13th World Conference on Earthquake Engineering
Vancouver, B.C., Canada
August 1-6, 2004
Paper No. 172

PRELIMINARY STUDY FOR EVALUATION OF EARTHQUAKE RISK TO THE HISTORICAL STRUCTURES IN KATHMANDU VALLEY (NEPAL)

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SUMMARY

In this study, an attempt to assess the seismic vulnerability of the historical infrastructures like temples and stupas of Kathmandu valley, Nepal was carried out. The estimation of periods of multi-tiered temples was done by using empirical equations. To estimate the periods of soil, theoretical transfer function of SH waves was used. It is found that there may not be severe impact to the temples located at the valley floor during far field earthquakes due to difference in predominant period of temples, stupas and the ground. However, temples and stupas which have experienced some past earthquake motions could exhibit longer natural period due to existing cracks. In such cases, there are possibilities of resonance effect because the period of temples and stupas are closer to the predominant period of the ground. Likewise, the temples located at the border of the Kathmandu Valley may have severe damage from resonance effect due to the short periods of temples and sites near rock outcrops. It is observed that most of the important temples like Pashupatinath, Nyatpol, Gujeshwori, Krishna Mandir, Banglamukhi and stupa like Boudhnath are situated over geological formations which may be at risk of liquefaction under sever seismic impact. These results are from the preliminary phase of analysis, and detailed field measurements such as the periods of structures, soil and various sub-surface structures are necessary for the further investigation.

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INTRODUCTION

Nepal lies in a region of high seismic activity and has a long history of destructive earthquakes. Large earthquakes with magnitude of 5 to 8 on the Richter scale have been experienced throughout the country during past 200 years, of which 279 earthquakes had epicenters in and around Nepal [1]. The 1934 Nepal-Bihar earthquake had severely affected the lives and building stocks of Kathmandu Valley (Figure 1) [2] and [3]. In Kathmandu city itself, one quarter of all houses were believed to be destroyed. This earthquake was not an isolated event but three earthquakes of similar size have occurred in Kathmandu valley in the 19th century viz. in 1810, 1833, and 1866 AD.

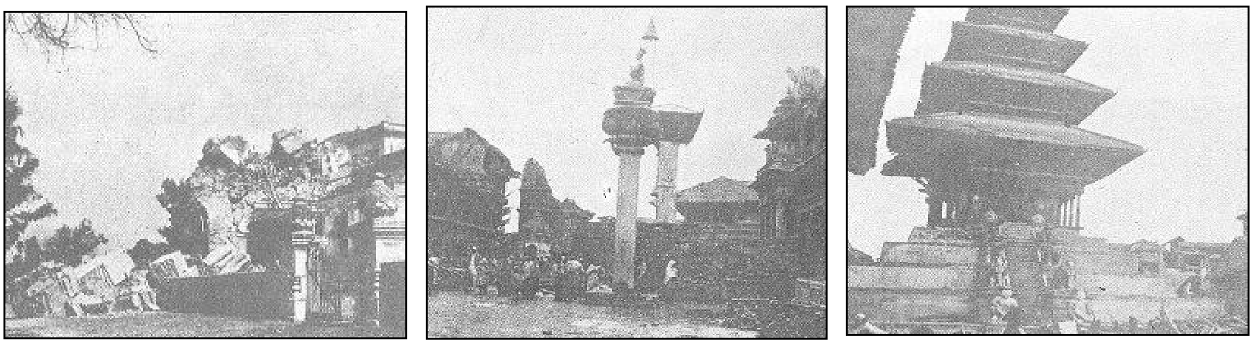


Figure 1: Damage of 1934 Earthquake in Kathmandu Valley.

It is speculated that similar kind of an earthquake near Kathmandu valley would leave behind significantly greater devastating sites in respect of loss of lives, casualties and property damages. Rapid population growth caused the development of uncontrolled and non-engineered settlements. This practice has enhanced the valley's vulnerability to earthquakes. Some research has been carried out in a scattered manner but ample research to combat such serious problems has not yet been done in full scale. Therefore, there is an urgent need for research in the sector of Risk Assessment and Management to conserve the culture and heritage valley from the upcoming possible disaster.

