Silkyara Bend – Barkot Road Tunnel
Geotechnical Report

Of

2 Lane/ 2 Lane upgradation proposal of Highway between Km 144.00 (Dharasu) and Km 220.00 (Yamunotri) falling along NH - 94 and 123 in the State of Uttarakhand

Submitted to

Ministry of Road Transport & Highways
(Government of India)

By

TASPL

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Description	Proportion of tunnel excavation	RMR'	GSI	Q
Amphibolite/epidiorite	80.40%	81 - 85	86 - 90	40 - 1000
Meta-sandstone/siltstone/ phyllites	17.89%	61 - 65	66 - 70	Apr-40
Closely fractured phyllites	1.71%	21 - 40	26 - 45	0.1 - 1

Table 2 : Percentage of Rock Class

Description of rock class	Proportion of tunnel	Tunnel Length
Class A	5%	227.5
Class B	5%	227.5
Class C	50%	2275
Class D	30	1365
Class E	10	455
Total	100%	4550

1.4 Discontinuities & Rock Mass Parameters

Majority of discontinuity encountered along tunnel portal area are taken as reference for discontinuities along tunnel alignment for doing Unwedge analysis. Direction of tunnel alignment is N175^0

Table 3: Discontinuity Sets for Tunnel

Joint Set	Dip Direction (°)	Dip Amount (°)	Friction Angle (Φ_j), (°)	Cohesion (c_j), MPa
J1	N35-60	40-55	26	0.01
J2	N315-355	55-78	26	0.01
J3	N230-260	40-58	26	0.01

1.5 Wedge Stability Analysis

The possibility for wedge formations due to intersection of the joints defined above is also checked with Unwedge software. The stereographic projections for tunnel are shown in Figure- 1 for tunnel directions N186^0 The formation of wedges due to three joint sets without any support system and with support system (50 mm thk. shotcrete) is shown in Figures 2.

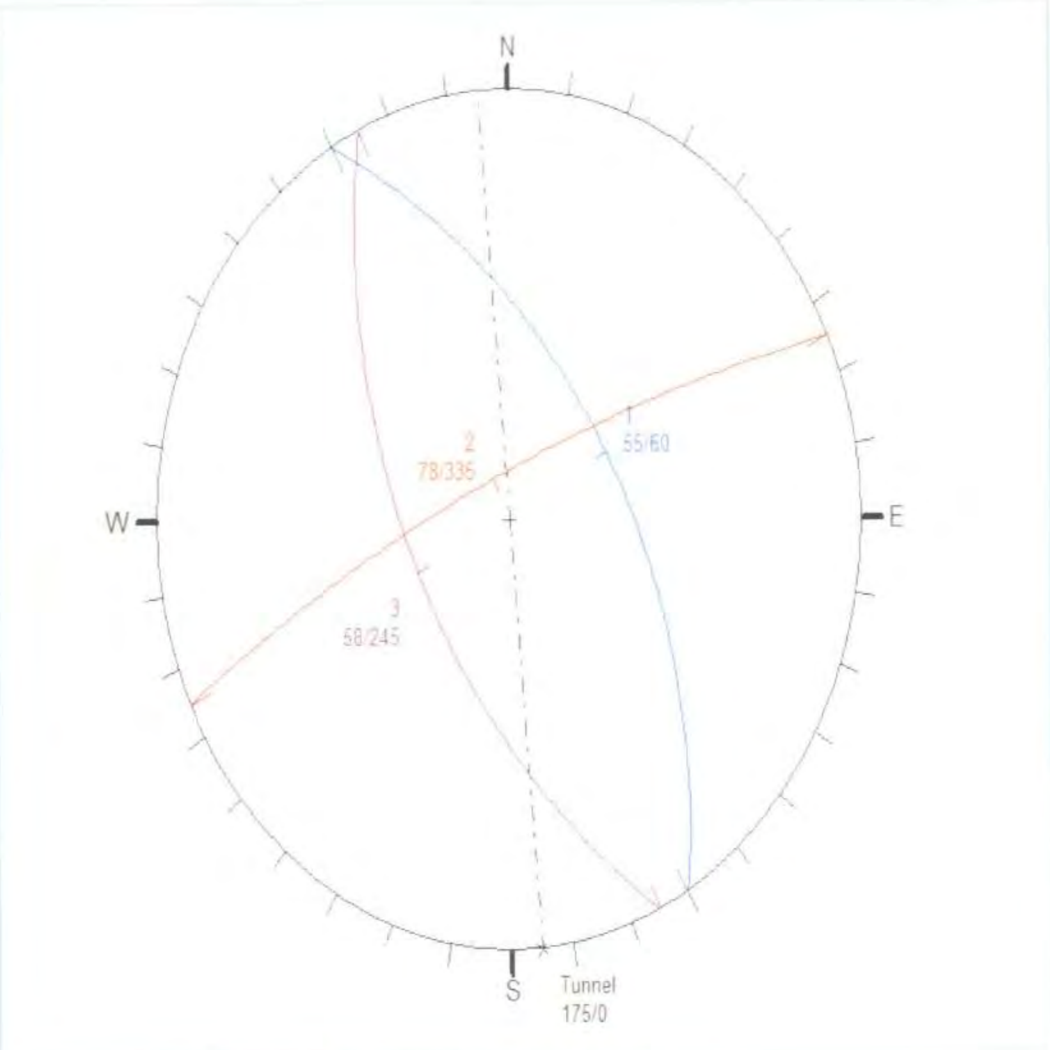

Figure-1: Stereographic Projection of Tunnel

Table 4: Rock Mass Parameters Extracted from Intact Rock

Description		Unit	Class A	Class B	Class C	Class D	Class E
Intact Rock Properties	UCS	MPa	80	70	60	50	40
	GSI		85	65	50	30	20
	m_i		18	18	18	18	18
	D		0.3	0.3	0.3	0.3	0.3
	E_i	MPa	25000	25000	25000	20000	20000
	v		0.2	0.2	0.2	0.25	0.3
	Rock Cover	m	500	500	500	150	100
Rock Mass Parameters	c (peak)	MPa	5.258	2.569	1.759	0.52	0.278
	Φ (peak)	deg	52.728	46.406	40.187	40.65	37.334
	c (residual)	MPa	4.588	2.043	1.318	0.334	0.162
	Φ (residual	deg	50.93	41.459	32.859	30.079	25.069
	Tensile Strength	MPa	1.31	0.225	0.057	0.009	0.003
	Deformation Modulus	MPa	18896	11366	4986	1107	692
In-Situ Stress	Vertical Stress (σ_3)	MPa	13.5	13.5	13.5	4.05	2.7
	In Plane Horizontal Stress (σ_1)	MPa	13.5	13.5	13.5	4.05	2.7
	Vertical Stress (σ_3)	MPa	13.5	13.5	13.5	4.05	2.7

In-situ stress has been considered as hydrostatic condition due to unavailability of data .Which will be later verified using hydro-fracture test in proposed drill hole during detail design.

2 Road Tunnel

A 14.075m (W) x 9.9.00m (H) (excavated size) D shaped tunnel having total length of 4551m is proposed. The following rock mass properties and supports system have been considered in the analysis of different type of rock classes:

3 Empirical Design of Rock Support

As per geological report, general rating of rock mass for the Tunnel has been estimated. The Table-5 shows the values of different geo-mechanical parameters for different classes of rock, which are adopted for the design of rock support:

Table-5: Geo-mechanical Parameters adopted for different Classes of Rock

Rock/ support Class	Type of Rock (Q Range)	Q adopted	Jr
Class A	Very to Extremely Good Rock (40-1000)	40	3
Class B	Good Rock (40-10)	10	3
Class C	Fair Rock (4-10)	4	2
Class D	Poor Rock (1-4)	1	1.0
Class E	Very Poor Rock (0.01-1)	0.1	1.0

3.1 IS Code Method

3.1.1 Estimation of Support Pressures

Section 3.5 of IS 13365 (Part-2):1992 details method to assess the ultimate rock support pressures on roof and wall for squeezing and non-squeezing ground. Ground is termed as squeezing or non-squeezing based on the height of overburden, H, above the crown of tunnel. If H is less than 350×Q1/3 the ground is non-squeezing, otherwise it is termed as squeezing. In the present case the height of overburden above the crown of Tunnel is moderate (varies from 30m to 500m), hence the ground has been considered as non-squeezing for the design of rock support of Tunnel for Class-A to B and Squeezing for Class C to E. For non-squeezing ground IS: 13365 (Part-2) has recommended empirical equations for calculating ultimate and short term support pressures on roof and wall. However, in present case short term support pressures have been neglected and only ultimate support pressures have been considered for the design.

a) Ultimate roof Support Pressure (for Crown)

The ultimate roof support pressure is related to ultimate rock mass quality (Qru) by the following empirical relation:

$$P_{ru} = \frac{2Q_{ru}^{-1/3}}{J_r} f$$

Where:

Pru = ultimate roof support pressure in kg/cm²

Q_{ru} = ultimate rock mass quality for roof = Q

Jr = joint roughness number

f = correction factor for overburden = maximum of {1, 1 + (H-320)/ 800}

H = overburden above crown or tunnel depth below ground level in meters.

b) Ultimate wall support pressure

The ultimate wall support pressure (P_{wu}) in kg/cm² can be obtained from the following equation:

$$P_{wu} = \frac{2Q_{wu}^{-1/3}}{J_r} f$$

Where, Qwu = ultimate wall rock quality index calculated from Table-4.

In view of the more favorable position of walls as compared to roofs, the following hypothetically increased value of wall rock quality (Q_{wu}) are used for different qualities of rock mass

Table-6: Equations for calculation of Qwu for different qualities of rock mass

Type of Rock	Range of Q	Q_{wu}
exceptionally good to good rock	Q>10	5 Q
fair to very poor rock	0.1 < Q < 10	2.5 Q
extremely poor to exceptionally poor rock	Q < 0.1	Q

Calculation of rock bolt parameters

The minimum spacing of rock bolts (in m) is calculated from the design rock pressure (in kPa, calculated and capacity of rock bolt (in kN) as per following equation.

$$\text{Spacing} = \sqrt{\frac{\text{Capacity of rock bolt}}{\text{Design Pressure}}}$$

The length of rock bolts, L (in m) is calculated by using the following formula

Minimum Length of Rock Bolt = $L = 2 + \frac{0.15B}{ESR}$

Where B is excavated Span in m.

3.1.2 METHODOLOGY

General design methodology for the rock support system comprises the following steps:

Step-1: Evaluation of the rock mass quality (Q) post excavation. In the present case Q value has been adopted on the basis of available geological data.

Step-2: Estimate the parameters like length of rock bolts and their spacing by different empirical relations as per IS Code method for different rock class.

Step-3: Calculate roof and wall support pressures as per **IS: 13365 (Part 2).**

Step-4: Perform detailed calculation and find suitable shotcrete thickness and spacing of rock bolt.

Step-5: Adopt the rock support measures.

3.1.3 ROOF PRESSURE FOR DIFFERENT CLASS OF ROCKS

Roof pressure is calculated as per Para 3.1.1 for different classes of rock and value is shown in Table-5 below.

