Monitoring the Stability of Two Parallel Caverns for Hydroelectric Project – A Case Study

P. Kumar
J.C. Jhanwar
S. Kiran
B. K. Jha
&
C. Bandopadhyay

Central Mining Research Institute, Regional Centre
3rd Floor, MECL Complex, Ambedkar Bhavan
Seminary Hills, Nagpur – 440 006, India
Tel/ Fax: 0712-2510604; E-mail: cmrirc@satyam.net.in

ABSTRACT

The Ghatghar hydroelectric project (GHEP) is under construction in the State of Maharashtra in India for the generation of 250 MW of electricity. The rock mass is composed of the typical basaltic trap formation viz. the compact basalts and the amygdaloidal basalts. The underground power house scheme consists of two major caverns, a machine hall and a transformer hall and intersections. The stability assessment of both the caverns and the intersection has been made through instrumentation. An extensive instrumentation scheme was implemented in these structures to have detailed knowledge on rock mass behaviour during and after the construction and to ascertain the efficacy of the support system. The instrumentation consisted of tape extensometers for measuring convergence, multi-point and single-point borehole extensometers for displacements, load cells for rock load and strain meters for rock strain. These instruments were installed during the process of cavern excavation. The observations so far have revealed that the caverns and other structures are stable.

The support system in the caverns consists of 6m long fully grouted rock bolts at a spacing of 2m centre to centre and 50mm thick steel fiber reinforced shotcrete (SFRS). This paper describes the instrumentation scheme and analysis of the monitoring data to evaluate the stability of the caverns.

Keywords: Cavern, monitoring, tape extensometer, borehole extensometer, rock bolt load cell, deformation

1. INTRODUCTION

The construction of two underground caverns, a machine hall and a transformer hall are the main features of Ghatghar Hydro-Electric Project (GHEP). The underground caverns are located at an average depth of 300m from the surface. The machine hall is 94m long, 23.4m wide and 47m high while the transformer hall is 77m long, 20m wide and 30m high. Both the caverns are parallel to each other and are separated by a 39m wide pillar and are connected by intersection galleries (Fig.1).

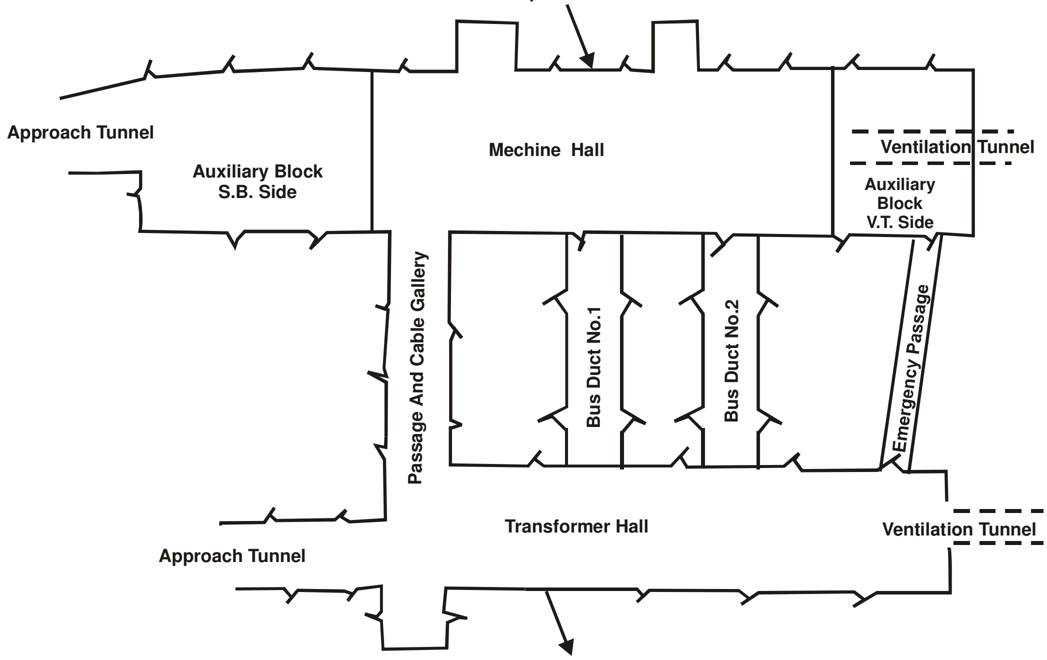

Fig. 1 – Layout plan showing the GHEP caverns and intersections

The rock mass around the GHEP is sufficiently strong as at the Koyna hydro project where three underground caverns have already been excavated and supported so far without any significant stability problem. In view of this, no significant stability problem was expected in GHEP caverns. The excavation of machine hall and transformer hall has been completed. The instrumentation scheme was implemented to monitor roof and wall deformations and rock bolt tension to study cavern stability and to evaluate the support system.

Thus, the paper presents in detail the instrumentation scheme and analysis of the monitoring data to evaluate the stability of the caverns.
The details on rock mass characterisation and on the design of support system at GHEP are beyond the scope of present text. These aspects are, however briefly highlighted in the paper.

