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RESEARCH ARTICLE

Source Parameters of Local Earthquakes in Nubra Region, NW Himalaya

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Abstract

The digital time histories of local earthquake data recorded during January 2010 to February 2011 by a local network of broad band seismographs in Nubra Valley region has been used to estimate the earthquake source parameters. The source parameters viz., seismic moment, source radius and stress drop of these events have been estimated following Brune's earthquake source model (1970). The low frequency spectral level and corner frequency has been estimated from the displacement spectra and has been used to estimate the source parameters. The seismic moment ranges between 2.1 x 10^{20} to 3.34 x 10^{23} dyne-cm for seismic events with magnitudes ranges between 2.7 to 5.0. The circular source radius (r) calculated using Brune's formula lies in the range 693.2 m to 1.296 km. The estimated stress drops ranges between 0.1 to 61.7 bars and found in agreement with the other region of Himalaya. The stress drop shows increasing trend with seismic moment for magnitudes less than 3.8 and becomes constant for higher magnitude events, this observation has been reported in various studies,

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 also experienced a large number of small magnitude earthquake (Magnitude<3.0).

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, corner frequency and source radius. 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. In Himalayan region various researchers (e.g., Singh et al., 1979; Sharma and Wason, 1994, 1995; Kumar et al., 2006; 2012; 2013a, b, c; 2014a, c; Paidi et al., 2013) have calculated source parameters for Himalayan and nearby regions. To the best of authors' knowledge, the source parameter studies using broadband data have not been carried out in Nubra Region, India so far. Because climatic conditions in this region is too harsh for operating and regular monitoring of seismic instruments, so this study will be first of its kind. In context with above reference the source parameters are calculated for local earthquake events in Nubra region, NW Himalaya using broad band data for the period January 2010 to February 2011. The source model relates the corner frequency and low frequency asymptote to source dimension, seismic moment and stress drop. In several studies stress drops and other source parameters have been computed on the basis of this model (Tucker and Brune, 1977; Fletcher, 1980; Hanks and Boore 1984; O'Neill, 1984; Andrews, 1986; Sharma and Wason, 1994; Bansal, 1998).

Nubra region is located in the eastern Karakorum region of northern Ladakh (fig.1). This region is higly glacierized containing more than 33 valley glaciers. NW-SE trending Siachen Glacier (second longest glacier outside the Polar Regions), is the major glacier system in the region, it lies in the Ladakh district of the state of Jammu and Kashmir. It originates from a cirque at the base of the ridge called "Indira Col" at an altitude of 6115 m and then follows a well defined, WNW-ESW trending valley. The snout is located at an altitude of 3570 m. The melting water of the glacier are the main source of the Nubra River, which drains into the Shyok River. The Shyok river is a major river system in the area, located in a typical U shaped glacier valley between Saltoro hills to the west and Karakoram Range to the east.

This region falls in the seismic **zone IV** (PGA 0.24g) of the seismic map of India (GSI, 2000). The major tectonic features of the region are Main Karakorum Thrust (MKT), Shyok Suture Zone (SSZ), Karakorum Shear Zone (KSZ), etc. Moreover this region is tectonically highly disturbed (Rai, 1983.) This region is almost virgin as far as seismological observations is concerned due to the harsh climatic conditions and remoteness of the area, the regular monitoring and operating a seismic network is a typical task. However four broadband seismometers has been installed during 2009 in this region (fig 2b). This region did not experience any major earthquake till date (as per the literature/record available). However the frequency of micro & small earthquakes is high in this region.

SEISMOTECTONICS OF THE STUDY REGION:

The collision between the Eurasian plate and the Indian plate started about 55 Ma ago [e.g., Yin and Harrison, 2000], and is still continuing at the present time [e.g., Wang et al., 2001]. This successive collision forms the Himalaya and the Earth's largest and highest plateau with anomalously thick crust. Different models have been proposed by various research workers to explain the origin of the Himalaya (e.g. Gansser, 1966; Valdiya, 1980; Seeber and Armbruster, 1981). The collision has also resulted into large scale thrusting and the same is progressed southward forming the Main Central Thrust (MCT) and Main Boundary Thrust (MBT). The Indus-Tsangpo Suture (ITSZ) located about 250 km. North of MCT marks the pre-collision boundary along which the Indian plate subducted below the Eurasian plate and the subduction ended in Eocene times (Gansser, 1964, 1980). Along the MCT, the Higher Himalaya overthrusted the Lesser Himalaya and along MBT, the Lesser Himalaya thrusted over the Siwaliks.

