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Geotechnical properties of the Fagfog Quartzite for curved-cuts along Mugling Narayanghat road section

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ABSTRACT

Slope cutting in hard and steep slopes are very difficult task. In Mugling-Narayanghat road section, near Mugling, hard quartzite rock was obstructing road expansion because of vertical slope. In the area rock of the Fagfog Quartzite is present which has very good geotechnical properties. In the area, rock mass classifications was carried out using RMR, Q and GSI where maximum and minimum rock mass class values are II and I respectively. Other properties of the area like unit weight (γ), uniaxial compressive strength (σci), Young's modulus (Ei), Poisson's ratio (v) and RQD were also calculated according to the rock mass classification. The slope was designed in such a way that the maximum stability for minimum excavation. All the analysis were carried out in numerical modeling using FEM, as much as possible replicating real ground condition. From the analysis total displacement at suitable cut angles was determined.

Key words: Rock mass class, curve cuts, slope stability, FEM

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INTRODUCTION

In the context of mountainous country like Nepal, it is very much difficult engineering work to construct the roadways. Most of the way pass through the high ridges and valleys. For the durable and stable roadways, many scientists have made the different analysis of rock mass properties. Without removing overburden of hill slope, roadways can be made and also can make enough wide by the help of cure cut slope techniques. Among Mugling-Narayanghat road sections, a hard-rock terrain section is one of the widening sections selected for the study. At present, width of the road is 6-10 m where the daily traffic movement is around 6000 vehicles (EA Report 2012). The concept for the widening the road width is from 6-10 to 9-11 m for ease. Widening of mountainous section is mostly hazardous to avoid unstable hill slope. For stabilizing the hill slope with less excavation work, it is more challenging. Rock slope excavation was needed at the study area for road extension. But the area consist steep slope with hard rocks. Therefore, the study is carried out to reduce the excavation by designing curve cut slope and analyzing their stability. Although the bed rocks are stable in the low angle cut, they are excavated more than 90 degrees which is worthless. Such type of excavation tradition is necessary to change by new curve designing technique for reducing cost and time based on hard rock and soft rock properties. The method of using rock mass strength and stability properties are quite useful for designing the curve slope and these techniques are widely in use.

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GEOLOGY OF THE STUDY AREA

The study area belongs to the Midland Group of Nawakot Complex (Fig. 1). It basically consists of the Fagfog Quartzite and Dandagaon Phyllite. It covers about a kilometer of the horizontal distance along the Mugling-Narayanghat road section. Since the area is small, it does not contain any kind of major geological structures like thrust and fault.

Geologically, Nepal Himalaya is divided into five tectonic zones (Gansser 1964); the Indo-Gangetic Plain, the Sub-Himalaya, the Lesser Himalaya, the Higher Himalaya and the Tibetan-Tethys Zone from south to north respectively. Thrust and fault are the major geological structures which separate the different tectonic zones. For the establishment of stratigraphy in the Himalayan territory, many geoscientists have worked within this region for a long time. Hagen (1969) has prepared a general geological map by traversing through all Nepal and published his entire work in 1969. He developed concept of the nappe structure in the Nepal Himalaya. He first delineated the Kathmandu Nappe with its root zone to the Langtang Himalaya through the Gosainkunda transect. Le Fort (1975) divided the Higher Himalayan Crystalline into three formations as Formation I, Formation II, and Formation III in ascending order. Formation I comprises banded gneiss, Formation II comprises calc-silicate gneiss and Formation III consists of augen gneiss. Stöcklin and Bhattarai (1977) categorized the rocks of central Nepal into two sequences, Kathmandu Complex as allocthonous sequence and Nawakot Complex as autochthonous sequence. These two complexes are separated from one another by a thrust known as Mahabharat Thrust (MT). The meta-sedimentary to sedimentary rocks of the

