Doubling railway line: mitigation techniques & strategies for tunnels

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ABSTRACT: In 1960, the Indian Railway completed the Kothavalasa–Kirandul (KK) Broad Guage (BG) line under East Coast Railway (ECoR) to transport iron ore. Currently, ECoR plans to double this 445 km railway line, which features 58 existing tunnels and 45 proposed for the second line. The existing line passes through steep gradients of 1 in 60 and 8-degree curves, traversing sparsely populated regions with dense forests. The proposed doubling aims to boost freight capacity. We were entrusted with the feasibility study, preparation of Detailed Project Reports (DPRs), and project management consultancy (PMC) for tunnel construction in the KK line. This paper focuses on the 51 km segment between Boddavara and Karakavalasa in Andhra Pradesh, discussing methodology, challenges, and recommendations for similar projects. Additionally, a case study of cavity formation during tunnel construction in the adjacent Jarati-Malliguda section highlights unexpected geological conditions encountered during the feasibility phase and their mitigation. The study underscores the importance of planning in a region prone to 175 days of intense rainfall annually, which significantly affects construction activities.

1 INTRODUCTION

RITES Limited was awarded the work to study the proposed alignment of 51-kilometer stretch within the Boddavara-Karakavalas a section of the KK railway line, fixing portal locations, geological & geo-technical investigations and preparation of detailed project report. This focuses on its planning procedures and methodology of a railway doubling project. Further the PMC works for one of the sections in connection with adoption of parallel doubling in Manabar - Jarati - Malligura section of KK line (Odisha), India is discussed to shed light on unexpected geological conditions that were not initially foreseen during the project's feasibility stage and its treatment with solutions without hampering project cost.

2 LOCATIONS OF PROJECT

2.1 *Location*

The KK Line pierces through three states of India i.e. Odisha, Andhra Pradesh & Chhattisgarh. The line has a length of 445 km, out of which 138 km lies in Andhra Pradesh which will be joining South Coast Railway, rest of the line will remain in the Rayagada division of East Coast Railway, 131 km lies in Odisha up to Khadapa, 176 km lies in Chhattisgarh up to Kirandul. The KK section is classified as a Group E-special class line with speed below 100 km/h. The doubling of this line will be for capacity augmentation and contribute to growth in the regions, steel plants and ore mines in states. This line is mainly used for freight purposes which is a huge profit benefiting Waltair Division. Nearly ₹3,000 crore (US$ 380 million) of profit comes through this line. The location of the project is shown in Figure-1.

The project discussed in this paper lies in Koraput district of Odisha (Southeastern Region of India) which lies in the eastern ghats of India with hills up to 900-950 m height with Koraput at 870 m elevation above Mean Sea Level (MSL).

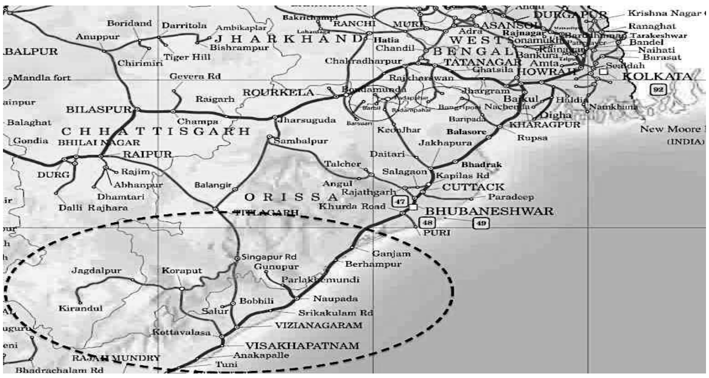

Figure 1. Location of the Project

2.2 *Geology of the Project Location*

This region is a part of the Eastern Ghats Mobile Belt (EGMB), covering parts of Odisha, Andhra Pradesh, Tamil Nadu, and a small part of Karnataka. The principal rock units of the eastern ghats are the granite gneisses, the charnockite series, the khondalite series, and the Granites. The charnockite series and the khondalite series are more in proportion in the hill ranges, whereas the granite gneisses are more in proportion in the plains between the hill ranges and the east coast. Three main stratigraphic units present here are the granite gneisses, the charnockite series and the khondalite series. Detailed mapping and geotechnical investigations further supported the observations.

