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Use of RMR System in Tunnel Construction through Siwalik Rock Mass: A Case Study of Siddhababa Section in Palpa , Western Nepal

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Abstract

This paper deals with engineering geological assessment by classifying rock mass of lower siwalik region at Siddhababa, Palpa, Nepal. Rock mass in siwalik zone changes regularly and it is challenging to assign and quantify these changing condition precisely. Interbedding of sandstone ,siltstone and mudstone cause the geomechanical characteristics of the rock mass to alter over a short distance. A comprehensive rock mass classification was conducted along the Siddhababa section of Siddhartha highway (NH10), covering the distance between Doban,Palpa to lower Siddhababa temple,Rupandehi. Using the Rock Mass Rating (RMR) system, rock mass in specified area was classified to identify variation in parameters across 32 locations.The variation of parameters of this system were depicted using various techniques, most likely through bar graphs and pie charts.

Keywords

RMR System, Siwalik Rocks, Siddhababa

1. Introduction

Nepal is a mountainous country located in one of the most active geological regions on earth at the intersection of Indian and Eurasian tectonic plates. Due to complex and diverse geology, country is prone to wide range of geological hazards such as earthquakes, landslides, floods and rockfalls [1]. The country is naturally divided into four primary geological regions that has its own distinctive stratigraphy and structural characteristics[2]. Among them, sub-himalayan zone commonly known as siwalik is situated between Main Frontal Thrust (MFT) at south and Main Boundary Thrust (MBT) at north which is 5 to 45 km wide[3]. Siwalik zone is mainly distinguished with geologically very young and weak fragile sedimentary rocks which are highly weathered and deformed significantly due to lithospheric plate dynamic between two plates. The weak geological rock mass condition in this zone is highly dominated by rocks such as mudstones, shale, sandstones, siltstones and conglomerates [3].

Rock mass condition in the siwalik zone changes frequently due to interbedding of competent and incompetent rock mass strata. As a result, alternating layers of thin erodible mudstone beds are observed between thick sandstone beds in most of the locations. Intense and rapid weathering in mudstone beds compared to strong and relatively non-erodible sandstone beds results in loss of own mass which eventually causes rockfall or excessive slides[4]. This region also experiences significant amount of rainfall during monsoon and alternating ridge and furrows contribute to parallel and rectangular drainage pattern which are predominantly controlled by bedding and joints. Highly jointed and fractured mudstone beds get washed away during monsoon hanging behind intact sandstone beds. As a result , rockfall is common natural hazard especially in the siwalik zone [5]. Due to the above facts, it is challenging to directly apply the prevailing classification systems in siwalik rock mass.

2. Study Area

The study area is located in Siddhababa road section of Palpa, Nepal which is near to town of Butwal. It extends approximately 3 kilometers and is situated within the siwalik hills. The research area begins at the lower Siddhababa temple and continues upto Ramapithecus park near Doban. Figure 1 and Figure 2 show alignment along which data is collected at study site and area map of Siddhababa area . Siddhababa section of Siddhartha highway in Lumbini province of Nepal is disturbed overwhelmingly by a large landslide by the three main types of young sedimentary rocks such as sandstone, siltstone, and mudstone. In this road section, siwalik rocks are exposed that contains interbedding of hard and soft rocks strata. The differential weathering pattern of hard rock sandstone and soft rock mudstone exhibit different properties in the presence of water resulting overhanging of sandstone washing away mudstone during monsoon season. Moreover ,rainfall problems are found to be unpredictable and incapable of being analysed with any precision that have been

Figure 1: Alignment Along which Data is Collected at Site

seen as hazard in this area. Rockfall related studies are not found much and are limited to the landslide study only along with some case study on rockfall events and its mitigation measures [6]. In addition to that , rockfall characters in siddhababa are found to be hazardous and need structural countermeasures. Basically, three types of slope failure are seen to occur; Block Failure, Gully Erosion, and Slope Scar collapse[7] .Due to rock calls, significant accidents have occurred along sidhhababa road. It is essential to study the area vulnerable to rock falls and to propose mitigating measures [8]

