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Landslide of Tunnel Face by Slip Circle Formation —Case Study

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LANDSLIDE OF TUNNEL FACE BY SLIP CIRCLE FORMATION-CASE STUDY

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ABSTRACT

Konkan Railway Corporation Ltd. (KRCL) has been assigned construction of 71 km Railway Line from Katra to Dharam in Jammu & Kashmir state of India. This line when constructed up to Quazigund will link the Kashmir valley with main Indian Railways network. Indian Railway Construction Co. (IRCON) is assigned the section from Dharam to Quazigund. Railway Line in the valley beyond Quazigund is in operation. The KRCL stretch is situated in high mountains and deep gorges requiring construction of large number of tunnels and major bridges. The strata in most of the tunnels is fragile and charged with water particularly in tunnels passing through shear Zones. Several problems were faced while tunnelling which were handled in consultation with experts from all over the world.

INTRODUCTION

Construction work started with tunnel T-1 in 2003 with project completion target as 15th Aug'07. The project is situated in inaccessible areas of mountainous region. For starting construction of any tunnel or bridge, road construction was essential. 155.64 km access road is required for 71 km railway line. It was not possible to start construction of access roads and feeder roads at many places. The road construction could be started only from two sides viz. Reasi side and Sangaldan side. Construction of tunnels was also started wherever access roads reached. Efforts were made to air drop the machinery at inaccessible locations for expeditious road construction in consultation with Indian Air Force to reduce the construction period. As such, it was impracticable to complete the project within original date of completion.

SALIENT FEATURES OF THE PROJECT

Table 1. Salient Features of Project

S No	Features	Details
1	Total length	70.80 km (km 30 to 100.8)
2	No. of tunnels.	31 (56.58 km i.e., 79.92%)
3	Tunnel shape.	D-shaped / elliptical / horse-shoe.
4	2 to 3km long tunnels.	5 Nos.
5	3 to 5km long tunnels.	1 No.
	> 5 km long tunnels.	3 Nos.
7	Longest tunnel.	T-29 (6.574 km)
8	Length of tunnel with two lines.	876m in 8 tunnels in station area.
9	Tunnel with two lines and high level platform.	1573m in 4 tunnels in station area.
10	Tunnel length with three lines.	558m in 3 tunnels in station area.
11	Tunnel with three lines and high level platform.	520m in 1 tunnel in station area.
12	Wider tunnel section	3.527 km. in station yards.
13	Road/walkway in tunnels longer than 3km.	3m wide road, 90cm walkway on other side.
14	Walkway in tunnels up to 3 km long.	90cm walkway on both sides.
15	Special steel Arch Bridges.	2 Bridges over rivers Chenab and Anji.
16	Other Bridges.	46 Nos.
17	Total length of Railway Line on bridges.	9.76 km (13.79%).
18	Earthwork in cutting and embankment.	4.46 km (6.29%).
19	Length of approach road / feeder road.	155.64 km.

SALIENT FEATURES OF THE TUNNEL T1

Table 2. Salient Features of Tunnel T1

S No	Features	Details
1	Length of Tunnel	2685m
2	Tunnel section	D-section, the weakest section along the vertical walls
3	Geology	Crushed dolomite mixed with Shiwalik formation at contact.
4	Location	Mostly within the Main Boundary Fault (Reasi Thrust)
5	Support system	Permanent steel rib supports
6	Free standing time	10 hours to few days in dry strata and almost zero in wet strata
7	Gradient	Falling gradient of 1 in 120 in ascending km direction.

GEOLOGY ALONG TUNNEL

Definitions of Formations and Faults Under Consideration

Shiwalik Formation: Shiwalik Formation is one of the youngest formations. It is available in three types.

Lower Shiwalik Formation consists of major hard sandstone bands and clay stone bands with occasional siltstone bands.

Middle Shiwalik Formation consists of a thick and soft sand rock with thin red to grey coloured clay stone.

Upper Shiwalik Formation consists of pebbly bed, boulders, conglomerate, clay layers and sand layers.

Sirban Dolomite Formation consists of dolomite with occasional shale and carbonaceous bands. It is the hardest and the oldest rock in the region. It is however highly jointed/ fractured and associated with thick to thin shear zones.

Scree Deposit is an accumulation of weathered mass at the foot of a cliff or on a hillside forming a sloping heap.

Reasi Thrust is a Main Boundary Fault. It separates younger Shiwalik formation from overlying older dolomite formation. Dolomite is resting on Shiwalik rocks. Max width of thrust in Tunnel no. 1 is 425m. The Shiwalik Formation is getting pushed under the dolomite rock due tectonic forces thereby crushing the rocks at their interface. The Reasi thrust is still considered as active thrust by the Engineering Geologists.

The alignment of the complete tunnel passes either through or along Reasi Thrust. Tunnelling was started in June'2003 from T1P1. Initial 425 m of the tunnel passed through middle Shiwalik formation (Sand rock with clay bands) from Km 30/000 to 30/425. The tunnel passes through dolomite/Scree deposit materials from Km 30/425 to 30/850. The balance portion of the existing tunnel alignment from Km 30/850 passes through highly crushed and water charged dolomite rock (thrust material).

