

Variation in Seismic Response of Basin Sediments in the Kathmandu Valley

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Abstract: The Kathmandu Basin, located within the Lesser Himalaya, consists of Plio-Pleistocene fluvio-lacustrine sediments overlying Precambrian-Paleozoic bedrock of the Kathmandu Complex. Its complex basement topography, variable sediment thickness, and contrasting geological conditions significantly influence seismic ground response. The basin contains loose sand and gravel along its margins, while silt and clay dominate the central areas. Sediment thickness reaches approximately 650 m, creating considerable variations in subsurface conditions. Historical earthquakes in 1934, 1989, and 2015 demonstrated differences in structural damage associated with local ground conditions and basin effects. Soft and unconsolidated sediments can amplify seismic waves, producing stronger ground shaking than nearby hard rock sites. This study examines variations in seismic response through subsurface velocity characterization and ground motion analysis. Borehole information and earthquake records from strong-motion stations installed on rock and sediment sites were used to develop shear wave velocity profiles. Modelling of an Mw 7.3 earthquake demonstrated differences in sediment response. Additionally, microtremor array measurements conducted at over 200 stations provided estimates of Vs30 and predominant frequency. The findings emphasize the importance of understanding subsurface geological variations and seismic amplification for assessing earthquake effects across the Kathmandu Basin and supporting infrastructure planning.

Keywords: Kathmandu basin, Seismic ground response, Basin effect, Ground motion amplification, Shear wave velocity, Vs30, Microtremor array, Sediment thickness.

Introduction

The Kathmandu Basin, an intermontane tectonic basin within the Lesser Himalaya is filled with Plio-Pleistocene sediment of fluvio-lacustrine facies sitting unconformably over the Precambrian-Paleozoic bedrocks of the Kathmandu Complex. Previous studies indicate that the rapid uplift of the Mahabharat Range south of Kathmandu (~ 2 ma) dammed the Proto-Bagmati River and created the Paleo-Kathmandu Lake which eventually drained around 12ka leaving a sediment-filled basin drained by the present Bagmati River system. The basin-fill sediments of Kathmandu mainly consist of loose sand and gravel on the fringes

and mostly silt and clay in the central part. Nevertheless, the basement topography of Kathmandu is highly undulated with around 650 m thick sediment at its thickest part while one can observe hillocks of bedrock jutting through the sediments to form rock exposures inside the basin at several places.

The earthquake shaking as combination of source, path, and site properties play a vital role in the effect of earthquakes on infrastructure. An earthquake with seemingly no effect above hard ground can be felt as a strong tremor that can cause severe damage in areas above soft or unconsolidated sediments due to the amplification of seismic waves. This variation in damage to structures was observed during the past earthquakes- namely in 1934, 1989, and 2015 earthquake. The basin effect evident during those earthquakes added to the woes. The variation in basement topography, geology, basin structure, and the depositional environment make it difficult to generalize the subsurface geologic structures and seismic ground response of the Kathmandu basin as a whole.

A thorough analysis of ground motion amplification in the basin is necessary to quantify the variation. The mapping of the subsurface velocity structures is a necessary precondition to achieve that goal. Available borehole data, earthquake records from the strong-motion seismic stations installed in the rock and sediment site of the basin gave the necessary details to prepare the shear wave velocity profile of the Kathmandu Basin (Figure 1). The modelling of Mw 7.3 earthquake using the velocity profile clearly demonstrate the variation in seismic response of sediments. Similarly, microtremor array measurements were carried out in 200+ stations around the basin to calculate the Vs30 and predominant frequency of the basin.

Influence of Basin Sediments on Seismic Ground Response

The seismic response of the Kathmandu Basin is strongly influenced by variations in sediment composition, thickness, and underlying bedrock topography. The basin contains loose sand and gravel

along its margins, while the central regions are predominantly composed of silt and clay. These differences in geological materials contribute to variations in ground shaking during earthquakes. Soft and unconsolidated sediments can amplify seismic waves, resulting in stronger tremors and potentially greater structural damage compared to areas underlain by hard rock. The irregular basement topography, with sediment thickness reaching approximately 650 m in some locations, further contributes to the complexity of seismic wave propagation within the basin.