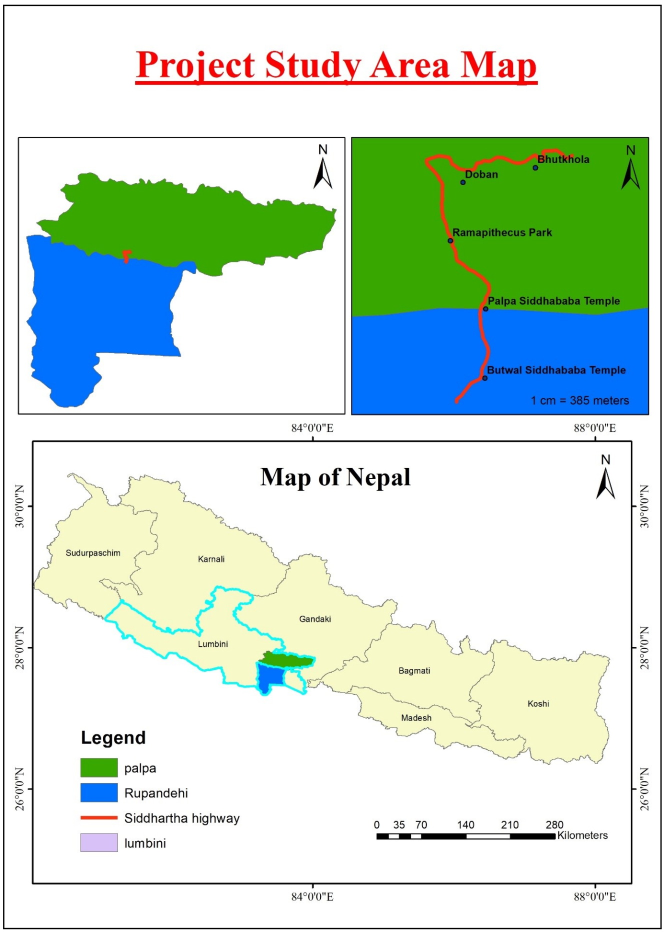

Figure 2: Project Case

To overcome obstacles by this landslide a road tunnel is proposed by Department of Roads deporting from upper Siddababa Temple to near Ramapithecus Park near Tinau Hydropower Plant Damside covering approximately distance of 1.126 km.

3. Engineering Geological Map

The process of creating the engineering geological map involves several key steps. Firstly, data is collected in the field and added to a topographic map with a scale of 1:25,000 obtained from the Department of Mines and Geology. These maps, along with geological maps at a scale of 1:250,000, are digitally converted and aligned with geographic coordinates 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 the dip and strike of geological features are incorporated into the maps using ArcGIS software.

Furthermore, various rock deposits are marked on the map using strike lines, and Rocscience Dips v6.008 software is employed to project the stereographic projections of joint sets onto the map. The culmination of these efforts results in the creation of an engineering geological map for the Siddababa region. This map is complemented by a geological profile extending from Bhutkhola in Palpa to Siddababa Mandir in Butwal, as in Figure 3.

