P - RESIDUAL STUDIES AROUND KOYNA DAM REGION, MAHARASHTRA, INDIA

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SYNOPSIS

An anomalous increase of about 0.4 seconds has been found to occur in the P - wave residuals around the Koyna Dam seismograph station prior to the devastating earthquake of Dec. 10, 1967 which occured in the vicinity of the dam. P - residuals were calculated from about 800 shocks, most of which originating in the Hindukush and Burma regions. These were averaged over intervals of six months commencing from January 1964 to June 1969. However, owing to large inaccurancies in the arrival times of events prior to January 1966, definitive changes in the P - wave velocity can be considered to have begun a year before the event of Dec. 10, 1967. Residuals of Satara station, about 42 kms. NE of Koyna were also studied but they did not yield useful information owing to a very large scatter in the residual data.

INTRODUCTION

Premointory changes in the ratio of compressional and shear wave velocities were observed by Aggarwal et. al. (1), Scholz et. al. (9) and Whitcomb et. al. (12), prior to the occurrence of a number of earthquakes. Nur (7) and Scholz et. al. (9) independently proposed a model to explain the observed anomalous behaviour of seismic waves which enabled estimation of the time of occurrence of these primonitory changes preceeding an earthquake as well as variations in other geophysical parameters such as tilt, resistivity, radon content and seismic activity.

It was also confirmed that the change in the V_p/V_s ratio was due predominently to the change in the P-wave velocity, in turn caused by dilatancy hardening of the rock mass in the focal region. Extensive laboratory investigations by Brace and Martin (2) and Gupta (4) and other workers have shown that the V_p/V_s ratio decreases at stresses as low as half the breaking strength of the material. This inelastic phenomena whereby a large number of incipient microfractures progressively lead to volumetric change with increasing tectonic stress is termed as dilatancy hardening.

The dilatancy diffusion model of Nur (7), Scholz et. al. (9) is based on two postulates: (i) creation of dry cracks due to increase in tectonic stress, (ii) diffusion of the fluid present in the surrounding area into the focal region to fill the newly created cracks or voids.

The change in the P - wave velocity occurs as soon as voids have opened just enough to allow a small amount of vapour. This greatly reduces the bulk modulus, thereby causing a reduction in the P - wave velocity. This anomalous decrease in the velocity continues for a period which can be detected and resumes its normal value just prior to the event.

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A diffusionless dilatancy model was also proposed by Stuart (10) which differs from the diffusion model in the sense that the voids created in the wake of dilatancy hardening close again just before the earthquake owing to reduced stress levels caused by nonlinear constitutive properties of the fault zone material. Unlike the diffusion model, therefore, in which the volume increase caused by dilatancy should be maintained from the time of the amonalous change in V_p/V_s until the occurrence of the earthquake and decrease slowly thereafter as the event is diffusion controlled, the diffusionless model provides that the excess volume should vanish before the earthquake as the cracks close.

Accordingly, Wyss and Holcomb (13) suggested that the study of P - residuals in the difference between the observed and computed arrival times of P - waves at a station, vary near to the source can provide a powerful tool for predicting imminient earthquakes. This method was successfully applied for predicting a few earthquakes, the Matsushiro event by Wyss and Holcomb (13), the Gisborne and Sedden earthquakes by Wyss and Johnston (14) and Gisborne event by Sutton(11).

Koyna Earthquake of Dec. 10,1967: The Koyna earthquake of Dec. 10, 1967 occurred in a traditionally nonseismic area of the Indian Shield, commonly known as the Deccan Traps. The event occurred within 5.0 kms. of the Koyna Dam and had a magnitude of 6.3. Its epicentre and focal depth as determined by the India Meteorological Department were 17°23'N, 73°45'E and 8.0 kms respectively.

The Shivaji Sagar Lake reservoir formed by the Koyna Dam was impounded in the year 1962, whereafter a persistant increase in seismicity was observed by the engineers supervising the dam site. However, the first notable event of magnitude in this area occurred in Sept. 1967 just prior to the main Koyna shock (3). This succession of event is a piece of the dilatancy diffusion model and strongly suggests a similar type of mechanism to have occurred in the Koyna Dam. Recently the Deep Seismic Sounding (DSS) experiments carried out by N.G.R.I. (Kaila, private communication) confirmed the existance of a deep fault underlying the Koyna Dam, which could have provided an easy channel to the reservoir water to diffuse into the dilatant zone.

