Evaluation of a Preliminary Support Design of Railway Tunnel Adit in Inner Lesser Himalaya India: An Empirical Analysis

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Abstract. This article addresses the excavation method and support design for the adit tunnel in the Rudraprayag District, Lesser Himalayas of India, using Rock Mass Rating (RMR), Tunneling Quality Index (Q), and New Austrian Tunneling Method (NATM). Based on ONORM B 2203 correlations with RMR and Q systems, the New Austrian Tunneling Method rock structure classes were developed. Because the geology was constantly changing, NATM concepts were applied. The RMR-based rock mass estimates were overestimated, but the qualitative investigation was correct. The NATM method is more appropriate for a Garhwal Himalayan rock with varying rock mass uncertainty. The present adit research reveals several outstanding questions about rock mass quality, tunnel behavior during construction, and use. The analysis results might be used to build new tunnels in comparable terrain in other parts of the world.

Keywords: NATM; RMR; Tunneling Quality Index (Q); Excavation Method; Support Analysis; Lesser Himalaya

1. Introduction
In recent years, several highways and railway tunnels providing quick and efficient routes over mountainous terrain have been created in Uttarakhand Himalaya. The railway track between Rishikesh and Karnaprayag is being built in Uttarakhand's Garhwal region, which is prone to landslides and earthquakes. According to the Seismic Zone Map of India SEISAT [1], this location falls within zone V. This railway track is 125 kilometers long, and the entire tunneling distance will be 105.47 kilometers. The 9.5-kilometer-long tunnel-13 will travel through Rudraprayag and will be constructed using the 672-meter-long adit (Figure 1). The geological and geotechnical parameters of the adit, as well as the construction challenges, are examined in this section. Following extensive analysis, a suitable excavation process and support system were developed. It is horseshoe-shaped and measures 8.7 m width by 7.05 m height, when excavated of overall 672 m length of the adit tunnel, 426.5 m was driven utilizing the drill and blast technique using the Sandvik DT922i, Jumbo machine. The overburden
thickness begins at 28 meters at the portal and reaches a maximum of 443 meters at the adit-tunnel's junction.

The techniques for classifying rock masses are very useful for selecting excavation methods and supporting design systems. Numerous approaches for classifying rock masses are employed to generate a picture of the rock mass composition and properties to offer early estimates of support needs [2]. The adit tunnel's rock mass was classified using an internationally known rock mass classification method, specifically the Q [3], RMR [4], and the NATM, based on ONORM B 2203 [5].

Figure 1. Location map of the study area showing the location of the adit

2. Geology of the adit site
The Himalayas are a textbook example of an orogenic system that was formed as a result of the continent and continent collision [6-7]. The basic layout of the Himalayan chain is about E-W. The orogenic belt has captured the interest of geoscientists worldwide because it denotes the southern limit of the Earth's biggest active crustal deformation zone, which resulted from the 55-million-year-old collision of India and Asia. According to [8-10], and others, it is separated longitudinally into five main geological divisions: Sub-Himalayan Sequence (SH), Lesser Himalayan Sequence (LH), Greater Himalayan Sequence Complex (GH), Tethyan Himalayan Sequence (TH), and Indus-Tsangpo Melange Zone (ITSZ).

Numerous scientists, including [11] and most recently [8], have made substantial contributions to the existing structural and stratigraphic understanding of the Garhwal Himalaya, which includes the study region. The region is mostly defined by the inner lower Himalayas. The North Almora Thrust (NAT),
which marks the northern edge of Almora klippe, it acts as a barrier between the Outer lesser Himalaya and Inner Lesser Himalayas. It distinguishes the phyllites of Chandpur from the quartzites of the Garhwal Group. The region is geologically composed of quartzite with subordinate purple phyllite and basic metavolcanics from Berinag formation (Figure 2).

The structure is a key tectonic factor in the Himalayan orogeny. The Main Boundary Thrust (MBT) and the Main Central Thrust (MCT) in (Figure 3) define the Lesser Himalayan, which is influenced by a series of thrusts, some of which are closely folded. The Tons Thrust, Ramgarh Thrust, and Berinag Thrust are three of the region's most significant faults. Between the North Almora push and the Alaknanda fault lies the research region. The NAT is exposed in the Project area as a multiple fault zone with five major and several minor faults.

