A GEOTECHNICAL REPORT ON KHUTANI HYDRO ELECTRIC PROJECT (21 MW), PITHORAGARH DISTRICT, UTTRAKHAND

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CONTENTS

Cover Photo: A view of Sarju river course, upstream of dam axis (u/s of Suspension Bridge) having a slide zone at right, above Badargad nala confluence with Sarju River.

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1. INTRODUCTION:

The project area comes within a part of the Western Himalaya containing the Himalayan Tectogen. This comprises rock types varying from Proterozoic to Phanerozic periods. The Himalayan region or Extra Peninsular part can be divided into four zones from south to north. These are: i) Sub or Outer Himalaya, ii) The Lesser Himalaya, iii) The Higher Himalaya and iv) The Tethys Himalaya (Misc. Pub. 30, GSI, 2012, pp-5). The tectonic boundary between Outer Himalaya and the Lesser Himalaya is marked by Main Boundary Thrust/Fault (MBT). Similarly the tectonic boundary between Lesser Himalaya and Higher Himalaya is marked by the Mai Central Thrust (MCT). The boundary between the higher Himalaya and Tethys Himalaya at further north is marked by the South Tibetan Detachment System (STDS).

The present area containing the Khutani Small Hydro Electric Project comes mainly within the Lesser Himalayan Region (zone-ii). The rock types occurring in this site are: phyllite, shale, slate, quartzite, limestone, dolomitic limestone, garnetiferous mica schist etc. belonging mainly Garhwal Group of Proterozoic age. As per the lithological characters and prevailing literature, the area comes under the Meso-proterozoic (1600-1000 Ma) period, which is characterized by the extensive development of quartzite with penecontemporaneous volcanic flows and carbonates. This succession is well exposed in the inner part of the Lesser Himalaya and is bounded by North Almora Thrust (NAT) in the south and Main Central Thrust (MCT) in the north. The basal quartzite–metavolcanic association is known as Dharagad Formation in Tons-Yamuna area and as Rudraprayag =Rameshwarghat =Rautgara formations in Garhwal and Kumaon regions (Table-I). This sequence is succeeded by a carbonate-predominant sequence called the Deoban Group in Tons-Yamuna region and Pithoragarh Formation of Garhwal Group in Garhwal-Kumaon region (Misc. Pub 30, GSI, Part-XIII, Uttar Pradesh and Uttarakhand, 2012, pp-15). The carbonate zone passes upward into quartzite-volcanic flows association which constitutes the Berinag Formation in Garhwal -Kumaon region. The quartzite-volcanic facies of the Rudraprayag=Rameshwarghat =Rautgara Formation and carbonate facies of Pithoragarh Formation constitute the Garhwal Group in Garhwal-Kumaon region. Thus it appears that occurrence of calcareous facies or limestone/dolomitic limestone is characteristic of Garhwal Group or upper series of rock formations in Pithoragarh district.

2. STRUCTURES:

Structurally the Uttarakhand Himalaya can be divided into four NW-SE curvilinear tectonic belts each characterizes by its own distinct geological setup bounded by prominent dislocation zones. These tectonic belts from North to South ((Misc. Pub. 30, GSI, 2012, pp-13) are:

NORTH

Tethyan Himalayan Belt

South Tibetan Detachment System (STDS)

Main Central Thrust (MCT)

Main Boundary Fault (MBF)

Foot Hill Fault (FHS)

Quaternary Formations

SOUTH

3. GEOLOGICAL SETUP OF THE PROJECT AREA:

The following is the Regional geological setup of the area containing the Khutani SHEP (Ref. Misc pub. 30, GSI, 2012, pp-33)

Table- 1:- Stratigraphic succession of the area in and around the project is as follows:

