SENSITIVE ANALYSIS FOR ASSESSMENT OF CRITICALITY OF ABUTMENT SLOPES THROUGH NUMERICAL MODELLING - A CASE STUDY OF KOTESHWAR HEP, UTTARAKHAND, INDIA

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ABSTRACT

Koteshwar Hydro Electric Project (Koteshwar HEP) is an integral part of 2400 MW Tehri Hydropower complex comprising 1000 MW Tehri Hydro Power Project, 1000 MW Tehri Pumped Storage Plant and 400 MW Koteshwar HEP to develop hydroelectric potential of river Bhagirathi in Uttarakhand, India. Koteshwar HEP comprises of a 97.5m high concrete gravity dam across river Bhagirathi with a dam toe surface power house. Project commissioned in 2011-12.

Construction activities suffered badly due to failure of right bank in November 2005. In order to appreciate the problems deeper and considering the geological setup, 3D Stability analysis of both abutments altogether with dam and other structures were carried out during advance stage of construction i.e. in 2009. The behavior of the abutment slopes and the supports were ascertained through three-dimensional numerical program based on the distinct-element method for discontinuum modeling using 3DEC software. In comparison to the left abutment slopes, the right abutment slopes were found to be more critical for the stability analysis. Analyses indicated the requirement of additional supports and consequently un-tension Bundled Anchors (70 nos.) of 120 ton capacity were installed on right bank to provide stability to the slope. No negative movements are recorded through instruments, installed of monitoring the slope.

1. INTRODUCTION

Koteshwar HEP is located about 22km downstream of Tehri Dam on river Bhagirathi in Uttarakhand (Figure 1). Koteshwar HEP is an integral part of 2400 MW Tehri Hydropower complex comprising 1000 MW Tehri Hydro Power Project (Tehri HPP – commissioned in 2006), 1000 MW Tehri Pumped Storage Plant (Tehri PSP – under construction) and 400 MW Koteshwar HEP (commissioned in 2012) to develop hydroelectric potential of river Bhagirathi. The project comprises of 97.5m high gravity dam with top elevation at EL 618.5m across river Bhagirathi, a dam toe surface powerhouse with installed capacity of 4 x 100 MW on the right abutment and a 593m long diversion tunnel of 8m diameter passing through left abutment. Koteshwar HEP is situated on the asymmetric valley of the river Bhagirathi running in SW-NE direction. The valley has steep (55°-70°) left bank slope and gentle (45°-50°) right bank slope (Figure 2). Pindaras terrace, above dam and power house on right bank, has been capped with thick deposit of river borne material (RBM). Construction activities suffered badly due to failure of right bank in November 2005. In order to appreciate the problems deeper and considering the geological setup, 3D Stability analysis of both abutments altogether with dam and other structures were carried out during advance stage of construction i.e. in 2009.

2. GEOLOGICAL SETUP

The Project site is located within the lesser Himalayan geotectonic block. A huge succession of slates/phyllite with bands of quartzitic phyllites and clayey phyllite (metamorphosed Argillite) constitutes the typical bedrocks of the area. This sequence has been classified as Chandpur Formation of Jaunsar Group (Proterozoic age) (Figure 3). The Koteshwar HEP fall in the Zone IV of Seismic Zonation Map of India and tectonically located in middle part of the Lesser Himalaya at a distance of ±25km to the north-east from the MBF and at a distance of ±30km to the south-west from the MCT. The Srinagar thrust is another major fault of the second order at a distance of 13-15km to the north east from the project. The thrust strikes NW-SE and separates the phyllites of the Chandpur formation (upper Proterozoic) from the carbonate-quartzitic complex of the middle proterozoic (Garhwal group). Lithologically they consist of slaty phyllites and arenaceous phyllites. On the basis of mineralogical composition, three lithounits viz., Quartzitic phyllite, Phyllite and Clayey phyllite are exposed in the area.

