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Design of Cross Passage Interconnecting Two Parallel Highway Tunnels Near Jaipur- A Case Study

Anil Swarup, R. K. Goel*

CSIR-CIMFR Research Centre, Roorkee, India

**E-mail: anilsw@gmail.com*

ABSTRACT

Twin parallel highway tunnels have been constructed on Jaipur-Agra highway (NH-11) in India and commissioned in January 2013. The tunnels are named as Ghat-ki-Guni tunnels and were excavated through jointed quartzites of Jhalana hill. The quartzites have been classified in three rock classes. The two parallel tunnels have rock barrier of 20m between them. To provide the escape route in case of emergency, the parallel tunnels are interconnected at two locations by cross passages. The cross passages were excavated after the excavation of main tunnels. Conventionally, the interconnecting cross passage is designed perpendicular to both the parallel tunnels. But, in this case, as per Indian Road Congress (IRC) code, the interconnecting cross passage was designed at an angle of 30° on one side and 150° on the other side at the intersection with the main tunnel creating a V-shaped rock wedge at 30° side of the intersection. The parametric numerical analysis has shown that the shear stress zone increases when the intersection angle of cross passage with the main tunnel is changed from conventional 90° to 30°. Thus, the support design of the intersection zone of the main tunnels and the cross passage having V-shaped rock wedge in both the tunnels was a challenging task, which has been accomplished by using the results of numerical analysis and applying the Q-system based approach for support design. The monitoring using the tell-tale of glass strip across the crack shows no further widening of crack.

Keywords: Interconnecting angular cross passage; V-shaped rock wedge; Support design; Numerical analysis; Glass strip; Tell-tale

1. INTRODUCTION

Ghat-Ki-Guni area with heritage rich buildings on both sides of the road was the only eastern entry and exit points in Jaipur city in Rajasthan state of India. It was a highly accident-prone area. Traffic pollution was damaging the heritage structures. This was a concern for both to Government of India and Government of Rajasthan. To bypass the Ghat-ki-Guni area twin parallel tunnels have been constructed through Jhalana hill and commissioned in January 2013. As such, the tunnels have been named as Ghat-ki-Guni tunnels. The tunnels are connecting the Jaipur city with National Highway number 11 (NH-11) going to Agra city. Each tunnel is taking care of uni-directional road traffic. The two parallel tunnels have rock barrier of 20m between them. The alignment of 810m long twin D-shaped highway tunnels is trending in N110° direction.

To provide the escape route for emergency and for the maintenance purpose, the parallel tunnels have been interconnected at two locations by D-shaped cross passage. Conventionally, the interconnecting cross passage between two parallel tunnels is kept perpendicular to the tunnels (Oberaigner and Romerio, 2007; Facibeni et al., 2011). In addition to the minimum length of conventional perpendicular cross passage, it is expected that it will have less geotechnical problems and support design issues in comparison to angular cross passage. Therefore, the perpendicular cross-passage is convenient, cost-effective and mostly preferred. For the pedestrians escape, it is acceptable. But, for heavy vehicle movements in case of road tunnels, it is understood that turning the heavy vehicle on a perpendicular cross passage would require more space and would take more time than turning it on a cross passage at angle of 150° (other side making acute angle of 30°). Thus, the perpendicular cross passage may not provide smooth escape route for vehicular traffic in case of emergency. Therefore, for the ease of vehicular movement, the interconnecting cross passage making an angle of 150° at one side and 30° on the other side with the main tunnel is suggested in Indian Road Congress (IRC:SP:91-2010) code. In the Ghat-ki-Guni tunnels the interconnecting cross passage has been designed as per the IRC code (Fig. 1) and discussed in this paper.

India follows left-hand traffic (LHT) and accordingly Fig. 1 shows the direction of cross passage between the two tunnels for the LHT traffic movement. It can be visualized in Fig. 1 that the movement of traffic will be faster through angular cross passage. In the case of right-hand direction traffic (RHT) countries the cross passage shall have different direction (changed angle direction).

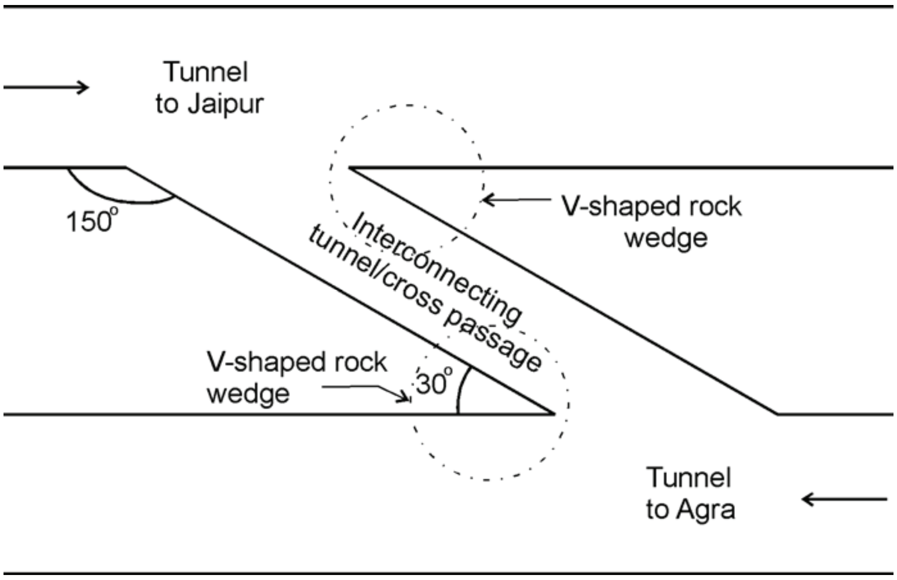

Figure 1 - Layout showing interconnecting cross passage at an angle of 150° to main tunnel and V-shaped rock wedge for left-hand direction traffic (LHT) movement

The 30° angle of cross passage formed a V-shaped rock wedge at the intersection with main tunnel, which is critical from the point of view of its stability and support design (Fig. 1). The paper covers the numerical modeling results to study the induced shear stresses at the intersection in case of angular and perpendicular cross passages. The perpendicular cross passage is studied to compare the results. The results of numerical modeling with the empirical Q-system have been used to design the supports for affected zone at the intersection of angular cross passage and the main tunnel. The design aspects of main tunnel supports are not discussed in the paper. The content of the paper is mainlytaken from Goel and Swarup (2016).

