Rockmass characterization at Saptkosi multipurpose high dam project in Nepal

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Abstract

Spatkosi multipurpose high dam project is aimed at tapping the immense hydropower potential of mighty Saptkosi River in Nepal, by constructing a 269m high earth core rock fill dam. Though the geological and geotechnical investigations at the project site were initiated in 1946 however they still remain incomplete. The exploration program, however, was not supplemented with the geo-mechanical testing of the rock samples or drill cores. The logging of drill cores and exploratory drifts also lacked the present day geotechnical parameters.

The present endeavor has been to evolve a comprehensive geotechnical model of the rock masses at Saptkosi dam site and it has been done in a systematic way by i) delineating and standardizing the rock types by their physical and textural characters and also after studying them in thin section, ii) faithfully collecting the field data for the discontinuities, iii) structurally analyzing the discontinuities by stereo plotting, iv) grouping the discontinuities into different sets, v) calculation of basic rock mass parameter RQD with the help of volumetric joint count Jv, vi) estimation of Uniaxial Compressive Strength (UCS) and point load value with the help of field character and by comparing with the chart for strength properties, vii) calculation of rock mass parameters like Q, RMR, Qc and GSI following the standard practices of Barton, Beiniawski and Hoek, viii) calculation of other parameters like Emass, FC, CC, Vp, Pr and Lugeon by fitting the values of Q, RMR, Qc and GSI into standard equations, ix) using the evaluation version of free software Roc Lab V1 for determining the Hoek - Brown parameters and Mohr Coulomb constants for different rock masses, and x) comparing, cross checking and back calculating the different parameters with each other, which have been derived from different systems.

1. Introduction:

The Saptkosi high dam project envisages to generate about 3000 MW of hydroelectricity by constructing a 269m high earth and rock fill dam across Saptkosi and once completed it will be one of the highest dams in South- East Asia and would be, fourth highest in the world. It is likely to usher in sweeping changes in the socio-economic condition of the people in Nepal and also bring respite to the people in the command area, especially from the frequent flood hazards.

The present Dam site is located across a narrow gorge about 1.6 Km upstream of, the well known pilgrimage town, Barakshetra, close to foothills, in Eastern Nepal. It can be approached by an un-metaled road up to Barakshetra. The site has been visited by a number of workers ever since the site was identified for a high dam, as early as 1946, the earliest and notable being J. B. Auden, K. K. Dutta, Subramanian, F. A. Nickel, M. S. Jain etc.

The geological and geotechnical investigations at the project site were started in 1946 by the officers of Geological Survey of India and a Detailed Project Report was submitted to the project authorities. The earlier investigations brought out the broad geological outline of the project area but the geotechnical parameters collected are not adequate to characterize or classify the rock masses at the site and it is largely because of the fact that majority of the modern day rock mass classification systems (except for Laufer's and Terzhagi's) were not in vogue at that time. The term used for defining the geotechnical characters for different rock masses were Fractured Quartzite, Hard Quartzite, Shattered Quartzite etc. which do not fit into the present day classification systems and neither it gives any idea about their geomechanical properties.

The detail geological mapping on 1:1000 scale of a part of the left bank of Saptkosi dam site was carried out in order to define the litho-units up to river bed level and to collect field structural data accurately so that the basic input parameters for characterizing the rock masses can be generated. The input parameters have been used for empirically calculating the various geo-mechanical characteristics of different rock masses and finally a comprehensive geotechnical model for the delineated rock masses has been evolved. In the absence of tested values of any of the characters this geotechnical model will enable the designers to have a preliminary synoptic view of the rock mass characters at the dam site and also help in preliminary design of various surface and underground structures like dam, diversion tunnels and shaft spillways etc.

2. Regional geological framework:

Regional geological set up in the area epitomizes the general litho-tectonic framework of the Himalayas. The NW – SE trending rocks of the Lesser Himalayan thrust sheet represented by meta-sedimentary sequence of Kosi series, at the dam site, are overlain by epi-metamorphic Daling rocks followed towards south by Gondwana group of rocks, overlie the molasse deposits of Siwaliks along the Main Boundary Fault (MBF). The Himalayan Frontal Fault (HFF) delimits the tectonic boundary of Siwaliks against the plains of Ganga basin to the south of MBF. The Gondwana rocks, represented by carbonaceous shale, slate, quartzite and boulder bed are in a highly deformed state cut across by a number of shear planes. The underlying rocks of Siwalik Group comprise of sandstone, shale and clay beds which are involved in broad open folding and further split by several intra-formational faults most prominent of them being the Nahan thrust.

Main Boundary Fault is the most prominent tectonic dislocation, encountered only 1.5 Km downstream of the dam site, close to Kokah khola nala. The fault seems to attain sub-vertical dips inducing severe deformation and shearing in the adjacent rocks. Considering the sub-vertical dip of this fault and its location on ground vis-à-vis dam, it is anticipated that it may go more than 3km below the dam seat. The contact between Kosi and Gondwana rocks, shown as an unconformable by earlier workers, as validated by ground evidences, is definitely tectonic in nature and is marked along the trace of Sonakhumbi nala on the left bank of Saptkosi river.

