Challenges in Design and Execution of a Transportation Tunnel

Rakesh Kumar

UV Global Geosolutions Pvt. Ltd., Delhi
rakesh_iitd@rediffmail.com

Abstract. Many hydroelectric, transportation, rail and metro rail projects are under construction in the country. The underground structures for these projects especially tunnels and caverns are mostly constructed on/in rocks. The presence of joints, shear zones and shear seams significantly effect the rock behaviour under loading and unloading conditions. The shear zones and heavy seepage conditions pose challenging conditions for engineers and shall be handled in systematic manner.

The paper presents the analysis of double lane tunnel of more than 9.5 m diameter in a poor & challenging geological conditions for a project, located in Northern India. The in-situ stress conditions are anisotropic in nature with major in-situ stress ratio of 0.55 and minor in-situ stress ratio of 0.45, thereby making the tunnel behavior complex. The three major joint sets along the tunnel alignment adds to the complexity of the problem. The stress-deformation analysis has been carried out using RS 2 software using Mohr Coulomb model. The excavation has been simulated in two stages for the tunnel i.e. heading and benching. The analysis has been carried out, to decide upon the optimal support system for the tunnel. The wedge analysis is also carried out to find out the effect of intersecting joints along the tunnel alignment.

Based on the stress-deformation analysis and analyzing the stress behavior, deformation characteristics and plastic zones around the tunnel, the optimal support system is decided and implemented at site. The support measures in terms of shotcrete with wiremesh/SFRS, forepoling, lattice girders and grouting are adopted.

Keywords: Joints; Wedge; FEM, Stress-Deformation.

1 Introduction

Tunneling in Himalayan region is challenging due to mix geological conditions, higher rock cover and high seismicity. Furthermore, the presence of water table becomes a major hurdle in negotiating the tunnels through such stratigraphy. The present paper describes a case study of highway tunnel through such challenging and poor geological conditions in Northern India. The analysis has been carried out using RS 2 software using Mohr Coulomb criteria. The other details of the model are described elsewhere [1].

2 Description of the Problem

The tunnel considered in this problem, is Horse shoe-shaped with more than 9.5 m diameter as shown in Fig. 1. It passes through a complex geology. The rockmass in the area is mainly dolomite of Sirban Limestone formation. The dolomites are jointed in nature. The three joint sets are encountered during geological mapping studies. The sheared dolomites are also present along the alignment. The geological section along the tunnel alignment is shown in Fig.2.

