

# ASSESSMENT OF SOIL-STRUCTURE RESONANCE PROBABILITY OF EDUCATIONAL BUILDINGS IN KAGESHWORI MUNICIPALITY

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## Abstract

This study focuses on assessing the possibility of soil–structure resonance in school buildings located within Kageshwori Manohara Municipality, Nepal, by comparing the natural time periods of the ground and the structures. Ambient vibration measurements were carried out using geophones to determine the predominant period of both the selected school buildings and the nearby free-field sites. The Nakamura Horizontal-to-Vertical Spectral Ratio (HVSr) technique was applied to ambient noise data to identify the predominant soil period, which was found to range between 1.14 and 3.23 seconds, reflecting the local ground response characteristics. Similarly, the natural periods of the buildings, obtained through the Floor Spectral Ratio (FSR) or Horizontal-to-Horizontal (H/H) method, ranged from 0.11 to 0.37 seconds. Since the soil and building periods do not coincide, the likelihood of resonance occurring in these school structures is quite low. However, the seismic vulnerability index values of the ground beneath the studied buildings fall between 44.96 and 282.61 (classified as Very High), suggesting that the area is composed of relatively soft ground with thin sediment layers. Furthermore, the results show that buildings tend to be more vulnerable in the east–west (EW) direction than in the north–south (NS) direction, highlighting the need for targeted retrofitting measures. Overall, this study provides important insights for engineers and decision-makers aiming to enhance the seismic resilience of educational buildings in this earthquake-prone municipality.

**Keywords:** Horizontal to Vertical Spectral Ratio (HVSr); Floor Spectral Ratio (FSR); Geophone; Soil-structure resonance

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## 1. Introduction

The Nepal Himalaya lies within one of the most seismically active regions of the world, positioned along the Himalayan belt. Here, the Indian plate is continuously subducting beneath the Eurasian plate at a rate of approximately 16–21 mm per year, resulting in the accumulation of significant strain energy (Banerjee & Bürgmann, 2002; Bettinelli et al., 2006; Y. Paudyal et al., 2012). This tectonic activity causes intense ground shaking during earthquakes, and the extent of ground response largely depends on the properties of the underlying soil. Therefore, understanding soil characteristics is crucial for predicting ground behavior during seismic events and enhancing resilience against potential damage.

Although parameters such as shear wave velocity and other geotechnical equations are useful for evaluating soil response, Nepal still lacks adequate strong motion data and monitoring instruments.

Consequently, microtremor studies serve as an effective alternative for investigating local site conditions. Historical earthquakes — including the 1934 Nepal-Bihar earthquake, the 1988 Udayapur earthquake, and the 2015 Gorkha earthquake — have caused severe destruction in the Kathmandu Valley (Chaulagain et al., 2018; Kawan et al., 2022; Shakya & Kawan, 2016; Sharma et al., 2016; Tallett-Williams et al., 2016).

The April 25, 2015 Gorkha earthquake (Mw 7.8), with its epicenter located at Barpak, Gorkha, about 77 km northwest of Kathmandu, was particularly devastating, resulting in 8,979 fatalities and leaving hundreds of people homeless (Ministry of Home Affairs (MoHA), 2015; Rajaure, 2021). In Kageshwori Manohara Municipality alone, approximately 6,045 buildings collapsed and 15,452

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were partially damaged. In addition to tectonic factors, characteristics of ground motion — including frequency content, duration, and amplitude — along with local soil conditions, significantly influence the severity of earthquake-induced damage. Y. R. Paudyal et al. (2012) highlighted that the fluvio-lacustrine deposits of the Kathmandu Basin amplified seismic ground motion during the 1934 earthquake. This emphasizes the importance of conducting seismic site response studies in areas like Kageshwori Manohara Municipality, which lies within the geologically sensitive Kathmandu Valley.