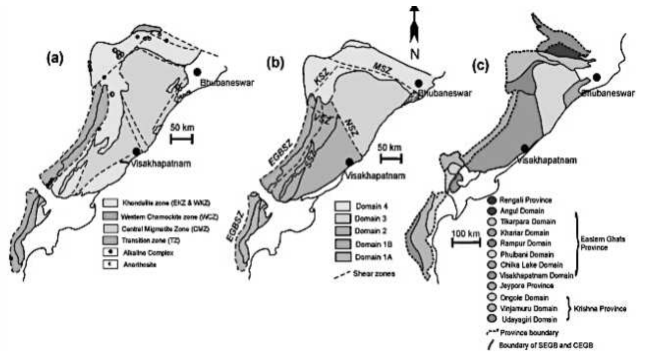

Figure 2. Geology of the project area

3 METHODOLOGY FOR PLANNING ALIGNMENT

3.1 *General Methodology*

Initially the data and information available from employer and generated from desk study was analysed and a base alignment was plotted on google earth. Based on these studies, the alignment was proposed by establishment of a digital terrain model for the tunnel route of the project on SRTM or ASTER. Further locations were decided for geotechnical investigations, and the data collected form site was analysed and then preliminary designs and cost estimates were prepared. Figure 3 depicts the flowchart for steps of alignment study.

3.2 *Site Reconnaissance: Studies and Key Observations*

Input Data by Railways: At the outset, the railways handed over an alternative route to RITES Limited for an initial assessment of its viability and to evaluate its techno-economic implications.

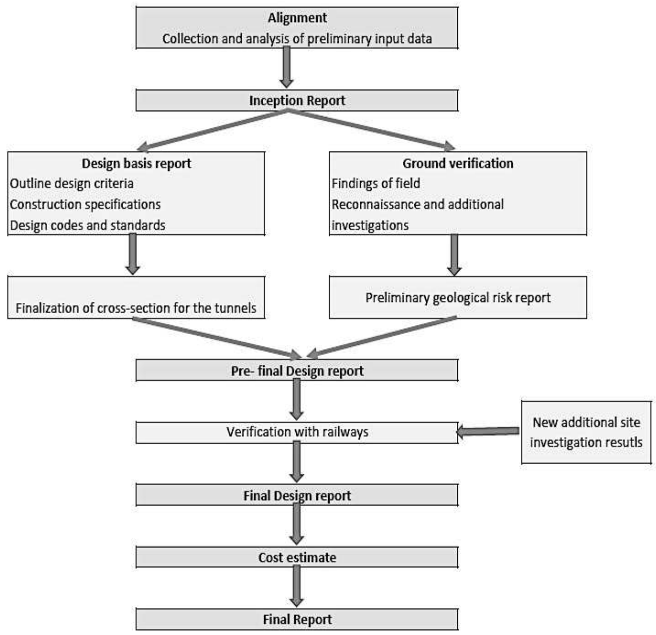

Figure 3. Flowchart depicting the study methodology.

3.2.1 *Site Studies and Verification of Existing Alignment*

The existing alignment spans 51 km from Boddavara to Karakavalasa. The section includes five stations: Boddavara (Ch:33), Shivlingapuram (Ch:45), Tyada (Ch:51), Chimdipalli (Ch:63), Borra (Ch:72), and Karakavalasa (Ch:83). The area's topography is diverse, featuring waterfalls, meandering rivers, green forests, mountains, hills, and undulating plains. Portions of the tunnels are unlined, with deep valleys on the right and high cuttings on the left across much of the section. Some patches of slope stability arrangements are present at station yards and intermediate high cutting's locations.

3.2.2 *Site Studies, Concerns & Re-Verification for Detour Alignment*

- The detour alignment matches the starting and ending stations of the section, i.e., Boddavara and Karakavalasa, while the intermediate five stations are proposed at new locations.
- For all new stations, the yard is designed at a 1 in 1200 grade compared to the existing 1 in 260 grades. A land strip of 100m on the station building side and 50m on the opposite side has been proposed for acquisition to accommodate necessary rail infrastructure.
- After Boddavara Station (Ch:33), the ghat section begins, featuring deep valleys ranging depths from 30–120m.
- The new Shivlingapuram Station (Ch:48) is planned at a lower level on the north side of the existing station, resulting in dual maintenance of stations at the same location.

