INSTRUMENTATION AND MONITORING OF UNDERGROUND POWER HOUSE CAVERN FOR TEESTA V H.E. PROJECT-A CASE STUDY

B. K. Ojha
Ex- Chief Engineer/NHPC

Abstract: The Teesta river has been planned for cascade development for power generation in six stages aggregating a total generation of 3635MW in the State of Sikkim. The Teesta-V power station was commissioned by NHPC in March 2008 and other stages are in construction/DPR stage. This paper deals with problems encountered during excavation and remedial measures adopted when cracks were observed in the crown and side walls of the cavern. The instrumentation and monitoring the behaviors of rock during excavation has been discussed in this paper.

I. INTRODUCTION

The Teesta-VHydroelectric project is a run of the river scheme comprising concrete gravity dam of 92m height channelizing the river discharge through 17.8Km long tunnel and vertical pressure shaft by utilizing gross head of 216m for generation of 510MW of power. The salient features of the project include 9.5m dia horse-shoe shaped head race tunnel, 30m diameter and 92m deep surge shaft and three nos. of 4.7m dia steel lined pressure shaft to carry the design discharge of 292 cumecs to underground power house to feed three units of 170MW each generating 2573MU electricity in 90% dependable year. The underground complex was designed with Power House and Transformer Cavern of size 117.5x22.0x47m and 100.5x14.0x15m dimensions respectively at a depth of over 170m from the surface. The layout plan of Power House Complex is shown in Fig-1.

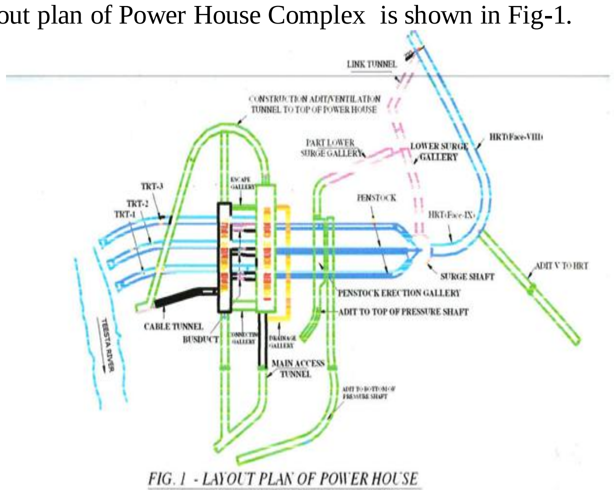


FIG. 1 - LAYOUT PLAN OF POWER HOUSE

Though the regional geological scenario favoured S-E orientation; the secondary structures observed in the homogeneous and massive phylliticquartzites in the vicinity of the Cavern location were favourable to proposed orientation. Main consideration in orienting the Cavern are to make the longitudinal axis perpendicular to the strikes of the faults and joints and parallel to the direction of maximum rock stress and to ensure that the layout sits well with water conductor system. In present case the longer axis of the Cavern has been kept askew(25°-30°) to the major discontinuity to the foliation plane. The cavern has been aligned on the basis of an optimum compromise between the direction of the strike and the direction of such features so as to ensure that interior rock formation is confined to the shortest dimension of the cavity. Moderately jointed phyyllitic quartzites, quartzites and closely foliated quartzitic phyllites very closely foliated bands of phyllites were encountered during the excavation of the Cavern. The flat jack tests conducted in the exploratory drift indicated residual stresses in horizontal direction as 28Kg/cm2 and in vertical direction 22.6Kg/cm2.

II. EXCAVATION SEQUENCE AND SUPPORT SYSTEM

The rockmass accommodating the Power House cavern and associated works is under stress mainly due to the weight of the overlaying rock and due to tectonic stresses. The stress analysis around the opening has the limitation due to heterogeneous character of rockmass, irregularities in the boundaries, presence of numerous shear seams and slide planes and the rock behavior under elastic conditions. The Power House Cavern was excavated in three sections namely central, lift and right with the excavation of a longitudinal central gullet of size 8mx7.5m at crown level for the full 117.5m. The central section was driven through fresh and blocky to massive quartzitic phyllites transverse mainly by a N-S set and 80° towards NSW and WS. A few of the joints were filled with gougy material while rest was tighter planer. The rock mass in the Power House Cavern has an estimated RMR value ranging from 50-57 in service bay and up to PS-2 area and in the range of 45-55 beyond PS-2 and up to control block area. Analysis of the wedge failures and the length of over stressed zones- including potential wedge identification and study of the data base of wedge according to location and physical characteristics were useful in designing the rock support system for the cavern. It was decided to create a double support system with regards to length and installation methods to differentiate the action of the longer bars from the shorter ones. Accordingly a systematic pattern of rock bolts have been provided in the roof and side walls. The 6m long 36mm dia expansion shell type rock bolts at 1.5m c/c in staggered fashion and 12m long 36mm dia rock bolts spaced at 4.5m c/c have been installed and subsequently cement grouted to full length.

