1.06	0.000
BH06	61028	1.63	0.465
BH07	61078	0.95	0.169

BH08	61128	1.32	0.395
BH09	61178	1.10	0.112
BH10	61228	1.06	0.000
BH11	61278	1.24	0.187
BH12	61308	1.13	0.307

12.3.4.2 Recommended Porosity considering 1D zone of influence:

Chainage	**Statistical / Reduction Method** **($n = \mu \pm \sigma$ across boreholes within ±10 m of FL and CL)**	**Reference Standards / Guidelines**
60780 to 61180	1.51	IS 1124:1974; ISRM (1981)
61180 to 61320	1.36	

12.3.5 Hardness



12.3.5.1 Mean And Standard Deviation in Hardness considering 1D zone of influence in each Borehole:

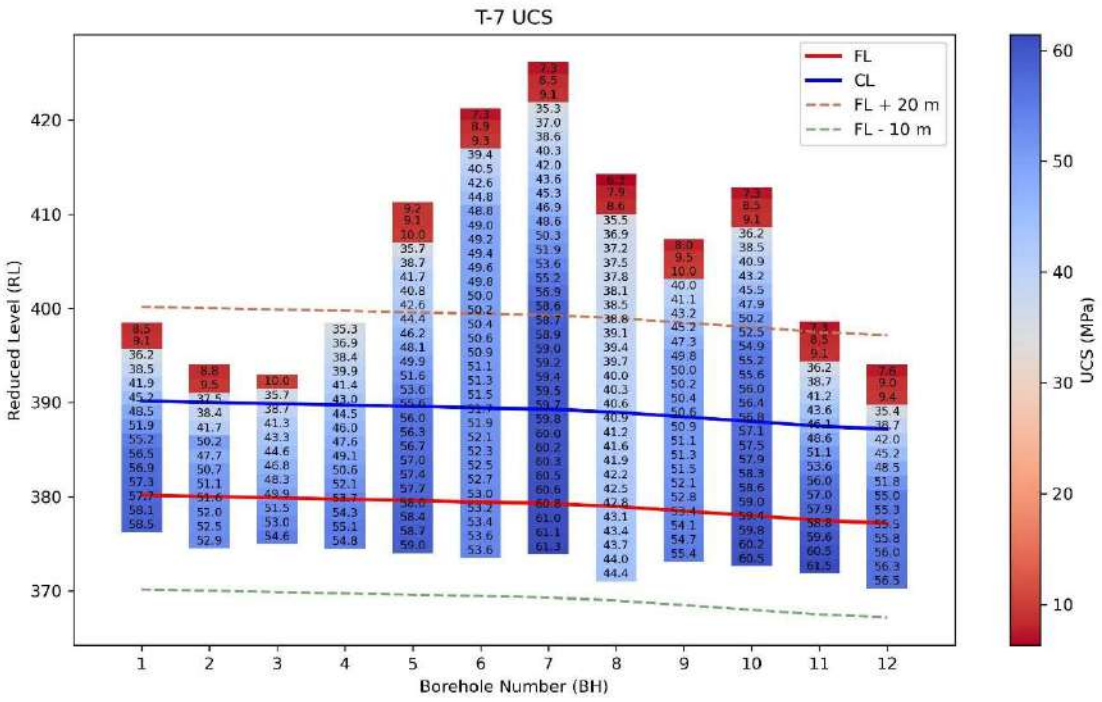
BH No.	Chainage	Mean	Std
BH01	60778	8	0.52
BH02	60828	7	0.52
BH03	60878	8	0.53
BH04	60928	7	0.00
BH05	60978	8	0.00
BH06	61028	8	0.00

BH07	61078	8	0.00
BH08	61128	8	0.00
BH09	61178	8	0.00
BH10	61228	8	0.00
BH11	61278	8	0.42
BH12	61308	8	0.52

12.3.5.2 Recommended Hardness considering 1D zone of influence:

Chainage	**Statistical / Reduction Method** **(Hi = μ - σ across boreholes within ±10 m of FL and CL)**	**Reference Standards / Guidelines**
60780 to 61180	7	IS 13311 (Part 2):1992; ISRM 1978
61180 to 61320	7	

12.3.6Compression Test



12.3.6.1 Mean And Standard Deviation in UCS considering 1D zone of influence in each Borehole:

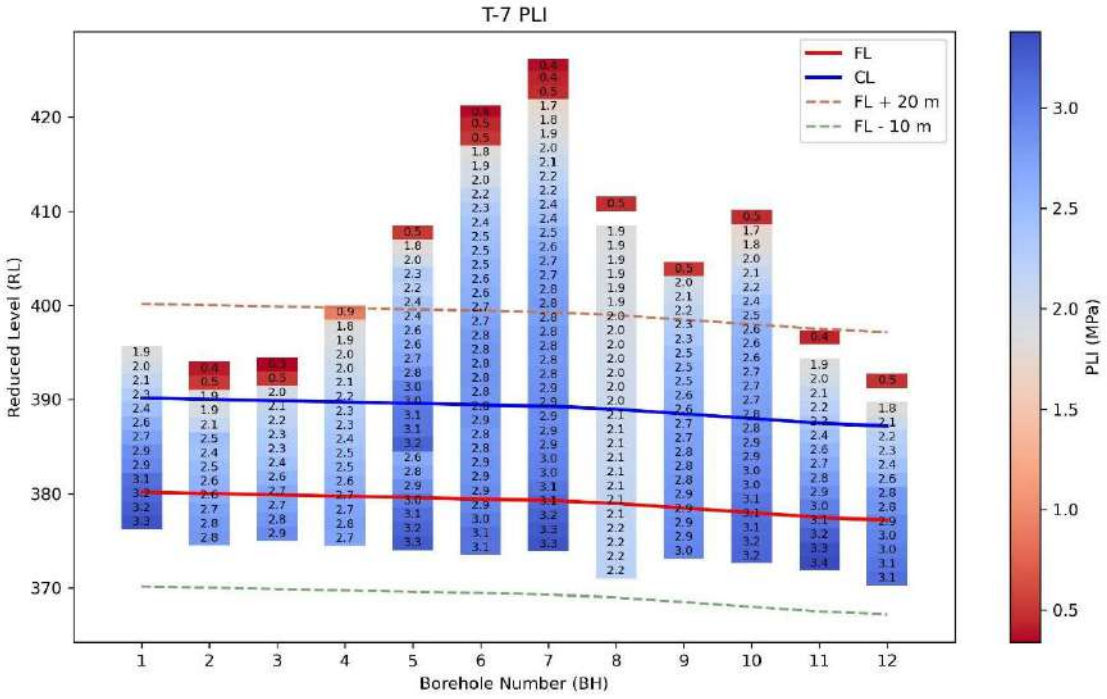
BH No.	Chainage	Mean	Std
BH01	60778	54.59	4.56
BH02	60828	48.87	4.93
BH03	60878	47.20	5.21
BH04	60928	50.78	3.84
BH05	60978	57.52	1.03
BH06	61028	52.72	0.67
BH07	61078	60.56	0.48

BH08	61128	42.65	1.12
BH09	61178	52.72	1.62
BH10	61228	58.83	1.14
BH11	61278	56.45	4.19
BH12	61308	52.54	5.08

12.3.6.2 Recommended UCS considering 1D zone of influence:

Chainage	**Statistical / Reduction Method** **(UCS_k = μ - σ) across boreholes within ±10 m of FL and CL)**	**Recommended Design Value** **(UCS_d = (μ - σ) × f(RMR)), where (f(RMR) = 0.1–0.7)**	**Reference Standards / Guidelines**
60780 to 61180	45.31	13.59	IS 9143:1979; IS 13365 (Part 2):1998; Hoek & Brown (2002, 2019)
61180 to 61320	51.21	25.60	

12.3.7Point Load Test



12.3.7.1 Mean And Standard Deviation in PLI considering 1D zone of influence in each Borehole:

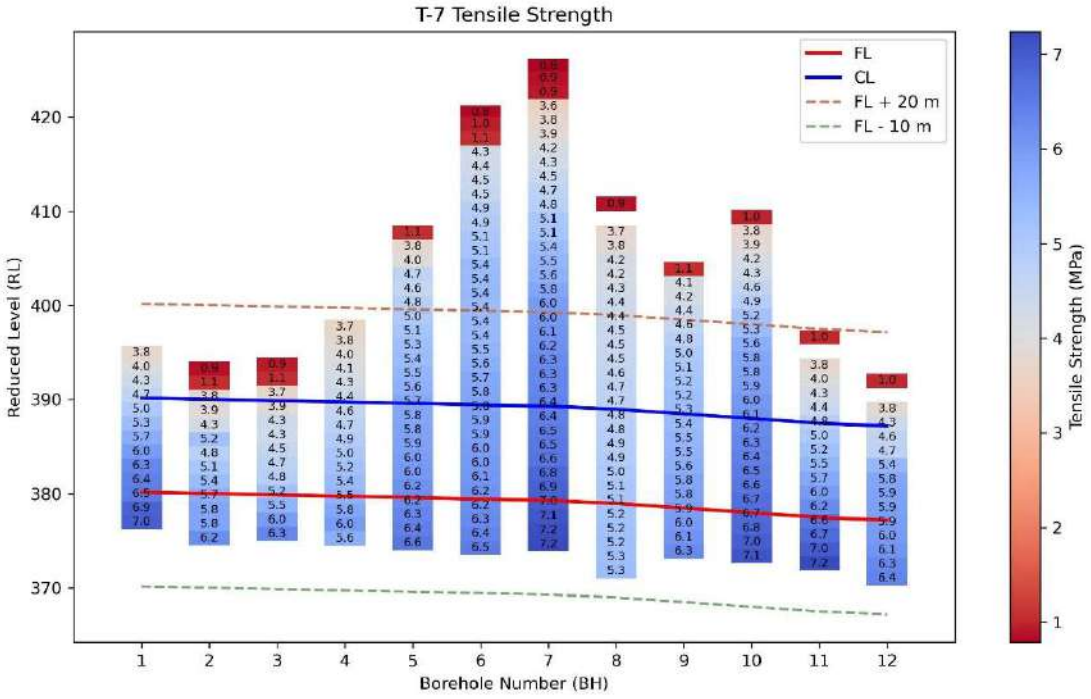
BH No.	Chainage	Mean	Std
BH01	60778	2.94	0.30
BH02	60828	2.50	0.29
BH03	60878	2.50	0.28
BH04	60928	2.54	0.18
BH05	60978	3.03	0.20
BH06	61028	2.92	0.11
BH07	61078	3.08	0.15

BH08	61128	2.13	0.05
BH09	61178	2.83	0.09
BH10	61228	3.02	0.14
BH11	61278	2.94	0.33
BH12	61308	2.76	0.32

12.3.7.2 Recommended PLI considering 1D zone of influence:

Chainage	**Statistical / Reduction Method** **(PLI_k = μ - σ) across boreholes within ±10 m of FL and CL)**	**Recommended Design Value** **(PLI_d = (μ - σ) × f(RMR)), where (f(RMR) = 0.1–0.7)**	**Reference Standards / Guidelines**
60780 to 61180	2.32	0.69	IS 9143:1979; IS 13365 (Part 2):1998; Hoek & Brown (2002, 2019)
61180 to 61320	2.61	1.30	

12.3.8 Brazilian Test



12.3.8.1 Mean And Standard Deviation in Tensile Strength considering 1D zone of influence in each Borehole:

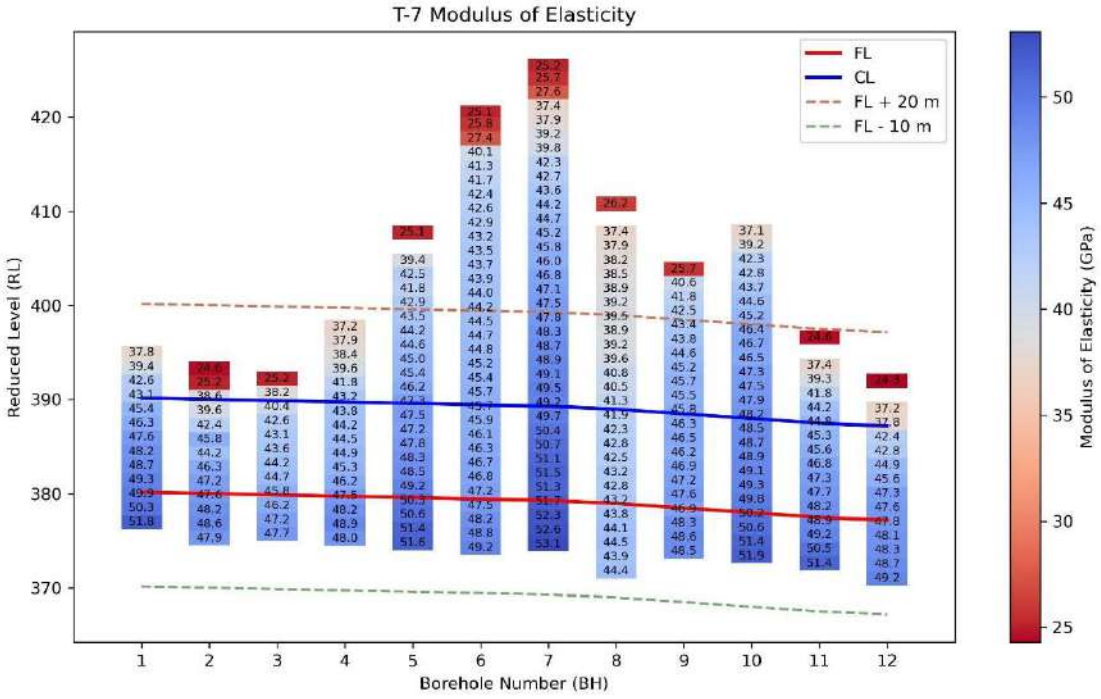
BH No.	Chainage	Mean	Std
BH01	60778	6.12	0.68
BH02	60828	5.21	0.73
BH03	60878	4.98	0.78
BH04	60928	5.27	0.45
BH05	60978	6.12	0.27
BH06	61028	6.11	0.22
BH07	61078	6.83	0.29

BH No.	Chainage	Mean	Std
BH08	61128	5.06	0.18
BH09	61178	5.79	0.30
BH10	61228	6.64	0.27
BH11	61278	6.12	0.76
BH12	61308	5.72	0.58

12.3.8.2 Recommended Tensile Strength considering 1D zone of influence:

Chainage	**Statistical / Reduction Method** **(mean value across boreholes within ±10 m of FL and CL× 0.8 (account for anisotropy))**	**Recommended Design Value** **(μ - σ)**	**Reference Standards / Guidelines**
60780 to 61180	5.66	4.92	IS 10082:1982; Hoek & Brown (1997); ISRM Suggested Methods
61180 to 61320	6.15	5.47	

12.3.9 Modulus of elasticity test



12.3.9.1 Mean And Standard Deviation in Elasticity considering 1D zone of influence in each Borehole:

BH No.	Chainage	Mean	Std
BH01	60778	48.61	2.00
BH02	60828	45.78	2.91
BH03	60878	44.55	2.25
BH04	60928	46.14	1.86
BH05	60978	49.24	1.63
BH06	61028	47.13	1.18

BH No.	Chainage	Mean	Std
BH07	61078	51.44	1.04
BH08	61128	43.28	0.85
BH09	61178	47.30	0.91
BH10	61228	49.84	1.15
BH11	61278	48.09	1.97
BH12	61308	46.61	2.35

12.3.9.2 Recommended Modulus of Elasticity considering 1D zone of influence:

Chainage	**Statistical / Reduction Method** **(Ei = μ - σ across boreholes within ±10 m of FL and CL× 0.8 (account for anisotropy))**	**Recommended Design Value** **(Ed = (μ - σ) × f(RMR)), where (f(RMR) = 0.1–0.7)**	**Reference Standards / Guidelines**
60780 to 61180	43.84	13.15	IS 13365 (Part 2):1998; Hoek & Diederichs (2006)
61180 to 61320	45.84	22.92	

12.3.10 Abrasion test

12.3.10.1 Mean And Standard Deviation in Abrasion value considering 1D zone of influence in each Borehole:

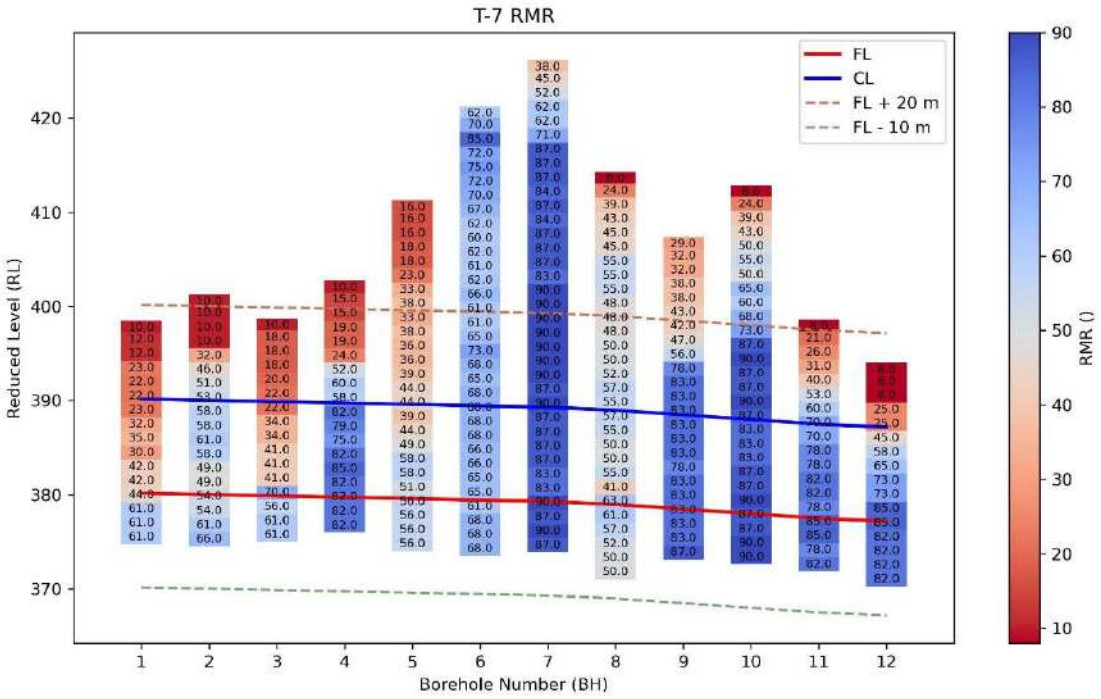
BH No.	Chainage	Mean	Std
BH01	60778	2.337	0.156
BH02	60828	2.163	0.145
BH03	60878	2.101	0.167
BH04	60928	2.235	0.119
BH05	60978	2.471	0.092
BH06	61028	2.312	0.042
BH07	61078	2.635	0.031
BH08	61128	2.071	0.110
BH09	61178	2.284	0.063
BH10	61228	2.475	0.036
BH11	61278	2.411	0.163
BH12	61308	2.299	0.185

12.3.10.2 Recommended Abrasion Value considering 1D zone of influence:

Chainage	**Statistical / Reduction Method** **(A= μ + σ across boreholes within ±10 m of FL and CL)**	**Recommended Design Value** **(A_v < 25%): Slightly abrasive; 25–35%: Moderately abrasive; >35%: Highly abrasive. (CAI = 0.5–6).**	**Reference Standards / Guidelines**
60780 to 61180	2.485	Moderately abrasive	IS 2386 (Part 4):1963; ISRM (2007); CERCHAR (1986)
61180 to 61320	2.551	Moderately abrasive	

12.4Geological assessment:

12.4.1RMR:



12.4.1.1 Mean And Standard Deviation in RMR considering 1D zone of influence in each Borehole:

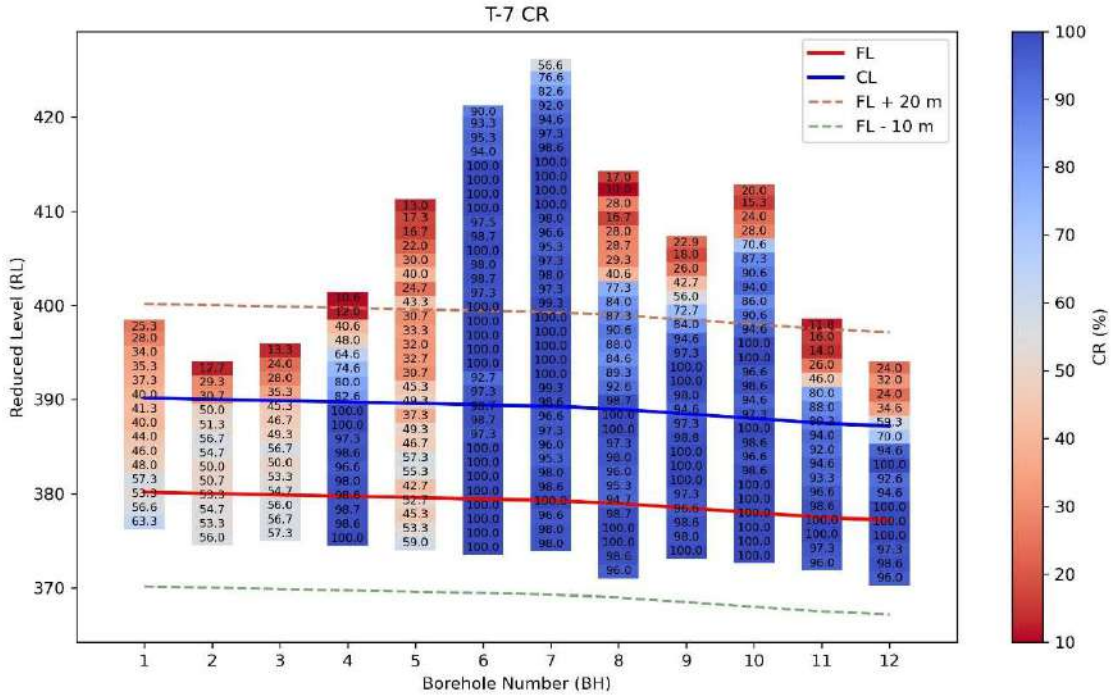
BH No.	Chainage	Mean	Std
BH01	60778	43	13.9
BH02	60828	57	5.4
BH03	60878	46	15.1
BH04	60928	81	2.8
BH05	60978	52	6.5
BH06	61028	66	2.2

BH No.	Chainage	Mean	Std
BH07	61078	87	2.3
BH08	61128	53	5.9
BH09	61178	83	2.1
BH10	61228	87	2.9
BH11	61278	80	4.4
BH12	61308	74	13.0

12.4.1.2 Recommended RMR considering 1D zone of influence:

Chainage	**Statistical / Reduction Method** **(Average across boreholes within ±10 m of FL and CL)**	**Recommended Design Value** **(RMR_d = μ - σ)**	**Reference Standards / Guidelines**
60780 to 61180	65 (Class II)	49 (Class III)	IS 13365 (Part 2): 1998, Cl. 5.1 + Note on "representative values"
61180 to 61320	80 (Class II)	70 (Class II)	

12.4.2 Core Recovery:



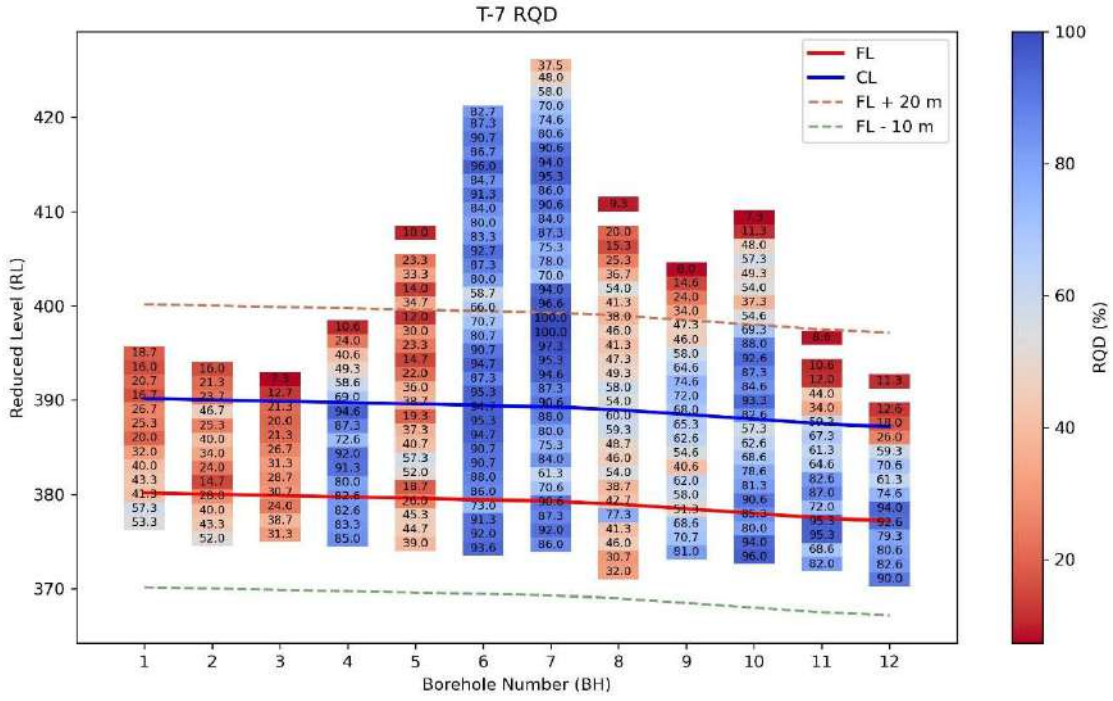
12.4.2.1 Mean And Standard Deviation in Core Recovery considering 1D zone of influence in each Borehole:

BH No.	Chainage	Mean	Std
BH01	60778	49.99	8.04
BH02	60828	53.06	2.46
BH03	60878	52.60	4.44
BH04	60928	98.64	1.15
BH05	60978	49.90	6.90
BH06	61028	99.51	0.90
BH07	61078	97.44	1.37

BH08	61128	97.88	1.99
BH09	61178	98.66	1.31
BH10	61228	99.38	1.14
BH11	61278	96.24	2.78
BH12	61308	94.88	8.66

Overall Mean	Std
83.11	22.12

12.4.3 RQD:



12.4.3.1 Mean And Standard Deviation in RQD considering 1D zone of influence in each Borehole:

BH No.	Chainage	Mean	Std
BH01	60778	35.60	13.74
BH02	60828	34.80	11.65
BH03	60878	27.40	5.87
BH04	60928	85.13	6.49
BH05	60978	38.03	13.09
BH06	61028	89.99	6.33
BH07	61078	81.51	9.79
BH08	61128	48.05	13.12
BH09	61178	61.47	11.21
BH10	61228	79.43	13.08
BH11	61278	77.60	12.53
BH12	61308	73.72	19.60

12.4.3.2 Recommended RQD considering 1D zone of influence:

Chainage	Statistical / Reduction Method (Average across boreholes within ±10 m of FL and CL)	Recommended Design Value (RQD_d = μ - σ)	Reference Standards / Guidelines
60780 to 61180	58.43	33.27	IS 11315:1985; Deere (1963)
61180 to 61320	76.81	61.57	

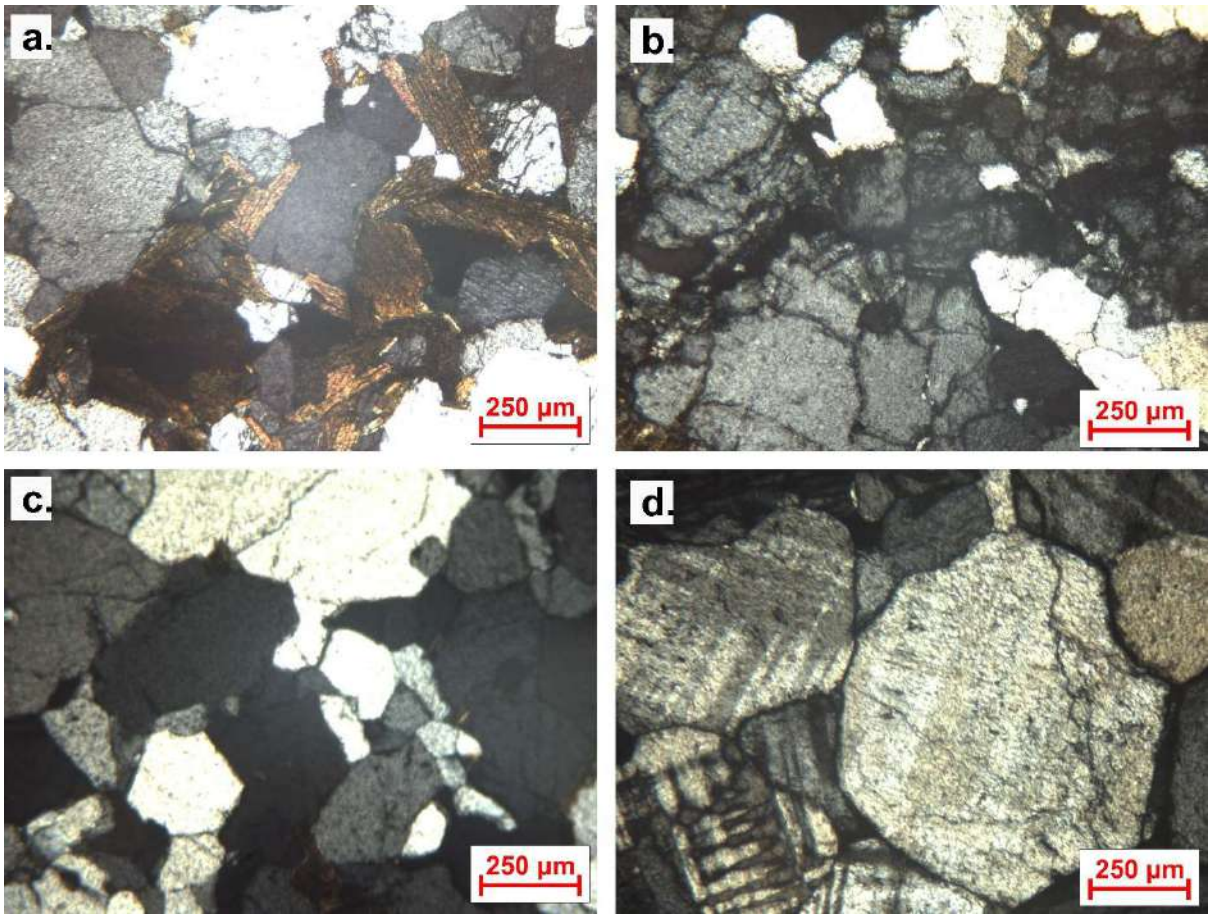
12.5 Petrographic Assessments:

12.5.1 Description of rock Masses

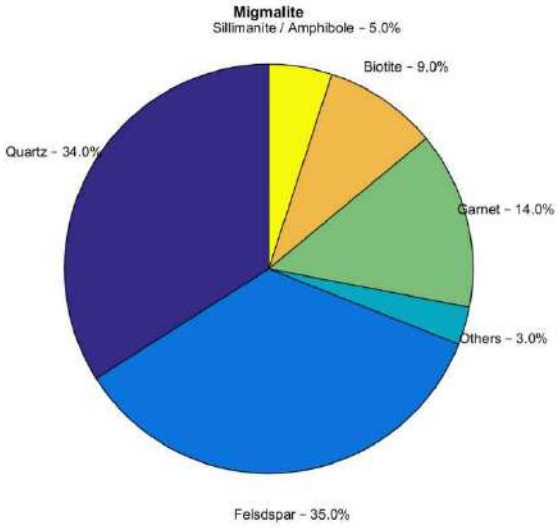
12.5.1.1 Migmatite

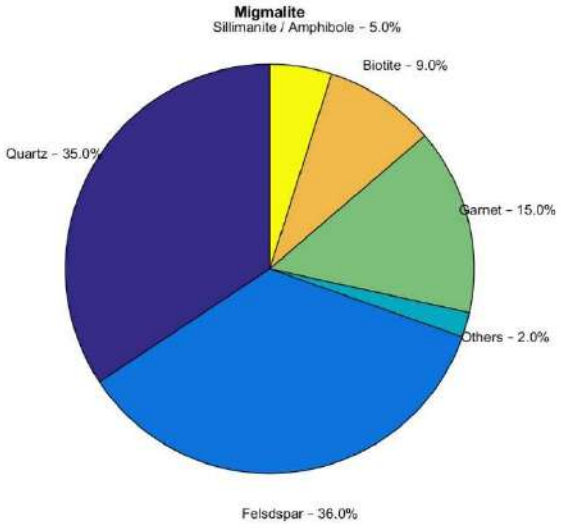
Migmatites of the Eastern Ghats consist of quartz- and feldspar-rich leucosome with garnet- and biotite-bearing melanosome/restite. Petrographic and modal descriptions are consistent with dominant quartz + feldspar (~60–70 %) and subordinate garnet and biotite as reported by Sarkar et al. (2007) and Sengupta et al. (2011).

