Support assessment and 3D stress analysis of large underground excavations: A case study using 3DEC

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Presented by

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INTRODUCTION

Objectives

- The design of support system and analysis of stress regime distribution during stage wise excavation of the two large parallel caverns and associated components.

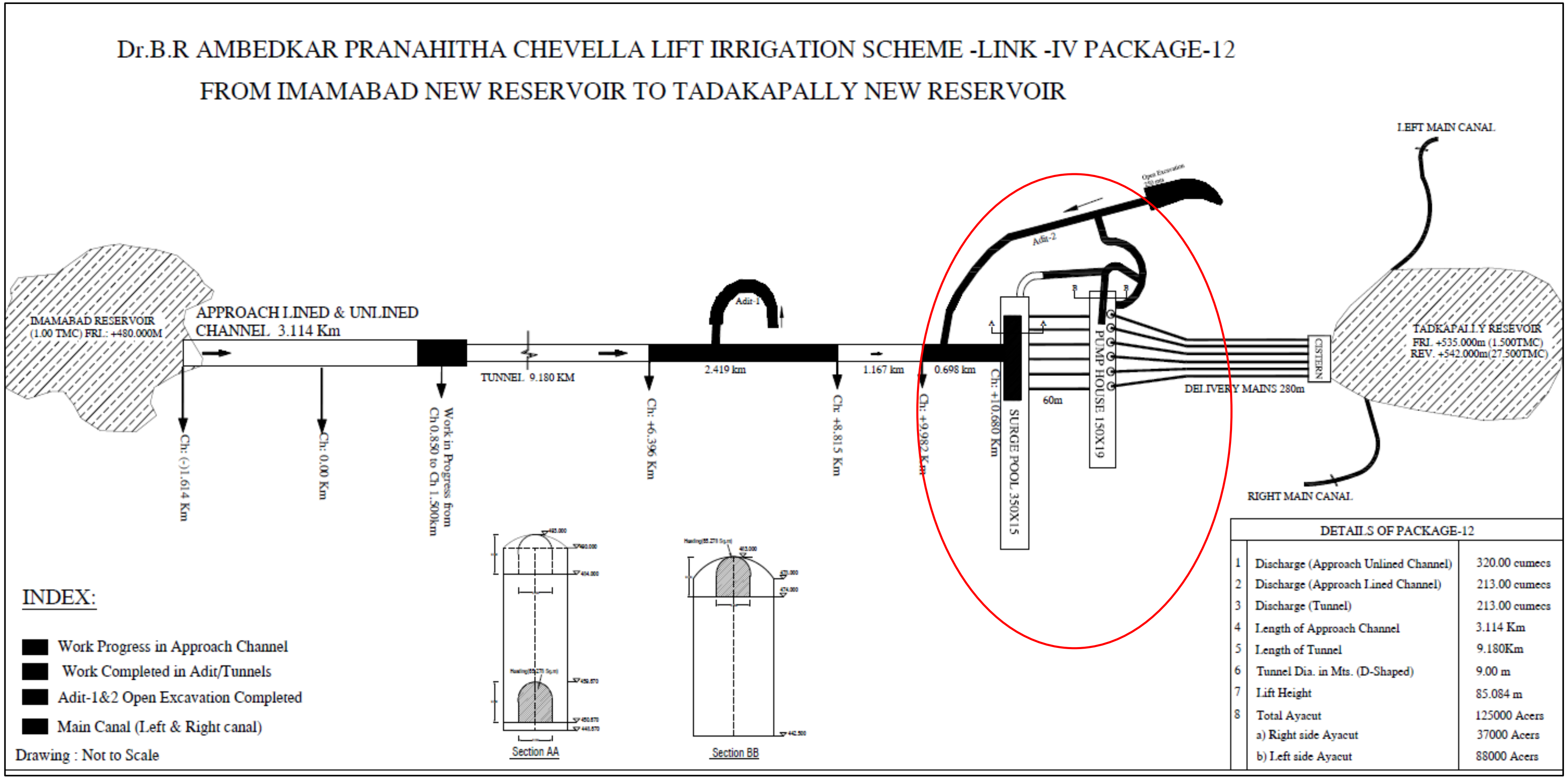
- The global stability of the excavations was evaluated by using Three-Dimensional Distinct Element Code (3DEC) (Itasca 2013).