		Jaunsar area		**Uttar Kashi-Pithoragarh area**		
Age	Group	Formation	Lithology	Group	Formation	Lithology
Meso-proterozoic		Chirpatyakhal Granite		Coarse to medium grained, porphyritic granite with pockets of biotite and tourmaline		
		Garhwal Volcanics		Vesicular, amygdular and massive basalt and dolerite dykes		
	Deoban Group	Sauli	Carbonaceous slate, quartzite, dolomite with stromatolitic and cherty limestone	Garhwal	Berinag = Nagnithank	quartzite, slate with associated basic metavolcanics

		Bajmara	Stromatolitic limestone and slate		Pithoragarh =Shyalana / Lameri/Tejam	Limestone, dolomite, phyllite, shale and cherty quartzite
		Dharagad	Massive quartzite, shale		Rautgara = Uttarkashi	Interbedded quartzite, slate with lensoidal limestone, grey, green and purple slate with quartzite
					Agastmuni	Schistose grit, sericite phyllite, slate and quartzite with basic volcanics
Undifferentiated Proterozoic	Dudatoli Granite					Porphyroblastic biotite muscovite granite
	Ramgarh					
	Almora					
	Basic Intrusives					Amphibolite and metanorite

The litho-units of Uttarkashi and Pithoragarh area are almost same and comparable with Jaunsar area. In Pithoragarh area, mainly Garhwal Group of rocks belonging to Mesoproterozoic area occurs. The main rock types occurring in and around the project area are: Limestone, dolomitic limestone, quartzite and cherty quartzite, stromatolitic limestone and slate. Metavolcanics and intrusive amphibolites are also seen.

4. THE INDIVIDUAL PROJECT COMPONENTS:

The project components include a 20m high concrete diversion dam with gated intake structure, open/cut and cover feeder channel, desilting chamber, 4000m long HRT, two nos. of adit tunnels, surge shaft, penstock and a surface power house. All these structures are contemplated at left bank of Sarju river.

4.1. Diversion (Dam) site:

As per the DPR 2011, a low height concrete gravity dam is proposed across the Sarju River at about 100m downstream of the junction of Sarju and the Badargad nala to divert water of about 50.5 cumec. During the site visit the co-ordinates of right bank location along the dam axis is taken as N. Lats 29^{0} 46’38.43” and E. Longs.79^{0} 49’30.65”. The trend of the dam axis across the river is N80^{0}E-S80^{0}W and the flow of the river is towards S20^{0}E. The FRL has been fixed at 799m for the reservoir of this dam. Both the abutment hills in the dam site is having a slope of about 45^{0}. At the dam axis of right bank proper, no bedrock is seen, however sporadic bedrock occurs in and around this dam axis at right abutment hill at u/s and d/s of dam axis. The general trend of foliation of bedrock at right abutment is $N85^0W$-$S85^0E$ dipping 50^0 northeasterly. This exposure of bedrock is located at about 70m upstream of the dam axis in riverbed level of right abutment. The rock types occurring in this right abutment hill are medium to thinly bedded, moderately hard limestone, black phyllite, chert, garnetiferous quartz-mica schist etc. Thus in most of the stretches, the right abutment hill is covered with slope wash debris and the river bed is partly covered with River Borne Materials (RBM). Excepting the upper reaches of left abutment in the dam site similar slope wash debris in abutment and RBM is found in the riverbed section. In the left abutment hill, bedrock occurs at higher level along the dam axis having a trend of $N40^0W$-$S40^0E$ dipping 35^0 northeasterly. Thus as per left bank data the dam axis is askew by about 60^0 to that of foliation trend. On an average the dam axis is askew by at least 40^0 to that of foliation trend. Rock types occurring in the left bank dam axis are hard bands of limestone ranging in thickness from 0.20m 00.30m alternating with thin shale bands noted in the upper level of the abutment hill. At places these limestones are having stromatolitic or algal structures embedded on it. These are formed by the growth of blue green algae in limestone deposits mostly during Pre-Cambrian times and phosphatic in nature. From the stability analysis it is seen that the flow of the river in the dam site is $S20^0E$ and the strike of foliation of enclosing bedrock $N50^0$ to 80^0W-$S50\ ^0$ to 80^0E dipping upstream side at 40^0 to 50^0. Thus in the dam site the flow of the river is more or less across the strike which indicates a geologically stable criterion for a concrete dam. The occurrence of limestone in the abutments as well as in riverbed is a concern, which has to be addressed by grouting. At places, limestone is sandy in nature, therefore, the extent of cavern formation may not be extensive. In the dam site bedrock in the riverbed is expected at about 7m depth or earlier. Along the abutment, bedrock is expected at about 5m to 6m or earlier. The present water span across the Sarju river in the dam axis is about 30m. Three bore holes have been suggested along the dam axis, one at river bed close to the right abutment, and the other two at river banks (in left and right abutments) along the dam axis. Two more bore holes were also suggested in either end of bucket location in downstream of the dam. The major foliation and joint data in and around the dam axis is given in the following Table (Table-I):