2. GEOLOGY

The Deccan Traps, which cover this project area, belong to a volcanic rock series of different basalt varieties formed after cooling and consolidation of lava. The GHEP underground construction passes through different varieties of Deccan trap basalts viz.

compact (Porphyritic) basalt, amygdaloidal basalt and volcanic breccia with diverse engineering characteristics. The project area occupies predominantly compact basalts. The joints are mostly tight and undulating with generally rough to very rough contact surfaces. Random joints are difficult to identify due to the low continuity of such joints. Shear zones are occasionally visible.

2.1 Compact (porphyritic) Basalt

In general, the flow of compact basalt is thick and very extensive. However, the flow shows jointed nature. These joints are contraction cracks. Ideally, a compact basalt flow shows three mutually perpendicular sets of joints, two vertical and one horizontal. The rock mass is broken into rectangular blocks due to these joints. The size of these blocks varies from $15cm^3$ to $3m^3$. The porphyritic basalt is weaker than the compact porphyritic basalt.

2.2 Amygdaloidal Basalt

Amygdaloidal basalts are massive in nature, generally joint-free, but have extensive gas cavities that are filled with secondary minerals. Amygdaloidal basalts with white infillings and amygdaloidal basalts with green infillings are the two main varieties present in the area.

2.3 Volcanic Breccia

Volcanic breccia is associated with the flows of Deccan Trap basalts. In volcanic breccia, the fragments of different varieties of basalts are caught up in gray unaltered lava matrix or in hydro-thermally altered red tachylytic lava matrix or the fragments are held together due to zeolitisation.

3. ROCK MASS CHARACTERIZATION

The rock masses were characterized using Barton's Q (Barton et at., 1974) and Bieniawski's rock mass rating RMR (Bieniawski, 1976) classification approaches.

The Q and RMR so determined varied from 5.9 to 25 and from 60 to 76 respectively (Jethwa et al., 2001). The rock masses were thus classified as fair to good. The fair category belongs to the amygdaloidal basalt, which was encountered at a few locations in lower pressure adit shaft, ventilation tunnel & tailrace tunnel. The majority of rock mass at GHEP, however, belongs to the good category, i.e. the compact basalt.

4. SUPPORT SYSTEM

The estimation of support requirements at GHEP caverns was made using empirical approaches as well as numerical modeling (Jethwa et al., 2001). The salient features of support system implemented are given in Table 1 and a typical diagram of support system used in the cavern is shown in Fig. 2.

Table 1 - Support details for Ghatghar caverns

Location	Support system
Roof / walls of Machine hall and Transformer hall	• 6m long, 25-28 mm diameter, full column grouted rock bolts, tensioned (8 tonnes) at 2m centre to centre • 50 mm thick steel fiber reinforced shotcrete

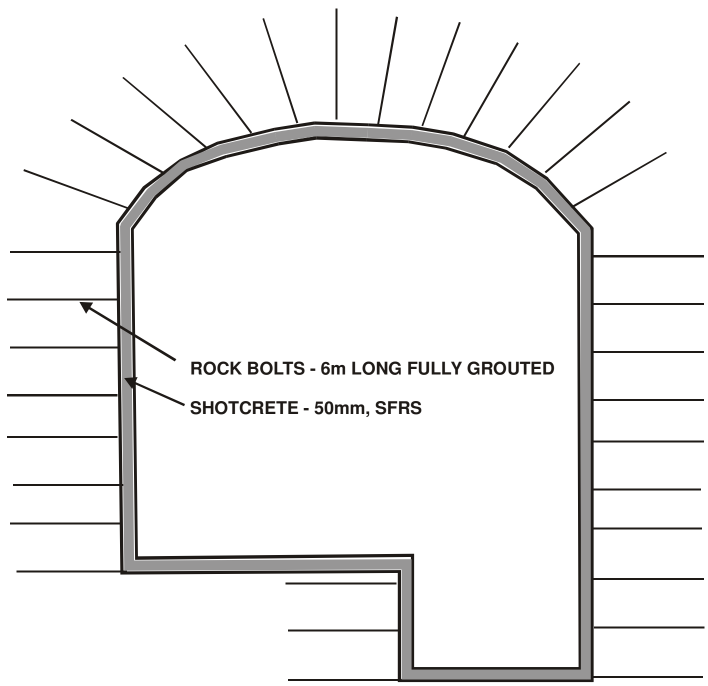

Fig. 2 – A typical support system at GHEP cavern

5. INSTRUMENTATION SCHEME

5.1 Objective

The main objective of the instrumentation was to measure different parameters in the roof and the wall of Machine hall and Transformer hall as given below:

(i) roof and wall convergence,
(ii) rock displacement around the cavern roof and walls,
(iii) rock bolt load, and
(iv) block displacement or joint opening in roof and wall.

5.2 Type of Instruments

The type of instruments and their purpose under this instrumentation scheme are described in the Table 2.

Table 2 - Types of instruments and their purpose

S.No.	Name of Instruments	Purpose
1.	Multi-Point Borehole Extensometer (MPBX)	Measuring displacement in rock mass around two caverns
2.	Single Point Borehole Extensometer (SPBX)	Joint opening/block movement, at random locations
3.	Strain Meter (SM)	Measuring axial strain in rock
4.	Tape Extensometer (TE)	Convergence measurement
5.	Rock Bolt Load Cell (RBLC)	Measuring load on rock bolt

5.3 Location

The location of instrumented sections were chosen to monitor the performance of the caverns near the two ends as well as at the centre.

