DIRECT GPS MEASUREMENT OF KOYNA DAM DEFORMATION DURING EARTHQUAKE

Nisha Radhakrishnan
Department of Civil Engineering, Indian Institute of Technology Bombay
E-mail: p2nisha@civil.iitb.ac.in

Abstract: On June 8th, 2005, the Koyna region in Western Maharashtra, India was affected with a felt earthquake of magnitude M 4.2. This earthquake was followed by an aftershock of M 3.6. For monitoring the deformation of the dam, a GPS receiver was set up on the top of the dam by the Indian Institute of Technology Bombay (IITB) and was continuously operating, even during the time of the earthquakes. The GPS Group at the IITB has been working over 5 years in the field of deformation measurements and analysis of Koyna Dam under a research project funded by the Department of Science and Technology, Government of India. A GPS network has been established for this purpose, and observed periodically, in order to investigate the potential of the GPS Technology in deformation measurement analysis. The data collected by the receiver on June 8th, 2005, was used to analyse the movement of the dam due to the earthquakes. Analysis of the data just before and after the earthquakes occurrence showed a displacement of 2.3 cm in the northwest direction. After this period, a displacement of 2.1 cm in the opposite direction (southeast) was observed i.e. the station attained its original position. These results reflect the movement and the response of the dam body to the occurrence of the mainshock and its aftershocks. This result indicates the high stability of Koyna Dam. Keywords: Koyna Dam, earthquake, GPS measurements, Displacement.

1. Introduction

Koyna Dam, a rubble concrete dam and the reservoir formed went under construction in 1962 and were completed in 1963. The height of the Dam is 85 m, with 892 sq. km of catchment area. The dam and the reservoir are located on the Indian Peninsular shield, one of the oldest continental blocks on the earth's surface. Prior to the year 1962, this shield was referred to as a stable rock. But the December 11th, 1967 earthquake of M 6.3 in the Koyna region contradicted all these beliefs. However, the dam in the region withstood this significant seismic activity without much damage. The seismicity associated with the Koyna reservoir is believed to be unique in the world as it is one of the few sites where earthquakes of magnitude greater than 5 continue to occur [1, 2].

Dam and Crustal deformation studies using GPS are being carried out in this active region of Koyna, by the GPS team of Indian Institute of Technology Bombay (IITB), under a research project funded by the Department of Science and Technology (DST), Government of India. The objective of this project is to study the seismologically disturbed region of Koyna area and the behaviour of the dam body, using geodetic GPS technique. It includes establishing dense GPS network in the identified seismically active area, its repeat observations, detailed

GPS data processing using scientific software, estimating parameters responsible for deformation and developing methodologies for checking the stability of the region. A GPS network comprising of 34 stations has been established on the dam and surrounding regions and observed over 12 epochs, from December 2000 to June 2005. Of the 34 stations, 12 stations are established on the dam body, and the rest in the area surrounding the dam. Of the 12 stations on the dam, one GPS station is set up on the top most point of the dam and runs continuously throughout the day and throughout the campaigns. The remaining stations are generally observed for 6-8 hours [3].

The aim of this paper is to analyse the deformation of the dam due to the earthquakes that occurred during the recent campaign in June 2005. This was done by processing and analysing the continuously recorded GPS data collected before and after the earthquakes. The objective is to detect the co-seismic movement of the dam body.

2. Earthquake Information

On June 8th, 2005, at 3 : 02 : 10.7 am IST, an earthquake with M 4.2 (focal depth 10 km) occurred about 20 km southeast of Koyna Dam, Western Maharashtra, India. The latitude and longitude of this earthquake was recorded as 17º 14.6' and 73º 46.7' respectively. This earthquake was felt throughout the Koyna region and was felt by the GPS team too. This earthquake was followed by an aftershock of M 3.6 (focal depth 8 km) that occurred at 4 : 34 : 21.2 am (i.e., 1.5 hours after the main shock) at a latitude 17º 15.7' and longitude 73º 44.5'. The information of the earthquakes was collected from the Koyna Dam Authorities.

