3D Monitoring & its Significance in Tunneling: Special Emphasis on Tunnel T-74R of USBRL Project, India

A. Ahmed1*, S. Mishra2, A. K Singh3, MD A. Azad4
1Deputy General Manager/Geology, ICT
2Associate Professor, G.D Goenka University
3Managing Director/ PMT Infrascience
4Department of Geology (CAS) University of Delhi-110007
*E-mail: aejazsz89@gmail.com

ABSTRACT

Nowadays, Tunnels are the major transportation network throughout the world. The importance of tunnel and its associated system also increases as the demand of Tunnel construction increases day by day. It has its significant importance in water conveyance networks as well as communication networks. As it is spreading fast over the world, the assessments of deformations are becoming an important part of tunneling system. The paper deals with the 3D monitoring system for the safety perspective and to make proper judgement about the condition of tunnels related to the information obtained in the measuring equipments. It also enables to react under various rock setting with the precise and reliable monitoring results. As we observed in the T-74R tunnel, where deformation of the tunnel's support system is a natural occurrence, the T-74R's main support system was also affected. The groundmass is prone to deformation due to its poor state and proximity to the principal thrust. The finding of the T-74R tunnel utilising 3D monitoring devices is important. They have provided the information about actual ground behaviour conditions.

Keywords: 3D Monitoring, Tunneling, Measurements, Instrumentation

1.0 INTRODUCTION

The USBRL Project’s Tunnel T-74R is situated in Banihal, Ramban district of Jammu & Kashmir. From 125+300 to 133+910, it runs through metamorphic rocks from the Ramsu and Machal formations in the Higher Himalayan tectonic belt, which is separated from the Lesser Himalayan tectonic belt by the Main Central Thrust, or MCT (see Fig. 1). However, because of the poor and unpredictable geological conditions, tunneling is a challenging activity in the Himalayan area [1-3]. The groundmass underwent multiple periods of deformation owing to the collision of the Indian and Eurasian plates, weakening the rocks of the sub- and lower Himalayas [4]. Construction on or through this distorted groundmass is thus difficult [5].

As a young fold mountain, neotectonic activity is significant, causing delays in building and damage during operation. So, the New Austrian Tunneling Method (NATM) is used a lot to build safe tunnels in these situations [6]. NATM is founded on the notion of
tunneling by recognising the ground's reaction to an underground opening and mobilising its self-supporting

Fig. 1 Geological map of the region with the tunnel alignment superimposed

Capacity [6–8]. Creating a hole in the earth disturbs the balance of in-situ tensions. The openings surrounding ground reaches equilibrium by deforming and eventually becomes self-supporting. The final lining of tunnels cannot be done until the earth reaches equilibrium. So, to monitor the ground's activity, 3D monitoring points and geotechnical sensors are used [9]. The tunnels are designed for the predicted ground type and behaviour. However, while tunneling, particularly in the Himalayas, the encountered ground type and activity may change. The 3D monitoring system from USBRL Project Tunnel T-74R is shown here, along with its implications for understanding ground behaviour and a comparison between predicted and actual deformation.

Accidents in tunnel while under construction occur often. As a result of advances in database and communication technologies, a 3D tunnel construction monitoring system has been developed. The technology allows construction workers to examine 3D simulations in multiple settings. Construction progress simulation, automated alert warning and trend projection are all included in the 3D interactive operation. The method provides improved safety and visual construction site monitoring. It also improved the construction progress and offered solid technical assistance for the Tunnels' safety construction. 3D Monitoring is a novel approach that monitors tunnel deformation, surface settlements, ground water table depletion, face and unsupported ground instability, daylighting collapse, support failure, etc.
These deformations inside the tunnel cause damages and even collapse of tunnel in the future. So, in order to protect and to increase the life span of tunnels, such parameters are monitored by an advanced technique known as 3-Dimensional Monitoring systems.

There are various reasons why 3D monitoring should take place in every tunneling system.

Some of the observations are listed below:

- To ensure the tunnel's safety and to validate design assumptions
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- Successful tunneling requires the ability to respond accurately and reliably to the diverse rock conditions.
- Any instrument must be dependable, simple, straightforward, and quick to install, use, and calibrate without interfering with building activity.
- The monitoring equipment must be long-lasting and resistant to damage before to and during installation.