History has given Kathmandu valley some of the world's best examples of art and architecture. UNESCO has recognized Pashupatinath temple, Changu Narayan temple, Boudhnath stupa, Kathmandu Durbar square, Patan Durbar square and Bhaktapur Durbar square as World Heritage sites in this valley. But these precious heritage structures are at the risk of possible damages by upcoming earthquakes. Therefore, proper research to understand the behavior of these structures with respect to soil is needed for possible upcoming seismic impact prediction. This preliminary research attempts to assess vulnerability of the historical infrastructures like temples and stupas of Kathmandu Valley.

OBJECTIVES

The overall objective of this study was to build a database of available geo-spatial and geohazard information and to study the vulnerability of the historical temples and stupas in the Kathmandu Valley to earthquakes using Geographic Information System (GIS).

THE STUDY AREA: KATHMANDU VALLEY

Physiographic Settings

Kathmandu valley is Nepal’s large intermontane basins in the Lesser Himalayas which lies in the central part of Nepal between the Siwalik (Sub-Himalayan) and the Higher Himalayan ranges. It is located at the latitude range of $27^{0}31’27”$- $27^{0}50’13”$ N and longitude range of $85^{0}12’6”$- $85^{0}31’52”$ E. It is mainly comprised of three districts viz. Kathmandu, Lalitpur and Bhaktapur. Siwalik zone consists of fluvial sedimentary rocks of Neogene to Quaternary age. Figure 2 shows the zone is bounded to the north by Main Boundary Thrust (MBT) and the south by the Main Central Thrust (MCT). Lesser Himalayan metasedimentary rocks have been thrust southward over the Siwalik rocks along this thrust; and a larger part of the Siwalik must be found buried beneath the cover of the over thrust Lesser Himalayan rocks to the north. Higher Himalayan zone includes the rocks lying north of the MCT and below and south of the fossiliferous Tethys Himalayan zone [4].

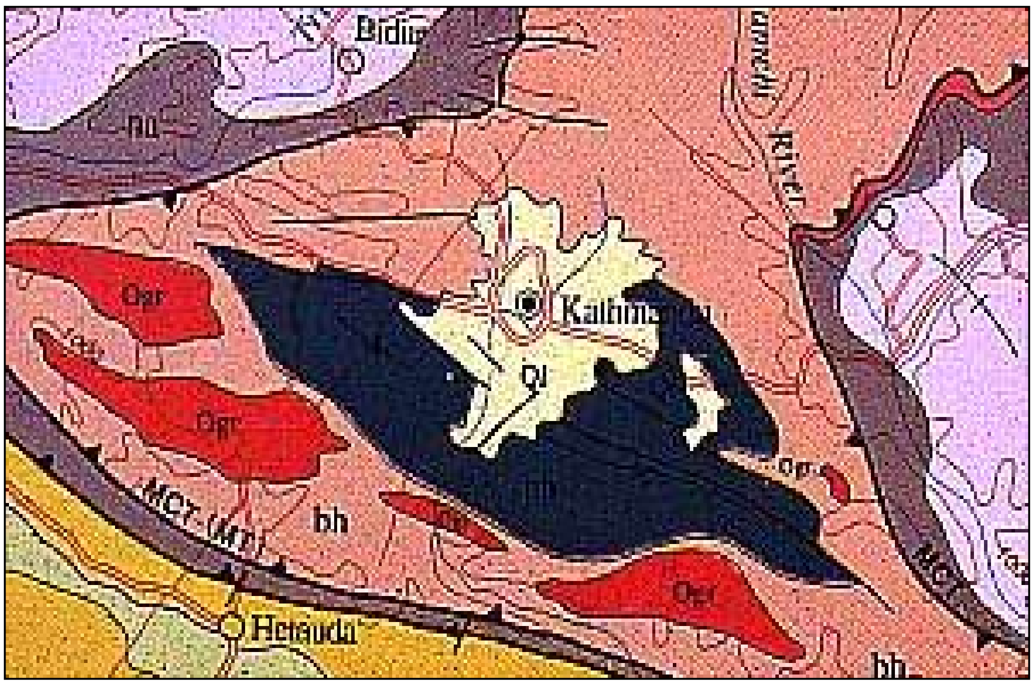


Figure 2: Geological Map of Kathmandu Valley sectioned from Geological Map of Nepal

