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# Engineering Geological Assessment for Tunnelling in Siwalik Region: A Case Study of Siddhababa Area in Western Nepal

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## Abstract

This paper focuses engineering geological assessment for tunnel construction within the Siwalik Zone, specifically at the Siddhababa section, connecting the Terai zone to the Lesser and Higher Himalayan zones. The study area spans from Bhutkhola (Doban) to Siddhababa Mandir (Butwal side) along the Siddhartha Highway. The main objective is to evaluate the feasibility of tunnel construction through the Siwalik rock mass in this region. The assessment involves a comprehensive classification of the rock mass along the proposed tunnel route using three key methods: Rock Mass Rating (RMR), Rock Mass Quality (Q), and Geological Strength Index (GSI). The predominant rock types in the study area were Sand Stone, Silt Stone, and Mud Stone. The study encompassed the preparation of an engineering geological map and a geological profile of the study area. The findings of this investigation are crucial for making informed decisions regarding the viability of constructing a tunnel in the Siwalik region.

## Keywords

Siwalik ,Siddhababa, RMR, Q system

## 1. Introduction

The Himalayan geology of Nepal, situated between the Indian Plate and the Eurasian Plate, presents a challenging landscape with altitudes ranging from 60 meters to the world's highest peak at 8848.86 meters above sea level[1]. This diverse topography is divided into distinct geological zones, including the Siwalik, Lesser Himalaya, Higher Himalaya, and Tibetan Tethys, each separated by dynamic tectonic boundaries such as the Main Frontal Thrust, Main Boundary Thrust, Main Central Thrust, and the South Tibetan Detachment System[2]. The Siwalik Zone, situated at the southern border of the Himalayan range, is a remarkable geological region characterized by parallel ridges and valleys formed over millennia due to the accumulation of sediments carried down by the evolving Himalayas. The sedimentary rocks in this region consist mainly of sand stone, mud stone, silt stone and conglomerates. Weak rock mass quality, significant weathering and fracturing, rock stresses, and groundwater are key geological and engineering factors contributing to stability challenges during tunnel construction in Nepal [3]. Recognizing the historical significance of tunneling in Nepal, from ancient shelters and mineral extraction to contemporary hydro power and infrastructure projects, underscores its vital role. However, the inherently fragile rock conditions in the Siwalik region demand thorough geological assessments and expert tunneling techniques.

## 2. Study Area

The study area as shown in Figure 1 is situated on the border region of Palpa district and Rupandehi district within the Lumbini province of Nepal. Located in the Sub-Himalayan zone, the study area spans from 27°44'43.52"N,83°28'31.76"E to 27°43'19.18"N,83°28'9.55"E, covering approximately 4.6 km.

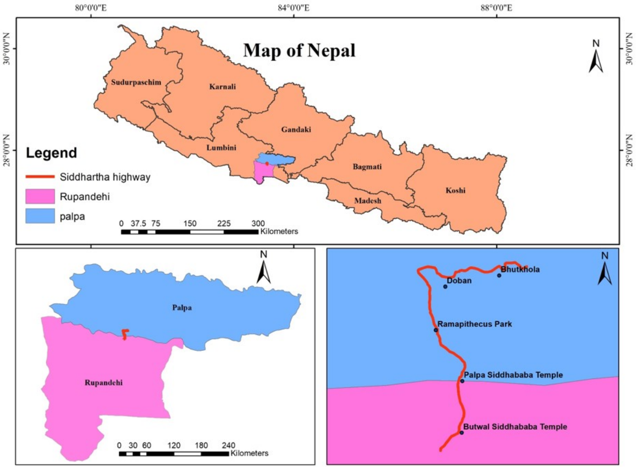

**Figure 1:** Study area in map of Nepal

The region encompasses the section between the "Welcome to Palpa" gate and Bhutkhola (Doban) along the Siddhartha Highway, passing by the Ramapithecus park.

