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Kishanganga hydroelectric project (J&K India) head race tunnel tunneling by Tbm under Himalaya mountains dealing with adverse conditions

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ABSTRACT: Kishanganga Hydroelectric Power Plant, located in Indian Kashmir, close to Pakistan border, is under construction by Hindustan Construction Company L.td. SELI Spa, as specialized Subcontractor, is excavating by TBM 14,6km of the Headrace Tunnel, 23km long. The tunnel crosses geological formations composed by basalt, meta-siltstone and meta-sandstone with overburden up to 1300m and several fault zones. The TBM is a Universal Double Shield with diameter 6,18m, which installs hexagonal precast segmental lining. A specific new TBM design have been implemented for the application in the Himalaya geological formations to overcome high stress conditions due to high overburden, variability of the geo-mechanical characteristics and groundwater conditions. Geological risks and adverse conditions are managed by TBM special characteristics and experience of SELI team. TBM has already excavated the first formation of Basalt, overcoming collapsing ground, with three main geological events, and very hard rock. Presently, the TBM is excavating in a formation composed of metasiltstone and metasandstone, with monthly productions more than 500m and daily productions up to 40m. Fareoff location of the jobsite forces SELI team to solve hard logistic problems. TBM excavation data are sharply recorded for possible improvements of TBM design for future application in similar conditionsIntroduction

1 Introduction to the Project

Kishanganga Hydroelectric Project 330 MW is taking place in the remote area of Jammu & Kashmir about 52 km north of Srinagar. Dam site is located in Guresh and Head Race Tunnel (HRT) lays along 23 km of which 14,6 km of Tunnel Boring Machine (TBM) excavation until the power house located in Bandipora District. SELI supplied a brand new Double Shield Universal (DSU) TBM 6,18m diameter, to perform the 14.6km HRT.

Figure 1. Kishanganga HEP map

HR Tunnel is lined by precast concrete segments having hexagonal shape as shown in the tunnel section below.

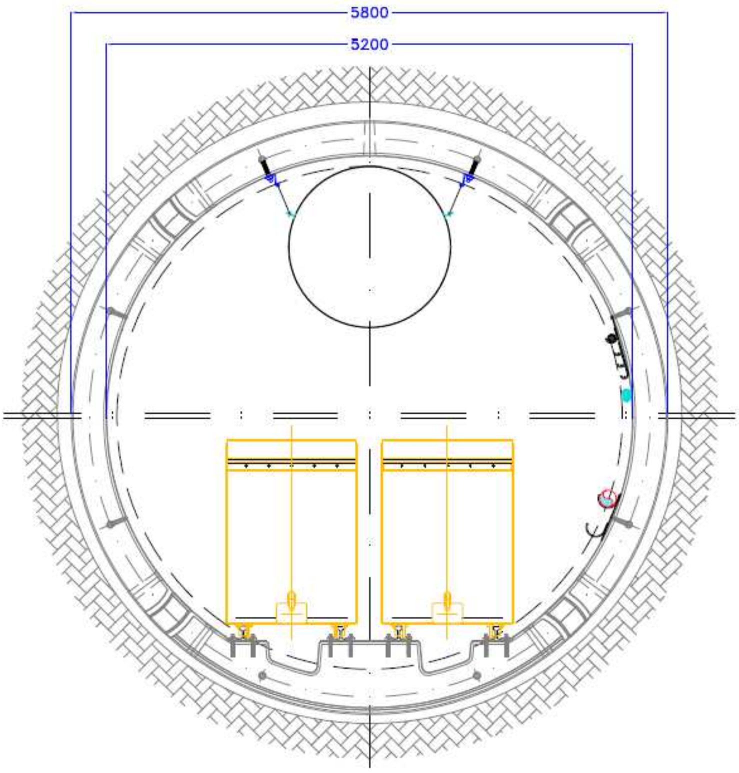

Figure 2. HRT typical section

The following geological chart and section summarize the geological information enclosed in the design documents delivered to SELI, highlighting the likely rock class distribution that might have been encountered by the TBM, and those conditions which might be critical in terms of TBM progress. Nevertheless, only visual surface investigation has been performed, which is very poor in order to reveal main fault zones, hydrogeology and thermal conditions. Anyway, shear and squeezing zones, significant water pressure and flow and geothermal anomalous conditions may be encountered in some areas, according to the studies performed. Therefore, SELI team has to tackle all events promptly according to its experience and proper methodology.

