# Excavation and Stabilisation of Right Bank Shaft Spillways, Tehri Dam project, District Tehri Garhwal, Uttarakhand

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**Abstract**

*Shaft spillways of Tehri dam project form part of the discharge carrier network which has been designed to cater a routed flood of 15,540 cumecs. Two vertical shafts, each of 12.2m finished diameter, were constructed on the right bank and they were connected with the right bank diversion tunnels T-3 and T-4 respectively so as to function as shaft spillways, after the initial requirement of diversion was over. These shafts are joined with the de - aeration ducts (Excavated dia 9m), right from the top. A 26m long separation chamber has been constructed ahead of each of the de-aeration ducts nearly 170m below the top level (i.e. El± 830.20m). The T-3 shaft is also connected with the intermediate level outlet (ILO) at El± 700m. At the bottom portions the shafts eccentrically join the horizontal diversion tunnels so as to impart swiveling motion to the falling water.*

*This paper deals with the excavation and stabilisation of these intricately designed structures in a heterogeneous geological regime.*

## Introduction

The prestigious mega hydroelectric project i.e. Tehri dam project, located in Tehri Garhwal district of Uttarakhand is the highest rock fill dam in south-east Asia. The project envisages generation of 2000MW of hydroelectricity, in two stages, by making a 246.20m high (from deepest foundation of El 593.30m) rock fill dam across Bhagirathi River. The mammoth reservoir will spread for 42 sq km and will have a gross storage of 3540 million cubic meters.

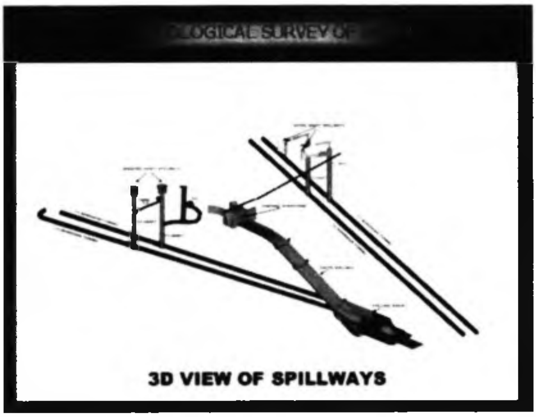


Fig. 1. 3D Layout of Spillways

The spillway system of Tehri dam has been designed for a probable maximum flood of 15540 cumecs (1:10,000 year inflow), however, the routed flood discharge at maximum water level (MWL) of 835.0m through the spillways would be of the order of 13400 cumecs. The spillway arrangements at Tehri dam project comprises of the following (Fig-1)

(i) Gated chute spillway on the right bank, with its intake level at El±815m, having 3 bays, each of 10m widths and separated through of 4m thick piers. It would involve a drop of 220m, which required suitable arrangements for energy dissipation at the toe.

(ii) Two ungated shaft spillways connected to both the right bank diversion tunnels T-3 and T-4,

(iii) Two gated shaft spillways, with intake level at El±815m, connected to both the left bank diversion tunnels T-1 and T-2,

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(iv) An intermediate level outlet (ILO) at El 700m connected to the right bank shaft of Tunnel T-3. It will function as emergency outlet.

## Regional Geology and Tectonic Set Up

The Tehri dam project area lies within the Main Himalayan Belt (MHB), in the midlands of Lesser Himalaya, which is bounded to the north and south by regional tectonic features i.e. Main Central Thrust (MCT) and Main Boundary Thrust (MBF), respectively. The former separates the meta sedimentary sequence of Lesser Himalaya to the North from the Crystalline rocks of Higher Himalaya and the latter disjoins the physiographic unit from the molassic sediments of Siwaliks, in the south (Fig-2).

The Lesser Himalayan sequence around Tehri dam project exposes rocks belonging to Jaunsar Group (Chandpur phyllites and Nagthat quartzites), Krol Group (Blaini - Shales & Diamictites, Krol - Limestone & Dolomites, Tal - Chert, Phosphorite & Quartzites) and Garhwal Group (Quartzites, Limestone & Dolomite and Metabasic intrusive).

