Geotechnics of Birahi Ganga Small Hydel Project, Chamoli District, Uttarakhand

K.C.C.Raju* & K.Ravidranath**

Abstract

The paper evaluates the geotechnics of the Birahi-Ganga Small Hydel Project which envisages generating 32.7 MW in two stages as the run-of-the –river schemes utilising gross head of 367 m with 11 cusecs of water. The structures and tunnels mainly lie within the limestones/dolomitic limestones with minor bands of shale belonging to Pipalkoti formation of Garhwal Group. The rocks have been subjected to three phases of folding and faulting. The limestones of Pipalkoti formation are thrown into antiforms and synforms. Major faults are however not known in the area of the project although the surrounding area is dissected by major thrusts like Main Central Thrust (MCT) and a number of major transverse faults.

Based on the geological mapping, geological sections are prepared which depict that fairly compact and hard limestones available at depths of 2 to 10 m would form the foundation of all the structures viz. (1) Diversion dams, (2) Intake structures, (3) Power houses and other appurtenant structures. Geological sections are prepared for tunnels of the Original project and alternative alignments and the tunnelling media has been evaluated and classified. The tunnelling media classified according to Rock Mass Rating of Bieniawski and Rock Quality Tunnelling Index "Q" of Barton et al falls in Good and Fair classes with minor stretches falling under Poor class. These studies have shown that the major portion of tunnelling media do not require supports. Spot bolting/ systematic bolting are however required and these are to be carried out wherever tunnelling conditions warrant. Based on the seismic studies, horizontal seismic coefficient of 0.24 g and the vertical seismic coefficient of 0.12 g are recommended to be adopted in the design of structures. These studies have thus established that the project is feasible and that the geological conditions are quite favourable for the project.

Introduction

The River Birahi Ganga, one of the prominent rivers in the district Chamoli, Uttarakhand (Fig.1) is a tributary to the River Alaknanda. The River Birahi Ganga originates from snow capped Kumaon Himalayan mountain ranges, flows in general westerly direction and joins the Alaknanda River about 6 km upstream of Chamoli. This river is in youthful stage and has cut deep gorge and runs in ravines and rapids at several places all along its course. In the recent past, it was witnessed that the river had cut the mountains so deep and formed a gorge, resulting the mountains crumbling and collapsing to form a major landslide that totally blocked the river course by forming a natural dam across the river. This blockade resulted in forming a mighty lake in the Himalayas, popularly known as Gohana Lake. The lake continued its existence for about 70 years and as erosive nature of the river continued, the river overcame the hurdle by breaching the natural dam in July, 1970 and now continues its sojourn as usual.

The Government of Uttarakhand to fully harness the hydro-power potential of this river proposed three individual run-off-river schemes in the Birahi valley. The lower most of the schemes is at 2 km upstream of its confluence with the Alaknanda River, which is already in execution. In the upper reaches of the valley, the remaining two individual small hydro-electric schemes (Stage-I and II) are proposed.

*Director (Retd)., GSI

Table 1 : Project features of original scheme

Original Scheme	Gross head (rated head)	Designed discharge	Type of machine	Diversion structure	Length of hrt	Capacity (mw)
Stage-I	212 m (206 m)	11 cumecs	Pelton	Diversion dam with spillway & Gates	5980 m	20 mw (3x6.6 mw)
Stage-II	155 m (150 m)	10 cumecs	Francis	Diversion dam with spillway & Gates	3175 m	12.7 mw (3x4.23 mw)

Note: The designed discharges and installed capacities are based latest discharge data.

Alternative schemes combining the two stages into one single combined scheme were also studied. But the Construction Agency preferred the original scheme of Stage-I and Stage-II and this paper deals only with this scheme.

Interpreted derivatives of CARTOSAT-I & LANDSAT imagery

Base maps generated

As the area of the project is very rugged with steep slopes and inaccessible terrain, Cartosat-1 and Landsat imagery have been used to generate a series of maps. These are (i) Digital Elevation Model (DEM), (ii) Ortho-imagery and (3) Contour map; all on a scale of 1: 10000. The contour map is prepared with contour interval of 10 m (Fig.2). Geological & Structural, Geomorphological and Hydro geological maps have also been prepared from interpretation Landsat imagery. The data derived from these studies have been utilised in the geotechnical evaluation of the project.