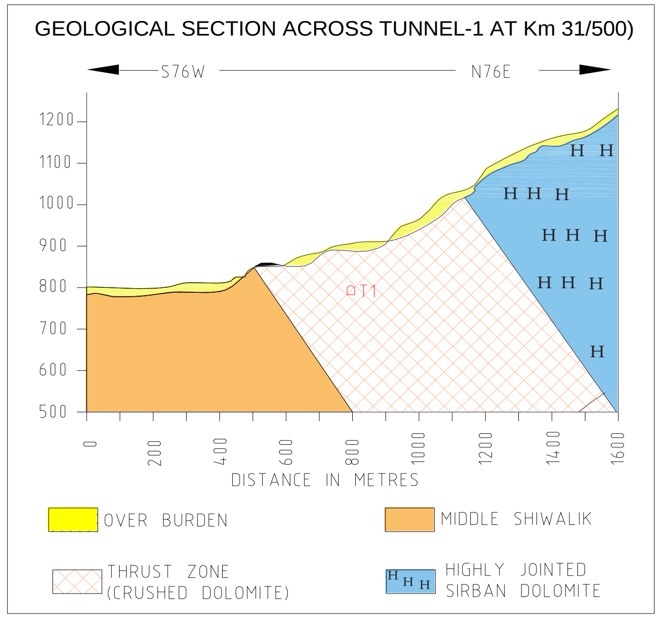

Fig. 1. Geological section across Tunnel-1 (Ch. Km 31.500).

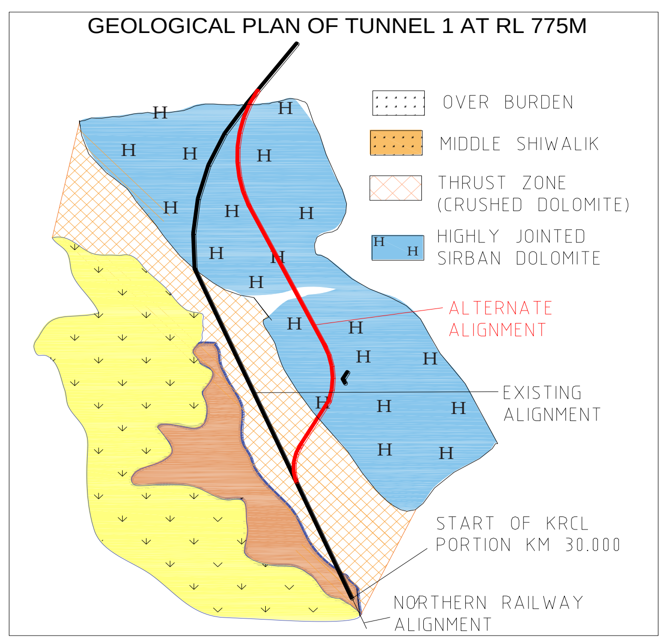

Fig. 2. Geological plan at elevation 775m showing existing & proposed alternate alignment of tunnel T1 and tunnel T2.

Tunnelling was done with great difficulty as the strata encountered was very poor consisting of scree material (Loose rock debris), sand rock, thin layers of clay bands with heavy seepage of water in thrust zone. The free standing time of the strata was almost negligible and was flowing with water. The tunnelling beyond Km 30/935 was done by multi-drift method after thorough pre-consolidation by fore-poling with SDA's and extensive cement grouting. Seepage of water varied from 30 litres per second (LPS) to 80 LPS. The tunnel is in falling gradient of 1 in 120. The continuous dewatering was carried out by using 6 pumps. Due to very poor strata, the progress of only 11m tunnelling in heading could be achieved in a period of 10 months from September 2006 to July 2007. The tunnelling beyond Km 30/950 was done by adopting double rib steel supports to avoid any convergence of the tunnel in such poor strata. This methodology proved to be quite successful. The geology of the tunnel as predicted by M/s Rail India Technical and Economic Services (RITES) and actual geology extrapolated to the complete length of the tunnel is shown in Fig. 3.