Table-7: Roof pressure for different classes of rock

Rock Class	Q	J_r	P_{roof} (kN/m^2)
Very to Extremely Good Rock	40	3	30.95
Good Rock	10.2	3	48.80
Fair Rock	4	2	77.17
Poor Rock	1	1.0	289.10
Very Poor Rock to Extremely Poor Rock	0.1 to 1	1.0	527.84

4 Stress-Deformation Analysis for Tunnel

4.1 Loads

For the Stress-Deformation analysis, In-Situ Stress corresponding maximum vertical cover above the tunnel is considered in the analysis.

4.2 Method of the Analysis

The stability analysis of the Tunnel have been carried out using Finite Element Programme PHASE2, as a continuum model using Mohr-Coulomb yield criteria and stresses and deformations around the tunnel are estimated to check the stability of the tunnel. The numerical model of excavated cavity has been conceived as plain strain model with external boundaries at about 45m (approx. 3 times of openings) from the excavated tunnel boundaries so that the boundary conditions will have negligible influence on the stress field around it. Six node triangular finite elements with fine meshing is used close to the excavation boundaries of the tunnel, so that the variations in the stress field could be captured with higher precision. Size of the elements is gradually increased toward the external boundaries to reduce the number of elements and calculation time. External boundaries are taken as fixed and insitu stresses are applied as per the loading corresponding to cover for tunnel.

A stress relaxation of 40% has been considered between the excavation of cavity and installation of support. This models the deformations and corresponding field stress release from the time after blasting and up to installation of support.

Excavation sequence, wherever stage excavation is defined, of the tunnel has been simulated in the model using the stage construction approach. For all Class of rock mass, heading and benching excavation has been simulated as Stage-1 is generation of model and initialization of in-situ stress, stage-2 is material softening of heading portion, stage-3 is heading excavation and support, stage-4 is material softening of benching portion and stage-5 is benching excavation and installation of rock support.

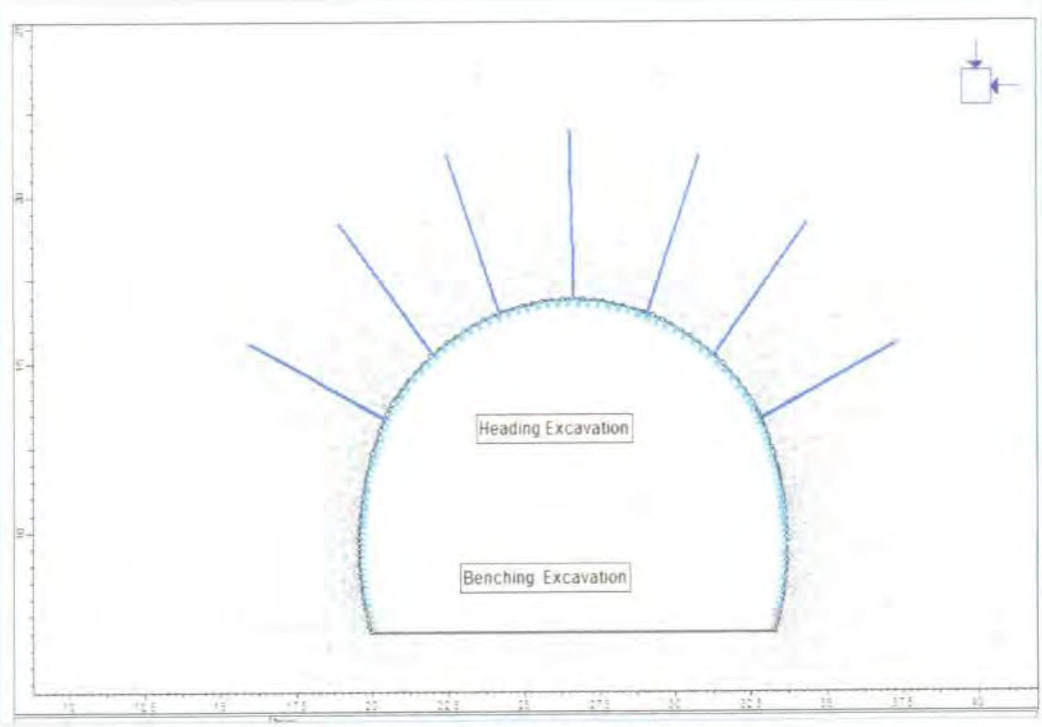

Figure-6: Discretization Model of Excavation

4.3 Assumptions in the Analysis

Following major assumptions were made while designing the support system for tunnel:

1. The geometry of the tunnel is the same along the tunnel length, permitting the three-dimensional problem to be modelled in two dimensions (Plane strain conditions).

2. The rock mass surrounding the tunnel is homogenous, isotropic in all directions.

3. The modulus reduction method is used to simulate the advancement of tunnel excavation and modulus of the tunnel material is reduced by 40% in the analysis before the installation of support system in each stage, however the strength parameters are assumed same as that of the original rock mass material.

4. The excavation is carried out in two stages (in conservative manner) as shown in Figures in subsequent section.

5. An additional precaution as pipe roofing and face support shall be taken in very poor rock class E, although effect of pipe roofing is not considered in the analysis.

6. For Class E 250 mm thick shotcrete is also considered in the analysis at the floor after excavation of heading and benching to control the heave.

4.4 Class-A Rock mass

- Rock Unit Weight - 27 KN/m³
- Ultimate Compressive Stress - 80 MPa
- Geological Strength Index - 85
- Young's Modulus - 18896 MPa
- Poisson Ratio - 0.20
- Dilation Angle - 40

Support System: Spot bolts of 25 mm dia. 5.0 m long as initial support@ 2.5 m c/c with 50 mm thick plain shotcrete and 400 mm thick concrete lining as final support.

Results & Discussion: The major principal stresses and deformations around the tunnel are shown in Figure 7& 9 respectively. The maximum stress value generated in the rock mass is 63 MPa and maximum deformation at the tunnel boundary is only 7.38 mm. Hence the support system provided is adequate. Axial force in Bolt is around 45 kN. Plastic Zone is within permissible limit.

