Successful excavation of surge shaft in weak rockmass

A case study of 240MW URI-II HE Project, NHPC, J&K

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***Abstract*- Surge shaft serves to absorb the hammering effect of water from pressure tunnel generated due to the sudden stoppage of turbines, by accommodating surges/mass oscillations during load rejection/acceptance until the conduit velocity attains a steady state in water conductor system of a hydel Project. The location of surge shaft is constrained by alignment of pressure tunnel (HRT) and power house. In the past at various places there were incidences of failures during the excavation/ construction as well as post-operative problems due to charging of hill slopes. This paper is an attempt to bring out site specific measures vis-a-vis geological conditions encountered in construction of a 26.6m dia (excavated), 78m deep (EL1275 to 1197m) surge shaft for accommodating surge water of 4.235 Km long, 8.4m dia HRT. This surge shaft was constructed in weak to medium strong intricately folded, fractured sequence of Murree formation (RMR 25-50). The shaft excavation included an open excavation of slope overlooking the shaft and shaft sinking with full face up to El 1275M to 1266.5M, a pilot shaft from El 1266.5M to El 1197M and side slashing. Pre-grouting, peripheral control blasting and variations in blasting pattern such as contour blasting, Air-deck blasting and line drilling, followed by systematic rock support, and were practiced at Uri-II Surge shaft for its successful completion.**

***Keywords*- Surge shaft; HRT; THPS; Murree Formation; Bedrock; RMR; NATM; Rock Bolt; Contour Blast; Pre-grouting; Line Drilling; Air-deck blasting; Pull out test; Shotcrete; wiremesh; chain link fabric; ribs**

I. Introduction

URI- II H.E. Project is a run off the river scheme located (Fig.1) in Baramulla district of J&K, to harness hydro electric potential of the River Jhelum. A gross head of approx. 130 m will be utilized for generating 240 MW of power through four units of 60 MW each. A small reservoir of adequate capacity will be provided as an operating pool. The major project components comprise of a 42m high concrete gravity dam across river Jhelum near Salamabad village downstream of Uri town, an intake Open channel, one desilting basin, a 4 .235 Km long 8.4m dia head race tunnel, an open to sky 78m deep surge shaft, 2 nos 5m dia pressure shafts, an underground powerhouse complex housing 133m long machine hall, 177m long Transformer cavern cum GIS hall & 91m long MIV cavern and 3.7 Km long tail race tunnel, having its outlet located in Golta nallah for debouching water back into Jhelum river.

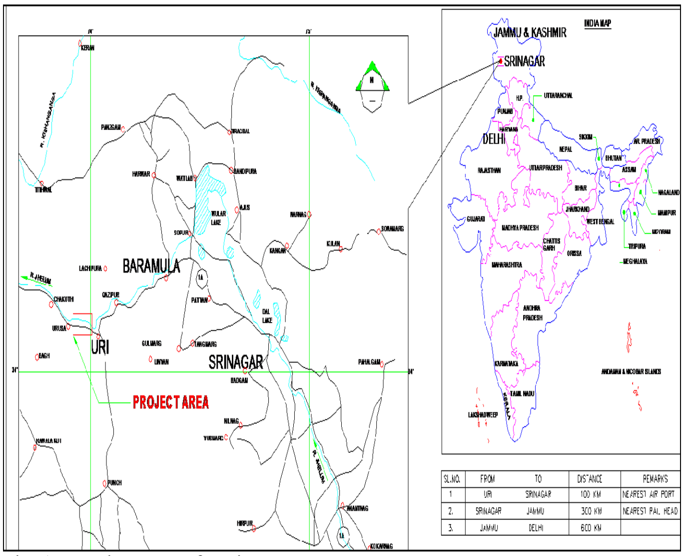


Fig. 1 Location Map of Project

II. Surge Shaft

The 25m (finished) and 26.6m(excavated) dia and 77.6 meter high restricted orifice type open to sky surge shaft is located at village Sadvania of Uri Tehsil connecting to 4.235Km long 8.4m dia HRT. The general arrangement of surge shaft, HRT and Powerhouse is shown in Fig. 2. Top level of surge shaft is EL 127, 5m based on transient studies. The maximum upsurge and minimum down surge levels have been worked out to be at EL 1273.20 m and EL 1207.2 m respectively by surge analysis. The excavation of surge shaft comprised of slope open excavation from El. ± 1340M to El. 1275M and then shaft sinking from El. 1275 to 1197.4M.