2. THE MAIN TUNNEL AND CROSS PASSAGE

The size of each two-lane uni-directional tunnel has been selected considering the requirement of one lane, edge strips, crash barriers/kerbs and walkways as per IRC:SP:91-2010. Accordingly, the D-shape tunnel has been designed to get the maximum vertical clear space (Fig. 2a). For the D-shaped cross passage the wall height is kept similar to the main tunnel and the width is designed to take care of the minimum vertical clearance for single lane traffic, Fig. 2b (IRC:SP:91-2010). With tunnel length more than 500m, the interconnecting cross passage is required at every 300m interval (IRC:SP:91-2010). Therefore, two interconnecting cross passages have been constructed at an angle of 30° at the location given in Table 1. Following are the salient features of finished main tunnels and cross passage (Table 1).

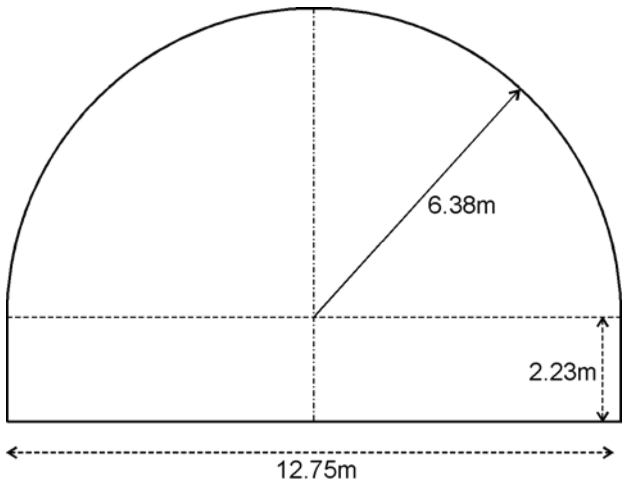

Figure2a - Finished main tunnel geometry and size

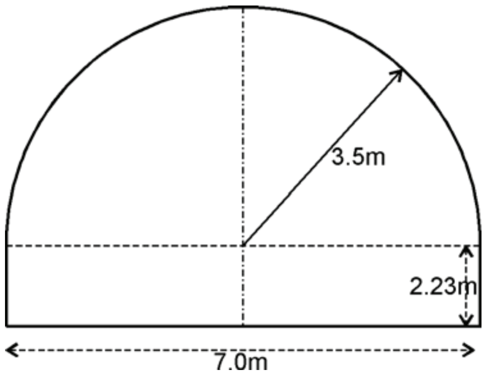

Figure 2b - Finished cross passage geo-metry and size

Table 1- Salient features of main tunnel and interconnecting cross passage

S. No.	Features	Main Tunnel	Interconnecting Cross Passage
1	Number of tunnels	Two parallel	Two (between chainage 1200 & 1300m and 1500 & 1600m; chainage from Jaipur end)
2	Rock pillar width between tunnels	20m	--
3	Length	810m	40m
4	Shape	D-shaped	D-shaped
5	Finished width	12.75m	7.0m
6	Finished wall height	2.23m	2.23m
7	Total height	8.61m	5.73m
8	Tunnel alignment direction	N 110°	N 140°

3. GEOLOGICAL AND GEOTECHNICAL DETAILS

The area in general comprises of Aravalli mountain ranges, which have the oldest granitic and gneissic rocks at their base, overlain by the rocks of the Aravalli Super group, Delhi Super group, the Vindhyan Super group and younger rocks. These rocks are metamorphosed at certain places and show rich occurrences of minerals of great commercial importance.

The Ghat-ki-Guni area and Jhalana hills comprises of quartzites and mica/sericite schists of Delhi Super Group. These rocks are structurally disturbed and are complexly folded and sheared. They have been intruded by number of veins. Subsurface geology has been obtained from the five boreholes drilled along the tunnel length from the surface (Project Report, 2010). Accordingly, the geological longitudinal section prepared along the tunnel is shown in Fig. 3.

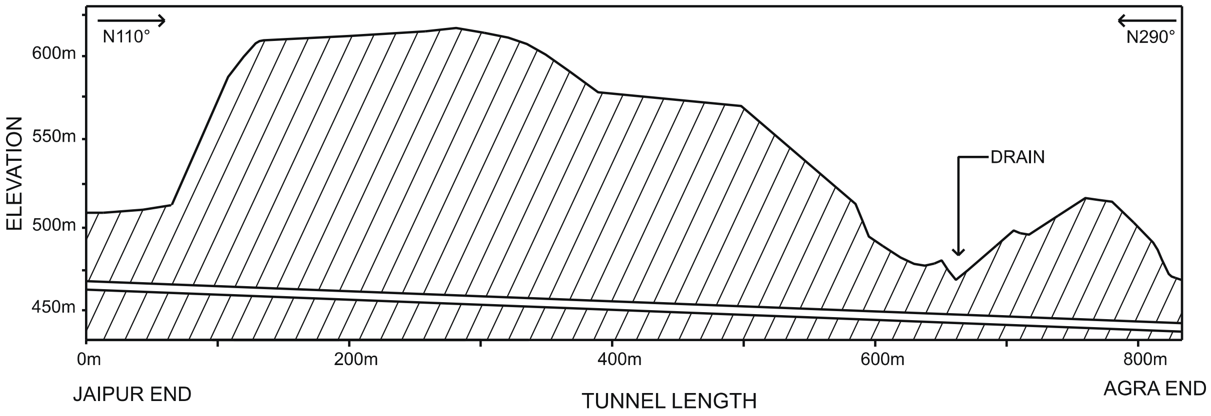

Figure 3 - Longitudinal section along tunnel through Jhalana hill

From the borehole data all along the tunnel length the exposure of quartzite is expected (Project Report, 2010). The quality of quartzite varies depending upon the presence of number of joint sets, weathering of joint surfaces, mineralized veins, folds and shears. Maximum tunnel depth is about 150m at about 280m inside the tunnel from Jaipur end (Fig. 3). The minimum tunnel depth, on the other hand, is about 40m below the drain at a distance of 670m from Jaipur end. Around this location class-III rock mass was encountered. Details of various rock mass classes are given in the following paragraphs.