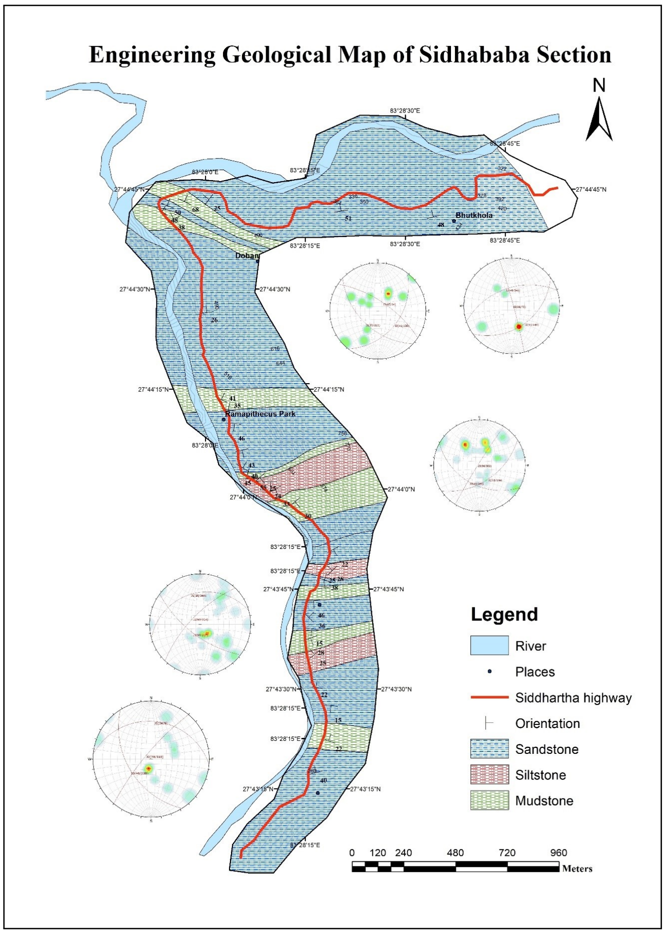

Figure 3: Engineering Geological Map of Study Area

4. Rock Mass Classification

The majority of existing correlations between the Rock Mass Rating (RMR) and Q indexes, which are rock mass classification systems, have been established using geological data from Europe, America, and the Oceania region. In recent times, the Himalayan region has experienced significant infrastructure development involving extensive underground excavations for transportation and hydropower projects. This situation calls for the development of an empirical relationship between two widely used rock mass classification systems: Bieniawski's RMR and Barton's Q system, utilizing local data specific to the Himalayan context. To achieve this goal, geological data obtained from four hydropower projects situated in the Lesser Himalayan and Central crystalline rock regions were employed. The intention was to create a practical link between these two rock mass classification systems through empirical formulation. This developed relationship holds the potential to serve as a valuable tool for geologists and geotechnical professionals working within this geographic area.The authors suggest employing both RMR and Q-systems of rock mass classifications concurrently at project sites, and subsequently validating the outcomes using the established empirical correlation. However, it's emphasized that this correlation should not be applied universally to determine RMR from Q-index or vice versa, as this could yield misleading results. Furthermore, there is room for enhancing the proposed empirical relationship by including more data points from a variety of ongoing underground excavation projects in the Himalayan region. Despite this, the current study contributes to previous research efforts and sets the stage for further exploration in this field [9].

According to Godwin (2020) , during the feasibility and preliminary design stages of a project, when very little detailed information is available on the rock mass and its stress and hydrologic characteristics, the use of a rock mass classification scheme is found to be considerable benefit. Rock mass classification schemes have been developing for over 100 years since Ritter (1879) attempted to formalize an empirical approach to tunnel design, in particular for determining support requirements. Bieniawski RMR (1976, 1989) and Barton et al. Q (1974) classifications of rock mass are the two types of classification that is found to be frequently used. Both approaches uses geological, geometric and engineering design parameters to arrive at a numerical value for the quality of their rock mass [10].

Rock mass classification is the process of grouping or classifying a rock mass according to predetermined relationships (Bieniawski, 1989) and giving it a distinctive description (or number) based on similar characteristics so that the behavior of the rock mass could be predicted. An assembly of rock material is referred to as a rock mass.There are now three basic methods used in the design of rock tunnels: analytical, observational, and empirical. The analytical technique is currently the least employed in engineering practice due to the extremely complex nature of rock masses and the challenges associated with their characterization. It is not the analytical procedures themselves that are to blame for this, as some of them have been highly sophisticatedly created, but rather the inability to provide the required input data because the ground circumstances are rarely sufficiently studied. As a result, analytical methods like the finite element method, boundary element method, closed form computational solutions, photoelasticity, or analog simulation are primarily useful for determining the impact of different parameters or processes and for contrasting various design schemes[11].

RMR System

Rock Mass Rating System, a geomechanical rockmass classification system, developed by Bieniewaski (1989) is developed through a total of 49 case histories and it was later enhanced to include 62 coal mining case histories in 1984 and an additional 78 case histories relating to tunneling [12].

5. Field Assessment and Data Collection

Table 1 and Figure 4 show field data from 32 locations that are entered onto a spreadsheet. Through their respective parameters, RMR values are calculated, and their rock class is determined. While siltstone and fine-grained sandstone are only found in a few locations, the majority of the locations in the project area are dominated by sandstone and mudstone (13 and 12 locations respectively). This outcome is consistent with the description of the rock mass in the siwalik rock mass condition.