The most prominent tectonic feature in the immediate vicinity of Tehri dam (5 Km NNE) is the Srinagar Thrust which separates the rocks of overlying Garhwal Group (Older) from the underlying Jaunsar Group (Younger). It is a longitudinal linear feature following the regional Himalayan trend i.e. NNW – SSE.

PLATE-

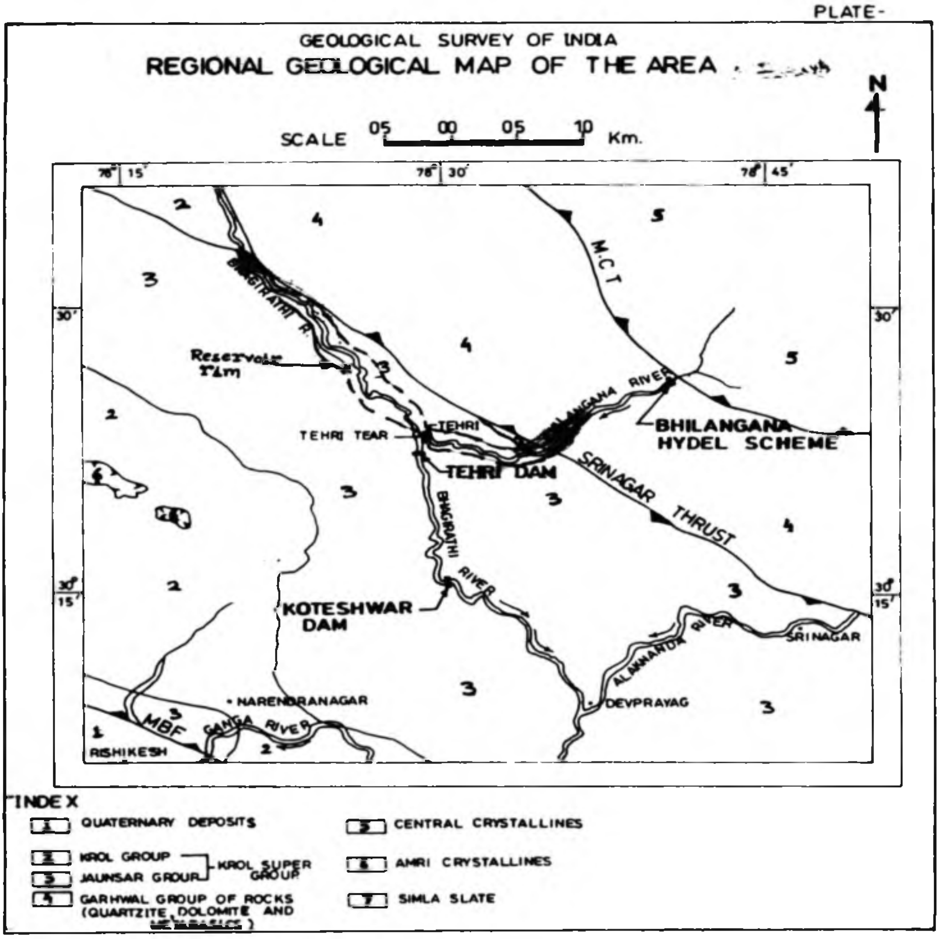


Fig. 2. Regional; Geological Map of the Area

## Geology at the Site

The rocks in the Tehri gorge occupy one limb of southeasterly plunging anticline, the other limb outcrops upstream of the Tehri gorge and is cut by Tehri tear further towards the northeast. The rocks exposed at the Tehri dam site form an uniterrupted sequence of Chandpur phyllites (Proterozoic-III) which have variable proportions of argillaceous and arenaceous constituents. Considering the rhythmicity of intercalated bands of arenaceous and argillaceous material and varied degree of tectonic effects in them, the phyllites at the dam site have been classified into mainly four lithological variants.

i) Phyllitic quartzite massive (PQM)

ii) Phyllitic quartzite thinly bedded (PQT)

iii) Quartzitic phyllite (QP)

iv) Sheared/schistose phyllite (SP)

## Right Bank Shaft Spillways

Right bank shaft spillways were planned to join the diversion tunnels (T-3 & T-4) at 450 chainage from the inlet. The crest of these 230m deep ungated shafts has been provided at El 830.2m and they have been designed to operate automatically as soon as the reservoir level reaches El 830.2m. The intake of these shaft spillways is funnel shaped structure with uncontrolled circular weir of 34.0m dia. Vertical shafts join eccentrically (by 6m) with the tunnels at lower level, through a swirling device, which imparts a swirling motion to the flow in the tunnels for energy dissipation. Each shaft spillway on the right bank can pass a rated discharge of 1950 cumecs.

