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550.34(547.1)

A note on the anomalous tilt preceding the Koyna earthquake of 10 December 1967

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ABSTRACT. Employing the tiltgraph data of the Koyna Dam Observatory published in the reports of the Central Water and Power Research Station, Khadakwasla, Pune (1970), weekly mean value of the daily variation of the tilt has been computed for a period of six months starting from November 1967 to March 1968, which covers the main shock of 10 December 1967 and its aftershocks.

A plot of the weekly means on the time scale gives a systematic change in tilt and cloys finally (a high value of 1.2 micro radians in this case) preceding the earthquake. Further it abruptly reverses by 180° in its direction about two weeks prior to the major shock which may be considered a precursor. The analysis and the results obtained thus are discussed for the 10 December 1967 earthquake and its aftershocks in the Koyna region.

The daily tilt observations in the Koyna dam published by Guha *et al.* (1970) are carefully examined and the weekly means of the daily tilts are calculated in micro radians to correlate with the disastrous earthquake of 10 December 1967 and the aftershocks thereof. The tilt precursion method is considered to be one of the important tools for the prediction of the earthquakes in a given area of known fault systems. The tilt observations, however, are to be supported by other crustal monitoring instruments like the strain gauges, watertable recorders, *P* and *S* wave velocity measuring meters, accelerometers and magnetic field recorders. With the limited data available on the daily tilts, the analysis carried out and conclusions drawn here might be somewhat presumptuous but at the same time it is a test to the compatability of tilt precursion when no other data is available. It is known that the gross tilts due to rainfall and change in temperatures appear to obliterate the tilts of tectonic nature. The weekly means obtained from the daily variation of tilt would help to smoothout the errors introduced by the factors of rainfall and temperature change. It may be pointed out that the daily tilts reported are, however, not continuous and suggest intuitively that the tilt meter is activated by the factors other than rainfall and temperature change.

The tiltmeters, installed by Central Water & Power Research Station (CWPRS) in the dam are torsion pendulum type and they were located as shown in the approximate sketch in Fig. 1. K_3 and K_4 are the tiltmeter observatories located on the monoliths 10 and 17 respectively and on either side of the shear zone. Further details of the tilt-graphs and their functions are well documented in the publication of the CWPRS by Guha *et al.* (1970). It is expected that the tilt-graphs installed in the dam would reflect the slow creep instability of the crust before an earthquake and possibly the deformation of the foundation system.

2. From the CWPRS reports of earthquakes in Koyna region for over five years starting from 26 April 1964 to 27 June 1969, one earthquake on an average magnitude greater than 3 occurred on every 5th day which means that it is difficult to assign aseismic times in this region. But, the tilt-graph did not respond for almost all the shocks of lower magnitudes. It appears that there is an indication of tilt precursion for the major earthquake of 10 December 1967 and the following analysis bears this amply.

Fig. 2 shows the variation of weekly means of daily tilt of N-S component for the period from November 1967 to March 1968. The curve initially gave a steady increase three weeks earlier to the main shock of 10 December 1967 and a reversal occurred in the direction of the tilt from south (0·52 microradians) to north (0·76 microradians). This took place more than one week's time earlier to the major shock. Thereafter, the mean weekly N-S tilt anomaly shows no significant variation for about 5 weeks. It is interesting to note that the N-S tilt slowly increases and reverses in the second week of February 1968 from north (0·63 microradians) to south (1·15 microradians) during when one aftershock of magnitude 4·5 has occurred. This anomalous tilt might probably be due to the crustal adjustment after the major shock.

