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ESTIMATION OF FOCAL PARAMETERS FOR UTTARKASHI EARTHQUAKE USING PEAK GROUND HORIZONTAL ACCELERATIONS

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ABSTRACT

The focal parameters of Uttarkashi earthquake of October 19, 1991 (M_s 7.00, m_b 6.5) have been estimated using strong ground motion data. The fault plane parameters namely, dip, strike and slip angle are estimated using high frequency radiation in the form of peak ground accelerations at near distances. The observed radiation pattern is obtained using the peak ground accelerations in the azimuthal direction of the stations. The observed radiation pattern is then compared with the theoretically computed radiation pattern for S waves for different values of focal parameters. The focal parameters estimated by minimizing the error between observed and theoretically computed radiation patterns are: strike - N 315°, dip - 14°, and slip angle - 144°. The results obtained using strong ground motion data are compared with the fault plane solutions computed using comparatively long period waves reported by various agencies. The matching of results obtained in the near field and the far field show that the rupture over the fault plane may not have too much of scatter in different parts.

KEY WORDS : Radiation pattern, strong motion data, focal parameters, Uttarkashi earthquake

INTRODUCTION

The Uttarkashi earthquake (M_S = 7.0 , m_b = 6.5) rocked the Garhwal Himalaya at 02.53 hrs (IST) in the morning of October 20, 1991. This moderate earthquake created havoc in Uttarkashi and nearby areas with the death toll reaching upto 2000 and considerable damage to property. The focal parameters for this earthquake have been estimated by USGS, IMD, New Delhi and Harvard University (Khattri et al., 1994). The focal mechanism has been worked out based on the first ground motion, moment tensor solutions and centroid moment tensor solutions.

One of the important observations of Uttarkashi earthquake has been through the strong motion recordings. The Uttarkashi earthquake triggered 13 accelarographs in Garhwal Himalaya region. In the present study an endeavor has been made to estimate the focal mechanism parameters (dip, strike directions, and slip angle) form of acceleration time history being recorded at 13 stations using high frequency radiation in the near filed.

STRONG MOTION DATA

The Department of Earthquake Engineering, University of Roorkee, have deployed a strong motion array in the UP Himalayas (Chandrasekaran and Das, 1992). Each station consists of three component strong motion accelerographs with analog recorders. The locations of the stations are marked in Figure 1. Thirteen stations have recorded the event out of 28 installed stations. The records obtained from these stations have been processed using standard procedures (Lee and Trifunac, 1979; Chandrasekaran and Das, 1990). The peak horizontal ground acceleration as reported by Chandrasekaran and Das (1995) in two orthogonal directions are given in Table I. Some of these stations were in the immediate vicinity of the epicenter of the earthquake (Fig. 1). The maximum recorded horizontal acceleration was 304 cm/sec^2 and the maximum vertical acceleration, 289 cm/sec^2. The largest motion in horizontal direction was observed at Uttarkashi and in the vertical direction at Bhatwari. The epicentral area lies just north of the main central thrust (MCT) north east of Uttarkashi (Fig. 1). The focal parameters are computed from the comparison of the radiation pattern worked out from the recorded peak horizontal ground acceleration in azimuthal direction of station from the earthquake source and the theoretically computed radiation pattern for S waves.

