The challenges of protecting heritage architecture in developing countries from earthquake disasters

M. B. Karkee, C. Cuadra & L. Sunuwar

Department of Architecture and Environment Systems,
Graduate School of Systems Science and Technology,
Akita Prefectural University, Japan

Abstract

This paper attempts to highlight the challenge of protecting the heritage architecture in developing countries through examples of Nepal and Peru where valuable world heritage sites in opposite parts of the globe face a common threat owing to earthquakes. The nature of the earthquake hazard in both of the countries is discussed in some detail and the importance of actions towards the protection of heritage architecture is emphasized. It is noted that the state of general disrepair adds to the seismic vulnerability of heritage architecture in developing countries. Besides, the repair after actual damage or destruction from earthquakes, even when timely undertaken, may lead to alteration of the valuable originality of heritage structures, owing to the unavailability of material or skill from the time of the original constructions. The need for initiatives towards preventive actions for protection from damage and prevention of collapse due to earthquake disasters appears quite evident.

Keywords: heritage architecture, earthquake hazard, seismic risk, temple, stupa, Inca, Nepal, Peru.

1 Introduction

Protection of life and property from natural disasters has been a subject of major emphasis in engineering research and practice involving development initiatives around the world in recent decades. Although the global toll from natural disasters seems to remain high in spite of this emphasis, international commitment to reduce the vulnerability of mankind to natural disasters through a
combination of improved design and construction practice, development of warning systems and cooperation in disaster preparedness, provides some hope for the future. However, there seems to be little effort made towards systematic evaluation of the vulnerability of heritage architecture to natural disasters. As may be expected, the problem of protecting heritage architecture in developing countries is particularly acute, owing to the demanding economic situation coupled with the dearth of public awareness. This paper attempts to highlight the challenge of protecting the heritage architecture in developing countries from earthquake disasters, through examples of the predicaments derived from preliminary studies in Nepal and Peru. Although located in different hemispheres of the world, these two countries manifest legendary heritage architecture while both are located in prominent seismic regions of the world.

Heritage architecture in developing countries is exposed to various kinds of risks emanating from human activity as well as from natural causes. The range of human activities contributing to the risk, for example, armed conflicts, terrorism, vandalism etc., are themselves more prominent in developing countries, while also being very diverse and complex in nature. The risks to heritage architecture from natural hazards such as earthquakes, floods, cyclones, landslides etc. are equally complex and least understood particularly in developing countries. When natural disasters strike in developing countries, the local economic realities make it impossible to pay attention to cultural heritage in the aftermath. Naturally, the international help also has to give priority to human suffering. Recent earthquake disasters, including the one in Bam, Iran, amply illustrate this situation. As the heritage architecture in developing countries is in a state of constant disrepair, not to mention about the lack of research concerning the hazard, seismic resistance and need for strengthening as necessary, the vulnerability to earthquake is quite apparent. By delineating the earthquake hazard to which the heritage architecture in two seismic regions in different part of the globe are exposed to, the paper aims to highlight the challenge involved in protecting the heritage architecture from earthquake disasters in developing countries. The cases of two developing countries, Nepal and Peru, are considered in this paper, indicate commonality of challenges involved.

2 The situation in Nepal

The seismic activities in the Himalayan region including Nepal are concentrated along north dipping planes forming the boundary region where the Indian plate underthrusts beneath the Eurasian plate. Figure 1 shows the distribution of peak ground acceleration (PGA) with 10% probability of exceedance in 50 years based on the studies by Bhatia et al. [1]. It may be noted that even in the context of global hazard consideration Nepal is clearly in a seismically active region of Asia. There are four UNESCO heritage sites in Nepal, two cultural and two natural. The heritage architecture of interest are in the two cultural sites, one of which is the Kathmandu valley and the other is Lumbini, the birthplace of lord Buddha, as indicated in Figure 1. Kathmandu valley is particularly well known for the extensive heritage architecture representing the socio-ethno-cultural
developments over the centuries. Consequently, attempt is made here to illustrate the situation in Nepal through investigation of the vulnerability of heritage architecture in Kathmandu valley to seismic disasters.

Figure 1: Regional earthquake hazard around Nepal (based on Bhatia et al. [1]).

