FIFTH INTERNATIONAL ITASCA SYMPOSIUM 2020 VIENNA, AUSTRIA

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Design of support system for surge shaft and powerhouse complex using *FLAC3D*

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Presented by
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Salient Features

Country	: India
Installed capacity	: 60 MW
Diversion structure	: Barrage of 18.5m height
Desilting chamber	: 1 No., 130m (L) x 25m (W) x 13.5m (H)
Head race tunnel	: Modified Horseshoe shape, dia.5.6m, 4342m (L)
Surge shaft	**: dia. 20m, Height 67.5m**
Pressure shaft	**: dia. 4m and length 154m (L)**
Machine hall cavern (MH)	**: 58m (L) × 18.8m (W) × 33.70m (H)**
Transformer hall cavern (TH)	**: 73.11m (L) × 12.2m (W) × 13.65m (H)**
Rock pillar between MH & TH	**: 35m**
Tail race tunnel	: D- shaped, dia. 8m and 235.62m (L)

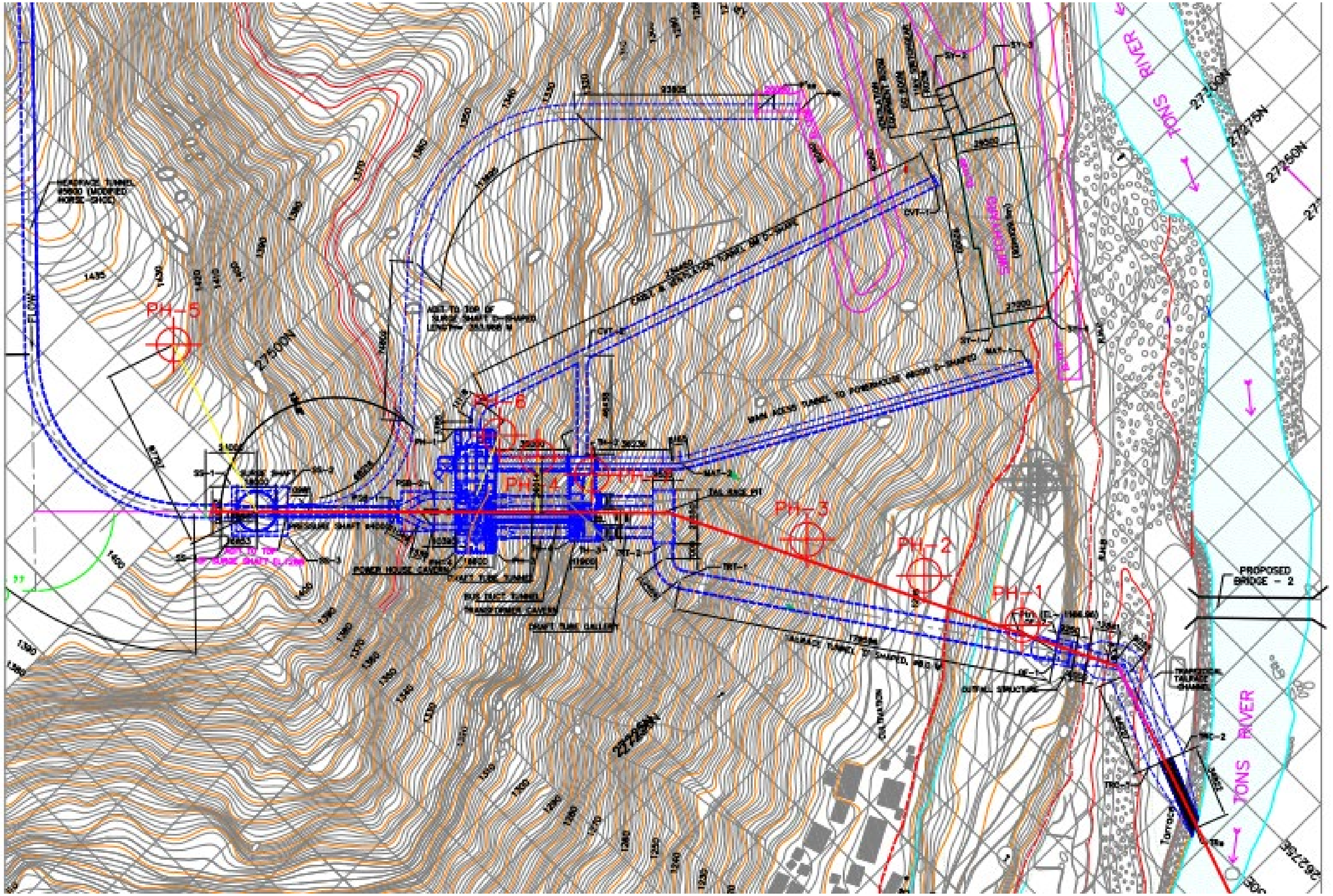
Objective

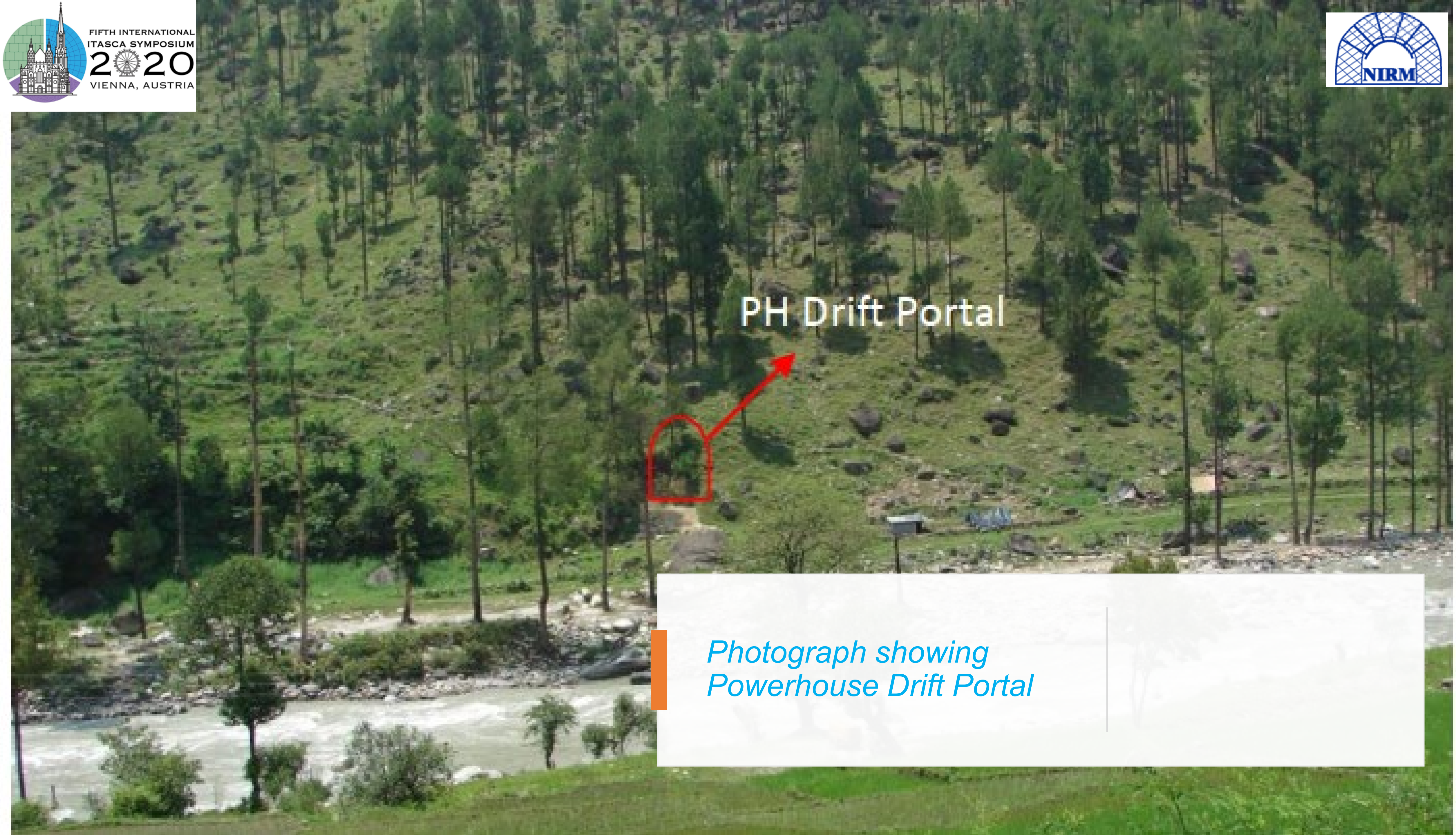
The primary objective of the study was to suggest suitable support system for surge shaft, machine hall cavern and transformer hall cavern

Geology of the area

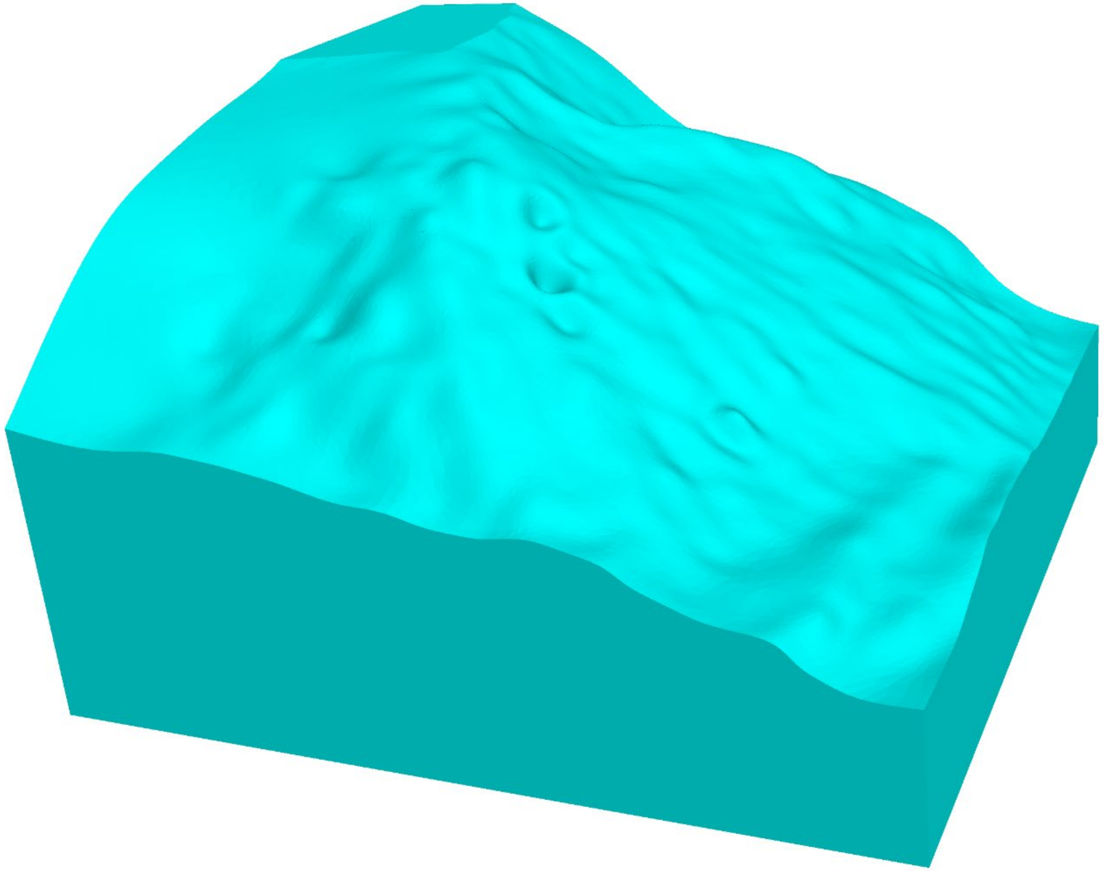
- The rock mass in the surge shaft and powerhouse complex consists of mainly metamorphic rock variants i.e. Porphyroblastic Gneiss, Biotite Gneiss, Quartzite Biotite Schist and Basic Rock.
- The rock mass in general is highly foliated and sheared.
- A drift having a length of about 327m reaching crown of powerhouse has been excavated.
- The powerhouse location was explored by seven drill holes.

