CHAPTER 3

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INSTRUMENTATION AND SEISMOLOGICAL NETWORK

3.1 INTRODUCTION

Time domain record of the earth's vibration is necessary for the quantitative analysis of seismic waves for investigating the subsurface structure beneath the earth. The developments in seismology started since ~1900 which were possible after the advent of instrumentation with precise timing systems. The recent advancement of digital seismic instrumentation made it feasible to detect the transient earth's vibrations continuously with a high sensitive detection capability and absolute timing. The instrumentation that records ground motions with respect to time is known as a seismograph, while the time history of the ground vibration recorded by it, is known as a seismogram. A seismograph has four components e.g. seismometer or sensor, data acquisition system or data logger, timing system and power supply unit.

The basic seismological instrument such as seismoscope that provides only the occurrence and direction of an earthquake existed in China as early as 132 AD. Subsequently, various different types of seismographs were invented by different workers (Ewing, 1884; Von Rebeur-Paschwuz, 1889; Galitzin, 1914; de Quervain & Piccard, 1924, 1927; Anderson & Wood, 1925; Berlage Jr, 1932; LaCoste, 1934; Benioff & Press, 1958; Dewey & Byerly, 1969). In earlier days, seismographs were of analogue type where seismograms were recorded on papers. In the 20th century, a mechanical seismograph known as Wood Anderson seismograph (Anderson & Wood, 1925) was designed using suspension torsion with taut wire as a small mass to photographically record the ground motion of earthquake's vibrations. This seismograph was used as a standard to define local Richter magnitude of an earthquake (Richter, 1958).

There were enormous developments in seismic instrumentation during the later half of the twentieth century that enables generation of high-quality data for unraveling subsurface structure and also for understanding geodynamic processes of a seismically active region. The analog seismographs were replaced by the digital instrumentation. The modern seismograph has high dynamic range with advanced force feedback systems (Wielandt & Streckeisen, 1982; Wielandt & Steim, 1986; Iwan et al., 1985). The recent 24-bit digital data acquisition system has the capability to record the ground motions from very small magnitude earthquakes to large magnitude earthquakes without saturation.

Considering the high seismic activity and for interpreting subsurface structure in the Himalaya, Wadia Institute of Himalayan Geology (WIHG), Dehradun has established a number of seismological stations in different parts of the Himalaya. Along the Satluj River valley, 18 digital Broadband seismological stations were installed in 2008 and 2013 to record local, regional and teleseismic earthquakes.

3.2 SEISMOGRAPH

A seismograph or a seismological station comprises a sensor or seismometer that senses ground vibrations and a data acquisition system (DAS) that converts the analog signal to digital format and stores the digital data in a storage device built inside the DAS. The DAS is attached to an external Global Positioning System receiver for synchronizing time and also to obtain accurate location and altitude of the seismograph station. The continuous power supply is a primary requirement of a remote seismograph station which can either be electrical connections or by solar panels. Solar panels are used for charging batteries attached to the power supply unit. The various components of a seismograph station are shown in Figure 3.1 and are described below:

(a) Seismometer (b) Digitizer (c) GPS

(d) Solar Panel (e) Battery

Figure 3.1 Components of a seismograph system (a) seismometer (b) DAS (c) Global Positioning System (GPS), power supply unit comprising (d) solar panel and (e) battery.

3.2.1 SEISMOMETER

The seismometer is a sensor which detects the ground motion and converts it into an electrical signal. It works on the simple principle of inertia of a suspended body that continues to be static in the response toany external ground motion. The relative ground motion detected by a seismometer is recorded in the three orthogonal directions. It recorded in two horizontal and one vertical direction, viz. east-west (E-W), north-south (N-S) and vertical (Z). Based on natural period, seismometers are classified as short-period seismometer (0.1 to 1 s), long-period seismometer (0.01to 0.1 s) and broadband seismometer (0.02 to 1000 s). In the present study, Trillium-240 broadband seismometers (Make M/s Nanometrics, Canada) are used at each station. These seismometers that can record a wide band of frequencies

~0.003-50 Hz at 100 SPS and allow recording of local, regional and teleseismic earthquakes. The frequency response curve of the Trillium 240 seismometer is shown in Figure 3.2.