### 2.0 Methodology

There are four parts to the methodology used in this study: (a) preparation of a database and a geological longitudinal profile of the tunnel that depicts the ground condition with overburden and support classes, (b) estimation of anticipated deformation at various zones along the study area's entire length, (c) analysis of actual 3D monitoring data from the tunnel, and (d) comparison of anticipated deformation with measured deformation. Primarily, ground behaviour is determined by the groundmass's geomechanically characteristics, which is why 3D monitoring points (bi-reflex targets) have been deployed (Fig. 2). We utilised the parameters from Ch. 125+712 to 127+662 in the Main Tunnel (South Portal) and Ch. 132+750 to 131+760 in the Main Tunnel (North Portal) for analysing ground and support system interaction (Fig. 3). The geological longitudinal profile and datasheet contain information on the litho-contacts, joints, faults, shear seams/zones, etc. that were acquired in the field during daily face logging. Additionally, this includes the projected and actual water conditions, overburden, etc. (Fig. 3 & Table 1).

During the excavation process for a tunnel, the ground's equilibrium is disrupted, resulting in deformation. The rock mass begins to deform half a tunnel diameter ahead of the advancing face and achieves its maximum deformation half a tunnel diameter behind the face [10]. Analysis of deformation incorporates notions of rock support interactions with rocks. Shotcrete, steel elements, and rock bolts were used to calculate the support pressure for each major support class evaluated in this study. The deformation zone (rp) forms around the aperture of the excavation in the plastic zone. The radius of the tunnel, overburden stress, and the geomechanical behaviour of the rockmass all have a role in determining the plastic zone's size. When the tunnel's principal support (Pi) is less than a critical support, rockmass failures occur (Pcr). The equations provided by Hoek and Brown [11] and Brady and Brown [12] were used to estimate Pi, Pcr, rp, and inward radial displacement (µ). (Tables 2 and 3) A Microsoft Excel spreadsheet has been produced, and the graphs have been displayed using both Microsoft Excel and Python software.

Deformation data has been acquired from the regular 3D monitoring reports, which show the real deformation. Each segment of Tunnel T-74R has five bi-reflex targets mounted. Instruments such as the TS-11 were used to achieve an accurate zero reading after they were
implanted in shotcrete (total station). Continuous three-dimensional displacement (X, Y, and Z) measurements were made on a regular basis (on a daily basis). Using the same reference points, an interconnected observation system was constructed that allowed for more thorough monitoring of the area. Points having a maximum displacement rate of less than a millimetre per month were utilised as reference points. The data was analysed and the deformation was examined in relation to the zero-reading recorded soon after the installation of the bi-reflex targets. The AAA Chart (Awareness, Alarming, and Action Limits) approach has been utilised to verify the area's stability after the processing of data. Graphs showing the same data in multiple ways, such as time-displacement diagrams and distance-displacement diagrams (here the second one has been used).
Finally, the predicted and actual deformation data were compared with the actual geological condition found during digging. Attempts have been made to determine the source of deformation in each zone and also to analyse differences between expected and actual deformation data for that specific geological zone, if there are any such differences. To account for both groundmass conditions and the overburden pressure, this has been taken into account. Because this is a tectonically active area, it's possible that the geological forces had a significant impact on the differences that were discovered.
Table 1: Geotechnical properties of rockmass