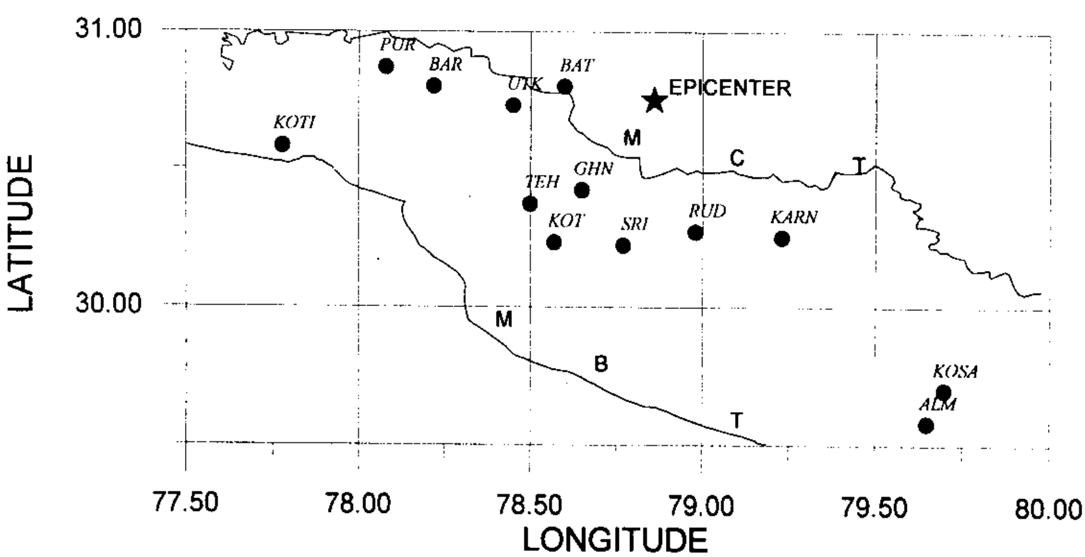

Fig. 1 Seismotectonic map of the region. locations of the stations (●) and the epicenter is marked (★)

RADIATION PATTERNS : OBSERVED AND THEORETICAL

The fault plane solution of an earthquake is generally worked out based on the first ground motion at various recording stations. The parameters are based on first P arrivals at comparatively larger distances representing the overall slip over the entire fault. The same parameters may also be worked out by comparing the energy release in various directions and its comparison with the radiation pattern for various values of these parameters. A scheme making use of projections has been applied for the computation of the observed radiation pattern using the peak ground horizontal accelerations recorded by stations around the source. The acceleration component a_β in the direction $\mathbf{n}_\beta$ may be computed (Bardet and Davis, 1996) by projecting the components a_1 and a_2 which are measured in directions $\mathbf{n}_1$ and $\mathbf{n}_2$ as

$$a_\beta = \mathbf{a}.\mathbf{n}_\beta = (a_1\mathbf{n}_1 + a_2\mathbf{n}_2) = a_1\mathbf{n}_1.\mathbf{n}_\beta + a_2\mathbf{n}_2.\mathbf{n}_\beta \tag{1}$$

The components $\mathbf{n}_1$, $\mathbf{n}_2$ and $\mathbf{n}_\beta$ are

$$\mathbf{n}_\beta = \begin{pmatrix} \sin\beta \\ \cos\beta \end{pmatrix}, \quad \mathbf{n}_1 = \begin{pmatrix} \sin\beta_1 \\ \cos\beta_1 \end{pmatrix} \text{ and } \mathbf{n}_2 = \begin{pmatrix} \sin\beta_2 \\ \cos\beta_2 \end{pmatrix} \tag{2}$$

where β, β_1 and β_2 are their respective azimuth angle. By equations (1) and (2) a_β becomes

$$a_\beta = a_1\cos(\beta - \beta_1) + a_2\cos(\beta - \beta_2) \tag{3}$$

The a_β will now give the peak ground horizontal acceleration in the direction $\mathbf{n}_\beta$ if the two orthogonal components a_1 and a_2 measured in directions $\mathbf{n}_1$ and $\mathbf{n}_2$ are known. The orthogonal azimuthal directions (angle) on which the accelerographs have been deployed in the field and the recorded peak ground horizontal accelerations recorded in their respective directions are given in Table I. The peak ground accelerations in the azimuthal direction of the station to the source are obtained using equation (3) using the whole accelerograms in two orthogonal directions. Fig 2 shows the acceleration computed in all the directions using the equation. The figure depicts the maximum acceleration in β=45° and β = 225°. This direction practically coincides with the direction of rupture on the fault. The accelerations in the azimuthal directions of the station to the source have been used to compute the observed radiation pattern of the source.