The instruments were installed perpendicularly with the cavern roof to monitor the roof behaviour and at different RL on the side walls to monitor the overall behaviour of cavern wall.

The location (in terms of chainages) of instrumented sections and the array of instruments in cross-section at these instrumented sections are shown in Figs. 3 to 7.

The instruments installed at different locations are as shown in Table 3

Table 3 - Cavity wise Instrument installed at GHEP

Location	Type of Instrument	No. of Instrument
Machine Hall	MPBX	17
	RBLC	24
	TE	3
Transformer Hall	MPBX	23
	RBLC	12
	TE	5
Bus Duct No.1	MPBX	6
	SM	12
Bus Duct No.2	MPBX	5
	SM	12
Passage & Cable Gallery	MPBX	3
Emergency Passage	MPBX	3
Access Tunnel to Transformer Hall	SPBX	1
Main Approach Tunnel	SPBX	3
Drain Passage	RBLC	6
Butter fly Pit No.2	RBLC	2
Muck Adit	MPBX	2

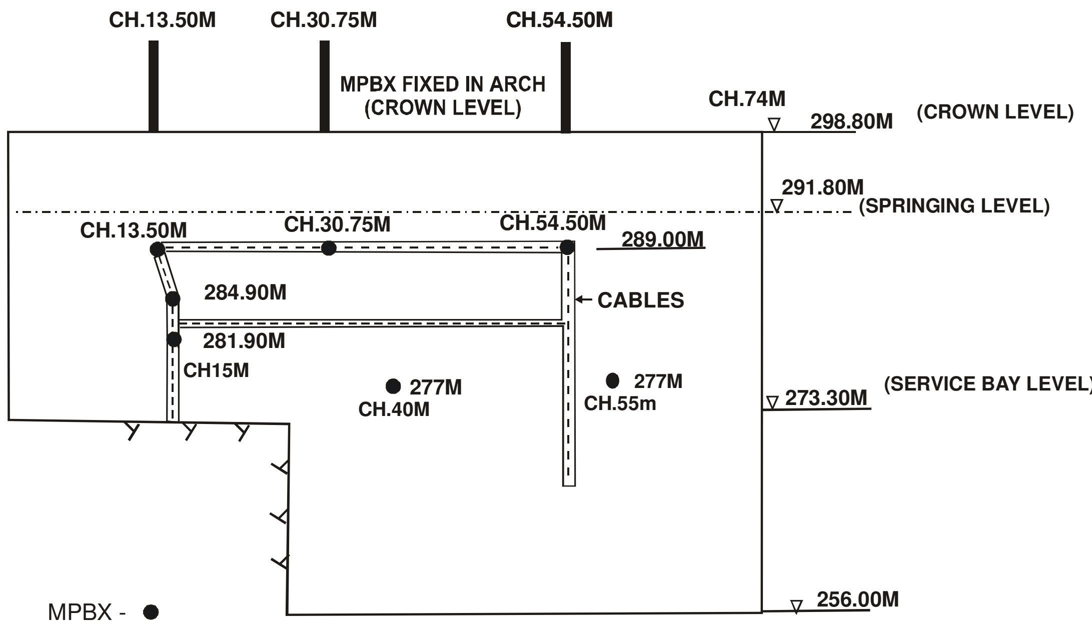

Fig. 3 – L-section of Machine hall showing upstream wall with Instrument locations and Cable layout.