- The new Chimdipalli Station (Ch:61) is planned on the right side of the existing yard. This involves significant filling, as the existing yard is adjacent to a steep valley on the right side, difficult construction feasibility and raising O&M concerns during operation.
- The new Gummakota Station (Ch:74) and New Mulapadu Station (Ch:93) are planned on the right-hand side of their respective yards. The proposed alignment intersects overhead power lines at eight locations, where adequate clearance is unavailable. Suitable shifting/diversion has been proposed.
- New Adaru Station (Ch:111) is planned on the right-hand side of the yard. The proposed detour doubling route will join the existing mainline at 1 in 400 grades, at the Karakavalasa station.

3.2.3 *Comments on Detour Alignment*

- A significant portion of the detour alignment traverses deep valleys requiring long viaducts, high retaining walls, and massive filling, leading to extensive additional land acquisition. Filling slopes follow a 2H:1V gradient as per railway standards.
- Since the area is water-charged, detailed hydrological studies are necessary for the new bridge locations. New access routes for construction could lead to further deforestation in greenfield areas.
- Although the proposed new up-line alignment offers a higher speed of 110 km/h compared to the existing 45 km/h, it is essential to ensure the entire system is synchronized for efficient operation. If only one part is upgraded, the system may not perform as expected.
- As the project involves a detour alignment, railway safety in tunnels will require additional adits, cross passages, and escape tunnels where applicable.
- Of the seven stations in the detour alignment, five are new, resulting in double maintenance of nearby stations. Most of the new stations are on embankments, while the current stations are on cuttings. Significant filling and additional land acquisition will be required for the new locations, potentially complicating execution.
- During the construction of the existing alignment, the Railways acquired additional land, including wider widths at structures for future doubling. However, the detour alignment cannot utilize this previously acquired land.
- Land acquisition in forest areas, environmental impacts on flora and fauna, and the construction of new access roads for approaches are significant concerns. These factors could further compromise the sustainability quotient of the project, especially in the case of a complete detour alignment.

3.3 *RITES proposed Methodology for Parallel Tunnel Alignment Study*

Following discussions of the pros and cons of the detour alignment, it was decided to explore an alternative parallel alignment. The proposed alignment was designed based on varying distances from the existing railway line, as determined by specific criteria outlined in Table 1 below. Adoption of only tunnel centre distance is discussed in this technical paper; however, each aspect is equally important in forming of alignment.

Table 1. Centre to Centre Track Distances structure-wise

S No.	Structure	Distance from Ex. Alignment
1	Tunnels & Its Approaches	25-35 m at Tunnels and 15-25 m at approaches
2	Major Bridge	20 m
3	Station Yard	Min. 5.3 m
4	Open Earthwork Sections	Min 6.5 m

Tunnel & Its Approaches:

During the excavation of a parallel tunnel cavity, the ratio between the major and minor principal stresses in the adjacent rock increases. The new stress state is influenced by factors such as:

- Shape and dimensions of the cavity
- Initial stress state in the rock
- Alignments Geological characteristics

With the parameters mentioned below, the ratio of x/a becomes ineffective for the horizontal tangential stress ratio and vertical stress ratio at the wall portion of the tunnel. Furthermore, the ratio of c/a becomes less ineffective for the horizontal tangential stress ratio for the given parameters. However, it shows a positive trend along the vertical stress ratio. Overall, with the given horizontal distance between the two tunnels, it is evident that the stress ratios are within permissible ranges, as shown in Figure 4.

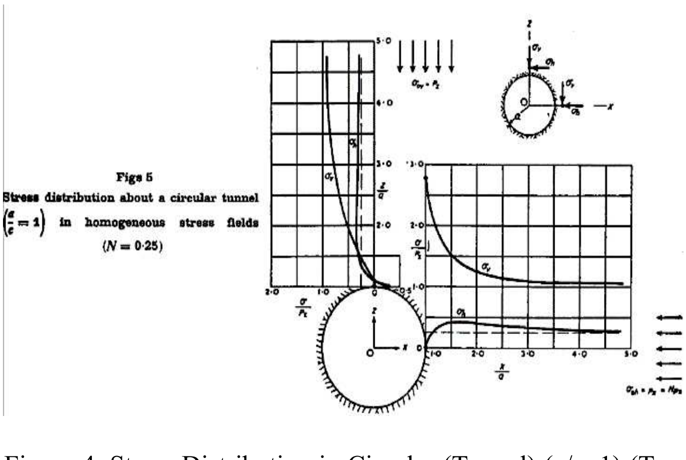

Figure 4. Stress Distribution in Circular (Tunnel) (a/c=1) (Terzaghi & Richter 1940)

