Estimation of source parameters of Chamoli Earthquake, India

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The devastating earthquake (mb = 6.6) at Chamoli, Garhwal Himalaya, which occurred in the morning hours on 29th March 1999, was recorded on Delhi Strong Motion Accelerograph (DSMA) Network operated by the Central Building Research Institute, Roorkee. In this paper the source parameters of this event calculated from the Strong Motion Data are presented. The seismic moment for this event has been found to be of the order of 10^{25} dyne.cm and the moment magnitude has been calculated in the range of 6.53 – 6.69 at different stations. The stress drop and source radius for the earthquake are also calculated.

1. Introduction

The Himalayas, stretching from the Pamir-Hindukush to the Arkans in Burma, is a classic product of a continent collision (Valdiya 1980, Seeber and Armbruster 1981, Ni and Barazangi 1984). The Himalayan seismic belt is known for its high seismicity for small to large magnitude earthquakes. This region has witnessed four large magnitude earthquakes (mag. >8.4) and nine earthquakes of magnitude >7.0 since 1897. Besides these it has experienced two more devastating earthquakes of magnitude greater than 6.0 in the last decade namely the Uttarkashi earthquake in 1991 and the Chamoli earthquake in 1999 (Rajendran *et al* 2000, Rastogi 2000). The effect of these earthquakes was felt up to approx. 300 km. in the city of Delhi. In the recent earthquake of Chamoli about hundred people have lost their lives, several hundred people were injured and about 50000 houses were damaged, apart from loss of property of worth crores of rupees. Aftershocks of this event were felt for several months.

When an earthquake takes place, certain amount of strain energy is released, resulting in a sudden drop of accumulated stress. Recent advances in the seismic source theory have improved our understanding of the body wave spectral characteristics and physical properties of the source such as seismic moment, stress drop and area of rupture. Brune (1970) has given a model to calculate source parameters using near and far field displacement amplitude spectrum as a function of the physical parameters at the source. Abercombie and Leary (1993); Zobin and Hasakov (1995) and several others are notable recent contributors in the field of source parameter studies, in different parts of the world. Singh *et al* (1979) and Sharma and Wason (1994, 1995) have calculated source parameters for Himalayan and nearby regions. To the best of this authors' knowledge, the source parameter studies using strong motion data have not been carried out in India so far, though similar work has been undertaken in other parts of the world. One of such recent study is done by Olafsson *et al* (1998) on the Vatnafjoll earthquake in south Iceland. In the present study the source parameters for the 1999 Chamoli earthquake are calculated at three different sites using strong motion data recorded on Delhi Strong Motion Accelerograph (DSMA) network maintained by the CBRI.

2. Data and methodology

Sixteen Digital Triaxial Strong Motion Accelerographs (Altus K2) have been installed in and around Delhi under the DSMA network. All the 16 instruments are installed either at the basement or on the ground floor of buildings. The locations of SMAs, which are operating in this region at present, are shown in figure 1.

The Chamoli earthquake of 1999 was recorded on DSMA network at six stations, three located inside Delhi city and three outside the city. These stations

Keywords. Chamoli earthquake; strong motion accelerograph; seismic moment; source radius; stress drop; moment magnitude.