Seismogenic potential of all the above discussed tectonic dislocations has not been studied so far and therefore it is not possible at present to comment on the impact of these on the stability of the structures.

3. Geology of the dam site:

Dam site exposes a thick pile of folded meta-sedimentary sequence of rocks of Kosi series which are juxtaposed against highly deformed carbonaceous rocks besides quartzites, dolomite and slate of Gondwana Group. The tectonised contact between the two units is marked in the southern vicinity of the dam site.

At higher tectonic levels, the rocks of kosi series are overlain by relatively higher grade of meta-sedimentary rocks, distinguished as Daling Group (Neo-Proterozoic), consisting essentially dark grey schistose phyllite. The nature of contact between them (Kosi/Daling) could not be established because of paucity of exposures, although it has been defined as Daling thrust by earlier workers (Auden, Dutta and Nickel).

Meta-sedimentary rock succession at the dam site, referred as Kosi series, by earlier workers, comprises quartzite, slate with coal stringers. Thin overburden material representing slope wash material, slide debris, rarely exceeding 1 – 2m, but for the slide affected zones, cap the bed rock in isolated stretches. The beds are dipping steeply at 50^0 – 70^0 towards upstream with a NW – SE strike. The dip reversals influenced by folding is common.

Quartzite is the most predominant unit with slate as the associated unit. The quartzite has further been differentiated into two viz i) Massive Quartzite (MQ) and ii) Bedded Quartzite, on the basis of thickness of beds and the textural condition. For adopting a simplified approach the quartzite with bed thickness less than 30cm have been grouped as bedded quartzite and conversely the one having bed thickness greater than 30cm have been termed as massive quartzite. The two units show marked difference in hand specimen and in thin section as well. A brief description of massive quartzite, bedded quartzite and slate is given below.

i) Massive Quartzite (MQ):

In hand specimen it is greenish grey to grayish white, hard and compact, medium to fine grained clearly showing signs of re-crystallization. It is more often than not difficult to mark the bedding plane in this unit as compared to bedded quartzite. The study of thin sections revealed that massive quartzite is mainly grain supported with the sub-rounded clasts of quartz set in a matrix of clayey contents with some ferruginous cementing material and calcite veins in some places. However it is worth mentioning here that there is near absence of metamorphic minerals in thin section, thus indicating that the rock has not undergone intense deformation or metamorphism.

ii) Bedded Quartzite (BQ):

It is greyish white, off white and sometimes pale red in hand specimen, moderately hard and compact. The bedding plane is clearly discernible in the form of fine laminations, color banding and grain size variation. In thin section the bedded quartzite is mainly matrix supported rock in which the sub rounded to sub angular clasts of quartz and feldspar are floating in clayey matrix. The feldspar grains show distinct signs of weathering and alteration. At places calcite veins are also seen. It also does not show any preferred orientation of mineral grains which would indicate any deformation or metamorphism.

iii) Slate (SL):

It is the argillaceous variant of Kosi series occasionally associated with MQ and BQ. It is a fine grained and fine textured rock, greenish grey to olive green and has clear development of cleavage/foliation. Its intercalations in BQ are well seen near the gauge and discharge (G & D) measurement site upstream of dam axis. The rock at many places attains splintery nature. The thin section shows that it is a fine to very fine grained rock predominantly matrix supported with occasional clasts of quartz. There is however definite indication of development of foliation planes of different origins. The state of weathering of rocks, at the site, were assessed in field as per the grades enumerated by Bell (1983) confirm to W1 – W2 grade. However in the tectonised and water saturated zones degree of weathering degrades to W3.

It is apparent from the geological map that MQ constitute more than 55% of the mapped area and will thus cover a large part of the proposed dam foundation.

3.1 Structures:

Folds:

The rocks of Kosi series are involved into a series of antiforms and synforms ranging from upright to inclined and even overturned folds. The earliest generation is represented by tight isoclinal folds with high amplitude and thickened hinges. The upright to inclined open folds of second generation are well displayed at the outcrop level and are recognizable by variation in the attitude of bedding planes. Folds of third generation are characteristically open with sub-horizontal axial planes dipping due SE with low (about 20^0) plunge.

Faults:

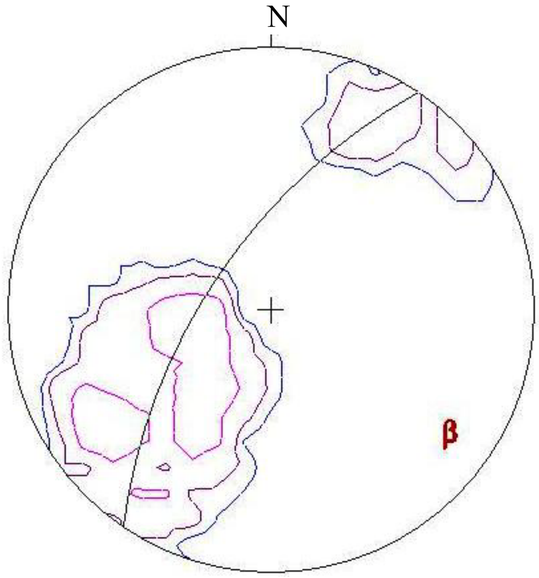
A number of tectonic dislocations/ weak planes have been identified and mapped of which the most important being a fault along Sonakhumbi nala. This fault brings chaotically crushed and complexly folded carbonaceous slates, coal, quartzite and boulder beds of Gondwana Group in juxtaposition with relatively less deformed splintery slate – quartzite sequence of Kosi series. It is, however, quite certain that the dam body, in its southern limits would be free from the effects of faulting.