- Geological data like Q-values, joint set data, rock contact details have been collected from the excavated central gullet of both the caverns. Weathered granite is observed in boreholes up to a depth of 24 m from surface

- Initially support was assessed based on guidelines given by Grimstad and Barton (1993)

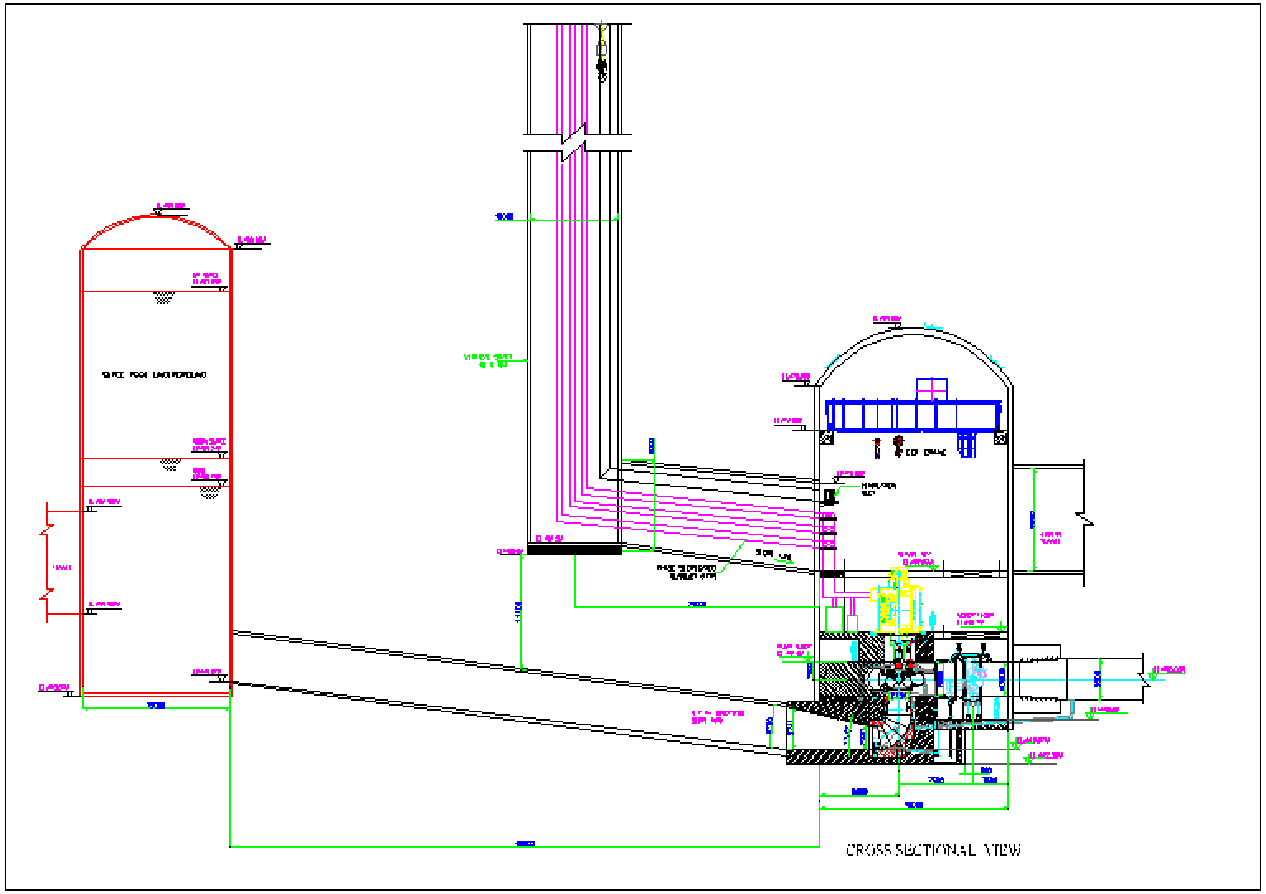
- Core samples collected from the exploratory drill hole from the pump house and surge pool area are tested for physico-mechanical properties

