Proceedings of 12th IOE Graduate Conference
Peer Reviewed
ISSN: 2350-8914 (Online), 2350-8906 (Print)
Year: 2022 Month: October Volume: 12

Planning and Construction Aspects of Hemja-Patichaur Road Tunnel, Western Nepal

Nikita Gurung [a], Krishna Kanta Panthi [b], Naba Raj Neupane [c]

[a, c] *Department of Civil Engineering, Pashchimanchal Campus, IOE, Tribhuvan University, Nepal*
[b] *Department of Geoscience and Petroleum, NTNU, Trondheim, Norway*
[a] grgyong2@gmail.com, [b] krishna.panthi@ntnu.no, [c] nneupane@gmail.com

Abstract
This paper evaluates and discusses the engineering geological conditions and tunnel construction method to be used on the proposed Hemja-Patichaur Road Tunnel (13.5 km). The proposed tunnel lies in the Lesser Himalayan region and the tunnel connects Kaski and Parbat districts of Gandaki Province. Development of this tunnel will substantially reduce both the travel distance and travel time and increase travel safety. Hence, the introduction of tunnel will lead to smooth transportation network. As the TBM excavates only circular geometry and the road tunnels are inverted-D shaped, the conventional drill and blast method was recommended. Also, the cost of the tunnel excavated by TBM is much higher than that of the drill and blast method. The cross-section of the tunnel is chosen on the basis of AADT and the length of the tunnel. Important aspects of tunnel installations like ventilation, lighting and safety equipment are discussed. Drillability condition was assessed to evaluate the deformability of the rocks. Quartzite, metasandstone and phyllite are the dominant rocks found along the tunnel alignment. The mapped RMR and Q values suggest the rock mass along the tunnel alignment will vary from good to poor class. Rock support was estimated using Q system of rock mass classification. Alignment of tunnel was fixed based on topographic condition and use of joint rosette. Quantities of the tunnel works were estimated based on tunnel size and rock mass class along the tunnel alignment. Preliminary cost estimates and construction time of the project were evaluated. Recommendations are given for further site investigations and detailed design and construction.

Keywords
Drill and blast, TBM, Q, RMR

1. Introduction

Nepal lies along the southern slopes of the Himalayan mountain ranges. Its territory extends roughly 800 km from east to west and 144 to 240 km from north to south. Within this very short width, the altitude of the country varies greatly from about 54 meters to 8848 meters above sea level, giving very rough terrain and steep mountainous topography [1].

Nepal contains some of the most rugged and difficult mountain terrain in the world. Being a landbound country, the primary mode of transport is road transport and hence priorities should be set for its development. Most of the pre-existing roads of Nepal don't satisfy the requirements of safety and efficient transport. Introduction of road tunnels will enhance the quality, efficiency and safety of the road network in Nepal. Road tunnels will also help to reduce traffic congestion in the city areas leading to a smooth transportation network. Development of a good road network means efficient transport, low construction cost, high safety standards, short route and preservation of the surrounding environment [2]

Construction of tunnels is governed by the ground and therefore site investigations are important to obtain ground characteristics and rock engineering parameters that have a direct influence on the selection of construction methodology and decisions regarding rock support. The only way to control the variations is to have a well-planned and organized pre-construction phase engineering geological investigations [3].

The use of underground space is not new in Nepal [1]. Underground caverns and tunnels have been used by the earlier generations for shelter, extraction of minerals, etc. At present, tunnelling works are done mainly for hydropower projects and to some extent for irrigation and drinking water supply. In the history of Nepal, the Churia tunnnel (Hetauda-Amlekhganj) of length 500 m is the oldest road tunnel used for transportation purpose. Likewise, the Naghdhunga tunnel of a length of 2688 m (and evacuation tunnel of 2557 m) is in progress and is scheduled for the year 2023. The proposed Hemja-Patichaur road tunnel (13.5 km) is a new plan to reduce the travel time and also the road length by almost 25 km and hence will be a lifeline for Pokhara for trade with Tibet, China.