Table 1 Summary of Rock Mass Classifications

Generalised Rock Type	Parameter	RMR89 (1)	GSI
Razdhan Formation	Meta-sandstones, with interbedded siltstone	56 to 78	40 to 60
	Thinly bedded meta-siltstones	50 to 60	35 to 45
	Folded siltstone with phyllite and associated shearing	10 to 50	10 to 30
Hasthoji Formation	Very thinly to thinly bedded shales with interbeds of meta-siltstone	20 to 50	15 to 30
Hafkhalan Formation	Thinly bedded meta-siltstone	40 to 57	30 to 45

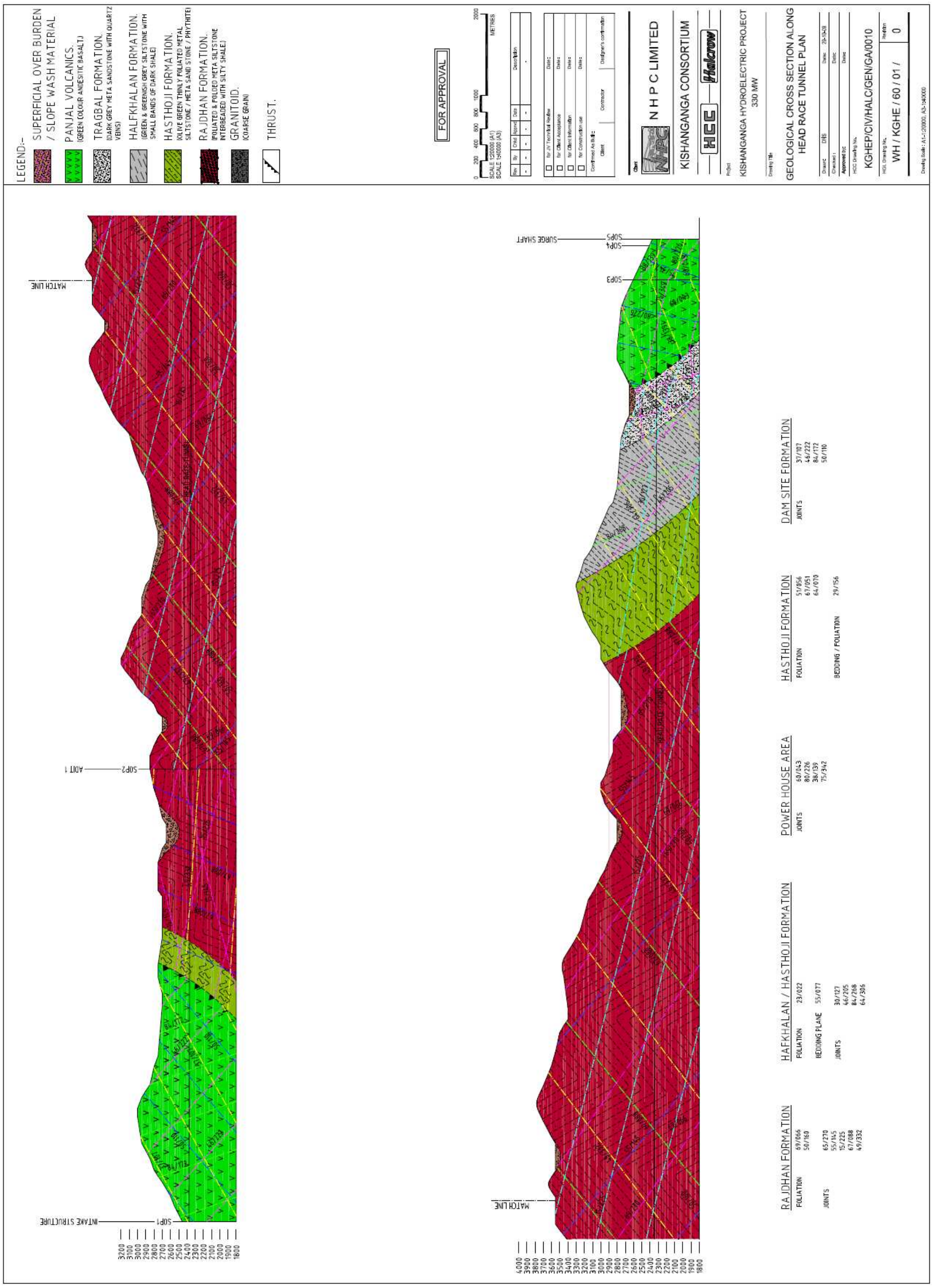

Figure 3. Head Race Tunnel geological section

2 TBM Double Shield Universal technical description

Main geological conditions predicted by SELI geological department, according to the geological information available, that would have compromised progress of the TBM include the following:

- squeezing of the ground onto the TBM shields with sufficient pressure to prevent TBM progress ;
- collapse of the rock face in front of the cutterhead, which may stop rotation of the cutterhead ;
- significant groundwater inflow, possibly forming mudflows.

Considering the complexity of Kishanganga geology and SELI experience as TBM Manufacturer and TBM tunnelling specialized Contractor, all these factors have driven SELI to select a Double Shield Universal in order to tackle wide geological uncertainties, as mentioned above.

Why SELI proposed this type of machine in regard of the geological uncertainties foreseen:

- advancing speed faster than others due to the possibility to excavate and install segments meanwhile and reduce, for instance, the possibility to get the TBM blocked under squeezing conditions;
- shorter length of forward shield and smaller diameter of the tail shield which allow better drivability in squeezing rocks ;
- telescopic shield which can be open or close to release material pressure on the shields in squeezing conditions. In addition it is provided by windows for rock pre-treatment in particular conditions ;
- equipped by main thrust and auxiliary cylinders which allow to move each shield at any time and have more thrust available per shield surface ;
- shields can be move backward in case of collapsing material to avoid cutter-head blockage and proceed with rock pre-treatment ;
- active driving system which allows better drivability especially in difficult rock conditions ;

Additional features were designed specifically for Kishanganga DSU TBM to face geological occurrences and monitoring geological conditions during construction phase:

- overcutting system composed by copy cutter 19" ;
- proper eccentricity of TBM shields axles which provides thicker gap at TBM's crown portion and contributes to avoid blockage ;
- TBM conical shields design attributes smaller side surface and less probability to the TBM to get stuck under squeezing condition ;
- cement/resins treatments at different sections of TBM through dedicated windows and holes in order to treat the ground;
- fore-poling system at tail shield whenever very unfavourable rock conditions are detected, in order to overpass the geological adverse condition;
- nos.8 electrical motors (8x315 kW) to guarantee high torque and Revolutions Per Minute (RPM) ;
- exceptional thrust system capable up to 43429 kN ;
- probe drilling equipment and data recorder to collect and plot data in real time.
- dewatering system composed by 2 slurry pumps, max flow 5000 l/min each, and 2 additional submersible pumps max flow 3800 l/min each.

Figure 4. Kishanganga TBM DSU

3 Logistic of the project

Kishanganga TBM arrived at Mumbai port in July 2010, nevertheless due to riots and curfew in Kashmir region, transportation of TBM, back up and all the equipment to site could start only in October 2010 and ended in December 2010.
Several difficulties were overcome during the transportation along about 2300Km, from Mumbai to Bandipora village, near the site, due to narrow roads and to a road tunnel which forced to modify the truck where the main bearing was laid.

Figure 5. Main bearing transportation

An accurate and sharp delivery schedule of bulks and containers to site was planned to optimize the limited working area available at TBM portal yard and avoid loss of time during the TBM assembly. Equipments belonging to TBM machinery and excavation activity and segments storage were carefully designed and positioned at TBM portal area, which is located at 2300m above sea level along mountain slope. Tippler equipment was designed with a translation device for locomotives and muck cars to save external room.
Moreover, Kashmir region and in detail the road from Bandipora to TBM site are affected by adverse weather conditions during winter time (from December to April). In fact adverse climate conditions influence all activities in terms of material delivery, manpower transportation and equipment management and maintenance. Therefore, SELI is managing the spare parts supply taking in account

also this environmental conditions in order to guarantee a minimum stock availability to cross the winter period.

Figures 6. TBM site during winter time (left) and tippler equipment (right)

4 TBM production in excavated tunnel

The Kishanganga TBM has already excavated the Panjal Volcanic formation of Basalt and Andesite, overcoming collapsing ground, with three main geological events, which stopped the TBM for total 97 days and very hard rock.
In this formation, three main geological events occurred at chainages 0+265, 0+378 and 0+404 (from April to August 2011). TBM was slowed down by a RMR class V rock, with unfavourable orientation of the joints and low cohesion, due to the clay filling, which caused the falling of a big quantity of blocky material inside the cutterhead, leading to the cutterhead buckets blockage and causing a large over excavation at crown.