3. GPS Data Analysis

The GPS measurements at Koyna Dam area including the dam body itself are usually carried out two – three times per year by the GPS team using Trimble 4000SSI and Trimble 5700 dual frequency geodetic GPS receivers. During the latest campaign in June 2005, an earthquake with M 4.2 followed by its aftershock of M 3.6 occurred on June 8th, 2005. A GPS receiver was set up the previous day on the top of the dam (Figure 1) and was continuously operating even during the time of the earthquakes. After the occurrence of these earthquakes, the attention was focused to study the co-seismic movement of the dam body due to these earthquakes and was done by analysing the GPS data collected before and after the earthquakes. Data collected 2.5 hours before the earthquakes and the 2.5 hours including the main shock and after shock was considered to study the co-seismic movement of the dam. The data collected in next 2.5 hours after the earthquakes were also considered to study the response of the dam after the earthquakes. The collected data was processed using Bernese v.4.2 Software [4]. To get very high accurate results, three of IGS stations BAHR in the Arabian plate, LHAS in the Eurasian plate and IISc in the Indian plate, were used in addition to the Koyna Dam station (Figure 2).

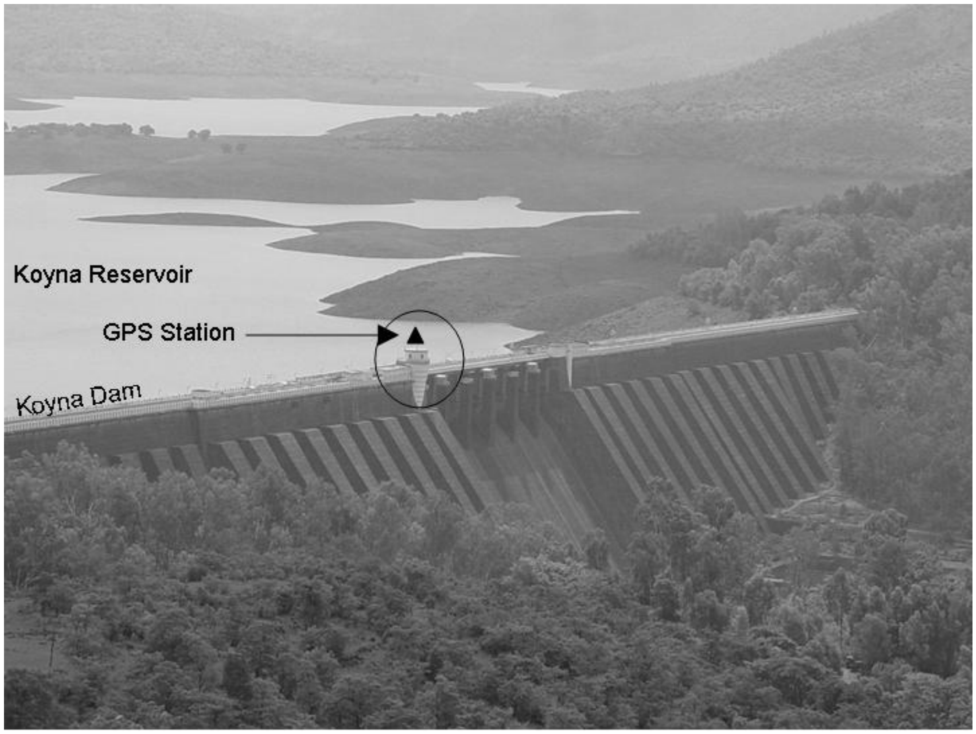

Figure 1: Location of GPS station on the Koyna Dam body, Western Maharashtra, India

