PECULIARITIES AND GEOTECHNICAL EVALUATION OF SPILLWAY STRUCTURES IN TEHRI DAM PROJECT

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Abstract

A large number of failures or damages to spillway structures are reported all over the world. Thus, a very careful consideration is required in the design of spillway after taking into account the geological complexities and attributes. 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 connecting to the respective diversion tunnels and an intermediate level outlet provided at different level. The existing four diversion tunnels are proposed to be used for discharging waters collected from shaft spillways and intermediate level outlet.

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

Introduction

Spillway provides an arrangement to pass surplus flood discharge and thus act as saviour of dams, in event of high flood. Thus, a very careful study is required in the design of spillway after taking into account the geological complexities and attributes. Tehri dam spillways have been designed to cater for a probable maximum flood (PMF) of 15,540 cumecs corresponding to a flood frequency of 1 in 10,000 years 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 after taking into consideration the various geotechnical aspects and detailed model studies carried out by Hydroproject Institute, Moscow and UPID (IRS) (Fig -1).

- 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 morning glory type 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 (I.L.O.) 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

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through 80m long, 12 m dia circular tunnel followed by 10 m long transition from 12m circular to 11m standard horse shoe section tunnel.

1. Chute Spillway Structure

A 578 m long chute spillway, generally sloping at 27^0 consists of 3 bays of 10.50 m wide each with crest level at El 815 and bottom level at El. 596 m (El 584 foundaion level for stilling basin), is provided with two piers, each 4 m wide. The control structure is 39.5 m wide including piers, which will be flaring to 50m at the bottom i.e. near the junction 140 m long stilling basin (the energy dissipator). Three tainter type gates have been provided in the control structure part. A central drainage gallery has been provided along the central 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.

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 35^0 but subsequently on the advice of GSI (Nawani & Sanwal 1998), the slope was changed to 27^0 to avoid location of D_1 and L_1 shear at junction of chute and stilling basin.

The geological section along central line of discharge carrier from control structure to d/s 450m chainage (mapped till july 2002) shows the accepted foundation level and disposition of various shears and joints.

Disposition of major L shears plotted along central line with respect to the designed slope ruled out possibility of daylighting of any major shears in downstream part, hence shear keys were not provided.

The progressive excavation for achieving the foundation grade was taken up in chute spillway foundation aligned in the southerly (N 185^0) direction. In this process, overburden mass and distressed/ highly weathered rock mass were removed and acceptable foundation grade was achieved, more or less, coinciding with the anticipated acceptable foundation level as projected by the G.S.I. at times at much deeper level than the level depicted by the design drawings. 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 preferably at W_0 (fresh rock) and maximum upto W_1. In the 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 underlined by GSI by consolidation grouting. Five numbers prominent joint sets were identified traversing the foundation and numerous L and D type shears of different orders have also been identified and were given dental treatment. The bedding and foliation joints which are dipping at 38^0-65^0/N190-220 and 30^0-48^0/ N170-185 and are moderately smooth were found to be responsible for planar failure in the inclined portion. The joints dipping in northwesterly direction (38^0-60^0/N296-350) and the joints dipping in northeasterly direction (25^0-73^0/N020-090) were found unfavourable and cause 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 taken 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).
- All the sloping area where designed slope exceeds 27^0 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 with tensioned rock bolts of L = 6m, dia = 25 mm, 2m c/c spacing.
- All major shears and selected minor shears with wide affected zones were given dental treatment in order to make the foundation monolithic and increase its compressive strength. Dental treatment to these shears was given as per the Shastas formula.
- Drainage pipes connecting water charged shear zones and other water seepage areas, were provided connecting to the central drainage gallery.
- In the stilling basin to decrease erodability of material the design thickness of concrete has been increased and silica cement lining is proposed.
- The design consultants have prescribed M60 concrete. High performance concrete-HPC with the use of Micro silica fumes for the lining of shafts of LBSS, RBSS and propose to use the same in stilling basin/energy dissipation arrangement components. This will also take care of abrasion resistance, (TAC May 2002)

2. Underground Spillway System

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

Two vertical shafts (T-1 and T-2) forming vertical leg for the intake tunnels are being excavated for respective diversion tunnels (both have invert at El 632.0 m). These diversion tunnels were plugged and will act as 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. Excavated dia of these D-shaped tunnels varies from 12.5mx12.5m to 15.5m x 22.0m and the finished dia varies from 10.5m x 10.5m to 12.0m x 19.0m with the invert R.L. varying from El 800.0m to El 782.0m. Two no. aeration tunnels at El 842.0m with a length of 47.75m for T-1 and 55.25m for T-2 in D-shape (excavated dia 4.0m x 4.2m) have been provided for aeration purpose for vertical shafts and horizontal intake tunnels.

