Journal of Geology & Geophysics

OPEN ACCESS Freely available online

Research Article

Frequency Dependent Damage Pattern in Kathmandu Valley Due to Mw 7.8 Gorkha Earthquake

Navin Thapa[1], Kiran Pandey[2], Subesh Ghimire[1]* and Kamala Kant Acharya[1]

[1]*Central Department of Geology, Tribhuvan University, Kathmandu, Nepal*

[2]*Center for Earthquake Research and Information, University of Memphis, Tennessee, USA*

ABSTRACT

The Mw 7.8 Gorkha Earthquake (25th April 2015) is powerful earthquake ripped through Central Nepal occurs about 77 Km northwest of Kathmandu Valley. Several studies reveal the fact that comparatively larger earthquake damage in the Kathmandu valley are associated with the valley ground structure. Study focus on reason behind clustering of damages due to mainshock (7.8 Mw) inside Kathmandu valley in certain pattern and its dependency with frequency content of the shattered waves. Data used to meet objective of present research are ground motion data and damage data, for ground motion data seismic stations inside the valley are use. The damage data are collected by both primary and secondary sources. Frequency domain spectral analysis is incorporated in research and found that the maximum power and amplitude, associated, and attributed for particular narrow frequency band. Spatial component of frequency is wavelength which may indicate periodic repetition of maximum power with crest and trough. To estimate spatial distribution of maximum amplitude simplified wave relation is used. Study reveals that the lateral extension of the peak destruction zone as fourth of wavelength and the successive distance between peak destruction zones is half of wavelength. Peak destruction zone, the zone where the damage is maximum and lies either on crest or trough of the propagated wave. Study reveals that propagation of waves is S45oE form the epicenter of Gorkha Earthquake. Heterogeneity in damage on peak destruction zone can be contributed by the variation in geology of Kathmandu Valley.

Keywords: Earthquake engineering; Gorkha earthquake 2015; Seismotectonics; Damage pattern

INTRODUCTION

The Himalayan arc is one of the major zones of deformation that have enthralled the indentation of India in to Eurasia [1]. It is assumed that about 50% of the plate convergence is consumed across this narrow belt of the Himalaya [2]. Moderate to great earthquakes have struck the region frequently and paleoseismology provides evidence of mega earthquake with magnitude exceeding M 8.5 [3].

The April 25, 2015, Mw 7.8 at 11:56, powerful earthquake ripped through Central Nepal at about 77 km northwest from the capital city of Nepal, Kathmandu. The earthquake was followed by 25 aftershocks of greater or equal to 5 local magnitude along with another major shock of Mw 7.3 of May 12th, 2015 with epicenter in Dolakha district [4]. According to the report of Nepal government 8,792 people dead and more than 750,000 houses were either collapsed or damaged partially [5].

Kathmandu valley lies between latitude of 24°32' N to 27°16; N and longitude of 85°31'28"E to 85°31'53"E. Since the Kathmandu valley is the part of a collisional orogenic belt, it has experienced periodic large earthquakes in past centuries. Geological exploration in Kathmandu valley has revealed that valley is an ancient lake deposit, which extends several hundred meters at the deepest point and is comprises of thick layers of clay, silt, sand, and gravel in irregular layers of deposition ranging in age from the late Pliocene era to the present [6]. These sediments overlying the basement rock of the Phulchauki Group and the Bhimphedi Group of the Kathmandu Complex. Based on previous studies as well as paleo-climatic study of the Kathmandu Basin conducted by Sakai et al. [7], the valley sediments is divided into three groups: (1) marginal fluvio-deltaic facies in the northern part, (2) open lacustrine facies in the central part, and (3) alluvial fan facies in the southern part. The basin sediment thickness and material properties vary from place to place, which may cause trapping and focusing of seismic waves during an earthquake, leading to an evident change in resonant frequency over short distances.