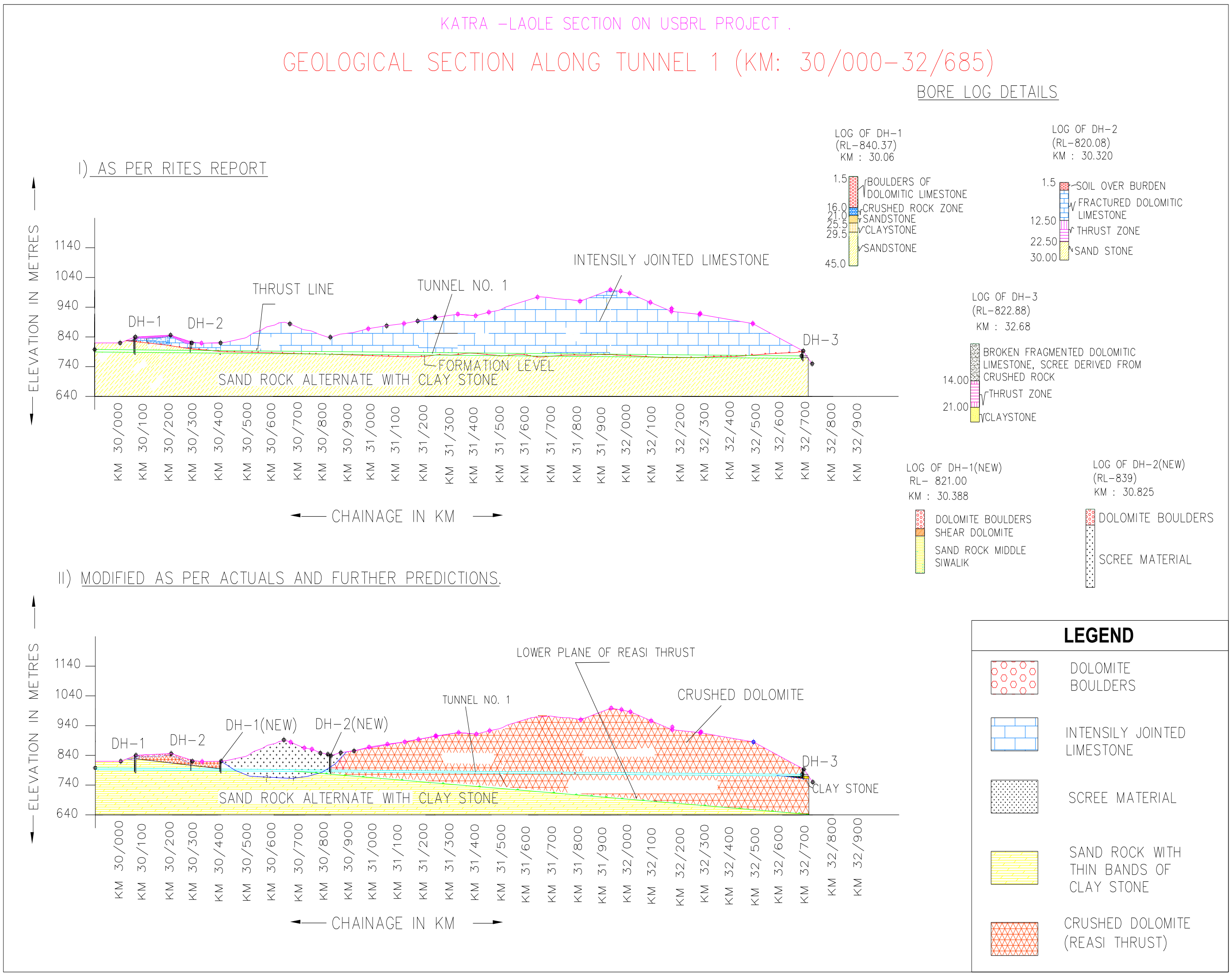

Fig. 3 Geological mapping along Tunnel T-1

<u>Bore hole details for tunnel T1</u>

Bore hole logs were analysed. The geologist's interpretation of bore logs at tunnel grade is brought out in Table 3. The landslide took place near the location of bore hole no. DH 3, where strata is crushed dolomite of Reasi thrust. Strata at the start of the tunnel (near bore hole DH 1) consist of sand rock with bands of clay stone.

Table 3. Bore Hole Details for Tunnel T1

S No	Bore Hole	Change (Km)	Surface RL (m)	Geology at tunnel grade
1	DH 1	30.060	840.37	Sand rock with bands of clay stone
2	DH 2	30.320	820.08	Sand rock with bands of clay stone
3	DH 3	30.680	822.88	Crushed dolomite of Reasi thrust
4	DH 1 New	30.388	821.00	Sand rock with bands of clay stone
5	DH 2 New	30.825	839.00	Scree material

Fig. 4. Complete view of slide at T1P2

Fig. 5. Site office uplifted by 1.5m.

Fig. 6. Damaged portal 2, tunnel 1 after the slide.

COLLAPSE OF TUNNEL FACE T1 P2

Tunnel excavation was started in Feb'2004. Tunneling of 237m in heading and 228m benching was completed till Feb'2005 through crushed dolomite charged with water except for small stretch of tunnel excavation through Clay Band. The tunneling was very difficult as frequent cavity formations took place due to water seepage of about 5 liters per second through highly crushed dolomite on this face. It had about 10 to 15 hours free standing time after excavation where the strata was dry and had almost no free standing time in wet conditions.

Continuous seepage of brownish water mixed with clay was observed, but it could not be related to the situation that could cause landslide. It was taken as localized clay as a part of crushing and mixing up of two types of rocks at contact in the thrust material. On 10.02.2005, the false portal of 20m length including part of the main tunnel apparently about 75m collapsed due to major slope failure by slip circle around the portal area. There was some well formation on the top of the collapsed tunnel. False portal barrel was badly damaged. The site office and workshop buildings were uplifted by about 1.5m by up heaving. Fig. 4. to Fig. 6. show the pictures after the land slide and damaged portal P2 of tunnel no.T1.

The site situation was so dangerous that nobody dared to go nearby. Fortunately there were no workers inside the tunnel on that day due to some dispute with the contractor that prevented casualties. The site was visited by various experts from India and abroad. After about one year the expert advices started coming. The problem was divided primarily in three parts for effective handling:-

- Stabilization and Reconstruction of Portal
- Re-Entry to Tunnel and Rehabilitation of Damaged Tunnel

- Stabilization of Hill Slope after Portal Construction and Re-Entry to the Tunnel.

Stabilization and reconstruction of Portal

Mumbai based consultant visited the site, collected necessary information and suggested scheme for stabilization of collapsed portal on 15.02.06. They suggested in-situ RCC Micro-piles of 300mm diameter, 10m to 15m depth beneath RCC false portal and around in a particular pattern to stitch together strata across the Clay Band that resulted into landslide causing extensive damage to the tunnel. They also suggested construction of RE wall for slope stabilization. Schematic diagrams are shown in Fig. 7 & Fig. 8.