A. Surge Shaft Slope Open Excavation:

The surge shaft hill slope below El. ± 1340M was excavated with provision of two berms at El±1309M and El. 1290M. Minor modification in the slope has been made to suit the site condition.

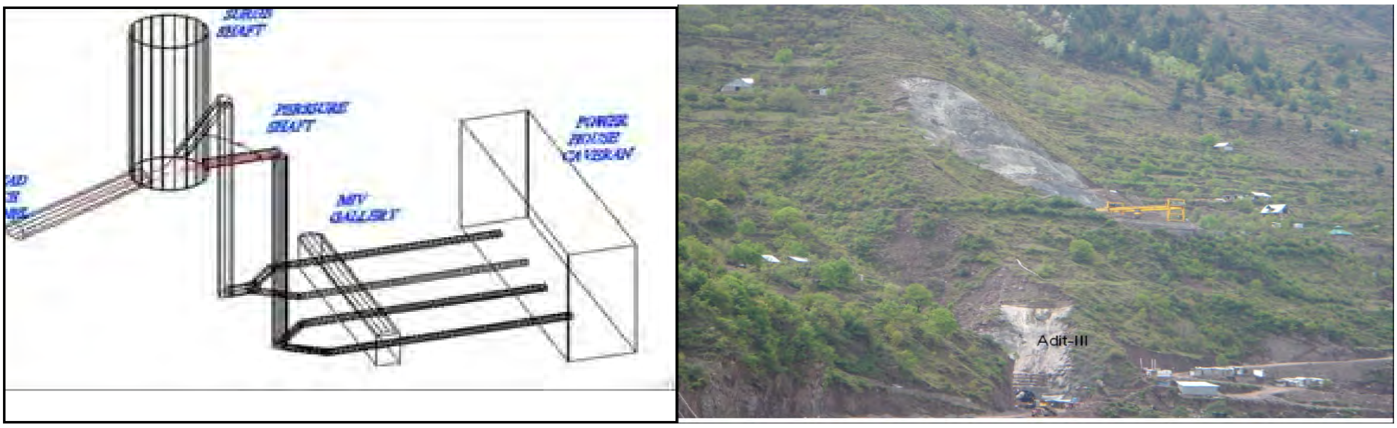


Fig 2. Surge shaft Layout 3D View

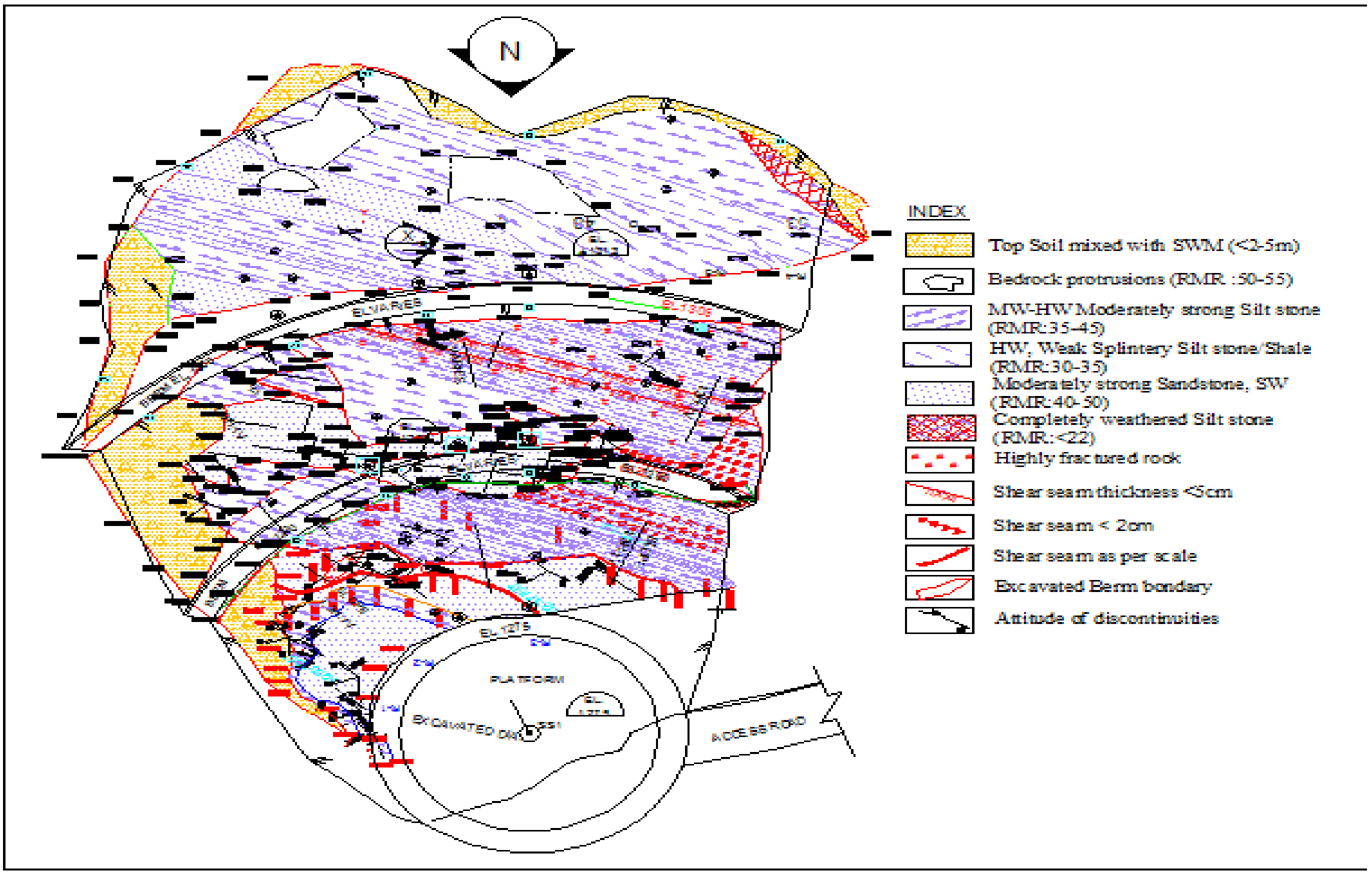


Fig. 3 Geological plan of surge shaft hill slope

1) *Site Geology*

The geological plan of surge shaft hill slope (Fig.3) reveals the major part of the slope overlooking surge shaft exposed Murree group of rocks striking NW-SE with southwest dip, amount varying between 35-65º. The bedrock comprised of alternate bands of grey sandstone, brownish siltsone with intermittent dark brown to purple splintery shale bands was encountered. However, between El 1332 - 1340 towards northern side and between El 1300 -1317 towards eastern side, part of the slope is covered with overburden represented by scree material constituted of silt, clay and various sizes of boulders of siltstone, sandstone. The majority of the slope excavation did not require blasting, excepting for few places where hard bands of sandstone were encountered.

2) *Rock Support for Surge shaft slope excavation:*

The excavated slope was supported with the help of 100-150mm thick shotcrete, 3 to 4m long rock bolts/anchors with chain link fabric & wire mesh as per site requirement. Chain link was provided at very undulatory surfaces vis-a-vis encountered hard rock protrusions of sand stone bands. In addition, consolidation grouting, drilling of pressure relief holes and construction of drains at El.±1340M (above the cut slope), El. ±1309 and El ±1290M were also provided. Looking to the nature of rock material two rows of 6m long rock bolts instead of 3m were provided above the berm at El 1309M to strengthen the toe of the slope. Below El 1290m to El 1275, the slope was excavated with steeper angle for accommodating the platform for gantry. As such 6m/9m long rock bolts were provided above El. 1275M to strengthen the rock mass. Further a 1m thick cladding wall was also constructed from El 1275M to 1280M to strengthen the toe of the bottom slope.

