Journal of Nepal Geological Society, 2014, Vol. 47 pp. 23-34

Ground response of the Kathmandu Sedimentary Basin with reference to 30 August 2013 South-Tibet Earthquake

S. Rajaure[1, *], B. Koirala[1], R. Pandey[1], C. Timsina[1], M. Jha[1], M. Bhattarai[1], M. R. Dhital[2], L. P. Paudel[2], S. Bijukchhen[3]

[1]*Department of Mines and Geology, Lainchaur, Kathmandu, Nepal*
[2]*Central Department of Geology, Tribhuvan University, Kirtipur, Kathmandu, Nepal*
[3]*Hokkaido University, Sapporo, Japan*
**Corresponding author: srajaure@gmail.com*

ABSTRACT

Ground acceleration of the 30 August 2013 (M4.9), South Tibet Earthquake has been recorded by five accelerometers deployed in the Kathmandu Valley. Analysis of the ground acceleration record reveals that that the EW component was dominant across the valley, and with the exception of one, all stations on sediments recorded PGA much higher than the station on rock. The site response functions, evaluated as the Fourier spectral ratios of the horizontal components on soil relative to the corresponding component on rock, are remarkably similar in the low frequency range (<0.8 Hz) and reveal strong amplification that likely corresponds to basin effects. By contrast, the high frequency site response shows strong variability across the soil sites, likely attributed to the underlying stratigraphy of the shallow soil layers of the valley. The most pronounced differences manifest in the frequency range >2Hz, which is consistent with the variability in PGA across the valley. Because of the small intensity of this event, the empirical site response recorded can be, approximately, considered linear. As such, this study establishes a reference for future studies on nonlinear site response, which is likely to be triggered during future stronger earthquakes.

Key Words: Peak ground acceleration, Fourier amplitude spectra, ground response, spectral ratio

Received: February 22, 2014 **Revision accepted:** May 20, 2014

INTRODUCTION

The Kathmandu valley is an intermontane tectonic basin in the Lesser Himalaya of central Nepal. The valley hosts Kathmandu, the capital city of Nepal, as well as two other major cities, Patan and Bhaktapur, and many newly developing urban areas. The population of the Kathmandu Valley is rapidly increasing than ever before.

The valley has experienced varying degree of ground shaking/destruction in the past earthquakes (Pandey and Molnar 1988). The damage pattern of the 1934 (M 8.1) earthquake (Bilham et. al. 1995), in particular suggests that ground amplification due to fluvio-lacustrine sediments plays a major role in intensifying the ground motion in the basin (Paudyal et. al. 2013).

The valley has been reportedly destroyed many times in the past by historical earthquakes (e. g. Chitrakar and Pandey 1986). Most recently, Kathmandu Valley was heavily damaged by the 1934 Bihar-Nepal Earthquake (e.g., Pandey and Molnar 1988; Rana 1935 and NSET 2011). Rana (1935) compiled an extensive report on the destruction as well as casualties caused by the 1934 earthquake. Pandey and Molnar (1988) and Paudyal et. al. (2013) conclude that the variation in the destruction pattern in the Kathmandu Valley was possibly a consequence of variable ground response-Se of the Kathmandu Valley sediments, which resulted in amplification of seismic wave amplitudes. The estimated intensity distribution of the 1934 great earthquake (Fig. 1) varies from IX to X MMI (Pandey and Molnar 1988, NSET 2011) within different unconsolidated sedimentary deposits in the Kathmandu Valley.

Study of seismic ground response using ground acceleration data for different parts of the valley has not been previously possible in Kathmandu Valley because of lack of accelerometers in the Valley. In this paper we present results on seismic ground response of the Kathmandu Valley Sediments using instrumentally recorded data of the 30th August 2013, South Tibet Earthquake (M4.9) at five sites in the Valley (Fig 1).

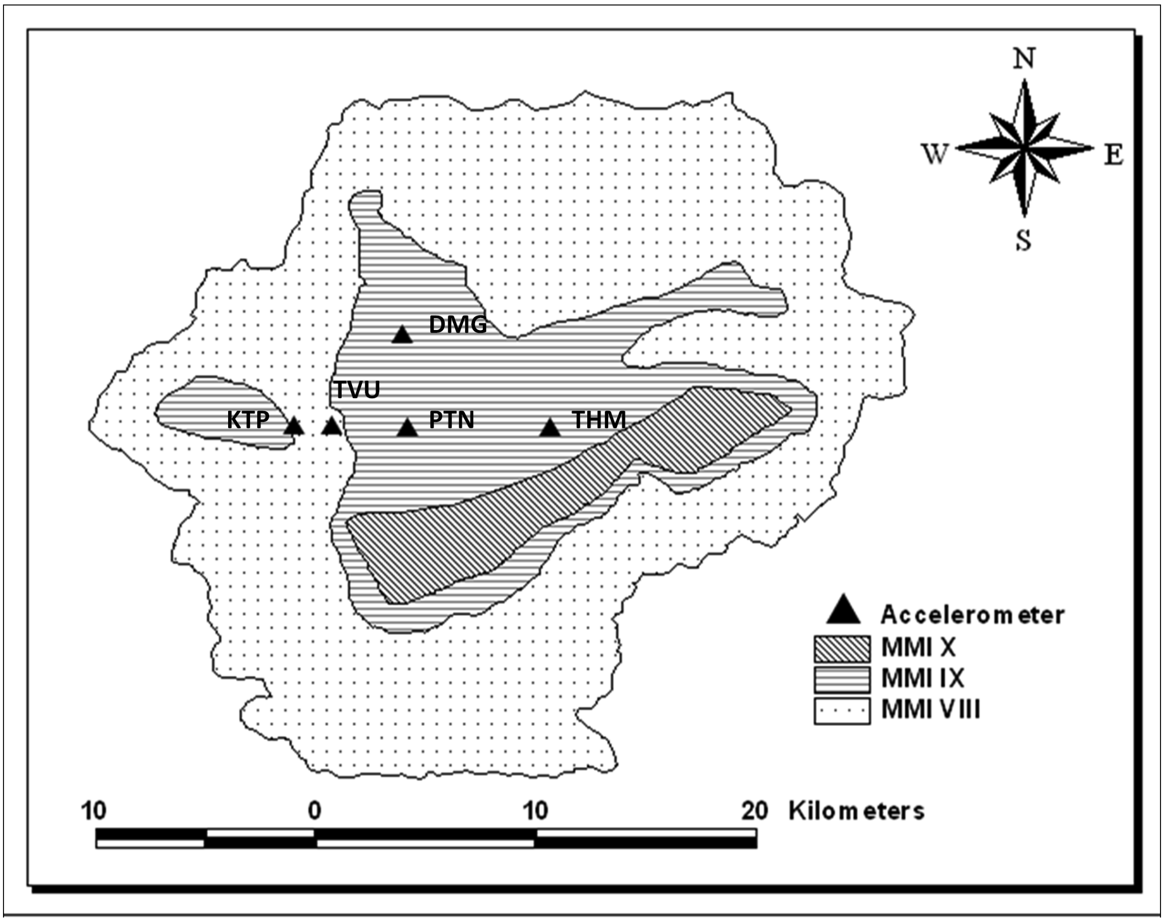

Fig. 1: Intensity distribution of the 1934 Bihar-Nepal Earthquake in the Kathmandu Valley (modified after NSET, 2011). The triangle shows the location of presently installed accelerometers in the Kathmandu valley.

