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Comparative Study of Rock Mass Classification Systems: A Case Study of Nagdhunga-Naubisea Road Tunnel

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Abstract

Ground classification systems have been widely used to characterize the soil or rock mass for the analysis and design of underground structures. Deformation characteristics of rock mass around the underground excavation boundary varies according to types of rock and their properties, in situ stress condition and types of support used. Broadly used classification systems for underground structures are Rock Mass Rating (RMR) and Rock Quality Index (Q- Systems) but in-case of the Nagdhunga-Naubisea road tunnel Nippon Expressway Company Limited used NEXCO-System. Literally, the NEXCO classification is based on the velocity of elastic wave, geological condition, boring core condition, competence factor, stability of tunnel face and convergence. However, in-case of Nagdhunga-Naubisea road tunnel, grade point is computed using the similar parameters that are used in RMR- System and Q-System. This research focuses about comparison between ground classification from RMR, Q-system and NEXCO system. The geological descriptions obtained from project office at chainages (0+497 to 0+502), (0+508 to 0+513), (0+581.8 to 0+587.8) and (0+584.2 to 0+590.2) were used to correlate the relationship between RMR, Q-system and NEXCO system of rock mass classification systems. Results showed that from RMR, the ground classification is “poor” at all the chainages whereas from Q-system is “very poor” at chainage (0+508 to 0+513) and “poor” at other chainages. Similarly, from NEXCO- system it was found that “DII” at chainages (0+497 to 0+502) and (0+508 to 0+513) and CII for chainages (0+581.8 to 0+587.8) and (0+584.2 to 0+590.2). These results revealed that the ground classification from NEXCO as DII is similar to poor from RMR and poor or very poor from Q system where as CII from NEXCO is similar to poor from both RMR and Q system.

Keywords: NEXCO-parameters, Massive and Layered Rock, NEXCO-system, Q-system, RMR-system

1. INTRODUCTION

There are various classification systems developed and in use till date for analysis and design for underground excavation. Deformation behaviors of rock masses are governed by rock types, properties of rock masses, in-situ stress condition and types of support use [1]. Analysis and design of underground structures requires the reliable estimation of strength and deformation behaviors of rock mass [2]. The stability of underground excavation depends upon the rock mass quality and mechanical processes by which the rock is formed [3]. The stability of underground excavation basically depends upon the combined effect of rock mass quality and mechanical processes. Decomposition and dissolution causes chemical weathering, which depend upon the environmental and climatic region [4]. The intact rock mass is considered homogeneous, even few discontinuities does not represent the strength of rock mass [3]. The mislead interpretation of rock mass classification provides uneconomical support system [5], hence reliable estimation of strength and deformation is prerequisite for the analysis and design of underground structure. The strength of intact rock is obtained through laboratory test such as uniaxial compressive test, tri-axial test and point load test [6]. Ground classification systems are basis for information about the work site and support to be used. The frequently used classification systems are RMR and Q-Systems, while in case of Nagdhunga - Naubisea road Tunnel NEXCO classification system is used. The correlative model was prepared based on face mapped data obtained from work site where all three methods are adopted. Study area is located in Bagmati Province, Kathmandu and Dhading District of Nepal. In central part of Nepal rock are subdivided into Nuwakot and Kathmandu complexes based on the metamorphism [7]. The planned route for Nagdhunga-Naubisea tunnel is geologically located in rock of lesser Himalaya and consist of low-grade metamorphic rocks such as phyllite, metasandstone as well as quartzite [8]. The planned tunnel belongs to the rock of the tistung formation and the sopang formation, Phulchowki group of the Kathmandu complex [9]**.** The length of proposed tunnel is 2.688 Km having longitudinal gradient 3.5%. The geomechanics classification system, also known as rock mass rating (RMR) [10], is developed on the basis of experience in numerous tunnel projects and cases in South Africa. Since then, this classification system has been modified especially on the rating to inflow of water, condition of discontinuity and its spacing. For the classification of rock mass using this approach, the uniaxial compressive strength of intact rock, rock quality designation (RQD), spacing of joints, condition of joints, orientation of joints, and the condition of ground water have to be known.