The Lesser Himalaya is a wide, stratigraphically and structurally complex zone that lies immediately north of the Siwalik Fold Belt and is separated from it by the south-verging Main Boundary Thrust (MBT). It is geomorphologically more mature belt consisting of Riphean-Phanerozoic sedimentaries occurring at the basal part and they are autochthonous in the inner belt and uprooted, displaced, fractured and thrusted on the younger formation along the plane of Main Boundary Thrust (MBT). The majority of the Lesser Himalaya is composed of thrust sheets and nappes of metasediments and metamorphic rocks with granitic intrusions of the Midland Group [5].

Evolution of Kathmandu Valley

Kathmandu valley evolved during the Pliocene and early Pleistocene. It was submerged and after emergence accumulated fertile soil from late Quaternary sediments. The Kathmandu valley infilling consists of three million years old fluvial and lacustrine sediments delivered mainly from the mountains in northern parts of the basin. The prehistoric Kathmandu lake was breached at Katuwal lake, which reduced the lake level to its current small size north of Chovar hill. There is a legend that explains the draining of this prehistoric lake. According to the legend the lake was drained by the Goddess of Learning 'Manjushree' who came from Tibet and cut, with her mighty sword, the drainage gap which is known today as the Chovar gorge [6]. This legend expresses metaphorically, with some accuracy, the actual geological evolution of the Kathmandu basin.

Topography and River Network

The Kathmandu valley is surrounded by the high rising mountains such as Shivapuri (2732 m) in the north and Phulchoki (2762 m) in the south. The undulating topography of the mountains with steep slopes reflects the general nature of SE-NW striking geological structure. The basin is in the middle part of the lesser Himalaya, and bounded by the Mahabharat lekh (hill range) to the south and Shivapuri lekh (hill range) to the north [4].

The average elevation range of the valley floor is from 1200-1400 m. The surface of Kathmandu valley is generally broad and almost flat except towards the boundaries of the valley, where rivers are deeply incised. Well developed terraces, formed by erosion from rivers, are common in the valley. The valley has a width of about 32 km in E-W and 30 km in N-S directions, and covers an area of about 583 square kilometers marked by surface watershed.

The main rivers in the study area are Vishnumati, Dhobi Khola, Manohara, Hanumate, Nakhu Khola and Bagmati. All tributaries drain towards the center of the basin in the Bagmati river, which cuts the Mahabharat lekh (hill range) in the south and drains the river water to the Gangetic plain through the Chovar gorge as the main drainage channel of the basin (Figure3).