GEOLOGICAL SETTING

The Kathmandu valley is located in the Lesser Himalaya (Fig. 2). The basin falls in the Midland zone of the Lesser Himalaya, and is bounded by the Mahabharat Lekh in the south and the Shivapuri Lekh in the north. The basement of the Kathmandu basin is a huge nappe (Kathmandu nappe) formed by thrusting along Mahabharat Thrust (MT), probably the southward extension of the Main Central Thrust (MCT). It is made up of the Precambrian Bhimphedi Group and Paleozoic Phulchoki Group (Stöcklin 1980).

The Kathmandu basin-fill sediments unconformably lie on the Kathmandu Complex rocks (Fig. 3). The sediments range in age from 2.5 Ma to about 20 kyr with a total thickness of about 600 m at the central part of the basin. The sediments are divided into seven formations on the basis of their sedimentary facies (Sakai 2001). The lowermost and oldest unit is the Tarbhir Formation. It is mainly composed of boulders and cobbles. The Lukondol Formation is a mud-dominant sequence of marginal lacustrine facies. In the southern part of the valley, The Lukondol Formation is overlain by the Itaiti Formation. The Itaiti Formation is a cliff-forming gravel dominant sequence. In the central part of the valley, the Lukondol Formation is overlain by the Kalimati Formation, dominantly carbonaceous laminated clay. In the northern part of the valley, The Kalimati Formation is overlain by the Gokarna and Thimi Formation. Both the formation are made up of fluvio-lacustrine sandy sediments. The Patan Formation rests on the top of the basin sediments. It is also made up of the fluvio-lacustrine sandy facies.

SEISMICITY

The Kathmandu Valley has witnessed a number of destructive earthquakes in the past (e.g., Chitrakar and Pandey 1986; Bilham et. al. 1995; Bilham and Ambraseys 2004). The destruction caused by the 1934 Bihar-Nepal Earthquake (M 8.1) and 1988 Udayapur earthquake (M6.5) are still in the living memory of Nepali people.

The National Seismological Centre (NSC) of Department of Mines and Geology (DMG) has been operating a network of seismic stations designed to study micro-earthquakes in Nepal. The network began operation in 1995 and has collected a large volume of data. Pandey et. al. (1995) and Pandey et. al. (1999) have studied the seismicity distribution in Nepal using data from the network of the Department of Mines and Geology.

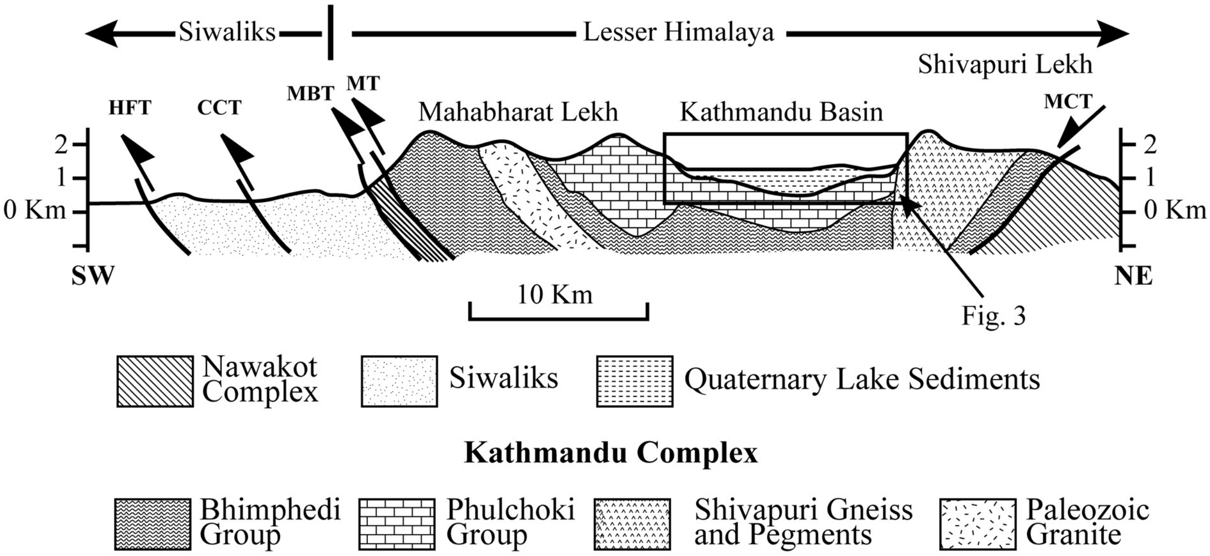

Fig. 2. Schematic geological cross-section across the Kathmandu valley in central Nepal Himalaya (Modified after Sakai et al. 2002). MCT: Main Central Thrust, MT: Mahabharat Thrust, MBT: Main Boundary Thrust, CCT: Central Churia Thrust, MFT: Main Frontal Thrust.

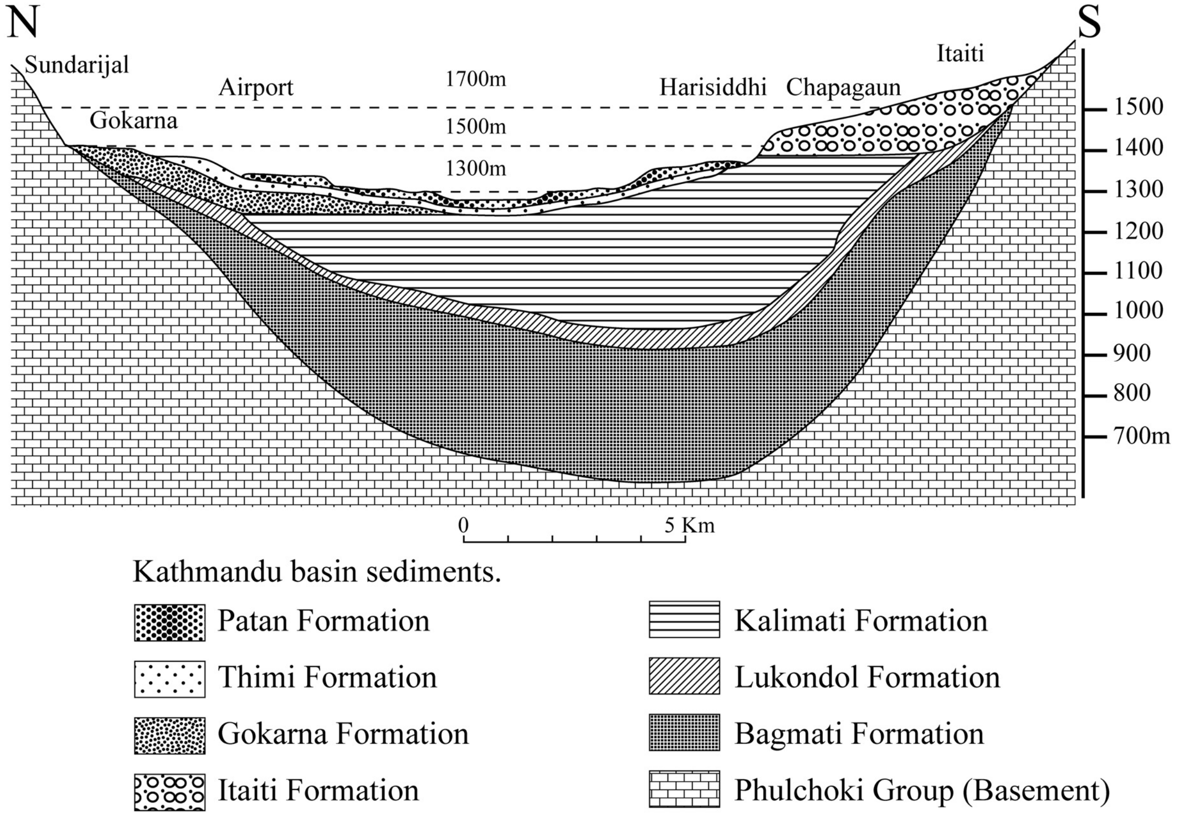

Fig. 3: Schematic geological cross-section of the basin-fill sediments of the Kathmandu sedimentary basin (Modified after Sakai 2001).