2. The Hemja-Patichaur project

Figure 1: Study Area (Source: Provincial Government, Gandaki Province)

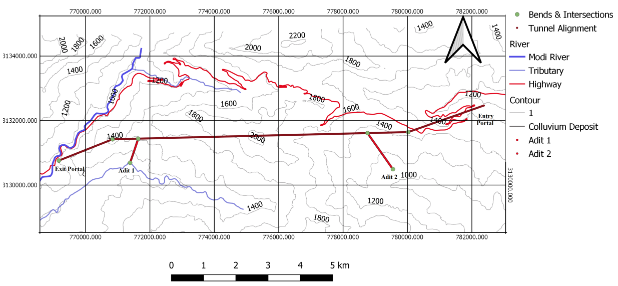

Figure 2: Topographical map of Hemja-Patichaur area along with tunnel alignment

The project area covers the western part of Kaski District and the eastern part of Parbat District of Gandaki Province. The project area lies in Lesser Himalayan Region and is surrounded by steep hills. The proposed entry portal at Hemja (Kaski District) lies at an altitude of 1164 m and the proposed exit portal lies at Dimuwa (Parbat District) at an altitude of 912 m (Fig. 1 and 2). Topographically, the project area lies in middle mountain zone. The lowest part of the area is 900 m amsl at Patichaur and highest part is 2050 m amsl which is in between Kande and Salyan.

As shown in topographic map (Fig. 2), the proposed entry portal is at Hemja whereas the proposed exit portal is at Dimuwa. A construction adit tunnel of 770 m length is introduced at a distance of 2.6 km from the exit portal (Dimuwa side) and a second construction adit of length 1370 m is placed at a distance of 3.79 km from the entry portal (Hemja side) to ease the construction work using drill and blast tunneling. The Phyllite-Quartzite boundary, i.e. the geological boundary, which separates the Kusma and Kunchha Formation was found at a distance of 2.19 km from the Dimuwa side. Active fault was found only at Thamarjung area which indicates that the proposed tunnel alignment passes favorably with respect to tunnel stability condition and rock support optimization. However, highly sheared zones will be met at some locations which should be taken care of during tunnel excavation.

3. Geology of the project area

The project area lies in the Lesser Himalayan zone. It is bounded to the north by the Main Central Thrust (MCT) and to the south by the Main Boundary Thrust (MBT). The zone mainly has unfossiliferous sedimentary and metasedimentary rocks such as slate, phyllite, schist, quartzite, limestone and dolomite. There are also some granitic intrusions in this zone [4]. The project area mainly comprises rocks like quartzite, metasandstone and weathered phyllite. The sheared zones and faults are frequently encountered in the area. The structure of rock mass is influenced by its foliation, faulting and presence of joints or weakness zones. Orientation (i.e. strike and dip) of the foliation plane, joints and faults were measured by field mapping carried out during this study.

Among the 36 mapped locations, an active fault was observed at Location 3 (28°16’14.28”N and 83°45’7.14”E) in the Thamarjung area. If a tunnel is crossed by active fault, the tunnel might be damaged by the sudden movement of the fault. The degree of weathering is in general very intensive which decreases the self-supporting capacity of the rock mass. Hence, weakness and fault zones should be addressed properly during tunnel excavation so that sudden tunnel collapses are avoided. An intercalation of Metasandstone and Phyllite was observed at Location 28 (28°15.639'N and 083°52.573'E) at an altitude of 898 m. This type of intercalation may lead to the deformation of rock mass and may result in severe stability problem during construction.

