IOSR Journal of Applied Geology and Geophysics (IOSR-JAGG)
e-ISSN: 2321–0990, p-ISSN: 2321–0982.Volume 5, Issue 1 Ver. I (Jan. - Feb. 2017), PP 46-51
www.iosrjournals.org

Engineering Geological Evaluation of Siyan Gad Small Hydroelectric Project, Uttarakashi District, Uttarakhand

Bagri, D.S[1], Bipin, P[2] and Anbalagan, R [3]
[1]*HNB Gharwal University, New Tehri, Uttarakhand, India*
[2]*Research Scholar, Department of Earth Sciences, Indian Institute of Technology Roorkee, India*
[3]*Professor, Department of Earth Sciences, Indian Institute of Technology Roorkee, India*

Abstract: *The proposed Siyan Gad small hydroelectric project is a run of the river scheme, on Siyan Gad River near Harsil in Uttarakashi district of Uttarakhand. The water will be diverted by a 6m high weir through a 2.72 km long power tunnel to a surface power house near Jhala village to produce 5 MW of electric power. The whole project is located within the rocks of Harsil Metamorphics of Vaikrita Group. This study includes detailed discussion and control measures for engineering geological problems likely to be encountered during construction or post construction period. The rocks at the project site are classified according to Rock Mass Rating (RMR) system and also by Q-system in order to predict rock load and support requirements.*
Keywords: *Siyan Gad small hydroelectric project, RMR, Q-system, in-situ stresses, remedial measures.*

I. Introduction

The Himalayan region is rich with perennial rivers, which are potential enough to meet the rapidly rising energy requirements, but construction of micro to mega hydroelectric projects are challenged by the fragility and high seismicity of the terrain. The stability of underground openings is dependent on rock mass condition, in-situ stresses, support stiffness, size and shape of cavity, method of construction and sequence of construction among other factors.

The Siyan Gad small hydroelectric project is a run-of-river scheme for generation of 5MW by exploiting hydro-power potential of Siyan Gad stream, a tributary of Bhagirathi River. The Siyan Gad stream is fed by rain, spring water and glacial ice melts. The small hydroelectric projects in general have five major components namely Diversion Weir, Water Conductor System, Forebay, Penstock and Power House. Location Map of the study area shown in Fig 1.

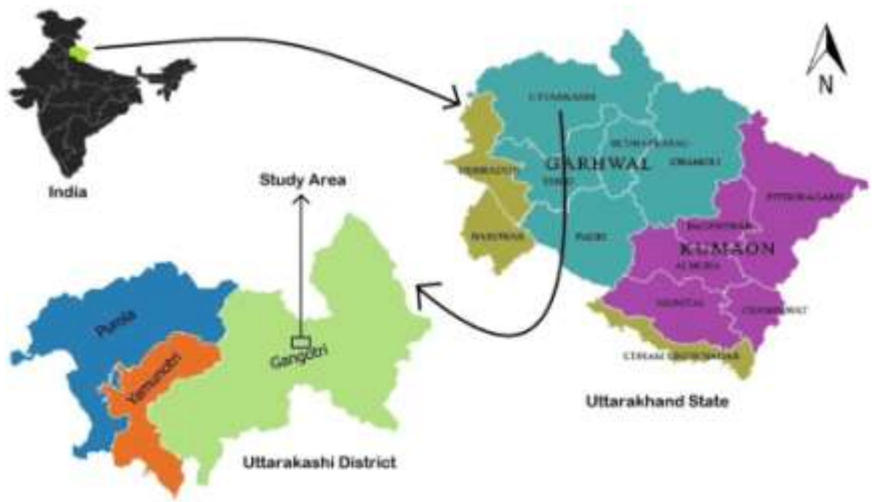

Fig.1. Location map of the study area

II. Geology of Project Site

The Siyan Gad small hydroelectric project is situated in Higher Himalayan terrain of Garhwal region. The rocks in the area belong to Vaikrita Group, named by Griesbach (1891). The medium to high-grade metamorphics of Vaikrita Group is known as Harsil Metamorphics. The lithology encountered in this area includes mainly micaceous quartzites, which consist of thick quartzite bands alternating with thin bands of mica schist. The mica bands mainly consist of biotite and muscovite minerals. Because of the presence of thick quartzites, the rocks form steep slopes and ridges in the area. The hill slopes contain thick cover of slide debris all along the valley, which is mixture of angular to sub angular rock blocks mixed with silt to sand size soil matrix. Geology of the project area is shown in Fig. 2.

