

# **3D Stability Analysis of Left and Right Abutment Cut Slopes of a Hydroelectric Project in Himalaya**

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**Presented by**

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# Description of the Problem

- **Slope Stability Issues on Left and Right abutment of a Concrete Gravity Dam**
- **Location : Lower Himalayas**



# Geology

## **Left Abutment**

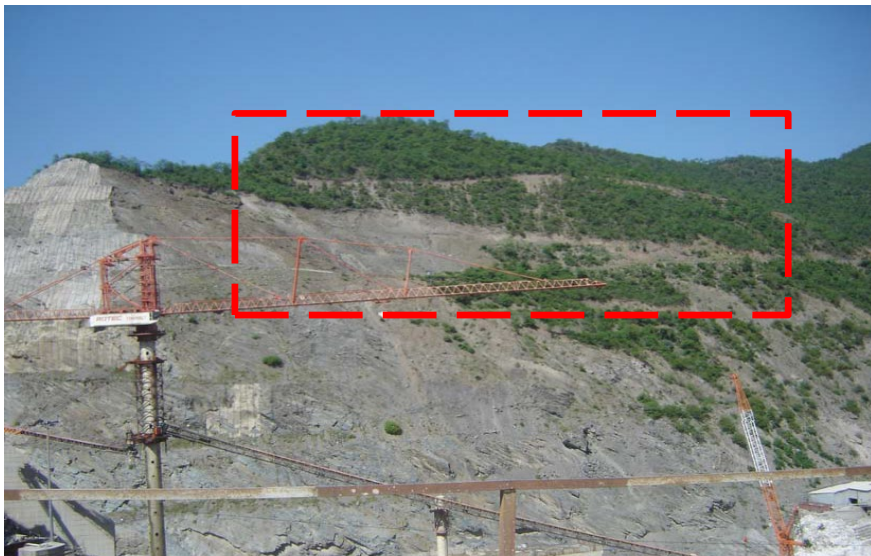
- **The upstream section of left abutment slope consists of massive phyllites**
- **The dam is situated on stable massive phyllites**
- **The upper elevations of downstream left abutment slopes constitute both massive phyllites and thinly bedded phyllites**
- **The upper elevations of left abutment slope consist of slump mass**

## Left Abutment



← **Upstream side of left abutment slope**

**Left abutment slope near dam axis** →



← **Slump mass region in downstream of left abutment slope**

**Concrete wall provided at lower slopes of left abutment till ch:150m from dam axis** →



# Geology

## Right Abutment

- The geology of right abutment slope comprises mainly massive phyllites, thinly bedded phyllites, puckered limonitic phyllites and sheared phyllites formation
- Puckered phyllites and thinly bedded phyllites on the upstream side.
- Puckered limonitic phyllites formation extend up to 90m-120m downstream side of right abutment slope
- A band of sheared phyllites is running along right abutment from upstream side till 30m-45m chainage on the downstream side
- Thinly bedded phyllites existing at the upper elevations (above El 630m) were found to disintegrated and highly fractured
- Rock mass obtained from these areas could be easily broken into pieces by hand. Hence, these areas were considered to be highly susceptible to slope movements and failures. The upper elevations (above El 670m) of right abutment slope towards downstream side consisted of loose river bed material

## Right Abutment



← **Highly  
disintegrated  
thinly bedded  
phyllites on right  
abutment slope**

