Excavation and Support System for Powerhouse Cavern at Tala Hydroelectric Project in Bhutan

Rajbal Singh
Central Soil and Materials Research Station,
Olof Palme Marg, Hauz Khas,
New Delhi-110016, India
Email: rajbal_s@yahoo.co.in

ABSTRACT

The paper is aimed at sharing the experience gained in excavation and support system and installation of 12/15m long Dywidag rock bolts in underground powerhouse hall cavern at Tala Hydroelectric Project in Bhutan. Site specific procedures evolved keeping in view the availability of construction machinery and associated quality assurance aspects have been high-lightened which could be practiced for similar situations in other projects.

Keywords: Powerhouse; Support system; Rock bolts; Instrumentation

1 INTRODUCTION

Tala Hydroelectric Project is a run of the river scheme, located 3 km downstream of the existing 336 MW Chukha Hydroelectric Project on river Wangchu in South-West Bhutan in Eastern Himalayas. The installed capacity of the project is 1020MW (6 x 170MW). The project taken up for execution from the zero level of infrastructure development from October 1997 has been commissioned fully on 30th March 2006 with commissioning of 1st unit on 31st July 2005.

The powerhouse complex consists of two main caverns of size 206m x 20.4m (span) x 44.5m for machine hall and 191m x 16m (span) x 24.5m for transformer hall with 39m thick rock pillar in between with multiple openings like pressures shafts manifolds, bus ducts/passage ducts, tailrace tunnel (TRT) manifolds, drainage and grouting gallery, construction adit and main access tunnel etc. Figure 1 shows the layout of powerhouse complex.

The ridge, which houses the powerhouse cavern is occupied by fresh and hard, inter banded sequence of quartzite, phyllitic quartzite, phyllite with quartzite boudins and amphibolite schist partings. These rocks are highly puckered and folded into synforms and antiforms.

This paper deals with the experience gained in excavation and support system and installing long rock bolts as the support system of powerhouse cavern at Tala Hydroelectric Project in Bhutan Himalayas.

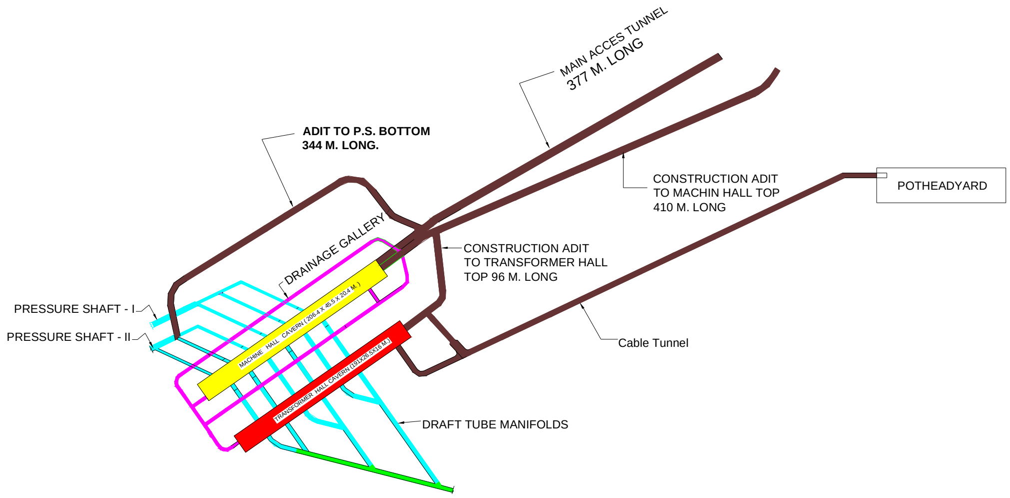


Fig. 1- Layout of powerhouse complex

2 EXCAVATION AND SUPPORT SYSTEM

Excavation of powerhouse cavern was taken up by conventional drill and blast method starting with excavation of 7m wide and 7.5m high central gullet with its invert level at EL 531m, suiting to the final profile of the cavern. The excavation sequence along with time duration in powerhouse cavern is shown in Fig. 2.