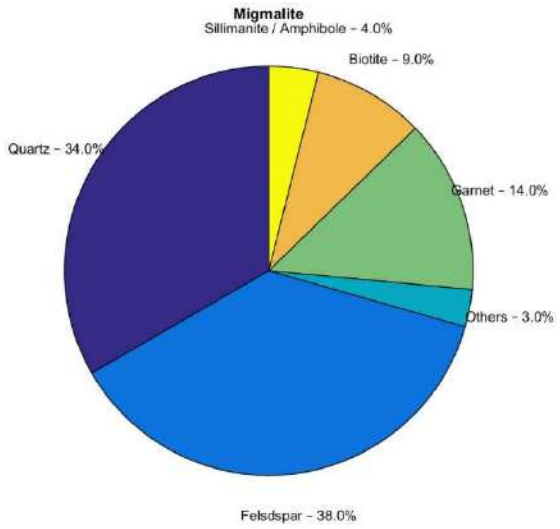
12.5.2 Micro Photographs

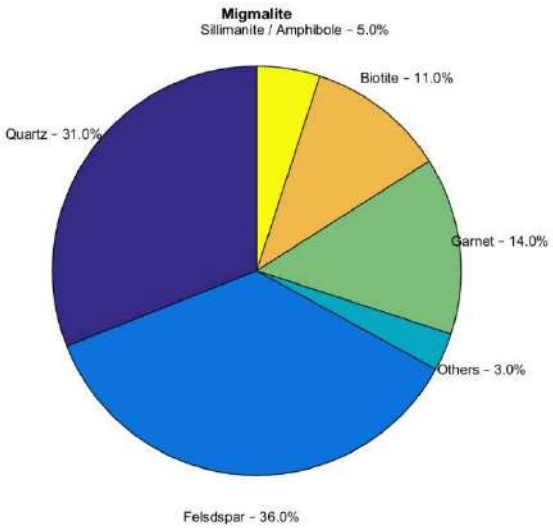


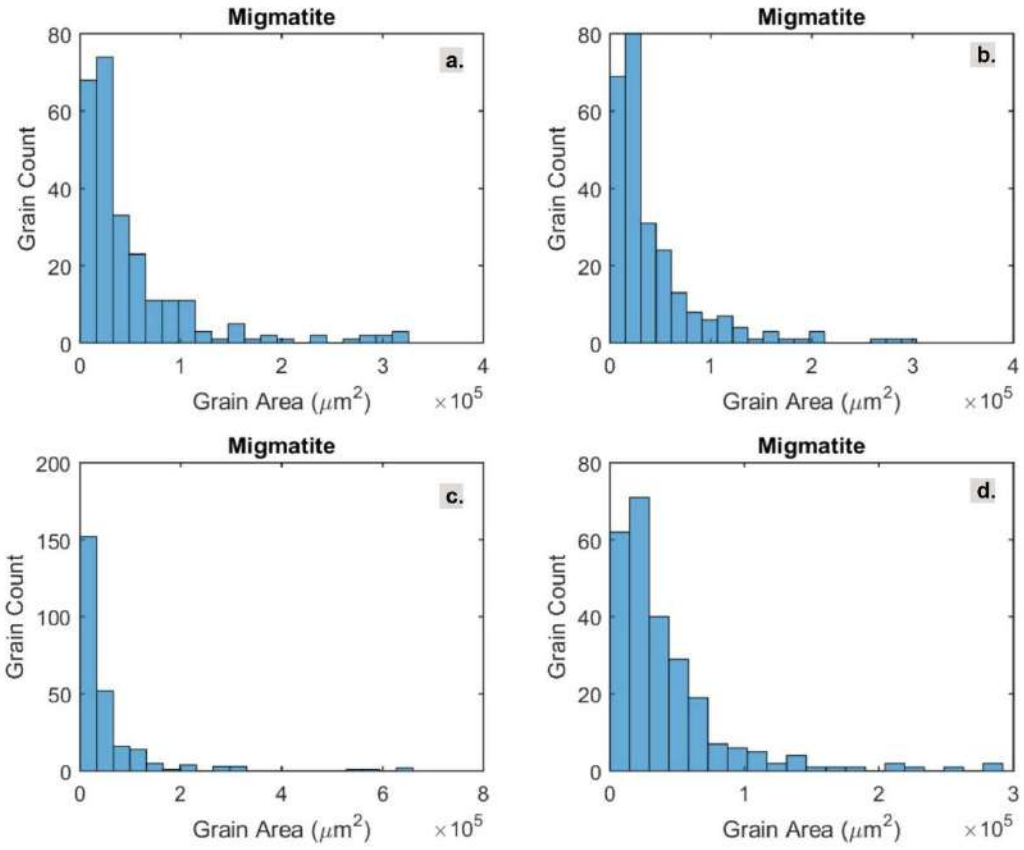
12.5.3 Mineral percentage and grain size distribution



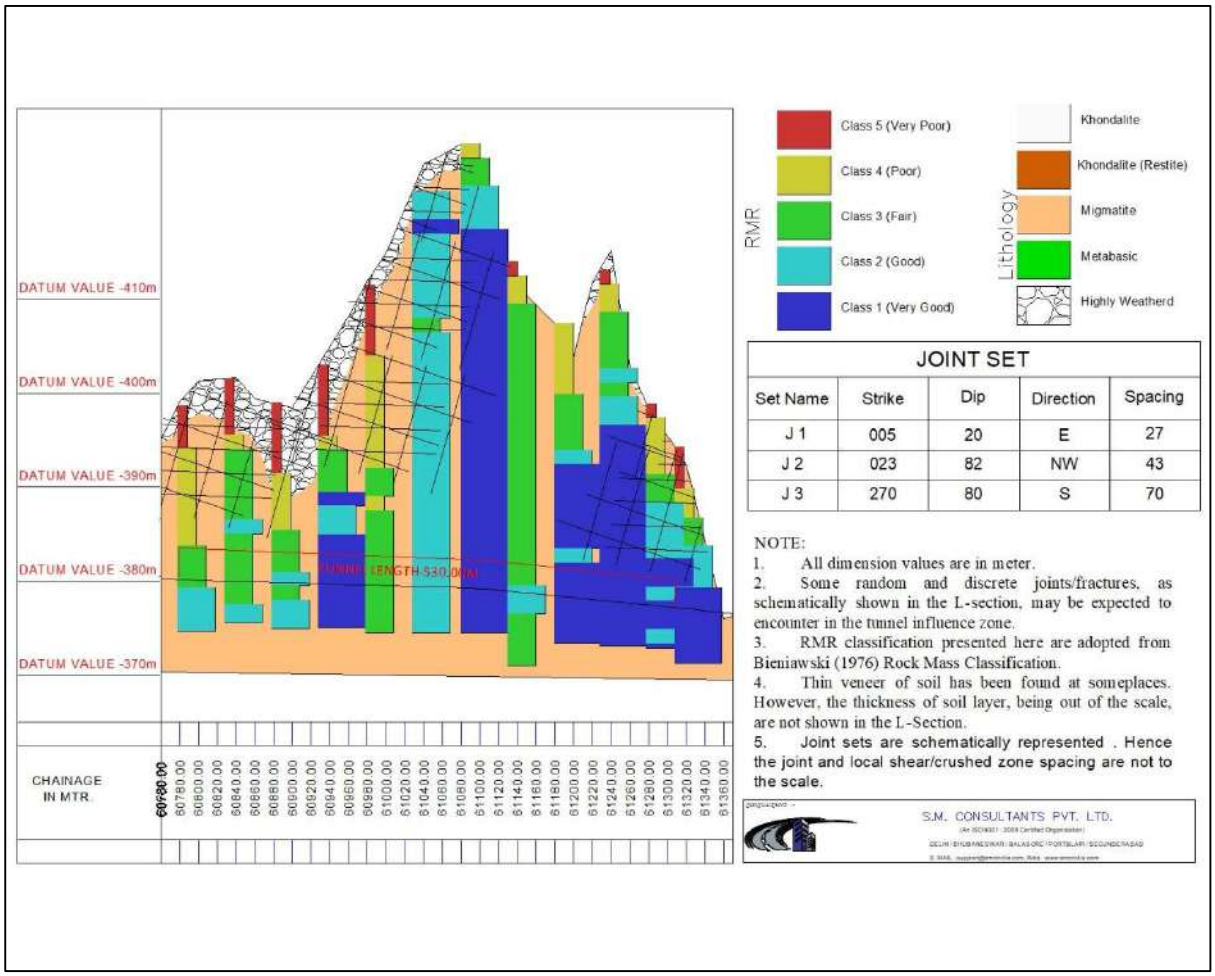







Migmatite
a.
Grain Count
Grain Area (μm^2)
$\times 10^5$
Migmatite
b.
Grain Count
Grain Area (μm^2)
$\times 10^5$
Migmatite
c.
Grain Count
Grain Area (μm^2)
$\times 10^5$
Migmatite
d.
Grain Count
Grain Area (μm^2)
$\times 10^5$

12.6L section:



JOINT SET				
Set Name	Strike	Dip	Direction	Spacing
J 1	005	20	E	27
J 2	023	82	NW	43
J 3	270	80	S	70

NOTE:

1. All dimension values are in meter.
2. Some random and discrete joints/fractures, as schematically shown in the L-section, may be expected to encounter in the tunnel influence zone.
3. RMR classification presented here are adopted from Bieniawski (1976) Rock Mass Classification.
4. Thin veneer of soil has been found at someplaces. However, the thickness of soil layer, being out of the scale, are not shown in the L-Section.
5. Joint sets are schematically represented . Hence the joint and local shear/crushed zone spacing are not to the scale.

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13TUNNEL 8: GEOLOGICAL & GEOTECHNICAL ASSESMENT

13.1Exploratory drillings

As per the requirement of scope of work outlined in the terms of reference, 5 bore holes were drilled with a cumulative length of 143m at different locations along the proposed alignment. Necessary care has been taken during drilling operations by deploying good quality diamond drill machines to obtain good core recovery to obtain RQD values. The locations of the boreholes were selected in such a way, so that these holes intersect the envisaged ground/ strata conditions at different depths. The location and details of boreholes drilled; total depth of drillings is shown in table below.

Chainage	BH	GL	FL	Depth
61529	BH-1	385.657	374.985	18.00
61579	BH-2	401.518	374.485	32.00
61629	BH-3	406.615	373.985	39.00
61679	BH-4	391.968	373.485	24.00
61709	BH-5	389.122	373.185	30.00

13.2TUNNEL-8 SRT

13.2.1Location:

Sr. No.	Chainage	Line	Spread	Location (T-08)		Length
				Start	End	In meter
1	61.529km to 61.709km	L1	S1 to S2	61.529km	61.709km	180

13.2.2 Seismic survey results and conclusion

Table 13.1: Summery of Tunnel-1 SRT test

Variation of maximum range of thicknesses below EGL (M)			Avg. V_p (m/sec)	Calculated V_s (m/sec)	Dynamic Young's Modulus (MPa)	Shear Modulus (MPa)
Layer	From	To				
Layer-I	0.50	1.00	700	327	466	172
Layer-II	1.00	4.50	2200	1132	7441	2819
Layer-III	4.50	25.00	3800	2101	28238	11031

Sample Calculation:

The Young's Modulus E is the uni-axial stress-strain ratio. Its dynamic value is expressed by the following equation:

$$\mathbf{E} = \frac{\rho V_p^2 (1+\mu)(1-2\mu)}{1-\mu}$$

Where, E = Dynamic Young's Modulus in kN/m2

Vp = 700 m/sec

ρ = 1.6 gm/cc ≈ 1.60 kN.s2/m4 (mass density)

μ = 0.36

So, calculated E = 466480 kN/sqm ≈ 466 MPa

The Shear Modulus G is the stress-strain ratio for simple shear. Its dynamic value is obtained by the following:

$$G = \frac{E}{2(1+\mu)} = \rho V_s^2$$

So, Shear Modulus G comes out to be 171500 kN/sqm ≈ 172 MPa

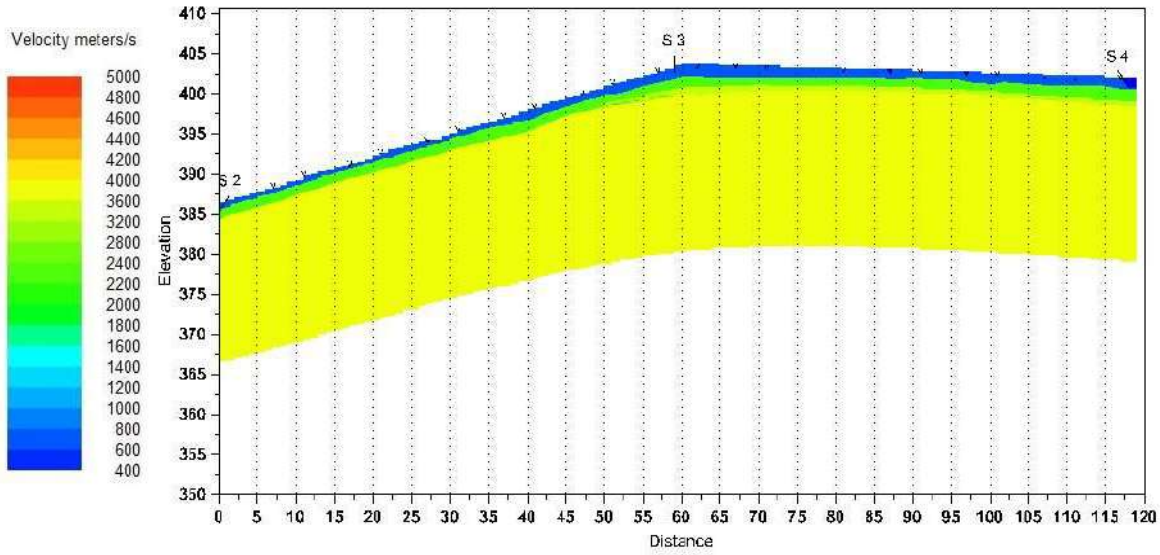
Again,

$G = \rho V_s^2$ giving Vs = √(G/ρ)

So, calculated Vs = 327.395 m/sec, say 327 m/sec

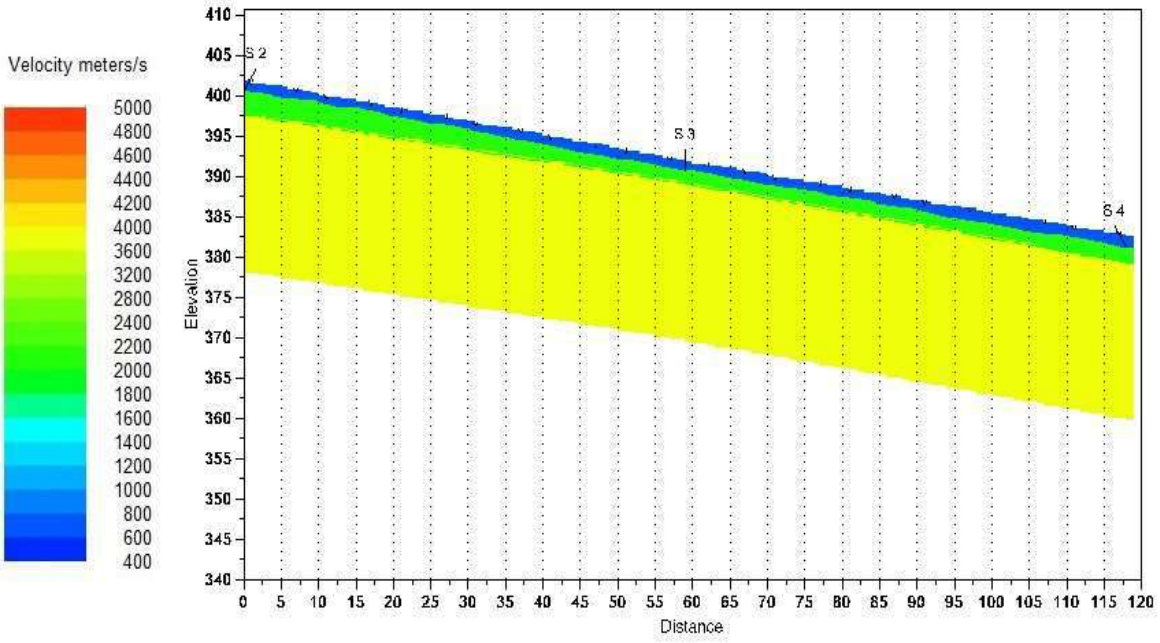
SEISMIC PROFILE(T08)

T08L1S1



Shot point depth computation

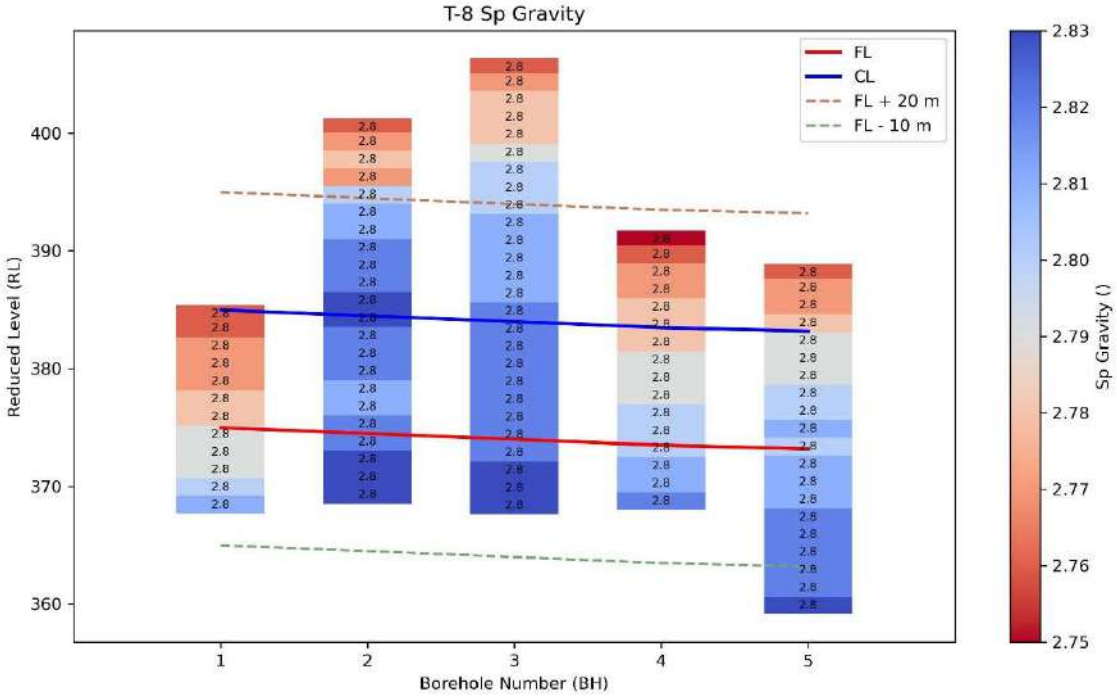
T08L1S2



Shot point depth computation

13.3 Assessment of the engineering properties of rock sample:

13.3.1 Specific Gravity



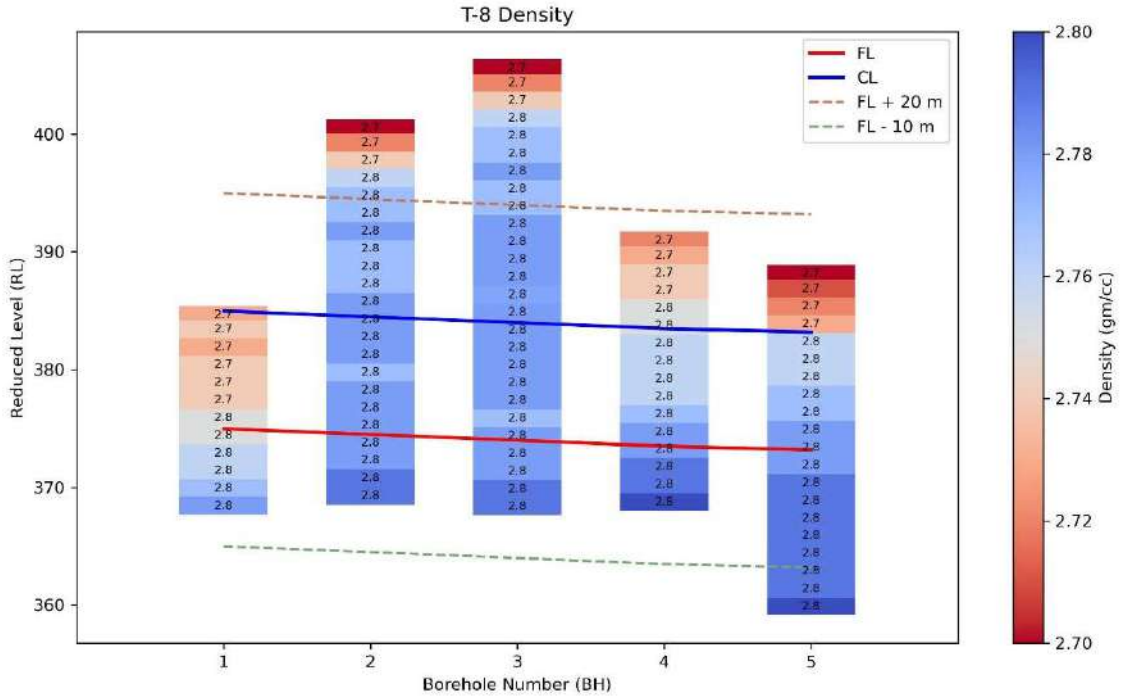
13.3.1.1 Mean and Standard deviation Specific Gravity considering 1D zone of influence of each borehole:

BH No.	Chainage	Mean	Std
BH01	61529	2.78	0.016
BH02	61579	2.82	0.008
BH03	61629	2.82	0.005
BH04	61679	2.80	0.012
BH05	61709	2.81	0.011

13.3.1.2 Recommended Specific Gravity considering 1D zone of influence:

Chainage	Statistical / Reduction Method (Sp = μ - σ across boreholes within ±10 m of FL and CL)	Reference Standards / Guidelines
61520 to 61720	2.79	IS 13030:1991; IS 1124:1974

13.3.2 Dry Density



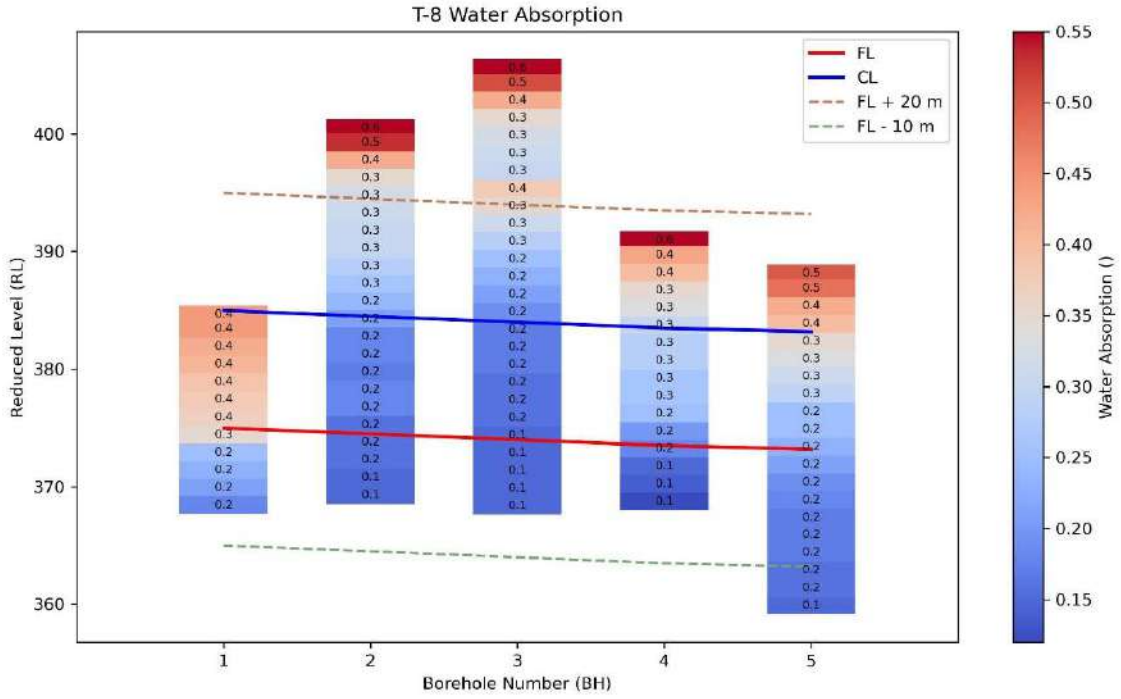
13.3.2.1 Mean and Standard Deviation in Density considering 1D zone of influence of each borehole:

BH No.	Chainage	Mean	Std
BH01	61529	2.75	0.016
BH02	61579	2.78	0.005
BH03	61629	2.78	0.005
BH04	61679	2.78	0.015
BH05	61709	2.78	0.012

13.3.2.2 Recommended Density considering 1D zone of influence:

Chainage	**Statistical / Reduction Method** **(d = μ - σ across boreholes within ±10 m of FL and CL)**	**Reference Standards / Guidelines**
61520 to 61720	2.76	IS 13063:1991

13.3.3 Water absorption Test



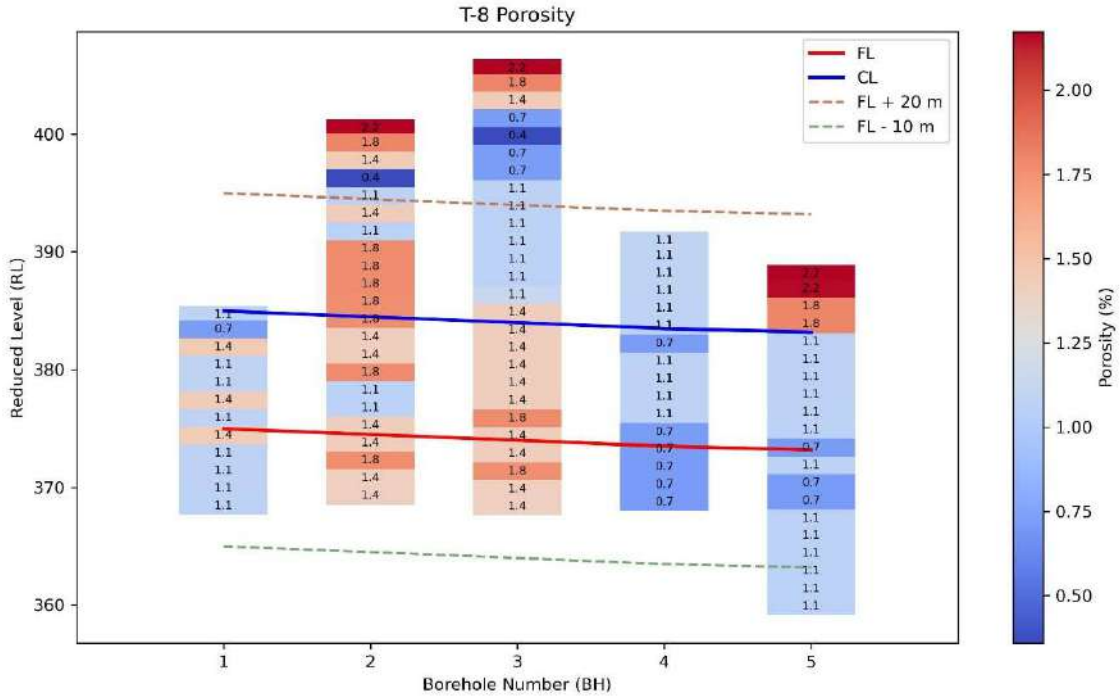
13.3.3.1 Mean and Standard Deviation in Water Absorption Value considering 1D zone of influence:

BH No.	Chainage	Mean	Std
BH01	61529	0.34	0.095
BH02	61579	0.17	0.018
BH03	61629	0.16	0.009
BH04	61679	0.21	0.061
BH05	61709	0.24	0.064

13.3.3.2 Recommended Water Absorption Value considering 1D zone of influence:

Chainage	Statistical / Reduction Method (A= μ + σ across boreholes within ±10 m of FL and CL)	Reference Standards / Guidelines
61520 to 61720	0.31	IS 13063:1991; IS 2386 (Part 3):1963

13.3.4Porosity



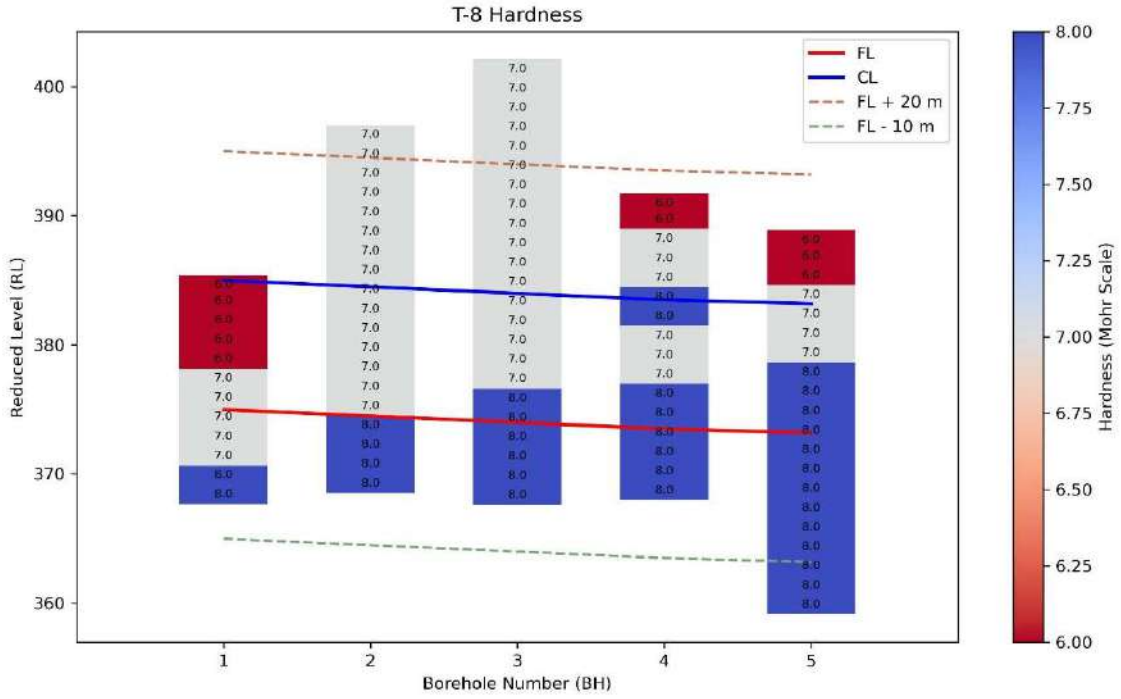
13.3.4.1 Mean And Standard Deviation in Porosity considering 1D zone of influence in each Borehole:

BH No.	Chainage	Mean	Std
BH01	61529	1.14	0.207
BH02	61579	1.45	0.246
BH03	61629	1.48	0.143
BH04	61679	0.86	0.186
BH05	61709	0.99	0.157

13.3.4.2 Recommended Porosity considering 1D zone of influence:

Chainage	**Statistical / Reduction Method** **(n = μ ± σ across boreholes within ±10 m of FL and CL)**	**Reference Standards / Guidelines**
61520 to 61720	1.18±0.31	IS 1124:1974; ISRM (1981)

13.3.5 Hardness



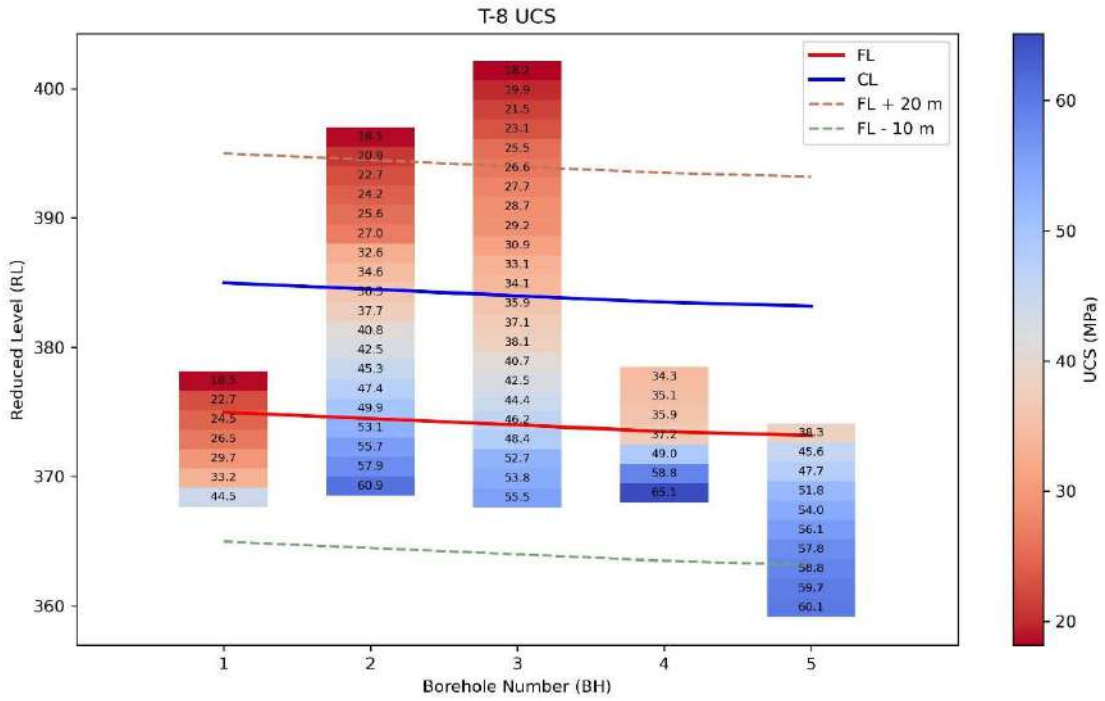
13.3.5.1 Mean And Standard Deviation in Hardness considering 1D zone of influence in each Borehole:

BH No.	Chainage	Mean	Std
BH01	61529	7	0.75
BH02	61579	7	0.50
BH03	61629	8	0.52
BH04	61679	8	0.48
BH05	61709	8	0.44

13.3.5.2 Recommended Hardness considering 1D zone of influence:

Chainage	Statistical / Reduction Method (Hi = μ - σ across boreholes within ±10 m of FL and CL)	Reference Standards / Guidelines
61520 to 61720	7	IS 13311 (Part 2):1992; ISRM 1978

13.3.6Compression Test



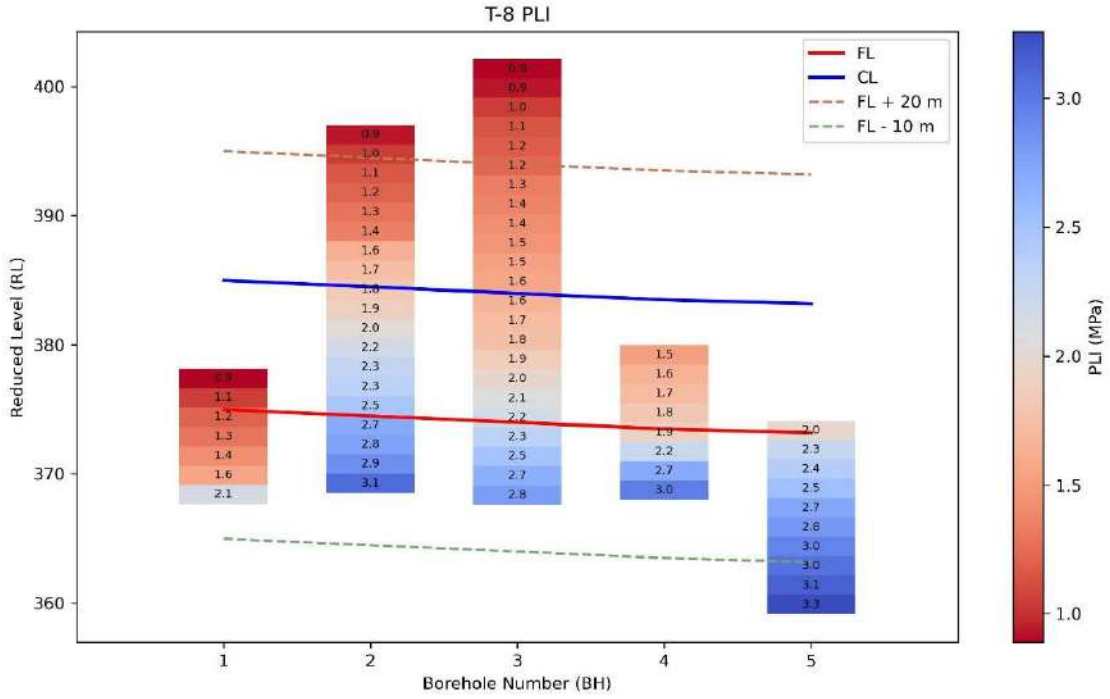
13.3.6.1 Mean And Standard Deviation in UCS considering 1D zone of influence in each Borehole:

BH No.	Chainage	Mean	Std
BH01	61529	28.51	8.49
BH02	61579	47.96	8.28
BH03	61629	45.03	6.91
BH04	61679	45.07	12.69
BH05	61709	50.18	6.82

13.3.6.2 Recommended UCS considering 1D zone of influence:

Chainage	**Statistical / Reduction Method** **(UCS_k = μ - σ) across boreholes within ±10 m of FL and CL)**	**Recommended Design Value** **(UCS_d = (μ - σ) × f(RMR)), where (f(RMR) = 0.1–0.7)**	**Reference Standards / Guidelines**
61520 to 61720	33.05	6.61	IS 9143:1979; IS 13365 (Part 2):1998; Hoek & Brown (2002, 2019)

13.3.7Point Load Test



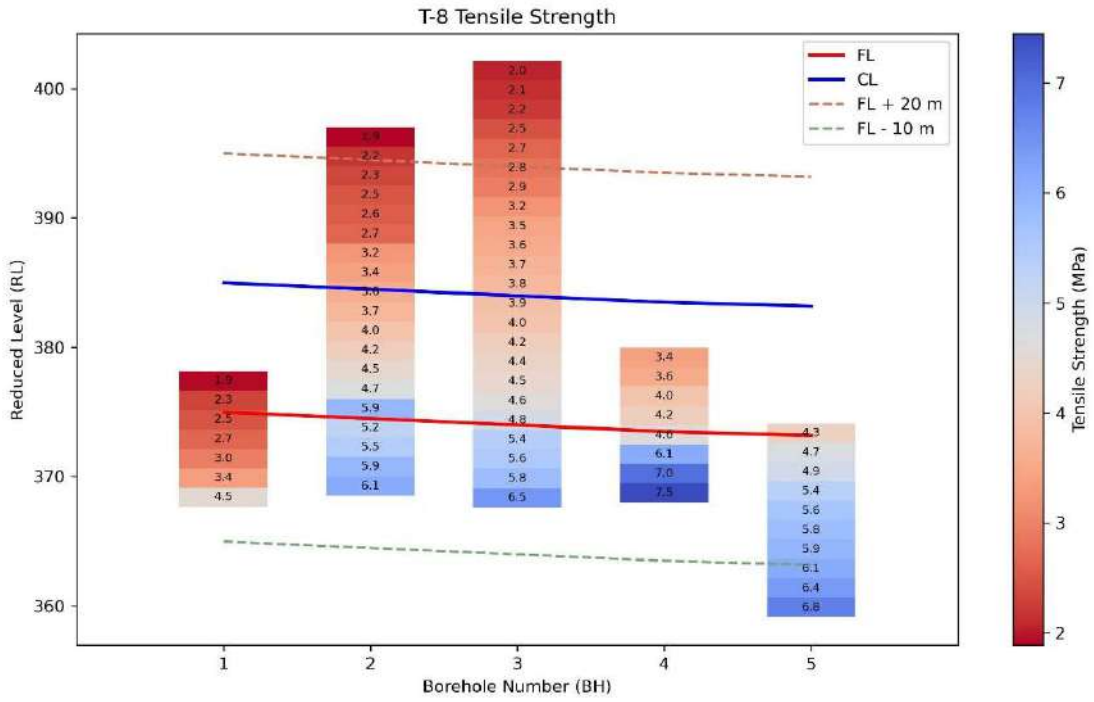
13.3.7.1 Mean And Standard Deviation in PLI considering 1D zone of influence in each Borehole:

