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Geotechnical evaluation of spillway structures at Tehri Dam Project, Uttaranchal

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Abstract

A large number of failures or damages to spillway structures are reported all over the world. A very careful consideration is therefore needed in the design of spillway taking into account the geological complexities. Six spillways have been provided in the design of Tehri dam project to take care of excess floodwaters. These include a chute spillway on the right bank, two shaft spillways each on the right and left bank connected to the respective diversion tunnels and an intermediate level outlet.

Peculiarities and geological conditions at the chute spillway and shaft spillway area have been discussed. A geotechnical assessment based on disposition of shears and joints responsible for planar and wedge failure, status of weathering grade etc. has also been made for providing treatments for the safety of chute structures. Stability measures adopted have also been discussed for shaft spillway structures.

Introduction

Tehri dam spillways have been designed to cater to a probable maximum flood (PMF) of 15,540 cumecs corresponding to a flood frequency of 1 in 10,000 years and considering the hydrometeorological condition in its reservoir catchment of 7511 km^2. For passing the estimated routed flood of 13,200 cumecs, following spillway arrangements have been finalised, on the basis of various geotechnical aspects and detailed model studies carried out by Hydroproject Institute, Moscow and UPID (IRS).

- A gated chute spillway on the right bank to pass a discharge of 5480 cumecs at MWL at El 815.00m.
- Two gated shaft spillways with their crest at El 815 m connected to both the left bank diversion tunnels T-1 and T-2 for a rated discharge of 3815 cumecs at MWL.
- Two ungated shaft spillways with their crest at El 830 m connected to both the right bank diversion tunnels T-3 and T-4 for 3946 cumecs discharge at MWL.
- A gated intermediate level outlet on right bank for discharge of 1200 cumecs on the right bank at El 700 m.
- At the lower end of each shaft spillway a swirl device will be provided. It will be joined to the existing tunnel through 80m long, 12 m dia circular tunnel followed by 10 m long transition from 12m circular to 11m standard horse shoe section tunnel.

The spillway proposals have been discussed in detials, along with their layout design drawings, by Vishnoi and Govil (2004).

Chute Spillway

A 578 m long chute spillway comprises approach channel, control structure,

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discharge carrier and baffle. The control structure consists of 3 bays each of 10.50 m width with crest level at El 815 and bottom level at El, 596 m (El 584 foundaion level for stilling basin), and is provided with two piers, each 4 m wide. Three tainter type gates have been provided in the control structure part. A central drainage gallery has been provided along the centre line of chute spillway. Three aerators have been provided at El 769.60m, El 728.60m and El 646.60m located at a distance of 230.00 m, 310.00m and 410.00m (end chainages) in glacis portion. The control structure is connected with 140m long stilling basin through sloping (27°) discharge carrier.

Geological conditions

Location of the discharge carrier has been preferred on the right bank to avoid over crowding of structures on left abutment, where underground power house complex is located. The topography of the area on the right bank necessitated removal of enormous quantity of overburden and weathered rock down to a depth of about 200m, so as to reach desired foundation grade. Earlier the Russian consultant of THDC had proposed to slope the spillway at 35° but subsequently on the advice of GSI (Nawani & Sanwal, 1998) the slope was changed to 27° to avoid location of D1 and L1 shear at junction of chute and stilling basin. The accepted foundation level and disposition of various shears and joints present in the area are depicted in Fig 1.

During the progressive excavation in chute spillway area, overburden mass and distressed/highly weathered rock mass were removed and acceptable foundation grade was achieved, more or less, coinciding with the anticipated foundation level as projected by G.S.I. Excavation confirmed more or less interpreted assessment and the foundation exposed predominantly phyllitic quartzite massive (PQM), phyllitic quartzite thinly bedded (PQT) sequence with a few isolated sheared phyllite (SP) patches. Foundation grade was accepted at W_0-W_1 (fresh) rock In area where W_2 grade was exposed, the foundation was lowered to W_0-W_1 grade. Foundation of the control structure and the left guide wall where rock mass was found to be of W_1 grade of weathering after excavation, need for strenghtening the rock mass was recommended by GSI through consolidation grouting. Five prominent joint sets were identified traversing the foundation and numerous L and D type shears of different orders have also been identified and were provided with dental treatment. The bedding and foliation joints which are dipping at 38°-65°/S10°-40°W and 30°-48°/S10°E toS05°W and are moderately smooth were found to be responsible for planar failure in the inclined portion. The joints dipping in northwesterly direction (38°-60°/N10°-65°W) and the joints dipping in northeasterly direction (25°-73°/N20°E to E) were found unfavourable and caused wedge failure in combination with the bedding/ foliation joints. These joints were found more susceptible to failure in the wet zones. The bedding joints which were found to get transformed into bedding (L) shears were also considered as unfavourable discontinuities leading to planar failure.