Tectonically Nubra region is highly disturbed (Rai, 1983).The major tectonic feature of the region are Karakoram fault, Altagh fault, Karakoram shear zone, Shyok Suture zone, Khalsar thrust, etc (fig 2a). The Karakoram fault separates rocks of the Karakoram and Ladakh terranes. The Karakoram fault is a major NW-SE-aligned dextral strike-slip fault and it merges with the Indus-Tsangpo suture zone (which is the zone of collision between Indian and Asian plates). The Karakorum Range lies on the western end of the Tibetan Plateau, between the Kunlun Mountains on the north and the Himalayas on the south. It is 3 km wide zone which separates the Indian Himalaya and Ladakh batholiths from the Qiangtang terranes of Tibet to the north. Karakoram Shear Zone (KSZ) is intensely mylonitized granite gneiss, volcanic, conglomerate, slate- phyllite-limestone intercalations, amphibolites and serpentinite intervene the Shyok Suture Zone and the frontal Asian Plate margin along the Nubra –Shyok Valleys for nearly 200 km to form the 1-5 km wide KSZ.

The local residing in this region experience huge shaking many times (pers communication). The frequency of micro and small earthquake is very high in this region. The available digital earthquake time histories recorded in this region have been utilized to estimate the earthquake source parameters of this region.

DATASET & METHODOLOGY

The data set used in the present study consists of the time series waveform data recorded during the period Jan. 2010 – Feb 2011 by network of broadband seismographs installed in Nubra valley, NW Himalaya. The instrument records the data in continuous mode at 100 samples per seconds. Each station is equipped with a 3-component Trillium 120P Broadband sensor, a Taurus 24-bit digitizer and a synchronized GPS clock. The frequency response of the sensor used is 120 sec to 145 Hz. The local events (Table 1) used in this study are segregated from the catalogue of earthquake events. The moment magnitudes of the events lie between 2.7 to 5.0. The earthquake event recorded on 28 Oct 2010 at three field seismic stations, stn1, stn2, stn3, shown below in time series (fig. 3) and displacement spectra of P-phase in fig. (4).

Source parameters viz., seismic moment, source radius and stress drop of 17 local events recorded during the period Jan. 2010 to Feb. 2011 have been estimated by analyzing the P-wave spectra of the events. A total data window length of 800 sec and 4 sec for P-phase is used for all events. This length is sufficient to resolve corner frequency above 0.92 Hz. The Fast Fourier Transform (FFT) algorithm of Cooley and Turkey (1965) is applied to compute the signal spectrum (See in Fig 4. at different stations).