Another system developed for the rock mass classification is termed as rock quality index (Q system). This system of classification is also known for Norwegian technical institute rock mass classification system. This rock mass classification system is basically governed by the number of joint sets (Jn), discontinuity roughness (Jr), joint alteration (Ja), water pressure (Jw), stress reduction factor (SRF) and rock quality designation (RQD) [11].

$$\text{Rock mass quality (Q)} = \left(\frac{RQD}{Jn}\right).\left(\frac{Jr}{Ja}\right).\left(\frac{Jw}{SRF}\right) \quad (1)$$

The parameters used in RMR and Q systems are not factual, requires significant degree of interpretation. They relate to a particular structure at particular depth, the validity of designing using these classification systems is only for planning stage, not for final design. Q system fails to properly consider joint orientation, joint continuity, joint aperture and rock strength[12].

The criteria for NEXCO ground classification are based on quantitative indicators of each parameter which was suggested by East Nippon expressway company limited, Central Nippon Expressway Company limited and West Nippon Expressway Company limited. Classification is based on the parameters: elastic wave velocity, geological condition, boring core condition, competence factor, stability of face and convergence parameters [13]. Rock type is classified as massive and layered. The rock which in which the joint plane become dominant surface of discontinuity, isotropic, homogeneous and strength does not vary appreciably from point to point is referred as massive and the rock having bedding plane or schistosity plane become dominant surface of discontinuity is referred as layered. The ground classification based on NEXCO gives the qualitative description of rock mass and also considers the convergence of the ground at selected location. This gives more realistic ground classification in comparision of conventional ground classification systems [13]. The extremely hard, slightly deterioration due to weathering, RQD of (40 – 70) % and convergence within the elastic limit of (15-20) mm is referred as CII, whereas the strong weathering and alteration, remarkable looseness due to water, RQD of 10% or less and maximum convergence within the elastic limit beyond two times the diameter is (60-120) mm is referred as DII ground [13]. The strength of intact rock (A), weathering alteration (B), spacing of discontinuities (C), condition of discontinuities (D), quantity of water, degradation by water (E) and effect of discontinuity are the common parameters for ground classification by NEXCO system. Beside these common parameters rock quality designation is incorporated within the spacing of joints by NEXCO system. The joint alteration number and joint water reduction factor used in Q-system has similar theoretical background with weathering alteration and adjustment of ground water and degradation by water respectively in NEXCO System. The ratings for each parameter based on different system have different score.

2. METHODOLOGY

2.1 Data collection

Face mapped data at particular sections of underground exaction was considered as the primary data for this research work. Figure 1 shows the locations considered for data collection. The parameters for each section are weighted based on literatures and previous findings. Well established parameters for ground classification are strength of rock mass, weathering alteration, spacing of discontinuities, condition of discontinuities, effect of discontinuities strike and dip, quantity of ground water and degradation by water. The last two parameters are adjusted based on literature. Observation was done at left, center and right at each section. Figure 2 shows a tunnel face and the existing parameters considered for Rock Mass Classification. The strength of rock mass was obtained by striking the normal blow of hammer and observing its response. Rock Quality Designation (RQD) is obtained from rock cores or volumetric joint count, using Palmstorm's equation. The discontinuities parameters were obtained by visual observation. For ground water condition, a pipe is inserted in the roof and the water from the pipe is collected within specified time. The volume of water obtained is noted and this is used for rating. The observed data were used for ground classification.


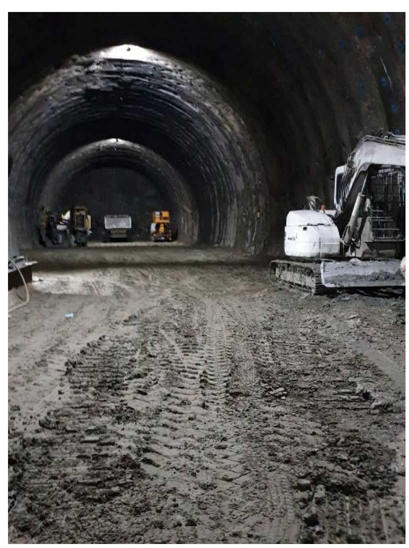

Figure 1: Picture of selected locations collecting facemapping data

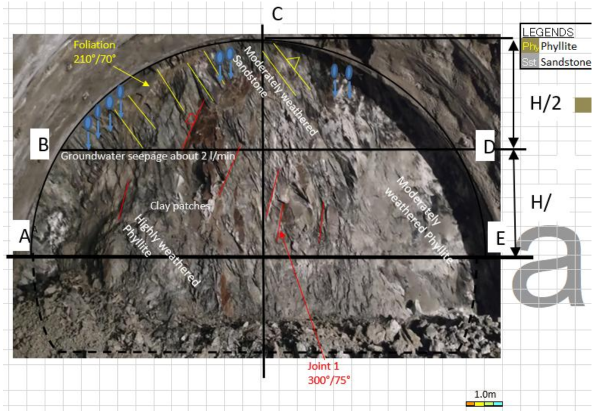

Figure 2: Sample of face mapping at a selected location (at chainage 0+502)

