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Sediment thickness beneath the Indo-Gangetic Plain and Siwalik Himalaya inferred from receiver function modelling

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ABSTRACT

The Indo-Gangetic Plain and the adjoining Siwalik Himalaya are the seismically most vulnerable regions due to high density of human population and presence of thick sediments that amplify the seismic waves due to an earthquake in the region. We investigate the sedimentary structure and crustal thickness of the region through joint inversion of the receiver function time series at 14 broadband seismograph locations and the available Rayleigh velocity data for the region. Results show significant variability of sedimentary layer thicknesses from 1.0 to 2.0 km beneath the Delhi region to 2.0–5.0 km beneath the Indo-Gangetic Plain and the Siwalik Himalaya. As we progress from the Delhi to the Indo-Gangetic Plain, we observe a decrease in the shear velocity in sedimentary layer from ~2.0 km/s to ~1.3 km/s while the layer thickness increases progressively from ~1.0 km in south to 2.0–5.0 km in the north. Average *S*-velocity in the sedimentary layer beneath the Siwalik Himalaya is ~2.1 km/s. Crustal thicknesses varies from ~42 in the Delhi region, ~48 km in the Indo-Gangetic Plain, ~50 km in the western part of Siwalik Himalaya to ~60 km in the Kumaon region of Siwalik Himalaya.

1. Introduction

The Indo-Gangetic Plain and the adjoining Siwalik Himalaya, with a human population of over 500 million, are the seismically most vulnerable regions due its proximity to the Himalayan seismic zone and the presence of thick sediments that amplify the seismic waves generated even from small-magnitude earthquakes. The neighboring Himalaya region has experienced several moderate sized earthquakes, and the great 1803 Kumaon earthquake, which cause severe damage and took a heavy toll of life. Recent space geodetic measurement by Bilham et al. (2001) suggests a significant slip deficit in this segment of the Himalaya, capable of generating a great earthquake in the near future. It is, therefore, important to minimize the loss, by appropriately designing man-made structures. This necessitates detail knowledge of sedimentary structure is required to synthesize ground motion for possible earthquake scenario to quantify seismic hazard in the region.

The sedimentary structure beneath the Siwalik Himalaya and the Indo-Gangetic Plain was inferred from gravity, seismology (both earthquake and explosion) and drilling data from the Oil and Natural Gas Commission (ONGC). Based on modelling of Rayleigh and Love wave group and phase velocity dispersion measurements between Delhi and Shillong (north-east India), Tandon and Chaudhury (1964) and Chaudhury (1966, 1969) suggested an average ~3 km of the sediment beneath the Ganga plain. Using the short period surface wave phase velocity data along paths parallel to the northern edge of the Ganga plain and western Himalayan foothills, Tandon and Chaudhury (1968) estimated 5–6 km thickness of sedimentary column. Mitra et al. (2011) estimated ~2.5 km thick sediments with Vs ~2.0 km/s beneath the Ganga Plain based on modelling multimode Rayleigh and Love wave group velocity data from 4 stations (green triangle in Fig. 1). Recent receiver function (RF) study (Srinivas et al., 2013) over the Indo-Gangetic Plain (between 79–81°E and 26–29°N) shows sediments with Vs of 0.72–2.5 km/s and thicknesses varying from 0.7 to 3.7 km (magenta triangle in Fig. 1). Hetenyi et al. (2006), using RF data from 10 broadband stations (black triangles in Fig. 1, along 85°E) of the Hi-CLIMB seismological experiment, produced a high resolution image of the base of the Himalayan foreland basin at ~5 km depth. Previous data from ONGC drilling in the Indo-Gangetic Plain show the basement depth variation of 1–6 km from south to north (for east of 79°E) and 0–4 km from south to north (for west of 79°E) (Sastri et al., 1971; Rao, 1973; Karunakaran and Ranga Rao, 1979; Singh, 1996). Two exploration