According to hypothesis created, the damage in the Kathmandu valley is not haphazard, in fact, it follow the physical law of wave

***Correspondence to:** Subesh Ghimire, Central Department of Geology, Tribhuvan University, Kathmandu, Nepal, E-mail: shghimire2001@gmail.com

Received: July 15, 2019; **Accepted:** January 21, 2020; **Published:** January 28, 2020

Citation: Thapa N, Pandey K, Ghimire S, Acharya KK (2020) Frequency Dependent Damage Pattern in Kathmandu Valley Due to Mw 7.8 Gorkha Earthquake. J Geol Geophys 9:471. 10.35248/2381-8719.20.9.471

propagation. This study aims to study influence of local geology and topography on the intensity of ground shaking caused by April 25th, Mw 7.8, Gorkha earthquake. The amplification of the ground motion due to local site effects resulted in several damage in Kathmandu valley. The frequency- dependent model is analyzed in this study. This will helps to determine the deformation pattern in Kathmandu valley due to April 12th, Mw 7.8 major shock.

METHODOLOGY

Data collection

Data for the damage of structure were collected by the field assessment as well as extracted from other reliable sources. During field assessment, first, the areas like Balkhu, Kirtipur, Kuleshwor, Balaju, and Basantapur Durbar Square were visited right after the earthquake. Thereafter, for the assessment of monument destruction, Lalitpur, Bhakatpur and Kathmandu districts were studied. During the assessment for monument, destruction parameters like: general impression of damage, geology, orientation of temple after disaster, geomorphology of the location, building material, etc. were considered. After the field assessment, data collected by reliable sources like NGA, UNOSAT and Copernicus were collected. Damage assessment done for Mw 7.8 Gorkha earthquake by NGA, UNOSAT and Copernicus found that a total of 12578 buildings were mapped, out of which 33.2% (4170) buildings were marked as 'No damage", around 46% (5750) of building were categorized as 'Moderate to severe damage and rest 20% (2658) were found destroyed. Among these data 3656 number of mapped building were inside the valley which are considered in the study. Structural damage is not classified or selected based on age and engineering practices.

For the Ground Motion data, stations within the Kathmandu Valley were considered; namely, station of DMG, Hokkaido University (TVU, THM, and PTN) and USGS (KATNP). For the data of epicenter, USGS catalogue was used.

Wavelength calculation

Damage in the Kathmandu valley was not hap hazard, in fact, it follows the physical law of wave propagation. The amplification of the ground motion due to local site effects resulted in several damage in Kathmandu valley. The frequency- dependent model is analyzed in this study. This helps to determine the deformation pattern in Kathmandu valley due to April 25th, Mw 7.8 major shock.

Frequency containing the maximum power were picked from all the stations. From the simple wave relation (Figure 1), we calculated the wavelength. The relation between the frequency and the wavelength is: $V=f \times \lambda$, where, V is the velocity of seismic wave, f is its frequency, and λ is the wavelength, Kramer[8] formulated relationship between frequency, thickness and shear wave velocity as follows: $F_0=V_s/(4T)$, where F_0 is frequency, V_s is shear velocity and T is the thickness. Frequency is calculated from the waveform data. For the thickness, Sakai mentioned that the Kathmandu Valley is an ancient lake deposit and is made of thick layers of clay, silt, sand, and gravel. The maximum thickness of the valley soil is 500-600 m at the center of the valley [7]. Also, Pandey (2000) [9] mentioned that shear wave velocity of granular section is about 1200 m/s and 600 m/s for the lacustrine clay in the Kathmandu valley sediment.

Fourier amplitude and power spectra

To discuss the destructive power of observed ground motion in Kathmandu valley, spectral analysis was carried out. Fourier transforms to the frequency domain shows that NS and EW components of all Stations were dominated by low frequency. Dominant frequency of mainshock recorded at each station of two components (NS, EW) are tabulated along with the maximum amplitude and power spectra.

Spectral acceleration shows mainshock has a higher value over a lower range of frequency (0.22 Hz) at KATNP station. Figure 2 shows the dominant frequencies of mainshock in all three direction recorded at respective stations. In all station that are on soil and rock site, all of the components are dominated by low frequency less than or equal to 1 Hz. Station KTP (Rock site) has variable frequency content, with peak Fourier amplitude and power spectra for the EW component at 4.137 Hz, the NS component at 3.023 Hz and the UD component at 0.126 Hz. The peak value of Fourier amplitude and power spectrum of all station are presented in Table 1 on the basis of frequency of occurrence.