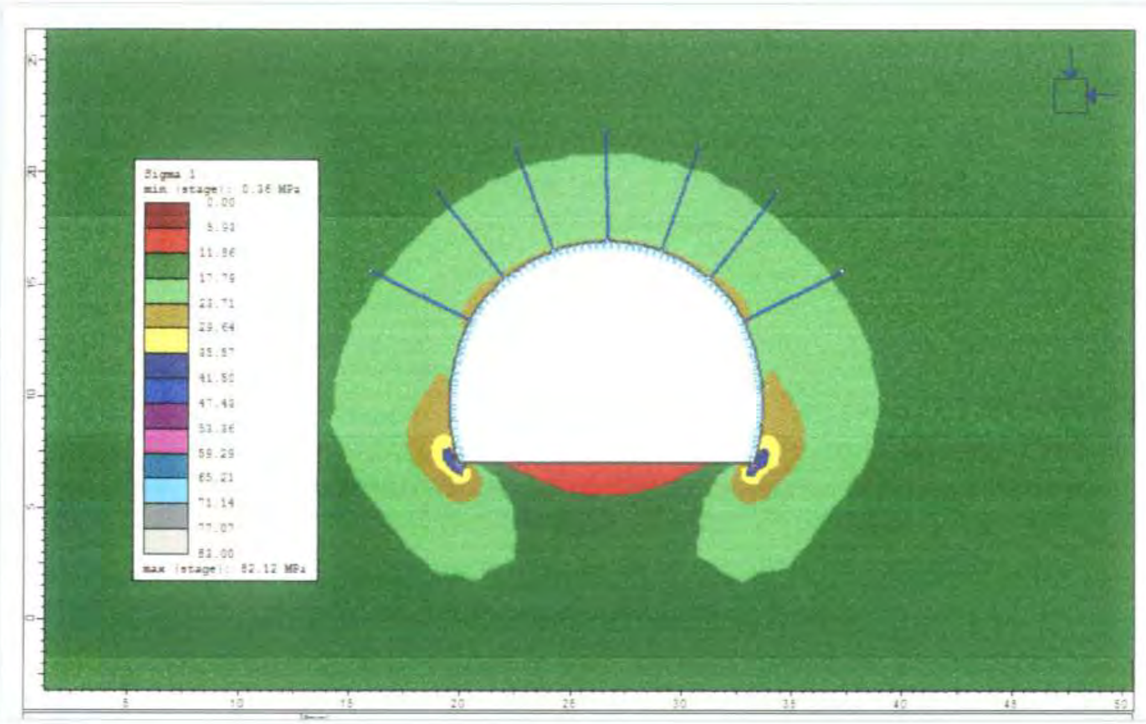

Figure-7: Major Principal Stresses

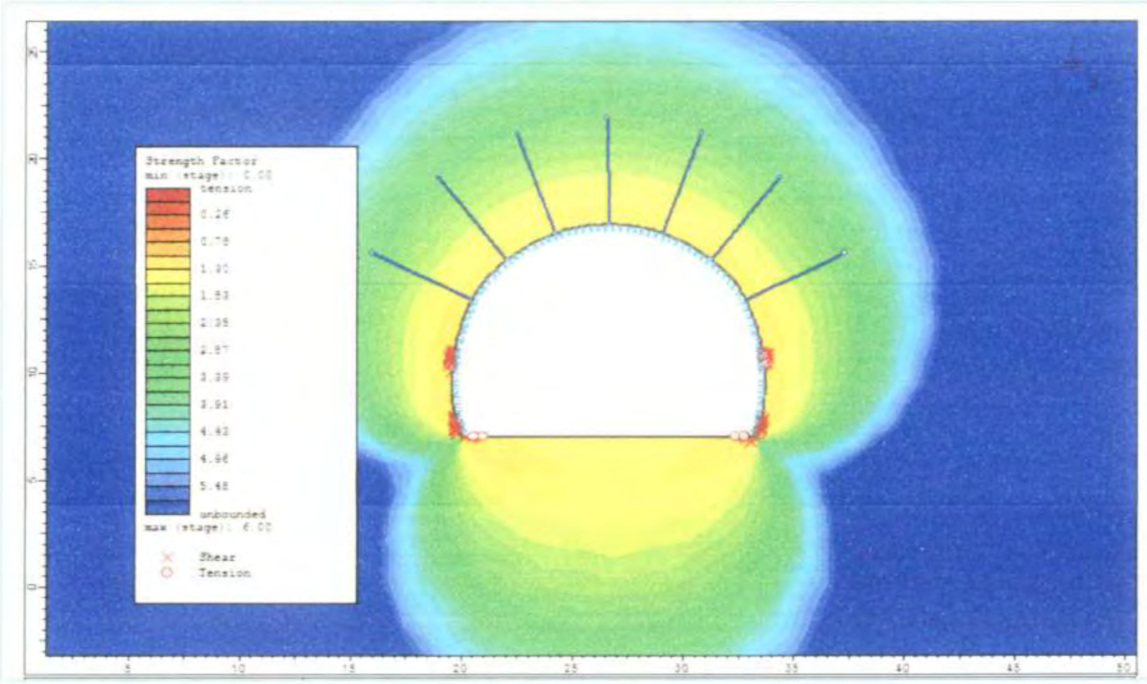

Figure-3: Yielded Element and Strength factor

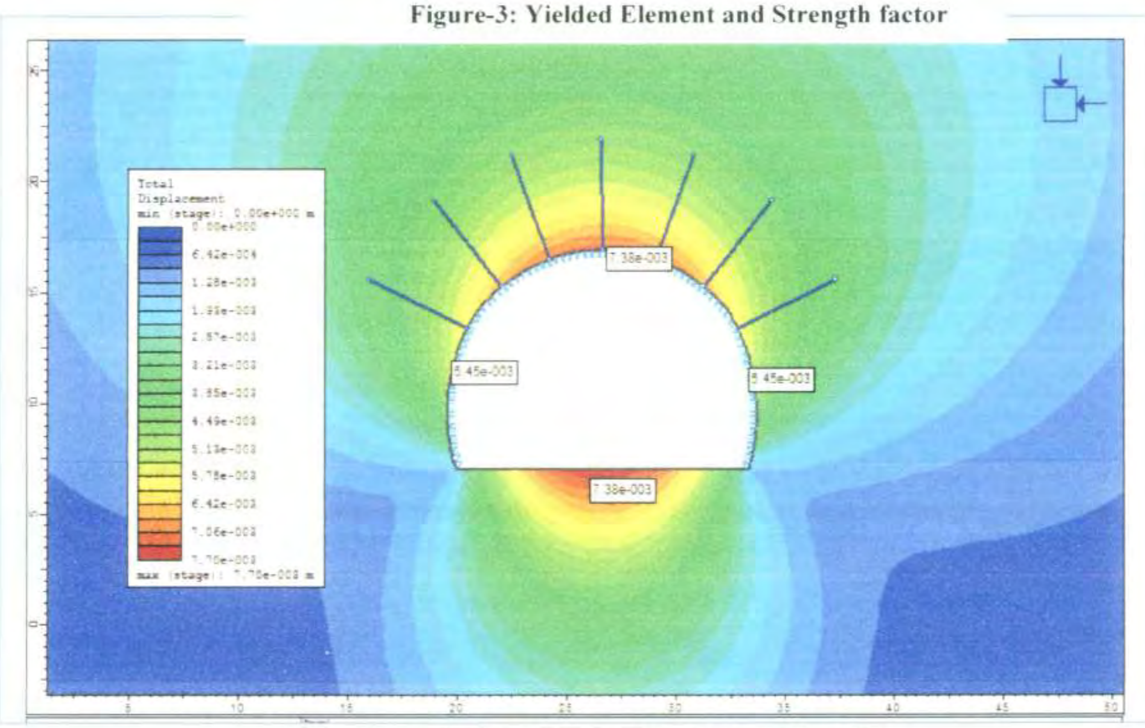

Figure-8: Total Displacement around Opening

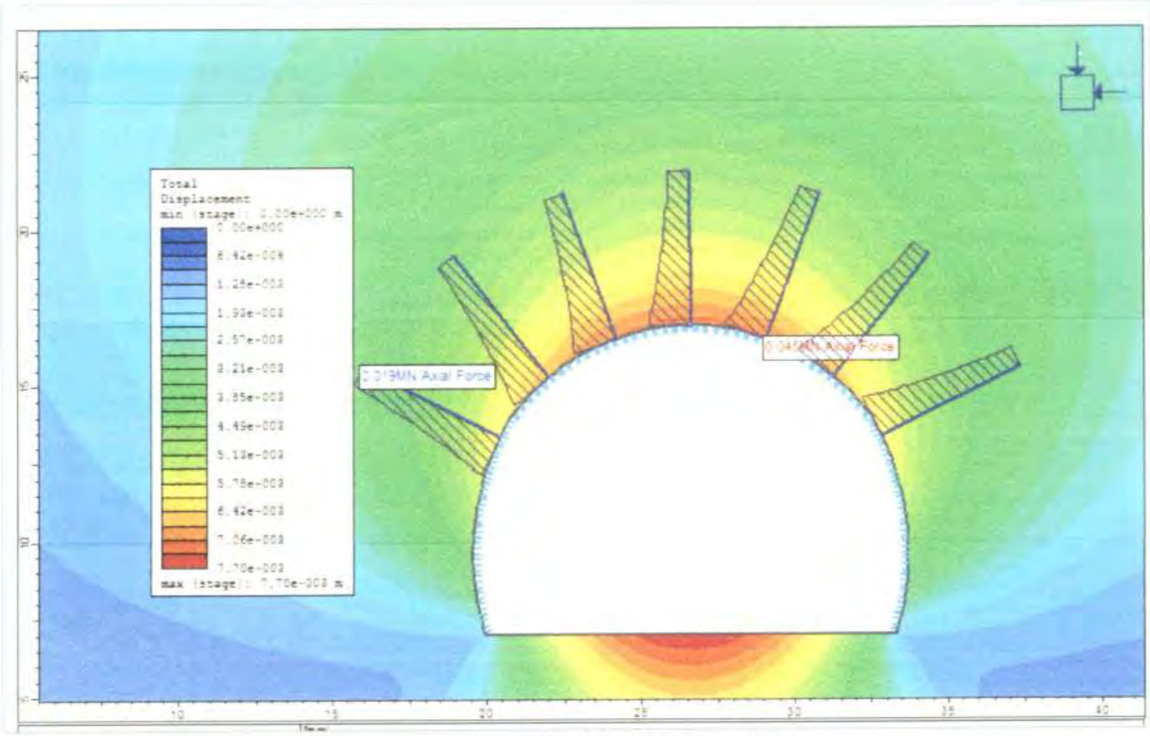

Figure-9: Axial Force in Bolts

4.5 Class-B Rock mass

- Rock Unit Weight - 27 KN/m3
- Ultimate Compressive Stress - 70 MPa
- Geological Strength Index - 65
- Young's Modulus - 11366MPa
- Poisson Ratio - 0.20
- Dilation Angle - 40

Support System: 75 mm thick shotcrete and fully grouted rock bolts of 25 mm dia. 5.0 m long and 2.0 m c/c spacing as initial support and 400 mm thick concrete lining as final support.

Results & Discussion: The major principal stresses and deformations around the tunnel are shown in Figure 10 & 12 respectively. The maximum stress value generated in the rock mass is 38 MPa and maximum deformation at the tunnel boundary is only 14.0 mm. Hence the support system provided is adequate. Axial force in Bolt is around 190kN. Plastic zone is within rock bolt which justify the adequacy of rock bolt.