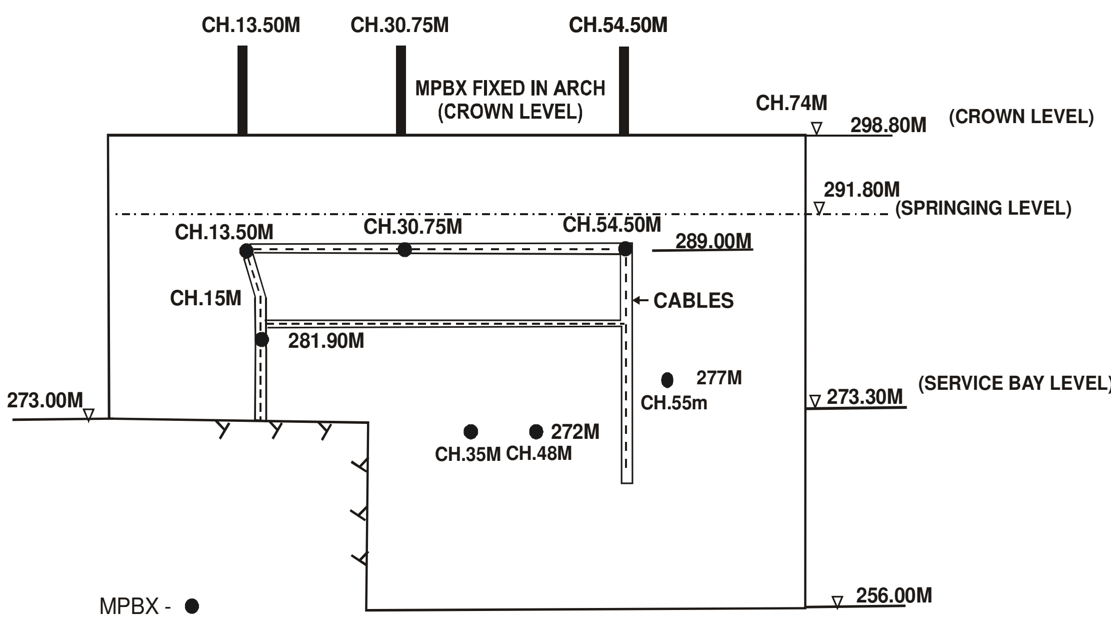

Fig. 4 - L-section of Machine hall showing downstream wall with instrument locations and cable layout

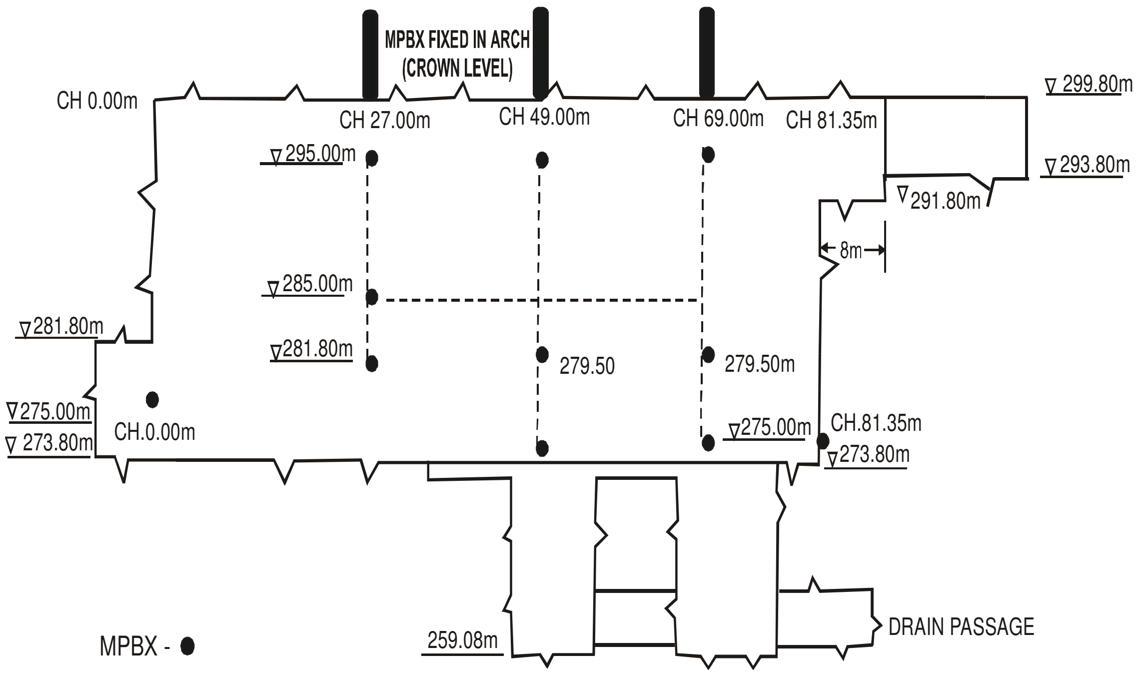

Fig. 5 – L-section of Transformer hall showing upstream wall with instrument locations and cable layout

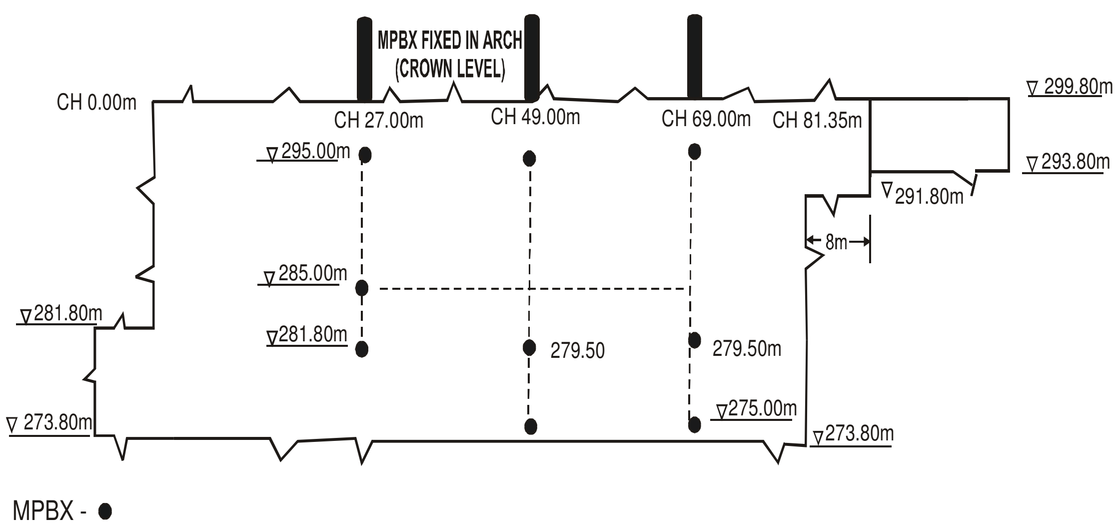

Fig. 6 – Longitudinal section of Transformer hall showing downstream wall with instrument locations and cable layout

