Performance Monitoring of Underground Structure by Extensometer - A Case Study

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ABSTRACT - Each and Every type of Dam has its distinctive requirements of monitoring parameters and distinctive variety of instrumentations. Instrumentation is used to measure the response (deformation, stress etc.) of soil or rock to changes in loading or support arrangements, and from the measurements taken, the need for modifications to the loading or support arrangements is determined such that process is controlled. However instrumentation is additionally indispensable for site investigation, design verification, long term monitoring of the soundness of the structure and in particular, its safety. Geotechnical instruments are our eyes and ears inside the structure and supply valuable data for taking applicable corrective actions before it's too late.

Disturbances in rock and soil masses is also caused by geological or structural factors beyond the periphery of a tunnel that are subjected to stresses from all the directions. Excavation of any cavity like an underground power house or boring of a tunnel, ends up in the release and readjustment of three dimensional stresses around the cavity. This results in movement within the surface reckoning on time. In such instance, instruments like Extensometer installed in boreholes can be used to check ground movement/disturbance of a section of rock/soil mass and adjacent encompassing strata with the help of anchors fully at completely different depths. It provides good sample distribution and data redundancy even under conditions of site accessibility. The depth of anchor varies with the kind of rock strata and the location of the fixed point with respect to which the deformations are to be measured.

Keywords: Instrumentation, Geotechnical, Underground Powerhouse, Crown, MPBX, SPBX, Deformation etc.

I. INTRODUCTION

When an excavation is not stable, underground safety and integrity of nearby structures become a major concern. When an excavation is marginally stable, early detection of instability is possible through use of instrumentation and remedial measures such as supplemental support work can be implemented on a timely basis to stabilize the structure. The efficacy of remedial measures can also be measured with same set of instruments. Based on observations of engineering properties by instruments installed in the underground works acts as guide for any proactive remedial actions. If 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 its behavior. The use of proper instrument at appropriate time can give very valuable information, which can help to prevent a likely major mishap.

In such instances, instruments installed in boreholes like a borehole extensometer can be used to test ground disturbance at different depths into a rock mass, and to

provide good sample distribution and data redundancy even under conditions of limited site accessibility. Instrumentation used in the construction of underground powerhouses, tunnels and subways can be implemented in three stages before, during construction and during operation.

2. EXTENSOMETER AND ITS USES IN THE GEOTECHNICAL FIELD

An extensometer is a high precision instrument especially designed to measure the elongation of a material under stress. This instrument is ideal for tensile tests. It can also determine yield strength, tensile strength, yield point elongation, strain-hardening exponent, and strain ratio.

Besides this, extensometers have a tremendous scope of work in the geotechnical field. They are available in numerous varieties and sizes depending upon the application area.

Various uses of extensometer are

- To find out performance of underground cavity or tunnel and roof or wall of mines etc., throughout excavation & effectiveness of the support system.
- To predict potential roof or wall fall before it happens. Roof or wall fall in an underground cavity is almost invariably preceded by measurable sag because the strata opens up, and therefore sometimes the movement occurs at an increasing rate as fall conditions are approached. Unsuspected roof and wall fall conditions are approached that may result in serious accidents.
- To measure and monitor the movement in a very slope or foundation due to the excavation of underground cavities or due to the construction of a heavy structure like concrete, rock fill, masonry or earth dam over the foundation.
- To measure the extensometer work? Types and sizes relying upon the application area.
- To measure horizontal and vertical movement in foundations and embankments.
- To measure the movement of natural and cut slopes, quarry and mining excavations.
- To calculate the displacement of retaining walls, piers & abutments.
- To measure the displacement around tunnels & underground cavities.
- To be used for extremely correct measurements of relative deformations of multiple segments along the entire pile length. To be specific, extensometers are used for the

measurement of the variation of the distance between the pile head and a selected level of the testing pile.

- To be used for measurement of the vertical displacement of the dam bottom in respect to the foundation base rock, a borehole extensometer is used. The measurement should be taken at all locations where foundation deformation is anticipated to take place.
- To monitor displacement between dam and the abutment of the dam body.