BH No.	Chainage	Mean	Std
BH01	61529	1.37	0.41
BH02	61579	2.40	0.41
BH03	61629	2.13	0.39
BH04	61679	2.07	0.53
BH05	61709	2.52	0.34

13.3.7.2 Recommended PLI considering 1D zone of influence:

Chainage	Statistical / Reduction Method (PLI_k = μ - σ) across boreholes within ±10 m of FL and CL)	Recommended Design Value (PLI_d = (μ - σ) × f(RMR)), where (f(RMR) = 0.1–0.7)	Reference Standards / Guidelines
61520 to 61720	1.58	0.3	IS 9143:1979; IS 13365 (Part 2):1998; Hoek & Brown (2002, 2019)

13.3.8 Brazilian Test



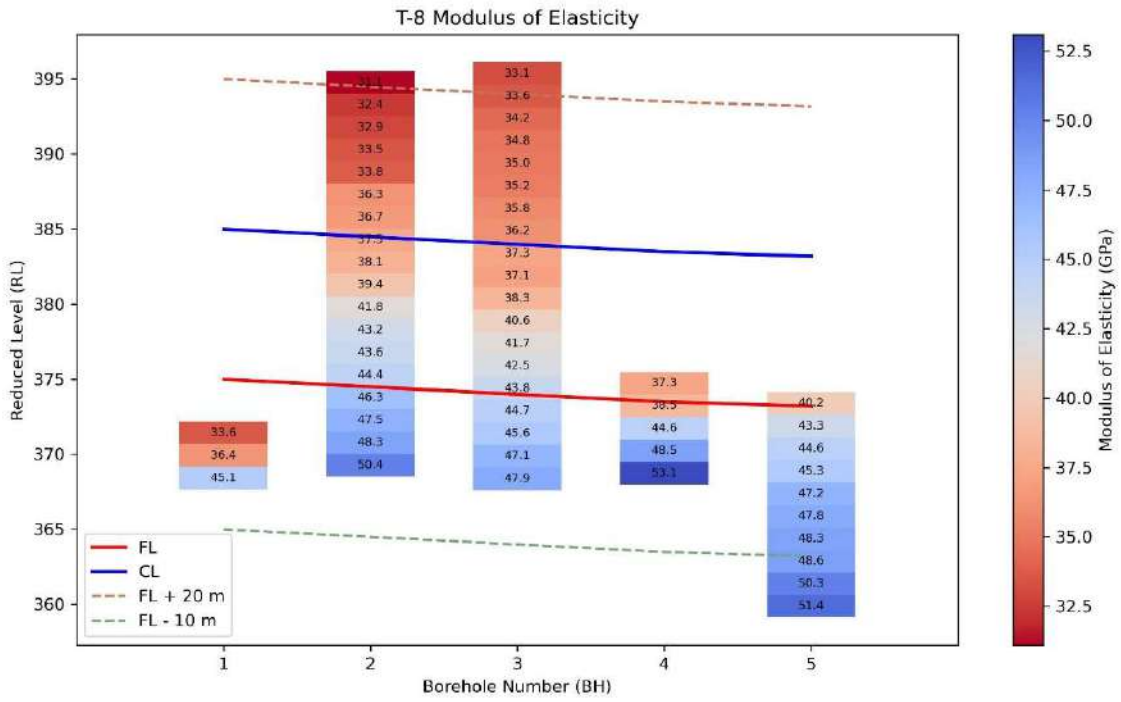
13.3.8.1 Mean And Standard Deviation in Tensile Strength considering 1D zone of influence in each Borehole:

BH No.	Chainage	Mean	Std
BH01	61529	2.88	0.84
BH02	61579	4.84	0.92
BH03	61629	4.87	0.83
BH04	61679	5.04	1.58
BH05	61709	5.24	0.62

13.3.8.2 Recommended Tensile Strength considering 1D zone of influence:

Chainage	**Statistical / Reduction Method** **(mean value across boreholes within ±10 m of FL and CL× 0.8 (account for anisotropy))**	**Recommended Design Value** **(μ - σ)**	**Reference Standards / Guidelines**
61520 to 61720	4.64	3.40	IS 10082:1982; Hoek & Brown (1997); ISRM Suggested Methods

13.3.9 Modulus of elasticity test



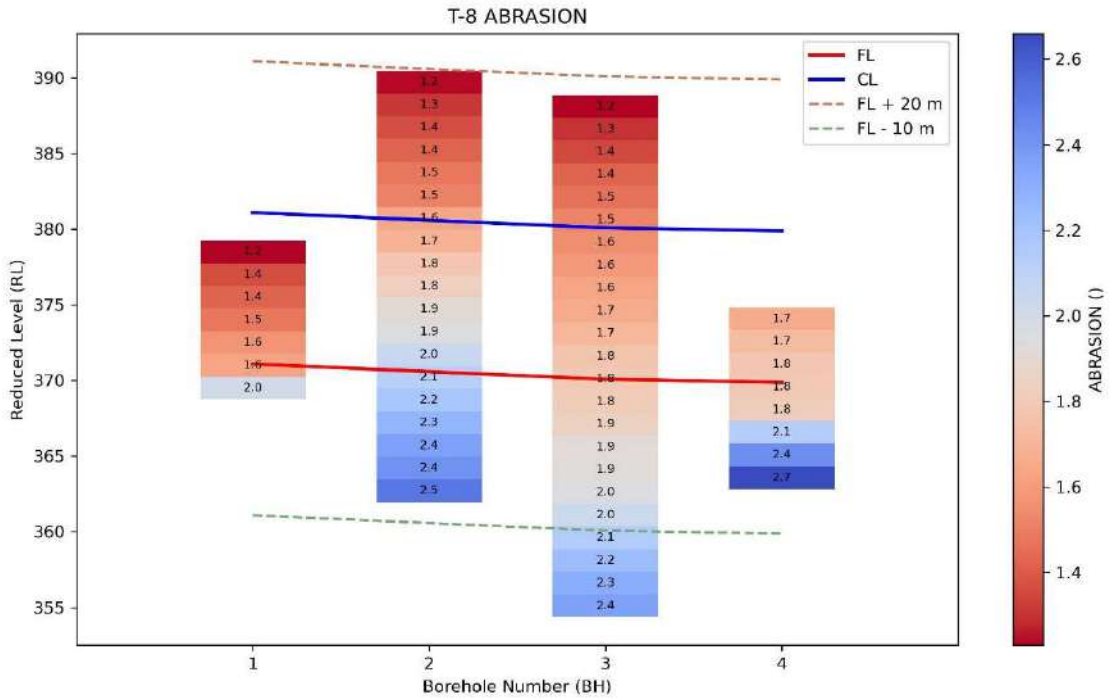
13.3.9.1 Mean And Standard Deviation in Elasticity considering 1D zone of influence in each Borehole:

BH No.	Chainage	Mean	Std
BH01	61529	38.37	6.00
BH02	61579	43.68	4.24
BH03	61629	42.42	3.80
BH04	61679	44.40	6.67
BH05	61709	45.24	2.87

13.3.9.2 Recommended Modulus of Elasticity considering 1D zone of influence:

Chainage	Statistical / Reduction Method (Ei = μ - σ across boreholes within ±10 m of FL and CL× 0.8 (account for anisotropy))	Recommended Design Value (Ed = (μ - σ) × f(RMR)), where (f(RMR) = 0.1–0.7)	Reference Standards / Guidelines
61520 to 61720	38.74	7.74	IS 13365 (Part 2):1998; Hoek & Diederichs (2006)

13.3.10 Abrasion test



13.3.10.1 Mean And Standard Deviation in Abrasion value considering 1D zone of influence in each Borehole:

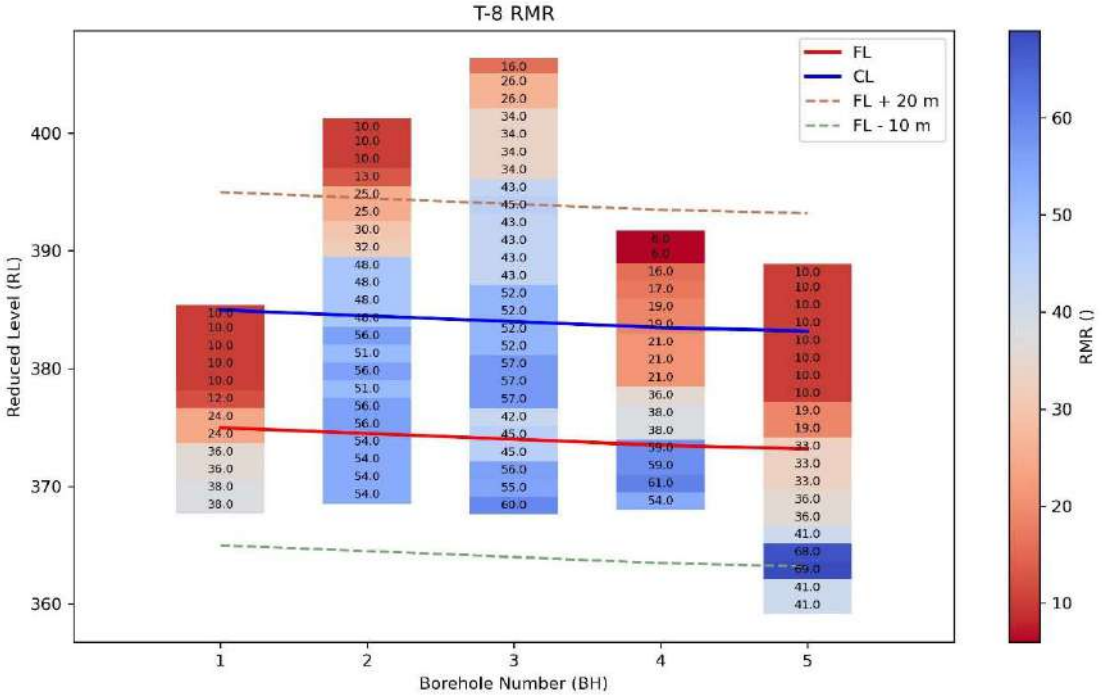
BH No.	Chainage	Mean	Std
BH01	61529	1.53	0.25
BH02	61579	2.12	0.25
BH03	61629	2.03	0.20
BH04	61679	2.00	0.37
BH05	61709	1.93	0.34

13.3.10.2 Recommended Abrasion Value considering 1D zone of influence:

Chainage	**Statistical / Reduction Method** **(A= μ + σ across boreholes within ±10 m of FL and CL)**	**Recommended Design Value** **(A_v < 25%): Slightly abrasive; 25–35%: Moderately abrasive; >35%: Highly abrasive. (CAI = 0.5–6).**	**Reference Standards / Guidelines**
61520 to 61720	2.28	Slightly abrasive	IS 2386 (Part 4):1963; ISRM (2007); CERCHAR (1986)

13.4Geological assessment:

13.4.1RMR:



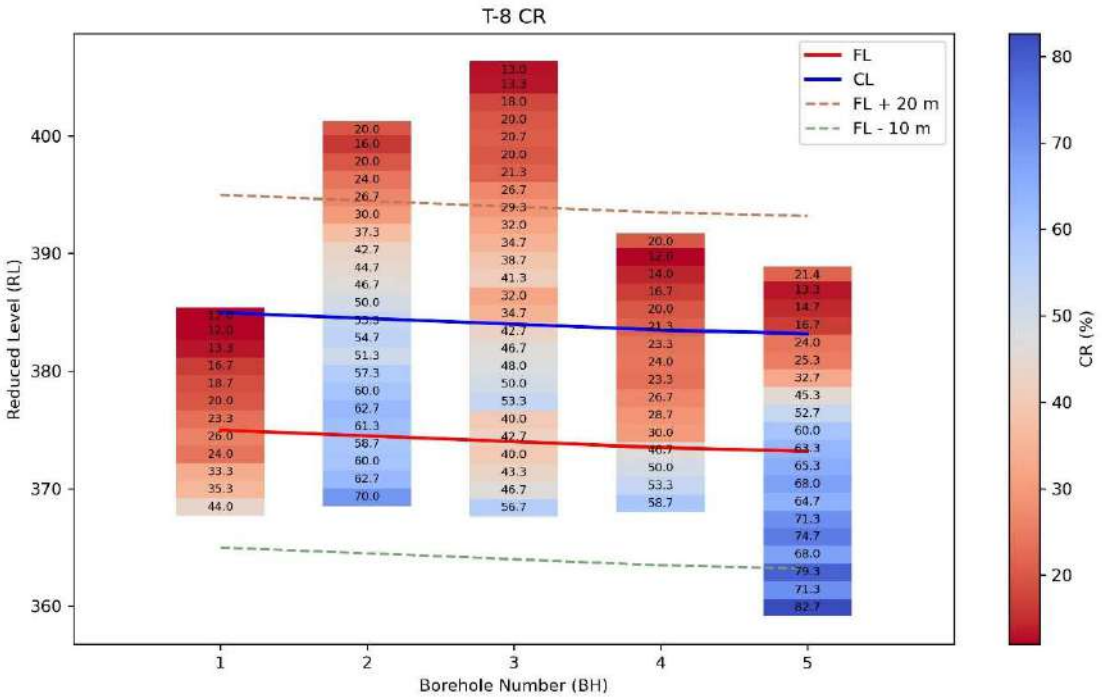
13.4.1.1 Mean And Standard Deviation in RMR considering 1D zone of influence in each Borehole:

BH No.	Chainage	Mean	Std
BH01	61529	22	12.54
BH02	61579	54	2.62
BH03	61629	53	5.99
BH04	61679	41	16.53
BH05	61709	28	16.90

13.4.1.2 Recommended RMR considering 1D zone of influence:

Chainage	Statistical / Reduction Method (Average across boreholes within ±10 m of FL and CL)	Recommended Design Value (RMR_d = μ - σ)	Reference Standards / Guidelines
61520 to 61720	38 (Class IV)	21 (Class IV)	IS 13365 (Part 2): 1998, Cl. 5.1 + Note on "representative values"

13.4.2 Core Recovery:

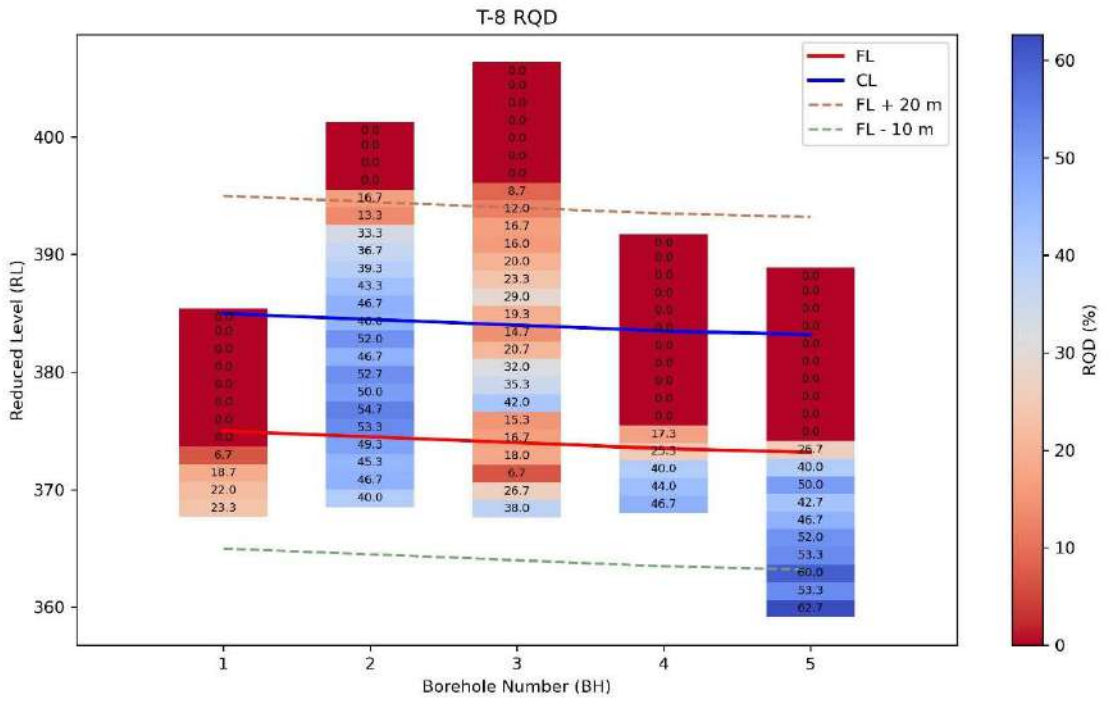


13.4.2.1 Mean And Standard Deviation in Core Recovery considering 1D zone of influence in each Borehole:

BH No.	Chainage	Mean	Std
BH01	61529	23.22	10.06
BH02	61579	59.27	5.17
BH03	61629	46.36	5.37
BH04	61679	36.46	14.00
BH05	61709	55.02	17.62

Overall Mean	**Std**
44.22	17.48

13.4.3 RQD:



13.4.3.1 Mean And Standard Deviation in RQD considering 1D zone of influence in each Borehole:

BH No.	Chainage	Mean	Std
BH01	61529	5.89	9.56
BH02	61579	48.78	4.34
BH03	61629	24.18	11.33
BH04	61679	17.33	20.14
BH05	61709	23.95	23.98

13.4.3.2 Recommended RQD considering 1D zone of influence:

Chainage	Statistical / Reduction Method (Average across boreholes within ±10 m of FL and CL)	Recommended Design Value (RQD_d = μ - σ)	Reference Standards / Guidelines
61520 to 61720	23.82	3.05	IS 11315:1985; Deere (1963)

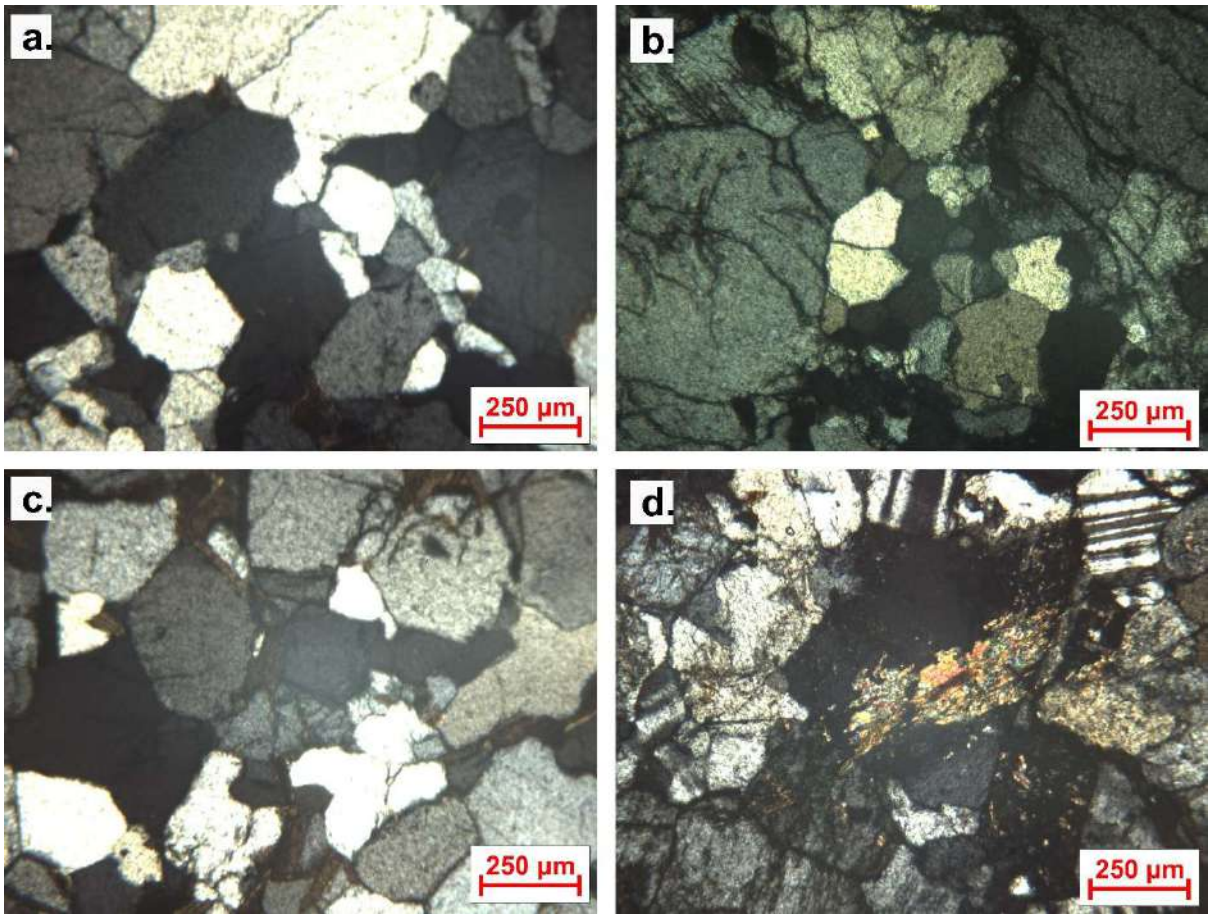
13.5 Petrographic Assessments:

13.5.1 Description of rock Masses

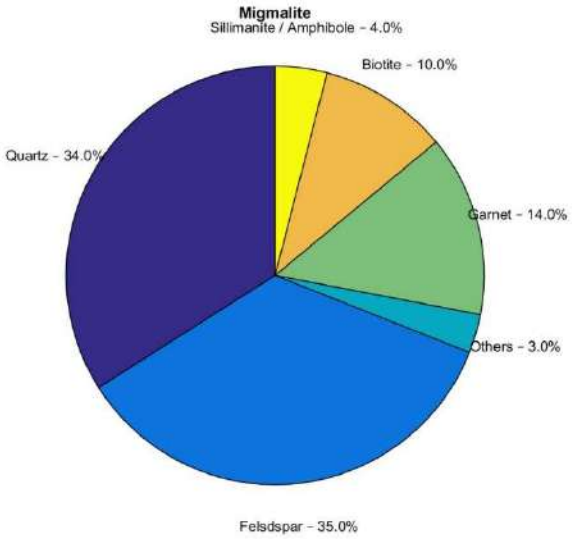
13.5.1.1 Migmatite

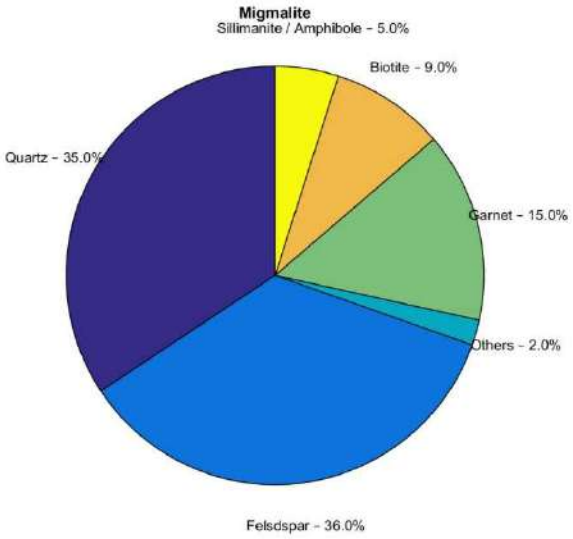
Migmatites of the Eastern Ghats consist of quartz- and feldspar-rich leucosome with garnet- and biotite-bearing melanosome/restite. Petrographic and modal descriptions are consistent with dominant quartz + feldspar (~60–70 %) and subordinate garnet and biotite as reported by Sarkar et al. (2007) and Sengupta et al. (2011).

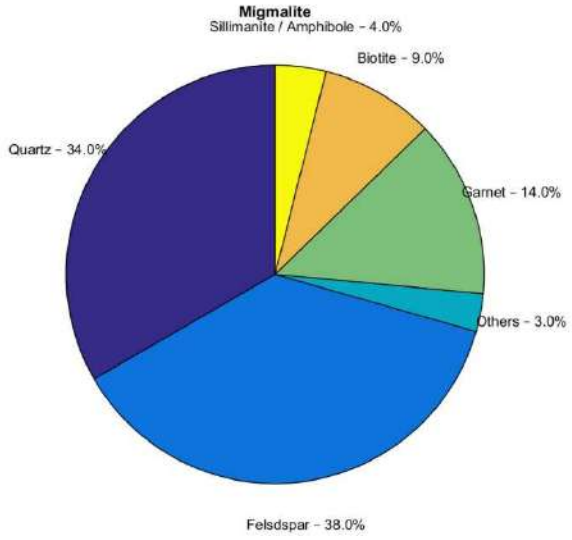
13.5.2 Micro Photographs

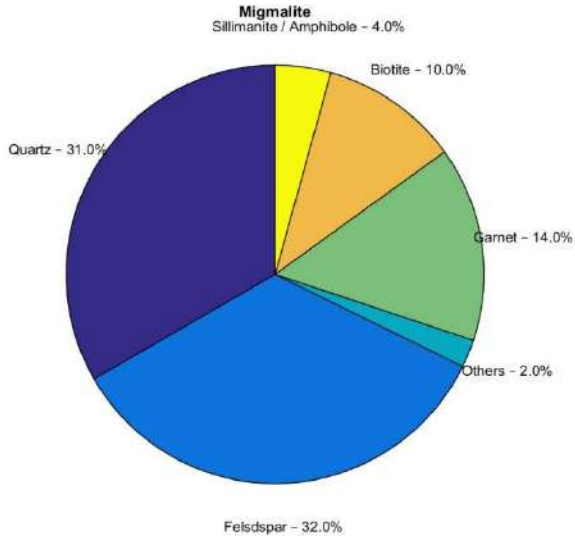


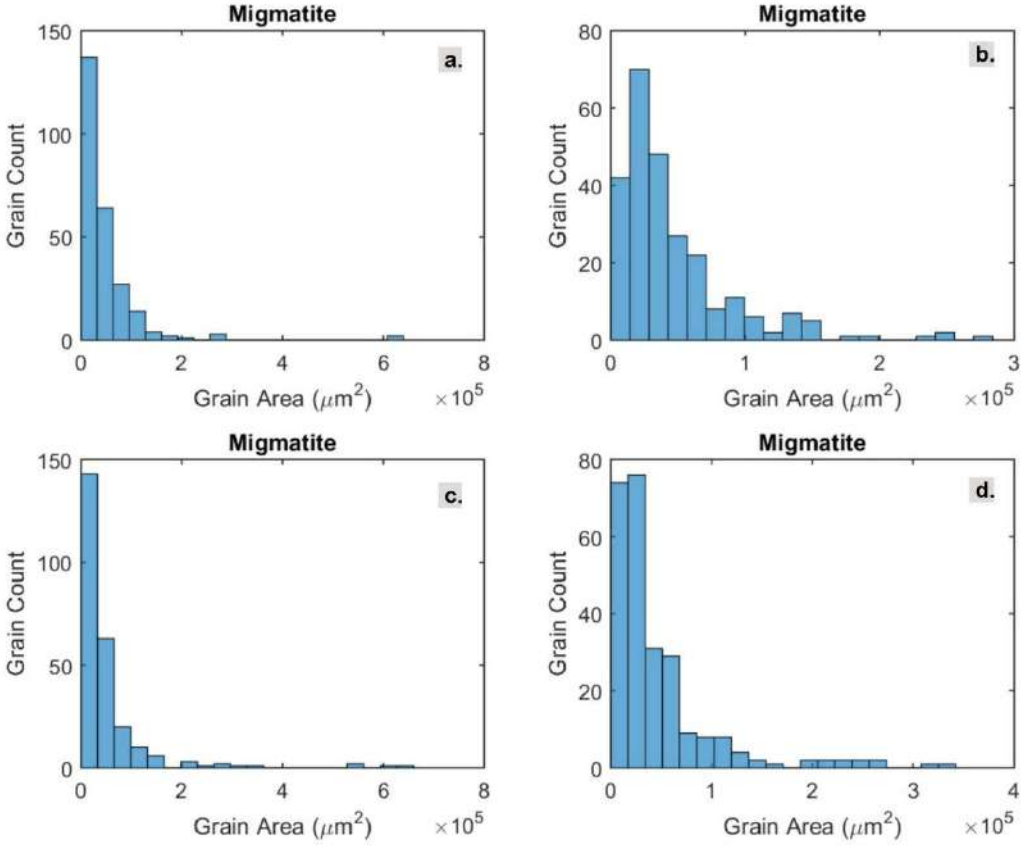
13.5.3 Mineral percentage and grain size distribution



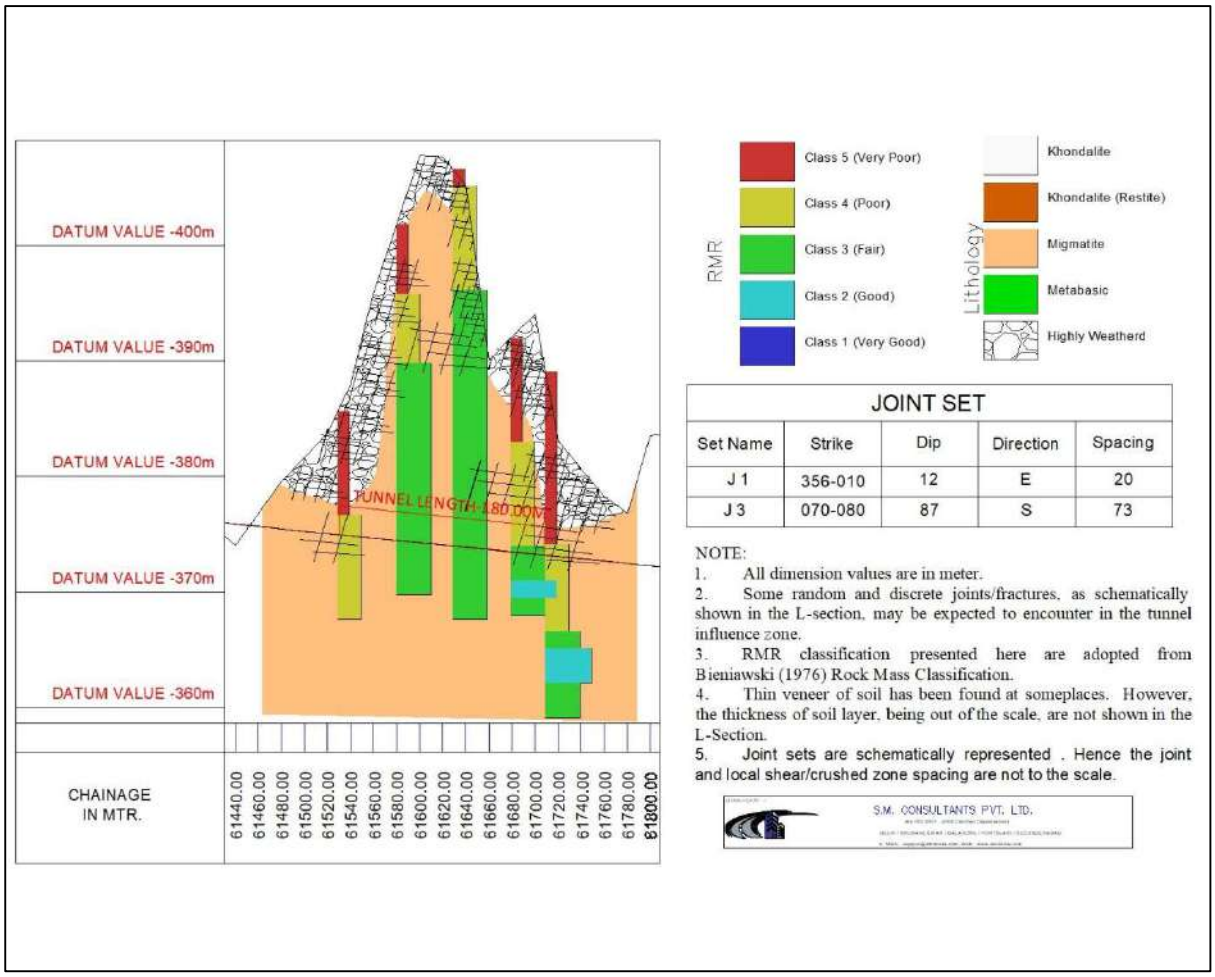








13.6L section:



JOINT SET				
Set Name	Strike	Dip	Direction	Spacing
J 1	356-010	12	E	20
J 3	070-080	87	S	73

NOTE:

1. All dimension values are in meter.
2. Some random and discrete joints/fractures, as schematically shown in the L-section, may be expected to encounter in the tunnel influence zone.
3. RMR classification presented here are adopted from Bieniawski (1976) Rock Mass Classification.
4. Thin veneer of soil has been found at someplaces. However, the thickness of soil layer, being out of the scale, are not shown in the L-Section.
5. Joint sets are schematically represented . Hence the joint and local shear/crushed zone spacing are not to the scale.

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14TUNNEL 9: GEOLOGICAL & GEOTECHNICAL ASSESMENT

14.1Exploratory drillings

As per the requirement of scope of work outlined in the terms of reference, 4 bore holes were drilled with a cumulative length of 101m at different locations along the proposed alignment. Necessary care has been taken during drilling operations by deploying good quality diamond drill machines to obtain good core recovery to obtain RQD values. The locations of the boreholes were selected in such a way, so that these holes intersect the envisaged ground/ strata conditions at different depths. The location and details of boreholes drilled; total depth of drillings is shown in table below.