Joints:

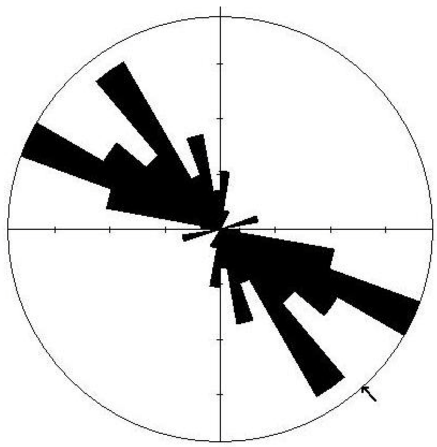
Joint sets of various order and inclination have been systematized into eight groups and their characteristics have been shown in table-1. Orientation and interplay of different joint sets has been analyzed with respect to slope disposition to check for failure conditions. The plots of contours with beta axis and the rose diagrams of the prominent joint sets are given in figures 1.

Table 1
Details of Joints on the Left Bank of Saptkosi High Dam Project

Sl. No.	**Joint**	**Dip**	**Azimuth**	**Spacing (cm)**	**Continuity (cm)**	**Remarks**
1	J1	$55^0 – 80^0$	030^0-080^0	5 - 100	100 - 500	Bedding Joint shows variation in attitude due to antiformal and synformal closures, smooth planar
2	J1a	$60^0 – 85^0$	200^0 –235^0	5 - 100	100 - 500	
3	J2	$75^0 – 85^0$	$170^0 – 185^0$	2 – 10	100	Foliation joint, smooth planar
4	J3	$55^0 – 75^0$	$250^0 – 270^0$	5 – 80	100 – 300	Moderately smooth, wavy, forms gliding plane at places
5	J4	$60^0 – 75^0$	$295^0 – 325^0$	10 – 50	200 – 500	Smooth planar, slickenside, forms wedges with J1 and J2
6	J4a	$40^0 – 50^0$	$290^0 – 315^0$			
7	J5	$55^0 – 80^0$	$325^0 – 340^0$	10 – 100	50 – 150; broken +300	Moderately smooth planar
8	J6	$65^0 – 75^0$	$160^0 – 170^0$	4 – 50	50 - 200	Moderately smooth planar to Rough undulatory
9	J7	$50^0 – 65^0$	$110^0 – 130^0$	50 – 150	100	Random, Smooth planar
10	J8	$45^0 – 65^0$	$180^0 – 210^0$	10 – 30	100 – 200	Rough, forms wedges with J3



Stereo Plot of J1 (S0)



Rose Diagram of J1 (S0)

Figure 1 Contour and Rose Diagram of J-1

3.2 Rock mass parameters :

3.2.1 Rock Quality Designate (RQD):

Although a number of holes were drilled on left bank but their logs do not have any mention of RQD, it has thus been decided to calculate RQD using volumetric joint count (Jv) method (RQD = 115 – 3.3 x Jv).

Table 2
RQD for Different Rock Types at Saptkosi High Dam Project, Nepal

Rock Type	Jv	RQD
Massive Quartzite	10 - 14	82 – 68.80 (Say 80 – 70)
Bedded Quartzite	16 – 18	62.20 – 55.60 (Say 60 – 55)
Slate	20 – 22	49 – 42.40 (Say 50 – 40)

3.2.2 Uniaxial Compressive Strength (UCS):

In the absence of measured lab data, the field estimates of the uniaxial compressive strength of the rock masses have been taken in to consideration for calculating the rock mass parameters viz RMR and Q.

From the above table the comparable UCS of different rock types is as given below.

Table 3
UCS and Point Load Values for different rock types at Saptkosi High Dam Project, Nepal

Rock Type	Grade	Field Character	UCS (MPa)	Point Load Index (MPa)
Massive Quartzite	R5	Specimen requires many blows of geological hammer to fracture it	100 - 250	4 – 10
Bedded Quartzite	R4	Specimen requires more than one blow of geological hammer to fracture it	50 – 100	2 – 4
Slate	R3	Can not be scraped or peeled with a pocket knife, specimen can be fractured with a single blow of a geological hammer.	25 - 50	1 - 2

Thus the UCS values adopted for calculation of rock mass parameters for different rock masses are 150 MPa (Massive Quartzite), 100 MPa (Bedded Quartzite) and 50 MPa (Slate).