3. Engineering Geological Condition
This area is always full of surprises when it comes to underground construction because the geology changes so often [14]. Engineering geological parameters have been used to look at adit and figure out how good the rock is, how long it will take to stand up, and how much support it will need. [15] and his correlation were utilized to determine the RQD of the rock mass units in question by using a joint volumetric count. Ranges from 25% to 60%. III, IV, and V are the rock mass classes found from chainage 25.2 to 424 meters of the adit-7. At the portal, up to chainage 21.20 meters, there is an "adverse geological occurrence" (AGO) due to river-borne material (RBM). In the excavated face, there are three sets of joints that go from vertical to sub-vertical and horizontal to sub-horizontal. The detail of engineering geological property along the alignment is given in (Table 1).

![Figure 2. Study area geological map [12].](image)
Table 1. Anticipated engineering geological property along the adit alignment

| Chainage (m) | 0.0 - 100 | 100 - 500 | 500 - 672 |
|-------------|-----------|-----------|-----------|
| **Geology** |           |           |           |
| Structural Domain | Inner Lesser Himalaya |         |           |
| Group | Garhwal Group |         |           |
| Formation | Berinag Formation |         |           |
| Lithotype | Quartzite | Quartzite | Quartzite |
| **Discontinuity Properties** |           |           |           |
| Foliation | Persistence (m) | 5-10m | 5-10m | 5-10m |
| Roughness | Rough | Rough | Rough |
| Filling | Crushed rock | Crushed rock | None |
| Aperture (mm) | 5-100m | 5-100mm | Tight |
| Spacing (mm) | 5-200cm | 6-200cm | 15-80cm |
| Foliation | Persistence (m) | 0.5-1.50m | 0.5-1.50m | 0.5-1.50 m |
| Roughness | Rough | Rough | Rough |
| Filling | Crushed rock | Crushed rock | Crushed rock |
| Aperture (mm) | Tight | Tight | Tight |
| Spacing (mm) | 5-80cm | 5-80cm | 5-80cm |
| **Rock Mass Properties** |           |           |           |
| Rockmass strength | Strong to medi-strong | Strong - very strong | St. - V. strong |
| Weathering | Fresh - Slightly W. | Fresh | Fresh |
| Anticipated Q-values | 0.38 - 5.4 | 3.3 - 3.9 | 3.3 - 5 |
| Anticipated rock class | V | IV | III |
| Anticipated G.W. condition | Dry - wet dry | dripping |
| Anticipated wedge failure | Failure of from crown & wall | wedge failure from the crown |
| Anticipated squeezing Co. | There will be no squeezing | mid squeezing |
| Rock cover (m) | 28 m | 216 m | 443m |
4. Rock mass rating characterization system

[16] Developed the method for determining the rock mass rating. Determined from 49 case history based on his experiences in the shallow tunnel. Subsequently, classification has undergone several significant changes. [17] Regarded the RMR system as a very efficient method for examining rock mass conditions and establishing appropriate support, and enabling effective communication on engineering projects. The rock mass rating is computed by [18] from the total of ratings (weighting) of six input parameters: 0 to 15 for UCS, 3 to 20 for RQD, 5 to 20 for joint spacing, 0 to 30 for joint conditions, and 0 to 15 for groundwater conditions. The rating values range from 0 to 100, and the aggregate of the individual ratings for each parameter is used. Adjustments for discontinuity orientation in excavation are performed by adjusting the rating from 0 to -12. The RMR method was used to classify the rock mass quality over the entire excavated length of 426.5m adit-7. The entire excavated area was classified into six zones i.e. chainages 00.00m (at the entry portal up to 21m), Chainage 25.20m, chainages 41.9m, chainages 218.80m, chainages 401m, chainages 426.5m near the adit-tunnel junction (Table 2). The entry portal shows very poor rock mass due to adverse geological occurrence (AGO) it is a river-borne material. The RMR varies from 39 to 69 and rock description in different chainages is shown in (Table 2).