## 3. Geology of the Study Area

The study area falls within the Siwalik Zone, situated at the southern foothills of the Himalayas and bounded by the Main Boundary Thrust (MBT) to the north and the Himalayan Frontal Thrust (HFT) to the south as shown in Figure 2. This geological region spans approximately 2,000 km from East India to West Pakistan and is characterized by distinctive parallel ridges and valleys, shaped through the gradual accumulation of sediments eroded from the ascending Himalayan range over millions of years. Research suggests an approximate age of 14 million to two million years for this geological domain[2]. The Siwalik Zone lies between the lesser

Himalayan zone to the north and the Gangetic plain to the south, with elevations ranging from 200 to about 1,000 meters above sea level[2]. It is divided into Lower, Middle, and Upper Siwalik units, predominantly composed of sedimentary materials including mud stone, sandstone, and conglomerate. These rocks are relatively youthful and structurally feeble, concealed beneath overthrust lesser Himalayan metamorphic rocks along the MBT. The presence of sandstone, shale, and conglomerate makes these formations delicate and susceptible to erosion, exacerbated by their positioning amidst active tectonic thrusts (MBT and HFT) and their inherently youthful sedimentary composition.

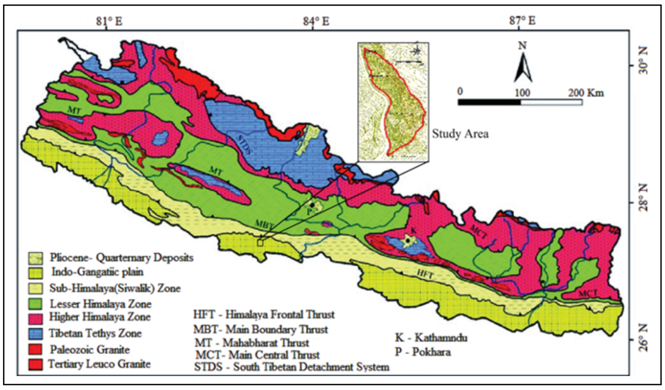

**Figure 2:** Geological map of Nepal showing the study area (after Amatya and Jnawali, 1994)

The Siddababa section, located within the Siwalik Zone, comprises recent sedimentary rocks like sandstone, silt stone and mud stone. Predominantly composed of sandstone with a specific gravity of 2.45 to 2.60, the rock mass is also influenced by varying degrees of weathering [4]. Notably, mud stone layers are interspersed in some regions, and the rock mass displays three discernible joint sets and bedding arrangements [4]. Siwalik rocks, known for their softness, are prone to rapid disintegration and erosion, leading to heightened vulnerability to slope-related hazards such as rockfall and landslides. The presence of alternating mud stone and sandstone beds results in diverse weathering patterns. Mudstone tends to erode and flow as a slurry upon exposure to water, while sandstone remains relatively resistant to moisture, often causing overhanging formations that contribute to rockfall and debris fall incidents [5].

## 4. Rock Mass Classification

Surface mapping is conducted across 32 distinct location along the Siddababa section. This assessment encompasses the determination of RMR, Q value, and GSI value for these locations, alongside the identification of prevalent rock types along the section. The primary rock type encountered is sandstone, while interbedded of mud stone and sandstone along with silt stone are observed in some segments.

### 4.1 Rock Mass Rating (RMR)

Z.T. Bieniawski introduced the Rock Mass Rating (RMR) system, also known as Geomechanics Classification, in 1973, refined through extensive case histories[6]. The method employs six field-measurable parameters: uniaxial compressive strength of intact rock, rock quality designation (RQD) indicating intact material percentage, discontinuity spacing, condition of discontinuities, groundwater influence, and orientation of discontinuities[6]. These values are combined to yield an overall RMR, guiding support selection for underground excavations.