SCHEMATIC DIAGRAM



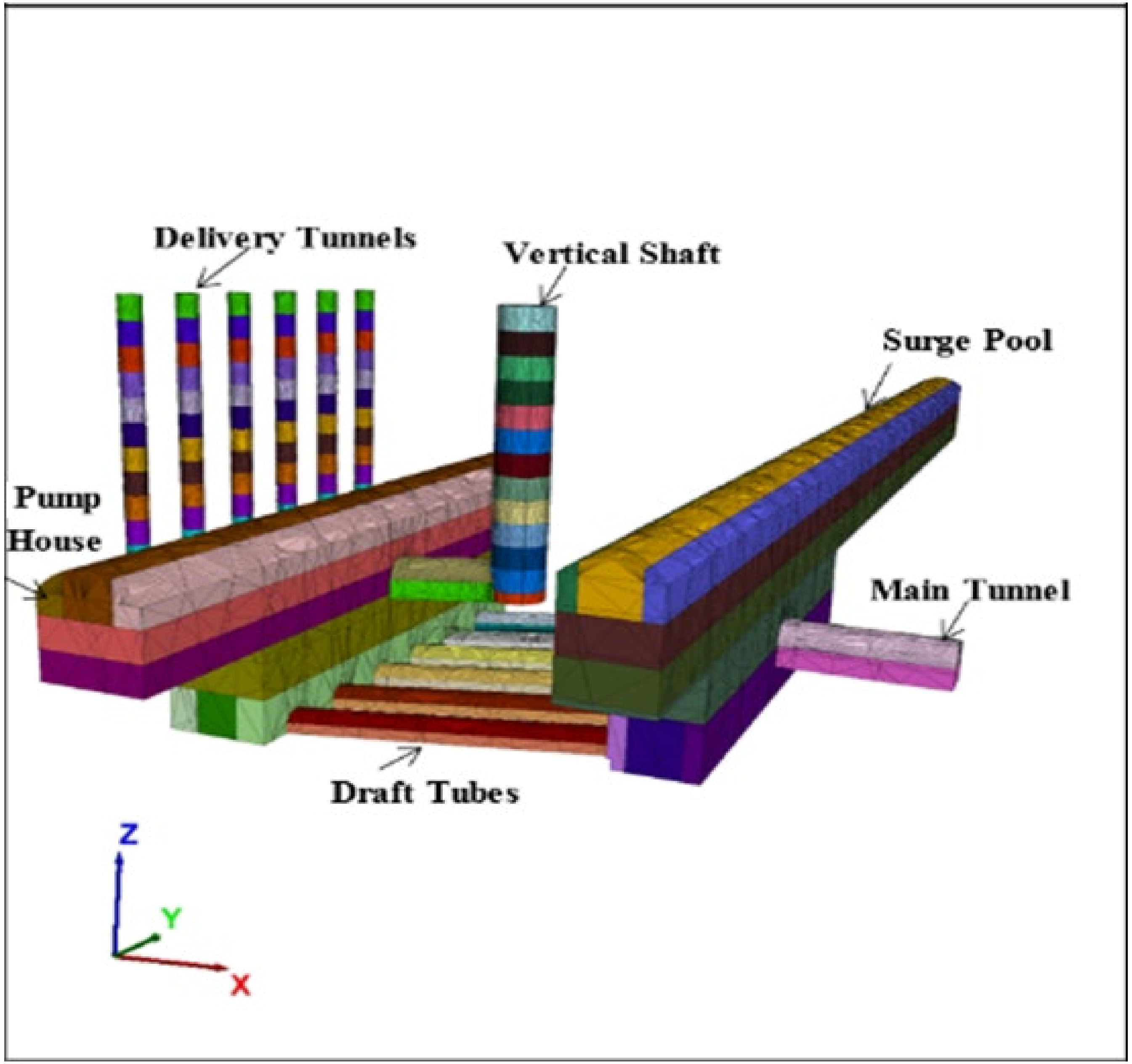
- ❑ **Surge pool connected to main tunnel of length 9.18 km, vertical shaft having a diameter of 10 m and 60 m depth, four draft tubes and delivery tubes having a diameter of 3.6 m**

SECTION VIEW



1. **Main tunnel (9m dia. D-shaped tunnel, 9.18 km long)**
2. **Surge pool 350m (L) x 15m (W) x 44.33m (H)**
3. **4 No`s Draft tubes (60m (L) x 5.25m (W) x 3.7m (H) each)**
4. **Pump house 150 (L) x 19m (W) x 40.5m (H)**
5. **Vertical shaft i.e. cable shaft (10m dia., 64m depth)**
6. **4 No`s Delivery tunnels (15m (Horizontal Length) x 3.6m dia. each)**