The determination of the ground's fundamental period was carried out using the Horizontal-to-Vertical Spectral Ratio (HVSr) method, first introduced by Nogoshi and Igarashi (1971) and later popularized by Nakamura (1989). This technique is widely applied because alternative approaches are often costly and invasive (Gosar, 2010; Mucciarelli & Gallipoli, 2001; SESAME, 2004). Y. Paudyal et al. (2012) utilized the HVSr method to map the spatial variation of the fundamental frequency of soil deposits across the Kathmandu Valley, reporting values ranging from 0.49 to 8.9 Hz. In the present study, microtremor measurements were conducted to determine the fundamental period of both the ground and the buildings belonging to educational institutions within Kageshwori Manohara Municipality. A total of 24 schools comprising 40 buildings were included in the analysis. The obtained fundamental periods of the ground and buildings were then compared to assess the potential for soil-structure resonance in the study area.

## 2. Geology of Study Area

Geologically, the intermontane basin of Kathmandu Valley is formed within the Kathmandu nappe, which lies in the lesser Himalaya belt surrounded by Phulchowki and Chandragiri mountain ranges in the southern part, whereas the Shivapuri range in the northern part. Kageshwori Manohara municipality, one of the emerging urban local bodies of Nepal, lies in the northeastern part of the Kathmandu Valley covering an area of 28.8 km<sup>2</sup>. The basement of the municipality is formed from Precambrian to Paleozoic rocks which are highly faulted, folded, and fractured igneous and meta-sedimentary rocks (Sakai, 2001; Stöcklin, 1980). A 500-600 m thick Quaternary fluvio-lacustrine deposit was overlaid over these basement rocks (Paudel & Sakai, 2009; Yoshida & Igarashi, 1984). According to O. M. Shrestha et al. (1999), Kageshwori Manohara is situated in a weak geological structure with numerous fault lines, low bearing capacity, and loose soil structure, particularly influenced by the Manohara and Hanumante river systems. The study area is majorly formed from the Kalimati Formation, Thimi Formation, Gokarna Formation, and Tokha Formation as shown in Figure ??.

The central and northeastern part of Kageshwori Manohara municipality is predominantly composed of the Kalimati Formation with recent floodplain deposits of the Manohara and Hanumante rivers, while the Tistung Formation is observed in the southern section. The Kalimati Formation consists of black clay, grey to dark silty clay with fine sand substrate, organic clay, and peat layers (Paudel & Sakai, 2009; Sakai, 2001). The Gokarna Formation in the area is characterized by light to brownish-grey, fine laminated, and poorly graded silty sand, which is loose to slightly compact with moderate to high bearing capacity (Sakai, 2001; O. M. Shrestha et al., 1999). The Tistung Formation comprises slate, quartzite, and phyllite, whereas the Tokha Formation, also present in parts of the municipality, consists of fine-grained micaceous sand and silt with occasional clay lenses (Stöcklin, 1980; Yoshida & Igarashi, 1984). The majority of Kageshwori Manohara's urban and peri-urban communities are built on the Gokarna Kalimati formations. The dominant soil type over these formations is Kalimati clay/black clay, classified as soft soil, which is the primary contributor to seismic amplification in the municipality's free field due to its low bearing capacity and loose structure (O. M. Shrestha et al., 1999).

## 3. Methodology

Ambient vibration measurements were conducted using a high-sensitivity Atom-3C geophone velocimeter (Geometrics, USA), operating at a natural frequency of 2.5 Hz. The instrument captured three orthogonal components of ground motion: two horizontal (East-West and North-South) and one vertical (Up-Down). The study focused on determining the fundamental predominant period of both the ground and structures across 24 educational buildings, encompassing 40 individual structural units. Data acquisition was performed at a sampling rate of 250 Hz, with recording durations of 20 minutes for buildings and 30 minutes for ground measurements.