Treatment provided

- Consolidation grouting was carried out in the foundation of the control structure and the left guide wall, where rock mass was found to be of W1 grade weathering. The rock mass at the foundation grade was further strengthened by consolidation grouting through 6 m deep, 3 m c/c spaced holes using 2.5 to 3 Kg/cm^2 pressure (A.K. Jain et.al., 2002).
- Sloping areas where designed slope exceeds 27° was strengthened by timely installation of the rock bolts of 12m length and 40mm/36mm dia, provided at 3m c/c spacing and the rest including aerator part was provided

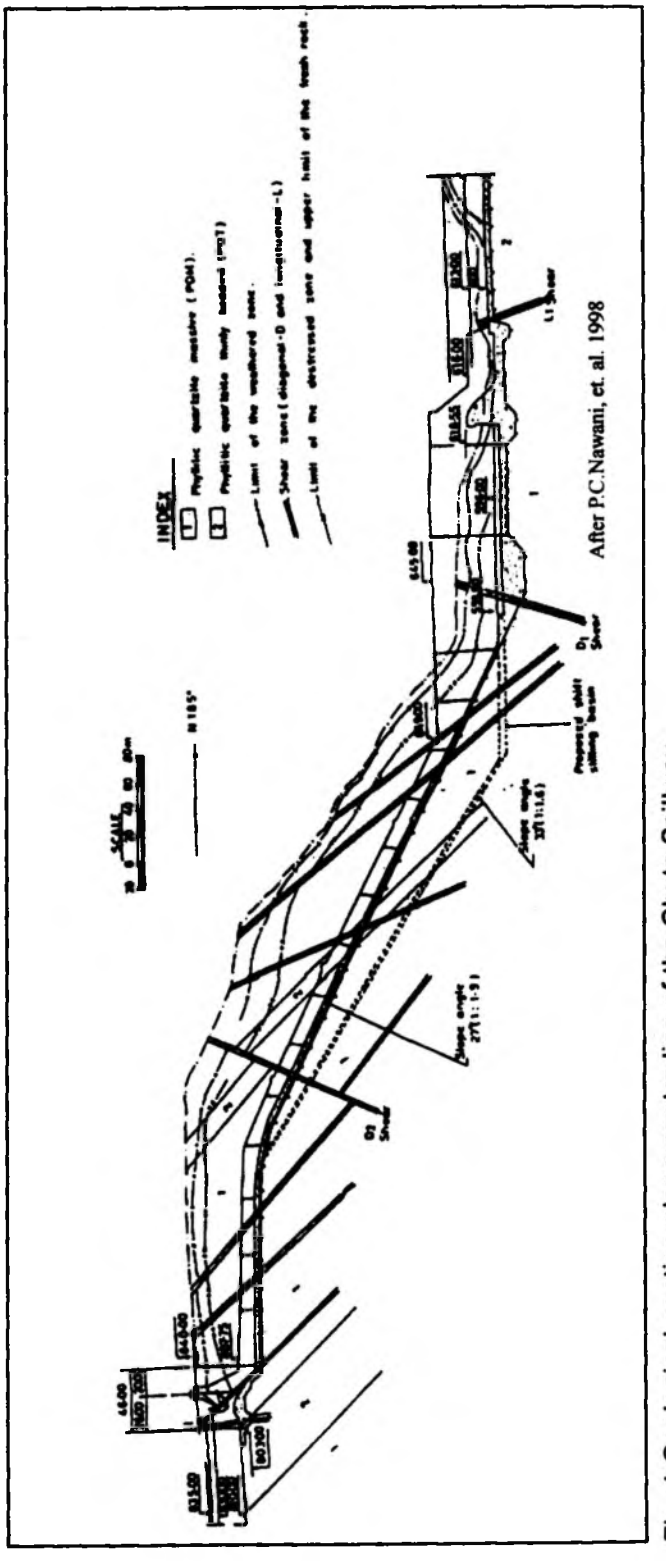

Fig. 1:Geological section along centre line of the Chute Spillway

with tensioned rock bolts of 25mm dia and 6m length at 2m c/c spacing.

- All major shears and selected minor shears with wide affected zones were rendered dental treatment.
- Drainage pipes were provided in water charged shear zones and other water seepage areas, to discharge the collected water in the central drainage gallery.
- In the stilling basin the design thickness of concrete has been increased and silica cement lining is proposedin order to decrease erodibility of material.
- The design consultants (Anon., 2002) have prescribed M60 concrete, high performance concrete (HPC), in combination with Micro silica fumes have been proposed in stilling basin/ energy dissipation components take care of abrasion resistance.

Underground Spillway System

a. Left Bank Shaft Spillway (L.B.S.S.)