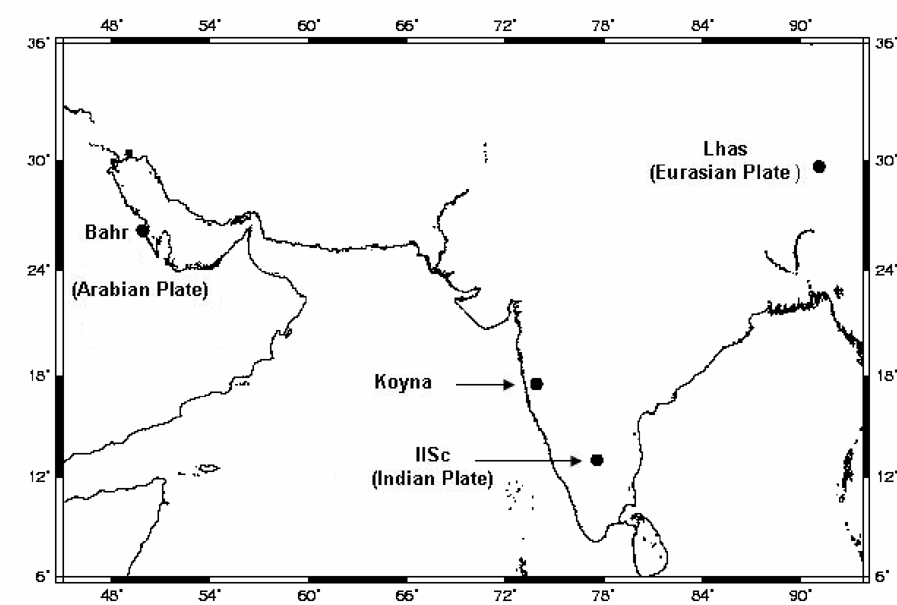

Figure 2: Distribution of IGS stations and Location of Koyna region

3.1. Change in RMS values

The processed data was analysed and remarkable changes in the RMS values of the Dam station geodetic coordinates (latitude and longitude) were observed before, during and after the earthquakes (Table 1). These RMS values were plotted against the time to understand the change in the RMS for latitude, longitude (Figure 3). The maximum values of RMS for both latitude and longitude were observed for the data collected from 3:02-5:30 am, i.e., during the occurrence of the main earthquake and its aftershock. These values were found to shoot up from what was observed just 2.5 hours before the earthquakes (0:32-3.02 am). This increase in RMS may be accounted to the movement of the dam and in turn the GPS receiver, caused by the vibrations of the earthquakes. It is observed from the analysis of the results that for the data collected from 5:30-8:00 am, i.e., after the earthquakes, the RMS values for latitude and longitude are small compared to the values observed for during the earthquakes. This shows the dynamic displacement of the dam.

Data time	RMS (m) (Global)	RMS (m) (Latitude)	RMS (m) (Longitude)
2.5 Hrs before Earthquakes (0:32 – 3:02 am)	0.0019	0.0006	0.0011
2.5 Hrs including Earthquakes (3:02 – 5:30 am)	0.0019	0.0018	0.0093
Next 2.5 Hrs after Earthquakes (5:30 – 8:00 am)	0.0019	0.0006	0.0006

Table 1: The RMS values of geodetic coordinates for Koyna Dam GPS station before and after the June 8th 2005 earthquakes