Rajaure et. al. (2013) relocated the seismicity of Nepal applying the double-difference relocation technique (Waldhauser and Ellsworth 2000) to local earthquakes recorded by seismic network of the Department of Mines and Geology (DMG). The result of Double Difference Relocation is presented in Fig. 4. The figure shows a continuous belt of microseismic activity all along the Nepal Himalaya, which constrains and better delineates the seismicity belt reported earlier by Pandey et. al. (1995) and Pandey et. al. (1999). The microseismic activity is intense in far-west Nepal and far-east Nepal (Fig. 4). This belt is simple and narrow in the east of 82°E (Pandey et. al. 1999 and Rajaure et. al. 2013); however it is complicated and is separated into two sub-parallel belts between 82°E and 80°E. Majority of the local earthquakes along the seismicity belt are shallow focus earthquakes with depth ranging between 0 and 25 km.

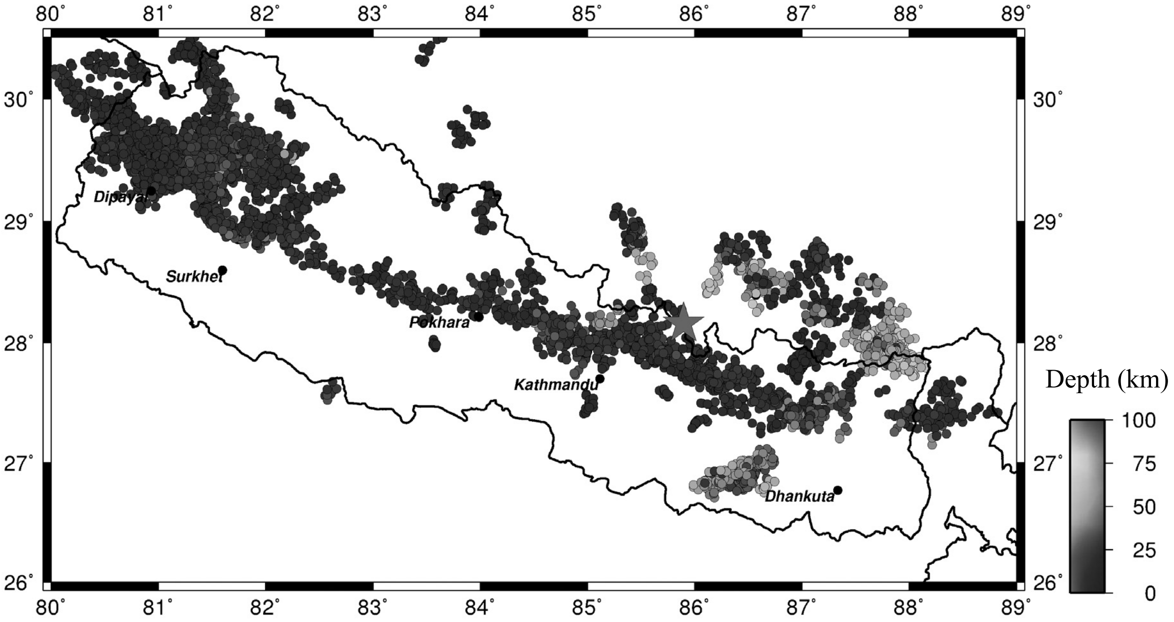

Fig. 4: Epicenter distribution (1995-2004, Ml>2.0) in Nepal (modified from Rajaure et. al. 2013). The epicenters are scaled to depth. The red star stands for the 30 August 2013, South Tibet earthquake.

PREVIOUS STUDIES

Pandey (2000) studied the seismic response of the Kathmandu valley sediments using microtremor data recorded at 60 sites in the valley and implemented a quantitative assessment of site amplification using horizontal relative spectra of microtremor to a reference site. In his study, he found that the predominant amplification peak is around 2 Hz, whereas the relative peak amplification factor is about 12 to 15.

Bhattarai et. al. (2011) reported analysis of accelerometric data recorded at DMG and at Kakani (KKN) site (about 20 km in the north of Kathmandu Valley on rock). They analyzed two earthquakes one of which occurred at a distance of 25 km (15 July 2010, M_L 3.4 (NSC)), in Nepal, and other occurred over 110 km distance (17 October 2010, M_L 5.7 (NSC)) in South Tibet. The study shows large peak ground acceleration (PGA) at a hard rock site located at about 110 km from the epicenter which they speculate might be caused by topographic amplification at KKN.

Paudyal et. al. (2012) carried out seismic microzonation of the Kathmandu Valley using microtremor data recorded in the Kathmandu valley. They applied horizontal-to-vertical spectral ratio technique to estimate the predominant period at the sites. They mentioned that the sites over thick sedimentary deposit, in the central part of the valley, are characterized by amplifications at long period. The authors point out that their results raise concerns due to the continuing construction of new multi-storied buildings in this part of the valley, since the natural periods of these structures is likely to be close to the fundamental period at sites of observation.

DATA

The National Seismological Centre (NSC) of the Department of Mines and Geology (DMG), in collaboration with Departement Analyse Surveillance Environnement (DASE), France, has installed 8 accelerometers in Nepal to study attenuation pattern of seismic wave amplitudes. One of the eight accelerometer owned by DMG has been installed in the premises of DMG at Lainchaur. Similarly, to study the seismic ground response of the Kathmandu Valley sediments, the Central Department of Geology (CDG) of the Tribhuvan University, in collaboration with the Hokkaido University, Japan installed four accelerometers (KTP, TVU, PTN, THM (Fig. 5, Table 1)) in different parts of the Kathmandu Valley along an E-W profile. The accelerometer installed by DMG is GeoSIG type (sampling rate 200 sps), operated on triggered mode, and the other accelerometers installed by the TVU comprise Mitsutoyo JEP-6A3-2 accelerometers (sampling rate 100 sps) operated on continuous mode.

We have used ground acceleration data of the 30 August 2013, South Tibet Earthquake recorded by all five accelerometers installed in the Kathmandu Valley (Table 1, Fig 5). This earthquake (Mb 4.9) occurred at 28.16^{o}N latitude, 85.89^{o}E longitude (Fig. 4), at a depth of 54.6 km (USGS) at 17:48:42.98 (UTC time, USGS). The earthquake occurred approximately 76 km in North-East direction from the Kathmandu Valley, which was felt in all parts of the Valley. A fault plane solution for this earthquake is not available; however we presume a normal fault mechanism for this earthquake based on fault plane solution of past earthquakes in the area (Sheehan 2008; Torre et. al. 2007; Rajaure et. al. 2013).

Ground acceleration data recorded by five accelerometers was cut at 17:47:41 UTC to produce a record length of about 90 seconds. 'Seismo Signal' software (Earthquake Engineering Software Solutions) was used for necessary processing of the data to determine ground motion amplitude parameters. The data was band pass filtered between 0.1 and 25 Hz using a Butterworth filter. DIAMANT, a Matlab tool (Hernandez, et. al., 2011), was used to compute spectral ratio relative to the rock site (KTP) as a reference.