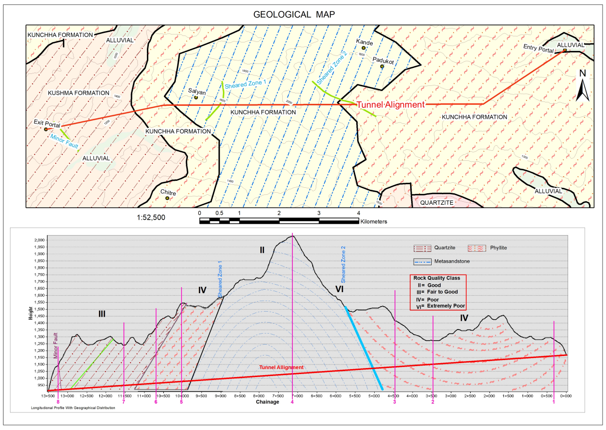

Figure 3: Longitudinal profile along with tunnel alignment

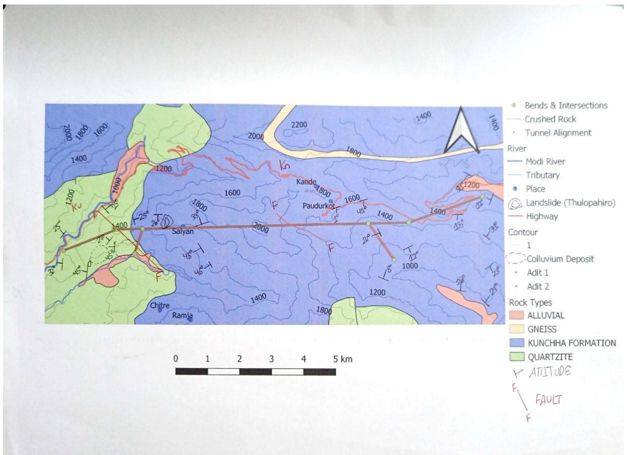

Figure 4: Engineering geological map along with tunnel alignment

4. Tunnel Design

4.1 Tunnel Alignment

Plotting of joint rosette is one of the main tools to plan the orientation of tunnels. For a shallow seated tunnel, the bisector of the bigger angle of the joint rosette is the suitable alignment. In the case of high rock stress conditions, it would be necessary to consider the orientation according to the orientation of the major principal stress as well. From the joint rosette, it can be seen that the line of intersection of the two major joint sets is almost along the East-West direction which matches the direction of the proposed tunnel alignment.

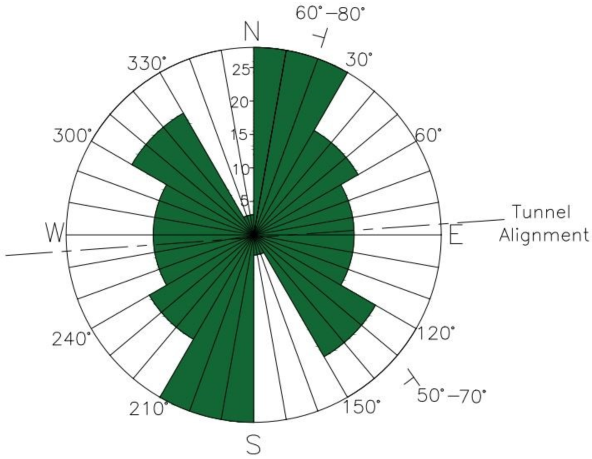

Figure 5: Engineering geological map along with tunnel alignment

4.2 Selection of Excavation Method

At present, both the Tunnel Boring Machine (TBM) and the conventional drill and blast methods are widely used. Selecting the appropriate choice of the excavation method is crucial in hard rock underground projects. Selecting the most appropriate excavation method is not simple as it depends on several parameters and rock mass quality conditions [4]. The construction process varies with the varying ground conditions i.e. each tunnel project is unique. Since the rock tunnel is a structure that utilizes the support function of the ground, it must be designed considering the geographical conditions[5].

The drill and blast method provides greater flexibility and, as a result, consequently better chances to deal with unforeseen conditions. Both methods are affected by the ground water, but TBM is more constrained than the drill and blast system if pre-grouting is required. The drill and blast method has less variance in tunnelling speed when excavating in favourable versus unfavourable conditions than the TBM approach. Massive rock is not favourable for fast penetration in TBM, but it is advantageous for drill and blast because of the lack of tunnel support needs.

4.3 Tunnel cross-section

Traffic capacity is the ability of the roadway to accommodate traffic volume. The capacity is based on a number of current traffic conditions on the road. The capacity controls design elements including the type of highway, the number of required lanes, the width of the lane, intersection geometry, etc.

The AADT recorded at Kusma by the Department of Roads from the year 2011-2021 was taken as reference for the cross-section optimization. The values of AADT of each year were increased by 20 percent considering the increment in traffic volume in future. Data were extrapolated using FORECAST command in Excel for a design period of 55 years and the value of AADT was found to be 10000. The tunnel cross-section according to Fig. 6 will thus be T9.5 which will give a construction width of a tunnel of 10 m.