Rock cores of five boreholes were inspected. In general, top 3 to 4 meter thick zone is weathered rock and after that the fresh rock is available. Borehole to borehole and in one borehole in different core boxes, the core recovery and RQD is varying. The core recovery in some cases is upto 80.9%. Similarly, the maximum recorded RQD is 75% (Project Report, 2010). The laboratory value of uniaxial compressive strength varies from 45MPa to 100MPa in most of the cases. The variation in strength is mainly because of presence of mineralized veins and degree of weathering of quartzites.

Quartzite rock has three joint sets plus random. The joint orientation is (dip/dip direction) 80°/SW; 70°/NW; 40°/SSW and 20°/N125° (random joint). Joint spacing varies from 0.10m to 0.60m. As such, from the volumetric joint count the RQD is about 30-75%. The joint surface is rough & irregular planar and joint walls are slightly stained to moderately weathered with coating of clayey and sandy material. At places, water seepage was observed with more seepage reported during tunnel construction below the drain during monsoon in the tunnel (Fig. 3). As suggested by Goel and Mitra (2015), the weathering effect on the rock mass shall be used for long-term assessment of supports and seepage in tunnels and in intersection zones. The rock mass quality (Q) value, based on these observations, is ranging from 0.5 to 8.66 and the geological strength index (GSI) value ranges from 35 to 70. For the purpose of study, the rock mass encountered in the tunnel has been classified in three classes. The Q and GSI values for the three rock classes are given in Tables 2 and 3 respectively.

Table 2 - Rock mass quality (Q) for three rock classes

Rock Class	RQD	J_n	J_r	J_a	J_w	SRF	Q
I	75	9	1	1	1	1	8.66
II	50	9	1.5	2	0.6	2.5	1.65
III	30	12	1.5	3	0.6	2.5	0.5

Notations: RQD – rock quality designation; J_n – Barton's joint set number; J_r – Barton's joint roughness number; J_a – Barton's joint alteration number;J_w – Barton's joint water reduction factor and SRF – Barton's stress reduction factor

Table 3 - GSI value for three rock classes (average value in bracket)

Rock Class	Rock Mass Description	GSI value
I	Blocky to very blocky rock mass with rough unaltered to stained joint walls	60-70 (65)
II	Very blocky rock mass with rough to planar moderately altered and mineralized joint walls	45-50 (47)
III	Folded and very blocky rock mass with slightly rough to planar moderately altered and mineralized joint walls	35

At the intersection of tunnel with cross passage, more problems were expected especially because of the V-shaped rock pillar between tunnel and cross passage and presence of highly jointed rock mass having above Q and GSI values. Therefore, to keep the cross passage location in rock class-I & II, the cross passages was excavated after the construction of main tunnels and when the deformations in the main tunnel have stabilized. Figure 4 shows a photograph of cross passage from main tunnel.

Figure 4 -Interconnecting cross passage during construction

The excavation of main tunnels was started from Agra end using drill and blast method. The work was completed in about 18 months. Mainly the rock bolt and shotcrete supports were used. Since the paper mainly covers the cross passage, the support design of main tunnels has not been discussed in the paper.

4. NUMERICAL ANALYSIS FOR TUNNEL AND CROSS PASSAGE INTERSECTION

A number of computer-based numerical methods have been developed, which provide the approximate solutions to these problems. In practice, it is almost impossible to integrate mechanical characteristics of all the joint systems explicitly in a theoretical model (Wang and Zhu, 2006).

Thus, a practical equivalent continuum approach has been used based on Hoek and Brown failure criterion, in which properties are assigned to rock mass so as to represent the overall response of jointed rocks (Hoek et al., 2013). As such a numerical analysis was carried out using three dimensional finite difference code (FLAC^{3D}) to study the induced shear stresses in the rock mass at the intersection of cross passage with main tunnel having angles of 30° and conventional perpendicular interconnecting cross passage, i.e. 90°. The analysis for conventional cross passage (90° angle) has been carried out for the comparison purpose. To get a better understanding of the induced stresses and for the parametric numerical analysis, in addition to rock class-I, class-II and class-III are also modeled and studied. The results of the numerical analysis have been used with the Q-value to design the supports.

4.1 In Situ Stresses and other Input Parameters

In general, the vertical stress is obtained using the following Equation 1.

$$\sigma_v = \gamma D \qquad \text{MPa} \qquad (1)$$

where D is the depth below ground surface and γ is the unit weight of rock mass which is assumed as 0.027 MN/m^3 (or 2.7g/cc).

Horizontal in situ stresses in the area have been assumed to be equal to the vertical in situ stress. Thus, for a tunnel depth of 150m and unit weight of the rock as 2.7g/cc, the input values of vertical and horizontal stresses are taken as 4.05MPa for the numerical analysis.

The mechanical rock properties as obtained from the laboratory tests (Project Report, 2010) along with the GSI values for three rock classes are given in Table 4. The values of Hoek-Brown parameters, m_b, s and a in Table 4 have been obtained using RocLab software of Rocscience (www.rocscience.com).