| Zone No. | Tunnel meter | Length (m) | Chainages (Km) | UCS (Mpa) | Friction angle (θ) | Cohesion (c) (Mpa) | Modulus (E) (Mpa) | Poissons ratio (ν) | Rockmass UCS (rcm) (Mpa) | Rockmass constan t (k) | Critical pressure (pcr) (Mpa) |
|----------|--------------|------------|----------------|----------|-------------------|-------------------|------------------|-------------------|-------------------------|-------------------------|---------------------------|
| 22       | 1450-1500    | 50         | TM:126788      | 43       | 28.93             | 1.30              | 5844.32          | 0.3               | 4.41                    | 1.94                    | 6.65                      |
| 22       | 1450-1500    | 50         | TM:126800      | 43       | 28.93             | 1.30              | 5844.32          | 0.3               | 4.41                    | 1.94                    | 6.65                      |
| 23       | 1500-1550    | 50         | TM:126811      | 43       | 29.22             | 1.32              | 6190.62          | 0.3               | 4.50                    | 1.95                    | 6.18                      |
| 23       | 1500-1550    | 50         | TM:126817      | 43       | 29.22             | 1.32              | 6190.62          | 0.3               | 4.50                    | 1.95                    | 6.18                      |
| 23       | 1500-1550    | 50         | TM:126822      | 43       | 29.22             | 1.32              | 6190.62          | 0.3               | 4.50                    | 1.95                    | 6.18                      |
| 23       | 1500-1550    | 50         | TM:126829      | 43       | 29.22             | 1.32              | 6190.62          | 0.3               | 4.50                    | 1.95                    | 6.18                      |
| 23       | 1500-1550    | 50         | TM:126836      | 43       | 29.22             | 1.32              | 6190.62          | 0.3               | 4.50                    | 1.95                    | 6.18                      |
| 23       | 1500-1550    | 50         | TM:126846      | 43       | 29.22             | 1.32              | 6190.62          | 0.3               | 4.50                    | 1.95                    | 6.18                      |
| 23       | 1500-1550    | 50         | TM:126860      | 43       | 29.22             | 1.32              | 6190.62          | 0.3               | 4.50                    | 1.95                    | 6.18                      |
| 24       | 1550-1600    | 50         | TM:126871      | 40       | 28.93             | 1.21              | 5636.77          | 0.3               | 4.10                    | 1.94                    | 5.87                      |
| 24       | 1550-1600    | 50         | TM:126878      | 40       | 28.93             | 1.21              | 5636.77          | 0.3               | 4.10                    | 1.94                    | 5.87                      |
| 24       | 1550-1600    | 50         | TM:126886      | 40       | 28.93             | 1.21              | 5636.77          | 0.3               | 4.10                    | 1.94                    | 5.87                      |
| 24       | 1550-1600    | 50         | TM:126896      | 40       | 28.93             | 1.21              | 5636.77          | 0.3               | 4.10                    | 1.94                    | 5.87                      |
| 24       | 1550-1600    | 50         | TM:126907      | 40       | 28.93             | 1.21              | 5636.77          | 0.3               | 4.10                    | 1.94                    | 5.87                      |
| 25       | 1600-1650    | 50         | TM:126920      | 40       | 28.93             | 1.21              | 5636.77          | 0.3               | 4.10                    | 1.94                    | 5.46                      |
| 25       | 1600-1650    | 50         | TM:126933      | 40       | 28.93             | 1.21              | 5636.77          | 0.3               | 4.10                    | 1.94                    | 5.46                      |
| 25       | 1600-1650    | 50         | TM:126945      | 40       | 28.93             | 1.21              | 5636.77          | 0.3               | 4.10                    | 1.94                    | 5.46                      |
| 25       | 1600-1650    | 50         | TM:126957      | 40       | 28.93             | 1.21              | 5636.77          | 0.3               | 4.10                    | 1.94                    | 5.46                      |
| 26       | 1650-1700    | 50         | TM:126976      | 40       | 28.93             | 1.21              | 5636.77          | 0.3               | 4.10                    | 1.94                    | 4.88                      |
| 26       | 1650-1700    | 50         | TM:126990      | 40       | 28.93             | 1.21              | 5636.77          | 0.3               | 4.10                    | 1.94                    | 4.88                      |
| 26       | 1650-1700    | 50         | TM:127004      | 40       | 28.93             | 1.21              | 5636.77          | 0.3               | 4.10                    | 1.94                    | 4.88                      |
| 31       | 1900-1950    | 45         | TM:127261      | 45       | 29.51             | 1.40              | 6708.20          | 0.3               | 4.81                    | 1.97                    | 3.29                      |
| 32       | 1950-2000    | 50         | TM:127301      | 43       | 29.51             | 1.34              | 6557.44          | 0.3               | 4.60                    | 1.97                    | 3.28                      |
| 34       | 2050-2100    | 50         | TM:127387      | 44       | 29.51             | 1.37              | 6633.25          | 0.3               | 4.70                    | 1.97                    | 3.88                      |
| 36       | 2150-2200    | 50         | TM:127472      | 43       | 29.51             | 1.34              | 6557.44          | 0.3               | 4.60                    | 1.97                    | 3.64                      |
| 36       | 2150-2200    | 50         | TM:127487      | 43       | 29.51             | 1.34              | 6557.44          | 0.3               | 4.60                    | 1.97                    | 3.64                      |
| 36       | 2150-2200    | 50         | TM:127502      | 43       | 29.51             | 1.34              | 6557.44          | 0.3               | 4.60                    | 1.97                    | 3.64                      |
| 37       | 2200-2250    | 50         | TM:127515      | 43       | 29.51             | 1.34              | 6557.44          | 0.3               | 4.60                    | 1.97                    | 3.60                      |
### Table 2: Estimation of Anticipated deformation in South Portal