Chainage	BH	GL	FL	Depth
61919	BH-1	386.748	371.085	21.00
61969	BH-2	394.962	370.585	30.00
62019	BH-3	393.356	370.085	28.00
62040	BH-4	386.827	369.875	22.00

14.2TUNNEL-9 SRT

14.2.1Location:

Sr. No.	Chainage	Line	Spread	Location (T-09)		Length
				Start	End	In meter
1	61.919km to 62.040km	L1	S1	61.919km	62.040km	121

14.2.2 Seismic survey results and conclusion

Table 14.1: Summery of Tunnel-1 SRT test

Variation of maximum range of thicknesses below EGL (M)			Avg. V_p (m/sec)	Calculated V_s (m/sec)	Dynamic Young's Modulus (MPa)	Shear Modulus (MPa)
Layer	From	To				
Layer-I	0.50	1.50	700	327	466	172
Layer-II	1.50	7.50	2400	1235	8855	3354
Layer-III	7.50	25.00	3800	2101	28238	11031

Sample Calculation:

The Young's Modulus E is the uni-axial stress-strain ratio. Its dynamic value is expressed by the following equation:

$$\mathbf{E} = \frac{\rho V_p^2 (1+\mu)(1-2\mu)}{1-\mu}$$

Where, E = Dynamic Young's Modulus in kN/m2

Vp = 700 m/sec

ρ = 1.6 gm/cc ≈ 1.60 kN.s2/m4 (mass density)

μ = 0.36

So, calculated E = 466480 kN/sqm ≈ 466 MPa

The Shear Modulus G is the stress-strain ratio for simple shear. Its dynamic value is obtained by the following:

$$G = \frac{E}{2(1+\mu)} = \rho V_s^2$$

So, Shear Modulus G comes out to be 171500 kN/sqm ≈ 172 MPa

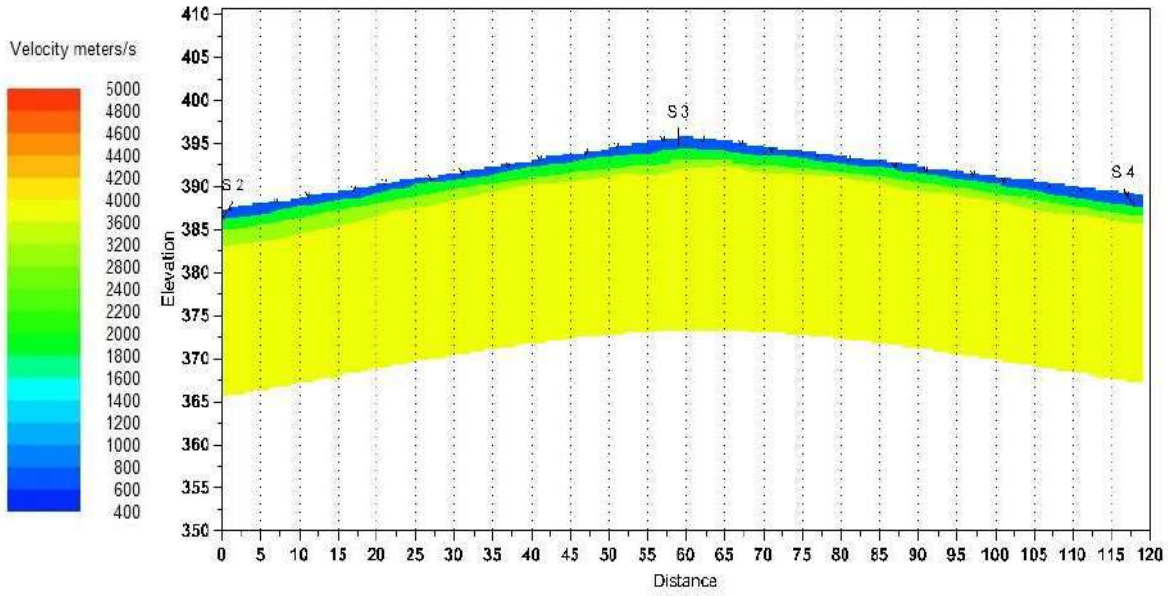
Again,

$G = \rho V_s^2$ giving Vs = √(G/ρ)

So, calculated Vs = 327.395 m/sec, say 327 m/sec

SEISMIC PROFILE(T09)

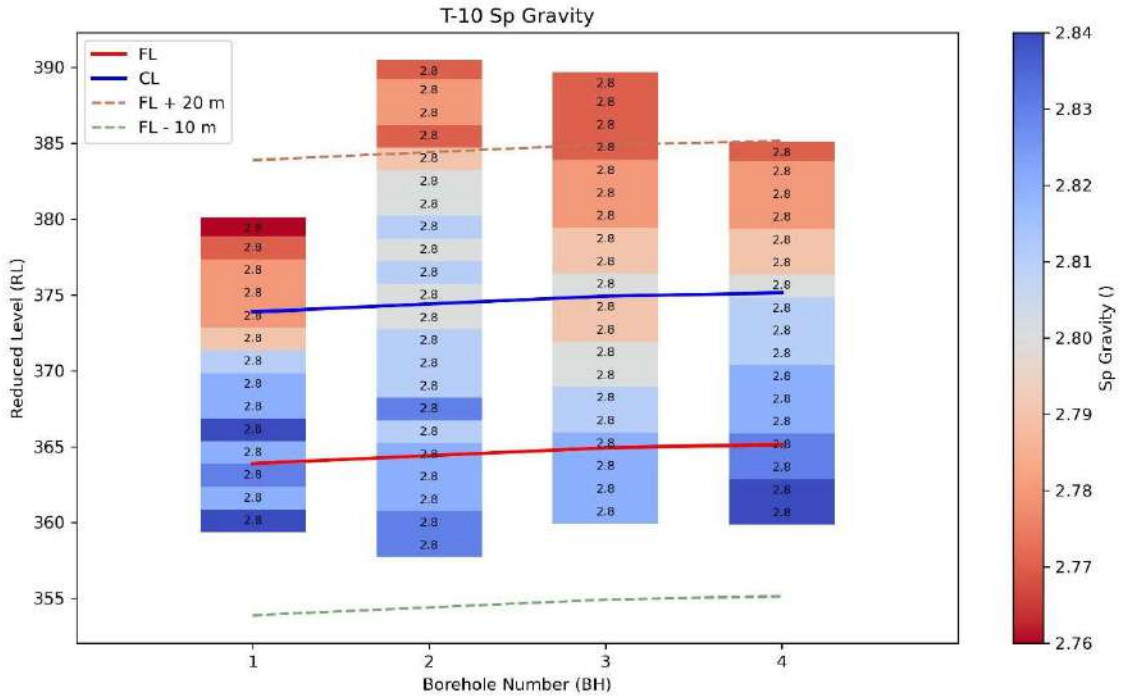
T09L1S1



Shot point depth computation

14.3 Assessment of the engineering properties of rock sample:

14.3.1 Specific Gravity



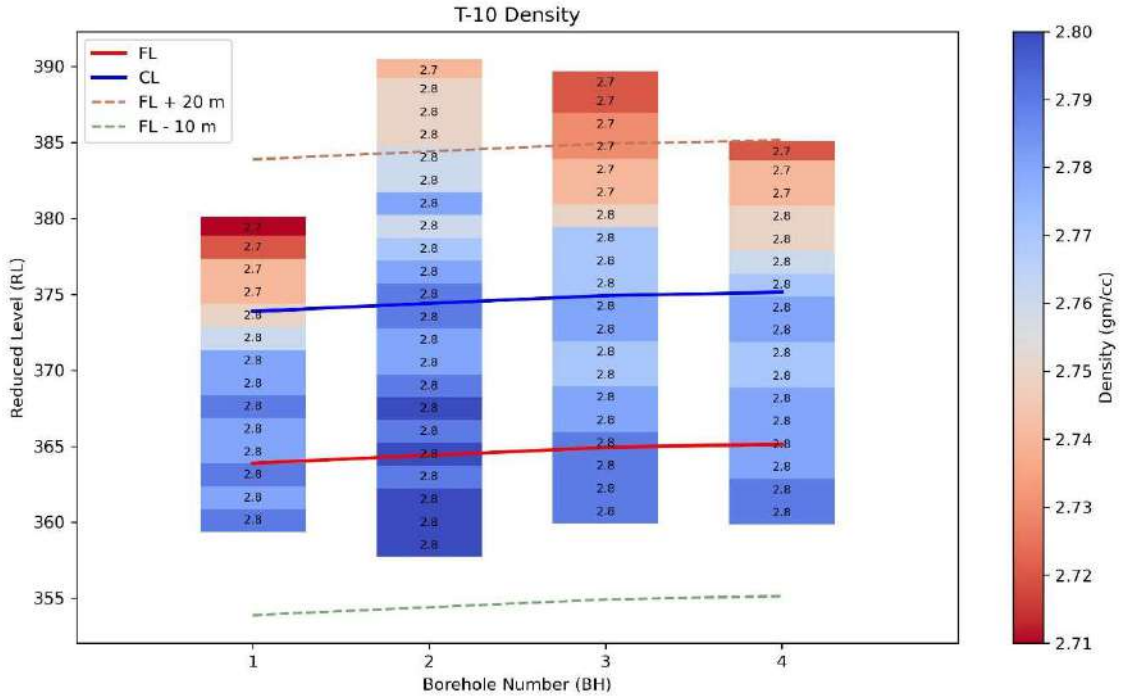
14.3.1.1 Mean and Standard deviation Specific Gravity considering 1D zone of influence of each borehole:

BH No.	Chainage	Mean	Std
BH01	61919	2.82	0.014
BH02	61969	2.83	0.013
BH03	62019	2.82	0.011
BH04	62040	2.82	0.014

14.3.1.2 Recommended Specific Gravity considering 1D zone of influence:

Chainage	Statistical / Reduction Method (Sp = μ - σ across boreholes within ±10 m of FL and CL)	Reference Standards / Guidelines
61918 to 61960	2.80	IS 13030:1991; IS 1124:1974
61960 to 62060	2.81	

14.3.2 Dry Density



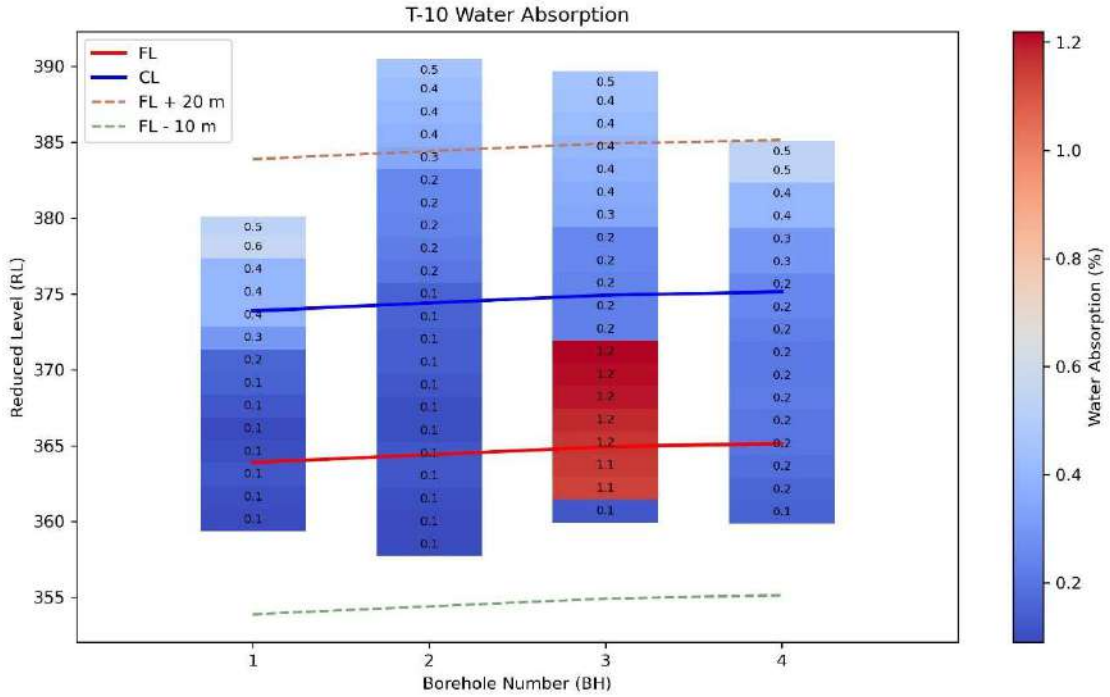
14.3.2.1 Mean and Standard Deviation in Density considering 1D zone of influence of each borehole:

BH No.	Chainage	Mean	Std
BH01	61919	2.77	0.011
BH02	61969	2.78	0.008
BH03	62019	2.80	0.009
BH04	62040	2.80	0.011

14.3.2.2 Recommended Density considering 1D zone of influence:

Chainage	**Statistical / Reduction Method** **(d = μ - σ across boreholes within ±10 m of FL and CL)**	**Reference Standards / Guidelines**
61918 to 61960	2.76	IS 13063:1991
61960 to 62060	2.78	

14.3.3 Water absorption Test



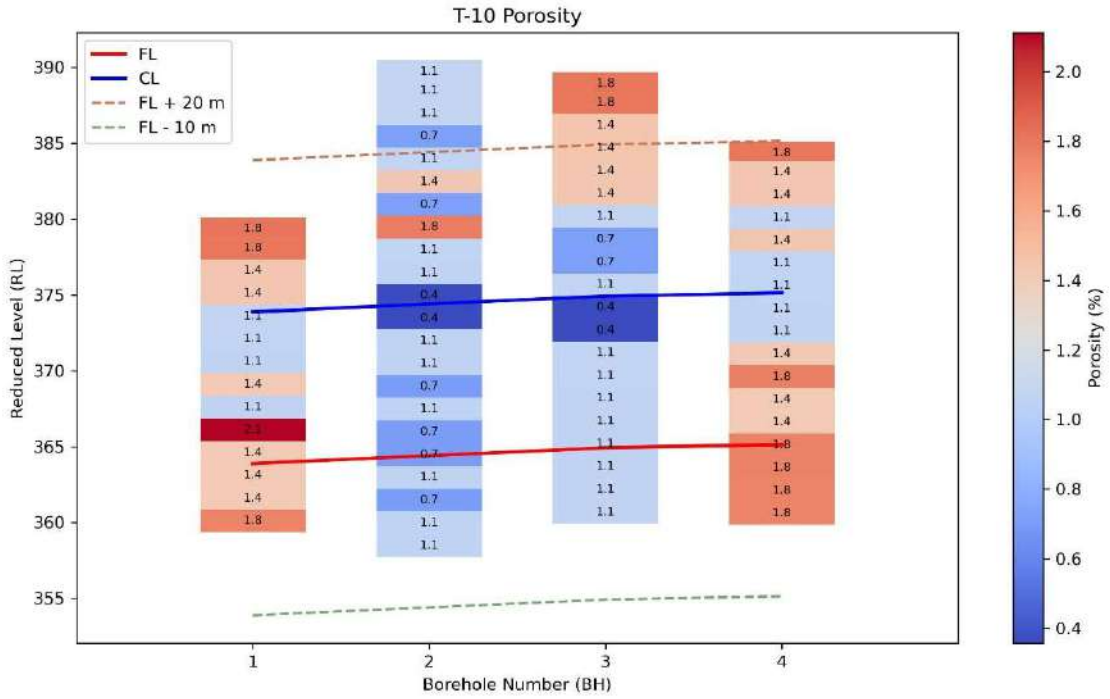
14.3.3.1 Mean and Standard Deviation in Water Absorption Value considering 1D zone of influence:

BH No.	Chainage	Mean	Std
BH01	61919	0.20	0.067
BH02	61969	0.19	0.065
BH03	62019	0.14	0.036
BH04	62040	0.15	0.040

14.3.3.2 Recommended Water Absorption Value considering 1D zone of influence:

Chainage	Statistical / Reduction Method (A= μ + σ across boreholes within ±10 m of FL and CL)	Reference Standards / Guidelines
61918 to 61960	0.27	IS 13063:1991; IS 2386 (Part 3):1963
61960 to 62060	0.21	

14.3.4Porosity



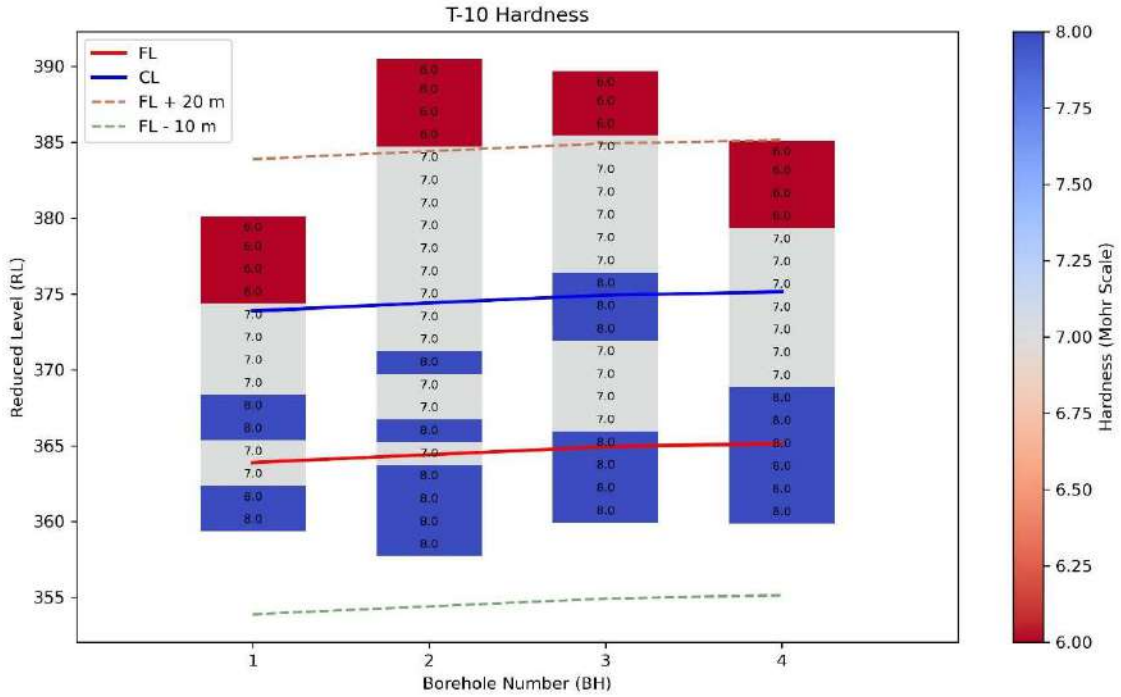
14.3.4.1 Mean And Standard Deviation in Porosity considering 1D zone of influence in each Borehole:

BH No.	Chainage	Mean	Std
BH01	61919	1.74	0.26
BH02	61969	1.73	0.25
BH03	62019	0.78	0.32
BH04	62040	0.74	0.35

14.3.4.2 Recommended Porosity considering 1D zone of influence:

Chainage	**Statistical / Reduction Method** **(n = μ ± σ across boreholes within ±10 m of FL and CL)**	**Reference Standards / Guidelines**
61918 to 61960	1.74±0.26	IS 1124:1974; ISRM (1981)
61960 to 62060	1.09±0.55	

14.3.5 Hardness



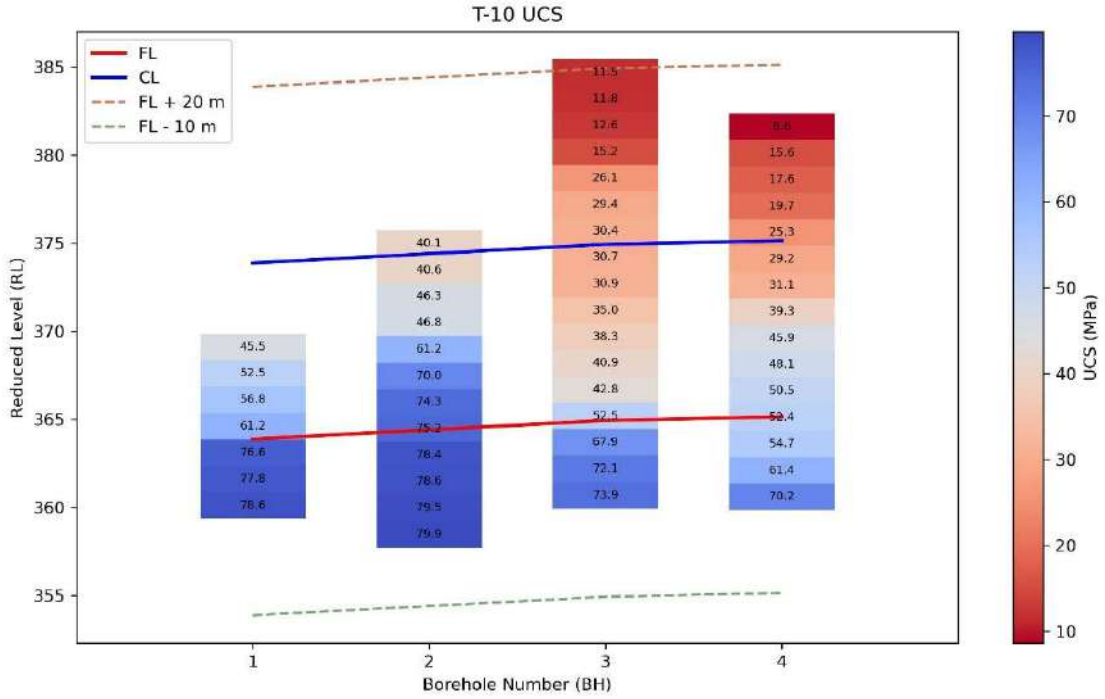
14.3.5.1 Mean And Standard Deviation in Hardness considering 1D zone of influence in each Borehole:

BH No.	Chainage	Mean	Std
BH01	61919	8	0.42
BH02	61969	8	0.00
BH03	62019	8	0.00
BH04	62040	8	0.00

14.3.5.2 Recommended Hardness considering 1D zone of influence:

Chainage	Statistical / Reduction Method (Hi = μ - σ across boreholes within ±10 m of FL and CL)	Reference Standards / Guidelines
61918 to 61960	8	IS 13311 (Part 2):1992; ISRM 1978
61960 to 62060	8	

14.3.6Compression Test



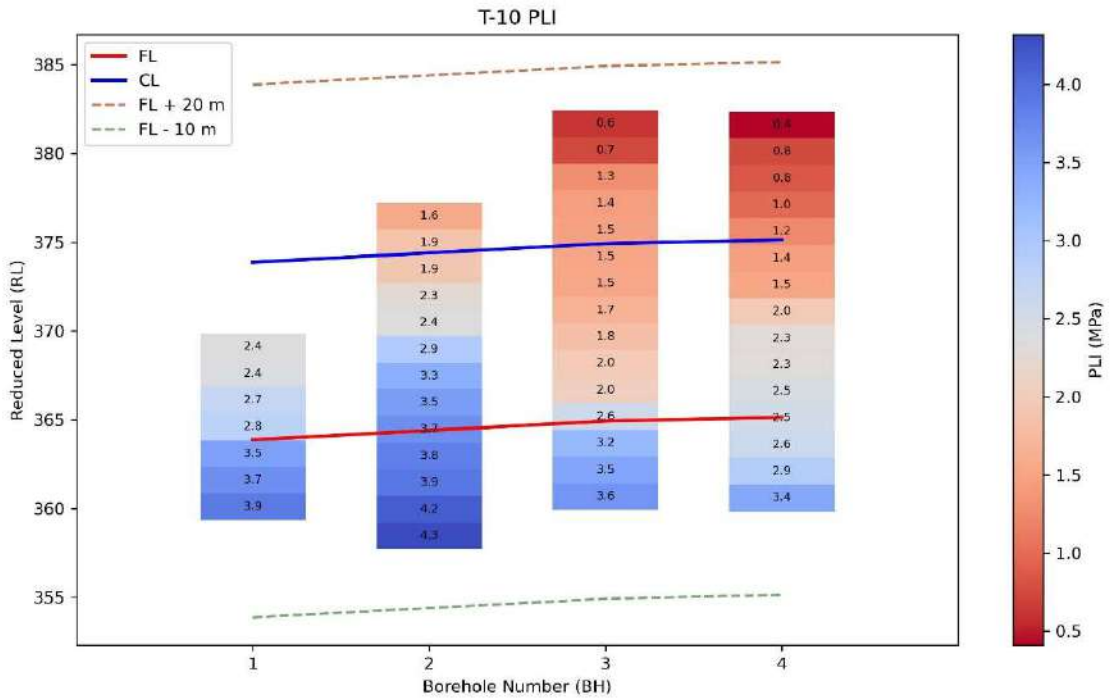
14.3.6.1 Mean And Standard Deviation in UCS considering 1D zone of influence in each Borehole:

BH No.	Chainage	Mean	Std
BH01	61919	46.39	13.71
BH02	61969	51.44	8.58
BH03	62019	67.12	9.46
BH04	62040	42.00	16.12

14.3.6.2 Recommended UCS considering 1D zone of influence:

Chainage	**Statistical / Reduction Method** **(UCS_k = μ - σ) across boreholes within ±10 m of FL and CL)**	**Recommended Design Value** **(UCS_d = (μ - σ) × f(RMR)), where (f(RMR) = 0.1–0.7)**	**Reference Standards / Guidelines**
61918 to 61960	32.68	3.27	IS 9143:1979; IS 13365 (Part 2):1998; Hoek & Brown (2002, 2019)
61960 to 62060	37.95	3.79	

14.3.7Point Load Test



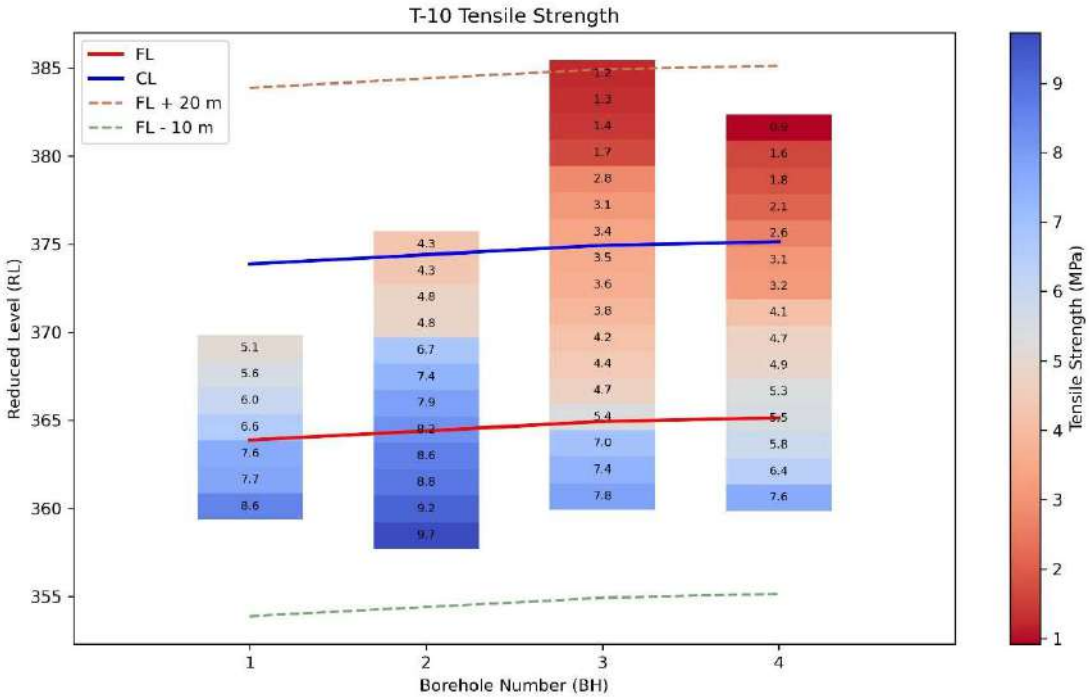
14.3.7.1 Mean And Standard Deviation in PLI considering 1D zone of influence in each Borehole:

BH No.	Chainage	Mean	Std
BH01	61919	2.29	0.70
BH02	61969	2.47	0.42
BH03	62019	3.43	0.57
BH04	62040	2.11	0.85

14.3.7.2 Recommended PLI considering 1D zone of influence:

Chainage	Statistical / Reduction Method (PLI_k = μ - σ) across boreholes within ±10 m of FL and CL)	Recommended Design Value (PLI_d = (μ - σ) × f(RMR)), where (f(RMR) = 0.1–0.7)	Reference Standards / Guidelines
61918 to 61960	1.59	0.16	IS 9143:1979; IS 13365 (Part 2):1998; Hoek & Brown (2002, 2019)
61960 to 62060	1.83	0.18	

14.3.8 Brazilian Test



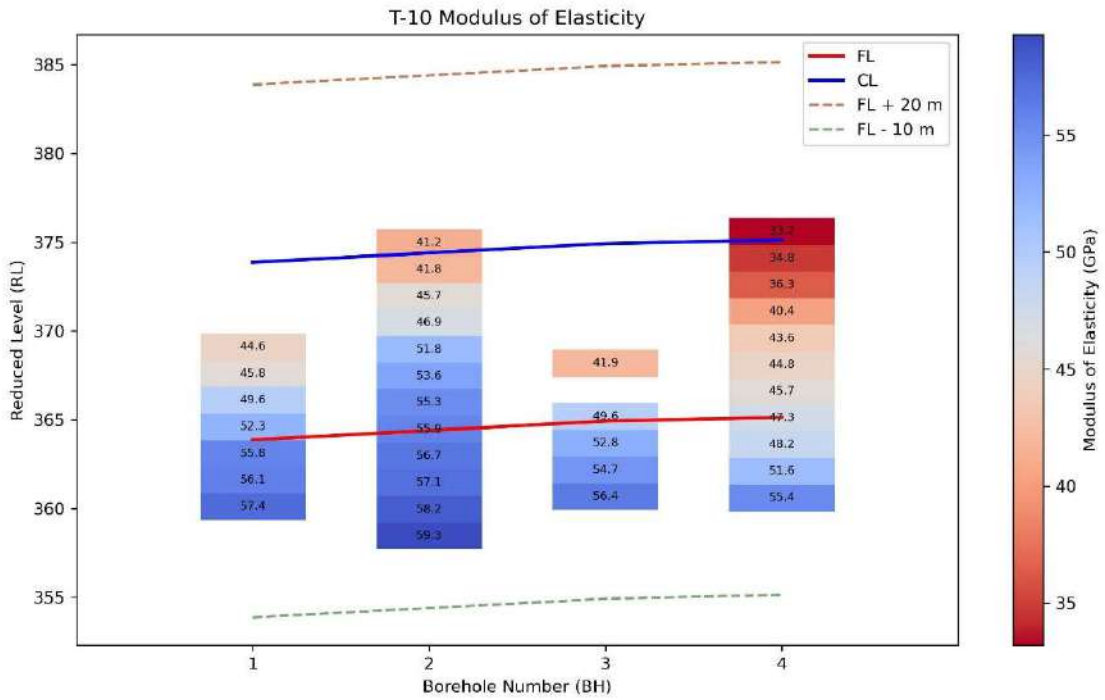
14.3.8.1 Mean And Standard Deviation in Tensile Strength considering 1D zone of influence in each Borehole:

BH No.	Chainage	Mean	Std
BH01	61919	4.78	1.74
BH02	61969	5.67	1.05
BH03	62019	6.98	1.22
BH04	62040	4.60	1.82

14.3.8.2 Recommended Tensile Strength considering 1D zone of influence:

Chainage	**Statistical / Reduction Method (mean value across boreholes within ±10 m of FL and CL× 0.8 (account for anisotropy))**	**Recommended Design Value (μ - σ)**	**Reference Standards / Guidelines**
61918 to 61960	4.78	3.05	IS 10082:1982; Hoek & Brown (1997); ISRM Suggested Methods
61960 to 62060	5.75	4.07	

14.3.9 Modulus of elasticity test



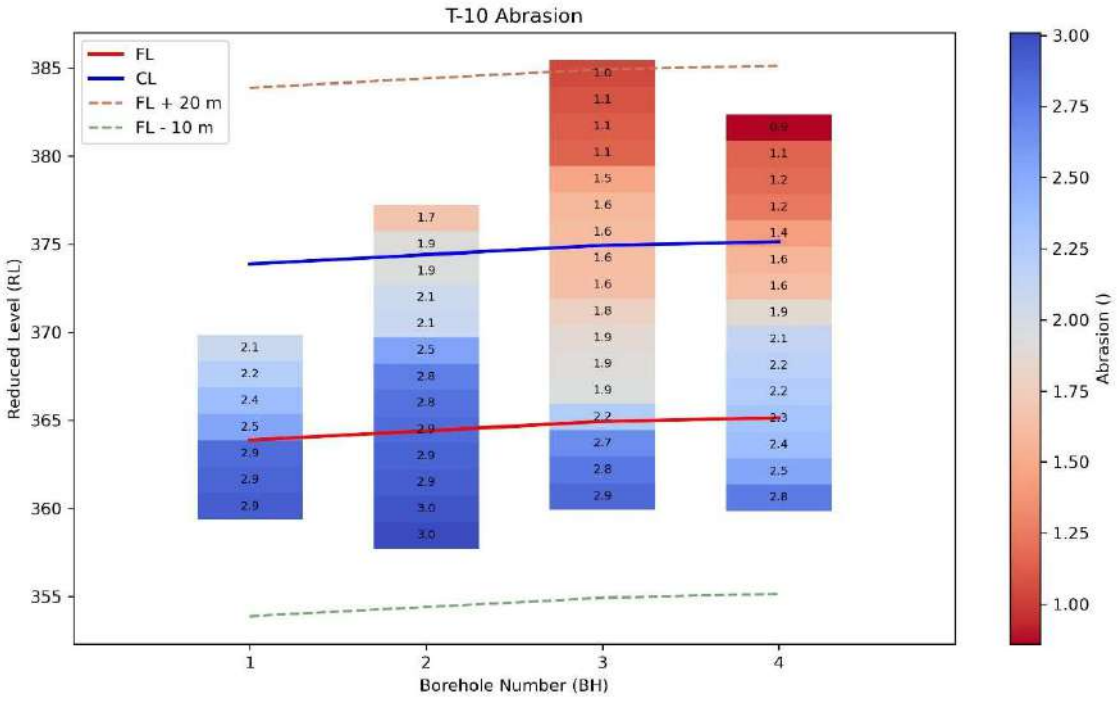
14.3.9.1 Mean And Standard Deviation in Elasticity considering 1D zone of influence in each Borehole:

BH No.	Chainage	Mean	Std
BH01	61919	50.8	4.5
BH02	61969	46.4	4.2
BH03	62019	55.8	1.9
BH04	62040	41.2	8.7

14.3.9.2 Recommended Modulus of Elasticity considering 1D zone of influence:

Chainage	Statistical / Reduction Method (Ei = μ - σ across boreholes within ±10 m of FL and CL× 0.8 (account for anisotropy))	Recommended Design Value (Ed = (μ - σ) × f(RMR)), where (f(RMR) = 0.1–0.7)	Reference Standards / Guidelines
61918 to 61960	46.3	4.63	IS 13365 (Part 2):1998; Hoek & Diederichs (2006)
61960 to 62060	38.7	3.87	

14.3.10 Abrasion test



14.3.10.1 Mean And Standard Deviation in Abrasion value considering 1D zone of influence in each Borehole:

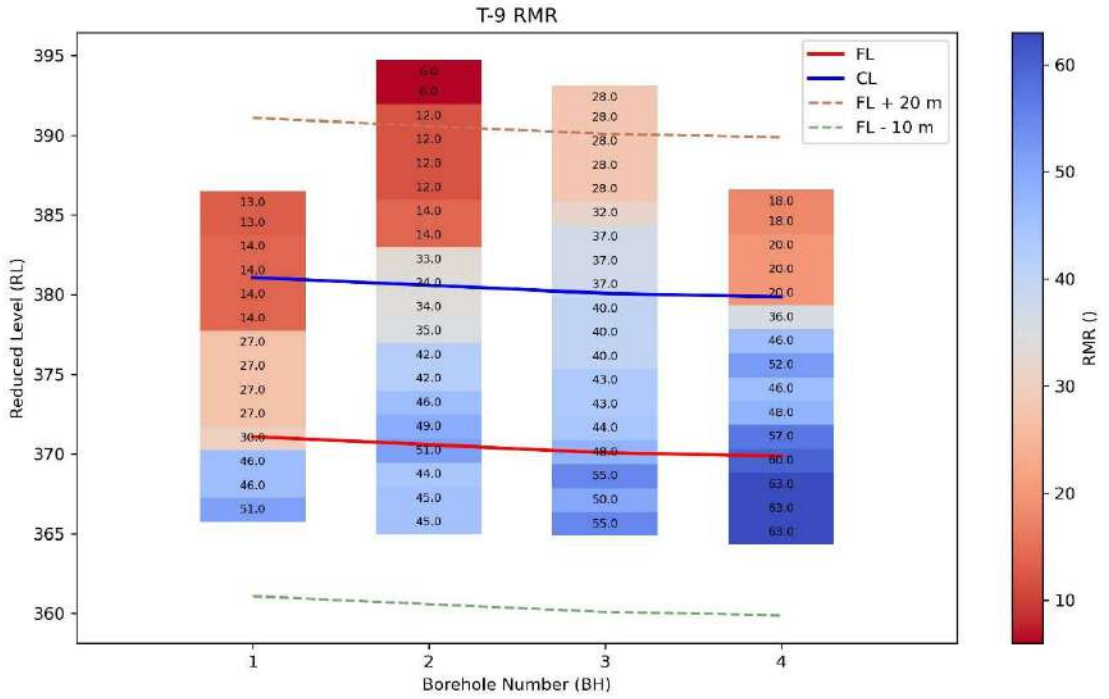
BH No.	Chainage	Mean	Std
BH01	61919	1.93	0.47
BH02	61969	2.24	0.25
BH03	62019	2.68	0.26
BH04	62040	1.96	0.51