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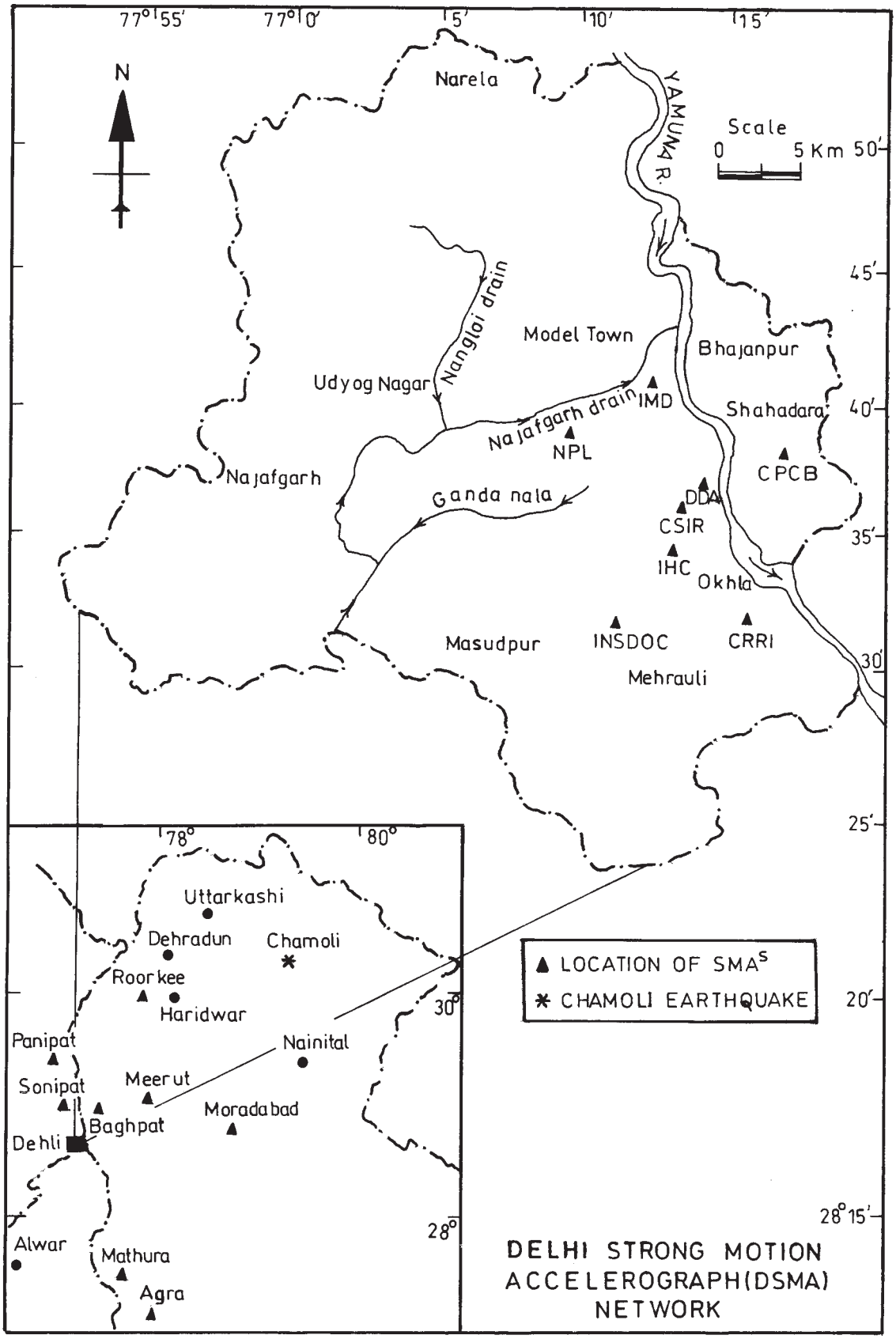


Figure 1. Locations of strong motion accelerographs network.