2.1 Kathmandu valley

United Nations Educational, Scientific and Cultural Organizations (UNESCO) listed Kathmandu valley, the capital city of the Kingdom of Nepal, as the world cultural heritage in 1979. The actual heritage architecture sites in Kathmandu valley consist of seven groups of ancient constructions. Of these, two are famous Hindu temples of Pashupati Nath (Figure 2) and Changu Narayan (Figure 3) two are ancient Buddhist monuments (stupas) of Swayambhu Nath (Figure 4) and Bouddha Nath (Figure 5). The remaining three consist of former residential palace areas of Hanuman Dhoka (Figure 6), Patan Darbar (Figure 7) and Bhaktapur Darbar (Figure 8). Altogether, the heritage sites include about 130 architectural monuments of exceptional and unique architecture, including pilgrimage centres, temples, shrines, bathing sites and gardens, representing the ancient civilization of Kathmandu valley. The architectural expressions are so unique and unparalleled that they represent the religious, political and cultural life of ancient Kathmandu valley [13]. Another unique feature is that most of the sites are considered valuable cultural and religious assets for both the Hindus and the Buddhists.
With rapid urbanization of Kathmandu valley in recent years, the heritage structures are threatened by encroachment due to recent constructions while also facing lack of proper upkeep and maintenance, resulting in the inclusion of Kathmandu valley in the list of endangered heritage sites by the UNESCO heritage committee [13]. The primary reasons for inclusion in the endangered list are: (1) encroachment of heritage properties and the lack of properly defined buffer around them, (2) absence of technical personnel and skilled labours to restore the damaging structures within these heritage properties, and (3) lack of proper laws and regulations from the side of Government of Nepal and local
municipalities to safeguard these heritage properties [13]. Although not appearing to be directly related, these reasons, nevertheless, also contribute to seismic vulnerability of heritage structures. Considering the hazard in the region, the heritage architecture of Kathmandu valley is vulnerable to damage by frequently occurring earthquakes.

Figure 8: Bhaktapur 55 windows palace and hidden and full views of Nyatapola.

Historically, Kathmandu valley was ruled by kings of various dynasties such as Mahishpals, Kirants, and Lichchhavis, who commissioned construction of palaces and temples as symbols of their prestige. The famous Mauryan emperor Ashoka of present day India visited Kathmandu in the 3rd century BC to spread Buddhism, and commissioned construction of stupas (also known locally as Chaityas) at four corners of Patan in Kathmandu valley. Originally built of brick masonry in 250 BC and gradually turned into grassy mounds that they appear today, the four Ashoka stupas or Chaityas may be the most ancient surviving religion monuments in Kathmandu valley. Most of the other temples and stupas considered as heritage properties date back to kings of Malla dynasty starting around 12 Century AD. During the Malla dynasty, there were three separate kingdoms of Kathmandu, Bhaktapur and Patan, and the respective Durbar (royal palace) squares in each are world heritage sites of Kathmandu valley.

2.2 Earthquake hazard in Kathmandu valley

Kathmandu valley lies in the foothills of Himalayas constituting the boundary between Indian and Eurasian plates. Indian plate is said to be moving north at the rate of 21mm/year [3] in continuation of the process of forming the great Himalayas. Three distinct thrust faults designated as MFT (Main Frontal Thrust), MBT (Main Boundary thrust) and MCT (Main Central Thrust) in Figure 9 are identified as part of this tectonic process. It may be noted that the Kathmandu valley is located close to the north of MBT and MCT. Historical accounts indicate that the valley has suffered major destructive earthquakes repeatedly, for example in 1255, 1408, 1681, 1810, 1833, and 1866 [8]. The last known destructive earthquake was in 1934 January when one fourth of Kathmandu valley’s urban infrastructures including the heritage structures were damaged or destroyed. The heritage structures within the royal palace compounds were
mostly damaged and repaired later. Figure 10 shows the typical damage caused by the earthquake. The death toll is estimated to be about 10,000 in Kathmandu valley.

Figure 9: Geological section of Nepal Himalayas through Kathmandu valley.

The evidence of attempts at what may be considered as seismic detailing in temples and stupas in view of the materials used in their construction indicates that the builders from ancient times were conscious of the frequent earthquake hazards in Kathmandu valley. For example, most of the typical temple structures have symmetrical plan and wood is used extensively as joists and struts while making innovative connections between elements of temple, even though burnt brick masonry is the basic construction material. Temple forms consisting of artistic wooden struts supporting eves of sloping roofs add to abundant redundancies in the structural systems.

Figure 10: Heritage architecture damaged by the 1934 Bihar-Nepal earthquake.

However, the maintenance of heritage structures has not been getting adequate attention due to various reasons. The most important reason is probably the poor economy of Nepal, which may be primarily responsible for the lack of regular maintenance of these important structures. The need for maintenance
appears to be realized only when there is alarming danger of collapse. With proper management, the heritage architecture itself can generate funds for maintenance. However, the revenue generated from these places is generally so meager as to be inadequate for regular maintenance. Besides, these structures are likely to be partly damaged and weakened by frequently occurring Himalayan earthquakes [15].