Two vertical shafts (T-1 and T-2) forming vertical legs for the intake tunnels, are being connected to respective diversion tunnels (both have invert at El 632.0 m). These diversion tunnels were plugged and will act as water carrier for shaft spillways on the left bank. Respective bell shaped intake tunnels to above shafts have been provided for entry of excess water from reservoir to vertical shafts. Two small tunnels at El 842.0m with a length of 47.75m for T-1 and 55.25m for T-2 (both D-shaped) have been provided for aeration of vertical shafts and horizontal intake tunnels.

Initially pilot shaft from El 842.0m to El 676.0m (T1) and El 842.0m to El 685.0m (T2) through respective aeration tunnels were driven with excavated diameter varying from 3.6m to 6m in circular shape. These shafts were geotechnically assessed.

T-1 shaft : The pilot shaft has been widened to 15.0 m from El. 842.0m. The excavations have revealed that PQT and PQM interbands are exposed in T1 while PQM becomes dominant in T2 and is silicified at places. The bedding dips at 44°-68°/ S10°-45°W and foliation in 34°-50°/S15°E to S. Besides bedding and foliation two prominent joint sets observed are dipping in 42°-80°/ N10°-70°W and 25°-70°/N20°-70°E A random set of joint is dipping in 40°-75°/ S40°-75°E.

Four major L-shear (clay gouge more than 10cm thick) were recorded at different levels which are dipping at 50°/S40°W, 43°/S5°E, 43°-55°/S5°W and 38°-50°/S10°-20°W direction. The Q value and RMR values of the rockmass in the shaft have been estimated as 4-7.5 and 35-56 respectively. Joints dipping in NE or NW direction when combined with bedding/foliation joints, were responsible for the wedge failures. Similarly water charged / wet shear zones associated with unfavourable joints had caused failure.

T-2 shaft : Similar to T-1 shaft, widening of T-2 pilot shaft from 3.6m to 15.0m diameter was commenced from El 842. The shaft has been widened to its full diameter upto junction with deaeration tunnel (crown level at El 685.0m).

With same geological setup as in T1 shaft one major shear (with clay gouge > 10cm thick) was recorded in this shaft. However, five major L-shears (at different levels) were also recorded.

Both the shafts (T1 and T2) are being lined for a finished diameter of 3.0m to 12.0m changing at various levels.

Treatment provided: Immediate rock bolting (L=4.8m, dia 25mm, @ 1.5mm c/c spacing) just after excavation was done. Steel rib supports (spacing varying from 75cm-100cm) were provided in the critical zones and in the part where diameter of the shaft increases. Perforated drainage pipes of 6m length were provided in the water

seepage/dripping zones associated with shear zone. Shotcrete (50:50) with chainlink/wire-mesh was also provided. High performance concrete with the use of Micro silica fumes are prescribed for lining the shafts on the advice of design consultant (Anon., 2002).

b. Right Bank Shaft Spillway (R.B.S.S.)

Two ungated vertical shafts (T-3 and T-4) on the right bank are under excavation with their crest level at El 830.2m to provide escape route to water from reservoir to respective horizontal diversion tunnels (T-3 and T-4). The foundation of these 12m dia open to sky in funnel shape (at El 830.20m) concrete structure will be at El 809.0m from where shaft will continue downwards till they meet T-3 (invert El 606.00m) and T-4 (invert El 609.00m) tunnels. Both the shafts are being provided with deaeration duct all along and the separation chambers at lower level (El 666m).

T-3 Shaft : The top of the shaft between El 830.2m to El 809.0m is funnel shaped. Weathered slumped rock was present at this location and hence the same had to be removed. Initially 6m wide circular pilot shaft had been excavated, which was geotechnically assessed. Later on, this pilot shaft was widened to 14.0m diameter upto El 766.0m and for 15.00m below El 766.0m. A number of thin shear seam have been encountered. Two major L-shears (clay gauge >10cm thick) were observed at El 793.0m and at El 726.0m The Q and RMR values of the rockmass have been assessed as 6-8 and 48-57 respectively between El 820m and El 762.0m and 5-6 and 44-50 respectively between El 762.0m and 714.0m.

T-4 Shaft : The structure and geology is similar to T-3 shaft. The 6m wide pilot shaft is being widened (El 766.0m till date) to 14.0m diameter. Q and RMR values of the rock mass exposed here have been assessed as 2.5 and 25 respectively (El 820m to ± 800m); 2.5-5 and 25-48 respectively (El 800m-790m) and 4.5-7 and 45-55 respectively (below El 790.0m). A major diagonal shear (D-3) dipping in 60°-75°/N10°-40°W direction was recorded between El 820m and ± 788m, on both sides (hill and valley side of the shaft). This water charged shear zone has been responsible for a number of wedge failures when cut across by the bedding/foliation joints and shears.