The central gullet was supported with 32mm diameter and 6m long rock bolts with expansion shell (end anchorage) at 3.0m x 1.5m pattern. SFRS of 100mm thickness was applied after installation of rock bolts. After the roof support of central gullet, its widening was taken up first on downstream side followed by upstream side by keeping a distance of about 20m between faces of semi-widened sections. Concurrent supporting in the widened portion was completed with 6m and 8m (6m+2m) long and 32mm diameter rock bolts (alternate) both ways staggered @ 1.5m c/c along with SFRS of 75mm-100mm thick.

Many problems were encountered during crown excavation and finally it was supported with conventional support system of steel ribs of ISMB 350 with 12 mm thick plates on both the flanges @ 0.6 m c/c in conjunction with 32mm diameter and 8m/10m long rock bolts @ 3m c/c staggered, after collapse of large portion of the crown.

Having faced collapse during crown widening, methodology of excavation and support system for benching operation was reviewed through investigations by a borehole camera, testing for physical properties of the rock mass and on review 3-D numerical analysis so as to have proper and smooth benching down of the cavern. Support system decided for the walls of powerhouse cavern comprises 3 shotcrete layers of 50mm each and 12m long and 32mm/26.5mm diameter Dywidag rock bolts (resin anchored) and fully grouted with cement grout (with tensile strength equal to 57 tons) @ 1.5m c/c with 100mm x 100mm x 5mm wire mesh. The support system provided in the powerhouse cavern walls was based on the numerical analysis using 3D elastic discontinuum modeling of the rock mass around crown of powerhouse cavern and factor of safety failure against criteria was considered basis for deciding the length/diameter of the rock bolts and associated supporting measures. The support system provided during the benching of powerhouse has been discussed by Singh et al. (2002, 2003).