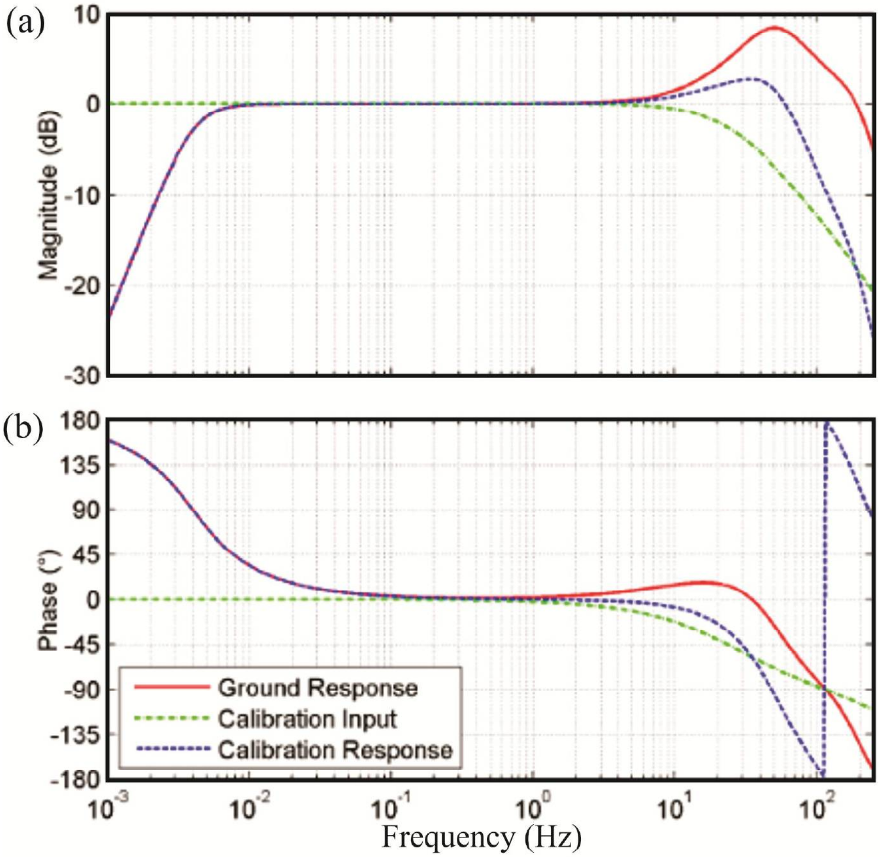

Figure 3.2 Frequency response curves (a) amplitude and (b) phase for Trillium-240 seismometer where the nominal ground motion frequency response of the seismometer is shown by a solid red line and the calibration input circuit response and the sensor calibration response are shown by dashed green and blue line, respectively.

The symmetric triaxial arrangement of the sensing elements ensures uniformity between vertical and horizontal outputs. The Trillium 240 seismometer has the ability of automatic mass centering that enables both local and remote mass centering. The characteristics of seismic wave motion obtained from a seismometer are defined by its response parameters namely;

(1) Poles, (2) Zeros, (3) Normalization frequency, (4) Normalization factor and (5) Ground motion sensitivity and are listed in Table 3.1.

Table 3-1 Ground motion response nominal parameters.

Sl.No	Parameter of seismic wave motion	Values
1	Poles	$-0.0183 \pm 0.01803i$, -124.9, $-197.5 \pm 256.1i$, $-569 \pm 1150i$
2	Zeros	0, 0, -90.0, -164.2, -3203
3	Normalization Frequency	1
4	Normalization factor	4.532×10^5
5.	Ground motion sensitivity at f_0	1196.6