Treatment provided : Rock bolting (L=5m, dia 25mm, @ 1.5m c/c spacing) all along with spot bolting in critical reaches vulnerable to wedge failure, followed by chain link shotcrete (50:50)were provided and a few critical zones were provided with steel ribs for further strenghthening at different elevations. After complete widening this shaft will be lined for 12.0m diameter. High performance concrete with the use of micro silica fumes are prescribed for the shaft lining.

During excavation for de-aeration duct the foundation of winch collapsed from El 820m to El 811m. Later, on design considerations, the platform around T-4 shaft was lowered to El ± 809m so that glory hole structure could be constructed. The studies for design foundation are still going on as the rock here is still not fresh (W1-W2) and some shear zones dipping towards valley have been recorded. Additional provision of a concrete structure to join two shafts has been kept in the new design to take care of vibrations during seismic events.

Intermediate Level Outlet (I.L.O.)

An intermediate level outlet tunnel has been provided (invert El 700.0m) with an objective to regulate the flow during first filling of the reservoir, to evacuate the reservoir in any emergency and to release the irrigation water committed for the down stream supply in case of power house shutdown. The total length of ILO from its intake to its junction

with shaft T-3 is 273.68m. The ILO has been designed to pass a minimum of 276 cumecs at minimum reservoir level i.e. at El 740m. This circular bell mouth 8.5m diameter tunnel will join its gate shaft (i.e. gate chamber) and then will become D-shaped and will connect to T-3 shaft and diversion tunnel. At the inlet, the section has been kept $15m^2$ converged to $8.5m^2$ in a length of 14m through straight line transition in the sides and a circular transition of 16m radius on roof. The $8.5m^2$ section has been changed to 8.5m circular section in 12m length. Initial alignment of tunnel is in N190° direction i.e. roughly perpendicular to the rock strike, but for joining the shaft, it takes U turn and thus becomes parallel to the rock strike. The tunnel is initially driven through weathered PQT rock followed by PQM and PQT interbands dipping in 48°-58°/S05°-50°W and the foliation dipping in 38°-56° due South to S05°W direction.

Besides bedding and foliation joints, two prominent joint sets viz. northeasterly (35°-70°/N25°E to due East) and northwesterly (35°-62°/N20°-80°W) have been recorded.

A number of shear zones (some are water charged) of various dimensions were encountered at different RD. The rock mass classification parameters assessed are Q=6-11, and RMR=42-70. As the tunnel is nearly parallel to the rock face initially, low rock cover on the valley side was observed. Structurally controlled failures, due to disposition of bedding and northwesterly joints resulted in wedge failures at the crown level, in some parts. A crumpled/ puckered zone of more than 3m width was identified at RD 192m (at right invert) which continues upto RD 247m (crown), and is formed due to the combination of two L-shears. A number of wedge failures were also recorded in this zone due to adverse relationship with joints in the poor rock

Mostly rock bolts were suggested for rock mass stability followed by shotcrete but in vulnerable reaches where major overbreaks at the crown level were observed, steel rib support were provided as additional stability measures. In the initial reaches of ILO (ch 0.0m to 14.39m), marked by reduced lateral cover special measures were incorporated for strengthening. This included giving rib support and additional reinforcement to lining . Concrete grade of M-25 has been used for lining ILO in the upstream of gate shaft. Recommendations have also been made to make a toe wall to prevent entry of muck/debris material lying adjacent to ILO inlet.

Gate Shaft for Intermediate Level Outlet Tunnel (I.L.O.) : The gate shaft for I.L.O. is provided for operating, repair, maintenance and other activities related to the gates in the I.L.O. (invert El 700.0m). Through this shaft, the hoisting arrangement will be made for regular radial gate and stop logs at its upstream. An oval shaped shaft had been excavated from El 840.0m platform. The ILO tunnel upstream of gate shaft upto ch. 195m shall remain submerged in water all the time whereas the flow shall pass through the downstream portion on opening the gate. Cladding has been provided between El 810m to El 840 m to protect weathered rock slopes/reduced lateral cover surrounding the gate shaft because this area will remain in the submergence zones.

Conclusions

Sufficient provision has been made in the design of Tehri dam to take care of excess floodwaters through chute spillway, four shaft spillways and one intermediate level outlet. Varied geotechnical problems have been encountered during their excavation. In chute spillway, its down dip alignment resulted in some local slope failures during excavations and these have been checked by rock bolting etc. In shaft spillway on right bank, weak rock zones have necessitated redesigning the structure. There is virtually

no problem in the left bank spillways. Widening at the junction has been proposed to take care of vibrating effects in shaft spillways. The ILO has been adequately strengthened on the basis of geological advice in the initial reaches of intake portion and in portion affected by shears running parallel to it at some places.

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