Photo-1: Stromatolitic structure on limestone beds indicated by 'U' shaped structures at left abutment hill near dam axis..

Table-I:

Discontinuity set Nos.	Dip amount	Dip direction	Remarks
S_1 (Fol.)/J_0	35^0	50^0	Foliation joint, rough, planar to slight undulatory, at places impregnated by quartz and calcite vein, spacing 15cm to 30cm, persistence >5m, aperture .about 1mm or less.
J1	70^0	185^0	Joint, rough planar, unstained, impregnated by thin quartz vein, spacing 45cm to 1m, persistence >5m, aperture 1mm
J2	60^0	235^0	Continuity 3 to 4m, spacing 0.5 m to1.5m, rough planar. Partly stained, planar to rough undulatory, aperture nil.
J3	30^0	180^0	Continuity 2.5 to 4m, spacing 1.5 m to 3m, rough planar. Unstained, aperture nil.

4.2. Reservoir area:

The Full Reservoir Level (FRL) is kept at 799m for the project. Geological study of reservoir competency indicates that from dam axis upstream near upto Badargad nala confluence with Sarju river or upto the suspension bridge, limestone alternating with sandy limestone, phyllite, calcite vein etc. form the country rock of reservoir periphery. Upto this extent grouting may be required if cavern formation is extensive. Further upstream along the Sarju river no limestone band is found to occur, instead phyllite, quartzite, phyllitic quartzite, garnetiferous quartzite, thin bands of steatite and talc occurs as bedrock and abutment rock. Therefore, no apprehension of cavern formation is found upstream of Badargad nala junction within the reservoir area. During the reservoir area study, upstream of the Badargad nala junction, feasibility of an alternate dam site (N. Lats 29^0 46'57.1" and E. Longs.79^0 49'08.7") was noticed. If required, however this location can be explored further. This site is also feasible with a top span of only 64m and both the abutments contain competent bedrock. There is no limestone in this site, rather, the site comprises phyllite , quartzite, phyllitic quartzite and mica schist.

The other concern with the reservoir area is the peripheral submergence of the small hillock, where the Sapteswar Temple is situated just at the joining place of Badargad nala and Sarju river. This site containing the Temple was thoroughly studied to have remedial measures for the problem. There is also a lower temple than that of Sapteswar in the same locality. The Sapteswar temple proper does not come under submergence, but the lower temple comes. At surrounds of this complex bedrock occurs upto a certain extent comprising sandy limestone, phyllite and schist. A RCC wall of 8 to 15m high to be constructed on bedrock all around this temple complex, which would solve the submergence problem of the temple. Also a new structure called 'Pathik Ashram' (Rest House) is being constructed along with a boulder protection wall at the right bank of Sarju river, upstream of suspension bridge. But this structure will come within the submergence area as it is almost at riverbed level. Therefore to address these problems, a second option of dam site upstream in the Sarju river may be searched for if required.

4.3. Dam intake:

The revised dam intake structure, a gated structure along with the dam would be housed within the bedrock along with the dam abutment. At this upper level of left abutment, mainly medium bedded limestone would be occurring along with minor phyllite. The site is stable for intake.