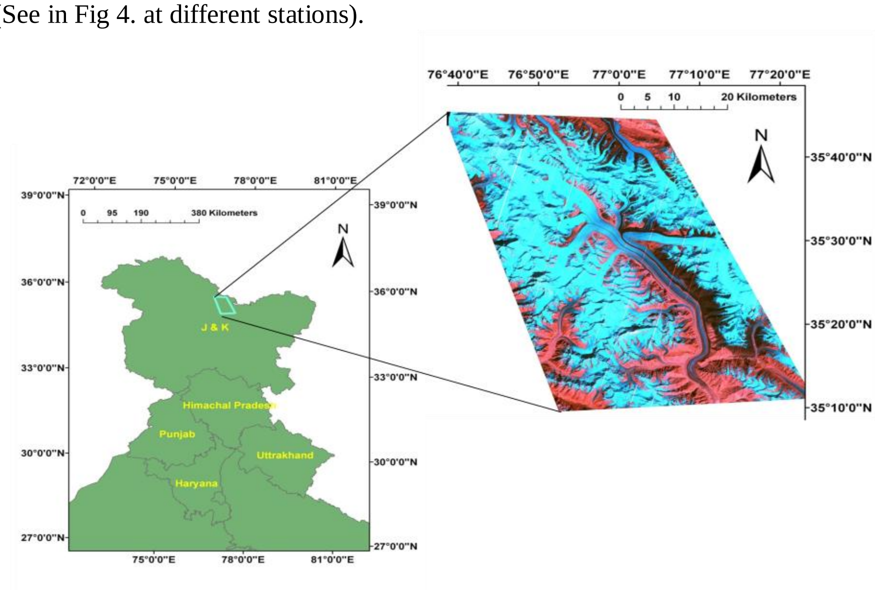

Figure 1: Geographical position of Study area

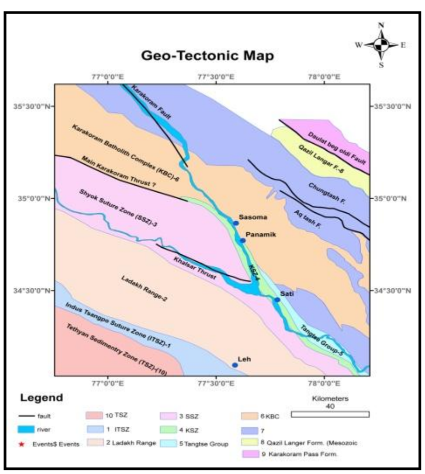

Figure. 2(a): Geological and Tectonic Map of study area

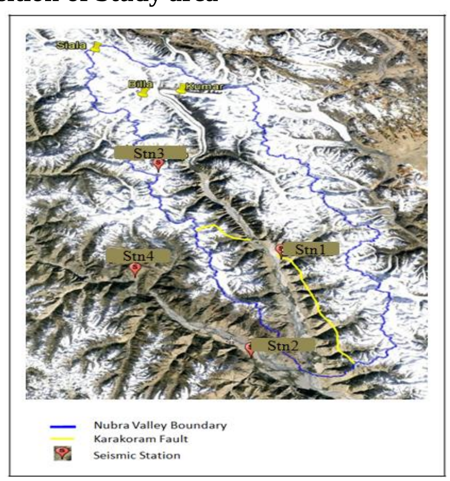

Figure 2(b): Locations of seismic observatories

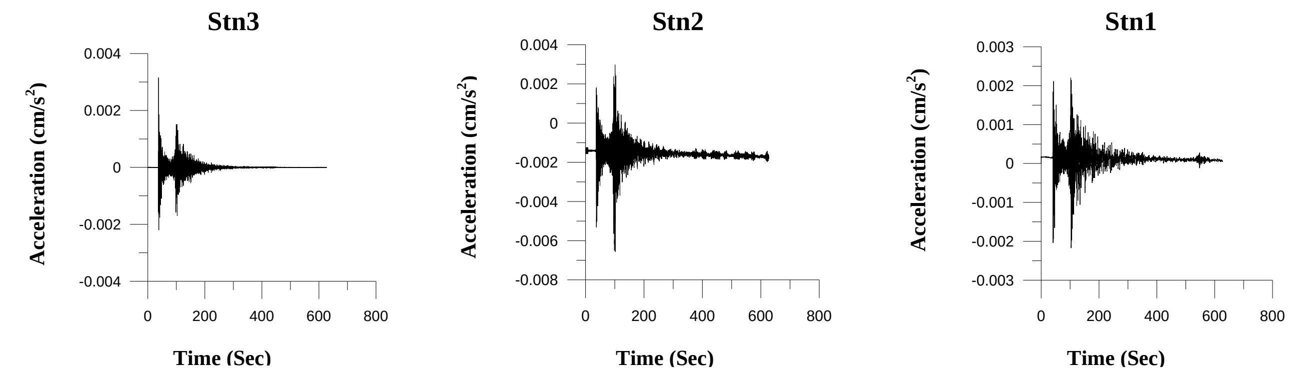

Figure 3: An example of earthquake time series recorded on three seismic stations.