These shafts were provided with the 9m diameter de-aeration ducts to release the air separated from the air-water mix. The de-aeration ducts were joined with the main shafts with the reverse curve. At 160m below the surface nearly 26m long and 11m deep separation chambers were constructed ahead of the de-aeration ducts (Fig-3).

Fig. 3. 3D View of Right Bank Shaft Spillways

The excavation of T-3 shaft (excavated dia 14m) was taken up by widening the pilot shaft from El±820m. The excavation was continued in circular section from El±820m to El ±614m below which the excavation of the main shaft was taken up concurrently with the de-aeration duct connected to it. Excavation of T3 duct (Excavated dia 9m) was started subsequent to the excavation of the main shaft for the initial part otherwise it preceded pari-passu with the main shaft. The function of the duct is to give vent to the air, separated in the separation chamber, from the air-water mix in the shaft spillway.

## Geological Observations

During the excavation of the shaft and de-aeration duct, different bands of PQT, PQM and puckered/ sheared PQT rocks were encountered (Fig —), which accounted for nearly 13%, 60% and 27% respectively through the logged length of the two openings between El±820m and El±614m (Fig-4). Excavation of the shaft and duct was done with ease in PQM and PQT whereas sheared and puckered PQT posed a lot of problems.

The bedding plane was found dipping at 48-65°/N 195-220 whereas the primary foliation plane is dipping 35-45°/N160-180.The details of prominent joints are given in Table 1.

A number of shear zones of various orders were delineated in the shaft and their details are given in the table below. The major L

**Table 1:** Details of joint sets in T-3 shaft and De-aeration duct (RBSS)

| Joint set | Dip amount | Dip azimuth | Spacing (Cm) | Continuity (m) | Roughness | Remarks |
|---|---|---|---|---|---|---|
| J1 | $40^0$-$60^0$ | N190-220 | 5-100 | 5 | Smooth planar | Bedding (S0) joint |
| J2 | $35^0$-$40^0$ | N165-185 | 20-30 | 3-4 | Smooth planar | Foliation (S1) joint |
| J3 | $35^0$-$84^0$ | N270-355 | 5-100 | 0.80-5 | Rough Undulating to Mod. Smooth planar | Shearing effect at places, making wedges with J1 and J2 joints |
| J4 | $35^0$-$73^0$ | N010-080 | 2-80 | 0.50-6 | Rough Undulating to Mod. Smooth planar | Quartz vein filled, making wedges with J1 and J2 joints |
| J5 | $30^0$-$82^0$ | N110-180 | 2-80 | 0.50-3 | Rough Undulating to Mod. Smooth planar | Random joints |

shears, which intersected the N330 axis ($C_L$ of the shaft) were noticed at El 801m, 725m, 692.50m and 639m. A zone of multiple shear seams was recorded between El 656m to El 624m which was well projected in the geological sections prepared by GSI earlier and it warranted a very cautious approach in sinking the shaft section through it.

## Rock Mass Parameters:

For major part, the shaft and the duct were excavated through fair rock mass i.e. Q values ranging from 4 - 8 and RMR 44 – 57 however at lower levels poor rock mass with Q values as low as 1.5 (in the shaft) and 1.33 (in the duct) was intersected.

**Critical Reaches:** During the excavation and widening of the shaft and duct few critical reaches were identified and they are discussed below.