4.4. Feeder Channel:

As per the new layout, structures like dam intake, feeder channel, desilting chamber, inlet to HRT etc. are likely to be located in bed rock and some in slope wash debris in the left bank. The bedrock comprises medium bedded limestone, phyllite quartz vein and meta-volcanics. The one side of these structures lying along the left abutment hill may have to be housed within the bedrock and the other side facing towards the river would have to be supported by suitable protective measures as required. Present surface location of feeder channel is in rolled boulders and slope wash debris. Here bedrock is expected at reasonable depth. No slide zone is visible at upper reaches of the feeder channel. However, after toe cutting, some slope instability may occur, which would be treatable. The feeder channel ends near a depression created by a small nala.

4.5. Desilting Chamber:

As per the design level, formation cutting in the site may have to go upto a reasonable depth from n.s.l. In this site bedrock is expected at about 4m to 5m depth and the desilting chamber site will be located in medium grained, hard limestone alternating with thin bands of quartzite and phyllite having almost a N-S trend. Geologically the site appears to be feasible as the structure will be housed in bedrock. One bore hole is suggested in the outlet side of the desilting chamber.

4.6. HRT Intake:

The location of HRT intake starts in a stable spur after a small nala depression i.e. in the right bank of the nala. Presently the site is covered with slope wash debris comprising small rock debris and soil. Bedrock is expected in the site at about 4m to 5m depth inside. Bedrock rock is exposed in road cutting section directly above this structure and comprises medium bedded sandy limestone, thin bedded phyllite alternating with vein quartz and chert. The trend of foliation of bedrock of this location is N45^{0}W-S45^{0}E dipping 45^0 north easterly. The GPS location at upper level of this site is N. Lats. 29^0 46’30.2” and E. Longs.79^0 49’25.80”. The HRT intake may require somewhat false portal as chert bands although hard in nature, becomes friable after long exposure to atmosphere. The vertical un-weathered rock cover above the overt level of the structure appears to be sufficient and the site appears to be feasible from geotechnical point of view. One bore hole is suggested in this intake portal.

4.7. Head Race Tunnel (HRT):

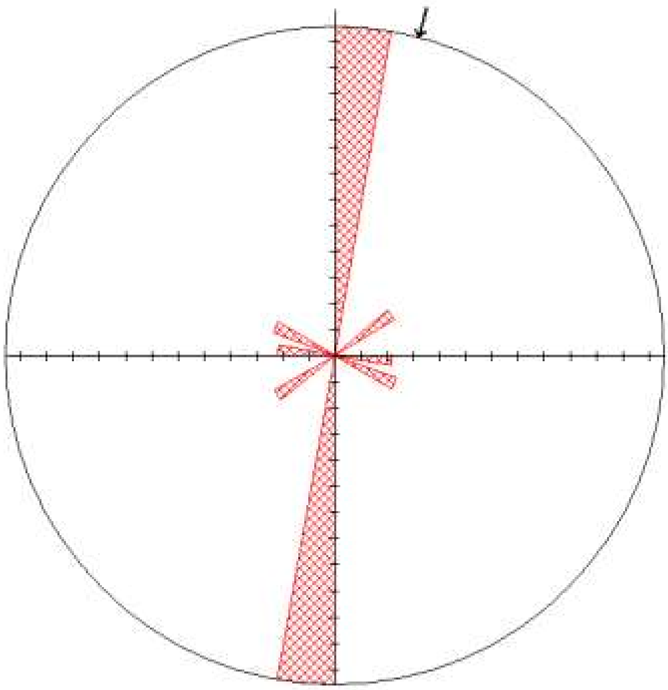
A 4000m long Head Race Tunnel is contemplated to divert water to power house. The rock types to be encountered along the stretches of HRT are limestone, sandy limestone, phyllite, quartzose phyllite, shale and meta-volcanics. These are in general good tunneling media other than the thinly foliated phyllite and shale. After coming out form desilting chamber and upto the 1st kink band the alignment of HRT is approximately N10^0E-S10^0W and the trend of foliation is N50^0-60^0W-S50^0-60^0E dipping north easterly. As per this the HRT will be at an angle of 60^0 to that of foliation trend of the bedrocks, which is a good tunneling condition. From the 1st kink to the second kink, the trend of HRT as per the revised design is about N25^0W-S25^0E. As the regional trend of foliation of bedrock is N50^0-60^0W-S50^0-60^0E, the tunnel section is askew by about 30^0 to 35^0 which is a moderate tunneling condition. From 2nd kink to near upto adit-I site, the HRT has a N10^0W-S10^0E trend, which makes an angle of about 400 with regional foliation trend of bedrocks. This is also a moderate tunneling condition. Beyond the 3rd kink or adit-I location, the trend of HRT upto surge shaft site is N35^0W-S35^0E, thus the alignment of HRT is askew by about 20^0 to that of foliation of bedrock, which is not a good tunneling condition and if the same trend of bedrock persists all along tunneling will be somewhat time consuming. Near Adit-II location the HRT has a low vertical cover of about 25m for a short length as per the revised layout plan; this stretch has to be checked. The following table (Table-II) shows the structural data of entire HRT section.