Table 4 - Input parameters considered for three rock mass classes for numerical analysis

S.No.	Parameter	Class-I	Class-II	Class-III
1	Geological strength index (GSI)	65	47	35
2	Uniaxial compressive strength of intact rock (σ_{ci}), MPa	100	75	45
3	Young's modulus, GPa	37.5	25	17.5
4	Brazilian tensile strength (σ_t), MPa	8	6	5
5	Poisson's ratio	0.2	0.2	0.2
6	Parameter m_i (σ_c/σ_t)	12.5	12.5	9
7	Disturbance factor (D)	0	0	0
8	Parameter m_b	3.581	1.883	0.883
9	Constant 'a'	0.502	0.507	0.516
10	Constant 's'	0.0205	0.0028	0.0007

4.2 Mesh Generation and Analysis

The mesh or grid used for analysis for intersection zone having angle 90° and 30° (or 150° from other end) of cross passage with main tunnel is shown in Figs. 5a and 5b respectively. The interconnecting cross passage tunnel is modeled as full geometry model.For ease of mesh generation in the 3D model, the size and shape of cross passage is kept equal to the main tunnel. A coarse grid was selected for the parametric analysis to quickly assess the stability conditions. Additional stress was applied at the boundaries to simulate the overburden. The model was stepped to equilibrium using solve command.

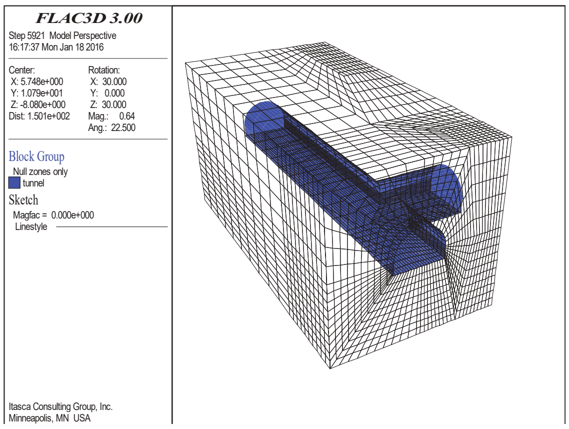

Figure 5a - Mesh of the intersection zone with 90° angle

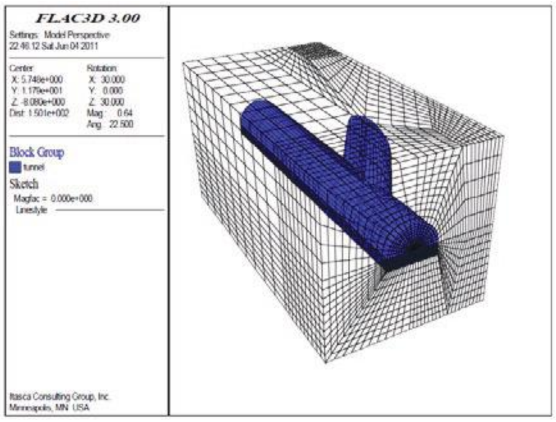

Figure 5b - Mesh of the V-shaped intersection zone with 30° angle

The parametric analysis has been carried out for intersection angles of 90° and 30° of interconnecting cross passage with main tunnel. For each intersection angle, three classes of rock i.e. class-I, II and III have been studied.

4.3 Results of Numerical Analysis

As mentioned earlier, generalized Hoek and Brown failure criterion (Hoek et al., 2002) has been applied for the numerical analysis and the induced shear stresses are plotted. The elements in red and green colour in figures are under shear. Red colour is showing 'shear-p' element indicate elastic state now, but yield in shear in past (ITASCA, 2003). Similarly, green colour shows 'shear-n' alongwith and 'shear-p' indicating yield in shear now, i.e. on the completion of analysis. This shows that the elements in 'shear-n' are likely to fail and therefore are of more concern. Hereinafter 'shear-n' has been referred as 'shear stress zone' in the paper. Figures 6a, 7a and 8a show the shear stress zones for the three rock classes respectively for intersection angle of 90°, whereas Figs. 6b, 7b and 8b show the depth of shear stress zone for three rock classes for 30° intersection angle.

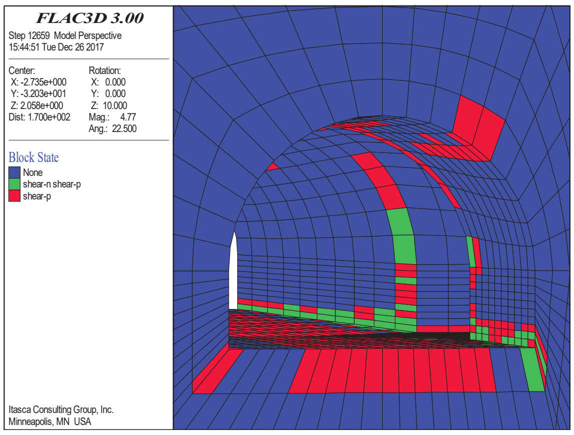

Figure 6a - Shear stresses in rock class-I with interconnecting cross passage at 90°

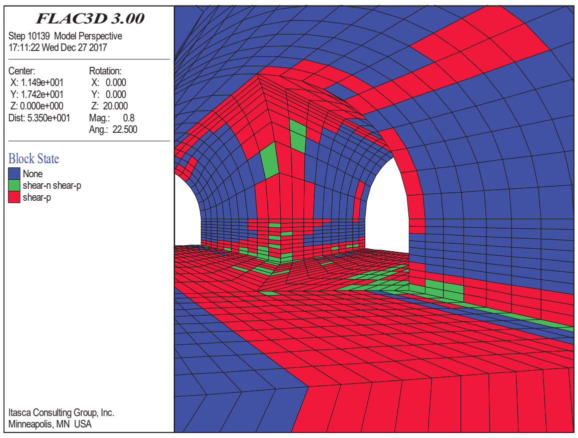

Figure 6b -Shear stresses in rock class-I with interconnecting cross passage at 30°

