3D stability analysis of left and right abutment cut slopes of a hydroelectric project in Himalaya

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1 INTRODUCTION

Stability of cut slopes plays a significant role in maintaining the integrity of hydroelectric dam and its appurtenances. In most of the power projects, surrounding soil/rock profile are re-graded to facilitate movement of men and machinery causing changes to in-situ stress conditions leading to disturbances in the form of displacements and slope failures. The fragile geological conditions in Himalaya have caused significant number of landslides and mass movements in the area. In this study, the stability of cut slopes abutting a concrete gravity dam along the river Bhagirathi in lesser Himalayas is analyzed with *3DEC* (Itasca 2007).

Analysis of the abutments can be considered crucial for safety of the dam as both sides of abutment consisted of combination of weak and strong rock variants. Thus, a study was undertaken to analyze the stability of cut slopes and the dam using discrete element analysis software. Entire slope at both the abutments were modeled, as interaction between concrete dam and slopes may also have significant influence on the analysis. This study involved prediction of displacements and factor of safety of the cut slopes based on the input topography, geological details and geotechnical parameters. The existing support system was also analyzed for its adequacy.

2 3D MODELLING OF CUT SLOPES

The geology of abutment slope comprises mainly massive phyllites, thinly bedded phyllites, puckered limonitised phyllites, sheared phyllites formation and loose riverbed material. A band of sheared phyllites was found extending along right abutment from upstream side till 30 m - 45 m chainage on the downstream side (Nawani 2006). Presence of sheared phyllite band at close vicinity of the foundation of dam could be critical with regards stability of the slope. A comprehensive model incorporating all the geological features with actual geometry of the slopes and dam body was prepared in *3DEC* and is shown in Figure 1 (Sripad et. al).

The actual slope profile is taken as the outer boundary of the model and the model is subjected to gravity loading. In-situ stress field was applied with K_H=0.75 and K_h=0.5 as per the input provided by the project authorities (Anon 2006). The major horizontal stress is taken along the river flow direction and minor horizontal stress is taken perpendicular to it. Four sets of prominent joints were explicitly modelled in the 3D Model. The rock mass properties for the model are arrived based on the empirical estimates given by Hoek & Diederichs (2006) using the intact rock parameters like Uniaxial compressive strength, GSI, elastic Young's modulus and mi as suggested by Nawani 2006. The estimated rock mass properties are listed in Table 1.