**Sheared  
phyllites  
existing on the  
right abutment  
slope** →

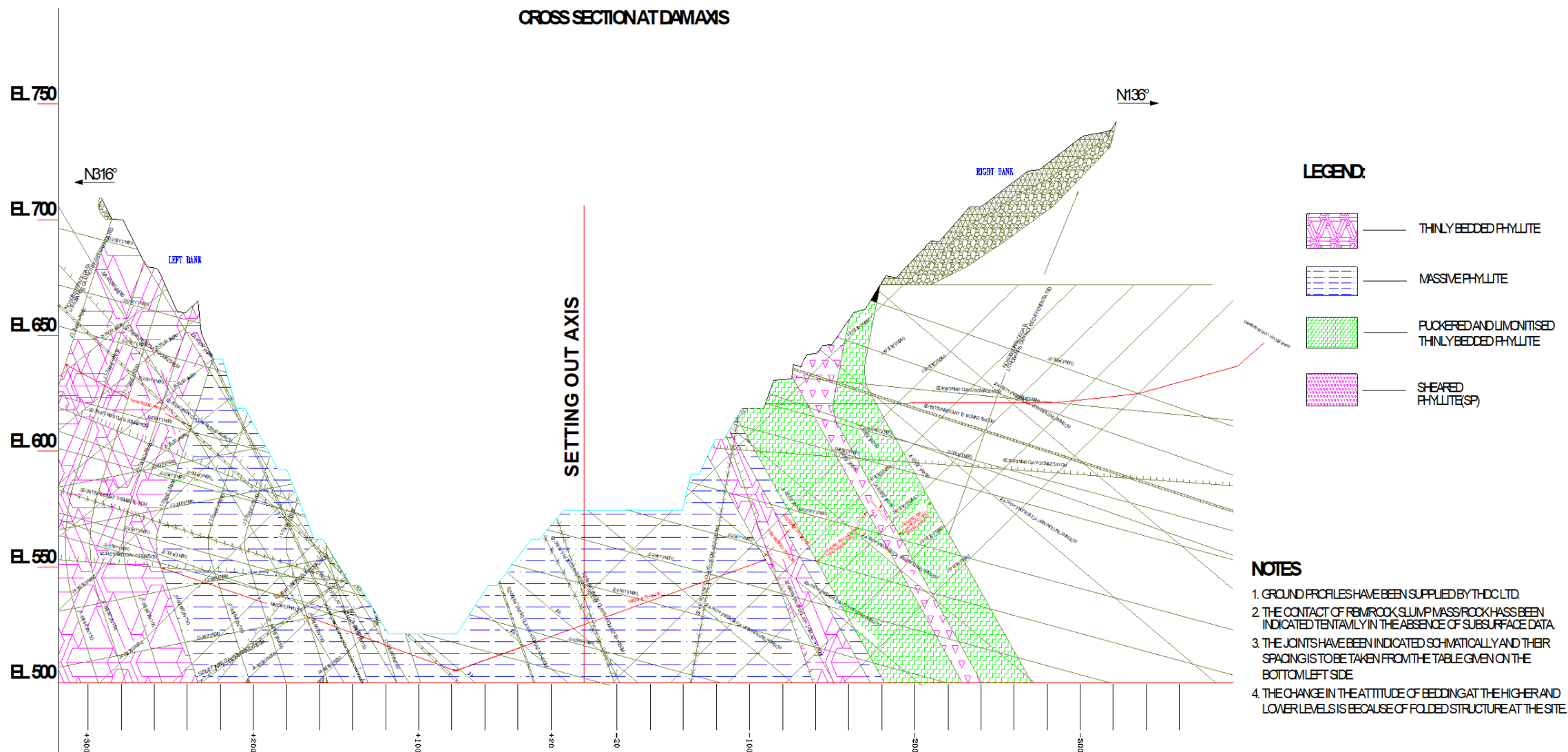


← **Highly  
disintegrated  
thinly bedded  
phyllites**

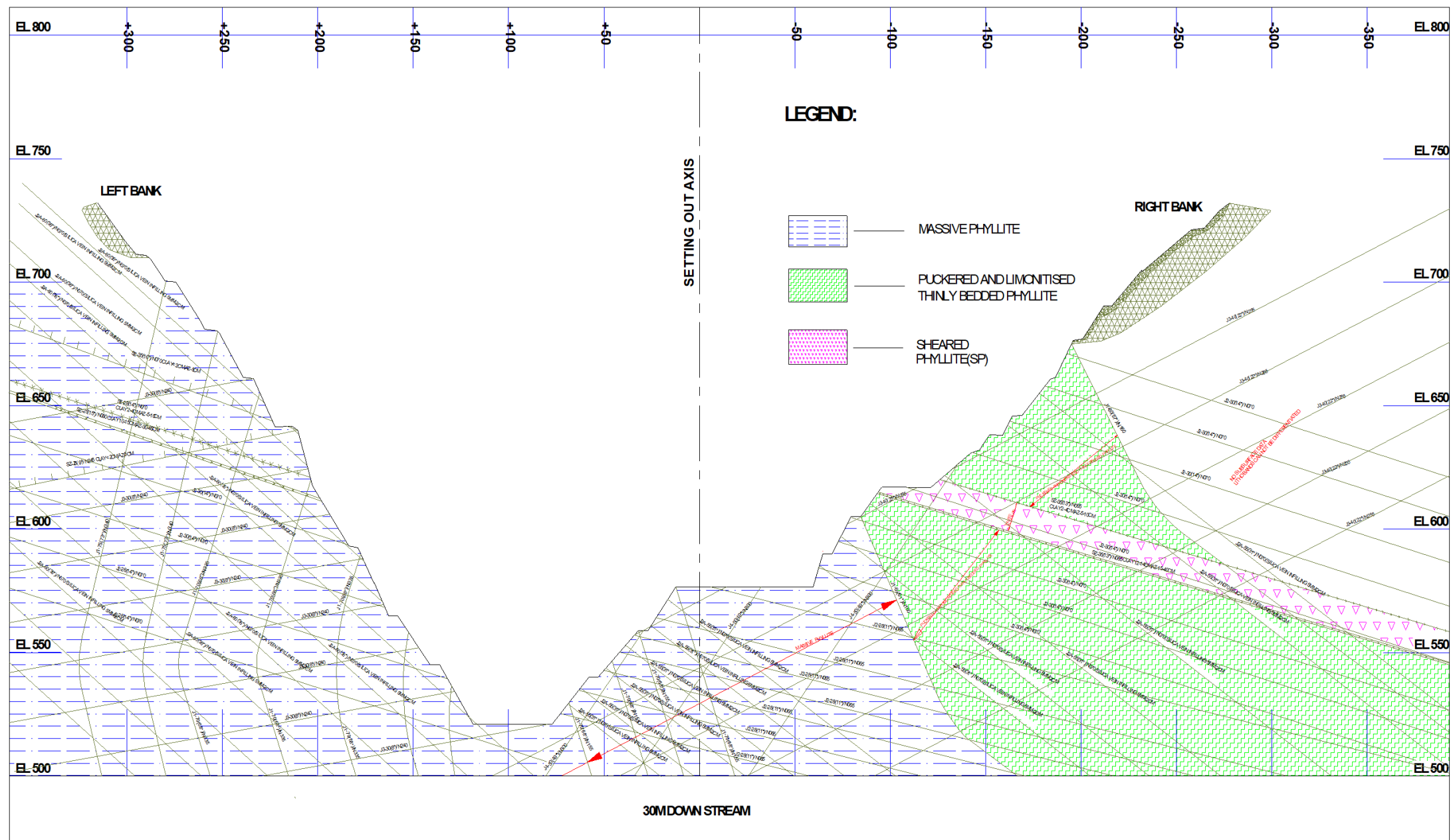
**River bed material  
visible on the upper  
slopes of right  
abutment** →



# Geological Section at Dam Axis



# Geological Section at 30m D/s





## 3DEC 4.10

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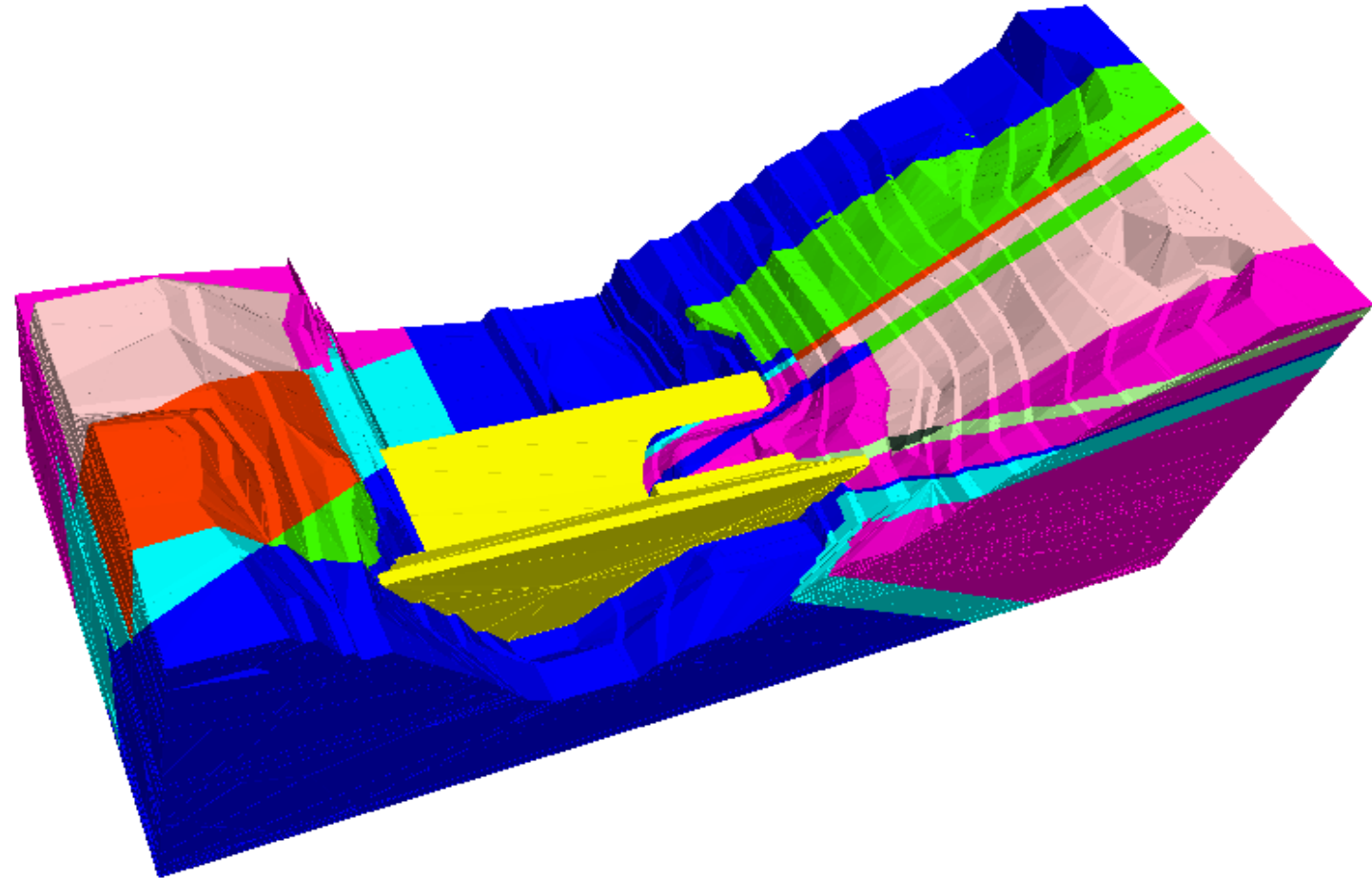
Step 2500