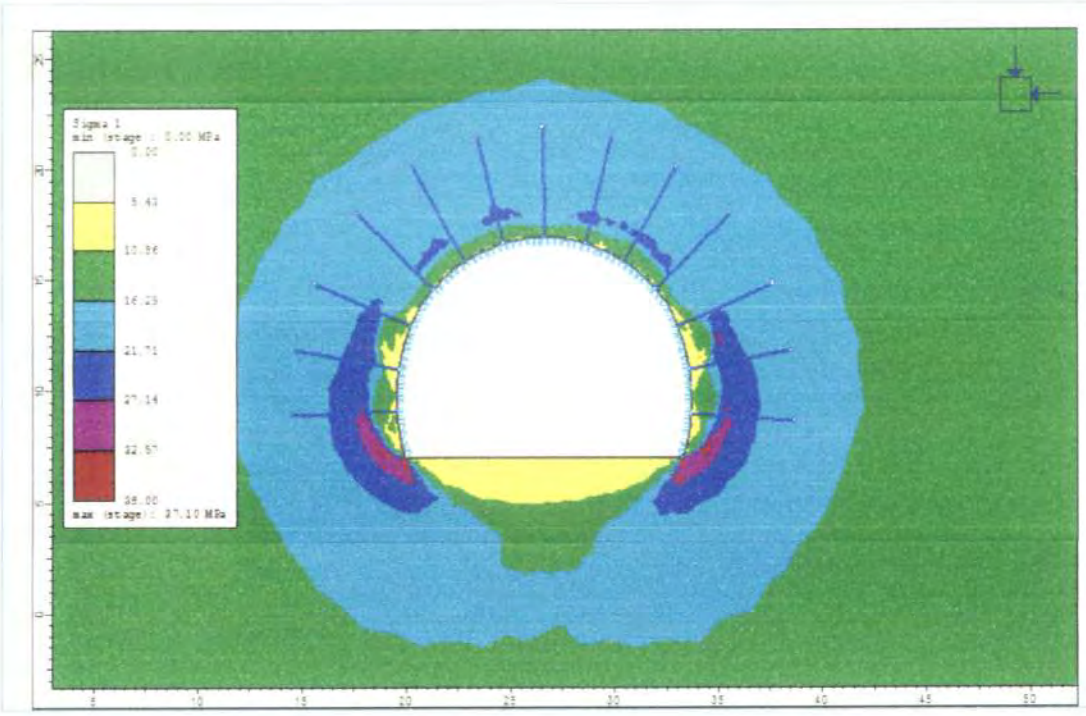

Figure-10: Major Principal

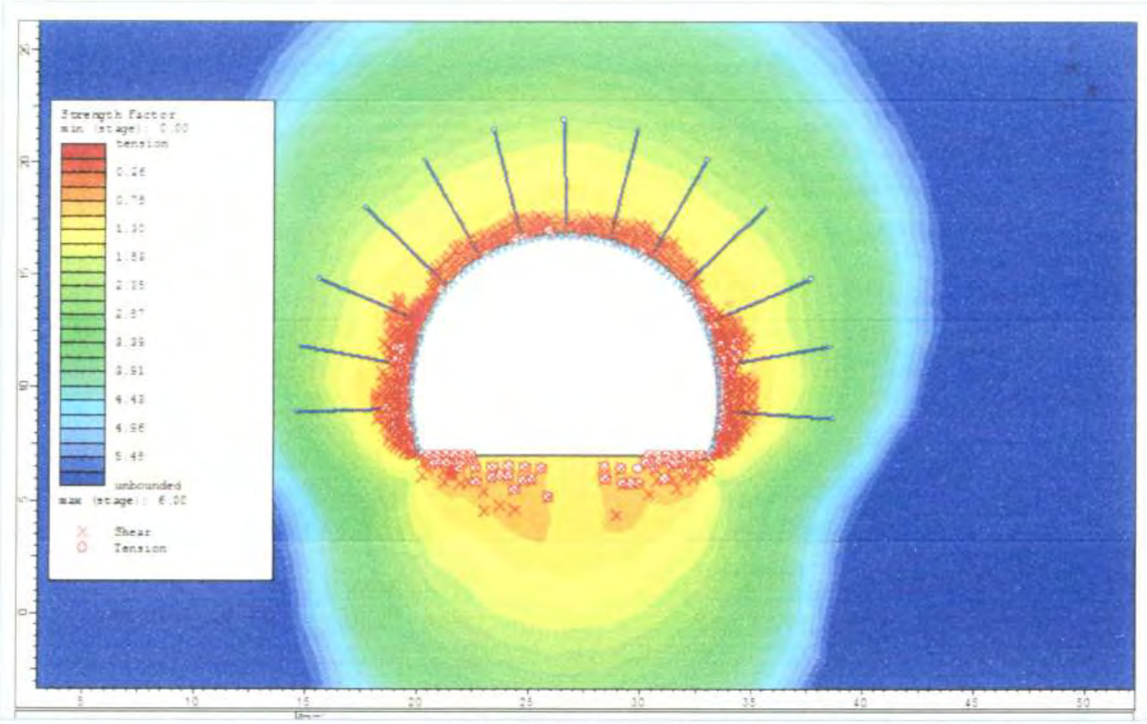

Figure-11: Yielded Element and Strength factor

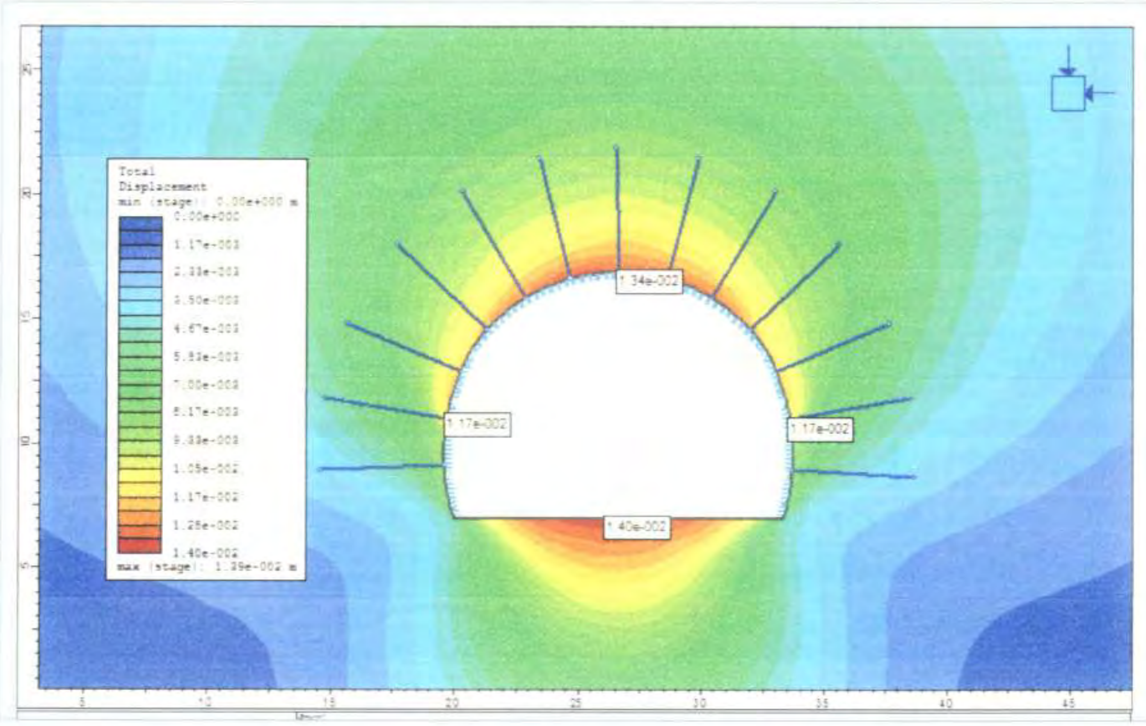

Figure-12: Maximum Deformation

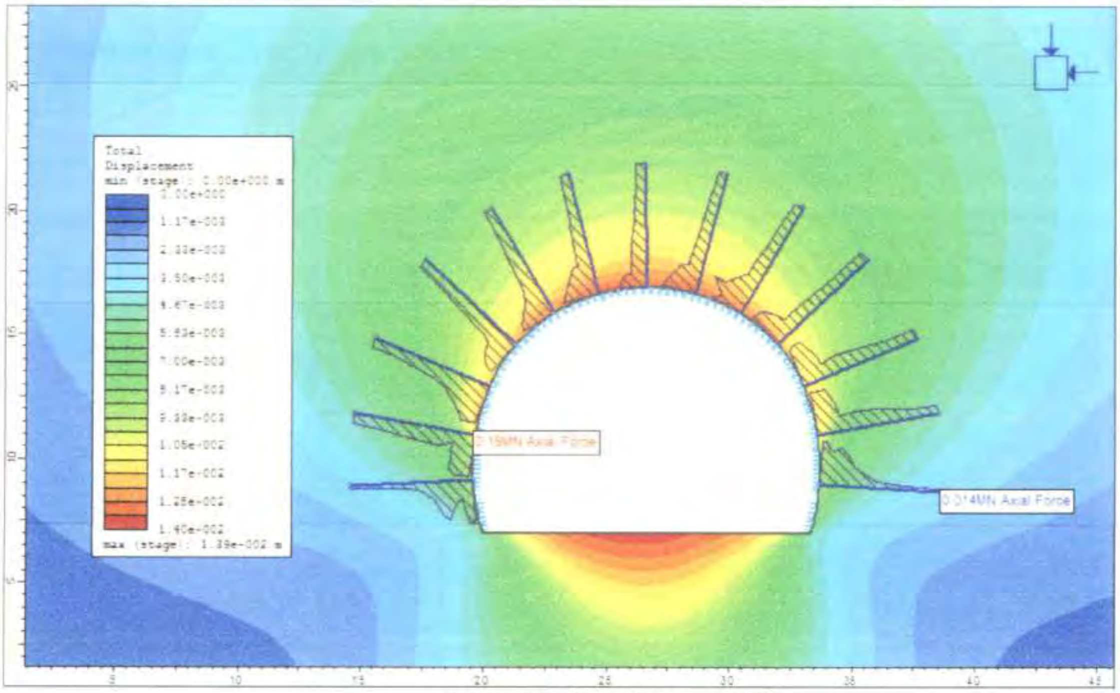

Figure-13: Axial Force in Bolts

4.6 Class-C Rock mass

- Rock Unit Weight - 27 KN/m3
- Ultimate Compressive Stress - 60 MPa
- Geological Strength Index - 50
- Young's Modulus - 4986 MPa
- Poisson Ratio - 0.20
- Dilation Angle - 40

Support System: 100 mm thick shotcrete with wire mesh and rock bolts of 25 mm dia. 5.0 m long and 1.50 m c/c spacing as initial support and 400 mm thick concrete lining as final support.

Results & Discussion: The major principal stresses and deformations around the tunnel are shown in Figure 14 & 16 respectively. The maximum stress value generated in the rock mass is 29.00 MPa and maximum deformation at the tunnel boundary is only 53.0 mm. Hence the support system provided is adequate.