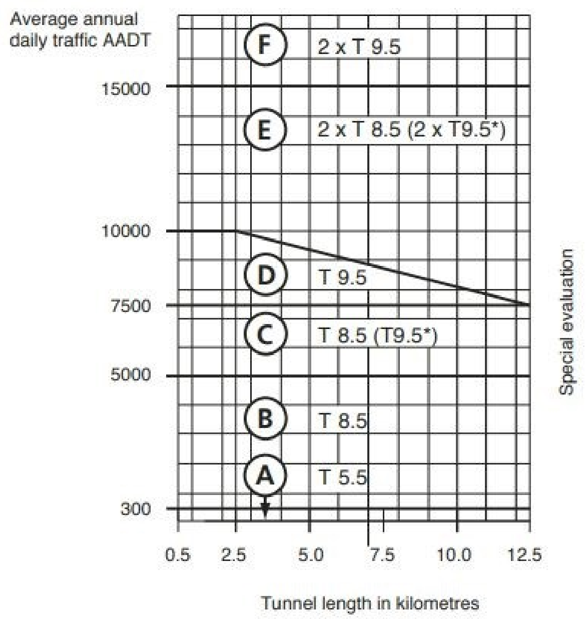

Figure 6: Tunnel categories (Source: Norwegian Road Tunnel manual)

5. Methodology

5.1 Preliminary study

Desk study is the preliminary stage of the research. Preliminary information was obtained by reviewing the geological and topographical maps, use of aerial photos and literature review consisting of review on types of tunnel construction methods and review on rock mass classification systems. After that field mapping started which lasted for 5 days. The field mapping was conducted at 36 various locations (Table 1). RMR and Q-values were determined in order to assess the quality of rock mass and to estimate need for tunnel rock support. Various computer software like QGIS, Autocad were used for the analysis part and joint rosette was drawn manually to check the feasibility of the proposed tunnel alignment. Topographical and engineering geological maps were drawn using QGIS.

5.2 Data collection

The attitude of the geological structures i.e. strike, dip direction and dip amount was measured using a Brunton compass. Global Positioning System (GPS) was used to know the altitude, latitude and longitude of various project locations. Surface field mapping was done to calculate the RMR and Q-values to determine the quality of rock mass. Uniaxial Compressive Strength (UCS) was calculated with the help of a Geostone hammer. A tape was used to measure the spacing and opening of the discontinuities. Physical properties were examined to know the type of rock and its name. An acid test was carried out for the existence of carbonaceous rocks in the area. An engineering geological map was also developed by collecting geological hazard parameters.

5.3 Prediction of rock support

Barton et al (1974) proposed a Tunnelling Quality Index (Q) whose numerical value varies on a logarithmic scale from 0.001 to a maximum of 1000 and is defined by:

$$Q = (RQD/Jn) * (Jr/Ja) * (Jw/SRF)$$

where, RQD is the Rock Quality Designation
Jn is the joint set number
Jr is the joint roughness number
Ja is the joint alteration number
Jw is the joint water reduction factor
SRF is the stress reduction factor

During the reconnaissance survey of the proposed road tunnel, face mapping at several locations of the rock exposure was studied. A support system at different chainages is predicted based on the Q-chart (Fig. 7). Excavation Support Ratio (ESR) = 1 (for road tunnels) was used to estimate the support class and support type using Fig. 7. The estimated tunnel support requirements are presented in Table 1.