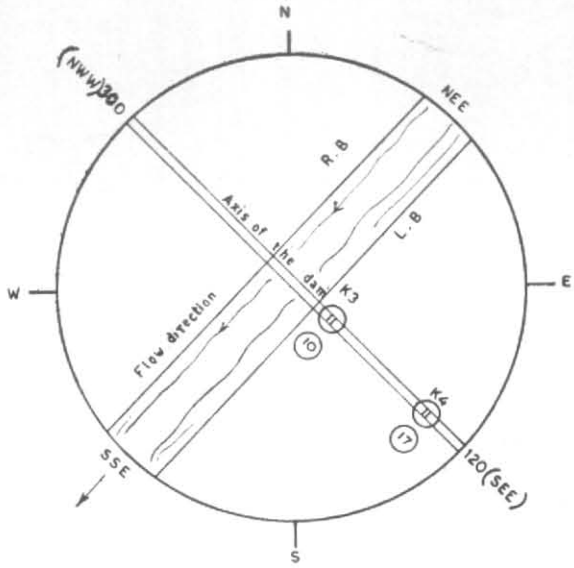

Fig. 1. Approximate sketch diagram of the river Koyna and location of the tilt meters

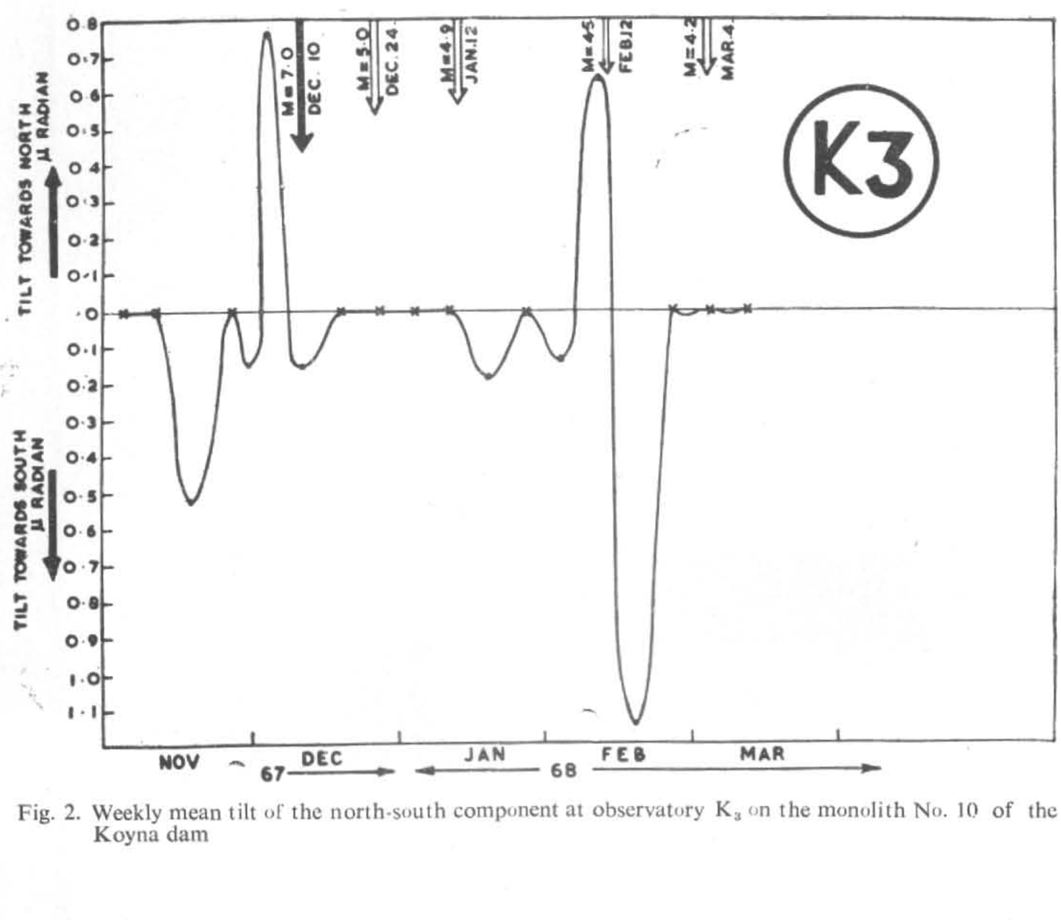

Fig. 2. Weekly mean tilt of the north-south component at observatory K_3 on the monolith No. 10 of the Koyna dam