Table 1: Location (coordinates) of accelerometers (Fig. 5) used in this study

Site code	Latitude N)	Longitude (E)	Location
KTP (rock)	27.68182	85.27261	Kirtipur Municipality office
TVU (soil)	27.68145	85.28821	Central Department of Geology/TU
PTN (soil)	27.68082	85.31897	Engineering College, Pulchowk
THM (soil)	27.68072	85.3772	University Grant Commission Office, Bhaktapur
DMG (soil)	27.71881	85.31678	Department of Mines and Geology, Lainchaur

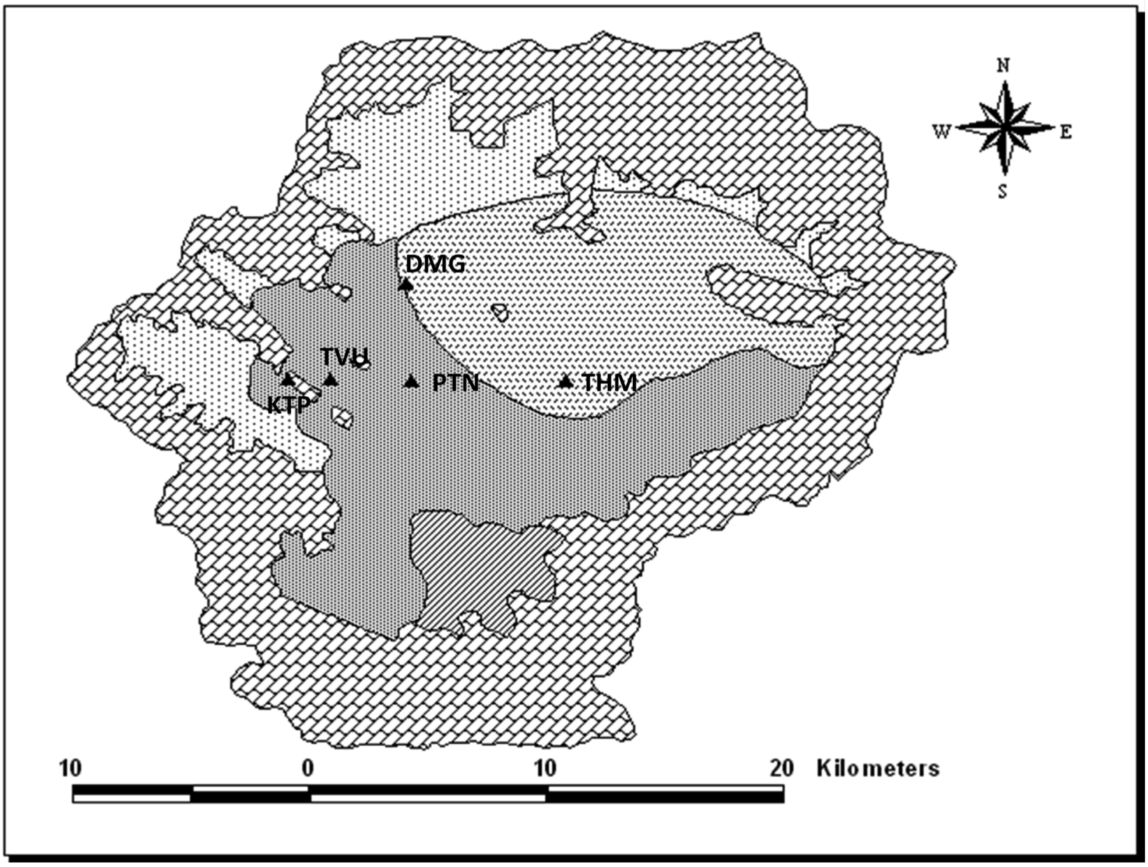

Fig. 5: Geology of the Kathmandu Valley (modified from Sakai and Kuwahara 2002) with the location of five accelerometers (black triangles).

RESULTS

Peak ground acceleration is one of the most common parameters used in engineering applications. The records of the ground acceleration history are presented in Fig. 6 through Fig. 8 recorded by three components (E-W, N-S and V) at KTP, TVU, PTN, THM and DMG sites respectively. The maximum PGA (24 gal) is recorded by the E-W component at the DMG site (Fig. 6), which is a soil site. Similarly, the rock site (KTP) has recorded the smallest PGA (6 gal) on the corresponding E-W component (Fig. 8). The PGA recorded by the E-W component at TVU and THM sites are comparable (Table 2, Fig. 6, 7 and 8).

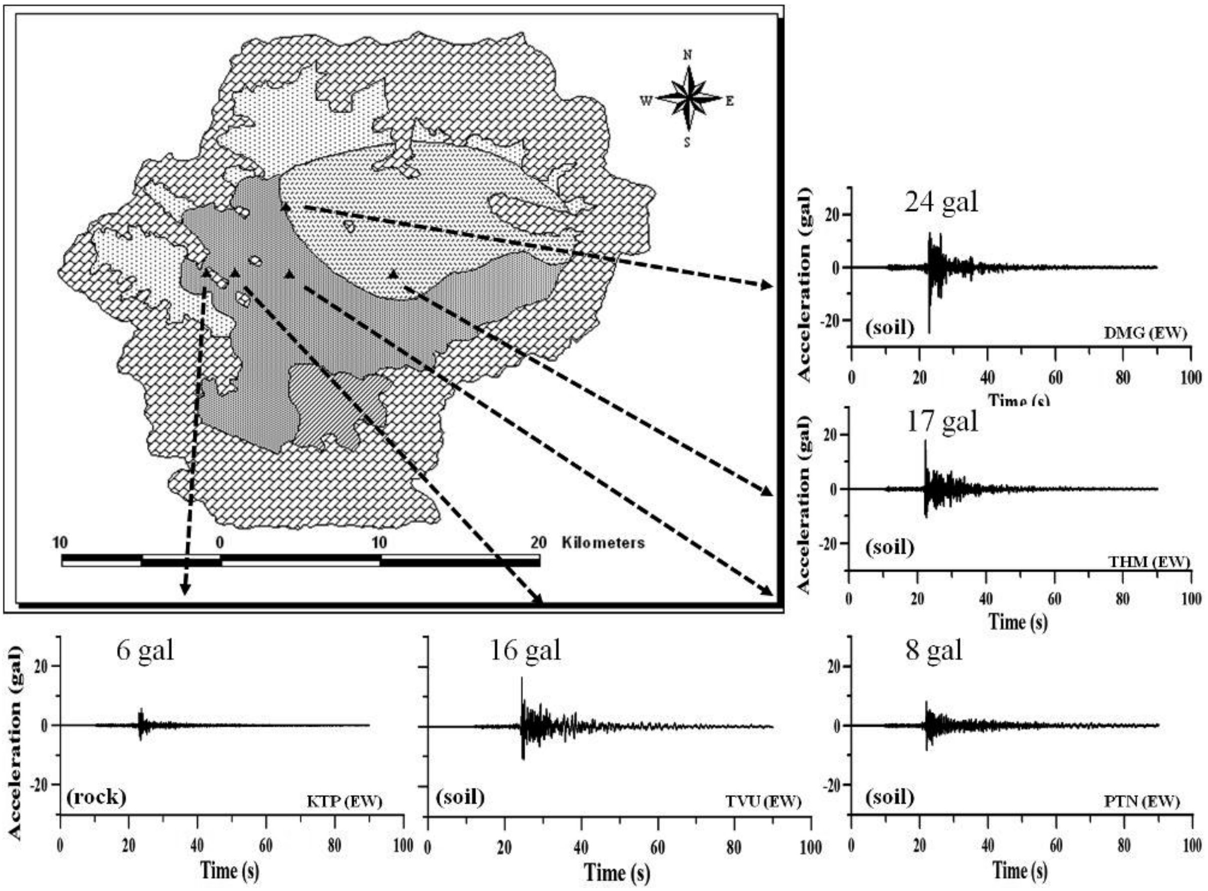

Fig. 6: Ground acceleration history recorded by east-west component at the five sites. Note the duration as well as the amplitudes, at soil sites, are larger in comparison to the rock site (KTP) site.