14.3.10.2 Recommended Abrasion Value considering 1D zone of influence:

Chainage	**Statistical / Reduction Method** **(A= μ + σ across boreholes within ±10 m of FL and CL)**	**Recommended Design Value** **(A_v < 25%): Slightly abrasive; 25–35%: Moderately abrasive; >35%: Highly abrasive. (CAI = 0.5–6).**	**Reference Standards / Guidelines**
61918 to 61960	2.40	Slightly abrasive	IS 2386 (Part 4):1963; ISRM (2007); CERCHAR (1986)
61960 to 62060	2.76	Moderately abrasive	

14.4Geological assessment:

14.4.1RMR:



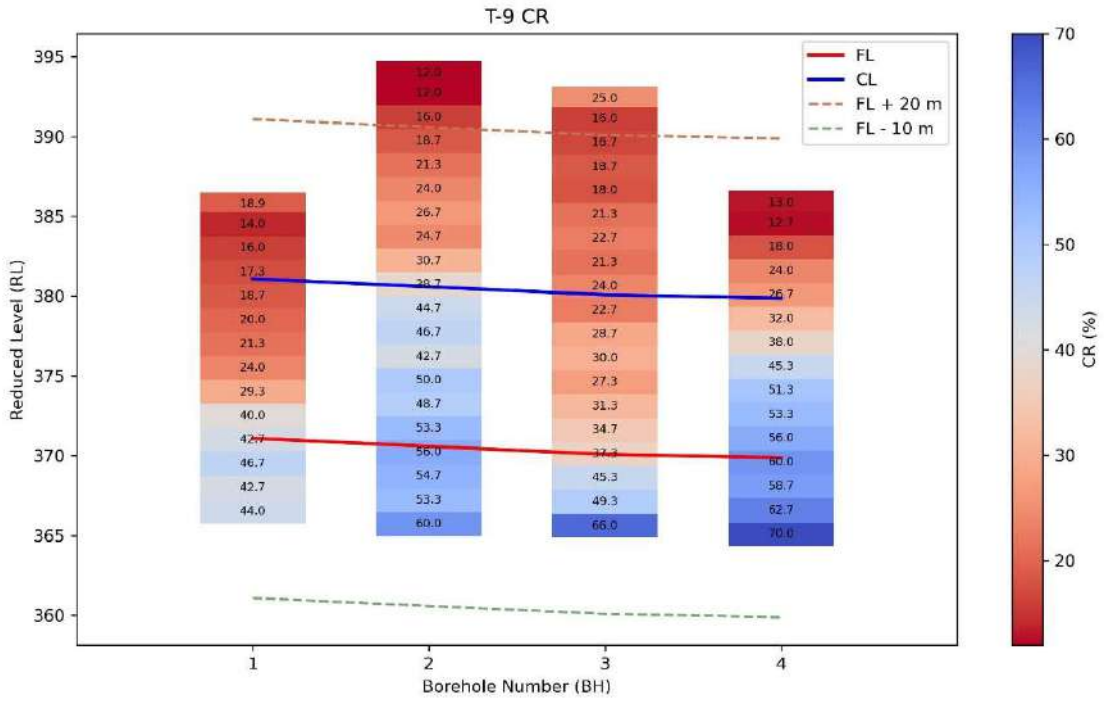
14.4.1.1 Mean And Standard Deviation in RMR considering 1D zone of influence in each Borehole:

BH No.	Chainage	Mean	Std
BH01	61919	31	12.88
BH02	61969	43	5.42
BH03	62019	46	5.88
BH04	62040	53	9.29

14.4.1.2 Recommended RMR considering 1D zone of influence:

Chainage	Statistical / Reduction Method (Average across boreholes within ±10 m of FL and CL)	Recommended Design Value (RMR_d = μ - σ)	Reference Standards / Guidelines
61918 to 61960	31 (Class IV)	18 (Class V)	IS 13365 (Part 2): 1998, Cl. 5.1 + Note on "representative values"
61960 to 62060	48 (Class III)	39 (Class IV)	

14.4.2 Core Recovery:

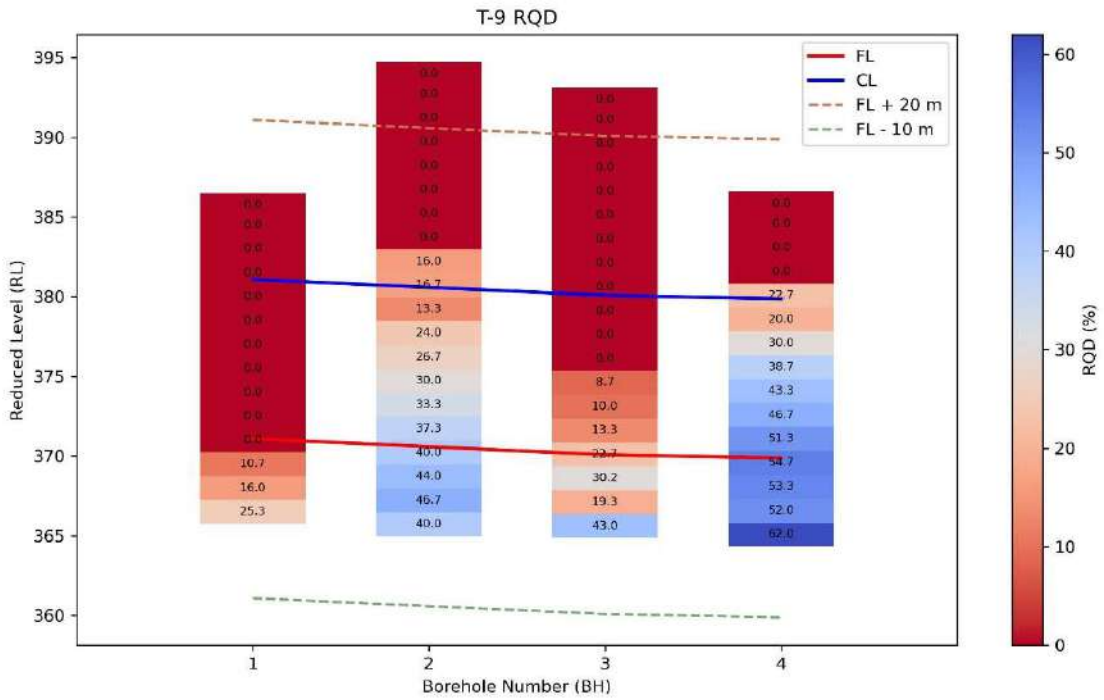


14.4.2.1 Mean And Standard Deviation in Core Recovery considering 1D zone of influence in each Borehole:

BH No.	Chainage	Mean	Std
BH01	61919	32.934	11.29823
BH02	61969	51.001	5.425887
BH03	62019	37.266	12.98137
BH04	62040	52.733	11.54543

Overall Mean	**Std**
43.48	13.45

14.4.3 RQD:



14.4.3.1 Mean And Standard Deviation in RQD considering 1D zone of influence in each Borehole:

BH No.	Chainage	Mean	Std
BH01	61919	5.20	9.07
BH02	61969	33.53	10.21
BH03	62019	14.72	14.28
BH04	62040	45.20	12.63

14.4.3.2 Recommended RQD considering 1D zone of influence:

Chainage	Statistical / Reduction Method (Average across boreholes within ±10 m of FL and CL)	Recommended Design Value (RQD_d = μ - σ)	Reference Standards / Guidelines
61918 to 61960	5.20	-3.87	IS 11315:1985; Deere (1963)
61960 to 62060	31.15	13.59	

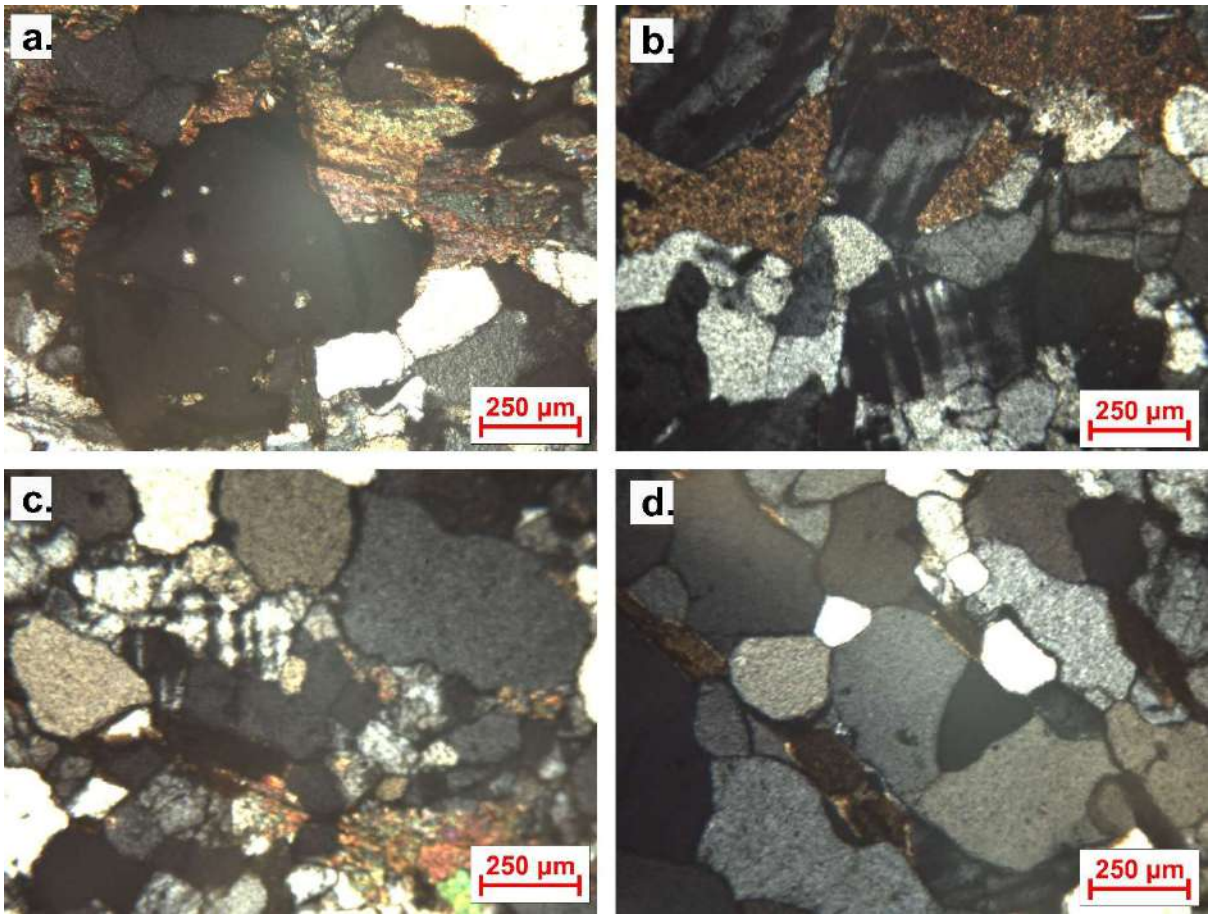
14.5 Petrographic Assessments:

14.5.1 Description of rock Masses

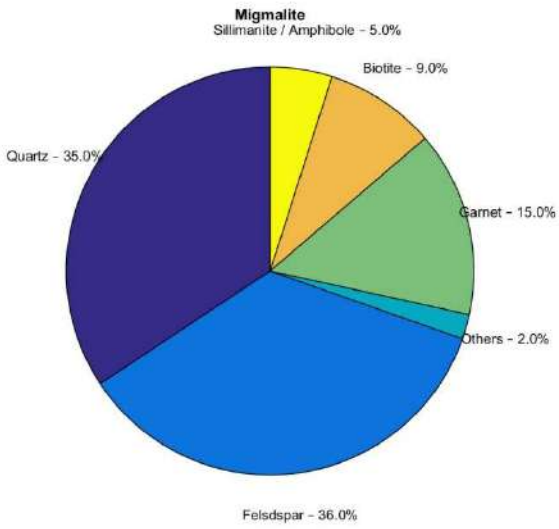
14.5.1.1 Migmatite

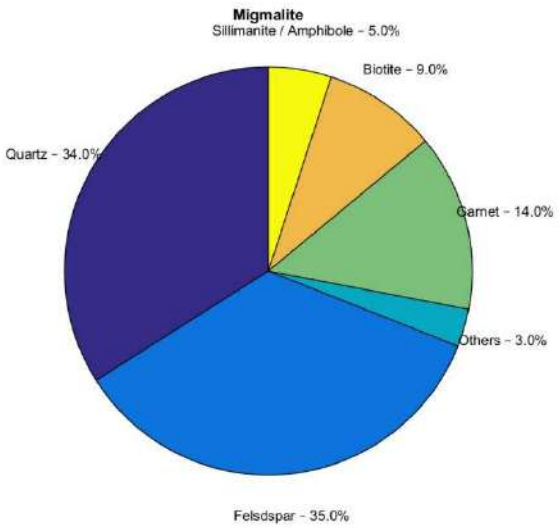
Migmatites of the Eastern Ghats consist of quartz- and feldspar-rich leucosome with garnet- and biotite-bearing melanosome/restite. Petrographic and modal descriptions are consistent with dominant quartz + feldspar (~60–70 %) and subordinate garnet and biotite as reported by Sarkar et al. (2007) and Sengupta et al. (2011).

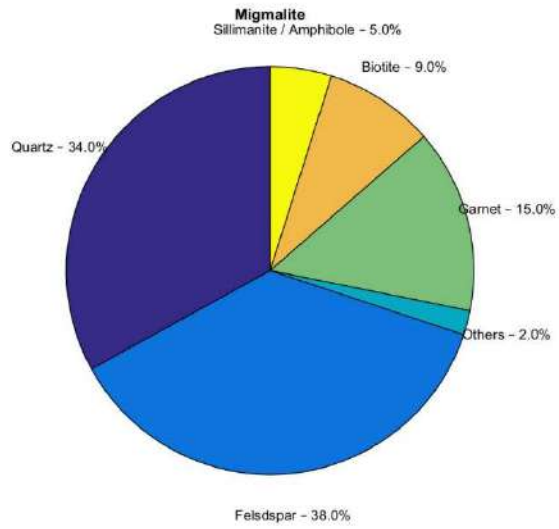
14.5.2 Micro Photographs

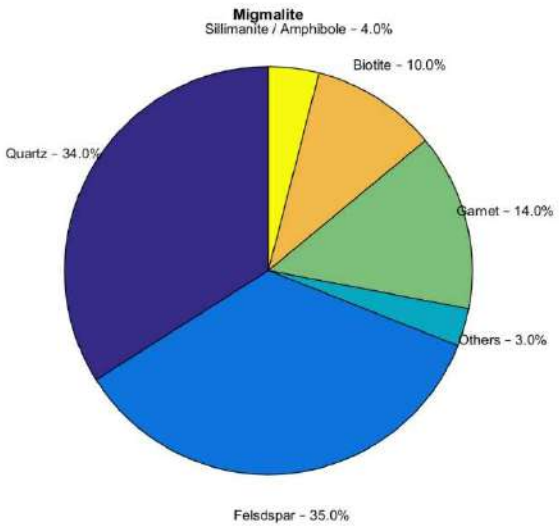


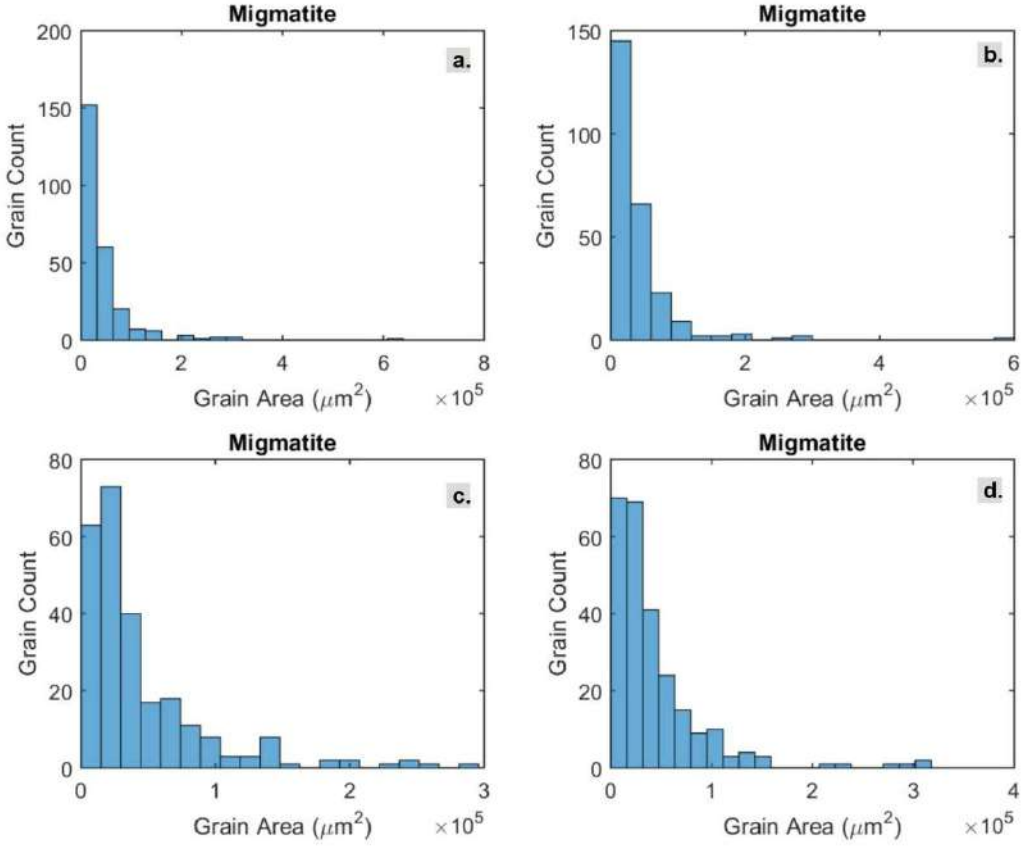
14.5.3 Mineral percentage and grain size distribution



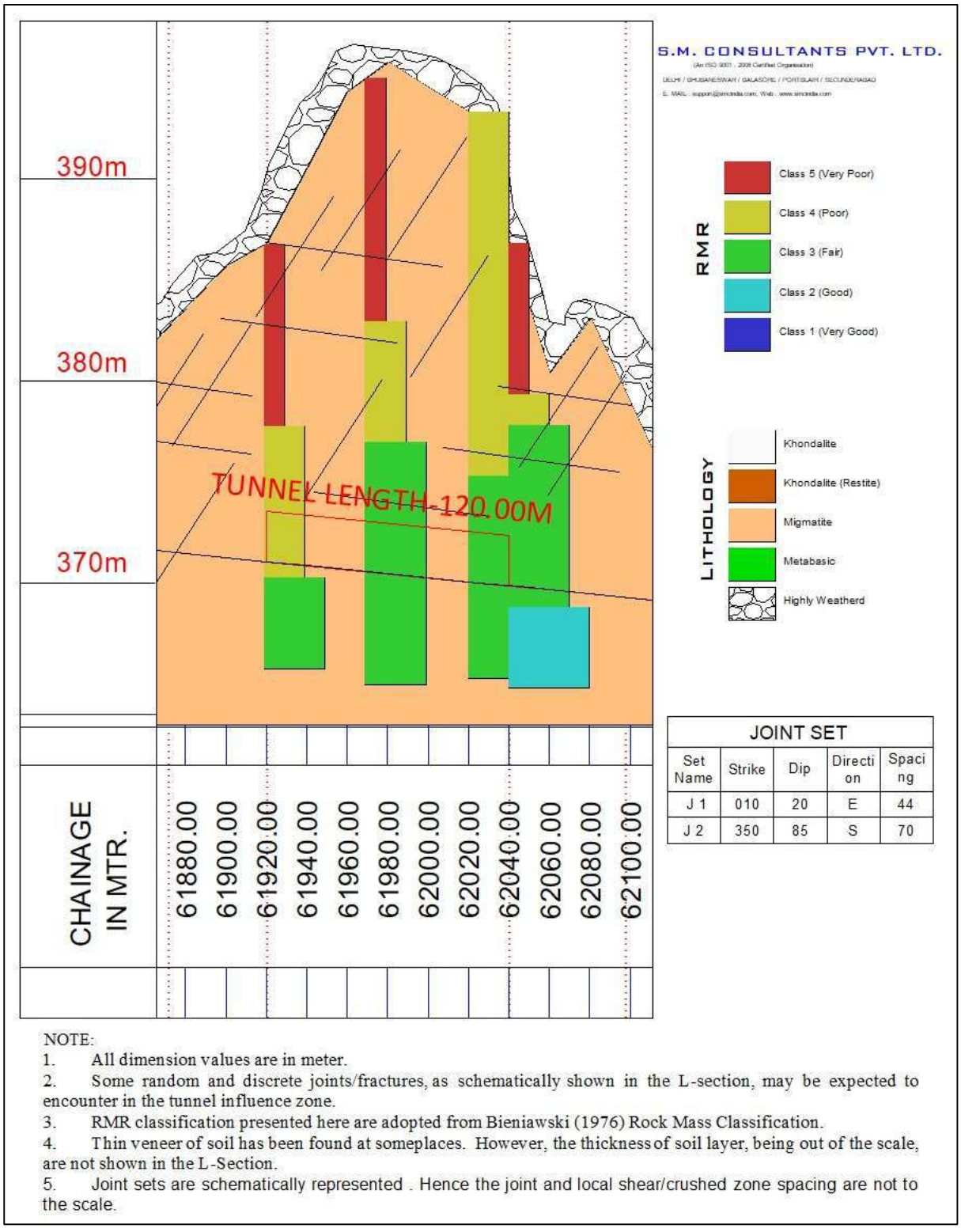








14.6L section:



JOINT SET				
Set Name	Strike	Dip	Direction	Spacing
J 1	010	20	E	44
J 2	350	85	S	70

NOTE:

1. All dimension values are in meter.
2. Some random and discrete joints/fractures, as schematically shown in the L-section, may be expected to encounter in the tunnel influence zone.
3. RMR classification presented here are adopted from Bieniawski (1976) Rock Mass Classification.
4. Thin veneer of soil has been found at someplaces. However, the thickness of soil layer, being out of the scale, are not shown in the L-Section.
5. Joint sets are schematically represented . Hence the joint and local shear/crushed zone spacing are not to the scale.

15 TUNNEL 10: GEOLOGICAL & GEOTECHNICAL ASSESMENT

15.1 Exploratory drillings

As per the requirement of scope of work outlined in the terms of reference, 4 bore holes were drilled with a cumulative length of 109m at different locations along the proposed alignment. Necessary care has been taken during drilling operations by deploying good quality diamond drill machines to obtain good core recovery to obtain RQD values. The locations of the boreholes were selected in such a way, so that these holes intersect the envisaged ground/ strata conditions at different depths. The location and details of boreholes drilled; total depth of drillings is shown in table below.

Chainage	BH	GL	FL	Depth
63080	BH-1	380.355	363.873	21.00
63130	BH-2	390.716	364.399	33.00
63180	BH-3	389.93	364.925	30.00
63200	BH-4	385.351	365.136	25.50

15.2TUNNEL-10 SRT

15.2.1Location:

Sr. No.	Chainage	Line	Spread	Location (T-10)		Length
				Start	End	In meter
1	63.080km to 63.200km	L1	S1	63.080km	63.200km	120

15.2.2 Seismic survey results and conclusion

Table 15.1: Summery of Tunnel-1 SRT test

Variation of maximum range of thicknesses below EGL (M)			Avg. V_p (m/sec)	Calculated V_s (m/sec)	Dynamic Young's Modulus (MPa)	Shear Modulus (MPa)
Layer	From	To				
Layer-I	0.50	1.50	500	234	238	88
Layer-II	1.50	4.50	1900	978	5298	2007
Layer-III	4.50	25.00	3400	1879	21702	8477

Sample Calculation:

The Young's Modulus E is the uni-axial stress-strain ratio. Its dynamic value is expressed by the following equation:

$$E = \frac{\rho V_p^2 (1+\mu)(1-2\mu)}{1-\mu}$$

Where, E = Dynamic Young's Modulus in kN/m2

Vp = 700 m/sec

ρ = 1.6 gm/cc ≈ 1.60 kN.s2/m4 (mass density)

μ = 0.36

So, calculated E = 466480 kN/sqm ≈ 466 MPa

The Shear Modulus G is the stress-strain ratio for simple shear. Its dynamic value is obtained by the following:

$$G = \frac{E}{2(1+\mu)} = \rho V_s^2$$

So, Shear Modulus G comes out to be 171500 kN/sqm ≈ 172 MPa

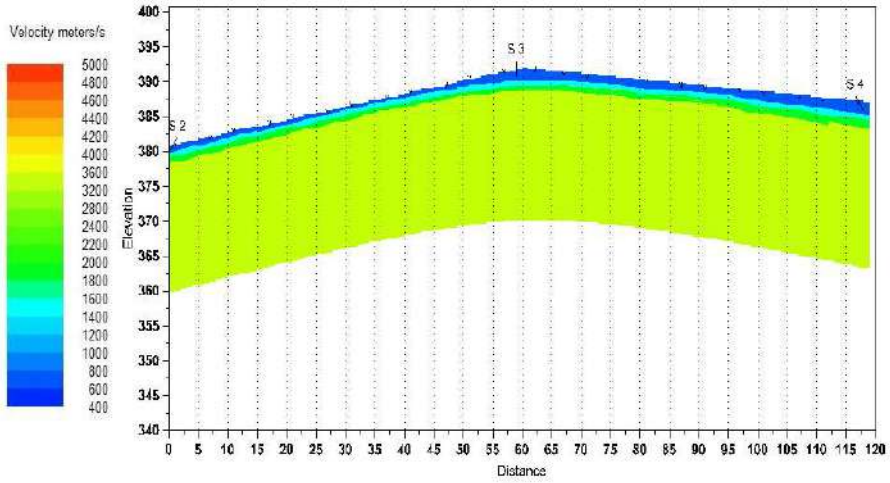
Again,

$G = \rho V_s^2$ giving Vs = √(G/ρ)

So, calculated Vs = 327.395 m/sec, say 327 m/sec

SEISMIC PROFILE(T10)

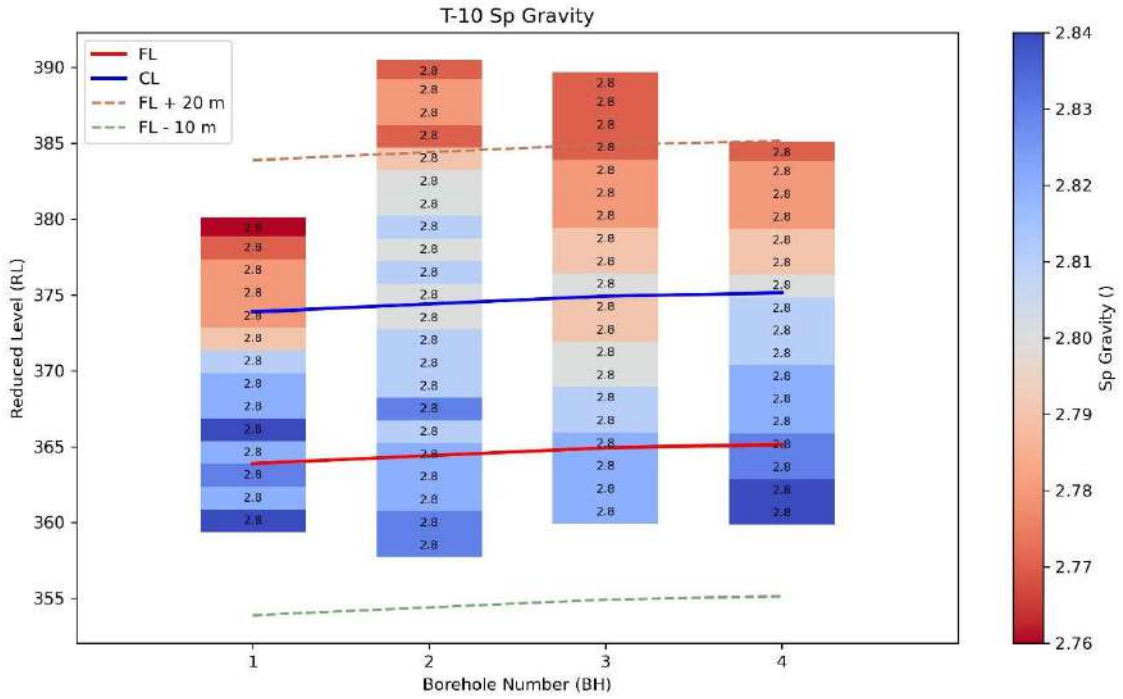
T10L1S1



Shot point depth computation

15.3 Assessment of the engineering properties of rock sample:

15.3.1 Specific Gravity



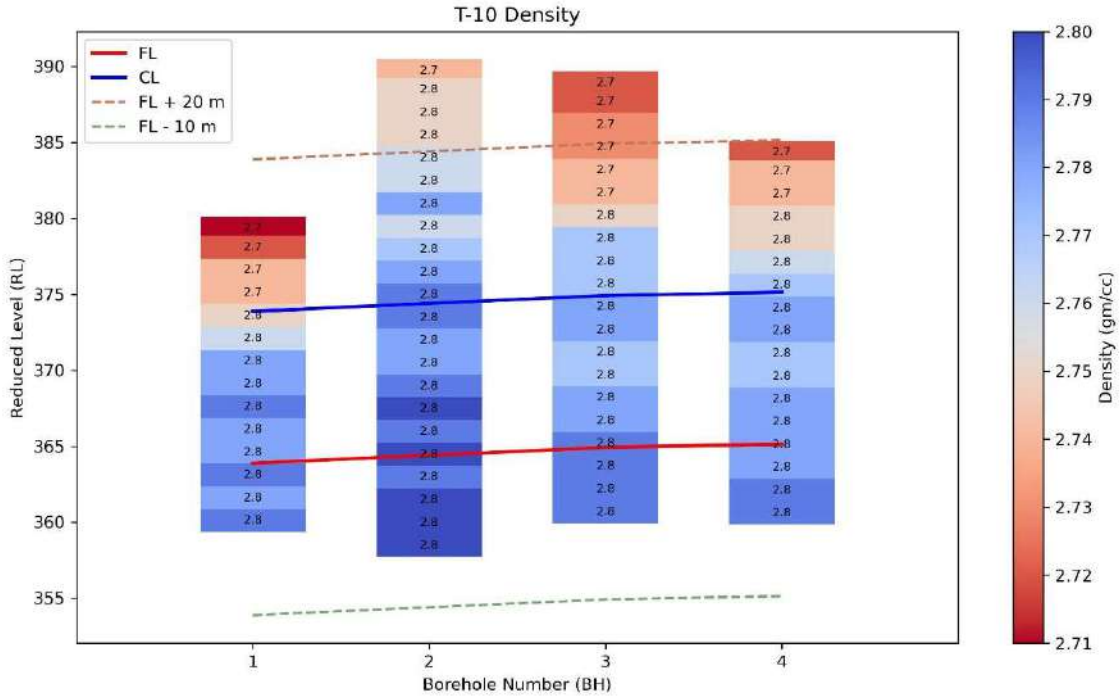
15.3.1.1 Mean and Standard deviation Specific Gravity considering 1D zone of influence of each borehole:

BH No.	Chainage	Mean	Std
BH01	63080	2.82	0.02
BH02	63130	2.82	0.01
BH03	63180	2.81	0.01
BH04	63200	2.82	0.01

15.3.1.2 Recommended Specific Gravity considering 1D zone of influence:

Chainage	Statistical / Reduction Method (Sp = μ - σ across boreholes within ±10 m of FL and CL)	Reference Standards / Guidelines
63080 to 63200	2.80	IS 13030:1991; IS 1124:1974

15.3.2 Dry Density



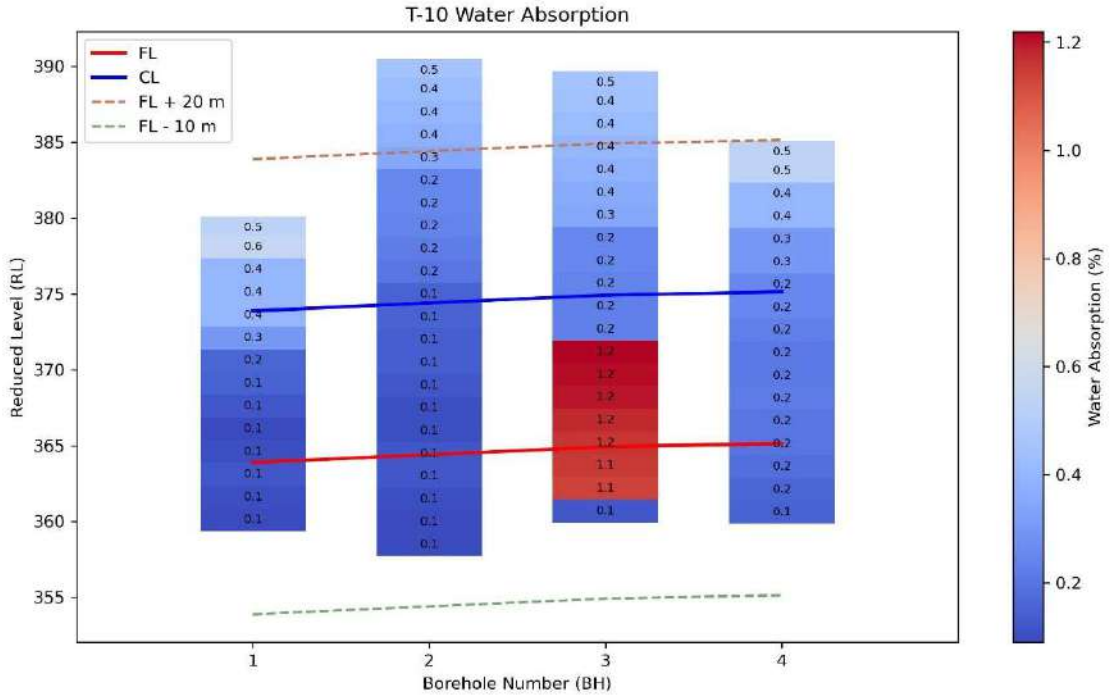
15.3.2.1 Mean and Standard Deviation in Density considering 1D zone of influence of each borehole:

BH No.	Chainage	Mean	Std
BH01	63080	2.78	0.01
BH02	63130	2.79	0.01
BH03	63180	2.78	0.01
BH04	63200	2.78	0.01

15.3.2.2 Recommended Density considering 1D zone of influence:

Chainage	**Statistical / Reduction Method** **(d = μ - σ across boreholes within ±10 m of FL and CL)**	**Reference Standards / Guidelines**
63080 to 63200	2.77	IS 13063:1991

15.3.3 Water absorption Test



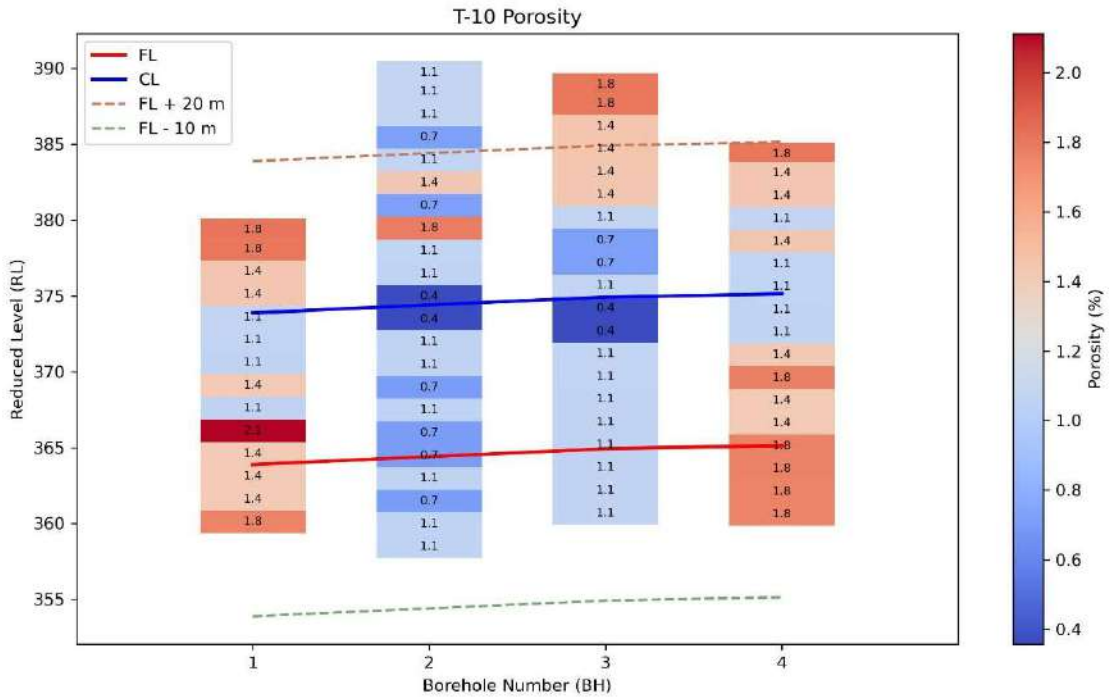
15.3.3.1 Mean and Standard Deviation in Water Absorption Value considering 1D zone of influence:

