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1. Regional Geology

The area lies in the lesser Himalaya belt and forms the northern faulted limb of the Doon Syncline, where Pre-Tertiary rocks of Pre-Cambrian and Palaeozoic age (?) have thrust over the younger Upper Tertiary rocks and quaternary sediments along Main Boundary Thrust/Fault. The Main Boundary Fault (MBF) is the main tectonic element in the area. The exposed formations in the area north of Main Boundary Thrust strike in a Northwest-Southeast trend. These formations dip in the northeast and form the southern limb of the Mussoorie Syncline (the syncline axis falls north of the mapped area). Mainly four groups of rocks striking NW-SE and dipping 30° to 66° due northeast are exposed along Song valley.

The general stratigraphy and lithology of the various formation in the area is as tabulated below in Table 1.

TABLE 1: STRATIGRAPHIC SUCCESSION OF THE PROJECT AREA

Formation		Group
Dun Gravels		Dun Gravels
Upper Middle and Lower Siwalik		Siwalik Group
E	Krol	Mussoorie Group
D		
C		
B		
A		
Infra Krol		
Blaini Boulder Bed		
Nagthat		
Chandpur		Jaunsar Group

The area falls into tectonically active zone. Evidences of Neotectonic movements have been reported in the area. Along the left bank slopes of Song rive opposite Khairi-Kachar-Saura-Saroli reserved forests, a number of slides scars and debris cones are visible all along the bank from upstream of the confluence of Sirwalgarh Rao with Song to the confluence of Chiller Rao with it appears to be taking place along a 6km long NW-SE trending lineament.

2. Topography & Physiography

The Song river system is composed of a good number of tributaries of which the main are BandalNala, Chiphaldinadi and some small streams from the south as well as north faces. Most of the streams are perennial and spring fed. Most of the rain water goes as run off but some percentage gets in-filtered into the joints and crevases and comes out in the form of spring which form the bulk water of this river.

A large number of springs on the south hills of this river are located in the phyllite quartzite silt stone association of rocks which have been equated to Chandpur. Various lineaments / fractures in this formation which underlie the massive, hard, highly metamorphosed quartzite have mostly given rise to spring formation.

Considerate amount of water is contributed to Song river from the northern hill slope having large number of tributaries with the water sources mainly from springs. The Song drainage basin at dam site has a total area of 85 sq.km. approximately. The width of the water bearing stream in the Song river is approximately 6.0 – 10.0 m wide with an average water depth of 0.6 m.

3. Geology of Dam site

Dam axis is aligned in N330° & is located at about 1.25 km upstream of ChiphaldiNadi. At dam site, bed rock is very well exposed on both the abutments up to hill top and in the upstream of dam axis i.e. in the reservoir area. Slopes of both the abutments are steep in order of 60° - 70°. Bedrock belongs to Nagthat Formation characterized by greenish grey to reddish brown/purple, banded to massive, medium to fine grained quartzite. The hills on either bank rise from R.L. 880 to more than R.L. 1000 m. the bed rock i.e. Nagthatquartzites dipping 45°–58° due N050°– N055° i.e. in the upstream direction. At dam site, the Song river flows in N240° direction. The total width of river at river bed level is about 45m - 60m.

River bed of the Song river in and around dam axis is occupied by River Borne Material (RBM) comprising of boulders, cobbles, pebbles and gravels of various rock types embedded in the sandy matrix. The size of the boulders in the river bed varies up to 2m in size. Bank to bank river width is about 36m. On the basis of site geology, geomorphology and sub-surface exploration, it has been inferred that the depth of river borne material (RBM) in the river bed may vary up to 28m or little more.

Right abutment of dam is strong in nature to host the dam structure. Bedrock is very well exposed on this abutment from the river bed to the higher elevations i.e. beyond top of dam. The bed rock is dipping in upstream direction with a dip ranging in between 45°-55°. Joint spacing ranges between 0.50m – 1.00m giving a blocky structure.

Lithology of the left bank are almost similar to that of right bank except it has narrow topography at the top of dam axis i.e. at EL.983.00m. Bedrock is very well exposed on this abutment from the river bed to the higher elevations i.e. beyond top of dam. The bed is dipping in upstream direction with a dip ranging in between 45°-55°. Joint spacing is ranging in between 0.50m – 1.00m giving a blocky structure.