A series of dramatic experiments carried out in the Rangely Oil fields to study the effect of interstitial fluid pressures on seismicity, by injecting water in the wells. An increase in pore pressure was observed to increase the level of seismicity by initiating sliding along a neighbouring fault, as the resulting frictional resistance decreased in consequence (5), (8).

Data: About 800 events were selected for the present study of P-wave residuals. Most of these occurred between January 1966 and June 1969 and originated from one of the following regions:

1. The Hindukush and adjoining area, mostly deep focus events.
2. The Arabian Sea upto the Carlsberg ridge, and
3. The Andaman and Nicobar Island region, Burma and Western Indonesia.

In addition to these, a few nuclear explosions from Algeria, Kazakh, Chase and Longshot were also selected.

The P - wave residuals for these events, selected from the USCGS and the ISC bulletins, were obtained with respect to the arrival times computed according to the Jeffreys - Bullen tables (6). Shocks very close to the Koyna Dam were excluded because of the possibility of their contributing large residuals owing to regional geological variations. The deep focus earthquakes of the Hindukush region are expected to be the most reliable as they can be assumed to have occurred without any P - wave time anomaly in the source region where ligho - static pressures are quite high. The data fluctuates about the mean value by approximately 1.0 secs. over an interval of six months and the standard deviation ranges from 0.1 to 0.15 secs.

Residuals observed at the Koyna Dam: The Koyna seimograph network at present consists of 10 seismograph stations and is shown in the Figure 1. Prior to the event of Dec. 10, 1967 four observatories: Koyna, Maharashtra, Satara and Govalkot were functioning. The Koyna Dam seismograph station consists of Benioff and Helicorder instruments with a recording speed of 60 mm/secs. and with an accuracy of upto 0.1 sec. but only the Wood-Anderson records were available for the year 1964 and the times not very accurate until January 1966. There is thus a large scatter in the residuals pertaining to this period and exact time of their initiation could not be inferred. Yet the Koyna Dam seismograph station clearly showed an increase of about 0.4 secs. (Figure 2) in the P - residuals before the main event, this anomalous change appears to have set in atleast a year before the occurrence of the main shocks.

Unluckily, the residuals pertaining to the Satara seismograph station calculated for the same period as those for Koyna yielded no useful results owing to a large scatter in data.

CONCLUSIONS

The study of the P - wave residuals at Koyna reveals that an increase of about 0.4 secs in P - residuals occurred in the source region of the Koyna earthquake. Assuming a 10% reduction in the P - wave velocity of 7.2 km/s would require the dimensions of the dilatant region to be about 25. kms to explain the P - wave residual anomaly, considering the P - wave velocity in the Koyna region a little too high. A notable feature of this residual anomaly lies in the fact that it has been observed to be associated with a predominantly strike-slip faulting. Anomalous tilts were similarly observed at Devenvillie, a predominantly strike-slip fault.

The reliability of the residuals obtained here is considered to be fairly satisfactory because of a large population (800 events) of events analyzed and secondly due to the deep focus earthquakes and nuclear explosions which are expected to provide very accurate times.

Furthermore, the precursor period of about 1.5 years associated with this event fits very well in the magnitude and time relation:

$$\log t = 0.68M - 1.31$$

where t is in days and M, the magnitude. The P - residual studies thus appear to be equally well applicable for the analysis of earth-

quakes associated with strike-slip faulting and routine monitoring of P - residuals can be regarded as an important tool for predicting earthquakes.

The more accurate picture of the anomaly can be obtained by subtracting the long-term residuals of Poona from the residuals at Koyna, as both can be assumed to be situated in the same tectonic region.

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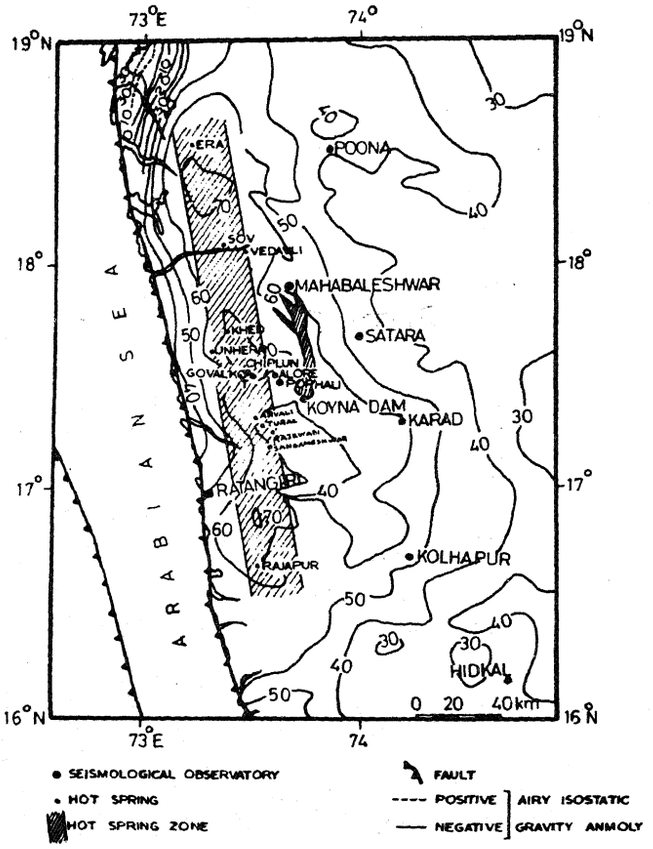