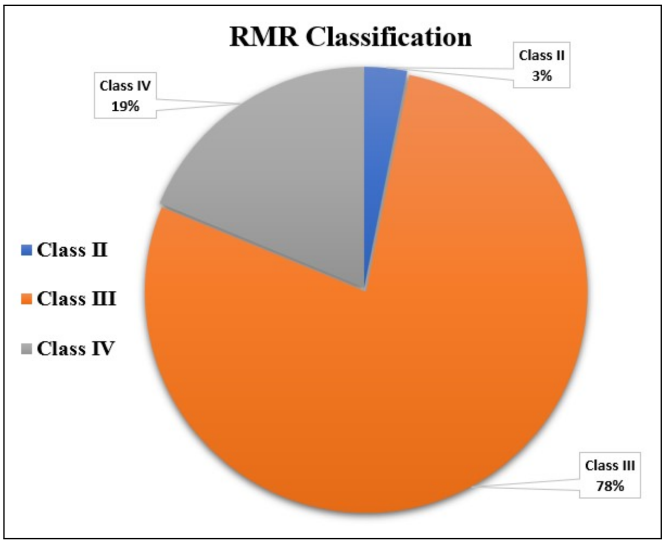

**Figure 3:** Rock mass classification using RMR

The Rock Mass Rating (RMR) assessments conducted across 32 locations revealed RMR values ranges from 33 to 61, indicating diverse rock mass qualities. Rock types are categorized into Class III (78%), Class IV (19%), and Class II (3%) based on RMR, as shown in Figure 3.

### 4.2 Rock mass quality (Q value)

The Rock Mass Quality (Q) System, developed by Barton et al. in 1974 at the Norwegian Geotechnical Institute, serves as a quantitative classification approach for rock masses, based on about 200 tunnel and cavern case histories[7]. It involves six parameters - RQD, joint set number (Jn), joint roughness number (Jr), joint alteration number (Ja), joint water inflow/pressure (Jw), and stress reduction factor (SRF) - combined into the Q index formula. The resulting Q value ranges from 0.01 to 1000 on a logarithmic scale[7].

The equation is:

$$Q = \frac{RQD}{Jn} \cdot \frac{Jr}{Ja} \cdot \frac{Jw}{SRF}$$

The Q system, used in conjunction with the RMR system, served for the classification of rock masses. The graphical representation in Figure 5 illustrates the variation in Q values at 32 different locations. These Q values ranged from 2.64 to 0.29, displaying fluctuations in nearby areas.

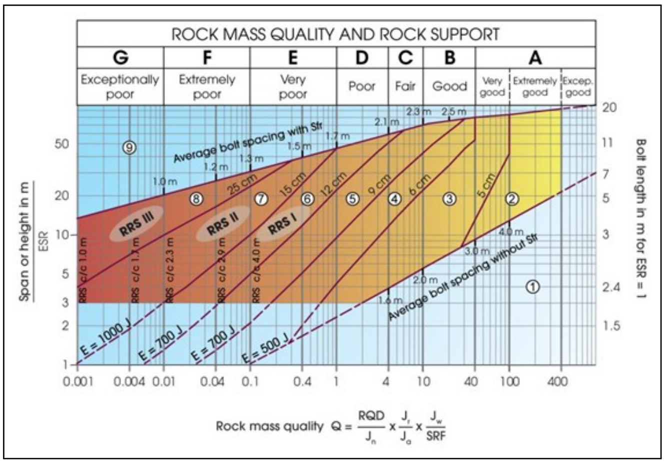

**Figure 4:** Permanent support recommendations based on Q-values and span/ESR[7]

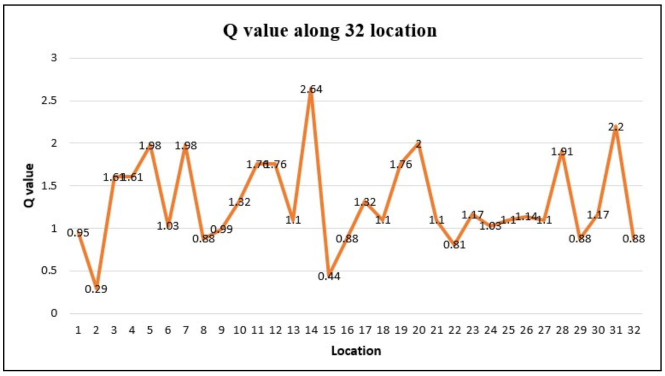

**Figure 5:** Graphical representation of Q value variation across 32 different location

The variation in Q value along the study section is due to rock types and various rock mass parameters such as RQD, joint set characteristics, joint alternation, joint roughness, joint water reduction factor and stress reduction factor. The distribution of rock mass classifications is depicted by the pie chart in Figure 6, revealing that the majority (72%) of the rock mass falls under the poor category (Class D). In contrast, only a small portion (3%) is classified as very poor (Class E1), while (25%) are categorized as very poor (Class E2).