| S. No. | Chainage  | Max. Tunnel Displacement Anticipated (mm) | Tunnel     | Overburden (m) |
|--------|-----------|------------------------------------------|------------|----------------|
| 1      | TM :126788| 21.48                                    | South Portal | 754            |
| 2      | TM :126800| 21.48                                    | South Portal | 754            |
| 3      | TM :126811| 17.98                                    | South Portal | 716            |
| 4      | TM :126817| 17.98                                    | South Portal | 716            |
| 5      | TM :126822| 17.98                                    | South Portal | 716            |
| 6      | TM :126829| 17.98                                    | South Portal | 716            |
| 7      | TM :126836| 17.98                                    | South Portal | 716            |
| 8      | TM :126846| 17.98                                    | South Portal | 716            |
| 9      | TM :126860| 17.98                                    | South Portal | 716            |
| 10     | TM :126871| 18.60                                    | South Portal | 671            |
| 11     | TM :126878| 18.60                                    | South Portal | 671            |
| 12     | TM :126886| 18.60                                    | South Portal | 671            |
| 13     | TM :126896| 18.60                                    | South Portal | 671            |
| 14     | TM :126907| 18.60                                    | South Portal | 671            |
| 15     | TM :126920| 16.30                                    | South Portal | 631            |
| 16     | TM :126933| 16.30                                    | South Portal | 631            |
| 17     | TM :126945| 16.30                                    | South Portal | 631            |
| 18     | TM :126957| 16.30                                    | South Portal | 631            |
| 19     | TM :126976| 13.48                                    | South Portal | 575            |
| 20     | TM :126990| 13.48                                    | South Portal | 575            |
| 21     | TM :127004| 13.48                                    | South Portal | 575            |
| 22     | TM :127261| 6.70                                     | South Portal | 444            |
| 23     | TM :127301| 6.78                                     | South Portal | 438            |
| 24     | TM :127387| 8.41                                     | South Portal | 500            |
| 25     | TM :127472| 7.86                                     | South Portal | 473            |
| 26     | TM :127487| 7.86                                     | South Portal | 473            |
| 27     | TM :127502| 7.86                                     | South Portal | 473            |
| 28     | TM :127515| 7.80                                     | South Portal | 470            |
Table 3: Estimation of Anticipated deformation in North Portal

| S. No. | Chainage      | Max. Tunnel Displacement Anticipated (mm) | Tunnel    | Overburden (m) |
|--------|---------------|------------------------------------------|-----------|----------------|
| 1      | CH:131764.497 | 2.67                                     | North Portal | N/A            |
| 2      | CH:132340.182 | 1.02                                     | North Portal | 118            |
| 3      | CH:132351.366 | 0.42                                     | North Portal | 162            |
| 4      | CH:132368.000 | 0.42                                     | North Portal | 118            |
| 5      | CH:132378.000 | 0.42                                     | North Portal | 118            |
| 6      | CH:132395.085 | 0.42                                     | North Portal | 92             |
| 7      | CH:132409.300 | 0.42                                     | North Portal | 92             |
| 8      | CH:132472.720 | 0.64                                     | North Portal | 108            |

Fig. 2: Schematic diagram showing arrangement of 3D monitoring points in X-section
3.0 Result and Discussion