Despite being a soil site, the PTN site (Pulchowk Campus, Lalitpur) shows comparatively smaller PGA than at other soil sites (TVU, THM and DMG). Smaller PGA at PTN site than expected implicates either bedrock is at shallow depth under the area or the thickness of clay layers is small in comparison to at other soil sites.

Table 2: Peak ground accelerations observed at five sites

Site	Peak ground acceleration (gal, 1 gal = 1 cm/sec^2) recorded by accelerometers		
	Vertical	North-South	East-West
KTP (rock)	7	7	6
TVU (soil)	7	10	16
PTN (soil)	5	8	8
THM (soil)	7	11	17
DMG (soil)	8	17	24

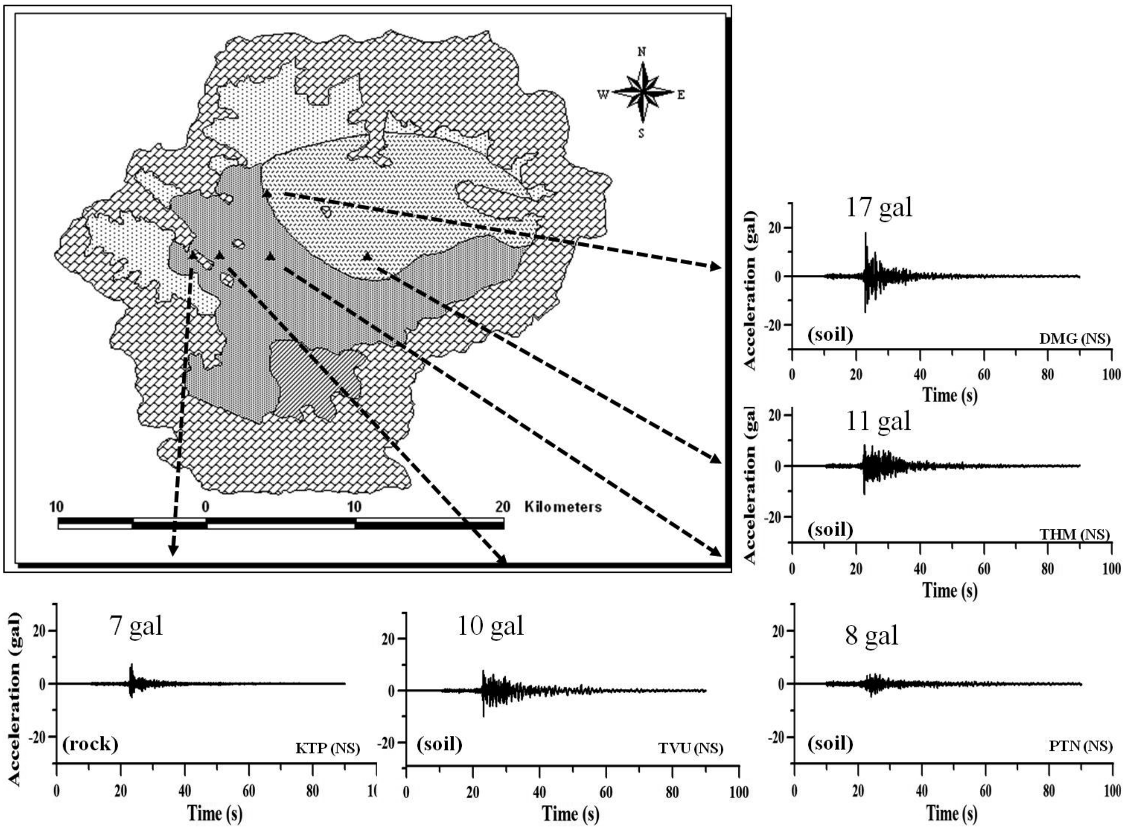

Fig. 7: Ground acceleration history recorded by north-south component at the five sites. Note the duration as well as the amplitudes, at soil sites, are larger in comparison to the rock site (KTP) site.

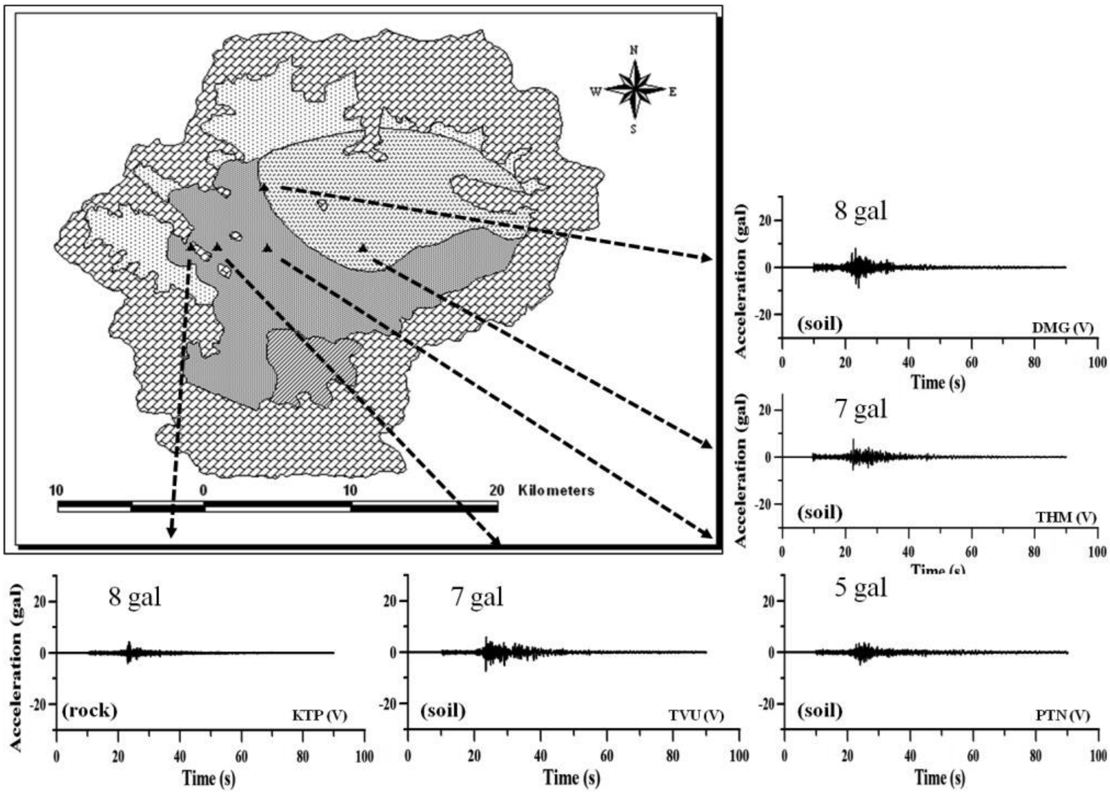

Fig. 8: Ground acceleration history recorded by vertical component at the five sites.

