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Study of the Deformation of Koyna Region using Global Positioning System

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ABSTRACT: Monitoring of the recent crustal movements of the area surrounding the Koyna Dam in Western India is being carried out since December 2000. For studying the deformation field along a structural fault located downstream of the dam, a network of well-distributed geodetic points has been established and GPS observations have been carried out from December 2000 to September 2004. The data from ten field campaigns were analyzed and the deformations between each pair of epochs and the rate of deformation between the first and last epoch for all geodetic points were estimated.

1 INTRODUCTION

The Koyna Dam and its reservoir, Shivaji Sagar Lake, are located in the watershed of the Krishna River in the state of Maharashtra, India. The Koyna Dam and the reservoir formed by it went under construction in 1956 and were completed in 1961. They are part of the Deccan Plateau of Western India, which is located in the Peninsular Shield region. The Dam is a 103m high and 800 m long rock-filled concrete structure, with an 872 sq km of catchment area. It is an intake structure and includes an underground powerhouse, a transformer hall, a control valve house, and a tailrace tunnel.

The Indian Peninsular plate, one of the oldest continental blocks on the earth's surface, was traditionally referred to as a stable rock by geologists, which remained immune from any major seismic disturbance. But the December 11, 1967 earthquake at Koyna in the state of Maharashtra, Western India with a magnitude M of 6.3 on Richter Scale, contradicted this belief and evoked interest on the part of geologist, geodesists, dam experts and engineers (Joshi and Kulkarni 1986). However, the dam in the region withstood this significant seismic activity without any major damage. This occurrence in the Central Indian shield has led to serious introspection among geo-scientists and led to various studies dealing with the stability of the dam structure and the surrounding regions (Manake and Kulkarni 2002).

After the construction of the dam, to understand the movement of the dam, Koyna authorities had set up a survey network using theodolites to monitor the stability of the dam structure from 1965 - 1968. After the 1967 earthquake, the emphasis was made to study the movement of the dam due to the earthquake. From the analysis of the data collected from 1965 – 1966 before the earthquake and immediately after the earthquake in 1968 – 1969, they observed a dam movement of 5 – 8 mm in the south-east direction. The dam was found to be stable with only a few cracks after the earthquake. This stability was accounted to be due to the length of the dam and the movement of the dam was mostly found to be due to the effect of water level. They observed that the earthquake did not have any effect on the dam. These studies were validated with tiltmeter observations and were confirmed as correct (Gahalaut and Kalpana 2001).

Reports say that the earthquake was associated with left-lateral faulting on the Koyna River Valley Fault in Koyna Nagar near the site of the Koyna Dam (Gahalaut et al. 2004). Analysis of the earthquake data collected since the first major earthquake recorded in 1967, five years after water was impounded in the reservoir, suggests that the fault zone under the Koyna Dam may have been weakened by the annual reservoir filling. It is suggested that with the passage of time, the region is likely to experience earthquakes, even with minor periodic fluctuations in the reservoir level. The spatial and temporal patterns of recurring earthquakes in the region suggest the possibility of the fault zone becoming further unstable, progressively lowering the stress needed to trigger an earthquake. 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 (Rajendran and Harish 2000, Talwani 1997).

Therefore, in order to study the crustal and Dam deformations at active region of Koyna, a team from Indian Institute of Technology Bombay (IITB) has been conducting studies using Global Positioning system (GPS), a spatial technology, under a research project funded by the Department of Science and Technology (DST), Government of India. The main 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 points has been established on the dam, along the fault line and other deformation areas surrounding the dam and have been observed over ten epochs, from December 2000 to September 2004. The data collected have been processed, evaluated and analysed at IITB for the purpose of deformation analysis. The main objective of this paper is to study the pattern of the deformation along the fault line located downstream of the dam.

2 DEFORMATION ANALYSIS

In order to understand the mechanism of deformation along the fault zone, eight points have been established as shown in Fig. 1. The points have been distributed on both the sides of the fault line. These points were observed using GPS over 10 campaigns in Dec.2000, May.01, Oct.01, Sept.02, Dec.02, May.03, Sept.03, Dec.03, Apr.04 and Sept.04 respectively. The measurements were carried out by Trimble 5700 and 4000SSI dual frequency geodetic GPS receivers. The collected data was analyzed using Bernese v 4.2 Software (Hugentobler et al. 2000). The deformation rates between the successive campaigns were calculated for all geodetic fault points. The results of the analysis are represented in Figs. 2-10.