In the longitudinal geological profile, there are several lenses of meta-conglomerate phyllite with some areas of medium-coarse grained quartzitic phyllite. In tunneling, there is one main fault with several shear seams (Fig. 3). The rockmass UCS varied from 25 to 100 Mpa, although local fault and shear zones exhibited UCS of 1–5 Mpa. The joint kinematic analysis revealed that the failure modes were mostly planar and wedge. Tunnel T-74R has four to five significant unavoidable collapse zones. The geological profile study revealed that all strongly deformed zones were linked to faults, shear zones, etc. However, variations in geomechanical behaviour between phyllite and quartzitic phyllite, as well as water intrusion, caused certain failures. It is computed that the support pressure, deformation radius, and radial
displacement are all equal over the whole tunnel zone (Tables 2, 3, 4, and 5). The primary rock support class adopted at the analysed sites in Tunnel T74R is C1*/C1F (89.07%), with subordinate B (3.18%), C (7.29%), and D (7.29%). (0.44 percentage).Class B had a support pressure of 0.70 Mpa, Class C had a pressure of 1.30 Mpa, Class C1F had a pressure of 1.45 Mpa, and Class D had a pressure of 1.79 Mpa (Table 4 & 5).T74R's South Portal has 39 zones, each 50 m long, ranging from Ch.125+712 to Ch.127+662. The overburden at South Portal varies from 325 to 803 m. As a result, the in-situ stress is 6.5–16.06 Mpa (maximum at zone 20). The rockmass found in this location is fair, with a GSI ranging from 48 to 60. South Portal's rockmass has a GSI of about 50, which is on the lower side, in zones 19 and 20 where there is the highest overburden and in-situ stress. Its radius is 4–6.5 m (maximum at zone 19), and its estimated inward displacement is 2.3–24.00 mm (Table 2). The North Portal has 19 zones, each 50 m long, from Ch.132+750 to Ch.131+760. Overburden varies from 52 m (zone 5) to 254.2 m (zone 14). The in-situ stress varies depending on the overburden and rockmass. North Portal has lower overburden and in-situ stress than South Portal. The radius of the deformation zone is 4 to 4.13 m at the North Portal, indicating the absence of a deformation zone encircling the tunnel and very minor inward movement of the main tunnel support, which is 3.17 mm at zone 14. (Table 3). Tunnel T-74R's North and South Portal stresses were derived using the predicted GSI along the tunnel [13]. However, this assessment during the building stage allows us to evaluate the support systems built according to the rockmass encountered. Strain is the tunnel closure to tunnel diameter ratio. This stress is believed to be the product of tunnel depth and rockmass unit weight. During the tunneling process, no substantial stresses were recorded along the tunneling zone. A rapport of plastic zone and tunnel diameter with a ratio of rockmass strength and in-situ stress has been displayed (Fig. 4 & 5). These figures reveal a negative association, i.e., low rockmass increases the plastic zone under high in situ stress. In South Portal-MT, the ratio of plastic zone to tunnel radius is roughly 4, whereas in North Portal-MT, it is around 1.5. Tunnel closure has been predicted for the encountered rockmass support system based on the radius of the plastic zone surrounding the excavated region and the rockmass strength under specific in-situ stress. This study examined the link between tunnel closure and diameter ratios, as well as rockmass strength and in-situ stress (Fig. 6 & 7). No tunnel closure was emancipated in North Portal-MT, but in South Portal-MT, a small amount (max. ratio of 0.0025) was emancipated using the established support system in the encountered rockmass. The largest tunnel closure was expected in the 0.4 ratio region, where the rockmass was in poor condition and the in-situ stress was significant (Fig.9).

3D monitoring sites built at South Portal recorded data from chainages 126+788 to 126+822 with comparable overburden (716 m to 754 m). From chainage 126+822 to 126+886, there were several ongoing displacement fluctuations. From chainage 126+886 to 126+907, there is a sharp climb (50-150 mm) of 21 m in length. Maximum displacement was 225-250 mm between chainages 126+940 and 126+950, where the overburden was 631 m high (Fig. 8).The largest displacement was 26.6 mm at chainage 131+764.497, but at chainage 132+340.182, where the overburden was 118 m high, the displacement was practically the same (30 mm). 132+340 chainage, 182 mm displacement, 19.9 mm at 162 m overburden, 40.2 mm at 118 m overburden. Despite the same height of overburden, maximum displacements increased by 14.3 mm at only 10 m. A maximum displacement of 80 mm was found around chainage 132+390. When the overburden was only 92 m high, the maximum displacement of structures dropped suddenly, followed by an increase in displacement at the
same overburden height. The findings obtained by calculating the projected deformation of
the implemented support system theoretically and seeing the actual deformation on the
installed deformation monitoring targets are considerably different (Table 6; Fig.10).