BH No.	Chainage	Mean	Std
BH01	63080	0.16	0.10
BH02	63130	0.12	0.02
BH03	63180	0.88	0.48
BH04	63200	0.20	0.03

15.3.3.2 Recommended Water Absorption Value considering 1D zone of influence:

Chainage	Statistical / Reduction Method (A= μ + σ across boreholes within ±10 m of FL and CL)	Reference Standards / Guidelines
63080 to 63200	0.73	IS 13063:1991; IS 2386 (Part 3):1963

15.3.4Porosity



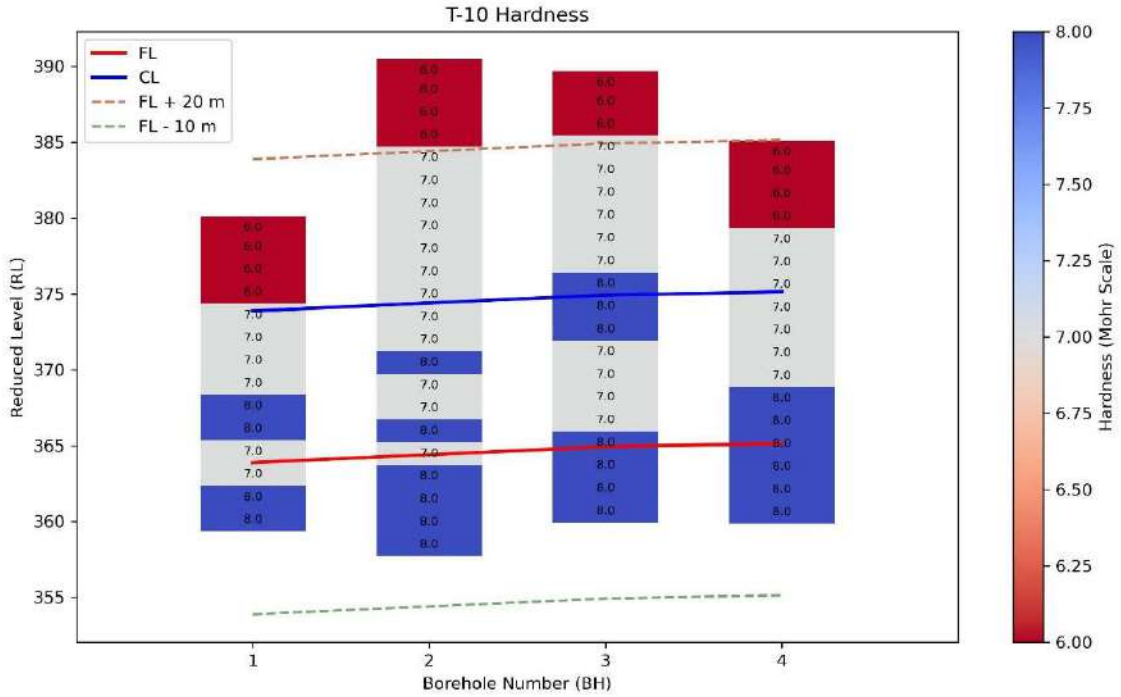
15.3.4.1 Mean And Standard Deviation in Porosity considering 1D zone of influence in each Borehole:

BH No.	Chainage	Mean	Std
BH01	63080	1.38	0.34
BH02	63130	0.87	0.24
BH03	63180	0.93	0.30
BH04	63200	1.52	0.29

15.3.4.2 Recommended Porosity considering 1D zone of influence:

Chainage	**Statistical / Reduction Method** **($n = \mu \pm \sigma$ across boreholes within ±10 m of FL and CL)**	**Reference Standards / Guidelines**
63080 to 63200	1.57	IS 1124:1974; ISRM (1981)

15.3.5 Hardness



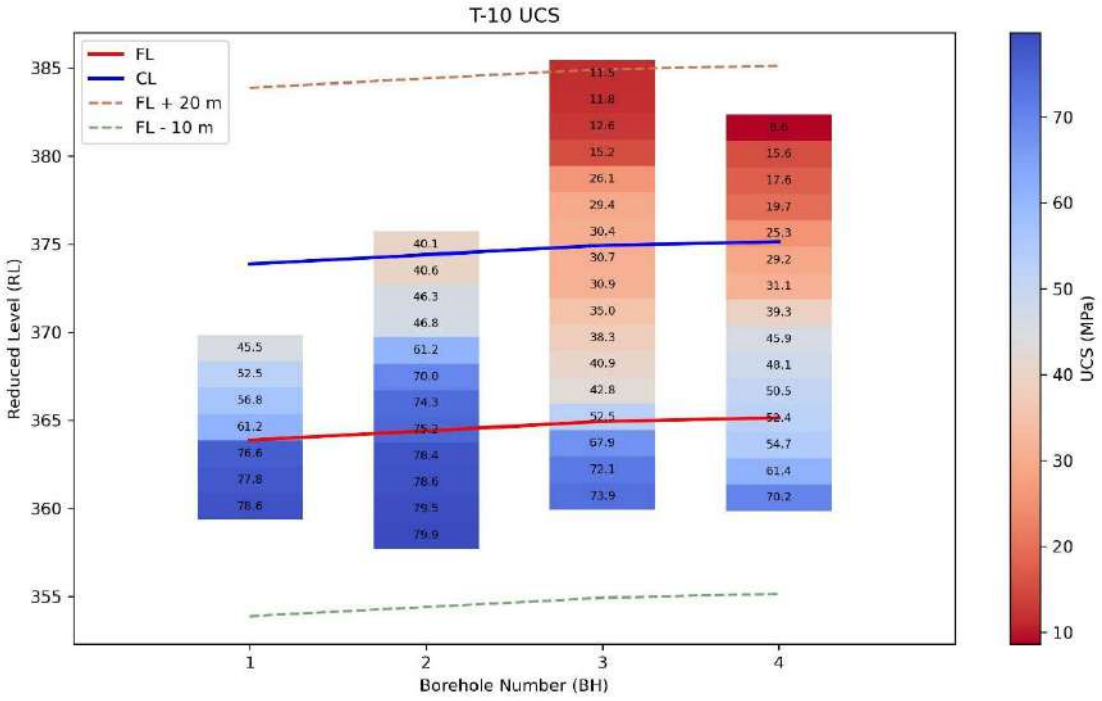
15.3.5.1 Mean And Standard Deviation in Hardness considering 1D zone of influence in each Borehole:

BH01	**63080**	**7**	**0.52**
BH02	63130	8	0.52
BH03	63180	8	0.52
BH04	63200	8	0.52

15.3.5.2 Recommended Hardness considering 1D zone of influence:

Chainage	Statistical / Reduction Method (Hi = μ - σ across boreholes within ±10 m of FL and CL)	Reference Standards / Guidelines
63080 to 63200	7	IS 13311 (Part 2):1992; ISRM 1978

15.3.6Compression Test



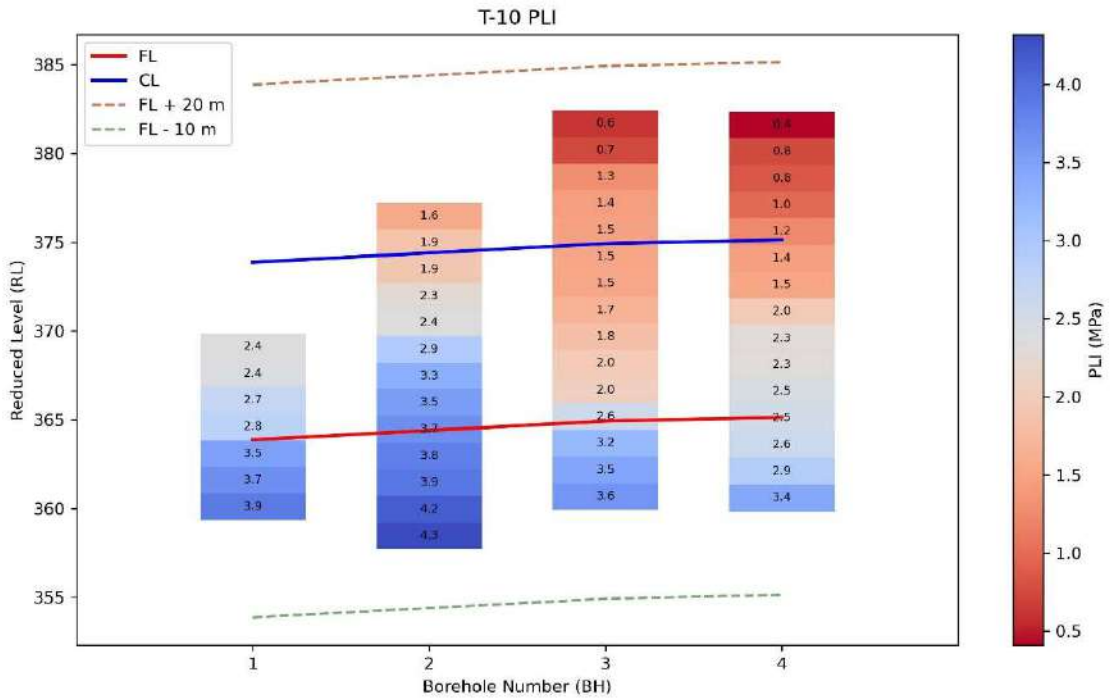
15.3.6.1 Mean And Standard Deviation in UCS considering 1D zone of influence in each Borehole:

BH No.	Chainage	Mean	Std
BH01	63080	64.15	13.51
BH02	63130	66.44	15.09
BH03	63180	48.49	16.99
BH04	63200	48.28	12.74

15.3.6.2 Recommended UCS considering 1D zone of influence:

Chainage	**Statistical / Reduction Method** **(UCS_k = μ - σ) across boreholes within ±10 m of FL and CL)**	**Recommended Design Value** **(UCS_d = (μ - σ) × f(RMR)), where (f(RMR) = 0.1–0.7)**	**Reference Standards / Guidelines**
63080 to 63200	40	12	IS 9143:1979; IS 13365 (Part 2):1998; Hoek & Brown (2002, 2019)

15.3.7Point Load Test



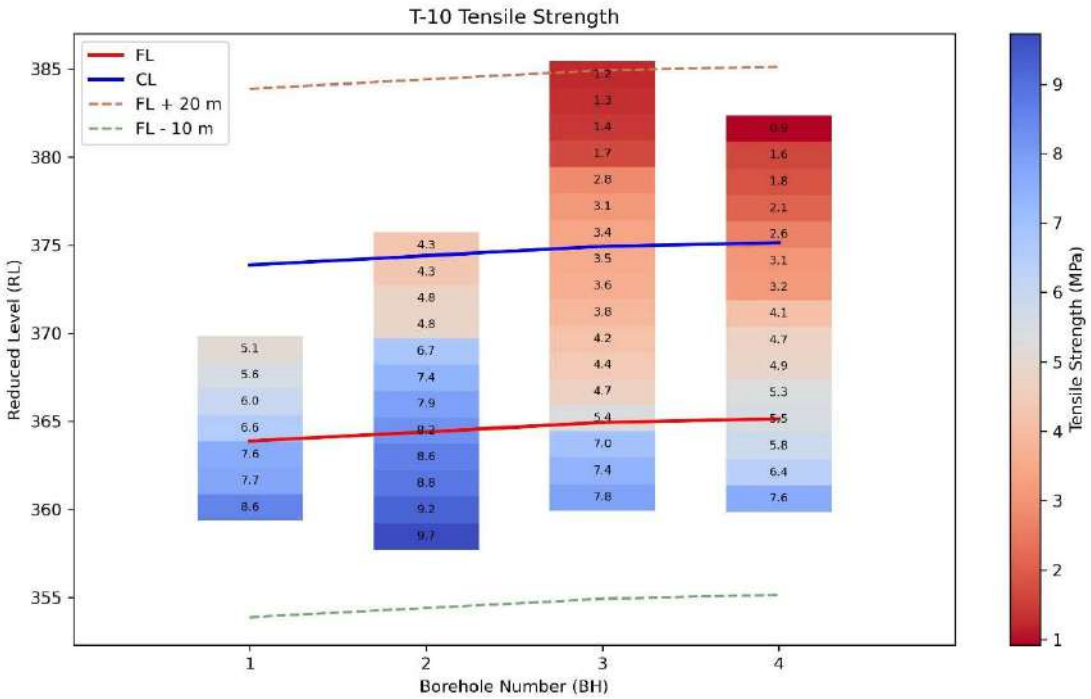
15.3.7.1 Mean And Standard Deviation in PLI considering 1D zone of influence in each Borehole:

BH No.	Chainage	Mean	Std
BH01	63080	3.049	0.632
BH02	63130	3.298	0.816
BH03	63180	2.342	0.814
BH04	63200	2.349	0.599

15.3.7.2 Recommended PLI considering 1D zone of influence:

Chainage	Statistical / Reduction Method (PLI_k = μ - σ) across boreholes within ±10 m of FL and CL)	Recommended Design Value (PLI_d = (μ - σ) × f(RMR)), where (f(RMR) = 0.1–0.7)	Reference Standards / Guidelines
63080 to 63200	1.92	0.6	IS 9143:1979; IS 13365 (Part 2):1998; Hoek & Brown (2002, 2019)

15.3.8 Brazilian Test



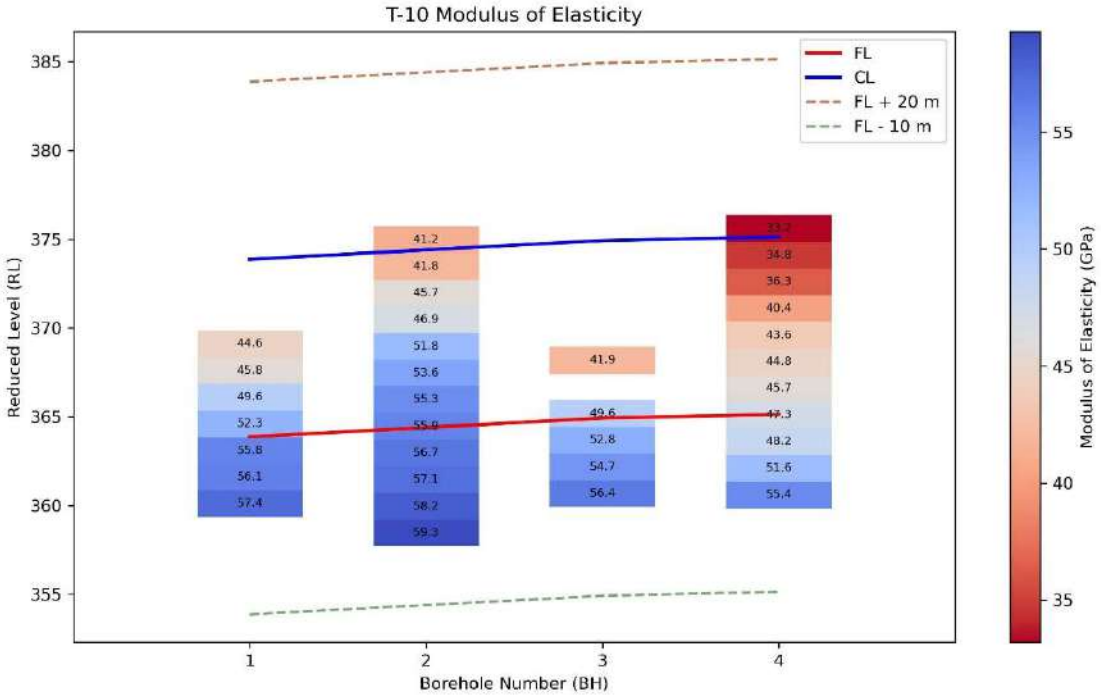
15.3.8.1 Mean And Standard Deviation in Tensile Strength considering 1D zone of influence in each Borehole:

BH No.	Chainage	Mean	Std
BH01	63080	6.731	1.278
BH02	63130	7.335	1.908
BH03	63180	5.193	1.635
BH04	63200	5.080	1.399

15.3.8.2 Recommended Tensile Strength considering 1D zone of influence:

Chainage	**Statistical / Reduction Method** **(mean value across boreholes within ±10 m of FL and CL× 0.8 (account for anisotropy))**	**Recommended Design Value** **(μ - σ)**	**Reference Standards / Guidelines**
63080 to 63200	6.07	4.22	IS 10082:1982; Hoek & Brown (1997); ISRM Suggested Methods

15.3.9 Modulus of elasticity test



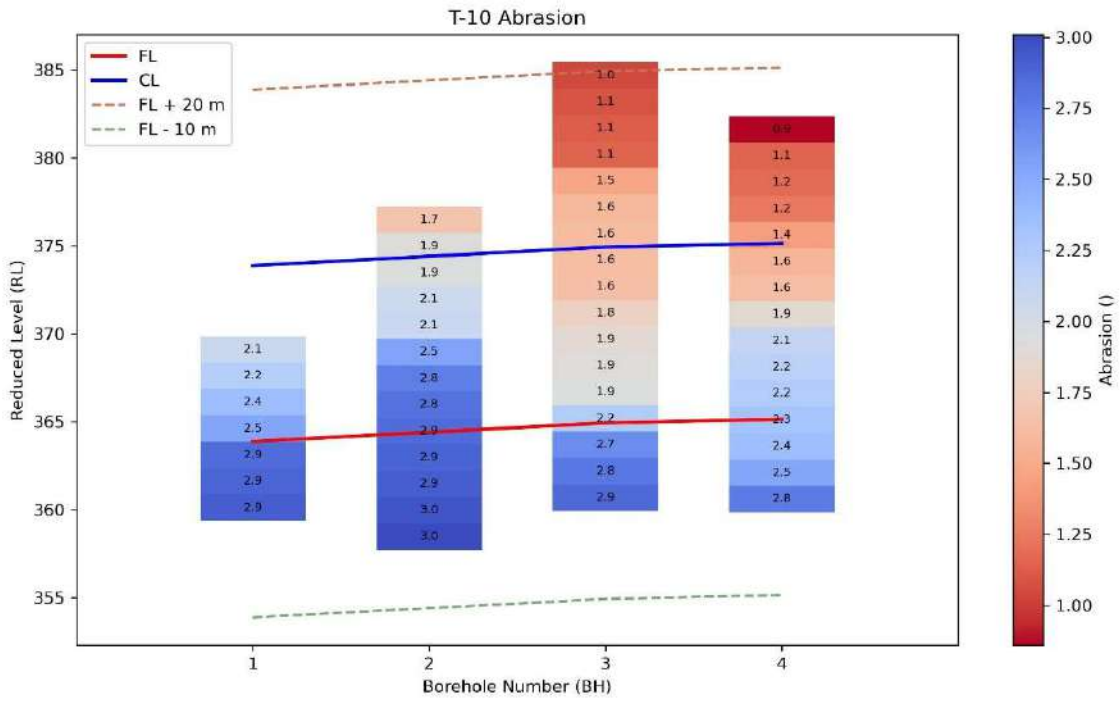
15.3.9.1 Mean And Standard Deviation in Elasticity considering 1D zone of influence in each Borehole:

BH No.	Chainage	Mean	Std
BH01	63080	51.66	5.14
BH02	63130	52.94	5.73
BH03	63180	51.08	5.72
BH04	63200	44.81	6.41

15.3.9.2 Recommended Modulus of Elasticity considering 1D zone of influence:

Chainage	Statistical / Reduction Method (Ei = μ - σ across boreholes within ±10 m of FL and CL× 0.8 (account for anisotropy))	Recommended Design Value (Ed = (μ - σ) × f(RMR)), where (f(RMR) = 0.1–0.7)	Reference Standards / Guidelines
63080 to 63200	43.36	13.01	IS 13365 (Part 2):1998; Hoek & Diederichs (2006)

15.3.10 Abrasion test



15.3.10.1 Mean And Standard Deviation in Abrasion value considering 1D zone of influence in each Borehole:

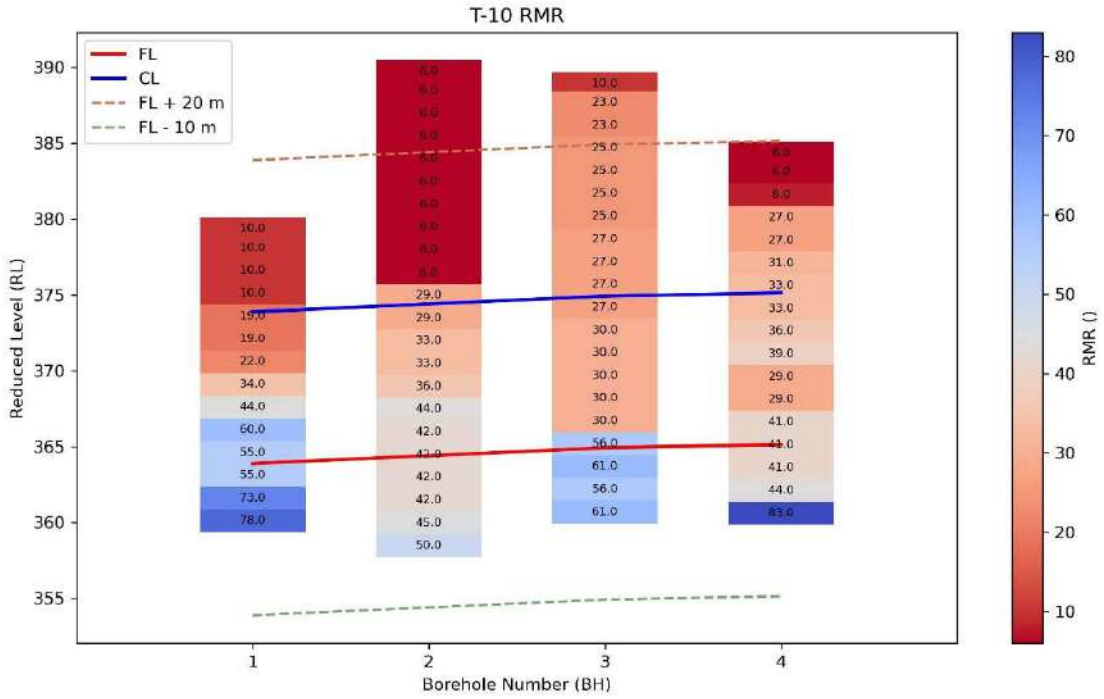
BH No.	Chainage	Mean	Std
BH01	63080	2.55	0.34
BH02	63130	2.62	0.40
BH03	63180	2.13	0.48
BH04	63200	2.16	0.38

15.3.10.2 Recommended Abrasion Value considering 1D zone of influence:

Chainage	**Statistical / Reduction Method** **(A= μ + σ across boreholes within ±10 m of FL and CL)**	**Recommended Design Value** **(A_v < 25%): Slightly abrasive; 25–35%: Moderately abrasive; >35%: Highly abrasive. (CAI = 0.5–6).**	**Reference Standards / Guidelines**
63080 to 63200	2.81	Moderately abrasive	IS 2386 (Part 4):1963; ISRM (2007); CERCHAR (1986)

15.4Geological assessment:

15.4.1RMR:



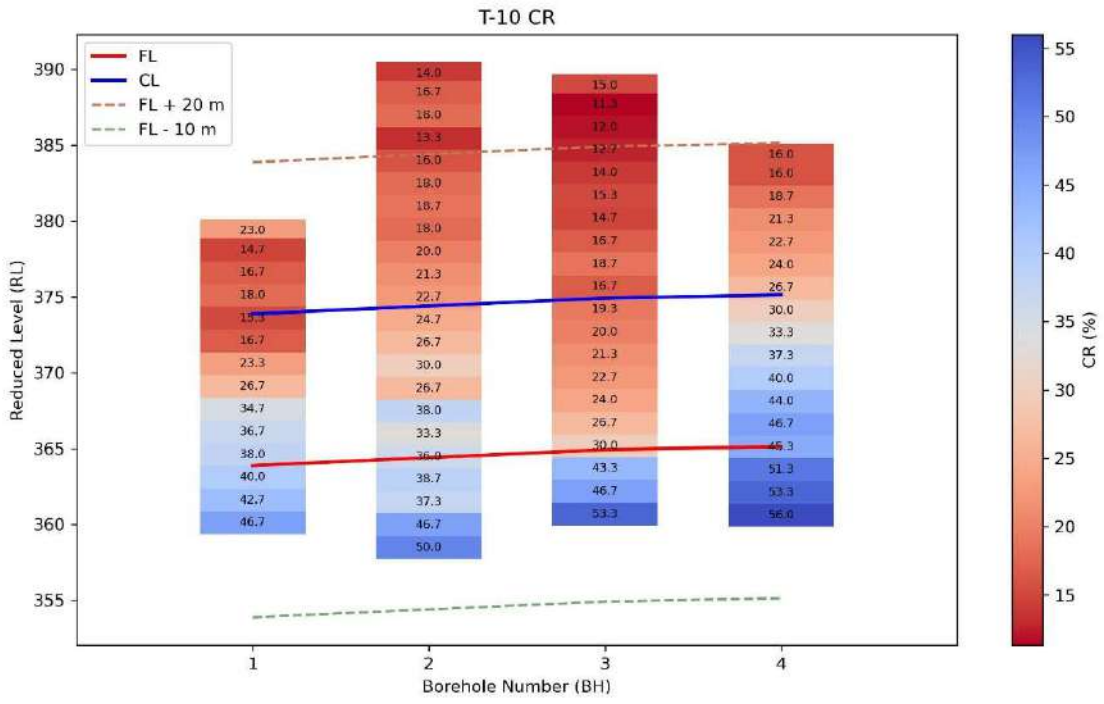
15.4.1.1 Mean And Standard Deviation in RMR considering 1D zone of influence in each Borehole:

BH01	**63080**	**45.9**	**21.84008**
BH02	63130	39.81818	6.258086
BH03	63180	41.1	15.09562
BH04	63200	41.6	15.45747

15.4.1.2 Recommended RQD considering 1D zone of influence:

Chainage	Statistical / Reduction Method (Average across boreholes within ±10 m of FL and CL)	Recommended Design Value (RMR_d = μ - σ)	Reference Standards / Guidelines
63080 to 63200	42 (Class III)	27 (Class IV)	IS 13365 (Part 2): 1998, Cl. 5.1 + Note on "representative values"

15.4.2 Core Recovery:

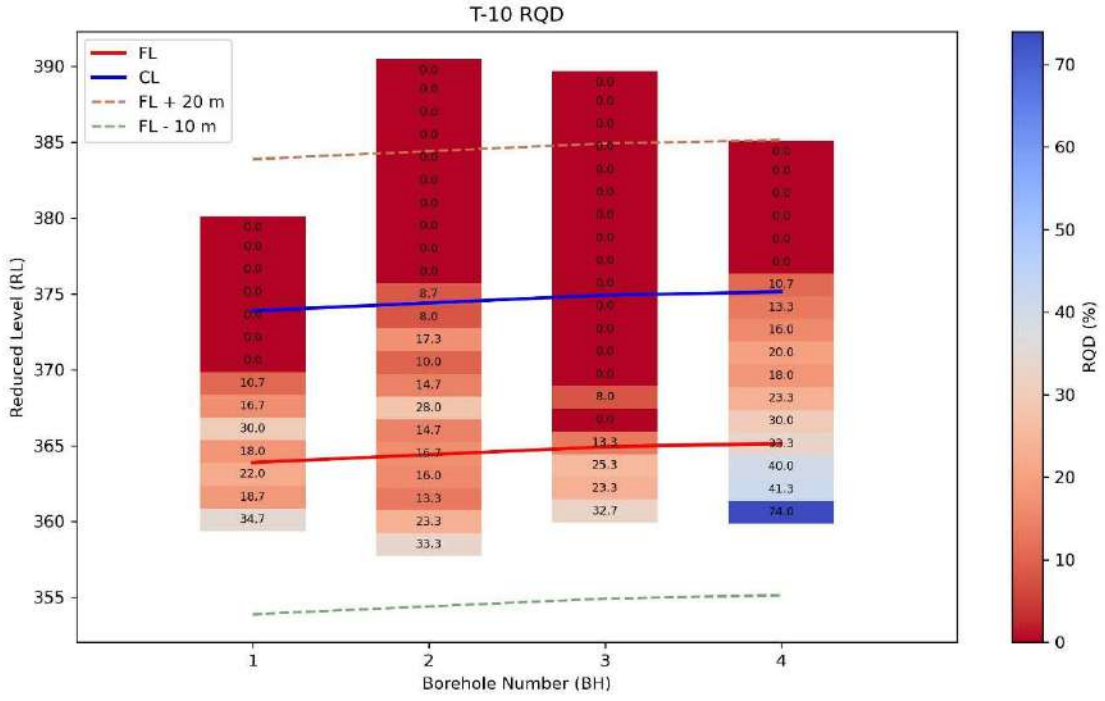


15.4.2.1 Mean And Standard Deviation in Core Recovery considering 1D zone of influence in each Borehole:

BH No.	Chainage	Mean	Std
BH01	63080	32.062	10.92496
BH02	63130	35.26909	8.141249
BH03	63180	30.73	12.40185
BH04	63200	43.731	8.584459

Overall Mean	**Std**
35.44	10.96

15.4.3 RQD:



15.4.3.1 Mean And Standard Deviation in RQD considering 1D zone of influence in each Borehole:

BH No.	Chainage	Mean	Std
BH01	63080	15.06	12.38
BH02	63130	17.75	7.60
BH03	63180	10.27	12.65
BH04	63200	30.93	18.04

15.4.3.2 Recommended RQD considering 1D zone of influence:

Chainage	**Statistical / Reduction Method** **(Average across boreholes within ±10 m of FL and CL)**	**Recommended Design Value** **(RQD_d = μ - σ)**	**Reference Standards / Guidelines**
63080 to 63200	18.49	4	IS 11315:1985; Deere (1963)

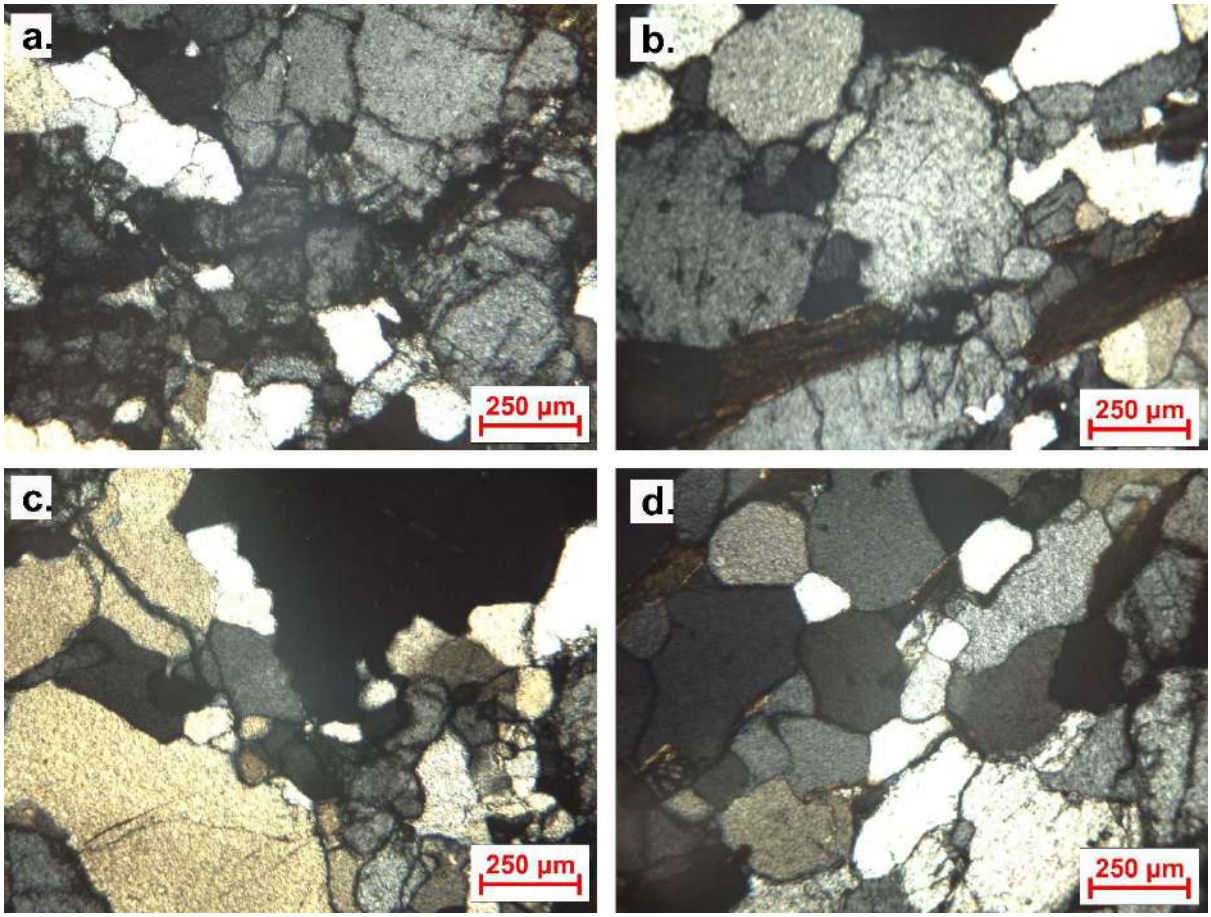
15.5 Petrographic Assessments:

15.5.1 Description of rock Masses

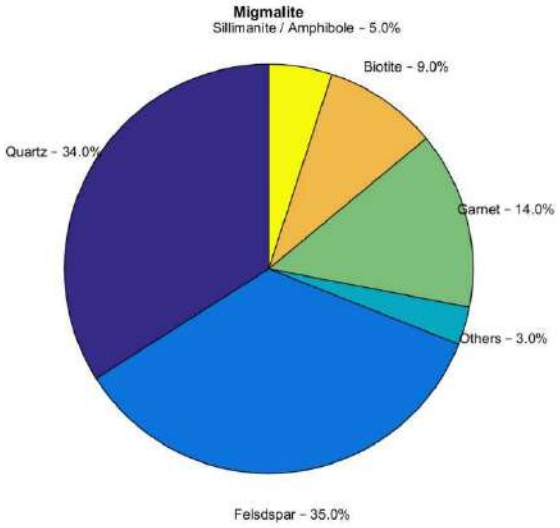
15.5.1.1 Migmatite

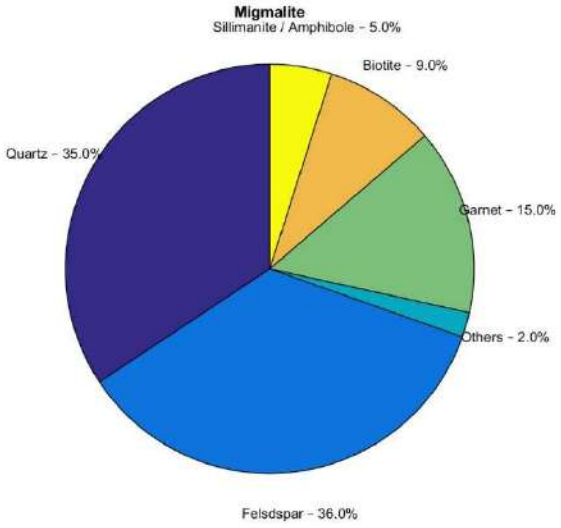
Migmatites of the Eastern Ghats consist of quartz- and feldspar-rich leucosome with garnet- and biotite-bearing melanosome/restite. Petrographic and modal descriptions are consistent with dominant quartz + feldspar (~60–70 %) and subordinate garnet and biotite as reported by Sarkar et al. (2007) and Sengupta et al. (2011).