Discontinuities observed in the bedrock along right bank are tabulated under **Table 2**.

TABLE 2: DETAILS OF DISCONTINUITIES AT RIGHT BANK OF DAM AXIS

S. No	Joint Name	Dip Direction/Amount	Persistence	Spacing	Remarks
1	Foliation (F)	N 055°/45°	>30m	20 to 125cm	Joint
2	J1	N 295°/85°	10cm to 2.5m	20cm to 2.5m	Joint
3	J2	N 140°/62°	>50m	Random	Joint
4	J3	N 200°/55°	20cm to 1.5m	25cm to 2.0m	Joint
5	J4	N 110°/80°	20cm to 2.5m	10cm to 2.5m	Joint
6	J5	N 295°/85°	50cm to 3.0m	10cm to 80cm	Joint

Discontinuities observed on the bedrock along right bank are tabulated under **Table 3**.

TABLE 3: Details of Discontinuities at Left Bank of Dam Axis

S.	Joint	Dip	Persistence	Spacing	Remarks
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No	Name	Direction/Amount			
1	Foliation (F)	N 045°/45°	>30m	20 to 125cm	Joint
2	J1	N 307°/85°	10cm to 2.5m	20cm to 2.5m	Joint
3	J2	N 130°/60°	>50m	Random	Joint
4	J3	N 225°/85°	20cm to 1.5m	25cm to 2.0m	Joint

4. Investigations for the Dam site

Dam site has been explored through intensive surface and sub-surface investigations before and during year 2018. Following means of investigations has been done and are also in progress:

- Drilling
- Drifting
- Test Pits
- Geophysical Tests
- Laboratory & In-situ testing
- Other studies

Investigations for the project can be differentiated under two categories i.e. completed before 2018 and Completed/under progress (2018 onwards). Details of the investigations are tabulated below in **Table 4**.

TABLE 4: SUMMARY OF INVESTIGATIONS

Type of Investigation	Completed Before 2018	Completed /In progress (2018 onwards)
Drilling	24 nos.	5 holes completed 3 holes under progress
Drifting	2 (one on each abutment at base level)	2 drifts completed on left abutment (at mid and top level) 2 drifts completed on right abutment (at mid and top level)
Geophysical Tests	7 nos. of Vertical Resistivity 6 nos. of Seismic profiles	6 profiles of Seismic tests - completed 10 profiles of Electrical Resistivity tests - completed
Surface Geological mapping of Dam Area	Completed by GSI in 2002-03, 03-04 and 04-05	Re-mapping at large scale under progress
Geological mapping of Reservoir area	Not done	In progress
Geological mapping of Water Pipeline alignment and Water Treatment Plant area	Not done	In progress
Auger Drilling along Water Pipeline	--	In progress
Test Pits along water Pipeline alignment	--	In progress
Plate Load Test (PLT)	---	Location yet to be assigned based on geological mapping
Laboratory testing for Disturbed and Undisturbed samples (DS & UDS)	---	Location yet to be assigned based on geological mapping
In situ Rock mechanic Tests inside the drifts		Completed in right bank and left bank bottom level drifts in Sep 18 At mid level drifts tests are under progress.

5. Exploratory Drilling

Till date, dam site has already been investigated by twenty four (25) number of drill holes out of which 20 drill holes were completed before 2018 and rest 5 holes are completed in 2018. While 3 holes at dam site are under progress. The total drilling done for the dam site is 1332.00m while another 105m drilling is under progress. The details of all the drill holes completed and under progress are tabulated below in Table 5 & 6.

The location of all the holes and drifts which are already completed and are under progress is shown below in Figure 1 while the section of the dam axis showing the location of drifts is shown in Figure 2.

