Geotechnical assessment regarding feasibility of proposed additional spillway site, Hirakud dam project, Sambalpur district, Odisha

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Abstract

Presently Hirakud dam faces heavy siltation problem for which the storage capacity of reservoir has been drastically reduced. Flooding problem due to heavy rains at the upstream catchment area is another major issue. For mitigating the said problems, it has been decided to construct an additional spillway in left dyke area of the Hirakud dam. A comprehensive study in the form of both surface and subsurface geological conditions of the proposed additional spillway site was made to know the feasibility of the scheme. Surface geological studies indicate that the area is covered with intensively fractured, shattered and pulverized quartzite. Extreme ferrugination of rock mass and presence of slickenside lineation are the notable feature. Three sets of joints including foliation joint are the main planar structural feature. Two, NE-SW & NW-SE trending structurally weak zones run along the central part of the saddle (may be sub vertical faults). The saddle is consisting of extensively fractured & brecciated quartzite, which indicates presence of a fault. Subsurface data indicate presence of small fractured, brecciated core pieces along with rock powder (gougy mass/ rock flour) showing both extremely poor core recovery and RQD. Based on detailed surface geological study & subsurface exploration data, it has been observed that the proposed additional spillway site does not appear to be suitable for construction of a spillway in view of presence of fault along and across the proposed spillway alignment.

1. Introduction:

25.8 km long Hirakud Dam, composite in nature and the longest Dam in Asia has been constructed across Mahanadi River at about 15 km upstream of Sambalpur town of Odisha (Figure-1). The main Dam is located between two hillocks viz. Lambadunguri in the left and Chandidungri on the right. Two spillways in the main dam on the left and right side are located on the Main River channel. Power house is located at the downstream toe of right flank of the main dam. Two earthen dykes on left and right sides with a combined length of about 21 km have been constructed to close the saddle gaps. Reservoir spread is 74309 km at the full reservoir level. The project provides 159106 Ha of Kharif and 108385 ha of Rabi irrigation in Sambalpur, Baragarh, Bolangir and Subernpur district of Odisha. Water released through the power house irrigates additional 2, 51,000 ha of CCA in Mahanadi Delta. Combined installed capacity of power generation is 347.86 MW through Main Dam power house and Chiplima power house (22 km downstream of dam). The project provides flood protection to 9,500 km^2 of delta area in undivided districts of Cuttack and Puri.

The project record shows that the existing spillway capacity of the dam at full reservoir level (FRL) is 42,450 m^3/sec (15 lakh cusec). This amount of design flood can be passed through the existing under sluices (26,885 m^3/sec) and the spillway crest radial gates (15, 565 m^3/sec). Subsequently the design flood has been revised and the capacity value changed to 69,632 m^3/sec (24 lakh cusec). Therefore presently the main issue is to pass the excess 9 lakh cusecs of discharge. To alleviate this problem, five alternatives have been taken in to consideration for the safety of the structure, which are detailed below:-

1. Raising the height of the existing dam.
2. Construction of additional spillway between Gandhi hillock & adjacent hillock on left bank.
3. Additional spillway in the right dyke area.
4. Lowering the spillway crest level with a corresponding increase in height of the spillway crest gates and;
5. Additional spillway on the left of left spillway replacing part of existing earth dam.

Out of the above said five alternatives, the project Authority considered for construction of additional spillway in left and right side of the Hirakud dam. Out of 9 lakh cusecs of water, 7 lakh cusecs will be discharged through two additional spillways and remaining 2 lakh cusecs will be accommodated in the reservoir itself. In the first phase, it was decided to construct an additional spillway in left dyke area with 3 lakh cusecs of discharge (figure 2). The proposed 91 m wide spillway will be an ogee type gated spillway having 5 radial gates of each 15 m x 15 m size with crest level fixed at RL 177.024 m. For energy dissipation, 142 m long stilling basin will be provided where stilling basin invert level has been fixed at RL 75 m. From stilling basin, water will be transported through 250 m wide spill channel to the river. A general layout plan of this project is given here (Fig 3).

2. Geomorphology & Drainage:

The proposed site is located across a roughly NW-SE (N40°W-S40°E) trending saddle across Lambadunguri Reserved Forest at an elevation of RL 213.05 m. The height of elevation in the right side hill is RL 272m and in the left side hill is 242 m and the lowest elevation is RL 172 m at the foothills. Mahanadi River is the main drainage of the area under study and flows towards SE direction. Drainage pattern is dendritic to sub dendritic in nature with moderate drainage density and is mainly controlled by Mahanadi River. The rocky river bed, entrenched meanders and steep river bank indicate that the drainage basin has attained considerable maturity. A number of seasonal tributaries, debouching into the Mahanadi are originated from the plateau region and flow in a north-easterly direction. Important among these are Soran Khola and Deodarha nala.

3. Regional Geological set up:

The proposed additional spillway site is located across a roughly NW-SE trending saddle across Lambadunguri Reserve forest. The rock types observed around the area belong mainly to Archaean age and are represented by quartzite, quartz-sericite schist, sericite

schist and phyllite constituting the oldest metasedimentaries and younger intrusive of granitic rock and dolerite. Granite and granite gneiss are the most prominent rock types occupying the plains and meadow lands. The Proterozoic Group is the youngest represented by arkosic sandstone, grits and shales which in general, lie unconformably over granitic surface. The general strike of foliation of schists, quartzites and gneisses is NW-SE with sub vertical to vertical dips. The strike of the foliation changes locally WNW-ESE due to local folding and faulting. (Raj. 1971).