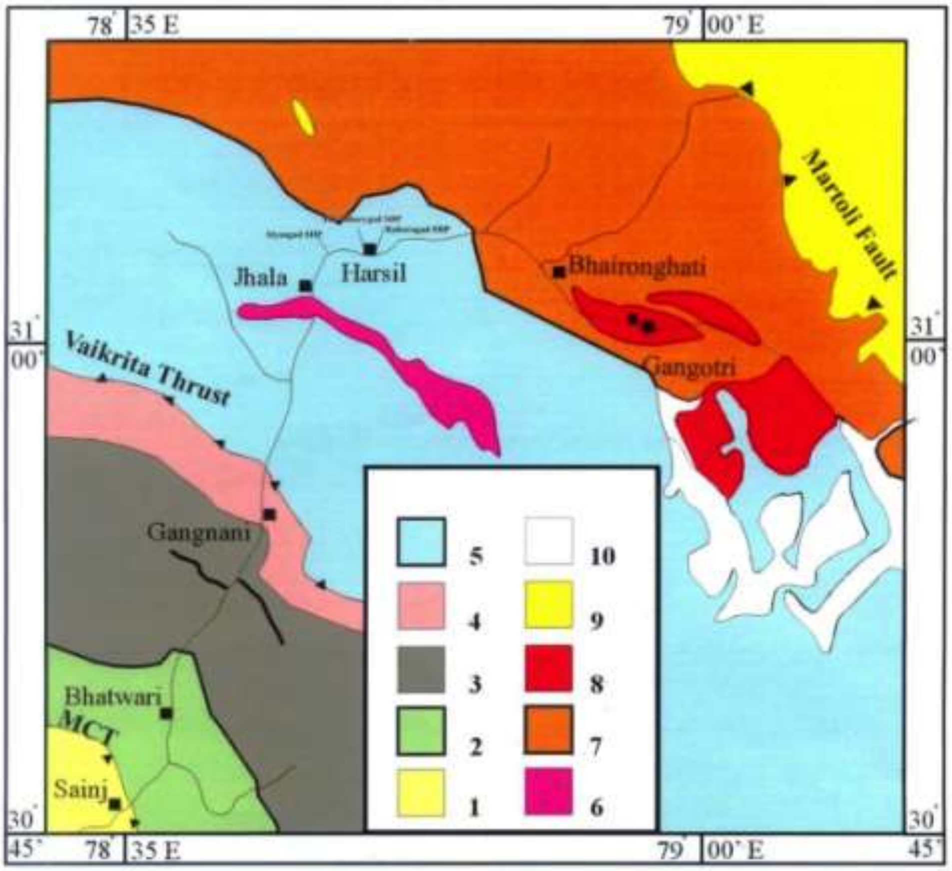

Figure Geological map of the Higher Himalayan Crystalline (HHC) Belt along the Bhagirathi Valley, Garhwal. Legend: 1: Lesser Himalayan (LH) Proterozoic sequence, Higher Himalayan Crystallines (HHC) 2: Bhatwari Group-porphyroclastic granite gneiss, garnetiferous mica schist, amphibolite, 3: mylonitized augen gneiss, mica schist, amphibolite, 4: phyllonite, schist, 5: sillimanite/kyanite/staurolite/garneti-ferous schist/gneiss/ migmatite, 6: angen gneiss, 7: Bhaironghati granite, 8: Gangotri leucogranite, 9: Tethyan Sedimentary Zone (Martoli Group), 10: Glaciers, debric etc. Abbreviations: MCT - Main Central Thrust, VT - Vaikrita Thrust, MF - Martoli Fault

Note : (From Manicvasgam et al, 2002) (Modified)

Fig.2 Geology of the project area

III. Engineering Geological Problems of Project Components

3.1 Diversion Weir

The diversion weir is located in a fairly narrow valley at EL ± 2764m. The 6m high weir will be located on glacio-fluvial material consisting of assorted size fractions ranging from silt to big boulders. The in-situ rocks consisting of quartzite and schist are found at deeper levels. The trench weir is a suitable structure, in view of fact that the big boulders, which may be transported during floods, can be comfortably passed over the weir without any damage. The moving boulders may tend to damage the intake structure. The toe erosion of slope by running water may lead to landslides on the right bank, just upstream of the portal site. The slope should be treated with suitable retaining wall at the toe and flattening the slope above in addition to increasing shear strength with suitable anchors.

