Treatment of a Highly Deformed Rock Mass Zone in the Control Gate Shaft area, Tehri Dam Project, District Tehri Garhwal, Uttarakhand

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Abstract

This prestigious multipurpose mega-hydroelectric project envisages generation of 2000 MW of hydroelectricity, in two stages, by constructing a 246.2m high (from deepest foundation at El.593.30m) earth and rock fill dam, at Tehri, across river Bhagirathi in Uttarakhand.

The construction of four control gate shafts viz., CGS-1, CGS-2, CGS-3 and CGS-4 was taken up from the platform (at El ± 840m) on the left bank. These 110m deep shafts of excavated dia of 13m between El± 840m and El 830m and 11m below El 830m are connected to the four HRT at El ±729m. The shafts 1, 2 & 3 were excavated without encountering major geotechnical problem and they encountered bands of phyllitic quartzite massive (PQM) and phyllitic quartzite thinly bedded (PQT) rocks, dipping 52-60°/205-225.

This paper mainly deals with the excavation and stabilization of vertical shafts in a deformed rock mass zone. Excavation of CGS-4 through a 35m wide zone of deformed/tectonic mass was a challenging task which was accomplished by modifying the sequence of excavation and adopting innovative methodologies viz multiple drifting and sinking of pile shafts in the deformed mass. Stabilisation of this mass was also crucial as the slopes on the upstream side were coming in the draw down level of the reservoir.

Introduction

Tehri dam project envisages generation of 2000 MW of hydroelectricity in two stages of 1000 MW each viz stage-i Hydropower Plant (HPP) and stage-II Pump Storage Plant (PSP). There are four head race tunnels (HRT), for either stage power plant, which bifurcates into eight penstocks. The power intake structure has been constructed at El±720m and its top platform is at El±745m.

Excavation of CGS-4 through a wide zone of deformed/tectonised mass was a critical activity. Stabilisation of this mass was crucial as the slopes on the upstream side were coming in the draw down level of the reservoir and the two control gate shafts were to be excavated through the deformed zone. The slopes occupied by deformed rock mass, between El ± 745m and El ± 840m, have been provided with concrete cladding on the surface along with a system of pile shafts. The excavation of CGS-4 was undertaken by making lateral multiple drifts in the deformed zone and backfilling them with high strength concrete. A number of pile shafts were sunk at different levels between El ± 790m and El ± 840m and in the process the deformed mass was replaced by high strength concrete.

Regional Geology

The Tehri dam project area lies well within the Lesser Himalaya which is bounded in the north and south by regional tectonic features i.e. Main Central Thrust (MCT) and Main Boundary Thrust (MBT), respectively. The former separates the meta sedimentary sequence of Lesser Himalaya from the Crystalline rocks of Higher Himalaya and the latter disjoins the Lesser Himalayan rocks from the molassic sediments of Siwaliks, in the south.

Geological Survey of India, Dehradun

As per the generalised stratigraphy of the Main Himalayan Belt the rocks of Lesser Himalaya are exposed around Tehri dam project area and they are divisible into two major tectono-stratigraphic units- the Krol Super Group (Proterozoic III to Eocene) and the Garhwal Group (Proterozoic II). The rocks of the Garhwal Group (Sedimentary cycle-II of Ravishanker et al, 1989), directly come in contact with the rocks of relatively younger Krol Super Group, which also includes Jaunsar Group of rocks (Chandpur phyllites and Nagthat quartzites) along a major high angle reverse fault known as Srinagar Thrust.

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 fault, further towards the northeast. At least two generations of folding are clearly discernible in the area, of which the earliest tight and nearly isoclinal, overturned folds of pre-Tertiary time are well recorded in the area. Minor folds/puckers plunging at 15º-30º towards southeast represent second generation of folding and the broad open folding of Tertiary time has resulted into abnormally low dipping beds at the higher contours and their gradual steepening at lower elevations.