Reconstruction of false portal

Micro-piling was done under the portal. Pile cap was cast as a part of bottom of the portal. After casting of pile cap under the portal, the rain caused flow of loose debris covering major part of the pile-cap i.e. portal-bottom. Therefore casting of RCC false portal was done in stages as per design adopted in Indian Railways amalgamated with micro-piling as shown in Fig. 9. First 21m length of false portal out of total 28m could be constructed from bottom to top by using proper shuttering on exterior surface. Frequent flow of debris was taking place even with little rain which was obstructing the portal construction. Construction of balance 7m of false portal was not feasible with conventional method by RCC construction. Therefore it was constructed from top to bottom in heading and benching. Construction Stages of are shown in Fig. 10 to 15.

Schemes for making re-entry to the collapsed tunnel

Various experts visited the site including design engineers of National Hydro Power Corporation Limited (NHPC) and the members of the technical advisory committee (TAC) for the project. They suggested the schemes as under for re-entry to the tunnel face:

Scheme suggested by design engineers of NHPC. NHPC suggested re-entry by making an umbrella of grouted piles 6m long by jet grouting inclined at 5 to 15 degree like fore-pole umbrella. Excavation by multi drift up to 4m keeping 2m grouted pile umbrella well supported. Provide another layer of umbrella of grouted piles 6m long by jet grouting. This process was to be continued till proper re-entry to the tunnel was made. Although they suggested this scheme, they did not have any arrangements to do it in the field. After having their scheme, efforts were made to search out some competent executing agency, which could make it possible to re-enter the tunnel for resuming normal tunnelling. One agency M/s. TecSoil of Italy could be contacted to do the job as per scheme suggested by NHPC.