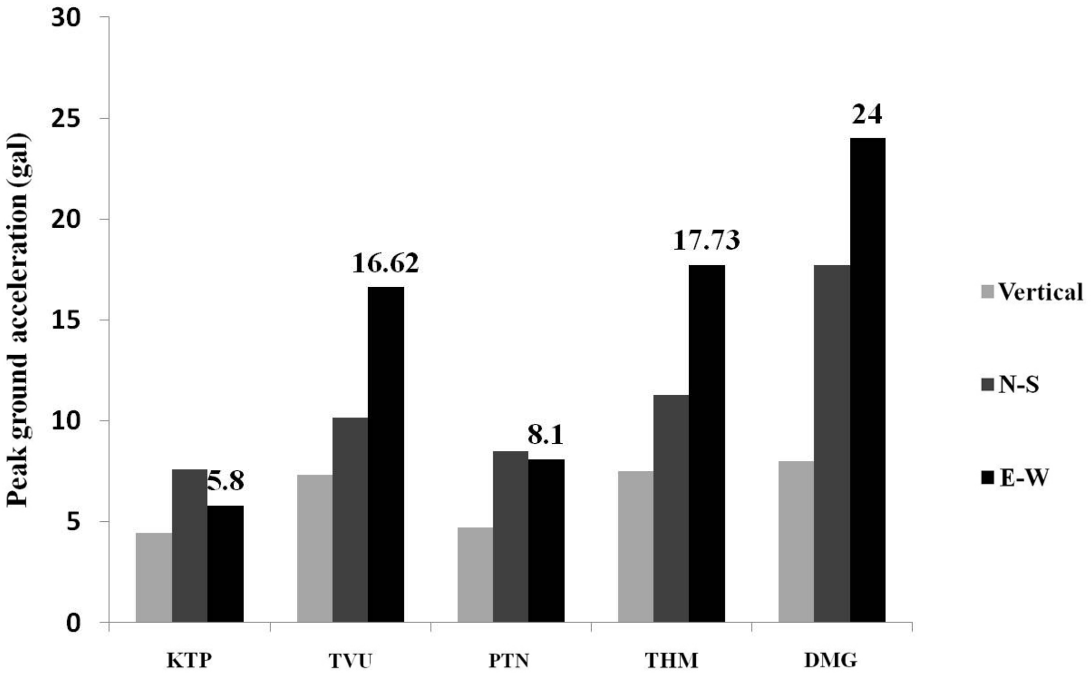

Fig. 9: Peak ground acceleration (PGA)s observed by three components (E-W, N-S and V) of accelerometers at the five sites (KTP is a rock site and others are soil sites.)

The Fourier amplitude spectra of the ground acceleration history (for E-W and N-S components) are presented in Fig. 10. Three soil sites (TVU, THM and DMG) show large peaks of Fourier amplitudes distributed at frequencies between 2 Hz and 5 Hz. The N-S component at the rock site (KTP) reveals a peak at a frequency larger than 5 Hz; however, the E-W component shows two peaks at less than 5 Hz. The Fourier amplitudes at the rock site are smaller, in the case of all components, than that at the rock sites. Three soil sites, namely TVU, THM and DMG show, more or less, similar characteristics, whereas PTN shows difference.

Spectral ratios at a soil site relative to a reference site, especially a rock site, are used to investigate site effect of the subsurface geology to seismic motion. In this study, spectral ratios are calculated assuming the PGA at the rock site (KTP) represents the PGA at bedrock beneath the sedimentary deposit in the Kathmandu Valley. The spectral ratios are calculated at four soil sites (TVU, PTN, THM and DMG) relative to the reference (rock) site (KTP). The spectral ratio (Fig. 11) shows peaks (amplitude 30 to 50) at 0.3 to 0.5 Hz at the low frequency range. Similarly there is another peak (amplitude 10 to 20) at 1.5 Hz of the record.

DISCUSSION AND IMPLICATIONS

It is well known that the Kathmandu Valley experienced substantial damage from the 1934 Bihar-Nepal earthquake. This earthquake killed about 4,296 people (Pandey and Molnar 1988) in the Kathmandu Valley only. It was reported that the destruction pattern was not same in the valley (Rana 1935; Pandey and Molnar 1988). As per the earthquake intensity map redrawn by NSET (2011), the KTP (rock) site falls in Modified Mercalli Intensity (MMI) Zone VIII and the other sites, which overlie thick sediments, fall in MMI zone IX. Such a variation is attributed to the amplification of seismic wave amplitude in areas underlain by soft sediments.

In this study also, we observed variations in the levels of ground acceleration (PGA) as recorded by accelerometers at different places in the valley. The largest ground acceleration (24 gal) is recorded by the east-west (E-W) component of the accelerometer installed in the Department of Mines and Geology (DMG), which is a soil site. Similarly the smallest acceleration (6 gal) on the horizontal components is recorded by the E-W component at the reference (KTP, rock site).