3. MULTI POINT BOREHOLE EXTENSOMETERS (MPBXS)

MPBX is a precise instrument and can measure small movements at various depths accurately. It consists of one or more rods different material and lengths anchored at different depths in a borehole and a reference head at the surface. Usually mounted straight up to measure movement of the reference vertical head in relation to the anchor zone(s). It can also be installed in different orientations. The complete assembly is inserted into the borehole and then grouted, fixing the anchors to the rock or soil but allowing free movement of each rod within its sleeve.

Relative movement between the anchor and the reference head is measured manually with caliper or linear transducers, assembled on the reference head for remote monitoring. The depth of anchor varies with the type of rock strata and the location of the fixed point with respect to which the deformation is to be measured. Single point bore hole extensometers (SPBX) are used in order to assess deformations and stress changes of different sections of rock mass. MBPX contains a number of anchors (2 to 6) at different depths. The displacement ranges commonly used are from 50 to 150 mm, various types of transducers can be used, ranging from mechanical devices such as vernier calipers, dial gauge and depth micrometers to electronic sensors such as bonded and weldable strain gauges, potentiometer, and linear variable differential transformers (LVDT).

SPBX and MPBX are available in both mechanical and electronic types. The electronic version is preferred in applications where access at the head of the extensometer for the purpose taking reading is not easily available. The cabling to the electronic SPBX or MPBX, and the instrument itself, has to be carefully protected during excavation and blasting. Cable free instruments are also now being tried to do away with the difficulties of cable protection. Electronic transducers permit remote readout, the use of automatic and semiautomatic data systems, and simple interfacing with computers. Mechanical transducers have the advantage of simplicity and low cost.

Figure 1 shows one such instrument, the multiple position borehole extensometer (MPBX) fabricated in CSMRS and installed at Sardar Project site, Gujarat. A typical borehole extensometer (as shown in Figure 2) consists of an instrument head, usually mounted at the collar of a drill hole, and one or more in-hole anchors, each fixed in position at a known initial depth in the hole. Each anchor is connected by means of a rod or wire to an individual transducer in the instrument head. As the rock or soil mass is deformed, the distance between each in-hole anchor and the instrument head changes, and the changes are measured by the individual transducers.

Fig. 1: Multi point borehole extensometer (MPBX) fabricated in CSMRS

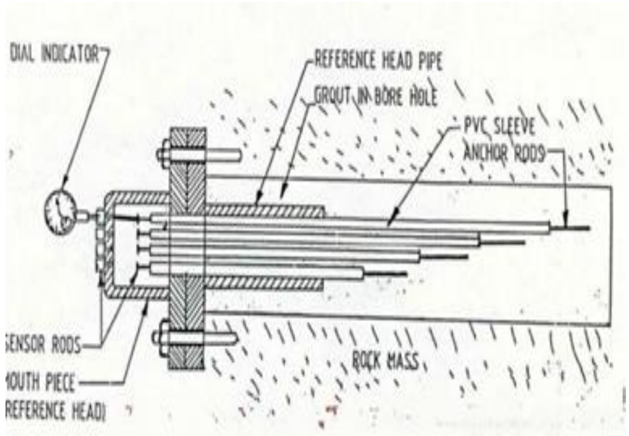

Fig. 2: Typical Multi position borehole extensometer (MPBX)

Extensometers provide direct measurements of displacement magnitude, usually noted in relation to time. Its Changes with time and magnitude are used to calculate deformation rate (time rate of change of magnitude) and acceleration (time rate of change of the deformation rate). Extensometers measure only that component of displacement which is occurring parallel to the axis of the borehole.

The selection of an extensometer for a particular application requires consideration of the site geology, desired hole depth, number of anchors, probable deformation magnitude ,required sensitivity and readout mode (mechanical or electronic).