**Table 4 : Support Pressure Estimation in South Portal**

| Zone No. | Tunnel meter Length (m) | Chainages (Km) | Pull length | Actual Support | Max. overburden (m) | Support pressure (Mpa) |
|----------|------------------------|----------------|-------------|----------------|--------------------|----------------------|
|          | Start | End  | Start | End  |                  |                 |                       |
| 1        | 400   | 450  | 50    | 125+712 | 125+759.3  | 3.1                | C1(F)                | 325  | 1.33 |
| 2        | 450   | 500  | 50    | 125+761.5 | 125+809.2 | 2.8                | C1(F)                | 329  | 1.34 |
| 3        | 500   | 550  | 50    | 125+810.7 | 125+859.2 | 1.6                | C1(F)                | 340  | 1.44 |
| 4        | 550   | 600  | 50    | 125+860.7 | 125+909.2 | 2                  | C1(F)                | 353  | 1.40 |
| 5        | 600   | 650  | 50    | 125+910.6 | 125+959.5 | 2.5                | C1(F)                | 375  | 1.36 |
| 6        | 650   | 700  | 50    | 125+962 | 126+008  | 3.7                | C1(F)                | 398  | 1.31 |
| 7        | 700   | 750  | 50    | 126+010.4 | 126+058.5 | 3.7                | C1(F)                | 410  | 1.31 |
| 8        | 750   | 800  | 50    | 126+061.3 | 126+108.8 | 4                  | C1(F)                | 458  | 1.31 |
| 9        | 800   | 850  | 50    | 126+110.8 | 126+160  | 4                  | C1                  | 476  | 1.31 |
| 10       | 850   | 900  | 50    | 126+163 | 126+210  | 4.5                | C1                  | 505  | 1.30 |
| 11       | 900   | 950  | 50    | 126+212 | 126+260.5 | 3                  | C                    | 545  | 0.73 |
| 12       | 950   | 1000 | 50    | 126+262.5 | 126+309.5 | 2                  | C                    | 580  | 1.40 |
| 13       | 1000  | 1050 | 50    | 126+311 | 126+360.5 | 1.5                | C1                  | 644  | 1.45 |
| 14       | 1050  | 1100 | 50    | 126+362 | 126+410.5 | 2.3                | C1                  | 687  | 1.37 |
| 15       | 1100  | 1150 | 50    | 126+412 | 126+460  | 1.5                | C1                  | 702  | 1.45 |
| 16       | 1150  | 1200 | 50    | 126+461.5 | 126+509.5 | 1.5                | C1                  | 721  | 1.45 |
| 17       | 1200  | 1250 | 50    | 126+511 | 126+560.5 | 1.5                | C1                  | 743  | 1.45 |
| 18       | 1250  | 1300 | 50    | 126+562 | 126+610  | 1.5                | C1                  | 768  | 1.45 |
| 19       | 1300  | 1350 | 50    | 126+611.5 | 126+659.5 | 1.5                | C1                  | 798  | 1.45 |
| 20       | 1350  | 1400 | 50    | 126+661 | 126+710.5 | 1.5                | C1                  | 803  | 1.45 |
| 21       | 1400  | 1450 | 50    | 126+712 | 126+760  | 1.5                | C1                  | 791  | 1.45 |
| 22       | 1450  | 1500 | 50    | 126+761.5 | 126+810  | 1.5                | C1                  | 754  | 1.45 |
| 23       | 1500  | 1550 | 50    | 126+811 | 126+860  | 1.5                | C1                  | 716  | 1.45 |
| 24       | 1550  | 1600 | 50    | 126+861.5 | 126+910  | 1.8                | C1                  | 671  | 1.41 |
| 25       | 1600  | 1650 | 50    | 126+911 | 126+959.5 | 1.5                | C1                  | 631  | 1.45 |
| 26       | 1650  | 1700 | 50    | 126+960.75 | 127+009.5 | 1.3                | C1                  | 575  | 1.49 |
| 27       | 1700  | 1750 | 50    | 127+010.75 | 127+060.5 | 1.5                | C1                  | 558  | 1.45 |
| 28       | 1750  | 1800 | 50    | 127+062 | 127+109.75 | 1.5               | C1(F)               | 545  | 1.45 |
| 29       | 1800  | 1850 | 50    | 127+111 | 127+157.75 | 1.8                | C1(F)               | 520  | 1.41 |
| 30       | 1850  | 1900 | 50    | 127+160.75 | 127+210.25 | 3                  | C1                  | 479  | 1.34 |
| 31       | 1900  | 1950 | 50    | 127+211.75 | 127+260.5 | 1.5                | C1                  | 444  | 1.45 |
| Zone No. | Tunnel meter Length (m) | Chainages (Km) | Pull length | Actual Support | Max. overburden (m) | Support pressure (pi) (Mpa) |
|---------|------------------------|----------------|-------------|----------------|---------------------|---------------------------|
| 32      | 1950 2000 50           | 127+262 127+310| 1.5         | Cl             | 438                 | 1.45                      |
| 33      | 2000 2050 50           | 127+311.5 127+359.5| 1.5         | Cl             | 463                 | 1.45                      |
| 34      | 2050 2100 50           | 127+361 127+410.5| 1.5         | Cl             | 500                 | 1.45                      |
| 35      | 2100 2150 50           | 127+412 127+460| 1.5         | Cl             | 500                 | 1.45                      |
| 36      | 2150 2200 50           | 127+461.5 127+510.057| 1.8        | Cl             | 473                 | 1.41                      |
| 37      | 2200 2250 50           | 127+512 127+559.5| 1.9         | Cl             | 470                 | 1.40                      |
| 38      | 2250 2300 50           | 127+561 127+610.5| 1.5         | Cl             | 483                 | 1.45                      |
| 39      | 2300 2350 50           | 127+612 127+657| 3           | Cl             | 492                 | 1.34                      |