3.2.2 DATA ACQUISITION SYSTEM

Data Acquisition System (DAS) converts analog signal obtained from the seismometer to digital format and store it in a storage device built inside the DAS. Nanometrics Taurus DAS is used at each station for recording the earth's vibrations. It is a portable device having a 24-bit digitizer for 3-channel (E-W, N-S, and Z) and counts values ranging from – 8388608 (-2^{23}) to 8388608 (2^{23}) and provides a dynamic range of 138 dB. A higher dynamic range of the digitizer helps to record the ground motion from very small to large magnitude earthquakes. It consumes minimum ~750 mW power. The system is operated by Linux operating system having a web browser user interface. It displays the output in various formats like mini SEED, ASCII, and SEISAN. The sampling rate of a recorded data stream can be fixed at 10, 20, 40, 50, 80, 100, 120, 200, 250, 500 SPS. It has two removable media: compact flash (4 GB) and IDE disk drive (40 GB). The operating temperature range of Taurus DAS is from -20^{o} to 60^{o} C with a compact flash card and from 5^{o} to 55^{o} C with IDE hard disk. The sensor configuration e.g. mass lock/unlock, mass center and calibration can be done through the Taurus DAS.

3.2.3 GLOBAL POSITIONING SYSTEM

Global Positioning System (GPS) is a major component of a device which provides the accurate time and position of a location using satellite signals. The Taurus DAS has an internal voltage controlled crystal oscillator clock (VCXO) having an accuracy of < 100 μs. The GPS receivers are connected to the internal clock for time synchronization and are usually installed in the open sky to receive the transmitted signals from satellites. It performs the time synchronization and notifies the correct time and location to the DAS.

3.2.4 POWER SUPPLY UNIT

Power supply unit is an essential unit of a seismological station. External DC sources such as batteries are used in most of the seismological stations for uninterrupted power service. In a case of remote site locations, solar panels are used to charge the batteries. For one battery of 12 volts, one solar panel of 75 Watt is used for charging. The power consumption of 12 volts is 1.4 to 2.0 Watt.

3.3 INSTALLATION OF SEISMOGRAPH

3.3.1 SITE SELECTION AND NOISE SURVEY

All the seismic stations were established on solid basement rock rather than soft sediment to have low noise level. In case, to get such ideal site, special care was taken for construction of a seismic pier. Following sequence of steps are followed for site selection.

1. A Geological survey was carried out for selecting the locations of seismic stations and locations having their loose soil were avoided and hard rock topography was preferred.
2. Topographical features like extremely deep and steep slope valleys were avoided as it can affect the recording of the seismic event and its amplitude.
3. Sites having high cultural noise such as from construction sites, industrial and agricultural sites, railway track, traffics and natural environmental noise sources like near lake, river was avoided.
4. Stability of the station and ease of servicing of the instruments were also considered while selecting the site.
5. Sites having exposure to sunlight with an open sky were chosen as it helps in charging batteries through solar panels. The GPS antenna also required an open sky to receive signals from the satellites.

For noise survey usually 24 hours' data is collected from each selected sites. The Power spectral density (PSD) function is calculated for each hour. The PSD obtained for each hour is compared with the ideal seismic noise spectral density functions viz. New low noise model (NLNM) and new high noise model (NHNM) developed by Peterson, (1993). The sites where the observed PSD plots of background noise fallwithin the NLNM and NHNM are finally selected for installation of seismological equipment. The efficiency of seismological sites is tested following the same way at all sites. The example of PSD plot of one-hour background noise data recorded at one of the selected siteshas been shown in Figure 3.3. The obtained band of PSD of recording site falls nearly within the curves of standard low and high noise models, which indicates that the selected site is considered to be efficient for the installation of seismometers. The validation of the ambient noise levels at selected site enhances the performance of installed seismological station. A proper evaluation of noise survey for selecting a site increases the quality of recorded seismograms.