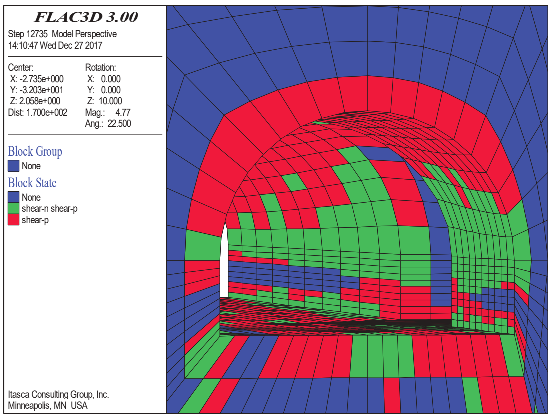

Figure 7a - Shear stresses in rock class-II with interconnecting cross passage at 90°

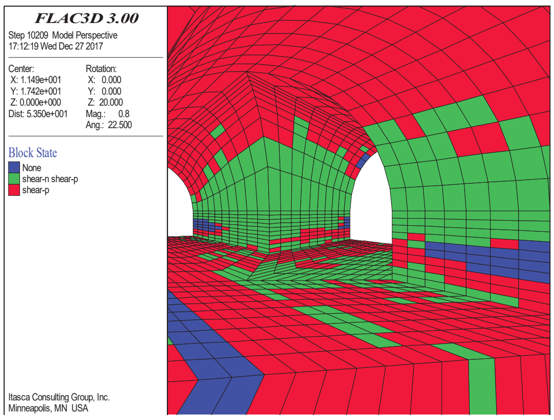

Figure 7b -Shear stresses in rock class-II with interconnecting cross passage at 30°

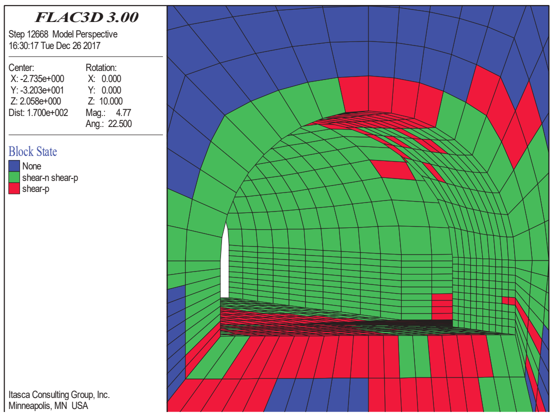

Figure 8a - Shear stresses in rock class-III with interconnecting cross passage at 90°

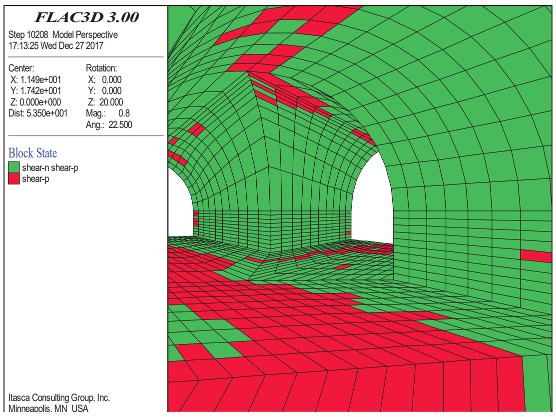

Figure8b -Shear stresses in rock class-III with interconnecting cross passage at 30°

Figures 9 to 11 show the plan view of shear stress zone below the spring level for the three rock classes for both the intersection angles. This plan view has given the information about the depth of shear stress zone in the walls.

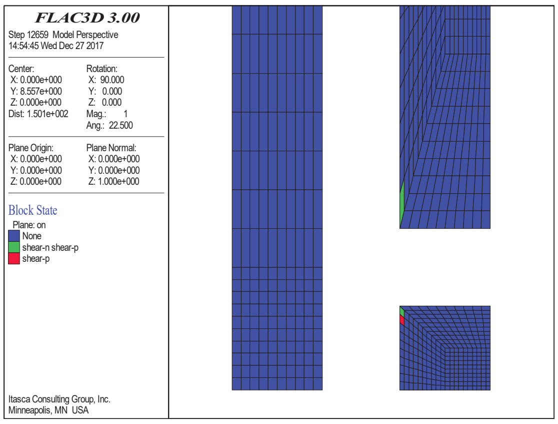

Figure 9a -Shear stresses in a plane cut at spring level in rock class-I with inter-connecting cross passage at 90°

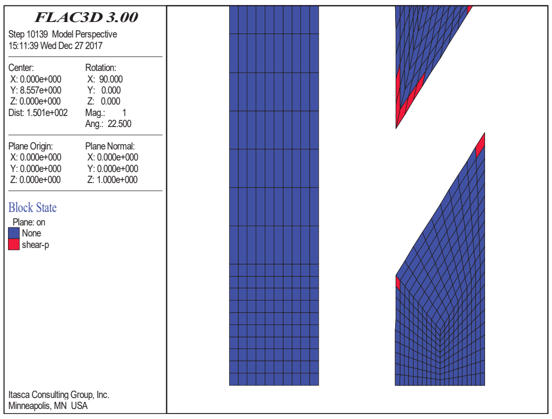

Figure 9b -Shear stresses in a plane cut at spring level in rock class-I with interconnecting cross passage at 30°