The recorded velocity-time histories were processed using GEOSPY, an open-source software designed for microtremor data analysis. To mitigate transient noise, an anti-triggering algorithm was implemented within GEOSPY. The short-time average (STA) and long-time average (LTA) were configured to 1 second and 25 seconds, respectively, with STA/LTA ratios constrained between 0.2 and 2, following SESAME (2004) guidelines. After noise filtering, 25–30 stationary time windows were extracted for spectral analysis. Fast Fourier Transformation (FFT) was applied to each window to derive the Fourier amplitude spectra, which were subsequently smoothed using the Konno-Ohmachi smoothing function with a bandwidth coefficient of 40 (Konno and Ohmachi, 1998) and a 5% cosine taper. The horizontal- to-vertical (H/V) spectral

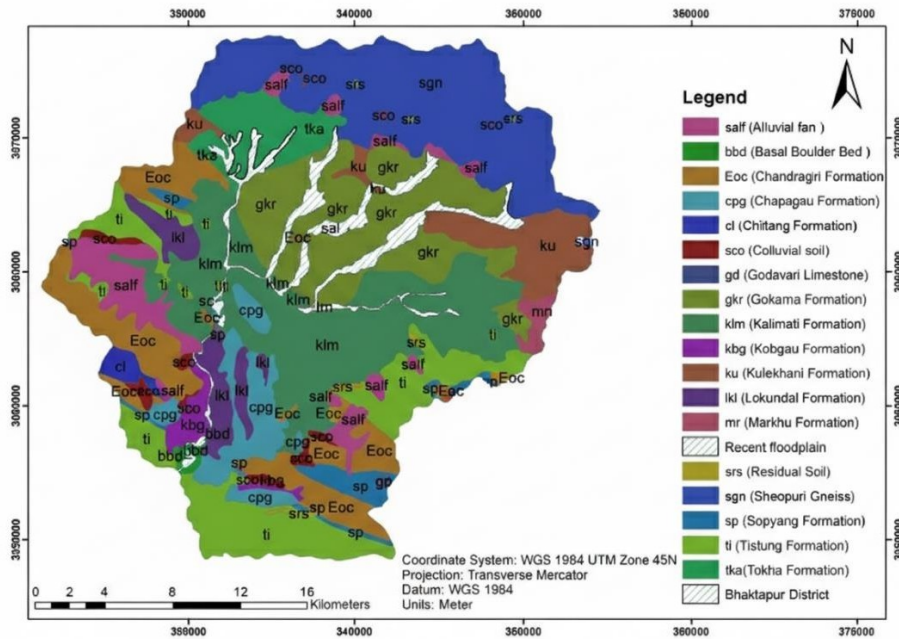


Figure 1. Engineering geological map of Kathmandu Valley (Redrawn and modified after O. M. Shrestha et al. (1999))