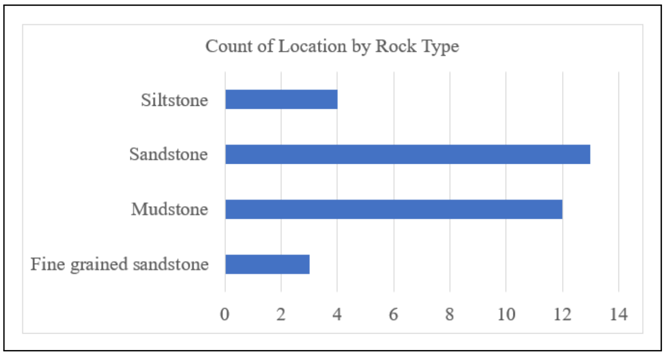

Figure 4: Count of Location by Rock Type

Table 1: RMR Value and Rock Class over 32 Locations

Location	Rock Type	RMR Value	Rock Class
1	Sandstone	53	3
2	Mudstone	33	4
3	Sandstone	54	3
4	Mudstone	49	3
5	Sandstone	48	3
6	Mudstone	44	3
7	Sandstone	48	3
8	Sandstone	48	3
9	Sandstone	50	3
10	Mudstone	49	3
11	Sandstone	61	2
12	Sandstone	35	4
13	Sandstone	40	4
14	Mudstone	50	3
15	Siltstone	38	4
16	Mudstone	43	3
17	Siltstone	50	3
18	Mudstone	38	4
19	Mudstone	40	4
20	Sandstone	42	3
21	Siltstone	55	3
22	Sandstone	53	3
23	Sandstone	58	3
24	Mudstone	49	3
25	Sandstone	55	3
26	Mudstone	53	3
27	Mudstone	49	3
28	Siltstone	51	3
29	Sandstone	51	3
30	Sandstone	55	3
31	Mudstone	49	3
32	Sandstone	51	3

5.1 RMR Parameters

The Siwalik rock mass condition varies depending on the type of rock present in the formation. The rocks in the formation include sandstone, shale, siltstone, conglomerate, and mudstone. Figure 5 illustrates the formation of the rock mass, which consists of several of different bands of rocks whose strength has been significantly altered. Sandstone's uniaxial compressive strength is determined to be between 50 and 170 MPa, but mudstone's strength values are found to vary between 5 and 50 MPa.

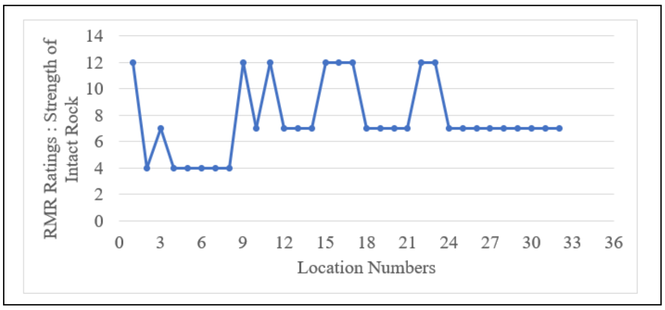

Figure 5: RMR Ratings for Strength of Intact Rock over 32 Locations

Rock Quality Designation (RQD) is an important parameter for determining the strength and stability of rock masses. RQD values typically range from 0 to 100% , with higher values indicating better rock quality. It is calculated as the percentage of intact or sound rock material (drill core greater than 10cm) over a specified length of core sample. Figure 6 illustrates the variation of RQD over 32 locations. Locations 11, 21, 23, 25, and 30 have the highest RQD values (75–90%). Similarly, results have been identified for the minimum values, which was less than 25% at positions No. 2 and 15. Sandstone exhibits higher RQD values, while mudstone exhibits lower RQD value.

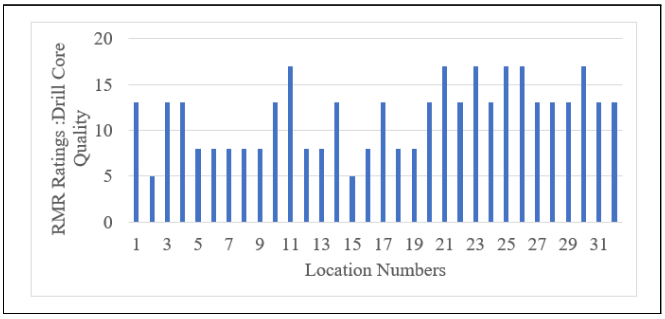

Figure 6: RMR Ratings for Drill Core Quality over 32 Locations

Spacing of discontinuities refers to the distance between adjacent fractures, joints, faults, or other forms of discontinuities in a rock mass. Sedimentary rocks can contain various types of discontinuities, such as bedding planes, joints, faults, and shear zones, which can affect the strength and stability of the rock mass. The variations in RMR ratings for the spacing of discontinuities over 32 places are visible in Figure 7 .While several locations containing sandstone show higher ratings whereas locations 2 and 28 show the lower ratings. In case of mudstone, spacings have been determined to be closely packed.