Mathematical calculation of wavelength

Dominant frequency of the mainshock recorded at each station of components (NS, EW) are tabulated along with the maximum amplitude and power spectra (Table 2). Using the relationship between frequency, wavelength and propagation velocity wavelength of recorded waves at each station is then calculated (Table 2). Considering a complete wavelength, there occur two maximum amplitude: one with maximum positive value (Crest Value) and other with negative value (Trough value) (Figure 1). These calculated crest and trough are then plotted in the map (Figure 4).

RESULTS AND DISCUSSION

Projection of calculated peak destruction lines and zone in Kathmandu valley map

We found that the maximum power and amplitude was associated with particular narrow frequency band. Which can be attributed for the particular frequency. Spatial component of frequency is wavelength which indicates periodic repetition of maximum amplitude with crest and trough. Amplitude is the maximum

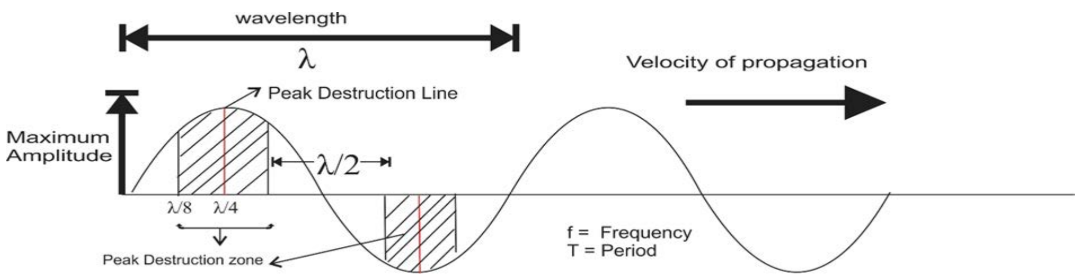

Figure 1: Schematic representation of wave travelling, showing peak destruction line and peak destruction zone (dense parallel line).