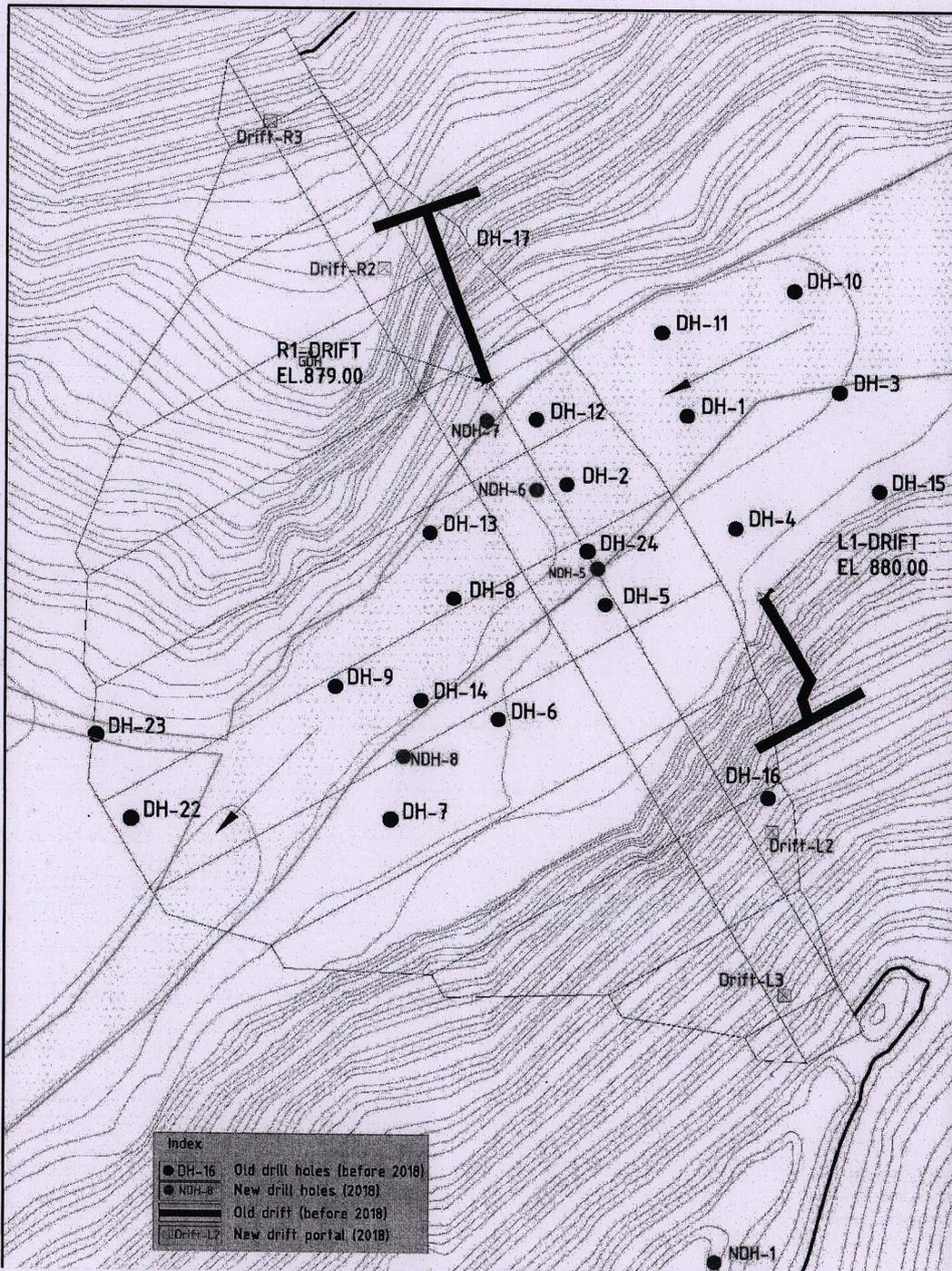


Figure 1: Location of drill holes and drifts (at Dam site)