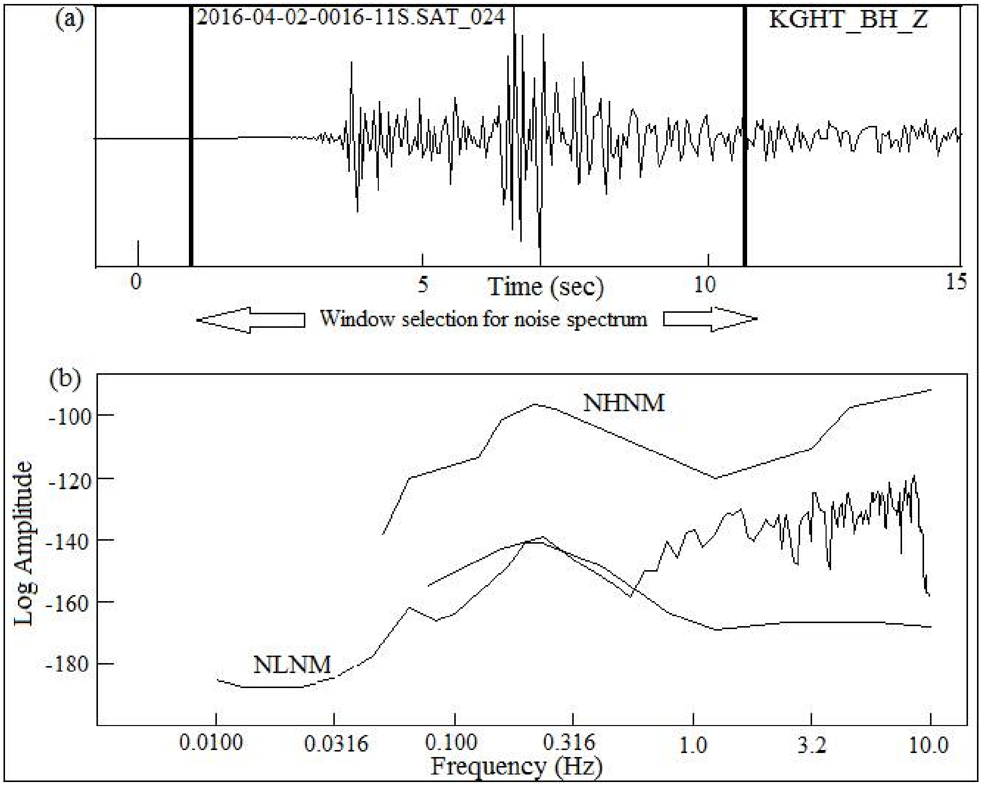

Figure 3.3 (a) Vertical component seismogram recorded at KGHT station and (b) corresponding noise spectrum observed at recording site.

3.3.2 INSTALLATION OF SEISMOMETER

For installation of a seismometer, the seismic vault is constructed to maintain the temperature and reduce the possibility of tilting due to rainfall and wind effects at the site. In case the selected site is on the solid hard rock, the seismic vault is made over the rock surface. For sites, where exposed hard rocks are not observed on the surface, a pit of ~80 x 80cm is dug till the hard rock basement is found to construct the seismic vault. A smooth concrete mounting surface is prepared to place the sensor at that depth. The seismic vault is covered by a hut. The DAS and power supply unit are kept away from the sensor. The GPS antenna and solar panels are placed at the top of the hut (Fig. 3.4).