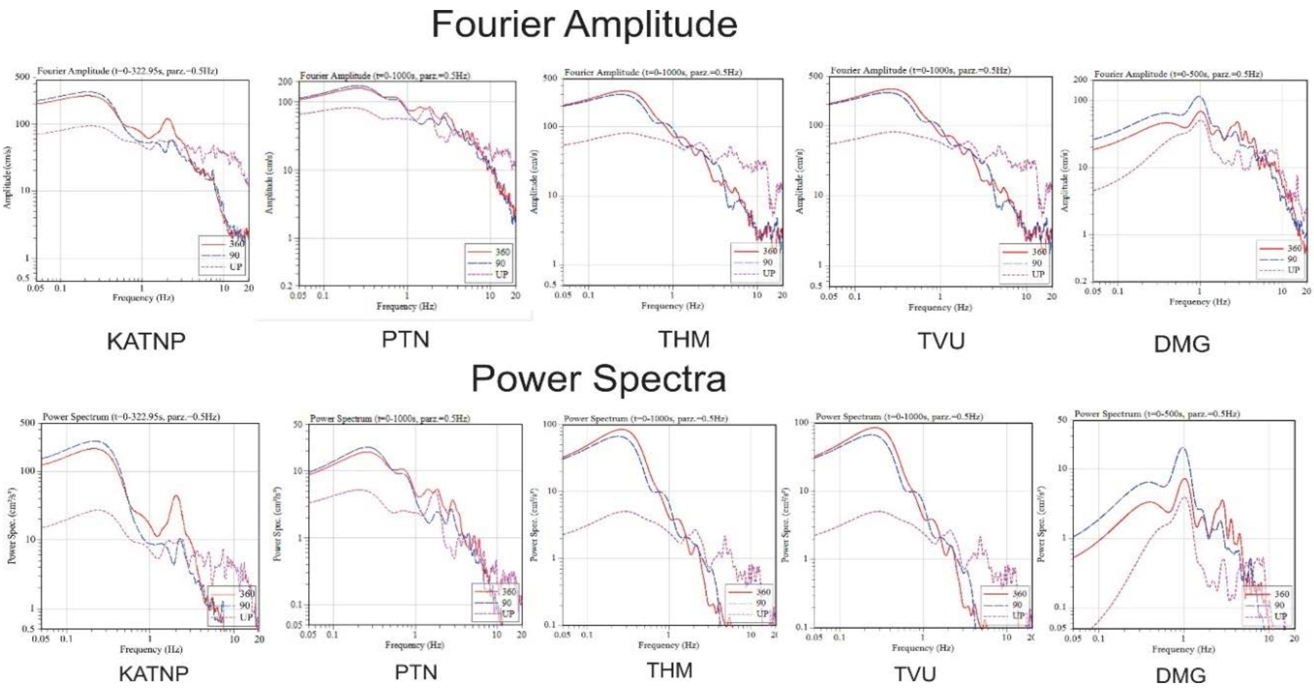

Figure 2: Fourier amplitude and power spectra of KATNP (USGS), DMG, PTN, THM, TVU of Hokkaido University.

Table 1: Fourier amplitude and power spectra of KATNP (USGS), DMG provided department of mines and geology, PTN, THM, TVU of Hokkaido University, all stations are on soil site.

Stations	PTN		THM		TVU		DMG		DMG	
Component	NS/360	EW/90	NS/360	EW/90	NS/360	EW/90	NS/360	EW/90	NS/360	EW/90
Power spectrum (cm^2/s^3)	45.77	64.25	301	242.1	121.3	111	14.62	48.32	654.6	918.1
Fourier amplitude (cm/s)	244.9	290.2	628.2	563.3	398.7	381.5	97.87	178	436.2	548.5
Frequency (Hz)	0.242	0.242	0.259	0.232	0.391	0.327	1.051	0.949	0.21	0.217

Table 2: Peak frequency of different component at different stations (KATNP, TVU, THM, PTN, DMG).

Stations	Component	Frequency (Hz)	Velocity (m/s)	Wavelength (m)	Half Wavelength (m)
PTN	NS/360	0.242	950	3925.619	1962.809
	EW/90	0.242	950	3925.619	1962.809
THM	NS/360	0.259	950	3667.953	1833.976
	EW/90	0.232	950	4094.827	2047.413
TVU	NS/360	0.391	950	2429.667	1214.833
	EW/90	0.327	950	2905.198	1452.599
DMG	NS/360	1.051	950	903.901	451.950
	EW/90	0.949	950	1001.053	500.526
KATNP	NS/360	0.211	950	4502.369	2251.184
	EW/90	0.217	950	4377.880	2188.940
Average	-	-	-	3173.409	1586.704

displacement of points on wave, which is degree or intensity of change. It represent peak value of power. On the basis of which the destruction in the Kathmandu valley due to seismic wave generated by Gorkha earthquake was assumed to be clustered on the area or peak destruction line. The calculated peak destruction line (PDL) is the line containing maximum amplitude (Destructive power) of the wave which might be either positive or negative (Figure 1). Wavelength calculated are projected in the map with the radius of multiple of 1586.704 m (half of wavelength) from the epicenter of the Mw 7.8 Gorkha Earthquake (28.231°N 84.731°E) which is represented by thin line and termed as calculated peak destruction line (Figure 4). Azimuth of propagation direction is S45°E. First wavefront that struck the Kathmandu valley was about 76.96 km from epicenter. Distance between two wavefront (PDL) is 1586.704 m i.e. half of wavelength. The peak destruction zone is calculated thereafter (Figure 4). The lateral extension of the peak destruction zone is equal to one fourth of wavelength (793.35 m). Figure 4 shows the calculated Peak Destruction Line (PDL) and Peak Destruction Zone (PDZ) in Kathmandu Valley.