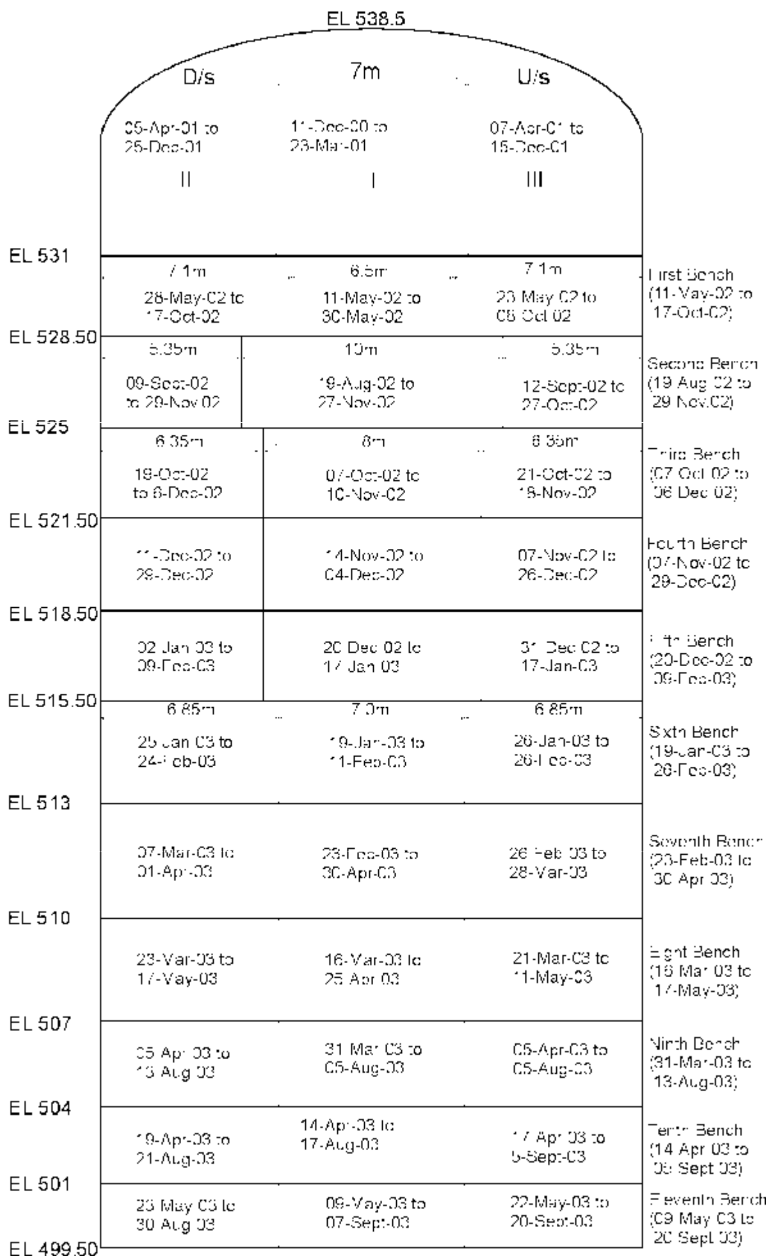


Fig. 2 – Excavation sequence in powerhouse cavern

The systematic rock mass excavation with controlled blasting and concurrent support system during benching down in the powerhouse cavern was adopted. Bench depths were fixed between 2.5m to 3.5m depending upon the rock mass conditions. In the first bench, the rock mass was excavated by providing central gullet of 6m width. Adopting safe blast design in staggered manner, sides through nitches of 3m sizes were excavated. As the rock parameters improved with every bench, width of central gullet was increased to 8m and opening of sides was done with 6m long nitches in the second bench. The lengths of nitches were increased subsequently to 9m in third bench onwards to enhance the pace of excavation. During bench excavation, wall support system was ensured within 36 hours after the excavation except for a few events such as in the initial nitches.

Spacing of the nitches was staggered so that in no case the full span was opened at one instance. The inclination of rock bolts were provided as 5^o downward to facilitate grouting according to geological orientations. This process of excavation in first bench was very slow. To enhance the rate of excavation and after attaining confidence in support system, dimension of the nitches were increased slowly and stepwise from 3m to 6m and from 6m to 9m with a depth of 3m. During this process, excavation could be increased from 2600m^3 per month to 14000m^3 per month.

The geological considerations dictated providing 26.5mm diameter and 15m long Dywidag rock bolts in the walls of powerhouse cavern at specific locations, especially around pressure shaft manifolds and tail race tunnel (TRT) manifolds. Accordingly at a few locations, 15m long Dywidag rock bolts were provided and pull out test were conducted to ascertain the efficacy. To achieve 15m length of Dywidag rock bolts from 12m long rock bolts available at site, 12m long rock bolt was coupled with 3m piece near the wall face.

Instrumentation to monitor the loads and deformation on ribs/rock bolts was done to assess affect of excavation on the stability of cavity and also the efficacy of the support system.

3 MATERIAL TESTING OF DYWIDAG ROCK BOLTS

Dywidag rock bolts (post tensioning, prestressing steel bar) have been imported from M/s. Stalhwerk Annahutte, Germany having following properties:

Chemical Properties:
C= 0.69%, Sr= 0.23 %, Mn= 0.65 %, P= 0.013%, S= 0.010%

Physical Properties:
Yield Strength = 1033 MPa (571 KN for 26.5 mm dia rock bolts)
Tensile Strength= 1122 MPa (620 KN for 26.5 mm dia rock bolts)
% Elongation = 8%; reduction in the area at rupture = 19 -22 %

The rock bolts were tested from each lot. The ultimate tensile strength of more than 61 tons was obtained during testing for Dywidag rock bolts as given in Table 1.

Table 1 - Tensile strength test on Dywidag make steel rock bolts

Sl. No.	Dia (mm)	Yield Strength (MPa)	Tensile Strength (MPa)	Elongation (%)	Remarks
1	32.0	-	11186.1	-	Without coupling
2	32.0	-	11168.8	-	Without coupling
3	32.0	-	11282.5	-	Without coupling
4	32.0	-	11186.1	-	With coupling
5	26.5	1010.0	1097.2	7.30	Brittle failure with no neck formation in all rock bolts
6	26.5	1009.6	1094.3	7.16	
7	26.5	1003.0	1021.5	4.15	
8	26.5	1006.1	1023.5	9.43	
9	26.5	999.0	1023.5	7.17	
10	26.5	1016.8	1029.8	9.43	
11	26.5	1020.3	1029.3	9.43	
12	26.5	1018.0	1028.0	9.40	
13	26.5	1013.2	1089.2	11.70	
14	26.5	995.4	1091.2	6.41	
15	26.5	1006.1	1088.1	7.17	

Three Dywidag steel bars of 32mm diameter and one coupling of Dywidag were also tested for tensile strength of rock bolts at Central Soil and Materials Research Station (CSMRS 2002). All 3 samples of rock bolts were found to have tensile strength varying from 1116.8 MPa to 1128.3 MPa with an average value of 1122.6 MPa, which was equivalent to about 90 tons load. For 32 mm diameter Dywidag rock bolt, the steel strength specification is 835/1030 MPa with a yield load of 67.1 tons and ultimate load of 82.8 tons. For testing the strength of rock bolts with coupling, the Dywidag rock bolt sample broke near the coupling and its tensile strength was 1118.6 MPa, which is exactly equivalent to rock bolt without coupling (Table 1).