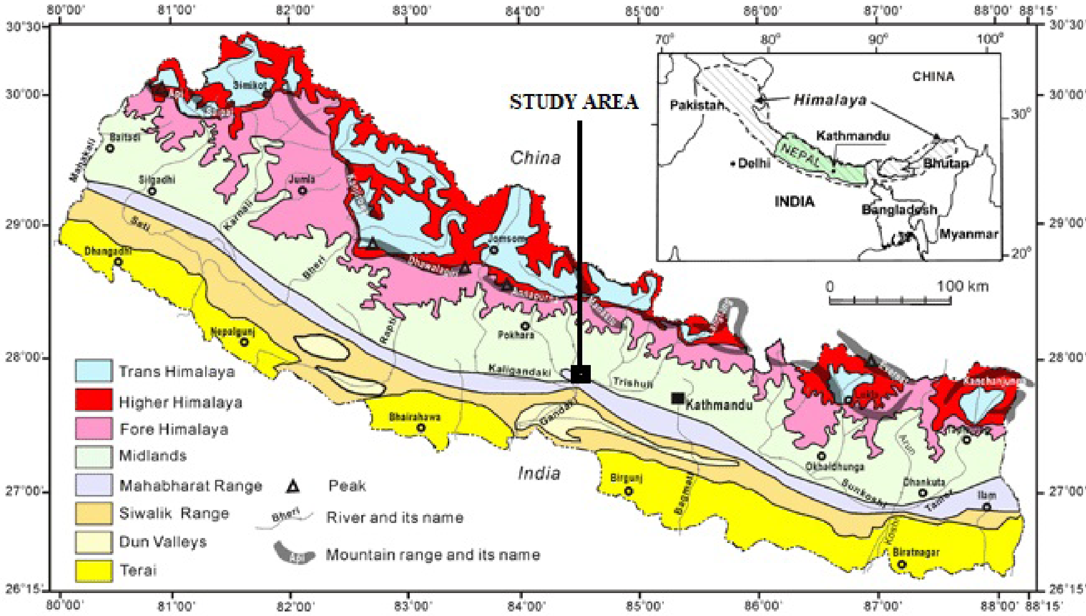

Fig. 1: Location of the study area (after Dahal and Hasegawa 2008).

Nawakot Complex and the Kathmandu Complex are further divided into four groups. They are Lower Nawakot Group, Upper Nawakot Group, Bhimphedi Group and Phulchauki Group in ascending order. The geological age of these rocks are Precambrian to Lower Paleozoic.

MATERIAL AND METHODS

The study area is located in Mugling-Narayanghat road section in the Chitwan District of Nepal. The spot of the study area is 2 km towards Narayanghat from Mugling Bazar lies at 27°51'20.1"N and 84°33'36.4" E (Fig. 2). Geologically the study area lies on the Midland Group of the Lesser Himalaya. The research is based on the Mugling-Narayanghat road widening concept. Mainly three rock mass classification systems were carried out to design the curve cut slope where hard rocks are making the excavation work slow and high time consuming. During the field work, the data required for cut designing, Rock Mass Rating (RMR), Rock Mass Quality (Q), Geological Strength Index (GSI) were measured and calculated. In this study, above mentioned classification schemes were used to design and check the stability of the curve-cut slope for widening the road rather than full excavation. Numerical modeling (FEM) was done for designing the curve-cut slope and analyzing its stability.

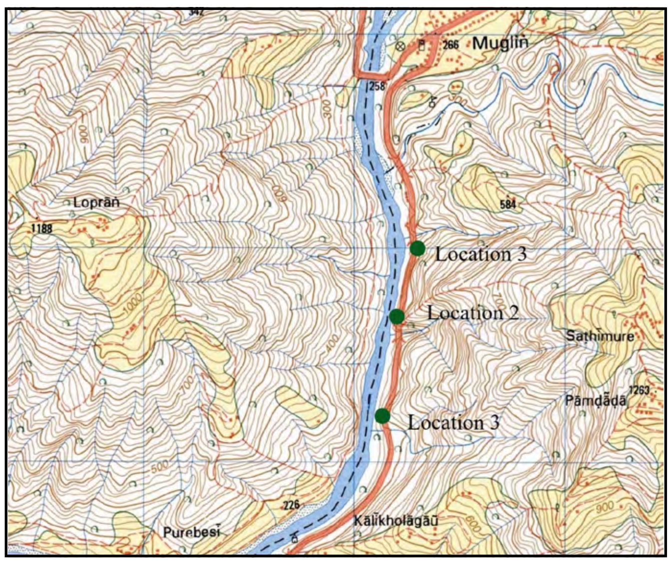

Fig. 2: Location of study area.

RESULTS

Geotechnical properties of rock

During the data collection from the field, different geological instrument and method were used to gain the desire data for the further analysis. Rock samples were collected from each of the five rock units for the determination of geotechnical properties like unit weight (γ), uniaxial compressive strength (σci), Young's modulus (Ei), Poisson's ratio (ν), Rock Quality Designation (RQD), RMR, Q and GSI according to the rock mass classification.

Schmidt rebound hammer (N)

Schmidt rebound hammer (N) was used to check the Uniaxial Compressive Strength (UCS) of intact rock in the different location in the field. From those data UCS was calculated location wise which is shown in the Table 1.