4. Methodology:

Both surface and subsurface geology have been studied in detailed to assess the feasibility of the proposed additional spillway site.

4.1 Detailed geological mapping:

Detailed surface geological mapping (Figure 4) of the proposed additional spillway aligned in N40°W-S40°E covering 200 m across x 300 m along flow direction reflects presence of quartzite and quartz-sericite schist occupying the ridges and granite/ granite gneisses exposed in the low lying areas (Figure 5). Fresh & hard ferruginous cherty quartzite was exposed along the left flank of the saddle at proposed spillway site (Figure-6). The quartzite is intensively fractured, highly sheared, brecciated and deeply iron stained in nature and silicified in later phase. Upstream part of saddle (NE face of ridge) is covered with sandy soil and slope wash material. At the downstream foothill of the ridge, brecciated mass and gougy material has been observed. At the right ridge hillock, highly weathered & decomposed quartzite forming powdery rock mass was also observed (Figure 7). Seepage was observed at the foothill in both sides of the ridge along the saddle. Towards the downstream i.e. at the proposed stilling basin area, highly weathered, decomposed and sheared quartz-sericite schist and granite gneiss has been exposed.

Strike of bedding in the quartzite is E-W with 65° to sub-vertical dip towards south (d/s of the proposed spillway). Foliation is almost parallel to the bedding and strikes at N75°E – S75°W to E-W with steep dip (60° to 75°) towards SE to sub-vertical. Due to intensive deformation, traces of bedding have been obliterated in quartzite. Schistosity in quartz sericite schist is N 60^0W-S60^0E to E-W with sub vertical dip towards south. Apart from the closely spaced foliation/ foliation joint (1cm to 5 cm), following three sets of joints have been observed in the quartzites for which the detailed characteristics are given below in the following table:-

Table 1
Attitude and properties of discontinuity planes observed at proposed additional spillway site.

Joint set	Attitude	Characteristics
J1	N75°W-S75°E strike with 38° easterly dip to sub-vertical	a) Strike persistence: Continuous b) Spacing: 2 cm to 20 cm c) Aperture-Tight d) Roughness- Rough, planar e) Condition: Silica filled, cutting across the foliation/foliation joint.
J2	N10°-35°E - S10°-35°W to N-S strike with 40° to 75° westerly dip to sub-vertical	a) Strike persistence: Continuous b) Spacing: 2 cm to 20 cm (cross joint) c) Aperture-Tight d) Roughness- Rough, planar e) Condition: Silica filled
J3	N35°W-S35°E strike with 70° to 80° north-easterly dip	a) Strike persistence: Discontinuous b) Spacing: 2 cm to 20 cm c) Aperture-Tight d) Roughness- Rough e) Condition: Silica filled

Surficially, the rocks are closely fractured/ jointed, deeply iron stained and a number of furrows have been noticed. Due to intensive shearing at places, rock mass was become pulverized, shattered and powdery in nature.

4.2 Subsurface Exploration:

In order to assess the subsurface condition, exploratory cores from ten bore holes (5 holes in & around spillway, 3 holes in stilling basin & 2 holes in spill channel) have been studied for which the details are given in the following table 2:-

Table 2
Synoptic log of bore holes drilled around proposed additional spillway site & proposed dyke alignment site

Bore Hole No.	Location	Depth drilled (m)	Depth to foundation grade rock level (m)/ RL (m)	Remarks
Spillway site				
1	48 m u/s of axis & 28 m left of centre line	80.5	41.5/ 168.940	Intensively fractured, brecciated, sheared quartzite & gougy material occurs from 3 m depth up to 41.5 m depth with intermittent fair rock mass. Overall rock quality is poor (structurally weak zone).
2	Spillway axis, left abutment	75	7.47/ 201.50	Fresh & hard but highly fractured quartzite occurs up to 43 m depth. Rock mass quality improves from 43 m depth with fair RQD.
3	28 m u/s of axis; 14 m left from	84.5	-	Brecciated quartzite with pulverized rock mass (gouge), porous & friable rock mass from surface level up to drilled depth i.e. 84.8 m with a patch of fresh &

	centre line			hard but intensively fractured rock between 55.8 m & 69.8 m depth.
9	Right side of the spillway axis	80.3	0.52/ 218.27	Brecciated rock mass encountered at depth 13 m to 15 m depth below NSL (RL between 205.79 m and 203.79 m. Powdery/ gougy material encountered at depth 77 m to 78 m below NSL (RL 141.79 m and 140.79 m).
11	Central part of axis.	75.5	15.39/ 192.56	Highly weathered & decomposed quartzitic intercepted at 2.5 m (RL- 205.45 m) depth below NSL. Fresh & hard quartzite is at 15.39 m (RL 192.56 m) depth below NSL. Highly crushed & powdery quartzitic rock is intercepted from 55.5 m depth to drilled depth.
Stilling Basin site				
4	49 m d/s of axis, 4 m left from centre line	75.4	45.03/ 138.42	Sludge of highly weathered & decomposed granite gneiss from surface level to 45.03 m depth.
7	108 m d/s of axis, 1 m right from centre line	40.0	-	Sludge of highly weathered & decomposed granite gneiss extends up to drilled depth of 40.0 m (RL 135.07 m).
8	88 m d/s of axis, 2 m right from centre line	75.0	48.94/ 128.135	Sludge of highly weathered & decomposed granite gneiss up to 33.5 m depth. Fresh & hard rock from 48.94 m depth.