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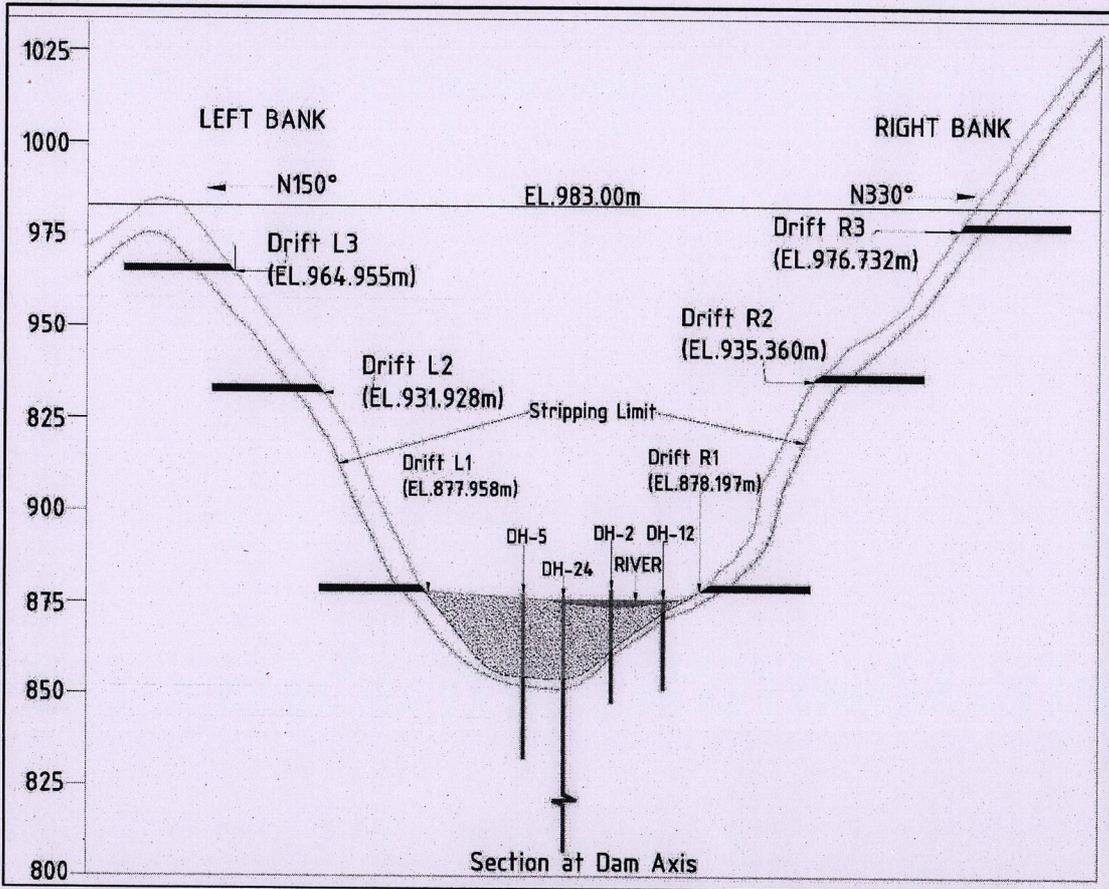


Figure 2: Section at dam axis showing location of drill holes and drifts

TABLE5: DETAILS OF DRILL HOLES (COMPLETED BEFORE 2018)

Sr. No.	Drill Hole No.	Location	Ground/ Coller El. (m)	Co-ordinate	Total Depth (m)	Overbur den Depth (m)	Rock Type
1	DH-01	River Centre 30m US of dam Axis	881.48	E229595.063, N3355634.873	60	22.50	Quartzite
2	DH-02	River Centre Dam Axis	878.70	E229572.085, N3355621.270	31	16.75	Quartzite
3	DH-03	Left Bank 60m US of Dam Axis	879.20	E229624.085, N3355639.622	35	14.76	Quartzite
4	DH-04	Left Bank of Dam Axis	879.09	E229604.457, N3355612.919	105.00	21.50	Quartzite
5	DH-05	Left Bank of Dam Axis	877.58	E229579.603, N3355597.734	100.10	23.00	Quartzite
6	DH-06	Left Bank, 60m D/s of Dam Axis	877.00	E229559.083, N3355575.058	35.10	26.80	Quartzite
7	DH-07	Left Bank, 45m D/s of Dam Axis	876.34	E229538.174, N3355555.418	35.10	25.80	Quartzite
8	DH-08	Left Bank, 60m D/s of Dam Axis, River Bed	875.24	E229550.355, N3355598.680	100.20	6.06	Quartzite
9	DH-09	90m D/s of Axis	874.74	E229527.538, N3355581.225	100.10	8.35	Quartzite
10	DH-10	U/s of Dam Axis	876.68	E229615.457, N3355659.643	30.20	11.25	Quartzite