4. CASE STUDY: DETAILS OF SARDAR SAROVAR PROJECT, GUJARAT

Sardar Sarovar Project is an inter-state multi-purpose river valley joint venture project for four states of Gujarat, Madhya Pradesh, Maharashtra and Rajasthan with a terminal major dam on river Narmada close to village Navgam, Kevadia Colony in Narmada District of Gujarat (also located on map in fig 3). This dam is the third highest concrete gravity dam (163 m from deepest foundation level) in India. The first is the Bhakra Dam (226 m) in Himachal Pradesh and the second is Lakhwar (192 m) in Uttar Pradesh. The project on full completion is expected to water for irrigation of 18.4 lakh hectares of land across 15 districts and 73 suburbs including drought prone regions in Gujarat as well as two districts of Rajasthan, Power benefits of 1450 MW will be shared among MP, Maharashtra and Gujarat in the ratio of 57:27:16.

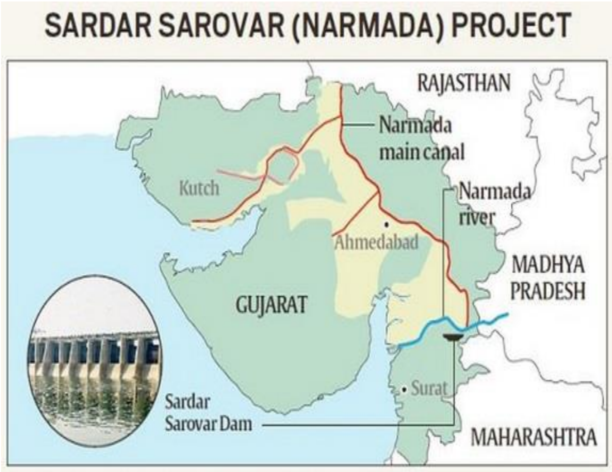

Fig 3: Sardar Sarovar Dam located on Map

Fig. 4: River BED Power House (RBPH)

Project has constructed a 163 m high concrete gravity dam with a length of 1210 m (at top RL of 146.50 m). The dam has a reservoir of 214 km length with an average width of 16.1 km. The underground powerhouse (210 m length x 22 m width x 57.5 m height) has generation capacity of 1200 MW through 6 units of 200 MW each and a canal head surface powerhouse of 250 MW from 5 units of 50 MW each. Total generation capacity of the project is 1450 MW.

The Full Reservoir Level (FRL) of the Sardar Sarovar Dam is fixed at RL 138.68 m (455 feet). The Maximum Water Level is 140.21 m (460 feet.) while minimum draw down level is 110.64 m (363 feet.). The normal tail water level is 25.91 m (85 feet.).

4.1 Distress Zone in Powerhouse Cavern

The River Bed Power House (RBPH) of Sardar Sarovar Project (as shown in Fig-4) is the underground powerhouse, whose cavern mainly consists of hard and competent sub-horizontal basalt flow, separated by pockets of hard and compact agglomerate of sedimentary rocks (Bagh beds). The basalt is intruded by vertical/inclined dolerite dykes and sills. Faults of small magnitude displace the dolerite dykes and sills. The shear zones and instrumentation on upstream and downstream wall of underground powerhouse have been shown in Figs. 5 and 6 respectively.