2.2 Data analysis

The observed and collected parameters at each section (left, center and right) were assigned the weightage according literature. The weightage of all the parameters, for each section, are added and final grade point is computed by NEXCO system: $\frac{(right+(crown\times2)+left)}{4}$ (2)

The RMR and Q-value at each section were obtained from the observed data and corresponding literatures.

2.3 Ground classification

The computed grade points and rating for each section were used for ground classification of corresponding sections by three methods. The ground classifications obtained by RMR-system, Q-system and NEXCO-system at respective sections were compared. The systematic research design framework is presented in figure 3.

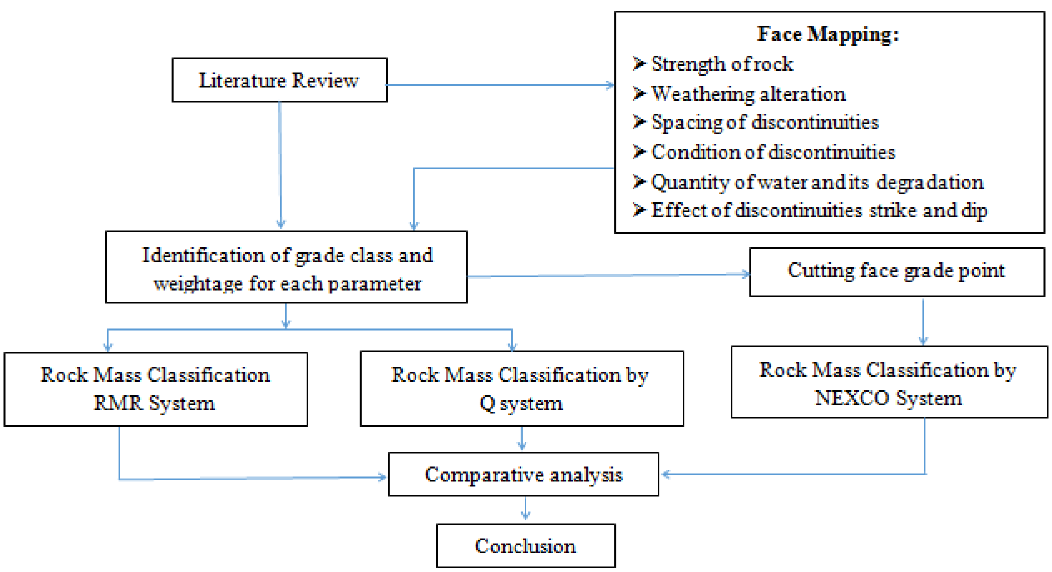

Figure 3: Research design framework

Table 1: Grade point for different kind of rock by NEXCO System [13]

Grade point for different kind of rock																					
	Qualitative description of rock mass	Strength of intact rock material						Weathering/ Alteration				Spacing of discontinuities					Conditions of discontinuities				
Types of rock		1	2	3	4	5	6	1	2	3	4	1	2	3	4	5	1	2	3	4	5
Massive	Hard rock	38	30	23	15	8	0	17	11	6	0	23	17	12	6	0	22	17	11	6	0
	Medium hard to soft rock	30	24	18	12	6	0	20	13	7	0	22	17	11	6	0	28	21	14	7	0
Layer	Medium hard rock	25	20	15	10	5	0	31	21	10	0	16	12	8	4	0	28	21	14	7	0
	Soft rock	32	26	19	13	6	0	23	15	8	0	20	15	10	5	0	25	19	13	6	0

Table 2: Adjustment for groundwater and degradation [13]

Parameter and score		Quantity of Ground Water			
		1	2	3	4
Degradation by water	1	0	0	-5	-10
	2	0	-5	-7	-10
	3	-5	-7	-10	-15
	4	-7	-10	-15	-20