Eleven samples of 26.5mm diameter rock bolts were tested for evaluation of the mechanical properties of rock bolts. Yield strength varied between 995.4 and 1020.3 MPa. Tensile strength varied between 1088.1 and 1129.8 MPa. Elongation of the specimen after failure varied between 4.15% and 11.7%. It may be mentioned here that the entire specimen tested had a definite yield point and no neck formation was noticed at the time of failure thereby confirming brittle failure. It is to be mentioned here that the sample which has snapped due to movement of rock mass at site had exhibited high strength of the order of 1000 MPa, sharing similar failure trend as witnessed in the laboratory

Similar approach was adopted for resin capsules supplied by M/s. Sika Qualcrete Ltd. and M/s. Fosroc Minetek Pvt. Ltd. and compressive strength of the order of 60 MPa was obtained in the site laboratory conforming to the specifications.

Ordinary Portland Cement (OPC) of 43 grade was used in various components of powerhouse. Compressive strength between 46.80 MPa and 55.33 MPa was obtained against IS requirement of 43 MPa at 28 days. In addition to testing in THPA site laboratory, weekly test certificates were received from Penden Cement Authority Ltd. (PCAL), Bhutan, authorised supplier of cement.

4 INSTALLATION OF DYWIDAG ROCK BOLTS

Following is the sequence of activities adopted for installation of 12m/15m long Dywidag rock bolts:

- Marking: Locations for fixing of the rock bolts were marked on excavated surface.
- Drilling: 12m long and 51mm diameter hole was drilled with the boomer using three additional extension rods. Hole was drilled five degree downward to facilitate grouting.
- Cleaning of holes: Hole was cleaned using compressed air. GI pipe inserted in the hole, repeatedly till the hole was thoroughly cleaned.
- Inserting of resin capsules: Fast set resin capsules of 300mm length and 40mm diameter were inserted in the hole manually, using a loading stick of 10m length, 20mm diameter, made of GI pipe, plugged at one end with soft wood to avoid puncturing of resin capsules.
- Inserting of cement capsules: 2 Nos. 25mm diameter 200mm long cement capsules were inserted with the help of loading stick, to serve as barrier between the cement grout and resins capsules.
- Pre-grouting: Hole was grouted with neat cement slurry of w/c ratio of 0.4 using Atlas Capco Uni grout pump. For grouting the already downward drilled hole, 7m long GI pipe connected with the grout pump hose pipe was inserted inside the hole and grout was pumped, GI pipe was pulled out side slowly when the grout started flowing outside the hole. Face was sealed with the gunny bag.
- Inserting of Rock Bolts: Rock bolts already cleaned from rust and dust was then inserted manually up to a depth of 6m and then mechanically inserted with the help of the boomer drifter. While inserting with the boomer spinning was done. Spinning was continued for the required time so that the resin was properly mixed with the hardener.
- Post grouting: Post grouting was done by inserting GI pipe just at the mouth of the hole, to account for the grout, which was spilled during insertion of rock bolt and spinning. While regrouting gunny bag was kept at the face of the hole by holding it by hand, till the grout started pushing outside the gunny bag.
- Hole was then plugged with the thick cement paste after removing the gunny bag.
- Bearing plate and nut with the washers was fixed.
- Pretensioning: Rock bolt was pre-tensioned by direct pulling of the rock bolt with DSI hydraulic jack, operative with the compressed air.

- With above procedure maximum of 12 rock bolts of 26.5 mm diameter of 12m length were installed in a shift of 12 hours.

Same procedure was adopted for installing few 15m long and 26.5mm diameter Dywidag rock bolts, but coupling to attach two pieces of bolt 12m and 3m was utilized, which interalia dictated drilling 76mm diameter hole in first 3m length to accommodate the coupling.