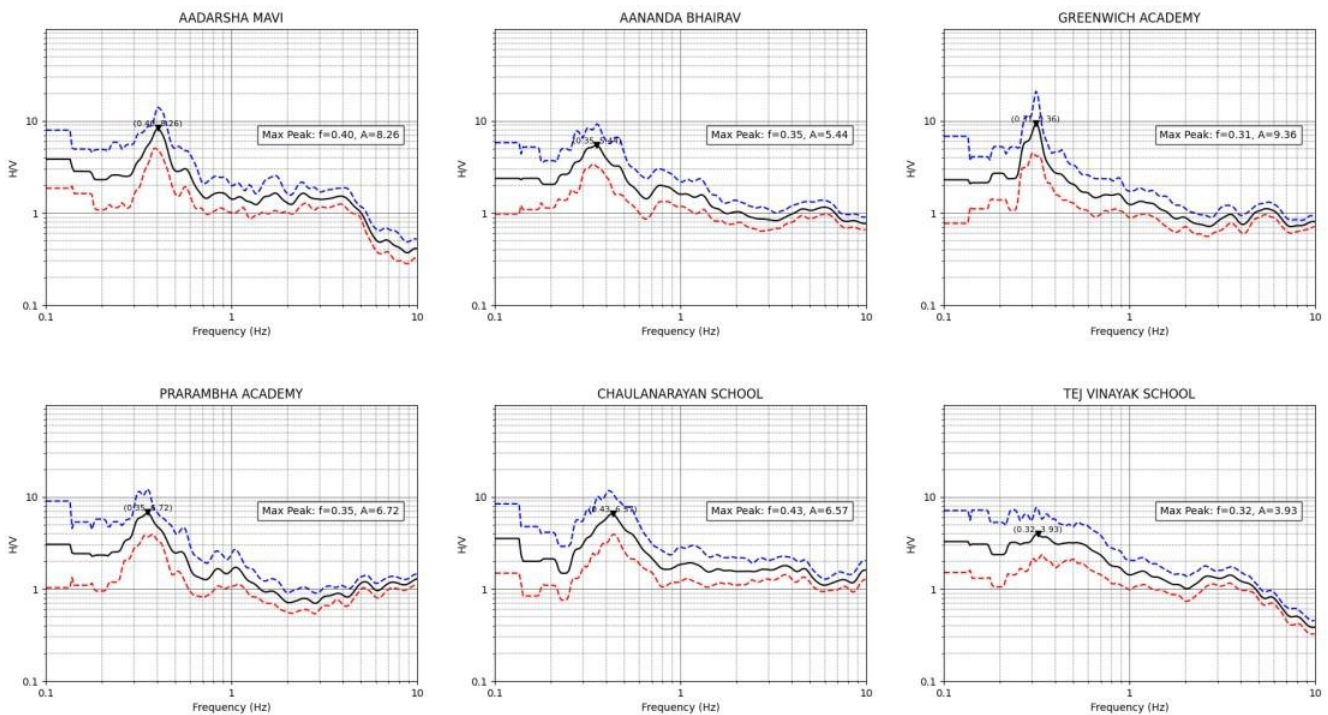


Figure 2. Some representative HVSR graphs of measurement stations of the study area

ratio was computed using the square average method to obtain the average spectral characteristics of H/V spectral ratios obtained from each analyzed window of a particular measured point. The fundamental period of the free field was determined by the clear peak in the HVSR, following

Gosar et al. (2010) and SESAME (2004). HVSR peak reliability was assessed per SESAME (2004) standards. The floor spectral ratio (H/H) identified the fundamental period of educational buildings, with its peak indicating the structures' fundamental period. Comparing HVSR and