Table 3: Cutting face grade point, types of ground and support pattern by NEXCO-system [13]

General grade point and support type						
Natural ground classification	DII	DI - a	CII	CII - a	CI	B
Support pattern	DII, DI – b	-	CII - b	CII - a	CI - b	B
Grade point	~30	20~40	35~50	45~60	55~70	65~

2.4 Ground Classification by NEXCO System

Table 4: NEXCO rating for different chainages

Descriptions	Rating											
	West main tunnel chainage: 0+497 to 0+502			West main tunnel chainage: 0+508 to 0+513			West main tunnel chainage: 0+581.8 to 0+587.8			West main tunnel chainage: 0+584.2 to 0+590.2		
	Left	Crown	Right	Left	Crown	Right	Left	Crown	Right	Left	Crown	Right
Strength of intact rock material (A) (N/mm^2)	3	4	3	3	3	3	4	3	3	4	3	2
	15	10	15	15	15	15	10	15	15	10	15	20
Weathering/ Alteration (B)	3	2	2	2	2	2	3	2	2	3	2	2
	10	21	21	21	21	21	10	21	21	10	21	21
Spacing of discontinuities (C)	4	4	4	4	4	4	4	4	4	4	4	4
	4	4	4	4	4	4	4	4	4	4	4	4
Conditions of discontinuities (D)	4	5	4	4	4	4	5	4	3	5	4	3
	7	0	7	7	7	7	0	7	14	0	7	14
Effect of discontinuity strike and dip	5	5	5	5	5	5	5	5	5	5	5	5
	3	3	3	3	3	3	3	3	3	3	3	3
Quantity of groundwater (E)	1	1	1	1	1	1	2	1	1	2	1	1
Degradation by water (E)	1	1	1	1	1	1	2	1	1	2	1	1

Table 5: Natural Ground Classification from NEXCO-system

Chainage	Location	A	B	C	D	E (Adjustment)	Total	Grade point	Natural ground classification
	Right	15	21	4	7	0	47	38.25	DII
0+502	Center	10	21	4	0	0	35		
	Left	15	10	4	7	0	36		
	Right	15	21	4	7	0	47	47	CII
0+513	Center	15	21	4	7	0	47		
	Left	15	21	4	7	0	47		
	Right	15	21	4	14	0	54	41.75	CII
0+587.8	Center	15	21	4	7	0	47		
	Left	10	10	4	0	-5	19		
	Right	20	21	4	14	0	59	43	CII
0+590.2	Center	15	21	4	7	0	47		
	Left	10	10	4	0	-5	19		

Observations were conducted at various chainages along the tunnel alignment. Readings for left, crown and right side of each section were meticulously recorded. The grade classes were determined in accordance with the literature cited in tables 1 and 2 along with on-site observations. Subsequently, rating was assigned based on the identified grade classes, utilizing the information from table 2. The computed cutting face grade points were then correlated with the types of ground, as describe in table 3. Tables 4 and 5 display the NEXCO rating corresponding to various chainages and the natural ground classification from the NEXCO system, respectively.

2.4 Ground Classification by RMR and Q Systems

RMR and Q-rating was calculated at the same chainages for which the NEXCO rating were computed. Ratings for all the required parameters were done based on field observation and literature review. The rating for each parameter and corresponding ground classification results for RMR-system and Q-system are shown in table 6 and table 7 respectively.

Table 6: RMR rating at different chainages

Geomechanics Classification					
S.N.	Description	Rating Chainage to chainage			
		0+497 to 0+502	0+508 to 0+513	0+581.8 to 0+587.8	0+584.2 to 0+590.2
1	Uniaxial compressive strength of rock	4	4	4	4
2	Rock quality designation (RQD)	8	4	8	8
3	Spacing of discontinuity	8	10	8	10
4	Condition of discontinuity	10	10	10	10
5	Groundwater condition	10	10	10	10
6	Orientation of discontinuity	-5	-5	-5	-5
	Rock Mass Rating (RMR-rating)	35	33	35	37