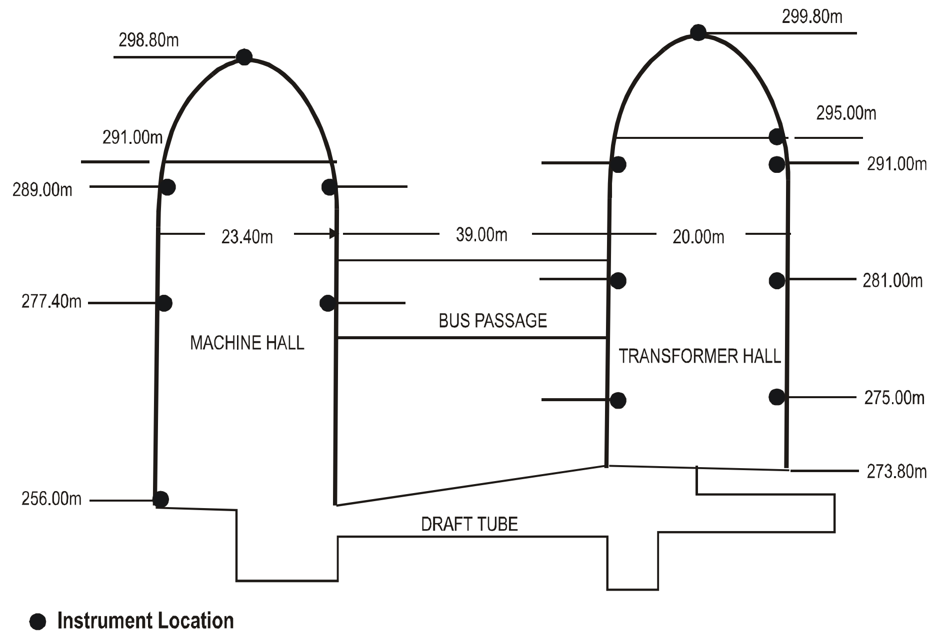

Fig. 7 – Cross-section of cavern openings with instrument locations at different RL

6. OBSERVATIONS AND DATA ANALYSIS

The instruments were monitored for various parameters periodically and the respective measurements were plotted against time to understand the movement behaviour.

6.1 Machine Hall

6.1.1 Roof deformation

The three MPBX installed in the crown of machine hall roof at chainages 13.5m, 30.75m & 54.5m have shown deformation of 0.4mm, 0.22mm and 0.38mm respectively. It can be seen that the maximum deformation has not exceeded 0.4mm. Plot of rock movement in respect of one MPBX at Ch. 13.5m is shown in Fig. 8. The sudden rise in displacement as shown in Fig.8 took place during excavation period in which mouth piece of MPBX was affected by blasting.

6.1.2 Wall deformation

The wall deformations were measured by MPBX on the upstream as well as on the downstream walls at chainages 13.5m (Figs. 9 &10), 14m, 24.5m, 30.75m and 54.5m at various reduced levels (RL). The observations over a period of 5 month didn't show any deformation in the upstream wall (Fig. 9). In the downstream wall, on the other hand, the observations showed a maximum deformation of 2.8 mm over a period of 12 months, i.e. 0.012% of width of machine hall, which was insignificant. In fact, the sudden rise in rock movement from around 1.0mm to 2.8mm on 16.7.02 was during the excavation in which the mouthpiece of MPBX was affected by blasting.

The wall closure by tape extensometer could not be measured beyond three months days after installation due to approach problem. The measured wall closure for over three months, however did not exceed 1mm.

6.1.3 Rock bolt tension

Rock bolt load cells were pre-tensioned and installed at different chainage and reduced levels (RL) in both machine hall and transformer hall. Observations indicated that load cells did not experience any significant load indicating that the rock bolt is not under tension.

6.1.4 General assessment

The roof and the wall deformations measured by MPBX, the wall closures measured by tape extensometer and the rock bolt tension measured by load cells are all too low and are under elastic limit. The maximum wall deformation observed to be at 0.012% of the width of machine hall. The movement is too insignificant to be correlated with the excavation stages. The measurements, thus, indicate that the roof and walls are stable.

6.2 Transformer Hall

6.2.1 Roof deformation

Three MPBX were installed in the crown of transformer hall at chainages 27m, 49m and 69m. Observation from these MPBX indicate that the maximum convergence has not exceeded beyond 0.3mm. Rock movement as observed from one of these MPBX at ch.49m is shown in Fig. 11.

6.2.2 Wall deformation

The deformations on the downstream and the upstream walls were measured from MPBX at chainages 27m, 49m (Fig. 12) and 69m (Fig.13) and 81.35 m at various reduced levels (RL). The maximum deformation observed was around 2.2mm which is insignificant. At two locations, at chainage 27m, RL 281.8m on the upstream wall and at chainage 49m, RL 295m of the transformer hall, wall deformations of about 4.5mm and 3.5 mm respectively were observed. The maximum wall deformation observed was thus at 0.022% of width of transformer hall.