Table-II:

Discontinuity set Nos.	Dip amount (Range in degrees)	Dip direction (Range in degrees)	Remarks
S_1 (Fol.)/J_0	35^0 to 40^0	30^0 to 35^0	Foliation joint, rough, undulatory, unstained, at places impregnated by quartz/calcite vein/chert band, spacing 30cm to 70cm, persistence >8m, aperture 0.50mm to tight.
J1	50^0 to 55^0	280^0 to 285^0	continuity 3 to 5m, spacing 0.40m to 1.00m, gap slight but filled by silicic vein materials in few sets, rough planar to rough undulatory, rarely stained.
J2	75^0	185^0	Continuity 2.5 to 4m, spacing 0.5 m to1.5m, rough planar, unstained, gap nil, impregnated by few mm thick quart/calcite vein.

J3	75^0 to 80^0	325^0	Continuity 2.5 to 4m, spacing 0.5 m to1.5m, rough planar, unstained, gap nil, impregnated by few mm thick quart/calcite vein.

Thus slightly more than half of the HRT from the initial stretch would be having moderate to good tunneling condition as its skewness with bedrock to tunneling direction ranges from 35^0 to 60^0.baring the last stretch from near adit –I to surge shaft site, which is askew by hardly 20^0 to that of foliation trend of HRT or is near parallel to the foliation trend. Lithologically, there is not much of variation in rock composition or rock types along the HRT section, the repetition of calcareous sandstone, limestone, dolomitic limestone, shale, phyllite, meta-volcanics and intrusive quartz vein etc. forms the country rock in the tunneling sector. The major structural element to the north of HRT is Main Central Thrust (MCT), lying at about 25 to 30 km north of the project site and to the south of HRT another structural element is North Almora Thrust at about 20km away (south) from the project components. Thus the HRT is in between these two major structural domains and in general there should not be much of disruption in tunneling work for these two major structural elements at north and south. However, some geological surprise cannot be ruled out in the progressive tunneling work. The classification of rockmass within the HRT could not be done this time as detailed geological mapping is required for this type of interpretation and by detailed geological mapping more information on structural trend would be gathered to streamline the probable problematic zones along the HRT alignment. The stereographic projection (Fig-2.) also indicates that an angle of 30^0 to 35^0 is there in between HRT and foliation plane of bedrock. The Joint set J3 has a bigger skewness to HRT alignment. As per the rose diagram (Fig-1) of same data along HRT, the mean direction shown is 82^0-262^0, which indicates that the average trend of all the discontinuities along the HRT is near perpendicular to it.