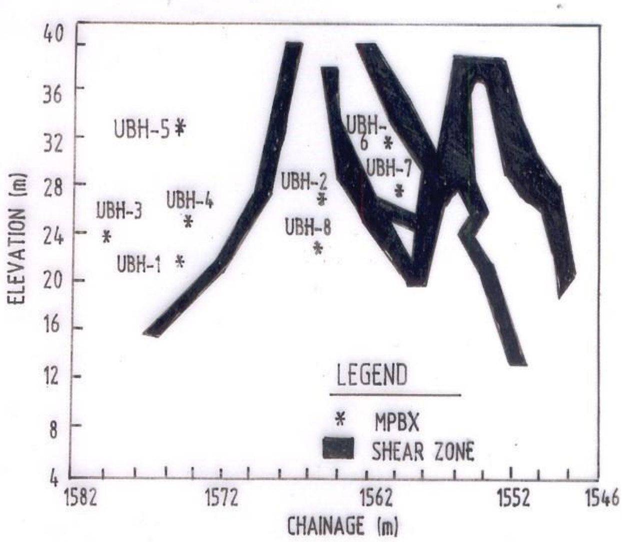

Fig. 5: Instrumentation on upstream wall of powerhouse cavern along with shear

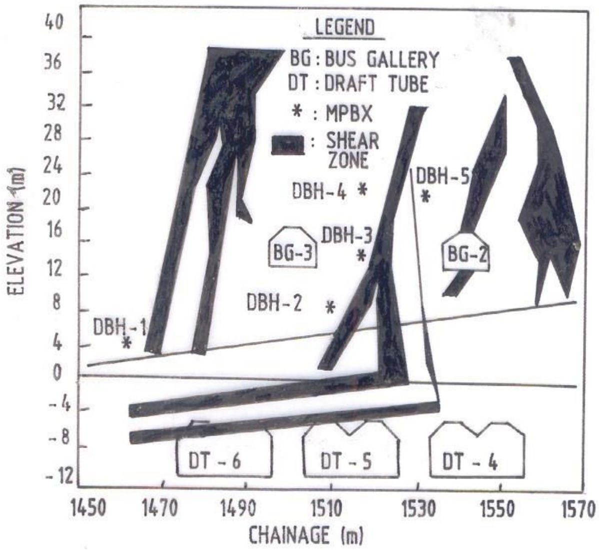

Fig. 6: Instrumentation on upstream wall of powerhouse cavern along with shear zone

4.2 Extensometer instrumentation by CSMRS:

CSMRS has initially introduced some instruments in 1992 and thereafter at various locations. Present status of extensometers installed, which are in working order, is given in Table-1 and persistent monitoring of rock deformation utilizing these instruments are being done on annual basis since January, 1993. Total number of extensometers in working are 13 nos as appeared in
Table 1.

Table – 1:-Location of extensometers

Sr. No	Instrument	Location	EL (m)	Chainage (m)	Date of installation
MPBXs					
1	UBH-1	Upstream wall of power house	25.50	1564.00	01/1993
2	UBH-2	Upstream wall of power house	20.05	1570.95	01/1993
3	UBH-3	Upstream wall of power house	21.00	1580.50	01/1993
4	CMX-1	Crown of powerhouse	82.00	1482.00	07/2000
5	CMX-2	Crown of powerhouse	93.00	1508.00	05/1991
6	CMX-3	Crown of powerhouse	95.00	1518.00	07/2000
7	CMX-4	Crown of powerhouse	90.00	1497.00	05/1999
SPBX					
8	DGX-1	Drainage & grouting Gallery	38.00	1492.00	09/1995
9	DGX-2	Drainage & grouting Gallery	38.00	1496.00	09/1995
10	DGX-3	Drainage & grouting Gallery	38.00	1533.00	09/1995
11	DGX-5	Drainage & grouting Gallery	37.50	1560.00	09/1995
12	DGX-6	Drainage & grouting Gallery	37.50	1563.35	09/1995
13	DGX-7	Drainage & grouting Gallery	37.50	1566.39	09/1995

4.3 DATA REPRESENTATION AND INTERPRETATION OF MPBX INSTRUMENT

Extensometer measurements are in the form of displacement magnitude, noted corresponding to time at different depth from the face of excavation. Time is the most useful independent variable, and it facilitates the correlation of extensometer data with information from other sources.

The information vital for at least a primary assessment of safety and stability can be extracted quite easily from the raw (field book) data, or from straightforward graphs of displacement versus time. Hazards are reflected in unprocessed data in stepwise or exponential changes in progressive readings, and all data should be scanned routinely for any such sign. May be obviously, early detection is extremely important in providing a maximum amount of time for preparatory or remedial actions.

To prepare displacement graphs, a reference datum is identified and a format chosen. In extensometer applications, the instrument head is located in the part of the geologic mass, which is being most actively deformed. Extensometer hole is drilled deep enough to place the deepest in-hole anchor well beyond the zone of influence of the deformation. The chart showing displacement of the deepest anchor then may be plotted as a straight line and used as a reference datum of ordinate for the calculation of displacements measured at successively shallow anchor depths.