Sr. No.	Drill Hole No.	Location	Ground/ Coller El. (m)	Co-ordinate	Total Depth (m)	Overburden Depth (m)	Rock Type
11	DH-11	Right Bank at Dam Axis	876.68	E229590.228, N3355651.163	30.60	7.40	Quartzite
12	DH-12	Right Bank of Dam Axis	876.16	E229566.245, N3355633.951	25.10	3.50	Quartzite
13	DH-13	Right Bank, 60m D/s of Dam Axis	875.17	E229545.634, N3355611.591	25.10	2.55	Quartzite
14	DH-14	45m d/s of Dam Axis	875.14	E229544.046, N3355578.633	28.10	17.50	Quartzite
15	DH-15	30m U/s of Dam Axis	878.50	E229631.760, E N355620.273	25.10	9.00	Quartzite
16	DH-16	Left Abutment (Dam Axis) (horizontal hole)	933.60	E229610.758, N3355560.166	25.05	0.00	Quartzite
17	DH-17	Right abutment (Dam Axis) (horizontal hole)	933.00	E229553.913, N3355665.478	35.30	0.00	Quartzite
18	DH-22	Dam Site (Plunge Pool area)	873.51	E229488.803, N3355555.214	35.50	28.00	Quartzite
19	DH-23	Dam Site (Plunge Pool area)	873.14	E229482.173, N3355571.492	35.00	23.75	Quartzite
20	DH-24	Dam Axis, Left Bank	876.50	E229576.105, N3355608.232	150.00	22.50	Quartzite
Total Depth (m)					1045.00		

TABLE6: DETAILS OF DRILL HOLES (2018 ONWARDS)

Sr. No.	Drill Hole No.	Location	Ground/ Coller El. (m)	Co-ordinate	Total Depth (m)	Overburden Depth (m)	Remark
1	NDH-1	Left bank abutment top	993.830	N3355469.81, E229600.860	33		Completed
2	NDH-2	Left bank abutment top	1003.305	N3355420.385, E229587.812	50		Completed
3	NDH-3	Left bank abutment top	1014.701	N3355357.565, E229600.58	50		Completed
4	NDH-7	Dam Axis-Right Bank	875.476	N3355633.617, E229556.606	35		Completed
5	NDH-8	Bucket Area (proposed by GSI, Dehradun)	875.201	N3355567.63, E229540.652	120		Completed
6	NDH-4	Dam Axis-Left Abutment	877.396	N3355587.17, E229587.34	35		In progress
7	NDH-5	Dam Axis	875.361	N3355604.863, E229578.04	35		In progress
8	NDH-6	Dam Axis-Centre of River	875.148	N3355620.129, E229566.332	35		In progress
9	NDH-9	D/s Coffor dam axis-Left Bank		N3355491.12, E229306.35	35		In progress
10	NDH-10	D/s Coffor dam axis		N3355562.80, E229347.48	35		In progress
11	NDH-11	D/s Coffor dam axis-Right Bank		N3355617.35, E229378.84	35		In progress
12	NDH-12	Plunge pool area		N3355482.021, E229362.966	35		In progress
13	NDH-13	Plunge pool area		N3355457.153, E229377.124	35		In progress

6. Exploratory Drifts

Total six exploratory drifts i.e. 3 on each abutment, has been excavated for both the abutments of the dam having a total length of 299.00m.

3D logging of drifts at base level on either abutment has been completed by GSI while Logging of other four drifts at mid and top level on both abutment is under progress. Details of completed and in progress drift is given in **Table 7**.

