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Active seismic and passive microtremor HVSR for assessing site effects in Jammu city, NW Himalaya, India—A case study

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ABSTRACT

1-D shear wave velocity structure is important for site effect studies and geotechnical engineering, but it is quite difficult and expensive to derive from the conventional geophysical techniques. Active (MASW) and passive (microtremors, HVSR) methods were conducted at 30 sites in the frontal part of the Himalaya which is characterized by soft sediments and strong seismological effects. Shear wave velocity (*Vs*) in the range of ~238 m/s to ~450 m/s has been obtained from 30 m thick layer of quaternary sediments overlying Lower Miocene bed rock (Upper Siwalik Conglomerate) in Jammu city, NW Himalaya. The shear wave velocity (*Vs*) along with seismic input motion of Chamoli earthquake (mb 6.8) has been used to obtain site response spectrum. The response spectrum suggests five to seven times increase in peak ground acceleration for single or two storey buildings and by eight to twelve times increase in amplification ratio with respect to input ground motion. The amplification spectrum shows peak amplification of ~2 Hz–~3 Hz in the central part and ~1.75 Hz–2 Hz in the northern, southwestern and southeastern parts of the city. The advantage of microtremor HVSR is that it yields direct estimate of the fundamental frequency which is found to vary from ~1 Hz to ~3 Hz for same sites. Further, the 1-D velocity models obtained from ModelHVSR Matlab routine have been compared with the soil models prepared by derived using MASW. The comparison shows correlation between soil models for sites having high shallow impedance contrast between the overlying sediments and very stiff material (bedrock) underneath as than sites having less impedance contrast.

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1. Introduction

The Himalayan mountain front is composed of tertiary sediments (Siwalik and Murrees Groups) overlain by thick unconsolidated quaternary deposits. Thick unconsolidated sediments can cause profound ground motion amplification as it has been noticed during the 2001 Bhuj earthquake and the 1985 Mexico earthquake (Ansal, 2004; Mahajan et al., 2004). Most of the growing cities, along the Himalaya, are located on such type of deposits and so high degree of hazard in the adjoining area results in large seismic amplification in those cities—Jammu city, located on unconsolidated Quaternary sediments (in the form of fan deposits) in the north–western Himalaya is one of them (Fig. 1). Geographically Jammu city is located

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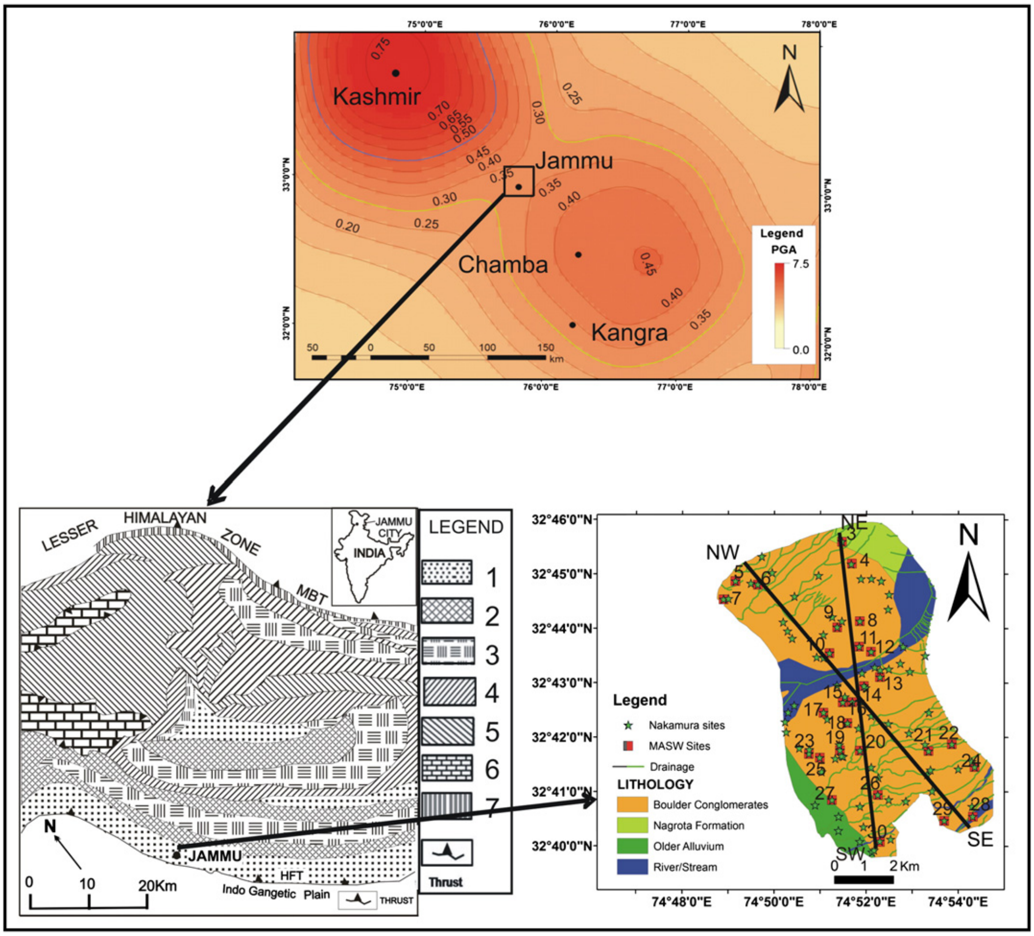