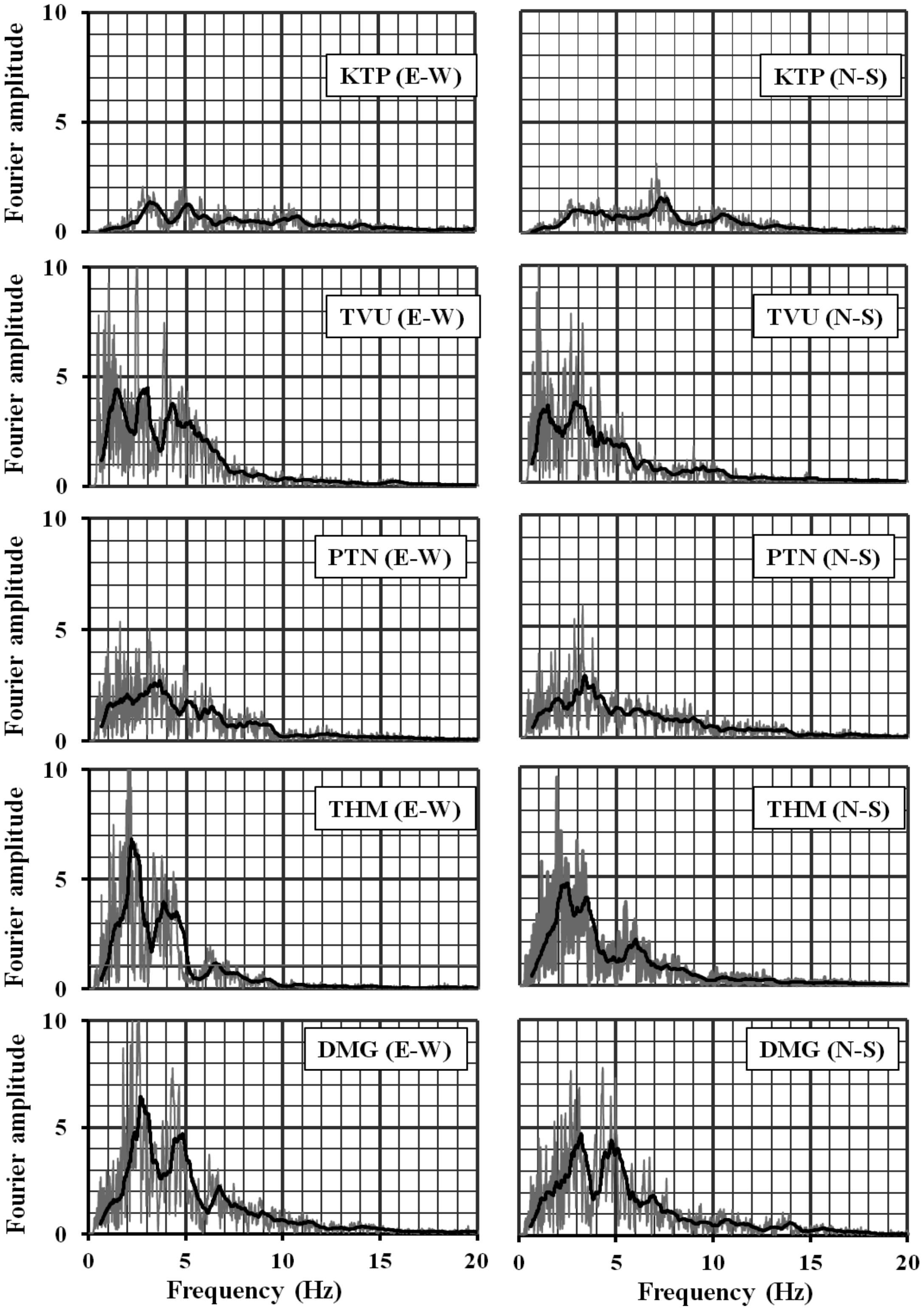

Fig. 10: Fourier amplitude (cm/sec) spectra of ground acceleration data recorded by two components (E-W and N-S) of accelerometers at the five sites.

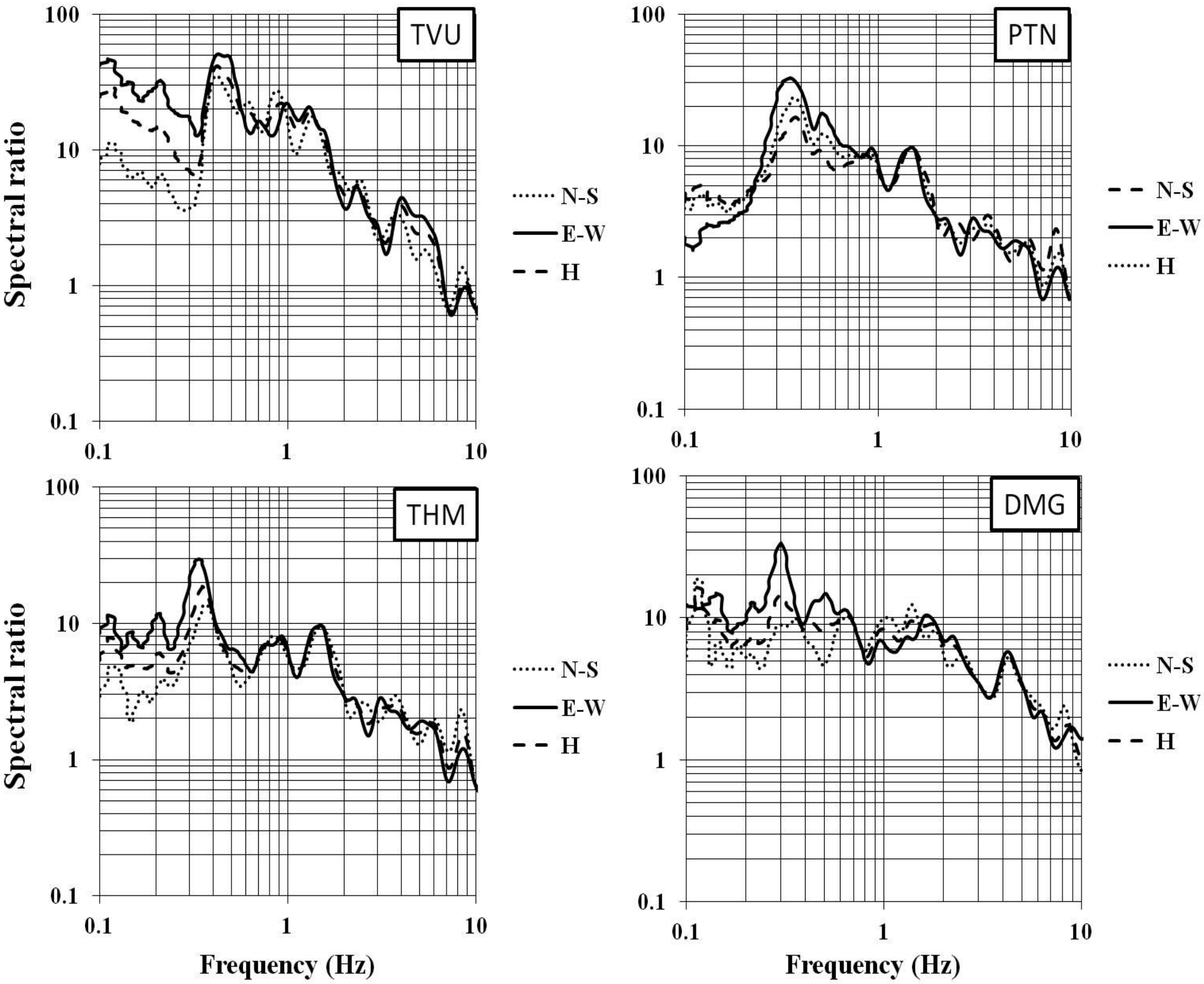

Fig. 11: Spectral ratios calculated at the four soil sites (CDG, ENG, UGC, and DMG) with reference to the rock site (KTP). N-S, E-W and, H stand for north-south, east-west and mean of the horizontals components respectively).

The peak ground accelerations (16 gal) recorded by the E-W component (Fig. 7) at the TVU (soil site), which is merely a few hundred meters from the KTP (rock site, Fig. 6), and that recorded by the E-W component (17 gal) at the THM (soil site), Sanothimi, Bhaktapur (Fig. 9) are almost equal. The large difference in PGA observed between KTP (6 gal) and TVU (16 gal) implicates geology is very different at these two sites despite they are very close. It can be inferred that the TVU, a soil site, possibly overlies thick succession of clay. The accelerometer installed in the Pulchowk Campus, Institute of Engineering, Lalitpur shows surprisingly smaller value of PGA in comparison to other soil sites (DMG, THM, and TVU). The smaller PGA and Fourier amplitude at PTN implicates that possibly rock is present at shallow depth beneath the site.

The spectral ratio (Fig. 11) shows large amplitude at 0.3 to 0.5 Hz at the four soil sites (TVU, PTN, THM and DMG) relative to the reference rock site (KTP). The peaks at 0.3 to 0.5 Hz possibly represent the response of the basin, whereas that at 1.5 Hz could be the one dimensional response of soil column. Additionally, there are peaks at higher frequencies (>1.5 Hz), which are different for each site. The peaks at higher frequencies, which are different at the sites, are likely to be the response of shallow sedimentary layers, implying that there is strong spatial variability of soil properties across the valley. The peaks at 0.3, 0.5 and 1.5 Hz correspond to buildings of approximately 33, 20 and 6 stories respectively, which in turn reveals the vulnerability of these structures to future events.

The four soil sites that cover a large fraction of the valley surface show remarkable similarity (in low frequency range) in terms of site amplification except in the very high frequency range, and are dominated by long period amplification effects due to resonance of the basin. This similarity doesn't contradict the PGA differences observed at the soil sites, because the PGA is a high frequency characteristic of ground motion–

namely, the sites that only differ in the very near surface in terms of geology and have site amplification very similar in longer periods, like THM, PTN and DMG, can still have very different PGAs, especially since this event is very small magnitude, and thus very rich in high frequencies.