Figure 7: RMR Ratings for Spacing of Discontinuities over 32 Locations

RMR ratings for length of persistence in discontinuity condition are taken into account considering underground excavation and its ratings are consistent over 32 places and are found to be over 3-10m. Figure 8 demonstrates how the 100% stacked line varies in persistence length. It is found to be straight line.

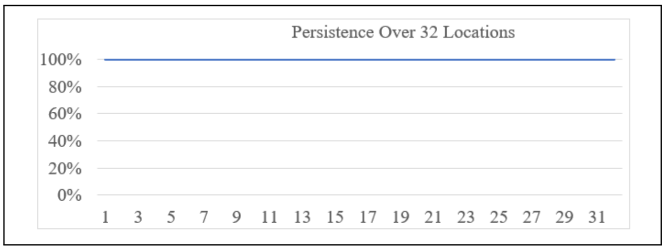

Figure 8: RMR Ratings for Persistence over 32 Locations

Figure 9 indicates the variance in discontinuities separation across the data collected site. The separation of discontinuities refers to the distance between the two surfaces of a fracture, joint, or fault that has experienced some degree of displacement or movement. Only up through particular locations Nos. 2-8, 9-17, and 19–25 have the discontinuities separation condition noticed to be consistent. There is an extensive amount of separation between discontinuities in weak rockmass conditions like mudstone.

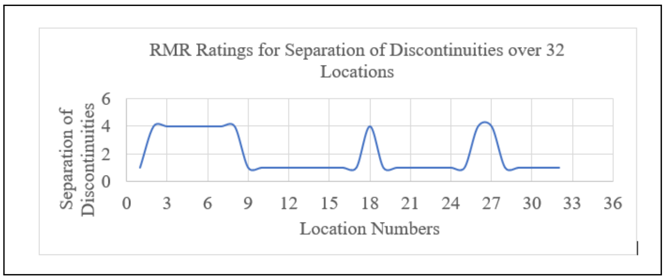

Figure 9: RMR Ratings for Separation of Discontinuities over 32 Locations

The roughness condition of a rock surface refers to the degree of irregularity or roughness of the surface, which can be influenced by various factors, including the depositional environment and subsequent geological history of the rock. The majority of the time, as shown in Figure 10, shows presence of highly roughness conditions along with slightly and smoothly rough conditions. Most of the time, sandstone is rough, whereas mudstone is naturally smooth.

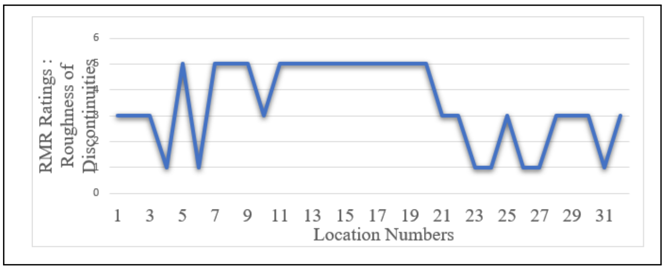

Figure 10: RMR Ratings for Roughness of Discontinuities over 32 Locations

Figure 11 through the scatter chart shows infilling conditions over studied site. The nature of infilling condition is similar in most of the cases except in locations no 9 10 12 and 18.

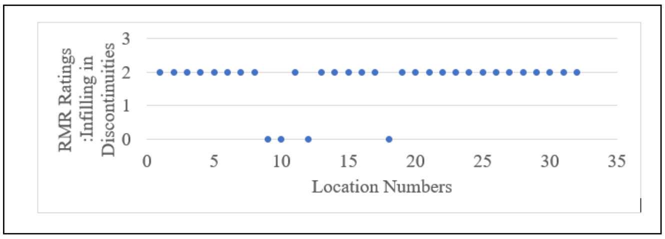

Figure 11: RMR Ratings for infilling in Discontinuities

Figure 12 shows the nearly identical weathering patterns across the study site. Maximum rocks are found to be moderately weathered but highly weathered in case of locations 12 ,15 and 16. Weathering is an important process that can significantly impact the properties and characteristics of sedimentary rocks. Understanding the degree and type of weathering that occurs in sedimentary rocks is important for various geological and engineering applications.