The folded metasedimentary rocks, occupying one limb of southeasterly plunging anticline, exposed at the Tehri dam site form an uniterrupted sequence of Chandpur phyllites (Pt 3 Proterozoic-III) which have variable proportions of argillaceous and arenaceous constituents. Based on few characteristics like rhythmicity of intercalated bands of arenaceous and argillaceous material and varied degree of tectonic effects, the phyllites at the dam site have been classified into mainly four lithological variants.

Phyllitic quartzite massive (PQM)
Phyllitic quartzite thinly bedded (PQT)
Quartzitic phyllite (QP)
Sheared/schistose phyllite (SP)

Control Gate Shafts (CGS)

Four vertical control gate shafts (Excavated diameter 11m) have been constructed from El±840m. These 110m deep shafts (CGS1, CGS2, CGS3 & CGS4) join the four HRT'S at a distance of 128.80m, 129.40m, 137.90m and 181.80m respectively from the location of intake structures. Through these four shafts, the control gates have been lowered to the four HRT'S and the hoisting arrangements are located on a platform developed at El±840m.

Geology of CGS Area

Predominantly phyllitic quartzite-thinly bedded (PQT) was exposed above HRT-2, which was also seen between HRT-1 and HRT-2, and further towards the downstream part. Phyllitic quartzite-massaive (PQM) was exposed on the slopes above HRT-1 and in the downstream. Highly deformed and tectonised variants of PQT were exposed beyond upstream extremity of HRT-2 whereas thin bands of quartzitic phyllite were noticed within the PQM rocks, in the downstream part.

The rock mass condition in the area u/s of control gate shaft CGS 2 and d/s of CGS 4, more precisely on CGS 3 location, was found to be very poor, influenced by numerous major/minor D & L shears at different levels. However the rock mass condition d/s of CGS 2 and in CGS1 area was fair to good.

Four prominent joint sets were recorded in the area which were dipping i) 50º-72º/N195-220 (bedding joints), ii) 36º-54º/N160-190 (foliation joints), iII) 45º-85º/N285-325 (northwesterly dipping joints) and iv) 65º-81º/N015-060 (northeasterly dipping joints). The intersection of northwesterly dipping joints with bedding/foliation joints has caused frequent local wedge failures. Close spacing of northeasterly dipping joints was characteristically well displayed in the deformed zone, close to diagonal shear. Minor shearing effect was also noticed along these joints.

A total of sixteen longitudinal (L) shears dipping at 42º-70º/N170-225 and one diagonal shear dipping at 80º/N052, with variable thickness of clay gouge ranging from less than 2cm to more than 10cm, were delineated in the area. Of which the diagonal shear, D_3 a major one (80º/N052) recorded in the upstream reaches, had rendered the rock mass highly shattered and deformed. The D3 shear also marked the boundary between tectonised PQT (SP) and PQT.

Deformed Rock Mass Zone

During the course of geological investigations a 35m wide and extensive deformed/tectonic zone was delineated, which occupied a huge structural wedge confined within two major shears one longitudinal shear (L-11) and the diagonal shear (D-3) between El±910m - El±835m on the cut slope and on the platform at El 840m (CGS area). The zone extended from the upstream of HRT2 and d/s of HRT4 alignment with its maximum depth (+40m) anticipated at the location of HRT3 shaft, based on the rock mass condition encountered during excavation of the pilot shaft from HRT3 .

The sheared phyllite formed a substantial proportion of the deformed zone mentioned above, therefore it deserves a special mention in terms of lithological characteristics.

Sheared Phyllite (SP)

The sheared phyllite (SP) is the tectonised variant of PQM, PQT and QP rocks; and they are developed mostly in the vicinity of major shear zones and form weak zones charactrerised by mylonites, phyllonites, talcose, highly fissured rocks, crumpling and intensive schistosity.

Excavation in Deformed Rock Mass Zone

In view of the extremely poor geological conditions and the movements noticed in the deformed rock mass zone the excavation of the platform at El±840m, the CGS3&4 and the slopes above and below the platform was a daunting task, thus as a corollary, the excavation in the CGS area was meticulously planned and executed in a phased and segmental manner.