The exploratory bore holes drilled at the left abutment and right abutment shows presence of fresh but intensively fractured quartzite at 7.47 m and 0.52 m depth respectively below ground surface, whereas at the centre of the spillway fresh quartzite occurs at 15.39 m depth. The bore holes drilled along the centre of upstream and downstream also did not intercept fresh rock up to a reasonable depth. At the proposed stilling basin, fresh rock was not intercepted up to reasonable depth (33.5 m -45 m) (Figures 8, 9 & 10)

4.3 Synthesization of the geotechnical parameters:

The geotechnical parameters of the rock mass intercepted in the drill holes were interpreted. The test results have been correlated with drill core log and the same is furnished below in the following table (Table 3):-

Table 3
Rock mass characteristics

Hole No	Stretches with/ poor rock mass (depth in 'm')	Core recovery (%)	RQD %	Powdery zone (depth in 'm')	Weak rock mass zone (depth in 'm')	Uniaxial compressive strength (N/mm^2)
1	3-36.5 38.5-40.5 41.5-43.5 61.5-62.5	0-45 53-55 91-100 76	0-33 10 36-39 59	-	17.1-20.1 35.5-38.5 38.5-47.5 53.5-80.5	52-35 51.80 25.29-49.07 18.25-38.18
2	5-6 49-52 59-62 71-72	58 70-76 57-80 60	0 22-39 13-24, Rarely 59 0	-	1-43 58-67	17.77-67.56 59.81-78.15
3	2-3 5-18 21-55.8 69.8-84.8	56 50-60 0-61 13-25	0 0-23 0-24 0	31-44.8 44.8-84.8	0-32 48.8-60.8 69.8-75.8 78.8-84.8	16.15-79.47 46.93-78.46 26.65-28.76 30.93-38.17
4	0-41.4 41.4-44.4	0 50-63	0 13-27	0-41.4	41.4-75.4	14.33-43.54
5	3-6.5	0-47	0-16	2.8-4.5	4.5-30.5	24.15-77.15
6	1.4-2.85	0	0	-	21-27	35.71-39.79
7	0-40	0	0	0-40	-	-
8	0-33.5 35.5-42.5 42.5-48.5	0 31-47 52-66	0 0-21 0-14	0-33.5 33.5-38.5 42.5-44.5 47.5-48.5	33.5-39.5 42.5-45.5 57.5-69.5	24.97-40.87 28.95 50.71-69.16
9	13.0-18.0 23.0-25.0 27.0-29.0 32-33 35-48 49-55 58-61 61-64 64-66 67-73 77-79	56-71 59-61 63-69 29 27-52 23-43 30-45 47-56 36-41 33-71 50-63	0-27 38-42 0 0 0 0 10-11 0 0-12 0 0	-	0-33 36-54 66-72 78-80	40.09-71.69 27.85-47.28 44.49-45.12 43.79
10	3-6.1 6.1-7.1 7.1-13.1 13.1-16.1 19.1-27.1 27.1-44.1	0 31 19-28 29-34 22-55 12-29	0 10 0 0-21 0 0	19.1-44.1	-	Test result not available
11	2.5-12.5 18.5-20.5 20.5-27.5 32.5-37.5 37.5-39.5 39.5-40.5 45.5-46.5 46.5-59.5	0 47-56 21-33 30-68 54-64 78 52 23-64	0 0 0 0 10 12 0 0	55.5-59.5 59.5-75.5	-	Test result not available

5. Discussions:

Surface geological studies of the proposed additional spillway site, located on a NW-SE trending linear ridge indicate presence of intensively fractured, shattered and pulverized quartzites. The rock mass have been dissected by three sets of joints along with foliation joint. A NE-SW trending structurally weak zone runs along the central part of the NW-SE trending saddle (NE-SW trending sub vertical fault?). Due to the presence of these two cross linear structural features, rock mass become intensively shattered, pulverized , sheared and at places brecciated forming small fractured core pieces along with rock powder (gougy mass/ rock flour) showing both poor core recovery and RQD which points to the fact of likely presence of faults along & across fridge.

Core logging of bore holes no. 1 & 3 drilled at the u/s part of the proposed additional spillway site indicates presence of intensively fractured, brecciated & sheared quartzite with low core recovery & very poor to poor RQD. Based on drill core log data geological cross section and longitudinal sections were prepared and geotechnical parameter values are plotted on the map to understand the subsurface condition of the site. (Figures 11, 12, 13 & 14). Brecciated quartzite (angular to sub angular rock fragments of quartzite set in siliceous & /or pulverized rock mass, fault gouge), highly porous and friable rock mass extends up to drilled depth. Occurrence of highly fractured (brecciated) & sheared core pieces from surface level up to drilled depth with intermittent interception of sludge of gougy/ pulverized rock mass etc. conforms likely presence of a structurally weak zone. Three drill holes (drill hole no. 2, 11 & 9) drilled on the proposed spillway alignment intersected fresh but intensively fractured quartzite rock at depth 7.47 m at the left side & 0.52 m at the right side and at depth rock becomes highly pulverized and forms powdery mass. Study of geotechnical parameters also indicate a very poor quality of rock mass in terms of competency as reflected from low uniaxial compressive strength (17.77-78.15 N/mm^2).

6. Conclusions:

Based on surface geological observations and sub-surface geological data the following conclusions are derived:

a) The proposed additional spillway site located on a topographic saddle, which appears to be structurally controlled. Presence of brecciated rocks on the saddle, seepage on either flanks of the saddle at the foothills, pulverized/gougy rock mass in the upstream end of the saddle indicates likely presence of a structurally weak zone along and across the topographic saddle.
b) The drill cores from the site show signs of intensive fracturing & pulverization forming gougy and brecciated rock mass. Sludge of highly weathered & decomposed granite gneiss up to deeper level at the downstream, also towards presence of a weak zone.
c) Study of geotechnical parameters also indicate a very poor quality of rock mass in terms of competency as reflected from low uniaxial compressive strength for construction of a concrete gravity structure.

Based on the above facts, the site does not appear to be suitable for a spillway site from geological point of view and search for alternative site has been recommended.

Acknowledgement:

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1. Report on Hirakud Dam- Arrangement for Passing Additional Discharge for Revised Design Flood. Central Water Commission, March, 2015.
2. Sahoo, D. and Munda, R. C., (2016): Report on feasibility stage geotechnical investigation of additional spillway site of Hirakud Dam Project, Sambalpur district, Odisha. GSI, unpubl. Progr. Report for field season 2015-16.

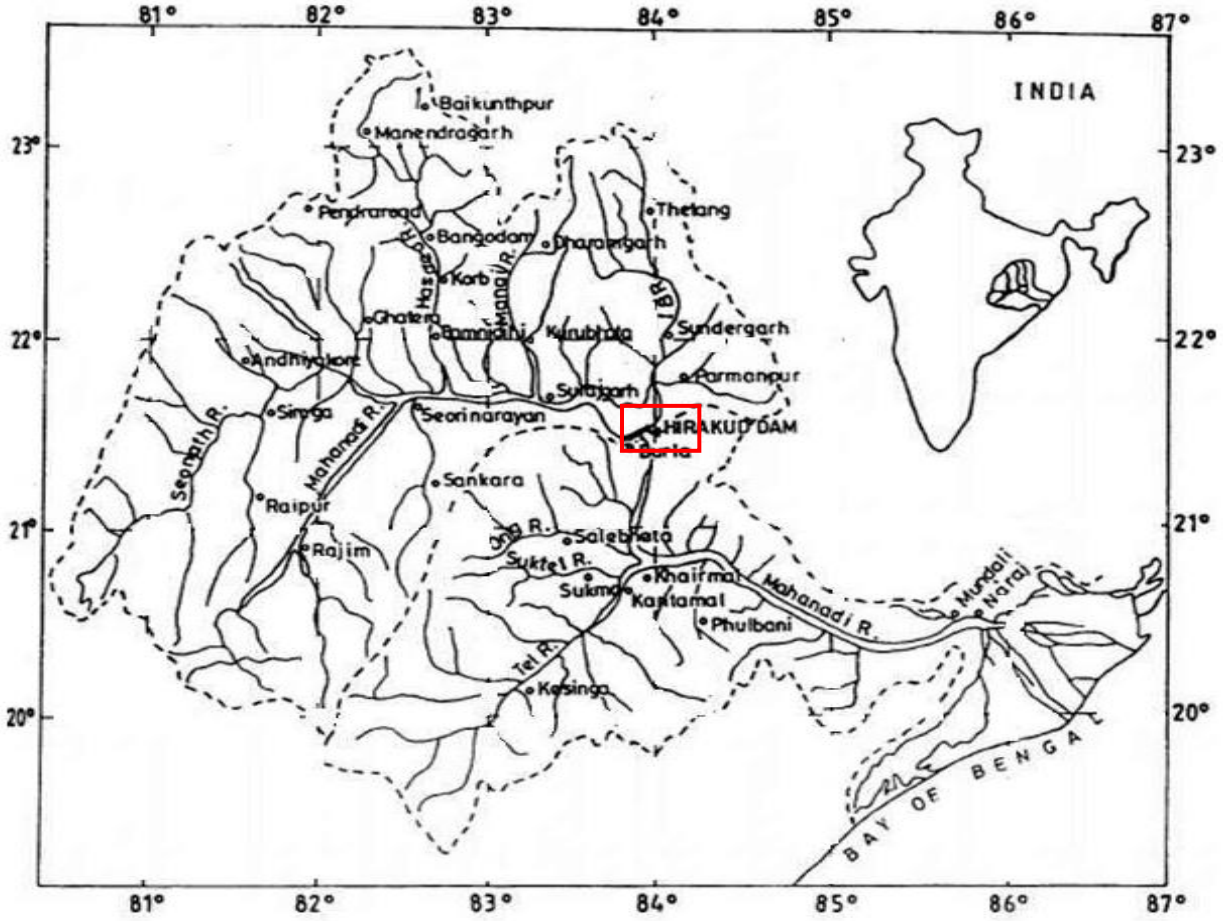

Figure 1 Location map of the Hirakud dam

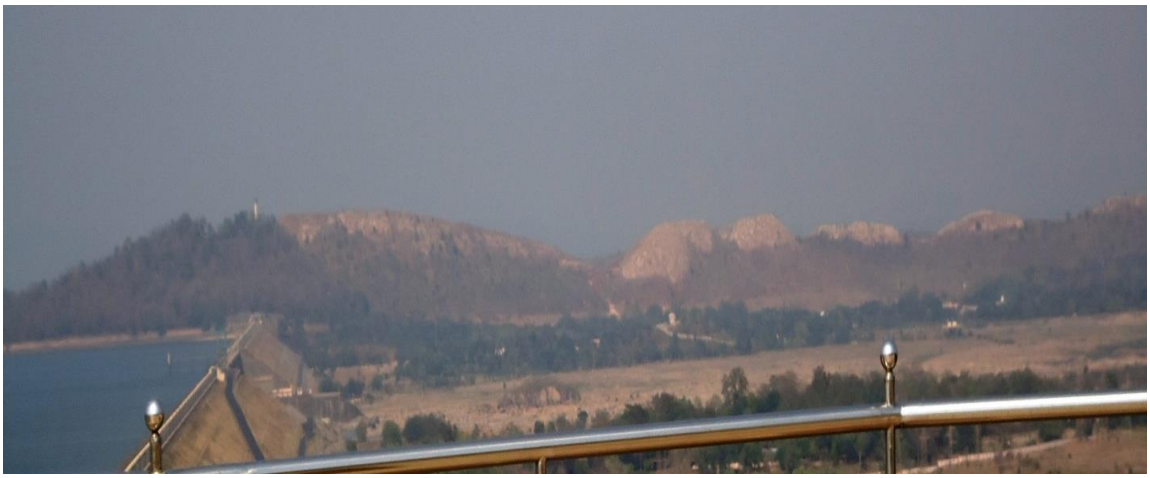

Figure 2 Photograph showing panoramic view of Hirakud Main Dam & Proposed spillway site in Lambadunguri reserve forest.

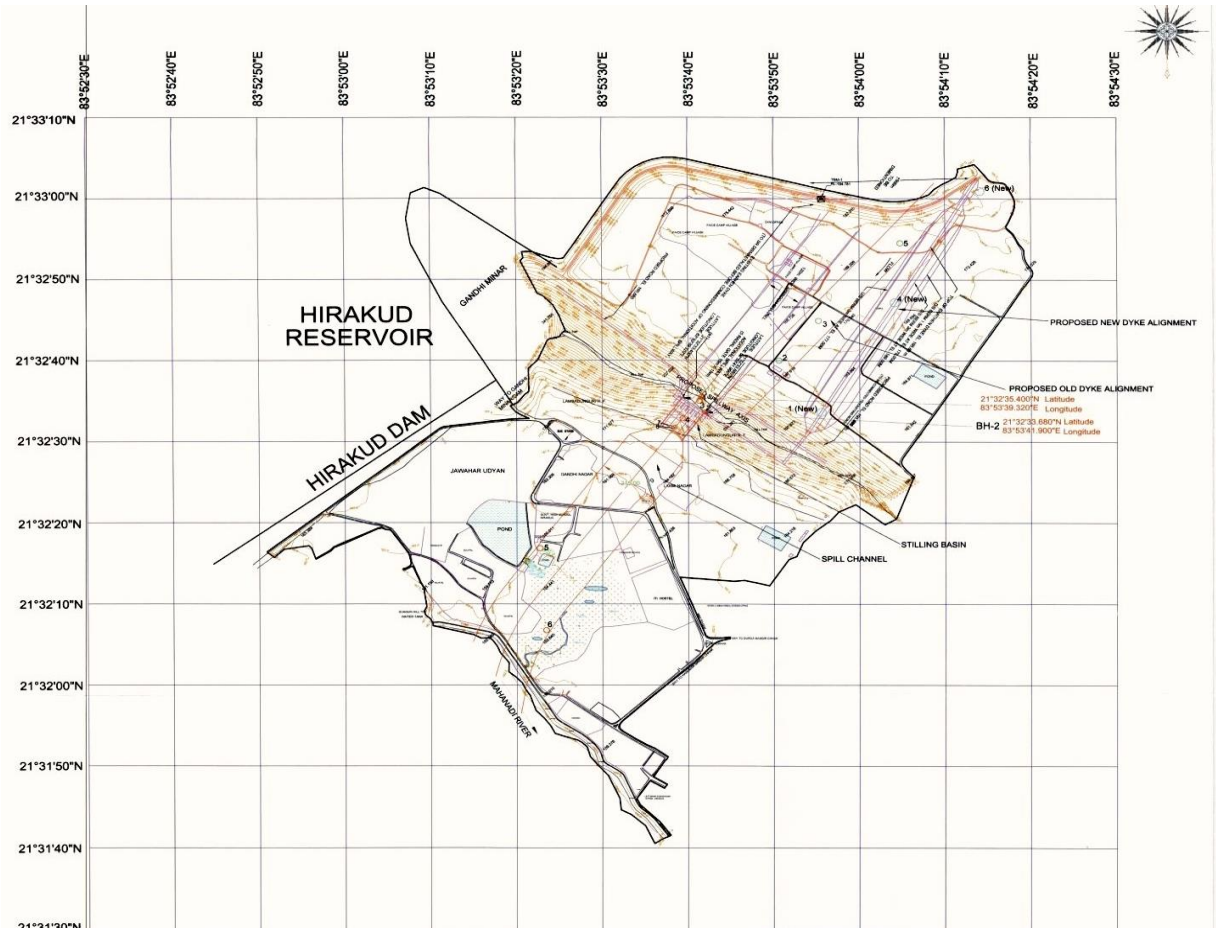

Figure 3 General layout plan of the proposed additional spillway site, Hirakud Dam Project, Sambalpur, Odisha.

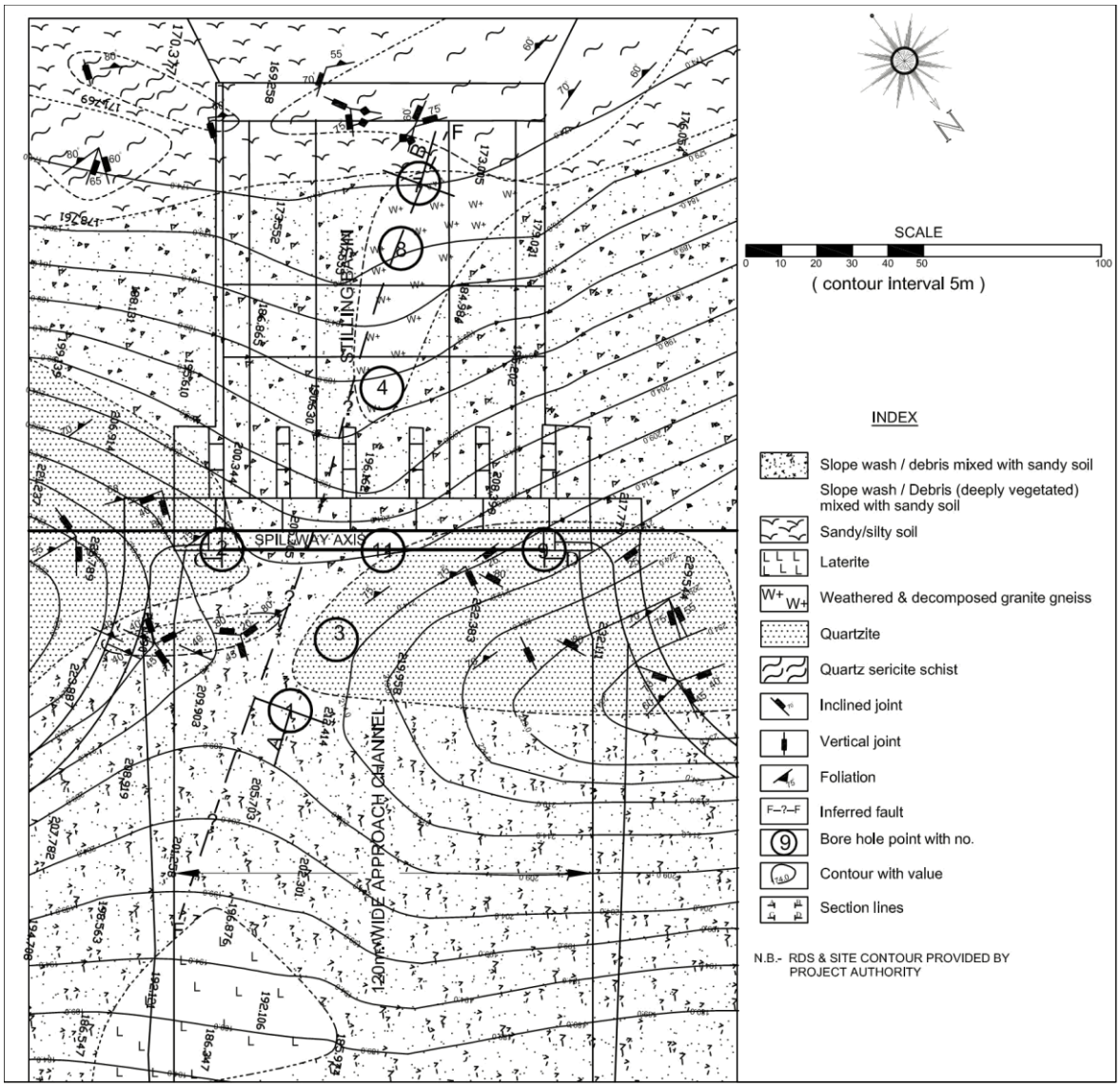

Figure 4 Detailed Geological map of additional spillway site.
(Bore holes are also plotted in map)

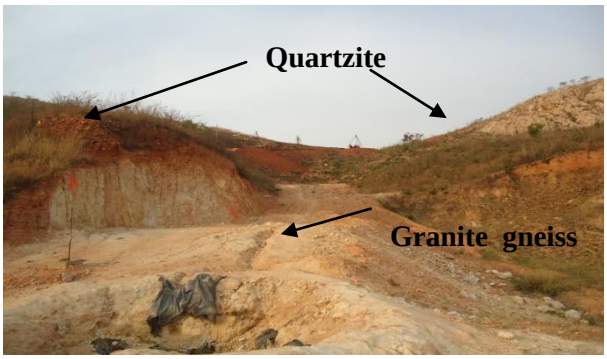

Figure 5 A close view of the proposed additional spillway site exposing presence of quartzite ridge and granite gneiss exposed at the base. (Photo facing downstream).

Figure 6 Exposure of fresh & hard ferruginous cherty quartzite along the left flank of the saddle at proposed spillway site.

Figure 7 Highly weathered & decomposed quartzite forming powdery rock mass at the downstream slope of the ridge.

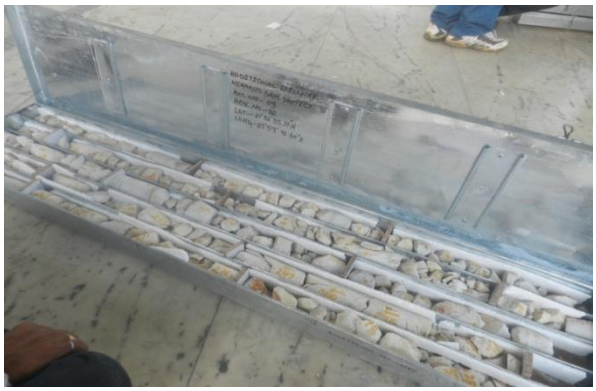

Figure 8 Highly fractured and crushed quartzite in hole no.3.