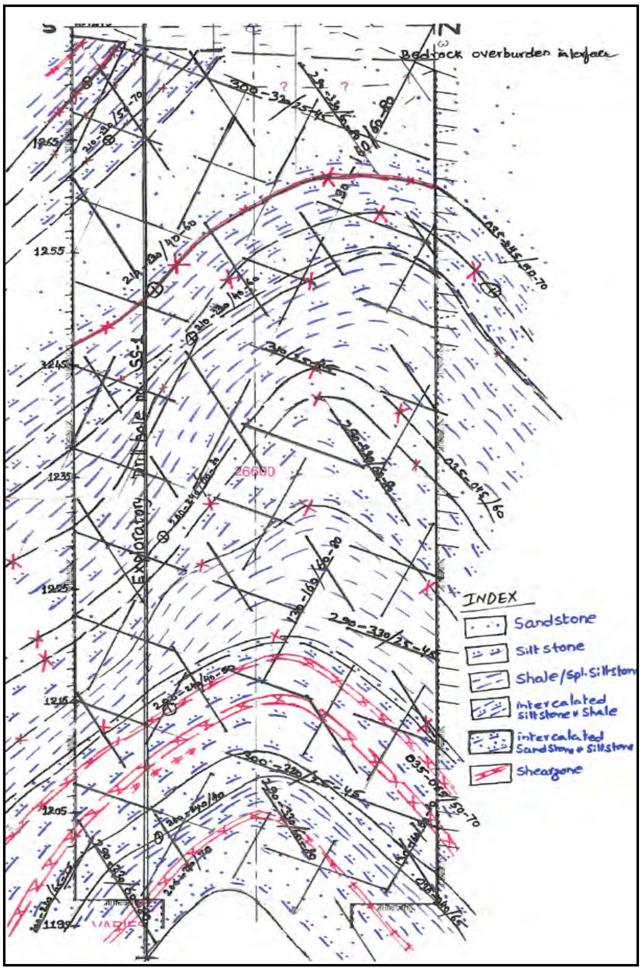


Fig. 4 Geological X-Section of Surge Shaft (NS)

B. *Surge Shaft Excavation*

The excavation of surge shaft was carried out as per the measures indicated in the construction drawing. The excavation was carried by contour blasting method. The shaft sinking was carried out from El 1275M t0 EL. 1266.5M for full face. Below El 1266.5M, a central pilot hole of 3m dia was excavated down to El 1197.4M. The slashing of the shaft was carried out thereafter. The pilot shaft thus acted as chute for muck disposal through bottom adit to surge shaft via Adit-III to Head Race Tunnel (HRT).

1) *Site Geology*

Bedrock was available in part between El 1275M and 1266M. Overburden comprised of slope wash material predominantly clay mixed with few boulders was encountered in north-west quadrant. The bedrock comprises of an alternate sequence of sandstone, siltstone & shale was encountered in the surge shaft. Sandstone bands are strong to very strong. Ssiltstones are of medium strong nature whereas the shales are weak & splintery in nature. The rockmass is dissected by moderately steep to steep bedding planes with reversal of bedding (S1=190-250/40-75 and S1-A=000-055/45-75) indicative of folding and other divisional planes viz. 130-160/50-80, 310-340/70-80 with few random sets/cross-shears having attitude 310-000/10-40, 270-290/20-35 etc.

Wedges/dip surfaces have been formed due to the intersection of bedding planes with adversely oriented sets of discontinuities vis-à-vis geometry of structure. The ge ological data is briefed in table below:

Fig.5 Sinking of Surge Shaft

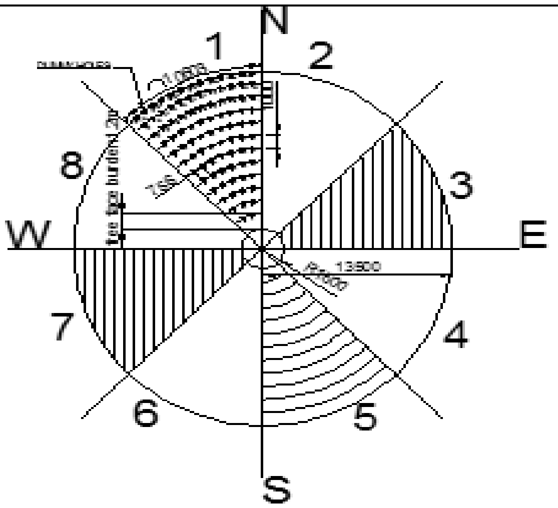
2) *Surge Shaft Sinking*

Surge shaft sinking was planned from top El 1275M. The excavation procedure includes drilling & blasting, mucking & hauling from Surge shaft top road with the help of single operating EOT crane. Due to the extended time cycle involved in this procedure, an alternative conduit was explored for mucking identified through THPS via Adit-III to HRT. At the central orifice portion of the shaft bottom at El 1197.4M, sacrificial rock support by means of 6m long rock bolts and thick shotcrete welded wiremesh was provided to ensure safety & contain the surrounding rock mass at the junction of adjacent structures viz HRT & THPS (Top Horizontal Pressure Shaft). Thereafter a 3m dia pilot shaft was excavated which served the purpose for mucking from El 1266.5M to EL1197.4 M.