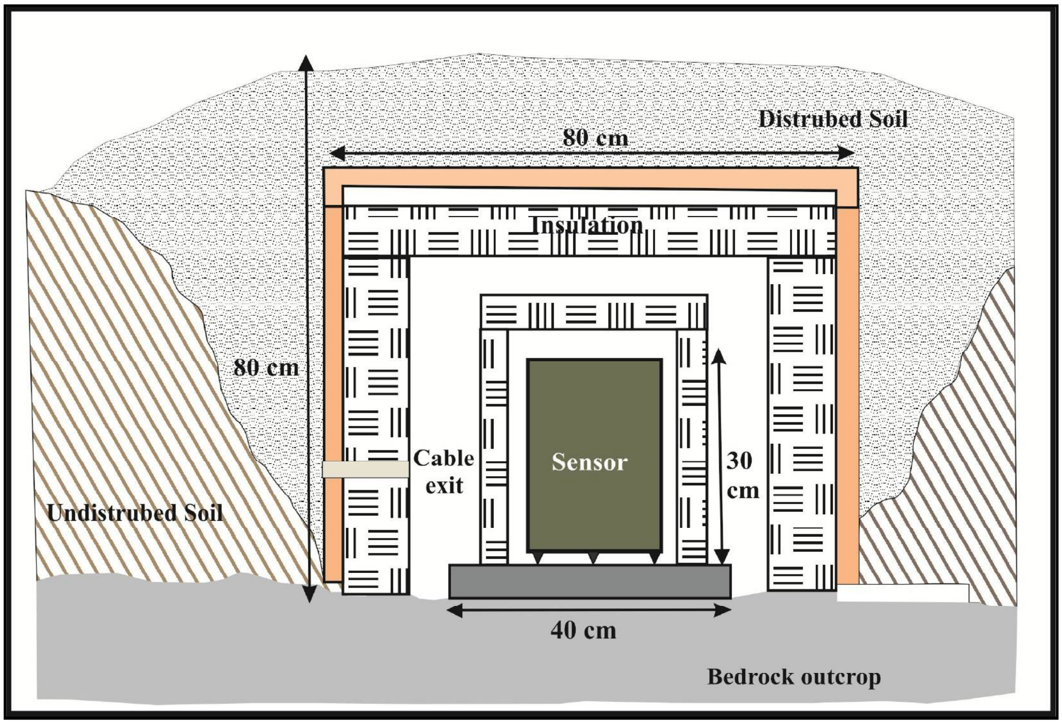

Figure 3.4 Cartoon showing seismological Pit and Hut construction at seismological site.

Following steps are followed for the installation of a sensor inside a seismic vault.

1. A North-South (N-S) line is drawn on the mounting surface.
2. The sensor is placed over the N-S aligned line to align the brass and steel pointers with the marked directions while the brass pointer faces the north. This is done by rotating the base of the sensor while observing it from the above.
3. The leveling of the sensor is done using each of the adjustable feet of the sensor so that the bubble in the spirit level came entirely within the inner circle. The height of feet is adjusted by turning the brass locking.
4. The sensor cable is linked to the sensor and the DAS followed by connecting the power supply unit with the digitizer.
5. The GPS antenna is mounted on the roof and connected it with DAS. Following the similar way, all the equipments are installed at different locations and thus a seismic station network has been developed. The field setup of a campaign mode seismological station is shown in Figure 3.5.

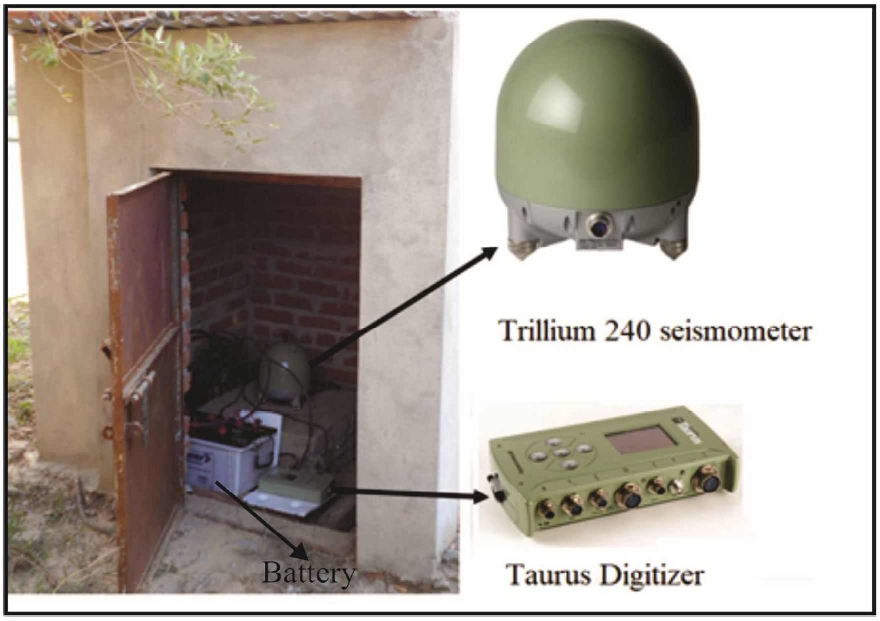

Figure 3.5 Field setup of a campaign mode seismological station equipped with Trillum 240 seismometer, Taurus digitizer and battery.