01/10/2009 12:20:48

### Block

Colorby: Material

- Massive Phyllite
- Massive Phyllite (W)
- Thinly bedded phyllite
- Puckered limonitised phyllite (W)
- Puckered limonitised phyllite
- Sheared Phyllite
- Thinly bedded phyllite (W)
- Dam
- Sheared Phyllite (W)



# Translation of Site Geology into a 3D Discontinuum Model

## Input Material Parameters for 3DEC Model

	PQM (Massive Phyllites)		PQT (Thinly bedded <u>Phyllites</u> )		PQT(W1-W2) <u>Limontised Puckered Phyllites</u>		Sheared Phyllites (SP)
	Non-weathered	Weathered	Non-weathered	Weathered	Non-weathered	Weathered	
<b>Uniaxial Compressive Strength (UCS), MPa</b>	<b>75</b>	<b>50</b>	<b>60</b>	<b>45</b>	<b>45</b>	<b>40</b>	<b>35</b>
<b>GSI</b>	<b>64</b>	<b>50</b>	<b>55</b>	<b>45</b>	<b>50</b>	<b>40</b>	<b>18</b>
<b>Mi</b>	<b>10</b>	<b>7</b>	<b>7</b>	<b>6</b>	<b>7</b>	<b>6</b>	<b>4</b>
<b>Intact Elastic Modulus (<u>Ei</u>), MPa</b>	<b>56250</b>	<b>32500</b>	<b>33000</b>	<b>24750</b>	<b>18000</b>	<b>16000</b>	<b>10500</b>
<b>Unit Weight, kg/m<sup>3</sup></b>	<b>2600</b>	<b>2600</b>	<b>2600</b>	<b>2600</b>	<b>2600</b>	<b>2600</b>	<b>2600</b>
<b>Cohesion, MPa</b>	<b>1.42</b>	<b>0.67</b>	<b>0.86</b>	<b>0.52</b>	<b>0.64</b>	<b>0.42</b>	<b>0.13</b>
<b>Friction Angle, deg</b>	<b>40.05</b>	<b>27.58</b>	<b>31.21</b>	<b>23.40</b>	<b>26.84</b>	<b>20.45</b>	<b>8.89</b>
<b>Rock Mass Elastic, MPa</b>	<b>12120.50</b>	<b>2974.46</b>	<b>4139.73</b>	<b>1669.74</b>	<b>1647.39</b>	<b>816.38</b>	<b>256.15</b>
<b>Shear Modulus, (G), MPa</b>	<b>5201.93</b>	<b>1293.24</b>	<b>1799.88</b>	<b>732.34</b>	<b>722.54</b>	<b>362.83</b>	<b>113.84</b>
<b>Bulk Modulus (K), MPa</b>	<b>11882.84</b>	<b>2478.72</b>	<b>3449.78</b>	<b>1264.95</b>	<b>1248.02</b>	<b>544.25</b>	<b>170.77</b>