To estimate the focal parameters the radiation pattern (Aki and Richard, 1980) for S waves given by

$$R(\beta) = f(\lambda, \delta, i, \beta, \phi_s) \tag{4}$$

where $\lambda, \delta, i, \beta$ and ϕ_s are slip angle, dip, emergence angle, azimuthal direction for the recording station and strike of the fault, respectively are computed. The $R(\beta)$ will give all the possible cases for various values of slip angle, dip, azimuthal direction of the recording station and strike direction. These values have been computed for the various stations by giving their azimuthal directions and emergence angle. To match the computed values of the radiation pattern with the observed values, the radiation of energy in the direction of each station have been computed using equation (3). The best fit were obtained by looking at the least square difference between the observed and the computed radiation patterns for various possible cases for the focal parameters, i.e., dip, slip angle and the strike direction. The points at which the least difference between the observed and the computed radiation pattern is minimum, will give the estimates for the slip angle, dip, azimuth and strike. Due to different site conditions at each site, the site response will be different disturbing the amplitude decay with distance (see Table I) which may in turn increase the errors while matching such observed data with the theoretically computed radiation patterns. The magnitude of the difference (observed minus computed) will also depend on the heterogeneity, the complex geology and tectonics of the region and the different site conditions at various sites. Theoretically, considering the region to be homogenous and same site conditions at each site, the error should be minimum which is not the case in the present study.

TABLE I PEAK HORIZONTAL GROUND ACCELERATIONS RECORDED AT 13 STATIONS

Sl. No.	Station	Component	Acceleration (cm/sec*sec)
1	ALMORA	N53°W	17.41
		N37°E	21.02
2	BARKOT	N10°E	93.18
		N80°W	80.47
3	BHATWARI	N85°E	248.37
		N05°W	241.89
4	GHANSALI	N00°E	115.59
		N90°E	114.89
5	KARNPRAYAG	N05°W	60.99
		N85°E	77.35
6	KOSANI	N25°W	28.34
		N65°E	31.50
7	KOTESHEWAR	N30°W	98.85
		N60°E	65.23
8	KOTI	N10°E	20.64
		N80°W	40.95
9	PUROLA	N65°W	73.95
		N25°E	91.68
10	RUDRAPRAYAG	N53°E	52.29
		N37°W	50.67
11	SRINAGAR	N50°W	65.44
		N40°E	49.44
12	TEHRI	N63°W	71.41
		N27°E	61.13
13	UTTARKASHI	N15°W	237.27
		N75°E	303.99

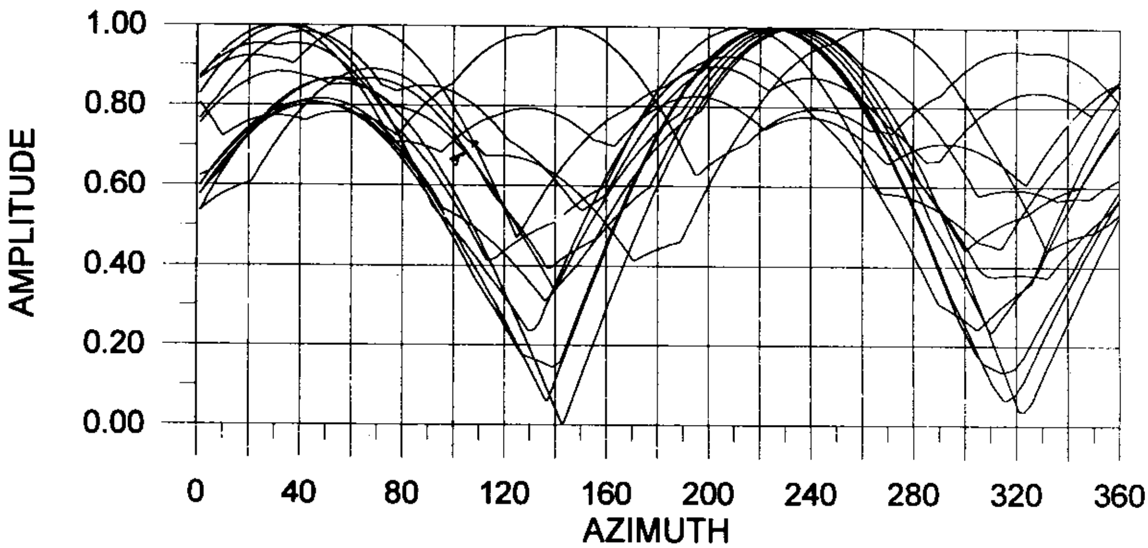

Fig. 2 **Variation of peak ground acceleration with azimuth angle for the 13 stations**