Assume:

- Poisons ratio of surrounding rock = 0.2
- The overburden at the tunnel portal from crown (z) = 10-12 m
- Clear Centre to Centre Distance b/w tunnels (x) = 25 m
- The Width to Height Ratio (a:c) = 9:9 = 1:1
- The excavated diameter of the proposed tunnel, D = 9 m
- The safe distance b/w proposed, and existing centreline's is calculated as below-
- Distance from centre of proposed tunnel to minimized stress zone = 2.5 x D = 22.5m
- Radius of existing tunnel = 0.5 x D = 4.5m
- Length of existing trolley refuge (trolley refuges are also towards proposed tunnel) = 3.5m
- Margin for overbreak's due to over excavations = 2m
- Safe distance b/w proposed and existing tunnel = 32.5m

Hence, the adopted safe distance b/w center of proposed and existing tunnels to be kept 35m.

3.4 *Remote Sensing (RS) for Geological Mapping*

The project gets started with the planning phase by sketching the first plan in an Arc GIS software. ArcGIS surface analysis was used to generate contours, slope, aspect, and hill shade from DEM and then photogrammetric maps were prepared to facilitate portal locations and other studies. The geological map of study area had been prepared based on latest Remote Sensing Technique.

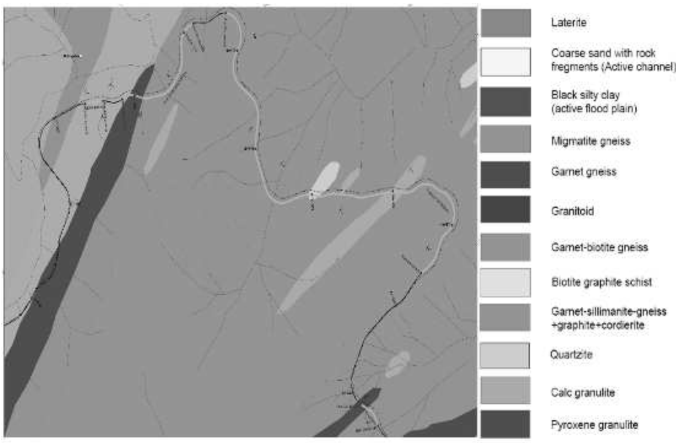

Figure 5. Geological Map of Location using RS technique

3.4.1 *Comments on merits of choosing Parallel Alignment*

- Major section is in cutting through competent rock mass; therefore, it can be assumed that that 2H:1V or steeper can be provided with minimum support along the alignment in cutting heights more than 6-8 m.
- The area is water charged, hydrological studies for the existing bridges can be referred in detail and this may be useful in estimating proposed bridges configurations.
- The proposed new upline alignment is designed with higher speed i.e., 60 kmph as compared to existing line speed i.e., 45 kmph. Therefore, upline speed is enhanced by a slight percentage, the overall system is benefitted as currently the upline speed was 40-45 kmph and downline speed was restricted to 30-35 kmph to avoid derailment.
- Additionally, the existing tunnels could be useful for escape tunnel and portions where the existing tunnel is opening, there adits are provided for efficient safety rescue exits.
- Out of 5 stations in existing alignment all stations are planned in vicinity of the existing alignment using same station buildings and providing 3-4 lines (main + Loop) as per requirement. No requirement of land acquisition was required within station top point limits. Railways had already done additional land acquisition in past during execution of existing alignment by acquiring wider width at each structure for future doubling, the benefit of available land acquisition can be therefore redeemed. Figure-6 depicts the alignments of existing (white) proposed detour(magenta) and proposed parallel(red) briefly. The merits and demerits of detour and parallel alignment are discussed in detail, prima facie through details mentioned in Table 2. The cost comparison for both the alignments was done on costing based on recent awarded works in East Coast Railway zone and the results stated that the detour alignment was 37 % more costlier than the parallel alignment as per rates worked out in year 2021-22. The information regarding rates and costing is sensitive and cannot be made public.