3.2 Desilting Basin

The underground desilting tank size of 48m × 8m × 4.4m at EL ± 2760m is proposed at a distance of about 25m from the intake within the rock slope. A thick pile of river born materials mixed with slide debris is present above the rock. Since the height of the desilting tank is 8m, a minimum rock cover of 24m is required above the crown. This cover is available above the proposed site.

3.3 Power Tunnel and Adits

It is envisaged to conduct the diverted water from intake through desilting chamber to Forebay by a "D" shaped power tunnel of size 2m × 2.5m over a length of 2.72km. To construct the power tunnel, two approach adits have been proposed at ch 0.53km and at ch 1.53km. The tunnel mostly passes through the rocks of harsil metamorphics consisting of micaceous quartzites. Thick quartzite bands alternate with thin bands of garnetiferous biotite-muscovite schist. The rocks exposed on the surface were studied for their rock mass characters using RMR system. The rocks show good to very good RMR values; they are likely to behave more stable under excavated conditions in general. However, under specific conditions such as highly jointed and sheared rocks, the tunnels may undergo overbreak during construction. The tunnel will be crossing two deeply incised streams on its way. Since the streams were developed along shear zones, the sheared rocks coupled with water charging due to stream course may cause overbreak during excavations. Controlled blasting with adequate supports will help to minimize the overbreak tendency during excavation. The adits will be located on a smooth hill slopes (35°-45°) having thin debris cover. It will be located just before the two deeply incised streams joining Siyan Gad. In this location, rocks show 3 prominent sets of joints. Based on the surface observations, suitable supports may have to be installed in the shear zones and in the highly fractured zones.

3.4 Forebay

The forebay is proposed near Purali village at EL ± 2760m. At this site the slope is steep to very steep in nature. Thick quartzite bands are found intercalated with thin mica bands. The mica bands mainly consist of biotite and muscovite minerals. The quartzite bands are more massive with least development of foliations dipping into the hills. In view of steep hill slopes, the excavations for forebay may involve excessive cutting by blasting, which may cause instability of hill slopes. Suitable control measures including stable cut slope and grouted anchoring of rock slopes have to be provided at the site to avoid any instability problems.

3.5 Penstock Alignment

The proposed penstock alignment is about 750m long and will be aligned roughly in N145º – N325º direction. The alignment falls partly on rocks and partly on debris lying on rock slopes. The alignment in higher reaches close to forebay at EL ± 2760m has rock slopes having fairly steep slopes of the order of about 40° which get flattened to about 20° in lower levels. Further down from the rock slopes, the alignment is located over the debris materials lying on moderate to fairly steep slopes. Though the debris materials seem to be well compacted and stable, the bed rock may not be available at shallow depth. Hence, foundation anchors of 1m to 4m may be designed within the debris seen on the slopes.

3.6 Power House

The power house of 60m × 20m × 30m dimension is located on the right bank of Bhagirathi River just above the maximum reservoir level (MRL) of the proposed Bharonghati project. It may be located at EL ± 2440m near the village Jhala. The terrace on which the power house will be located is fairly large in size and has very gentle gradients. The site has thick overburden, which mainly consists of debris materials comprising angular to sub-angular rock blocks mixed with silty soil matrix. The cutting of the terrace for power house may entail considerable excavation on the hill side. Here a proper cut slope and stability measures may have to be designed taking into consideration the topography and the geology of the area. The power house back slope is of terraced agricultural field with stable and gentle slopes. The back slope of power house shall be further stabilized by providing gabion walls. Any seepage of water from nearby hill shall be guided through open catch drains and through weep holes to be provided in retaining walls meant for stabilizing the cut slope.

IV. Rock Mass Classification of Project Site

The rocks exposed in each component of project site have been classified using rock mass rating (RMR) system (Bieniawski, 1979) and Q-system (Barton *et al.*, 1974). The shear strength parameters cohesion (c) and angle of friction (Φ°) are assessed by RMR system. Q-system has used to derive rock pressures and support requirements. The ratings of RMR and Q-system are shown in Table 4.1 and Table 4.2 respectively.