The wall closure was also measured by tape extensometer and was found to be negligible.

6.2.3 Rock bolt tension

Pre-tensioned rock bolt load cells were installed at different chainages and reduced levels in the transformer hall cavern. The rock bolt tension was measured at these locations until these locations became inaccessible for further measurement. The rock bolts have not experienced any tension.

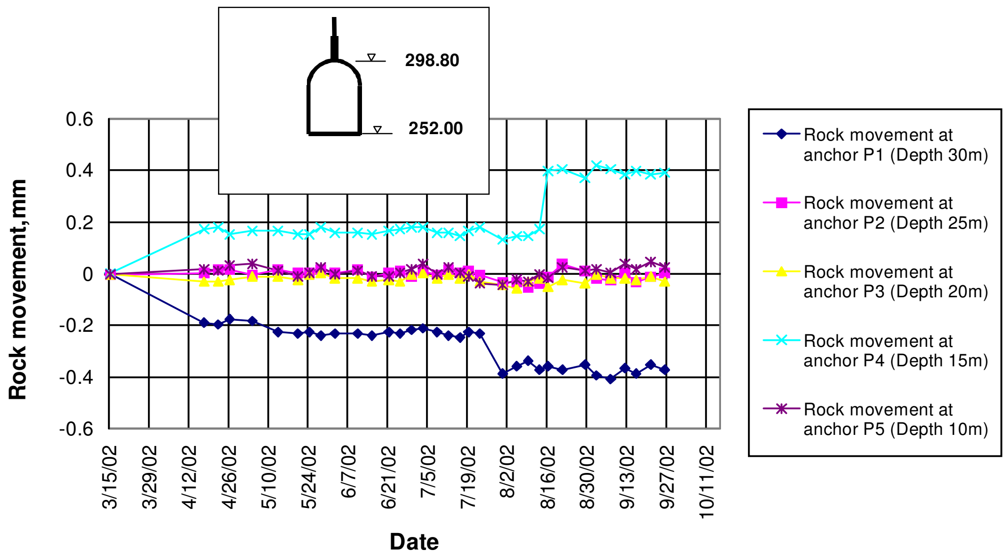

Fig. 8 - Rock movement observations from MPBX at Ch. 13.50m, RL-298.80m, Inst. 208 at Machine hall crown

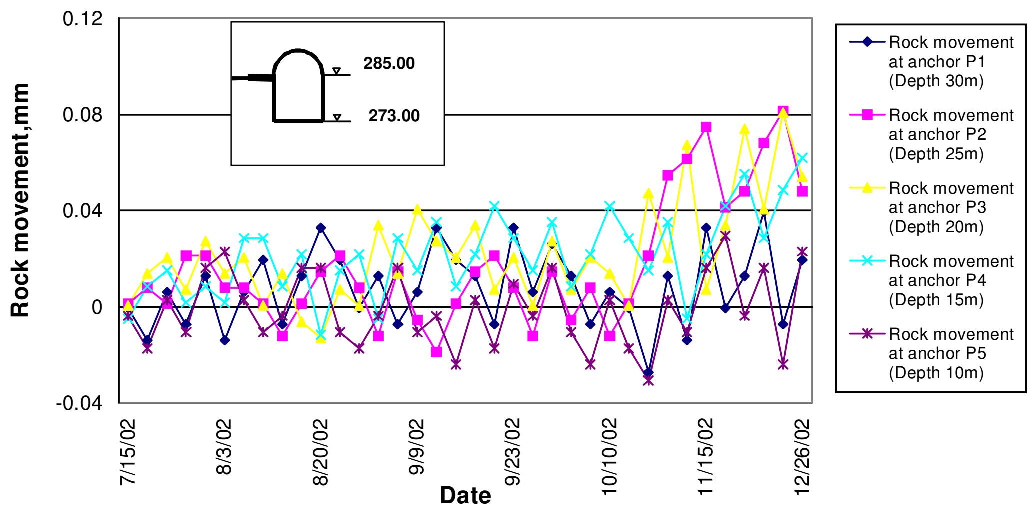

Fig. 9 - Rock movement observation from MPBX at Ch. 13.50m, RL-285m, Inst. 224 at Machine hall upstream wall