# Model Studies

**MODEL -1 : Discontinuum 3D Model with Existing Supports**

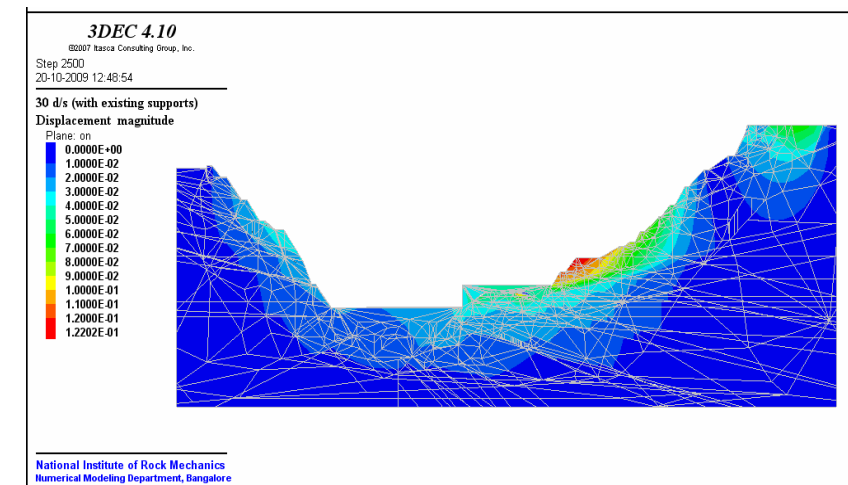
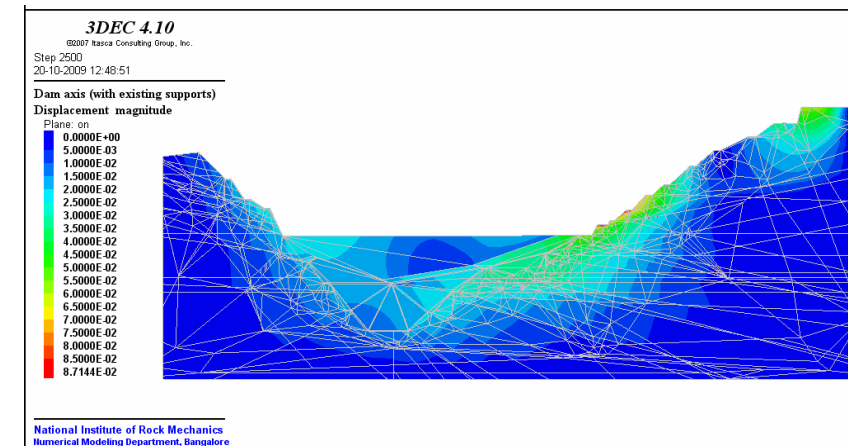
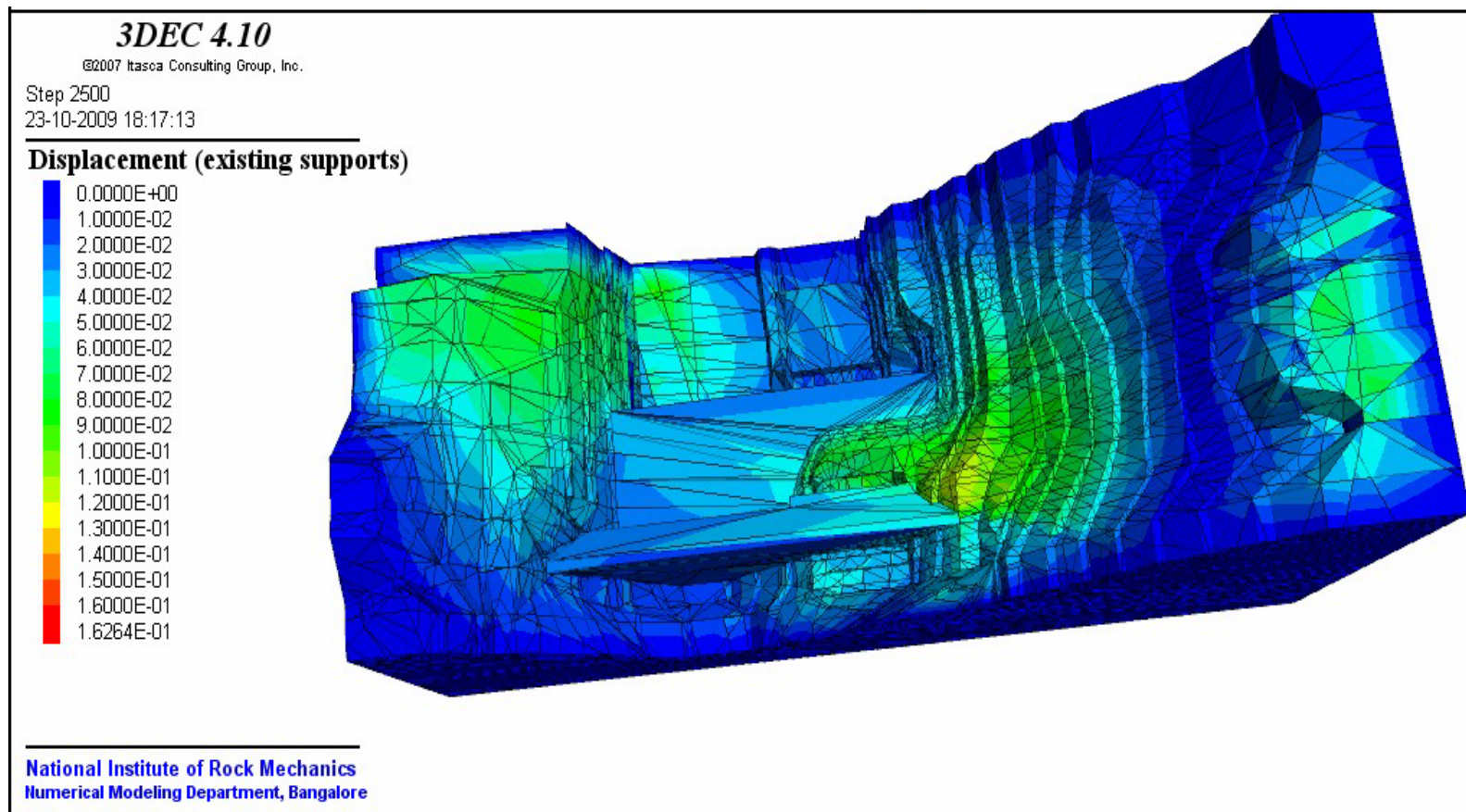
**MODEL -2 : Discontinuum 3D Model with Existing Supports and Cable Anchors  
(with pretension)**

**MODEL -3 : Discontinuum 3D Model with Existing Supports and Cable Anchors (without  
pretension)**

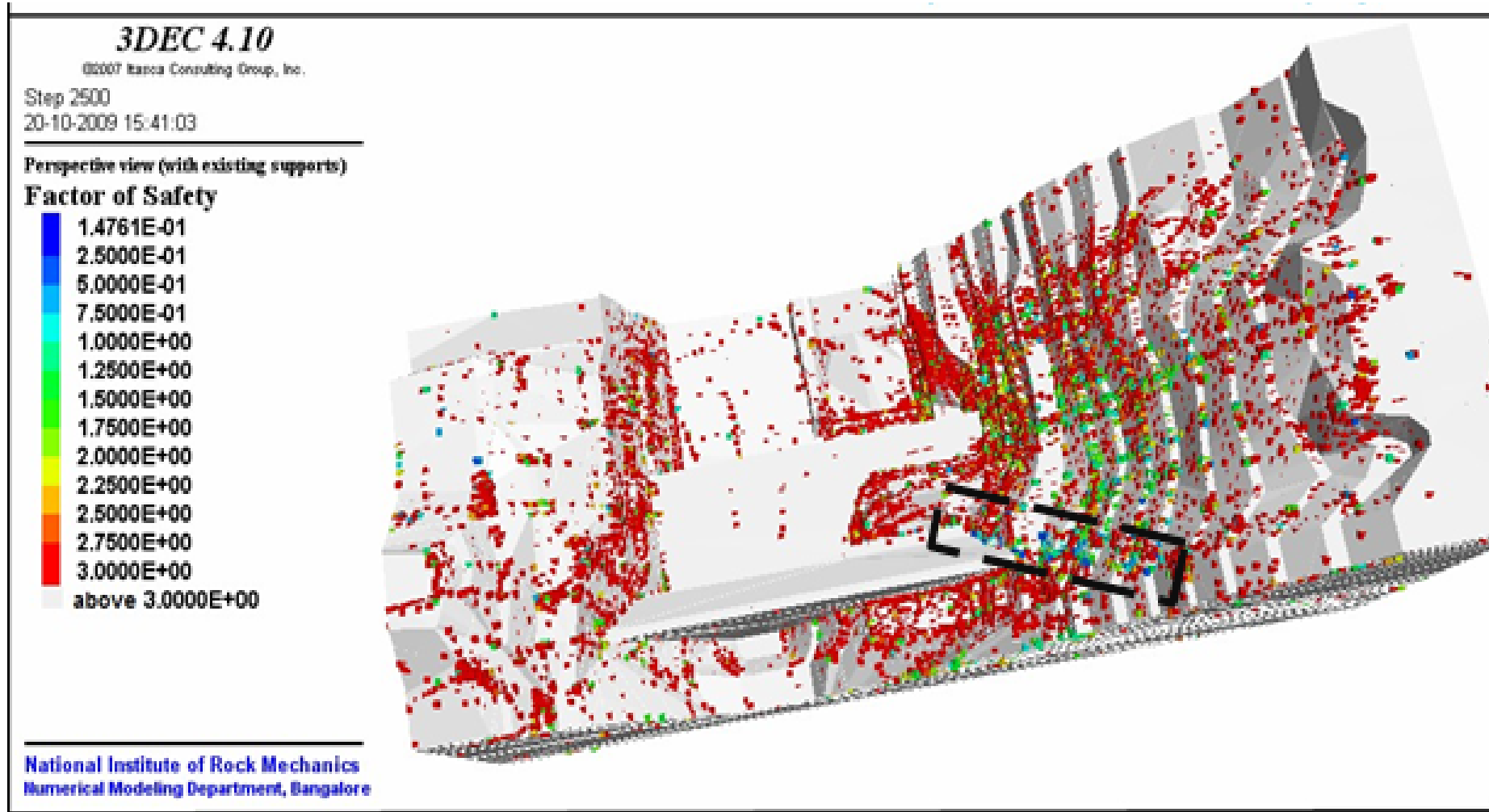
**In-Situ Stresses :  $K_H=0.75$ ;  $K_h=0.50$**