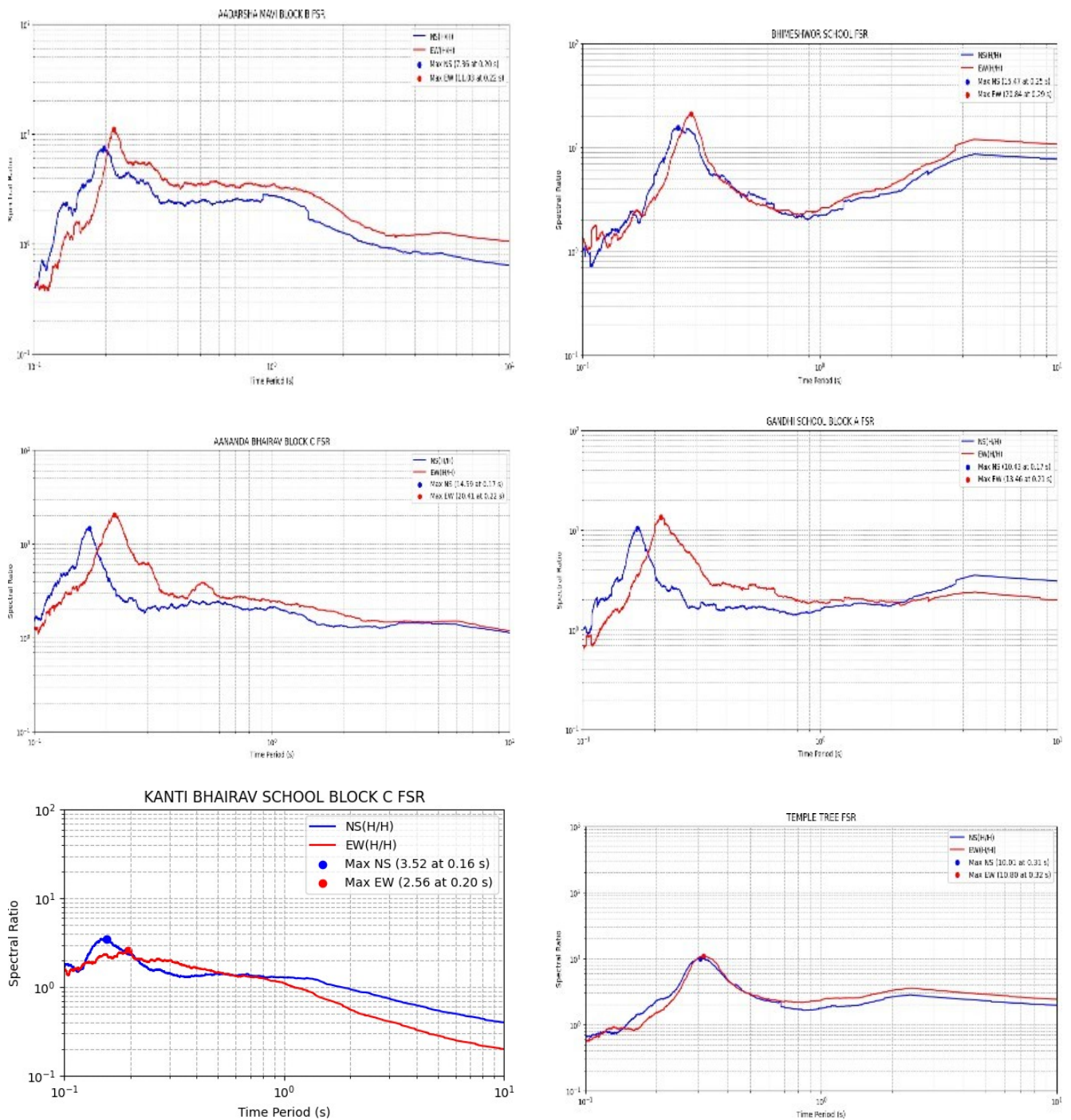


Figure 3. Some representative building period graphs of measurement stations

H/H periods revealed potential resonance in the buildings, critical for seismic vulnerability analysis.

#### 4. Results and Discussion

Representative HVSR plots from free-field stations at educational buildings are shown in Figure ?? . Most stations'

HVSR curves meet the reliability and clarity criteria outlined in SESAME (2004). Non-compliant stations were excluded from soil-structure resonance analysis. The microtremor data revealed diverse HVSR frequency peaks, including clear low- and high-frequency peaks, multiple peaks, broad peaks, and flat H/V curves, indicating heterogeneous subsurface soil and geological variations in

the study area.

Low-period site responses likely result from shallow sediment layers overlying bedrock, with clear HVSR peaks indicating strong impedance contrast between sediment and bedrock. Flat HVSR curves, observed in some cases, may reflect stiff sediment deposits over bedrock, leading to low impedance contrast and reduced amplitude. Multiple peaks in HVSR curves suggest impedance contrasts between multiple soil layers.

Velocity-time history data in three components (Up-Down, North-South, East-West) were recorded on the top and bottom floors of educational buildings and transformed into the frequency domain using Geopsy software (v3.5.2). Konno-Ohmachi smoothing (constant = 40) and anti-triggering were applied to remove transient noise, though frequency spectra showed minimal variation without noise removal. Clear peaks were observed across all signal components. Processed data were saved in .spec file format. The floor spectral ratio (FSR) was calculated using Python 3.12, determining the fundamental period via the H/H ratio of horizontal components (longitudinal and transverse) between top and bottom floors. Typical H/H ratio and building period graphs are shown in Figure ???. The fundamental periods of the buildings ranged from 0.11 to 0.37 seconds. Comparison with codal provisions revealed that codal periods exceeded those derived from microtremor measurements.

