# Digital seismic network: to map Himalayan orogen and seismic hazard

According to the Gutenberg–Richter law[1], at least one earthquake of magnitude greater than 7 occurs every month along the seismically active belts in the world. Earthquakes are the manifestation of fault slip at depths, thus, there is no direct method to measure or observe them. However, seismometers can record ground velocity or acceleration caused by the occurrence of an earthquake when a fault slip occurs at depth. Therefore, setting up a seismic network is inevitable to understand the physics of earthquake processes, thereby, mitigating earthquake hazard.

In continental India, 90% of seismicity is confined to the Himalayan collisional zone. Frequent occurrences of large and damaging earthquakes characterize this region, which is in the zone of convergence of the Indian plate and the Eurasian plate. In the past century, the Himalayan frontal arc experienced at least four $M_w$ 8 or larger earthquakes[2,3]. The largest among them was the 1950 $M_w$ 8.6 Assam earthquake.

Although the entire Himalayan belt is seismically active, based on synthesis of seismicity and palaeoseismic records of earthquakes in the Himalaya, however, it is believed that the region between the 1905 Kangra ($M_w$ 7.8) and 1934 Bihar–Nepal ($M_w$ 8.2) earthquakes could be a potential seismic zone (Figure 1), where future major earthquakes could occur. The last major event that ruptured the mega thrust in this segment was the 2015 Gorkha earthquake ($M_w$ 7.9) affecting northern India and Nepal. GPS measurements along the Himalayan arc gave an estimate of $6.6 \times 10^{19}$ m/yr strain deficit, equivalent of the energy of a great earthquake[4]. According to these estimates, the 2015 Gorkha earthquake and its major aftershock have not released the entire energy of the region[5]. Hence, it is imperative to focus on Northwestern Himalaya by studying the seismogenesis, assess the impact of earthquakes on the population, and create awareness among people to mitigate the seismic risk due to a future major earthquake.

After the occurrence of the recent 25 April 2015 Nepal earthquake of $M_w$ 7.9, CSIR-National Geophysical Research Institute (NGRI), Hyderabad, began setting up a modern seismic network of digital broadband/strong-motion stations to prepare better for expected future large and damaging earthquakes. The network has been designed to provide fast and accurate estimates of hypocentral and source parameters of potentially devastating earthquakes for emergency response applications and also for carrying out comprehensive characterization of Himalayan seismicity, which is necessary for long-term hazard assessment and mitigation activities.

In October 2017, the CSIR-NGRI deployed a semi-permanent seismic network of 76 broadband and 19 strong-motion stations in Uttarakhand district of the Himalayan region (Figure 1). In the near future another 40 strong-motion accelerometers will be added to the present network. As of today, only 15 broadband stations have been linked to the central server of the CSIR-NGRI seismological observatory through the GPRS facility; and in the near future another 40 stations will be linked through the GPRS facility. These will help in near real-time transmission of data, which has so far enabled and will further enable us to locate the earthquakes in near real-time. Out of 95 stations, 4 are equipped with strong-motion velocity meters. The stations are strategically located to maximize the use of data from them (Figure 1) and for locating earthquakes with better accuracies. Each broadband station is equipped with a 24-bit Reftek recorder and a broadband Reftek sensor (natural period of 120 sec). While the strong-motion station is equipped with a 24-bit Basalt (Kinematics) or Titan (Nanometrics) accelerograph system, time tagging is done using a GPS receiver system. At each broadband seismograph site, continuous data are being recorded at 100 samples per second (sps), while the accelerometer data are being recorded at 200 sps in continuous mode. The objective of this