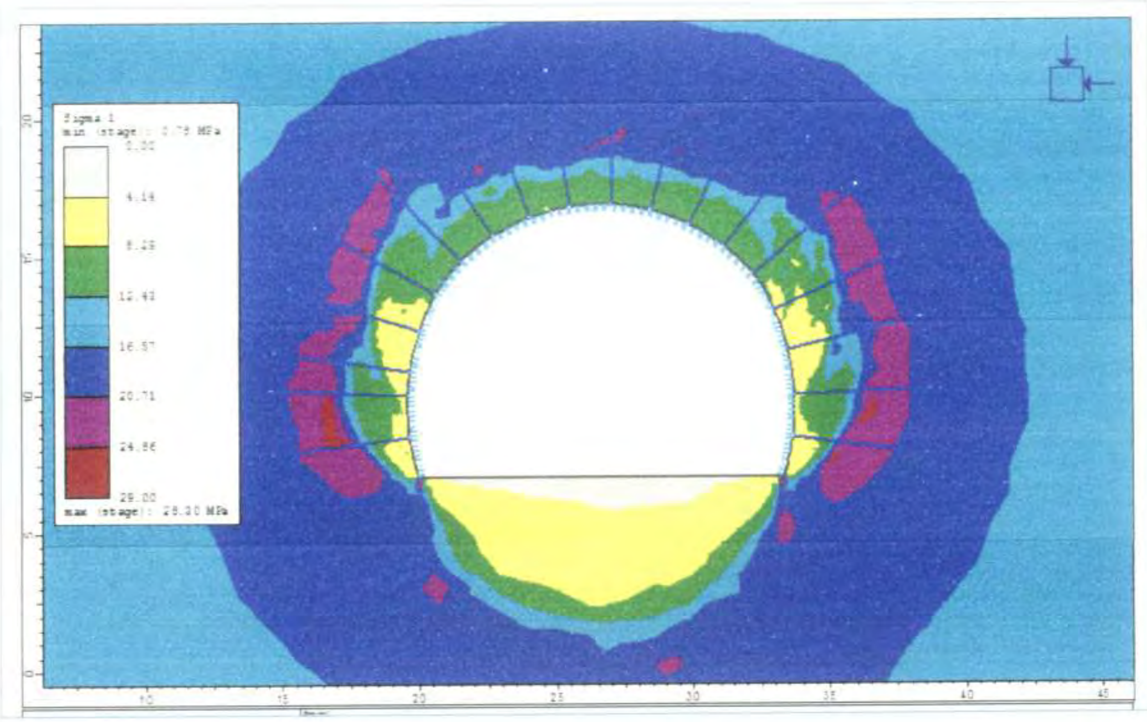

Figure-14: Major Principal Stresses

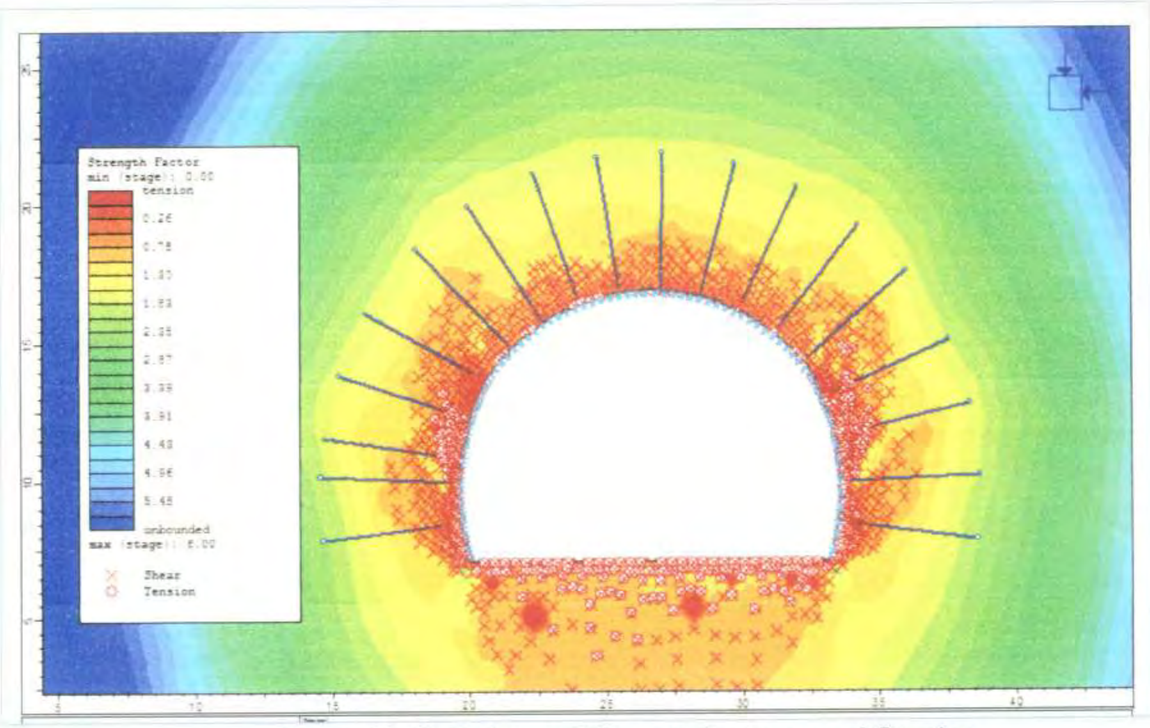

Figure-15: Yield Zone and Strength Factor around Opening

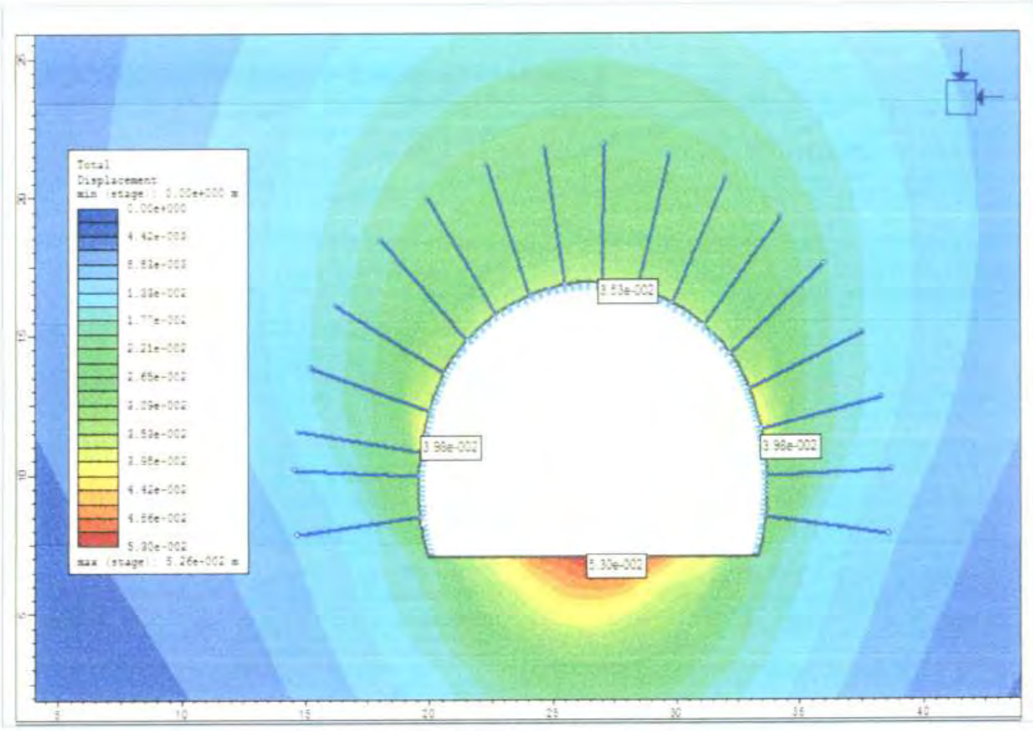

Figure-16: Maximum Deformation

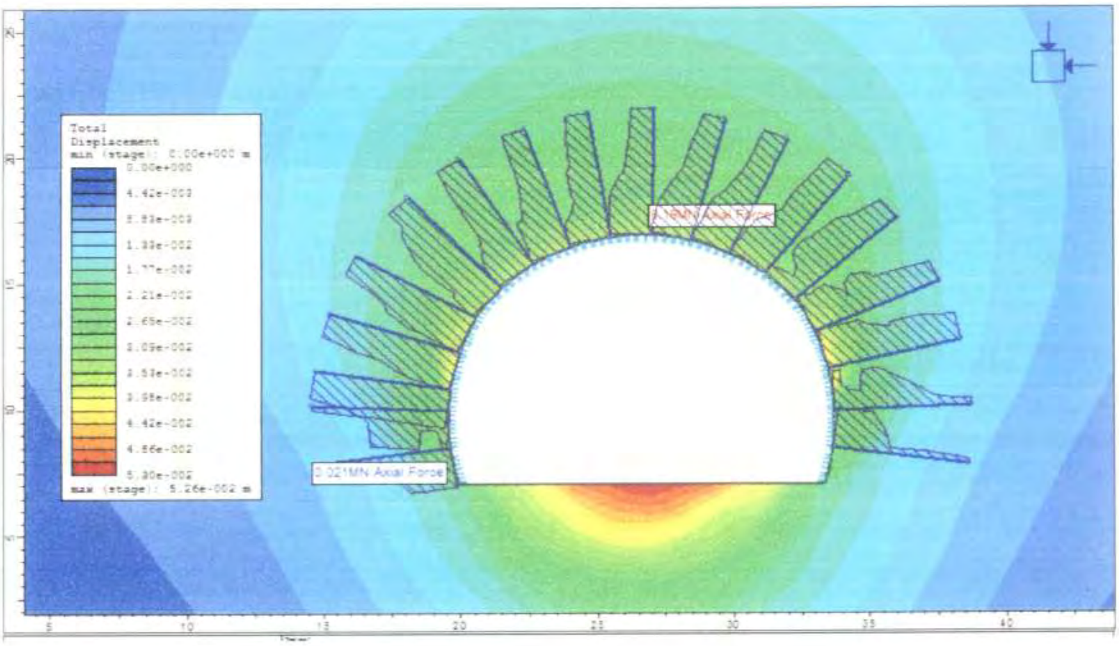

Figure-17: Axial Force in Bolts

4.7 Class-D Rock mass

- Rock Unit Weight - 27 KN/m3
- Ultimate Compressive Stress - 40 MPa
- Geological Strength Index - 30
- Young's Modulus - 1107 MPa
- Poisson Ratio - 0.25
- Dilation Angle - 40

Support System-1: 100 mm thick shotcrete with wire mesh, rock bolts of 25 mm dia. 6.0 m long and 1.5 m c/c spacing and steel ribs of ISMB 250 @ 1000 mm c/c as initial support and 400 mm thick concrete lining as final support.

Support System-2: 100mm thick shotcrete, rock bolts of 25 mm dia. 5.0 m long and 2 m c/c spacing and 3 bar lattice girder @ 1000 mm c/c as initial support and 400 mm thick concrete lining as final support.

Results & Discussion: The major principal stresses and deformations around the tunnel are shown in Figure 18 & 20 respectively. The maximum stress value generated in the rock mass is 7.8 MPa and maximum deformation at the tunnel boundary is only 81.0 mm. Hence the support system provided is adequate.