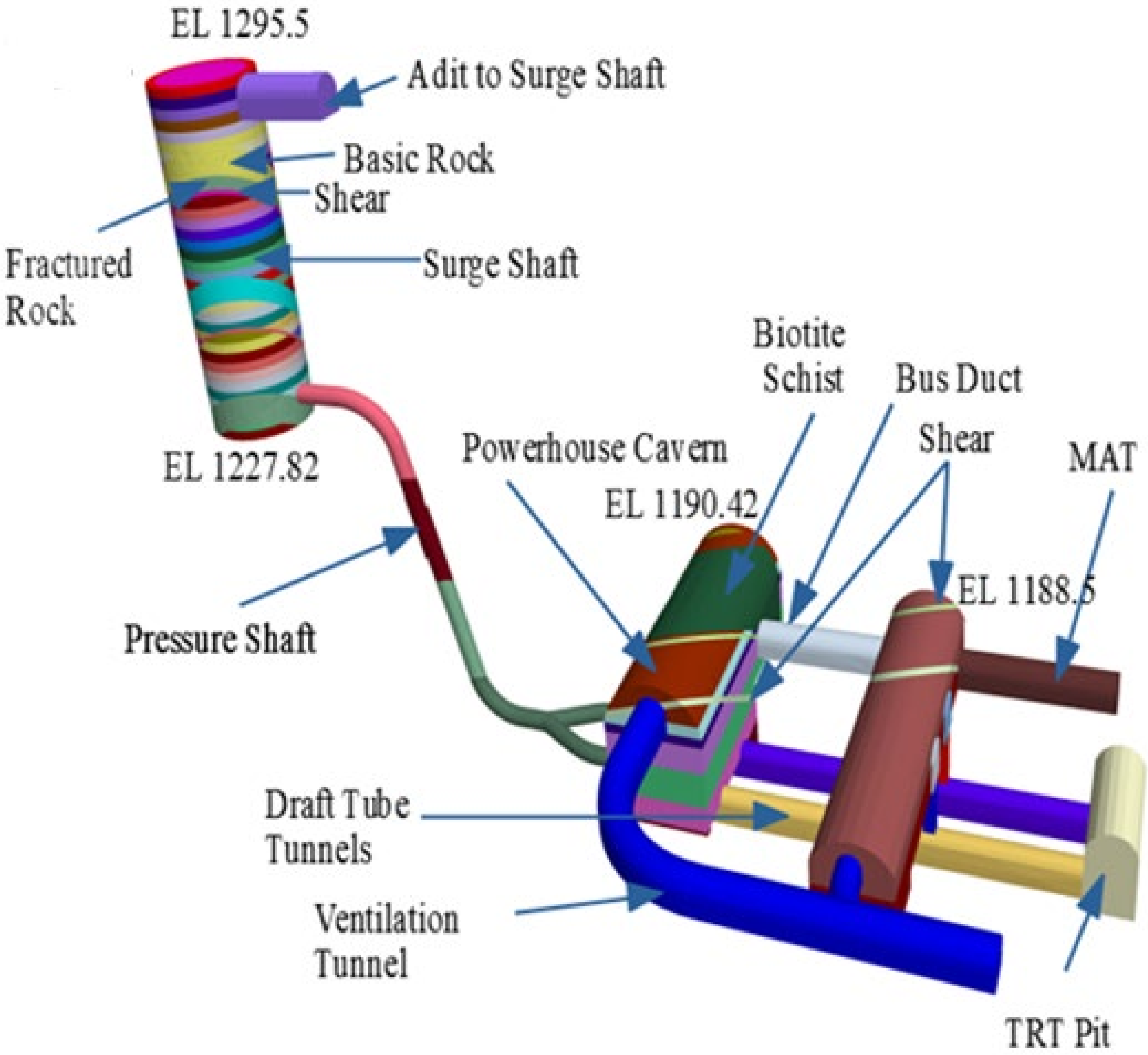
Layout Plan



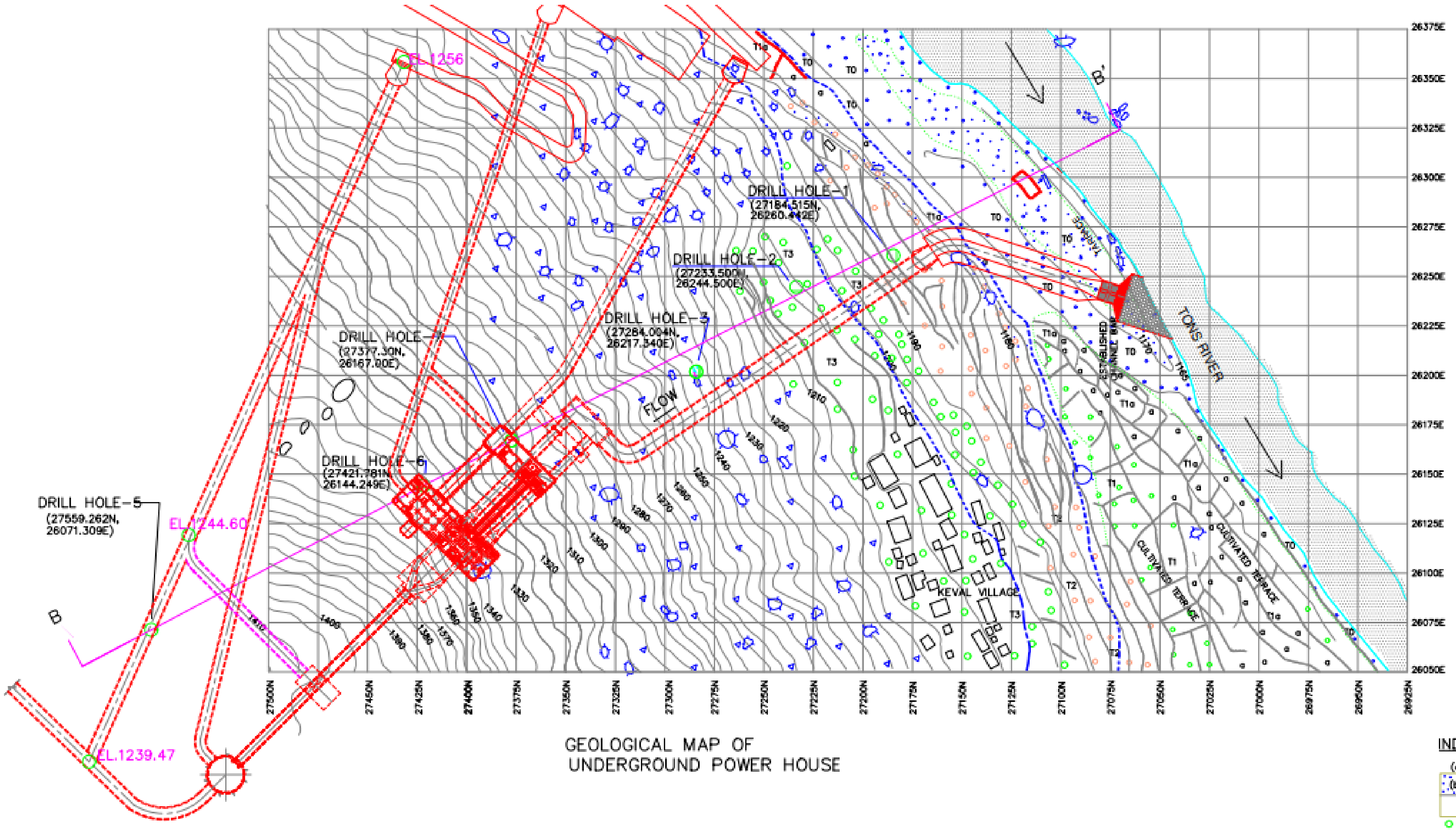


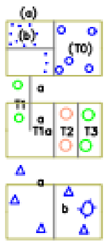
Photograph showing Powerhouse Drift Portal