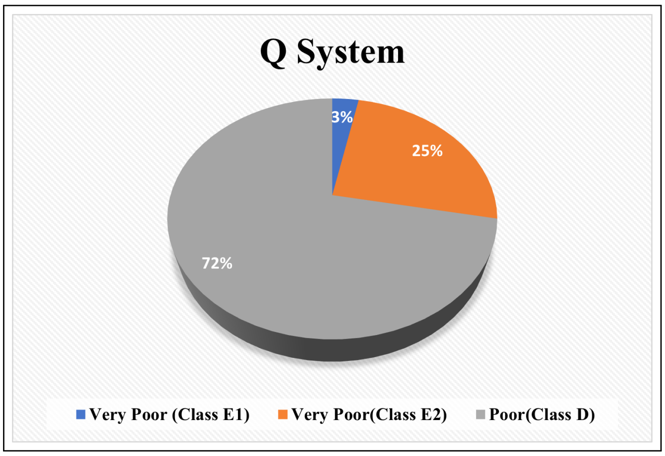

**Figure 6:** Rock mass classification using Q-system

### 4.3 Geological Strength Index (GSI)

Marinos and Hoek proposed a special GSI chart for the classification of heterogeneous rock masses such as flysch[8]. To determine the GSI value, a classification chart of GSI for heterogeneous rock masses given by Marinos and Hoek (2001) is utilized in the field to classify rock masses across 32 distinct. The variation of GSI values at these locations, illustrated in Figure 7, spans from a high of 55 to a low of 25 on average along the study area. Similarly Table 1 represents overall rock mass classification on 32 location of study area.

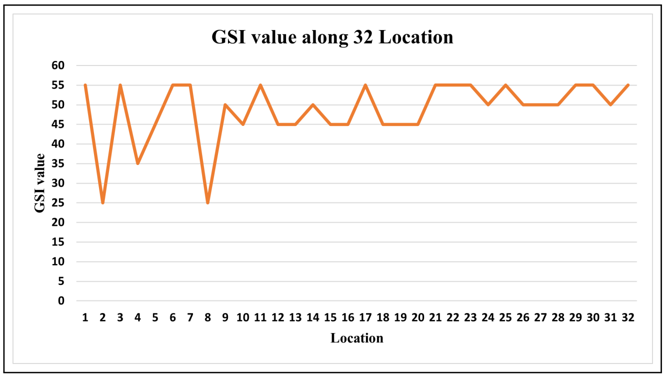

**Figure 7:** GSI value variation across 32 different location

**Table 1:** Rockmass Classification along Siddababa Section

| Location | RMR value | Q value | GSI | Rock type |
|---|---|---|---|---|
| 1 | 53 | 0.95 | 50-60 | SST |
| 2 | 33 | 0.29 | 20-30 | SST |
| 3 | 54 | 1.61 | 50-60 | SST |
| 4 | 49 | 1.61 | 30-40 | MST |
| 5 | 48 | 1.98 | 40-50 | SST |
| 6 | 44 | 1.03 | 50-60 | MST |
| 7 | 48 | 1.98 | 50-60 | SST |
| 8 | 48 | 0.88 | 20-30 | SST |
| 9 | 50 | 0.99 | 45-55 | SST |
| 10 | 49 | 1.32 | 40-50 | MST |
| 11 | 61 | 1.76 | 50-60 | SST |
| 12 | 35 | 1.76 | 40-50 | SST |
| 13 | 40 | 1.1 | 40-50 | SST |
| 14 | 50 | 2.64 | 45-55 | MST |
| 15 | 38 | 0.44 | 40-50 | SILST |
| 16 | 43 | 0.88 | 40-50 | MST |
| 17 | 50 | 1.32 | 50-60 | SST |
| 18 | 38 | 1.1 | 40-50 | MST |
| 19 | 40 | 1.76 | 40-50 | MST |
| 20 | 42 | 2 | 40-50 | SST |
| 21 | 55 | 1.1 | 50-60 | SILST |
| 22 | 53 | 0.81 | 50-60 | SST |
| 23 | 58 | 1.17 | 50-60 | SST |
| 24 | 49 | 1.03 | 45-55 | MST |
| 25 | 55 | 1.1 | 50-60 | SST |
| 26 | 53 | 1.14 | 45-55 | MST |
| 27 | 49 | 1.1 | 45-55 | MST |
| 28 | 51 | 1.91 | 45-55 | SILST |
| 29 | 51 | 0.88 | 50-60 | SST |
| 30 | 55 | 1.17 | 50-60 | SST |
| 31 | 49 | 2.2 | 45-55 | MST |
| 32 | 51 | 0.88 | 50-60 | SST |