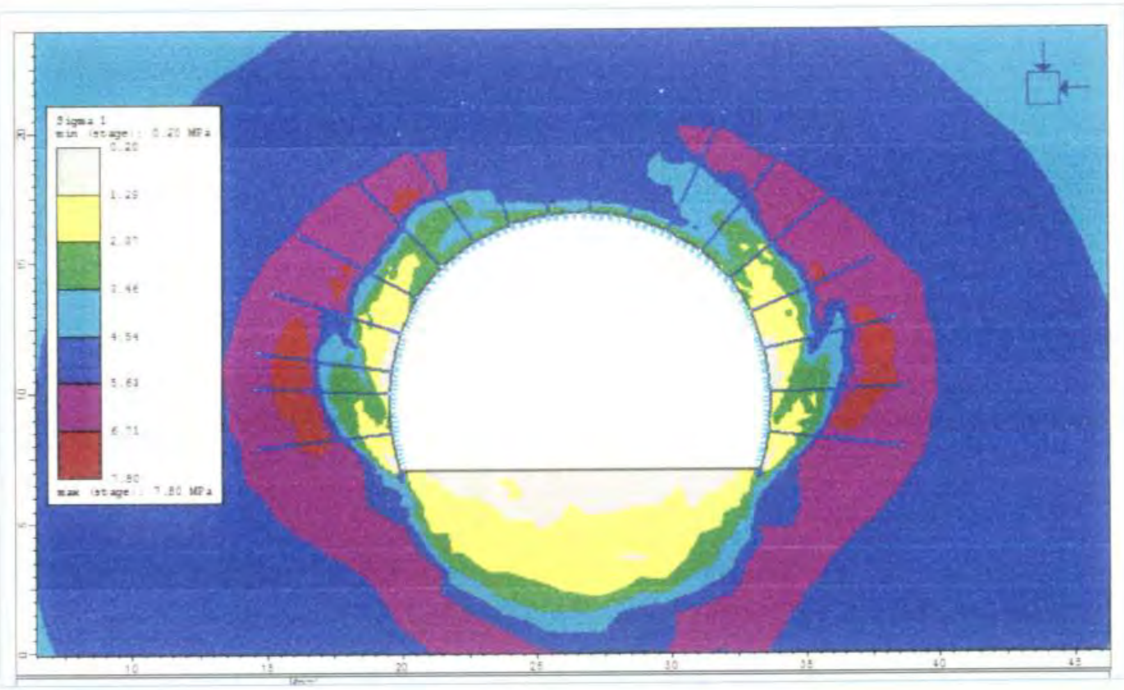

Figure-18: Major Principal Stresses

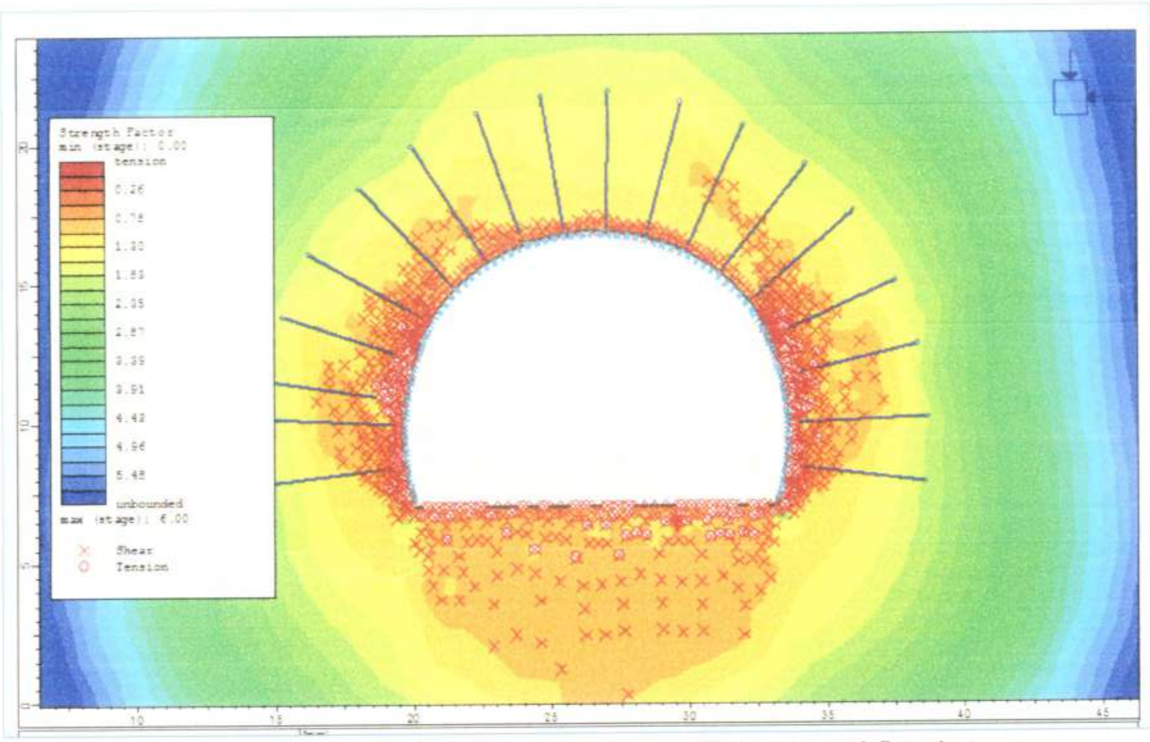

Figure-19: Yield Zone and Strength Factor around Opening

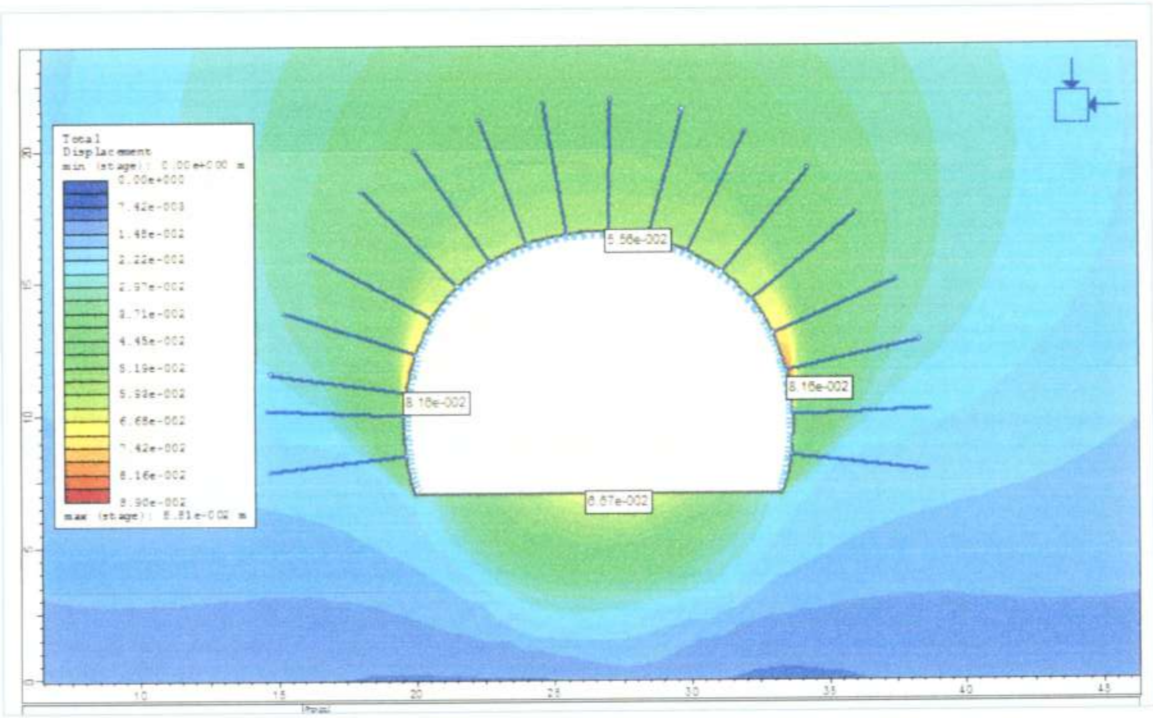

Figure-20: Maximum Deformation

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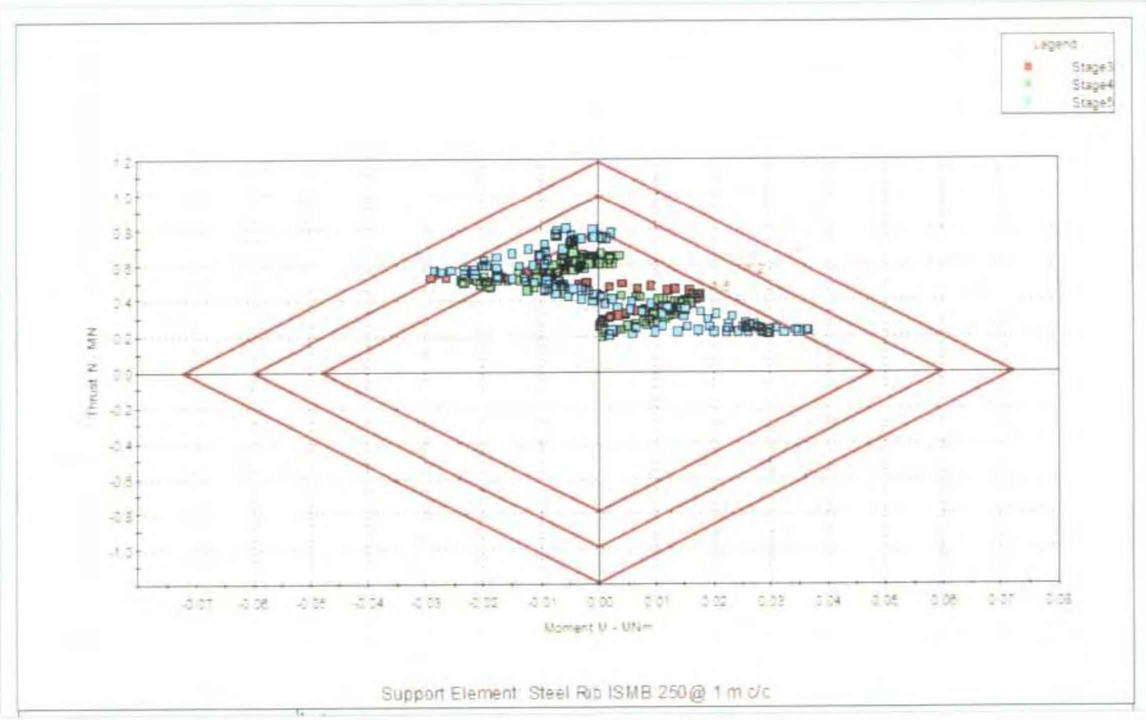

Figure-21: Moment Vs Thrust Capacity ISMB 250@ 1 m c/c

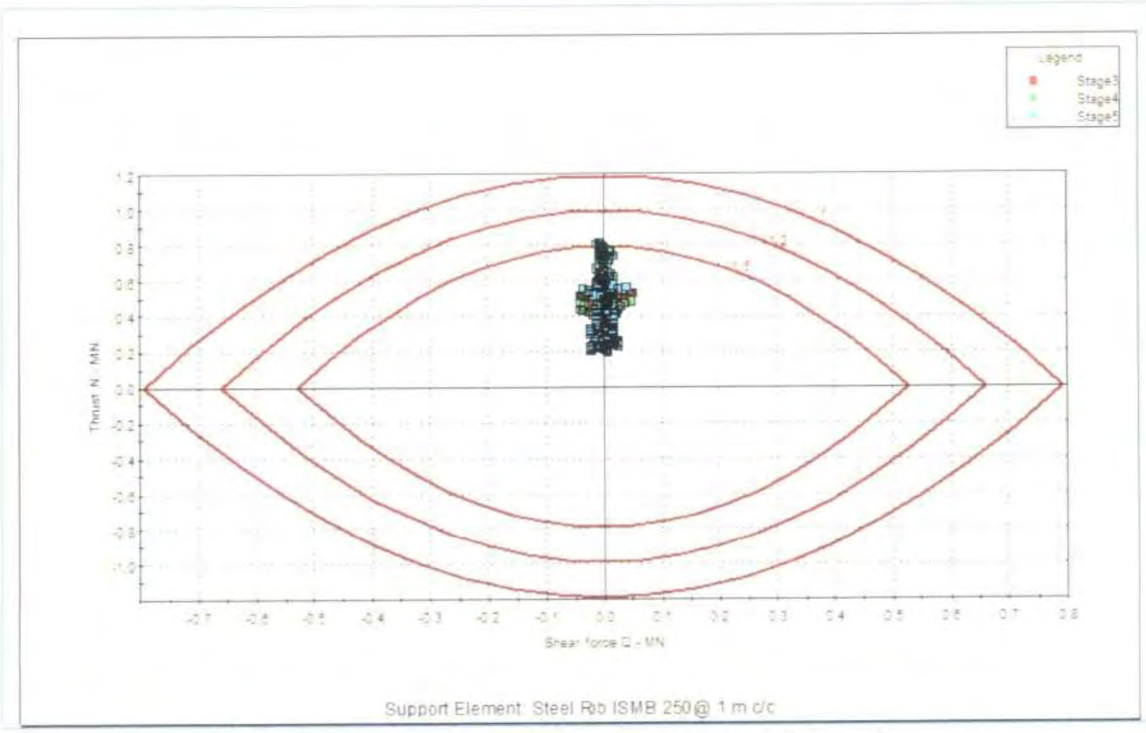

Figure-22: Shear Vs Thrust Capacity ISMB 250@ 1 m c/c

4.8 Class-E Rock mass

- Rock Unit Weight - 27 KN/m3
- Ultimate Compressive Stress - 30 MPa
- Geological Strength Index - 20
- Young's Modulus - 692 MPa
- Poisson Ratio - 0.30
- Dilation Angle - 40

Support System-1: 100 mm thick shotcrete with wire mesh, rock bolts of 25 mm dia. 6.0 m long and 1.5 m c/c spacing and steel ribs of ISMB 250 @ 500 mm c/c as initial support and 400 mm thick concrete lining as final support.

Results & Discussion: The major principal stresses and deformations around the tunnel are shown in Figure 23 & 25 respectively. The maximum stress value generated in the rock mass is 5.00 MPa and maximum deformation at the tunnel boundary is only 128.0 mm. Hence the support system provided is adequate.