- Establishing the collar beam/portal of the shaft was a problematic task in view of the poor and highly jointed rock mass in the initial reach i.e. between El± 820m to El± 812m.
- Because of the reverse curve geometry, the junction of the main shaft with the de-aeration shaft was critical since the bridging action of the circular section was completely missing.
- The junction of the main shaft with the ILO at El± 700m was very critical and it created lot of problems during the excavation of sloping glacis of ILO.
- At the location of separation chamber i.e. between El 661m to El 649m the longest dimension of the cavity became 49m (14m shaft + 9m duct + 26m separation chamber) and excavation of this huge cavity at a depth of 160m from the surface was critically reviewed and shaft sinking was done with utmost care and continuous monitoring.
- The swirling device area i.e. the junction of the main shaft with the diversion tunnel between El±620m and El±603m was also very critical. This section of the shaft on the right side of the centre line of the main shaft (facing the flow direction) was cut in half parabolic shape and this peculiar geometry lead to toe cutting of the bedding/foliation joints and created overhang section which was very difficult to execute and stabilize.

## Geotechnical Problems:

- Highly puckered, jointed, silicified and sheared rock mass was encountered between El± 659m - El± 614m and the condition was worsened by the intersection of multiple shear seams in this reach. As such, the rock mass in this reach was assessed as poor (Q value 3.33-4.5 and 1.67-3.48 between El±649m and El± 638m). Some of the shear zones were charged with water, which significantly reduced the shear strength of rock mass.

- The existence of poor rock mass between El± 661m to El± 649m and vertical load of the rock column (exceeding 150m) led to problem of wall convergence along the longest axis of the cavity which was manifested in the form of bending, buckling and uplifting of the ribs noticed at different levels. Bending was also noticed in the horizontal cross steel studs provided to join the steel ribs across the reverse curve area.
- The section of the shaft between El± 693m to El± 686m, just below the ILO junction, was subjected to loading during the excavation and the rock mass was also charged with water which resulted in the failure of rock mass from the area. The triggering factor for the failure seem to be the concentration of heavy pore water pressure around the shaft caused due to heavy rains. Reduction in the shear strength due to lubrication led to the dislodgement of rock mass, which fell on to the slip form at El±678m, despite the support provided.
- A 10 m long and 10cm wide linear crack was noticed on the right side wall of T3 duct at the junction with the main shaft (at El±690m). There was high stress concentration near the junction with the duct. Excavation for lowering the floor of ILO aggravated the stress conditions near the junction and because this section of the shaft and the duct was not lined, it led to de-stressing and failure of mass.
- Repeated fall of material was noticed between El ± 618m to El ± 631m, in the swirling device area which also posed a threat to the safety of the ring beam at El± 631m, above which the concrete lining of the shaft was in progress.

## Stabilisation Measures in T-3 Shaft Spillway

- From El ± 812m to El± 662m, the rock bolting (L-5m; dia 25mm; @1.5m c/c) and chain link shotcreting was provided as the main stabilisation measure (as per design specifications) with steel rib in few critical reaches. Considering the squeezing and wall convergence, the support system was revised by increasing the bolt length from 5m to 7m with steel rib support at close intervals.
- In the de-aeration duct close spaced steel rib support was recommended from El± 662m downwards, considering the load of vertical rock cover (exceeding 150m) and the wall convergence which was manifested by the bending/buckling of the ribs and cross studs provided at the junction with the main shaft.
- Tape extensometers were installed to monitor the extent and rate of convergence, if any, taking place in the cavity, during the excavation and during the time gap between the excavation and lining.

**Table 2:** Major Shears exposed in T-3Shaft (RBSS)

| Sl No | Dip (°) | Azimuth | Clay thickness (cm) | Affected Zone (cm) | Filler | Remarks |
|---|---|---|---|---|---|---|
| 1 | 42-55 | N 185-220 | 12-14 | 15-25 | Clay+crushed Rock+quartz vein | - |
| 2 | 55-58 | N 205-215 | 10-13 | 20-35 | Clay+crushed Rock+quartz vein | Puckering, silicification along shear, converts into minor shear at El 732m |
| 3 | 38 | N185 | 12-18 | 20-28 | Clay+crushed Rock+quartz vein | Converts into minor shear at El 689m between N240- and N330 direction |
| 4 | 58-60 | 205-220 | 10-17 | 20-35 | Clay+crushed Rock+quartz vein | Puckering along shear, converts into minor shear at El636m towards right of N240 direction |
| 5 | 52-60 | 200-215 | 10-12 | 30-50 | Clay+crushed Rock+quartz vein | Converts into minor shear at El 655m between N060 and N150 direction |