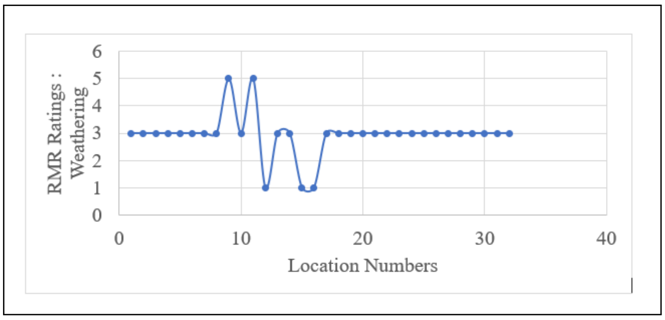

Figure 12: RMR Ratings for Weathering over 32 Locations

Similarly, it is found that ground water is flowing at locations 18, 22, and 23. Mudstone could be seen at site 18, whilst sandstone is present at locations 22 and 23. The above total ratings has been modified to account for tunnel direction. Project prefer a fair tunnel alignment with a rating of negative five.

In general, the Siwalik rocks are composed of a variety of sedimentary rocks, including sandstone, siltstone, shale, and conglomerate. These rocks have been subjected to significant tectonic activity and weathering over time, which has resulted in a variance of rock mass conditions. Rock mass conditions in the siwalik zone can vary depending on several factors, including the rock type, structure, and weathering. Some areas of the siwalik zone may have relatively intact and strong rock mass, while others may have highly weathered and fractured rock mass that are more susceptible to instability and failure. Rock mass are categorized after field assessment according to RMR and Q system of classification. Study discovered that numbers of rock mass (25 numbers) fall into the third class and among them rock mass at location number 11 is the strongest, although there are six more rocks in the fourth class as shown in Figure 13.

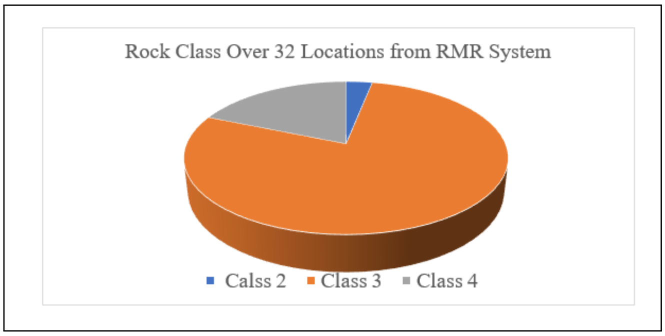

Figure 13: Rock mass classification according to RMR System

6. Results and Discussion

Based on this work, following results can be made:

- **Uniaxial Compressive Strength :** Following rock mass classification on site, the validation of UCS results has been conducted using the Schmidt rebound hammer test. The findings from the Schmidt hammer test are as follows:
  Sandstone demonstrates the highest UCS, with a central rock mass value of 78.67.
  Mudstone exhibits a lower UCS value, with a central rock mass value of 30.9.
  Siltstone also has a lower UCS value compared to sandstone, with a central rock mass value of 48.67.These findings align with the results obtained through geological hammer blows.
  Also ,sandstone exhibits susceptibility to breakage with multiple blows from a geological hammer, while low-strength mudstone can even crumble under firm blows. This suggests that the Siwalik rock mass experiences frequent and substantial variations in its rock mass state. The uniaxial compressive strength of sandstone falls within the range of 50 to 170 MPa, whereas mudstone's strength values fluctuate between 5 and 50 MPa which is also validated from schmidth rebound hammer test .
- **Rock-Quality Designation (RQD) :** The most practical and reliable way to determine the Rock Quality Designation (RQD) is by examining drill core samples that are longer than 10 cm in length. However, in Siwalik rock formations, there are certain situations where it's impossible to obtain rock samples exceeding 10 cm in length due to the presence of thinly interbedded sandstone, mudstone, and siltstone layers. In such cases, RQD estimation must rely on empirical methods.