Table 5: Support Pressure Estimation in North Portal

| Zone No. | Tunnel meter Length (m) | Chainages (Km) Katra | Pull length | Actual Support | Max. overburden (m) | Support pressure (pi) (Mpa) |
|---------|------------------------|----------------------|-------------|----------------|---------------------|---------------------------|
| 1       | 0 50 50 50            | 132+738.8 132+690   | 4.5         | Cl             | 129                 | 1.30                      |
| 2       | 50 100 50             | 132+6888 132+639.5  | 4           | B              | 129                 | 0.71                      |
| 3       | 100 150 50            | 132+637 132+589.5   | 3.5         | Cl             | 129                 | 1.32                      |
| 4       | 150 200 50            | 132+587.5 132+540   | 3.5         | ClF            | 110                 | 1.32                      |
| 5       | 200 250 50            | 132+538.5 132+489   | 2.5         | ClF            | 52                  | 1.36                      |
| 6       | 250 300 50            | 132+488 132+436.1   | 3           | ClF            | 108                 | 1.34                      |
| 7       | 300 350 50            | 132+435.1 132+386.5 | 1.1         | ClF            | 92                  | 1.54                      |
| 8       | 350 400 50            | 132+385.5 132+336.3 | 1.45        | ClF            | 118                 | 1.46                      |
| 9       | 400 450 50            | 132+335.3 132+286.4 | 1.5         | ClF            | 162                 | 1.45                      |
| 10      | 450 500 50            | 132+285.1 132+235.9 | 1.25        | D              | 196                 | 1.80                      |
| 11      | 500 550 50            | 132+234.9 132+186.1 | 1.5         | ClF            | 218                 | 1.45                      |
| 12      | 550 600 50            | 132+184.6 132+136.6 | 1.5         | ClF            | 239.6               | 1.45                      |
| 13      | 600 650 50            | 132+135.1 132+087.1 | 1.5         | ClF            | 253.1               | 1.45                      |
| 14      | 650 700 50            | 132+085.6 132+036.1 | 1.5         | ClF            | 254.2               | 1.45                      |
| 15      | 700 750 50            | 132+034.6 131+985.6 | 2           | ClF            | 251.7               | 1.40                      |
| 16      | 750 800 50            | 131+984.1 131+934.6 | 1.5         | Cl             | 250                 | 1.45                      |
| 17      | 800 850 50            | 131+933.1 131+884.1 | 1.5         | Cl             | 243                 | 1.45                      |
| 18      | 850 900 50            | 131+882.6 131+833.1 | 1.5         | ClF            | 232.5               | 1.45                      |
| 19      | 900 950 50            | 131+831.6 131+785.1 | 1.5         | ClF            | 235                 | 1.45                      |