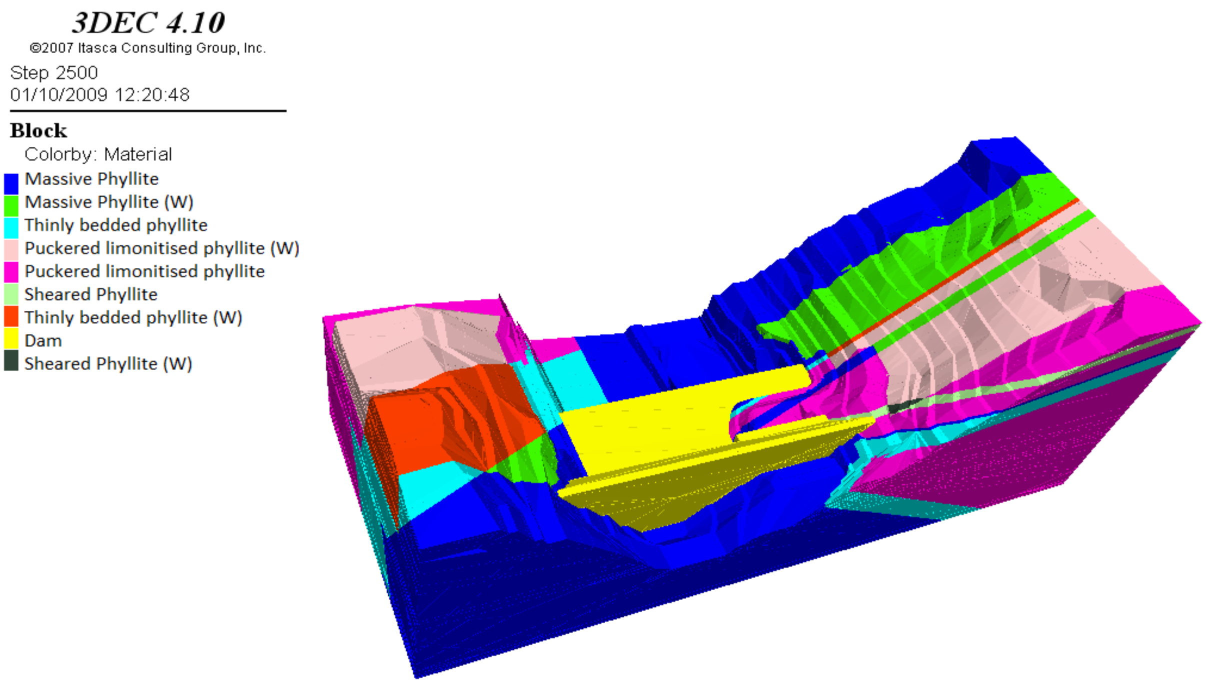

Figure 1. Model of the abutment cut slopes with different materials and dam body.

Table 1. Input parameters for the 3D Model.

	PQM (Massive Phyllites)		PQT (Thinly bedded Phyllites)		PQT(W1-W2) Limontised Puckered Phyllites		Sheared Phyllites (SP)
	Non-weathered	Weathered	Non-weathered	Weathered	Non-weathered	Weathered	
Uniaxial Compressive Strength (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 RESULTS AND DISCUSSION

In this study, initially the slopes were modelled with the already installed support system. Maximum displacement was found to be 162.64 mm. The model showed significant displacement at upper elevation of left abutment slopes beyond 150 m chainage in downstream side. Similarly, the right abutment slopes from dam axis to 150 m chainage and El of 570 m to 640 m experienced significant displacement. It was observed that due to the orientation and angle of the slopes, the vertical component of the displacements was higher than the horizontal component. The factor of safety was calculated using Drucker-Prager yield criteria. The

Drucker-Prager yield criteria is a three-dimensional failure criterion, which takes into account the intermediate principal stresses in addition to the commonly used major and minor principal stresses. On right abutment slope, factor of safety was found below 1.5 in the areas where sheared phyllites are exposed. The results also revealed that nearly 961 rock bolts were on the verge of yielding.

Considering significant failures on right abutment in the first model, supports were revised in the second model and cable anchors of 120 tons capacity were designed at 10 m × 10 m spacing at the following locations. Cable anchors from EL 590 m to 630 m at 30 m d/s to 130 m d/s; from EL 605 m to 630 m at dam axis to 20 m d/s and from EL 628 m to 660 m at 10 m u/s to 20 m u/s. Model results were obtained with no tension in cable bolts and with pretension of 70 tons. The displacements observed in all three models are compared in Figure 2. It may be noted that at every section, there is a reduction in the displacement and maximum reduction in displacement is up to 27.3%. It was also observed that there was no effect of pre-tensioning on the displacement. Model results with pre-tension of cable bolts showed that there was overall increase in the factor of safety (by nearly 38%). However nearly 77 cable anchors reached their yield strength. Model results with no pre-tensioning revealed that there were only 7 cable anchors reaching the yield capacity, but the factor of safety reduced marginally. The factor of safety values on the cut slopes with cable anchors are shown in Figure 3.

4 CONCLUSIONS

The 3D model demonstrated the stress distribution and displacement patterns in abutment slopes in Himalaya. The complex geological features along with the existing cut slopes were modeled realistically in the 3D discontinuum model using *3DEC*. Model studies showed the efficacy of the cable anchors when it was not pre-tensioned and suitability of the such type to slopes developed in Himalayan rock conditions.