Table 1: UCS calculation from Schmidt Rebound Hammer test

N	Location	L1	L2	L3
	Range	48-57	52-62	50-56
	Mean	53.7(10)	57(12)	53.7(11)
UCS	135MPa	170Mpa	135MPa	

Rock quality designation (RQD)

For the calculation of Rock Quality Designation (RQD), volumetric joint count technique was used. From each location RQD was determined to know the quality of rock and also for calculation of Rock Mass Rating (RMR) and Rock mass Quality (Q). The determined value of RQD and its qualitative description is given below in Table 2.

Table 2: Rock Quality Designation with qualitative description

Location	L1	L2	L3
RQD value	83	98	93
Qualitative description	Good	Excellent	Excellent

Rock mass rating (RMR)

In order to determine the rock mass rating (RMR), (Bieniawski 1989) version rock mass rating system was used. For the five different locations all above parameter were determined and RMR was calculated. The location wise RMR value, its class and classification of rock mass from is given in Table 3.

Table 3: RMR, rock class and classification at three locations.

Location	L1	L2	L3
RMR basis Value	77	82	85
Rock Class	II	I	I
Classification	Good	Very good	Very good

Geological strength index (GSI)

Geological strength index (GSI) of the rock masses for the study area were determined by using the modified GSI chart of (Sonmez and Ulusay 2002).

Table 4: Geological Strength Index.

Location	L1	L2	L3
Rock type	Quartzite	Quartzite	Quartzite
GSI	750	85	90

Excavation problem

For the stable slope, cut slope is excavated more than 90 degree angle which is time consuming and costly. In the context of hilly countries like Nepal it is difficult to construct the road ways for transportation. Practices are easier in the soft rock or sediment deposited site but very difficult in the hard bed rock containing area. In the study section the bed rock is of the Fagfog Quartzite which is very hard for the excavation. Due to following the old tradition of road construction and lack of using different modern technique in hard rock and soft rock the work is being more time consuming and costly.

Numerical analysis of the low excavation

The 2D numerical analysis predicted a maximum displacement of x in areas supported with y thick materials. In numerical analysis, it is anticipated that 50% of the total deformation of the rock mass happens immediately after excavation, before the application of rock support. Hence, the total deformation may be double the initial deformation. The curve cut slope is made to widen the highway for the international trading ease. The excavation is in low curve, high curve or straight in the roof part according to the stable condition of the structure and the rock type. The in-situ vertical and horizontal stresses are obtained from the overlying column of rock and the lateral stress ratio (K, a ratio of horizontal to vertical stress) was calculated from the value of Poisson's ratio. Since the main emphasis of this study is to observe the deformation around the opening, the far-end boundaries have been restrained in both horizontal and vertical directions (Fig. 3). The discontinuities were then incorporated into the model based on field conditions. The meshing used in the model is graded 3-node triangle, which is further refined near the opening.

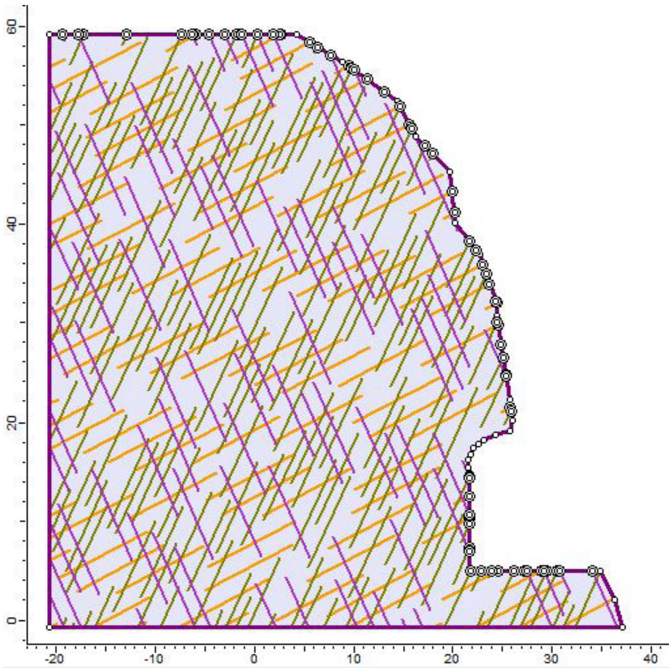

Fig. 3: Diagram showing geometry of the model and boundary condition used in the simulation (joint and other parameters are changed for different rock type and location).