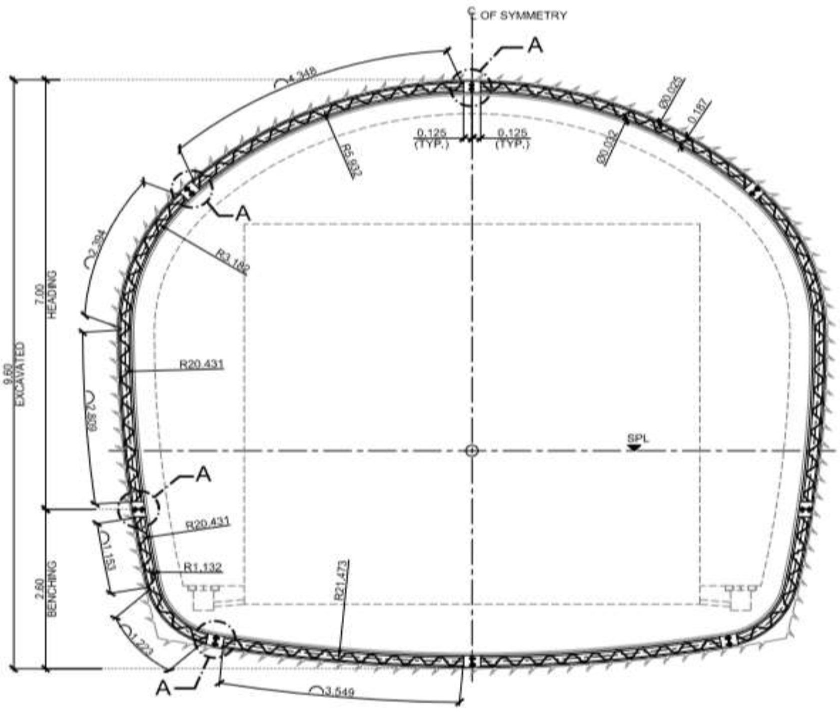

Fig. 1. Tunnel section

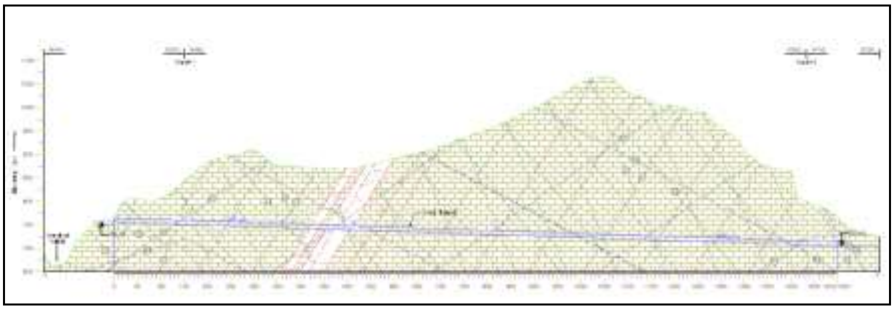

Fig. 2. Geological section along the tunnel alignment

3 Geotechnical Parameters

The extensive geotechnical investigation has been undertaken for this tunnel. Based on the investigation data, the geotechnical parameters for the rockmass are adopted as shown in Table 1 and for joints as shown in Table 2.

Table 1. Design parameters for the analysis

Description		**Unit**	**Very Poor Rockmass (Rock Class V)**
Intact Rock Properties	UCS	MPa	50
	GSI		15
	mi		9
	Ei	MPa	30000
	v		0.25
Rock Mass Parameters	c (peak)	MPa	0.34
	Φ (peak)	deg	30.66
	c (residual)	MPa	0.22
	Φ (residual)	deg	22.01
	Tensile Strength	MPa	0.009
	Deformation Modulus	MPa	1093.47
Rock Mass Parameters Damage Zone	c	MPa	0.141
	Φ	deg	14.863
	Tensile Strength	MPa	0.002
	Deformation Modulus	MPa	700.555

Table 2: Joint sets along the tunnel

Joint Set	Dip Direction (°)	Dip Amount (°)	Friction Angle (Φ j), (°)	Cohesion (cj), MPa
J1 (ID 1)	N027	71	32	0.035
J2 (ID 2)	N290	71	32	0.035
J3 (ID 3)	N141	69	32	0.035

The hydraulic fracturing tests are carried out in drifts and revealed the anisotropic stress-conditions. The in-situ stress ratio for major principal stresses is 0.55 and minor principal stresses is 0.45. The rock cover of 150-200 m is available in the stretch where poor geological conditions are anticipated.

4 Properties of Support System

Support in the form of shotcrete and lattice girder is designed for the tunnel. The following support properties are considered for the shotcrete & lattice girder:

The shotcrete is modelled as plastic standard beam element, so that the excess forces are transferred to the adjacent rock mass and support element, if the shotcrete yield at any point.

- Concrete strength 35 MPa
- Modulus of Elasticity 29.58 GPa
- Residual Compressive Strength 7 MPa
- Tensile Strength 4.14 MPa

Lattice Girders

- Depth of Section 187 mm
- Cross-sectional Area 1784 mm^2
- Moment of Inertia 1.16×10^{-5} m^4
- Modulus of Elasticity 200000 MPa
- Permissible Compressive Stress 500 MPa
- Permissible Tensile Stress 500 MPa

5 Analysis and Results

The wedge analysis is carried out to check the wedge failures along the tunnel alignment direction N 250^0. The stereographic projection for the tunnel along with joints is shown in Fig. 3. The results of wedge analysis without support system and with support system are shown in Figs. 4 & 5 respectively.