SST = Sandstone  MST = Mudstone  SILST = Siltstone

## 5. Tunnel Orientation

The joint set rosette serves as a valuable tool for tunnel planning. In shallow tunnels, the alignment strategy involves following the bisector of the larger angle within the joint set rosette. However, in high-stress environments, considering the major principal stress's orientation becomes crucial. In such scenarios, aligning the tunnel parallel to the major principal stress is recommended[9]. This approach enhances both stability and safety of the tunnel.

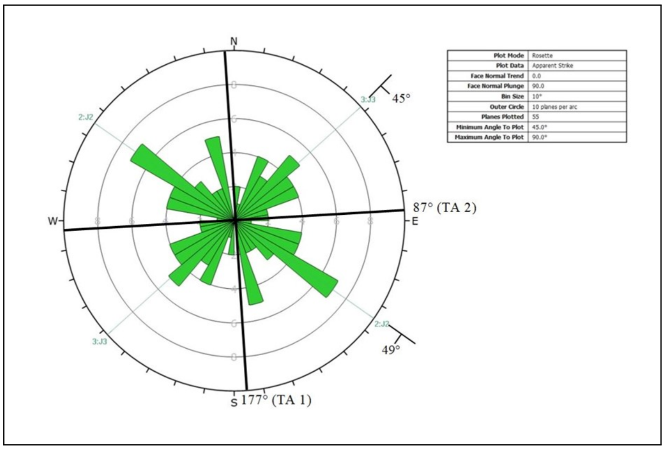

**Figure 8:** Joint Rosette showing orientation of best tunnel alignment

Determining the most suitable tunnel alignment entails analyzing the orientations of discontinuities in the adjacent rock. In this specific case, the optimal alignment, deduced from joint orientation measurements across 32 locations, corresponds to the trend of 177° (TA 1) as depicted in Figure 8. Along with TA 1, another alignment TA 2 also gives the possible alternative alignment. But as in the field, tunnel is needed to be constructed along north-south direction so only TA 1 is taken as the best tunnel alignment in our study area based on attitude measurement along 32 locations.This alignment takes into careful consideration the discontinuity orientations, aiming to minimize potential tunnel wall instability or failure.

## 6. Engineering Geological Map

An engineering geological map is a specialized geological representation designed to provide comprehensive information for engineering projects. It presents detailed insights into the local geology, encompassing physical and mechanical attributes of geological materials like rocks, soils, and potential geohazards. These maps are typically crafted following thorough geological surveys involving sampling, mapping, and laboratory testing of collected materials. This results in a comprehensive depiction of the area's geological conditions, aiding in hazard assessment and project evaluation.

The creation of the engineering geological map involves several steps. Initially, field data are gathered and incorporated into a topographic map (scale 1:25,000) sourced from the Department of Mines and Geology. These maps, alongside geological maps (scale 1:250,000), are digitized and geo referenced using ArcMap 10.4.1 software. Additionally, a contour map is generated using Digital Elevation Map (DEM) data from the USGS.gov website. On-site measurements of dip and strike are integrated into the maps using ArcGIS software. Furthermore, different rock deposits are marked on the map through strike lines, while Rocscience Dips v6.008 aided in projecting joint sets' stereographic projections onto the map.