Table 2: Ratings for RMR Parameters over 32 Locations

Loc	UCS	(RQD %)	Spacing	Persistence	Separation	Roughness	Infilling	Weathering	Ground Water
1	12	13	15	2	1	3	2	3	7
2	4	8	5	2	4	3	2	3	10
3	7	13	15	2	4	3	2	3	10
4	4	13	15	2	4	1	2	3	10
5	4	8	15	2	4	5	2	3	10
6	4	8	15	2	4	1	2	3	10
7	4	8	15	2	4	5	2	3	10
8	4	8	15	2	4	5	2	3	10
9	12	8	15	2	1	5	0	5	7
10	7	13	15	2	1	3	0	3	10
11	12	17	15	2	1	5	2	5	7
12	7	8	10	2	1	5	0	1	7
13	7	8	10	2	1	5	2	3	7
14	7	13	15	2	1	5	2	3	7
15	12	5	8	2	1	5	2	1	7
16	12	8	10	2	1	5	2	1	7
17	12	13	10	2	1	5	2	3	7
18	7	8	10	2	4	5	0	3	0
19	7	8	10	2	1	5	2	3	7
20	7	13	10	2	1	5	2	3	4
21	7	17	15	2	1	3	2	3	10
22	12	13	15	2	1	3	2	3	0
23	12	17	15	2	1	1	2	3	0
24	7	13	15	2	1	1	2	3	10
25	7	17	15	2	1	3	2	3	10
26	7	17	15	2	4	1	2	3	10
27	7	13	15	2	4	1	2	3	10
28	7	13	1	2	1	3	2	3	10
29	7	13	15	2	1	3	2	3	10
30	7	17	15	2	1	3	2	3	10
31	7	13	15	2	1	1	2	3	10
32	7	13	15	2	1	3	2	3	10

To calculate RQD using various empirical methods when RQD percentage is zero, certain techniques can be adopted. Firstly, if there is a complete absence of drill core longer than 10cm in a location, efforts should be made to correlate it with different empirical approaches. If significant discrepancies arise in the results, it may be necessary to extend the sampling location to cover all exposed surfaces. The interbedding conditions should be thoroughly examined across the entire exposed surface. To validate the results, a weighted area approach can be used. This involves marking out additional one-meter-square sections both lengthwise and breadthwise. Core samples obtained from at least four of these one-meter square area should be averaged to determine the RQD value. Secondly, in certain cases, the interbedded layers of sandstone, mudstone and siltstone may be thinly laminated, such that they do not significantly impact the quality of the drill core. In such situations, where the rock core exceeds 10 cm but contains discontinuities, it is advisable to correlate the results with empirical approaches provided by different methodologies. In summary, identifying continuous one-meter sections of single rock samples in Siwalik rock formations can be challenging. For example, if a 40 cm-long mudstone layer is followed by a 60 cm-long sandstone layer, the RQD value can be correlated with the unconfined compressive strength (UCS) of these respective rock types. If the UCS strength of mudstone is 30 MPa and that of sandstone is 50 MPa, the ratio would be 3:5. In this case, the 40 cm mudstone length can be multiplied by 0.6, and the 60 cm sandstone length by 1.67. The total RQD length would then be 24 cm + 100 cm, equaling 124 cm, instead of the previously calculated length. This approach is to make the drill core samples more homogenous.

- **Spacing of Discontinuities** In the Siwalik zone, when classifying the rock mass using the RMR (Rock Mass Rating) system, one of the significant challenges lies in the identification of discontinuities within the rock formations. This difficulty arises from the fact that, in certain situations, the rock layers in this zone are extremely thinly laminated. To accurately identify these discontinuities, detailed mapping is essential. When mapping the exposure surface at a smaller scale, it may encompass the entire rock exposure, but it might fail to capture smaller joints and micro-interbedding conditions between the rocks. On the other hand, detailed mapping at a finer scale will reveal more joints and interbedding conditions, but it is a more time-consuming process. The decision to opt for detailed mapping depends on the level of risk and professional judgement expertise and level of accuracy required in classifying the rock mass, especially in the context of underground excavation projects. The choice of mapping scale also depends on factors such as available time, funding resources, and the criticality of accurate rock mass classification for the specific project.

- **Condition of Discontinuities :** When assessing the condition of discontinuities within rock mass, it is crucial to focus on five key parameters. Firstly, the persistence length of discontinuities plays a significant role. When examining the entire exposed surface, it's common to find persistence lengths exceeding 10 meters, and in some cases, they may even extend 20 meters. However, the critical concern lies in identifying those discontinuities that affect underground excavation, particularly in tunneling projects. Smaller persistence of discontinuities may become negligible over shorter distances, making it essential to prioritize major and longer discontinuities when determining persistence length. Calculating smaller persistence lengths may result in an overall lower RMR rating, potentially leading to an overly optimistic and over safe assessment of rock mass stability. Hence, it often relies on the judgment and expertise of professionals.