**Major Horizontal Stress – along the flow of the River**

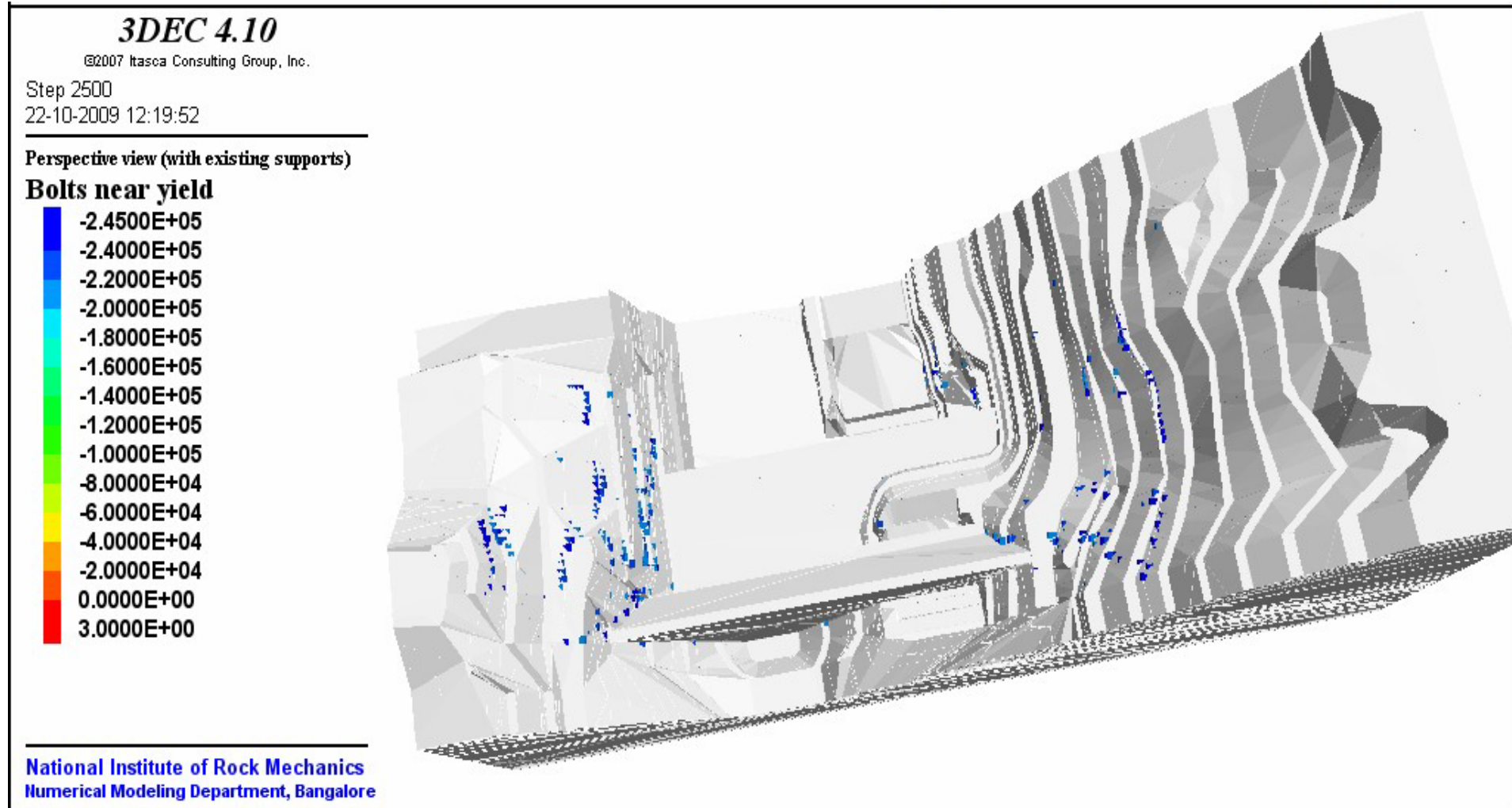
# Model -1 Results



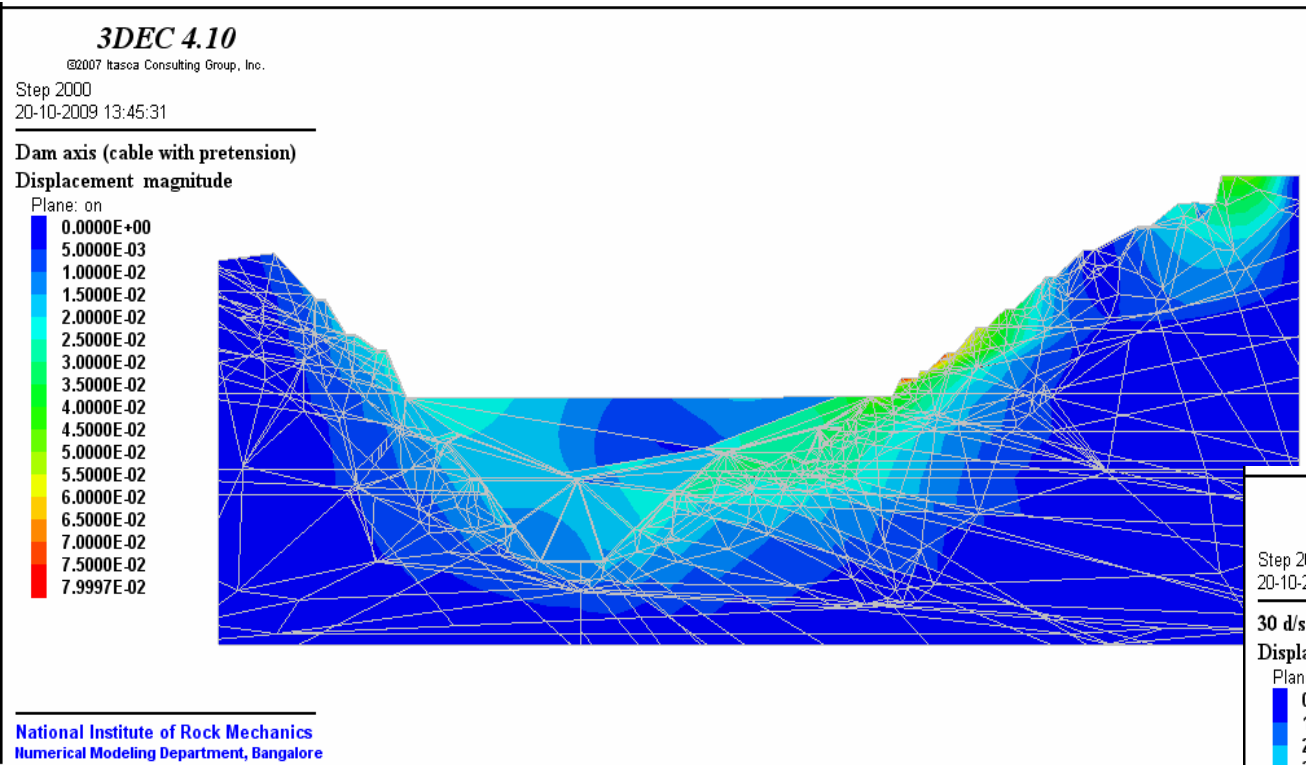
- Maximum displacement was found to be 162.64 mm.
- The model showed significant displacement at upper elevation of left abutment slopes beyond 150 m chainage in downstream side.
- Similarly, the right abutment slopes from dam axis to 150 m chainage and EL of 570 m to 640 m experienced significant displacement