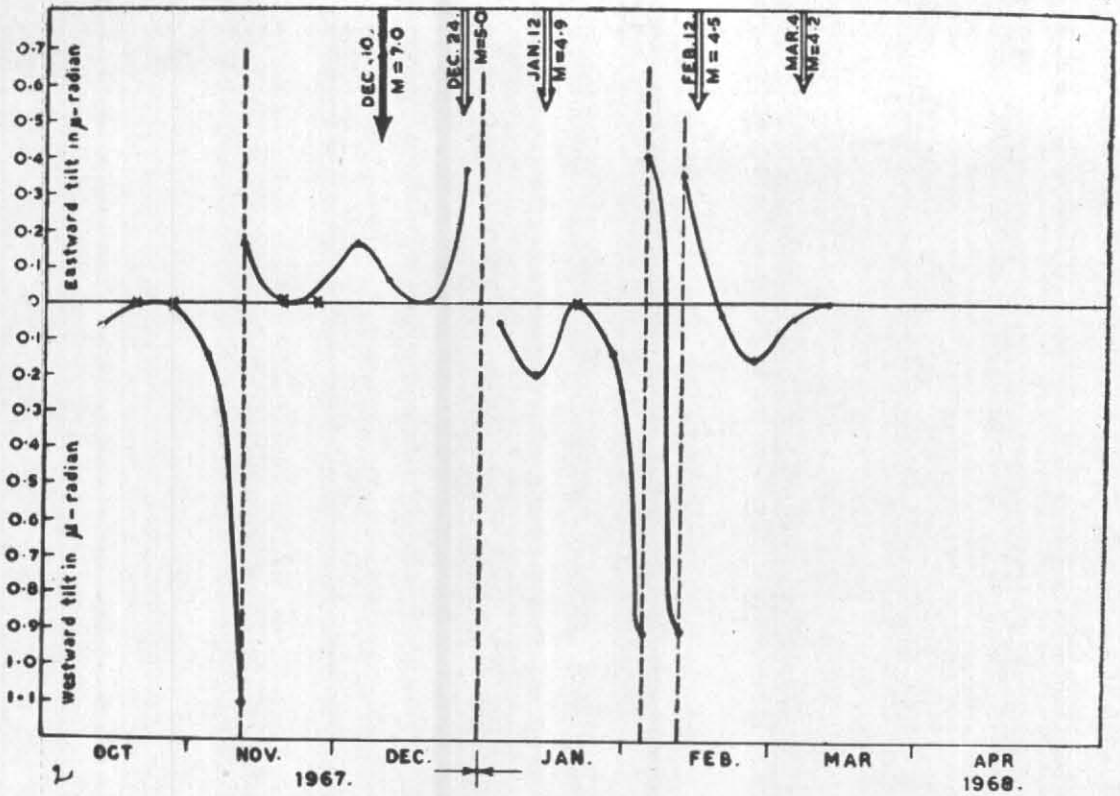

Fig. 3. Weekly mean tilt of the east-west component at observatory K_3 on the monolith No. 10 of the Koyna dam