Table 2. Comparison of Existing vs Detour & Parallel Alignment

S. No	Parameter for consideration	Existing Alignment at Site	Detour Alignment	Parallel Alignment by RITES
1	Route Length	51 km with 5 stations	92 km with 7 stations (2 old and 5 new)	51 km with 5 Stations
2	Gradient	1 in 60 (uncompensated)	1 in 80 (compensated on curves)	1 in 60 (Uncompensated
3	Max. degree of Curvature	8 degrees	6.8degrees	8 degrees
4	Tunnel length	17.5 km	16.15 km	27 km
5	Minor Bridges	204	34	78
6	Major Bridges	16 (length - 1.05 km)	20 (length - 8.174 km)	8 (length - 0.6 km)

S. No	Parameter for consideration	Existing Alignment at Site	Detour Alignment	Parallel Alignment by RITES
7	Road Crossings	One crossing near Borra, No ROB and RUB	Four Crossing, 3 ROB and 7 RUB	One crossing near Borra, No ROB and RUB
8	Speed	45 km/hr	110 km/hr	55-60 km/hr
9	Station Gradient	1in 260 in all stations and 1 in 400 at Karakavlasa	1 in 1200 in all stations & 1 in 400 at Karakavlsa.	1in 260 in all stations and 1 in 400 at Karakavlsa

Therefore, Parallel alignment is most feasible and economic as compared subject to similar conditions with respect to detour alignment and it was approved by railways in due discussions and currently construction for doubling is in progress as per the proposed scheme.

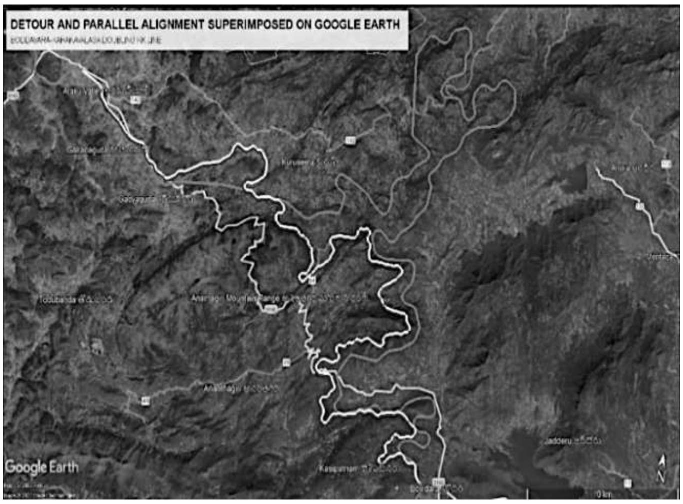

Figure 6. Existing, Parallel & Detour Alignment on Google Earth

4 CASE STUDY OF MITIGATION OF CAVITY FORMATION IN PROPOSED TUNNEL PARALLEL TO EXISTING TUNNEL

Effective planning and geotechnical investigations during the feasibility studies does not rule out guarantee non-occurrence of geological overbreak's in tunnelling. Therefore, a case study in similar project area of a cavity overbreak is discussed in this segment of technical paper and the solutions devised to address these challenges were formulated considering the adjacent operational tunnel, utilizing the allocated quantities specified in the contract to prevent non-scheduled variations, and project schedules.

4.1 *Geological /Geotechnical Studies During Pre-Excavation of Tunnel-1*

Tunnel-1 was planned with 320 m total length with extended cut & cover boxes both sides with offset distance of 28-33 m c/c with the existing alignment. The tunnel portal was planned at a max overburden cover of 8m at portal and 63 m in mid portion. The alignment is running perpendicular to the strike direction of the rock with steep dipping depicting fair condition, two boreholes and Geophysical surveys (Seismic Refraction Tomography) were conducted at the portal location and detailed geological mapping of existing tunnel. Water table met in both the boreholes ranging from 10 -13.5m depth. The Seismic depth probe reveals four-layered model with varying thickness. Refraction results indicates that the area is generally covered by 8.0m thick layer of overburden comprises of boulders/cobbles/fragment of weathered Granite/Granodiorite in silty/sandy matrix having seismic velocity of the order of 700 to 1178 m/sec.