In the first location, the quartzite rock mass was observed (Fig. 4). These rock mass lies in the Fagfog Quartzite of Nawakot Complex. It has three joint set with variation in spacing and persistence. For the first time curve cut design is given as negative angle, which is not favoring the cut slope. Total displacement is seen high in this curve cut design. To stabilize the curve cut slope, smoothing is done by making the cure with fewer angles. Almost in the horizontal plane, the cut slope is stable (Fig. 5). To check the other favorable condition for the stable cut slope, the cure angle is increased in positive angle. But no favorable condition is observed as in the horizontal cut. If other curve cut design is applied then more excavation is needed. In the second location (Fig. 6) also lies in the Fagfog Quartzite of Nawakot Complex. It also has three joint sets having variation in the persistency and spacing. Same kind of modeling is used in this location. When the curve of the cut slope is made negative from the horizontal plane, the cut slope is not stable as total displacement shows the instability of the curve edge. When the smoothing is increased and reached to the horizontal plane position, again instability condition is observed. Finally in the third design of low positive curve cut angle, the curve cut is stable. So the low curve cut is considered as stable cut design (Fig. 7).

Fig. 4: Hill slope at Location 1.

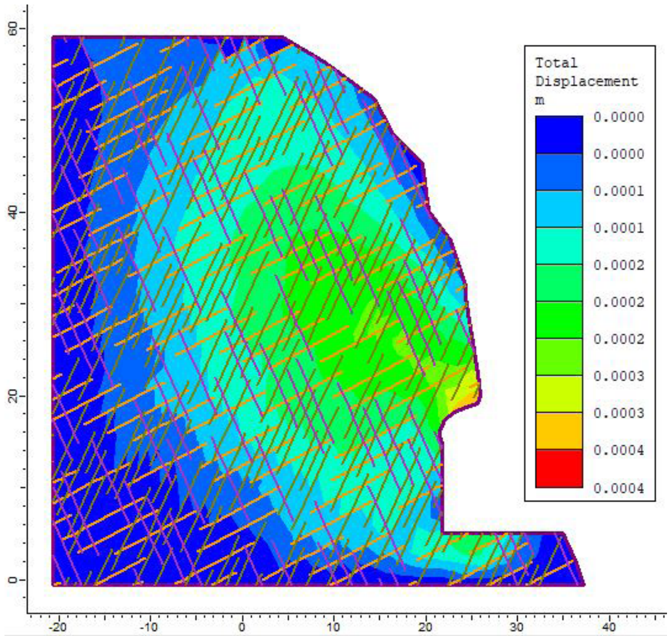

Fig. 5: Total displacement occurred in Location 1 due to high curve cut slope.

The third location (Fig. 8) which is also lies on quartzite rock mass. Similar stability analysis with the different angle of curve cut slope is analyzed in this section. In the negative curve cut slope of numerical modeling, instability with high total displacement is observed. When the smoothing is done in the cure cut angle, in the horizontal plane also, stability condition is not observed. Before making the final concept about the stability position of the curve cut, further more low curve is made to observe its stability if there is any more possibility. The total displacement shows favorable condition at low curve cut slope (Fig. 9). From the study in the different three location of Mugling-Narayanghat road, given results were drawn. In the location L1, various cut angles were modeled taking angle zero for horizontal, positive for upward angle and negative for downward angles, three of them are shown in Figs. 3, 4 and

Fig. 6: Hill slope at Location 2.

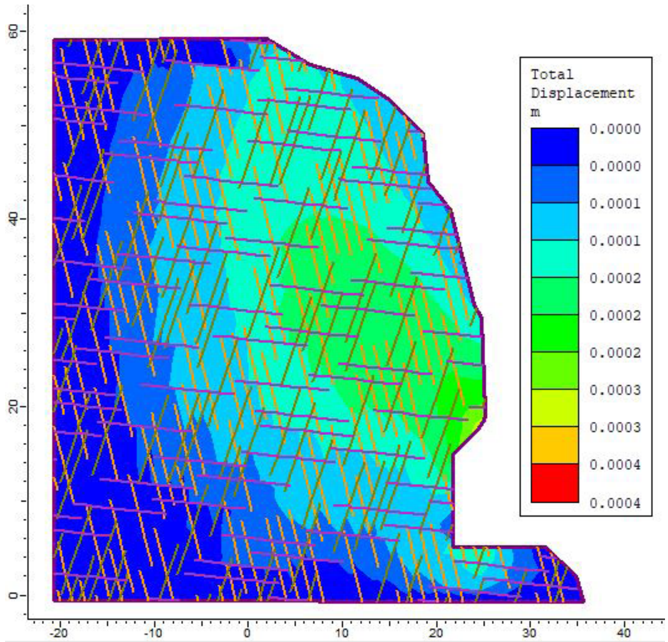

Fig. 7: The total displacement occurred in Location 2 due to straight cut slope.