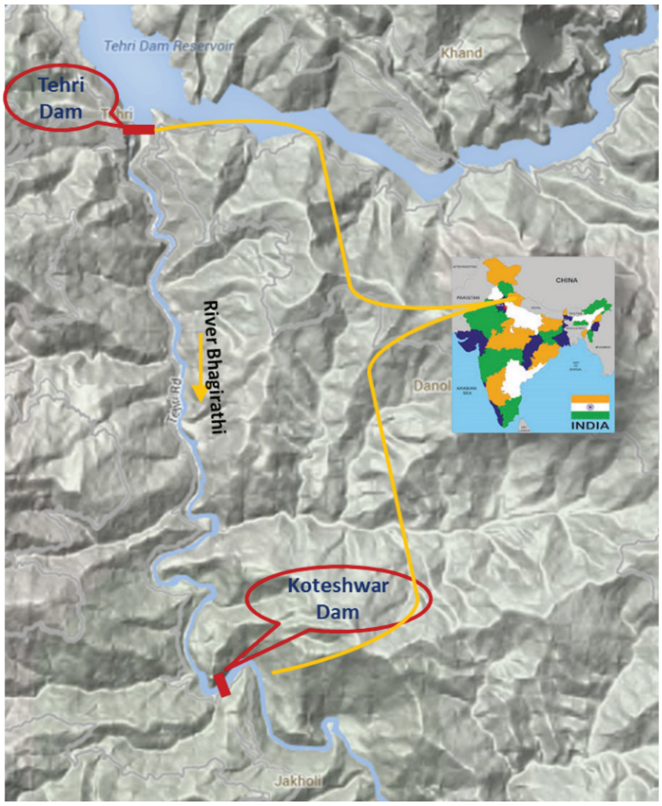

Figure 1 : Location map Koteshwar HEP

Figure 2 : View of upstream portion of the Dam

These lithounits form complicated sequential rhythmicity of several orders. Quaternary deposits are often found in the area and represented by the alluvial material of the flood plain, river bed and above flood plain terraces of the river Bhagirathi as well as by a complex of different slope deposits.

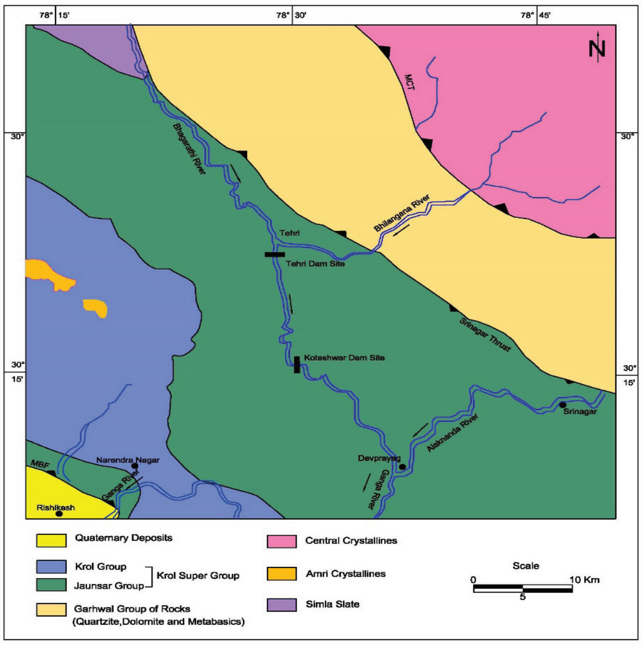

Figure 3 : Regional Geology Map of Koteshwar HEP (After Nawani et al 2006)

The bedding planes dipping 48°-70°/N100°-150° on the right abutment form the limb of an anticline which has another limb on the left abutment dipping 55°-85°/N320°-360°. This reversal in the dip direction due to the anti-formal closure is pronounced at the dam site but the plunge of the fold closure towards downstream direction is well traceable. A total of five set of joints including the bedding and foliation have been identified at the site. The three zones of varying strength of the rock-mass were distinguished on the basis of intensity of weathering and de-stressing processes. The disposition of right bank slopes is not straight and seen exposed in curvilinear pattern due to collapse of the sheared material along the bedding and foliation planes, thus exposing the strikes of the bedding/foliation plane in the mid portion of the area.

The rockmass exposed in the project are classified mainly as Phyllitic Quartzite Massive (PQM) and Phyllitic Quartzite Thinly bedded (PQT) and Sheared Phyllites (SP). These are crisscrossed by a number of prominent structural discontinuities like joints, shears etc. RBM is exposed in the higher elevations (above EL ± 670m) on the right bank. In addition to this, the slope wash material and the slump mass are present on left bank slopes.

At right abutment, the slope comprises mainly PQM, PQT formations with puckering and shearing at places. Phyllite with puckering has been extended between RD 90m and RD 120m downstream along right abutment slope. A band of sheared phyllites is running along right abutment from upstream to RD 30m-45m on the downstream. Thinly bedded phyllites exposed at the upper elevations (above El 630m) are disintegrated and highly fractured. Rock mass obtained in these areas are fragile in nature and could be easily disintegrated. Hence, these areas were considered to be highly susceptible to slope movements and failures. Geological sections at RD 30m and RD 120m downstream of dam axis are shown in Figure 4 & 5 respectively. The Weathering condition of rockmass at different levels on both abutments has been considered in the analysis.