In order to advance the TBM through the collapsed areas and overcome the collapsed zones, the following special measures were implemented, thanks to the TBM features:

- Injection of foam and resin to fill the cavities, stop voids propagation and falling of blocky material.
- Excavation of a by-pass tunnel over the TBM to reach the cutterhead, by erection of trapezoidal ribs along the shields, execution of shotcrete, installation of wiremesh and bolts, up to the cutterhead location.
- Consolidation of collapsed ground at cutterhead portion by VTR Wiborex, resins injection and cement grout, from the by-pass and from the cutterhead.
- By-pass tunnel extension, about 1meter ahead to set the cutterhead free from the collapsed material, cleaning the frontal and side areas.
- TBM advancing through the stabilized ground up to the end of the collapsed zone. Meanwhile geological investigations, consolidation by steel Wiborex and cement grout injection of the ground ahead, and keep boring by TBM the stabilized ground under the covered zone.

After the first 400m of blocky and collapsing material, the Basalt formation encountered became very hard with UCS values up to 200 MPa, density 2.9-3.0 g/cm^3, Drilling Rate Index 24. TBM advanced with high thrust values up to 11500 kN, maintaining a penetration rate of 6-8 mm/min and high cutters consumption. Nevertheless, the average monthly production recorded in this phase was 211m/month (see Figure 9), with a maximum daily production of 20m/day. High cutterhead maintenance time was recorded, due to adverse rock characteristics.

On the 29th of February 2012 TBM encountered extraordinary adverse rock mass conditions at Chainage 1+711,87, at the transition between Panjal Volcanics and Tragbal Formations. It was due to dark grey colored, foliated and flaky rock mass having high mica content and quartz veins with three joint plus random joint sets, some clay filling, highly weathered conditions.

Squeezing of the rock mass was observed: the wall of the tunnel was abutting against the TBM shield and there was no gap between them. The overburden at this location was about 500m.

The entire face and wall were loose and had very less stand up strength. Cavity formation took place at the face and crown: about 1,5m and 1m respectively.

In order to resume the excavation several actions took place as following and according to the methodology experienced by SELI:

- Released the pressure at shields by discharging accumulated material along surfaces.
- Cement treatments at different sections of TBM through dedicated windows at cutterhead, forward and telescopic shields (see Figure 8).
- Finally, when excavation was resumed, an overcutting performed by 19”copy cutter system was performed in order to create an overcut section.