| Parameters          | Chainage 00.00m | Chainage 25.20m | Chainage 41.9m | Chainage 218.80m | Chainage 401m | Chainage 426.5m |
|---------------------|-----------------|-----------------|----------------|------------------|---------------|----------------|
| UCS                 | AGO             | 7               | 12             | 12               | 7             | 12             |
| RQD                 | AGO             | 4               | 8              | 13               | 8             | 13             |
| Discontinuity spacing | AGO             | 10              | 10             | 15               | 10            | 10             |
| Discontinuity condition | AGO             | 8               | 14             | 19               | 20            | 19             |
| Ground-water        | AGO             | 15              | 15             | 15               | 4             | 4              |
| Orientation of joint | AGO             | -5              | -5             | -5               | -5            | -2             |
| Rating              | -               | 39              | 54             | 69               | 44            | 56             |
| Class number        | -               | I               | III            | II               | III           | III            |
| Description         | -               | Poor rock       | Fair rock      | Good rock        | Fair rock     | Fair rock      |

5. Tunneling quality index (Q) system

At the Norwegian Geotechnical Institute (NGI), [3] created the Q method of rock mass categorization for assessing tunnel quality of rock. Following a review of 200 tunnel case histories, the Q-system was suggested. Geological mapping in subterranean excavations may be used to calculate Q – values. It may be required to split the subsurface excavation into many pieces during mapping so that the fluctuation of Q-value within each segment is moderate. It is based on a numerical evaluation of the quality of the rock mass utilising six separate parameters and when the 6-parameters are combined, they define the three key elements that explain the stability in subsurface openings: block size, active stress factor, and inter-block shear strength. The block size is a ratio of the rock quality index (RQD) and multiple joints (Jn), while the shear strength of joints is defined by the ratio of joint roughness (Jr) to joint alteration (Ja). By dividing the joint water condition (Jw) by the stress reduction factor, the stress factor was established (SRF). At the adit-7 location, all characteristics were employed for various rock mass groups. Individual ratings were assigned using the tabular instructions, and final ratings were calculated
by multiplying the three quotients together. The field study results were used to provide stress reduction factor (SRF) ratings, and the ground condition was appraised using empirical techniques.

\[
Q = \frac{RQD}{J_n} \times \frac{J_r}{J_a} \times \frac{J_w}{SRF}
\]

Q-Values were calculated during the excavation along the adit chainages (Table 3). The Q-Values at entry portal up to chainage 25m varies from AGO to 0.62 showing very poor rock mass condition, visual observations describe the rock class V, while at chainage 41.9m and chainage 401m show poor rock. The rest of the entire chainage Q-values vary from 4.1 to 5 it corresponds to fair rock mass condition. In accordance with RMR and the Q-system, an excavation methodology and support system for adit has been proposed (Table 4). In (Figure 4), the cross-section of 672 m with horseshoe shape and dimensions of the excavated area are 8.7 m wide by 7.05 m high.

| S. No. | Chainage (in m) | Q-Values | Rock Class | Tunneling quality (Q) |
|-------|----------------|----------|------------|-----------------------|
| 1     | 00.00          | A.G.O (RBM) | V         | Very poor            |
| 2     | 3.00           | A.G.O (RBM) | V         | Very poor            |
| 3     | 3.4            | A.G.O (RBM) | V         | Very poor            |
| 4     | 5.3            | A.G.O (RBM) | V         | Very poor            |
| 5     | 15.60          | A.G.O (RBM) | V         | Very poor            |
| 6     | 21.20          | A.G.O (RBM) | V         | Very poor            |
| 7     | 25.2           | 0.62      | V         | Very poor            |
| 8     | 41.9           | 1.3       | IV        | Poor                 |
| 9     | 218.80         | 5.00      | III       | Fair                 |
| 10    | 230            | 4.58      | III       | Fair                 |
| 11    | 238.6          | 4.58      | III       | Fair                 |
| 12    | 291.60         | 4.68      | III       | Fair                 |
| 13    | 401.21         | 2.83      | IV        | Poor                 |
| 14    | 404.10         | 4.1       | III       | Fair                 |
| 15    | 406.60         | 4.1       | III       | Fair                 |
| 16    | 409.30         | 4.37      | III       | Fair                 |
| 17    | 412.30         | 4.37      | III       | Fair                 |
| 18    | 415.30         | 4.37      | III       | Fair                 |
| 19    | 416.30         | 4.37      | III       | Fair                 |
| 20    | 421.4          | 4.37      | III       | Fair                 |
| 21    | 424            | 4.37      | III       | Fair                 |
| 22    | 426.5          | 4.37      | III       | Fair                 |