Geotechnical Problems

During the excavation, geotechnical problems of different natures were encountered at different locations in CGS area and they are being discussed separately.

i) Slopes Above CGS Platform

The excavation of the slopes was started from El±910m the location of the platform for HRT control gate structures at El±840m on the left bank, as per the design considerations. The rock mass in general varied in the grade of weathering from W1 – W4 on the higher slopes to W1 – W2 on the lower slopes.

Formation of multiple structural wedges at different levels was noticed and all these wedges were limited by the major wedge defined by a major D shear (D3) and major L shear (L11) of the block tectonic model of Tehri dam site. Intersection of NW dipping joints with S0/S1 joints caused frequent wedge failures in the area.

Stability of these slopes was a prerequisite for the development of the platform required for lowering the control gate shafts and also for their operation.

ii) CGS Platform

The part of the platform in the foreground of CGS-3 and between CGS2 - CGS3 and CGS3 - CGS4 was occupied by overburden mass which substantially constituted of the slumped rock mass/deformed rock mass zone. The entire thickness of this weak zone was about 40-42m of which the deformed zone formed by the intersection of D-3 and L-11 shears was 32m. The contact of deformed zone and fresh bed rock was recorded at El±798m in the CGS – 3.

Few tensional cracks in arcuate pattern developed in the foreground of CGS-3 which were attributed to the movement, in the overburden and the slump mass zone between El 840m and 805m, after the winter rains in 1998 (late Feb to early March). The widening of 20cm and subsidence of the order of 40-50cm was noticed along the peripheral cracks. The slope movement was attributed to the toe cutting of the OB/slump mass during excavations for achieving the designed slope coupled with water circulation along slip surfaces. A scheme of geodetic monitoring was planned in the area and the measurements taken indicated that some of the reference points on the ground have moved downwards i.e. towards valley side by 30 cm.

Strengthening of this platform was required because the hoisting arrangements for the heavy control gates were to be made on it.

iii) CGS 3 & CGS 4

During the course of excavation of CGS 3&4, there was movement in the deformed rock mass which lead to formation of a big cavity and damaged the rib support in shaft number 4. Huge subsidence was observed on the platform (El ± 840m), between the locations of CGS-3 and CGS-2, due to mobilisation of the deformed mass, confined between two mega diagonal and longitudinal shears - D3 and L11, into CGS-4. The movement was along the D3 shear and other sympathetic diagonal shears.

The excavation of CGS-4 was done in a phased manner and the muck was removed from the top (El ± 840m) to a depth of 1m at a time. It was found that about 60% periphery (circumference) of the shaft was in good rock i.e. unaffected by the D-3 shear.

The above problems warranted a cautious approach in excavating the CGS4 through the deformed zone as there were high chances of big collapses from the shaft walls. The excavation sequence was thus revised.

iv) Slopes Below CGS Platform

The hill slopes in the HRT intake area, are moderate and have an average slope of 40 - 42°, between the control gate structure site and the portals of HRT (El + 720m). Topographically two westerly sloping spurs bound an intervening pronounced linear geomorphic depression which might have formed as a result of wedge failure caused by intersection of two major shears L-11 (dipping N280) and D3 shear dipping N355-022 direction. The linear depression was occupied by old slide debris and HRT-3 alignment falls with in this wedge failed depression confined between El 840m and El ± 767m.

The slopes above head race tunnels (HRTs) intake area from El ± 720m to El ± 840m were geotechnically assessed in detail and the vulnerable areas identified below the level of platform of HRT control gate (El ± 840m).

Considering the fact that the slopes below El±830m will come under submergence level of Tehri reservoir, the stability of these slopes became paramount.