Cartosat-1 launched on May 5th, 2005 is aimed to provide track stereo data from which an accurate Digital Elevation Model (DEM) can be generated. The derivatives of DEM are contours, slope, aspect etc having vital role in wide range of applications. The other important product dependent on DEM is Ortho-image, which is free from distortions due to view angle of the sensor and relief of the terrain. The ortho-image can be used as maps to make measurements and establish accurate geographic locations of features. The Cartosat-1 has been used probably in the Small Hydel Projects in the Himalayan terrain for the first time.

From stereo data of Cartosat–1, three types of outputs were generated, e.g., DEM, Contours and Ortho Image. First a visual comparison for all the three outputs (DEM, Contours and Ortho Image) was done, using small common area lying on these stereo data sets. It was found that DEM as well as contours generated using Cartosat –1 stereo data, were very much close to the ground information.

The stereo pair images of Cartosat-1 are used to create Digital Elevation Model (DEM) of the terrain which in turn has been used to study the topography. The precision geo-coded images of LISS IV MX are used in combination with DEM and the geological, geomorphological and hydro-geological maps of the project area have been prepared.

In order to understand the topography more meaningfully and to bring out the geomorphic units clearly, the contours generated using stereo data have been processed and a relief map is generated. The study of the parameters controlling the occurrence and distribution of ground water in the area are also worked out. The study of satellite image in 3 D view indicates that, the terrain forming as run off zone does not form as an aquifer, due to high relief and limited areal extent. It acts mainly as run off zone. Whatever limited recharge that is taking place is getting discharged immediately in the form of springs located around this zone.

Geomorphology

The area under study forms inner part of Lesser Himalayas and the outer part of the Great Himalayas. The terrain exhibits extremely rugged topography with very high relief and with altitudes ranging from 950 m to 6309 m. As the topography is controlled by dip slopes, which dip due northeast in general, the northern slopes are gentler than the southern slopes. Birahi valley is however a broad valley, prominently representing a glaciated valley.

The northern part of the project area is drained by the major river the Alaknanda, flowing south-westerly, with its tributaries like the Dhauli Ganga, Birahi Ganga and Nandakini. The Birahi Ganga originates in the Raunthi-Nanda Ghunti area, flows westward and joins the Alaknanda River at Birahi village located on left bank of the river Alaknanda. All the rivers in the area are perennial and mostly are glacial fed.

The general drainage pattern is dendritic, however, at places parallel to sub-parallel drainage pattern is also discernible. River terraces are commonly seen in the area along the Alaknanda River and its major tributaries. Five levels of terraces are common; at times these are paired in the area.

Apart from the riverine deposits mentioned above, lacustrine sediments have also been observed in old Gohana Tal area of Birahi Ganga valley. These sediments are characterised by pebble, gravel, sand, silt and clay from bottom towards top as observed in the sections exposed in the project area.

Geology

The area of the Birahi Ganga Small Hydel Projects and its environs is mainly formed of three distinct tectonic units represented by the Joshimath Formation Deoban/ Garhwal Group of rocks and Ghat Formation. The Garhwal Group of rocks are divided into two formations: 1. Pipalkoti Formation, comprising a sequence of limestones, slates, quartzites and 2. Chamoli Formation, comprising a sequence of quartzites, volcanic rocks and slates. The Chamoli Formation probably represents the upper most units of the Deoban / Garhwal Group, whereas, the Pipalkoti Formation represents the lower units. The Garhwal Group is exposed in a broad antiformal structure right from the Alaknanda valley to the Pindar valley. The Ghat Formation, which is the continuation of the Baijnath Crystallines, is exposed in a broad synformal structure and separated from the Garhwal Group. In northern most part of the area, the Tethyan sedimentary sequence is separated from the Joshimath Formation by a fault locally designated as the Malari Fault.