6. Excavation methodology and support system
Tunnel construction in Himalayan terrain is usually problematic due to the shifting geology, groundwater conditions, the rock mass characteristics, as well as in-situ stress conditions. According to geological and geotechnical findings, an adit tunnel was driven through a heterogeneous rock mass body that is jointed and of very poor, poor, and fair quality. Based on the above knowledge and experience in similar conditions in Himalayan rock, five basic support systems were suggested: lattice girders, rock bolts, steel ribs, shotcrete, and wire mesh. The support structure was designed by the New Austrian Tunneling Method (NATOM). As part of the NATM strategy, a qualitative ground classification system must be taken into account [4]. It is a "Build as you go" attitude with the following limitations. The NATM Drill & Blast technique has the benefit of allowing for excavation flexibility without altering the excavation operation [19].

"Not too stiff, Nor too flexible
Not too early, Nor too late"
The adit tunnel excavation was carried out in the following sequence of activities:

- Drilling for underground excavation with Sandvic DT922i jumbos utilizing a suitable blast pattern to keep the excavation profile consistent with the support system design drawings.
- Scaling down/mucking out the spoils.
- Application of the first layer of shotcrete for the present blast and the second layer of shotcrete based on the strata's nature.
- Rock bolts were installed according to the rock profile.
- Drilling for the next blast (advancement)

The excavation method and support system for very poor, poor, and fair rock mass categories of the adit tunnel is given in (Table 4) and Figure 4, and a summary is given below. Before the excavation, forepolling was done in the face for portal and rock class-V excavation.

- Shotcrete- fiber shotcrete thickness of 300 mm wet and dry cast
- Wiremesh- welded wire mesh in crow 150 x150 x 6mm
- Rock bolts- ø25mm, 4m long grouted rock bolt staggered 1500 c/c applied
- Steel rib-ISHB 150 where required.
- Forepolling- forepolling required length=6m, ø32mm
- Lattice girder- 32/25/10 mm accordingly – girders were used to secure the roof and side walls in every quality class of the rock mass.

**Table 4. Excavation and support quantities/m for a different type of rock class**

| Class-V (0.1 ≤ Q< 1) | **Portal** | **Round Length** | 0.75m³ |
|-----------------------|------------|------------------|--------|
|                       | **Excavation Volume Up to Pay Line (B-Line)** | 59.83m³ |
|                       | **Minimum Excavation Volume** | 56.84m³ |
|                       | **Shotcrete** | M 35 / A 10, Thick=300mm | 3.93m³ |
|                       | **Wiremesh** | 150 x150 x 6mm | 0.019 MT |
|                       | **Rock Bolts** | Fy 200KN, 4m | 69 R M |
|                       | **Steel Rib** | ISHB 150 (30.6kN/m) or equivalent section | 0.576 MT |
|                       | **Drainage Holes** | Ø75mm, Length=5m | - |
|                       | **Forepolling** | Length=6m, Ø32mm | 84 RM |

| Class-IV (1 ≤ Q < 4) | **Top Heading** | **Round Length** | 1.0m |
|-----------------------|------------------|------------------|------|
|                       | **Excavation Volume Up to Pay Line (B-Line)** | 39.73m³ |
|                       | **Minimum Excavation Volume** | 37.31m³ |
|                       | **Sfrs/Fibre Shotcrete** | ds=300mm | 2.23m³ |
|                       | **Wiremesh** | 150 x150 x 6mm | 0.019MT |
|                       | **Sn Bolts** | Fy 200KN, 4m | 48 RM |
|                       | **Steel Rib** | ISHB 150 (30.6kN/m) | 0.447 MT |
|                       | **Drainage Holes** | Ø 45mm, Length=5m | - |
|                       | **Forepolling** | Length=6m, Ø32mm | 84RM |
|                       | **Benching** | **Round Length** | 2.0m³ |
|                       | **Excavation Volume Up to Pay Line (B-Line)** | 21.12m³ |
|                       | **Minimum Excavation Volume** | 20.52m³ |
|                       | **Sfrs/Fibre Shotcrete** | ds=300mm | 0.9m³ |
|                       | **Sn Bolts** | Fy 200KN, 4m | 16 RM |
|                       | **Steel Rib** | ISHB 150 | 0.13 MT |