From the Figs. 2-5, it is observed that, during the periods Dec. 2000 – May.01, May.01 – Oct.01, Oct.01-Sept.02, Sept.02 – Dec.02, a remarkable deformation of 40-70 mm is observed. The deformation during Dec. 2000 – Oct01 may have been due to the pre- and post-seismic effect of the January 26th, 2001 Bhuj earthquake of M 7.1, which occurred in Gujarat, Western India, close to the area of study (Kayal et. al. 2004). Period from Sept.02 – Dec.02 recorded the maximum water level of 658.25 m. Thus, the deformation during this period may have been due to the maximum weight of the water and the simultaneous increase in the pore pressure in the rock due to pore pressure diffusion. The minimum rates of deformation of about 20-25 mm are observed during Dec. 02- May.03 and May.03- Sept.03 campaigns, as shown in Figs. 6 and 7.

The value of deformation shows a rise to about 30-40 mm during Sept.03 – Dec.03, Dec.03 – Apr.04 and Apr.04 – Sept.04 as shown in Figs. 8-10. This increase in the rate of deformation may be due to the accumulation of strains in the area and hence continuous monitoring will be useful for detecting the increasing or decreasing rate of the deformation.

It is apparent, from Figs.2-10, that the values of deformation vary from one epoch to another. At all the points, the trends of deformation are inhomogeneous. This might be explained by the fact that there is more than one force affecting the area. The calculation of strain rate regime is not suitable here because the baseline lengths between the stations are very small.

The rate of deformations of the geodetic fault points was calculated from the first campaign Dec. 2000 to the last campaign Sept. 2004. The results are given in Table 1. From these results, the average rate of deformation is found to be about 6 mm/year. The values of the deformation are represented in Fig. 11. From this Figure, it can be noted that the general direction of movement of the points located close to the Koyna Dam shows S-E trend and the points located at the other side of the fault show S-W trend.

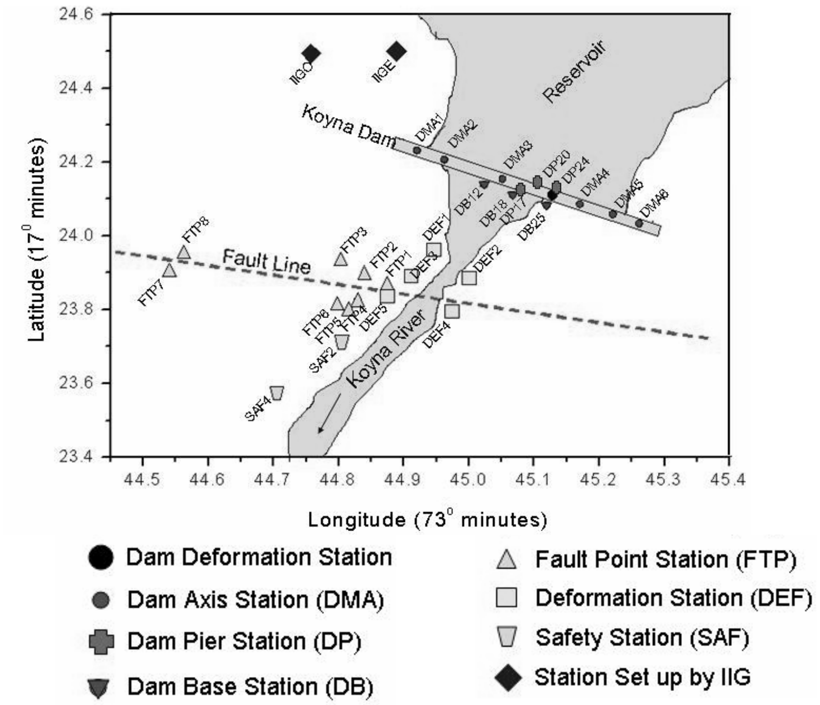

Figure 1 : Distribution of GPS network around the Fault and Koyna Dam area.

Table 1: Rate of deformations of Geodetic Points around Koyna fault from year 2000 to 2004.