Table 1: Prediction of rock support

Location	Q-value	Reinforcement Categories
1	3.23	Systematic Bolting and unreinforced shotcrete 5-6 cm
2	1.7	Fibre reinforced shotcrete and bolting, 6-9 cm
3	0.83	Fibre reinforced shotcrete and bolting, 6-9 cm
4	5.14	Systematic Bolting and unreinforced shotcrete 5-6 cm
5	0.6	Fibre reinforced shotcrete and bolting, 9-12 cm
6	3.11	Fibre reinforced shotcrete and bolting, 6-9 cm
7	10.28	Systematic Bolting and unreinforced shotcrete 5-6 cm
8	0.02	Fibre reinforced shotcrete>15 cm+reinforced ribs of shotcrete and bolting
9	0.01	Cast Concrete Lining, CCA or Sfr+RRS+B
10	9.72	Systematic Bolting and unreinforced shotcrete 5-6 cm
11	9.17	Systematic Bolting and unreinforced shotcrete 5-6 cm
12	10.56	Systematic Bolting and unreinforced shotcrete 5-6 cm
13	5.21	Systematic Bolting and unreinforced shotcrete 5-6 cm
14	0.4	Fibre reinforced shotcrete and bolting, 9-12 cm
15	0.15	Fibre reinforced shotcrete and bolting, 12-15 cm
16	0.54	Fibre reinforced shotcrete and bolting, 9-12 cm
17	0.5	Fibre reinforced shotcrete and bolting, 9-12 cm
18	1.47	Fibre reinforced shotcrete and bolting, 9-12 cm
19	0.36	Fibre reinforced shotcrete and bolting, 12-15 cm
20	1.93	Fibre reinforced shotcrete and bolting, 6-9 cm
21	0.03	Fibre reinforced shotcrete>15 cm+reinforced ribs of shortcrete and bolting
22	3	Fibre reinforced shotcrete and bolting, 6-9 cm
23	10.56	Systematic Bolting and unreinforced shotcrete 5-6 cm
27	0.21	Fibre reinforced shotcrete and bolting, 12-15 cm
28	0.55	Fibre reinforced shotcrete and bolting, 9-12 cm
29	1.22	Fibre reinforced shotcrete and bolting, 9-12 cm
30	0.71	Fibre reinforced shotcrete and bolting, 9-12 cm
31	0.97	Fibre reinforced shotcrete and bolting, 9-12 cm
33	0.89	Fibre reinforced shotcrete and bolting, 9-12 cm
36	0.25	Fibre reinforced shotcrete and bolting, 12-15 cm

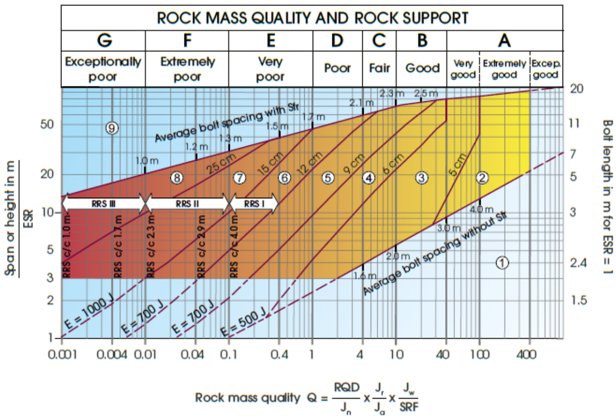

Figure 7: Q-system Support Chart (Barton et al., 1992)

6. Tunnel Installations

6.1 Lighting

Suitable lighting system like interior lighting, entrance lighting, emergency lighting and lighting outside the tunnel entrance should be provided in the tunnels to ensure easy functionality. Artificial lighting should be provided in the tunnels that have length of more than 300 m on straight sections and 150 m on curved sections. In the middle of the tunnel, there should be no less than 30 lux of illumination, 400-750 lux during the day near the portals, and no less than 30 lux at night.To provide smooth light adaptation, tunnel illumination should be changed gradually from the entrance to the inside as most accidents take place at the entrance.

6.2 Ventilation

The ventilation system is necessary to ensure the safe and comfortable driving inside tunnel. Vebtilation is necessary to maintain the oxygen level and there should be two-way ventilation in case of long tunnels. The generation of harmful gaseous material after blasting and the harmful substances emitted by the vehicles are removed through the ventilation system. .

Tunnels longer than 150 m should have provision of artificial ventilation system. The air inside the tunnels should not exceed speed of 6 m/s. Ventilation costs are influenced by factors like length, gradients, natural and mechanical ventilation caused by moving vehicles, type of system, and air quality restrictions.