Treatment of Deformed Rock Mass Zone

It was engineering compulsion that despite the extremely poor geological conditions certain vital structures were to be constructed in the area occupied by the deformed rock mass zone. However, before executing the designed slopes and the structures, proper understanding as regards to the nature and extent of the deformed zone and the tendency of movement in it was acquired. Different treatments were planned for the deformed zone, taking cognizance of the structural requirements on the slopes above and below the CGS platform and for the control gate shafts which included measures like grading of the slopes, rock slope stabilization, strengthening of the platform, multiple drifting in the CGS and pile shaft treatment.

i) Grading of the Slopes

The slopes between El ± 910m and El ± 840m were occupied by overburden and deformed mass therefore it was advised to grade them to a flatter angle not exceeding 1:1 (H: V). The rock bolting was attempted but did not succeed in the deformed rock mass, the surface was then treated with wire mesh-shotcrete leaving panels at constant intervals (2m) for surface draining. Similar treatment was given to slopes below El ± 890m.

It was later found that the slopes in the deformed zone did not respond well to the wiremesh-shotcrete treatments and the treated slope below El ± 890m failed. It was advised to decrease the slope of cut faces, erect a retaining wall in the deformed zone and increase the bench width at El ± 856m, for strengthening the slope stability. A cut off at the location of water recharging in the up slope (El ± 910m) was also provided.

ii) Rock Slope Stabilisation

Cut slopes occupied by fair to good rock PQM/PQT were provided with rock bolts (8-10m) followed by reinforced shotcrete. Drainage holes were provided on the slopes above El ± 840m at wet locations. Excavation of cut slopes below El ± 840m, particularly in the deformed zone confined within the area extended from u/s of HRT2 to d/s of HRT4, undertaken with utmost care by maintaining a very gentle slope down to El ±835m.

iii) Strengthening of CGS Platform

Shear keys and cross drifts backfilled with reinforced concrete for tying the deformed zone with the fresh and sound rock were provided. The overburden material above El±835m in the area between shafts 2 & 4m u/s, where the tension cracks have developed was removed. To reduce the pore pressure and increase the shear strength, drainage holes with perforated pipes to prevent soil migration from inside the shaft to drain the overburden were recommended. The holes were inclined 10^0 to the horizontal upward into rock.

Grouted anchors 25mm dia, 10m deep, about 1m c/c were provided at the d/s end of the platform at El 840m.

To strengthen the loose mass around CGS3&4, consolidation grouting was done in two different patterns. In the first stage the mass around CGS-3 between El ± 840m and El ± 770m was grouted by 10m deep holes at 3-5 Kg/cm^2 pressure and then the lower zone was grouted to a depth of 60m. The loose mass around CGS-4 was, however, grouted from inside the shaft after completing the concrete lining of the shaft.

iv) Multiple Drifting Through Deformed Mass

Concreting of the CGS-3 from El ±840m to El ± 792m (1-2m down to the contact with sound bed rock) was completed such that the top 10m was concreted in the first instance and the balance length before onset of monsoon. Concrete lining of this section was completed first by making a key into the rock and after that scooping of loose at lower level was undertaken.

For supporting the loose at lower level, five drifts of 1.5m x 1.7m dimensions, located radially along the shaft periphery were excavated through the loose material and these drifts were extended 2m into the sound rock (Fig). Subsequently, all these drifts were backfilled with reinforced concrete. After concreting the drifts, the loose mass from the intervening areas between the drifts was gradually removed and backfilled with reinforced concrete.

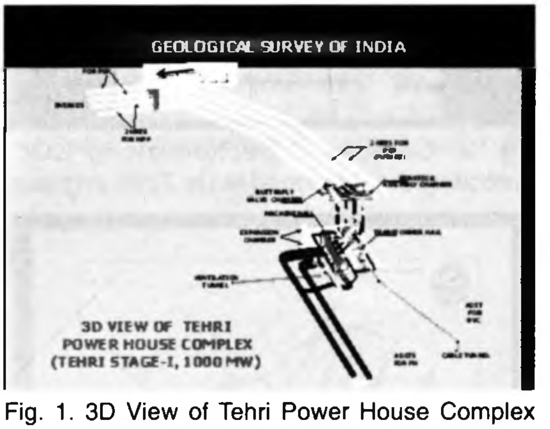

Fig. 1. 3D View of Tehri Power House Complex and Control Gate Shafts (CGS)

v) Pile Shaft Treatment

In order to strengthen the deformed masse on the valley side from the locations of control gate shafts a special treatment was envisaged wherein the entire deformed was to be removed in phases and to be replaced by high strength concrete. This was achieved by the provision of pile shafts of variable depths of 10m to 40m from El±835m, through the deformed mass and backfilling them with reinforced concrete.