EL 1295.5
Adit to Surge Shaft
Basic Rock
Shear
Fractured Rock
Surge Shaft
EL 1227.82
Biotite Schist
Bus Duct
Shear
Powerhouse Cavern
MAT
EL 1190.42
EL 1188.5
Pressure Shaft
Draft Tube Tunnels
Ventilation Tunnel
TRT Pit

Geological plan of powerhouse complex



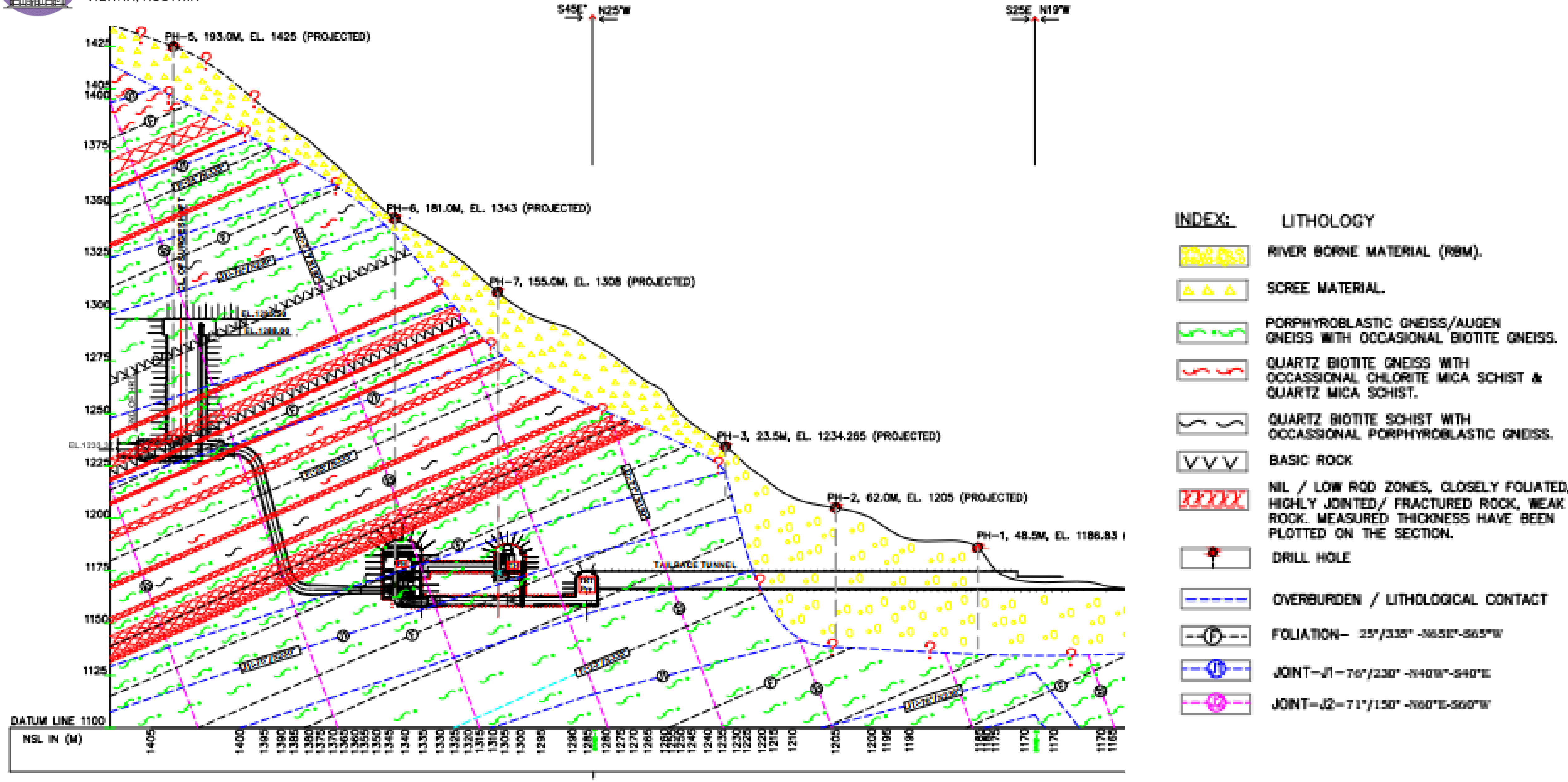


COARSE MEDIUM TO FINE GRAINED MICACEOUS SAND WITH PEBBLES & BOULDERS OF SCHIST, GNEISS AND QUARTZITE.
(a). PRESENT DAY RIVER CHANNNEL (b). ABANDONED CHANNEL

GRAYISH BLACK SILTY CLAY, SANDY AND MEDIUM TO COARSE GRAINED SAND WITH WITH SUBROUNDED TO ROUNDED PEBBLES AND BOULDERS OF GNEISS, SCHIST & QUARTZITE.

ANGULAR TO SUBANGULAR PEBBLES AND BOULDERS OF SCHIST, GNEISS BASIC ROCKS AND QUARTZITE WITH OXIDISED SILTY CLAY AND SAND (OVER BURDEN MATERIAL):
(a) DEBRIS (SLOPWASH)
(b) DEBRIS (OVER BURDEN) DEMINATED BY BIG ROCK BLOCKS

