Geodetic Structural Monitoring of Concrete Gravity Dam – A case study

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ABSTARCT:

Sardar Sarovar dam is one of the largest multipurpose (irrigation and hydroelectric) dam in India located on Narmada River, Gujarat. It is the third highest dam with a height of 163 m and length spanning over 1210 m. Due to the large reservoir capacity and height of the dam, it is necessary to monitor the deformation of dam during different levels of reservoir to ascertain dam stability. NIRM has established a geodetic monitoring system using total station to monitor the deformations of the dam crest since 2013 and monitoring is continuing till date. The dam consists of 64 Blocks, 33 non-overflow Blocks and 31 over-flow / spillway Blocks. The movements of the dam were monitored with respect to established control points, two on each bank respectively. These control points were used to establish monitoring stations on the right and left bank for collection of data.

In this paper, geodetic monitoring done manually at the site is discussed. The limitations with manual monitoring methods were identified. In order to have better accuracy and to have continuous data, keeping the long term monitoring perspective, it is suggested to go for advanced automatic geodetic monitoring system using Global Navigation Satellite System (GNSS) and advanced automatic total stations.

1 INTRODUCTION

Engineering structures like dams, bridges, high-rise buildings are subjected to deformations due to the factors such as rise in reservoir water levels, changes in ground water levels, environmental stress, structural overloads, tidal and tectonic movements etc. To ensure the proper functioning of the dams, monitoring of the dams using several methods are in practice. These methods are classified as the contact type (Non-geodetic methods – like Geotechnical instrumentation), non-contact type and semi contact type (Geodetic methods) based on the equipment's used for monitoring the deformations. The merits and demerits of different techniques that are in use and a case study on deformation measurement conducted at one of the largest concrete gravity in India using conventional geodetic monitoring is discussed.

1.1 *Non-geodetic methods (contact type or physical method):*

Non-geodetic techniques have mainly been used for relative deformation measurements within the deformable object and its surroundings. Geotechnical instrumentation can achieve very good 1D or 2D results but often limited to the area where the instruments are installed. Examples are Plumb lines and tiltmeters.

1.2 *Geodetic methods (semi contact and non-contact types):*

Geodetic techniques have traditionally been used mainly for determining the absolute displacements of selected points on the surface of the object with respect to some reference points that are assumed to be stable.

1.2.1 *Semi contact type:*

Triangulation or trilateration methods using Total stations and prisms (Conventional and automatic systems)

Advantages:

- Economical and easy to install and monitor

Disadvantages:

- Conventional geodetic method using terrestrial instruments for example total stations, EDM etc is comparatively a slow process to GPS method.
- It requires line of site (LOS) between sensor and target.
- It can monitor set of selected monitoring points and will not cover every portion of the entire structure.
- Accuracy will be affected by weather conditions (temperature etc)

GPS systems (Satellite based)

Advantages:

- Does not require line of site (LOS)
- GPS can operate day and night and measurements will not be affected by weather. Simple to installation and monitor

Disadvantages:

- Expensive and height accuracy is not good.

1.2.2 *Non-contact type (Remote sensing):*

Photogrammetry (Ground based or satellite based) is a measurement system comprised of photographs taken by precise metric camera and measured by comparator.

Advantages:

- Simultaneous monitoring of large areas and cost effective
- Disadvantages:
- Not effective in some lighting and weather conditions (fog, strong sun, rain etc)
- Low accuracy and precision

Terrestrial laser scanning (TLS) (Mario Alba et al., 2008)

Advantages:

- Which allows to capture dense point clouds made up of 3D unspecific points with a high degree of automation with poor accuracy for deformation measurement.
- TLS can be used to detect deformations occurring in the range direction.
- TLS can be used to evaluate the seasonal deformations of structures.

Disadvantages:

- Could not be useful for continuous monitoring.
- Low accuracy and difficult data management.

Ground based Interferometric SAR (GBInSAR)

Advantages:

- GBInSAR systems are capable to make measurement of deformation along the line of site (LOS).
- The spatial resolution of measurement is defined in both range and cross range directions.
- Intrinsic achievable accuracy enables its use for continuous monitoring of large structures.
- Density of tracked points is lower w.r.t TLS with an accuracy up to 0.1mm.

The commercial models of GBInSAR are IBIS-S and IBIS-L. The Cancano dam at Alta Valtellina, Italy (Mario Alba et al., 2008) was investigated using IBIS-L system to measure deformations due to reservoir filling.