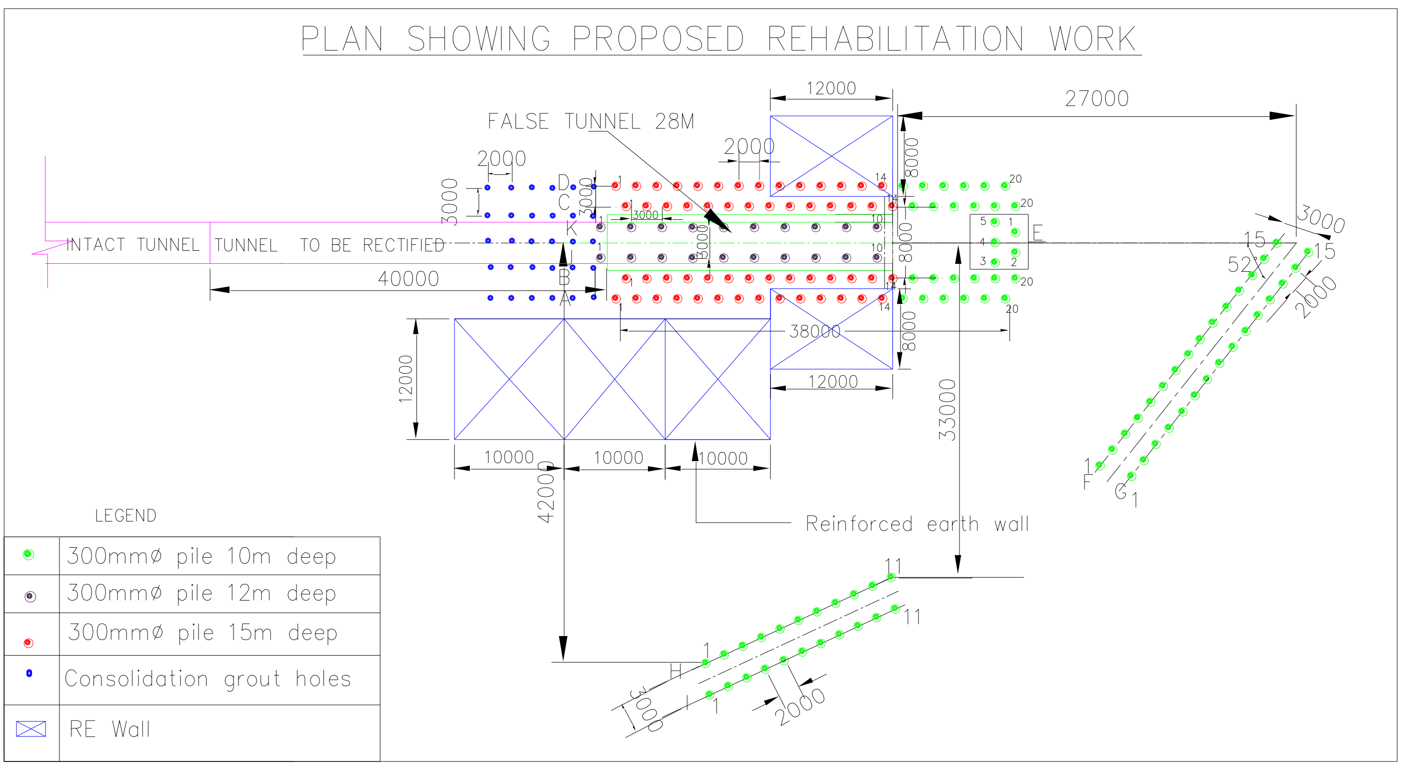

Fig. 7. Micro piling & RE Wall

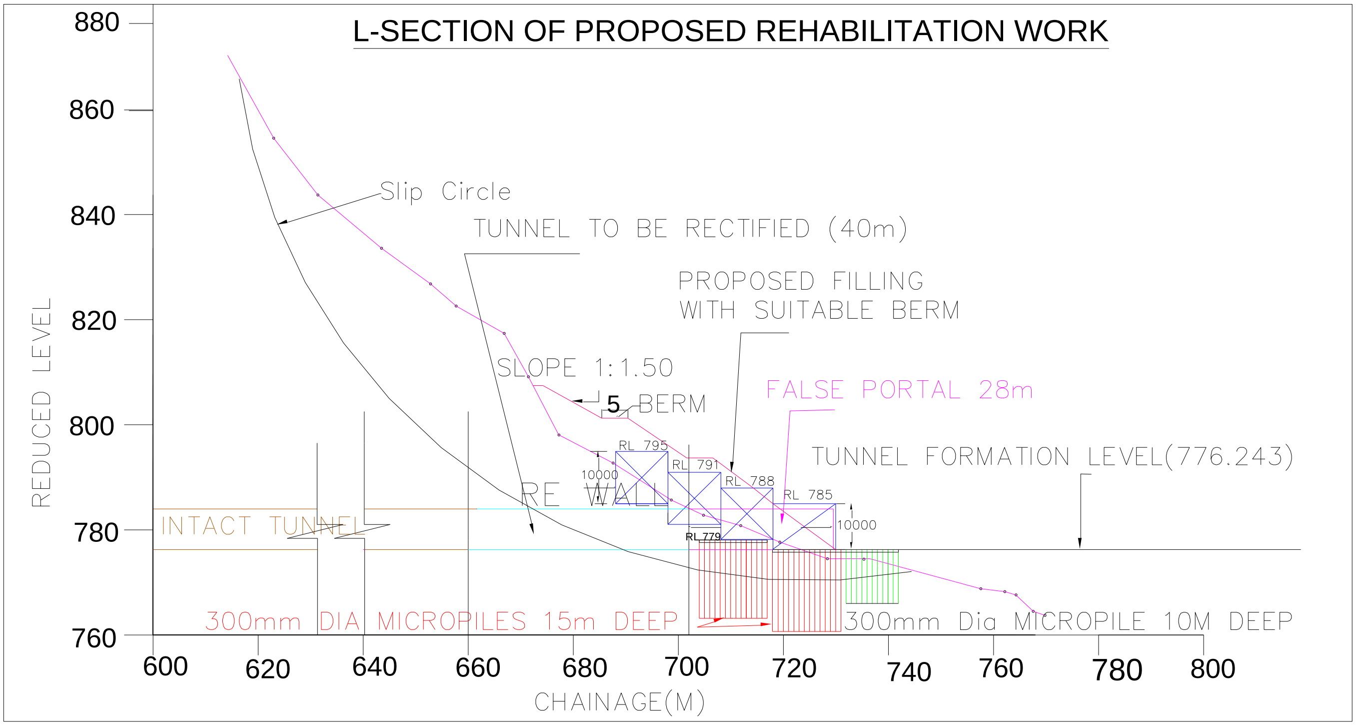

Fig. 8. Portal Rehabilitation Scheme

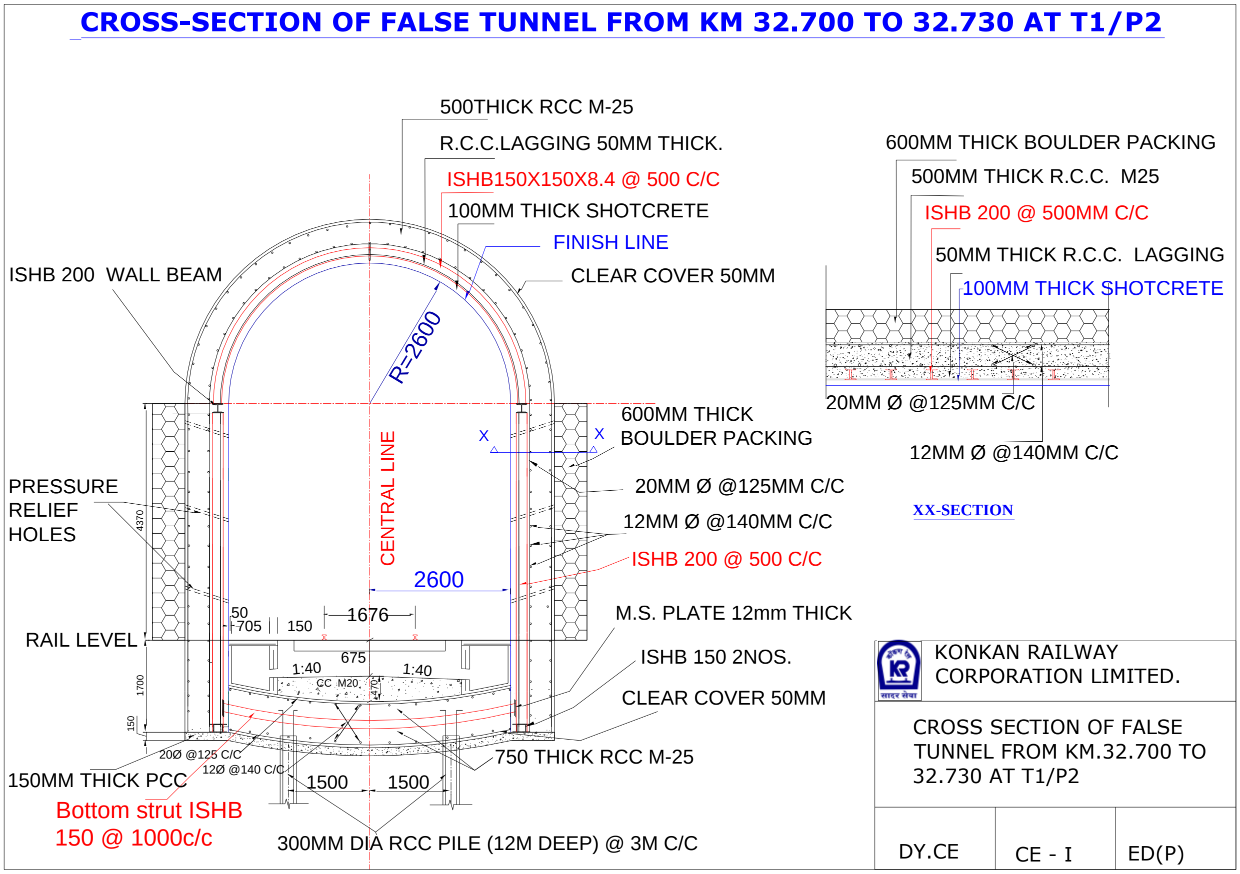

Fig. 9. False portal over micro-piles

The tunnel contractor submitted the report of M/s. TecSoil in Mar'07 for doing the jet grouting. They submitted an estimate of Rs. 213.5 million excluding cost of diesel, certain services and facilities, accommodation as well as transportation during the execution of work. They offered to complete the job in a period of 63 weeks including 9 weeks for mobilisation etc. as their equipment was to come to India from Italy after the job is assigned to them. The cost was probably very high as the equipments were to be imported specially for this job. The time period of 63 weeks was too much besides very high cost.

<u>Scheme suggested by Members of the technical advisory committee (TAC).</u> Members of TAC for the project suggested in July'06 to start the re-entry by making a canopy for safety of the workers. The details of the canopy were not elaborated. However at one time they suggested laying of Hume pipes inside whatever length was excavated for making re-entry to the collapsed tunnel for safety of the workers. The scheme did not appear workable.

<u>Making re-entry to the collapsed tunnel</u>

Finally, it was understood that the start of re-entry by making canopy appeared quite impracticable in the situation from safety point of view. The jet grouting scheme was very costly and quite time consuming. Decision was taken by the author, while working as Chief Engineer Incharge of the project to make re-entry in the following manner.

<u>Arch portion of balance 7m false portal</u>

1) Consolidation of loose mass by drill and grout using cement as grout material through drill holes on exterior.

2) Laying of wall beams of ISHB 200 at SPL to support the arch ribs taking support from 21m false portal at one end and well consolidated debris material on hill side.

3) Erection of steel ribs at 500mm spacing.

4) Erection/fixing of precast RCC leggings with steel ribs.

5) Casting of arch portion with M25 concrete.

Fig. 10. Micro pile cap as part of portal bottom

Fig. 11. Damaged Portal during construction

Fig. 12. Damage to ribs by boulder falling.

Fig. 13. False portal construction

Fig. 14. Micro pile cap casting outside portal

Fig. 15. Tunnel face joining existing tunnel at crown

<u>Heading/arch portion of tunnel section</u>