RESULTS AND DISCUSSIONS

All the 13 stations, which have recorded the accelerograms from the Uttarkashi earthquake, have been used to compute the observed radiation pattern. The observed peak ground horizontal accelerations have been computed for all the directions (Fig. 2). The figure depicts the maximum acceleration in $\beta = 45°$ and $\beta = 225°$. This direction practically coincides with the direction of rupture on the fault. From this data set the peak ground accelerations in the azimuthal direction of the stations to the source are chosen to form the observed radiation pattern. The theoretical radiation patterns using equation (4) have been computed for $\lambda = 1°$ to $180°$ and $\delta = 1°$ to $90°$ with given azimuthal angle and angle of emergence for each station in the same direction, i.e., azimuthal direction from station to source. The epicenter as reported by IMD, New Delhi has been taken for computations of the epicentral distances, azimuthal angle etc. (epicenter : 35.75° N and 78.86° E). This is based on local and regional data and is likely to be closest to the actual epicenter (Yu et al., 1995). The strike direction for the fault is assumed to be N315° based on the maximum release of energy in the rupture direction as shown in Fig. 2. Fig. 3 shows the differences (observed - computed) for various possible cases for dip and the slip angle. The minimum error for the dip as 14° and slip angle as 144° is 2.331. The error may be due to the mismatch of the two patterns or is because of variation in recorded accelerations at the sites due to their local site conditions, complex geology, tectonics and topography. The acceleration recorded at Uttarkashi is higher than that at Bhatwari which is closer to the epicenter as compared to Uttarkashi. Similar anomaly is seen in case of Koteshwar, Barkot and Purola after taking care for the radiation pattern. This increase will affect the error while computing the difference in the observed and computed radiation patterns.

The strike direction estimated as N315° by the maximum release of the energy (Fig. 2) is quit close to the results reported by various agencies (PDE, weekly - 332°; PDE monthly 296°; and CMT Harvard 317°).