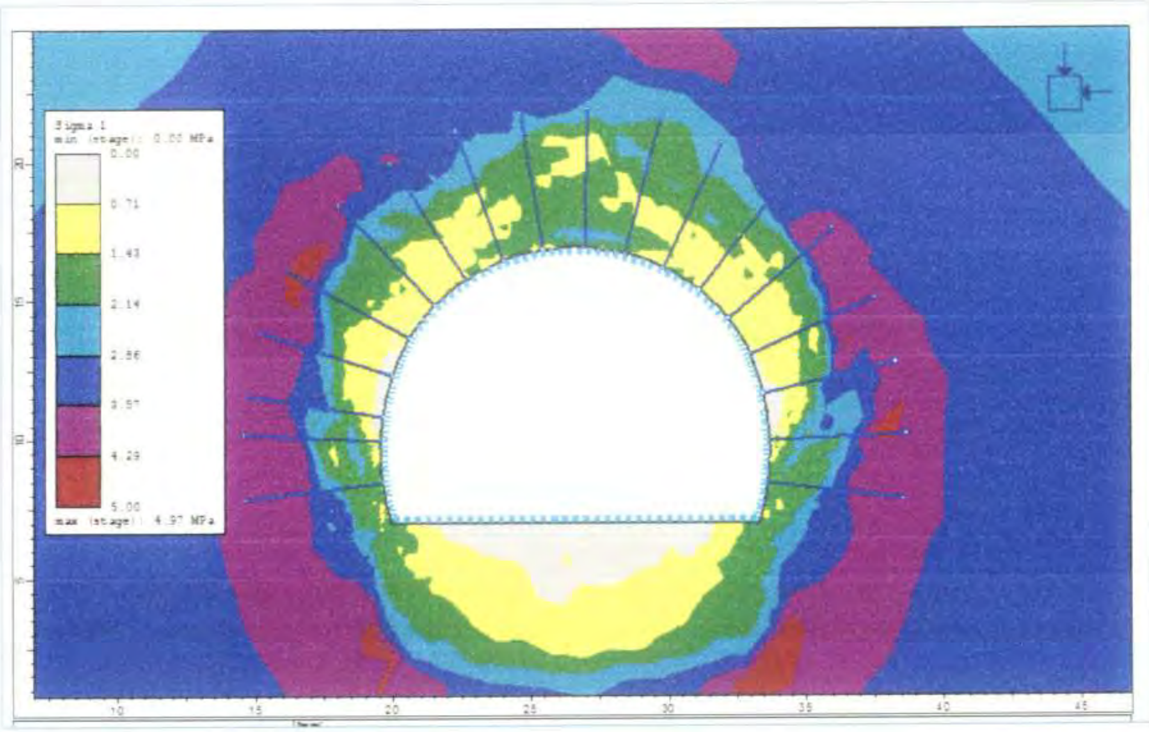

Figure-23: Major Principal Stresses

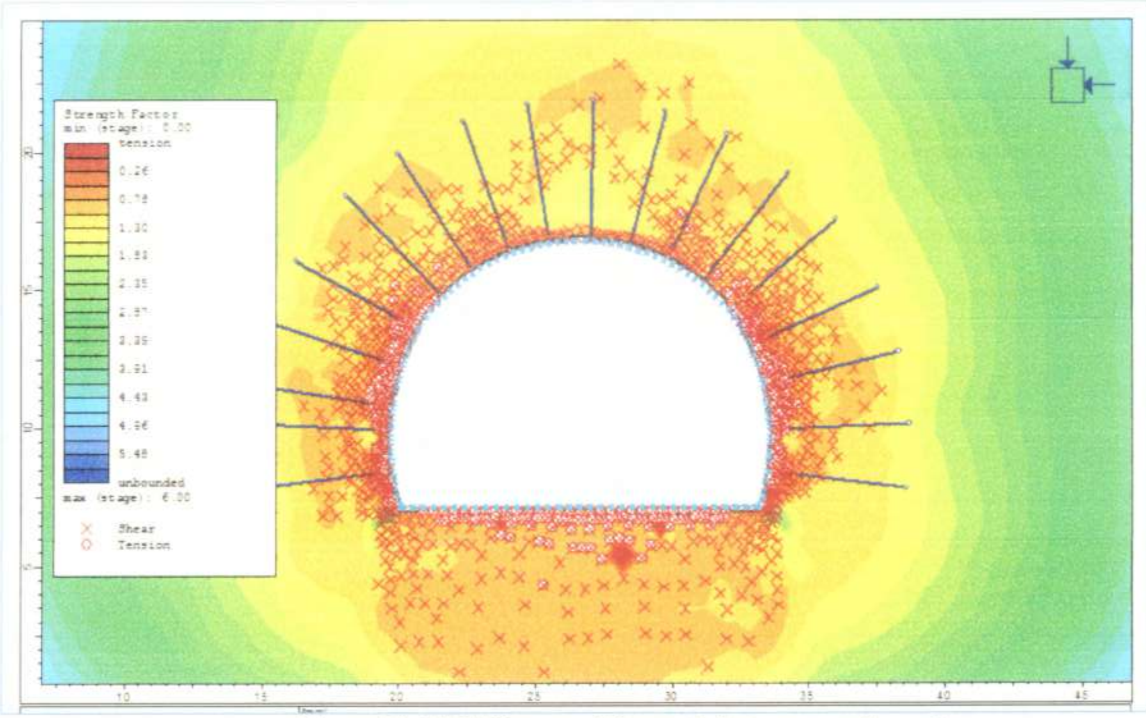

Figure-24: Yield Zone and Strength factor around opening

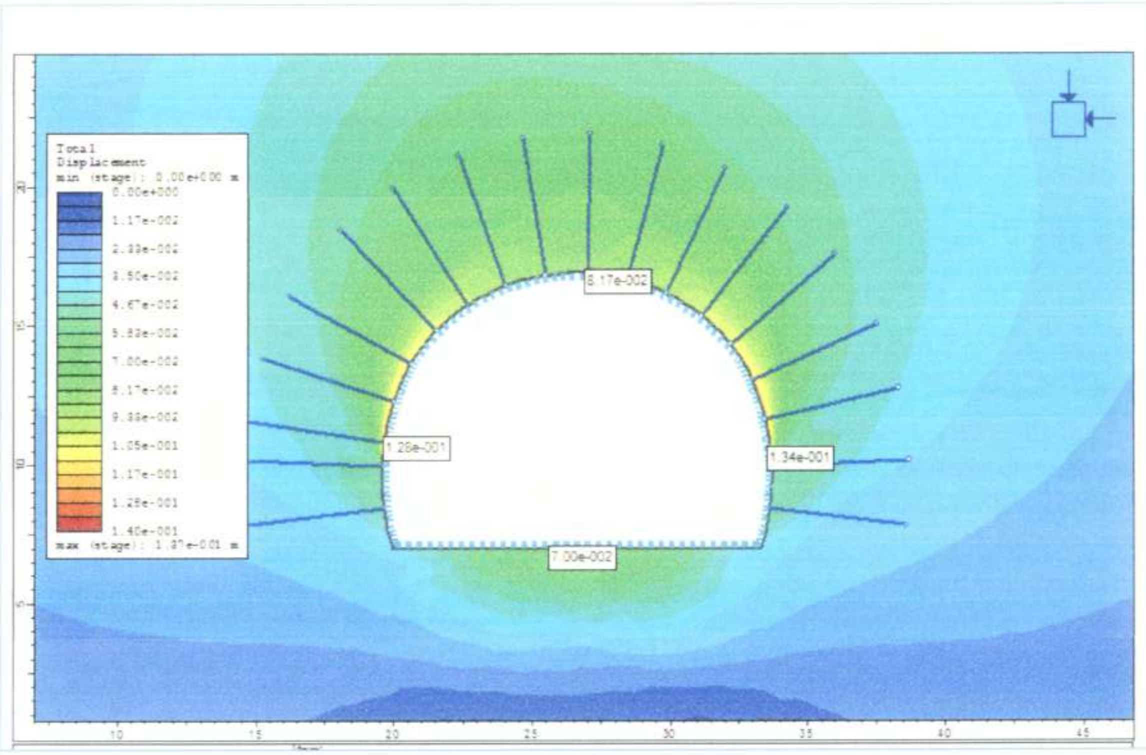

Figure-25: Maximum Deformation

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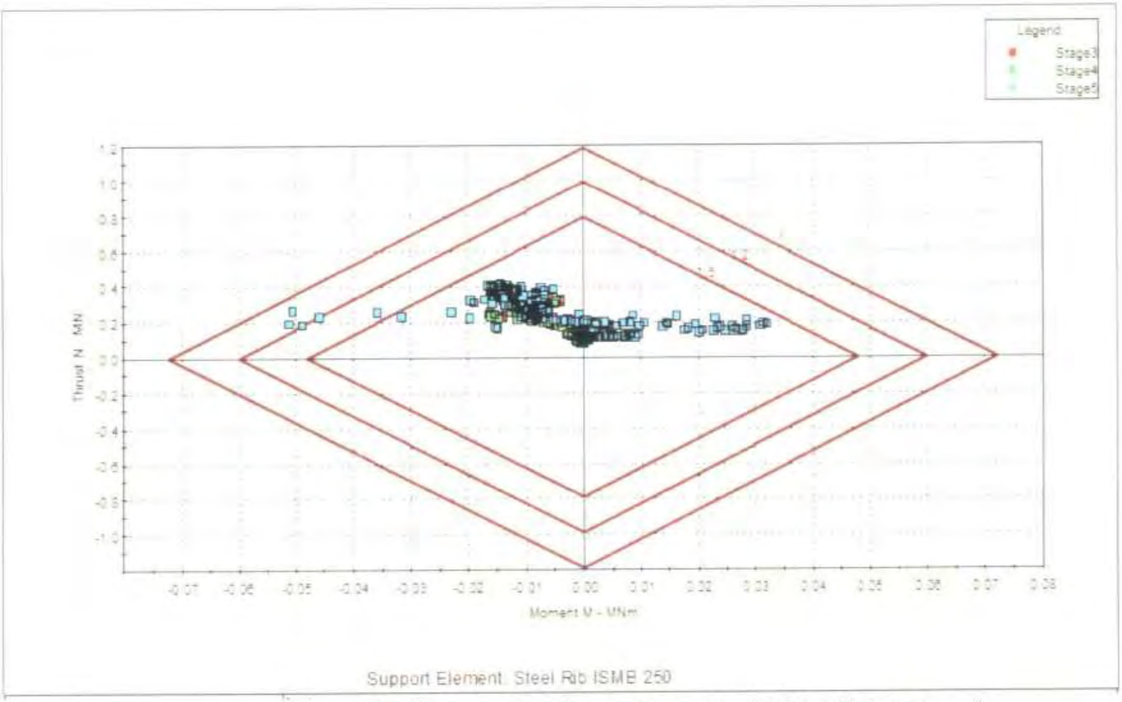