1) Start the work by making fore-pole umbrella with 51mm diameter, 6m long Self Drilling Anchors (SDA's) manufactured by Atlas Copco inside the arch portion of false portal at a close spacing of 300mm.

2) Stabilize the face by using 25mm diameter 2m, 4m and 6m long SDA's.

3) Create a plug of 6m fully consolidated with cement grout through 2m long SDAs and second layer of consolidation through 4m deep SDAs followed by third layer of consolidation through 6m deep SDAs of face.

4) Consolidation by extensive cement grouting through SDA's of fore-pole umbrella.

5) Once a solid plug of 6m is created, start excavation in heading by multi drift with Jack hammer without use of explosives as shown in Fig. 17. Not more than 1m at a time was excavated.

6) For every 1m lead, central portion of the tunnel face was excavated first leaving the sides intact.

7) Shotcrete the fresh surface with 50 thick SFRS (steel fiber reinforced shotcrete) immediately after excavation.

8) Erection of part steel ribs supported over temporary steel supports of ISHB 150 at top at a spacing of 500mm.

9) Erection/fixing of precast RCC leggings with steel ribs.

10) Back filling with concrete.

11) Repeat steps 5 to 10 for left drift and right drift in second and third sequence respectively as shown in Fig. 17.

12) Repeat this process for every metre lead up to 4m in a specific sequence viz. Central, left and right as extent of damage by the slide was lesser on left side of tunnel face.

13) Once 4m of excavation is completed out of 6m plug created by grouting and umbrella fore-poling, again another layer of umbrella fore-poling with 6m long SDAs through the available 2m plug thereby creating a further consolidated plug of 6m.

14) Excavation in heading was continued in the same fashion till the old tunnel was reached.

15) Filled up muck below SPL duly consolidated and stabilized was not disturbed as it was providing sufficient passive resistance against further flow of debris. Therefore benching was not started simultaneously.

16) Provide double steel rib supports at a spacing of 500mm at location of well formation to safe guard against any deformation under pressure from surrounding disturbed mass after slide. Double rib support layers with concrete filled in between enhanced flexural capacity many times as compared with single steel rib system.

17) Radial rock bolting and grouting at spacing of 1000mm longitudinally as well as peripherally in staggered manner with 25mm diameter 4500mm long SDA's.

18) The tunnel was in rising gradient in the direction of progress. As the contact with existing tunnel was met at crown, it was found that the existing tunnel was full of water.