3) *Drilling& Blasting procedure at site*

In order to optimize the time cycle of drilling, charging, mucking & installation of rock support, a 4 quadrant stage of excavation was envisaged. Explosive grade Class-II, Power gel-Gelatin stick (cartridge dia-40mm, length-300mm, W-390gm) with explosive power-350-400 KJ/100 gm was used. As the surge shaft was an open to air structure, in order to avoid misfires due to rain/wet surfaces NED (Cord-T-Ex) with long delays (0 to 15) were used.

There were hindrances at site posed by the local people inhabiting the hill complaining the ground vibration and



NOTE:-
1. Drilling Length=1.5m
2. Expected Pull= 1.2 (80%)
3. Rock Volume=71.5x1.2= 85.8 cum
4. Powder Factor= Charge/Volume=0.37Kg/cum
5. Rock class= Poor to Fair condition
6. Air-deck holes=Delay nos. 13 & 14.

DRILL- BLAST DETAILS							
Delay Nos.	Hole Length(mm)	Hole Dia (mm)	No. of Holes	Cartridge Unit Wt. (Kg)	No. of sticks/hole	Charge/ hole (Kg)	Total Charge/ Delay (Kg)
Dummy Holes	1500	45	6	0	0	0	0
1	1500	45	2	0.3900	1	0.3900	0.7800
2	1500	45	3	0.3900	1	0.3900	1.1700
3	1500	45	4	0.3900	1	0.3900	1.5600
4	1500	45	5	0.3900	1	0.3900	1.9500
5	1500	45	6	0.3900	1	0.3900	2.3400
6	1500	45	7	0.3900	1	0.3900	2.7300
7	1500	45	8	0.3900	1	0.3900	3.1200
8	1500	45	9	0.3900	1	0.3900	3.5100
9	1500	45	10	0.3900	1	0.3900	3.9000
10	1500	45	11	0.3900	1	0.3900	4.2900
11	1500	45	12	0.3900	1	0.3900	4.6800
13	1500	45	6	0.3900	0.5	0.1950	1.1700
14	1500	45		0.3900	0.5	0.1950	1.1700
Total			89	0.0000		0.0000	32.37Kg