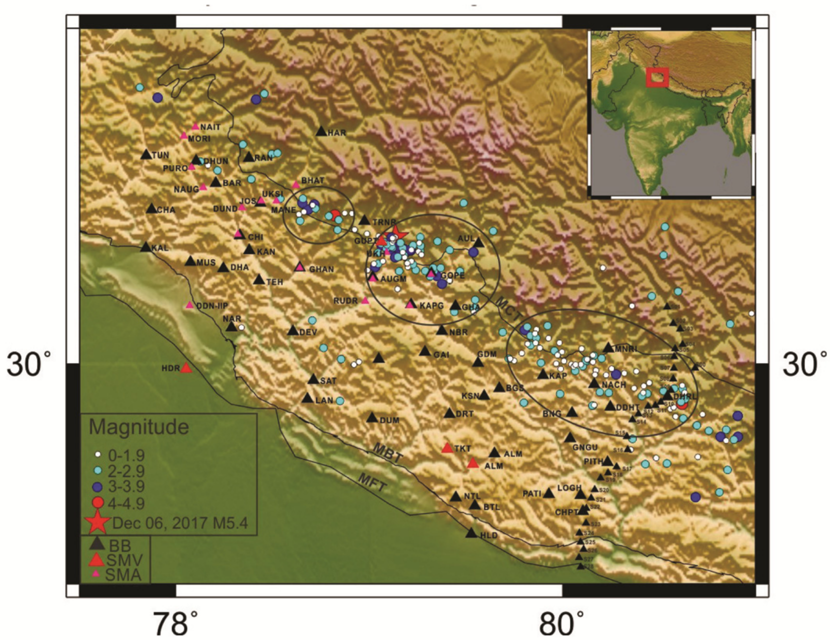


**Figure 1.** Location map of the seismic network deployed in Uttarakhand. Epicentres of earthquakes during February 2017–October 2018 are shown by filled circles. Smaller white filled circles mark events of $M_L$ 0–1.9. Medium-sized, light-blue filled circles represent events with $M_L$ 2–2.9, while medium-sized, dark blue filled circles mark events with $M_L$ 3–3.9. Large red filled circles represent events of $M_L$ 4–4.9. The red filled large star marks the epicentral location of a moderate size earthquake of $M_L$ 5.4, which occurred on 6 December 2017 (15 : 19 : 50.7). $M_L$ marks the Richter's or local magnitude. Filled black triangles mark three-component broadband seismographs, while filled red triangles represent four strong-motion velocity meters and filled pink triangles mark the strong-motion accelerographs. The two black elliptical zones indicate maximum present seismic activity. (Inset) The Indian sub-continent and political boundaries with its neighbouring countries. The red square marks the study area.

study is to assess seismic hazard of this region and will be used for evaluating the safety of bridges, hospitals and water tanks based on the site-specific ground motions. In seismic hazard assessment the inputs to be synthesized are the earthquake source, which includes location, magnitude, nature of faulting and displacement and characteristics of the medium.

This seismic network is being developed to monitor earthquakes in and around the most potential seismic zone in central Himalaya to provide more accurate data for calculating earthquake parameters. Using broadband records, the system will immediately calculate earthquake parameters useful for making decisions that provide highly accurate, timely warnings and information. The digital broadband and strong-motion waveforms are regularly stored in NGRI's databank. With the help of 15 broadband stations, which are connected in real time, this network is designed to provide accurate automatic earthquake locations and magnitudes necessary for impact assessment. Operation of the network also could provide new insights into associated spatio-temporal variations in seismicity, which is necessary for long-term earthquake hazard assessment and mitigation. Besides, offline strong-motion accelerographs are designed to provide support for engineering purposes.

About 200 earthquakes of $M_L$ 1.0–5.4 have been located using data from the above seismic network until October 2018 (Figure 1). The maximum size event of $M_L$ 5.4 occurred on 6 December 2017 (15 : 19 : 50.7). The epicentres of these events define an active seismic zone just south of the Main Central Thrust (MCT). However, some scattered seismic activity is also noticed in the region north of Main Boundary Thrust (MBT) and the region near Dharchula. The hypocentres of these events suggest a shallow-angle, north-dipping fault plane at 10–20 km depth, coinciding with the Main Himalayan Thrust.

The present understanding of the Himalayan earthquakes links them to the ramp structure in the Himalaya, formed by the sudden downward jump of the décollement surface (top of the Indian plate) by about 10–15 km[2]. Thus, data from the above seismic network will be used to map in 3D the crust–mantle structure and geometry of the decollement zone, which has been the locale for nucleation of large-magnitude earthquakes. Such information along with identification of locked zones can possibly provide a clue to the zones of potential major earthquakes. The Himalayan collision zone is a typical example of complex continental deformation at convergent plate boundary leading to long-time development of mountain and short-time release of energy in the form of earthquakes. The 3D map of lithospheric geometry and properties can help in translating the knowledge for understanding the geological evolution of Himalayan orogen.

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ACKNOWLEDGEMENTS. We thank CSIR, New Delhi for funding this study through Mission Mode Project on 'Safety and security of vital installations' and Focused Basic Research Project titled 'Synthesis of earthquake hazard scenario in NW Himalaya by investigating the multi-scale variations in structural and seismotectonic assemblages'.

**D. Srinagesh, Prantik Mandal, R. Vijaya Raghavan, Sandeep Gupta, G. Suresh, D. Srinivas, Satish Saha, M. Sekhar, K. Sivaram, Sudesh Kumar, P. Solomon Raju, A. N. S. Sarma, Y. V. V. S. B. Murthy, N. K. Borah, B. Naresh, B. N. V. Prasad** and **V. M. Tiwari***, CSIR-National Geophysical Research Institute, Hyderabad 500 007, India
*e-mail: director@ngri.res.in