Structure

Three distinct tectonic units recognised are Garhwal Group of rocks, Joshimath Formation and Ghat Formation. The Joshimath Formation is separated from the Garhwal Group of rock by a low angle thrust locally known as Helang Thrust. In the southern part of the area the Garhwal Group of rocks underlies the Ghat Formation with tectonic contacts on either side.

At least three phases of folding are recognised in the present area. The first phase of folding F1 is represented by tight, reclined folds, plunging in NE and SW directions. Two sets of faults are recognised in the present area.

Local geology

River Birahi Ganga flows in the project area in southwest and westerly direction. The area is characterised with an undulating and rugged terrain. It is covered with fairly dense forest. The slopes are steep on both the banks and river bed has a drop of about 500 m in last 15 km before the confluence. The rivers have carved deep valleys across the younger Himalayan Pre-Cambrian rocks and also generally followed lineaments. Meandering along the rivers is common. Glacial and fluvio-glacial deposits are common in the area,

Limestones and associated dolomites and shales of the Pipalkoti Formation are the main rock types met with in the project area. The petrographic studies indicate that, the limestone under microscope is fine grained and show banding. The banding is mostly represented by grain size. It shows a mosaic of calcite and dolomite. The slate shows well developed cleavage, represented by parallelism of mica and chlorite flakes. The principal minerals are quartz, feldspar, sericite and chlorite. The accessory minerals are graphite and pyrite.

The limestone exhibits solution activity and formation of solution channels and cavities at several places. The cavities and solution channels are especially observed along open joints and axial planes of folds present in the area. Several such cavities developed in limestone are noticed along the river banks on either side of Birahi Ganga River at all levels. Many of the solution channels present in the area are 10 to 30 cm in width, extend 0.5 to 1.0 m depth into hill slopes. Cavities extending about 20 m depth are prominently noticed on right bank of the river Birahi Ganga, about 500 m upstream to the proposed lower power house site. These cavities close down at depth and appear to be superficial.

Structure

The Pipalkoti Formation consisting of limestones, dolomites and shales is part of folded mountain range. These rock types are thrown into open folds as seen on either bank of the river and in the hill range. The folding pattern is shown in the geological sections of the two tunnels of Stage-I and II.

Birahi Ganga Fault trends in WNW-ESE direction and runs parallel to Birahi Ganga river course and marks the southern contact of the Pipalkoti Formation with the gneisses at Bhim Tal. Towards south east, it marks the contact between the Pipalkoti Formation and the Chamoli Formation and is off set by a cross fault to the west of Ramni. It is a vertical fault in the north-western part and in the south- east it assumes a steep angle of about 85° due south-west. A number of NE-SW trending vertical faults are observed along the Bhadra Gad, near Gauna along the Birahi Ganga, north of Joshimath near Jhinji etc.

The Geological Map of the project area showing the structure and tunnel alignments prepared form the inputs of regional assessment and detailed geological mapping is given as Fig. 3.

Rock mechanics tests

Six samples of limestone from the Birahi Ganga Small Hydel Project are collected, cored and tested. The results of these tests are tabulated as below :-

Geotechnical evaluation of stage-II of the project

Diversion dam with central gated spillway

Diversion Dam with a height of 5 m above the river bed (R.L. +1604.00) with Central Gated Spillway having FRL at RL +1610 is recommended. Based on the geotechnical studies, projections of the bed rock indicate to be available at a depth of 5 to 10 m i.e. around RL +1590 m.

Water conductor system

A Head Race tunnels of 3.175 km length and D-shaped with width of 3.0 m and height of 3.0 m to convey a maximum discharge of 10 cumecs of water to generate 12.7 MW (3x4.23 MW) of hydel power.

The detailed studies have indicated that fresh and hard limestone with thin intermittent bands of carbonaceous shale, chert, marble and quartz would be the tunnelling media (Fig.3). All these complex structural features are projected in the geological section (Fig.4) along the tunnel and these are based on the regional geo-topographical setting and not on actual traverses along the tunnel and hence tentative. Taking into consideration that these structural features will be met with in the proposed tunnelling, the tunnelling conditions are worked.

