Geotechnical problems encountered during the excavation of rock ledge for EOT Crane in underground Power house of Shongtong-Karchham Hydro Electric Project-450MW- A case study

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Abstract

The present study deals with a case history of the excavation practice and the stabilisation measures adopted during the excavation of the rock ledge for EoT in Underground Power house of the Shongtong-Karchham Hydro Electric Project in Kinnaur, Himachal Pradesh, India. The area around Shongtong-Karchham HEP falls in the Greater Himalayas. Characteristically the river Satluj in the project and vicinity flows through a moderately deep gorge flanked by steep slopes. These rocks in this part of Himalayas have been categorized in to Vakirata Group (Ravi Shanker. et. al. 1989). Rock mass mostly belongs to good to fair quality, with small poor quality as per estimated Q value. Power house cavern has been aligned along N43°-N223° after analyzing the discontinuities encountered in the exploratory drift and keeping in view the direction of the principal stress axis determined by Hydro-fracture studies Present alignment makes an angle of 83° with foliation joint (major/principal discontinuity) and is parallel to the principal stress axis. Instead of providing conventional system of columns and beams alongside the longitudinal walls as provisioned in the DPR, the design has been reviewed with a view to to save construction cost and time by utilising in situ rock mass of cavern walls for supporting crane beam to facilitate movement of Electrical Overhead Travelling (EOT) cranes for erection of Electromechanical equipment and their maintenance during operation stage.

1. Introduction:

All hydropower stations whether surface or underground need Electrical Overhead Travelling (EOT) cranes to facilitate erection of electromechanical equipment during construction stage and also their maintenance during operation stage. Generally a system of RCC columns and beams to facilitate the movement of EOT cranes is in practice but recently the concept of utilizing rock ledge to support crane beam has been adopted in the North Western Himalaya of India.

The Project is located on National Highway-05 between longitudes 78º16’50”E and latitudes 31º32’30”N (Fig. 1). The diversion site of the project is about 35Km upstream of Nathpa dam of Nathpa–Jhakri project and immediate upstream of Karcham-Wangtoo HEP (1000MW)

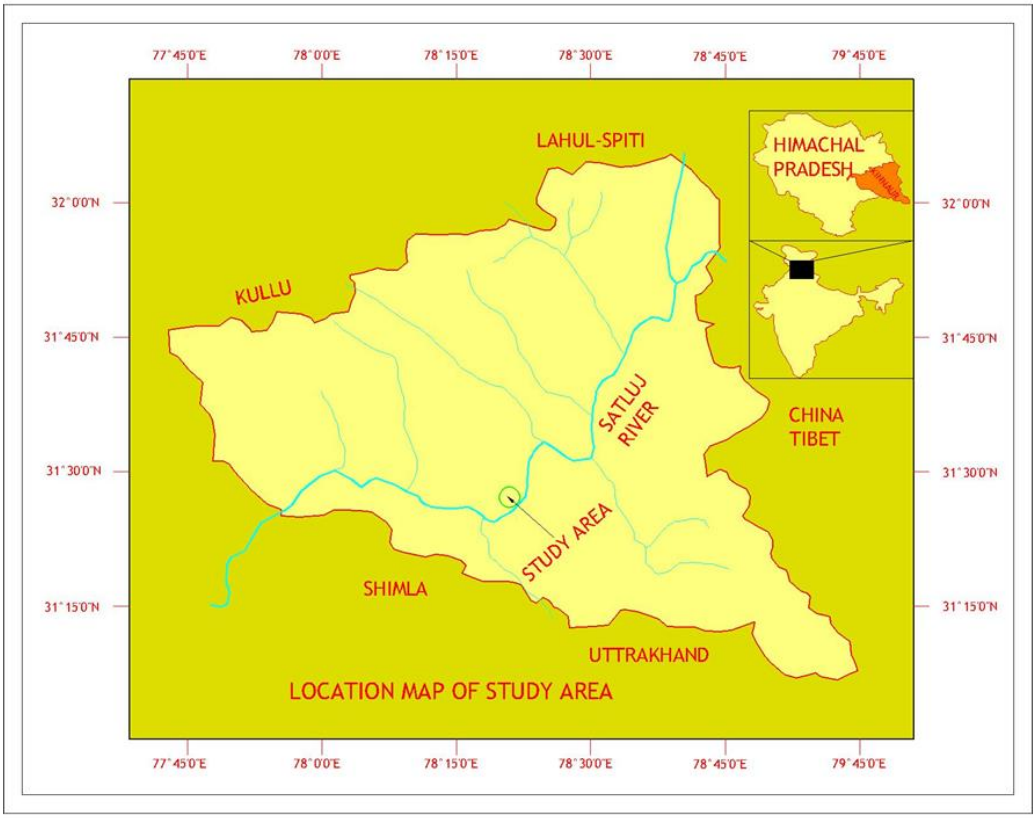


Figure 1 Location map of the Study area

Shongtong-Karchham Hydro Electric Project is a run-of River scheme under construction on left bank of River Satluj in District Kinnaur of Himachal Pradesh comprising construction of 24m high diversion barrage near village Powari about 1.5km upstream from the confluence of Tangling Khad with Satluj River, to divert 471cumecs discharge to four sedimentation chambers each 260m long excluding all particles down to 0.3mm. Water from sedimentation chambers is further carried through 7712.70m long head race tunnel of 10.50m diameter terminating in 30.60m diameter surge shaft and three 5.00m diameter steel lined pressure shafts, to feed three vertical Francis turbines housed in an underground power house cavern of size 131.15m (L) x23 m (W) and 54.05m (H) to generate 450MW of power (Fig. 3). A 10.50m diameter Tail Race Tunnel shall discharge the water back into Satluj River just downstream of power house. Design concepts for sizing and spacing of units in the underground cavern of Shongtong-Karchham HEP involved comprehensive studies of functional requirements of housing vertical axis Francis type turbines& its auxiliaries as per E&M requirements.