Damage pattern in the Kathmandu valley

Overlapping these peak destruction zone over the observed damage (structural damage, liquefaction and ground failure) shows that maximum destruction is clustered along and around the PDZ (Figure 4). Bhaktapur Durbar Square area, Kathmandu Durbar

Square area, Balaju and Gongabu area, Patan Durbar Square area are severely destroyed by Gorkha earthquake and form the present study, these areas falls under the peak destruction zone (Figure 4).

Over lapping these PDZ over observed damage, shows that maximum destruction is clustered along and around the calculated PDZ. This matching of PDZ and damage support the objective of research. However, heterogeneity is seen which might be due other constraint like site geology, topography and ill engineering practices, among them role of site geology is discussed here. Kathmandu Valley being narrow and deep basins during earthquake body waves transform into surface waves. This phenomenon creates two dimensional resonances, especially at the basin edge, results in significant amplification in the surface ground motion. The severe damages observed along the basin edges of Kathmandu Valley in Bhaktapur, Patan, Syambhunath, and Sakhu indicates the potential amplification due to basin edge. Most of the building structure in Sakhu and Bhaktapur either collapsed or suffered severe damage after the mainshock, and to be noted, these areas falls under the peak destruction zone (Figure 4).

When significant earthquakes like the 2015 Gorkha earthquake strikes the Kathmandu valley, the variation in geology and landscapes of the valley results heterogeneity in destruction pattern (Figure 5). Central part of the valley comprises of the Kalimati Caly, and the Recent Fluvial sedimentary deposit where the damage is severe. The Kalimati Clay is predominantly made up of black clay or silt beds with some thin beds of fine to very fine sand and diatomite [10]. The severe damage observed where the Kalimati Clay is distributed are Patan Durbar Square area, Guwarko, Balkhu,

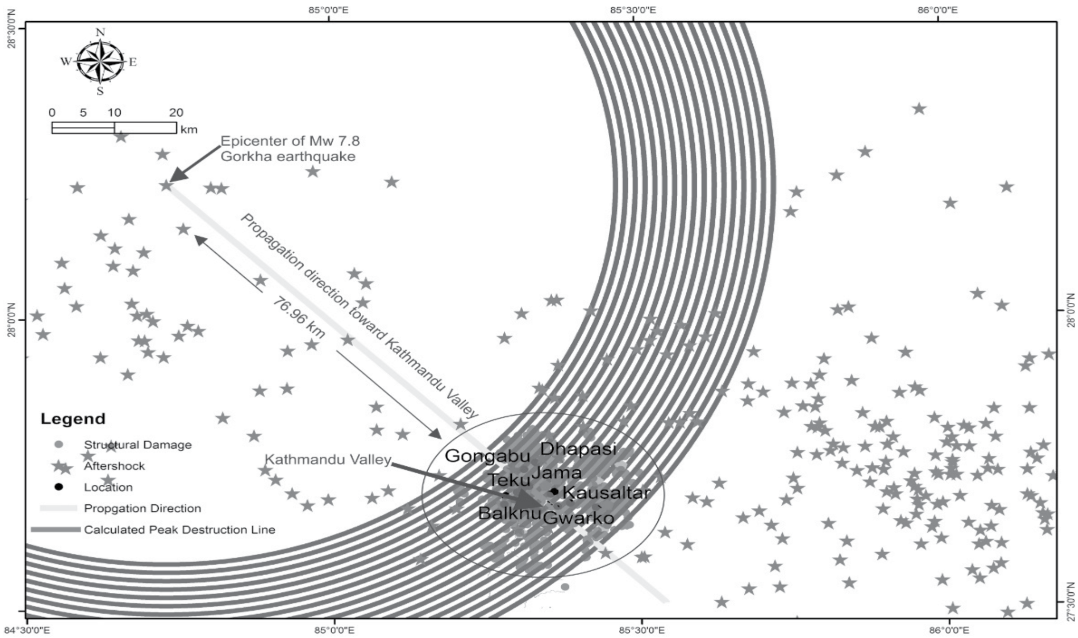

Figure 3: Projection of crest and trough from epicentre towards Kathmandu valley.