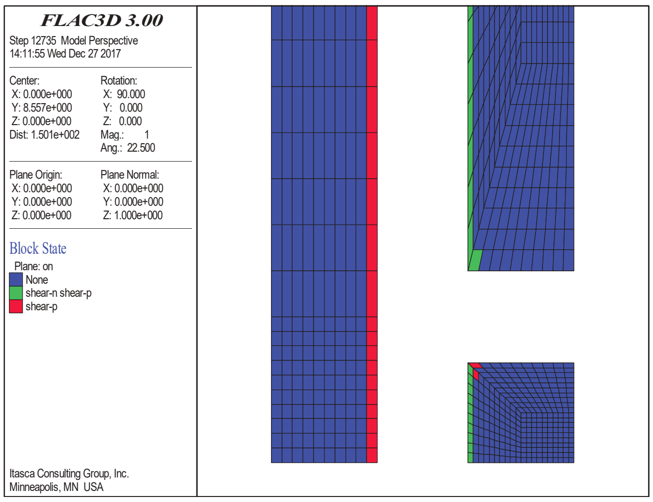

Figure10a -Shear stresses in a plane cut at spring level in rock class-II with interconnecting cross passage at 90°

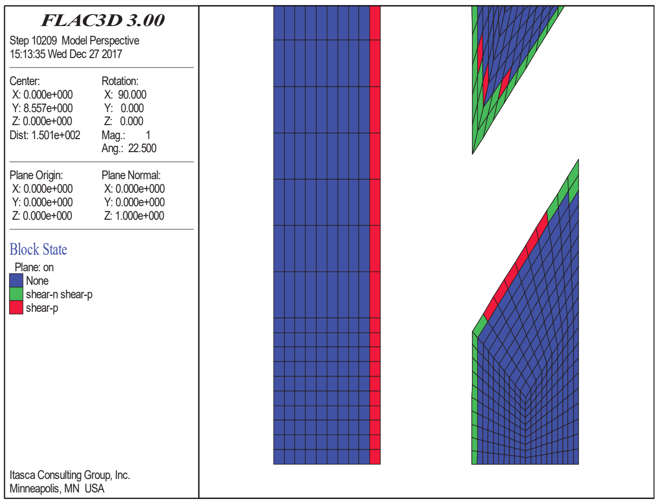

Figure10b -Shear stresses in a plane cut at spring level in rock class-II with interconnecting cross passage at 30°

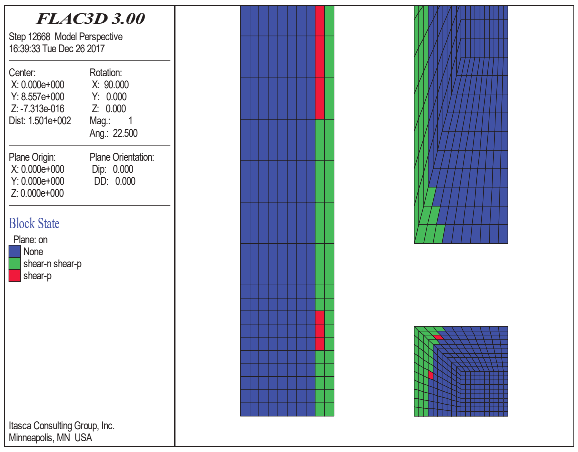

Figure 11a -Shear stresses in a plane cut at spring level in rock class-III with interconnecting cross passage at 90°

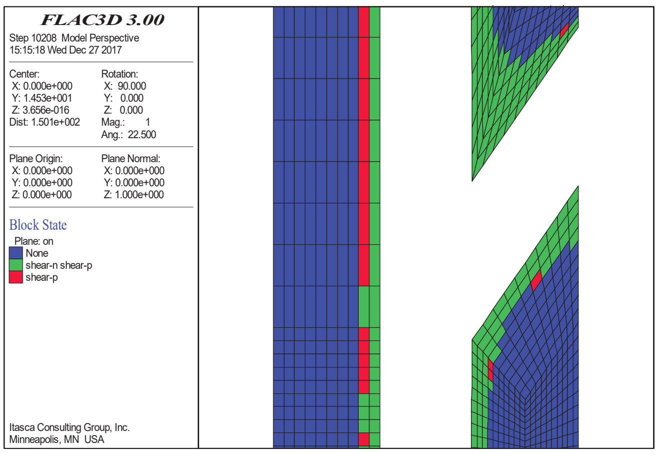

Figure 11b -Shear stresses in a plane cut at spring level in rock class-III with interconnecting cross passage at 30°

Figures 6 to 11 show that as the rock class changes from class-I to class-III, the shear stress zone increases at the intersection for both the intersection angles. The minimum zone of shear stress is at the intersection in class-I and maximum in class-III. On comparing the shear stress zone with the change in intersection angle, for the same class of rock, it is found that for intersection at 90° the extent of shear stress zone is less than the intersection at 30° (Figs. 6 to 11). The extent of shear stress zone on the two corners of intersection is practically almost same in 90° intersection angle, whereas in case of 30° intersection angle the extent of shear stress zone is more at 30° angle corner and less at 150° angle corner.

The increase in shear stress zone with the rock class-I to class-III in the 30° intersection of cross passage with main tunnel making V-shaped rock wedge is visible in Figs. 9 to 11. For rock class-I, very small zone of V-shaped rock wedge is under shear stress (Figs. 6b and 9b), but for rock class-III, the zone of V-shaded wedge under shear stress has increased (Figs. 8b and 11b). This analysis shows that though the conventional 90° angle is the better option for the interconnecting cross passage, the cross passage at an angle of 30° as per IRC:SP:91-2010 can be constructed with some extra supports.

As mentioned earlier, the cross passage was mainly planned to be constructed in rock Class-I and II. Therefore, the results of numerical analysis for rock class-II (Figs. 7b and 10b) have been studied for the extent of shear failure zones, which is shown in Fig. 12.

5. SUPPORT DESIGN

According to Bandis (2004), the rock mass having Q-value < 1 and more than 10 shall be treated as continuum. In our case, class-I and II rock mass are almost at the border of continuum rock mass. Therefore, the supports in the intersection zone of the cross passage and main tunnel have been designed using the results of numerical analysis (Section 4.3) and Q-system support chart of Grimstad and Barton (1993). As obtained from the numerical analysis, Fig. 12 shows the dimensions of intersection zone having length of 62.64m (L to M) in main tunnel, which is affected because of the cross passage.