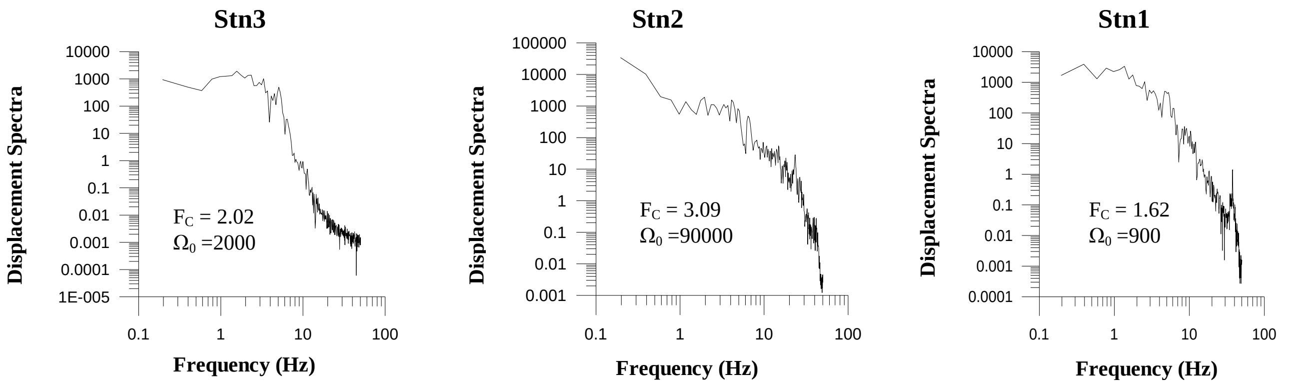

Figure 4:. Displacement spectra of P-phase of above time series data.

The long period spectral level (Ω_0), corner frequency (fc) were estimated from spectral analysis of the recorded digital waveforms and used to compute seismic moment (Mo), circular source radius (r) using following relations:

$$M_0 = (4\pi\rho V^3 / FR_{\theta\Phi})\ \Omega_0 \qquad (1)$$

$$r = 2.34V/2\pi f_c \qquad (2)$$

Where ρ is average density (= 2.67 g/cm^3), V is the P-wave velocity in the source zone (= 6.0 km/s), F is the free surface effect (= 2), $R_{\theta\Phi}$ is average radiation pattern (= 0.63), Ω_0 is long period spectral level.

Further the values of seismic moment and source radius are used to calculate stress drop (Δσ) and moment magnitude (M_W) using the following relations-

$$\Delta\sigma = 7M_0/16r^3 \qquad (3)$$

$$M_W = \log (M_0)/1.5 - 10.7 \qquad (4)$$

RESULTS AND DISCUSSIONS:

The source parameters viz., seismic moment, source radius and stress drop of local events have computed using Brune's source model (1970) by estimating the corner frequency and low frequency spectral level using displacement spectra (Table 1). The seismic moment ranges between 2.1 x 10^{20} to 3.34 x 10^{23} dyne-cm for seismic events with magnitudes ranges between 2.7 to 5.0. The circular source radius (r) calculated using Brune's formula lies in the range 693.2 m to 1.296 km.

Table 1: The hypocenter and source parameters of the earthquakes studied.

S. No.	Date	Time	Lat. (° North)	Long. (° East)	Depth (Km)	f_C (Hz)	R (m)	Seismic Moment (M_0) Dyne-cm	Stress Drop ($\Delta\sigma$) (bars)	M_W
1	30-05-2010	04:22	35.769	77.321	4.5	1.48	805.6	1.14E+21	1.0	2.8
2	07-12-2010	13:32	35.102	76.793	9.5	2.0	596.2	1.45E+22	29.9	2.7
3	15-07-2010	15:35	35.749	70.561	10.0	0.92	1296.0	3.34E+23	67.1	3.6
4	24-08-2010	08:34	36.49	71.282	6.3	1.75	681.3	5.88E+21	8.1	3.5
5	19-09-2010	04:12	36.931	71.478	0.1	1.35	883.2	4.52E+22	28.7	3.3
6	21-10-2010	08:05	32.841	72.978	10.0	1.35	883.2	2.10E+20	0.1	3.6
7	25-10-2010	04:33	37.645	73.746	10.0	1.05	1135.6	2.51E+21	0.7	3.3
8	28-10-2010	15:46	31.067	75.587	10.0	2.24	532.3	1.03E+22	29.9	3.3
9	11-09-2010	21:19	35.732	70.746	10.0	1.47	811.1	2.18E+21	1.8	3.3
10	14-11-2010	02:27	35.699	75.761	11.6	1.55	769.3	1.18E+21	1.1	3.7
11	22-11-2010	22:02	36.027	76.357	5.5	1.72	693.2	1.11E+20	0.1	3.5
12	25-11-2010	09:27	37.908	72.541	10.0	1.85	644.5	6.25E+21	10.2	3.8
13	12-02-2010	20:13	35.249	74.246	10.0	1.62	736.0	1.12E+21	1.2	3.8
14	12-03-2010	18:00	34.023	76.802	2.0	1.72	693.2	1.11E+21	1.5	4.4
15	12-07-2010	19:21	36.283	71.647	7.3	1.23	969.4	1.70E+21	0.8	4.0
16	19-12-2010	07:22	35.109	70.692	10.0	1.15	1036.8	3.93E+21	1.5	4.1
17	02-07-2011	16:22	36.671	71.236	10.0	1.17	1019.1	2.40E+21	1.0	5.0