Fault station id.	ΔN in m.	ΔE in m.	Rate of deformation (mm/yr)
FTP3	-0.003	0.02	5.06
FTP4	-0.018	-0.018	6.36
FTP5	-0.018	-0.016	6.02
FTP6	-0.004	-0.003	1.25
FTP8	-0.022	0.038	10.98

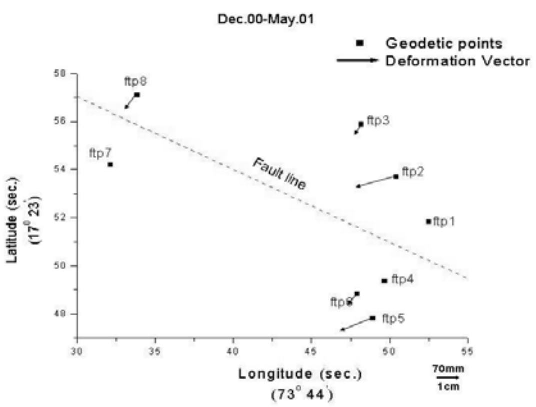

Figure 2 : Deformation vectors of the geodetic points along Koyna Fault from Dec.00 to May.01.

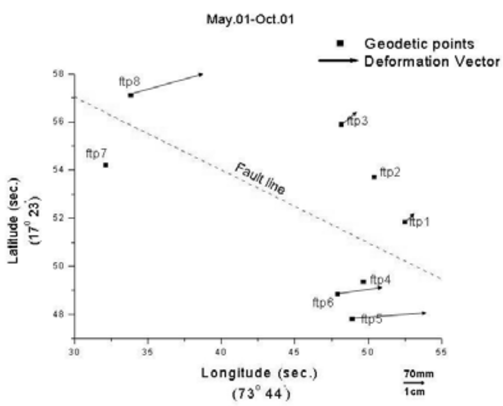

Figure 3 : Deformation vectors of the geodetic points along Koyna Fault from May.01 to Oct.01.

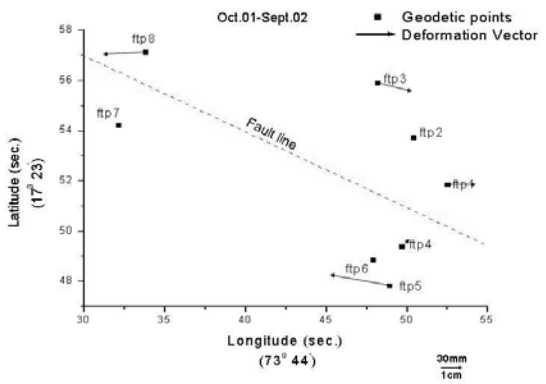

Figure 4 : Deformation vectors of the geodetic points along Koyna Fault from Oct.01 to Sept.02.

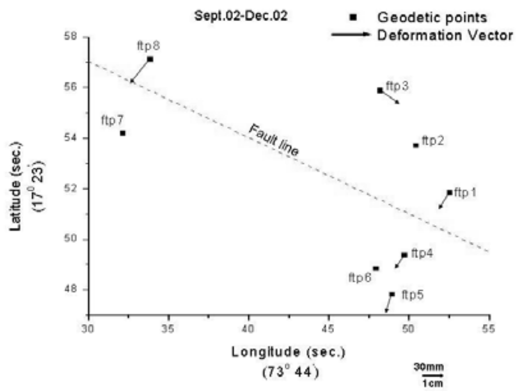

Figure 5 : Deformation vectors of the geodetic points along Koyna Fault from Sept.02 to Dec.02..

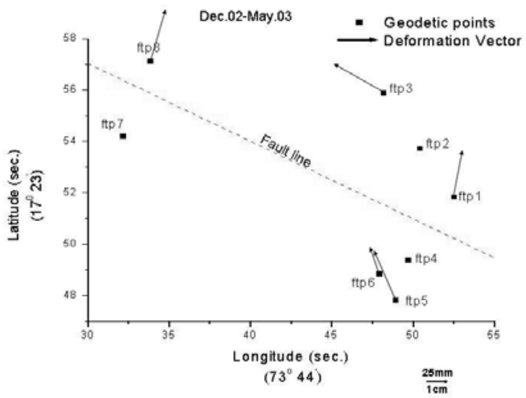

Figure 6 : Deformation vectors of the geodetic points along Koyna Fault from Dec.02.to May.03.