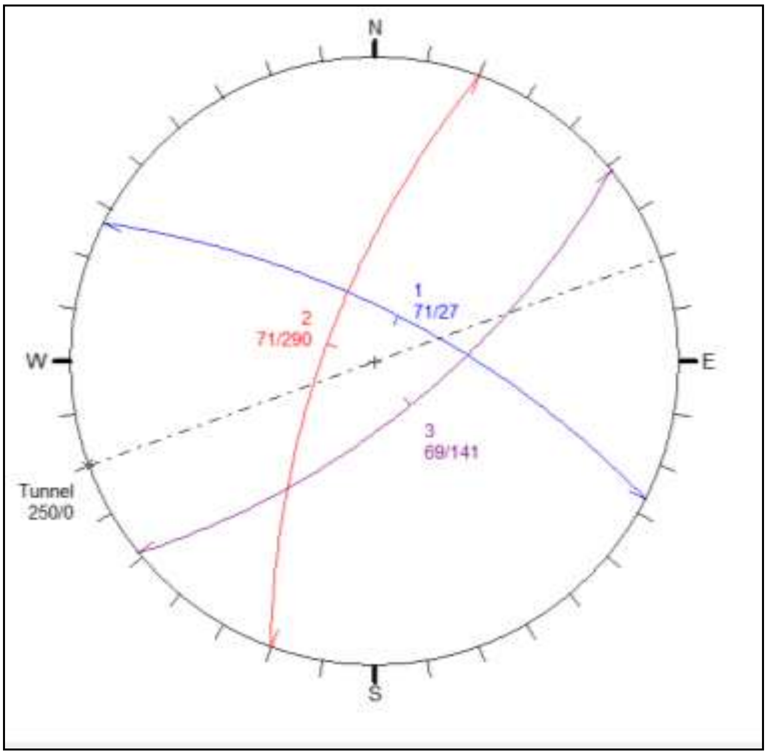

Fig. 3. Stereographic projections along the tunnel alignment

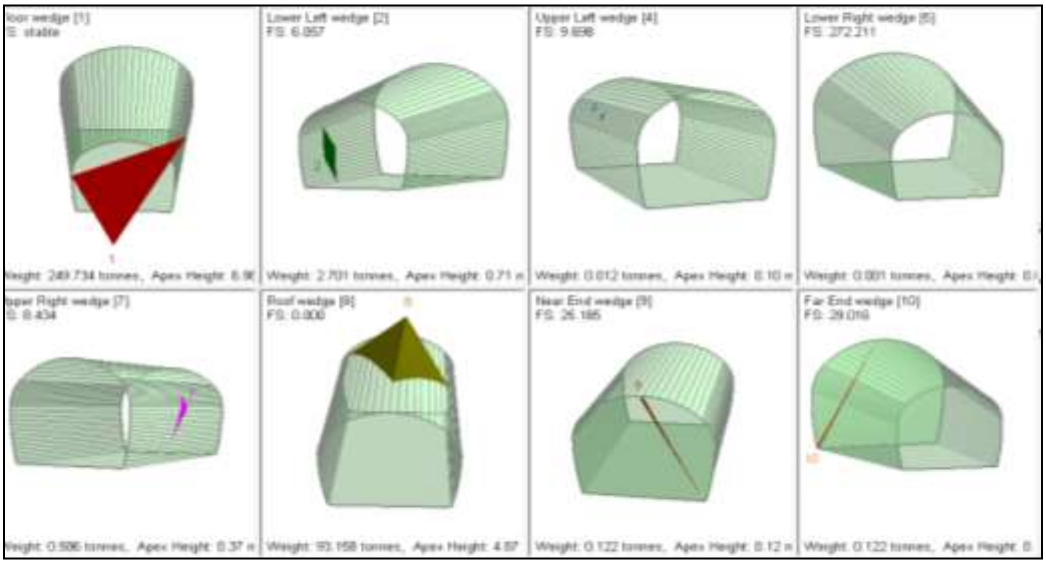

Fig. 4. Wedge formations along with factor of safety along tunnel without any support system