Geological section from surge shaft to powerhouse

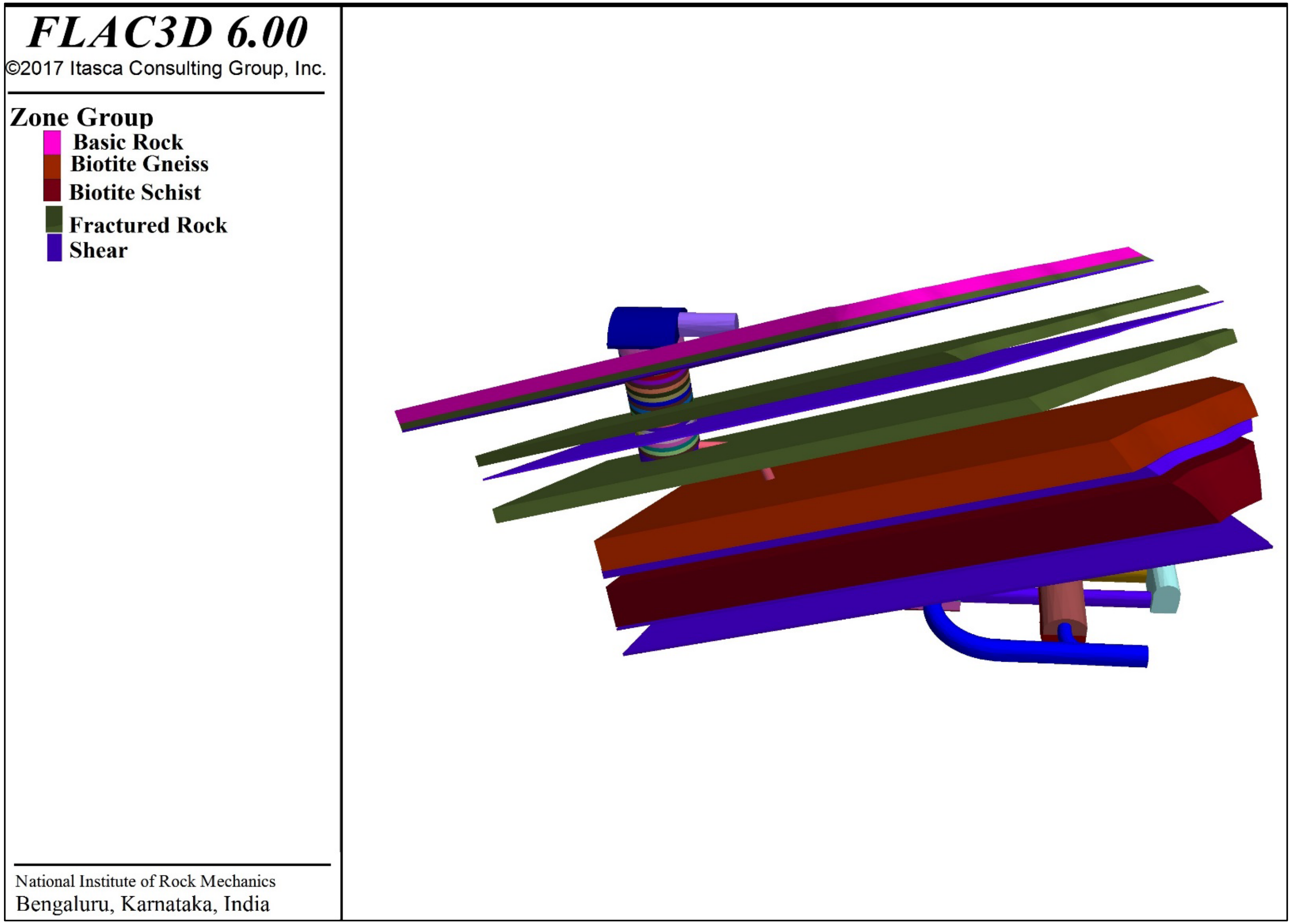


Rock variants and their thickness considered in the model

S. No.	Rock Type*	Thickness (m)	Elevation (m)	Projection Encountered
1	Basic Rock	5	1283.70	Surge Shaft
2	Fractured Rock	2.5	1278.20	
3	Shear	0.8	1275.30	
4	Fractured Rock	4	1260.00	
5	Shear	0.5	1250.76	
6	Fractured Rock	5	1235.82	
7	Biotite Gneiss	10	1218.00	Pressure Shaft
8	Shear	4.5	1205.00	
9	Biotitie Schist	20	1190.42	Powerhouse Cavern
10	Shear	1	1190.42	
11	Shear	1.4	1190.42	
12	Porphyroblastic Gneiss			Host Rock

* Rock variants are considered to be parallel to foliation (30^0/N020^0)

Geology considered in FLAC3D model



In-situ stress data

- Hydraulic fracture method has been used to determine the in-situ stresses.

Principal Stresses	
Vertical stress (σ_v) in MPa (for Overburden cover of 164.5m, density of rock 2.7gm/cc)	4.35
Maximum horizontal principal stress (σ_H) in MPa	5.38
Minimum horizontal principal stress (σ_h) in MPa	2.68
Maximum horizontal principal stress direction	N40°
$K_H = (\sigma_H)/\sigma_v$	1.24
$K_h = (\sigma_h)/\sigma_v$	0.62

- Maximum horizontal principal stress direction is N40° and the longitudinal axis of the powerhouse caverns is N45°

Material properties considered in model

Parameters		Units	Porphyr-oblastic Gneiss	Biotite Gneiss	Biotite Schist	Basic Rock	Fractured Rock	Shear
Uni-axial compressive strength	UCS	MPa	50	42.24	61.44	40.32	40.32	40.32
Geological strength index	GSI		52	45	51	36	32	20
Elastic Young's modulus of intact rock	Ei	GPa	22.85	21.24	24.75	18.54	18.54	18.54
Poisson's ratio	v		0.24	0.26	0.27	0.21	0.21	0.21
Density	γ	kg/m^3	2750	2600	2600	2600	2200	1800
m_i			20	28	12	12	12	12
Disturbance Factor D=0								
Elastic Young's modulus of rock mass	E_{rm}	GPa	7.9	4.7	8	2.2	1.7	0.7
Cohesion	c	MPa	0.829	0.725	0.839	0.483	0.44	0.253
Friction angle	φ	Deg	53.64	53.25	50.69	43.31	41.9	39.89
Disturbance Factor D=0.8								
Elastic Young's modulus of rock mass	E_{rm}	GPa	2.37	1.43	2.41	0.7	0.65	0.47
Cohesion	c	MPa	0.540	0.466	0.509	0.27	0.24	0.11
Friction angle	φ	Deg	44.83	42.83	41.55	30.42	28.19	23.31