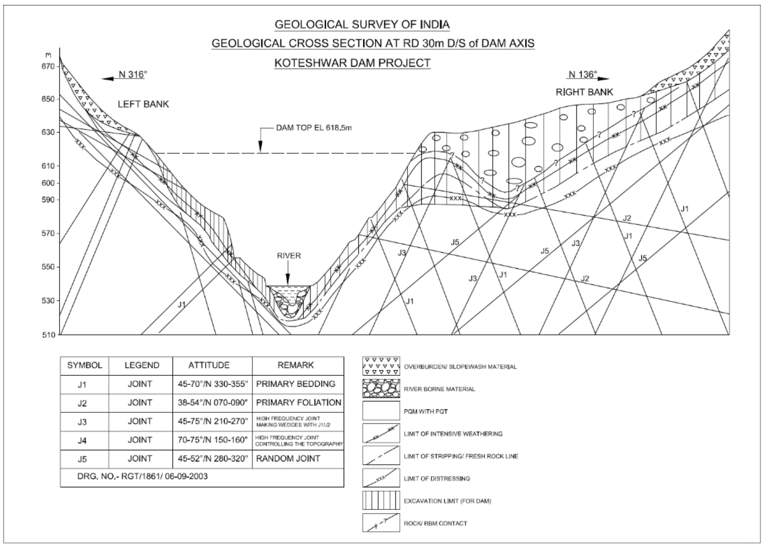

Figure 4 : Geological Section at RD 30m downstream of Dam axis

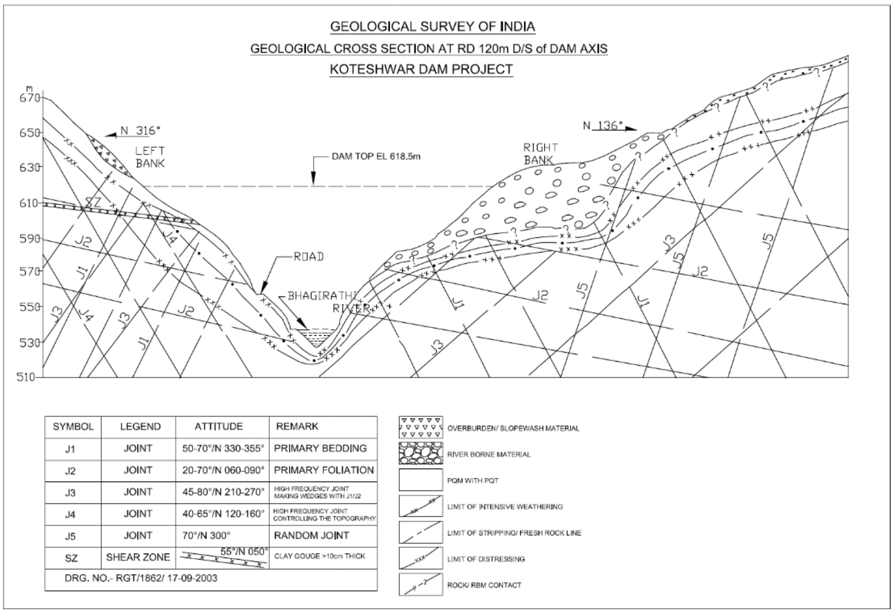

Figure 5 : Geological Section at RD 120m downstream of Dam axis

3. NUMERICAL MODELLING OF CUT SLOPES

Numerical modelling of cut slopes had been carried out by National Institute of Rock Mechanics (NIRM). The initial studies of seven sections were carried out using two dimensional discontinuum method during December 2008, which indicated requirement of additional supporting at some places. The behaviour of the abutment slopes and the supports were ascertained using three dimensional discontinuum model using 3DEC. A realistic 3D model using three-dimensional Distinct Element code, 3DEC from Itasca USA of the cut slopes of both abutments and the dam was prepared using the available plans and sections. Complex geological variations in the area were input to the model (Figure 6). The actual supports (5m long 25mm dia. & 10m long 32mm dia. rock bolt along with shotcrete and wiremesh) already installed in the area are simulated in the model.