6.3 Safety controls

There is a high chance of accidents in road tunnels because of the visibility conditions and quality of air inside the tunnel. Also, there is a high chance of fire due to confinement. Therefore, different safety systems like emergency telephone, push button alarm, fire detector, emergency information board, fire hydrant, guide board, smoke removal system, radio receiving panel, etc. should be provided in the tunnel to prevent the risks. The provision of functional and safety facilities in tunnels varies in different countries.

7. Time and Cost Estimate

Construction of tunnels is a cyclical process, hence cycle time for each activity (i.e. surveying, drilling, charging and blasting, mucking, ventilation and support) was calculated. Rock mass was classified into five classes according to the Q-values.

Total time for breakthrough = 5.2 years

Progress rate of excavation = 9.63 m per day

Table 2: Cost Estimate

Description of items		Unit
Adit length	2140	m
Total tunnel length	13500	m
Total bolts required	42681	nos
Total spiling dowels required	35972	nos
Total steel fibre shotcrete	56273.7	m³
Total steel arch ribs	3660	sets
Total concrete lining	2388.5	m³

Description of items	Unit rate	Cost (in NRs.)
Adit length	6235/m³	934,003,000
Tunnel length	6235/m³	5,892,075,000
Bolts	1123/m	47,931,098
Spiling dowels	970/m	34,892,840
Steel fibre shotcrete	54820/m³	3,084,924,980
Steel arch ribs	212495/MT	777,680,701
Concrete lining	15761/m³	37,645,791
Total Cost (in NRs.)		10,809,153,411

8. Conclusions

The choice between the drill and blast method and TBM is an often faced dilemma. When unfavourable conditions are encountered, the rate of advance will be greatly affected in a TBM-driven tunnel than in a drill and blast tunnelling. As the TBM excavates only circular geometry, the tunnel becomes prone to a higher vertical wall and we need to further increase the size of the tunnel which makes it even more expensive. The proposed road tunnel is inverted-D shape, so even if we excavate using TBM, the drill and blast has to be done later. Due to these limitations of TBM, the conventional drill and blast method was preferred.

The rose diagram (see figure 5) indicates that the orientation of the proposed road tunnel is favourable. Considering the future traffic density and the length of the tunnel, the cross-section T9.5 was chosen.

The quartzite, metasandstone and phyllite rocks were found along the proposed tunnel alignment. The value of the RMR and Q system was found to be good to poor. Support system was estimated using the Q-chart (Table 1).

The active fault was found only in the Thamarjung area and other minor fault zones were observed. Water leakage conditions should be checked frequently in those areas.

The total time for a breakthrough was found to be 5.2 years and the progress rate of excavation was 9.63 m per day which is quite feasible. However, proper mechanization might help to increase the excavation rate.

Very limited engineering geological data were available for this study. Due to this, the actual ground condition might vary from the predicted one. More laboratory tests and engineering geological investigation should be carried out in future to get better findings.

9. Recommendations

- Investigation done on rock mass classification and weakness zone along the tunnel alignment is inadequate.More investigations should be performed along with surface mapping.
- Detailed tunnel mapping should be performed and contain all the geological elements like major joints, fault zones, water leakage, rock types and areas with high-stress problems
- It is recommended to perform a better geological investigation so that the support applied is assessed effectively which will help to decide final support requirement.
- The critical sections should be analyzed in detail.
- Prediction of the rock mass quality is very important to determine the cost-effectiveness of the tunneling. The difference between the predicted ground conditions and actual site conditions should be checked.

Acknowledgments

The authors are thankful to NORHED-II project for providing the financial help for the project work.

References

[1] Krishna Panthi. *Analysis of Engineering Geological Uncertainties Related to Tunnelling in Himalayan Rock Mass Conditions*. PhD thesis, 02 2006.

[2] Krishna Panthi. *MSc thesis: Direct link between Hetauda and Kathmandu Evaluation of proposed road tunnels, Nepal*. PhD thesis, 06 1998.

[3] Krishna Panthi and Bjørn Nilsen. Comparison between predicted and actual rock mass conditions: a review based on tunnel projects in nepal himalaya. 05 2005.

[4] Javier Macias and Amund Bruland. D&b versus tbm: Review of the parameters for a right choice of the excavation method. 05 2014.

[5] JICA. *Guideline for Design of Road Tunnel*. 2018.