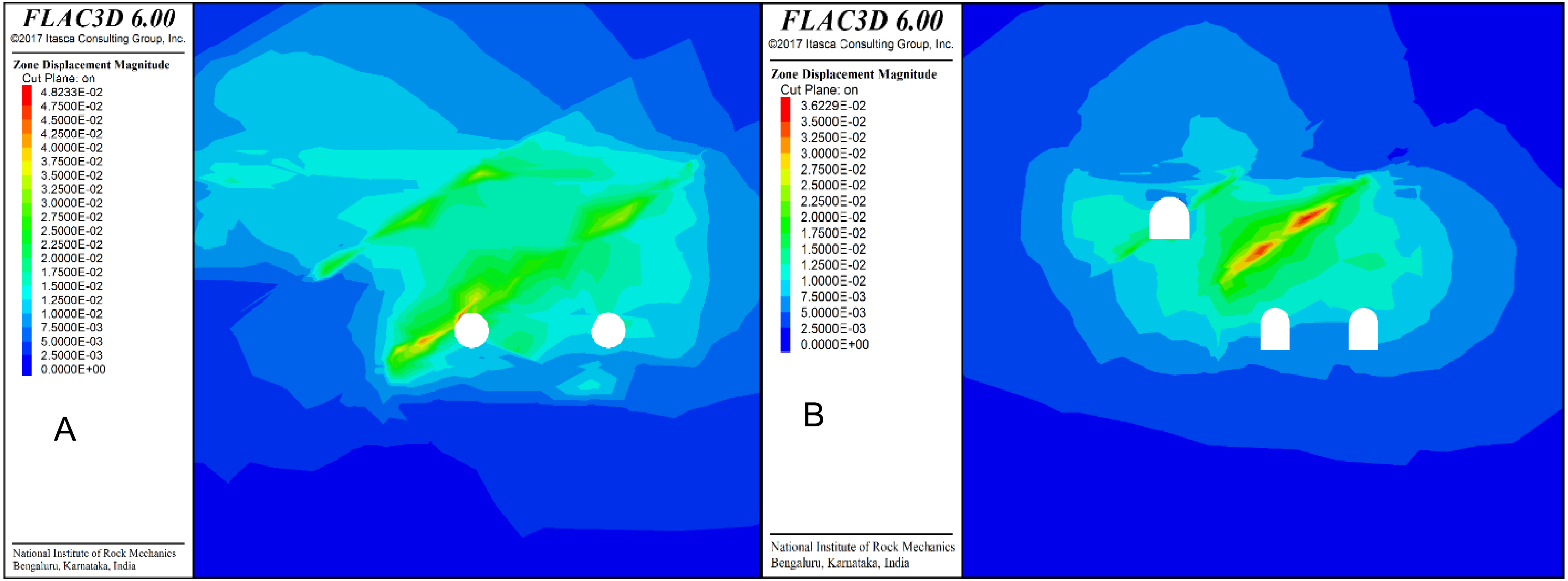
Excavation sequence considered in model

Stage	Components				
1	Surge shaft excavated at 2m depth intervals from EL 1295.5 to EL 1227.82				
2	Pressure shaft excavation				
3	Pressure shaft manifold and unit penstocks				
4	Ventilation tunnel to Powerhouse crown and Transformer hall crown				
	Powerhouse Cavern			***Transformer Hall Cavern***	
		From EL (m)	To EL (m)	From EL (m)	To EL (m)
5	Crown	1190.42	1185.40	1188.50	1185.50
6	Crown	1185.40	1182.95	-	-
7	Excavation of Main Access Tunnel to PH & TH				
8	Bench1	1182.95	1181	1185.50	1181
9	Bench2	1181	1175.35	1181	1174.88
10	Bench3	1175.35	1167.95	-	-
11	Bench4	1167.95	1162.55	-	-
12	Bench5	1162.55	1154.30	-	-
13	TRT Gates excavation				
14	Draft Tubes & TRT excavation				
15	TRT Pool/Chamber excavation				

Support system considered in the model

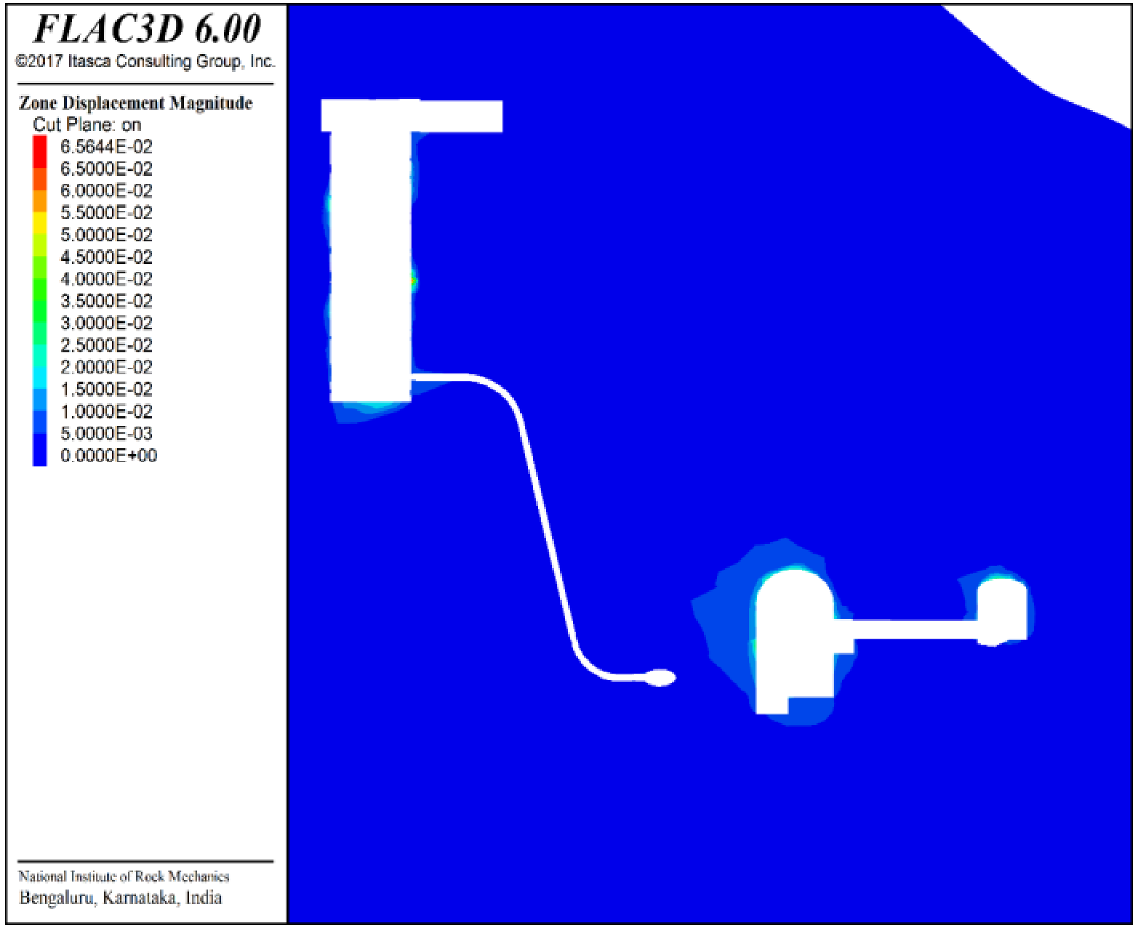
Component	Support System
Surge shaft	8 m long 32 mm dia. Fe500 rock bolts at 1.5 m c/c (staggered) 100 mm thick steel fiber reinforced shotcrete (SFRS)
Powerhouse crown	6.5 m long 32 mm dia. Fe500 rock bolts at 1.7 m c/c (staggered) 150 mm thick SFRS
Powerhouse walls	6.5 m & alternatively 10 m long 32 mm dia. Fe500 rock bolts at 1.7 m c/c (staggered) 150 mm thick SFRS
Transformer hall crown & walls	5 m long 32 mm dia. Fe500 rock bolts at 1.5 m c/c (staggered) 150 mm thick SFRS
Penstocks, draft tubes, ventilation tunnels & Main access tunnels	3 m long 25 mm dia. Fe500 rock bolts at 1.5 m c/c (staggered) 100 mm thick SFRS
TRT pit	4.5 m long 32 mm dia. Fe500 rock bolts at 1.5 m c/c (staggered) 100 mm thick SFRS