Figure-26: Moment Vs Thrust Capacity ISMB 250@ 0.5 m c/c

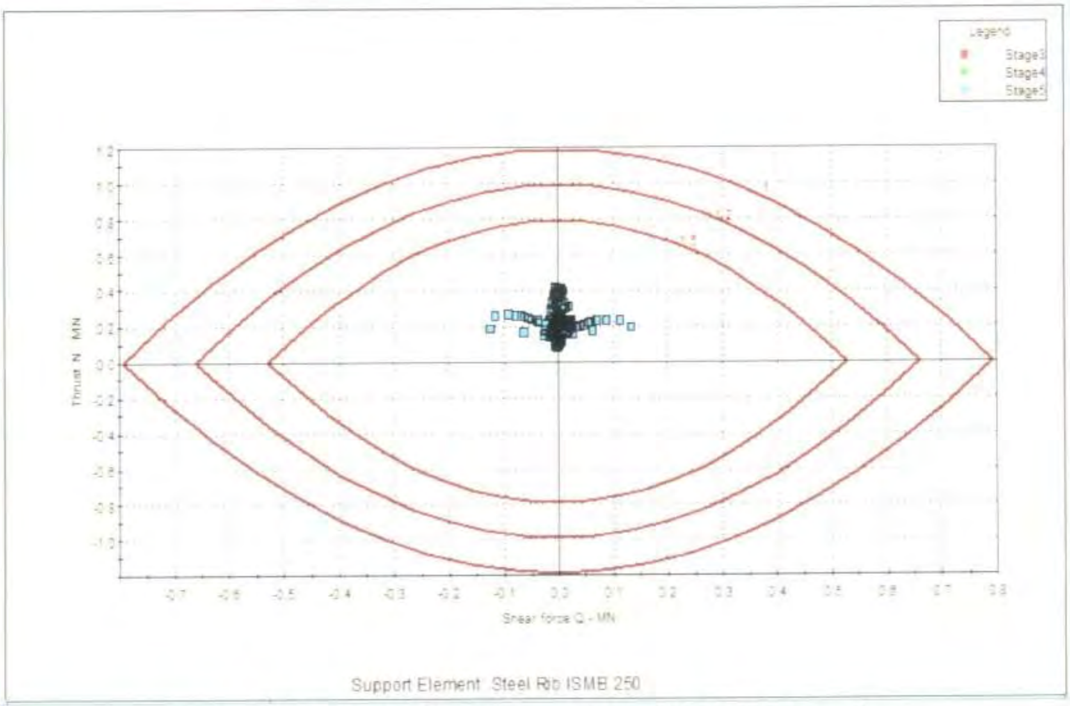

Figure-27: Shear Vs Thrust Capacity ISMB 250@ 0.5 m c/c

5 Analysis, Design & Results

Five numerical models for the rock mass types (Class A to E) defined earlier have been run with stress parameters expected in the field as defined above. The rock mass response to excavation of the tunnel in the different rock mass classes is analyzed. Further to this, the supports have been modeled in the numerical analysis software Phase² and checked for its adequacy. Results are presented below for different classes of rock. Results of the analyses are summarized in Table-.8

From the comparison of results presented in Table-,8 it is evident that the stability of the excavation is influenced primarily by the modulus values and strength properties of the rock mass. In particular, zones of possible yielding of the material extend to larger limits with reduced modulus and material properties. Rock mass properties as well as the far-field stresses adopted in the exercise have been assumed on the basis of literature and limited tests result available at this point in time. The steel supports in the analysis are modeled as a liner connected to the excavation nodes.

It is worth noting that the maximum predicted displacement of the Tunnel (in Class Class E type rock) is of the order of **128** mm and tunnel closure is in the range of **256** mm in the present analysis, which is less than 2% of excavated span and it falls under normally accepted limit for rigid support system as per IS: 13365 (Part 2):1992. However in rock class Class A, Class B, Class C and Class D tunnel closures are 16mm, 28mm, 102mm and 160 mm respectively, which is well within the allowable limit It is also observed that the material behavior improves with the increasing RMR values. The yielded rock mass zone has been observed to remain within the rock bolt lengths

Table-8: Summary of Analysis Results Tunnel

Case	Rock mass Class	Support Condition	Description	Comments on Analysis Results (After Full Excavation)
1	Class-A	With Support	• Heading and benching excavation. • 50mm thick Shotcrete. • 5m long, Φ25 (20MT capacity) fully grouted rock bolts @ 2.5m c/c.	• Significant yielding zone around (0.9m) but contained within rock bolt length. • Axial force in rock bolt is 4.5MT • Maximum deformation on tunnel boundary equal to 7.8mm. • No yielding of shotcrete above SPL, however at some place

Case	Rock mass Class	Support Condition	Description	Comments on Analysis Results (After Full Excavation)
				yielding of shotcrete at haunch portion is observed. • Though the maximum deformation after installation of support is not substantial, however as the joint sets are closely spaced (1.5m – 2m) the spacing of the bolts are not increased beyond 2.5m c/c
2	Class B	With Support	• Heading and benching excavation. • 75mm thick Shotcrete. • 5m long, Φ25 (20MT capacity) fully grouted rock bolts @2m c/c.	• Significant yielding zone around (1.5m) but contained within rock bolt length. • Axial force in rock bolt is 19 MT • No yielding in rock bolts is observed and overall excavation is stable. • Maximum deformation on tunnel boundary equal to 14 mm. • No yielding of Shotcrete above SPL, however at some place yielding of Shotcrete at haunch portion is observed, which not area of concern. • Though the maximum deformation after installation of support is not substantial, however as the joint sets are closely spaced (1.5m – 2m) the spacing of the bolts for Class B are not increased beyond 2m c/c

Case	Rock mass Class	Support Condition	Description	Comments on Analysis Results (After Full Excavation)
3	Class C	**With Support**	• Heading and benching excavation. • 100mm thick SFRS. • 5 m long, Φ25 (20MT capacity) fully grouted rock bolts @1.5m c/c.	• Significant yielding zone around (3m) but contained within rock bolt length. • Axial force in rock bolt is 19 MT • No yielding in rock bolts is observed and overall excavation is stable. • Maximum deformation on tunnel boundary equal to 52 mm. • No yielding of Shotcrete above SPL, however at some place yielding of Shotcrete at haunch portion is observed, which not area of concern. • Though the maximum deformation after installation of support is not substantial, however as the joint sets are closely spaced (1.5m - 2m) the spacing of the bolts for Class C are not increased beyond 1.5m c/c

Case	Rock mass Class	Support Condition	Description	Comments on Analysis Results (After Full Excavation)
4	Class-D	**With Support**	• Heading and benching excavation. • 100mm thick Shotcrete. • 6 m long, Φ25, fully grouted rock bolt @1.5m c/c. • Steel Rib (ISMB250) @ 1m c/c. • 75mm thick Precast Lagging. • 175 mm thick M15 Concrete Backfill.	• Maximum Yielding zone is around (3m) but contained within rock bolt length. • Some local yielding in rock bolts is observed however overall excavation is stable. • Maximum deformation on tunnel boundary equal to 82mm. • Stresses in Steel Rib is within permissible limits. • Shotcrete will yield at some places near haunch but that will be retained intact with support of lattice girder and bolt.
5	Class-E	**With Support**	• 100mm thick Shotcrete. • 6 m long, Φ25, fully grouted rock bolt @1.5m c/c. • Steel Rib (ISMB250 @ 0.5m c/c. • 75mm thick Precast Lagging. • 175 mm thick M15 Concrete Backfill • pipe roofing and Face Support as Additional Precaution	• Maximum deformation on tunnel boundary equal to 42mm. • Stresses in Lattice Girder within permissible limits. • Tunnel closure is 256 mm, which is less than 2%, that is allowable in case of Steel Ribs as support.

Excavation sequences in Phase2 is modelled in total five stage ,Stage-1 model generation and initialization of field stress ,Stage-2 material softening for heading portion , Stage 3 Heading excavation and support , Stage-4 material softening for Benching portion and Stage-5 is benching excavation and support installaton . The discretisation scheme with boundary conditions and excavation stages is shown above in Fig. 6. The results of the analysis in terms of major principal stresses and total displacement contours for various stages of excavation, yield zone around the tunnel after final excavation stage and axial forces in bolts after complete excavation are shown for all class of rock in Fig. 7to 27.

6 Recommended Support System for Tunnel

Based on the above analysis, the support system recommended for tunnel is, as shown in Table 9

Table -9: Recommended Rock Support System for Tunnel

Rock Class	RMR	Rock Support			
		Shotcrete	Lattice Girders	Rock Bolts	Pipe Roofing
Class A	81-100	50 mm thick shotcrete mainly above springing line	--	Spot bolting (where ever required) @2.5 m c/c	--
Class B	61-80	75 mm thick shotcrete	--	25mmΦ, 5 m long fully grouted rock bolts @ 2.0 m c/c in crown in staggered pattern	--
Class C	41-60	100 mm thick shotcrete with one layer of wire mesh 100mmx100mmx6 mm	--	Systematic rock bolting, 25mmΦ, 5 m long fully grouted rock bolt @ 1.5 m c/c staggered at crown & wall	--
Class D	21-40	100 mm thick shotcrete with one layer of wire mesh 100mmx100mmx6 mm.	Steel Rib ISMB250@ 1 m c/c as shown in drawings 75mm thick Precast Lagging.	Systematic rock bolting, 25mmΦ, 6 m long fully grouted rock bolts @ 1.5 m c/c staggered at crown & wall	If required

			175 mm thick M15 Concrete Backfill		
Class E	<20	100 mm thick shotcrete with one layer of wire mesh 100mmx100mmx6 mm.	Steel Rib ISMB250 @ 0.5 m c/c as shown in drawings. 75mm thick Precast Lagging. 175 mm thick M15 Concrete Backfill	Systematic rock bolting. 25mm Φ, 6 m long fully grouted rock bolts @ 1 m c/c staggered at crown & wall	114 mm Dia 8 mm thick .10.0 m long Pipe Roofing @ 300 mm c/c

i) Pipe roof umbrella of 114 mm dia. perforated pipes (Four perforations per metre), 8 mm thick. and 10 m long with overlap of 4 m with next pipe roof umbrella @ 300 mm centre to centre at an angle of 5^0 upward. The grouting at pressure of 5 kg/cm^2 shall be carried out through these pipes, to improve the strength of the material around the crown. Only after completing the one pipe (10 m length) drilling and grouting, the next pipe shall be drilled and grouted and so on for the remaining pipes. After Grouting, the pipes shall be filled with grout paste. The Steel rib ISMB 250 @ 0.5 m c/c shall also be placed after 100 mm thick shotcrete with one layer of wire mesh 100mm x 100mm x 6 mm as shown in drawings.

ii) 25 mm dia., 6 m long fully grouted rock bolts @ 1.5 m c/c in crown and walls shall be provided. The excavation shall be strictly done as per the excavation sequence/stages/ cycles and only after installation of the support system after each excavation cycle, the next cycle of excavation shall be undertaken in each stage of the excavation. The excavation cycle of 750 mm-1000 mm (For Class D & E) length shall be considered as per site conditions for excavation and support system and only after supporting this stretch, the next cycle of excavation shall be undertaken. Only after completing the above support measures in each stage, the next stage of the excavation shall be carried out. Before installation of pipe roof umbrella, the 100 mm thick shotcrete with one layer of wire mesh shall be applied on the face after each excavation cycle i.e. 750-1000 mm length and excavation sequence i.e. after every 6 m length, the pipe roof system, shall be executed in each stage of heading. The design parameters shall be validated at site by actual testing. The capacity of the rock bolts shall be validated at site and shall be communicated to the designer on priority. If the strata encountered during excavation is different than that of the strata considered in the design, then the above design shall be modified and this information shall be provided to the designer and the design shall be updated based on the actual design parameters. The measurement/monitoring of the deformation of tunnel shall be carried out in a systematic manner and this information shall be provided to the designer on continuous basis.