TABLE7: DETAILS OF DRIFTS AT DAM AXIS

Sr. no.	Drift No.	Location	Co-ordinate	Elevation (m)	Length (m)	Status
1	R-1	Right Bank Abutment	N3355633.617, E229557.975	878.197	52.0	Completed & Logged
2	R-2		N3355663.504, E229536.604	935.360	50.0	Completed but yet to be logged
3	R-3		N3355692.030, E229514.724	976.732	50.0	Completed but yet to be logged
4	L-1	Left Bank Abutment	N3355599.392, E229609.474	877.958	47.0	Completed & Logged
5	L-2		N3355553.690, E229611.518	931.928	50.0	Completed but yet to be logged
6	L-3		N3355521.793, E229614.003	964.955	50.0	Completed but yet to be logged

7. Geophysical Investigations

River bed area at dam site has also been explored through geophysical survey to confirm the sub-surface geological conditions. The geophysical exploration involves – Seismic Refraction Test (SRT) & Electrical Resistivity Test (ERT).

Earlier during 2004-05, Geophysical division of GSI has completed the 07 nos. of Vertical Resistivity Sounding (VES) and 06 profiles of Seismic Refraction Survey (SRS). The results confirm the depth of overburden in range of 12m-27m.

During year 2018, geophysical investigation has also been completed by Parsons. It includes Seismic refraction (SRT) along 06 profiles having total length of 690m and Electrical Resistivity Imaging (ERT/ERI) along 10 profiles having total profile length of 2950m.

8. Seismotectonic Aspects of the Project Area

The project area lies in the Seismic zone 'IV' of India as incorporated in the Indian Standard Criteria for Earthquake Resistant Design of Structures (IS: 1893 Part 1-2002). According to "Seismotectonic Atlas of India and its Environ (SEISET-6)" the project area lies in the Older cover sequence folded during Himalayan fold-thrust movement and is very close to the thrust area (unknown). Thus, the overall seismicity level in the project area is high.

Study for determination of site specific design earthquake parameters for the Song dam has been completed by Department of Earthquake Engineering, Indian Institute of Technology, Roorkee in 2018. The studies related to Site Specific Design Earthquake Parameters were taken up using the probabilistic and deterministic approaches of estimation of seismic hazard.

The site specific design earthquake parameters for MCE and DBE conditions are recommended as 0.495g and 0.278g for horizontal and 0.330g MCE and 0.185g DBE for the vertical ground motions. The design seismic coefficient for dam (primary structure) is evaluated as $\alpha_h = 0.18$ and $\alpha_v = 0.12$.

9. Laboratory Testing of samples from Drilling

Representative core samples recovered from the exploratory drilling has been tested in the laboratory for engineering properties of the rock mass, especially Uniaxial Compression Test (UCS). The laboratory tests were conducted by IRI, Roorkee.

Test completed so far includes mechanical property test (Porosity, Water Absorption, Sp. Gravity, Crushing/ compressive Strength, Modulus of Elasticity, Poisson's Ratio & Shear parameter) and Uniaxial compressive strength test.

The results shows that:

1. Compressive strength of rock varies from 435 to 2276Kg/cm²
2. Average compressive strength varies from 864 to 1359.55Kg/cm²
3. Specific gravity of rock varies from 2.625 to 2.643
4. Water absorption(%) varies from 0.174 to 0.230
5. Porosity(%) varies from 0.400 to 0.903
6. Modulus of elasticity is of the order of 5.06×10^5 & 6.19×10^5 Kg/Cm²
7. Poissons ratio is of the order of 0.204 & 0.208 Kg/Cm²
8. Cohesion on rock core sample comes as $C=172.9$ Kg/Cm²
9. Angle of internal friction on rock core sample comes to 38.9°

10. Insitu Rock Mechanic Tests inside the drifts

Rock mechanic tests inside the exploratory drifts on both the banks has been completed in lower level drifts i.e. in L1 and R1 while test in mid level drifts i.e. L2 and R2 are under progress.