3.2.3 Rock Mass Rating (RMR):

Bieniawski's chart for RMR_{89} has been followed for calculating the RMR for the three types of rock masses delineated at the site. It has been observed that the rock masses were slightly to moderately weathered in the surface conditions and their grade of weathering, in general, has been W1 – W2 with minor staining along some of the joints. The spacing of discontinuities has been indicated in table-1above. Most of the discontinuities, barring the shear zones, were having no coating or filling material.

Table 4
RMR for rocks at Saptkosi High Dam Project, Nepal

Rock Type	RMR_{89}	Corrected RMR				Class	Remarks
		Fair Slope	Favorable Slope	Fair Foundation	Fair Tunneling		
Massive Quartzite	78 - 73	53	73	71	73	Class II	Mainly class II
Bedded Quartzite	64 – 69	44	64	62	64	Class II	Lower side of Class II tending towards Class III
Slate	52 – 57	32	52	50	52	Class III	Mainly Class III

3.2.3 Rock Mass Quality (Q):

Configuration on the left bank indicated that three joint sets namely J1(a), J3, J4 and J8, individually or in combination will be directly or indirectly influencing the excavation of slopes in different sections/faces, therefore the ratings for Jr/Ja have been assigned considering the characteristics of these joints. RQD and UCS values as used for RMR have also been used here. The other Q values viz Q' and Qc have been calculated by the following equations (Barton 2002).

Q' = RQD/Jn x Jr/Ja Eqn. - 1
Qc = Q x σc/100 (σc = UCS of rock mass) Eqn. - 2

Table 5
Rock mass Quality (Q) for different rock types at Saptkosi High Dam Project, Nepal

Rock Type	Q'	Q			
		Low Stress	Low Stress (Portal)	Medium Stress (Dry Condition)	Medium Stress (Damp Condition)
Massive Quartzite	18.75 (Qc – 28.25)	7.5 (Qc – 11.25)	2.5 (Qc – 4)	18.75 (Qc – 28.25)	12.37 (Qc – 18.56)
Bedded Quartzite	9.6 – 13.75 (Qc–9.6-13.75)	3.8 – 5.5 (Qc–3.8 – 5.5)	1.27 – 1.8 (Qc–1.27–1.8)	9.6 – 13.75 (Qc–9.6-13.75)	6.33 – 9 (Qc –6.33-9)
Slate	5 – 7.5 (Qc – 3 - 4.5)	2 – 3 (Qc–1.2 – 1.8)	0.66 – 1 (Qc –0.36-0.6)	5 – 7.5 (Qc – 3 - 4.5)	3.3 – 4.9 (Qc-1.98-2.94)

3.2.4 Geological Strength Index (GSI):

The field geological condition of the rock types have been compared with the chart given by Hoek for estimating the GSI values.

Table 6
GSI values for different rock types at Saptkosi High Dam Project, Nepal

Rock Type	**Structure**	**Surface Condition**	**GSI**	**GSI (RMR_{89} -5) Refer Table for RMR above**
Massive Quartzite	Blocky	Fair – Good	65 - 70	73 - 5 = 68
Bedded Quartzite	Very Blocky	Fair – Good	50 - 60	64 - 5 = 59
Slate	Blocky Disturbed	Fair - Good	40 - 45	52 – 5 = 47

3.3 Rock mass characterization:

As stated above that there is no measured lab data since the rock and core samples were not tested for determining the geomechanical parameters. The rock mass at the dam site is being characterized using different empirical equation, as discussed below.

3.3.1 Using RMR values:

Bieniawski (1976) and Serafim et.al (1983) gave equations for estimating the value of modulus of deformation (Emass) using the RMR values for the said rock mass.

Emass = $2\,RMR - 100$ (Beiniawski 1976) Eqn - 3

Emass = $10^{(RMR - 10)/40}$ (Serafim 1983) Eqn - 4

3.3.2 Using Qc Value:

Barton (1995) & Barton (1996) gave empirical relation between Qc and modulus of deformation through

Emass = $10Qc^{1/3}$ (Barton 1995, 1996) Eqn - 5

3.3.3 Compromise between Q and RMR:

Another equation was given by substituting value of Q (calculated through RMR), in equation--- for estimating modulus of deformation as given below

Emass = $10^{(15\log Q+50-10)/40}$ (Barton 2002) Eqn - 6

Table 7
Values of Q, Qc and RMR adopted from table-5 & 6 above

Rock Type	**Q**	**Qc**	**RMR**
Massive Quartzite	7.5	11.25	73
Bedded Quartzite	4.65	4.65	64
Slate	2.5	1.5	52

The values when used in equation-3, 4, 5 & 6 gave the values of Emass as given in table below

Table 8
Emass for different rock types at Saptkosi High Dam Project, Nepal

Rock Type	**Modulus of Deformation (GPa)**			
	Equation Used			
	2 RMR – 100	$\mathbf{10^{(RMR - 10)/40}}$	$\mathbf{10Qc^{1/3}}$	$\mathbf{10^{(15logQ+50-10)/40}}$
Massive Quartzite	46	42.16	37.50	30.90
Bedded Quartzite	28	22.38	15.50	17.37
Slate	4	11.22	5	13