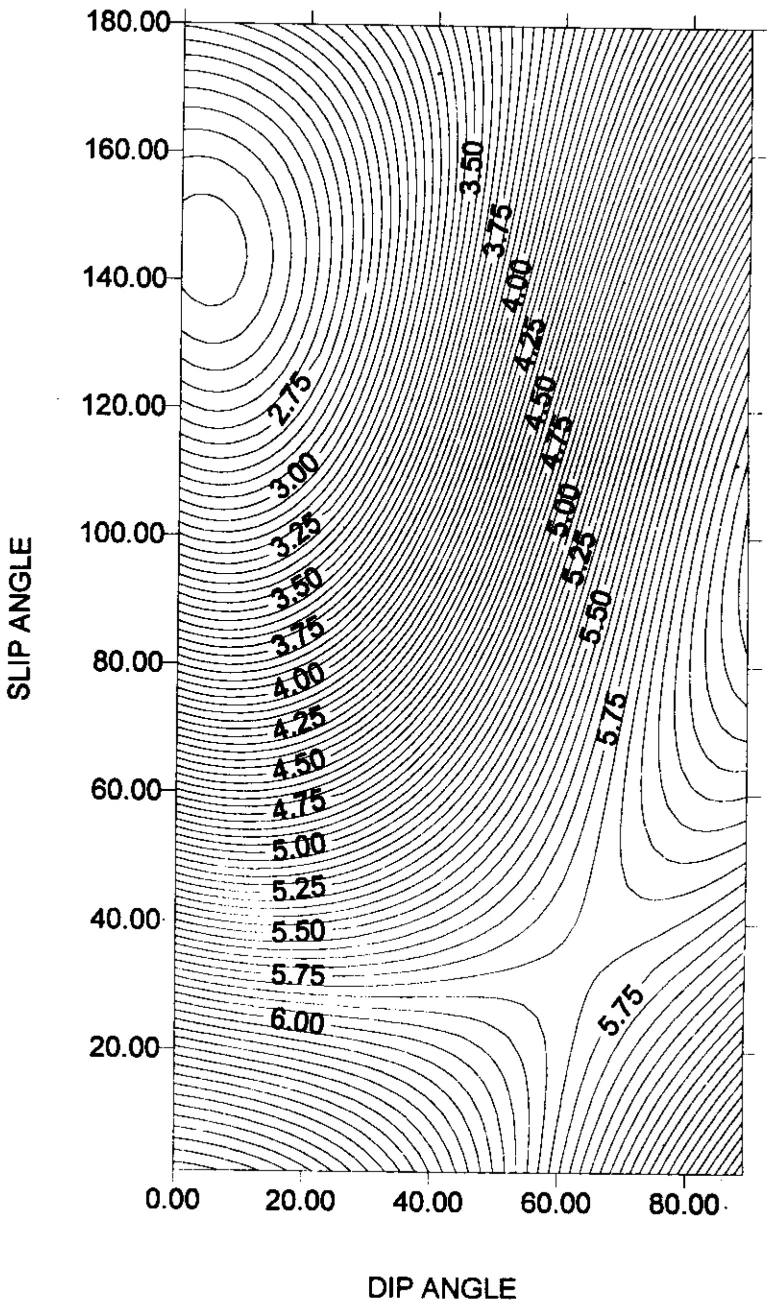

Fig. 3 **Contours of error in radiation patterns (observed - computed) with respect to slip angle and dip angle.**

The estimated dip is taken to be equal to 14° for which the difference between the observed and the computed dip is minimum as shown in Fig. 3, which shows the fault to be thrust type. PDE, monthly has reported this value to be 5° and 85° by P-wave first motion fault plane solutions and 38° and 85° by moment tensor solution for NP1 and NP2 respectively. The CMT (Harvard) reported the values to be 14° and 78° by Centroid Moment-Tensor solution for NP1 and NP2, respectively. The estimated value is quite close to the NP1 using fault plane solutions by CMT (Harvard).

The slip direction is estimated to be 144° at which the difference in the observed and the computed value of slip is minimum. The estimated value using the strong motion data is quite close to the reported values (PDE Weekly : NP1 - 133°, NP2 - 77°; PDE monthly: NP1 and NP2 90° using fault plane solutions and 172° and 52° using Moment Tensor solution for NP1 and NP2, respectively; CMT (Harvard): NP1 - 115° , NP2 - 84°).

On the basis of monitoring of local earthquakes Khattri et al., 1989 and Gaur et al., 1985 a regional NW-SE trend of seismic activity has been observed. A composite fault plane solution based on 21 earthquakes in the Garhwal Himalaya region reveals plane dips between 90 to 65 due south. The EW trending nodal plane has been preferred on the basis of presence of lineaments in the same direction (Jain, 1987). The results obtained by present technique matches well with the general source types in the region inferred based on above mentioned studies. In the Garhwal Himalaya low angle thrust faults have been reported and the majority of these are located to the south of MCT. The focal parameters obtained by horizontal peak accelerations also reveal a thrust fault with the strike trending towards NW-SE direction but the epicentral lies north of MCT which shows that the focal mechanism of the earthquakes occurring in the vicinity of the MCT are of same type on both the sides. . The matching of results obtained in the near field, i.e., the present study using the accelerograms and the far field, viz., other studies in which the focal parameters are computed using the first P arrivals, moment tensors etc. show that the rupture over the fault plane may not have too much of scatter in different parts.

CONCLUSIONS

The values for the strike, dip and slip angle are estimated using the strong motion data. Acceelererograms recorded at thirteen strong motion stations have been used to compute the observed radiation pattern. These values are compared with the theoretical S radiation pattern for all possible cases for dip and slip angle by considering the maximum energy release direction as the direction perpendicular to the faults strike direction. The estimates obtained are $\phi_S = 315°$, $\lambda = 144°$ and $\delta = 14°$. The estimates are quite close to the reported values. The strong ground motion is a very high frequency radiation in near field, which may represent radiation pattern from different pockets over the fault plane. . The matching of results obtained in the near field, i.e., the present study using the accelerograms and the far field, viz, other studies in which the focal parameters are computed using the first P arrivals, moment tensors etc. show that the rupture over the fault plane may not have too much of scatter in different parts.

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