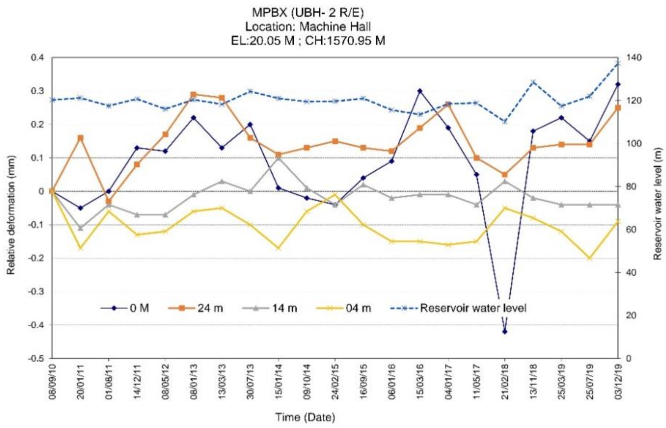

Fig 7: Plot of Relative Deformation Vs Time for MPBX Location UBH-2

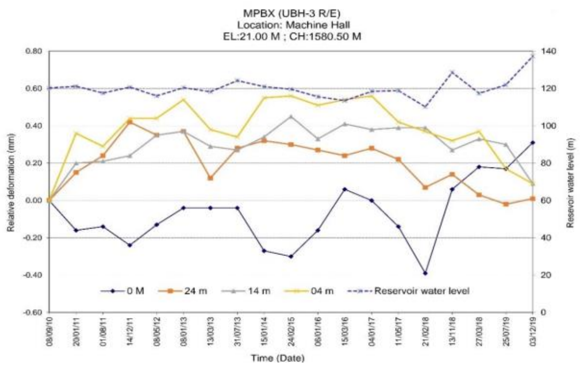

Fig 8: Plot of Relative Deformation Vs Time for MPBX Location UBH-3

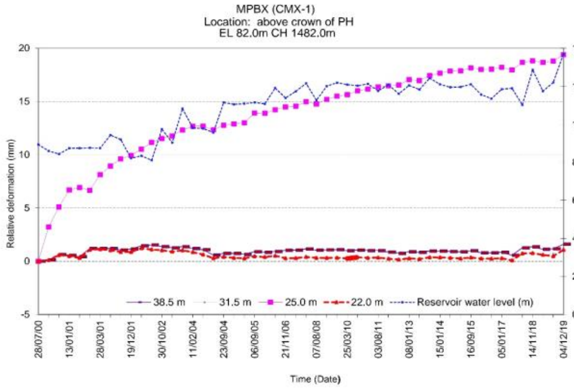

Fig 9: Plot of Relative Deformation Vs Time for MPBX Location CMX-1

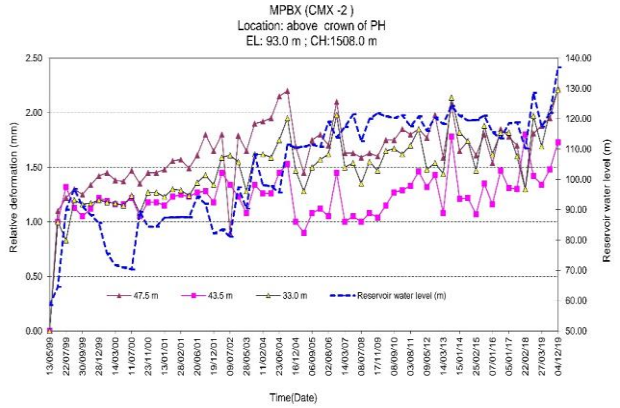

Fig 10: Plot of Relative Deformation Vs Time for MPBX Location CMX-2

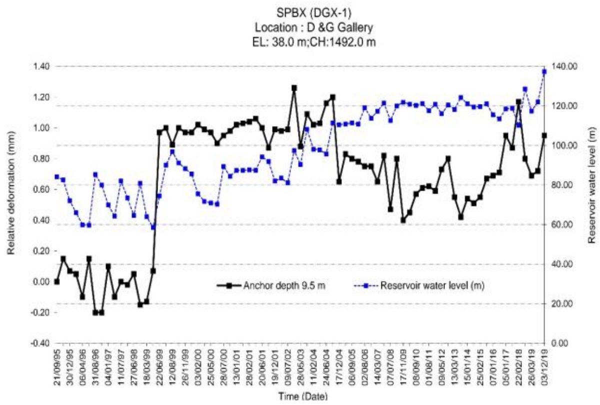

Fig 11: Plot of Relative Deformation Vs Time for SPBX Location DGX-1

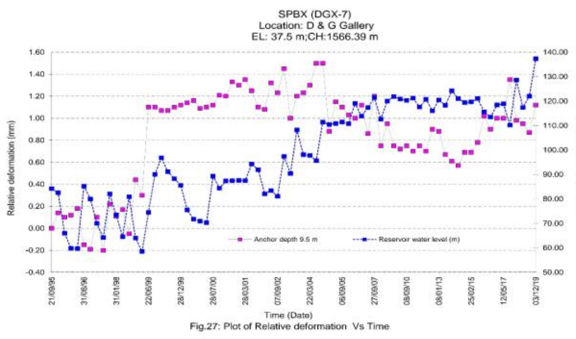

Fig 12: Plot of Relative Deformation Vs Time for SPBX Location DGX-7

.3.1 **Data Analysis**

Rock deformation analysis by using Borehole Extensometers (MPBXs& SPBXs):

a) Upstream Wall of the Powerhouse Cavern

UBH-2 R/E (EL: 20.05 m; CH: 1570.95 m) as shown in figure 7 and UBH-3 R/E (EL 21.00m; CH 1580.50m) as shown in figure 8 showed insignificant movements with fluctuations (rebound) for all rods were observed. However, fluctuations in movement can be correlated with reservoir water level variations.

b) Above Crown of Powerhouse Cavern

Four MPBXs were installed up to the crown of powerhouse from rock surface through the rock cover above the cavity.

Among these, the anchor rod of 25 m length i.e. CMX-1 (EL 82.0 m; Ch. 1482.0 m) as shown in figure 9 showed continuous downwards movement locally towards cavern crown. Initially, rate of movement was higher till September 2005 (13.91 mm in about 4 years and 11 months) thereafter the rate of movement is very less, but thereafter increased with slow rate (5.47 mm in about 14 yrs. and 2 months).