- Controlled blasting with minimum pull and dummy holes in the periphery was advised to avoid the over-breaks and wedge failures.
- The modification work at the sloping glacis of ILO was completed to designed level with steel ribs and rock bolts in a phased and segmental manner. Extension of steel columns for existing ribs of ILQ along with installation of 10m long rock bolts @2mc/c staggered on the walls and drainage holes @ 3m c/c on the ILO floor was also undertaken.
- Additional support system in the shaft reaches El 678m to El 716m was provided to ensure the stability of the rock mass, till such time the shaft was concrete lined.
- Modification in the swirling device area was completed by undertaking the excavation in segments and by supporting the upper sections with longer rock bolts (L-8m) and shotcreting.
- The shaft and the duct were ultimately provided with concrete lining of M30 and M60 strength.

## T-4 Shaft Spillway (RBSS)

Excavation and subsequent widening to the full dia of 14m, was taken up from the platform at El± 820m and continued downwards. In addition, the excavation was also started from the adit at El± 750m, in the downward direction to expedite the pace of work. This shaft has also been provided with the de-aeration duct, separation chamber and swirling device, conforming to the hydraulic design and is also designed for separating the air-water mix. The excavation T-4 duct was also undertaken from El±820 m and the duct has pierced through different bands of PQT, PQM and purckered /sheared PQT rocks.

## Geological Observation

The shaft and de-aeration duct pierced through different rock types viz. PQM (4.7%), PQT (51%) and highly jointed/puckered, sheared and deformed PQT (44.3%) rock mass. The bedding plane was found dipping at 45-65$^0$/N 195-220 and the foliation plane dipping 38-45$^0$/N160-185.The prominent joints details are given in Table -3.

A number of shear zones of various orders were delineated in the shaft and their details are given in the Table-4. The most significant of all, was the major diagonal shear (D3 shear of the block tectonic model) is dipping at 60-70/N330-345 (clay 10-15 cm; Az 1m ; clay and crushed rock). This major shear was encountered at El± 820m (on the face between N125- N035 axis) and continued down to El± 788m, beyond which it crossed the main shaft. The other major shears (clay >10cm), which intersected the N240 axis ($C_L$ of the shaft) were noticed at El 805m, 775m and 723m respectively.

## Rock Mass Parameters

In the upper reaches, the rock mass was comparatively better (Q values 5-8) whereas at lower levels, poor rock mass with Q values as low as 1.5 was intersected. The rock mass parameters for the entire shaft section are given in table-5.

**Critical Reaches :** Following reaches were assessed as critical in T-4 shaft and duct.

- The upper part of the shaft and duct i.e. between El± 820m - El± 790m was assessed to be critical because of the major diagonal shear (D-3 shear) and the poor/deformed rock mass associated with it.
- The junction of the main shaft with the de-aeration shaft was viewed as critical, because at this location the shaft section has a reverse curve and bridging action of the circular section was completely missing. Due to stress concentration at reverse curve portion, the rock mass was under high stress condition.
- The junction of the main shaft with the adit at El± 750m was also critical.

- The longest dimension of the cavity between El±661m and El±649m became 49m (14m shaft + 9m duct + 26m separation chamber). Excavation of this huge cavity was critically reviewed and shaft sinking warranted utmost care and continuous monitoring.
- The swirling device area i.e. the junction of the main shaft with the diversion tunnel between El 620m to El 603m was also very critical because of the shape and the poor geological conditions.
- Modifying the swirling device area and the excavation and lining of the invert of the diversion tunnel below it was a problem during excavation.