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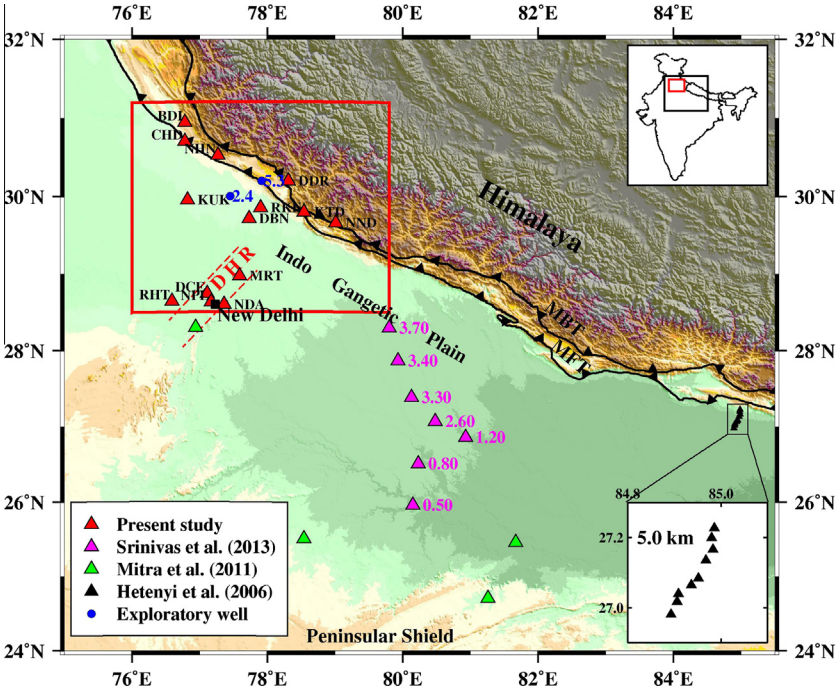

Fig. 1. Tectonic map of the study region (marked by red square), projected over topography along with major thrusts, MBT (Main Boundary Thrust) and MFT (Main Frontal Thrust). Location of the 14 broadband seismological stations (red triangle) installed in the region along with the locations of exploratory well (blue circle) and broadband seismological station locations of previous studies, shown in legends. Delhi-Haridwar ridge (DHR) is marked by red dashed line. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 1
Location of the stations of the study region along with the operational period.

Station code	Latitude (°N)	Longitude (°E)	Elevation (m)	Operation period
BDI	30.952	76.782	365	12/2002–09/2003
CHD	30.714	76.785	289	12/2002–11/2003
KUK	29.961	76.820	214	05/2003–12/2003
DDR	30.200	78.310	1300	11/2006–06/2008
KTD	29.800	78.540	1079	03/2005–10/2006
NND	29.670	79.010	1355	04/2007–06/2008
NDA	28.620	77.360	189	02/2006–07/2008
MRT	28.980	77.590	216	02/2006–07/2008
NPL	28.640	77.170	224	06/2005–07/2008
DBN	29.710	77.730	214	07/2007–06/2008
NHN	30.540	77.250	590	07/2007–06/2008
RHT	28.650	76.590	450	10/2004–06/2005
RKE	29.863	77.899	256	02/2005–09/2005
DCE	28.750	77.120	204	07/2006–07/2008

wells (blue circle) at Saharanpur and Mohand show sedimentary thickness of 2.4 and 5.3 km, respectively (Sastri, 1979). Gravity study also shows basement variations of 0–3 km from south to north (Dasgupta et al., 2000).

In the present study, we estimate the sedimentary column thickness and shear velocity and also crustal thickness in the part of the Indo-Gangetic Plain and the Siwalik Himalaya (between 76–79.5°E and 28.4–31.2°N; red rectangle in Fig. 1) through joint inversion of RF and Rayleigh wave group velocities.

2. Geology and tectonics

The Himalaya is divided into number of sequences, viz., the Siwalik (outer) Himalaya, the lesser Himalaya, the higher Himalaya, and the Tethyan Himalaya. The Siwalik Himalaya is the southern part of the Himalaya, bounded by a major north-dipping Main Frontal Thrust (MFT), and the Main Boundary Thrust (MBT) (Fig. 1). The Siwalik hills are the southernmost and geologically youngest east–west mountain chain of the Himalayas and are primarily composed of sandstone and conglomerate rock formations. The Indo-Gangetic Plain constitutes the foreland basin south of the Siwalik Himalaya and separates the Himalaya from the Peninsular shield. It is one of the major sedimentary basin on the world, filled with alluvium deposited by major rivers like the Ganga, Yamuna, Indus and Brahmaputra and is formed on the flexed Indian lithosphere (Lyon-Caen and Molnar, 1985). The Delhi region is a flat terrain covered by older and newer alluvium. A NNE-SSW trending ridge exposed in the southern and central part of Delhi, is known as the Delhi-Haridwar Ridge (DHR; red dashed line in Fig. 1). Its continuation beneath the Ganga basin was mapped using shallow