## 5. Conclusion

The microtremor Horizontal-to-Vertical Spectral Ratio (HVSR) technique was utilized to assess the spatial distribution of predominant periods for educational buildings and its respective ground in Kageshwori Manohara Municipality. Measurements were conducted at 24 educational sites, encompassing 40 buildings, using geophones. HVSR analysis, performed with Geopsy (v3.5.2), yielded ground fundamental periods ranging from 1.14 to 3.23 seconds. The Floor Spectral Ratio (FSR) method determined building dominant periods between 0.11 and 0.37 seconds. Comparison with codal provisions showed longer fundamental periods than those from microtremor data, suggesting no resonance risk between ground and structures. Regression analysis indicated a stronger correlation between building frequency and height alone compared to height combined with base dimensions, though multivariable regression confirmed both parameters significantly influence the fundamental period. The seismic vulnerability index of the buildings ranged from 44.96 to 282.61, identifying several structures as high-risk, particularly on soft, thin sedimentary deposits. Buildings exhibited higher seismic vulnerability in the east–west direction than in the north–south direction. These findings offer critical insights into site-specific seismic behavior

and structural response, aiding seismic hazard mitigation, earthquake-resilient design, and preservation of educational and heritage structures in the study area.

## References

- Akkaya, İ. (2020). Availability of seismic vulnerability index (k g) in the assessment of building damage in van, eastern Turkey. *Earthquake Engineering and Engineering Vibration*, 19(1), 189–204.
- Banerjee, P., & Bürgmann, R. (2002). Convergence across the northwest Himalaya from GPS measurements. *Geophysical Research Letters*, 29(13).
- Bettinelli, P., Avouac, J.-P., Flouzat, M., Jouanne, F., Bollinger, L., Willis, P., & Chitrakar, G. R. (2006). Plate motion of India and interseismic strain in the nepal himalaya from GPS and DORIS measurements. *Journal of Geodesy*, 80(8), 567–589.
- Chaulagain, H., Gautam, D., & Rodrigues, H. (2018). Revisiting major historical earthquakes in Nepal: Overview of 1833, 1934, 1980, 1988, 2011, and 2015 seismic events. *Impacts and insights of the Gorkha earthquake*, 1–17.
- Gosar, A. (2010). Site effects and soil-structure resonance study in the kobarid basin (NW Slovenia) using microtremors. *Natural hazards and earth system sciences*, 10(4), 761–772.
- Gosar, A., Rošer, J., Šket Motnikar, B., & Zupančič, P. (2010). Microtremor study of site effects and soil-structure resonance in the city of Ljubljana (central Slovenia). *Bulletin of earthquake engineering*, 8(3), 571–592.
- Helaly, A. L., & Ansary, M. A. (2021). Assessment of seismic vulnerability index of Rajuk area in Bangladesh using microtremor observations. *Soils and Rocks*, 44(2), e2021057420.
- Kawan, C. K., Maskey, P. N., & Motra, G. B. (2022). A study of local soil effect on the earthquake ground motion in Bhaktapur city, Nepal using equivalent linear and non-linear analysis. *Iranian Journal of Science and Technology, Transactions of Civil Engineering*, 46(6), 4481–4498.
- Konno, K., & Ohmachi, T. (1998). Ground-motion characteristics estimated from spectral ratio between horizontal and vertical components of microtremor. *Bulletin of the Seismological Society of America*, 88(1), 228–241.
- Ministry of Home Affairs (MoHA). (2015, December). *Nepal Disaster Report 2015* (tech. rep.) (Chief Editor: Rameshwor Dangal). Government of Nepal, Ministry of Home Affairs & DPNepal. Kathmandu, Nepal. <http://www.drrportal.gov.np/uploads/document/329.pdf>