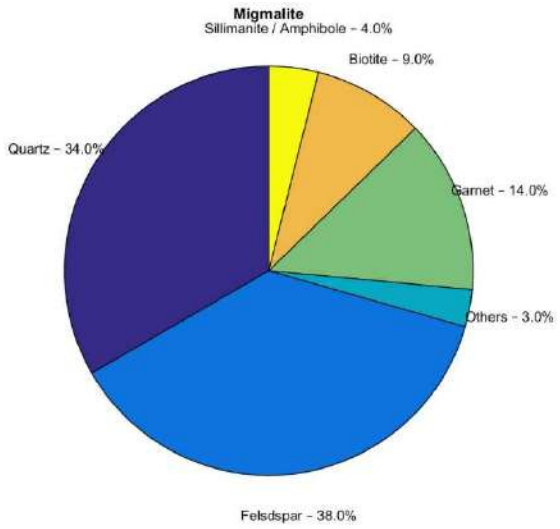
15.5.2 Micro Photographs

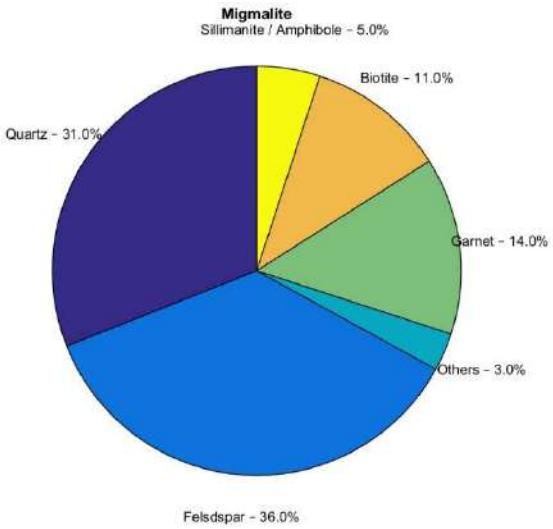


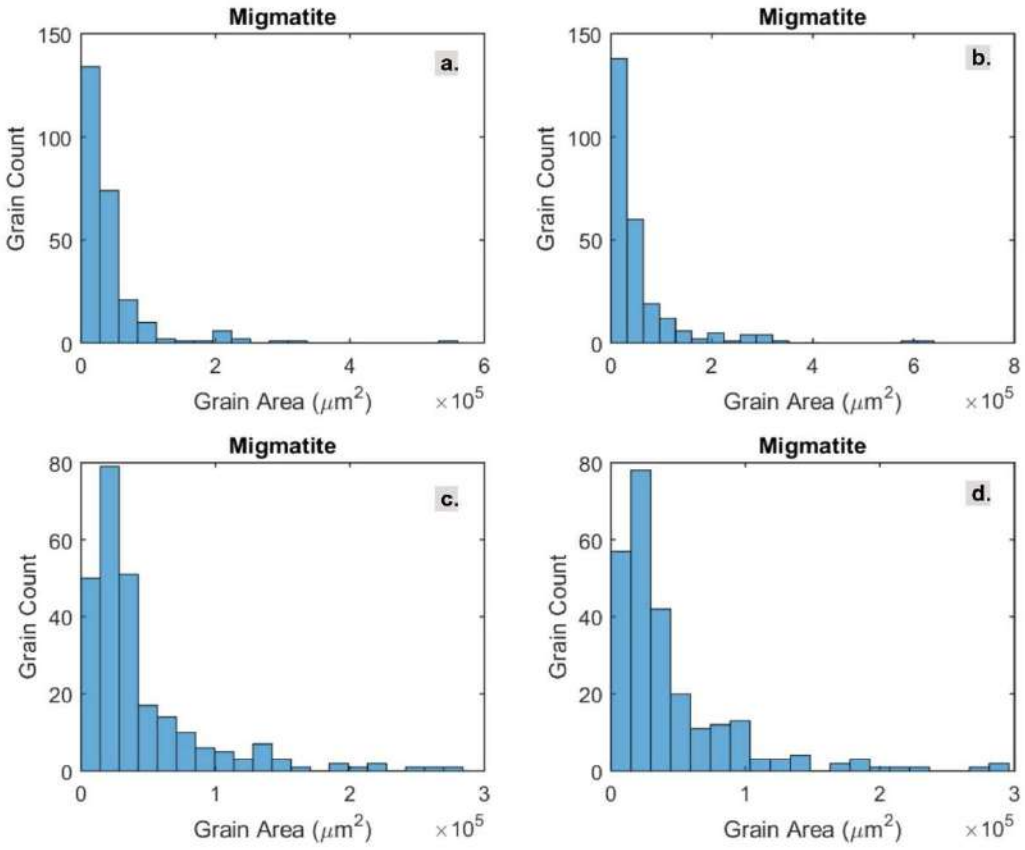
15.5.3 Mineral percentage and grain size distribution



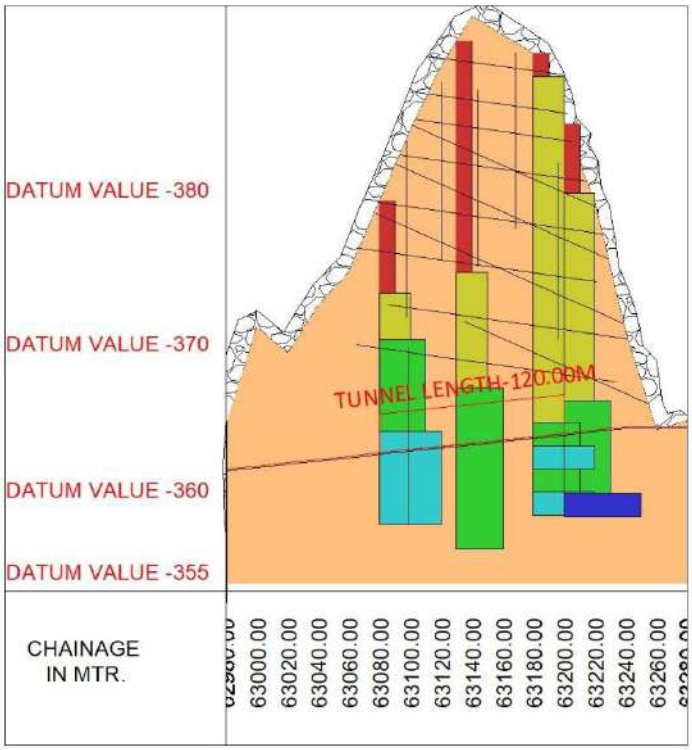








15.6L section:



NOTE:

1. All dimension values are in meter.
2. Some random and discrete joints/fractures, as schematically shown in the L-section, may be expected to encounter in the tunnel influence zone.
3. RMR classification presented here are adopted from Bieniawski (1976) Rock Mass Classification.
4. Thin veneer of soil has been found at someplaces. However, the thickness of soil layer, being out of the scale, are not shown in the L-Section.
5. Joint sets are schematically represented . Hence the joint and local shear/crushed zone spacing are not to the scale.

RMR
- Class 5 (Very Poor)
- Class 4 (Poor)
- Class 3 (Fair)
- Class 2 (Good)
- Class 1 (Very Good)

LITHOLOGY
- Khondalite
- Khondalite (Restite)
- Migmatite
- Metabasic
- Highly Weathered

JOINT SET

Set Name	Strike	Dip	Direction	Spacing
J 1	060	70	SE	60
J 2	215	40	SE	85
J 4	120	87	SW	110

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16TUNNEL 11: GEOLOGICAL & GEOTECHNICAL ASSESMENT

16.1Exploratory drillings

As per the requirement of scope of work outlined in the terms of reference, 10 bore holes were drilled with a cumulative length of 313 m at different locations along the proposed alignment. Necessary care has been taken during drilling operations by deploying good quality diamond drill machines to obtain good core recovery to obtain RQD values. The locations of the boreholes were selected in such a way, so that these holes intersect the envisaged ground/ strata conditions at different depths. The location and details of boreholes drilled; total depth of drillings is shown in table below.

Chainage	BH Name	GL	FL	Depth
66440	BH-1	345.235	330.267	20.00
66490	BH-2	364.829	329.642	43.00
66540	BH-3	365.222	329.017	41.00
66590	BH-4	356.304	328.392	34.00
66640	BH-5	357.801	327.767	35.00
66690	BH-6	358.491	327.142	40.00
66740	BH-7	339.288	326.517	18.00
66790	BH-8	348.422	325.892	30.00
66840	BH-9	346.881	325.267	27.00
66890	BH-10	343.481	324.663	25.00

16.2TUNNEL-11 SRT

16.2.1Location:

Sr. No.	Chainage	Line	Spread	Location (T-11)		Length
				Start	End	In meter
1	66.440km to 66.890km	L1	S1 to S4	66.440km	66.890km	480

16.2.2 Seismic survey results and conclusion

Table 16.1: Summery of Tunnel-1 SRT test

Variation of maximum range of thicknesses below EGL (M)			Avg. V_p (m/sec)	Calculated V_s (m/sec)	Dynamic Young's Modulus (MPa)	Shear Modulus (MPa)
Layer	From	To				
Layer-I	0.50	1.50	700	327	466	172
Layer-II	1.50	4.50	2400	1235	8855	3354
Layer-III	4.50	25.00	3800	2101	28238	11031

Sample Calculation:

The Young's Modulus E is the uni-axial stress-strain ratio. Its dynamic value is expressed by the following equation:

$$\mathbf{E} = \frac{\rho V_p^2 (1+\mu)(1-2\mu)}{1-\mu}$$

Where, E = Dynamic Young's Modulus in kN/m2

Vp = 700 m/sec

ρ = 1.6 gm/cc ≈ 1.60 kN.s2/m4 (mass density)

μ = 0.36

So, calculated E = 466480 kN/sqm ≈ 466 MPa

The Shear Modulus G is the stress-strain ratio for simple shear. Its dynamic value is obtained by the following:

$$G = \frac{E}{2(1+\mu)} = \rho V_s^2$$

So, Shear Modulus G comes out to be 171500 kN/sqm ≈ 172 MPa

Again,

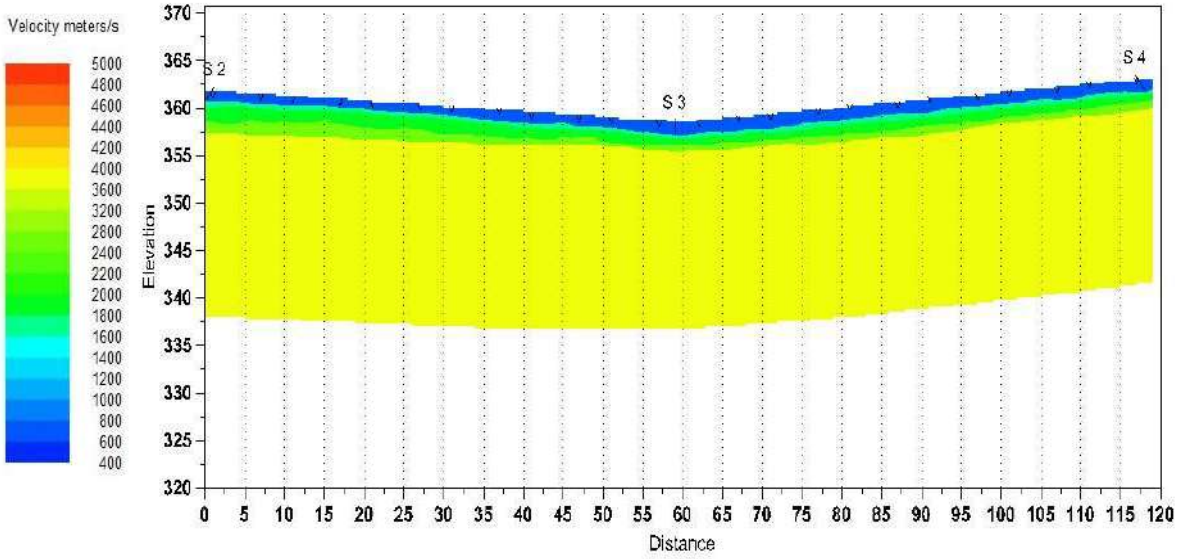
$G = \rho V_s^2$ giving Vs = √(G/ρ)

So, calculated Vs = 327.395 m/sec, say 327 m/sec

SEISMIC PROFILE(T11)

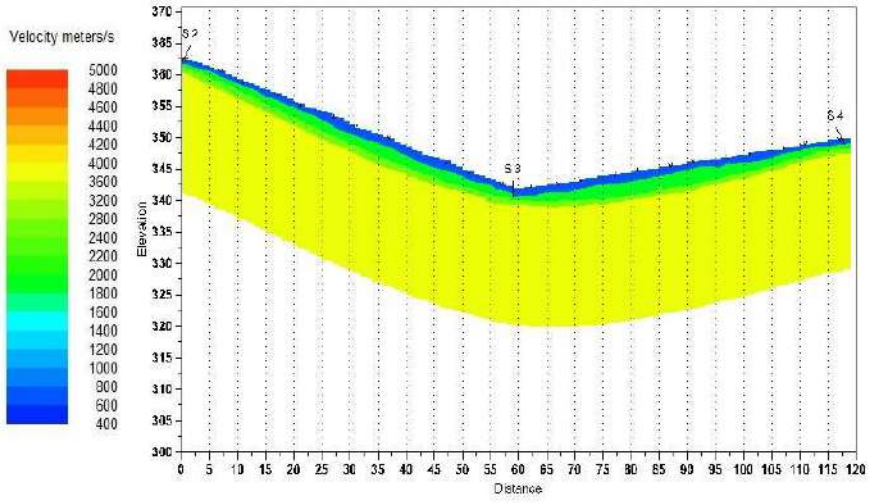
T11L1S1

T11L1S2



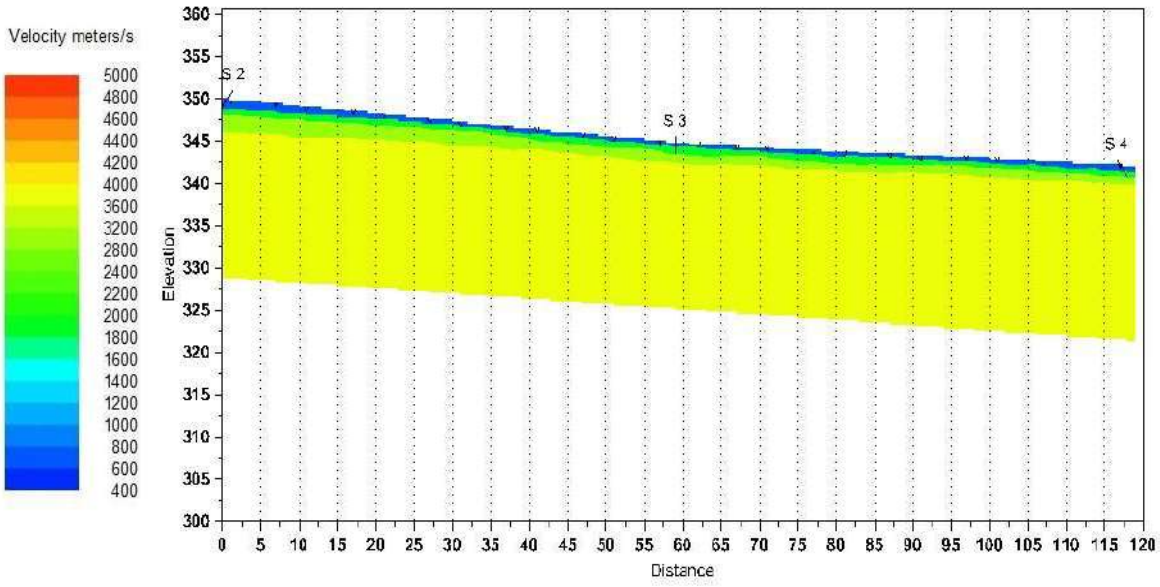
Shot point depth computation

T11L1S3



Shot point depth computation

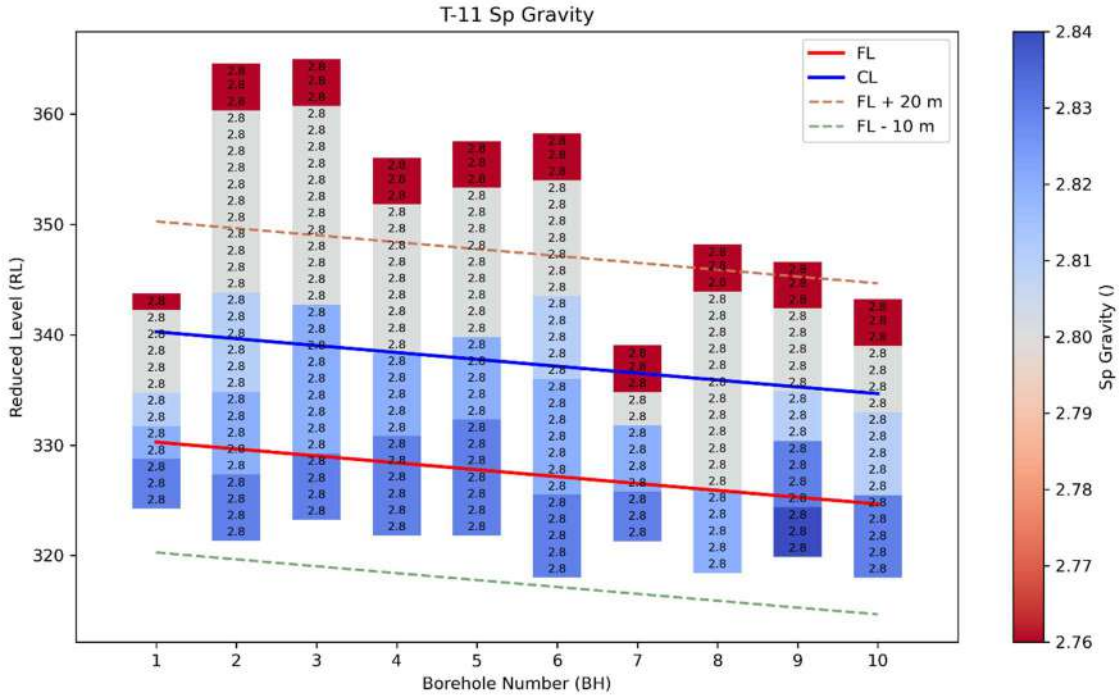
T11L1S4



Shot point depth computation

16.3 Assessment of the engineering properties of rock sample:

16.3.1 Specific Gravity



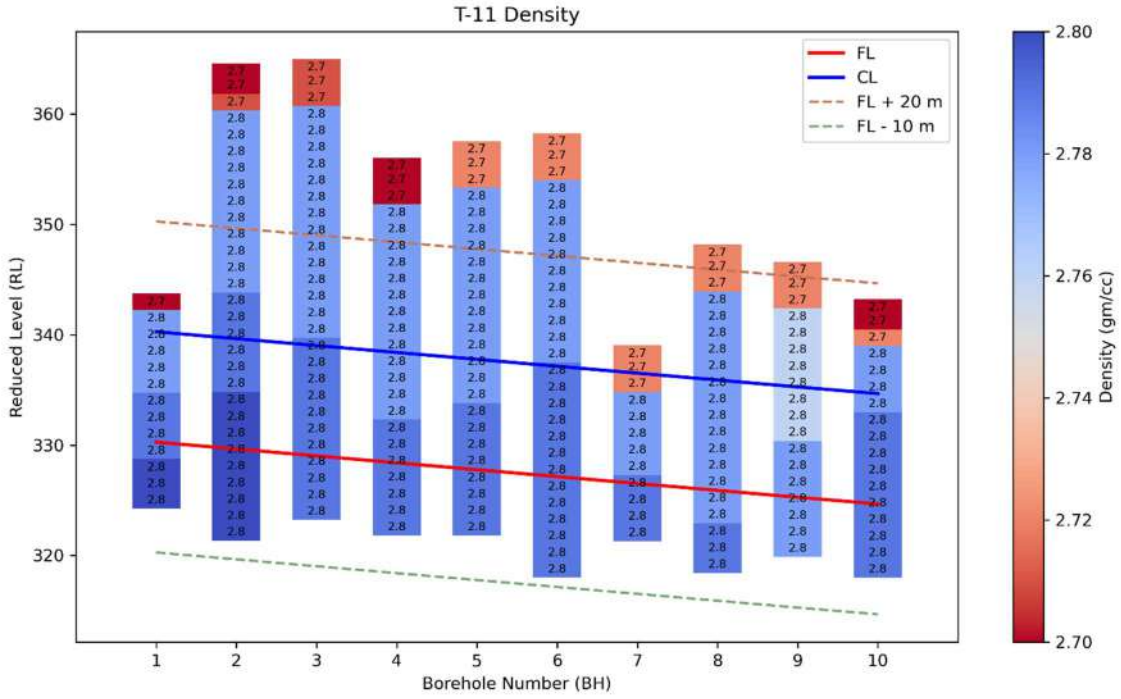
16.3.1.1 Mean and Standard deviation Specific Gravity considering 1D zone of influence of each borehole:

BH01	**66440**	**2.81**	**0.013**
BH02	66490	2.82	0.008
BH03	66540	2.82	0.005
BH04	66590	2.83	0.005
BH05	66640	2.83	0.005
BH06	66690	2.82	0.006
BH07	66740	2.81	0.022
BH08	66790	2.81	0.010
BH09	66840	2.83	0.013
BH10	66890	2.82	0.012

16.3.1.2 Recommended Specific Gravity considering 1D zone of influence:

Chainage	**Statistical / Reduction Method** **(Sp = μ - σ across boreholes within ±10 m of FL and CL)**	**Reference Standards / Guidelines**
66440 to 66480	2.80	IS 13030:1991; IS 1124:1974
66480 to 66900	2.81	

16.3.2 Dry Density



16.3.2.1 Mean and Standard Deviation in Density considering 1D zone of influence of each borehole:

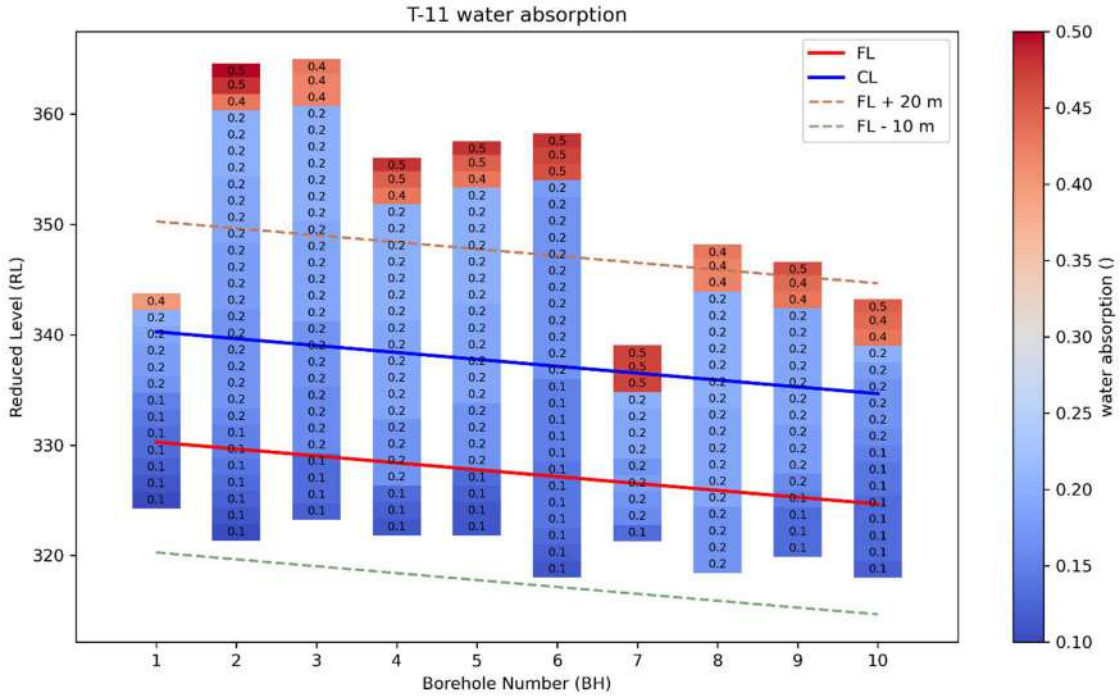
BH No.	Chainage	Mean	Std
BH01	66440	2.79	0.008
BH02	66490	2.80	0.005
BH03	66540	2.79	0.000
BH04	66590	2.79	0.005
BH05	66640	2.79	0.005
BH06	66690	2.79	0.000
BH07	66740	2.78	0.021

BH No.	Chainage	Mean	Std
BH08	66790	2.78	0.005
BH09	66840	2.77	0.010
BH10	66890	2.79	0.003

16.3.2.2 Recommended Density considering 1D zone of influence:

Chainage	**Statistical / Reduction Method** **(d = μ - σ across boreholes within ±10 m of FL and CL)**	**Reference Standards / Guidelines**
66440 to 66480	2.78	IS 13063:1991
66480 to 66900	2.78	

16.3.3 Water absorption Test



16.3.3.1 Mean and Standard Deviation in Water Absorption Value considering 1D zone of influence:

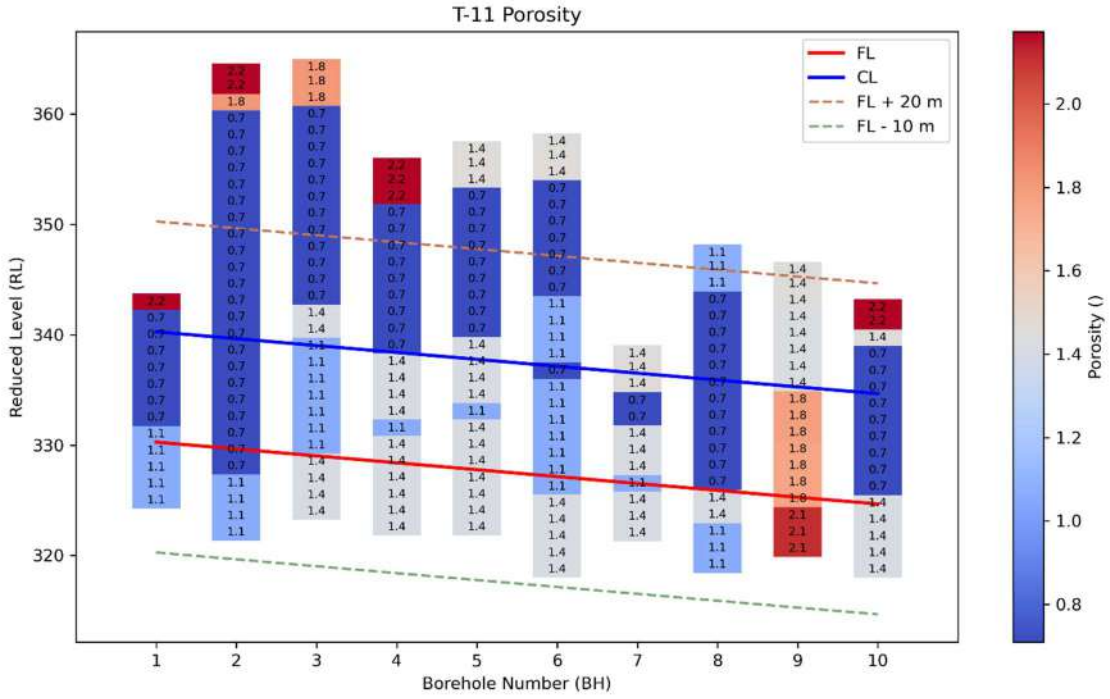
BH No.	Chainage	Mean	Std
BH01	66440	0.145	0.031
BH02	66490	0.145	0.025
BH03	66540	0.151	0.019
BH04	66590	0.164	0.030
BH05	66640	0.156	0.032
BH06	66690	0.142	0.015
BH07	66740	0.205	0.095

BH No.	Chainage	Mean	Std
BH08	66790	0.185	0.012
BH09	66840	0.162	0.025
BH10	66890	0.143	0.017

16.3.3.2 Recommended Water Absorption Value considering 1D zone of influence:

Chainage	**Statistical / Reduction Method** **(A= μ + σ across boreholes within ±10 m of FL and CL)**	**Reference Standards / Guidelines**
66440 to 66480	0.18	IS 13063:1991; IS 2386 (Part 3):1963
66480 to 66900	0.20	

16.3.4Porosity



16.3.4.1 Mean And Standard Deviation in Porosity considering 1D zone of influence in each Borehole:

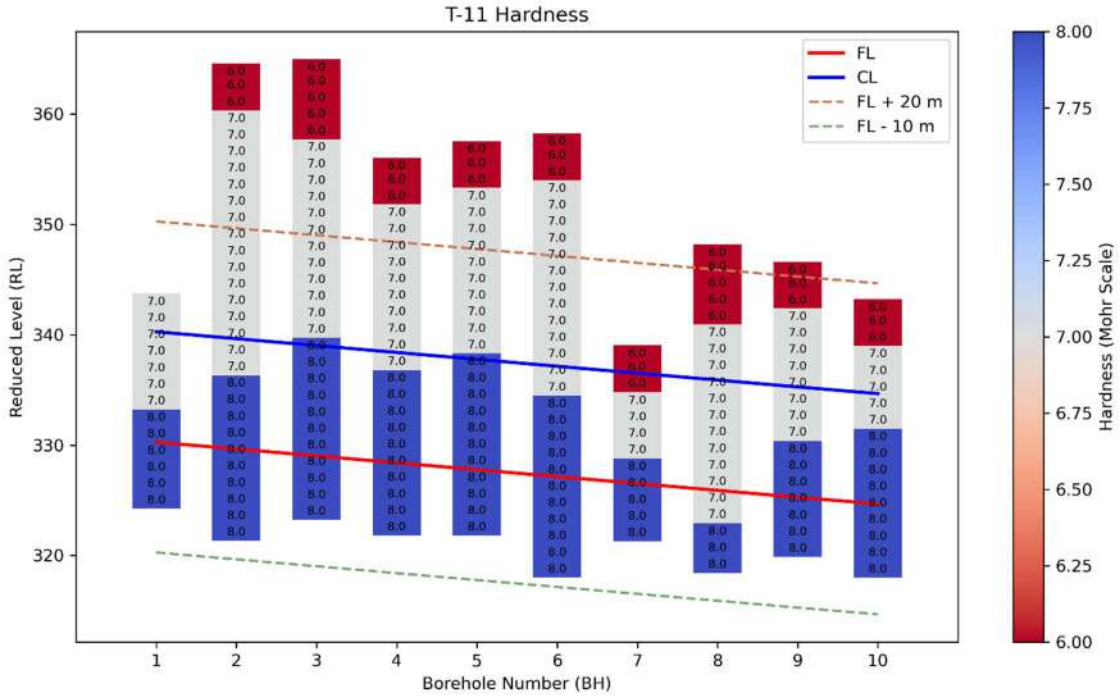
BH No.	Chainage	Mean	Std
BH01	66440	0.87	0.18
BH02	66490	0.83	0.17
BH03	66540	1.19	0.18
BH04	66590	1.38	0.11
BH05	66640	1.38	0.11
BH06	66690	1.17	0.22
BH07	66740	1.24	0.30

BH No.	Chainage	Mean	Std
BH08	66790	0.92	0.28
BH09	66840	1.87	0.16
BH10	66890	1.03	0.37

16.3.4.2 Recommended Porosity considering 1D zone of influence:

Chainage	**Statistical / Reduction Method** **(n = μ ± σ across boreholes within ±10 m of FL and CL)**	**Reference Standards / Guidelines**
66440 to 66480	0.87±0.18	IS 1124:1974; ISRM (1981)
66480 to 66900	1.21±0.36	

16.3.5 Hardness



16.3.5.1 Mean And Standard Deviation in Hardness considering 1D zone of influence in each Borehole:

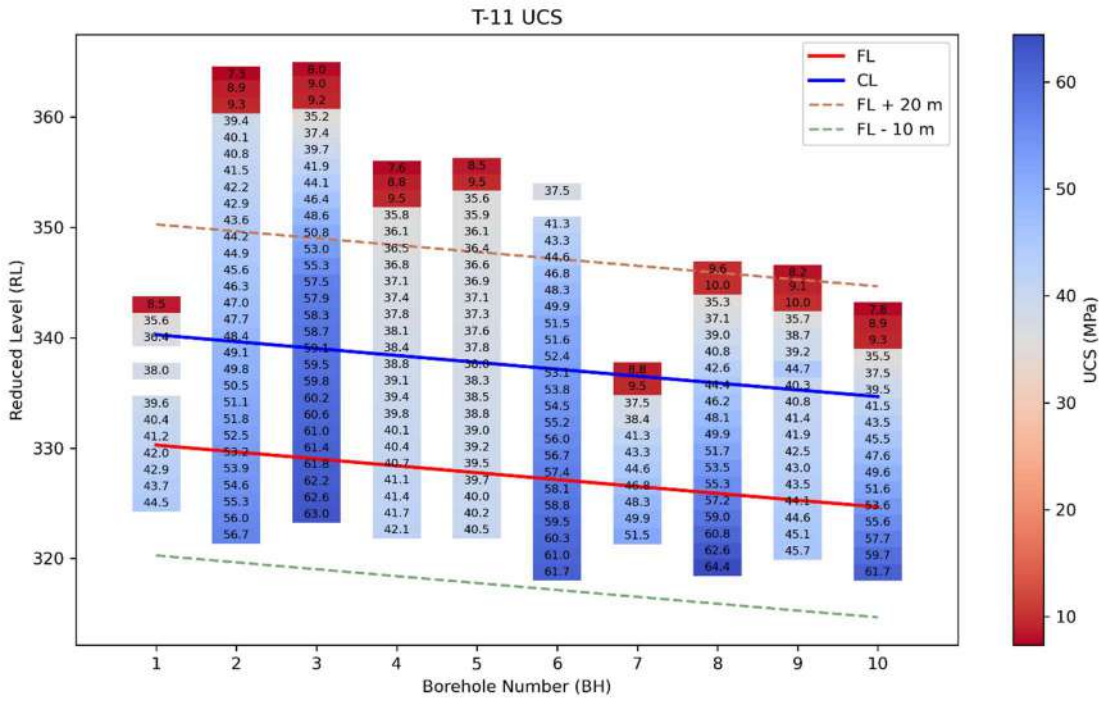
BH No.	Chainage	Mean	Std
BH01	66440	8	0.5
BH02	66490	8	0.4
BH03	66540	8	0.0
BH04	66590	8	0.3
BH05	66640	8	0.0
BH06	66690	8	0.4
BH07	66740	7	0.7

BH No.	Chainage	Mean	Std
BH08	66790	7	0.5
BH09	66840	8	0.5
BH10	66890	8	0.4

16.3.5.2 Recommended Hardness considering 1D zone of influence:

Chainage	**Statistical / Reduction Method** **(Hi = μ - σ across boreholes within ±10 m of FL and CL)**	**Reference Standards / Guidelines**
66440 to 66480	7	IS 13311 (Part 2):1992; ISRM 1978
66480 to 66900	7	