19) As the benching portion of tunnel section was not disturbed, the hydrostatic pressure could not force sudden water exit. Drainage of stagnated tunnel water was regulated in such a way that no erosion was caused by water flow.

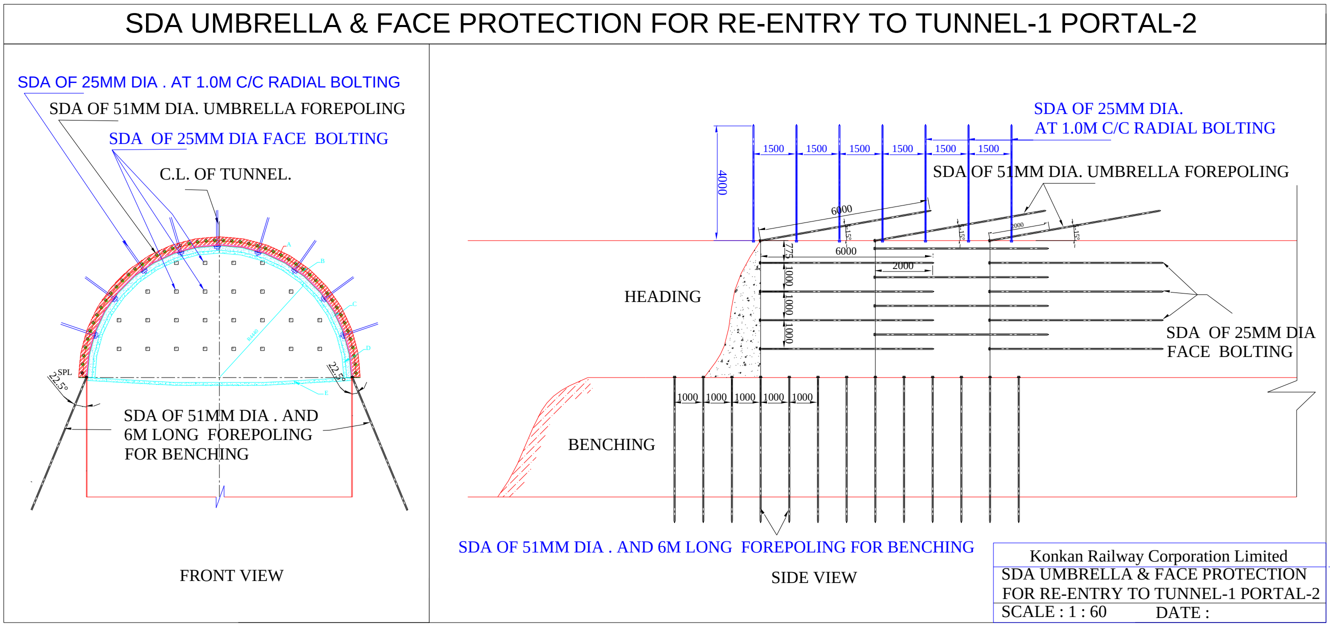

Fig. 16. Scheme for SDA Umbrella & face protection.