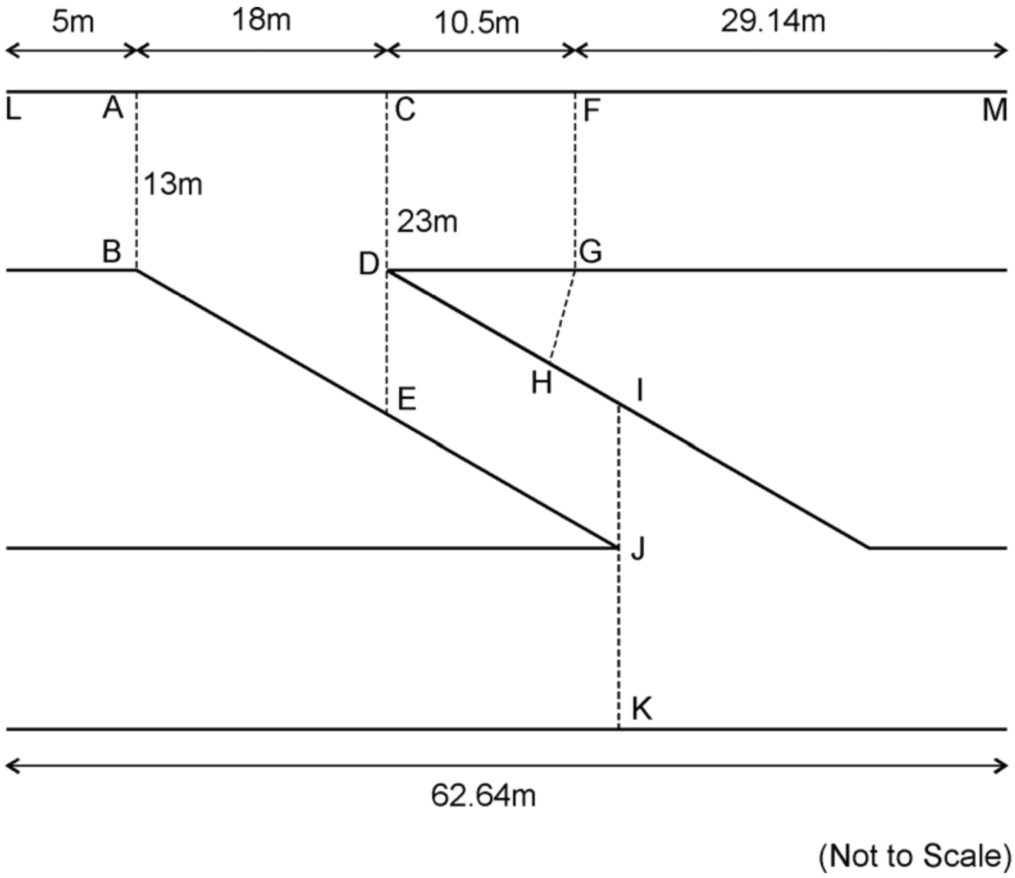

Figure 12 -Detailing of intersection zone dimensions for support

The Q-value for support design purposes in the main tunnel has been taken as 1.65 (Class-II). In the intersection area, as per Barton et al. (1974), the Q value would be 0.55 (Q=Q/3). Hence, considering the excavation support ratio (ESR) as 1 and excavation widths of main and cross passage as 13.5 and 7.5m respectively, the supports were designed for different zones shown in Fig. 12 as follows with the help of Grimstad and Barton (1993) support chart.

(i) *Zone BACDE (Fig. 12):* Its length in main tunnel is 18m (AC), widths 13m (AB) and 23m (CE). Because of three joint sets and roof span of upto 23m, possibility of formation of wedges were foreseen. It was also expected that first layer of SFRS may not provide sufficient strength to hold the larger dimensioned wedges/blocks, hence one round of 10m long forepole with bolts in the crown, spaced at about 1m spacing were also suggested at the start of excavation of cross passage. The final supports in this zone was –0.15m thick steel fibre reinforced shotcrete (SFRS) and 5 to 5.4m long 25mm diameter ribbed untensioned fully grouted rock bolts at a spacing of 1 to 1.5m centre to centre staggered with 15cm square base plate. SFRS in two layers; first 5cm thick layer after excavation and second 10cm thick after rock bolts installation.

(ii) *V-Shaped Wedge (DGH, Fig. 12):* The shear failure was obtained from numerical analysis upto a length of 10.5m in main tunnel and cross passage in the walls (DG and DH, Fig. 12). Hence, the angular V-shaped wedge (DGH) zone at the junction has been bolted below spring level (SPL) by providing bolts from cross passage wall to main tunnel wall upto 10.5m length having base plate and nut at both the ends. The bolts were installed at a spacing of 1.5 centre to centre in staggered fashion. The maximum bolt length in this zone was 5.4m (GH, Fig. 12). This support was provided in addition to the reinforced shotcrete and rock bolt support in the roof and walls of the cross passage and tunnel given below.

(iii) Cross Passage (DEIJ, Fig. 12): 15cm thick steel fibre reinforced shotcrete (SFRS) and 4m long 25mm diameter ribbed untensioned fully grouted rock bolts at a spacing of 1.5m centre to centre staggered with 15cm square base plate. SFRS in two layers; first 5cm thick layer after excavation and second 10cm thick after rock bolts installation.

(iv) Main tunnel (LA and CM, Fig. 12): This support was provided in roof and right & left walls for 39.64m (CM, Fig. 12) and 5m (LA, Fig. 12). The support comprises of 15cm thick steel fibre reinforced shotcrete (SFRS) and 25mm diameter 5.0m long untensioned fully grouted rock bolts at a spacing of 1.5 to 1.7mcentre to centre staggered with 15cm square base plate. Shotcrete in two layers; first 5cm thick layer after excavation and second 10cm thick after rock bolts installation

Same supports were used in both the main tunnels in the intersection zone.