Table 4.1 RMR values of rocks at different components

Parameters/ Properties of Rock Mass	Diversion	Inlet	Adit 1	Adit 2	Fore Bay	Power House
Point Load Index(MPa)	7	12	12	12	12	12
RQD	17	17	20	17	17	20
Spacing of Discontinuity	10	10	10	10	10	10
Condition of Discontinuity	30	25	30	30	30	25
Ground Water Condition	15	15	15	15	15	15
RMR value	79	79	87	84	84	79
Class No	II	II	I	I	I	II

Average stand up time	6 month for 8m span	6 month for 8m span	10 years for 15m span	10 years for 15m span	10 years for 15m span	6 month for 8m span
Cohesion(c) of Rock Mass(MPa)	0.3-0.4	0.3-0.4	>0.4	>0.4	>0.4	0.3-0.4
Frictional angle(Φ°) of Rock Mass	35°-45°	35°-45°	45°	45°	45°	35°-45°

Table 4.2 Description, rating of parameters & Q-values of different components

Parameters	Diversion	Inlet	Adit 1	Adit 2	Fore Bay	Power House
RQD	87	87	90.5	87	83.5	80
Jn	9	9	15	9	9	9
Jr	3	3	4	3	3	4
Ja	1	2	1	1	1	2
Jw	1	1	1	1	1	1
SRF	1	1	1	1	1	1
RQD/Jn	9.67	9.67	6.03	9.67	9.27	8.89
Jr/Ja	3	1.5	4	3	3	2
Jw/ SRF	1	1	1	1	1	1
Q-Value	29.01	14.51	24.12	29.01	29.01	17.78

V. Estimation of Support Pressure

5.1 Support pressure estimation using RMR

Support pressure can be calculated from the formula;

$P = [(100\text{-RMR})/100] \times_{\gamma} B$ (1)

P = Support Load

B = Tunnel Width in m

$_{\gamma}$ = Density of rock in Kg/m^3

It is seen than very low support is required for the rock type with high RMR and relatively high support pressure is required for rocks of low RMR. Support pressure estimation for Inlet, Adit 1, Adit 2 and Fore bay by using RMR system is given in table 5.1.

Table 5.1 Support pressure estimation from RMR

Parameters	Inlet	Adit 1	Adit 2	Fore Bay
RMR	79	87	84	84
Tunnel width(m)	2.5	2.5	2.5	2.5
Density of the rock(Kg/m^3)	2.67×10^3	2.61×10^3	2.57×10^3	2.86×10^3
support pressure(Kg/m^2)	1401.75	848.25	1028.00	1144.00
Support pressure(MPa)	0.01372	0.008362	0.01008	0.01121

5.2 Ultimate Support Pressure

Barton et al (1974, 1975) plotted support capacities of 200 underground openings against the rock mass quality (Q). They found following empirical correlation for ultimate support pressure:

$$P_v = \left(0.2 / J_r\right) Q^{-1/3} \qquad (2)$$

$$P_h = \left(0.2 / J_r\right) Q_w^{-1/3} \qquad (3)$$

Where,

P_v = Ultimate roof support pressure in MPa,

P_h = Ultimate wall support pressure in MPa,

Q = Rock mass quality

Q_w = Wall rock mass quality

Here, the Jr value plays very important role in stability of underground openings. Consequently, support capacities may be independent of opening size as believed by Terzaghi (1946)

The wall factor Qw is determined by multiplying Q by a factor which depends on the magnitude of Q as given below.

Range of Q	Wall Factor Q_w
> 10	5.0 Q
0.1 – 1	2.5 Q
< 0.1	1.0 Q

Barton et al further suggested that if number of joints less than three, the ultimate roof pressure and ultimate wall pressure can be calculated as follows:

$$P_v = \frac{\left[0.2\left(J_n\right)^{1/2} \times Q^{-1/3}\right]}{3\left(J_r\right)} \quad (4)$$

$$P_h = \frac{\left[0.2\left(J_n\right)^{1/2} \times Q_w^{-1/3}\right]}{3\left(J_r\right)} \quad (5)$$

Table 5.2 Shown the ultimate support pressure estimated for rocks at different components