Block shear tests on Rock to Rock and Rock to Concrete has been conducted to determine peak shear strength, residual shear strength, cohesion value (C) and internal friction angle (\emptyset). The tests were conducted on both the bank inside the drifts. The results from these tests are tabulated below:

TABLE 6: DETAILS OF DRILL HOLES (2018 ONWARDS)

Sr. No.	Drift Location/No	Nature	Parameter Tested		Result/Value
1	Left Bank L1	Rock to Concrete	Peak Shear Strength	C	8.4Kg/cm ²
				\emptyset	63°
			Residual Shear Strength	C	0.00Kg/cm ²
				\emptyset	62°
2	Left Bank L1	Rock to Rock	Peak Shear Strength	C	10.1Kg/cm ²
				\emptyset	64.5°
			Residual Shear Strength	C	-
				\emptyset	60°
3	Right Bank R1	Rock to Concrete	Peak Shear Strength	C	7.6Kg/cm ²
				\emptyset	63.5°
			Residual Shear Strength	C	0.00Kg/cm ²
				\emptyset	62.5°
3	Right Bank R1	Rock to Rock	Peak Shear Strength	C	12.4Kg/cm ²
				\emptyset	65°
			Residual Shear Strength	C	-
				\emptyset	57°

For the design purposes, C has been considered 5kg/cm² while \emptyset has been considered 51°.

11. Geotechnical Assessment of Components

The project structures are to be dealt with two types of strata i.e. overburden and bed rock. In the project area the overburden strata comprise of the two types of strata i.e.

River Borne Material: This strata occupies the mainstream and adjacent area i.e. area along the river bed and river channel. It mainly consists of rounded/sorted cobbles, pebbles boulders of various rock types intermixed with river sandy matrix. The source of material is the catchment of the river. Material is quiet compacted, hard and strong enough.

Scree/ Slopewash material: Occupies majorly the hill slopes and comprises of detached rock fragments including small to large size of rock mass intermixed with humus.

Bed rock: This comprises of Nagthat Formation characterised by greenish grey, off white, reddish brown/ purple, banded to massive, medium to fine grained, at places coarse grained quartzite which is hard and competent in nature.

i. Dam Foundation & Abutments

Slopes on both the banks of dam axis has exposed bed rock with scarce vegetation cover. However, at places they are occupied by thin cover of overburden material comprising of scree/ slopewash material. Bedrock is exposed on both the banks from river bed level up to the higher elevations and comprises of slightly weathered to fresh, foliated, jointed, hard and compact Quartzite. Logging of the drill holes reveals that the acceptable foundation grade would be available within 2-3m below the overburden material. The UCS values are fairly high (average 1248.45 Kg Cm²) in dam seat area to bear the load of the giant structure.

Permeability values of the bedrock in & around the dam area have been found low to moderately high i.e. ranging from 4.40 lugeon to 42.65 lugeon. Hence, the foundation rock will have to be sealed with grouting till attaining the permeability values below 1 lugeon. Based on the permeability values in the rock the grout curtain has to be extended to sound rock. Proposed test grouting will guide the spacing and pattern of the grout holes.

Based on completed drill hole it has been observed that the foundation of the dam in the river bed and on the abutments is likely to be laid upon sound rockmass.

Due to existence of number of joints with close spacing, wedge failure due to foliation and J1 joint along the Left abutment and due to J2 and J3 joint along the right abutment is expected towards the valley. Remedial for adequate support in the form of rock bolting and wire mesh s advisable during excavation of either abutment.

ii. Reservoir

The reservoir of the dam have an FRL of El.980.00m and is expected to be stretch for a distance of 3.70kmkm in the upstream of the dam and will have an submergence area of 70 hectare approximately. The valley which is going to be submerged in the reservoir have steep topography with plenty of rock outcrops on the higher reaches. However the flood plains/scree debris near to the river channel are presently utilized by the villagers for agricultural purposes. There are some villages in the reservoir area which are partly or fully gets affected by the submergence.

Geologically, the reservoir seems to be quiet water tight as the area is confined by the rock outcrops with small streams which meets Song river in the upstream of the dam.

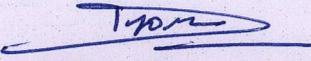
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Also Song being the most prominent drainage in the area and occupies the deepest drainage level, so there is no chance of leaking water in the adjacent valley/drainage system. The rocks in the reservoir from dam axis to upstream consists of Quartzite's, Shales and slates followed by Limestones in the upper reaches. The chemical properties of the limestones must be established before impounding to know its cavernous nature after filling of reservoir.