## Geotechnical Problems

- The excavation of the initial portion, between El± 820m- El± 790m posed problems during its widening to full diameter. Failure of rock mass along D-3 shear was recorded at different locations, during this excavation.
- Planar failure along major longitudinal (L) shear was recorded between El± 747 and El± 740m, at the junction of the main shaft and the duct (reverse curve portion) and it was attributed to the existence of poor/sheared rock mass in the high stress area.
- Formation of a 12m long 4-5 m deep cavity on N 215 axis (of the shaft) from

**Table 3:** Details of joints exposed at T-4 shaft (RBSS)

| Joint set | Dip amount | Dip azimuth | Spacing (Cm) | Continuity (m) | Roughness | Remarks |
|---|---|---|---|---|---|---|
| J1 | $30^0$-$68^0$ | N190-230 | 3-10 | 2-4 | Moderately Smooth | Bedding (S0) joint |
| J2 | $28^0$-$45^0$ | N155-195 | 5-15 | 1-3 | Moderately Smooth | Foliation (S1) joint |
| J3 | $40^0$-$85^0$ | N240-355 | 2-60 | 0.20-3 | Rough Undulating to Mod. Smooth planar | Calcite coating, quartz vein filled, enechelon pattern forming wedge with J1 and J2 |
| J4 | $20^0$-$85^0$ | N005-090 | 2-70 | 0.20-5 | Rough Undulating to Mod. Smooth planar | Iron stained, quartz vein filled, high frequency, forming wedge with J1 and J2 |
| J5 | $50^0$-$80^0$ | N090-155 | 20-100 | 1-3 | Rough Undulating | - |

**Table 4:** Major shears exposed in T-4 Shaft (RBSS)

| Sl No | Dip ($^0$) | Azimuth | Clay thickness (cm) | Affected Zone (cm) | Filler | Remarks |
|---|---|---|---|---|---|---|
| 1 | 55-70 | N 330-005 | 10-30 | 100 | Clay+crushed Rock+quartz vein | Starting at El820m and goes outside of shaft at El 788m, water dripping |
| 2 | 45 | N 205 | 12-15 | 20-30 | Clay+crushed Rock+quartz vein | Converts into minor shear at El 816m |
| 3 | 40 | N215 | 12-13 | 20 | Clay+crushed Rock+quartz vein | - |
| 4 | 50 | N210 | 10-11 | 20 | Clay+crushed Rock+quartz vein | - |
| 5 | 30-45 | N180-220 | 10-12 | 20-22 | Clay+crushed Rock+quartz vein | Branching into two minor shears at El 805m |
| 6 | 50-55 | N190-195 | 13-18 | 20-30 | Clay+crushed Rock+quartz vein | Converts into minor shear at El 782m |
| 7 | 40 | N050 | 10-12 | 40-50 | Clay+crushed Rock+quartz vein | Extends from El 759m to El 755m, water dripping |
| 8 | 52-64 | N200-220 | 10-14 | 20-22 | Clay+crushed Rock+quartz vein | Puckering, silicification, converts minor shear at El 730m left of N125 direction |

**Table 5:** Rock mass parameters in T,-4 shaft spillway

| Elevation (m) | Rock mass Parameters |
|---|---|
| 820-728 | Q=5-8,RMR=44-57 |
| 728-706 | Q=4-7,RMR=45 |
| 706-693 | Not available |
| 693-685 | Q=1.5-2.5, RMR =20 |
| 685-664 | Not available |
| 664-614 | Q=2.5-4.5, RMR=25- 30 |

El±725m to El±712m was a result of wedge failure/over break because of the intersection NE/NW joints with the bedding and foliation joints.

- Convergence on the walls of the shaft and duct was anticipated in the reach between El± 661m- El± 649m where the longest diameter of the cavity increased to 49m (seperation chamber reach).
- The load of vertical rock column (exceeding 150) below El± 670m was guiding factor for advancing the excavation.
- Rockmass between El± 674m to El± 614m was highly puckered and was intersected by multiple shear seams.
- Wedge formation was commonly noticed throughout the depth of the shaft.
- Water dripping was recorded along D-3 shear.