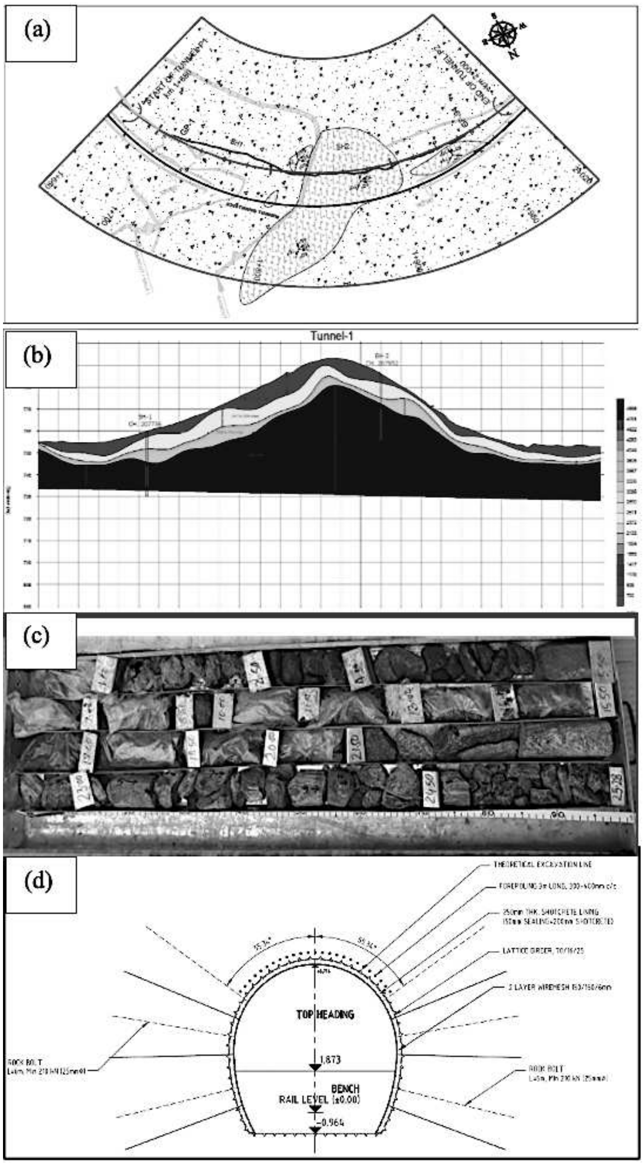

Figure 7. a) Geological Plan b) SRT results c) core photo d) Support Class Drawing being followed at the location

4.2 *Instrumentation & monitoring during tunnel operation*

During the tunnelling operation, the instrument monitoring systems were following types –Surface monitoring system such as inclinometer to monitor stability of portal slopes. Bi-reflex target, MPBX, pressure cell, strain gauge, etc. Cavity Formation: On 30th May 2022, at (Ch:1700) the vertical cover was 6-8 m and the face rockmass was in damp condition with little seepage observed on the face.

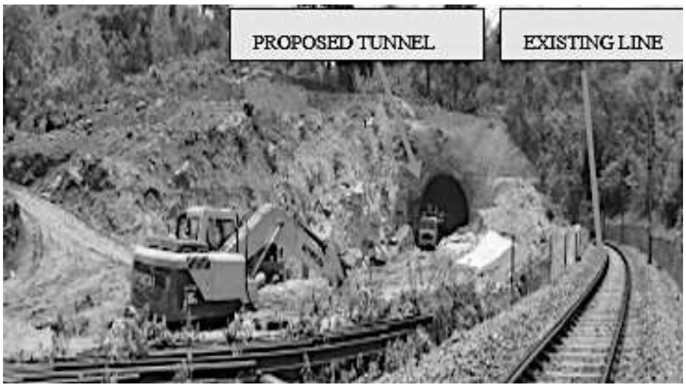

Figure 8. Pre-Cavity Photograph of Tunnel -1 (Prop & Existing)

Excavation till initial 20 m complete ted keeping next RL-1m completed at morning shift and support system installed by evening. Face mapping is attached in Figure-9 showing intermediate shear band with highly sheared rock mass. On 30th May 2022, the rain continuously poured for 3 days, suddenly on 4th Day when the rainfall stopped in morning 8 am, a cavity occurred at face and all the support provided at the face were dismantled. Huge quantity of loose rockmass cum debris came down which damaged lastly installed LG, forepoles and other supports as installed. Immediately at 9pm once again loose rockmass came down and damaged another set of LG with foreploes, therefore no further activities done at that night shift because it was risky to approach the face.

