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Engineering Geological Evaluation of Kakoragad Small Hydroelectric Project, Uttarakashi District, Uttarakhand

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Abstract: *The proposed Kakoragad small hydroelectric project is a run of the river scheme, on Kakora River near Harsil in Uttarkashi district of Uttarakhand. The water will be diverted by an 18m long rectangular trench type weir at an altitude of ±2942m. The diverted water will be carried to the powerhouse through power tunnels over a distance of 1629m to produce 12.5MW of electricity. The whole project is located within the rocks of Vaikrita Group. This study includes detailed discussions on geological setting in addition to highlighting the anticipated Engineering Geological problems likely to be encountered during construction of the project. The rocks at the project site have been classified using Rock Mass Rating (RMR) system and also by Q-system in order to predict rock load and support requirements.*
Keywords: *Kakoragad small hydroelectric project, RMR, Q-system, in-situ stresses, remedial measures*

I. Introduction

The snow fed perennial rivers of Himalaya have huge hydropower potential. This non-exhaustible resource is an effective means to meet the rapidly rising energy requirements of the country. Several mega and micro scale hydroelectric projects are already functioning in the Himalayan region, while many more are under construction as well as planning stages across the Himalayan Rivers. The suitable location for Run-of-the-River Schemes (RORS), in Himalaya is a challenging task due to the fragility and high seismicity of the terrain. Since the terrain is highly sensitive environmentally, safe water conductor structures such as tunnels are more preferred as compared to open channels, which involve huge cuttings of the slope and other attendant environmental issues. These structures have minimum environmental problems, easy to construct and maintain with extremely high stability against earthquakes. The stability of underground openings is dependent on rock mass condition, in-situ stresses, support stiffness, size and shape of the cavity, method of construction and sequence of construction practice among other factors. In the present case, the Engineering Geological problems associated with the construction of a small hydropower project has been discussed. Here, the proposed rectangular trench type weir will help to ensure free flow of water without stagnating the water across the river course.

The Kakoragad small hydroelectric project is a Run-of-the river scheme (RORS) for power generation by exploiting the hydro power potential of the Kakora stream, a tributary of the Bhagirathi River. The project is situated near Harsil, about 75km from Uttarkashi towards Gangotri (Fig 1). The Kakora stream is a perennial stream, which originates from the snow clad mountains having a peak elevation of 5900m and flows in the south-west direction up to Harsil village, where it meets the Bhagirathi River. This Engineering Geological problems of this small hydroelectric project have been discussed with particular reference to five important project components namely diversion weir, water conductor system, forebay, penstock and powerhouse.

II. Geological Setting Of Project Area

The Kakoragad small hydroelectric project is situated in Higher Himalayan terrain of Garhwal Himalaya. The rocks exposed in and around the project site belongs to Vaikrita Group. The region has undergone high grade metamorphism resulting in the formation of Garnet-Quartz-Mica Granulite interbedded with Biotite-Mica Schist. The Biotite-Mica Schist shows trapped emplacements of anhedral to subhedral crystals of quartz. Thick debris cover could be seen all along the stretch of the Kakora stream from Harsil and further upstream up to the proposed weir site. However, a small patch of rock is seen at the proposed weir site. Debris materials mainly consisting of big rock blocks mixed with silty soil are present close to the valley face on the left bank near diversion site and desilting tank. At the diversion site, rocks show well developed foliations with less developed joints. Huge thickness of debris found at