Rock mass rating (RMR)

The two most widely used Rock Mass Classifications; Bieniawski's **RMR** (1976 & 1989) and Barton et al's **Q** (1974) are used.

Table 2 : Results of rock mechanics tests

Sr no.	Location	Rocktype	Sp gr	Porosity %	Absorption	Crushing Strength Kg/cm^2		MODULUS OF ELASTICITY (Ultrasonic test) 10^5 kg/cm^2
						DRY	WET	
1	Diversion dam site-Stage-II	Dark grey limestone	2.85	0.84	0.30	1909	1265	5.32
2	Diversion dam site-Stage-I	Dark grey limestone-Medium bedded	2.86	1.16	0.41	290	237	6.59
3	Tunnel Inlet Portal site-Stage-II	Dark grey limestone-Medium bedded	2.82	1.83	0.65	1031	609	5.51
4	Power House Site-Stage-II	Limestone-Thick bedded	2.89	0.65	0.22	533	383	7.20
5	Power House Site-Stage-I	Yellowish limestone	2.81	0.56	0.20	387	270	7.13
6	Tunnel Inlet Portal site-Stage-I	Dark grey limestone	2.81	0.78	0.28	2326	2247	6.69

Palmstorm (1982) suggested that, when no core is available but discontinuity traces are available in surface exposures and in exploration adits, can used to arrive at the RQD and the formula is made use of.

RQD = 115- 3.3 Jv; Where Jv is the sum of the number of joints per unit length for all joint (discontinuities) sets as the volumetric joint count.

Rock quality tunnelling index-"Q"

Barton et al (1974) proposed a Tunnelling Quality Index- "Q" for the determination of the rock mass characteristics and tunnel support requirements. The numerical value of the index "Q" varies on a logarithmic scale from 0.001 to 1,000 and is defined by:

$Q = RQD/J_n \times J_r/J_a \times J_w/SRF$, Where RQD is the Rock Quality Designation, J_n is the joint set number, J_r is the joint roughness number, J_a is the alteration number, J_w is the joint water reduction factor & SRFis the stress reduction factor.

Based on the detailed geological mapping and analysis of joint pattern and their nature, values for the six parameters are worked out and these values are used in the computation of "Q" Values. They are tabulated.

The Tunnelling Quality Index "Q" of 4.1 and 0.4 are plotted on the graph of Fig. No.6. The tunnel does not require any supports or regular rock bolting. However, spot bolting where required may be provided. As regards the second category having a "Q" value of 0.4, the requirement of two rock bolts of 50 mm dia., 1.5 m length and spaced at 1 to 1.25 m in the crown portion of the tunnel are indicated. The tunnelling conditions evaluated on the basis of the analysis dealt with in the above paras are given in the geological section (Fig.4).

Surge Shaft

A Surge Shaft is proposed at the end of the tunnel at R.D. 2.8 km/3.15 km to take surge effect in the tunnel. Since a second kink in the tunnel alignment is suggested, the Surge Shaft will be at R.D. 3.10 km, where limestone is expected to be encountered in the excavations. One borehole B.H.No.11 is recommended at the location of surge shaft and briefly mentioned in relevant Para. However based on the assessment of the limestone occurring for over 100 m above the base of surge shaft, it is suggested that the excavation may be carried out to make it open to sky. The limestone can stand vertical excavations, but three metre wide benches may be provided at 20 m intervals. Systematic rock bolts and steel fibre reinforced shotcrete may be provided as support system.

Penstocks

Penstocks are proposed along the hill slopes

Table 3 : Rock mass rating as per geomechanics classification

Sr. no.	Parameter	Tunnel intake of Stage-II (upper stage) of alternative-I	Tunnel exit at penstock of stage-II (upper stage) of alternative-I
1	Strength of intact rock mass	50-100 MPa: Rating 7	25-50 MPa: Rating 4
2	RQD	50-75%: Rating 13	25-50%: Rating 8
3	Spacing of discontinuities	06-2 m : Rating 15	60-200 mm : Rating 8
4	Condition of discontinuities	Slightly rough etc.:Rating 20	Slickenside etc. Rating 10
5		Wet : Rating 7	Dripping : Rating 4
6	Rating adjustment	Fair : -5	Fair : 5
7	R.M.R.	57	29
8	Rock Mass Class	Class III: Fair Rock	Class IV : Poor Rock
9	Stand-up time	About 1 month, Roof falls at places.	About 12 Hrs.
10	Support requirement	No Supports	Spot bolting at specific points
11	Cohesion of Rock Mass (kPa)	200-300	100-200
12	Friction Angle of Rock (Deg)	25-35	15-25