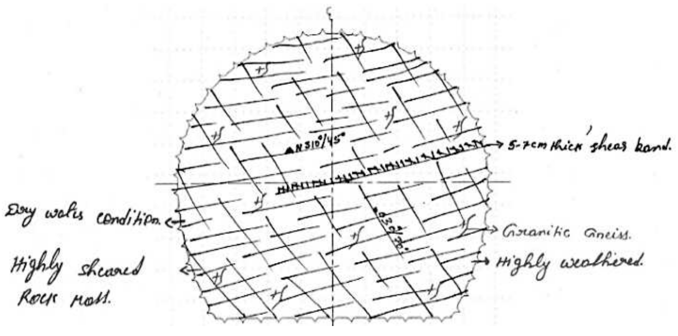

Figure 9. Face Mapping at RD 20 m i.e., Ch:1700

The cavity is visible in the upper part of the top heading. Fortunately, no casualties occurred during face instability. The relieving outcome was that the instruments installed in initial 20 m, showed very little deformation even after cavity outbreak and were in permissible limits. However, the overbreak extended further beyond 22 m (Ch:1722) i.e. RD 20 m to RD 42 m in increasing chainage and complete daylighting of tunnel at the mid-section occurred which can be seen in Figures 10 and 11.

Figure 10. Damaged LG, Fore poles, Wire Meshes at RD 20m

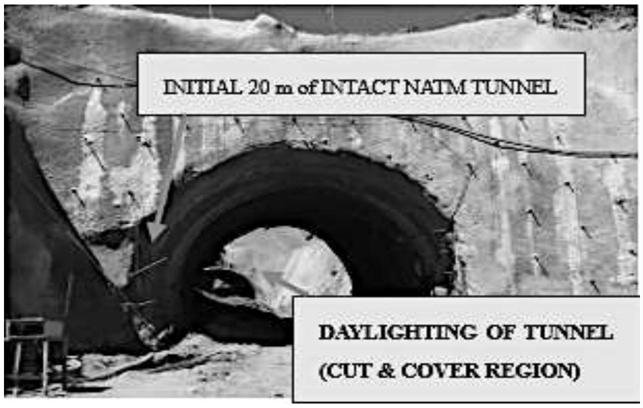

Figure 11. Complete Daylighting of Tunnel b/w Ch:1700 -1722

4.3 *Recommendations for treatment*

Continuous monitoring of existing tunnel was being done, and results were within permissible deformations and showed settling trends. The upper slope and the adjacent slopes were temporary contoured in such a way for efficient discharge of water. Also, relief holes were proposed in slope walls for dissipation of water pressures. Cut & cover box was planned in the mid portion to reinstate the ground and to ensure continuity between initial length of tunnel with the remaining leftover length. However, there were major problem in providing cut & cover box firstly limited site conditions due to muck disposal hill on both sides of existing tunnel. Also, Gantry machine fixing for outer and inner lining for cut & cover box was not possible in the mid tunnel location due to non-availability of horizontal clearance for mobilization of gantry machine.

Solution: Providing a support arrangement of lattice girder at 1m spacing centre to centre with base plates and wire mesh encircling the lattice upper portion tied with tie rods. The wire mesh was fixed to bent down fore poling and existing wire mesh. Galvanized iron sheet was placed as outer shuttering and shotcrete M25 was shot from inside so to provide a tunnel profile up to 150 mm thickness (50mm+100mm) in two layers. This thickness was provided to counter any possibility of shortcomings during operation and to ensure the inner profile of gantry to meet at the time of secondary lining throughout the chainages. Refer Figure-12 below. Furthermore, Support Class V was assumed at this length, however with this scheme saved an additional layer of wire mesh, lattice girder nos., shotcrete thickness, rock bolts 6 m lengths (1000 no.s).

Figure 12. LG, Wire mesh & GI sheets for Gantries' outer shuttering Gantry

The outer face of the cut & cover was wrapped in water proofing membrane 2mm thick and tunnel excavation material from support class 5 was backfilled on the cut & cover location contoured in such a way that the natural ground conditions, water channel routes are reinstated to the original.

5 CONCLUSIONS

The parallel doubling project in Indian Railways is a new initiative to increase the capacity, reduce congestion, efficiency and boosting economy of the country's rail network.

The only concern is the working operation of existing tunnel gets impacted and existing structures needs to be monitored closely for any deformation due to parallel construction activities. Due planning for alignment is mandatory for any project and criteria mentioned in this paper are recommended to be followed. The challenges encountered during the planning and construction of this project are intermittent shear bands, less overburden, extreme rainfalls, water ingress, steep alignment and cavity overbreak. The planning, design, and construction process adopted for this section will be helpful for future tunnelling in the parallel tunnelling projects (Doubling) for railways.

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