2. Geology of the area:

The area around Shongtong-Karchham HEP falls in the Greater Himalayas. Characteristically the river Satluj in the project and vicinity flows through a moderately deep gorge flanked by steep slopes. These rocks in this part of Himalayas have been categorized in to Vakirata Group (Ravi Shankar. et. al. 1989). Rocks belonging to Vakirata group comprise feldspathic gneiss, quartzite, high-grade schists, and magmatites, which are exposed in an arcuate pattern. These rocks are intruded by Rakcham and Nako granites (Fig. 2). The Vakirata Group has further been divided in to three formations, viz- Kharo, Morang, and Shiasu formations. Vakirata Group rests over the rocks belonging to the Jutogh, Salkhala, and Rampur Groups along ‘Vakirata Thrust’, which is also considered trace of the MCT in this area by some workers. The Jutogh Group of rocks comprises mainly garnetiferous mica schist, quartizites, massive and banded psammitic gneiss with subordinate carbonaceous, phyllites, and carbonate bands at places. Rocks belonging to Kharo Formation of Vakirata Group are exposed in the Barrage, Intake Desanding and part of Head race tunnel of the proposed project. Rocks belonging to Jutogh Group are exposed in the part of Head race tunnel, Surge shaft and Power house complex of the proposed project.

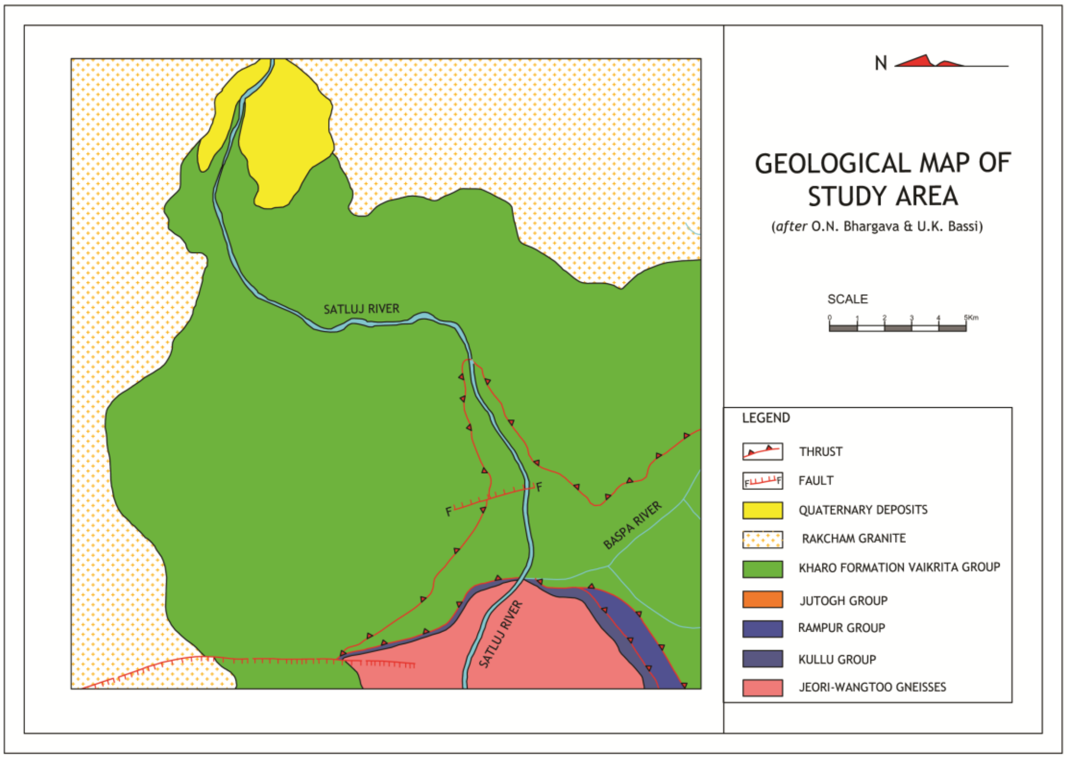


Figure 2 Geological map of the Study area

Underground powerhouse located near Ralli village on the left bank of Satluj River and exposes slightly weathered to fresh at the surface, gneisses and thinly foliated banded gneisses trending in N 40°W, N 65°W-S40°E, S65°E and dipping at 20°to 35° in a NE. The bedrock exposed in the area is traversed by three sets of joints in addition to foliation joint (most prominent).