Displacement contours



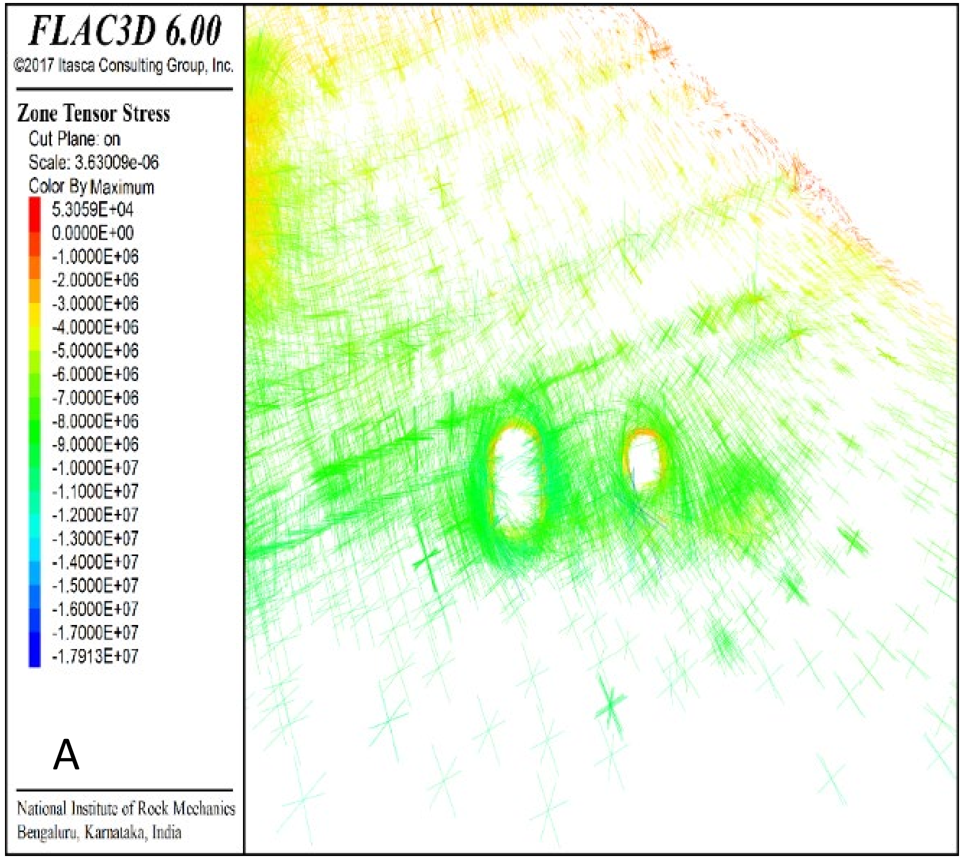
Displacement contours of powerhouse cavern (A) Upstream wall and (B) Downstream wall

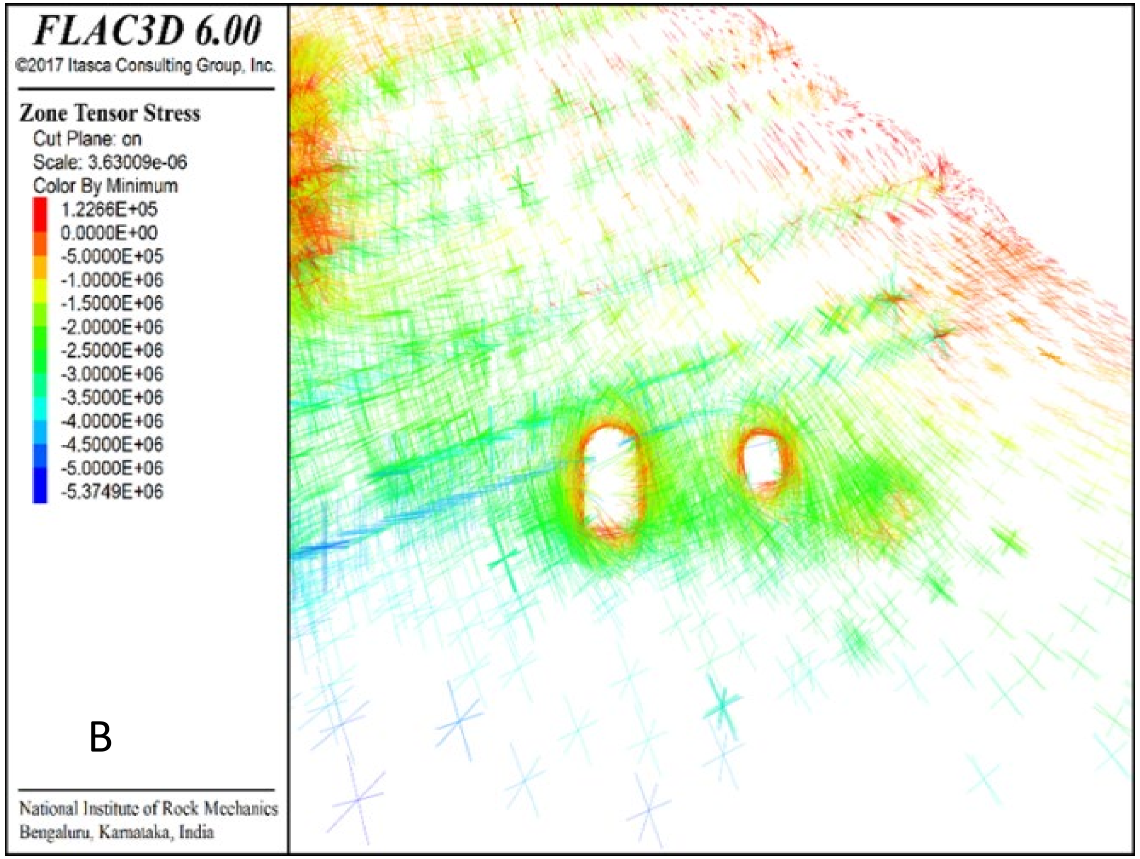
Displacement contours



Displacement contours at RD 15m from PH cavern after complete excavation

Maximum and minimum principal stress tensors





Principal stress tensors at RD 30 m from machine hall cavern (A) Maximum principal stress and (B) Minimum principal stress