Table 4 : Rock quality tunneling index-"q"

Parameter	Tunnel intake of Stage-II (upper stage) of alternative-I	Tunnel exit at penstock of stage-II (upper stage) of alternative-I
1. R.Q.D.	75	40
2. Jn	9	12
3. Jr	1.5	1.5
4. Ja	2	3
5. Jw	0.66	0.66
6. SRF	1.0	2.5
7. Q	4.1	0.4
8. Support requirements	No supports required	Spot bolting

by providing suitable anchor blocks. But it is now suggested to provide underground penstocks (pressure shafts), where inclined penstock tunnels have to be excavated from RL +1590 m to +1460 m. The fresh and compact limestone is expected to be met with in the excavation of the penstock tunnels.

The Surge Shaft and Inclined Pressure Shaft of 227 m also will have limestones in the tunnelling. This Pressure Shaft will have adequate vertical and horizontal cover. The Penstock tunnel will also have adequate vertical and horizontal rock cover. The Alternative Alignment appears to be geotechnically quite good and is recommended to be adopted. The geotechnical evaluation of the Adit, Approach channel with desilting basin and Power House are also done.

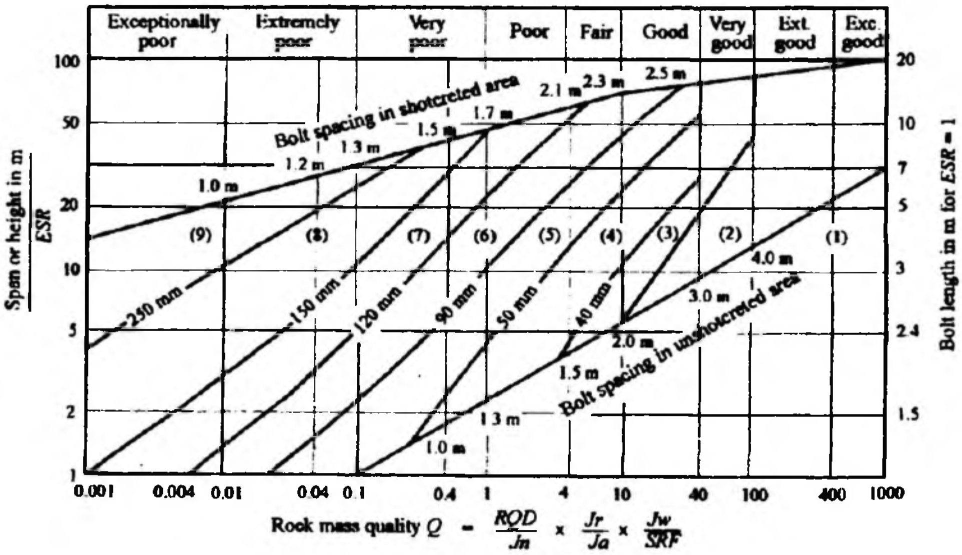
Geotechnical evaluation of stage-I of the project

General

The present scheme consists of Diversion Dam with Central Gated Spillway, 5.980 km long headrace tunnel and surface power house to utilise 11 cumecs of water to generate 20 MW (3x6.6 MW) of hydel power. The various components of the scheme have been examined and geological mapping carried out.

Diversion Dam-Stage-1

The study revealed that limestones with thin inter laminations of slaty limestone, dolomite, chert, marble and thin bands of quartz belonging to Pipalkoti Formation of Garhwal Group of rocks is the main rock type in the area. The limestone as exposed on either flank of the river is fresh and hard and exhibits three sets of joints.