3.4 SEISMIC NETWORK ALONG THE SATLUJ VALLEY

Total 18 BBS stations were established along the Satluj valley region starting from the Indo-Gangetic Plain to the Tethyan Himalaya. Each of these stations is equipped with the same instrumentation as described earlier. All these stations are campaign mode and standalone stations. Establishment of these stations is done in two phases. Initially, nine stations were installed in the Kinnaur region, Himachal Pradesh for the period of two years (2008-2010), named hereafter as Upper Satluj valley (USAT) network. Another nine stations were established in the lower part of Satluj valley for the duration of two years (2013-2015), named as Lower Satluj valley (LSAT) network. The stations of LSAT and USAT networks are shown in Figure 3.6. The details of these networks are described below.

3.4.1 LOWER SATLUJ VALLEY NETWORK

The LSAT network consists of nine BBS stations, namely Bhagpur, Ramgarh, Chicken, Garkal, Kandaghat, Sadhora, Digadhar, Rampur and Tapri, installed in 2013 and shown by red triangles in Figure 3.6. The average station spacing in between the stations is ~18 km. The seismological stations recorded data in continuous mode at a sampling rate of 20 SPS. The Bhagpur (BHAG) and Ramgarh (RMGR) stations were located on the alluvium of the Indo-Gangetic Plain (IGP). The Chicken (CKKN) and Garkal (GARH) stations lie over the sandstone and conglomerate rock formations of the Siwalik Group of rocks. Kandaghat (KGHT), Sadhora (SADH) and Digadhar (DIGA) stations lie over the Lesser Himalayan Sequence. Rampur (RMPR) station lies over the LHCS of the LKRW and Tapri (TAPR) station are located over the HHCS close to the MCT/VT. The BHAG, RMGR, and CKKN stations were under operation during the year 2014-2015 and recorded about 150 teleseismic earthquakes. The rest of the stations of the LSAT network (GARH, KGHT, SADH, DIGA, RMPR, and TAPR) recorded 300 teleseismic earthquakes during June 2013 - May 2015.