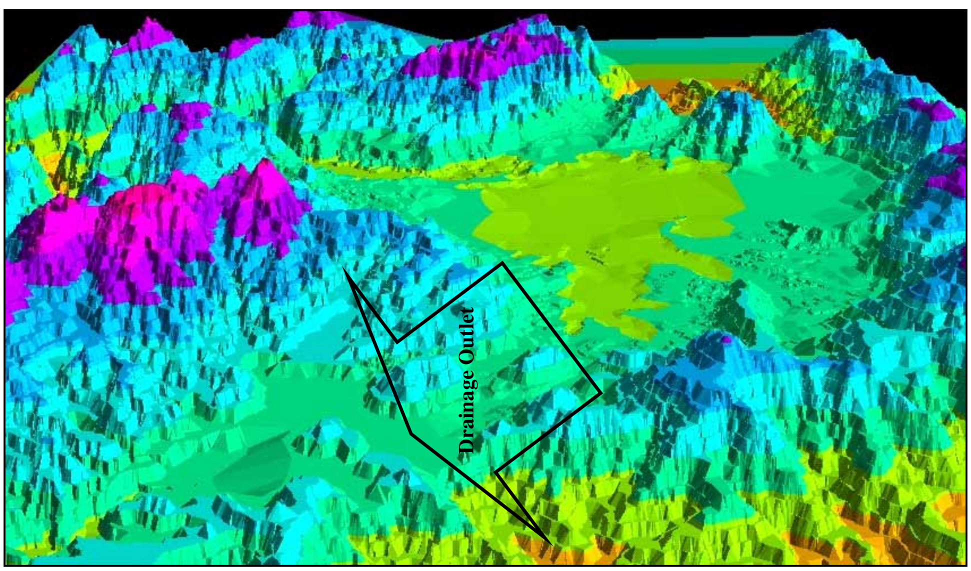


Figure 3: 3D View of Kathmandu Valley

Geological Setting

Kathmandu basin lies on the Kathmandu Nappe which consists of metamorphic Nappe and the overlying fossiliferous Tethyan sediments. The Kathmandu Nappe is composed of the Shivapuri gneiss and granite injection complex. The Kathmandu valley is mainly composed of two series of geological succession (Table 1). The basement is formed by the Precambrian to Devonian rocks, which are also surrounding the Kathmandu valley. The basement rock consists of Phulchoki group and Bhimphedi group of the Kathmandu complex. The rocks are mainly meta-sediments, intensely folded, faulted and fractured. They consist of quartzites phyllites, schists, slates, limestone and marbles with intrusions of acid and basic rocks. They are overlain by Quaternary sediments in the valley. The sediment cover has a thickness of 550 to 600 m in the central part of the valley [7].

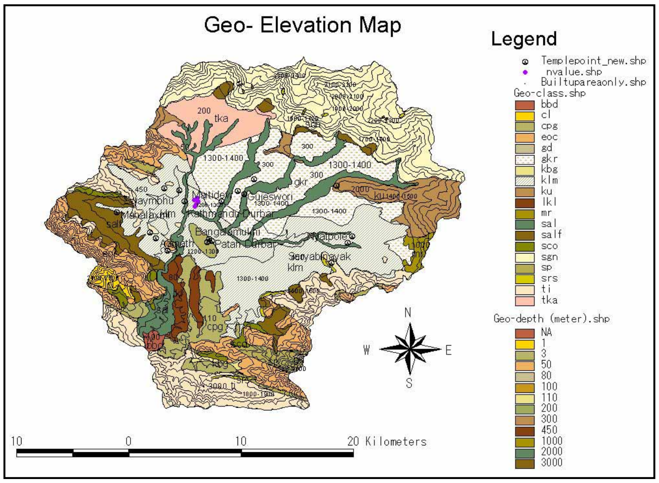
Table 1: Geological Succession of the Kathmandu Valley

(Modified after Stocklin & Bhattarai 1977 in DMG/DOI/BGR [7]

Cenozoic	Holocene		Fan gravel, Soil, Talus, Fluvial deposits (gravel, sand, silt)
	Pleistocene		Lake deposits (gravel, sand, silt, clay, peat, lignite & diatomaceous earth), Fluvial deposits (boulder, gravel, sand, silt)
--- Unconformity---			
Lower Paleozoic	Devonian	Phulchoki Group	Godavari Limestone- limestone, dolomite
	Silurian		Chitlang formation- slate
	Cambrian-Ordovician		Chandragiri Limestone- limestone, phyllite
	Cambrian		Sopyang Formation- slate, calcareous phyllite
Pre- Cambrian	Early Cambrian	Bhimphedi Group	Tistung formation-meta sandstone, phyllite
	-------------------------		------------------Unconformity-------------------------------------
			Markhu Formation- marble, schist
			Kulekhani Formation- quartzite, schist
			Metamorphic- Shivapuri gneiss
			Igneous Rocks- pegmatite, granite, basic intrusive

The Quaternary formation (unconsolidated material or sediments) of Kathmandu valley is classified as sal (recent alluvial soil), srs (residual soil), sco (colluvial soil) and salf (alluvial fan deposit). Plio-Pleistocene formation (slightly consolidated sediment) is classified as tka (Tokha formation), gkr (Gokarna formation), cpg (Chapagaon formation), klm (Kalimati formation),kbg (Kobagaon formation), lkl (Lukundol formation) and bbd (Basal boulder bed). Precambrian to Devonian formation (Hard rock) is classified as gd (Godavari limestone), cl (Chitlang formation), Eoc (Chandragiri formation), sp (Sopyang formation), ti (Tistung formation), mr (Marku formation), ku (Kulekhani formation), sgn (Shivapuri gneiss) [7].