2 GEODETIC MONITORING AT SARDAR SAROVAR DAM

Sardar Sarovar Dam is one of the largest dam in the world and a multipurpose (irrigation and hydroelectric) water resource project on Narmada River near Navagam, Gujarat. The salient features of the Dam is shown in Table 1. In terms of the volume of concrete involved for gravity dams, this dam will be ranking as the second largest in the world with an aggregate volume of 6.82 million cu m. Sardar Sarovar dam has a spillway discharging capacity of 85,000 cumecs (30 lakh Cusecs), which ranks third in the world.

Table 1. Salient Features of the Sardar Sarovar Dam

Sl. no	Feature	details
1	Length of main concrete gravity dam	1210.00 m
2	Maximum height above deepest foundation level	163.00 m
3	Top R.L. of dam.	146.50 m
4	Catchment area of river above dam site	88,000 Sq. km
5	Live storage capacity	0.5860 Mha-m (4.75 MAF)
6	Length of reservoir Maximum width Average width	214 km 16.1 km 1.71 km
7	Spillway gates Chute Spillway Service Spillway	Radial Gates 7 Nos. 60' x 60' 23 Nos. 60' x 55'
8	Spillway Capacity	85000 cumecs (30 lakh cusecs)
9	Total installed capacity of power generation	1450MW

The first filling of the dam up to the elevation about 120m was completed in the year 2006 in view of the power generation and water supply for irrigation and drinking purpose when the dam is still under construction. Later Sardar Sarovar Narmada Nigam Limited (SSNNL) has approached National Institute of Rock Mechanics (NIRM) in 2011 for deformation monitoring and requested to initiate the work. Accordingly, NIRM established a conventional geodetic monitoring system using total station and prism targets to monitor the deformations at the dam crest.

3 METHODOLOGY

Geodetic method of monitoring consists of various stages i.e. selection of location for control points, monitoring station, and monitoring points at different dam blocks. The scope of the work consists of

- Establishment of control point network using Differential Global Positioning System (DGPS) survey with periodical verification.
- Installation of monitoring points at the selective dam blocks.
- Regular monitoring of targets installed on selected dam blocks.
- Data interpretation and results

3.1 *Establishment of control point network*

Four control point monuments were designed and constructed (2 points on each bank) away from the dam in an undisturbed area. Figure 1 shows the construction of control points and Figure 2 shows the established control point network with WGS84 coordinate system consists of DGPSP1 to DGPSP4.

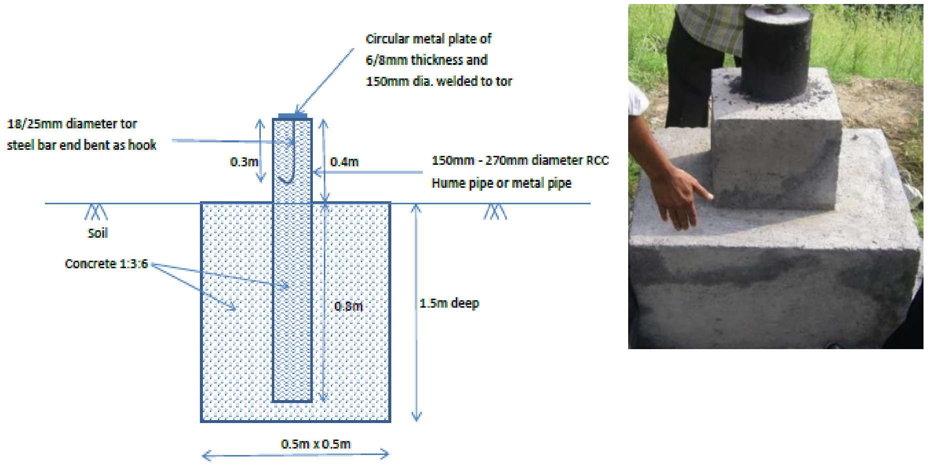


Figure 1. Construction of control point monument

Figure 2. Control point network at Sardar Sarovar dam

3.2 *Installation of monitoring points*

During the first phase, Leica GPR111 and GPR112 circular prisms were installed at seven different non-overflow blocks of the dam from left and right abutments. The location details of the monitoring points were given in Table 2.

Table 2. Details of installed monitoring points in 1st phase

Sl. No.	Point Id	Block No.	EL
1	MP-B58	58	146
2	MP-B57	57	143
3	MP-B52	52	143.49
4	MP-B51	51	143.54
5	MP-B11	11	142.75
6	MP-B9	9	142.15
7	MP-B7	7	142.17

3.3 *Monitoring and Data Collection*

Instrumentation used in the geodetic monitoring are mentioned below:

Control Points : Leica GPH 1P single-prism holder
Monitoring Points : Leica GPR111 and GPR112 prisms
Total station : Leica TDA5005A
Technical specifications
Accuracy Hz, V : 0.5”
Standard measurement : Accuracy 2mm+2ppm

During monitoring the measurements were done in manual mode using free station program. The monitoring targets at MP-B58, MP-B57, MP-B52 and MP-B51 which are about 500-600m distance are measured from right bank station with reference to the control points DGPSP1 and DGPSP2. Monitoring targets at MP-B7, MP-B9 and MP-B11 which are also about 500-600m are measured from left bank station with reference to the control points DGPSP3 and DGPSP4. Manual monitoring was carried out on bimonthly basis with total station using free station method and collected the data. Total 28 measurements were done during the entire period (69 months) from Nov’13 to Jul’19.