**It can be seen that most of the location on the slopes have factor of safety higher than 1.5. However, on right abutment slope, factor of safety was found below 1.5 in the areas where sheared phyllites are exposed.**



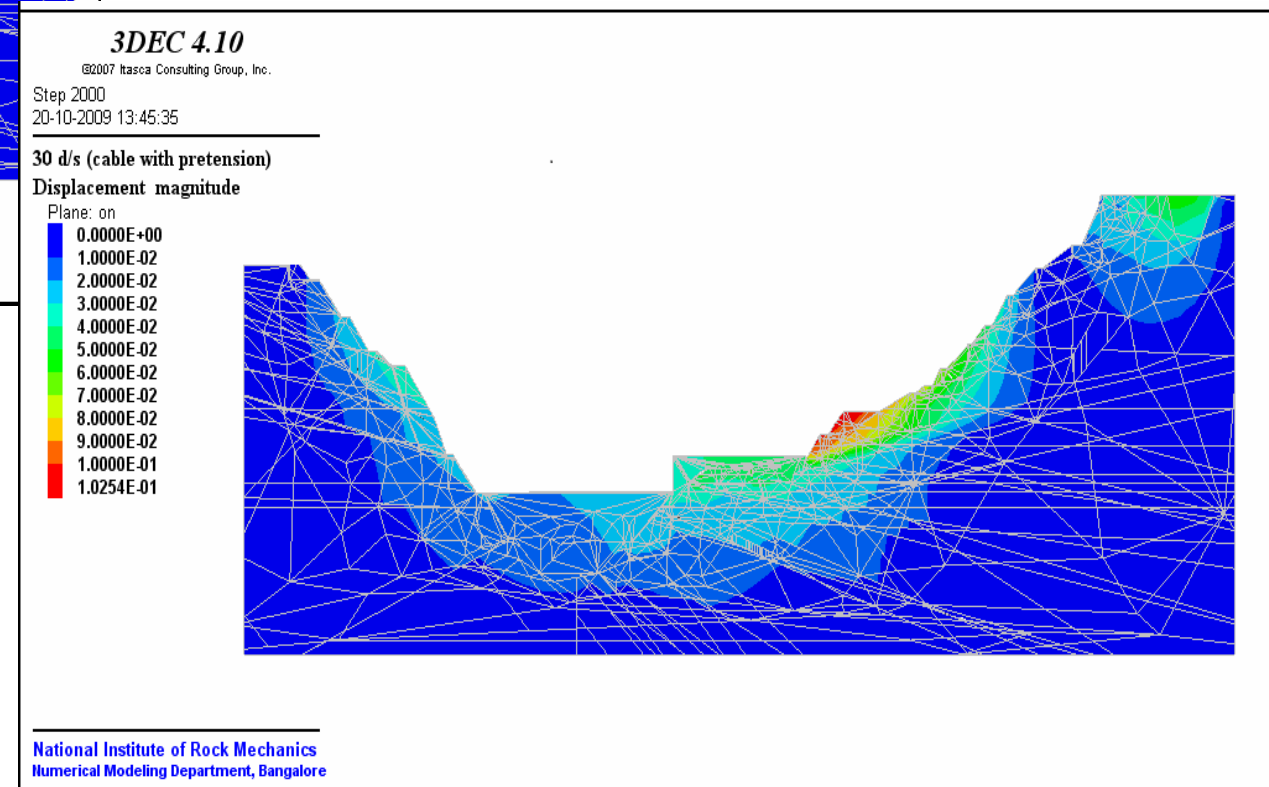
**The results also revealed that nearly 961 rock bolts were on the verge of yielding.**