DESIGN AND ANALYSIS



- The surface ground level elevation of the study area is 526 m, the crown of the pump house is 483 m and the bottom level is 442.5 m. The crown level of the surge pool is 493 m and the bottom level is 448.67 m

- Excavation of bench height varies from 6 to 11 m

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DESIGN AND ANALYSIS

- **Based on the central gullet geological mapping data of the pump house and surge pool, it was observed that the granitic rock mass is highly jointed and contains four predominant joint sets (J), dip (D)/ dip direction (DD) J1=80º/340º, J2=70º/154º, J3=80º/080º, J4 82º/264º and horizontal joint sets spacing varying from 6 to 60 cm.**

- **Classification of rock mass was carried out using Tunneling Quality Index (Q) Barton et al (1974) and the values range from 11.81 to 55.21**

- **From drill hole logs indicated highly disintegrated rock mass up to 2.5 m depth, and from 2.5 m to 24 m consisted of weathered granite followed by fresh granite**

- **The depth of overburden considered is 30 m for estimating the properties.**

- **A blasting zone thickness of 3 m is considered all around the excavations of the pump house and surge pool cavern. A disturbance factor of 0.8 was considered for arriving at the blast zone material properties.**

- **100 mm thick Steel Fibre-Reinforced Shotcrete (SFRS) is modelled as liner elements.**

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Property of rock mass based Hoek and Brown Criteria

Hoek and Brown Classification – Input Parameters				
Property	For Fresh Granite		For Weathered Granite	Unit
Uniaxial Compressive Strength, s_{ci} (lab Value)	217	217	100	MPa
GSI	66	66	66	
m_i	32	32	16	
Disturbance Factor	0	0.8	0	
Young's Modulus, E	75.7	75.7	37.5	GPa
Poisson's ratio, ν	0.25	0.25	0.25	
Hoek and Brown Failure Criterion - Parameters				
m_b	9.50	4.23	4.75	
s	0.022	0.0058	0.022	
a	0.50	0.50	0.50	
c	2.53	1.42	1.63	MPa
ϕ	71.3	68	64.11	deg
Rock Mass Parameters				
Uniaxial Compressive Strength of rock mass, s_c	32.59	16.36	15.02	MPa
Rock Mass Tensile Strength, s_t	0.52	0.29	0.48	MPa
Rock Mass Strength, s_{cm}	91.82	60.31	30.85	MPa
Elastic Modulus of Rock mass, E_{rm}	49.44	18.18	24.49	GPa
Bulk Modulus, K	28.15	10.3	14.07	GPa
Shear Modulus, G	20.24	7.44	10.12	GPa
Density	2600	2600	1800	kg/m^3

The rock mass parameters considered for analysis are estimated based on Hoek et al. (2002) and Hoek & Diederiches (2006)

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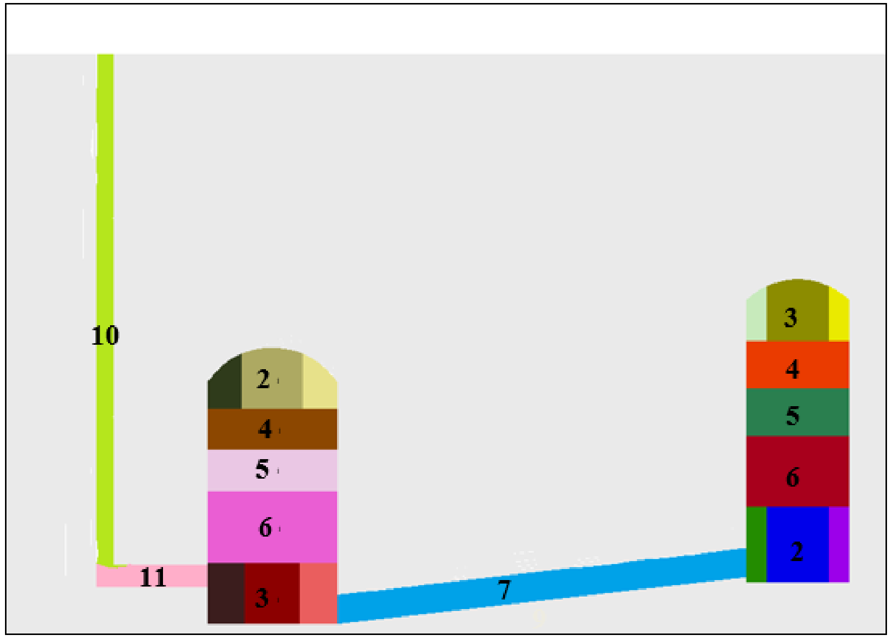
EXCAVATION SEQUENCE