Fig. 6 Typical Drilling & Blast Pattern

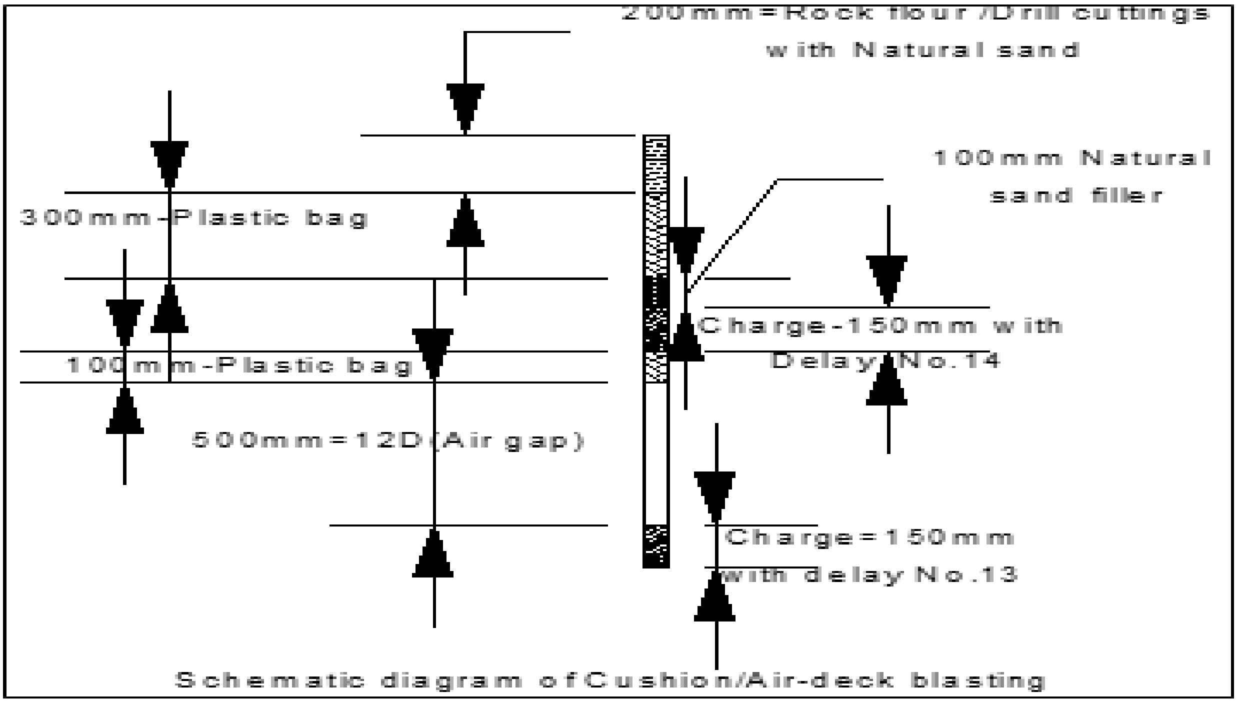


Fig.7 Schematic Diagram of Air-deck decoupling pattern

damages to their houses. Subsequently, few modifications were incorporated in the drill-blast pattern vis-à-vis excavation by dividing the shaft into 8 sectors. (Fig. 6). To achieve the fast progress, drilling and charging of two sectors on opposite quadrants. A time lag of 15 minutes was practiced for blasting opposite quadrants to optimize ground vibration. Powder factor of 0.37 to 0.45Kg/cum was utilized to excavate a rock volume of 85.8 cum with a design pull of

1.2m. For smooth blasting and optimizing over breaks/undercuts, Contour blasting pattern was resorted with S/B=0.8(spacing=750mm, burden=900-1000mm) as S=KD1, where K=16, D1=45mm dia of hole, drilled vertically.

Air-deck blasting was also done at the outer periphery of the shaft from EL 1205 to 1197.4m being close proximity of the shaft bottom to the already excavated free-face of HRT & junction of THPS. In this technique, the charges are decoupled with insertion of 2 different delays with air gap in-between, to attenuate the shock energy. This was mainly carried out to lessen the shattering effect at the periphery giving a smooth excavation line with reduced ground vibration. These decked holes acted as easers for dummy holes & resulted in good blast indications i.e. half-cast factor ≥50%. Line drilling was carried out to obtain a clean vertical profile along the walls of Surge shaft-HRT transition (central orifice portion), i.e. from El ± 1198M to 1187M. It was observed that due to splintery/fragmentary nature of rock mass, 64 Ø holes were found collapsing. As such 45 Ø holes @ spacing ±150mm was resorted. Total 1023 (45 Ø) holes were drilled with depth varying from 3.5m to 4.0m to excavate the curved length of 23.5m on either side of central orifice portion.

Despite best practices, at many times 'undercuts' were observed after the blast. While removing these undercuts, in addition to the time loss, over breaks had also occurred. The causative factors vis-à-vis geology were explored and the following findings were noted : (a) Improper stemming & tamping the filler material (rock cuttings) led to higher air-ground vibrations, (b) improper drilling with downward inclination varying between 60-70° to nearly vertical holes which led to cross-connection of adjacent holes causing escape of gases and non-uniform distribution of detonation pressure leading to sympathetic detonation transmission and misfires of certain delay nos. and (c) at many occasions, the dummy holes left at periphery couldn't be lifted up with crack propagation and detonation transmission. It was addressed by lessening the burden & alternate charging of holes with light charges. By doing so the overbreaks in the shaft were restricted to very marginal (less than 5%).

4) Rock Support for Vertical Shaft excavation

The rock support system was evolved giving cognizance to geological information collected during the pilot excavation and geological data of HRT & THPS which includes 100mm thick shotcrete with wiremesh, 9m long 32Ø rock bolts @ 1.5m c/c between EL1275-1255m & 1220-1197.4m, 7.5m long 25Ø rockbolts @ 1.5m c/c between EL1255 to 1220m (Fig.7). From EL 1270 to 1260m and from EL1220m to 1197.4 steel ribs-ISHB 200, spaced 500mm c/c were installed. The rib support was also provided between El 1250-1225m in stretches of 5m alternatively and backfilled with M15A20concrete. It is also mentioned here that after completion of 800mm RCC lining of the shaft, contact as well as consolidation grouting was envisaged. Further 5m long 45 Ø pressure relief holes @ 3m c/c were provided between El 1275M to 1242M.