## On Right abutment slopes :

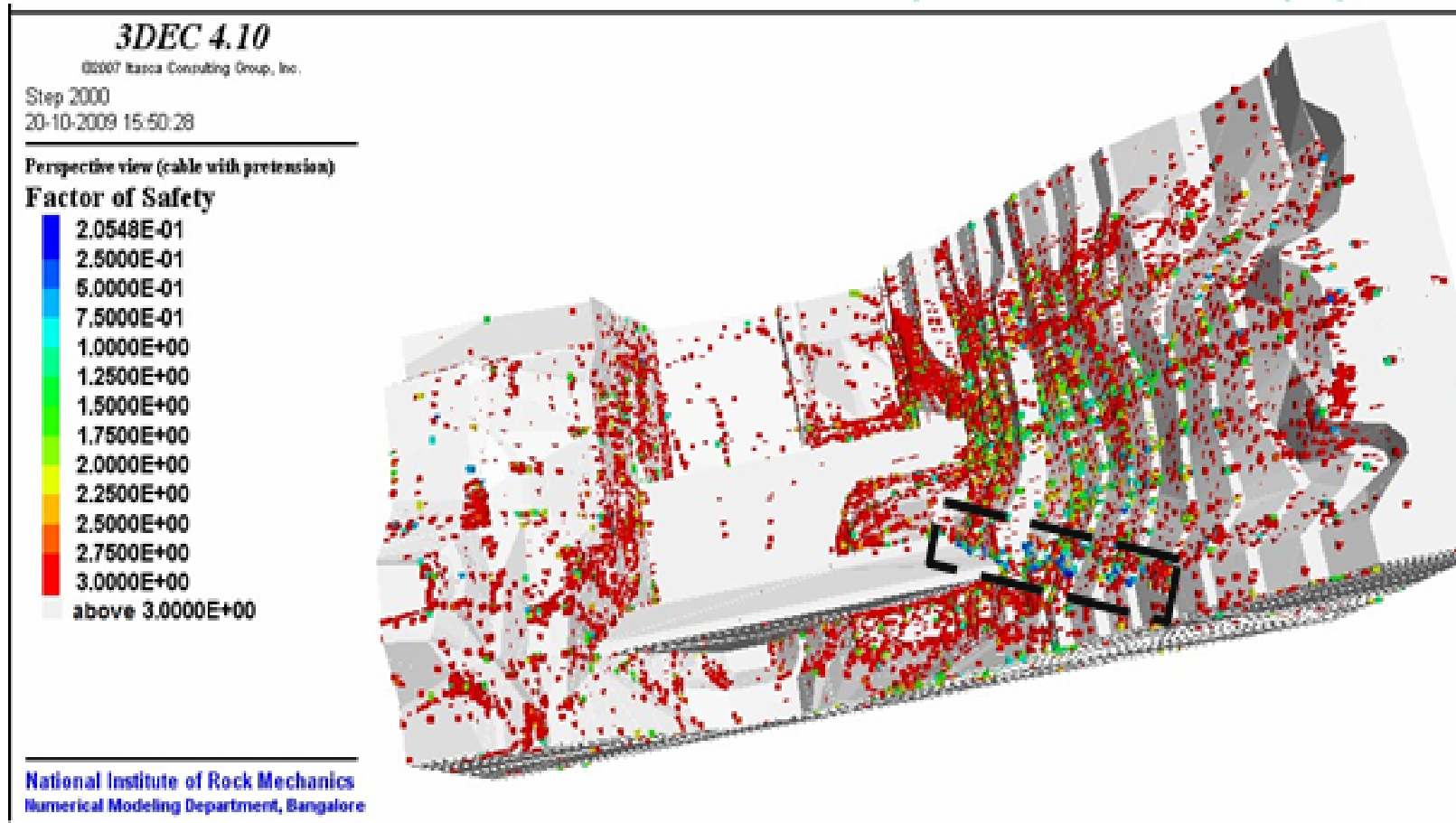
(Cable spacing 10m x 10m)

- Cable anchors from EL 590m to 630m at 30m d/s to 130m d/s
- Cable anchors from EL 605m to 630m at dam axis to 20m d/s
- Cable anchors from EL 628m to 660m at 10m u/s to 20m u/s



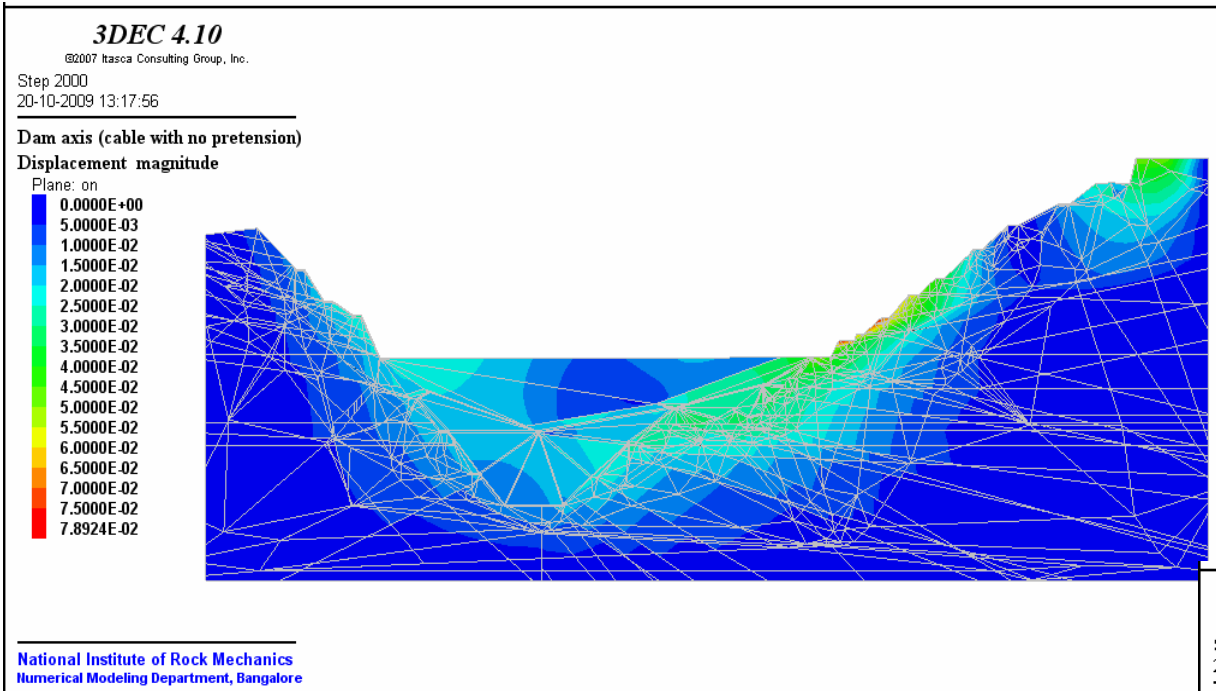
**Maximum Displacement at 30 d/s came down to 102.55 mm from 122mm with Pre-tensioned cable anchors**

**Maximum Displacement at Dam Axis came down to 79.99 mm from 87.14mm with Pre-tensioned cable anchors**



The number of bolts near yield was found to be 961. The results also revealed that nearly 77 pretensioned cable anchors were on the verge of yielding

It can be seen that the areas where sheared phyllite exist are more critical with FOS less than 1.5. However, the overall factor of safety has been improved by nearly 38% by providing cable anchors with pretension.