Additionally 200mm thick shotcrete in three layers was provided over double layer of welded wire mesh. The side walls have also been reinforced with similar rock bolts of 7.5m long at spacing of 1.5m c/c along with 12m rock bolts at 4.5m c/c in upstream wall and 9m long anchors in the downstream wall. The rock bolts were pretensioned for a minimum tension of 10T and after this cement grout to full length have been provided over a single layer of welded wire mesh. After the bolt installation, final layer of shotcrete was applied to limit the small wedge failure and in this way total 150mm thick shotcrete in two layers was applied in wall of the cavern. The Cavern Excavation was carried out in subsequent stages by blasting as shown in Fig.-2

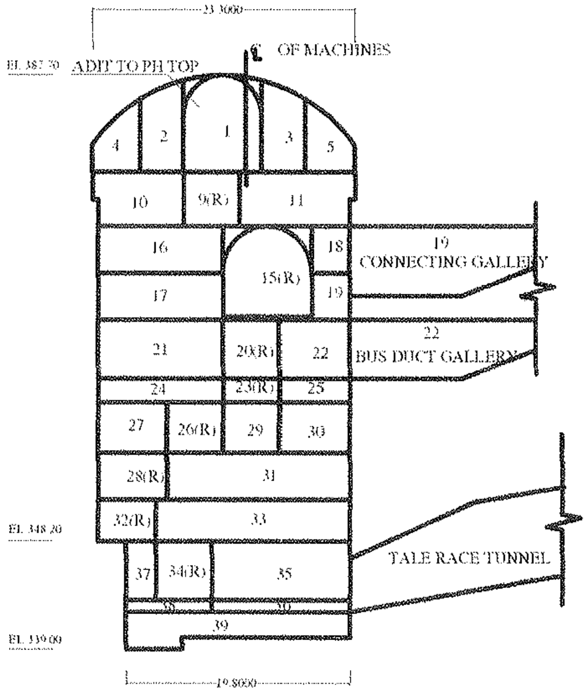


FIG. 2 - EXCAVATION SEQUENCE OF POWER HOUSE

The sequence and time consumed in excavation in various stages is summarized as under:-

S. No	Description	Elevation (m)	Period of excavation	Explosive consumed (in Kg)
01	Central gullet& Side Slashing	387.50 to 379.5	Feb 02 to Oct 02	20620.00
02	Benching excavation	379.50 to 349.50	Nov 02 to May 03	53290.00
03	Unit Excavation	349.5 to 340.00	June 03 to Dec 03	16000.00

A. Instrumentation

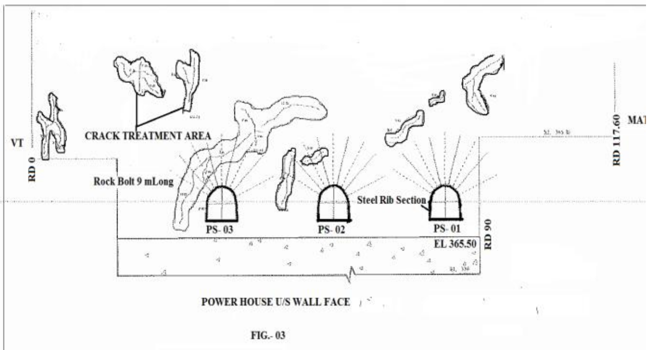
A programme of instrumentation and observation can play a major role in evaluating stability of an underground cavern. Factors influencing stability being mainly the strength of the rock mass and its stratigraphy, method and sequence of excavation and support etc. when an excavation is marginally stable, early detection of instability is possible through use of instrumentation and observations such that supplemental support could be installed on timely basis. When the enlargement of central section was in progress, some of the tight joints showed signs of distresses. The spring portion witnessed spalling but no rock burst was reported. In view of weak strata in certain stretches the consolidation grouting of crown were also done by drilling 45mm dia 6m deep holes. The grout consumption varied with a minimum of 2bags to 20bags of cement per hole. Though the Cavern and its ancillary openings remained dry, the drainage holes provided in the design for a depth of 9m at a spacing of 6m were essential to channelize the seepage water that may occur when the water conductor system is water charged. The excavation and provision of permanent rock support in the Power House crown was completed before the commencement of benching operation. Regular monitoring of the rock-mass of the cavern was being carried out for the roof portion and side walls using mechanical as well as remote reading Bore Hole Extensometer (MPBX) and Load Pressure Cells (LPC). The detail of instruments installed is furnished in Table-1. The instrumentation data regarding rock-mass behavior was quite handy in identifying the distress areas as benching excavation progressed.