| Class-IV | **Full Face** | **Round Length** | 1.5m³ |
|-----------|---------------|------------------|------|
|           | **Excavation Volume Up to Pay Line (B-Line)** | 57.83m³ |
|           | **Minimum Excavation Volume** | 54.89m³ |
| Description                  | Specifications               | Quantity/Size  |
|------------------------------|------------------------------|----------------|
| Sfrs / Fibre Shotcrete       | M35 / A10, ds=150mm          | 1.78m³         |
| Lattice Girder               | 32/25/10                     | 0.285 MT       |
| Rock Bolts                   | Fy 200KN, 4m                 | 34.68 RM       |
| Drainage Holes               | Ø 45mm, Length=5m            | -              |
| Class-III (4 ≤ Q < 10)       |                              |                |
| Round Length                 |                              | 2.0m³          |
| Excavation Volume Up to Pay Line (B-Line) |                  | 56.84m³        |
| Minimum Excavation Volume    |                              | 53.93m³        |
| Sfrs / Fibre Shotcrete       | ds=100mm                     | 1.90m³         |
| Wiremesh                     | 150 x150 x 6mm               | 0.019 MT       |
| Rock Bolts                   | Fy 200KN, 4m                 | 22 RM          |
| Steel Rib                    | ISHB 150 (30.6k9/m) or equivalent section | 0.576 MT       |
| Drainage Holes               | Ø 45mm, Length=5m            | -              |

**Diagram**

- **FULL FACE EXCAVATION**

- **FOREPOLING 6m, 32mm #3 SN/SD @ 5, 150mm C/C**
- **25mm, 4m LONG GROUTED ROCK BOLT STAGGERED 1500c/c**
- **FOR ARC AND FACE IMPROVEMENT PRE-GROUTING AS PER TS LOW PESSURE**
- **PAY LINE (B-LINE)**
- **MINIMUM EXCAVATION LINE**
- **SHOTCRETE ENCA. ISHB 150**
- **FOR M 300 THK SSF/FRS FIBER SHOTCRETE ENC. (ISHB 150)**
- **DRAIN 750x750mm**

- **Steel Rib**
- **ISHB 150**

- **Drainage Holes**
- **Ø 45mm, Length=5m**

- **Diagram a.**

- **Diagram b.**

- **Pay Line B**
- **Minimum Excavation Line**
- **Steel Rib ISHB 150**
- **50mm Deformation Tolerance**
- **Drain 750x750mm**
Figure 4. Support system for a. Adit tunnel portal. b. class-V. c. class-IV and d. class-III

7. Discussion and conclusions
A total of 426.5 meters of the 672-meter-long adit tunnel of the ongoing rail project between Rishikesh and Karanprayag has been driven. The adit tunnel's excavated diameter is 8.7 meters. The rock mass conditions varied throughout the tunnel alignment. Quartzite was discovered to contain a significant percentage of tectonically disturbed rocks of fair grade. The strata were medium-grained, jointed in places, and had small shear seams. There are three pairs of joints in the slightly to moderately worn quartzite. Crushed rock fills the joints, which are spaced anywhere from 5 to 80 cm apart. Due to difficult geological conditions, the NATM approach was used to suggest excavation sequences and support systems.

In different tunnel sections, various engineering properties resulted in varying rock mass quality evaluations. Furthermore, the quantitative quality rating based on the RMR and Q classification systems has varied. The key problems for the Lesser Himalayan rock were the method for identifying rock mass quality and the application of the examined classes. Is the difference due to various approaches or a distinct feature of the rock mass around the adit? The RMR and Q classification methods, both based on quantitative features of the rock mass, are used to classify the rock mass. A support system design was developed using NATM, a qualitative categorization approach.
According to RMR, the rock mass classes in the research region were IV, III, and II (poor rock, fair, and good rock categories). The grade of rock mass up to 21.2 m in the entrance portal (section 1) was classed as extremely bad rock-borne material (RBM). For quartzite rock of the whole rest alignment, the RMR ranged from 39 to 69. Jointed to fractured rock mass had the lowest value, whereas fresh rock mass had the highest. The support system was adjusted as a consequence of the constant assessment of rock mass quality, which indicated that actual geotechnical conditions were far better than predicted.

Empirical categorization techniques were also utilized in the tunnel design. The results showed that the rock mass estimation using RMR was overstated, while the qualitative assessment was accurate. For this sort of terrain and rock mass, the NATM approach, which is more adaptable, may be employed, which may help to guarantee that a tunnel is completed on schedule.

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