6. MONITORING OF SUPPORTS

Deformations of tunnel roof and walls have been monitored in the main tunnel and at the intersection of main tunnel and cross passage. The deformation, as expected, increases with tunnel face advance and stabilized as the tunnel face advances 3 to 4 times the tunnel diameter from the monitoring station. At most of the locations deformation monitoring was carried out for about four months. The maximum recorded radial deformations of tunnel roof and walls, in general, are less than 10mm in one to two months (depending on the tunnel advance rate) and remained stable thereafter. There was no sign of distress in the SFRS in the main tunnel.

Near V-shaped intersection in the main tunnel wall at couple of places minor cracks were observed in the shotcrete before installation of extra longer rock bolts in wall from main tunnel to cross passage. The longer rock bolts from main tunnel wall to cross passage wall (as detailed in section 5(ii) for V-shaped wedge) were installed. Subsequently, the glass tell-tale plate was fixed across the cracks. The glass tell-tale remains intact indicating no further widening of cracks. The tunnels are now open for public use. Figure 13 shows a photograph of finished tunnel under operation.

Figure 13 - Finished tunnel under operation

7. CONCLUSIONS

Following are the conclusions from the numerical analysis for the design of intersection between angular cross passage and min tunnel.

- Angular cross passage in road tunnels shall be preferred comparing to perpendicular cross passage for easy maneuvering of vehicles. The intersection angle shall be designed considering the rock mass class.
- The intersection between the cross passage and the main tunnel is showing the shear stress zone. The shear stress zone increases when the intersection angle is changed from conventional 90° to 30°.
- The V-shaped rock wedge formed by intersection angle of 30° is showing shear failure zone in walls in a length of 10.5m in rock class-II in main tunnel and cross passage. The shear failure zone reduces as the rock mass quality is improved to rock class-I as shown in Figs. 6b & 9b.
- The steel fibre reinforced shotcrete (SFRS) and rock bolt supports have been designed for the intersection zone and cross passage using the Q-system and the numerical analysis results.
- The approach of support design used in the present case study is found to be effective and the twin tunnels have been constructed and commissioned in January 2013.

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References

Bandis, S.C. (2004). Numerical Modelling of Discrete Materials in Rock Mechanics: Developments and engineering applications. In: H. Konietzky (ed.), Numerical Modeling of Discrete Materials in Geotechnical Engineering, Civil Engineering and Earth Sciences; Proceedings of the First International UDEC/3DEC Symposium, Bochum, 29 September-1 October 2004. Oxford: Taylor & Francis.

Barton, N., Lien, R., and Lunde, J. (1974). Engineering Classification of Rock Masses for the Design of Tunnel Support, NGI Publication No. 106, Oslo, p. 48.

Facibeni, L., Palomba, M., Carrieri, G., Russo, G. and Guvenc, A. H. (2011). Critical Aspects in the Design of the Chenani-Nashri Tunnel, In: Proc. Third Indian Rock Conference-Indorock 2011, Oct. 13-15, Org by ISRMTT Roorkee Chapter, Roorkee, India, pp. 201-210.

Goel, R.K. and Mitra, S. (2015). Importance of weathering in rock engineering, In: Proc. of Int. Golden Jubilee Conf. Engineering Geology in New Millennium EGNM-2015, Special Issue of Journal of Engineering Geology, October, New Delhi, pp.231-245.

Goel, R.K. and Swarup, A. (2016). Design of interconnecting cross passage between two parallel highway tunnels, In:Proc. Geosafe 2016, 1stInt.Symp. on Reducing Risks in Site Investigation,Modelling and Construction for Rock Engineering, May, China.

Grimstad, E. and Barton, N. (1993). Updating of the Q-system for NMT, In: Proc. Int. Symp. on Sprayed Concrete - Modern use of wet mix sprayed concrete for underground support, Fagernes, (Editors Kompen, Opsahll and Berg. Norwegian Concrete Association, Oslo).

Hoek, E., C. Carranza-Torres, C. and Corkum, B. (2002). Hoek-Brown Failure Criterion – 2002 Edition, In: Proc. NARMS-TAC Conf., Toronto, 2002, 1, pp. 267-273.

Hoek, E., Carter, T.G. andDiederichs, M.S. (2013). Quantification of the geological strength index chart, 47thUS Rock Mechanics/Geomechanics Symposium, San Francisco, CA, USA, June, pp.1757-1764.

IRC:SP:91-2010 (2010). Guidelines for Road Tunnels, Indian Road Congress, November 2010, p.128.

ITASCA (2003). Flac3D Command Reference,Itasca Consulting Group, Inc., Mill Place, Minneapolis, 2003, p. 141.

Oberaigner, M. and Romeiro, F. (2007). Site ventilation of a long deep tunnel: The lot bodio of the gotthard base tunnel, In: Proc. Underground Space-the 4thDimension of metropolises, Prague, Taylor and Francis, pp. 1717-1720.

Project Report (2010). Factual Report on Geotechnical Investigation for Tunnel at Alternate Route to Ghat-ki-Guni for Construction of Tunnel in Jhalana hills to connect NH-11(Agra road) in

Jaipur, Rajasthan,Vol. I (Tunnel Section), DBM Geotechnics and Constructions Pvt. Ltd., Mumbai, October, pp. 416.

Wang T. and Zhu, H. (2006). The application of FLAC^{3D} to the support of an underground cavern, CD, In:Proc. 4thInt.Symp. on Numerical Modeling in Geomechanics-2006, Madrid, Spain, Paper No. 02-01, Eds. R. Hart and P.Varona, Itasca Consulting Group, Inc. Minneapolis, USA.