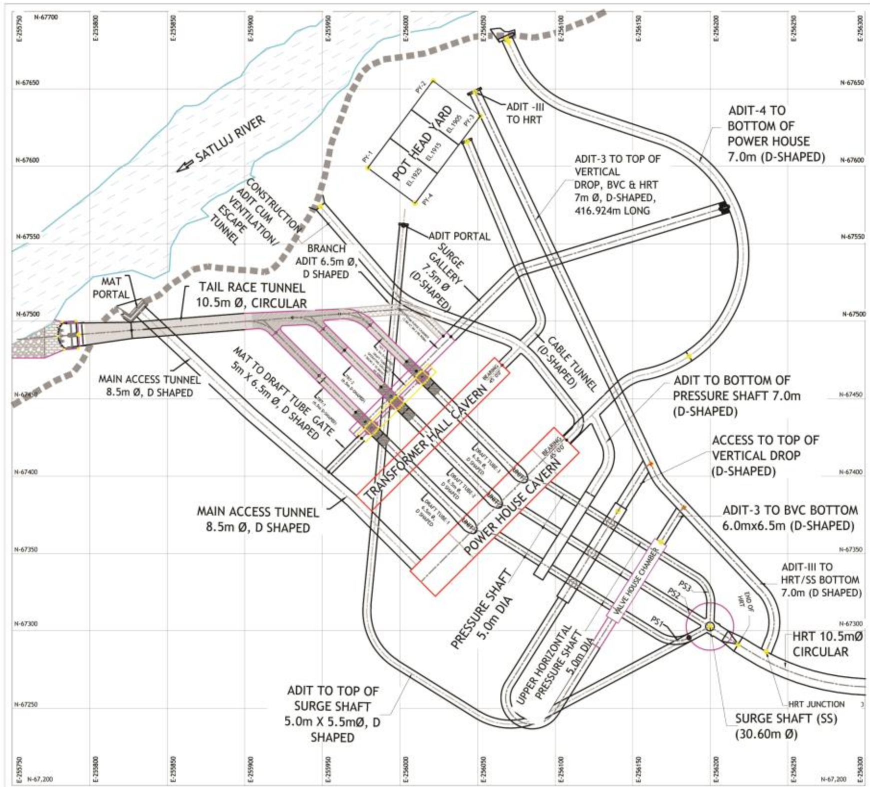


Figure 3 Plan of Powerhouse Complex

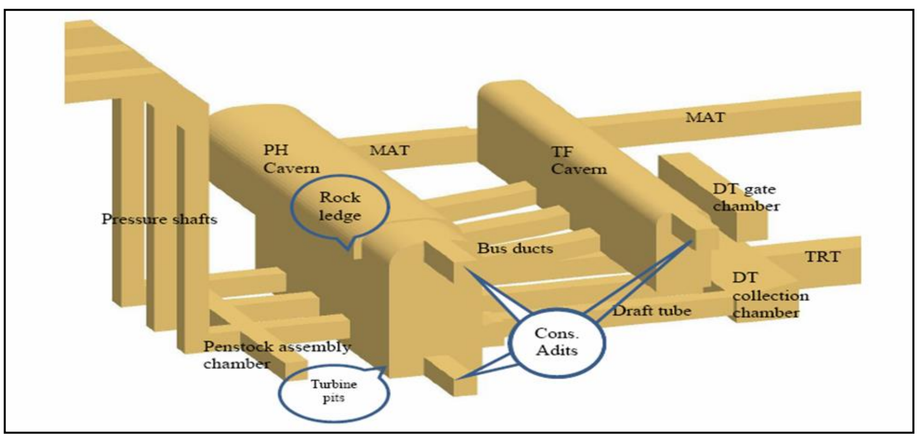


Figure 4 3D Model of Powerhouse Complex

3. Provision of Rock Ledge for EOT Crane Beam:

Initially in the Shongtong-Karchham HEP (i.e. at DPR stage) the crane was proposed to be mounted on RCC column and beam frames constructed along both the longitudinal walls of the cavern. Excavation of Escape Cum Ventilation tunnel and central gullet of power house revealed good quality of encountered rock mass. On account of encountering good geology during the excavation of central gullet of Power House Cavern, it was thought to review the earlier proposal of facilitating the EOT crane movement on column beam arrangement and alternatively provide a rock ledge of suitable width at EOT crane beam level to support crane rails to facilitate the early erection of electromechanical equipments.

Subsequently instead of providing columns & beams to facilitate movement of crane, the design has changed to save cost & time and rock mass of the cavern walls has been used to support crane beam to facilitate movement of Electrical Overhead Travelling (EOT) cranes of 440T capacity for erection of electromechanical equipment and their maintenance afterwards.

Depending upon the favorable geological conditions of the power house area for providing rock ledge for supporting EOT crane beam, 2m wide rock ledge extending on each side beyond the clear cavity width of 23m was provisioned in power house cavern for EOT crane movement and thus construction of a Mushroom shape cavern of 23m clear width of power house cavity and its top dome as 27m to accommodate 2.00m wide rock ledge on both sides has been provisioned (Fig. 4).