Figure 7. ground treatment at chainage 1+711,87

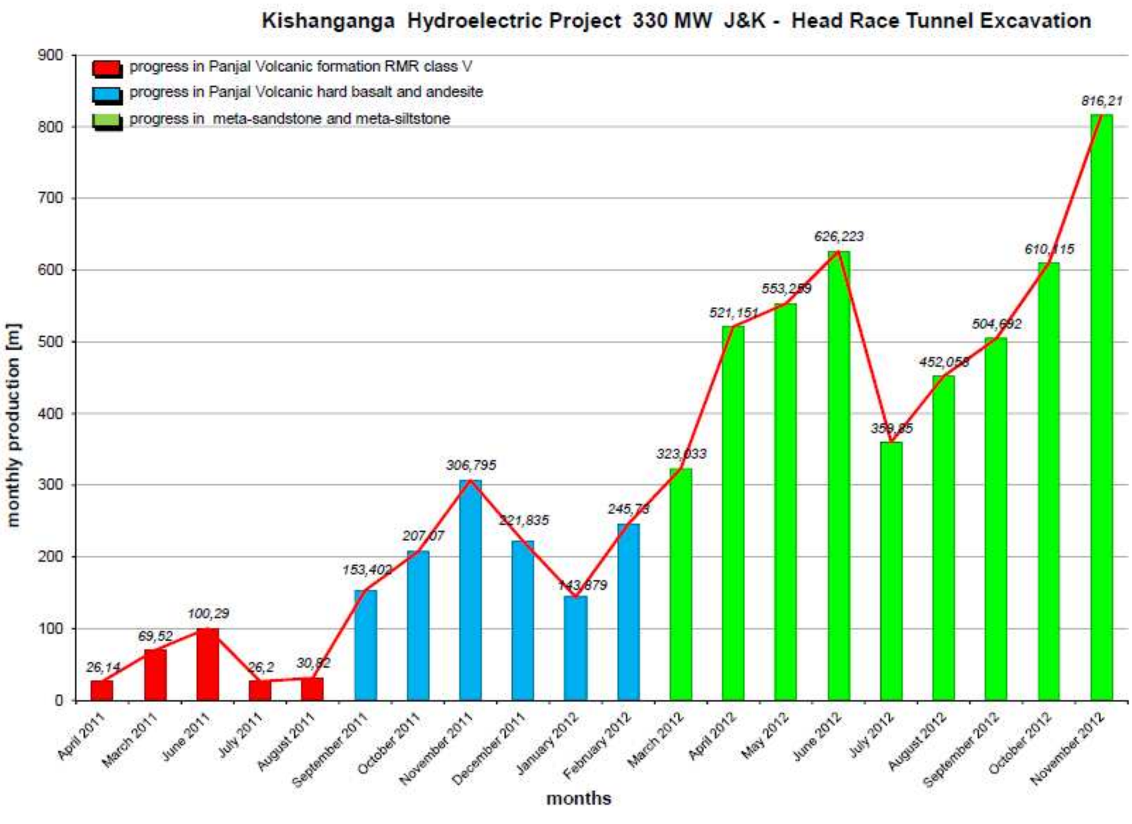

Figure 8. Kishanganga TBM monthly production

After crossing this fault zone, on the beginning of March 2012, the TBM encountered the first formation of meta-siltstone and meta-sandstone (Tragbal formation) which allowed a sensitive increasing of TBM production.

TBM has increased its penetration rate up to 60 mm/min, giving a good reply in terms of mechanical and electric reliability, daily cutterhead maintenance time reducing. In addition improvement of TBM crew's performance and organization allowed to increase TBM net boring hours.

To the end of September 2012 the TBM excavated a total length of tunnel of 4,900m, 3,340m of which in meta-siltstone formation, with a monthly average production of 420m/month, a maximum monthly production of 628m and a maximum daily production of 40m (see Figure 9).

5 TBM production forecast and conclusions

TBM is increasing its production and the forecast for the completion of the 14,630m of Headrace tunnel is highlighted in Table 1. SELI and HCC team foresee to complete the tunnel within the end of September 2014, one month in advance to the contractual date. This forecast still considers 220 days of geological stoppages due to the adverse conditions of Himalaya mountains which could be met, related to high overburden up to 1300m and squeezing phenomena, foreseen in the tunnel design. Nevertheless, based on the TBM behaviour and TBM crew performance, both in blocky and collapsing ground and in actual rock conditions - which should be homogenous along the next stretch of the tunnel - TBM production schedule seems to be suitable and final target to excavate 14 Km in Himalaya mountains in less than 40 months is achievable.

Table 2 Production forecast

TBM excavation schedule

30th September 2012 - 9727m to be excavated out of 14630m

		4a) Razdan Formation: 75% meta-sandstone, 20% meta-siltstone, 5% siltstone with phyllite					*4b) Razdan Formation: 85% meta-sandstone, 10% meta-siltstone, 5% siltstone with phyllite*					*Total*
Design Rock Parameter	Overburden range (m)	420 - 1062 m					1407 - 447 m					
	RMR Classes	II	III	IV	V	Total	II	III	IV	V	Total	
	GSI Index		40-60	35-45	10-30			40-60	35-45	10-30		
	UCS [MPa]	70	50	31	15		70	50	31	15		
	Lenght [m]	233	3268	934	233	4669	253	4046	506	253	5058	9727
	RMR Classes distribution	5%	70%	20%	5%		5%	80%	10%	5%		
	Estimated Penetration [m/h]	3,5	3,9	4,1	4,1		3,5	3,9	4,1	4,1		
	Advance [m/d]	22,3	27,0	24,2	9,7		22,3	27,0	24,2	9,7		
Production Forecasts	Working days [d]	10,5	120,9	38,6	24,0	194	11,3	149,7	20,9	26,0	208	402
	Average advance (m/day)					24,1					24,3	
	Stoppage due to geology [d]					90					130	220
	Total working days					284					338	622
	Total calendar days					328					390	718
	Total months											23,6

6 References

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