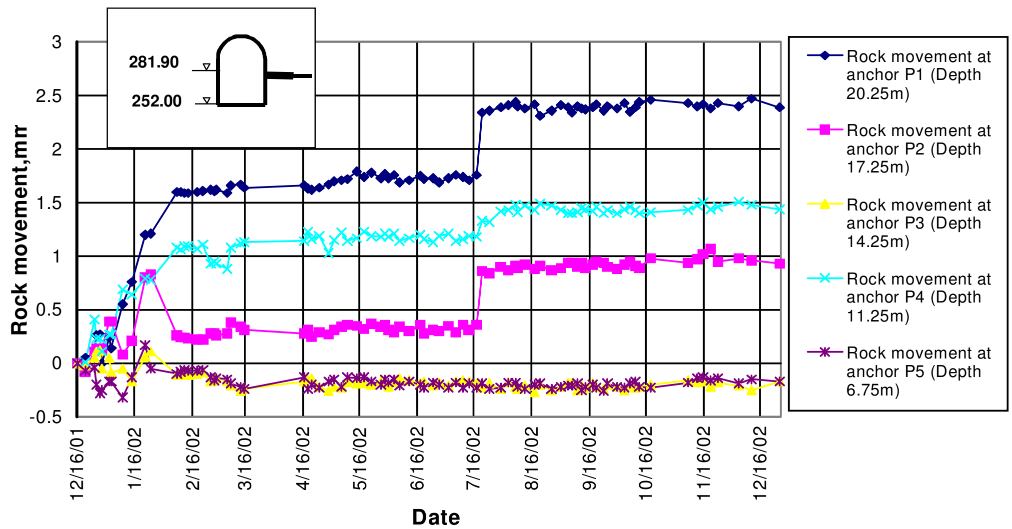

Fig. 10 – Rock movement observations from MPBX at Ch.13.50m, RL-281.90m, Inst. 269 at Machine hall downstream wall

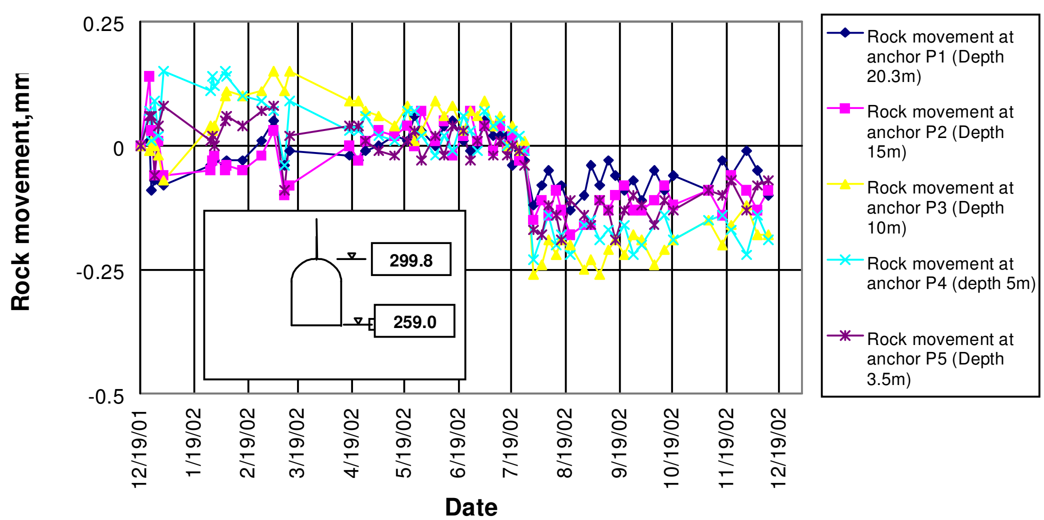

Fig. 11 – Rock movement observations from MPBX at Ch.49m, RL-299.80m, Inst. 248 at Transformer hall crown

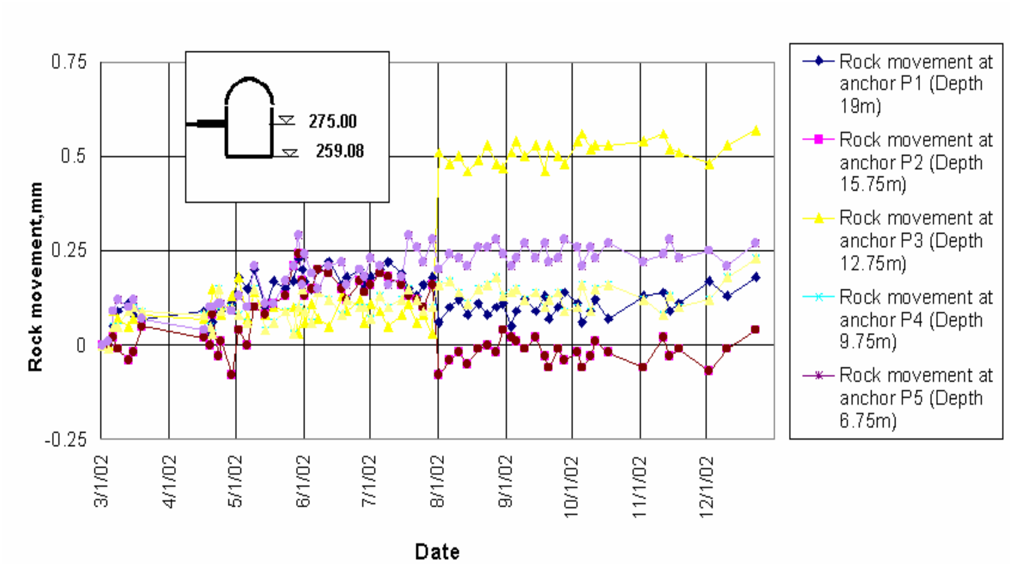

Fig. 12 – Rock movement observation from MPBX at Ch.49m, RL-275m, Inst.229 at Transformer hall upstream wall