3DEC simulates the response of discontinuous media (such as a jointed rockmass) subjected to either static or dynamic loading. The discontinuous medium is represented as an assemblage of discrete blocks. The discontinuities are treated as boundary conditions between blocks; large displacements along discontinuities and rotations of blocks are allowed. Individual blocks behave as either rigid or deformable material. Deformable blocks are subdivided into a mesh of finite difference elements, and each element responds according to a prescribed linear or non-linear stress-strain law. The relative motion of the discontinuities is also governed by linear or non-linear force-displacement relations for movement in both the normal and shear directions. 3DEC has several built-in material behavior models, for both the intact blocks and the discontinuities, that permit the simulation of response representative of discontinuous geologic, or similar, materials. 3DEC is based on a Lagrangian calculation scheme that is well suited to model the large movements and deformations of a blocky system.

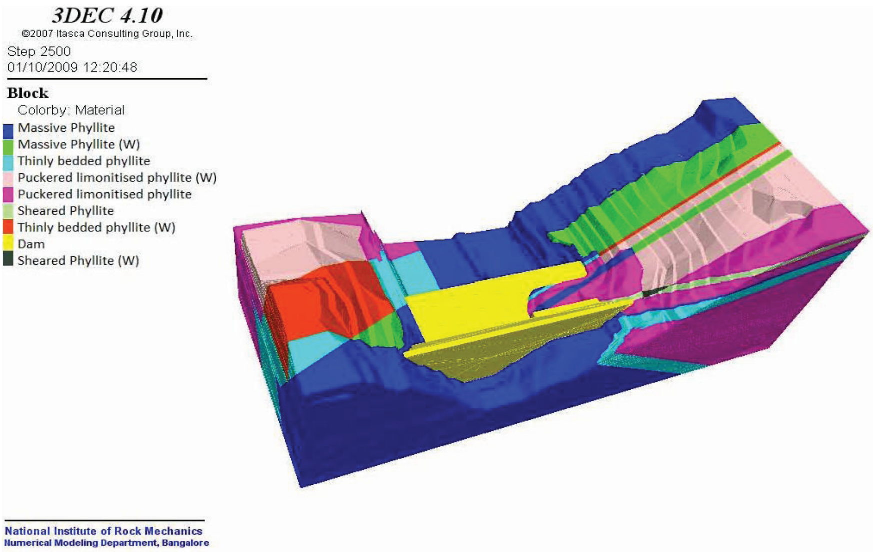

Figure 6 : 3D Discontinuum model of the left and right abutment slopes of different rockmass along with Dam

3.1 In-situ Stress

The Koteshwar HEP has the similar geological setup as of Tehri HPP and there are no major regional discontinuities in the nearby area to affect the major changes in the in-situ stress measurement. The insitu stresses used in the model are K_H (ratio of major horizontal to vertical stress) as 0.75 and K_h (ratio of minor horizontal to vertical stress) as 0.5. These values were selected with reference to the measured values at Tehri project using Hydro fracturing test. Thus, in the model the vertical stress is taken as gravity loading whereas the major horizontal stress is taken along the river flow direction and minor horizontal stress is taken perpendicular to it.

3.2 Physico-Mechanical Properties

The rock mass properties for the model were estimated based on the procedure outlined by Hoek & Brown (2002) using the input parameters of Tehri Project for this study as detailed in GSI bulletin No. B (62) (Nawani et al., 2006). The values are obtained from the ROCLAB are summarized in Table 1.

Table 1 : Physico-Mechanical properties of rockmass

	PQM (Massive Phyllites)		**PQT (Thinly bedded Phyllites)**		**PQT Limonitised Puckered Phyllites**		**Sheared Phyllites (SP)**
	Non-weathered	**Weathered**	**Non-weathered**	**Weathered**	**Non-weathered**	**Weathered**	
UCS, MPa	75	50	60	45	45	40	35
GSI	64	50	55	45	50	40	18
Mi	10	7	7	6	7	6	4
Disturbance Factor (D)	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Intact Elastic Modulus (Ei)	56250	32500	33000	24750	18000	16000	10500
Unit Weight, kg/m3	2600	2600	2600	2600	2600	2600	2600
Cohesion, MPa	1.42	0.67	0.86	0.52	0.64	0.42	0.13
Friction Angle, deg	40.05	27.58	31.21	23.40	26.84	20.45	8.89
Rock Mass Elastic, MPa	12120.50	2974.46	4139.73	1669.74	1647.39	816.38	256.15
Shear Modulus, (G), MPa	5201.93	1293.24	1799.88	732.34	722.54	362.83	113.84
Bulk Modulus (K), MPa	11882.84	2478.72	3449.78	1264.95	1248.02	544.25	170.77