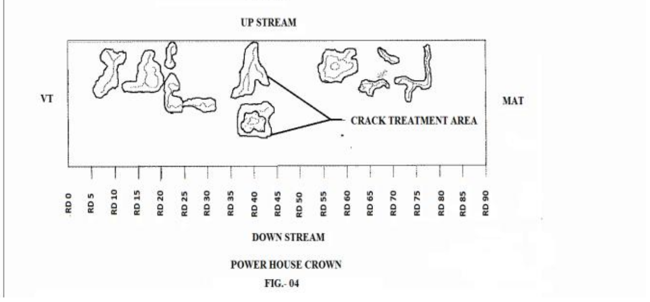
Table-1
INSTRUMENTS INSTALLED IN POWER HOUSE CAVERN UPTO JUNE-03

Sl No.	Instrument	Nos.	Location	EL	RD
1	LPC-1,2,3,4	04	Crown	387.5	3.50/62.50/92.50/20.00
2	LPC	06	U/s wall & D/s wall	380.00	3.50/62.50/92.50
3	MPBX-1,2,3	03	Crown	387.5	59.00/89.00/94.00
4	MPBX	06	U/s wall & D/s wall	382.50	59.00/89.00/94.00
5	SPBX-1	01	Crown	387.50	8.50

III. DISTRESS IN CAVERN AND STRENGHENING MEASURES

After the excavation of the cavern upto EL 349.50 (bottom of Pressure Shaft), the draft tube excavation upto EL 339.oom was completed in Unit-I and Unit-II area and excavation in Unit-III area was in progress when multiple vertical, horizontal and inclined cracks were observed along the upstream walls, crown and along the walls of pressure shaft openings.. Majority of cracks observed in the cavern were vertical and were developed parallel, perpendicular to long axis of the cavern. The cracks started from unit-III and control room area near pressure shaft openings and further extended in the walls of pressure shaft-II and III as shown in fig.3&4. These cracks were huge set back and urgent remedial actions including installation of additional instruments to monitor the rock-mass behavior was taken up.





The instruments showed wide variation during the period between last week of June to I[st]week of July. The cracks were monitored by means of glass strips embedded with cement mortar padding at both ends of the cracks. After few days, some of the glass strips were found broken, which confirmed the continued deformation and widening of cracks. To monitor the rockmass behavior additional instruments were installed as furnished in table-2.

Table-2
ADDITIONAL INSTRUMENTS INSTALLED IN POWER HOUSE CAVERN AFTER JUNE -03

Instrument	Nos.	Location	EL	RD
LPC	03	PS1/PS2/PS3	358	12
MPBX	03	PS1/PS2/PS3	358	12
TEP	03	PS1/PS2/PS3	358	12
TEP	09	U/S & D/S	382.50	12/18/40/46/62/68/3.5/83.5/38
TEP	02	U/S & D/S	365	55.00/32.00
TEP	01	U/S & D/S	380.00	59.00
LPC	01	U/S	346.00	36.10
LPC	01	D/s	374.00	92.50

The 14 nos. of Tape extensor meter (TEP) were installed in the distressed zones including above the openings of the three pressure shafts as these cracks were seen propagating from these areas. The additional rock support by way of installation of steel rib with backfill concrete upto 40m length in the bottom horizontal portion adjoining Power House Cavern of the three pressure shafts were done together with 9m long rock bolts. This immediately arrested the extension of cracks. The 9m long bolts were also provided in the upstream wall of the Power House Cavern below EL349.50m instead of 5m long rock bolts. Additionally 3 rows of 18m long rock bolts were installed in the upstream wall in control room areas. Low pressure cement grouting was done in this distressed zone. The cracks in shotcrete were found to be superficial in nature as wasseen aft er removing the shotcrete layer. The bolts were found intact. It is understood that the cracking might have occurred as wall height was higher and the relatively weak rock strata manifested with geological discontinuities in Control Room and Unit-III areas could have contributed to this problem especially as blasting operation was in progress in unit-3.The remedial measures proved effective as cavern showed the sign of stability as evidenced by instrument recordings. The balance excavation in Draft Tube pit of unit-III was mainly done with excavator with minimal use of explosives. Hardly the blast with one Kg of explosive was used sporadically to crack the rock mass if required.