The plot in Figure 5 shows the variation of estimated source radii of earthquakes with seismic moment has random nature, which infers that source dimension is independent to earthquake size in terms of seismic moment for this magnitude range.

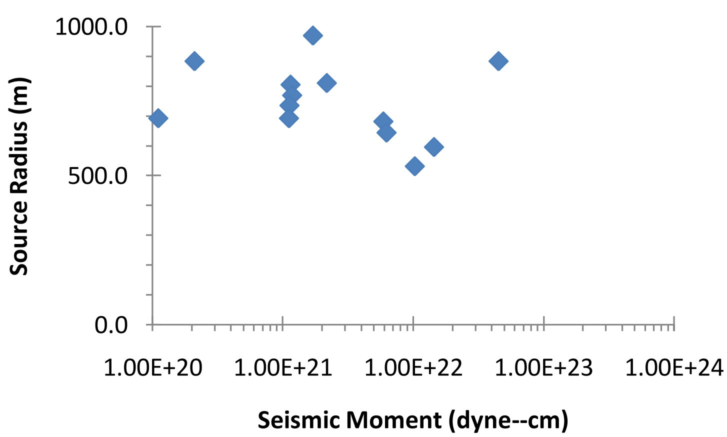

Figure 5: Plot of seismic moment vs source radius of earthquakes studied.

The stress drops of these earthquakes ranges between 0.1 to 61.7 bars and found in agreement with the other region of Himalaya. The average stress observed for Himalayan earthquakes is about 60 bars. The stress drop shows increasing trend with seismic moment for magnitudes less than 3.8 and becomes constant for higher magnitude events (Figure 6), this observation has been reported in various studies (e.g., Sharma and Wason, 1994, 1995; Kumar et.al., 2006; 2012; 2013a, c; 2014a, b, c; Paidi et al., 2013).

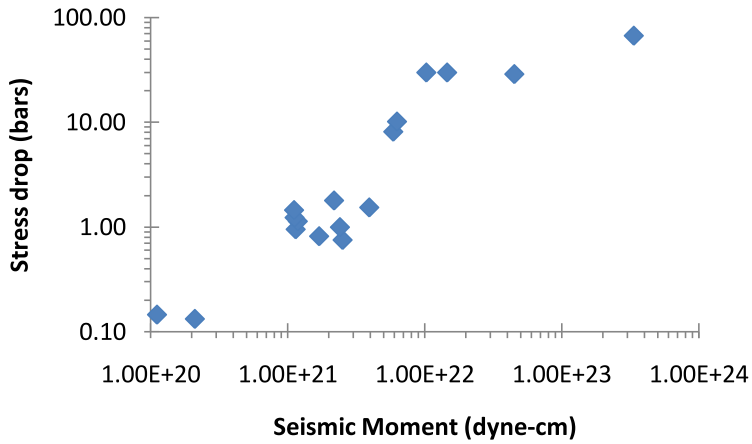

Figure 6: Plot of seismic moment vs stress drop.

CONCLUSIONS

The 17 local events studied have seismic moments between 2.1 x 10^{20} dyne-cm to 3.34 x 10^{23} dyne-cm and their moment magnitude ranges between 2.7 to 5.0. The source dimension in terms of the radius of circular fault varies from 693.2 m to 1.296 km. The stress drops of these earthquakes ranges between 0.1 to 61.7 bars and found in agreement with the other regions of Himalaya. The average stress drop observed for Himalayan earthquakes is about 58 bars by Kumar et al., 2008 and about 60 bars as reported by Kumar, 2011. For better understanding of the source parameters of local earthquakes more data will be useful from this region. However, these initial results show promise for spectral characterization of micro seismic events.

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