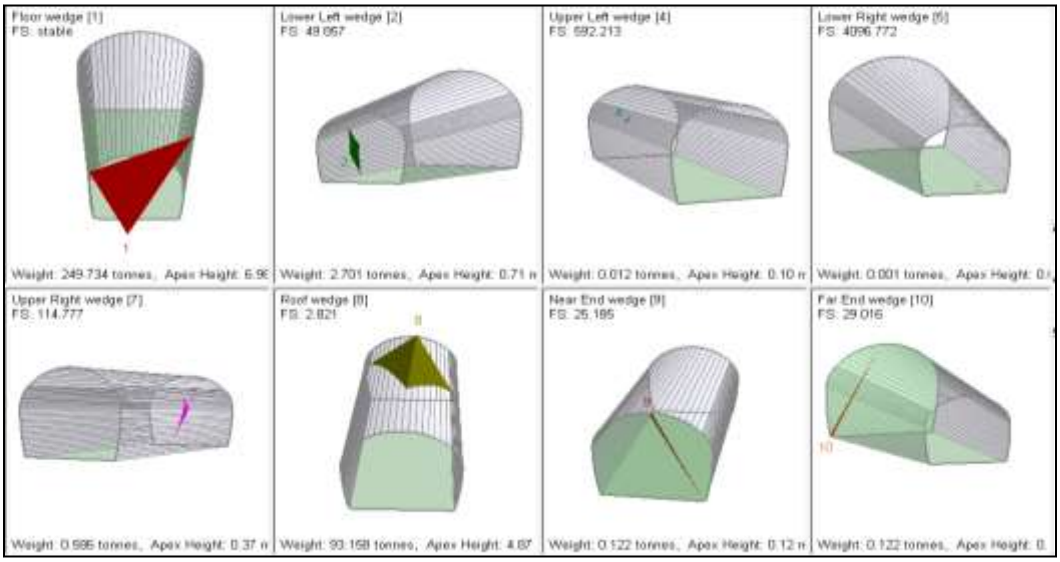

Fig. 5. Wedge formations along with factor of safety along tunnel with support system

The stability analysis of the tunnel has been carried out using Finite Element Programme RS 2, as a continuum model using Mohr-Coulomb yield criteria. The rock-mass encountered at project site was very poor and sheared and behavior was tending more towards soil. Hence Mohr-Coulomb model was adopted for analysis. During execution, the deformations were measured and were in close agreement with the predicted values of the model, which validated the analysis results. The excavation is carried out in two stages. The stage I is used for crown excavation and stage II is used for benching. The six noded triangular elements are adopted in the analysis. The boundaries are considered more than 5 times the size of the tunnel to simulate the far field conditions. The typical discretization boundary (including heading and benching) is shown in Fig. 6. The results of the analysis are presented in the form of major principal stress contours, total displacement contours and yielded zones in Figs.7 to 9. The support capacity plots for lattice girders are shown in Fig. 10.