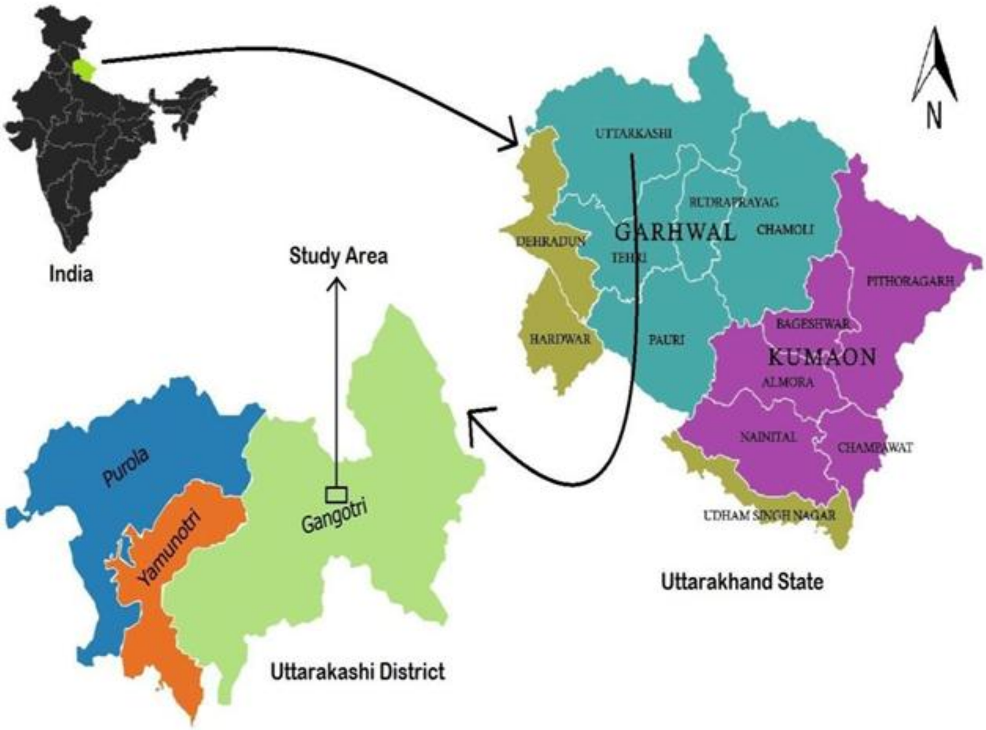

Fig.1. Location Map of study area

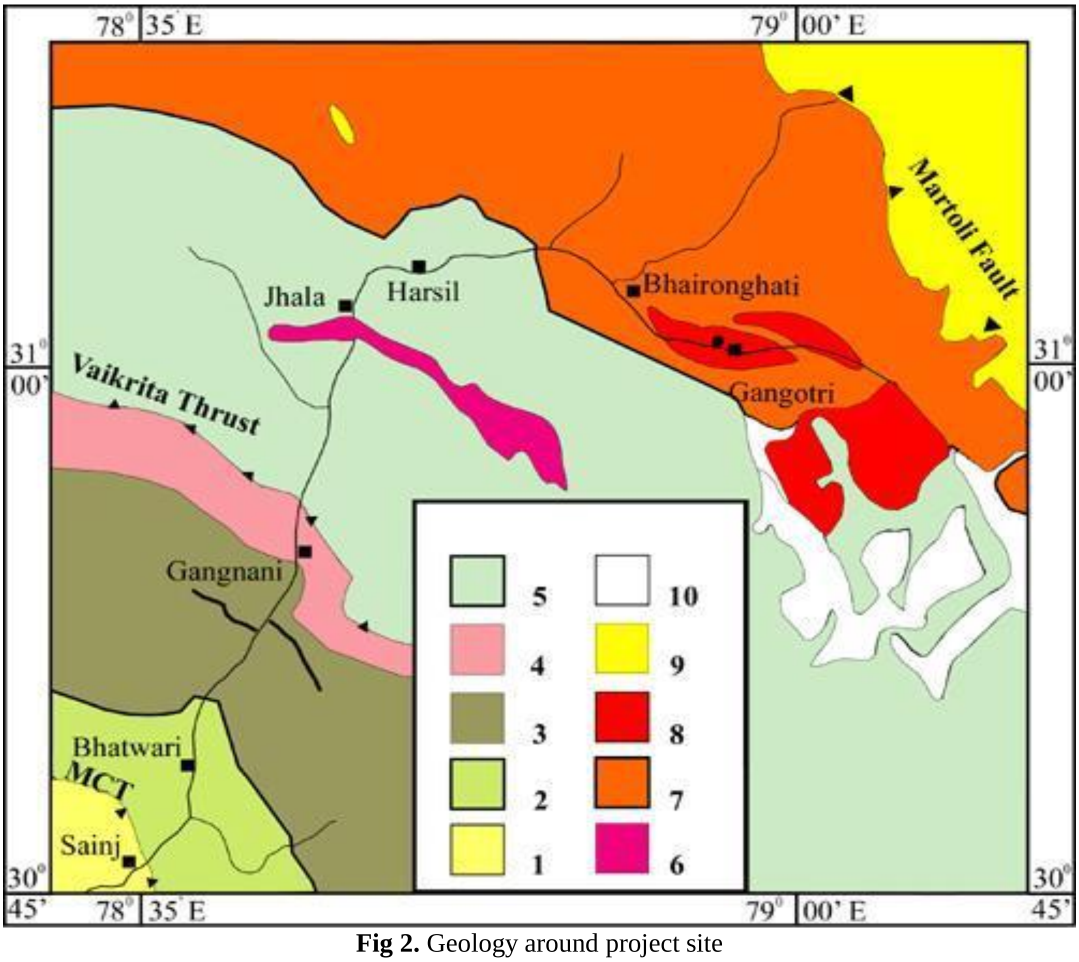

Fig 2. Geology around project site

1. Lesser Himalaya (LH) Proterozoic sequence: Higher Himalayan Crystallines (HHC)
2. Bhatwari Group-Porphyroblastic granite gneiss, garnetiferous mica schist, amphibolites
3. Mylonitized augen gneiss, mica schist, amphibolite
4. Phyllonite, schist
5. Sillimanite, kyanite, staurolite, garnetiferous schist, gneiss, migmatite
6. Augen gneiss
7. Bhaironghati granite
8. Gangotri leucogranite
9. Tethyan sedimentary zone
10. Glaciers, debris etc

diversion site surrounding the rock exposure contain minerals such as quartz, mica and other clay minerals. The in situ rocks exposures seen in diversion tunnel, forebay and powerhouse sites mainly consist of massive, hard and well jointed micaceous quartzites. Brown colored debris having silty clay matrix mixed with rock blocks of varying size are present along the proposed penstock site. The Geology around the project site is shown in Fig. 2.

III. Engineering Geological Problems Of Project Components

3.1 Diversion weir

Though the Kakora valley in general is tight and V-shaped in nature, the valley gets fairly widened to a width of about 20m to 25m at the proposed diversion weir site of the project (El ± 2942m). A small patch of in-situ rock present at the site is moderately weathered in nature. Fairly fresh to fresh rocks are likely to be available at depth. These are good rocks for tying the diversion weir on the left bank. Fairly fresh to fresh rocks are seen exposed on the right bank. The trench weir can be tied to the rocks seen on the banks

3.2 Desilting tank

The desilting tank is proposed to be located about 30m downstream of the weir site on the left bank at El ±2940m. The debris materials consisting of assorted rock blocks and alluvial boulders mixed with silty sand matrix are present at the site. In order to accommodate the tank, it may involve cutting of hill slope. Moreover, since the passage leading to the tank and tank itself will be located just adjoining the water course, suitable protection wall has to be designed around the construction area to protect it from floods.

3.3 Power tunnel