Table 6: Comparison chart of anticipated and actual deformation at important section
| S. No. | Chainage    | Max Displacement (mm) | Max. Tunnel Displacement Anticipated (mm) | Tunnel | Overburden |
|--------|-------------|-----------------------|------------------------------------------|--------|------------|
| 1      | TM:131764.497 | 26.6                  | 2.67                                     | North Portal | N/A        |
| 2      | TM:132340.182 | 28.5                  | 1.02                                     | North Portal | 118        |
| 3      | TM:132351.366 | 19.9                  | 0.42                                     | North Portal | 162        |
| 4      | TM:132368.000 | 40.2                  | 0.42                                     | North Portal | 118        |
| 5      | TM:132378.000 | 14.3                  | 0.42                                     | North Portal | 118        |
| 6      | TM:132395.085 | 80.2                  | 0.42                                     | North Portal | 92         |
| 7      | TM:132409.300 | 25.3                  | 0.42                                     | North Portal | 92         |
| 8      | TM:132472.720 | 16.04                 | 0.64                                     | North Portal | 108        |
| 1      | TM:126788   | 20                    | 21.48                                   | South Portal | 754        |
| 2      | TM:126800   | 21                    | 21.48                                   | South Portal | 754        |
| 3      | TM:126811   | 58                    | 17.98                                   | South Portal | 716        |
| 4      | TM:126817   | 68                    | 17.98                                   | South Portal | 716        |
| 5      | TM:126822   | 129                   | 17.98                                   | South Portal | 716        |
| 6      | TM:126829   | 123                   | 17.98                                   | South Portal | 716        |
| 7      | TM:126836   | 147                   | 17.98                                   | South Portal | 716        |
| 8      | TM:126846   | 119                   | 17.98                                   | South Portal | 716        |
| 9      | TM:126860   | 123                   | 17.98                                   | South Portal | 716        |
| 10     | TM:126871   | 110                   | 18.60                                   | South Portal | 671        |
| 11     | TM:126878   | 83                    | 18.60                                   | South Portal | 671        |
| 12     | TM:126886   | 106                   | 18.60                                   | South Portal | 671        |
| 13     | TM:126896   | 85                    | 18.60                                   | South Portal | 671        |
| 14     | TM:126907   | 52                    | 18.60                                   | South Portal | 671        |
| 15     | TM:126920   | 139                   | 16.30                                   | South Portal | 631        |
| 16     | TM:126933   | 218                   | 16.30                                   | South Portal | 631        |
| 17     | TM:126945   | 210                   | 16.30                                   | South Portal | 631        |
| 18     | TM:126957   | 257                   | 16.30                                   | South Portal | 631        |
| 19     | TM:126976   | 44                    | 13.48                                   | South Portal | 575        |
| 20     | TM:126990   | 24                    | 13.48                                   | South Portal | 575        |
| 21     | TM:127004   | 71                    | 13.48                                   | South Portal | 575        |
| 22     | TM:127261   | 38                    | 6.70                                    | South Portal | 444        |
| S. No. | Chainage    | Max Displacement (mm) | Max. Tunnel Displacement Anticipated (mm) | Tunnel      | Overburden |
|-------|-------------|-----------------------|------------------------------------------|-------------|------------|
| 23    | TM:127301   | 39                    | 6.78                                     | South Portal| 438        |
| 24    | TM:127387   | 26                    | 8.41                                     | South Portal| 500        |
| 25    | TM:127472   | 26                    | 7.86                                     | South Portal| 473        |
| 26    | TM:127487   | 63                    | 7.86                                     | South Portal| 473        |
| 27    | TM:127502   | 33                    | 7.86                                     | South Portal| 473        |
| 28    | TM:127515   | 48                    | 7.80                                     | South Portal| 470        |

Fig. 4: Plastic zone and tunnel diameter vs rockmass strength and in-situ stress in South Portal
Fig. 5: Plastic zone and tunnel diameter vs rockmass strength and in-situ stress in North Portal

Fig. 6: Tunnel closure and tunnel diameter vs rockmass strength and in-situ stress in South Portal

Fig. 7: Tunnel closure and tunnel diameter vs rockmass strength and in-situ stress in North Portal
Fig. 8: Displacement of monitoring targets due to deformation at different chainages at South Portal of T74R

Fig. 9: Displacement of monitoring targets due to deformation at different chainages at North Portal of T74R

Fig. 10: Comparison of actual and anticipated displacement curves of South & North Portal of T74 R
4.0 Conclusion

Tunnel T74R is located in one of the most seismically active areas of the Jammu & Kashmir Himalaya, therefore deformation of the tunnel support system was unavoidable. A poor groundmass near the principal thrust is prone to deformation. Our study compares the predicted and actual deformation of the support system based on ground conditions. The actual deformation monitoring data of T74R is found to be considerably different from the calculated deformation based on formulas, with the former revealing more deformation than expected for the installed support system in encountered groundmass. The discrepancy was largely due to not considering elements like horizontal/vertical stress ratio locally, shear strength characteristics of discontinuities in rockmass, and blasting effect. Besides technical concerns, various execution aspects also play a role in this variation. Also, the value of 3D monitoring resides in determining the real behaviour of the groundmass, as opposed to calculating it theoretically. Determination of shear strength parameters of joint in-fill material and joint data is required, as is the use of 3D monitoring data in final designs.

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