REINFORCEMENT CATEGORIES
1) Unsupported
2) Spot bolting
3) Systematic bolting
4) Systematic bolting with 40-100 mm unreinforced shotcrete
5) Fibre reinforced shotcrete, 50 - 90 mm, and bolting
6) Fibre reinforced shotcrete, 90 - 120 mm, and bolting
7) Fibre reinforced shotcrete, 120 - 150 mm, and bolting
8) Fibre reinforced shotcrete, > 150 mm, with reinforced ribs of shotcrete and bolting
9) Cast concrete lining

Q-0.4-AT TUNNEL EXIT
Q-4.1 AT TUNNEL IN TAKE

Fig.6. Estimated support categories based on tunnlling quality index "Q" (after grimstad & barton 1993)

The site is considered suitable for the construction of the Diversion Dam. The depth to foundations of the Diversion dam are estimated to be 10 m i.e., at RL +1320 m.

Headrace tunnel

D-shaped Headrace tunnel of 3.0 m height and 3.0 m width and of 5.980 km length is proposed to divert 11 cumecs of river water to the Power House generate 20 MW (3x6.6 MW) of power. The tunnel intake is proposed at RL +1335 m and exit at R.D. 5.980 km.

The limestone with thin interlamina-tions of chert, marble, carbonaceous shale and quartz is expected to be the tunnelling medium. All the complex structural features projected along the tunnel are considered and the tunnelling conditions are worked out.

Rock Mass Rating (RMR)

As in the case of tunnel of Stage-II, Rock Mass Rating (RMR) and Rock Quality Tunnelling Index "Q" are computed for the tunnel of Stage-I. The details are tabulated below.

The Tunnelling Quality Index "Q" of 5.5 and 2.2 are plotted on the graph of Fig. No.7. The tunnel in the Inlet does not require any supports or regular rock bolting. However, spot bolting where required may be provided. As regards the second category having a "Q" value of 2.2, the requirement of two rock bolts of 50 mm dia., 1.5 m length and spaced at 1.25 m in the crown portion of the tunnel are indicated.

The terrain and the geological structure have been described in the earlier paras. According RMR and "Q" systems, the tunnelling media falls under GOOD and FAIR class. The tunnelling medium is classified taking into consideration of geology, structure and geomorphology as well as the RMR and "Q" systems.

Alternative tunnel alignment

An Alternative Tunnel Alignment **"AEFGD"** has been selected and is shown on Fig.3. The new alignment is closer to the river course as compared to the Original Alignment **"ABCD"** which runs under high hill range.

A geological section (Fig.5) has been developed for the Alternative Alignment **"AEFGD".** Folded sequence of limestones form the tunnelling media. The rock cover over the crown of the tunnel varies from a maximum of 400 m at Ch.4400 m to a minimum of 70 m at Ch.4991 m. The horizontal cover is also quite adequate and varies from a maximum of 450 m at Ch.5000 m to a minimum of 50 m at Ch. 4991 m.

The Surge Shaft of the Alternative Alignment is located at Ch.5259 m. Fairly compact and fresh limestone is expected to be met with in the excavation of the Surge Shaft. The horizontal/side rock cover is also adequate. Wherever the limestones are highly jointed fractured rock bolting may be done for stabilisation.

Limestone will be encountered in the tunnelling. The side rock of the cover in the last one third reach of Inclined Pressure Shaft of 241 m appears to be inadequate and may cause instability problems. It is therefore advised to have the Surge Shaft at Ch. 4991 m as modification to the Alternative Alignment. With this modification, the Alternative Alignment is acceptable from geotechnical point of view and can be adopted.