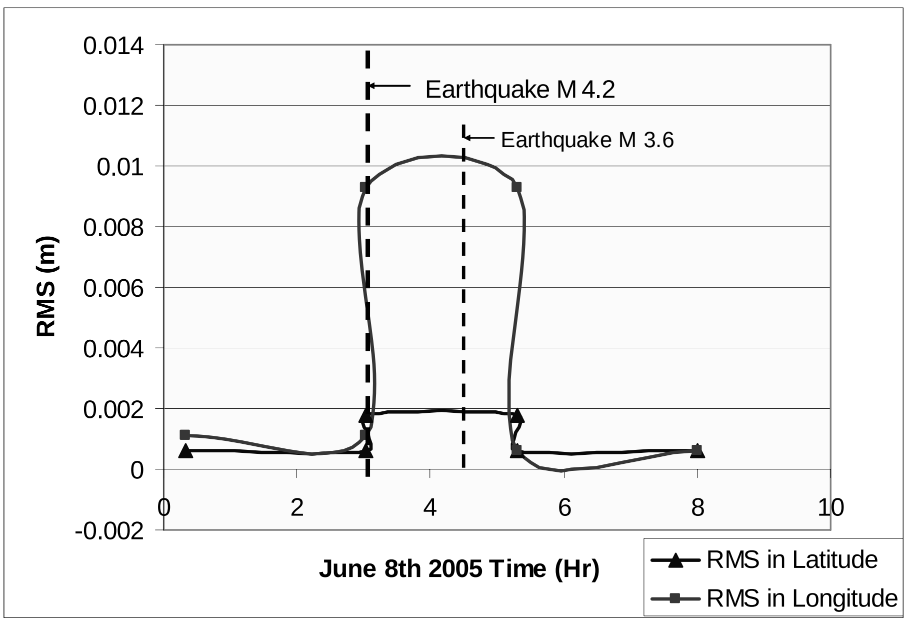

Figure 3: The changes in the RMS value with time for latitude and longitude before and after the earthquakes

To check the reliability of the results obtained for 2.5 hrs collected GPS data, the 2.5 hours data collected on 9th June 2005, a day when there was no earthquake in the region, was compared with that of the 24 hours data collected on the same day. The results are given in Table 2.

RMS (m)	2.5 hrs Data	24 hrs data
Latitude	0.0005	0.0002
Longitude	0.0006	0.0002

Table 2: Reliability check of 2.5 hrs data with 24 hrs data

It is observed that the RMS values of latitude and longitude for the 2.5 hours data obtained for 9th June 2005 approximately agrees with that of the 24 hours data of the same day. This justifies the reliability of the 2.5 hours data and thus the 2.5 hours data collected on 8th June 2005 to study the dynamic movement of the data is reliable.

3.2. Change in Displacement of Dam Station

Analysis of the periods 2.5 hours before and 2.5 hours including the earthquakes shows a displacement of about 2.3 cm (Table 3) in the northwest direction (Figure 4). This is due to the co-seismic effect of the main shock of M 4.2 and its aftershock M 3.6, which occurred southeast of the Koyna Dam (Figure 4). Tectonic features including the Koyna seismic zone and location of the earthquakes are also shown (Figure 4) [5, 6].

For detecting the change in the movement of deformation of the dam, analysis between the results obtained from the data collected 2.5 hours including the earthquakes and the next 2.5 hours after the earthquakes were carried out. The analysis shows a displacement of 2.1 cm (Table 4) with a southeast direction (Figure 4). The similarity in the value of displacements and their opposite direction of movement indicates that the dam body rebounds to its original position and is therefore a case of forced oscillations of an over-damped system (dam). This movement in different directions might be due to the high elastic property of the dam body.

Time	2.5 Hrs before earthquakes		2.5 Hrs including earthquakes		Deformation (m)	
Coordinate (sec)	Latitude	Longitude	Latitude	Longitude	Change in Latitude (m)	Change in Longitude (m)
	6.460469	7.746082	6.461223	7.745592	0.017	-0.015

Table 3: The resultant displacement of the Koyna Dam GPS station 2.5 hours before and 2.5 hours after June 8th 2005 earthquakes

Time	2.5 Hrs including earthquakes		Next 2.5 Hrs after earthquake		Deformation (m)	
Coordinate (sec)	Latitude	Longitude	Latitude	Longitude	Change in Latitude (m)	Change in Longitude (m)
	6.461223	7.745592	6.460656	7.745990	-0.017	0.012

Table.4: The resultant displacement of the Koyna Dam GPS station 2.5 hours after and next 2.5 hours after June 8th 2005 earthquakes