The outcome of these efforts is an engineering geological map of the Siddababa region, accompanied by a geological profile of the study area extending from Bhutkhola (Palpa) to Siddababa Mandir (Butwal) as shown in Figure 9. This map and profile together provide valuable insights of geological understanding and planning for tunneling projects.

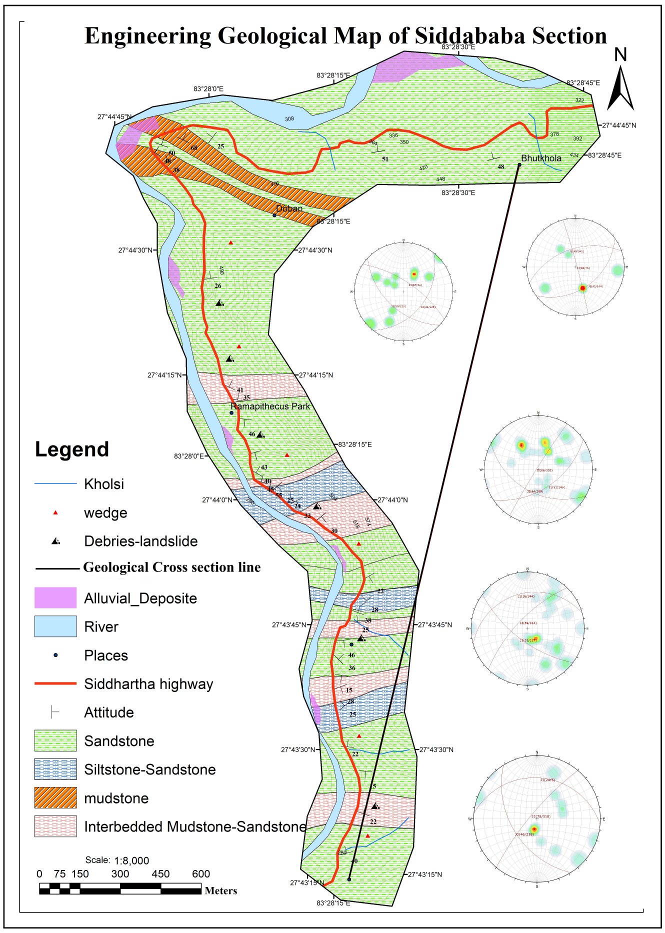

**Figure 9:** Engineering geological map of the study area

## 7. Result and Conclusion

The study conducted along the Siddababa section of Siddhartha Highway, situated in the Siwalik zone, revealed that the rock composition consists of sandstone, mud stone, and silt stone. These rocks exhibit varying weathering patterns due to alternating mud stone and sandstone beds, rendering them highly susceptible to slope instabilities and geohazards like rockfalls and landslides. Rock mass classification using