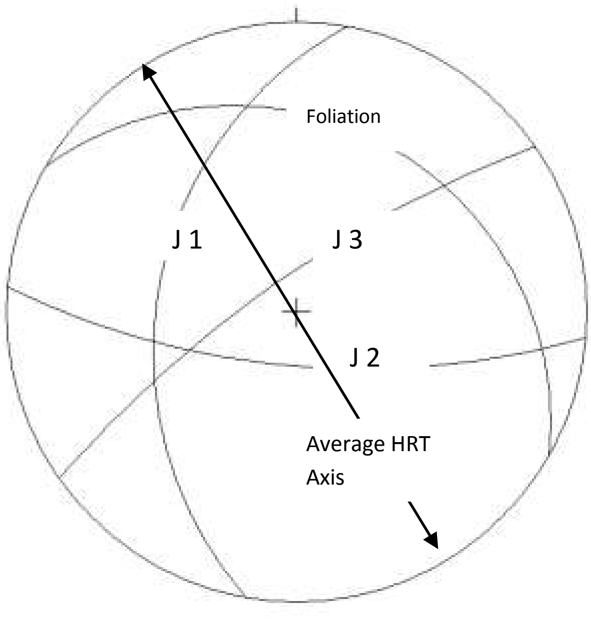


Data Description.

Data Frequency Azimuth linear sample line bias correction using strike length with sample line 0-000 (Mean angle used 5.1)
Axial (non-polar) data 4

Mean Resultant dir'n = 082-**262**

Fig-1. : Rose diagram of poles of uniformly taken discontinuity data of HRT in different places. (GEOrient version 9.5.0)



No. of Data = 4, Mean Principal Orientation = 64/33, Mean Resultant dir'n = 33-293, Mean Resultant length = 0.56, (Variance = 0.44), Calculated. girdle: 54/087

Orientations

ID	Dip	Directions
FP/J0	35	30
J1	50	280
J2	75	185
J3	80	325

Equal area net, lower Hemisphere

GEOrient Version-9.5.0

Fig-2. Stereographic projection of the major discontinuities along the HRT

4.8. <u>Adit-I:</u>

The revised location of adit-I was found to be inconvenient from the point of view of access road and construction of adit portal as the site is situated in a very steep scarp. Therefore, a suitable site was found to accommodate the structure at about 200m upstream of the existing one. The site is located at right bank of a small nala like depression. The n.s.l. at top of this proposed structure is covered with slope wash debris materials. In the adjacent locality of adit-I, thinly bedded phyllite with sandy limestone and quartzite is seen. These bedrocks have strike of foliation $N50^0W$-$S50^0E$ dipping 50^0 towards NE. As the trend of adit-I is almost E-W or $N85^0W$-$S85^0E$, the foliation trend of bedrock will be askew by about 35^0, which is a moderate tunneling condition. As per the site condition, the lateral and vertical cover of the tunnel seems to be adequate. The condition of portal could not be assessed at this stage because the proper site of relocated structure could not be reached during the visit. By shifting to this new location, the adit tunnel length would be reduced by at least 25m to 30m.

4.9. <u>Adit-II:</u>

This site exists as per the revised design and situated on the right bank of a nala depression, which makes an easy access to the bedrock in the design level. The bedrock found in this site is thinly bedded phyllite and schist, limestone alternating with shale and sandy limestone. The proposed invert level of the adit is about 780m. The portal site is alright, false portal upto minimum depth may be required. There is no problem with the lateral and vertical cover. The strike of foliation is $N60^0W$-$S60^0E$ dipping 35^0 north easterly. The trend of the adit tunnel as per the design is $N45^0E$-$S45^0W$, thus the bedrock will be askew by about 75^0 to the adit tunnel axis, which is a very good tunneling condition.

4.10. <u>Surge shaft:</u>

The revised top level of Surge shaft was 815m, but due to presence of a slide zone at adjacent northeast of this surge shaft location and inadequate lateral cover, during this visit, the site has been slightly shifted for about 30m west (upstream) to accommodate the structure. This new location is slightly higher, say 825m. Thus a total of about 10m excavation may involve reaching the design level in bedrock. The rock types occurring in the site are splintery shale, phyllite sandy limestone, quartzite and chert. Bedrock is likely to be available at reasonable depth. Presently the site is occupied by rolled boulders along with slope wash debris materials. The crown line of the adjacent slide zone is indicated by a curved line of rain cut, afterwards triggered by percolating rain water. The GPS location of the new site of surge shaft is N. Lats 29^0 44’49.4” and E. Longs.79^0 50’39.49”. The foliation dip in the site varies from 35^0 to 60^0; therefore not much of problem will be there as the average foliation dip is 45^0 as seen in upper reaches of the surge shaft hill. No strike of foliation was found as the area was inaccessible. The lateral cover is adequate in this site.