2.3 Earthquake hazard analysis of Kathmandu valley

To supplement the trend noticeable from regional probabilistic seismic hazard observed in Figure 1, attempt was made to analyze the local hazard in Kathmandu valley based on the database extending to 100 year obtained from the website of USGS-NEIC [14]. Figure 11 shows the distributions of earthquakes around Nepal for the period of 1904-2003 with earthquake magnitude of greater than or equal to 5.0. Earthquakes lying within 400 km radius of Kathmandu valley were considered for the probabilistic seismic hazard analysis. There are altogether 51 earthquakes within 400 km radius of Kathmandu. The highest earthquake magnitude is 8.39 (surface wave) corresponding to the 1934 Bihar-Nepal earthquake for which the moment magnitude comes out to be about 8.0.

![Figure 11: Earthquake occurrence in the region (1904-2003) and the annual probabilistic seismic hazard in Kathmandu valley in terms of PGA.](image)

In the absence of attenuation relationship of PGA for Nepal Himalayas, recently developed attenuation relationship for Taiwan [7] was utilized. Figure 11 also shows the annual hazard curve for Kathmandu valley [8]. For relative understanding of the nature of hazard, hazard curves for well-known earthquake prone cities of Sendai in Japan [7] and Los Angeles in USA [12] are shown for comparison. The annual hazard curve of Kathmandu valley is slightly lower but comparable with that of Sendai and Los Angeles cities. For PGA of less than about 0.2g, the hazard for Kathmandu is even higher than that of Los Angeles. It means that the earthquakes resulting in lower PGA are more likely in Kathmandu valley when compared to Los Angeles. Considering that the heritage architecture in Kathmandu valley are likely to be vulnerable to even lower level
of shaking, the risk involved can be understood to be clearly serious. It is quite apparent that the seismic risk of the stock of heritage architecture in Kathmandu valley is grave even when compared to other highly seismic prone cities.

Figure 11 also shows the most credible value (MCV), design basis value (DBV) and probable value (PV) defined as 2%, 10% and 50% probability respectively of being exceeded in 50 years. The MCV, DBV and PV of PGA for Kathmandu valley are about 0.72g, 0.47g, and 0.25g respectively. These values are generally defined for use in designing seismic resistant structures in codes of practices. For example, the DBV of 0.47g may be regarded as approximating the modified Mercalli intensity (MMI) scale of IX, when reinforced concrete structures are expected to suffer damage. Besides, the topsoil of Kathmandu valley consists of soft soil having shear wave velocity (Vs) less than 200 m/s, where local site amplification may be prominent. Observations at such lacustrine soils in Japan report local site amplification of twice that of rock sites [6]. In addition, the valley basin may result in the amplification of surface waves. Contribution of such aspects of earthquake effects on the local hazard within the valley would be valuable for clear understanding of the earthquake hazard to heritage architecture in Kathmandu valley.

2.4 Liquefaction hazard in Kathmandu valley

The soil condition in Kathmandu valley consists of soft lacustrine deposit of predominantly fine-grained soil with relatively hard rock as the bed of basin. Figure 12 shows the geo-elevation map and the liquefaction susceptibility map of Kathmandu valley [9]. As are the traditional valley settlements, the heritage sites in the valley are located over mainly three locally named geological formations: klm (Kalimati), gkr (Gokarna), and cpg (Chapagaon) formation. These geological formations belong to paleo-pleistocene age. The Pashupati Nath temple located on the bank of Bagmati river has high susceptibility to liquefaction. The palace squares of Hanuman Dhoka, Patan and Bhaktapur and the stupa of Boudanath are located at sites with moderate liquefaction susceptibility. Swayambhu Nath stupa and Changu Narayan temple are located on hillock-top sites with no likelihood of liquefaction.

![Geo-elevation map and liquefaction potential map of Kathmandu valley](image12.png)

Figure 12: Geo-elevation map and liquefaction potential map of Kathmandu valley.
Although free from risk of liquefaction, the heritage sites at hillocks, such as Swayambhu Nath stupa and Changu Narayan temple, are at risk from landslides. Bhattarai et al. [2] provide some account of landslide potential around the Changu Narayan temple and have recommended urgent detailed study and remedial actions.

3 The situation in Peru

Peru has many sites of cultural and natural heritage reflecting the earlier Inca era as well as the subsequent era following Spaniard conquistadors in the 17th century. Of the ten Peruvian heritage sites in the UNESCO world heritage list, six are considered cultural and two are considered natural. The remaining two are considered mixed category, meaning that the sites reflect the cultural as well as the natural heritage. The historic sanctuary of Machu Picchu, registered by UNESCO in 1983, is probably the most well known Inca heritage architecture. Attempt is made here to highlight the situation in Peru by exploring the nature of earthquake risk to which the Machu Picchu heritage site may be exposed.