6.5 Power house

A surface Power House is proposed on right bank of the river Birahi Ganga (Lat. 30° 22'30": Long. 79° 29'00"). A geological map of the proposed location is prepared on 1:500 scale delineating bed rock from the overburden (Plate No.11). A geological section is also prepared indicating the bed rock profile (Plate No.12). Major portion of the river bed and valley is covered with fluvio-glacial debris, where large boulders are embedded in sandy matrix. Rocky natural bench of limestone is identified on right bank

Table 5: Rock mass rating as per geomechanics classification

Parameter	Tunnel intake of Stage-I (Lower Stage) of Alternative-I		Tunnel exit at Penstock of Stage-I (Lower Stage) of Alternative-I	
1. Strength of intact rock mass	50-100 MPa:	Rating 7	50-100 MPa:	Rating 7
2. RQD	50-75%:	Rating 13	50-75%:	Rating 13
3. Spacing of discontinuities	06-2 m :	Rating 15	200-600 mm :	Rating 10
4. Condition of discontinuities	Slightly rough etc. :	Rating 25	Slickenside etc.	Rating 20
5. Ground Water	Wet :	Rating 10	Dripping :	Rating 4
6. Rating adjustment	Fair :	-5	Fair :	-5
7. R.M.R.		65		49
8. Rock Mass Class	Class II: Good Rock		Class III : Fair Rock	
9. Stand-up time	About 1 year		About 1 month.	
10. Support requirement	No Supports required		Spot bolting at specific points	

Table 6: Rock quality tunneling index-"q"

Parameter	Tunnel intake of Stage-I (Lower Stage) of Alternative-I	Tunnel exit at Penstock of Stage-I (Lower Stage) of Alternative-I
1. R.Q.D.	75	50
2. Jn	9	9
3. Jr	2	2
4. Ja	2	2
5. Jw	0.66	1
6. SRF	1.0	2.5
7. Q	5.5	2.2
8. Support requirements	No supports required	Spot bolting

of the river at about 10 m height above river bed, which has sufficient length and width and the Power House can be located conveniently.

Weathered to moderately weathered limestone is met with at the proposed power house site. Fairly fresh and hard limestone is expected from a depth of 2 m. The foundation level of the turbines is RL +1138.00, which is more than 2 m from ground surface, where fairly fresh and hard limestone would form the foundations. Tail Race level is around RL +1133.00 for which open Tail Race Channel or a short Tail Race Tunnel may be considered aligning along northerly direction.

Two Adits are proposed for this tunnel. As an alternative to the adits, Vertical Shafts of 6 to 8 m dia may be considered. These are quite acceptable from geotechnical and environmental considerations. The Surge Shaft can also be utilised for opening two faces and thus there will be altogether six faces for excavation of the tunnel in addition to two other faces at Inlet portal and from power house side.

Seismicity

Seismotectonic studies

The area covering a radius of 150 km around the proposed Birahi Ganga Small Hydro Power Project has been studied for seismicity making use of the Seismotectonic atlas of India and its environs of (2000) of Geological Survey of India. Seismically this area constitutes one of the most active domains of the Himalaya. Within a period of 181 years from 1816 to 1997, a total of 297 seismic events have been recorded. Out of these 32 events are of M =5.5. Frequency distribution of earthquakes indicates more than 50% population within the magnitude range 4 – 5. Area wise, seismicity is quite