In view of the rugged rocky mountains and thick vegetation cover of trees and bushes in the entire area, it is planned to construct a ‘D’ shaped power tunnel of 2m (width) × 2.5m (height) size to serve as the water conductor system with free water flow inside the tunnel. The inlet will be located at an elevation of ±2490m within debris materials. The power tunnel will be traversing through debris materials initially for a distance of about 100m and will pass through rocks afterwards. In the initial reaches, the tunnel may collapse during excavation due to loose nature of the debris materials. It is essential to provide continuous support in this reach until rock exposures are met with. The presence of groundwater inside the debris may also cause more unstable conditions on the roof of tunnel. Hence, the excavation should progress with utmost care so that over break conditions can be prevented.

3.4 Forebay

The forebay is planned to be located close to the top of the Kakora ridge at a height of EL ±2490m. The slopes are steep at the planned forebay site with inclinations of about 45º towards N160°. Since the foliation dip into the hill and one of the two joints is askew to slope direction, they do not pose problems of slope stability. The other joint, though dipping in the same direction as that of slope it dips an angle (75º) more than that of slopes(45º). Hence this also will not create any problem of instability to the slope. Overall, it may be mentioned that the intersection due to joints and foliations within the rocks do not form unstable rock wedges and as such the slopes in general are stable in nature.

3.5 Penstock

The penstock alignment, located in the Bhagirathi valley runs mostly on the debris materials resulted due to past landslides. The penstock with a diameter of 1.25m is located between elevations of 2939m and 2536m. The debris materials consist of brown colored silty clay matrix mixed with rock blocks of varying size ranging from 5 to 30cm, which constitute about 20% of the total materials. The debris materials are well compacted, stable and the bed rock may not be available at shallow depth, the thickness of the debris is likely to increase at lower levels close to power house. Hence, the anchor blocks may be designed taking into consideration of the debris present on the slopes.

3.6 Powerhouse

The powerhouse is located on the right bank of the Bhagirathi River at an elevation of 2536m on a small terrace close to the Bhagirathi River. The general slope above the powerhouse is about of 55º towards N 230º. At this site, the foliation which is the dominant geological discontinuity, dips into the hill and hence overall the slope is stable. However, the cut slopes and control measures have to be designed properly.

IV. Rock Mass Classification Of Project Site

The rocks exposed in different units of the 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 1 and Table 2 respectively.