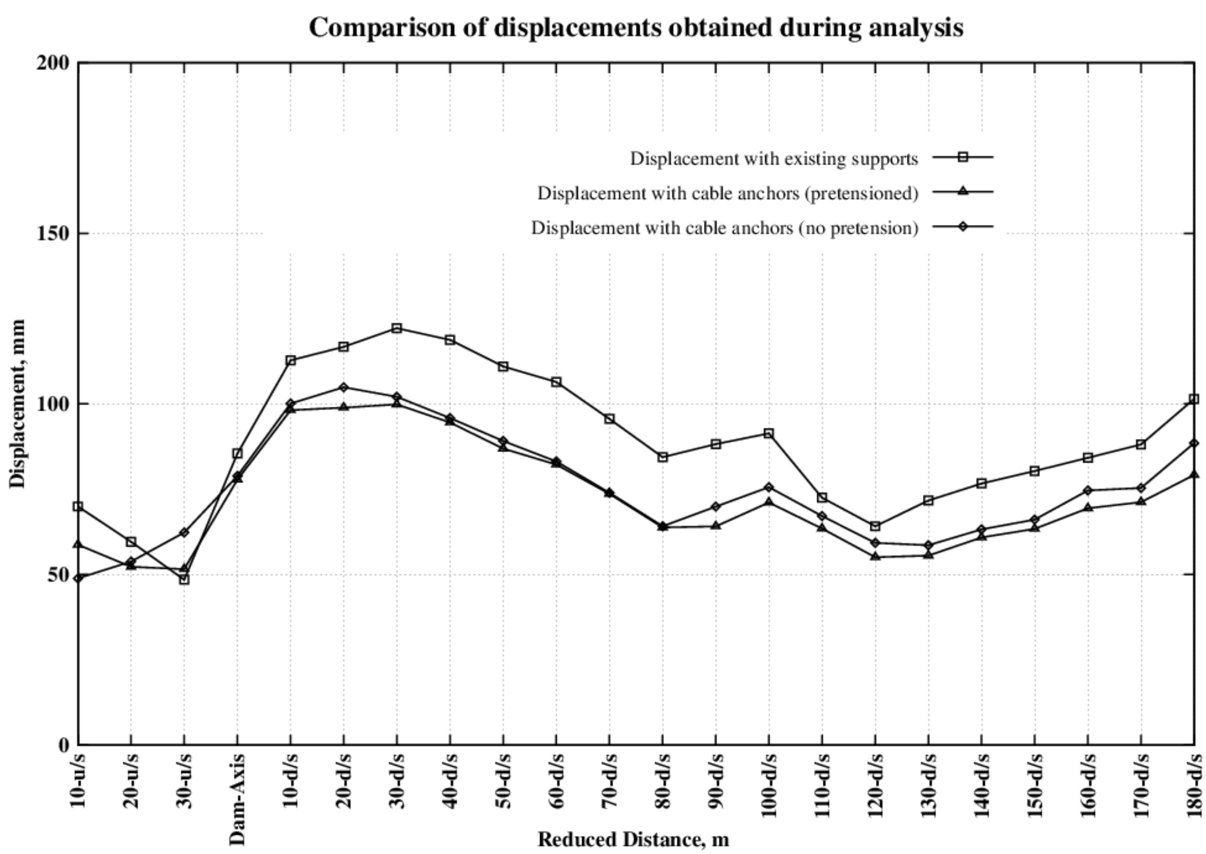

Figure 2. Comparison between displacements obtained during analysis

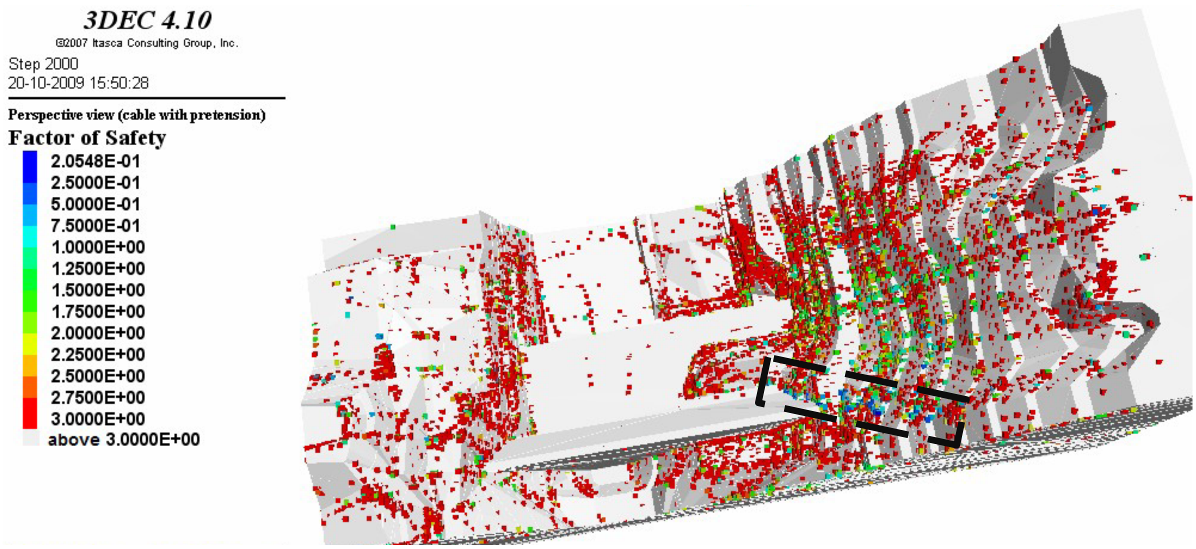

Figure 3. Factor of safety of slopes with existing supports and cable anchors (with pre-tension).

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