4. Sequence of Excavation:

Normal practice of excavating the arch first and providing treatment to the arch followed by the removal of the lower benches to the full size is followed in excavating the power house cavern. Central Gullet of the Power House cavern was excavated from the ventilation cum construction ADIT to the top of power house provisioned for the purpose. Rock supports in the central gullet (Stage-I) were provided and side slashing (Stage-II) excavation was carried out in a staggered manner up to the springing level of the cavern. Stage-III benching was carried out up to rock ledge level by adopting controlled blasting techniques. A 2.05m wide and 6.294m high, remaining burden (bark) above rock ledge level which was to be removed after completion of excavation up to 2.50m below the rock ledge level (1830.10m). However due to execution difficulties at the site, same was reviewed and removed simultaneously with benching up to 1m above the rock ledge level. Further benching up to 2.50m below the rock ledge level was carried out in parts as per sequence A, B, C, D & E so as to minimize/avoid damage to the wall (Fig. 5). Excavation up to stage-IV has been completed and excavation for stage-V is under progress i.e. up to +EL. 1816.60m (below MAT invert).

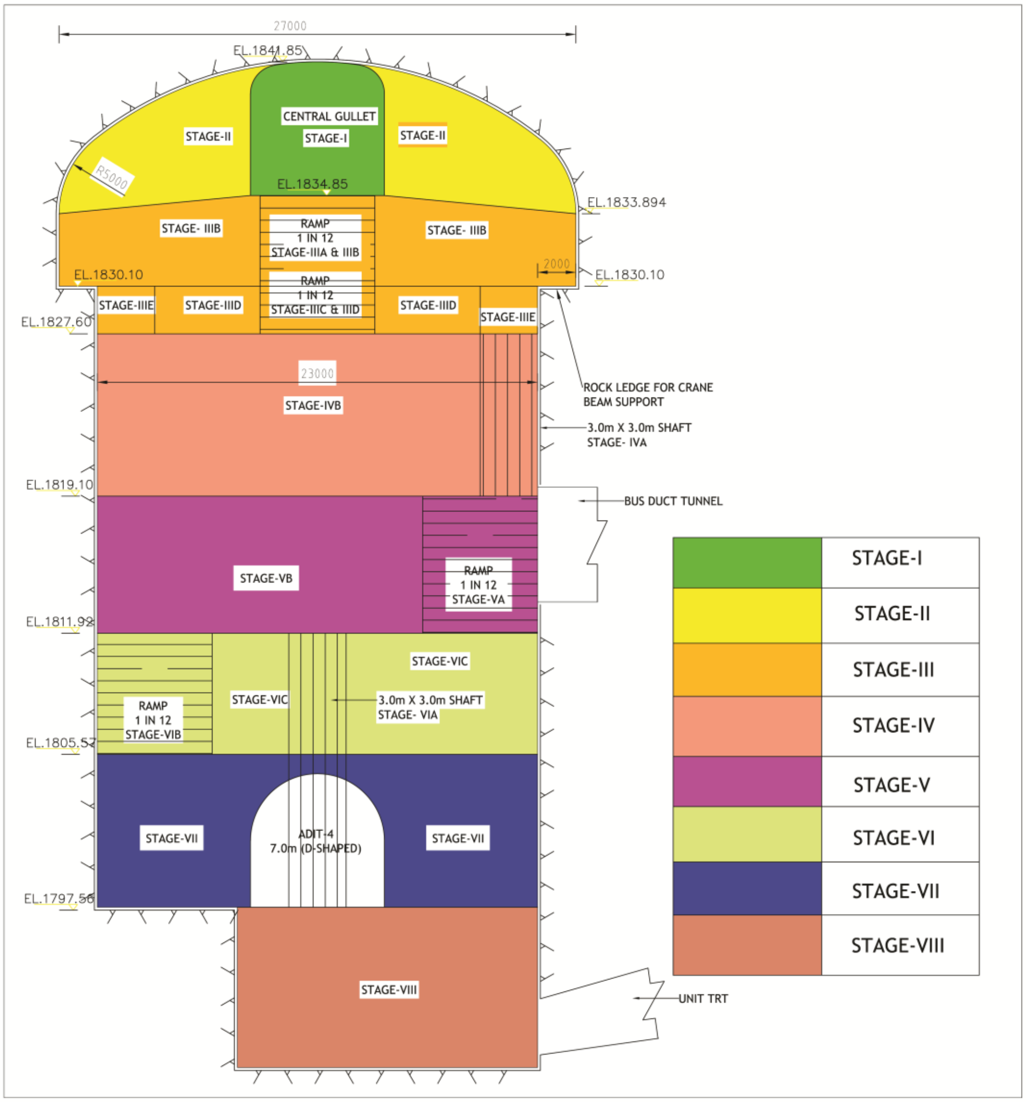


Figure 5 Sequence of stages adopted for excavation of power house cavity.

4.1. Geological conditions of Central Gullet:

The power house has been excavated through two different litho-units, i.e.; quartz biotite gneiss and banded gneiss belonging to Jutogh Group. The rock type encountered in power house during excavation of central gullet and benching up to rock ledge is quartz biotite gneiss and thinly foliated Banded gneiss belonging to Jutogh Group. The rock mass encountered is fresh/unweathered, moderately strong to strong in general, and is traversed by four sets of joints (Fig. 6). Among these, the joints disposed parallel to foliation are most prominent. Rock mass (Bieniawski, 1976) mostly belongs to good to fair quality, with small poor quality as per estimated Q value. The geology of powerhouse cavern and transformer hall cavern has been presented in the isometric model shown in figure 6.