Table 1. RMR values of rocks at different components

Parameters/ Properties of Rock Mass	Diversion	Inlet	Above tunnel H=3400m	Forebay	Power House
Point Load Index(MPa)	9.4	4.7	14.9	9.7	8
RQD	20	17	20	20	20
Spacing of Discontinuity	15	10	15	10	10
Condition of Discontinuity	30	30	30	25	30
Ground Water Condition	10	15	15	15	15
RMR value	87	84	95	82	87
Class No	I	I	I	I	I
Average stand up time	20yr for 15m span	20yr for 15m span	20yr for 15m span	20yr for 15m span	20yr for 15m span span
Cohesion(c) of Rock Mass(MPa)	>0.4	>0.4	>0.4	>0.4	>0.4

Table 2. Description, rating of parameters & Q-values of different components

Parameters	Diversion	Inlet	Above tunnel	Fore bay	Power House
RQD	98.5	85.3	95.2	95.2	91.9
Jn	6	6	9	12	6
Jr	3	3	4	3	4
Ja	1	2	1	2	0.75
Jw	1	1	1	1	1
SRF	1	1	1	1	1
RQD/Jn	16.4	14.2	10.5	7.9	15.3

Jr/Ja	3	1.5	4	1.5	5.3
Jw/ SRF	1	1	1	1	1
Q-Value	49.2	21.3	42	11.85	81.1
Frictional angle(Φ°) of Rock Mass	45°	45°	45°	45°	45°

Where Jn = Joint set number, Jr = Joint roughness number, Ja = Joint alteration number, Jw = Joint water parameter, SFR = Stress reduction factor, RQD = Rock Quality Designation

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 different units of the project is given using RMR system (Table 3).

Table 3. Support pressure estimation from RMR

Parameters	Diversion	Inlet	Above tunnel	Fore bay	Power house
RMR	87	84	95	82	87
Tunnel width(m)	2.5	2.5	2.5	2.5	2.5
Density of the rock(Kg/m^3)	2760	3680	2654.55	2700	3111.1
support pressure(Kg/m^2)	897	1472	331.80	1215	1011.10
Support pressure(MPa)	0.00879	0.014	0.00325	0.0119	0.0099

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:

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

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

Where,

Pv = Ultimate roof support pressure in MPa, Ph = Ultimate wall support pressure in MPa, Q = Rock mass quality

Qw = 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 Qw
> 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:

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

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

Table 4. Shown the ultimate support pressure estimated for rocks at different components

Parameters	Diversion	Inlet	Above tunnel	Fore bay	Power house
Q	49.2	21.3	42	11.85	81.1
Pv(Mpa)	0.0149	0.019	0.0144	0.029	0.01
Support category	9	13	9	13	9
Type of support	B(utg) 2.5-3m	Sb(utg)	B(utg) 2.5-3m	B(utg) 1.5-2m	B(utg) 2.5-3m
Wall factor (Qw = 5Q)	246.0	106.5	210.0	59.25	405.5
Ph (MPa)	0.0087	0.0115	0.0084	0.0197	0.0055
Support category	9	13	9	13	9
Type of support	B(utg) 2.5-3m	Sb(utg)	B(utg) 2.5-3m	B(utg) 1.5-2m	B(utg) 2.5-3m

Sb=Spot bolting, 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. Maximum unsupported span for rocks at different locations

Parameters	Diversion	Inlet	Above tunnel	Fore bay	Power house
Q	49.2	21.3	42	11.8	81.1
ESR	1.6	1.6	1.6	1.6	1.6
Maximum Unsupported Span	15.2	10.876	14.27	8.617	18.567

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 6. Bolt Spacing for rocks at different locations

Parameters	Inlet	Above tunnel	Fore bay	Power house
Pv (Mpa)	0.019	0.0144	0.029	0.01
Pv (Kg/cm^2)	0.1938	0.1469	0.2958	0.1020
Bolt Spacing	2.27	2.61	1.84	3.13

VI. Conclusions

The Kakaragad small hydroelectric project, a Run-of-the-river scheme, envisages the production of 12.5MW of electric power by constructing 1638m long power tunnel with a diameter of 2.5m. The tunnel runs through hard and massive leucogranite body with three sets of joints. No major fault zone has been observed along the tunnel alignment. The rocks provide a good medium for tunneling.

The quality of rock mass has been assessed by RMR method of Bieniawski (1979) and it indicates that the quality of rock is very good. For support system evaluation, the Q system by Barton (1974) has been used. The Q values of the rocks ranges between 11.85 and 81.1, which indicates that these rocks in general are self-supporting with minor support consisting of systematic bolting with 1.5 to 2m spacing and untensioned grouting. Rock mass quality assessment and geological evaluation along tunnel alignment proves that chosen alignment is good for tunnelling.

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