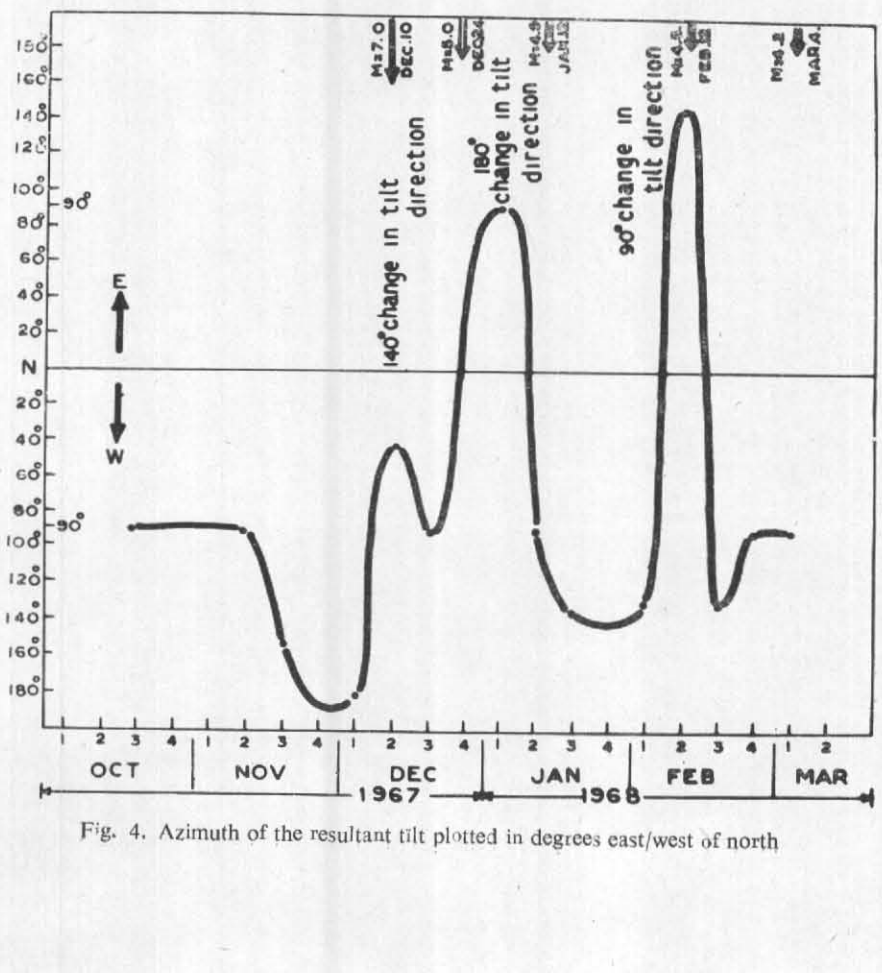

Fig. 4. Azimuth of the resultant tilt plotted in degrees east/west of north

3. Fig. 3 gives the weekly mean of daily variation of the E-W tilt component recorded at the same observatory K_3. The reversal from west (1·12 micro-radians) to east (0·15 micro-radians) took place three weeks earlier to the main shock and thereafter the anomalous nature of the tilt has continued. But the N-S tilt during this period does not show any variation. However, the E-W tilt rapidly reverses its direction before the after-shock of 12 February 1968. Depending on the direction of the crustal creep or deformation, it may be said that one component receives the tilt howsoever small it may be while the other keeps itself undisturbed. In this case of the N-S and E-W anomalous tilt components, the N-S component is greater after the first reversal and points towards the epicentre.

4. About the reversal in the tilt direction Rikitake (1976) reports that tilting in a fixed direction seems to change its direction prior to local earthquakes and that another steady tilting again occurs in a new fixed direction after the earthquake. This phenomenon has been observed in ten cases by the middle of 1974 as reported by Rikitake.

A plot of the azimuth of the resultant tilt is given in Fig. 4. The azimuth initially lies west of north and shifts to west. A change of 140° in tilt direction took place and the initiation of this change occurred one week before the main shock. For the remaining period, the azimuth cloys from east to west and west to east.

5. The Koyna region with the earthquake of 10 December 1967 has attracted the attention of many geologists, geophysicists and engineers in India. Wadia (1968) attributes the cause due to slippage in the Koyna region along a satellite fault of the main Malabar coast fault. Krishnan (1968) opines that the N-S trend of the *Koyna* river between Mahabaleswar and the Koyna dam suggests the river flows along a fault plane. Considering the geological factors of the Koyna region, it requires to develop a system to predict particularly intense earthquakes well in advance in order to take precautionary measures for the safety of the dam. As reported by Mortensen and Johnston (1974, 1976) for the San Andreas fault near Hollister, California, where an array of 14 shallow bore-hole tiltmeters have been monitored to get tilt precursion, a similar system along with the other monitoring instruments may be installed on either side of the *Koyna* river where it is considered flowing through the faulted zone. Further, the problem requires a study of the creep instablility model of the area to know the physical and mathematical implications regarding the creep and precursion with respect to the fault behaviour.

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