Fig. 1. Location map of the study area with regional tectonic framework. Inset shows a) seismic hazard map of the NW Himalaya (after Mahajan et al., 2010) indicating PGA values, b) regional geological map of Jammu region (modified after Raiverman et al., 1983), Numbers in legend represent different litho units: 1) Upper Siwalik, 2) Middle Siwalik, 3) Lower Siwalik, 4) Upper Murrees, 5) Lower Murrees, 6) Sirban Limestone and 7) Agglomerate Group, c) location of MASW as red square and Nakamura (HVSR) sites as stars on the geological map of Jammu city. N–S and NW–SE black lines drawn on the map shows the direction of cross section used for 1-D site effect study.

between the Kangra seismic zone in the east and the Kashmir seismic zone in the west (Fig. 1a) which have high seismic hazard potential (Mahajan et al., 2010; Fig. 1a). Recently, Jammu city has experienced a damage of intensity VI (EMS-98 scale) due to the Muzaffarabad earthquake (7.6 Mw) of that occurred on October 8, 2005 (Mahajan et al., 2006). The variation in ground shaking that has been observed in the city during Muzaffarabad earthquake in the city, demonstrates the effect of site amplification (Jayangondaperumal et al., 2008; Rai and Murthy, 2006).

Soil response modeling requires many input parameters related to subsurface conditions many of which are difficult to obtain from geotechnical and geophysical investigations (Slob et al., 2002). Among those elastic parameter of materials shear wave velocity (*Vs*), is considered as the best indicator of stiffness (Aki and Richards, 1980; Bullen, 1963) and hence it has long been recognized as a key factor in ground motion amplification and site response in sedimentary basin (Borcherdt, 1970) and is also used as an important parameter in building codes and design application (Kramer, 1996; Street et al., 2001). In India the building codes are primarily based on the Seismic zonation map (Seismic zoning map of India, BIS code, 1893, 2002) itself being based on the damage experienced from different earthquakes that have occurred in India since 1850, whereas, most of the site specific studies carried out by engineers for site characterization are based on standard penetration test (N_{SPT}).

Traditionally Standard Penetration Test (N_{SPT}) was found to be convenient among geotechnical engineers in order to estimate the stiffness of the soil column. Recent geophysical techniques such as downhole or crosshole profiling methods allow in-situ measurements of the shear-wave velocity with depth. However, the practice of these methods for microzonation studies in urban areas can be expensive (Hunter et al., 2002; Rix et al., 2001). Recently non-invasive seismic exploration has emerged as a promising alternative to estimate the shear wave velocity (*Vs*) and the resonance frequency. The data acquisition process in such seismic exploration is relatively cheap and fast and can be implemented in urban areas without too much difficulty. From the seismological point of view the shear wave velocity is the critical input parameter for any numerical ground motion simulation and estimation of site amplification.

One of the most widely used (and misused) method for estimating the site response is the Nakamura technique (Nakamura, 1989) where the spectral ratio between vertical and horizontal components of the records (H/V or HVSR analysis) provides a "good estimate of the fundamental frequency" but it holds good only in case of high impedance contrast. It is a cheap and fast technique which allows detailed mapping of these frequencies in an urban area (Mundepi and Mahajan, 2010; Parolai and Galiana-Merino, 2006; Parolai et al., 2001; Picozzi et al., 2009).

With the aim of estimating the site response of Jammu city, two different geophysical approaches have been used a) response analysis of a given input motion and 1-D soil model derived from MASW method b) ambient noise measurements using HVSR method which yields direct fundamental frequency.