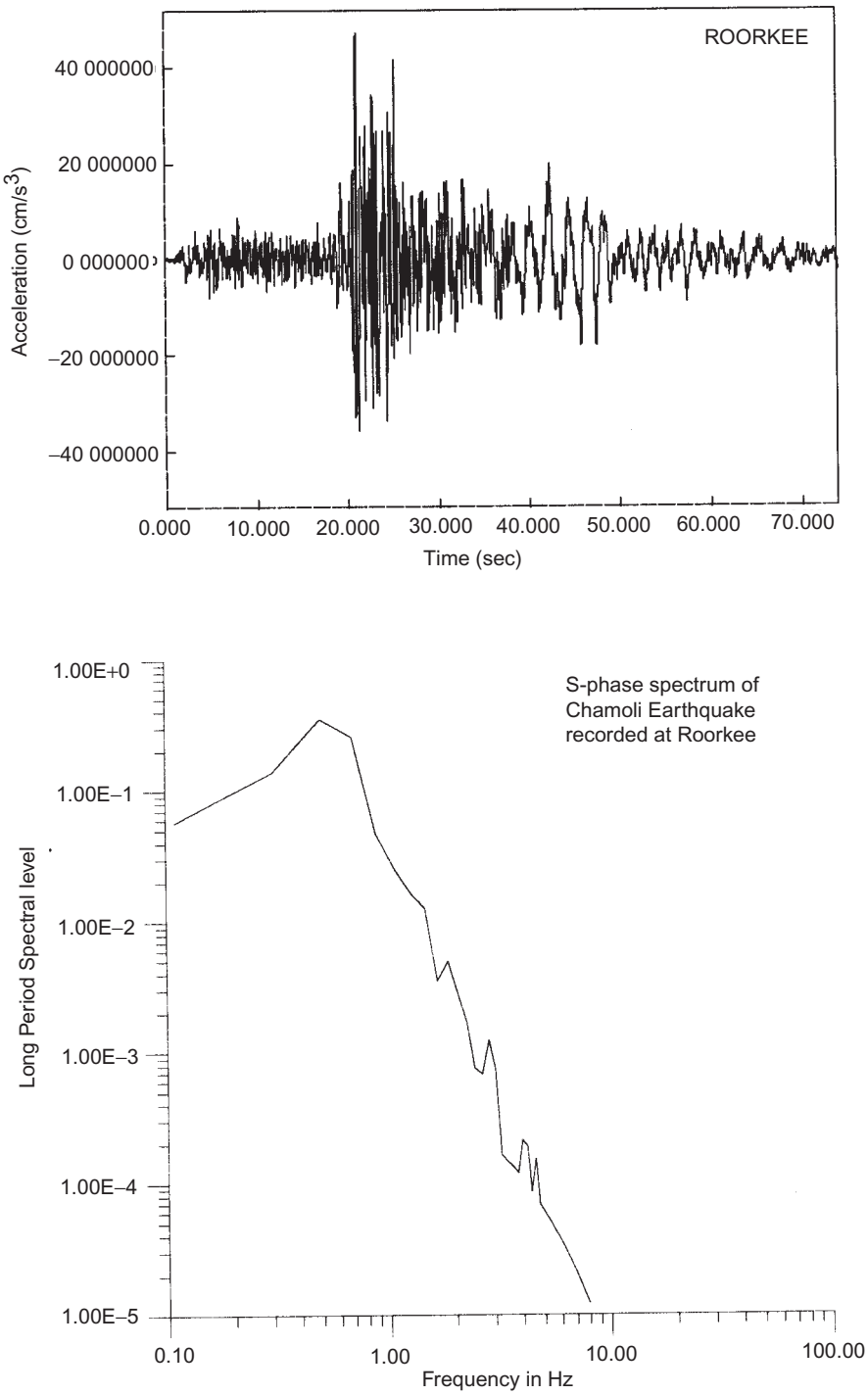
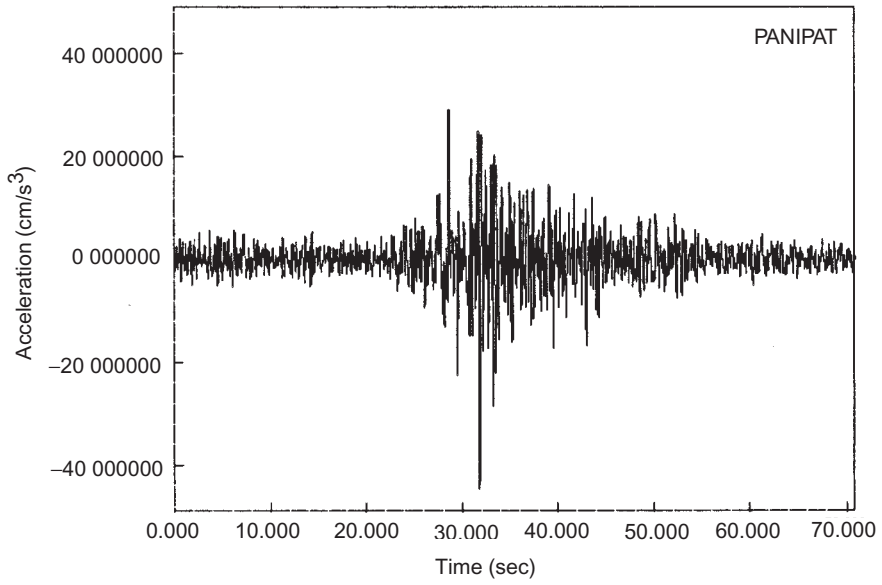