3.4 Analysis through Roc LabV1

The free evaluation version of the software Roc LabV1 has been used to calculate the Hoek Brown parameters, Mohr – Coulomb circle and also the values of Emass, Cohesion (C) and friction. This software is a program for determining rock mass strength based on generalized Hoek – Brown failure criterion. The input parameters like Uniaxial compressive strength (UCS) and Geological Strength Index (GSI) have been used as they were determined from field data whereas the other parameters like Ei and mi have been taken from the inbuilt prompts. The analysis has been done for general condition with the following assumptions

Unit weight of the rock masses	$0.026MN/m^3$,
Slope height	$\leq$ 50m
Cover over Tunnel	$\leq$50m (Portal Conditions)
Excavation/ Blasting	Good Blasting with no damages

Table 9
Input Parameters for different rock types at Saptkosi High Dam Project, Nepal

Rock Type	**UCS (MPa)**	**GSI**	**mi**	**Modulus Ratio**
Massive Quartzite	150	70	20	375
Bedded Quartzite	100	60	20	375
Slate	50	45	7	550

The results along with the plots of Hoek-Brown failure curve and Mohr-Coulomb curves have been shown in figures 2 to 4 below. The important parameters as determined for different rock types, in general condition, have also been tabulated below.

Table10
Rock mass parameters as determined through Roc Lab V1for different rock types at Saptkosi High Dam Project, Nepal

Rock Type	Hoek Brown Criterion			Mohr Coulomb		Rock Mass Characters	
	mb	s	a	Cohesion (MPa)	Friction (0)	Tensile Strength (MPa)	Modulus of Deformation Emass (GPa)
Massive Quartzite	6.85	0.0357	0.501	12.32	42.45	0.781	41.22
Bedded Quartzite	4.79	0.011	0.503	7.06	39.51	0.245	19.50
Slate	0.982	0.0022	0.508	2.05	26.11	0.113	6.15

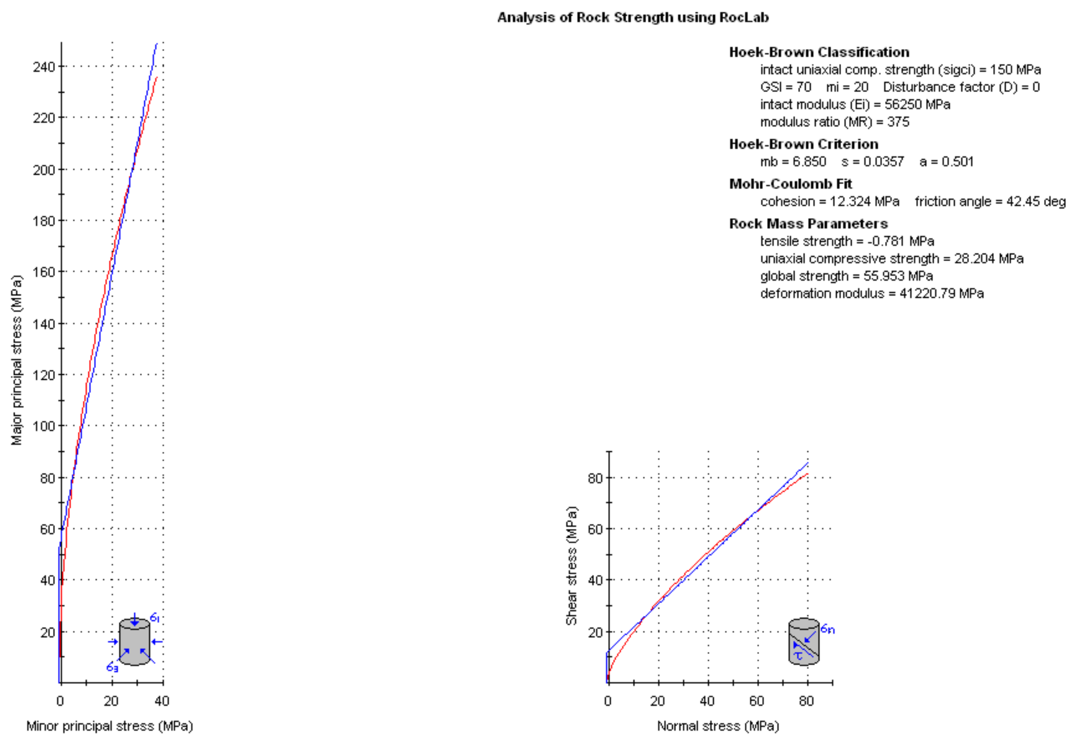


Figure 2 General Conditions Massive Quartzite at Saptkosi High Dam Project, Nepal