  The second parameter to consider is the separation of joints. In the siwalik rock mass, these separations are not uniformly distributed and can vary over shorter lengths, often even in the range of 20-30 cm. This variation is due to the interbedding conditions of weak and soft rock strata. During the monsoon season, erosion of weak rock can alter the separation of joints. Therefore, an averaging method should be employed when mapping for the separation of joints. The other parameter involves infilling, roughness, and weathering conditions. Siwalik rock masses exhibit dynamic characteristics, and the presence of infilling materials can significantly impact the properties of discontinuities. For instance, if clay is present between joints of sandstone, the roughness of the sandstones may be obscured by the clay and mud. Identifying these infilling materials requires conducting dispersion tests to determine their particle size. Once identified, the roughness condition of joints can be correlated with these materials. Additionally, on hillside rock exposures, jointing conditions can be affected by weathering and erosion processes. Careful attention should be given to identifying the presence of infilling and jointing conditions that may exist deep within the rock over an extended span for underground excavation.

  The fourth parameter is the weathering condition of the rock mass. In the siwalik zone, rock mass is highly weathered, and in certain circumstances, vegetation may be visible in certain span of time. To accurately assess weathering conditions, observations should be made over time, as weathering conditions change with the passage of time. Rock exposures can degrade rapidly, emphasizing the importance of regular monitoring over the different months in a year.
- **Ground Water :** In the context of siwalik rock masses, where rocks are highly permeable and porous, predicting groundwater conditions based entirely on a single time point can be challenging. Ground water conditions in such areas should be continuously monitored throughout the year. It is better to conduct at least two surface mapping, one during the monsoon season and another during the dry season, to gain a comprehensive understanding of groundwater dynamics.
- Input parameters should be based on size and position of the area to be supported. In order to tunnel through the Siwalik rock mass, measurement should account for the entire constructing site.
- Despite to what Palmstrom recommended in 2005, it is found challenging to link the RQD value with volumetric joint counts in siwalik rockmass condition. Measurements of the block size are seen to be difficult.

7. Conclusions

Based on this work , following conclusions can be made :

- In siwalik rock mass, when drill core samples longer than 10 cm are unattainable due to interbedded layers, empirical methods and rock type strength ratios can help determine meaningful RQD values for rating, ensuring accuracy in assessing rock quality.
- In the Siwalik zone, accurately classifying rock mass using the RMR system is challenged by interbedded rock layers, requiring a careful choice of mapping scale based on project criticality, resources, and expertise to identify discontinuities accurately.
- Detailed mapping at different scales is essential to identify discontinuities accurately, but it is dependent in mapping finer details and time and resources available. The choice of mapping scale is critical, influenced by risk, expertise, project requirements, and available resources.
- The assessment of rock mass discontinuities in the siwalik zone highlights the importance of persistence length, with discontinuities often exceeding 10 meters and even reaching 20 meters. However, it's crucial to focus on those discontinuities that impact underground excavation, as smaller persistence lengths may become negligible over shorter distances.
- The separation of joints within Siwalik rock masses is not uniformly distributed and can vary significantly over shorter lengths, sometimes within the range of 20-30 cm. This variation is influenced by interbedding conditions and can change during the monsoon season, necessitating the use of averaging methods when mapping for joint separation.
- The presence of infilling materials, such as clay between joints, can obscure the roughness of the rock surfaces. Conducting dispersion tests to identify these materials and their impact on joint roughness is essential. Additionally, weathering conditions in the Siwalik zone change over time and should be monitored regularly.
- Siwalik rock mass are highly weathered, with vegetation occasionally visible. Accurate assessment of weathering conditions requires observations over time, as they can deteriorate rapidly. Regular monitoring throughout different months of the year is crucial for an accurate assessment.
- In siwalik rock mass, predicting groundwater conditions from a single time point is challenging due to high permeability. Continuous year monitoring, including mapping during both monsoon and dry seasons, is

essential. There is importance of surface water discharge measurements and lugeon tests for accurate assessment of ground water condition. Experimental and averaging data from different months are crucial for reliable groundwater evaluations, especially for safety-critical projects during the monsoon season. For less critical projects, using average groundwater readings can be cost-effective.

Limitations :

- The estimated range of the compressive strength of rock mass is done according to field measurements of compressive strength of rocks from ISRM 1978. Hence it is reliant upon the engineer's or geologist's professional judgment.
- No numerical modelling is carried out.
- Only selected locations are used to map the exposed rock mass, which may not fully represent the complex conditions of siwalik rock masses, potentially missing important variations.
- The outer exposed rock mass is used as input for joint properties. Underground conditions in the siwalik rock mass could be different from what is predicted from exposure.
- No laboratory tests are performed; instead, the strength of the rockmass is estimated using geological hammer and knife.

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