The effects of local geological conditions were observed during the earthquakes of 1934, 1989, and 2015, when differences in structural damage highlighted the importance of site-specific seismic response. The interaction between seismic waves and sedimentary deposits can produce varying levels of ground motion amplification across the valley. As a result, areas within the same basin may experience different shaking intensities depending on their subsurface geological characteristics. The complex depositional environment and variations in basement structure make it difficult to apply a single generalized seismic response model to the entire Kathmandu Basin.

To investigate these differences, shear wave velocity profiles were developed using borehole information and earthquake recordings from strong-motion stations located on both rock and sediment sites. Ground motion modelling of an Mw 7.3 earthquake demonstrated variations in the seismic response of different sedimentary conditions. Furthermore, microtremor array measurements conducted at more than 200 stations were used to estimate Vs30 and predominant frequency throughout the basin. These investigations provide a basis for understanding how geological variations influence seismic ground motion and for assessing differences in earthquake response across the Kathmandu Valley.

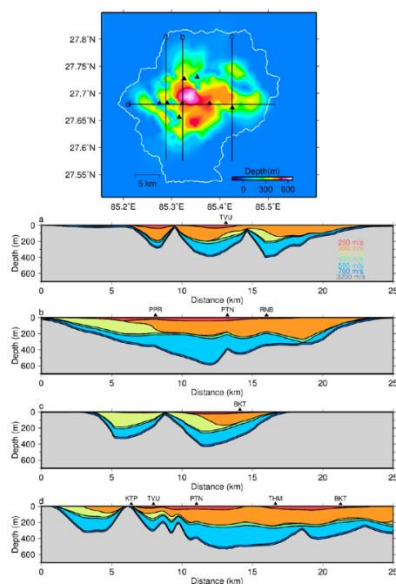


Figure 1. 3D velocity profile the Kathmandu Basin.

The 3-D velocity structure and the quantification of sediment property by Vs30 (Figure 2) and fundamental frequency can be an important tool in the disaster management study of the Kathmandu Basin. It can be used for study of probable scenario earthquakes and their effect in the basin in case of future earthquakes.

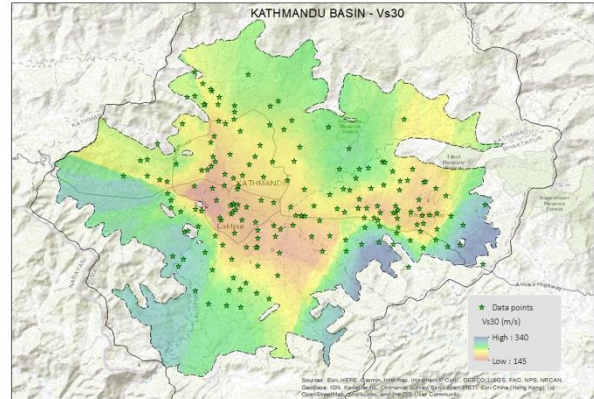


Figure 2. Vs30 map of the Kathmandu Basin.

Conclusion

The Kathmandu Basin exhibits significant variations in seismic ground response due to its complex geological structure, irregular basement topography, and differences in sediment composition and thickness. The presence of soft and unconsolidated sediments can amplify seismic waves, producing stronger ground shaking compared to hard rock areas. Observations from the earthquakes of 1934, 1989, and 2015 highlight the importance of local geological conditions and basin effects in understanding variations in structural damage across the valley.

The study emphasizes the importance of subsurface shear wave velocity characterization and ground motion analysis for evaluating seismic response. Borehole data, strong-motion earthquake recordings, and microtremor array measurements provide information for understanding variations in subsurface conditions. Modelling of an Mw 7.3 earthquake further demonstrates that sedimentary conditions can influence seismic ground motion differently across the basin.

Overall, the findings highlight the need for detailed geological and geophysical investigations rather than generalized assumptions about seismic behavior throughout the Kathmandu Valley. Understanding variations in sediment thickness, basement structure, shear wave velocity, and predominant frequency is essential for assessing ground motion amplification and supporting seismic hazard assessment and infrastructure planning within the basin.