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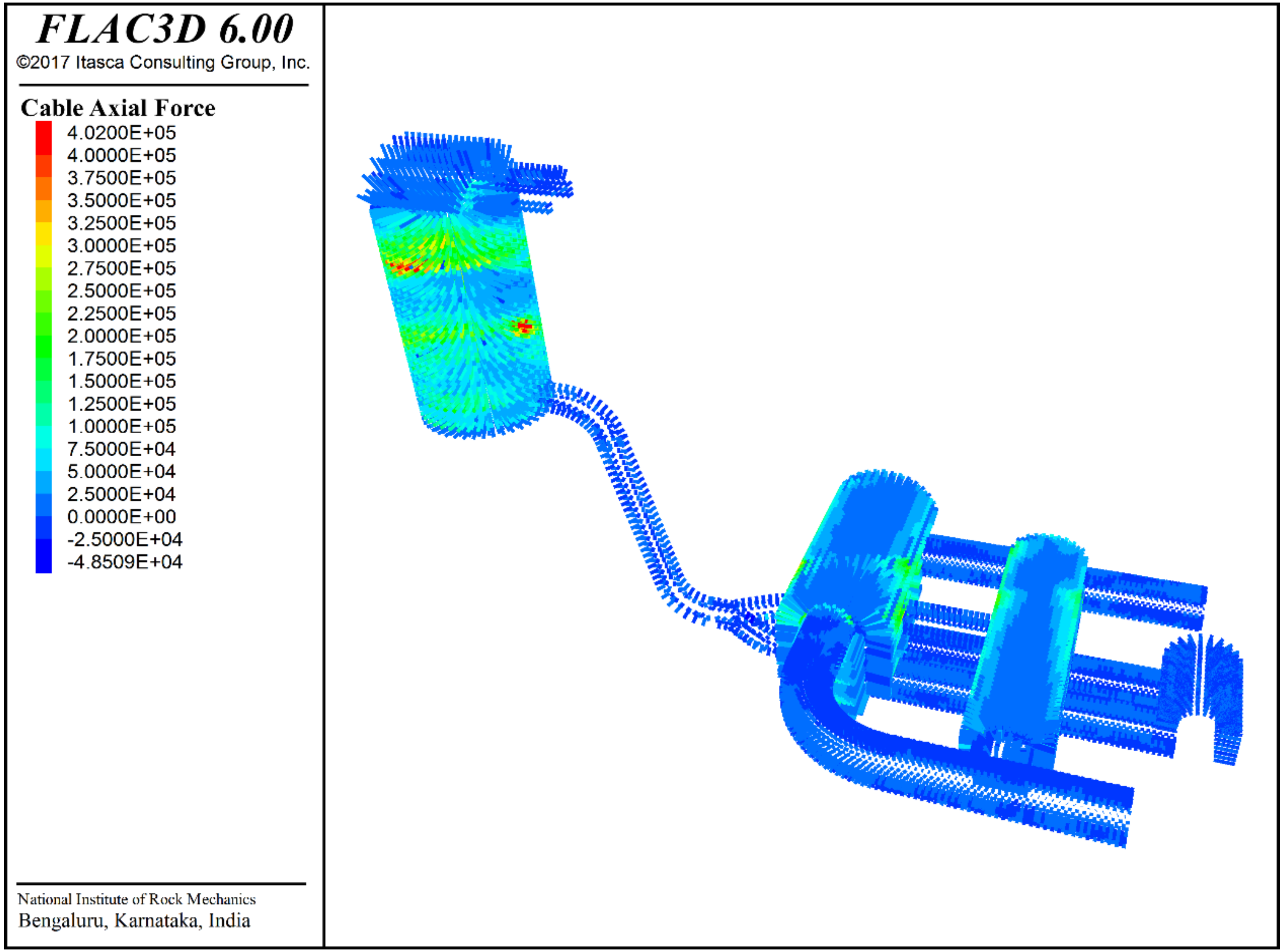
Yield zone extent

RD	Upstream (m)	Crown (m)	Downstream (m)	Remarks
0	2.2	2	2	
5m	6.73	2	2.5	
10m	10	3.1	5.33	Draft tube and unit penstock intersection area on d/s and u/s wall
15m	12	5.03	6	
20m	11.8	5.5	6.9	
25m	8.2	5	8.7	
30m	8.4	3.27	7.7	
35m	5.6	2	4.2	
40m	6.2	2.7	2.4	
45m	3.2	3.5	4	
50m	3.2	2.54	5	
55m	3.2	3.8	2	
58m	3.2	2	4	

Distribution of Axial force in rock bolts



Conclusions

- ❖The support system considered for the excavations is found to be satisfactory.
- ❖Fractured rock and shear zone material bands had considerable influence on the displacement pattern of surge shaft and on the crown and walls of machine hall cavern. Higher displacements of the magnitude 36 to 48 mm are observed at these locations.
- ❖At intersections where surge shaft and machine hall cavern excavation fall in fractured rock and shear zone, the spread of yield zone is more. At these places consolidation grouting may be carried out to a depth of about 8-10m, to improve the rock mass parameters.
- ❖The length of rock bolts needs to be increased to 8m near the junctions of unit penstocks, draft tube tunnels and at other tunnel junctions.

Conclusions

- ❖The orientation of the rock bolts must be decided based on the actual field conditions.
- ❖Proper instrumentation plan needs to be implemented to capture the behavior of the rock mass surrounding the surge shaft, powerhouse complex and also to quantify the performance of the support system. Back analysis of the model has to be carried out if the displacement values differ from the predicted value during the excavation stage.
- ❖In addition to regular instruments for measuring the displacement and loads, crack meters may be installed across shear joints and monitored regularly in order to assess the behavior of the shear joints.
- ❖Further optimization of the supports can be done during the construction stage based on the instrument observations of parameters like wall displacements, convergence and load on the rock bolts etc.

Thank You