16.3.6Compression Test



16.3.6.1 Mean And Standard Deviation in UCS considering 1D zone of influence in each Borehole:

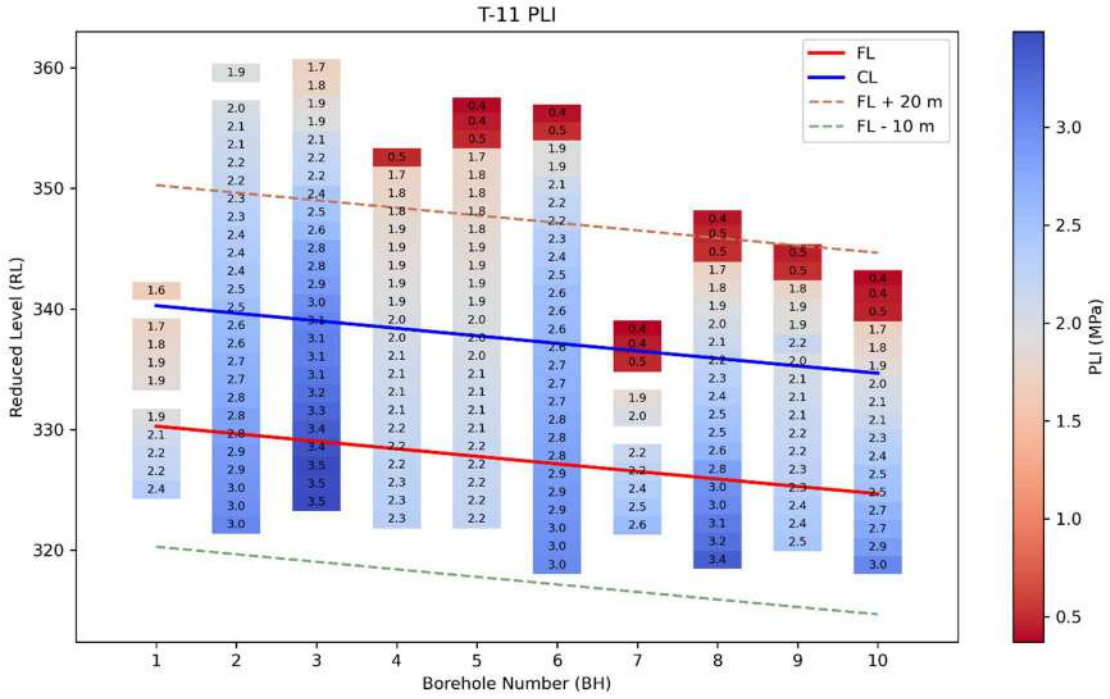
BH No.	Chainage	Mean	Std
BH01	66440	40.96	2.66
BH02	66490	52.88	2.49
BH03	66540	61.01	1.29
BH04	66590	40.41	1.09
BH05	66640	39.25	0.80
BH06	66690	57.39	2.80
BH07	66740	41.12	12.03

BH No.	Chainage	Mean	Std
BH08	66790	54.43	6.56
BH09	66840	43.26	1.63
BH10	66890	51.61	6.70

16.3.6.2 Recommended UCS considering 1D zone of influence:

Chainage	**Statistical / Reduction Method** **(UCS_k = μ - σ) across boreholes within ±10 m of FL and CL)**	**Recommended Design Value** **(UCS_d = (μ - σ) × f(RMR)), where (f(RMR) = 0.1–0.7)**	**Reference Standards / Guidelines**
66440 to 66480	38.30	7.66	IS 9143:1979; IS 13365 (Part 2):1998; Hoek & Brown (2002, 2019)
66480 to 66900	40.30	12.09	

16.3.7Point Load Test



16.3.7.1 Mean And Standard Deviation in PLI considering 1D zone of influence in each Borehole:

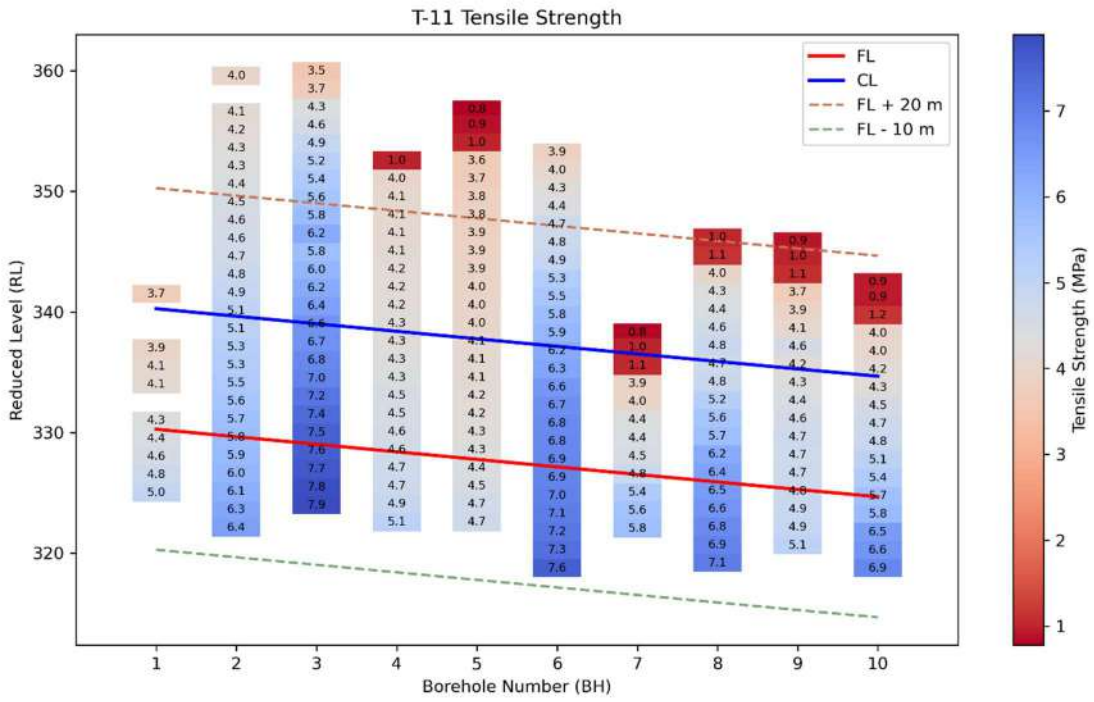
BH No.	Chainage	Mean	Std
BH01	66440	2.00	0.21
BH02	66490	2.82	0.14
BH03	66540	3.28	0.17
BH04	66590	2.18	0.10
BH05	66640	2.12	0.08
BH06	66690	2.83	0.13
BH07	66740	2.02	0.66

BH No.	Chainage	Mean	Std
BH08	66790	2.76	0.38
BH09	66840	2.25	0.13
BH10	66890	2.47	0.34

16.3.7.2 Recommended PLI considering 1D zone of influence:

Chainage	**Statistical / Reduction Method** **(PLI_k = μ - σ) across boreholes within ±10 m of FL and CL)**	**Recommended Design Value** **(PLI_d = (μ - σ) × f(RMR)), where (f(RMR) = 0.1–0.7)**	**Reference Standards / Guidelines**
66440 to 66480	1.78	0.36	IS 9143:1979; IS 13365 (Part 2):1998; Hoek & Brown (2002, 2019)
66480 to 66900	2.08	0.62	

16.3.8 Brazilian Test



16.3.8.1 Mean And Standard Deviation in Tensile Strength considering 1D zone of influence in each Borehole:

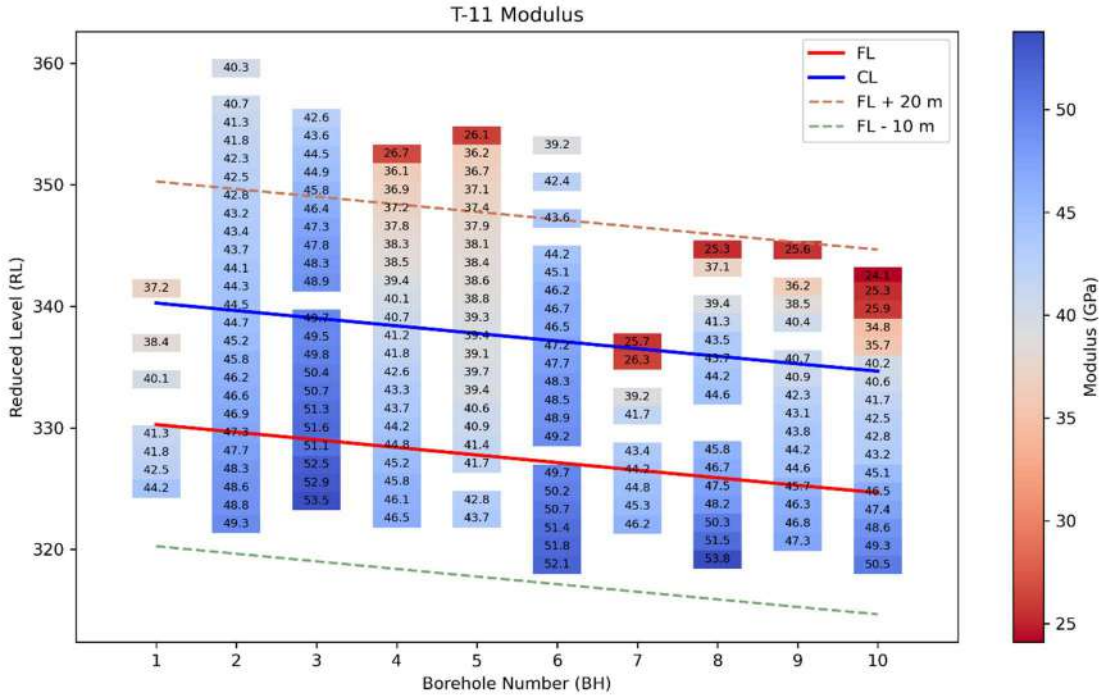
BH No.	Chainage	Mean	Std
BH01	66440	4.41	0.37
BH02	66490	5.75	0.41
BH03	66540	7.30	0.45
BH04	66590	4.59	0.25
BH05	66640	4.32	0.22
BH06	66690	6.88	0.37
BH07	66740	4.38	1.34

BH No.	Chainage	Mean	Std
BH08	66790	6.05	0.82
BH09	66840	4.71	0.24
BH10	66890	5.49	0.90

16.3.8.2 Recommended Tensile Strength considering 1D zone of influence:

Chainage	**Statistical / Reduction Method** **(mean value across boreholes within ±10 m of FL and CL× 0.8 (account for anisotropy))**	**Recommended Design Value** **(μ - σ)**	**Reference Standards / Guidelines**
66440 to 66480	4.41	4.04	IS 10082:1982; Hoek & Brown (1997); ISRM Suggested Methods
66480 to 66900	5.55	4.34	

16.3.9 Modulus of elasticity test



16.3.9.1 Mean And Standard Deviation in Elasticity considering 1D zone of influence in each Borehole:

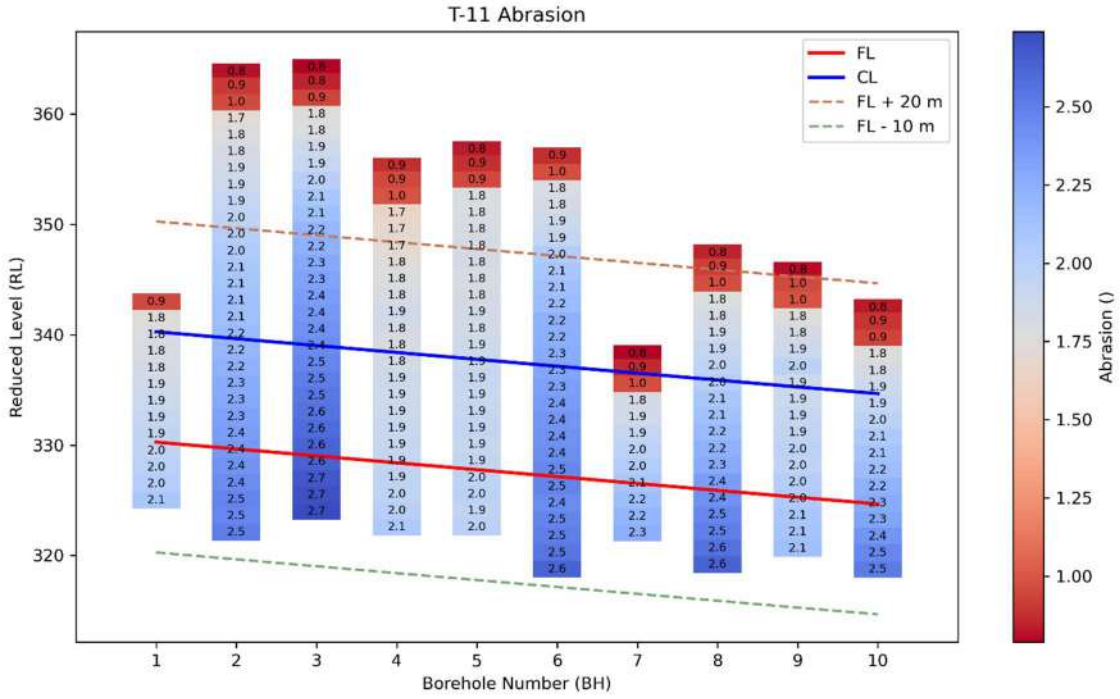
BH No.	Chainage	Mean	Std
BH01	66440	41.38	2.00
BH02	66490	47.12	1.48
BH03	66540	51.18	1.34
BH04	66590	44.11	1.76
BH05	66640	40.87	1.55
BH06	66690	49.64	1.62
BH07	66740	41.39	6.49

BH No.	Chainage	Mean	Std
BH08	66790	47.63	3.35
BH09	66840	44.50	2.06
BH10	66890	45.29	3.37

16.3.9.2 Recommended Modulus of Elasticity considering 1D zone of influence:

Chainage	**Statistical / Reduction Method (Ei = μ - σ across boreholes within ±10 m of FL and CL× 0.8 (account for anisotropy))**	**Recommended Design Value (Ed = (μ - σ) × f(RMR)), where (f(RMR) = 0.1–0.7)**	**Reference Standards / Guidelines**
66440 to 66480	39.39	7.88	IS 13365 (Part 2):1998; Hoek & Diederichs (2006)
66480 to 66900	41.77	12.53	

16.3.10 Abrasion test



16.3.10.1 Mean And Standard Deviation in Abrasion value considering 1D zone of influence in each Borehole:

BH No.	Chainage	Mean	Std
BH01	66440	1.92	0.09
BH02	66490	2.36	0.10
BH03	66540	2.59	0.10
BH04	66590	1.92	0.06
BH05	66640	1.94	0.03
BH06	66690	2.45	0.09
BH07	66740	1.93	0.37

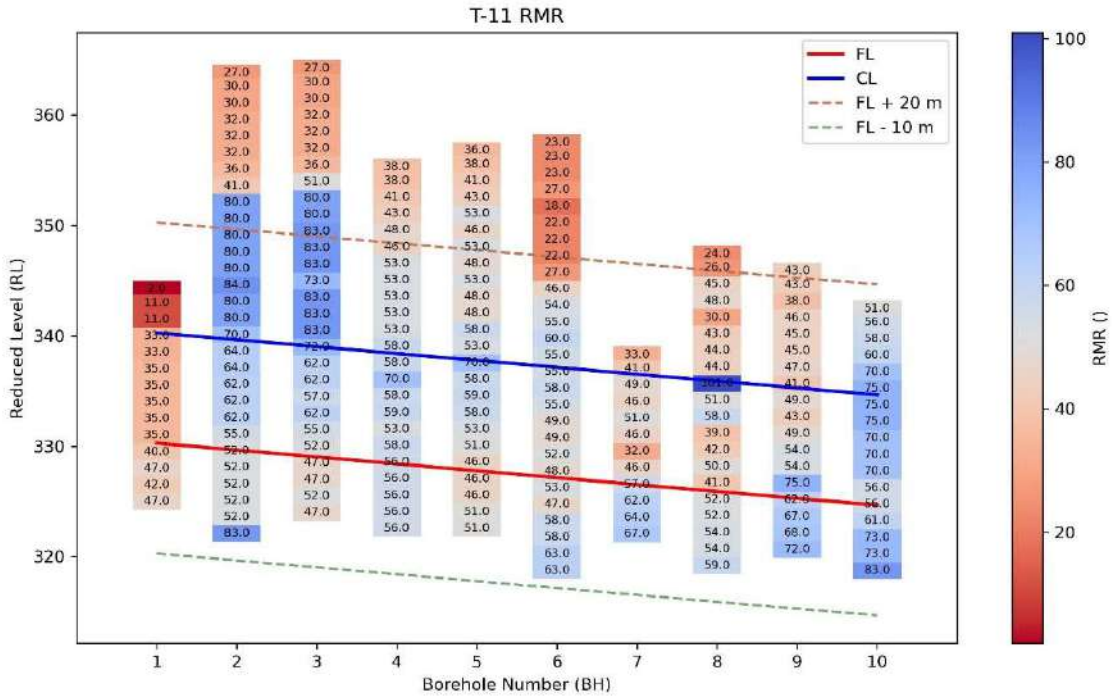
BH No.	Chainage	Mean	Std
BH08	66790	2.32	0.20
BH09	66840	2.01	0.08
BH10	66890	2.22	0.19

16.3.10.2 Recommended Abrasion Value considering 1D zone of influence:

Chainage	**Statistical / Reduction Method** **(A= μ + σ across boreholes within ±10 m of FL and CL)**	**Recommended Design Value** **(A_v < 25%): Slightly abrasive; 25–35%: Moderately abrasive; >35%: Highly abrasive. (CAI = 0.5–6).**	**Reference Standards / Guidelines**
66440 to 66480	2.01	Slightly abrasive	IS 2386 (Part 4):1963; ISRM (2007); CERCHAR (1986)
66480 to 66900	2.49	Moderately abrasive	

16.4Geological assessment:

16.4.1RMR:



16.4.1.1 Mean And Standard Deviation in RMR considering 1D zone of influence in each Borehole:

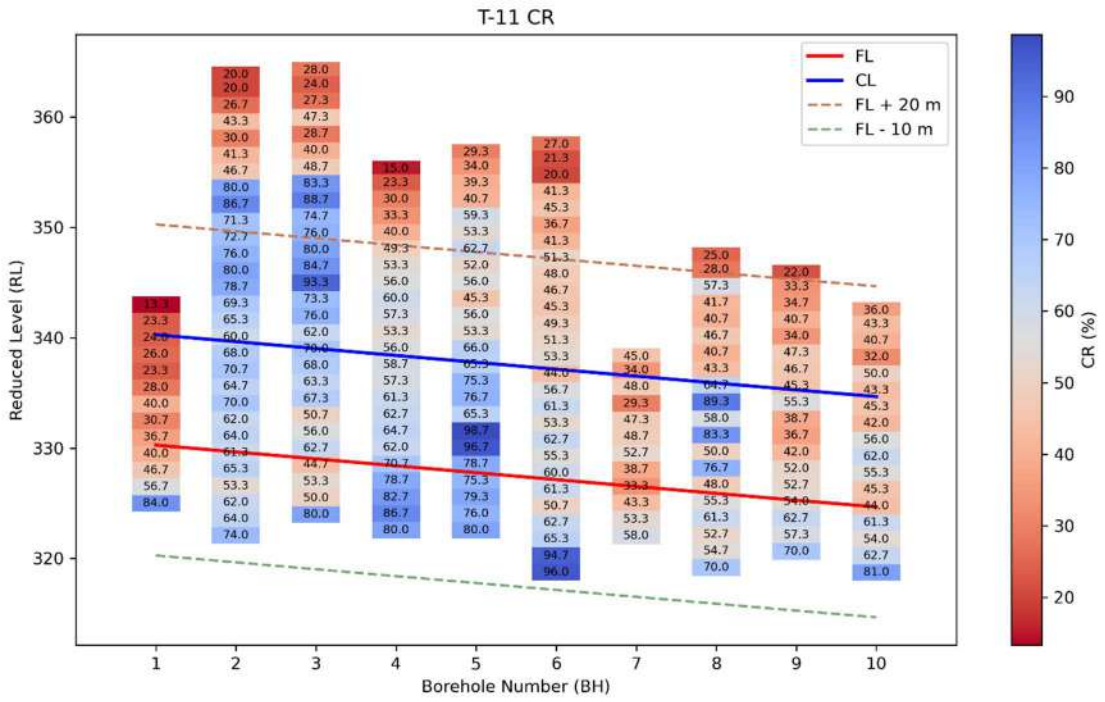
BH No.	Chainage	Mean	Std
BH01	66440	38	5.26
BH02	66490	59	9.11
BH03	66540	56	8.01
BH04	66590	58	4.35
BH05	66640	54	7.29
BH06	66690	54	5.39

BH No.	Chainage	Mean	Std
BH07	66740	52	10.60
BH08	66790	54	16.01
BH09	66840	59	10.98
BH10	66890	69	8.39

16.4.1.2 Recommended RMR considering 1D zone of influence:

Chainage	**Statistical / Reduction Method** **(Average across boreholes within ±10 m of FL and CL)**	**Recommended Design Value** **(RMR_d = μ - σ)**	**Reference Standards / Guidelines**
66440 to 66480	38 (Class IV)	33 (Class IV)	IS 13365 (Part 2): 1998, Cl. 5.1 + Note on "representative values"
66480 to 66900	57 (Class III)	47 (Class III)	

16.4.2 Core Recovery:



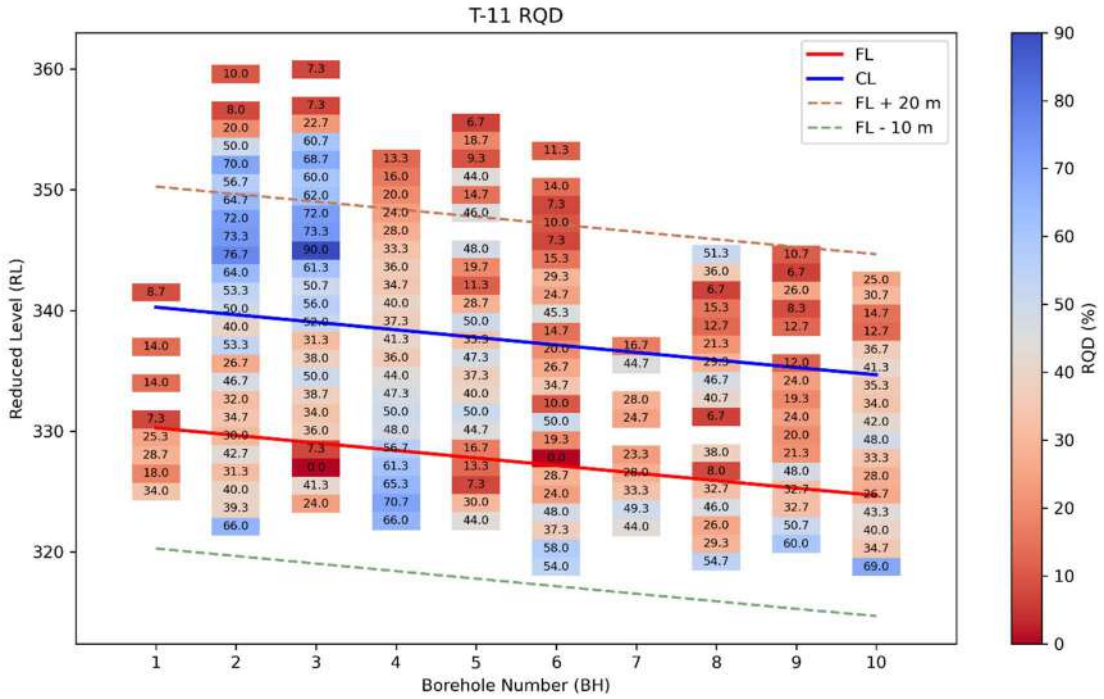
16.4.2.1 Mean And Standard Deviation in Core Recovery considering 1D zone of influence in each Borehole:

BH No.	Chainage	Mean	Std
BH01	66440	39.63	17.97
BH02	66490	64.94	5.37
BH03	66540	60.54	10.56
BH04	66590	69.57	10.59
BH05	66640	78.84	10.56
BH06	66690	63.38	15.32
BH07	66740	45.26	9.12

BH No.	Chainage	Mean	Std
BH08	66790	63.66	13.47
BH09	66840	52.13	10.51
BH10	66890	55.36	11.41

Overall Mean	**Std**
59.68	15.84

16.4.3 RQD:



16.4.3.1 Mean And Standard Deviation in RQD considering 1D zone of influence in each Borehole:

BH No.	Chainage	Mean	Std
BH01	66440	20.19	9.45
BH02	66490	40.22	11.08
BH03	66540	32.06	16.15
BH04	66590	53.33	11.34
BH05	66640	33.09	14.63
BH06	66690	31.59	17.53
BH07	66740	34.41	10.15
BH08	66790	32.54	15.17
BH09	66840	33.27	14.61
BH10	66890	39.48	11.70

16.4.3.2 Recommended RQD considering 1D zone of influence:

Chainage	Statistical / Reduction Method (Average across boreholes within ±10 m of FL and CL)	Recommended Design Value (RQD_d = μ - σ)	Reference Standards / Guidelines
66440 to 66480	20.19	10.74	IS 11315:1985; Deere (1963)

16.5 Petrographic Assessments:

16.5.1 Description of rock Masses

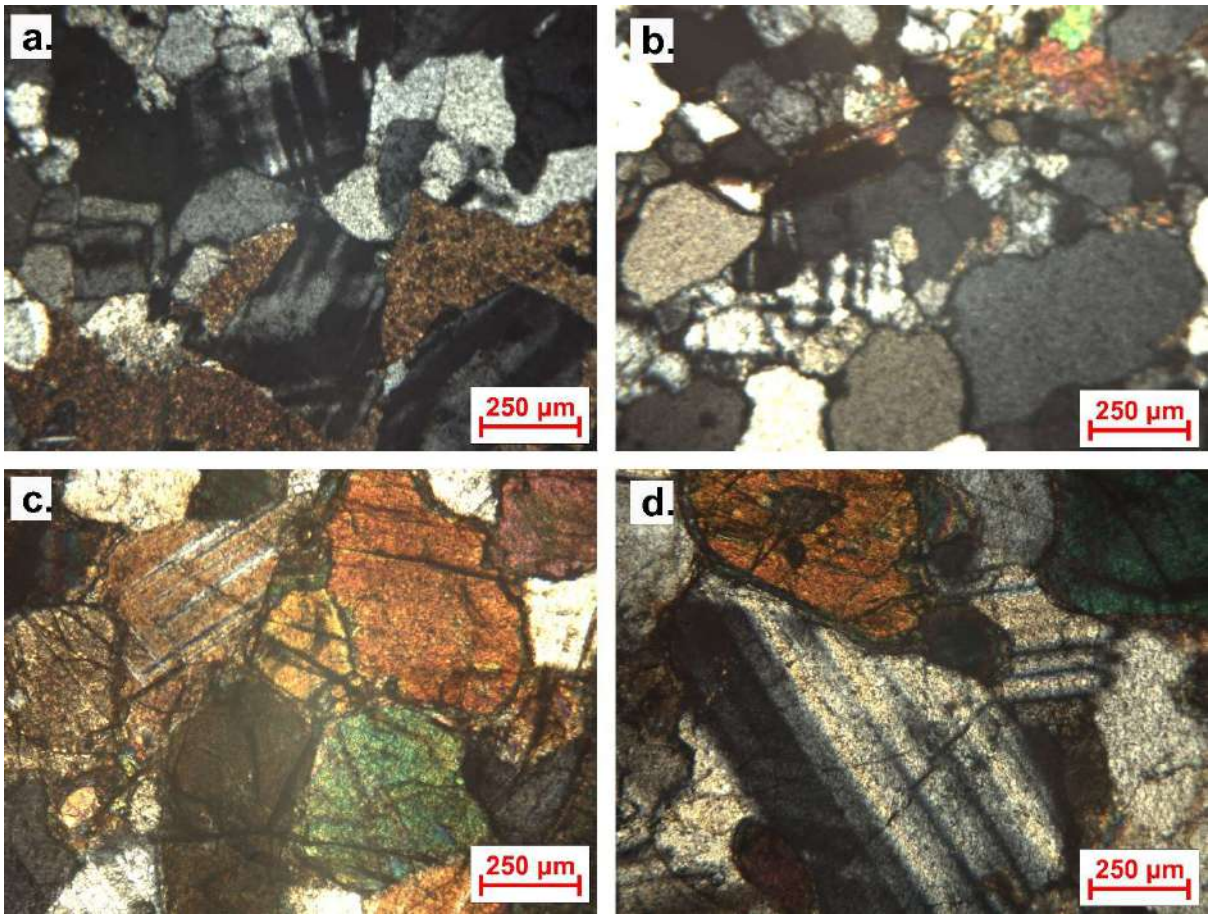
16.5.1.1 Migmatite

Migmatites of the Eastern Ghats consist of quartz- and feldspar-rich leucosome with garnet- and biotite-bearing melanosome/restite. Petrographic and modal descriptions are consistent with dominant quartz + feldspar (~60–70 %) and subordinate garnet and biotite as reported by Sarkar et al. (2007) and Sengupta et al. (2011).

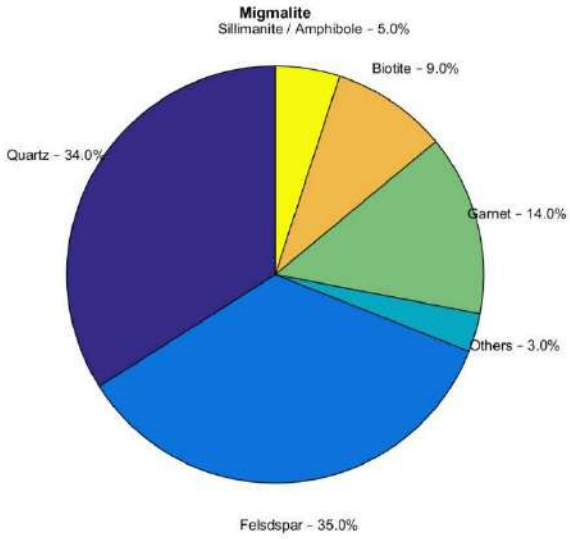
16.5.1.2 Khondalite (Restite)

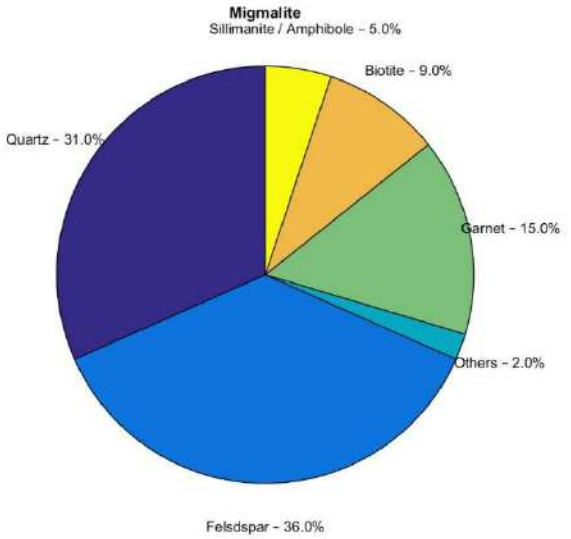
Restites represent refractory residues after partial melting of metapelites, enriched in garnet and ferromagnesian minerals and depleted in felsic phases. Modal characteristics inferred from petrographic descriptions of residual granulites and restitic layers in the EGMB.

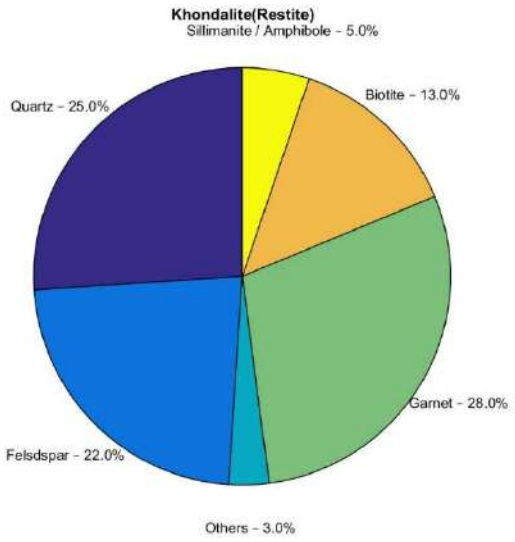
16.5.2 Micro Photographs

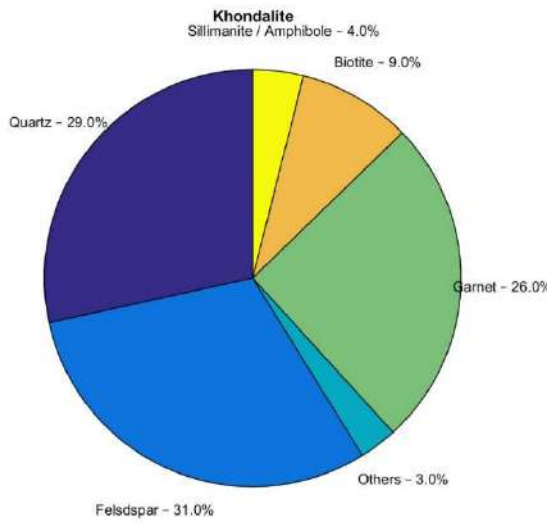


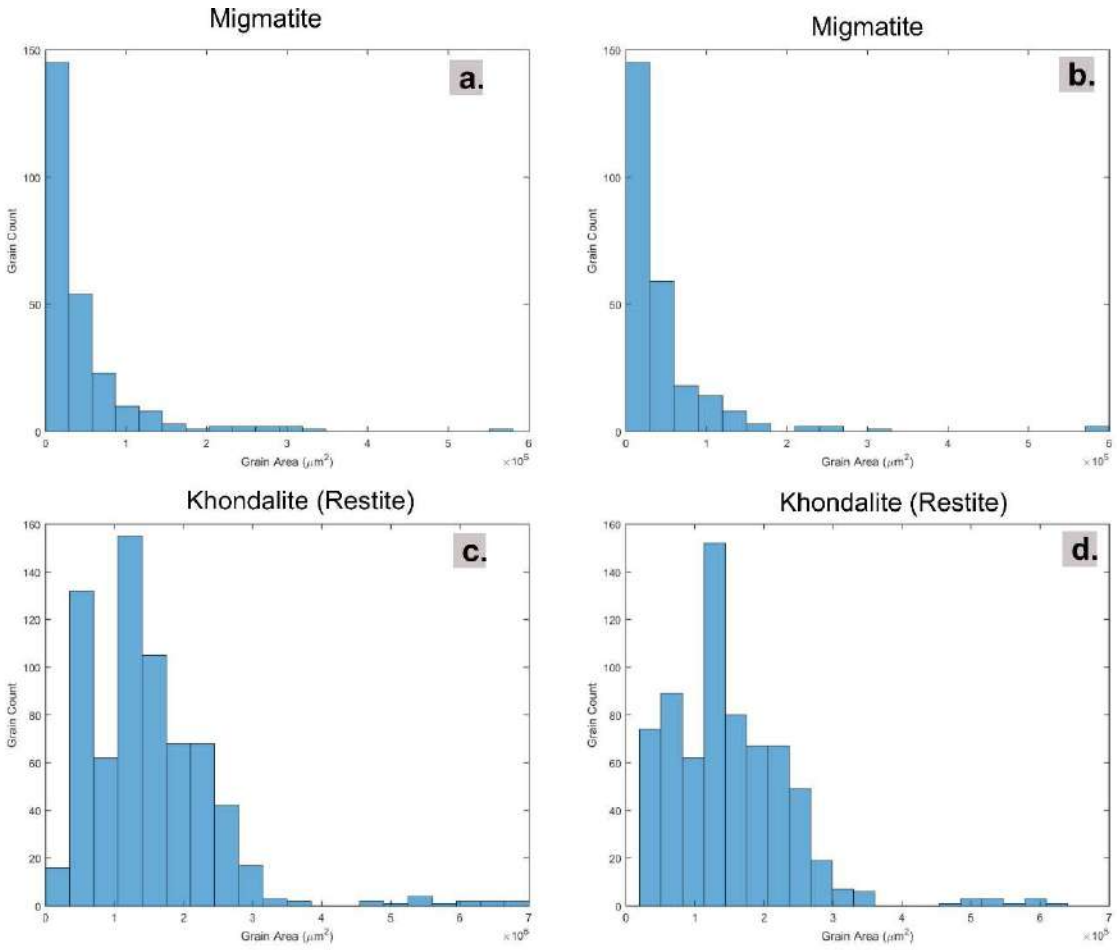
16.5.3 Mineral percentage and grain size distribution











16.6L section: