Geological investigation, a necessity in every stage of project advancement- A case study, Punasi reservoir scheme, Deoghar district, Jharkhand

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Abstract

The dam COT of a 21.34m high and 2133.6m long earthen dam across river Ajay in Deogahr district, Jharkhand was filled and raised up to desired height (EL 263.65m) on left bank between RD 00m to RD 869m (Ch 28.50) and RD 1006m (Ch 33) to RD 1616m (Ch 53) without geological consultation and completed with riprap, toe drains etc. by the project authority.

After a gap of nearly 15 years the geological investigation was carried out from time to time since 1999 from GSI on the request of the project authority. The positive cutoff was provided in the rock comprising granite gneiss, hornblende gneiss and pegmatite between RD 1921m (Ch 63)and RD 2133.6m (Ch 70) on the right bank, between RD 1616m(Ch53) and RD 1921mCh63) in the river bed and hitherto unconstructed portion between RD 869m (Ch28.50)to RD 1006m (Ch33) on the left bank. The earlier filling at RD 1616m (Ch53), just at left riverbank scaled almost vertically to tag with the present dam axis cutoff trench at river bed. But the exposed vertical cross section of the already filled cutoff across the dam axis reveal presence of approximately 4.45m of loose rive borne sand layer below 2.20m natural clay on which impervious core was laid for nearly 3.19m from NSL(EL.242.86m) and raised up to height of RL 260m.The drifted trees are also embedded in the sand layer. This sand layer at the base of the COT has an upstream and downstream connection, which will invariably be a very easy path of leakage after reservoir impounding, leading to piping and ultimately to dam failure.

The presence of huge thickness of sand layer on left bank beyond the present river course indicates obvious continuity further towards left. Since positive cutoff on rock where no sand is encountered between RD 869m (Ch 28.50) and RD 1006m (Ch33) was provided in presence of the author, a few drill holes were suggested from the top of the dam from RD 1006m (CH33) to RD 1616m. (Ch53) to find out the lateral continuity of the sand layer. The subsurface exploration indicates that the cutoff filling directly rests on hornblende gneiss at RD 1280.5m-Ch42 (Hole9).The other drill holes indicate sand layer below the dam axis gradually diminishes from 4.5m to 1.5m at RD 1433m-Ch47 (Hole8)towards left side. Since the dam has been raised to full height on the left bank, the dismantlement of the dam and subsequent refilling etc will involve a huge expenditure. Therefore a parallel positive cutoff along the heel of the dam from RD 1280m (Ch42) to RD 1616m(Ch53) was recommended to prevent leakage from upstream to downstream through sand layers below COT along dam axis on left bank. It was also suggested to tie the proposed parallel cut off transversely as closely as possible at RD 1616m (Ch 53) with the present dam axis cutoff to prevent entry of water from sides through sand layers. The suggestion was accepted by CWC, New Delhi and the project authority. At present positive parallel cutoff has been provided in the rock in heel portion and transverse cutoff filling is under progress. The casing materials of the dam on left bank were tested insitu for impermeability. The casing materials are found to be impervious. i.e. the dam is homogeneous in nature. Therefore possibility of seepage through dam body after reservoir impounding is also ruled out.

From the above it is reaffirmed that geological study should be an integral part in all stages of investigation from feasibility, preconstruction to construction stages of investigation of any irrigation /hydro electrical projects.

1. Introduction:

The Punasi reservoir scheme envisages construction of a 21.34m high and 2133.6m long earth dam across river Ajay near Punasi village in Deoghar district, Jharkhand.It also comprises dyke 'A' for a length of 121.95m between RD 2219.51m (Ch 72.79) and Rd 2341.46m (Ch76.80) and dyke 'B' for a length of 579.27m between RD 3170.73m (Ch104) and RD 3750m (Ch123) on the right bank. The reservoir scheme will store 1.498 x 10^8 cumec of water to irrigate a gross command area of 42,275.85 Ha. A chute spillway is under construction between RD 2652.44m(Ch87) and RD 2804.88m(Ch92) on right bank with a maximum discharge of 4272.725m/sec at F.R.L 261.21m when crest level of the dam being E.L. 263.65m

2. Geological Investigation:

The geological investigation was carried out by Geological Survey of India from time to time and not at a stretch on the request of the project authority as and when required basis. Preliminary investigation for site selection from geotechnical point of view was completed in 1961-62 and 1962-63.After almost one decade, a plane table survey along a new alignment as recommended by Central Water and Power Commission was carried out in 1970-71.GSI explored four sites in 1971-72 for spillway in original and alternative dam alignment and selected the site on right abutment between RD 2652.44m (Ch87) and RD 2804.88m (Ch92) along original axis on better rock condition.

After almost fifteen years the author was engaged to take up the investigation in 1986-87.In the mean time ,except for the stretch of 137m between RD 869m(Ch28.50) and Rd 1006.00m(ch33) ,the entire left bank of the dam from RD 00.00m to RD 1616m (Ch53) had been filled up ,raised to dam height, completed with riprap, toe drain etc. During investigation in 1986-87,28nos of bore holes drilled mostly along the dam axis in river bed and its upstream site and also on the right bank was logged to access the cut of depth. Another 23 nos of newly drilled holes on the right abutment beyond the dam end was also logged from the core boxes to find out the suitability of the spillway location. However no holes were drilled on left bank as the dam was already completed. From the study of the core it was recommended for a positive cutoff in rock to a depth of nearly 10 to 13m at river bed. However since no permeability tests were performed in any of the holes it was advised to carryout permeability test to find out the groutability of the rock below cut-off fill in the river bed as well as dyke portions.

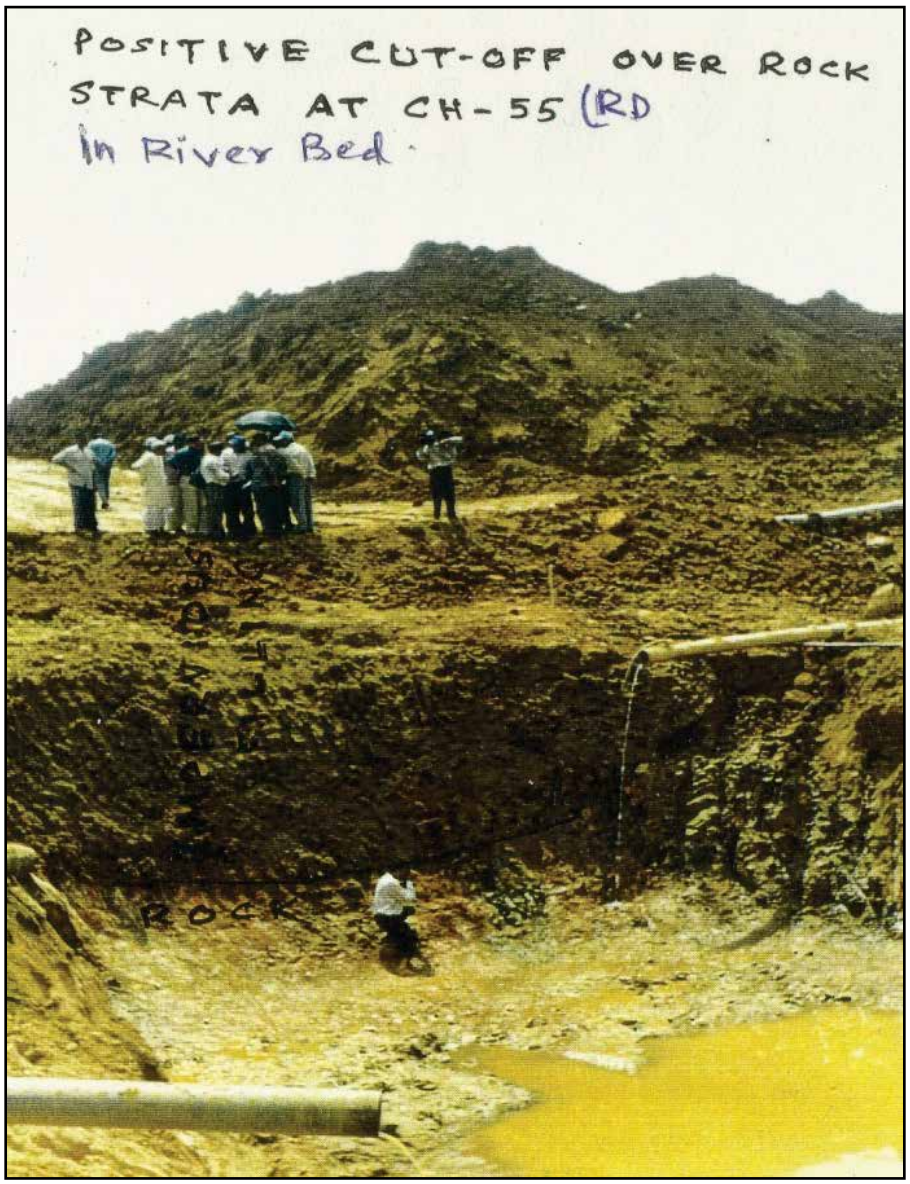
As reported by the project authority, in certain stretches of the dam has filled without excavating even one-third of the dam height, a rule of thumb followed in Bihar-Jharkhand though which is technically unacceptable. The project proposed for grouting from top of the dam. But in absence of any subsurface exploration/permeability on the left bank, efficacy as well as requirement of the grouting found to be unjustified. Drill holes with percolation tests were suggested at the unfilled stretch of the left dam alignment between RD 869m (Ch28.5) and RD 1006m (Ch33).

After examination of recent drill holes as well as earlier core boxes it is reaffirmed that the original spillway site selected by GSI between RD 2652.44m (Ch87) and RD2804.88m(Ch 92) will be most suitable as competent rocks will be available at much higher elevation than the other sides of dyke 'A' and dyke "B'.

During 1988-89, the spillway site was mapped when excavation level reached approximately around F.R.L in axial portion. The investigation from approach channel to stilling basin reveals the presence of competent granite gneiss, amphibolites, hornblende gneiss and pegmatite at much higher level than the design foundation depth. It was therefore proposed for an ungated chute spillway instead of gated ogee spillway to reduce huge excavation in rock in the tune of 8m to 11m.However a gated spillway has to be retained in the design to allow discharge of 4272cumec of water. Never the less the designed was modified and foundation was raised to 2m to 5m resulting a total reduction of nearly 2 lakh cum in rock and thus saving the cost of the project considerably.

In 1999-2000, the author during his visit from time to time ,has provided positive cut-off in the rock comprising granite gneiss, hornblende gneiss and pegmatite between RD 1921m(Ch63) and RD 2133.6m (Ch70) on right bank(Picture 1) and RD 1616m(Ch53) and RD1921m(Ch63) in river bed (picture 2). However in the stretch between RD 1637.20m(Ch53.70) and RD 1663.11m(Ch54.55) ,the project authority faced working difficulty to excavate further depth beyond 11.2m(excavated depth of the stretch) below river bed level. The maximum design depth was kept in the design as 10.65m (H/2) and accordingly excavation of the river bed was planned in such a way so that the machine can excavate from the last bench to the designed depth. However the rock depth was around 13m in this stretch (indicated by GSI earlier).The machine could not excavate further down from the last bench because of dewatering problem coupled with slope instability of river sand accumulating in the cut-off trench at a faster rate from slope than the excavation rate and ultimately filled the cut off by impervious clay .

Picture 1 Hornblende gneiss rock at the cut-off trench bottom at RD 1951m (Ch 64) on right bank



Picture 2 Cut-off bottom on granite gneiss & hornblende gneiss strata at RD 1677m (Ch 55) in river bed left bank dam filling can be seen beyond the cut off.

The vertical cross section encountered at RD 1616m (Ch53) on the left bank from the cut-off level at river bed reveals presence of nearly 4.45m river sand below the cut-off filling where dam has been raised to full height up to E.L 260m where NSL being E.L.242.86m.(picture 3). The sand layer at the base of the COT has an upstream to downstream connection which will invariably be a easy path of seepage after reservoir impounding, leading to piping ,differential settlement and ultimately failure of the dam. The drifted trees were also embedded in the sand. The natural clay layer above the sand layer and below the impervious filling is seen to pinch out upstream as seen in the vertical section. Pinching out of the natural clay layer is also observed in river bed section during cut-off filling.

Picture 3 Vertical cross-sections at RD1616m (Ch 53) on the edge of the left bank showing sand layer underlain by rocky strata below dam filling.

As the dam has been raised almost to full height in the left bank completed with riprap and toe drain etc. it is not possible to dismantle the dam, excavate the filled up material, provide the desired positive cutoff below sand layer and raised it again to desired dam height with new riprap etc. This will involve a huge expenditure. Therefore to minimize the possible leakage problem and considering the economic aspect, a positive cutoff up to bed rock level along the heel portion of the dam on left bank was recommended. It was also suggested to tie up the present dam axis cutoff at riverbed transversely with proposed upstream cutoff at the heel portion as closely as possible near RD1616m (Ch53) by an

impervious core up to NSL to prevent entry of water from the sides through pervious sand layer in between upstream and present dam axis cutoff.

Since the sand layer was very thick at RD 1616m (Ch53) at the edge of the left bank, it was obvious that the layer will continue further towards left. To know the lateral continuity of the sand layer towards left a few drill holes were suggested along the dam axis and also from the heel of the dam .One drill hole was suggested from the toe portion to find the upstream –downstream continuity of sand layer below the dam cutoff. Since positive cutoff on rock was provide in presence of the author (1999-2000) between RD 869m (Ch28.50) and Rd 1006m (Ch33) on left bank, the drill hole was restricted between RD 1006m (Ch33) and RD 1616m (Ch53).The project authority drilled 12 holes of which seven were drilled from top of the dam, four from the heel portion and one at toe portion. The author logged the bore holes during 2000-2001, and the comprehensive synopsis of sub surface exploration by core logs are given in the following table:

Table 1

Hole (no)	RD (in m)	Feature	R.L. (in m)	N.S.L. (in m)	Total Depth (in m)	Depth of sand (in m)	R.L. of Top of sand layer (in m)	R.L.Top of bedrock (in m)	Remarks
1	1585.36	Heel portion	245.10	242.10	11.58	5.0	238.70	234.10	Hole should have been drilled deeper (Ch52) for conclusive evidence of bed rock.
2	1524.40	Heel portion	246.12	243.00	14.35	4.7	239.60	235.00	Granite gneiss bed rock (Ch50)
3	1591.46	Top of dam	254.22	243.00	30.48	4.5	239.00	234.50	Pegmatite & granite gneiss
4	1554.88 (Ch 51)	Top of dam	258.55	242.80	30.48	4 .0	238.44	234.40	Pink granite
5	1524.39 (Ch 50)	Top of dam	258.86	242.40	30.48	3 .0	238.86	235.86	Pink pegmatite
6	1493.90 (Ch 49)	Top of dam	260.10	242.00	30.48	2 .0	237.60	235.60	Pink pegmatite
7	1463.41 (Ch 48)	Top of dam	259.66	242.00	30.48	2 .0	236.66	234.60	Pink pegmatite
8	1432.93 (Ch 47)	Top of dam	258.22	242.00	30.48	1.5	238.40	236.90	Granite gneiss
9	1280.49 (Ch 42)	Top of dam	259.60	245.20	30.48	Nil	----	242.00	Hornblende gneiss
12	1463.41 (Ch 48)	Heel portion	245.10	243.30	14.76	3.6	239.00	235.40	Pegmatite
13	1402.44 (Ch 46)	Heel portion	244.44	242.00	14.03	4.6	239.80	233.80	Granite gneiss & pegmatite
14	1402.44 (Ch46)	Down stream	243.50	242.00	8.84	3.0	242.00	---	No rock is encountered in drilled depth. Silty clay occurs below 4.5m depth.

Note: Actual N.S.L of the bore hole nos 1, 2, 12, 13 & 14 in heel and toe portions is lower than the ground level because holes were drilled in slope wash materials. Similarly N.S.L in other holes drilled to the filled materials is also much lower.

From the study of subsurface exploration, it is found that the dam fill materials directly rest over hornblende gneiss at RD 1280:49m. (ch42)The sand layer will continue for nearly 300m from RD 1616m (Ch53). Therefore, it is reaffirmed that the earlier suggestion of upstream positive cutoff from the heel of the dam may be provided up to RD 1280.49m (Ch42).

In view of jointed rock below positive cutoff in river bed, absence of percolation tests to determine the depth and spacing of grout holes in the bed rock, partial cutoff over sand in river bed portion between RD 1637.20 (Ch53.70) and RD 1663.10m (Ch54.55), and to avoid disturbance in compaction of already filled dam portion by grouting at this stage, a clay blanket at river bed portion is recommended to minimize the possible seepage problem. Since river is not closed, clay blanket may be easily tied up with impervious core of the dam.

The CoT of the parallel cut off on the upstream from the heel portion was mapped, geologically examined and positive cutoff on hornblende gneiss, granite gneiss and pegmatite rock from RD 1219.51m (Ch40) to RD 1616m (Ch53) was provided during 2001-2002(Picture 4 & 5).

Picture 4 Upstream parallel cut-off bottom showing granite gneiss intruded by pink pegmatite below sand layer at RD 1509m (Ch 49.5) on left bank.

Picture 5 Upstream parallel cut-off bottom showing mainly pink pegmatite below sand layer at RD 1463m (Ch 48) on left bank.

A joint meeting was held on 23rd Dec'2002 in CWC office, New Delhi between Central Water commission, Geological Survey of India, Kolkata and Water Resources Department, Jharkhand after a visit by a CWC team to the project site on June, 2002.It was decided to extend the upstream parallel cutoff from the heel to RD1158.54m (Ch38) provided sand layer is not encountered in this section.

The CWC also suggested for five drill holes to a depth of 15m along original dam axis at RD 579.27m(Ch19), RD 853.66m(Ch28), RD 1006.10m(Ch33).RD 1646.34m(Ch54) and RD 1676.83m(Ch55).Two drill holes were suggested at RD 1158.54m(Ch38) and RD 1463.41m(Ch48) along upstream parallel COT. The permeability of the rock strata in all the holes are to be observed at 3m intervals. In situ permeability tests in open pits in the casing materials are also suggested in the upstream portions at RD 1067.07m(Ch35), RD 1158.54m(Ch38) and RD1463.41m(Ch48).

The author examined the above proposed drill holes by CWC and analyzed the permeability tests during 2003-2004.The drill log shows that the COT filling directly rests on bed rock at RD 579.27m(Ch19),RD 853.66m(Ch28) and RD 1006.10m(Ch33).The COT also rests on rock in river bed at RD 1676.83m(Ch55). However the COT is partial as it laid on sand at Rd 1646.34m (Ch54) .This has already been mentioned in the report of 1999-2000 by the author.

All the upstream drill holes show that except for the hole at RD 1463.41m (Ch48) there is no sand layer above the rock confirming the GSI finding earlier. The water percolation tests show that the formation along the dam axis below the cutoff is impermeable to very impermeable in nature to the tune 1.02x10- ^{6} cm/sec to 6.56 x10^{-8} cm/sec. On the heel portions they are highly impermeable to the tune of 1.53 x 10 $^{-7}$ to 1.32 x 1.32 x 10 $^{-9}$ cm/sec.

Insitu permeability in open pits in casing materials show 3.70 x 10^{-5} cm/sec which is equivalent to almost 1 lugeon. On other words casing materials are also impervious i.e. the dam is a homogenous one at least towards its left bank.

The water percolation tests show that the formation along dam axis below COT filling is impermeable in nature, therefore grouting is not recommended as it will disturb the compaction of the dam which has almost to full height on both the banks and up to river bed level in river portion. However in view of the presence of weathered rock nearly 3m below COT in the river bed portion, where water percolation tests could not be carried out due to non-fixation of packers and also due to the presence of nearly 1m thick sand below COT at the river bed portion between RD1637.20m (Ch53.70) and RD 1646.34m (Ch54.55), earlier suggestion for clay blanketing for nearly 10H is again recommended. This clay blanket can be easily tagged with the impervious core of the dam as the dam is not closed yet in river bed section.

At the instance of CWC the upstream parallel cutoff was extended to RD1023.78m (Ch 33) so that it can be tagged with impervious core where dam was not raised .In other words sand layer is completely segregated by upstream parallel cutoff against leakage from upstream to downstream and by transverse cutoff in riverbed section and on left bank to prevent leakage from sides as well. The transverse cutoff in river bed section is proposed to tag with the dam axis cutoff around CH 56 to isolated the pocket of sand layer which could not be excavated during river filling between RD 1637.20m (Ch53.70) and RD 1663.10m (Ch54.55) COT bed was geologically mapped and positive cut off was provided in rocks comprising granite gneiss often profusely intruded by pink pegmatite, hornblende gneiss and hard amphibolites. No sand layer is encountered in this stretch of Cut off from RD1006m (Ch33) and RD1280.5m (Ch42) vindicating earlier observation by the author (pictures 6, 7, 8).

Picture 6 Fresh granite gneiss at C-O-T bed of parallel cut-off on left bank at RD 1265m (Ch 41.5)

Picture 7 Fresh hornblende gneiss at C-O-T bed of parallel cut-off on left bank at RD 1219.5m (Ch 40)

Picture 8 Upstream wall of parallel C-O-T showing weathered granite gneiss below soil overburden without sand layer at RD 1280m (Ch 42)

3. Conclusions:

(i) Preliminary geological investigation helps to select the proper spillway site and dam cutoff depth in river bed portion. As no drill hole was carried out on the left bank no proper evaluation could be done on left bank dam cutoff.

(ii) The project authority filled and raised the dam on left bank from RD 00.00m (Ch0) to RD 1616m(Ch53),just at the left bank edge, except between RD 869m(Ch28.50) to RD 1006m(Ch33) without any geological investigation.

(iii) The positive cutoff in the rock was provided in the rock on the right bank and in river bed portion. Due to working difficulty the project authority could not excavate the sand for nearly 1m depth between RD 1637.20m (Ch53.70) and RD1663.10m (Ch54.55), close to left bank in the river bed portion.

(iv) At RD1006m a thick sand layer of nearly 4.5m was encountered below the cutoff bed in the vertical section exposed during river bed COT filling. The sand layer has an upstream-downstream extension. This sand layer will be very dangerous being an easy path of leakage after reservoir impounding, leading to piping, differential settlement and ultimately to dam failure. An upstream parallel cutoff along the heel portion was recommended to prevent upstream to downstream leakage. This parallel cutoff was suggested to tag with the present dam cutoff in the river bed up to NSL to prevent leakage from the sides through sand layer.

(iv) A few drill holes were suggested from top of the dam to find out the lateral continuity of the sand layer towards left bank. From the study of the drill hole it was established that the sand layer continue up to RD 1280.5m(Ch42).Therefore parallel CoT was recommended to extend up to this RD from left bank. Now this measure could have been possible due to timely geotechnical investigation.

(v) Due to continuous persistence of GSI and suggestion by CWC water percolation tests were carried out finally in a few drill holes along the axis as well along parallel CoT. However in the top weathered layer of 1st 3m segment below the CoT filling (along dam alignment) and overburden (along heel portion) could not be tested due to non fixation of packer. But below the weathered bed rock of nearly 3m rocks are found to be impermeable.

(vi) Timely examination of the foundation of the spillway site at F.R.L. also helped to change the design of the spillway and save considerable expenditure by not excavating the competent rock to the tune of 8m to 11m as per original design.

(vii) From the case study of the Punasi project it can be safely said that geotechnical investigation in every stages of project advancement for Irrigation/Hydropower project are essential from safety point of view as well as on economical consideration.