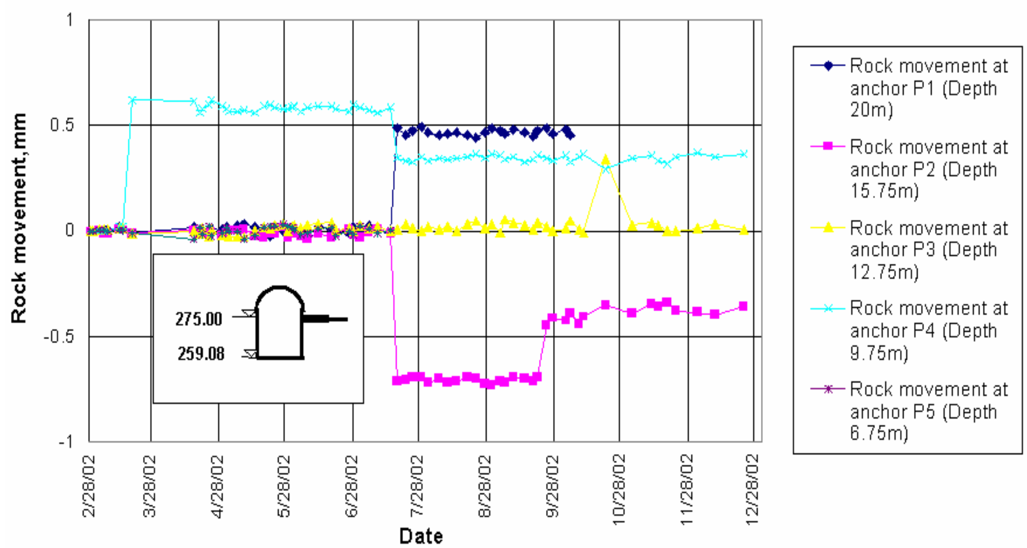

Fig. 13 – Rock movement observation from MPBX at Ch.69m, RL 275m, Inst.217 at Transformer hall downstream wall

6.2.4 General assessment

The roof and the wall deformation measured by MPBX, the wall closures measured by the tape extensometer and the rock bolt tension measured by the load cells are all significantly low. The maximum wall deformation was 0.022% of transformer hall width. These three types of measurements, thus collectively indicate that the roof and the walls of the transformer hall are stable.

6.3 Intersections

6.3.1 Bus ducts

A total of 11 multi-point borehole extensometers (MPBXs) and 24 strain meters, were installed in two bus ducts. These instruments were installed at different chainages and reduced levels (RL). The MPBXs were installed in the roof and strain meters were installed in the walls.

Rock movements as measured from two of these MPBXs have not exceeded 0.3 mm and were therefore insignificant. Rest of the 9 MPBXs could not be monitored till the preparation of this paper. The strain, as measured by strain meters, was also very low.

6.3.2 Passage and cable gallery

Three MPBX were installed in the roof of the passage and cable gallery at different chainages. The rock movements measured from these instruments was within 0.1mm and was thus insignificant.

7.0 CONCLUSIONS

The following conclusions are drawn.

(i) The rock mass encountered in the GHEP caverns is predominantly good and is mainly composed of compact basalts with amygdaloidal basalts at few places.
(ii) The rock movements as measured from various instruments were practically insignificant and within the elastic limit. The movements hardly show any correlation with the excavation stages.
(iii) Results obtained from monitoring reveal that the caverns and intersections are stable and the supports are adequate.
(iv) Monitoring of rock movements needs to be continued to ensure updated knowledge on the performance of these caverns in future.

Acknowledgement

The authors are thankful to the Department of Irrigation, Government of Maharashtra for sponsoring this study to CMRI and to Mr. S.S. Dabhadkar, Executive Engineer and other officials of GHEP for their support and facilities during the course of this study.

Sincere thanks are due to Dr. J.L. Jethwa, former Scientist-in-charge, CMRI Regional Centre, Nagpur for initiating this work and providing valuable contributions and to Mr. M.R. Saharan, Scientist for his inputs in this study.

References

Barton, N., Lien, R., and Lunde, J. (1974). Engineering Classification of Rock Masses for the Design of Tunnel Support, Rock Mechanics, Springer-Verlag, Vol. 6,pp. 189-236.

Bieniawski, Z.T. (1976). Engineering Classification of Jointed Rock Masses, The Civil Engineer in South Africa, Vol. 15, pp.335-344.

Bieniawski, Z.T. (1989). The Geomechanics Classification in Rock Engineering Applications, Reprinted from Proc. 4th Cong. of the Int. Society for Rock Mech.

Goel, R.K., Jethwa, J.L. and Paithankar, A. G. (1995). Indian Experience with Q and RMR System, J. Tunneling and Underground Space Technology, Vol. 33, No. 7, pp.749-755

Jethwa et al. (2001). Recommendation on Support Requirements and Excavation Sequence for Ghatghar Hydro Caverns, CMRI Project Report No. GC/MT/28/2000-01, July 2001, p. 39.

Jethwa et al. (2003). Rock Mechanics Instrumentation for Monitoring Performance of Ghatghar Hydro Caverns, CMRI Project Report No. GC/MT/N/4/2002-03, March 2003, p. 97.