As per this treatment plan, a total number of 29 concrete pile shafts of excavated dia 3.5m, in four rows of have been provided at El± 840m,El± 835m, El ±818m, El ±805m and El± 790m respectively. Considering the problems anticipated under reservoir impoundment and draw-down conditions these pile shafts have been designed accordingly. These shafts were concreted by thick RCC framework and covered by thick RCC slabs after backfilling the spaces within the RCC framework with rock muck. These were driven through the deformed rock mass down to the fresh bedrock, which later have been backfilled with reinforced concrete to function as a shear keys. Thus in the process, the deformed rock mass has been removed and replaced by concrete which will ensure stability to the slopes in the draw down condition. The distribution of the finally provided pile shafts at El± 840m, El± 835m, El ±818m, El ±805m and El± 790m are as follows.

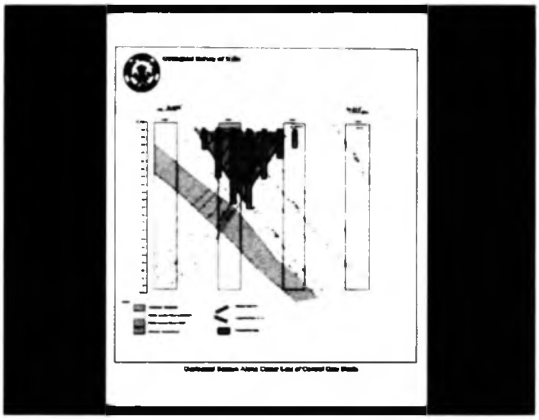

Fig. 2. Geological Section along CGS illustrating the Deformed Mass Zone in green

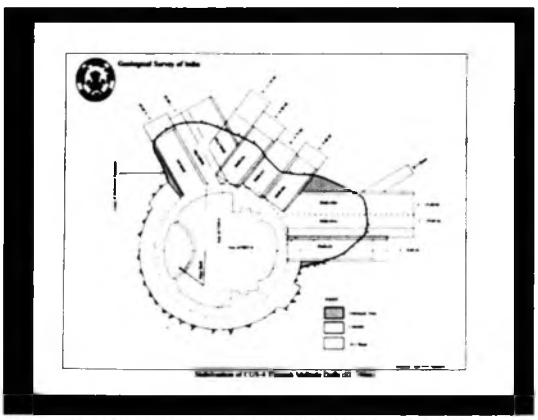

Fig. 3. Plan layout of Multiple Drifting in CGS-4

Table 1: Details of Pile Shafts in the MGS area

Location	No. of Pile Shafts	Min. Depth (m)	Max. Depth(m)
El±840m	5	10.00	29.50
El±835m	7	11.20	48.00
El±818m	6	10.00	30.50
El±805m	6	7.20	26.00
El±790m	5	6.00	29.50

vi) Concrete Cladding

The slopes between El±840m and El±720m covering the entire area from HRT-1 and HRT-4 were provided with concrete cladding, in order to protect them from the wave action during the draw down in the reservoir.

Conclusions

Construction of vital structures like control gate shafts, in extremely poor geological conditions was an engineering compulsion. Before executing the excavation on the slopes and the shafts, the extent of deformed mass was delineated. Depending upon the requirement of the structures, different treatment and stabilization measures were adopted at different locations.

The treatment of such a wide deformed rock mass is a clear testimony to the fact that even most difficult structures can be successfully constructed in the extremely poor geological regimes provided the sequence of excavation and the stabilization measures are innovatively evolved and implemented.

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