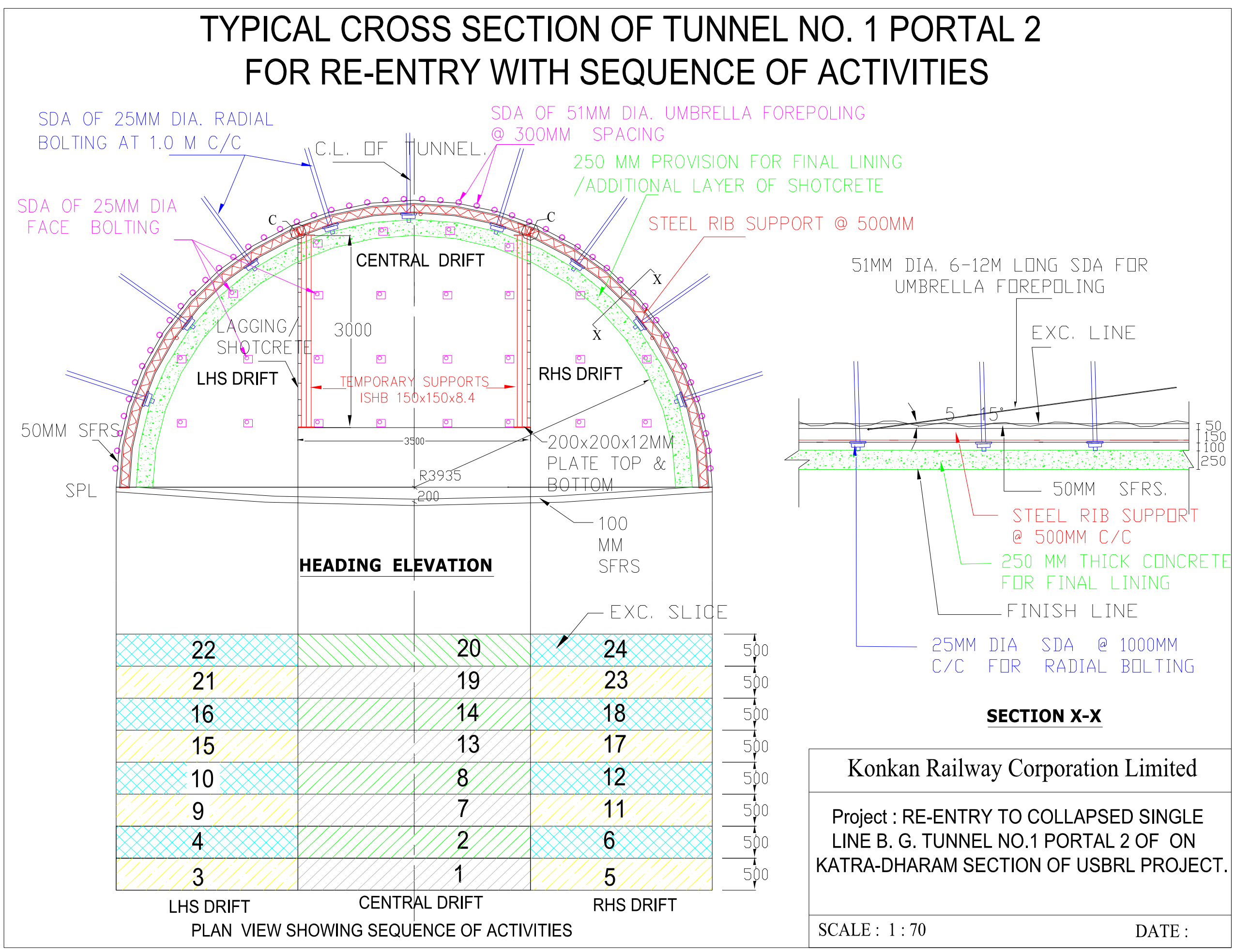

Fig. 17. Scheme for Re-entry by Multi drift.

Benching/excavation below SPL portion of tunnel section

After reaching the existing intact tunnel through heading, excavation of benching portion of the tunnel below SPL (springing level of arch) was started carefully in the following sequence:-

1) Forepoling for benching with 51mm diameter, 6m long SDA's was done as shown in Fig. 16.

2) Excavation was done by double drift method in benching with Jack hammer without use of explosives. Not more than 1m at a time was excavated.

3) For every 1m lead, left side of the tunnel face was taken up first as the extent of damage by the slide was lesser on left side.

4) Protecting the excavated surface with 50 thick SFRS immediately after excavation.

5) Erection of part steel ribs supported over bottom beam and bolted with wall beam of heading at top at a spacing of 500mm.

6) Erection/fixing of precast RCC leggings with steel ribs.

7) Back filling with concrete.

8) Steps 2 to 7 were repeated for right side also.

9) Radial rock bolting at spacing of 1000mm longitudinally as well as peripherally in staggered manner with 25mm diameter 4500mm long SDA's.

10) Grouting through radial SDA's.

11) Fixing of invert strut of ISHB 150 at spacing of 500mm i.e. at every rib.

12) Casting of invert concrete.

This scheme proved very successful and re-entry was made at a cost of about Rs. 5 million in a period of about 2 months. Collapsed portal was reconstructed and gained entry into main tunnel on 07.05.2007. Double rib steel supports were provided where considered necessary as per site conditions. The total amount spent towards portal development, stabilization and re-entry was Rs. 27 million.

Comparison of actual re-entry with TechSiol proposal

Table 4. Comparison of actual re-entry with TechSiol proposal

S No	Item	TechSoil proposal	Author's scheme	Remarks
1	Time period for making re-entry.	63 weeks after award of work.	8 weeks.	55 week time saved. Time taken was only 12.7% of TechSoil.
2	Cost.	Rs. 213.5 millions plus cost of logistics.	Rs. 5 millions.	Spent only 2.32% of bare cost.
3	Machinery and equipment.	Special imported Machinery and equipment required.	No special Machinery and equipment was required.	Local Machinery and equipment was used.
4	Transportation.	Involving huge expenditure.	Hardly any special transportation was needed.	Long distance international transport of machinery and equipment was avoided.
5	Setting up of office and establishments	Required for managing the special work.	Not required.	Existing setup was used.

The main tunnel was almost intact. However, huge quantity of water was accumulated throughout the tunnel i.e., behind Km 32/658 and some loose fall from crown at few locations inside the tunnel had occurred. Tunnel excavation was restarted from Km 32/459 in heading & 32/472 in benching from July 2007. The strata encountered was crushed dolomite without seepage of water which proved quite good for tunneling as the dry strata had sufficient free standing time.

Stabilization of hill slope over the new tunnel portal after re-entry to the tunnel.

Stabilization of the hill slope after rehabilitation of collapsed tunnel was planned as shown in Fig. 8 by adopting slope of 2H:1V and 5m wide berms at every 10m height. Construction of RE (reinforced earth) structures as shown in Fig. 7 was also part of slope stabilization work.

LESSONS LEARNT

Site selection for the tunnel inside main boundary fault was one of major deficiencies of the alignment. Any such major faults should be avoided in railway alignments which will have heavy axle loads further augmented by vibrations during train operation.

If it is not possible to avoid, the major faults should be crossed favourably in consultation with experts.

Sufficient geotechnical investigations before finalisation of railway alignment.

Proximity to main boundary thrust should be avoided. No tunnel portals should be located in thrusts and major shear zones.

No tunnel portals should be located in slide prone areas.

Safety of the structure during construction and in operation needs to be looked into from all possible angles.

Close monitoring of structures and surroundings need to be done at regular intervals.

CONCLUSION

The suggestions of the experts to handle the difficult situation are definitely preferable provided they have in depth knowledge of the area and are aware of all features. Highly technical solutions may be useful most of the times but may not be efficacious in certain situations. Therefore, non-conventional methods learnt by experienced should also be applied with due caution.

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