IV. INSTRUMENTATION DATA ANALYSIS

A. MULTIPOINT BOREHOLE EXTENSOMETER:

The multipoint borehole extensometer installed in the cavern crown and at the spring level at EL 382.50m showed appreciable deformation in the rock mass especially in the Unit-III and Control Block areas. The deformation in crown of the cavern as observed by these instruments during the entire excavation period was monitored and the plot of deformation is shown in Fig-5.

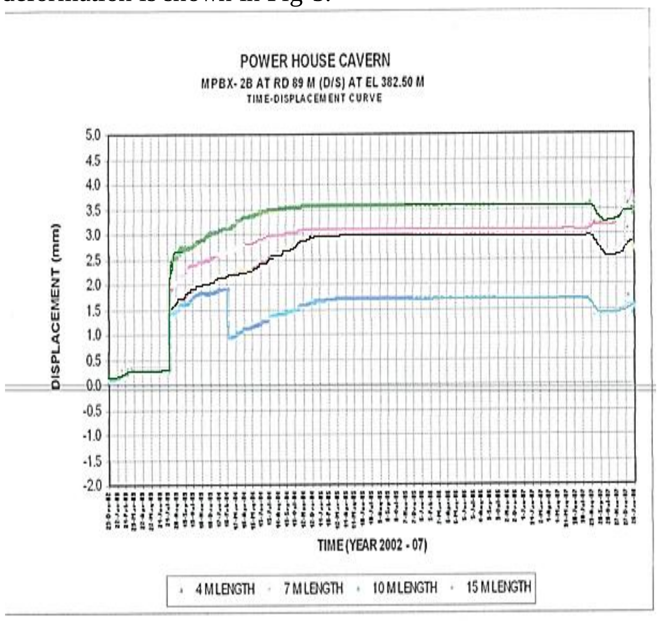
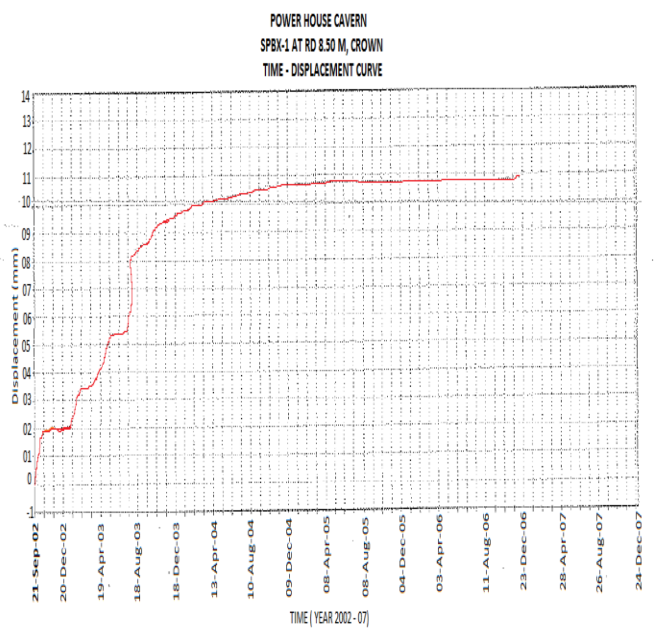