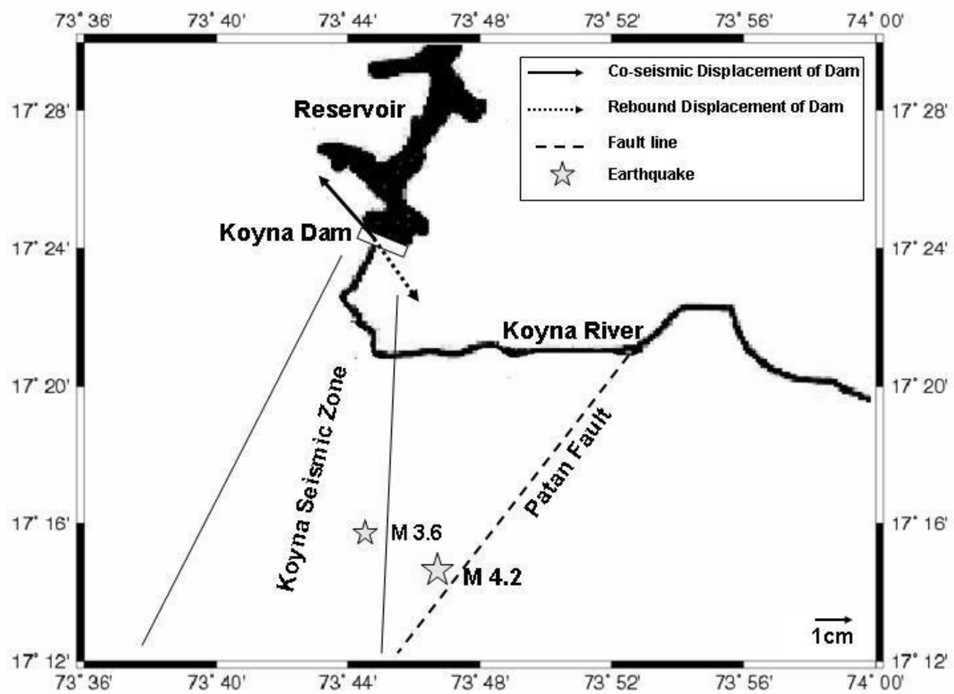

Figure 4: Displacement of the GPS station on Koyna Dam body before and after the earthquakes

4. Conclusion

This is probably the first case in India that the co-seismic displacement of a dam body was estimated using GPS data recorded during the time of occurrence of an felt earthquake and its aftershock.

The value of displacement of the dam obtained from GPS of 2.3 cm observed during the time of the earthquakes indicates that effect of the waves on the dam is small. This is probably due to the fact that the Koyna dam has rubble and concrete foundation that might be providing a damping to the seismic waves.

The return of the displacement of the dam to its original position after the earthquakes reflects the high response value of the dam foundation and this means the dam body is stable and not affected by the earthquakes. It might be because of these reasons that the dam did not suffer much damage due the December 11, 1967 earthquake of M 6.3.

It is highly recommended that continuously operating GPS deformation monitoring systems should be set up on all major dams and bridges in India, for monitoring deformations associated with earthquakes, in real time and should be interpreted in combination with response of dams and bridges.

Acknowledgements

The research project is funded by the Department of Science and Technology, Govt. of India, and supported by I.I.T. Bombay. The work has been done under the guidance of my supervisors Prof. Madhav N. Kulkarni, IIT Bombay, India and Prof. Kamal Sakr, Institute of Astronomy & Geophysics, Cairo, Egypt. The field work for the twelve campaigns was carried out by research fellows: V.S. Tomar, P. Pillai, Deepa Rai, S. Deshpande, D. Vaidya, and the author, under the guidance of supervisors. The earthquake information has been provided by the Koyna Dam authorities. The help given by the Executive Engineer, Koyna Dam, is gratefully acknowledged.

References:

[1] Rajendran, K., Harish, C. M.: Mechanism of triggered seismicity at Koyna: An evaluation based on Relocated Earthquakes, *Current Science*, 79 (3), pp 358-363, 2000.

[2] Manake, A., Kulkarni, M.N.: Study of the Deformation of Koyna Dam using Global Positioning System, *Survey Review*, July 36 (285), pp 497-507, 2002.

[3] Kulkarni, M.N, Radhakrishnan, N., Rai, D.: Deformation Studies of Koyna Dam, Western India, Using GPS, *GPS WORLD*, November 15(11), pp 14-19, 2004.

[4] Hugentobler, U., Schaer, S., Fridez, P.: Bernese GPS Software Version 4.2 Documentation, Astronomical Institute University of Bern, Switzerland. 2001.

[5] Pandey, A.P., Chadha, R.K.: Surface loading and triggering earthquakes in the Koyna-Warna region, western India, *Physics of the Earth and Planetary Interiors*, 139, pp 207-223, 2003.

[6] Talwani, P.: Seismotectonics of the Koyna-Warna Area, India, *Pure and Applied Geophysics*, 150, pp 511-550, 1997.