3.3 Analysis and outcome

After incorporating the above-mentioned geological features, in-situ stresses, geo-mechanical properties etc. in the model, analyses carried out for different support combinations for whole slope of the dam area. The model with the existing support system showed maximum displacement of 101mm and 122mm on left and right abutment respectively. The maximum displacement was observed in the area of sheared phyllite contact with the limonitised puckered phyllites. It was observed that due to the orientation and angle of the slopes, the vertical component of the displacements is higher than the horizontal component. Therefore, absolute values of displacements were taken into consideration while making the decision on the additional supports required at certain locations. The significant displacements values observed at various sections are shown in Table 2. Displacement behavior on both abutments at RD 120m downstream of dam axis is shown in Figure 7. Analyses indicate reduction in displacements up to 27.3%, after installation of cable anchors in addition to the existing supports, except at RD 30m u/s section.

Table 2 : Significant displacement values on the slopes at different level

Sections along the dam axis	Left abutment slope		Right abutment slope	
	Maximum (mm)	Elevation (m)	Maximum (mm)	Elevation (m)
30m upstream	-	-	48	608 - 615
20m upstream	-	-	70	643 - 659
10m upstream	-	-	59.61	643 - 658
Dam axis	-	-	85	628 - 658
10m downstream	-	-	112	616 - 628
20m downstream	-	-	116	605 - 628
30m downstream	-	-	122	592 - 627
40m downstream	-	-	118	589 - 628
50m downstream	-	-	111	587 - 616
60m downstream	-	-	106	590 – 616
70m downstream	-	-	95.6	588 - 632
80m downstream	-	-	84.43	590 - 632
90m downstream	-	-	88.24	602 - 617
100m downstream	-	-	91.37	606 - 631
110m downstream	72.5	574 - 653	72.5	599 -630
120m downstream	64.18	591 – 670	64.18	590 - 616
130m downstream	71.7	592 – 666	60	606 - 615
140m downstream	76.68	593 - 665	-	-
150m downstream	80.38	590 - 662	-	-
160m downstream	84.24	592 - 660	-	-
170m downstream	88.13	590 - 660	-	-
180m downstream	101	605 - 648	-	-

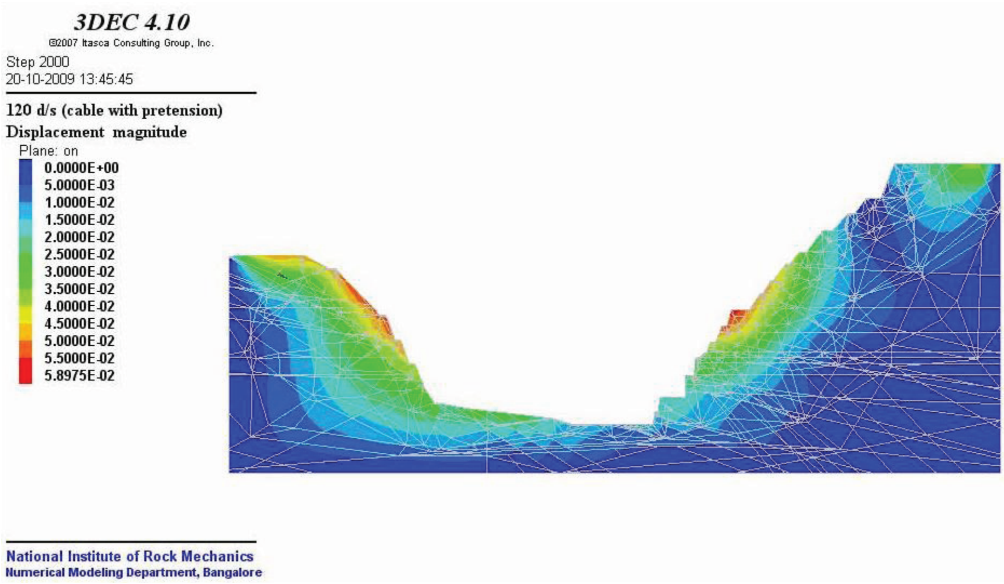

Figure 7 : Displacement behavior on both bank at RD 120m downstream of Dam axis

4. DISCUSSION

It was established from the model studies that the existing supports are not sufficient under these conditions considering observed magnitude of maximum displacement. It was planned to model cable anchors (120 tons ultimate capacity) at the following locations:

On Right abutment slopes: (Cable spacing 10m x 10m)

- Cable anchors from EL 590m to 630m at RD 30m d/s to RD 130m d/s

- Cable anchors from EL 605m to 630m at dam axis to RD 20m d/s
- Cable anchors from EL 628m to 660m at RD 10m u/s to RD 20m u/s

The installation of the cable anchors in the slump area is not practicable and effective. Hence, it was recommended to remove the slump mass on the left abutment slopes. But, due to sink hole formation on left bank slope, treatment of slope on left abutment done later on. Figure 8 and 9 shows the treated slopes downstream of Koteshwar dam at left and right abutment respectively.