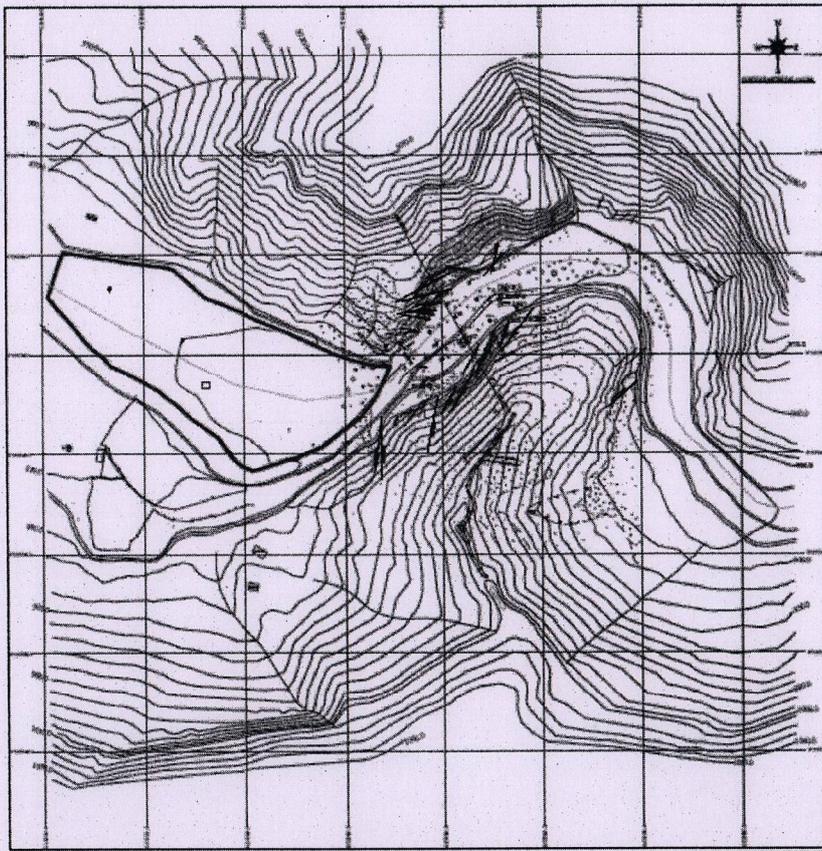
Reservoir area has been inspected and no adverse feature has been found which will lead to the instability/leakage from the reservoir. However, detailed surface geological mapping will reveal all the necessary information required for stability purposes

12. Conclusion

Detailed and updated geotechnical investigations and surface geological mapping of the entire project area in progress. Based on available data, prima facie it has been found that the site is suitable for construction of dam as discussed above. Reservoir is also quiet competent and seems to be water tight.


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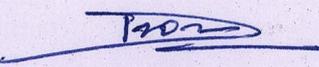



**GEOLOGICAL MAP OF
 DAM SITE AREA,
 WATER SUPPLY
 SCHEME, SONG RIVER,
 DISTRICT DEHRADUN,
 UTTARAKHAN**

- INDEX**
-  RIVER BORNE MATERIAL
 -  SAND
 -  QUARTZITE, GNEISS, ETC. (BY WHITE, PINK/RED) - MACTHAT FORMATION
 -  BEDDING PLANE/JOINT PLANE
 -  TRACE OF BEDDING PLANE/JOINT PLANE
 -  SCAR
 -  LANDSLIDE
 -  WELL HOLE
 -  DAM
 -  DAMAGED
 -  MINE
 -  CHANNEL BAR
 -  UNMETALLED ROAD

NOTE

1. CONTOUR PLANS AND LOCATIONS OF POINTS SHOWN ARE BY THE PROJECT AUTHORIZES.
2. DIMENSIONS OF DAMS IS SHOWN AS PER STANDARD CONSTRUCTION OF THE PROJECT.
3. THE CONTOURS AT 50M INTERVALS ARE DRAWN TO MATCH THE CLASST.


 सहायक अभियन्ता-प्रथम
 अनुसंधान एवं नियोजन खण्ड, देहरादून


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