4.11. Penstock:

The surface penstock would be laid down mostly on bedrock as per the profile seen from the surge shaft site and power house site as well. It will have a N20^0E-S20^0W alignment. After reaching the design level, anchor blocks may get support on the bedrock comprising quartzite/limestone, phyllite etc. The surge tank and penstock along with anchor blocks are feasible in the relocated site.

4.12. Power House site:

The site has been located in a terrace deposit at left bank of Sarju river. No bedrock is exposed in the site. In view of slight shifting of surge shaft site north-west (u/s), the power house site has also been slightly shifted upstream and tilted accordingly to re-adjust with the shifted penstock alignment. The GPS Location of the re-set power house near the joining place of penstock is N. Lats 29^0 44’46.2” and E. Longs.79^0 50’39.90”.In the adjacent locality at right bank of Sarju river foliation trend of bedrock is N40^0W-S40^0E, dipping at 35^0 towards south west. But the power house will be located on a river bank terrace enclosing bigger size boulder underneath. The site is a composite one of slope wash debris and river bed materials. A raft foundation may have to be design if bedrock is not occurring in the site at all. A slide zone is seen at north north east of surge shaft–penstock line, which may partly touch the eastern periphery of power house after toe cutting for construction. Therefore, to address the situation, suitable measures may be taken as deemed fit during construction time. The power house site is feasible from geological point of view. Exploration programme has been suggested in these structures as follows: i) one borehole at surge shaft, ii) one at the penstock alignment and ii) two in power house area.

Photo-2. Power House site on Sarju River Terrace.

Photo-3. Surge shaft old (1), S. Shaft (2) shifted due to slide.

4.13. Tail race Channel (TRC):

In view of shifting of the powerhouse site slightly north-west (u/s), the length of the TRC may be increased from earlier 50m to maximum 80m. The TRC will have to be accommodated on river borne materials comprising big boulders, sand, rock chips and small pebble. The minimum tail water level is kept at 742.80m.

5. SEISMO-TECTONIC ASPECT OF PROJECT SITE:

The present area containing the project site comes within the Lesser Himalayan Region. In Pithoragarh area, mainly Garhwal Group of rocks belonging to Meso-proterozoic period occurs. The northernmost structural elements of this Pithoragarh District is the Main Central Thrust (MCT) and the southernmost structural element is North Almora Thrust (NAT). However, the MCT is far away from this site. Thus the project area falls in the Himalayan tract of Garhwal Region (Seismotectonic atlas of India and its environs, Narula et al. 2002). One more major tectonic feature located at south east of the present area is Ramgarh Thrust.

In the recent years (1990 onwards) Uttarakhand has experienced two major earthquakes of magnitude more than 6. These are i) Uttarkashi earthquake of 19 October 1991, Mw 6.8, (Pilang-Bhatwari area, Uttarakhand, Lats.30.770 N, Longs.78.790 E). ii) Chamoli Earthquake of 29th March 1999, Mw-6.8 (Chamoli-Pipalkoti area, Uttarakhand, Lats. 30^{0}17.82' N, Longs. 79^{0}33.84'E), in which 115 people were killed in the Gharhwal region. The epicenter of this earthquake is 102km NNW of Almora and further away from the project site. As the project area is lying in Uttarakhand which is in highest seismic zone-V, therefore, suitable site specific coefficient may be incorporated in the design of dam and other main appurtenant structures keeping safety factor.