4 DATA INTERPRETATION AND RESULTS

The deformation measured in transverse direction (in flow direction), i.e. in E-W direction of the dam. It is to be observed that the reservoir water level was at 121.5m when the initial observations were taken in Nov’13. During the monitoring period, the reservoir water level varied with minimum level at 107.63m and maximum level at 130.32m. The absolute deformation measurements in easting direction for selected non-overflow blocks (B58, B57, B52, B51, B11, B9 and B7) are shown in Figures 4 to 7. Please note that, there is no deformation measurement data before first filling in 2006.

However, the present deformation data measured could not be cross checked with other deflection measurement instruments like Direct Plumb Line (DPL) and Invert Plumb Line (IPL) as the data were not available. A simple FLAC2D model has been prepared for block 52 by NIRM to compare the measured deformation data. Table 3 lists the deformation values (X displacement) according to reservoir water level and Figure 3 shows the model considered for block 52 in UDEC.

Table 3. Displacement values at Block No.52

Reservoir water level (m)	X-Displacement by FLAC2D (mm)	Average measured E-W displacement (mm)
114.5	2.5	1.72
118	3.5	4.54
121	4	4.32

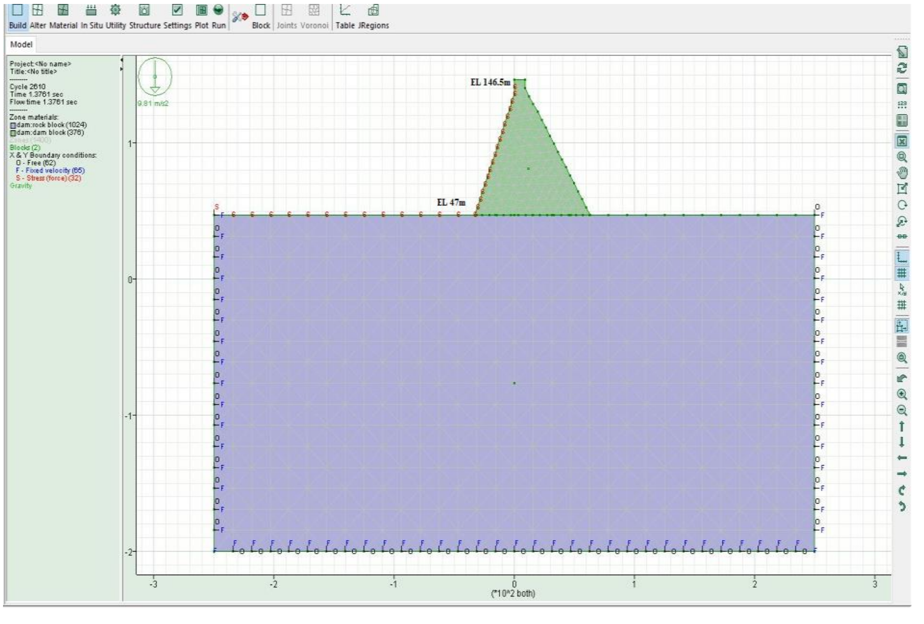
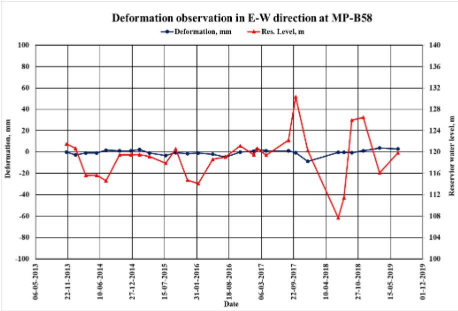


Figure 3. UDEC model of block no 52

Certain amount of variations recorded while measurements are because of changes in atmospheric conditions at site, scalar errors of EDM and error propagation in connecting surveys between total station and stable reference point (during free station setup). Other errors like line of site error, vertical index error, standing access tilt, earth curvature and refraction errors are auto corrected as specified by the total station manufacturer. In view of this, the variations of ± 5mm considered as error from the measured deformation values.