Initially pilot shaft for T-1 and T-2 shafts from El 842.0m to El 676.0m (T1) and El 842.0m to El 685.0m (T2) through respective aeration tunnels were excavated with excavated dia varying from 3.6m to 6m in circular shape. These shafts were geotechnically assessed and important shear zones, prominent joint sets, lithology and weathering grade etc. were recorded. The intake tunnels were initially excavated through heading only after making a false portal.

T-1 shaft : The pilot shaft has been widened for the excavated dia from 3.6m to 15.0 m in circular shape. Mapping data (on 1:200 scale) has 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 44^0-68^0/N190-225 and foliation in 34^0-50^0/N165-180. Besides bedding and foliation, two prominent joint sets observed are dipping in 42^0-80^0/N280-350 and 25^0-70^0/N020-070. A random set of joint is dipping in 40^0-75^0/N105-140.

Four major L-shear (clay gauge more than 10cm thick) were recorded at different levels which are dipping at 50^0/N220, 43^0/N175, 43^0-55^0/N185 and 38^0-50^0/N190-200 direction. The Q value and RMR values for the rocks 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, in the unfavourable directions of the shaft were responsible for the structurally controlled failures and formed wedge failures. Similarly, water charged/wet shear zones when associated with unfavourable joints had given rise to fall along joint planes.

T-2 shaft : Similar to T-1 shaft, widening of T-2 pilot shaft was commenced from El 842.0m for the excavated dia ranging from 3.6m to 15.0m in circular shape. The shaft has been widened to its full dia upto its junction with deaeration tunnel (crown level at El 685.0m).

The geology is similar to T1 shaft. No major shear (with clay guage > 10cm thick) was recorded in this part. However, five numbers of major L-shears (at different levels) were recorded.

Both the shafts (T_1 and T_2) are being lined for a finished dia 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 were done. Steel rib support (sp. varying from 75cm-100cm) were provided in the critical zones and in the portion 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 (TAC May 2002).

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

The topography and depth to firm rock necessitated glory hole structure on right bank as the location had comparatively steep walls and the firm rock quite deep. Morning glory spillways have very high vibratory effects and hence, the foundation demands special attention. 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) diversion 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 830.2mm 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 excavated for 14.0m dia (upto El 766.0m) and for 15.00m (below El 766.0m). A number of shears of minor status have been encountered, besides, two major L-shears (clay gauge + 10cm thick) observed at El 793.0m (at N150° line) and at El 726.0m (at N330° line). The Q value and RMR values of rocks have been assessed as 6-8 and 48-57 respectively between El 820m and El 762.0m and between 5-6 and 44-50 respectively between El 762.0m and 714.0m.

T-4 Shaft :

This structure and geology is similar to T-3 shaft. The 6m wide pilot shaft for T-4 diversion tunnel is being widened (El 766.0m till date) for 14.0m excavated dia. The rocks exposed here have Q and RMR value assessed as 2.5 and 25 resptively (El 820m to ± 800m); 2.5-5 and 25-48 respectively (El 800m-790m) 4.5-7 and 45-55 respectively (below El 790.0m). A major diagonal shear (D-3) dipping in 60°-75°/ N320-350 direction 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 planar and wedge failures when cut across by the bedding/foliation joints and shears.

Treatment Provided :