Stage	Components					
1	Main Intake Tunnel					
	Surge Pool			Pump House		
	EL, m From	EL, m To	Height, m	EL, m From	EL, m To	Height, m
2	459.67	448.67	11	483	474	9
3	493	484	9	451.5	442.5	9
4	484	477	7	474	468	6
5	477	469	8	468	462	6
6	469	459.67	9.33	462	451.5	10.5
7	4 No's Draft Tube Tunnels					
8	Vertical Shaft					
9	Inclined Tunnel connecting Vertical Shaft					
10	Vertical Delivery Shafts					
11	Horizontal Delivery Tunnels Vertical Delivery Shafts					



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INSITU STRESS

The insitu stress measurement at pump house was carried out by NIRM (2014) by hydro fracturing method. The measurement was done in NX size borehole drilled up to a depth of 70.30m. Following are the summary of results

Principal Stresses	
Vertical Stress (σ_v) in MPa (Calculated with a rock cover 42.00 m and density of rock = 2.7 gm/cc)	1.11
Maximum Horizontal Principal Stress (σ_H) in MPa	1.84
Minimum Horizontal Principal Stress (σ_h) in MPa	1.24
Maximum Horizontal Principal Stress direction	N 150^0
$K = \sigma_H/\sigma_v$	1.65

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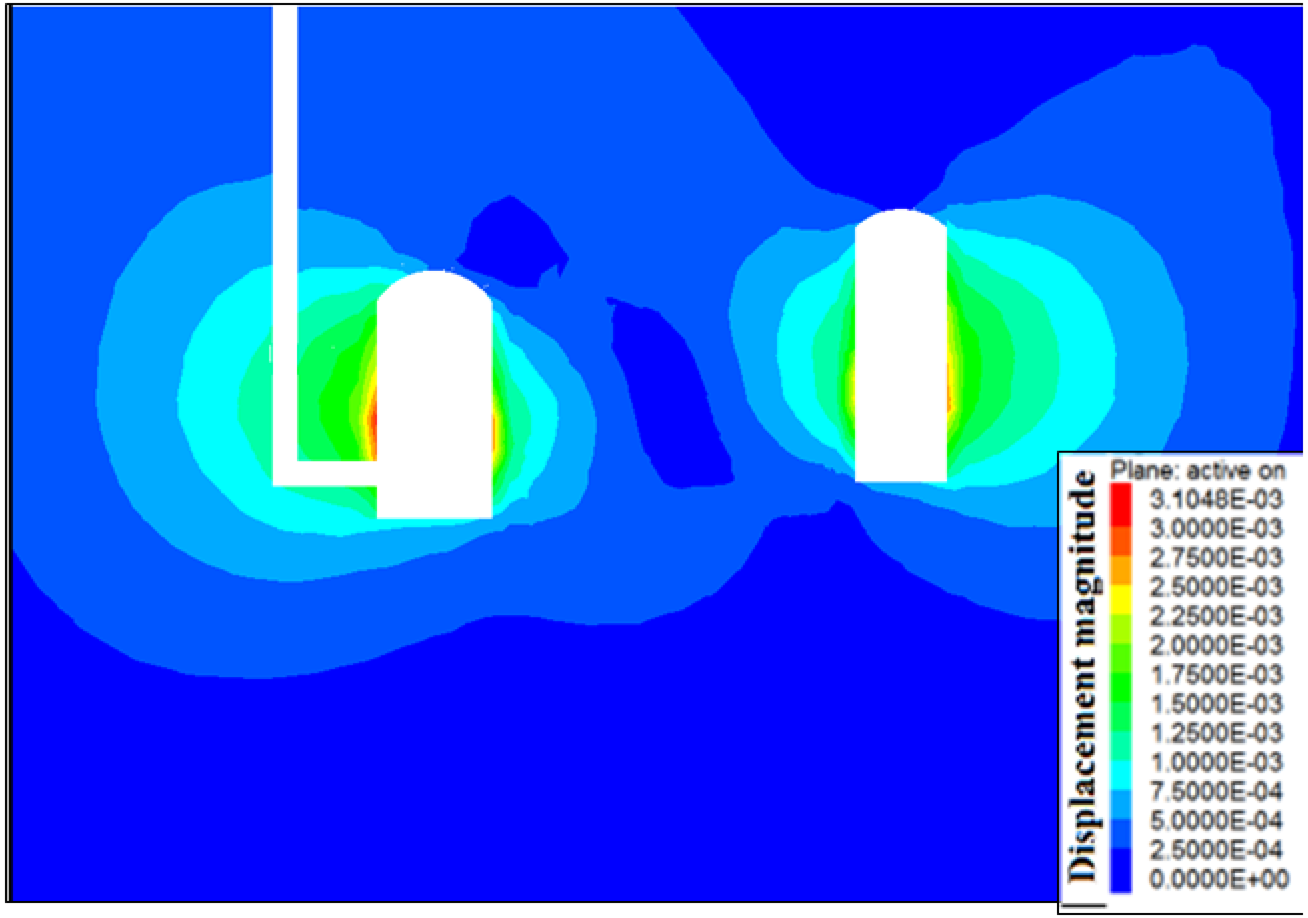
Joint Properties