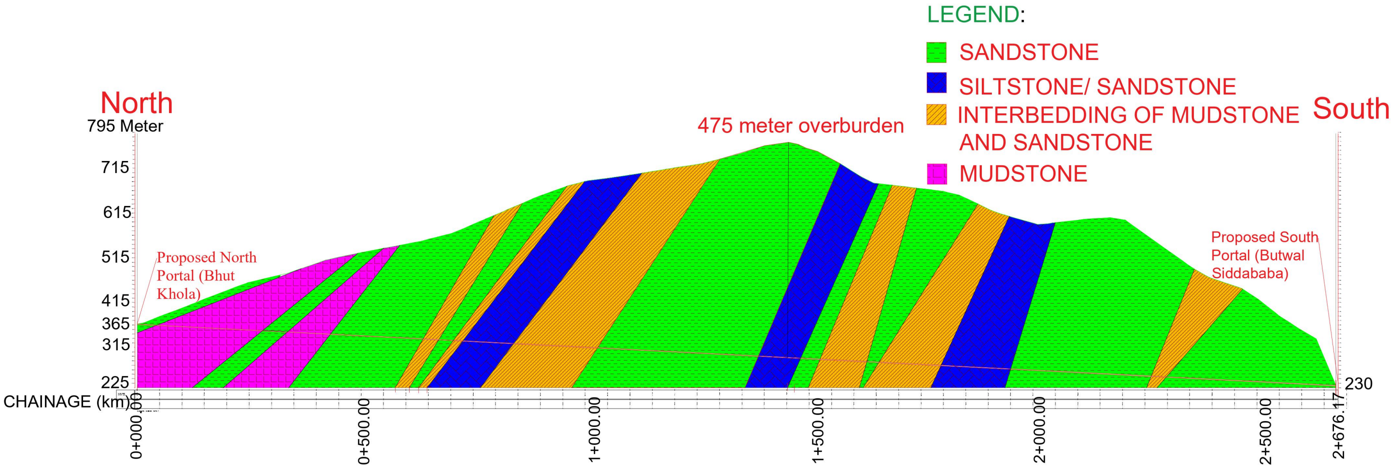

**Figure 10:** Geological profile of study area

RMR categorized most of the studied locations rock mass as Class III (78%) while Q-system categories (72%) of rock mass as poor (Class D). RMR, Q, and GSI values generated during surface investigations provide valuable information about the rock mass conditions, tunnel quality, and geological strength. By assessing and understanding these parameters, tunnel engineers can make informed decisions about tunnel alignment, excavation methods, and the level of support required at different sections of the tunnel route. These parameters help in optimizing the tunnel design and construction process for better safety and cost-effectiveness.

The optimal alignment for tunnel construction is determined at a trend of 177°. The study's emphasize the importance of accurate input parameters, expert input, and comprehensive geological assessments for engineering geological studies, particularly in the challenging Himalayan region. Thorough assessments are crucial for designing underground structures considering complex geological conditions and natural hazards. The significance of engineering geological maps is highlighted for safe and effective tunnel construction, aided by rock mass classification to estimate necessary support systems and optimal construction orientations while minimizing obstructions.

## 8. Limitation

The study's limitations encompassed a reliance on visual inspections utilizing Rock Mass Rating (RMR), Quality Index (Q), and Geographic Information System (GIS) charts and tables, omitting laboratory testing that could have provided comprehensive material insights. RMR, Q system are empirical methods which are used for empirical design of rock reinforcement and tunnel support developed based on case histories thus can't be fully relied for final support design . The surface mapping was confined to exposed rock masses along the road section, potentially limiting the comprehensive understanding of subsurface conditions. These constraints underscore the need of sub surface investigation for comprehensive geological assessments.

## Acknowledgments

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## References

[1] Government of Nepal. *An Introduction to Nepal (Nepal Parichaya)*. Ministry of Information and Communication, Sanchargram, Tilganga, Kathmandu, Nepal, modified 10th edition, Ashar 2079.

[2] B. N. Upreti. An overview of the stratigraphy and tectonics of the nepal himalaya. *Journal of Asian Earth Sciences*, 1999.

[3] K. Panthi. Analysis of engineering geological uncertainties related to tunnelling in himalayan rock mass conditions. *Tunnelling and Underground Space Technology*, 2006.

[4] K. Gnyawali, R. Shrestha, A. Bhattarai, P. Magar, A. Dhungana, I. Sukupayo, and R. Dumaru. Rockfall characterization and structural protection in the siddhababa section of siddhartha highway h10, nepal. *Journal of the Institute of Engineering*, 2016.

[5] C. Pokhrel, I. Adhikari, and R. K. Dahal. Qualitative rock-fall hazard mapping around the siddhababa area along the siddhartha highway in western nepal. *Journal of Nepal Geological Society*, 2022.

[6] Z. T. Bieniawski. *Engineering Rock Mass Classification*. A Wiley-Interscience Publication, 1st edition edition, 1989.

[7] Norwegian Geotechnical Institute. *Using the Q-system*, 2015.

[8] P. Marinos and E. Hoek. Estimating the geotechnical properties of heterogeneous rock masses such as flysch. *Bulletin of Engineering Geology and the Environment*, 60:85–92, 2001.

[9] G. L. Shrestha, L. Modi, and H. Project. Potential risks and earthquake effects to the underground constructions. In *Proceedings of the Nepal Tunnelling Conference 2017*, 2021.