Figure 2 (a). Fourier spectra of the S-phase data at Roorkee station for the Chamoli earthquake.

are CPCB (East Arjun Nagar), CSIR (Rafi Marg) and IHC (Lodhi Road) in Delhi and Baghpat, Panipat and Roorkee. For source parameter studies the data from Roorkee, Panipat and Baghpat stations have been used as the body waves were distinctly recorded on these stations. Delhi being much more distant from the epicentre, could not record body waves.

The hypocentral parameters of the Chamoli earthquake as provided by the India Meteorological Department (IMD) are: Date: 29th March 1999; origin time: 00:35:13.4 (IST); epicentre: 30.41°N; 79.42°E; depth: 21km and magnitude: ML 6.8 (IMD, 2000).

The source parameters were estimated by taking the fourier spectra of the pure S-phase displacement



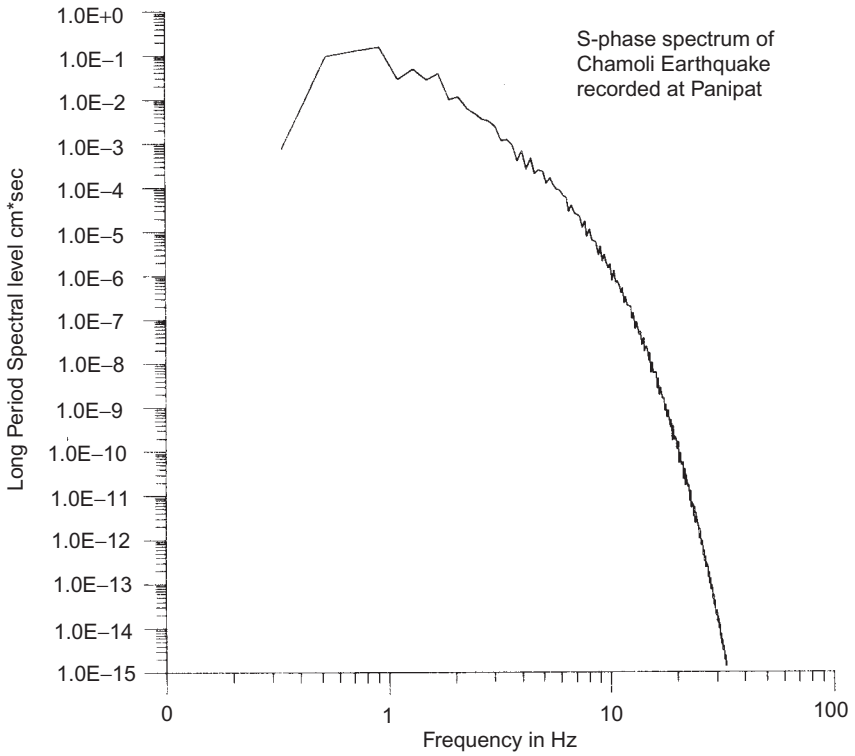


Figure 2 (b). Fourier spectra of the S-phase data at Panipat station for the Chamoli earthquake.