CMX 2 (EL: 93.0 m; CH: 1508.0 m) as shown in figure 10 showed no significant movement for all rods since September 2004. Fluctuations (rebound) in movement can be correlated with reservoir water level variations.

a) Drainage and Grouting Gallery

Out of seven nos. SPBXs installed in drainage and grouting gallery, one instrument is not working due to damage. For instance; graphical pattern of movement of 2 nos SPBXs DGX 1 (EL: 38.0 m; CH: 1492.0 m) & DGX 7 (EL: 35.0 m; CH: 1566.39 m) are appeared in figure 11 & 12 respectively. All SPBXs showed insignificant movement with fluctuations since December 2004.

4.3.2 REMEDIAL MEASURES

Based on the instrumentation in underground powerhouse of Sardar Sarovar Project, whenever the issue of excess deformation of shear zone was accounted, the project authorities has quickly taken the remedial measures like rock bolting, epoxy grouting and cable anchoring in consultation with design consultant viz. Central Water Commission. The same instrumentation was further utilized to affirm the adequacy of remedial measures.

5. CONCLUSIONS

The utilization of instrumentation is an indispensable part of any construction activity today. In light of instrumentation work in the powerhouse of Sardar Sarovar project in Gujarat, the MPBX demonstrated insignificant movements with fluctuations (rebound) for all rods. Maximum local movement of rock mass as monitored by MPBX (CMX-1) above crown of power house was 14.97 mm (25.0 m rod) which may be due to some loose strata in the borehole. However, fluctuations in movement can be correlated with reservoir water level variations. The present trend showed stabilized behavior in the powerhouse cavern. However, long term monitoring is further kept on observing the impact of post commissioning of flood gates of the project.

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