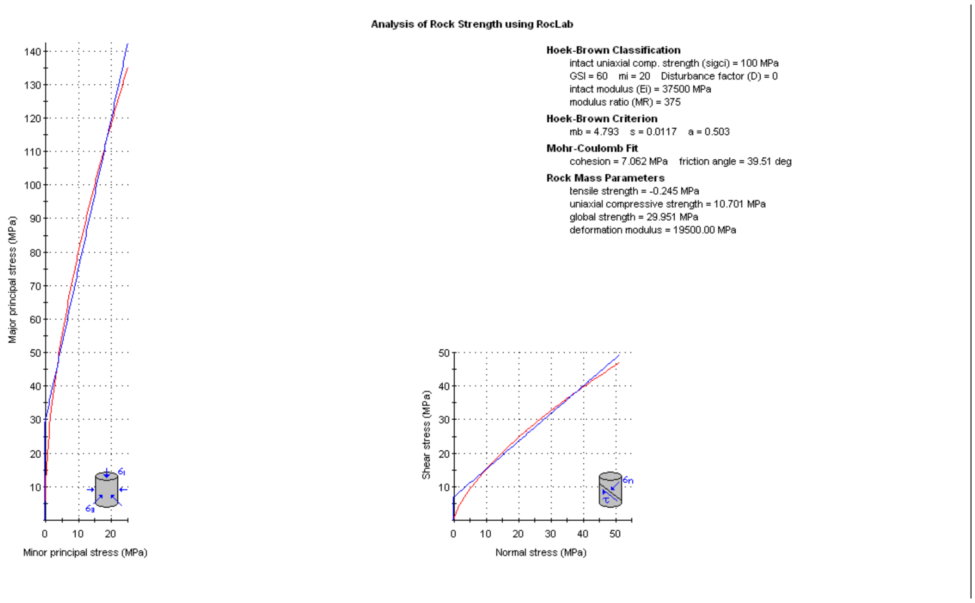


Figure 3 General Condition Bedded Quartzite at Saptkosi High Dam Project, Nepal

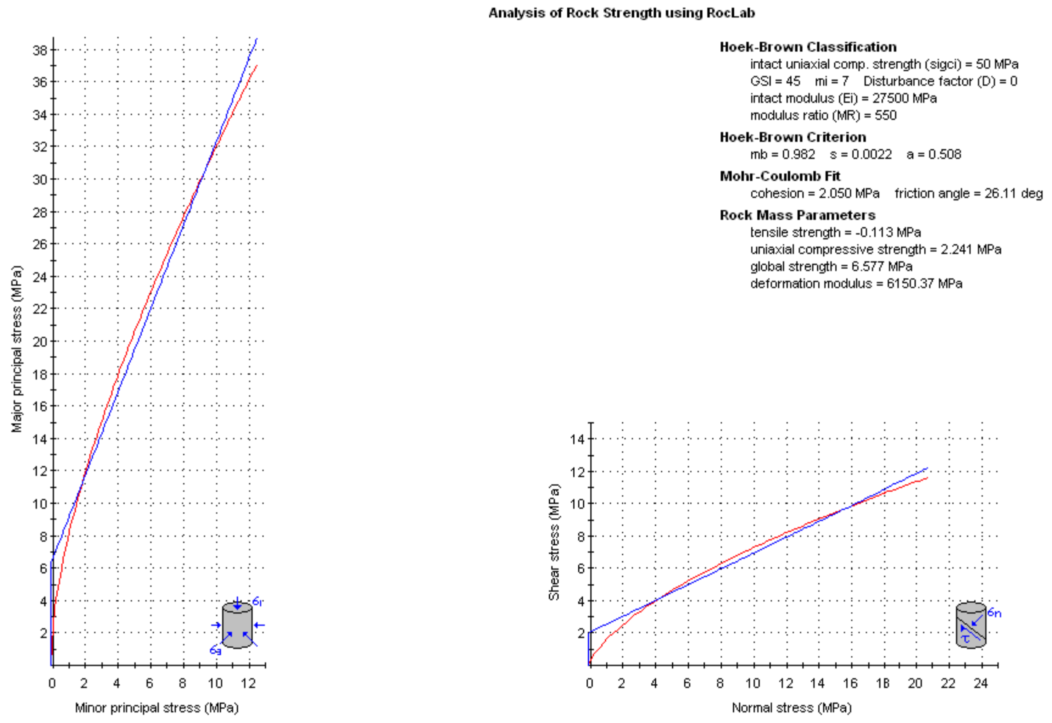


Figure 4 General Condition Slate at Saptkosi High Dam Project, Nepal

3.4 Correlation of Modulus Values:

The values of modulus of deformation as determined through equations3, 4,5 & 6 and also through Roc Lab V1 have been compared in the table-12 below. As it is clear from the table that there is fair correlation between the values determined through different methods. Thus it affirms the veracity of the different rock mass parameters (UCS, RQD, Q, RMR and GSI) as determined with the help of field observations and data.

Table 11
Comparison of Emass for different rock types at Saptkosi High Dam Project, Nepal

Rock Type	**Modulus of Deformation Emass (GPa)**					**Remarks**
	Roclab V	**$10^{(RMR-10)/40}$**	**2RMR - 100**	**$10\ Qc^{1/3}$**	**$10^{(15logQ+40)/40}$**	
Massive Quartzite	41.22	42.16	46 - 56	37.50	30.90	Comparable values through column 2, 3 & 5
Bedded Quartzite	19.50	22.38	28 – 38	15.5	17.37	All values nearly comparable except for that in column 4
Phyllite/ Slate	6.1	11.22	4	5	13	Comparable values through column 2, 4 & 5

3.5 Frictional Component (FC) and Cohesive Component (CC):

Barton (2002) has given empirical formula for calculating the frictional component (FC) and cohesive component (CC) by using the rock mass parameters that are used for determining Q.