Table 1
Summary of Characteristics of Discontinuities

Set	Dip Amount	Dip Direction	Continuity (m)	Spacing (cm)	Aperture (mm)	Roughness	Filling
J1	20^0-30^0	055^0-65^0	>20	3-40	Tight	RP- SP	NIL
J2	60^0-75^0	270^0-290^0	5-15	10-200	Tight	RP	NIL
J3	65^0-75^0	080^0-090^0	3-12	7-150	Tight	RU-RP	NIL
J4	65^0-75^0	160^0-170^0	3-7	Very Widely spaced	Tight	RP-RU	NIL

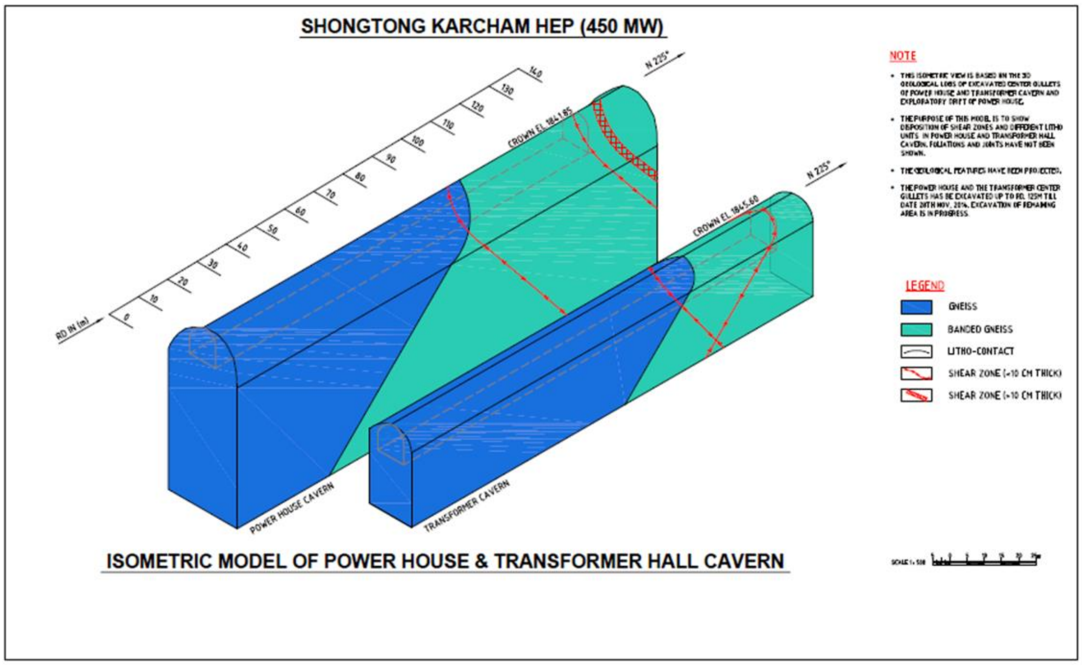


Figure 6 Isometric model showing the projected shear seam/zone and schist bands in Caverns

Power house cavern has been aligned along N43°-N223° after analyzing the discontinuities encountered in the exploratory drift and keeping in view the direction of the principal stress axis determined by Hydro-fracture studies Present alignment makes an angle of 83° with foliation joint (major/principal discontinuity) and is parallel to the principal stress axis. Stereo-net of prominent discontinuities, direction of in-situ stress and orientation of power house cavern is shown in figure-7.

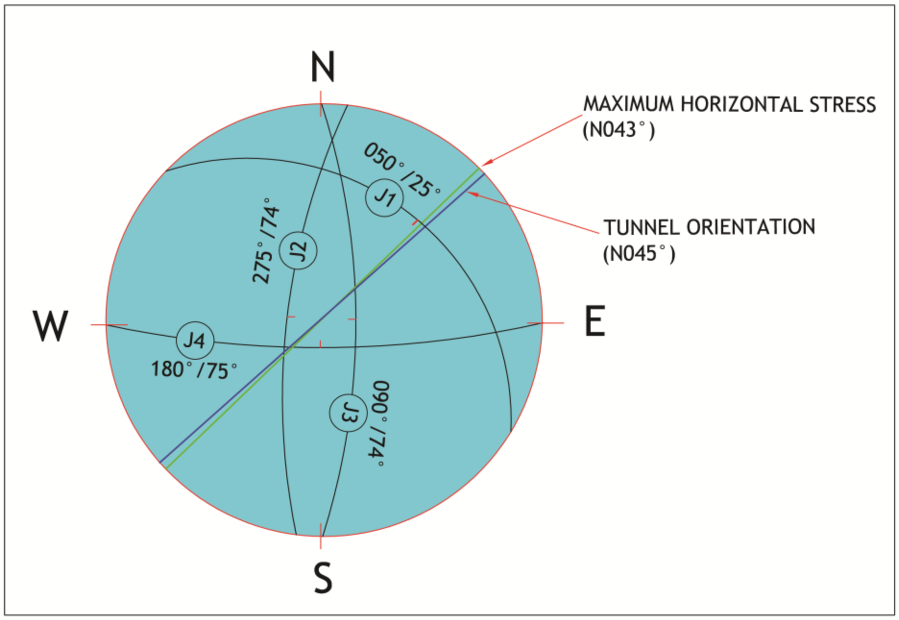


Figure 7 Stereo-net of prominent discontinuities, direction of in-situ stress and orientation of power house cavern

4.2. Geological conditions of Rock Ledge El. 1830.00m – El. 1827.00m:

Rock ledge has been excavated through quartz biotite gneiss from RD 0.00m to RD 50.0m and thinly foliated Banded gneiss between RDs 50.0m and 131.00m. The rock mass is fresh/unweathered, moderately strong to strong, moderately jointed in general, and is traversed by four sets of joints. Among these, the joints disposed parallel to foliation are most prominent. Entire excavated stretch is dry. Rock mass belongs to good poor quality i.e. (Class-II to IV) as per estimated Q value. During the course of geological mapping the details of discontinuities like their spacing, continuity, opening, nature of joint surface and filling were observed. Summary of these is given in table-2 & 3 below.