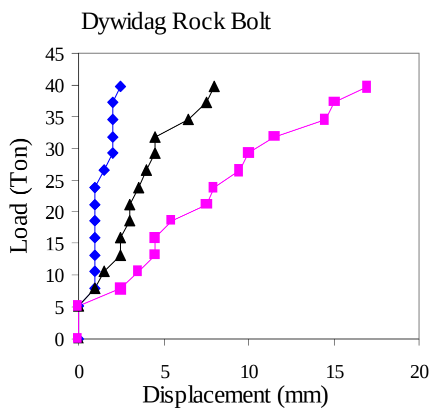
5 ROCK BOLT PULL OUT TESTS

5.1 Efficacy Test on Rock Bolts

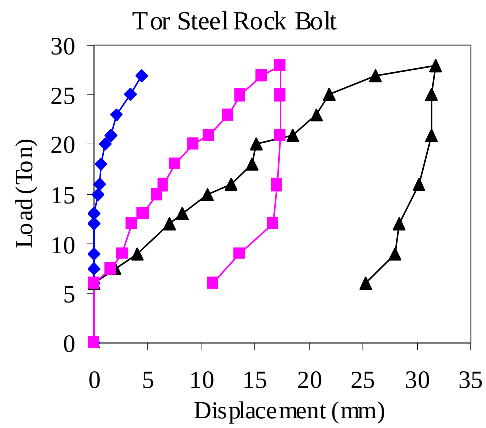
Pull out strength tests were conducted for assessing the efficacy of rock bolts. The anchorage length of 4m was determined by conducting efficacy tests for installation of rock bolts. The pull out tests for rock bolt in the powerhouse cavern were conducted as per the procedures laid down in ISRM (1981), ASTM (1998) and IS (1992). Figure 3 shows failure of thread portion during efficacy test. After completing efficacy test, random pullout tests on Dywidag rock bolts were conducted as shown in Fig. 4 on more than 2% of installed bolts to ensure that the rock bolts were capable of taking the requisite load. Further as an additional measure, against the requirement of 2%, around 2.9 % rock bolts were tested (i.e. 233 out of 8029 Dywidag rock bolts installed on upstream and downstream walls of the powerhouse cavern).

Fig. 3 - Failure of thread portion of 12m long Tor steel rock bolts during efficacy test

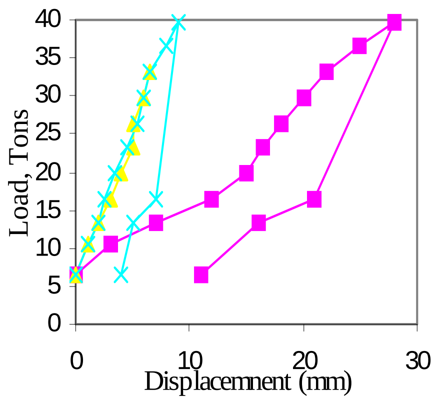
Fig. 4 - Set up of pull out test by Dywidag stressing machine



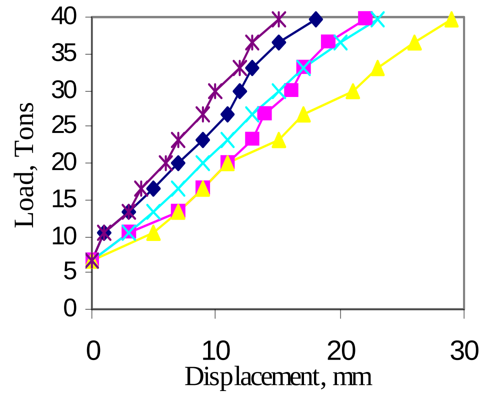
(a) Dywidag rock bolt 32mm φ
and 12 m long



(b) Tor steel rock bolt 32mm φ
and 12 m long



(c) Dywidag rock bolt 26.5mm ϕ
and 15m long



(d) Dywidag rock bolt 26.5mm ϕ
and 12m long

Fig. 5 - Load versus displacement plot for pull out test on rock bolts

It may be mentioned that out of 233 pull out tests conducted, no rock bolt failed in pull out tests. Load versus displacement plots for pullout tests conducted on Dywidag rock bolts are given in Fig. 5. Results of Tor Steel rock bolts are also shown in Fig. 5 for comparative study.