data (figure 2 a,b,c) using the standard fourier transformation programs. For this purpose the recorded acceleration data were integrated twice after applying the instrumental and baseline corrections. Before the marking of corner frequency and long period spectral level, the attenuation correction was applied assuming the well accepted 'Q' value of 300 for the Himalayan region as suggested by Sharma and Wason (1994). The variables like long period spectral level (Ω_o), corner frequency (f_c) were estimated and used to compute seismic moment (M_o), circular source radius (r) and stress drop ($\Delta\sigma$) using following relations

$$M_o = \{4\Pi\rho R(V_s)^3\Omega_o\}/R_{\theta\Phi},$$
$$r = 2.34V_s/2\Pi f_c,$$

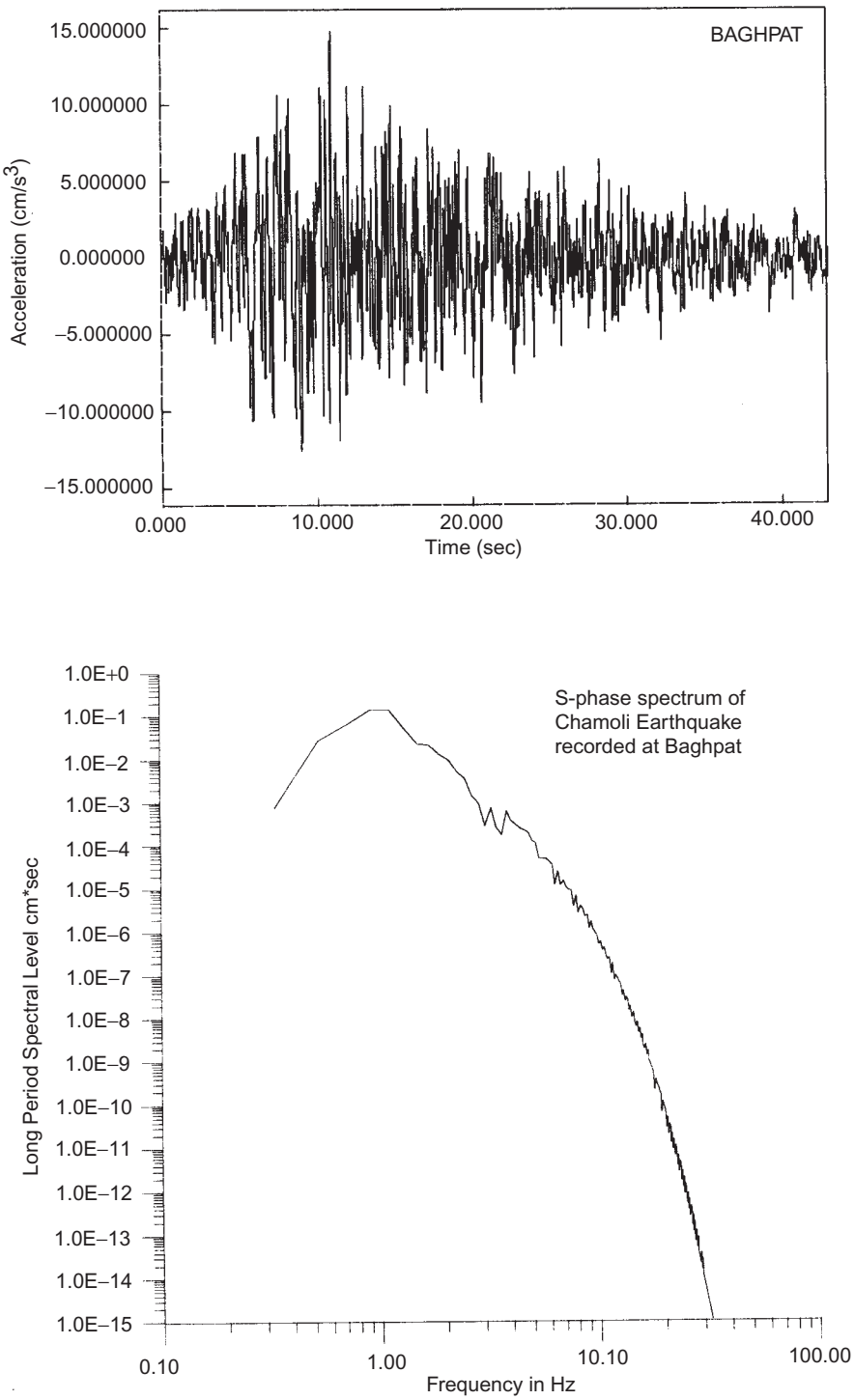


Figure 2 (c). Fourier spectra of the S-phase data at Baghpat station for the Chamoli earthquake.

where M_o represents the seismic moment in dyne.cm which is the measure of size of an earthquake source and R is the epicentral distance in cm. $R_{\theta\Phi}$ has been calculated for this event and the values come out to be 0.14. ρ is the density at the source in gm/cm^3 (Brune 1970). Quantities r and V_s denote the radius of the circular model in km and transverse wave velocity in km/sec respectively. Values of V_s and ρ are taken to be 4.77 km/sec (Wason *et al* 1999) and 2.7 gm/cm^3 respectively in the present calculation of source parameters of 1999 Chamoli earthquake.

The stress drop in bars for the circular source model can be estimated with the help of the equation developed by Brune (1970);

$$\Delta\sigma = 7M_o/16r^{3*}10^{-6}.$$

Table 1. *Results of source parameter studies.*

Station	Corner frequency (f_c)	Long period spectral level (Ω_o)	M_o in dyne.cm	Source radius (r) in km.	$\Delta\sigma$ in bars	Moment magnitude (M_w)