6. CONCLUSIONS:

i. For Khutani Small hydro electric project, it is contemplated to divert water from Sarju river by a 20m high concrete gravity dam having FRL level of 799m. A HRT of 4000m length, two adit tunnels and a surface power house at left bank of the river is proposed.
ii. The present area containing the Khutani Small Hydro Electric Project comes mainly within the Lesser Himalayan Region belonging Garhwal Group of rocks of Proterozoic age. The rock types occurring in this site are: phyllite, shale, slate, quartzite, limestone, dolomitic limestone and garnetiferous mica schist.
iii. The two main structural elements nearest to project site are the Main Central Thrust (MCT) in the north and the North Almora Thrust (NAT) to the south of the project site. However, these two thrusts are not too close to the project site.

iv. The regional foliation trend of the bedrock in the project area is N50^0 to 60^0W-S50^0 to 60^0E dipping mostly towards NE at moderate angle. The other sets of discontinuities or joints are mostly oblique to the foliation trend.

v. The location of dam site with steep abutment is suitable for a straight concrete gravity dam of 20m high, where bedrock is there in the abutment hills. As calcareous sandstone/limestone bed is there in the dam site and upto 100m upstream into the reservoir area, probable sinkhole formation at dam site is a concern.

vi. Seepage from the reservoir periphery is manageable but the location of Sapteswar temple within reservoir area is another issue. A 15m to 20m high boundary wall for a total length of about 120m may have to be constructed surrounding the complex to save it from submergence.

vii. The 4000m long Head Race Tunnel (HRT) would pass through good tunneling medium comprising quartzite, phyllite, limestone and calcareous sandstone. More than half of the total length of the HRT upto adit-I location will be askew by 35^0 to 45^0 to that of average HRT alignment, which is a moderate to good tunneling condition. From adit-I location to surge shaft, tunnel is askew to the bedrock by only 200 , which would be poor tunneling condition, if otherwise the foliation trend changes due to folding etc. Near adit-II location there is a low vertical cover (about 25m) zone of HRT, which has to be checked. Detailed geological mapping along the HRT alignment is required for detailed interpretation.

viii. The adit-I location was slightly shifted by about 200m upstream from the revised design to avoid a steep cliff overhead. Adit tunnel would be askew by 35^0 with respect to trend of foliation plane, which is a moderate condition and the vertical cover is adequate.

ix. The surge shaft was shifted by about 25m upstream from the revised design due to inadequate lateral cover and a slide zone. The dip amount of foliation plane in the site varies from 35^0 to 60^0, therefore excavation would be smooth. Bedrock will be available at shallow depth.

x. The surface power house at left bank of Sarju river is relocated as per the surge shaft/penstock location. The structure will be seated on a stable terrace comprising boulder and pebble zone. The relocation was also essential to avoid spalling from the adjacent slide zone lying close to the surge shaft.

xi. Thus, the overall project components as per the study, with required little bit of shifting from the revised design appears to be feasible from geotechnical and techno-economic considerations.

References:

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FIELD PHOTOS OF KHUTANI H. E. PROJECT

Photo- 1: A view of Sapteswar Temple at confluence of Sarju river and tributary Badargad nala, also a slide zone in the confluence.

Photo-2: View of Dam axis and HRT inlet portal along left bank of Sarju river course.

Photo-3: Shows dam axis across Sarju river

Photo- 4: Tunnel Inlet portal and desilting chamber site.

Photo-5: Showing left abutment along dam axis.

Photo-6: Left abutment uphill near dam axis bedrocks dipping into the hill.

Photo-7: Dam axis into the left bank along flag line.

Photo- 8: Bed rock of black phyllite alternating with schist & limestone at right bank, U/S of dam axis.

Photo-9: Bedrock at right bank, u/s of dam axis at suspension bridge site.

Photo- 10: Bedrock at lower periphery of Sapteswar Temple along Sarju river.

Photo-11: Very hard, medium grained limestone at left abutment, above the dam axis.

Photo-12: View of power house site at left bank of Sarju river.

Photo-13: Growth of stromatolitic structure on limestone beds indicated by 'U' shaped structures at left abutment hill near dam axis..