5.2 Tor Steel Rock Bolts

One row of 32 mm diameter 9 m long Tor steel rock bolts with a pretension of 18 tons was installed in the rock below the rib haunch beam at EL 530m. Efficacy of end anchorage of bolt was ascertained with resin capsules varying from 8 to 12 nos. of 40 mm diameter and 300 mm length. Failure of some rock bolts from end anchorage was noticed during pull out tests at an applied load of 7-10 tons. Most of the rock bolts could bear load up to 27 tons. Load up to failure was applied on few rock bolts and the rock bolts failed at the thread portion as shown in Fig. 3. Efficacy tests conducted revealed that rock bolts fully grouted with cement slurry gives better results than the rock bolts grouted with cement capsules.

5.3 Dywidag Rock Bolts

On account of high rock load development, it was decided to install 32mm diameter and 12m long high capacity (90 tons) Dywidag rock bolts. Subsequently, 26.5 mm diameter and 12m long Dywidag rock bolts of high capacity (57 tons) were installed for the wall support system in powerhouse cavern. As per DSI manufacturer of Dywidag rock bolts two type of grouting has been recommended for mono bar anchors. (a) single protection against corrosion. (b) double protection against corrosion. As per the design requirement the rock bolts needed to be resin end anchored and fully cement grouted and therefore the same were adopted as support system with 12 ton pretensioning.

5.4 Advantage of Dywidag Rock Bolts

The continuous bar threads on Dywidag rock bolts allow cutting at any point to adjust the length of rock bolt. Due to coarse thread, it is insensitive to rough handling and there is strong bond along the bar length for anchoring in resin or cement mortar. The continuous threads are also helpful in good mixing of resin cartridges through the thread ribs as shown in Figs. 6 and 7.

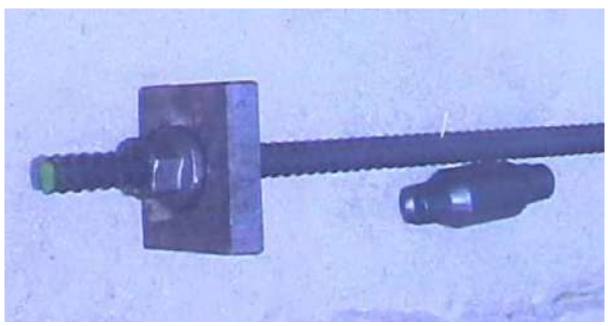


Fig. 6 - Dywidag rock bolt with square bearing plate and coupling

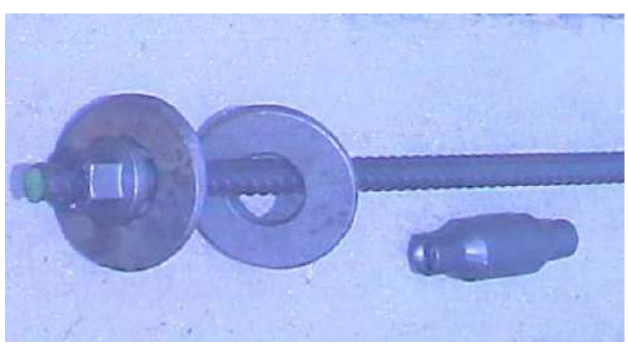


Fig 7 - Dywidag rock bolt with spherical nut and circular bearing plate and coupling

6 MONITORING OF ROCK BOLTS

Based on 3-D numerical modelling by 3-DEC, it was decided to install the instruments at critical RDs of 15m, 65m, 110m and 150m and at different elevations of 525m, 520m, 515m and 506m in the powerhouse cavern. The rock bolts in upstream and down stream walls were monitored by installing load cells on the plate of rock bolts (ASTM, 1998). Observations of load cells installed on rock bolts in powerhouse cavern are presented in Table 2.