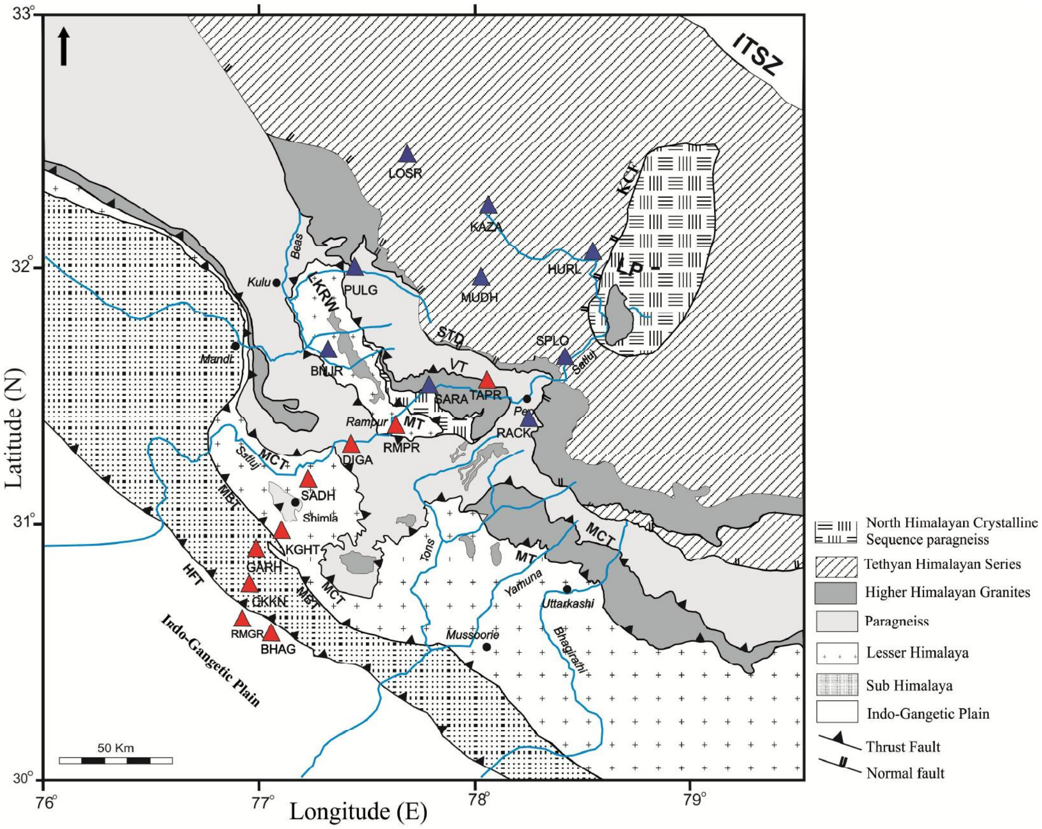

Figure 3.6 Location of BBS stations of both LSAT and USAT networks are shown by red and blue triangles.

3.4.2 UPPER SATLUJ VALLEY NETWORK

The Upper Satluj valley also comprised of nine stations e.g. Banjar, Sarahan, Pulga, Mudh, Spillo, Rackchham, Losser, Kaza and Hurling, installed in 2008 and shown by blue triangles in Figure 3.6. The average station spacing along this profile is ~20 km. The stations of the USAT network recorded data in continuous mode at a sampling rate of 100 SPS. The Banjar (BNJR) station lies over the Lesser Himalayan Sequence, Sarahan (SARA) station lies over the LHCS of the LKRW and Pulga (PULG) is located over the HHCS close to the MCT/VT while Rackchham (RACK) station is located close to the STD. Five stations of the USAT network namely Losser (LOSR), Mudh (MUDH), Kaza (KAZA), Hurling (HURL) and Spillo (SPLO) are located over the Tethyan Himalaya. The stations of the USAT network recorded 200 teleseismic earthquakes during the period from 2008-2010.

Table 3.2 Seismological stations used in this study with corresponding station code, locations and elevations.

Sl. No	Station Name and Station Code	Network name	Lat. (°N)	Long. (°E)	Elevation (m)	Time Period
1	Bhagpur (BHAG)	LSAT	30.546	77.057	303	2014-May 2015
2	Ramgarh (RMGR)	LSAT	30.632	76.887	261	2014-May 2015
3	Chicken (CKKN)	LSAT	30.760	76.943	449	2014-May 2015
4	Garkal (GARH)	LSAT	30.900	76.970	1494	June 2013-May 2015
5	Kandaghat (KGHT)	LSAT	30.970	77.120	1229	June 2013-May 2015
6	Sadhora (SADH)	LSAT	31.159	77.203	2111	June 2013-May 2015
7	Digadhar (DIGA)	LSAT	31.309	77.437	1979	June 2013-May 2015
8	Rampur (RMPR)	LSAT	31.396	77.640	920	June 2013-May 2015
9	Tapri (TAPR)	LSAT	31.520	78.090	1679	June 2013-May 2015
10	Banjar (BNJR)	USAT	31.646	77.347	1369	2008-2010
11	Sarahan (SARA)	USAT	31.529	77.796	1983	2008-2010
12	Pulga	USAT	31.997	77.448	2274	2008-2010

	(PULG)					
13	Mudh (MUDH)	USAT	31.959	78.033	3811	2008-2010
14	Spillo (SPLO)	USAT	31.650	78.441	2390	2008-2010
15	Rackchham (RACK)	USAT	31.393	78.356	3129	2008-2010
16	Losser (LOSR)	USAT	32.446	77.763	4137	2008-2010
17	Kaza (KAZA)	USAT	32.227	78.069	3701	2008-2010
18	Hurling (HURL)	USAT	32.062	78.551	3190	2008-2010