The most dominant part of the population settlements, temples and stupas in Kathmandu valley are over the gkr and klm (Figure 4). These formations are slightly unconsolidated sediment. The soils over gkr is light to brownish- grey, fine laminated and poorly graded silty sand; loose to slightly compact with moderate to high bearing capacity. The thickness of this geology goes up to 300 m or more. The elevation of this formation ranges from 1300-1400 m above sea level. This geology has moderate to low susceptibility to liquefaction which shows the infrastructures under this geology are prone to the liquefaction (Figure 5). It is recommended by the DMG/DOI/BGR [7] that for the heavy constructions, pile foundations should be used to avoid differential settlement.



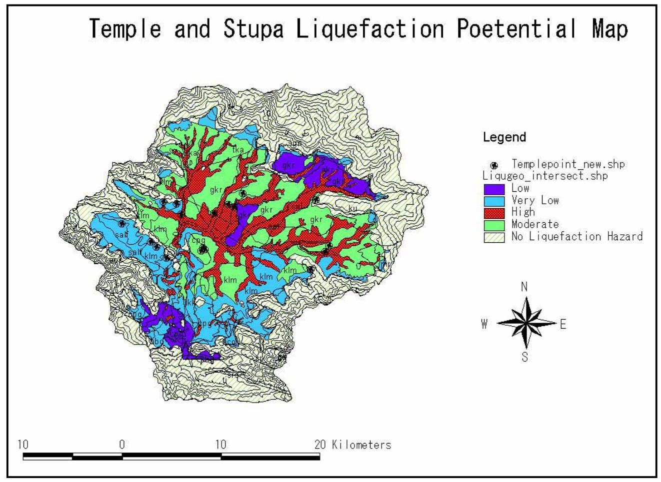


Figure 4: Geo-Elevation Map

Figure 5: Geo-Liquefaction Susceptible Map

The soil of klm is grey to dark silty clay and clayey silt with low to moderate bearing capacity, soft to firm consistency and moderate to high plasticity. Organic clay, fine sand beds and peat layers are common but occasionally lignite seams goes up to 2 m. The thickness this formation goes up to 450 m or more. The elevation of this formation ranges from 1200-1400 m above the sea level. This geology has low susceptibility to liquefaction (Figure5) which shows that the infrastructures under this geology are comparatively less prone to the liquefaction than the gkr formation.

TOOLS AND METHODOLOGY USED

The basic data was collected from various sources in Nepal. Further information was collected from internet and literature research. The base maps for topography, soil, land use, drainage network were obtained from the courtesy of International Center for Mountain Development (ICIMOD). The Geology map was extracted by manual digitization using PC Arc/Info software from the Engineering and Environmental Geological Map of The Kathmandu Valley (scale 1:50,000) published by the DMG/HMG [8]. The Liquefaction hazard map of Kathmandu Valley floor area was extracted from the same map but published by MoHPP/HMG [9].For the GIS mapping, GIS software Arc View version 3.2 and ILWIS 3.11 Academic version licensed to Akita Prefectural University were used. The entire map was transformed into Geographic coordinates from the UTM (Universal Transverse Mercator System) using the ‘Projection Utility Wizard’ of Arc View GIS to bring all the data in the same format.