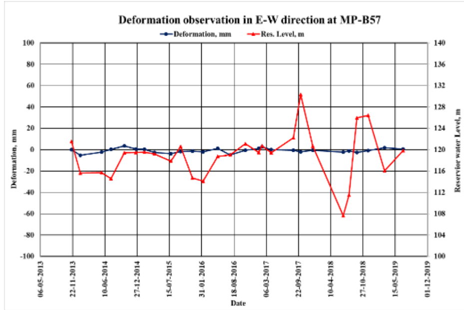
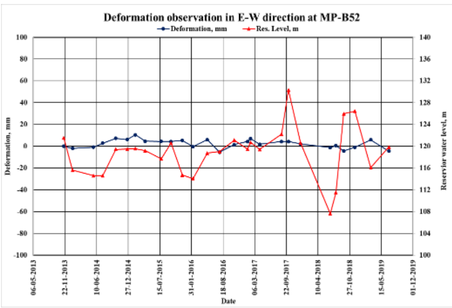


Figure 4. Deformation measurement at MP-B58 & MP-B57



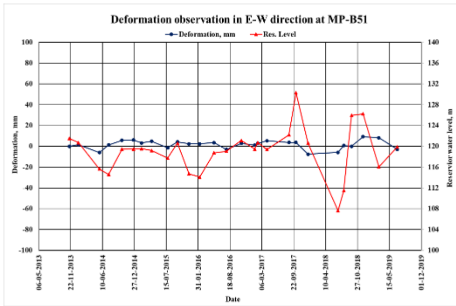
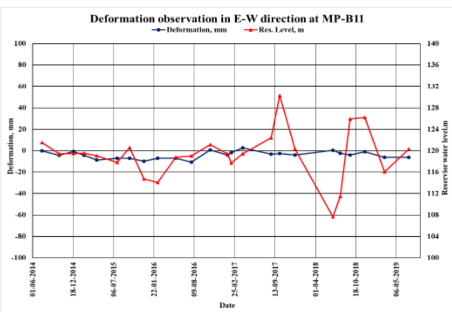


Figure 5. Deformation measurement at MP-B52 and MP-B51



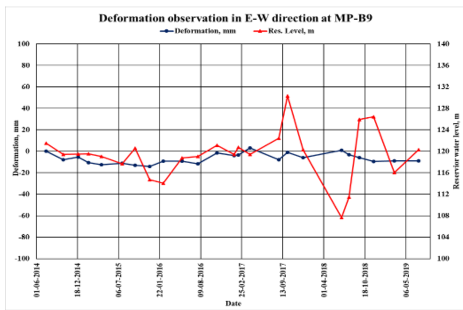


Figure 6. Deformation measurement at MP-B11 and MP-B9

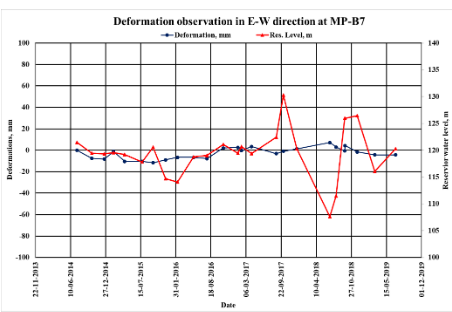


Figure 7. Deformation measurement at MP-B7

5 CONCLUSIONS AND RECOMMENDATIONS

- The deformation plots along the east-west direction (perpendicular to the dam axis) shows that the deformations varied in maximum of +10.44mm and minimum of -14.13mm at non-overflow Blocks.
- The deformation variations are comparable with the variations in reservoir water levels except in few observations.
- Could not compare the measured E-W deformations measurements since there is no data of plumb line or other instruments.
- A simple FLAC2D model results correlated well with the measured deformation data at Block No. 52
- Current study of geodetic monitoring has proved that there are certain limitations while measuring the large distances manually using total station. Hence, keeping the long-term monitoring perspective, it is recommended to go for advanced automatic geodetic monitoring systems using Global Navigation Satellite System (GNSS) and advanced automatic total stations from established total station manufacturers.

References

NIRM, 2019. Geodetic monitoring of Sardar Sarovar Dam, Gujarat. *NIRM unpublished report.*

IS 13073 (Part 2): 2000 Code of Practice for installation, maintenance and observation of displacement measurements for concrete and gravity dams Part-2, *Geodetic observation – Crest Collimation.*

Mario, A. Giulia, B. Alberto, G. Pier, P.R. Fabio, R. Marco, S. Paolo, V. & Katherine, Z. 2008. Measurements of dam deformations by terrestrial interferometric techniques. In Proceedings of the International Archives of the Photogrammetry, *Remote Sensing and Spatial Information Sciences, Beijing,* Vol. XXXVII, pp 133-139.