The west coast of South America is affected by frequent earthquake activities originating mainly from tectonic interaction between Nazca plate and South American plate. The Peruvian Institute of Geophysics (IGP) has published the catalogue of historical earthquakes in this region, consisting of information from 1471. However, the earlier records prior to instrumental measurement cannot be expected to be representative of the actual distribution of hazard. Figure 13 shows the epicentre distribution of historical earthquakes and colonial era and earlier era earthquakes separately. It may be noted that only earthquakes occurring around the populated areas seem to have been reported at earlier times.

Figure 13: Distribution of historical earthquakes (1471-1982) and colonial era and earlier earthquakes.
However, it is evident from the plot of earthquake catalogue that the seismic hazard in Peru is clearly serious with consequent implications for the challenge of protecting the heritage architecture from earthquake disasters. Figure 14 shows the distribution of earthquakes with magnitude greater than 4.0 from instrumental measurements of 20 years from 1983 to 2003 in the IGP catalogue. This data was used to evaluate the seismic hazard to Inca heritage architecture including Macchupichu. The methodology followed is given in Cuadra et al. [4].

### 3.1 Seismic hazard to Inca heritage architecture

For seismic hazard analysis, the centre of the triangle formed by Cusco, Machupicchu and Choquequirao was taken as the central point and earthquakes with epicentral distance within 200 km from the centre point were considered. Probabilistic seismic hazard in terms of PGA is shown in Figure 15, where hazard curves for Lima and Los Angeles are included for comparison [5].

![Figure 14: Earthquakes in various magnitude ranges from instrumental records.](image)

Results of the probabilistic seismic hazard analysis can also be expressed in terms of the return period shown in Figure 15, where PGA for different return periods with 10% probability of exceedance are plotted. It may be noted that the PGA for 100 year return period is around 0.25g for the region considered. Although this value is lower compared to those obtained for Lima and Los Angeles, the Inca constructions have already been in existence for several hundred years and it would be more logical to consider earthquake actions corresponding to a return period of several hundred years, which cannot be rationally evaluated based on the instrumental record over only about 20 years considered here for a case study. Besides, even lower level of acceleration may
produce failure in Inca stone structures or in portions thereof. In addition, the PGA levels in Figure 15 represent rock or stiff soil conditions, while the actual level of shaking depends on local site conditions at specific heritage sites where the local site amplifications and other effects may be important. Related to this is the need to account for the effect of local topographical configuration.

![Hazard curve and PGA versus return period for Inca heritage region of Peru compared with Lima in Peru and Los Angeles in USA.](image)

**Figure 15:** Hazard curve and PGA versus return period for Inca heritage region of Peru compared with Lima in Peru and Los Angeles in USA.

### 3.2 The Machu Picchu citadel

It was built before the arrival of the Spanish conquistadors and abandoned after the Inca Empire collapsed by the year 1540 A.D. During about four centuries, this citadel endured and survived under a thick rain forest, until discovered by Hiram Bingham in 1911. That Machu Picchu citadel endured through centuries of barrages from nature gives some indication of the Inca’s use of high standards and proven technology in the construction of stone structures. However, incessant environmental effects and inquisitive intrusion by humans has been taking its toll on this most popular of the Inca heritage architecture sites. Sasa et al. [12] have investigated the landslide risk by detailed survey of the site and some field measurements and have emphasized the possibility of large-scale landslide and the need for reliable monitoring of the site. Local landslides seem quite common and Figure 16 shows photographs from observation by the first two authors during their site visit in 2004.

As noted above, the seismic risk to the Machu Picchu citadel is as crucial. Considering that the earthquakes may also induce landslides in the steep topography with existing traces of past instabilities, the compound risk from seismicity and landslide needs to be investigated for long-term protection of the heritage site. As a means of evaluating the Inca heritage architectural units at Machu Picchu in a non-intrusive manner, a group of researchers at Akita Prefectural University in collaboration with University of Cusco San Antonio Abad have conducted microtremor measurements in the field. Figure 17 shows the scene of such measurement being undertaken at the temple of three windows in Machu Picchu and the typical results in the form of transfer function. The detailed analysis of the field measurements and other investigations are currently underway.
4 Conclusions

Heritage architecture in developing countries is exposed to various kinds of risks emanating from human activity as well as from natural causes. While mostly in a state of perennial disrepair, risks to heritage architecture in developing countries from natural hazards such as earthquakes, floods, cyclones, landslides etc. are particularly acute. The discussion of earthquake hazard to which the heritage architecture in Nepal and Peru, constituting two seismic regions in opposite parts of the globe, are subjected, provides an overview of the challenge involved in protecting the heritage architecture in developing countries from earthquake disasters.

References