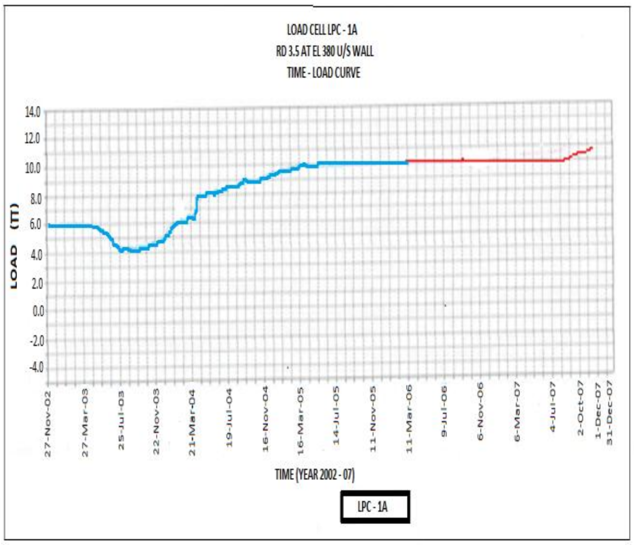
Fig. 5

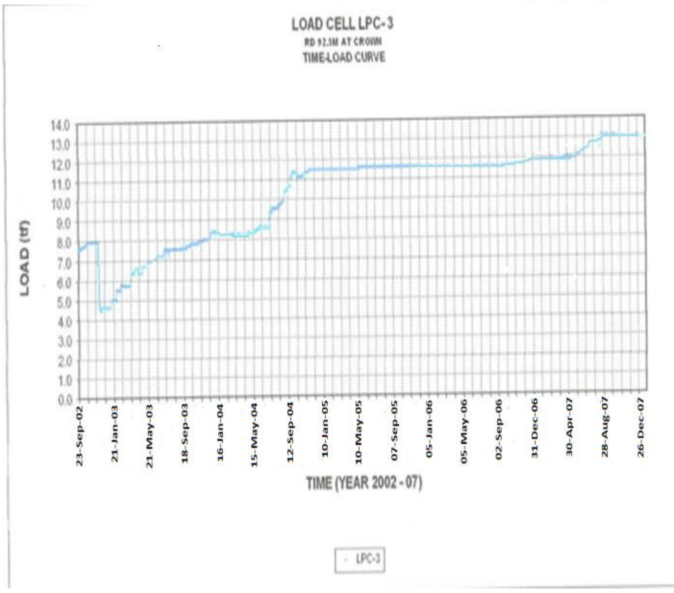
The deformation after top heading excavation (EL 387m to 379m) was not very significant. During the bench excavation upto EL349.50m the maximum relative deformation in the crown was of the order of 4mm whereas in upstream and downstream at EL 382.50m i.e. at spring level, the maximum relative deformation varied between 3mm to 5mm. After the development of cracks in shotcrete on the u/s wall of the cavern between EL 350 to 380m and in the crown, the bench excavation was suspended. The cracks were seen propagating in pressure shaft openings as well. The MPBX showed deformation to the tune of 2mm-2.5mm from last week of June to first week of July 2003 (within ten days). It is observed that there is more deformation in crown at RD 8.5m than deformation observed at RD45m and RD82m. This significant deformation was due to the presence of thick crushed to sheared and closely foliated zone (RMR-poor) in the vulcanite rock mass, between chainage RD 0 to 30m of the Power House Cavern. The maximum relative deformation recorded in the crown portion of the cavern during the suspended period of excavation i.e. during almost 4 months, varied from 5mm to 9.7mm nearest to the location at RD 8.5m as indicated by SPBX installed in the crown. The maximum cumulative deformation in the crown of the cavern after entire excavation has been observed as 38mm which got stabilized as strengthening measures were completed.



B. LOAD CELLS:

Electrical strain gauge load cells were installed in the crown initially. The load cells were locked at low tension value 6-8 Tonnes. The load/tension values were recorded by the load cells for each anchor in KN and the deformation as a consequence of increase in load was worked out for each month. After the appearance of crack in the upstream wall, additional load cells were installed in array with the tape extensometers on the walls to correlate the instrument datas for better understanding of the rock-mass behavior.The recordings from various load cells indicated gradual increase in the load on the instruments during excavation of Power House and its allied structures. However the readings were consistent with convergence data and were found within limits and tended to stabilize as strengthening measures were completed..





V. CONCLUSION

The instruments installed in the underground works acts as guide for any proactive remedial actions. When the underground excavation encounters a known or unexpected major geological feature such as a fault, shear zone or a highly jointed weathered rock zone, instrumentation can be used to monitor behavior, thereby confirming that the implemented construction measures address the issue of instability caused by the feature. Based on instrument behavior whenever there has been any distress sign, like deformation for shear zones etc. the required strengthening measures was timely taken in this Power House Cavern. For all engineering structures more so with mega underground structures proper use of instrumentation is very significant, before, during and after construction of the structures so as to prevent any mishaps either natural or due to unavoidable circumstances.

VI. ACKNOWLEGEMNT

The Author is thankful to NHPC and host of officers who worked in the project during that time and helped in compiling the reports.

REFERENCE

Detailed project report and various unpublished report of Teesta Stage-V Project, Sikkim.

Biographical details of the Author:-

Brajesh Kumar Ojha "FIE", Project Director (Energy Infratech Pvt. Limited)

"Presently working in Teesta III HE Project (1200 MW) in Sikkim".

Graduated in Civil Engineering from Bhagalpur University Bihar in 1984 and joined National Hydro Electric Power Corporation (NHPC) in Feb 1985. The author has worked in NHPC, the largest Hydropower Utility in India for more than 23 years. During this period he was involved in Design and Construction of various Hydropower Projects in India. He worked as Chief Engineer in charge of power house complex Teesta Stage V (510 MW) HE Project.