In order to georeference temple sites, the tourist map (1:50,000) of Kathmandu valley was scanned and brought to the geographic coordinates using the ‘Image Analysis’ extension of Arc View and from there the important temples and stupas are extracted. The digital elevation model (DEM) was reclassified into 100 m of elevation range and this map was overlaid with geology map and temples/stupa point data using ‘Geo-Processing wizard’ of Arc View GIS, which gave the output of ‘Geo-Elevation Map’. This map shows the location of particular temples and stupas over particular geology and soil type and its elevation. Overlaying of the temples and stupas point data with Liquefaction Map prepared by MoHPP/HMG [9] was done to prepare ‘Temple and Stupas Liquefaction Potential Map’. This map shows the potentiality of the particular temples or stupas for the Liquefaction.

Detailed information on the engineering and geotechnical properties of soil in Kathmandu Valley was not available. Therefore, the available borehole data in five sites of Kathmandu city viz. near Sundhara

Sanchayakosh, in front of RNAC building, Khulamanch, Mahaboudha and Jamal was taken from the paper of 'Geotechnical properties at Sundhara and Jamal area in Kathmandu' [10].This available data does not represent the whole Kathmandu Valley. The output attempts to give a broader overview of Kathmandu Valley. As the borehole depth for all five sites were not similar, all depth were considered the 20 m depth for N value. The geological rock base depth of this site is almost 450 m and the engineering base layer has to be greater than 20 m depth because of low N value for 20 m depth. Therefore, the actual natural period of the ground would be larger than the estimated one.

The inputs needed for the estimation of period of the ground are layer thickness, soil type, unit weight and SH wave velocity. The estimation of unit weight was done according to the nomograph as shown in Figures 6 and 7 by Sugimura [11].

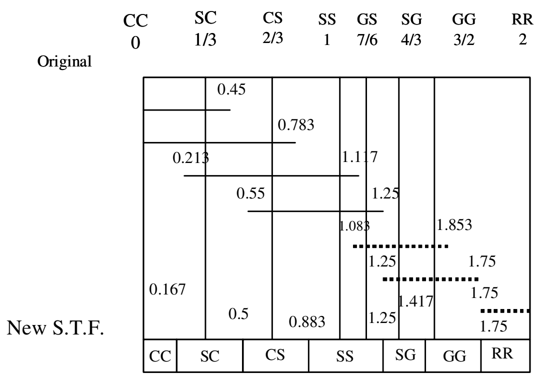


Figure 6: Determination of Unit Weight of Soils

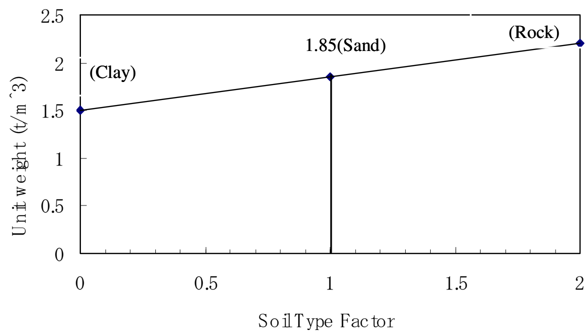


Figure 7: Definition of Soil Type Factors

SH wave velocity was calculated by using the formula:

$$V_s = \sqrt{\frac{1200 * N^{0.8} * 9.81}{\gamma}}$$

V_s = SH Wave velocity (m/s)

N = Corrected SPT value

γ = Unit weight (KN/m^3)

These input parameters like SH Wave velocity, unit weight and the thickness of each soil layer obtained from the borehole data were used to estimate the fundamental period of the ground at each site using theoretical transfer function of SH wave (Table 2).