## Stabilisation Measures

- Rock bolts L-5m Ø 25mm @ 1.5m C/C with chainlink shotcreting was provided as the main stabilisation measure for the main shaft. In the duct portion, for the upper part, from El±820m to El±712m, rock bolts (L-4.8m; dia 25 mm; @ 1.5m c/c) and chain-link shotcreting were provided as the main stabilisation measure together with steel ribs @ 75 cm c/c in critical reaches.
- In the areas where failure took place along D-3 shear, concrete back failing was provided.
- The support system was reviewed for the reach below El± 712m rock bolts (L-7; @ 1.5m c/c; Ø 25 mm) for the full section of the shaft were recommended.
- In the de-aeration duct close spaced steel rib support was recommended from El± 712m downwards, in view of the load of vertical rock cover (exceeding 150m) and the wall convergence which was manifested by the bending/buckling of the ribs. Cross studs provided at the junction with the main shaft.
- In the cavity portion between El± 725m - El± 712 m, spot bolting and shotcreting was done as the immediate rock stability measure. Subsequetly an arch of reinforced concrete was provided at El± 725m and the open spaces were backfilled with concrete.
- Additional grout holes were provided in this area to fill the open spaces wherever left between concrete and rock.
- Considering the excavation of separation chamber, anticipating wall convergence due to the enlarged dimension (49 along longest axis) added and the vertical loading of rock column (below El± 661m), continuous steel rib support was provided @ 75cm C/C.
- In the swirling device area, restoration of rock plug was done by a beam of concrete blocks 2m x 2m with a thin film of sand in between which acted as a toe support to the rock column. The modification of the invert of the diversion tunnel was taken in segmental manner and only after completing the excavation and lining up to the left SPL (facing the flow direction), the excavation of half parabolic portion of swirling device was taken. The entire work was completed without any problem.
- Drainage holes were provided in the water dripping areas and in wet zones to release the pore water pressure.
- Finally the shaft and the duct has been lined with a concrete of M30 and M60 strength.

## Conclusions

- The gigantic Tehri dam has a mammoth reservoir back of it having the live and gross storages of 2615 Million Cum and 3540 Million Cum respectively.
- The spillway system can cater to a flood of 15540 cumecs (1:10,000 years) whereas the two shaft spillways on the right bank i.e. T-3 and T-4 can pass a routed discharge of 1950 cumecs each.
- The right bank shafts are roughly 230m deep and they are intricately designed complex structures. The shafts (14m dia) are attached to de-aeration ducts (9m dia) throughout their length and the junction between the two has reverse curve geometry. Further, at a depth of 160m from the surface the ducts are joined by 26m long separation chambers.
- The shafts and de-aeration ducts pierced through fair and poor rock mass along their length and excavation of the complex structures in this geological regime was a challenging task. There was high stress concentration in the junction area of the shafts and ducts and influence of reverse curve geometry aggravated the conditions.
- During the early stages of construction some of the reaches like junction of main shaft and the de-aeration ducts, junctions of ILO (for T-3) and adit -750 (for T-4), separation chamber locations and swirling device areas were assessed as critical in view of the structural geometry and poor geological conditions. The apprehensions were corroborated by the failures during the progressive excavation as they were mostly concentrated in the reaches mentioned above. However major failures were averted by revising the sequence of excavation and support system well in advance of the excavation.
- Pattern rock bolting (L-5m Ø 25mm @ 1.5m C/C) with chain link shotcreting (two layers of 50:50) was advised as the main stabilisation measure whereas steel ribs were recommended in critical reaches. The vertical load on fair to poor grade rock exceeded after a depth of 150m from the surface, therefore deeper rock bolts (L=D/2 i.e. 7m) were recommended in the shafts.
- The modification work at the sloping glacis of ILO was undertaken in segmental and phased manner and the steel column support was extended concurrently with the excavation on the wall sections.
- Continuous steel rib support @ 1mc/c was provided between El± 661m and El± 649m, in the separation chamber reach in view of the enlarged diameter of the cavity (49m) and the poor geological conditions.
- Excavation at the swirling device areas was accomplished in a segmental manner and by providing concurrent support with the deeper rock bolts and shotcreting.
- The example of the right bank shaft spillways at Tehri dam thus amply demonstrates that even intricately designed complex structures of large size, located in a fragile geological regime and poor rock mass conditions, can be executed without facing major problems/failures provided the geological conditions and problematic reaches are well anticipated and the support system is critically reviewed as the need be.