FIG. 1. _MAP OF W. MAHARASHTRA SHOWING KOYNA RESERVOIR, SEISMOLOGICAL OBSERVATORIES HOT SPRING ZONE, GRAVITY ANOMALIES AND PROMINENT FAULTS. (Guha et-al 1974)

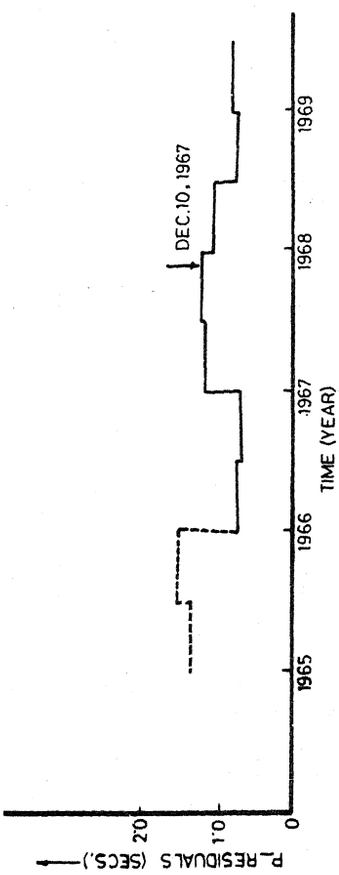

FIG. 2_AVERAGE P_RESIDUALS AT KOYNA DAM SEISMOGRAPH STATION. DATA PRIOR TO 1966 SHOWN AS DOTTED LINE OWING TO LARGE SCATTER. THE STANDARD DEVIATION IS 0.1 TO 0.15 SECS.

DISCUSSION

H.N. Srivastava (India)

Realising the size of the dilatant zone, the discussor would like to know whether similar residuals have been observed at any other observatory in the region ?

This study is very interesting from the Indian sub continent. At another place in Himachal Pradesh similar residuals were observed from earthquakes but the decrease in velocity was much more from kazakh nuclear explosions about 3 months before earthquake of Nov. 5, 1968.

S.P. Jalote (India)

Western coast is characterised by rift faults having vertical movements : The paper indicates strike slip movement. Could the author comment on the anomaly.

B.K. Rastogi (India)

In the dilatancy phenomenon, the P-wave velocity returns to normal value prior to the earthquake. Is it reflected in the anomaly prior to the Koyna earthquake of December 10, 1967 ?

I.N. Gupta (U.S.A.)

The dilatant source region in the case of a strike-slip mechanism earthquake is likely to be highly asymmetric with respect to azimuth. The discussor would like to know if any azimuthal dependence in the amount of P-wave residual was noticed.

Author's Closure

With regard to the question of Mr. Srivastava, we wish to state that we are currently investigating if P-wave residuals have occurred or are occurring elsewhere particularly around some of the reservoirs at the Himalayan foothills but have not come across a distinct indication so far. The information regarding the P-wave residuals having been observed prior to the Himachal Pradesh Earthquake of November 5, 1968 is indeed interesting.

With regard to the question of Mr. Jalote, we wish to state that the possible rift character of the Koyna earthquake fault similar to those of the west coast is a hypothesis, whereas the strikeslip character assumed in the paper is based on Fault Plane solutions. The Koyna earthquake fault is probably related to a nearby deep mantle-reaching fault delineated from Deep Seismic Sounding and bears no relationship to the west coast tectonics.

With regard to the question of Mr. Rastogi, we wish to say yes.

With regard to the question of Mr. Gupta, we wish to state that the azimuthal variation of P-residuals could not be brought out on account of the extreme paucity of data. In fact the data from all azimuths had to be used conjunctively to investigate the possible dilatancy phenomenon having preceded the Koyna earthquake.