C. Rock mass Strengthening Measures

Installation of Rock Support**-** In surge shaft, NATM (New Austrian Tunneling Method) i.e. Systematic &

1) Sequential installation of rock support concurrent to excavation was practiced which involved (a) scaling, (b)1st layer of shotcrete, (c) grouted rock bolting, (d) fixing of wiremesh and (e) 2nd layer of shotcrete. The above procedure was also ensured before erection of ribs & backfilling, in the stretches of rib areas.

TABLE I RMR AT DIFFERENT DEPTHS

Sl. No.	EL (M)		Rock types	RMR Range
	From (m)	To (m)		
1	1275	1260	Predominantly strong to very strong, moderately jointed, fractured sandstone and medium strong to strong siltstone along with intermittent bands of shale.	52-55
2	1260	1245	Alternate bands of thinly to moderately spaced medium strong Siltstone (60%) and weak to medium strong thinly bedded shale intercalations (20%) and strong to very strong sandstone bands (20%).	48-52
3	1245	1225	Alternate bands of thinly to moderately spaced medium strong Siltstone (60%) and weak to medium strong thinly bedded shale intercalations (40%).	48-52
4	1225	1215	Predominantly weak to medium strong shale (75%) and few bands of intercalated strong to very strong siltstone (15%) and sandstone bands (10%).	50-55
5	1215	1195	Alternate bands of sand stone, siltstone with intercalated shale bands oftenly associated with numerous thin shears and occasional occurrence of fractured/crumbled rock mass.	34-44

2) Pregrouting**-** Around surge shaft periphery, pre-grouting was resorted from top (i.e. El. 1275M) with 6m long 45Ø sub vertical holes (70-80°) to assist in rock excavation & rock supports for minimizing overbreak.

3) Pull out Tests**-** Systematic pull out tests were carried out after completion of a stage. There were few instances of failures of pull out tests of rock bolts (expansion shell type) with end anchorage failure as well as during tensioning with consequential freeing of bolt. This has been generally found associated with splintery & fragmentary nature of siltstone & shales.

As an instance, during the pull out tests in SE quadrant between EL 1214-1216m, a 9m long 32Ø rock bolt failed after application of hydraulic load of 24 ton registering a displacement of 49mm i.e. 9mm higher than the design limit. Similarly at El + 1204.5m, it was observed that during torquing few rock bolts', bolt head (shell) were getting detached/freed from the leaf-flange at the end of the hole due to the weak splintery/crumbled nature of siltstone and sheared shale reaches in S-SW and S-SE quadrants giving an apprehension of dilatational effect. This dilation of rock mass was associated with end anchorage failure of rock bolt. These areas were specifically identified and strengthened by consolidation grouting with 6m long 45mm dia holes, suitably oriented with 30-50° so as to cut across bedding planes (S1=190-230/60-75 and S1-A=025-055/45-75) and shear seams.

4) Consolidation Grouting at Shaft Bottom**-** in view of the nature and disposition of rockmass vis-à-vis the close proximity of the surgeshaft bottom with visible opened-up free-faces of HRT, PS-1 and PS-2 junctions at Surgeshaft, at El $\pm$ 1202m, consolidation grouting was carried out suitably oriented with 25-40° to provide an effective consolidation zone up to Surge shaft bottom i.e. EL 1197.4m.

5) Instrumentation**-** The behavior of the slope is monitored with the help of instrumentation. 3 nos of 10m deep single point bore hole extensometers (SPBX) were installed at berm at El ± 1314M, 3 nos of 15m deep SPBX were installed at El 1296M and 2 nos of 10m deep SPBX were installed at El 1276M. It has been observed from these instruments that there was a minor distress during the excavation of the shaft, but which was found stable later after construction of cladding wall at bottom toe of the slope and consolidation grouting at benches and below El 1290M to 1275M. The shaft sinking was also monitored by means of Tape extensometers, SPBX and pore pressure gauges etc and till date any significant distress has noted both in slope and shaft.

III. Conclusion

The excavation & concreting of Surge shaft, Uri-II HE Project was successfully completed & the project got commissioned in 2013. NATM was followed during the construction of surge shaft. Systematic rock support, optimized drilling & blasting patterns giving due cognizance to the geological environment at site, Slip form Technology was used during the concrete lining of shaft. Timely site specific treatments & remedial measures as per site requirement aided by geology, proved towards successful completion of excavated 26.6m dia and 77.6m deep circular vertical Surge shaft.

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