## Bibliography


1. Explanatory note for the geophysical investigations in Tehri dam core area (1990) : Unpublished Report Hydro Project V/C Technoprom export, Moscow, pp 1-19.
2. Guliaev, Yu. P. (1992) : Right bank. The shaft spillways. Engineering geological estimation, Tehri dam project. Report No. 2B-950/16.12.92. Technoprom export. Hydro Project, Moscow.
3. Mikhailov, A.D. and Artemiev, V.A. (1990) : Explanatory note for the results of geophysical investigations in the Bhagirathi river bed, Tehri. Unpublished

Report, Hydro Project, Moscow.

4. Narula, P.L. and Shome, S.K. (1989) : Geological and tectonic inputs for seismotectonic assessment of Tehri area. Unpublished Report, Geological Survey of India, December 1989.

5. Nawani, P.C., Rawat, J.S., Sanwal, R. and Khanduri, H.C. (1989) : A report on engineering geological investigations of the right bank of Bhagirathi river, for proposed spillway structure, with special reference to rock mass structure and interblock tectonic, at Tehri dam site, Tehri (Garhwal) U.P. Unpublished Report, Geological Survey of India, Special Investigations F.S. 1987-'88. •

6. Nawani, P.C., Rawat, J.S., Pangtey, T.S. and Sanwal, R. (1989) : A report on engineering geological investigations of stilling basin area at Tehri dam site. Unpublished Report, Geological Survey of India, Special investigation F. S. 1988-'89.

7. Nawani, P.C., Sanwal, R. Khanduri, H.C. and Rawat, J.S. (1989) : Block tectonic model of Tehri dam site, Tehri district, U.P. Published in Geological Survey of India Records, Vol. 122, pt. 1989.

8. Nawani, P.C., Rawat, J.S., Sanwal, R. and Khanduri, H.C. (1990) : Kinematic check and stability assessment of the proposed cut slopes of the chute spillway structures, Tehri dam project, India, Published in 6th International IAEG Congress, Netherlands, 1990, pp 2251-2256.

9. Nawani, P.C., Rawat, J.S. Pangtey, T.S., Sanwal, R. and Khanduri, H.C. (1990) : Engineering geological investigations of the right abutment for the design of spillway structures at Tehri dam site, Tehri Garhwal district, U.P. Published in Geolcgical Survey of India Records, Volume 123, pt. 8, 1990.

10. Second stage consultancy of spillway structures layout drawings and report on studies and analyses for supporting the proposed designs of spillway structures for the Tehri project. Hydro Project Institute, Moscow, 1989.

11. Third stage consultancy of spillway structures layout drawings and report on studies and analyses for supporting the proposed designs of spillway structures for the Tehri Project. Hydro Project Institute Moscow, 1991.

12. Nawani P.C. (1994) : Foundation Evaluation of Tehri Dam vis-à-vis Rock mass structure. Ph. D. Thesis, HNB Garhwal University.

13. Khanduri, H.C., Bahuguna, H., Bhattacharjee, N.R, and Dangwal, D.P. (2005) : Progress report no.41, On the construction stage Engineering Geological investigation of Tehri Hydro Power Complex, Tehri Garhwal district, Unpub. GSI report, F.S. 2003-2004.

14. Khanduri, H.C., Bahuguna, H., Biswapriya A.; Dangwal, D.P. and Chakraborty I.: Progress report no.42, On the construction stage Engineering Geological investigation of Tehri Hydro Power Complex, Tehri Garhwal district, Unpub. GSI report, F.S. 2004-2005.

15. Khanduri, H.C., Bahuguna, H.; Dangwal, D.P. and Chakraborty I.: Progress report no.43, On the construction stage Engineering Geological investigation of Tehri Hydro Power Complex, Tehri Garhwal district, Unpub. GSI report, F.S. 2005-2006.

16. Nawani, P.C., Sanwal, R. Khanduri, H.C., Bahuguna Harish and Dangwal D. P. (2006) : Tehri Dam Project: A Geotechnical Appraisal; Geological Survey of India, Bulletin Series B No. 62, Govt. of India Publication, ISSN: 0445 - 622X.

17. Khanduri, H.C. Bahuguna Harish and Nawani, P.C. (2007) : Geotechnical Aspects of Spillway Structures of Tehri Dam; Water and Energy International; Special Issue on Tehri Dam Project; Vol. 64 No.1; Central Bureau of Irrigation and Power, New Delhi; pp 84 – 91.