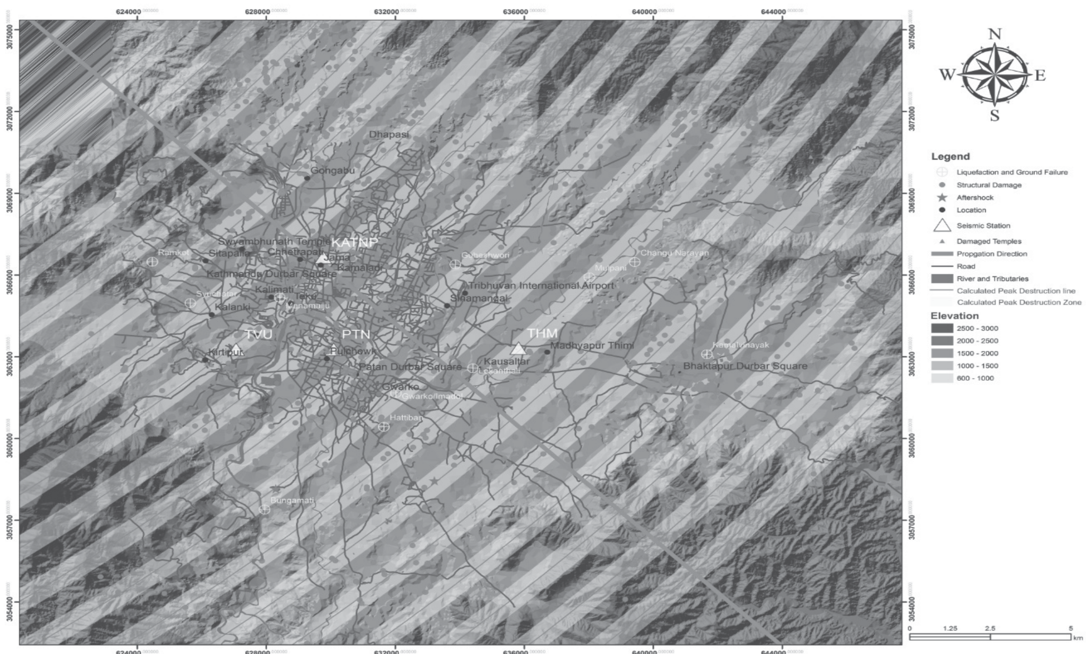

Figure 4: Map exhibiting relationship between the observed structural damage and calculated peak destruction zone.