- Mucciarelli, M., & Gallipoli, M. R. (2001). A critical review of 10 years of microtremor HVSR technique. *Bollettino di Geofisica Teorica ed Applicata*, 42(3-4), 255–266.
- Nakamura, Y. (1989). A method for dynamic characteristics estimation of subsurface using microtremor on the ground surface. *Railway Technical Research Institute, Quarterly Reports*, 30(1).
- Nogoshi, M., & Igarashi, T. (1971). On the amplitude characteristics of ambient noise (part 2). *J Seismol Soc Jpn*, 24, 26–40.
- Pandey, M. (1988). The distribution of intensity of the Bihar-Nepal earthquake of 15 January 1934 and bounds on the extent of the rupture zone.
- Paudel, M. R., & Sakai, H. (2009). Stratigraphy and depositional environment of late Pleistocene Sunakothi Formation in Kathmandu Basin, central Nepal. *Journal of Nepal Geological Society*, 39, 33–44.
- Paudyal, Y. R., Yatabe, R., Bhandary, N., & Dahal, R. (2012). A study of local amplification effect of soil layers on ground motion in the Kathmandu valley using microtremor analysis. *Earthquake Engineering and Engineering Vibration*, 11(2), 257–268.
- Paudyal, Y., Bhandary, N., & Yatabe, R. (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. (2021). Seismic hazard assessment of the Kathmandu valley and its adjoining region using a segment of the main Himalayan thrust as a source. *Progress in Disaster Science*, 10, 100168.
- Rana, B. (1935). Nepal ko maha bhukampa (great earthquake of Nepal). *Kathmandu, Nepal (in Nepali)*.
- Sakai, H. (2001). Stratigraphic division and sedimentary facies of the Kathmandu Basin Group, central Nepal. *Journal of Nepal Geological Society*, 25, 19–32.
- SESAME. (2004, December). *Guidelines for the implementation of the H/V spectral ratio technique on ambient vibrations: Measurements, processing and interpretation* (tech. rep. No. D23.12) (Sixth December). European Commission – Research General Directorate.
- Shakya, M., & Kawan, C. K. (2016). Reconnaissance based damage survey of buildings in Kathmandu valley: An aftermath of 7.8 Mw, 25 April 2015 Gorkha (Nepal) earthquake. *Engineering Failure Analysis*, 59, 161–184.
- Sharma, G., et al. (2016). Site response analysis of Kathmandu valley due to 2015 Gorkha earthquake. *Journal of Seismology*, 20(4), 1339–1355. <https://doi.org/10.1007/s10950-016-9591-2>
- Shrestha, O. M., Koirala, A., Karmacharya, S. L., Pradhananga, U. B., Pradhan, P. M., & Karmacharya, R. (1993). *Engineering and environmental geological map of the Kathmandu valley, scale 1:50,000* (tech. rep.) (Geological map). Department of Mines & Geology, Kathmandu, Nepal.
- Shrestha, O. M., Koirala, A., Hanisch, J., Busch, K., Kerntke, M., & Jäger, S. (1999). A geo-environmental map for the sustainable development of the Kathmandu Valley, Nepal. *Geojournal*, 49(2), 165–172.
- Shrestha, S. R., Karkee, M. B., Cuadra, C. H., Tokeshi, J. C., & Miller, S. N. (2004). Preliminary study for evaluation of earthquake risk to the historical structures in Kathmandu valley (Nepal) [Paper No. 172]. *13th World Conference on Earthquake Engineering*, 3.
- Stöcklin, J. (1980). Geology of Nepal and its regional frame: Thirty-third William Smith lecture. *Journal of the Geological Society*, 137(1).
- Talbot-Williams, S., Gosh, B., Wilkinson, S., Fenton, C., Burton, P., Whitworth, M., Datla, S., Franco, G., Trieu, A., Dejong, M., et al. (2016). Site amplification in the Kathmandu valley during the 2015 M 7.6 Gorkha, Nepal earthquake. *Bulletin of Earthquake Engineering*, 14(12), 3301–3315.
- Yoshida, M., & Igarashi, Y. (1984). Neogene to Quaternary lacustrine sediments in the Kathmandu Valley, Nepal. *Journal of Nepal Geological Society*, 4.

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