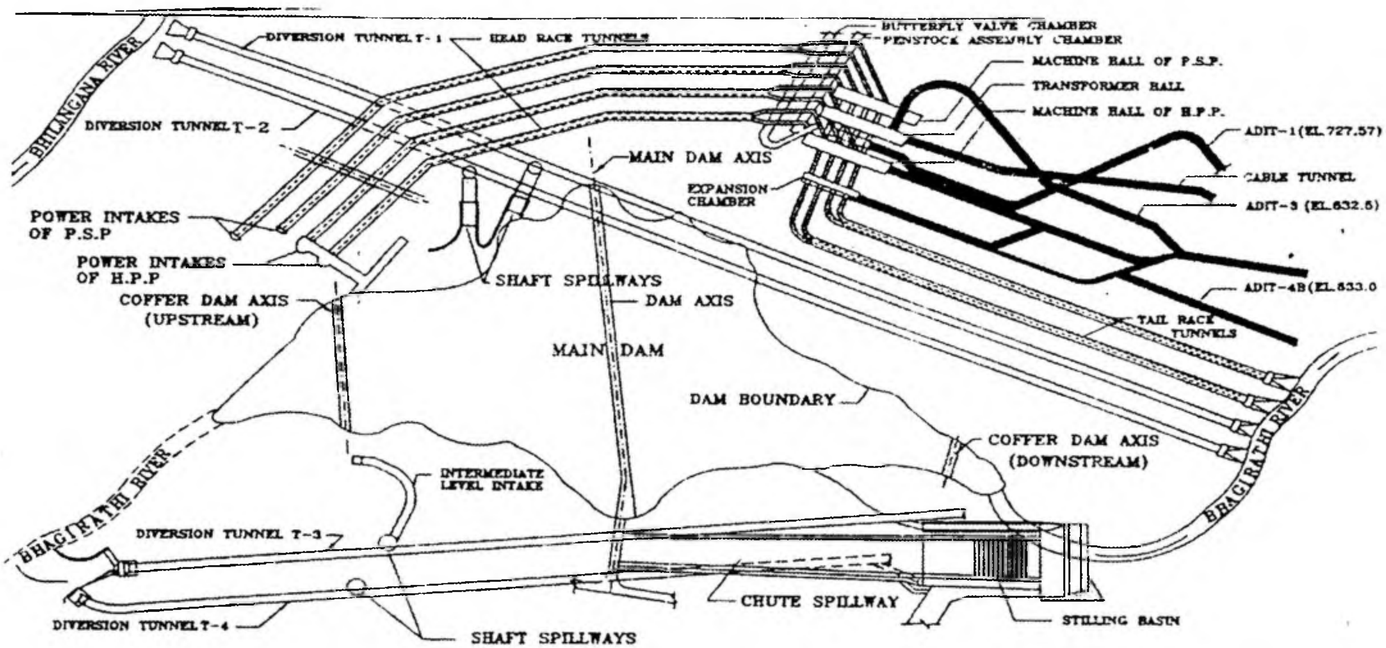
Rock bolting (L=5m, dia 25mm, @ 1.5m c/c spacing) all along with spot bolting in critical reaches vulnerable to planar and wedge failure were provided, followed by chain link shotcrete (50:50) application and a few critical zones were provided with steel ribs for further strenghthening in different elevations.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

During excavation for deaeration 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 can be constructed. The studies for design foundation are still going on as the rock here is still not fresh (W_1-W_2) 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) to regulate the flow during first filling of the reservoir, to empty the reservoir in any emergency and to release the irrigation/ down stream committed 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

Fig : 1 Layout of Tehri Dam Project Showing location of six spillways



S.K. Ghildyal
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minimum reservoir level i.e. at El 740m. This circular bell mouth 8.5m dia tunnel is joined to its gate shaft (i.e. gate chamber) and then will become in D-shaped and will join to T-3 shaft and diversion tunnel. At 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^2 circular section in 12m length. Initial alignment of tunnel is in N190° direction i.e. roughly perpendicular to the rock strike, but to join the shaft it takes U turn and thus becomes parallel to the rock strike. 3-D geological logging carried out upto RD 268m revealed that this tunnel is initially driven through weathered (W_0-W_1) PQT rock followed by PQM and PQT interbands dipping in 48°-58°/N185-210 and the foliation dipping in 38°-56°/N180-185 direction.

Besides bedding and foliation joints, two prominent joint sets viz. northeasterly (35°-70°/N025-090) and northwesterly (35°-62°/N280-340) have been recorded.

A number of shear zones (some are water charged) of various status were encountered at different RD. The rock mass parameters assessed are Q=6-11, 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 interplay of bedding and northwesterly joints resulted into 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) continues upto RD 247m (crown), formed due to the combined affected zone 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 mass.

Mostly rock bolts were suggested for rock mass strengthening 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) due to reduced lateral cover special measures were incorporated for strengthening this reach. 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. Recommendation 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.)

This 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 shall be made for regular radial gate and stoplogs at its upstream. An oval shaped shaft had been excavated from El 840.0m platform. The ILO tunnel u/s of gate shaft upto ch. 195m shall remain submerged in water all the time whereas the flow shall pass through the d/s 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 submergence zones.

Conclusion :

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 exacation. 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 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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