Table2
Summary of Characteristics of Discontinuities from RD. 0.00m to 50.00m

Set	Dip Amount	Dip Direction	Continuity (m)	Spacing (cm)	Aperture (mm)	Roughness	Filling
J1	20^0-30^0	055^0-65^0	>3	20-40 (30)	Tight	RP- SP	NIL
J2	60^0-75^0	270^0-290^0	0.5-3	20-100 (80)	Tight	RP	NIL
J3	65^0-75^0	080^0-090^0	0.2-3	20-100 (80)	Tight	RU-RP	NIL

Table 3
Summary of Characteristics of Discontinuities from RD. 50.00m to 131.00m

Set	Dip Amount	Dip Direction	Continuity (m)	Spacing (cm)	Aperture (mm)	Roughness	Filling
J1	20^0-30^0	055^0-65^0	>3	3-12 (5)	Tight to 2mm	RP- SP	NIL
J2	60^0-75^0	270^0-290^0	0.5-3	10-200 (80)	Tight to 3mm	RP	NIL
J3	65^0-75^0	080^0-090^0	0.3-3	7-200 (80)	Tight to 2mm	RU-RP	NIL
J4	65^0-75^0	160^0-170^0	0.5-2	Very Widely spaced	Tight	RP-RU	NIL

In general, initial 50.00m portion/stretch of rock ledge which has been excavated through gneiss lies in Rock Class II and portion/stretch beyond 50.00m excavated through thinly foliated banded gneiss lies mainly in rock class III. However, the presence of minor shear zones in banded gneiss has aggravated the rock mass conditions and has reduced the rock class to IV. Thinly sheared or crushed zones containing gneiss are considered to be a weak rock mass and, hence, this material kept in rock class IV.

Table 4
Rock Mass Classes for the Power House Rock ledge

Location	From	To	Rock type	Q value	Rock class	Category
Left wall	0.00	50.00	Gneiss	10.0-18.0	II	Good
	50.00	89.00	Banded Gneiss	6.0-8.90	III	Fair
	89.00	90.00	Banded Gneiss	1.00	IV	Poor
	90.00	98.00	Banded Gneiss	6.30-7.30	III	Fair
	98.00	100.00	Banded Gneiss	1.00	IV	Poor
	100.00	131.00	Banded Gneiss	5.50-8.70	III	Fair
Right wall	0.00	60.00	Gneiss	10.0-18.0	II	Good
	60.00	110.00	Banded Gneiss	4.50-8.50	III	Fair
	110.00	113.00	Banded Gneiss	1.00-1.50	IV	Poor
	113.00	119.00	Banded Gneiss	7.50-8.50	III	Fair
	119.00	122.00	Banded Gneiss	1.00-1.50	IV	Poor
	122.00	131.00	Banded Gneiss	4.80-5.80	III	Fair
Starting Wall			Gneiss	17.00-18.00	II	Good
End Wall			Banded Gneiss	4.80-7.30	III	Fair

As per estimated Q value 42% of the rock mass falls in class-II (Good) 55% of the rock mass in class-III (Fair) and 3% of the rock mass in class-IV (Poor).

5. Geotechnical Problems and Treatment:

During excavation of rock ledge, generally Good quality rock mass has been encountered up to RD 50.00m, as ledge has been excavated through massive gneisses in this stretch. However, after RD 50.00m onwards up to end of cavern RD. 131.15m, the rock ledge have been excavated through thinly foliated banded gneiss with av. spacing of 5cm in general (Photograph 1). As foliation is oriented nearly perpendicular to the longer alignment of the cavern with low dip amount against the direction of the drive, due to blasting, distressing at the top of bench (being unconfined in absence of a remaining bark) offered free escape for blast induced wave propagation resulted in splitting of rock mass along foliation with minor apertures on the vertical face of ledge contrary to the rock section in heading segment above SPL. In view of this closely spaced line drilling (@ 0.5m), split and controlled blasting with use of mechanical breaker has been used to develop the vertical face of ledge so that excavation induced apertures and disturbance to the rock mass of ledge can be contained/minimized.

Photograph 1 Photo showing thinly foliated banded gneiss

Photograph 2 Photo showing excavation induced apertures in thinly foliated banded gneiss

The bearing of the Powerhouse Cavern is N45º, and so the dip direction of J1 set (foliation) is offset by about 5º. This was sufficient for an oblique wedge to form on the surface of the exposed rock ledge, where the J1 intersects with J2 and J4. In such damaged reaches make up concrete of M: 25 grade has been provided with additional 32mm dia, 2.5m long fully cement grouted rock anchors duly embedded in rock and concrete to hold the concrete under loaded conditions of crane beam.