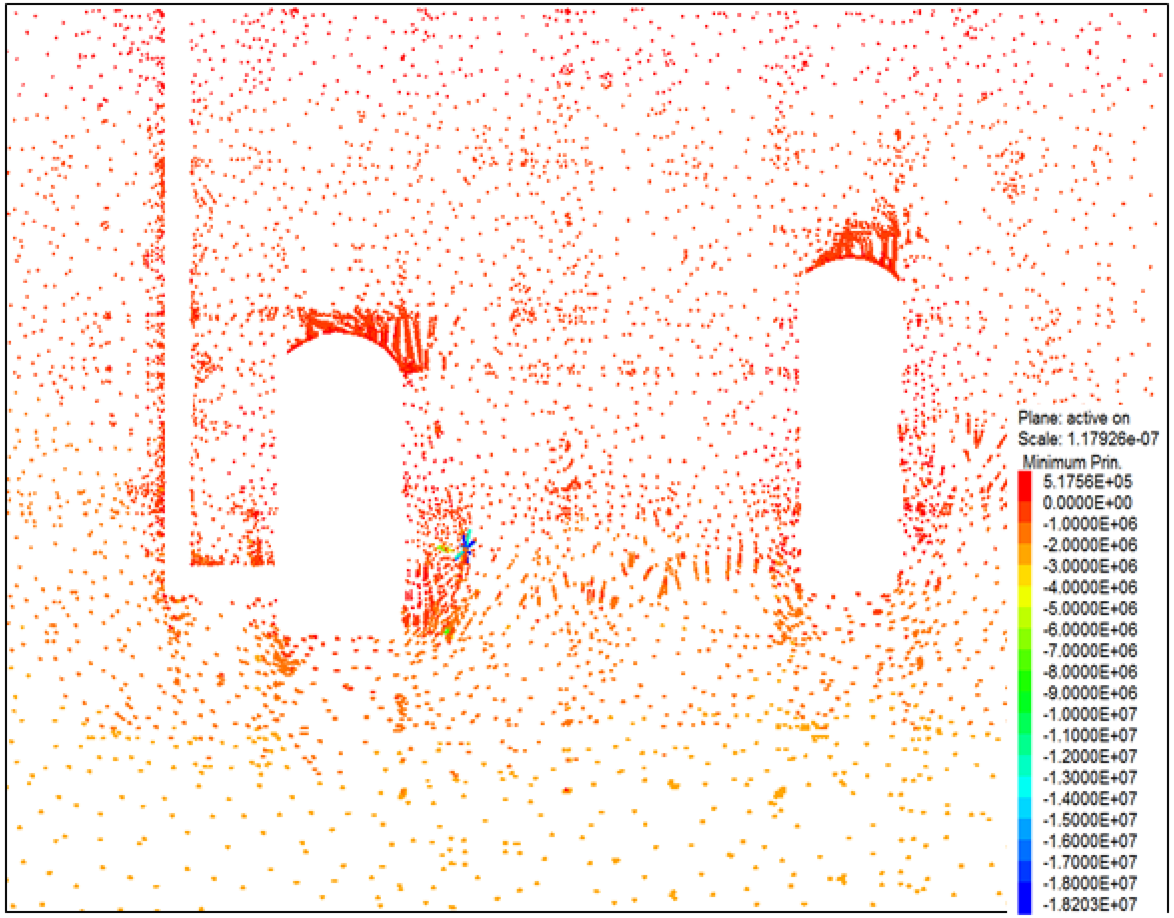
Property	Value	Unit
Joint Normal Stiffness	100	GPa/m
Joint Shear Stiffness	75	GPa/m
Joint Cohesion	8	MPa
Joint Friction	46	Deg.
Joint Tensile Strength	8	MPa