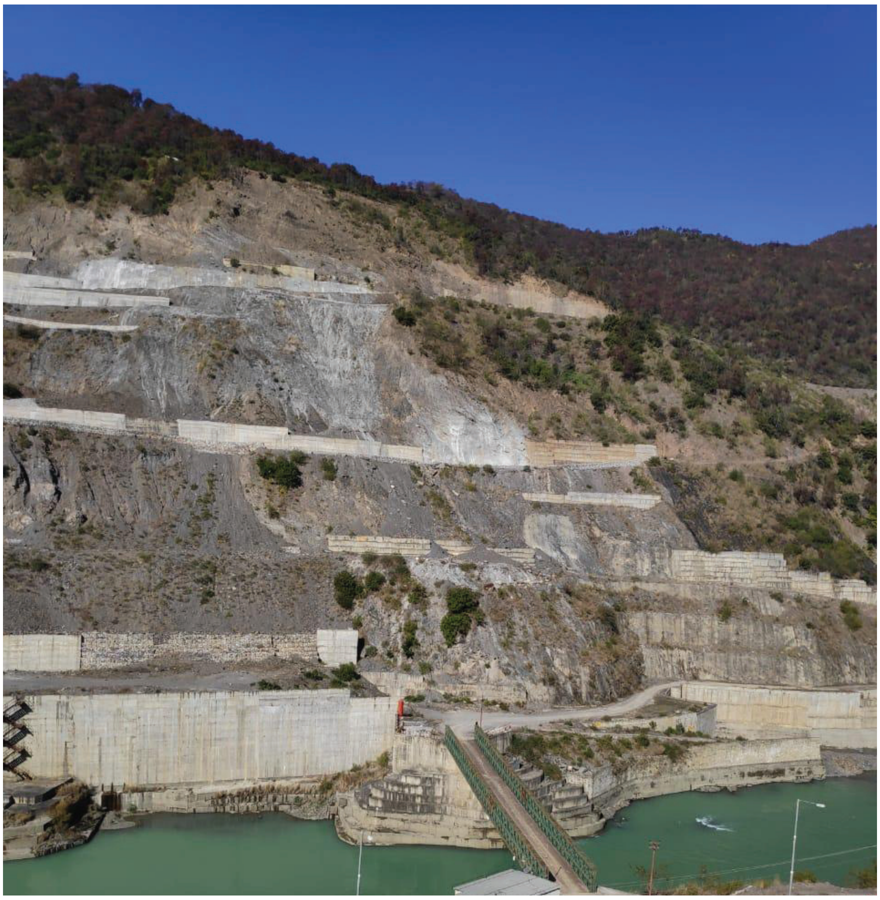

Figure 8 : Treated slope of left bank downstream of Dam axis

Figure 9 : Treated slope of right bank downstream of Dam axis

5. CONCLUSION

The 3D numerical model reveals the stress distribution and displacement patterns in abutment slopes of Koteshwar HE Project. The complex geological features along with the existing cut slopes were modelled realistically in the 3D discontinuum model using 3DEC. It was established from the model studies that the existing supports are not sufficient under these conditions. The model showed that the vertical component of the displacement is higher than the horizontal component. However, the displacements are not just occurring on the surface of the slopes, but significant amount of displacement is occurring inside the rock mass also. Keeping this aspect, the total displacements are considered while choosing the locations of the cable anchor. Keeping the long-term stability of the slopes, Cable anchors are recommended at few locations. The cable anchors at the recommended locations were modelled to see the support efficacy and the maximum axial force introduced in the cable anchors. Un-tension Bundled Anchors (70 nos.) of 120 ton capacity were installed on right bank. These Bundled anchors were of length 25m (minimum) out of which 5m were in fresh rock. Due to sinkhole formation on left bank slope, treatment of slope on left abutment done later on. No negative movements are recorded through instruments, installed for monitoring the slope.

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