CONCLUSIONS

The analysis of the ground acceleration data, recorded by five accelerometers in the Kathmandu Valley, reveals the response of the sediments of Kathmandu Valley to seismic motion. The observed PGA is not the same at all the soil sites, with the maximum value at DMG and the least at PTN. In the low frequency range, all sites show similar characteristic in terms of amplification, however at high frequencies, the pattern is different. Such variation at high frequency range, possibly, arises from the response of shallow sedimentary layers which, possibly, varies from place to place.

The Kathmandu Valley has witnessed rapid urbanization in the last two decades. The population in the Valley is increasing very rapidly because of various reasons prevailing in the country. It is very important to plan, in time, in order to minimize the possible loss of lives and property from unpredictable future earthquakes than rescuing afterwards. This study is a small attempt to assess the response of the Kathmandu Valley sediments to seismic ground motion in which ground acceleration data of an earthquake that occurred at 76 km distance from the valley and recorded by five accelerometers in the valley is used. To get a better represented picture of the ground response of the sedimentary deposit over the whole area in the Kathmandu Valley, it is important to install and operate a dense network of accelerometers, homogeneously distributed and closely spaced, in the Kathmandu Valley. The long term operation of such a network would help to record earthquakes from a range of magnitudes, mechanisms, distances and azimuths so that ground response of the valley sediments could be better estimated and constrained. Findings of such a study will be fundamental input in the seismic hazard assessment, building code revision and seismic vulnerability assessment of the valley, which would help to adopt appropriate countermeasures to minimize the loss of lives and property from future destructive earthquakes.

The result presented in this article is as observed for the mentioned earthquake which occurred in South-Tibet and should not be generalized in all cases because magnitude, source-site distance, directivity of fault rupture, mechanism of the fault rupture and azimuth of the causative fault plane to the source also play a role in the ground response.

ACKNOWLEDGEMENTS

The authors are grateful to Prof. Dr. Megha Raj Dhital, Central Department of Geology, Kirtipur, Kathmandu, Nepal for providing the data recorded at four accelerometric sites in the Kathmandu Valley. Similarly, special thank goes to Professor Dr. Nobuo Takai, Hokkaido University, Japan for installing four accelerometers in the Kathmandu Valley, without which this paper would not have been materialized.

We would like to express sincere gratitude to the Director General of the Department of Mines and Geology, Mr. Sarbjit Prasad Mahato for providing the ground acceleration data recorded at the DMG site and for his support to bring this article in this form. Similarly special thank goes to the Departement Analyse Surveillance Environnement (DASE, France) for its collaboration with DMG to install accelerometer in different parts of Nepal.

Likewise, we extend special thanks to the National Seismological Centre of Department of Mines and Geology and all personals involved in the installation, operation, maintenance of instruments and acquisition of acceleration data. We are thankful to Prof. Dr. Prem Nath Maskey, Pulchowk Engineering College, Pulchowk Lalitpur for his valuable comments and suggestions. At last but not least, we extend thanks to Ms. Menuka Shrestha for her help in drawing some of the figures included in this article.

REFERENCES

Bhattarai M., Gautam U., Pandey R., Bollinger L., Hernandez B., and Boutin V., 2011, Capturing first records at the Nepal NSC accelerometric network. Journal of Nepal Geological Society, v. 43 (Special Issue), pp. 137-144.

Bilham, R., 1995, Location and Magnitude of the 1833 Nepal Earthquake and its Relation to the Rupture zones of Contiguous Great Himalayan earthquakes. Current Science, v. 69(2), pp. 155-187.

Bilham, R., Ambraseys, N., 2004, Apparent Himalayan slip deficit from the summation of seismic moments for Himalayan earthquakes. Current Science, pp. 1500-2000.

Chitrakar, G. R. and Pandey, M. R., 1986, Historical Earthquakes of Nepal. Journal of Nepal Geological Society, v. 4, No. 1, pp. 7-8.

Hernandez, B., Bollinger L., and Boutin, V., 2011, DIAMANT. Traitement des donneìes acceìleìromeìtriques et calcul d'indicateur de nocivité sismique. Guide d'utilisation. CEA/ DIF/DASE/LDG/2011/DO, pp. 1-34.

Nakamura Y (1989), "A method for dynamic characteristics estimation of subsurface using microtremor on the ground surface," Quarterly Report of the Railway Technical Research Institute, 30 (1):25-33.

NSET, 2011, Earthquake intensity map of 1934 Earthquake in Kathmandu Valley.

Pandey M. R. and Molnar P., 1988, The distribution of intensity of the Bihar-Nepal Earthquake of 15 January 1934 and bounds on the extent of the rupture zone. Journal of Nepal Geological Society, v., 5, No., 1, pp 22-44.

Pandey M. R., 2000, Ground Response of Kathmandu Valley based on microtremors, 12WCEE, 2000 (unpublished)

Pandey, M. R., Tandukar, R. L. P., Lave, J. P., Massot, J. P., 1995, Interseismic Strain Accumulation on the Himalayan Crustal Ramp, Nepal. Geophysical Research Letters, v. 22, No. 7, pp. 751-754.

Pandey, M. R., Tandukar, R. P., Avouac, J. P., Vergne, J., Heritier, T., 1999, Seismotectonics of the Nepal Himalaya from a local seismic network. Journal of Asian Earth Sciences v. 17, pp. 703-712.

Paudyal, Y. R. et. al., 2012, Seismic Microzonation of Densely Populated Area of Kathmandu Valley of Nepal using Microtremor Observations. Journal of Earthquake Engineering, 16:8, 1208-1229.

Rajaure, S., Sapkota, S. N., Adhikari, L. B., Koirala, B., Bhattarai, M., Tiwari, D. R., Gautam, U., Shrestha, P., Maske, S., Avouac, J. P., Bollinger, L., and Pandey M. R., 2013, Double difference relocation of local earthquakes in the Nepal Himalaya. Journal of Nepal Geological Society, v. 46, pp. 133-142.

Rana, Maj. Gen. Brahma Shamsher J. B., 1035, Nepalko Mahabhukampa (The Great Earthquake of Nepal), Published in the Kathmandu by the author, second edition.

Sakai, H., 2001, Stratigraphic division and sedimentary facies of the Kathmandu Basin sediments. Journal of Nepal Geological Society, v. 25 (Sp. Issue), pp.19-32.

Sakai, H., Fujii, R., and Kuwahara, Y., 2002, Changes in the depositional system of the Paleo-Kathmandu Lake caused by uplift of the Nepal Lesser Himalayas. Journal of Asian Earth Sciences, v. 20, pp. 267–276.

Sheehan, A. F., Torre, Thomas de la, Monsalve, G., Schulte-Pelkum, vera, Bilham, R., Blume, F., Bendick, R., Wu, F., Pandey M. R., Sapkota, S., Rajaure, 2007, Earthquakes and Crustal Structure of the Himalaya from the Himalayan-Nepal-Tibet seismic experiment (HIMNT). Journal of Nepal Geological Society, sp. v., p. 8.

Stöcklin, J., 1980, Geology of Nepal and its regional frame:Geological Society [London] Journal, v. 137, pp. 1–34.

Torre, T. L. de la., Monsalve, G., Sheehan, A. F., Sapkota, S., and Wu, F., 2007, Earthquake processes of the Himalayan collision zone in eastern Nepal and the southern Tibetan Plateau, Geophys. J. Int. (2007), v. 171, pp 718–738.

Waldhauser, F. and Ellsworth, W. L., 2000, A Double-Difference Earthquake Location Algorithm: Method and Application to the Northern Hayward Fault, California. Bulletin of Seismological Society of America, v. 90, no. 6, pp. 1353-1368.