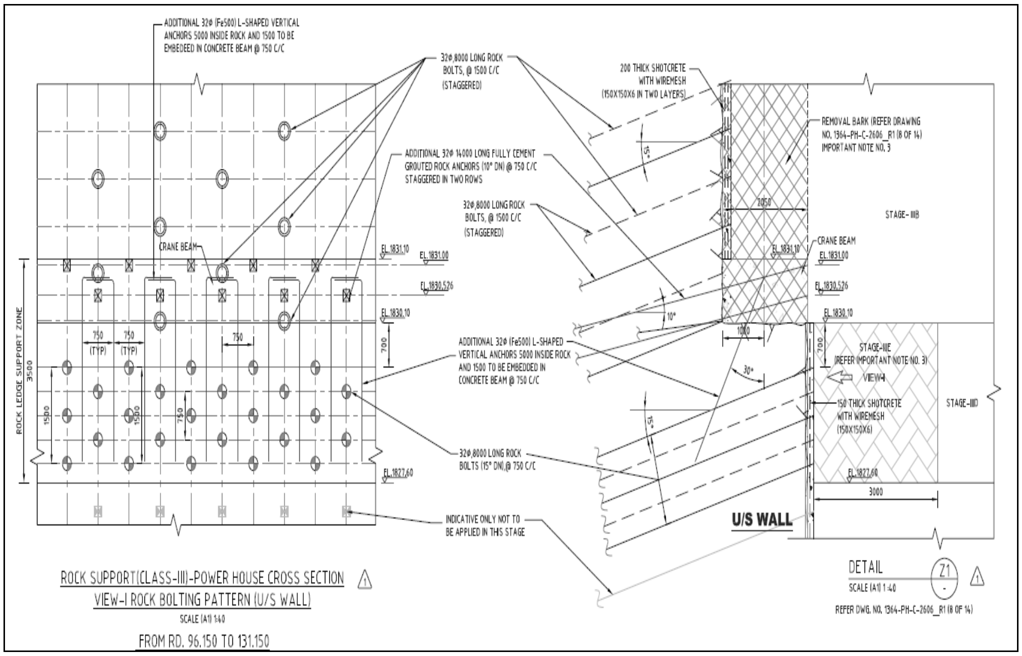
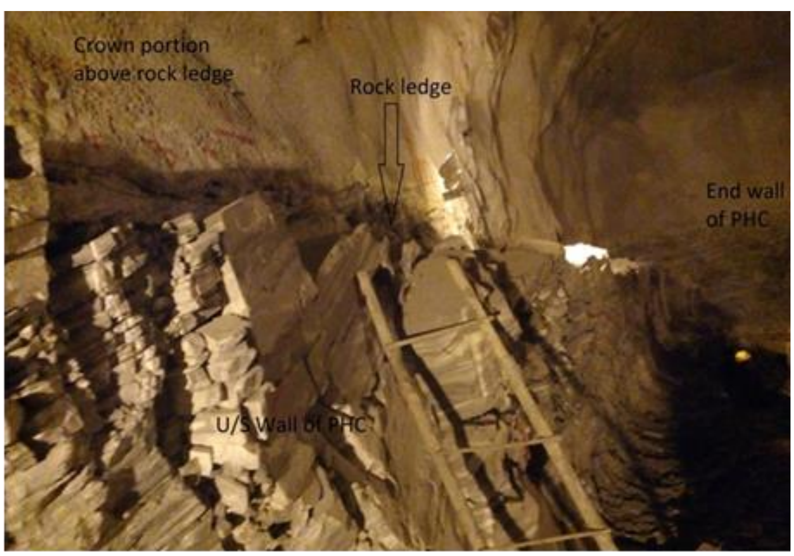


Figure 8 Typical arrangement of proposed rock ledge for supporting crane beam.

Considerable apertures (2-7 cm) (Photographs 2 & 3) along J2 plane has been observed between 104.00-113.00m and 116.00-120.00m, and the loose mass is resting in theses stretches over the J2 plane (dipping towards the cavern), these have been removed prior to application of shotcrete. The removed/scooped rock mass has been made up with shotcrete and double layer of wire mesh.



Photograph 3 Photo showing considerable apertures along J2 plane between 104.00-113.00m on the upstream wall.

At places due to low spacing of J2/J3 apart from foliation and splitting of rock mass along foliation resulting in disintegrated and fractured rock masses have been observed/encountered at several places, such critical reaches have been identified and loose martial has been removed prior to application of shotcrete. The removed/scooped rock mass has been made up with shotcrete and double layer of wire mesh.