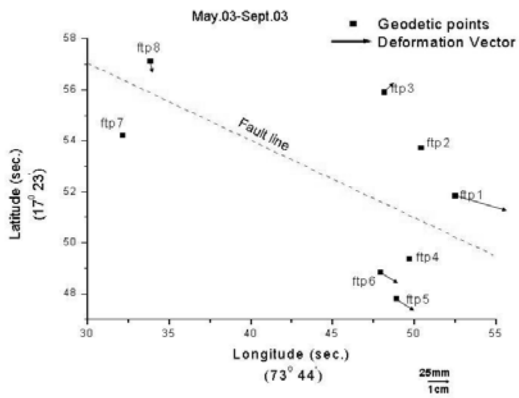

Figure 7 : Deformation vectors of the geodetic points along Koyna Fault from May.03 to Sept03.

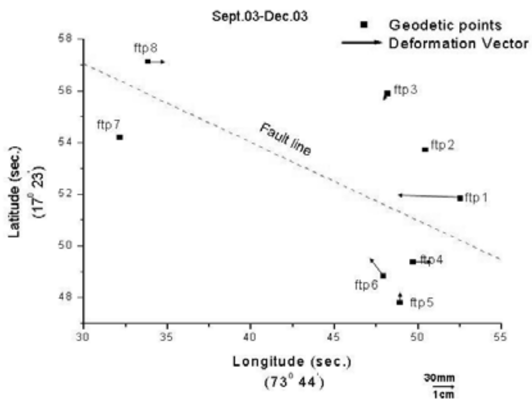

Figure 8 : Deformation vectors of the geodetic points along Koyna Fault from Sept.03 to Dec.03

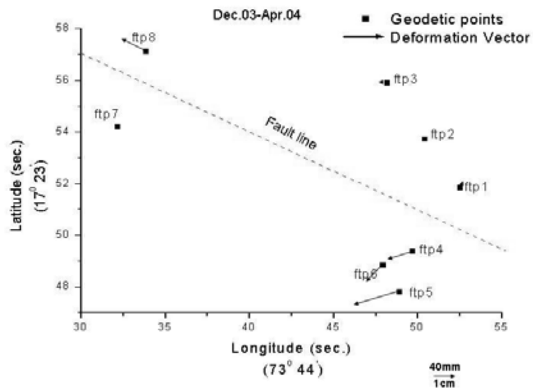

Figure 9 : Deformation vectors of the geodetic points along Koyna Fault from Dec.03 to Apr. 04.

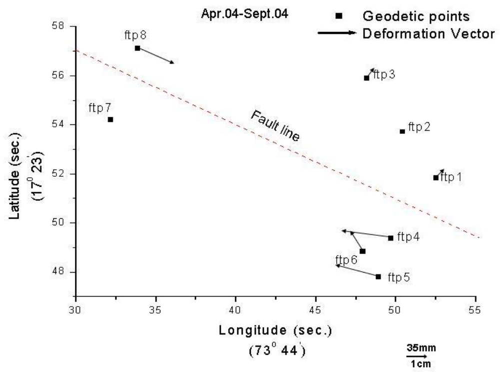

Figure 10 : Deformation vectors of the geodetic points along Koyna Fault from Apr.04 to Sept.04.

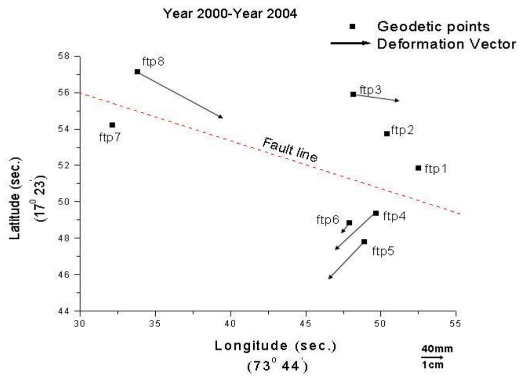

Figure 11: Deformation vectors of the geodetic points along Koyna Fault from Dec.00 to Sept.04.

3 CONCLUSIONS

The values of deformation of geodetic points around the fault area are found to be small. This shows high stability of the area downstream of the Koyna Dam and suggests that this fault line would not have any effect on the deformation of the dam. The analysis of the Strain rate regime at the fault area, which expresses the strain build-up of the minor blocks of the area, does not give significant values, probably because it is a very small area.

The period from 2000 to 2004 is short and may not show significant movements and thus, the fault might not be active during this period. So, it is highly recommended that, for the area of Koyna Dam, continuous measurements by GPS technique be taken up.

The number of geodetic points must be increased and spread to cover large area, to be able to get significant information about the fault trends and its location, in order to correlate the results with the seismic activity of the area, for monitoring the safety of the Koyna Dam.

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