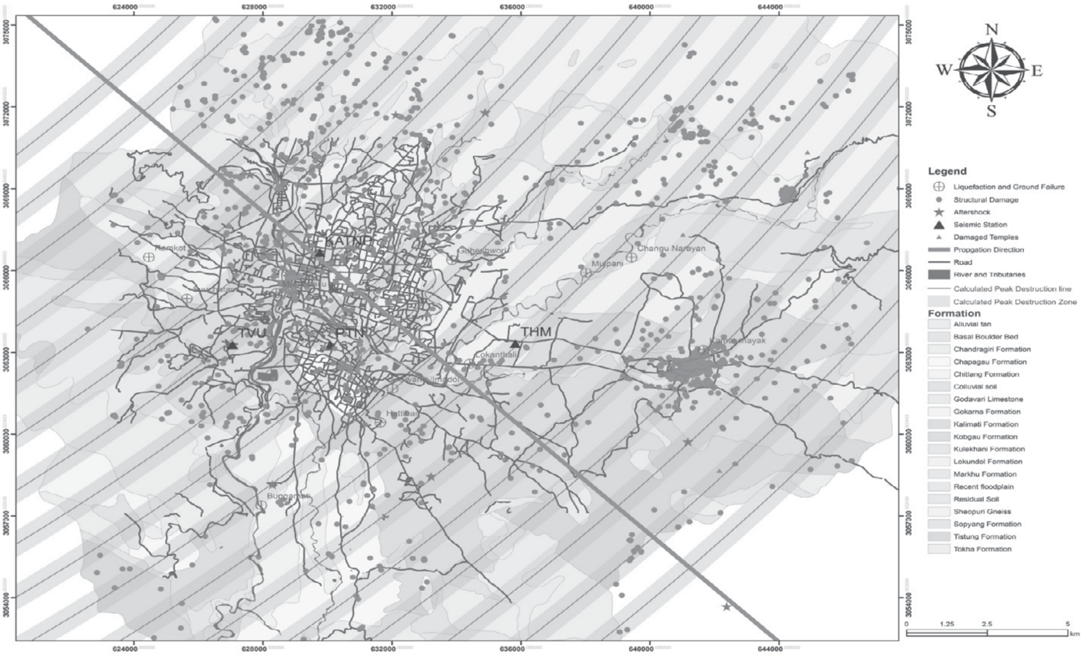

Figure 5: Comparison between structural damage data (red Dots only) and geology of Kathmandu valley (after DMG, 1998).

Kathmandu Durbar Square area, Bhaktapur Durbar Square area, Sitapaila, Kalanki etc (Figure 5) these are also the location that are under the Peak Destruction Zone (PDZ). Recent flood plain also termed as the Lower terrace deposits are extensive along the Bagmati and its tributaries. The sediments contain micaceous sand, pebbles and granules [11]. Places where recent flood plain deposit have sever destruction due to shaking of 2015 Gorkha earthquake, The structural damage and liquefaction observed in Gongabu area is comprises of this type of lithology. Along the Bagmati River and its tributaries: Bisnumati River, Manahara River severe destruction was observed which indicate that those area are more vulnerable during seismic loading.

Gokarna Formation is a fluvio-lacustrine deposit that occupies the north part of the valley. This formation is comprises of dark brown colored, laminated arkosic sand, silty clay, and peat [10]. Some part of this formation lies under the peak destruction zone (Figure 4) and is severely affected by 2015 Gorkha earthquake. Manohar, Dudhkhel on the north part of valley, Kaushaltar, Sinamangal area lies in this formation and is severely affected area. Liquefaction and ground failure are not densely present in this formation. Kausaltar is only one place that is noted for liquefaction after mainshock.

CONCLUSION

Present study focuses on the pattern of structural destruction caused by the 2015 Gorkha earthquake in the Kathmandu valley. Based on which following conclusion is derived:

- Using the relationship between wavelength, frequency and velocity, wavelength of propagated seismic wave is calculated which is 3173.409 m. The half of wavelength 1586.704 m shows the difference between peak destruction lines. Peak destruction line are the lines perpendicular to the propagation direction, which contain maximum amplitude and power of destruction.
- Peak destruction zone have width of 793.35 m: 396.67 m on both side of the peak destruction line.
- The investigation reveals that maximum destruction in valley were clustered along the crest and trough of the propagated wave, followed by mild damage and again the clustering of severe damage repeated at the distance of half of the wavelength. This type of severe damage pattern is perpendicular to propagation direction.
- Comparison between calculated peak destruction zone and observed damage date shows that the calculated peak destruction zone form theoretical assumption mostly include the maximum damage (Structural damage, liquefaction and ground failure) caused by the MW 7.8 Gorkha earthquake.
- Heterogeneity in damage on peak destruction zone can be contributed by the variation in geology of Kathmandu Valley. The Kalimati Clay, Gokarna Formation and the Recent Flood Plain deposits are the formation with massive destructions.
- Heterogeneity in damage on peak destruction zone is also controlled by slope constraint.

ACKNOWLEDGEMENT

We would like to acknowledge Central Department of Geology, Tribhuvan University for providing opportunity for the research. Likewise, we are highly indebted to Dr. Soma Nath Sapkota, Mr. Bishwa Silwal and Mr. Mukunda Bhattarai from Department of Mines and Geology (DMG) for being so generous as to provide me with much needed materials, literature that we could not possibly have discovered on my own. We would also like to express my gratitude to Center for Geological and Environmental Research (CGER) for providing stimulating atmosphere to work in, the much-needed time to relax and help me put things in perspective.

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