Roorkee	0.6	0.3	12.40×10^{25}	2.96	2091	6.69
Panipat	0.8	0.1	6.94×10^{25}	2.22	2775	6.53
Baghpat	0.9	0.1	7.07×10^{25}	1.98	3984	6.53

The moment magnitude (M_w) can be estimated using the following formula:

$$M_w = 2/3 \log 10(M_o) - 10.71$$

where M_o is seismic moment.

3. Results and discussion

The estimated seismic moment (M_o) for the Chamoli earthquake using strong motion data comes out to be in the range 6.94×10^{25} to 12.4×10^{25} dyne.cm. The circular source radius (r) using Brune's formula is in the range 1.98 to 2.96 km. The stress drops for this event varies from 2091 to 3984 bars. The details of the results are shown in table 1.

The peak ground accelerations recorded by DSMA network are shown in table 2. However, maximum peak ground acceleration of 352.83 cm/sec*sec was recorded for this event at Gopeshwar, which is located nearest to the epicentre (IMD, 2000). The peak ground acceleration value gradually decreased up to 11 cm/sec*sec at Delhi, which is about 300 km from the epicentre.

Table 2. *Peak ground acceleration values.*

Sl. No	Station	Peak ground acceleration (cm/sec*sec)
1.	CSIR HQ, Rafi Marg New Delhi	10.65
2.	CPCB, East Arjun Nagar New Delhi	15.00
3.	IHC, Lodi Road New Delhi	11.47
4.	Roorkee	46.63
5.	Baghpat	14.72
6.	Panipat	43.65

For a better understanding of the Chamoli earthquake, accelerograms recorded on near source strong motion stations, in addition with DSMA data, were also studied and logical ground motion attenuation pattern was found when compared. The values of peak ground acceleration went on decreasing with distance – its value was 352.83 cm/sec*sec at Gopeshwar, 46.63 cm/sec*sec at a distance of 160 km in Roorkee and went down up to 11 cm/sec*sec in Delhi.

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