Frictional Component (FC) = $\tan^{-1}$ (Jr/Ja x Jw)

Cohesive Component (CC) = RQD/Jn x 1/SRF x σc/100

The FC and CC for the rock types have been determined through theses equations and they have been compared with the values of c and phi determined through Roc Lab V1.

Table 12
Values of CC and FC for different rock types at Saptkosi High Dam Project, Nepal

Rock Type	**Values through Barton's Equation**		**Roc Lab V1 Values**	
	CC(MPa)	**FC(0)**	**C (MPa)**	**Φ (0)**
Massive Quartzite (Jn-2+r), RQD - 75	7.5 – 18.75 (SRF 2.5 – 1) **Avg. 13.12**	44.71 (Jr-1.5, Ja-1 Jw=0.66) & 33 (Jr-1, Ja-1 Jw=0.66)	12.32	42.45
Bedded Quartzite (Jn-3, RQD - 55)	6.11 (SRF - 1)	33(Jr-1,Ja-1 Jw=0.66)	7.06	39.51
Slate Jn-3, RQD - 45)	2.5 (SRF - 1)	26.56 (Jr-1, Ja-2 Jw=1	2.05	26.11

It is clear from the above table that the values determined from the Q parameters fairly correlates with those determined by Roc Lab V1.

3.6 P wave Velocity (Vp):

The velocity of P wave was determined by using the value of Qc in the following equation

$$Vp = 3.5 + \log Qc \qquad \text{Eqn. - 7}$$

The value of Qc for the rock masses, as given in table –7above has been used and the velocity of P wave in Km/sec is given in the table below

Table 13
Vp for different Rock Types at Saptkosi High Dam Project, Nepal

Rock Type	Vp (Km/sec)
Massive Quartzite	4.55
Bedded Quartzite	4.16
Slate	3.67

These values for Vp have been compared with the chart given by Barton 2002 (shown below) and calculated values were compared with the values of Vp as indicated in the chart and there is a perfect match with the line for all the depths.

3.7 Support Pressure (Pr):

Attempt has been made to calculate the support pressure that the underground opening may require in the different types of rocks at the site. The calculations have been done for near surface conditions and may only be applicable for portal reaches. The simple relation between Jr and Q has been used for these calculations as given by Barton 2002.

$$\text{Support Pressure (Pr)} = Jr / 20 \times Q^{1/3} \qquad \text{Eqn - 8}$$

Table 14
Support Pressure for different Rock Types at Saptkosi High Dam Project, Nepal

Rock Type	Jr	Q (Portal Condition)	Pr (MPa)
Massive Quartzite	1	2.5	0.060
Bedded Quartzite	1	1.5	0.10
Slate	1	0.833	0.18

3.8 Lugeon Value (L)

The value of Qc has been used for empirically calculating the value of Lugeon for different rock masses in near surface condition, by Barton (2002) equation given below. Value of Qc instead of Q has been adopted for calculation because it takes care for the effects of stresses on the rock masses and relates with the relative contrast in the strength properties. It is, however, emphasized here that these values of Lugeon are only indicative and should not be used directly for deciding the permeability and grouting pattern at the site, for which the results of site specific test grouting will be more accurate.

$$\text{Lugeon (L)} = 1 / Qc \qquad \text{Eqn - 9}$$

Table 15
Lugeon values for different Rock Types at Saptkosi High Dam Project, Nepal (Near Surface Condition)

Rock Type	Qc	Lugeon (L)
Massive Quartzite	4	0.25
Bedded Quartzite	1.5	0.66
Slate	0.48	2.08

4. Comprehensive geotechnical model:

The whole of the exercise done above was aimed at evolving a comprehensive geotechnical model for the rock masses at Saptkosi dam and it was done in a systematic way by i) delineating and standardizing the rock types by their physical and textural characters and also after studying them in thin section, ii) faithfully collecting the field data for the discontinuities, iii) structurally analyzing the discontinuities by stereo plotting, iv) grouping the discontinuities into different sets, v) calculation of basic rock mass parameter RQD with the help of volumetric joint count Jv, vi) estimation of Uniaxial Compressive Strength (UCS) and point load value with the help of field character and by comparing with the chart for strength properties, vii) calculation of rock mass parameters like Q, RMR, Qc and GSI following the standard practices of Barton, Bieniawski and Hoek, viii) calculation of other parameters like Emass, FC, CC, Vp, Pr and Lugeon by fitting the values of Q, RMR, Qc and GSI into standard equations, ix) using the evaluation version of free software Roc Lab V1 for determining the Hoek - Brown parameters and Mohr Coulomb constants for different rock masses, and x) comparing, cross checking and back calculating the different parameters with each other, which have been derived from different systems (Table-1).