Table 5
Critical reaches of the Rock Ledge in the Power house cavern

Location	Critical reaches, RDs. (m)	Depth (cm)	Remarks
Left rock ledge (Upstream)	92.70 to 93.70	30 to 40	Disintegrated and fractured rock mass need to be removed
	103.00 to 103.20	10 to 30	Disintegrated and fractured rock mass need to be removed
	104.00 to 113.00	20 to 50	Disintegrated and fractured rock mass resting on J2 joint need to be removed
	116.00 to 117.00	10 to 30	
Right rock ledge (Downstream)	50.50 to 52.00	30 to 40	1.50m X 2.00m wedge failure
	77.50 to 78.50	20 to 40	Fractured rock mass resting on J3 joint need to be removed
	119.00 to 122.00	30 to 40	Sheared/crushed rock mass along J3 joint need to be removed

Due to skinny rock mass over the Main Access Tunnel (MAT) from RDs. 120m to 131.15m, closely spaced foliation, J3 and the presence of sheared and crushed rock from RD's. 119m to 122m resulting in decreased rock strength and quality. Concrete column and beam has been proposed over the MAT intersection from RD's. 117m to 131.15m up to the overt level of MAT (El. 1819.10m) at this location.

Several minor shear seams/zones have been observed however keeping in view the thickness of the encountered weak features; none was expected to cause stability concerns. Recorded shear seams during site observations are tabulated in the table-6.

Table 6
Encountered shear zones/seams Zones in Power House Rock Ledge

Location	Sheared / Crushed zone lies in RDs. (m)	Attitude of sheared / crushed zones (Dip direction/Dip Amount)	Thickness (cm)	Remarks
Rock Ledge, U/S	45.00 – 53.00	Along foliation joint	< 2	Width of the shear includes the effected zone. All shears contain clay or rock crushed of 2-5 cm thickness.
	89.00 – 89.50	Along J2 (260°/80°)	2 – 5	
	96.80 – 97.10	Along J2 (260°/80°)	< 2	
	103.00 – 103.50	Along J2 (260°/80°)	2 – 5	
	108.60 – 108.90	Along J2 (260°/80°)	< 2	
	110.00 – 110.50	Along J2 (260°/80°)	< 2	
	112.20 – 112.50	Along J2 (260°/80°)	< 2	
	124.80 – 125.20	Along J2 (260°/80°)	< 2	
Rock Ledge, D/S	81.80 – 90.00	Along foliation joint	< 2	
	116.20 – 119.00	Along J3 (085°/65°)	< 2	
	120.00 – 122.00	Along J3 (085°/65°)	< 2	

As the performance of the rock ledge depends on the effective foundation width and the stability of the sidewalls, the effective foundation width of the rock ledge has been reduced to 1.5 m in view of loose zone/disturbed zone (due to excavation). This was not more than 0.5m deep as per observations at site. Although the crane load is moving distributed load, to be on conservative side during 3D numerical analysis using FLAC 3D it has been modelled as a single point load/concentrated load of 250 T and 25T is applied in vertical and horizontal directions respectively to access stability of excavation at the most critical section i.e. over the central bus duct gallery.

6. Instrument Data/Behavior:

Five sections of instrumentation comprising MPBX measuring at 5, 10 & 15m and load cells have been proposed in control bay and machine hall reach while additional four sections in between these instrumented sections are monitored by optical fibers and one section in service bay reach for monitoring the behavior of rock mass during further excavation and during load testing of EOT crane. Monitored data reveals that no major movements have taken place in Power House crown. Also as per the FLAC 3D numerical analysis, it is seen that the maximum total deformation occurs in most critical section of the cavern i.e. through bus duct 2 which is less than the 1% of permissible convergence of about 230mm.

7. Discussion and Conclusion:

In the case of rock ledge design, the vertical as well as horizontal loads from the crane wheels are directly transmitted to the rock mass below the ledge. Therefore, the design involves determining the amount of rock reinforcement required to ensure that adequate factor of safety is available against shear failure. Such rock reinforcement in the rock ledge area is in addition to the pattern rock bolts needed to support the cavern walls. Hence, concrete crane beam of size 1.5m (W) x 1.0m (D) is provided above rock ledge to act as crane support thereby providing an off set of 50cm between beam and rock wall face below ledge to safe guard against shear failure. Minimum clearance from the crane rail to the rock face above the ledge as required for crane operation has also been provided. Although the crane beam will be continuously supported on the rock ledge, conservatively looking at the geological conditions/data of damaged reaches of rock ledge (as mentioned above), the crane beam has been structurally designed for an unsupported span of 6m idealized as a continuous RCC crane beam with span of 6m .

After completion of excavation including rock support system and instrumentation of central gullet stage-I & side slashing stage-II up to springing level of the cavity, benching down was done as per the sequence given in Figure-3. Expecting difficulty in carrying out excavation up to a height 6.294m of the remaining burden (bark) above rock ledge level which was to be removed after completion of excavation up to 2.50m below the rock ledge level (1830.10m), the same was reviewed and removed simultaneously with benching up to 1m above the rock ledge level. Due to thinly foliated banded gneiss rock mass, some damage to the rock below ledge was observed which has been made up by levelling course of concrete after completion of excavation up to service bay level (1819.10m).

Considering successful implementation of the concept of supporting crane beam on rock ledge by making use of the in-situ rock mass in underground power house in Karchham Wangtoo HEP (1000 MW), Malana HEP (100 MW) in Himachal Pradesh and for Teesta-III (1200 MW) in Sikkim, the concept should be widely adopted in the future hydroelectric projects with underground power houses to cut short the construction time and achieve saving in cost of the project. Necessary technical back up of procedures, shape & design of rock ledge being adopted as per varying project specific rock mass conditions and requirements needs to be maintained and disseminated amongst the power corporations & technical institutions for future reference and guidance in the hydro power projects planned / proposed to come-up in future.

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