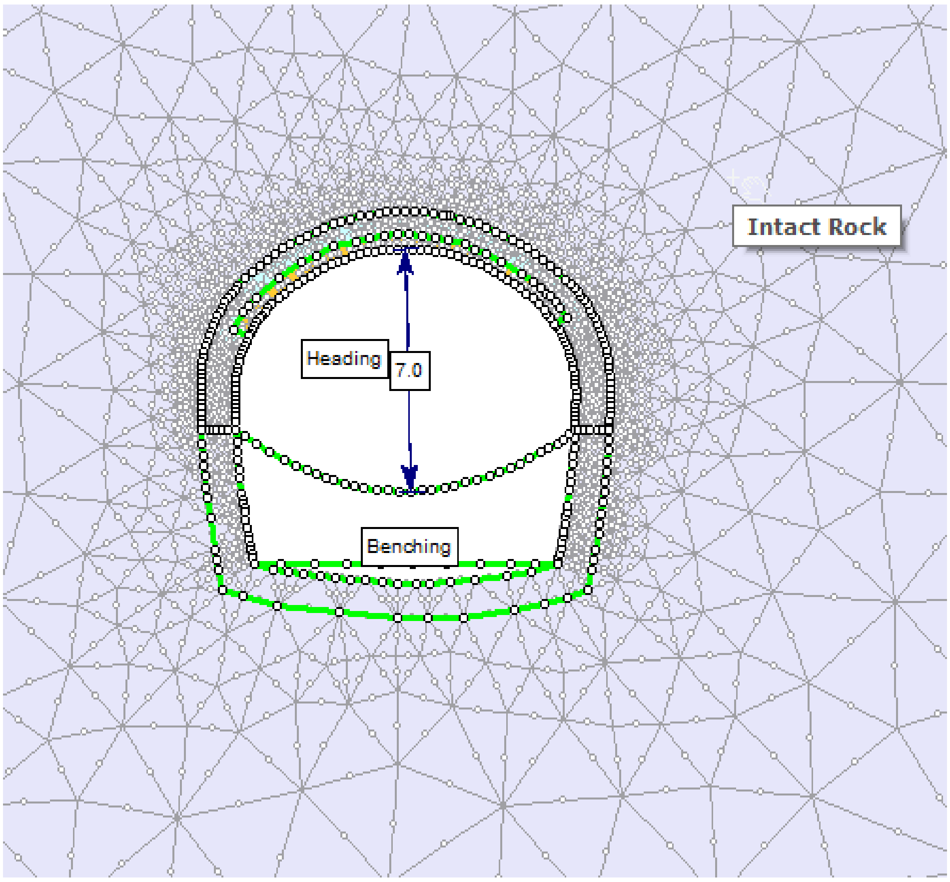

Fig. 6. Discretization around the tunnel

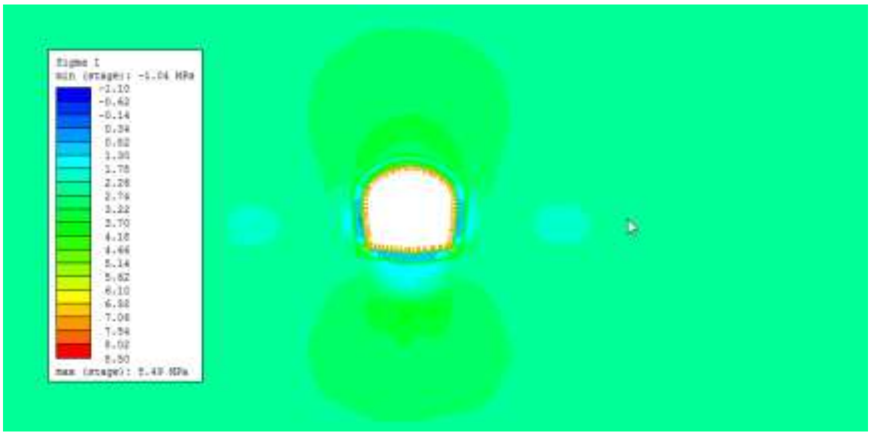

Fig. 7. Major principal stress contours around the tunnel

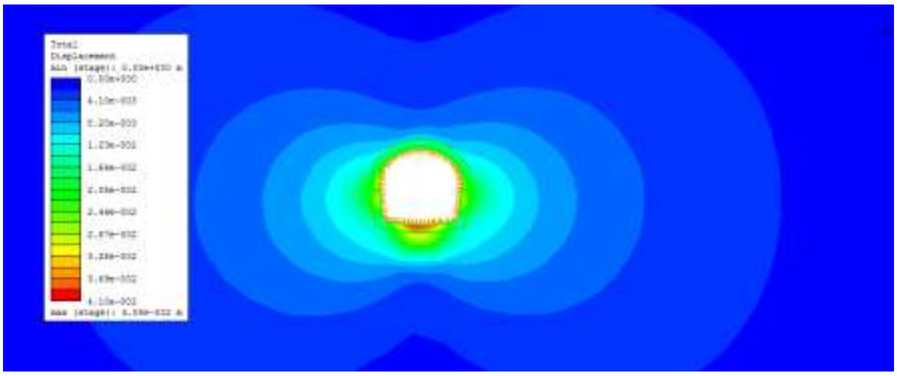

Fig. 8. Total displacement contours around the tunnel

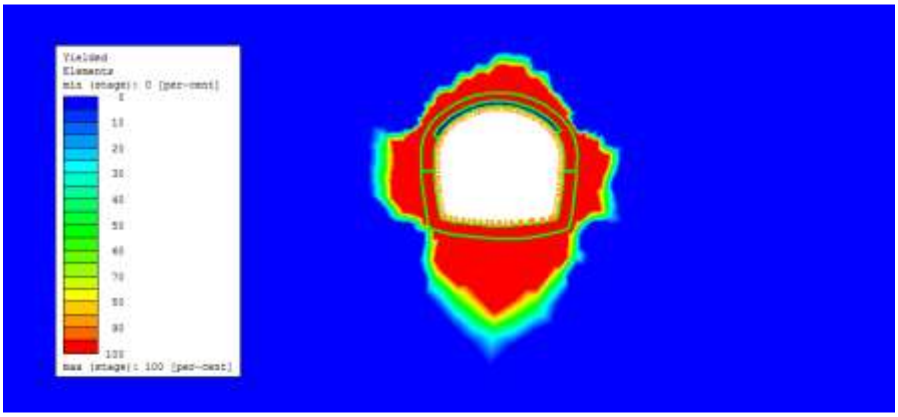

Fig. 9. Yield Zone around the tunnel

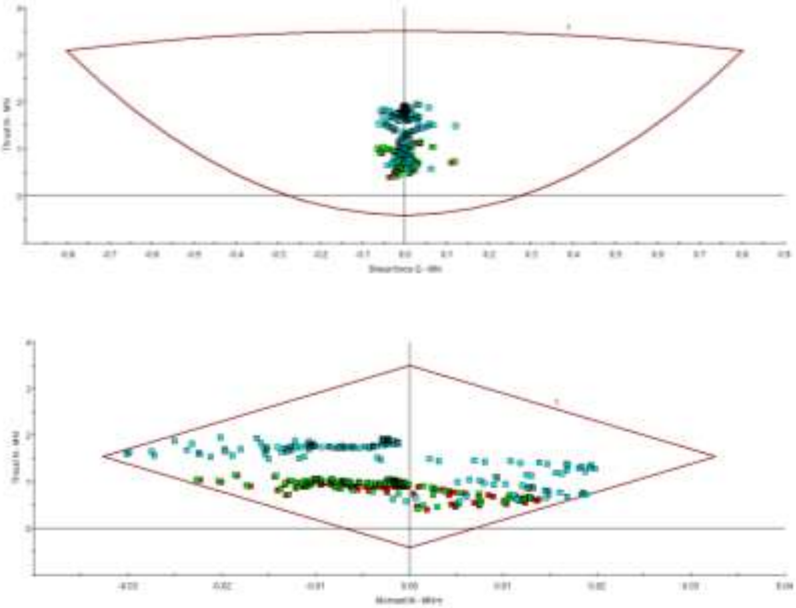

Fig. 10. Support capacity plots for lattice girders

6 Discussion on Results

From Figs. 4 and 5, it is seen that, some of the wedges are unsafe without support system and become safe after providing the support system in the form of 250 mm thick SFRS with encased lattice girder (130x32x25 mm).

From Figs. 6 to 10, it is seen that the maximum deformations around the tunnel crown are 15 mm and tunnel walls are 38 mm which are well within the permissible limit. The major principal stresses vary from 2 MPa to 8.50 MPa. The support capacity of the lattice girders is sufficient to undertake the design loads.

7 Recommendations of support system and conclusions

Based on the above analyses, the support system in the form of 250 mm thick SFRS with encased lattice girder (130x32x25 mm) @ 1 m c/c is recommended and implemented at site. In addition to this foreoploing with 32 mm dia., fully grouted self drilling anchors @ 250 mm c/c at crown is recommended and implemented at site.

During actual execution, heavy seepage of water was encountered, however the recommended support was sufficient to handle this pressure. However, in few locations the grouting was also carried out to arrest the seepage and carryout this work.

Acknowledgments

The views present in this paper are totally belong to author only. The author also like to thank the management of contractor and owner of the project for this work.

References

1. Manual documentation of RS2.