Since there is no test data available regarding to joint properties, following data are considered in the model.

RESULTS AND DISCUSSION

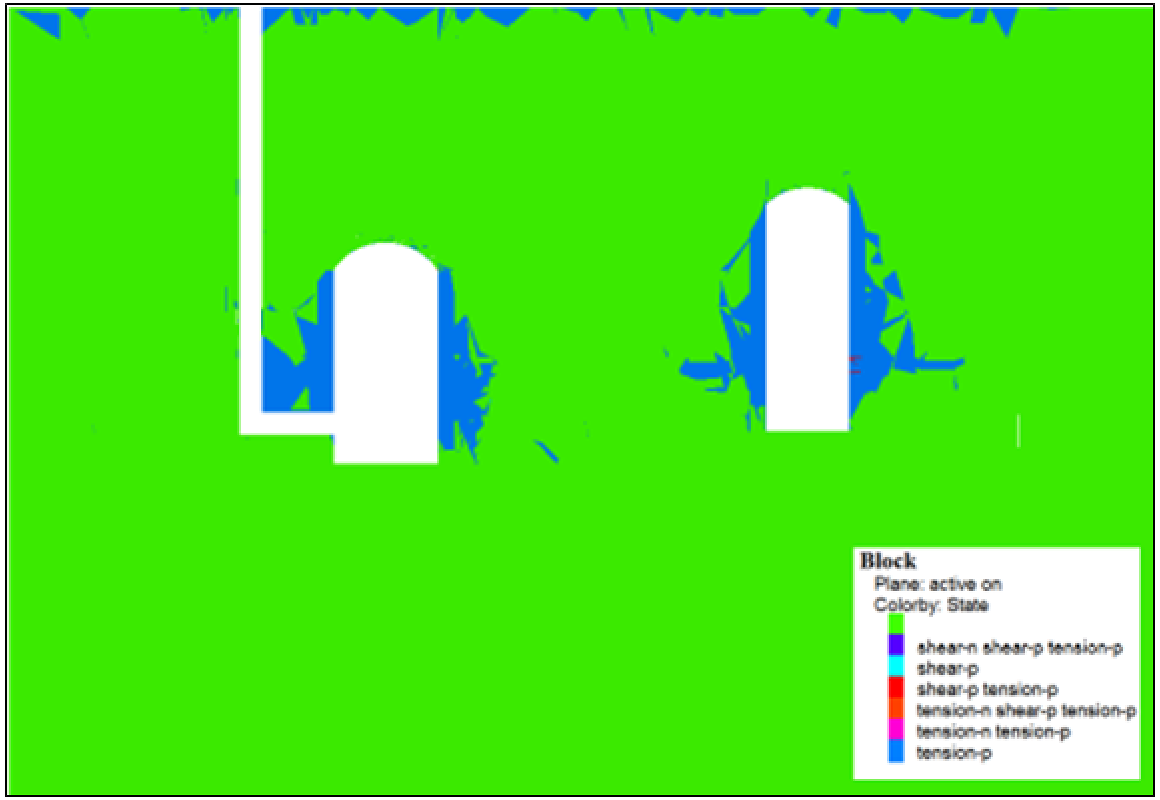


Displacement contours

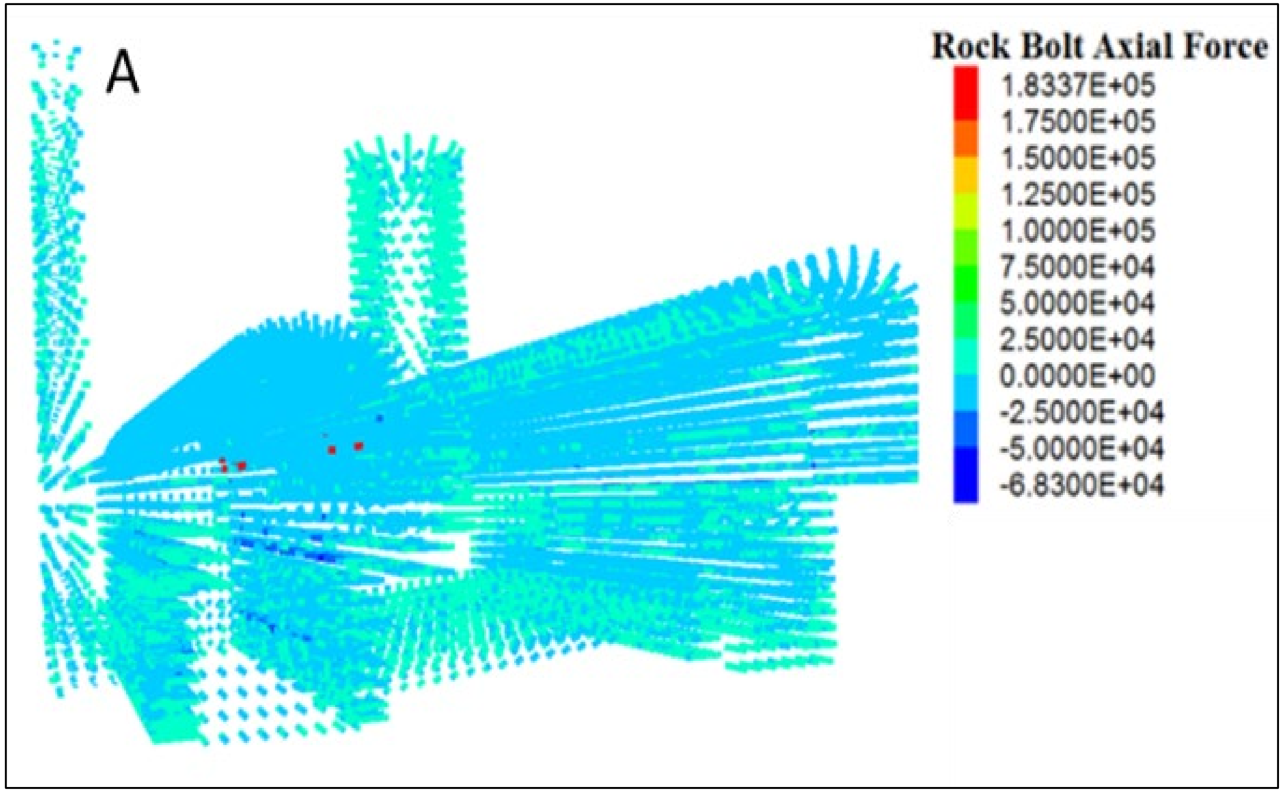


Minimum principal stress distribution

RESULTS AND DISCUSSION



State of rock mass



Axial force in rock bolts after complete excavation

CONCLUSIONS

- The crown displacements were negligible
- Wall displacements in the pump house and surge pool vary in the range of 2 to 3.7 mm
- The supports were found capable of arresting the movements further away from the cavern rock line.
- It may be noted that Strength to Stress ratio at most of the places is more than one
- The required supports for surge pool and pump house are estimated using empirical approach and their adequacy for the current geological setup was ensured using 3D discontinuum model.
- The support considered for pump house and surge pool is given below:
  - 25 mm diameter 5 m long rock bolt in crown @ 2.3 m c/c spacing
  - 25 mm diameter 6 m long rock bolt in walls @ 2.5 m c/c spacing
  - 100 mm SFRS to be put in crown as well as in the walls

Following recommendations are made to improve the stability of the caverns with the support system

- Controlled blasting techniques may be adopted in order to minimize the damage in the immediate vicinity of the excavation
- Systematic instrumentation needs to be implemented and observed during excavation to reconcile the model results

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Thank You