Table 2: Geotechnical Properties of Soil

Bore hole No.	Layer No.	Layer (m)	Soil type	N Value	Unit wt. (γ) (KN/m^3)	Vs (m/s)	Freq. (Hz)	Period of soil (s)
1	1	1.5	SM	9	16.42	200	2.39	0.42
	2	1.5	ML	6	15.45	180		
	3	7	ML	8	15.59	200		
	4	8	MH	7	15.56	190		
	5	2	MH	7	15.56	190		
2	1	5	SM	11	16.45	220	3.32	0.30
	2	1	SW-SM	7	16.66	180		
	3	1	ML	12	15.76	230		
	4	1	SW-SM	15	16.79	250		
	5	1	SP	20	16.93	270		
	6	11	SP	20	16.93	270		
3	1	8	SM	9	16.42	200	2.78	0.32
	2	2	SM	8	16.42	190		
	3	1	SM	12	16.48	230		
	4	9	SM	12	16.48	230		
4	1	1	SM	7	16.42	180	3.16	0.32
	2	2.2	ML	5	16.38	160		
	3	1.6	SP	13	15.80	240		
	4	2.6	SM	13	16.86	230		
	5	2.4	ML	21	16.62	280		
	6	2.4	SP	25	16.00	310		
	7	7.8	SP	14	16.72	240		
5	1	3	SM	12	16.48	230	3.61	0.28
	2	1	SM	5	16.38	160		
	3	1	SM	8	16.42	190		
	4	1	SM	7	16.42	180		
	5	1	ML	10	15.76	220		
	6	1	SM	26	16.69	310		
	7	1	SP	26	17.00	300		
	8	11	SP	26	17.00	300		

RESULTS AND DISCUSSION

The estimated period of the ground (without damping) by the theoretical transfer function of SH waves shows period longer than 0.28 s (Table 2). Jaishi [12] has estimated the period of multi-tiered temples in Nepal as less than 0.25s. The Geology of Nepal (Figure 2) clearly shows that Kathmandu valley is bordered by rock outcrops and the valley is approximately bowl shaped with alluvial deposits. The estimated periods of the ground and multi-tiered temples shows that there may not be severe impact to the temples and stupas located at the valley floor during far field earthquakes due to difference in predominant period of temples, stupas and the ground. However, temples and stupas which have experienced some past earthquake motions could exhibit larger natural period due to some cracks. In such case, there are possibilities of having resonance effect because the period of temples are closer to the predominant period of the ground.

Likewise, the temples located at the border of the Kathmandu Valley may have relatively severe damage from resonance effect due to the short periods of temples and sites near rock outcrops. The classification of temples and stupas lying in the sites of various degrees of liquefaction susceptibility is shown in table 3. The results shows that some religiously important temples like Pashupatinath, Nyatpol, Gujeshwori, Krishna Mandir, Banglamukhi and stupa like Boudhnath are situated over the geological formation which are may be at the high risk of liquefaction under the seismic impact (Figure 5).

Table 3: Likelihood of Liquefaction Susceptibility of the Temples and Stupas

High	Moderate	Very low	No Liquefaction
- Maitidevi	-Krishna Mandir	- Mahalaxmi	-Changu Narayan
-Pashupatinath	- Banglamukhi	-Uma Maheswor	- Surya Binayak
- Gujeshwori	- Boudhnath	- Bag Bhairab	
- Nyatpol	- Kamalbinayak	- Adinath	
		- Bijeswori	

These results are from the preliminary phase of analysis so the detailed field measurements like period of structures, soil and various sub-surface structures are needed for the further investigation. This present research attempts to contribute for further research in the sector of Earthquake Risk Assessment and Management in Kathmandu Valley.

CONCLUSION

Vulnerability analysis of historical heritage structures in Kathmandu valley was carried out using available data. It was found that some historically important temples viz. Nyatpol, Pashupatinath, Gujeshwori, Banglamukhi and stupas like Boudhnath may be at the risk of liquefaction under seismic impact. It was also found that the temples situated at the valley bottom are under less risk to impact from far field earthquake due to difference in predominant period of temples, stupas and the ground. Likewise, the temples situated at the border of the valley may have relatively severe damage due to the short periods of temples and sites near the bed rock. As this conclusion is drawn on the basis of preliminary analysis, there is a need of further research to get detailed field measurements to get more precise results.

ACKNOWLEDGEMENT

I would like to thank Akita Prefectural University (Japan) for supporting my research. I also would like to thank Prof. Madan B. Karkee for his continuous untiring support. At last, but not least, I would like to thank Dr. Laxman Sunuwar of Akita Prefectural University (Japan) and Ms. Gyami Shrestha of University of Wyoming (USA) for helping me improve my work.

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