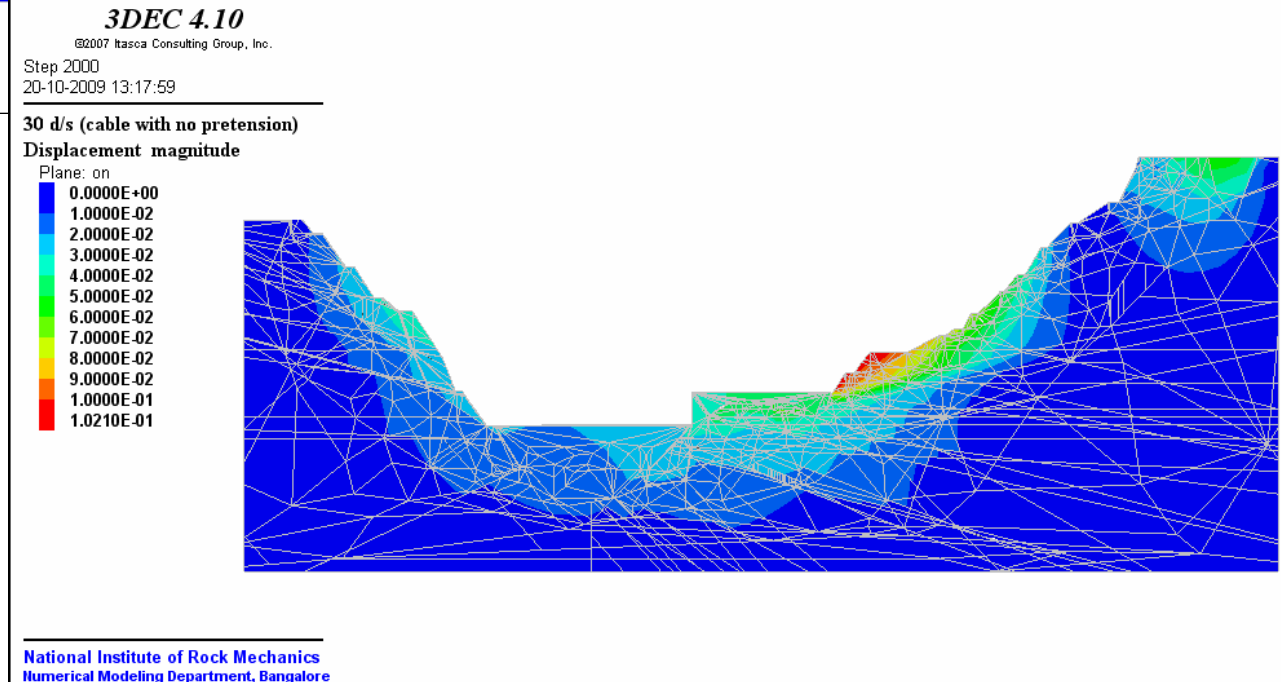


It can be observed that The number of rock bolts near yield remained same (961 nos) as Model 1 and Model 2 However, number of cable anchors near yield reduced from 77 nos in case of slopes provided with pretensioned cable anchors to 4 nos in case of slopes with no pretensioned cable anchors

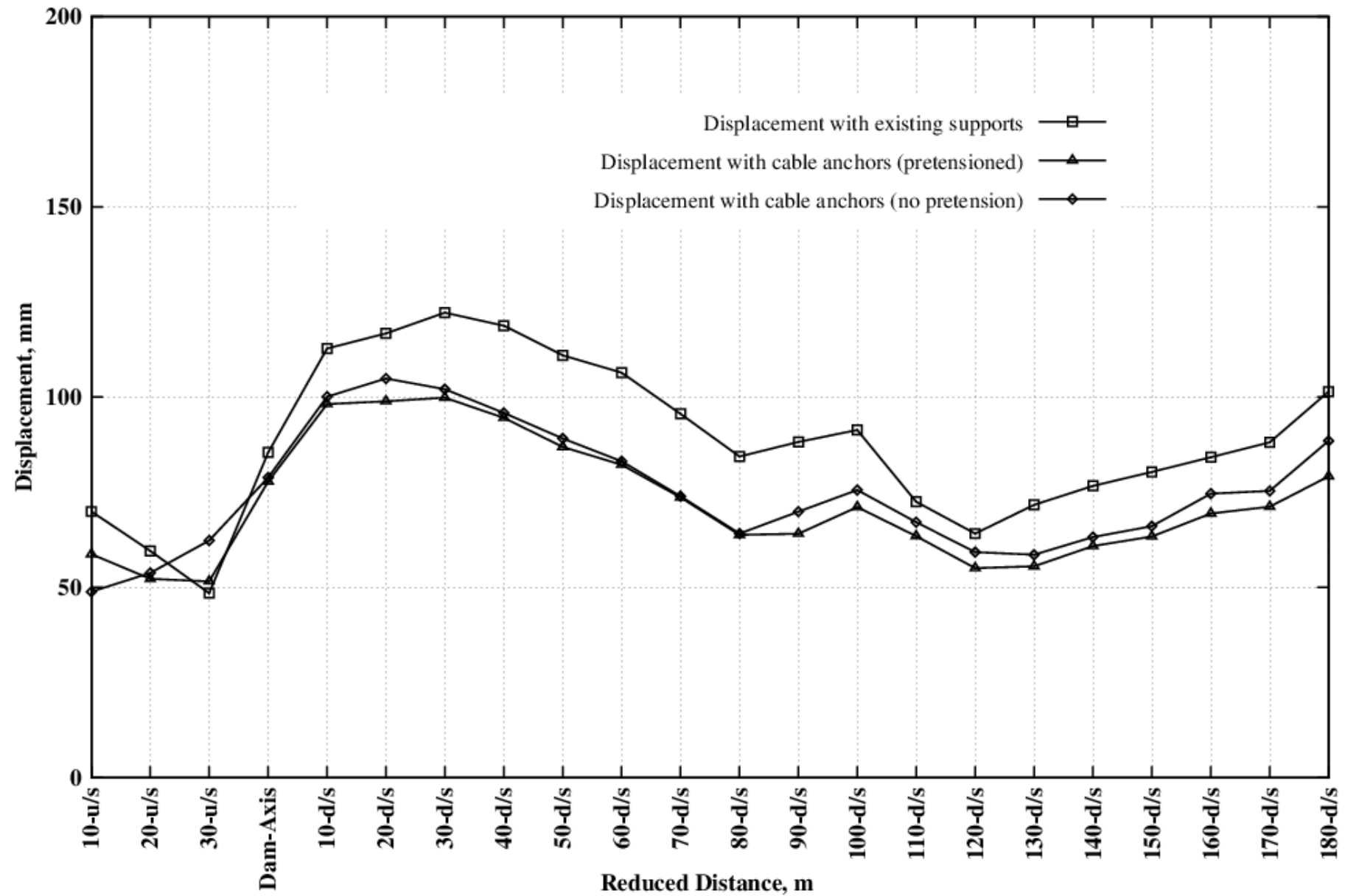
## With No Pre-Tensioning of the Cables

**No Appreciable Changes in Displacement compared to case with Cables –Pretensioned**

**The overall factor of safety of slopes, when cable anchors were not pretensioned, reduced by nearly 20% in comparison with slopes stabilized with pretensioned cable bolts.**



## Comparison of displacements obtained during analysis



# Conclusions

- **The first model with the existing support system showed maximum displacement of 162.64mm. The model shows significant displacement at upper elevation of left abutment slopes beyond 150m chainage in downstream side.**
- **Similarly, the right abutment slopes from dam axis to 150m chainage and EL of 570m to 640m experienced significant movement. The maximum movement was observed in the area of sheared phyllite contact with the limonotised puckered phyllites.**
- **It was observed that due to the orientation and angle of the slopes, the vertical component of the displacements are higher than the horizontal component.**

# Conclusions

- **The factor of safety at most of the location on the slopes was more than 1.5. However, on right abutment slope, factor of safety was found below 1.5 in the areas where sheared phyllites are exposed.**
- **The model studies clearly shows that cable anchors with no pretension are more suited for the present geological set up**



# Thank You