Figure 9 Drill cores of brecciated quartzite in hole no. 3.

Figure 10 Low core recovery & low RQD zone in hole no. 9.

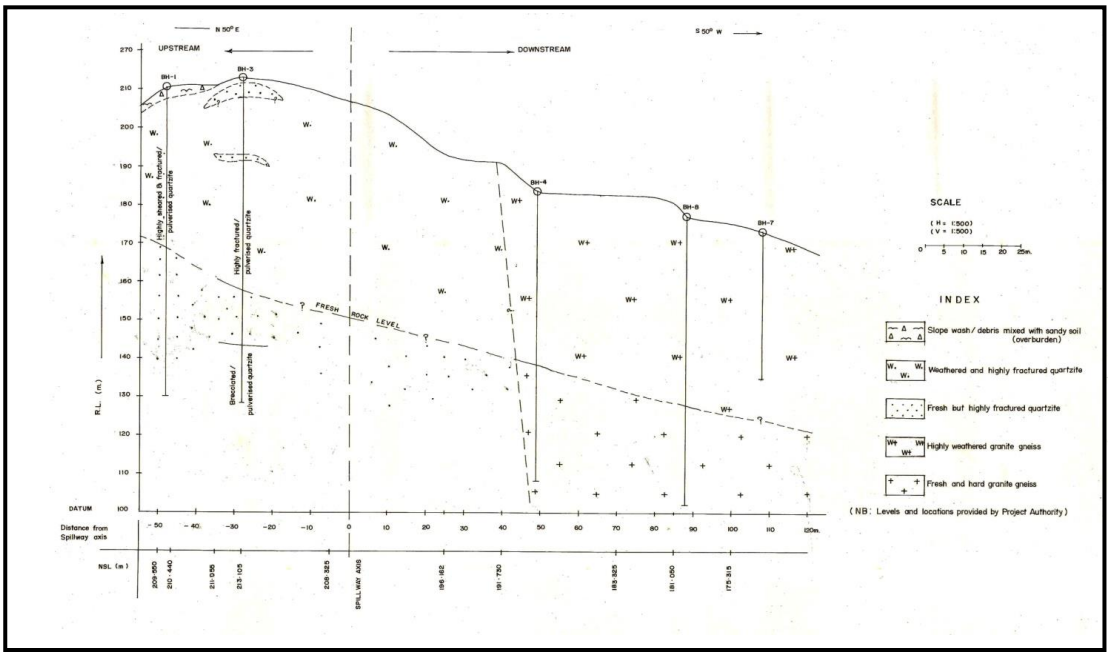

Figure 11 Geological sections from upstream to downstream of proposed additional spillway site.