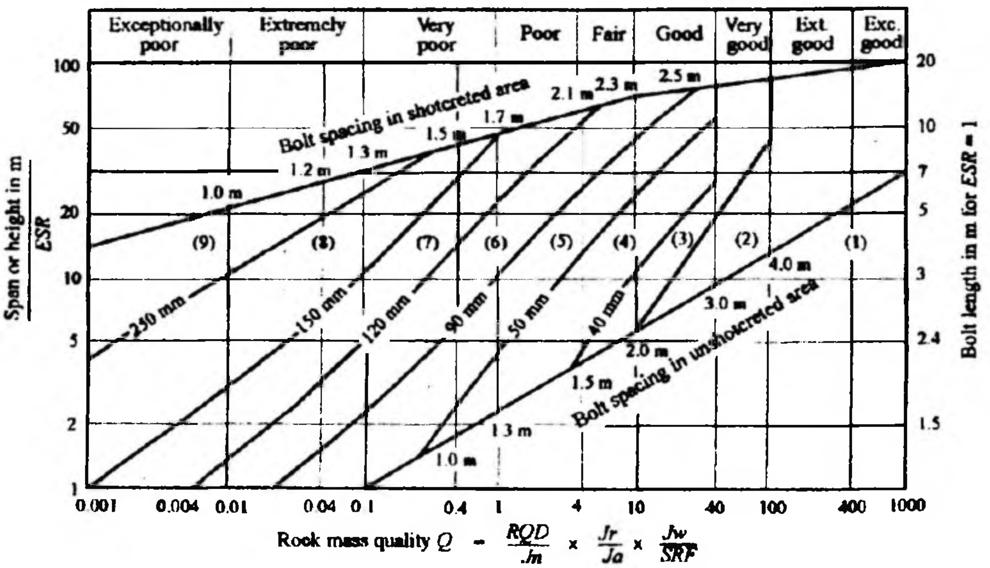


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Fig. 7. Estimated support categories based on tunnlling quality index "Q" (After Grimstad & Barton 1993)

high in the Main Himalayan belt, subdued within the Tibetan Plateau and a few events located over the Indo-Gangetic plains.

Several damaging earthquakes are recorded from this terrain. These are Dharchula earthquake of 28th August 1916, Kakpot Earthquake of 28th December 1958, Kinnaur Earthquake of 19th January 1975, Uttarkashi Earthquake of 19th October 1991, Chamoli Earthquake of 23 January, 1996, Garhwal Earthquake of 26th March, 1996 and Chamoli earthquake of 29th March 1999 has a Magnitude of 6.8 on Richter Scale.

The Project site is amidst the Main Central Thrust. The MCT lies at a distance of 10 km in the east and south-west. Alkanada fault is located at a distance of 25 km towards W-SW. All the transverse faults are away from the Project site except the Ramaganga fault. This fault is 25km towards south-east.

Seismic zones of India

Seismically, the project area falls within the Zone V, which has witnessed major earthquakes including two earthquakes in Chamoli. The Earthquake that occurred on 29th March, 1999 has a magnitude 6.8 M on Richter Scale while that occurred on 23rd January, 1996 is rated as magnitude 4.5 M on Richter Scale.

The I.S.Code No. 1893/2002 recommends a seismic factor of 0.08 for Zone V. Although the Diversion dams and the other appurtenant structures are of low height, an importance factor of 3 is provided in view of high seismicity in the area. The horizontal seismic coefficient works out to 0.24 g and this is recommended to be adopted,

Conclusions

The Birahi Ganga Small Hydro Power Project envisages the harnessing of the hydro-power potential of 32.7 MW locked up in river basin between erstwhile Gohana Lake and the confluence Birahi Ganga River with Alaknanda River. Geotechnical studies have established that the project is feasible and that the geological conditions are quite favourable for the project.

As the area of the project is very rugged with steep slopes and inaccessible. Cartosat-1 and Landsat imagery have been used to generate contour maps on a scale of 1: 10000 and other maps. The data derived from these studies have been utilised in the geotechnical evaluation of the project.

The geotechnical studies of the originally proposed scheme consisting of Stage-I and Stage-II have established that fairly compact and hard limestones would form the foundations of all the structures and tunnelling media. Based on the geological mapping carried out, geological sections have been developed, which provide the depth to foundations in case of (1) Diversion dams, (2) Intake structures, (3) Power houses and other appurtenant structures. In all the cases, fresh and sound limestone available at depths of 2 to 10 m has been recommended for foundations. Subsurface exploration by means of boreholes has been recommended to establish the suitability and depth to foundation grade.

In a similar way, geological sections are prepared for tunnels of the Original project and tunnelling media has been evaluated and classified. The Rock mass characters computed according to Rock Mass Rating of Bieniawski and Rock Quality Tunnelling Index "Q" of **Barton** et al. have shown that the major portion of tunnelling media falls in Good and Fair class with minor stretches falling under Poor class of rocks.

Seismically, the project area falls within the Zone V, which has witnessed major earthquakes including two earthquakes in Chamoli on 29th March, 1999 having a magnitude 6.8 M on Richter Scale while that occurred on 23rd January, 1996 is rated as magnitude 4.5 M on Richter Scale. The horizontal seismic coefficient of 0.24 g and the vertical seismic coefficient of 0.12 g are recommended to be adopted in the design of structures.