Table 7: Q Rating at different chainages

Rock tunneling quality index (Q)					
S.N.	Description	Rating Chainage to chainage			
		0+497 to 0+502	0+508 to 0+513	0+581.8 to 0+587.8	0+584.2 to 0+590.2
1	Rock quality designation (RQD)	25	25	25	25
2	Joint set number (Jn)	9	9	6	6
3	Joint roughness number (Jr)	1.5	1	1.5	1.5
4	Joint alteration number (Ja)	3	3	3	3
5	Joint water reduction factor (Jw)	1	1	1	1
6	Stress reduction factor (SRF)	1	1	1	1
	Rock Quality Index (Q-rating)	1.38	0.93	2.08	2.08

3. RESULTS AND DISCUSSION

Ground characterization is prerequisite for the analysis and design of underground structure. Prior to design, appropriate geo-physical method, geotechnical method and field observation was conducted for the acquisition of the ground characterization parameter. It is obvious that the entire reliability of the result is governed by the correctness of the input raw data. The result obtained in the table 8 is based on the available data from project office with the fair intention of the academic institution.

Table 8: Ground classification based on RMR, Q-system NEXCO classification

	RMR-system		Q-system		NEXCO-system	
Chainage to Chainage	Rating	Ground classification	Rating	Ground classification	Rating	Ground classification
0+497 to 0+502	35	Poor	1.38	Poor	38.25	DII
0+508 to 0+513	33	Poor	0.93	Very poor	47	CII
0+581.8 to 0+587.8	35	Poor	2.08	Poor	41.75	CII
0+584.2 to 0+ 590.2	37	Poor	2.08	Poor	43	CII

Ground classification as obtained from three different methods: NEXCO, RMR and Q systems is shown in table 8, reflects that from RMR, the ground classification is “poor” at all the chainages, but from Q-system it is found that “very poor” at chainage 0+508 to 0+513 and “poor” at other remaining chainages. from NEXCO-system, it was found to be “DII” at chainages 0+497 to 0+502 and CII for chainages 0+508 to 0+513, 0+581.8 to 0+587.8 and 0+584.2 to 590.2. From these results it can be concluded that the ground classification types of NEXCO: DII is similar to poor from RMR and poor from Q system. Similarly, CII is similar to poor from RMR and poor or very poor from Q-system. From these results of ground classifications, the required support systems can be obtained. The support systems obtained for the selected locations are: systematic bolt of 4-5m length with spacing of 1-1.5 m with wire mesh, shotcrete of thickness 10-15 cm and steel rib from RMR; fiber reinforced shotcrete and bolting from Q system; shotcrete of 15 cm thick and rock bolt of length 4 m and 1.2m spacing along circumferential direction from NEXCO system. This result indicates the difference in support estimation obtained by each method.

4. CONCLUSIONS

Ground classification as obtained from three different methods: NEXCO, RMR and Q system depicted that NEXCO: DII is similar to poor from RMR, and poor or very poor from Q system. Similarly, CII is similar to poor from both RMR and Q system. The provision of support system based on RMR value is fully grouted, 20mm diameter systematic bolting with its length of 4-5 meter which are spaced by the distance of 1-1.5 meter in crown and walls with additional wire mess. But the provision of support system based on Q value is fiber reinforced shotcrete having thickness 6cm and bolting of length 4m for poor ground and 10 cm thick shotcrete with bolting of length 4m for very poor ground. However, the support suggests by NEXCO system shotcrete of 15 cm thick and rock bolt of length 4 m by 1.2m spacing along circumferential direction. The rock of relatively hard and slightly deterioration due to weathering but which not deteriorate due to water is referred as poor rock mass in RMR and Q-system. This information examined that certain correlation between RMR-system, Q-system and NEXCO rock mass classification systems.

Suggestions and recommendations

This research was based on data available from the project office, to compare the ground classification adopted by NEXCO system with RMR and Q systems, NEXCO system should be performed for different variety of ground types and complete correlative model can be prepared. Ground classifications for different locations can be performed by the aforementioned methods to generate a relationship. Geological formation affects the types of ground, this study gives the ground behavior for lesser Himalayan region rock masses, further interpretation about ground classification can be obtained by similar process performed in different geological regions of Nepal.

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CONFLICTS OF INTEREST

There are no any conflicts of interest of authors with "Nagdhunga-Naubise Road Tunnel Project" of Nepal. The paper assigns the views of the authors only based on information and data presented herein. The contents do not reflect the official views of "Nagdhunga-Naubise Road Tunnel Project" of Nepal. This paper does not suggest any standard specification or regulation for underground construction in Nepal.

DATA AVAILABILITY STATEMENT

The data can be available by author upon request.

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