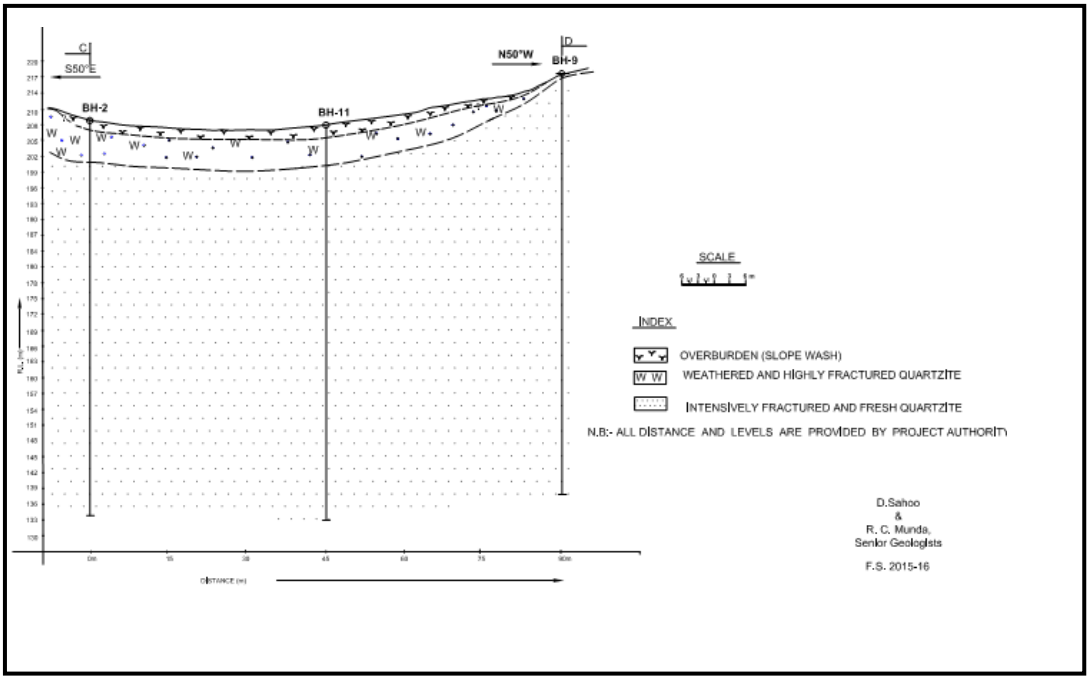

Figure 12 Longitudinal Section

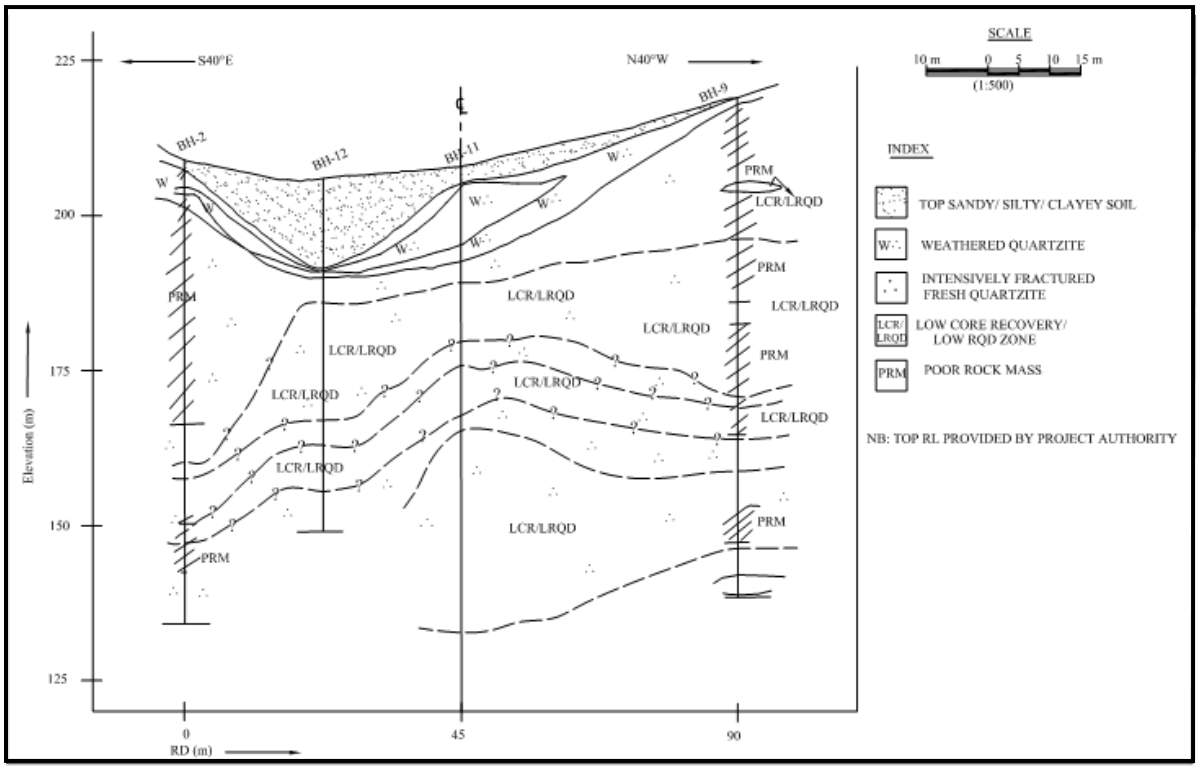

Figure 13 Geological L-section along proposed spillway alignment. Low RQD & low UCS portions are plotted in the map.

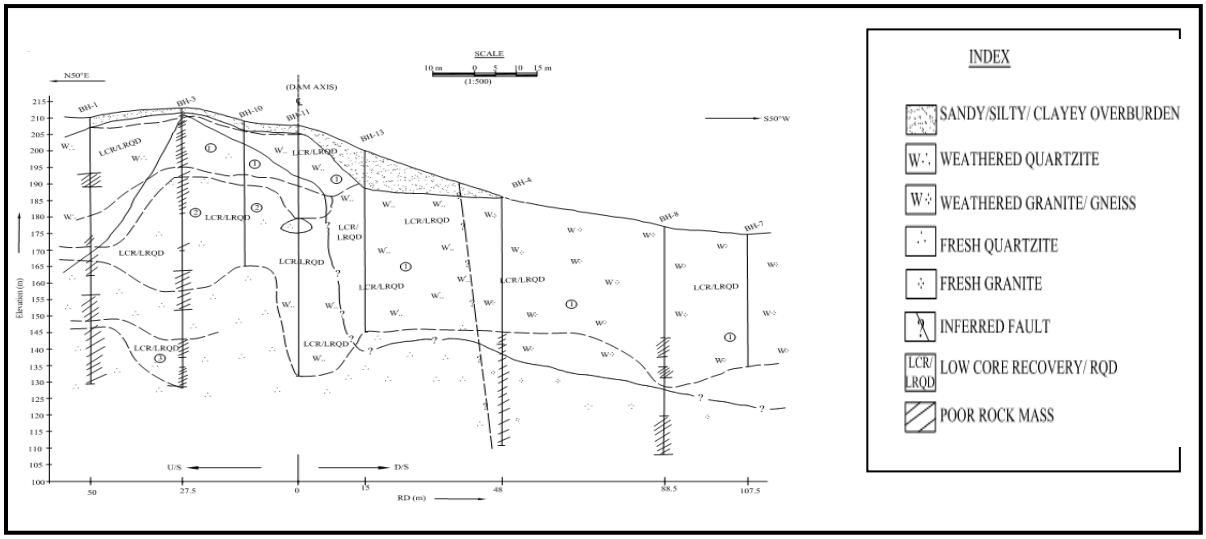

Figure 14 Geological L-section along proposed spillway alignment. Low RQD & low UCS portions are plotted in the map.