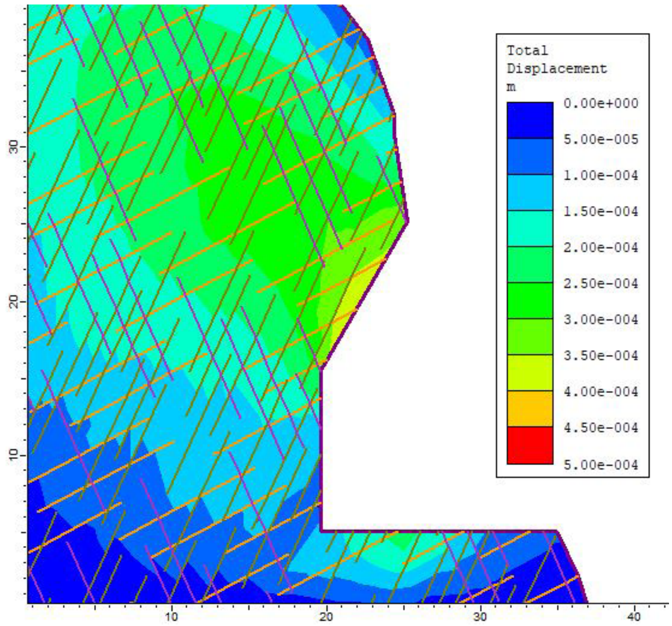

Fig. 9: The total displacement occurred in location 5 due to low curve cut slope.

Fig. 8: Hill slope at Location 3.

5. The most stable curve cut angle of L1 is at 5° angle almost horizontal, which is shown by the help of numerical modeling (Fig. 4). Similarly in the location L2 the curve cut is stable at an angle of 15° likewise L3 in 60°. These were checked among the various angle type of roof curve design for stabilizing the cut slope. From the results of the numerical modeling it was noted that most of the curve cut were stable at less than 45° which mean the low curve cut were suitable in the study area. The values of the total displacement calculated from the stable curve cut slope (Table 6).

Table 6: Values of total displacement calculated from numerical modeling.

Location	σ1 (MPa)	σ3 (MPa)	σm (MPa) (mean)	Total Displacement (mm)
L1	0.74	0.32	0.60	0.3
L2	0.20	-0.08	0.05	0.3
L3	0.30	0.00	0.20	0.5

The angle of the stable curve cut was compared with the value of the RMR, RQD and Q (Table 6). Almost all rock types having three sets of discontinuities with irregular discontinuities in the quartzite. As a result, the joint parameters like spacing, persistence randomly vary in the hard rock zone.

DISCUSSION AND CONCLUSION

The main purpose of the study was to provide as less excavation as possible in the high hill slope to widen the Mugling-Narayanghat Highway for preserving the time and cost. For this purpose, study of geological and geotechnical condition existing in those area were absolutely necessary. The rock mass classification systems were used for preliminary curve cut slope design as an empirical method. In this study, different angle for the curve cut slope was designed and analysed for the stability. Different location possesses different joint patterns, spacing and persistency, due to which the angle of curve cut varies. Anbalagan et al. (2003) has done the similar work in their study. In their study, they had done the

Table 7: Values of RMR, Q and RQD with stable cut angle.

Location	Lithology	Rock Class			Stable cut angle (°)
		RMR	Q	RQD	
L1	Quartzite	77	36.9	83	5°
L2	Quartzite	82	98	98	15°
L3	Quartzite	85	93	93	60°

Rock Mass Quality (Q) comparison with each location. They did the study of already constructed half tunnel which is similar to the curve cut slope. They had done some of the comparison of maximum unsupported span value of the tunnel with the Q value which is similar to this study. In the numerical modeling, stress distribution analysis was done as the stress distribution analysis done by them. Their study established a relationship between the Q and span of curve.According to the study of Siming and Xinpo (2008) shown pre-reinforced half-tunnel structure in high cut slope is stable and suitable for low cost and saving the time. They also had kept the thought of caring the vegetation in the high cut slope. Similar type of numerical modeling was done as in this study. They used different kind of support model for stabilizing the cut slope keeping the curve in same angle because the rock mass strength was low but in the present study the curve cut was smoothen in such angle that it can sustain without support. Curve cut slope technique was used in some of the hilly area of Nepal without designing and stability analysis though it is surviving since seven years (Figs. 10 and 11). This study is not useful only in the studied area but also can be used similar kind of technique for other place also where rock mass conditions are similar. Different researches are also going on in this side. The present study only dealing without support.

Fig. 10: Section view of curved-cut slope on the way to Manang.

Fig. 11: Front view of curved-cut slope on the way to Manang.

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