Parameters	Diversion	Inlet	Adit 1	Adit 2	Fore Bay	Power House
Q	29.01	14.51	24.12	29.01	29.01	17.78
Pv(Mpa)	0.02170	0.02733	0.01730	0.02170	0.02170	0.01916
Support category	13	13	13	13	13	13
Type of support	B(utg) 1.5-2m	B(utg) 1.5-2m	B(utg) 1.5-2m	B(utg) 1.5-2m	B(utg) 1.5-2m	B(utg) 1.5-2m
Wall factor (Qw = 5Q)	145.05	72.55	120.6	145.05	145.05	88.90
Ph (MPa)	0.01268	0.01598	0.01012	0.01268	0.01268	0.01120
Support category	13	13	13	13	13	13
Type of support	B(utg) 1.5-2m	B(utg) 1.5-2m	B(utg) 1.5-2m	B(utg) 1.5-2m	B(utg) 1.5-2m	B(utg) 1.5-2m

Key words: B systematic Bolting; (utg) = untensioned, grouted.

5.3 Estimation of Maximum Unsupported Span

The maximum unsupported span for different rock types under different conditions calculated from the following formula;

Maximum unsupported span = $2 \times ESR \times Q^{0.4}$

Here, Excavation Support Ratio (ESR) = 1.6

Table 5.3 maximum unsupported span for rocks at different locations

Parameters	Diversion	Inlet	Adit 1	Adit 2	Fore Bay	Power House
Q	29.01	14.51	24.12	29.01	29.01	17.78
ESR	1.6	1.6	1.6	1.6	1.6	1.6
Maximum Unsupported Span	12.3074	9.3286	11.4314	12.3074	12.3074	10.1186

5.4 Calculation of Bolt and Anchor Length

The Bolt (L) and Anchor Length (La) calculated by using following equation;

L = (2 + 0.15 B)/ ESR

La = 0.4 B/ ESR

Where, B is span of tunnel i.e. 2.5m

So, here

Length of Bolt (L) = [2+ (0.15×2.5)]/1.6 = 1.48 m

Anchor length (La) = (0.4×2.5)/1.6
= 0.625 m

5.5 Calculation of Bolt spacing/ Anchor spacing

Bolt spacing calculated by using following formula;

A = $1/\sqrt{P}$

Where, a = Bolt spacing

P = Support pressure capacity in kg/cm^2

Table 5.5 Bolt Spacing for rocks at different locations

Parameters	Diversion	Inlet	Adit 1	Adit 2	Fore Bay	Power House
Pv (Mpa)	0.02170	0.02733	0.01730	0.02170	0.02170	0.01916
Pv (Kg/cm^2)	0.22134	0.27877	0.17646	0.22134	0.22134	0.19543
Bolt Spacing	2.12554	1.89398	2.38054	2.12554	2.12554	2.26206

VI. Conclusions

The Siyan Gad small hydroelectric project is a run-off-river scheme exploiting the hydro power potential of Siyan Gad, a tributary of river Bhagirathi. A diversion weir is proposed at an elevation of 2764.2m to divert water through a 2.90km long power tunnel to the power house for the generation 5MW of electric power. The underground openings may face over break problems due to orientation of discontinuities and weak rock conditions. Thus suitable control measures should be taken based on systematic classification during construction.

The quality of rock mass has been accessed by RMR method of Bieniawski (1979) and Q system by Barton (1974) in order to determine the rock load and required support measures. Both methods have shown that the rock mass is of good to very good quality. The support pressure estimation indicates that the rocks fall in support category 13, where systematic 1.5 to 2m bolts with untensioned grouting.

References

[1]. Barton, N., Lien, R., and Lunde, J.; (1974), Engineering Classification of Rock Masses for the Design of Tunnel Support; Rock Mechanics, Springer-Verlag, vol.6; pp 189-236

[2]. Bieniaswksi, Z. T., (1989); Engineering Rock Mass Classification; John Willey & Sons. LTD., London; pp 30-90

[3]. Bagri, D. S., Lakshmanan, K., Anbalagan, R. and Bipin, P.(2016); Stability Evaluation Of Slopes Around Rim Of Reservoir of Diversion Dam Of Vishnugad–Pipalkoti Hydroelectric Project, Garhwal Himalaya, India; International Journal of Current Research Vol. 8, Issue, 11, pp.42565-42575, November, 2016

[4]. Singh, B., Goel, R. K.,(1999); Rock Mass Classification- A Practical Approach in Civil Engineering; Elsvier Science Ltd., Oxford; pp 34-89

[5]. Jain, A.K., Singh, S., and Manickavasagam, R.M.(2002); Himalayan Collision Technocic; Gondwana research group, Memoir no. 7; pp 57-101