Table 2 - Load Cell Observations

EL	Load(Tons)RDs (m) U/S Wall				Load(Tons)RDs (m) D/S Wall			
(m)	15	65	110	150	15	65	110	150
525	43.01	38.74	9.89	-	23.20	28.79	32.23	-
520	27.44	34.83	16.18	34.85	6.95	22.52	15.56	25.96
515	-	22.39	6.97	8.50	-	19.42	14.92	11.89
506	-	23.31	13.44	30.96	-	10.71	4.66	10.69

Maximum load shown by load cells is in the range of 43.01 tons at RD 15m and EL 525m, which is much lower than ultimate capacity (57 tons) of rock bolts. The loads up to 43.01 tons observed on upstream wall were higher than maximum of 23.20 tons on downstream wall.

7 PROBLEMS DURING INSTALLATION OF ROCK BOLTS

It was very difficult to have straight holes of longer depths with conventional drilling. It has been noticed that the holes gets deviated from its alignment wherever comparatively soft rock was encountered thus effecting the desired depth of 12m/15m for the rock bolt and also maintaining required spacing along the depth of the strata.

Due to substantial presence of quartz and phyllites in the rock formation, pieces of quartz get detached from the parent rock and choke the hole which make loading of resin capsules in the hole utmost difficult. Then the hole is cleaned from these pieces of quartz with the help of a cleaning stick, indigenously made for the purpose. It is very time consuming activity. At many locations, it became impossible to clean the holes, thus the holes were grouted and redrilled after 72 hours to restart the loading of resin capsules for installation of rock bolts.

At some locations due to excessive loosening of quartz pieces, hole diameter got enlarged at the anchorage location and the rock bolt was unable to take the pretension. However, after 7 days when pull out tests were conducted on these rock bolts, such rock bolts were able to take load up to 30 tons due to cement grouting and were behaving as fully grouted anchor bars.

8 CONCLUSIONS

Based on extensive quality control management during the installation of 12m and 15m long rock bolts in powerhouse cavern, following conclusions are drawn:

- Dywidag types rock bolt are preferred over Tor steel rock bolts due to following advantages:
  * High strength ensures less numbers of rock bolts compared that with tor steel rock bolts, thus reducing the support system cycle time and facilitating more progress of bench excavation in the same time frame.
  * Continuous bar thread allows cutting at any point for required length of rock bolt at site.
  * High bond along the length for anchoring into resin or cement grout.
  * Good mixing of resin capsules through the thread ribs.
  * Restressing is possible because of continuous threads.
  * Angle compensation through dished plates and spherical seats or domed nuts.
  * Coupling of bolts is possible at any length due to continuous threads.
- Support system with longer Dywidag rock bolts of 12m length, 26.5mm diameter @ 1.5m c/c with 12 tons pretension, wire mesh and plain shotcrete (M25A10) was successfully implemented in supporting walls of the underground powerhouse cavern at Tala Hydroelectric Project, considering the geology, observed instrumentation data and the numerical modelling.
- Strength of single piece and rock bolts with coupling was same in the case of Dywidag rock bolts. Hence, length of Dywidag rock bolts can be extended with coupling for installation of long rock bolts.
- Material of rock bolts need to be checked at random before installation.
- Rock bolts installed at critical section need to be monitored through requisite instrumentation. Maximum load of 43.01 tons was observed on rock bolt.

References

ASTM (1998). Standard Test Method for Rock Bolt Anchor Pull Test, American Society for Testing Materials (ASTM): D 4435-84.

CSMRS (2002). Report on Rock Bolt testing, Central Soil and Materials Research Station, New Delhi.

IS 13517 (1992). Indian Standard, Rock Bolts– Resin Type Specification, BIS, New Delhi.

ISRM (1981). Suggested Methods for Rock Bolt Testing, Rock Characterization Testing and Monitoring, Int. Society for Rock Mechanics (ISRM) Suggested Methods, Ed. E.T. Brown, pp. 163-168.

Singh, Rajbal, Chowdhary, A.K., Sharma, B.N., Goyal, D.P., and Khazanchi, R. N. (2002). Wall support system for powerhouse cavern of Tala hydroelectric project in Bhutan Himalayas, Indian Rock Conf. (INDOROCK), New Delhi, pp. 132-142.

Singh, Rajbal, Gupta, Manmeet, Puri, P.K., Sharma, B.N., Goyal, D.P. and Chug, I.K. (2003). Experience of long rock bolts in machine hall cavern at Tala hydoelectric Project, Int. Conf. on Accelerated Construction of Hydropower Projects, Gedu, Bhutan.