5. Use of rock mass characteristics in locating underground structures:

As per the present proposal, the underground structures to be located on the left bank (part of the mapped area) will be i) two diversion tunnels, ii) upstream and downstream surge shafts/expansion chambers, iii) two head race tunnels (HRT'S), iv) two tail race tunnels (TRT'S), v) six nos. of penstocks, vi) penstock assembly chamber (PAC), vii) butterfly valve chamber (BVC), viii) machine hall and ix) transformer hall. The two most important cavities i.e. machine hall and transformer hall, having a vertical cover of about 250m above them, may not encounter the stress related problems which is a favorable condition. Moreover, the rock mass characteristics indicate that the rock mass conditions at the locations of these structures will be better considering the improvement in the weathering conditions, tightening of joints and medium stress conditions (for a cover of 250m).

As per the model of rock mass characteristics (Table-1, it is imperative that the main cavities i.e. machine hall and transformer hall should be located in massive Quartzite (MQ) or thinly bedded Quartzite (TQ). Since the dip of the beds is mostly towards North-East, it is quite plausible that the proposed machine hall and transformer hall will be aligned across the dip of the beds. The part of these cavities lying within MQ/TQ would not require heavy support and this presents a favorable scenario.

The diversion tunnels, HRT'S and TRT'S may encounter all three types of rock masses and it is clear that the stretches of these tunnels piercing through slates, sheared phyllites and coal seams will encounter problems of over breaks and squeezing (specially in the water saturated zones) and these reaches would thus require steel support. It is however to be stated that the percentage of such weaker/poor strata is very low (<10%).

It will be advisable to locate the surge shafts within the MQ or TQ units.

6. Feasibility of surface and underground structures:

The outcome of comprehensive geotechnical model were applied to assess the feasibility of different surface and underground structures and it is clear that there is sharp contrast in the competency of the three rock masses delineated on the left bank of Saptkosi dam which is seen on the ground in the form of change in topography and difference in the weathering pattern. The above statement is well corroborated by the difference in the values of different strength properties as indicated in the table for comprehensive geotechnical model of rock mass character (table 16).

There is drastic variation in the values of modulus of deformation, tensile strength, point load and the UCS for the rock mass (Roc LabV1). There is a reduction of the order of 47.30% and 15% in the values of modulus of deformation for bedded quartzite and phyllite respectively when compared with the values for massive quartzite.

The zones having rock masses with significantly low values of modulus of deformation would require special treatments in the foundation. Similarly the marked difference in the values of cohesion i.e. reduction by 84% and in friction 38.50% for phyllite when compared with massive quartzite, warrants different support/stabilization measures for them while designing the abutment slopes.

Volume XXXIX, No. 2,
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Narrow valley, strong rocky abutments formed by predominantly hard and compact quartzite of high modulus and UCS values along with the steep upstream dipping beds present a befitting site for locating a high dam across river Saptkosi.

There will not be major problems in setting the portals at the inlets and outlets of diversion tunnel on the left bank and the intake portal of head race tunnels.

7. Conclusions:

The detailed geological mapping at Saptkosi dam site has enabled to classify litho types at the site and has also helped in recording the characteristic features of the structural elements mainly joint systems. The basic field data, collected, has been prudently used to derive various rock mass parameters and the characteristics which are deemed vital for geotechnical assessment of the site.

Rock mass characteristics have been derived for each rock unit utilizing the basic field inputs. Massive Quartzite (MQ) characterized by high values of UCS (100 – 250 MPa), RMR (73 – 78), Q (7.5) and GSI (65 – 70) is being rated as the most competent unit whereas Slate (SL) with the markedly low values of UCS (25 – 50 MPa), RMR (52 – 57), Q (2.0 – 3.0) and GSI (40 – 45) represents the least competent rock unit. Bedded Quartzite (BQ) forms the intermediate class in terms of rock mass characterization.

Rock mass parameters derived from the free version of software Roclab V1 further corroborate with the obtained high values of modulus of deformation (Emass) ranging from 37.50 GPa to 42 GPa for massive quartzite and lower values of Emass from 4 GPa to 11 GPa for slate.

The most competent and strong rock unit i.e. massive quartzite occupies about 55 percent of the mapped area on the left bank which presents an optimistic picture about the foundation conditions for the main dam.

The close correlation between the values of parameters derived from empirical equations and those from the Roclab V1 reflects the veracity of the collected field data.

The comprehensive geotechnical model as evolved here will prove to be of vital importance for virgin areas like Saptkosi where lab tested values are not available particularly during the early stages of investigations.

This model has given significant information about the rock mass conditions expected at the locations of the proposed underground structures and it will be key in finalizing the location and orientation of the major cavities, deciding the sequence of excavation and in selecting the appropriate support measures.

This maiden attempt on characterizing the rock masses at Saptkosi high dam in Nepal will facilitate preliminary design of different surface and underground structures. It is, however, cautioned here that this model is only indicative and should not be used as substitute, for final design purpose, for which the results of different sets of in situ tests will be of vital importance.

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