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Seismic damage assessment of Nepalese cultural heritage building and seismic retrofit strategies: 25 April 2015 Gorkha (Nepal) earthquake

Yi Pan[a,b], Xiaoyue Wang[a], Rui Guo[a,*], Shuang Yuan[a]

[a] Department of Building Engineering, School of Civil Engineering, Southwest Jiaotong University, Chengdu 610031, China
[b] Key Laboratory of High-speed Railway Engineering, Ministry of Education, Southwest Jiaotong University, Chengdu 610031, China

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ABSTRACT

The 2015 Gorkha (Nepal) earthquake caused tremendous damage to the cultural heritage buildings in the Kathmandu Valley. After the event, extensive field investigations were conducted to assess the seismic damages to the cultural heritage buildings in the Kathmandu, Patan, and Bhaktapur Durbar Squares. Major damages included failure of structural and non-structural components, tilting and collapse. Masonry-timber structures and masonry structures, the two structural types for the investigated heritage buildings, are analyzed separately in terms of the damage patterns. Damage classification criteria are proposed for the two structural types. Based on the criteria, a total of 68 structures investigated (52 masonry-timber and 16 masonry structures) are classified into four damage grades. The results show that only 30.8% of the masonry-timber structures and 18.8% of the masonry structures exhibited negligible to slight damage; the rest suffered more severe damage or even collapse. The seismic performance of the masonry-timber structures was slightly better than that of the masonry structures. Seismic retrofit strategies are recommended for the preservation of Nepalese cultural heritage buildings.

1. Introduction

On 25 April 2015 at 11:56 a.m. (Nepal Local Time), a 7.8 Mw (8.1 Ms) magnitude earthquake occurred in Gorkha, approximately 80 km northwest of Nepal's capital Kathmandu. The earthquake was also felt in China, India, and Bangladesh. A series of aftershocks followed the mainshock, causing more casualties. In the UNESCO World Cultural Heritage of the Kathmandu Valley, there were seven groups of heritage buildings and monuments including three Durbar Squares (Kathmandu, Patan, and Bhaktapur), two Buddhist stupas (Swayambhu and Bauddhanath), and two Hindu temples (Pashupati and Changu Narayan) suffering tremendous damage. After the quakes, a reconnaissance team consisting of some researchers from Southwest Jiaotong University went to the affected areas and conducted extensive field investigations on the World Cultural Heritage buildings under the support of local government officials and engineers in Nepal. The investigations focused on the seismic damages to the cultural heritage buildings clustered in the three Durbar Squares. According to the United States Geological Survey (USGS) [1], the intensity of earthquake in Kathmandu Durbar Square and Patan Durbar Square was VIII, and it was VII in Bhaktapur Durbar Square. Fig. 1 shows the intensity of earthquake in all seven groups of heritage buildings/monuments.

Most of the cultural heritage buildings in the three Durbar Squares are featured with masonry-timber structures and masonry structures. In the past, since the construction of the structures relied largely on the experience of local craftsmen without

* Corresponding author.
E-mail address: guor4867@swjtu.edu.cn (R. Guo).

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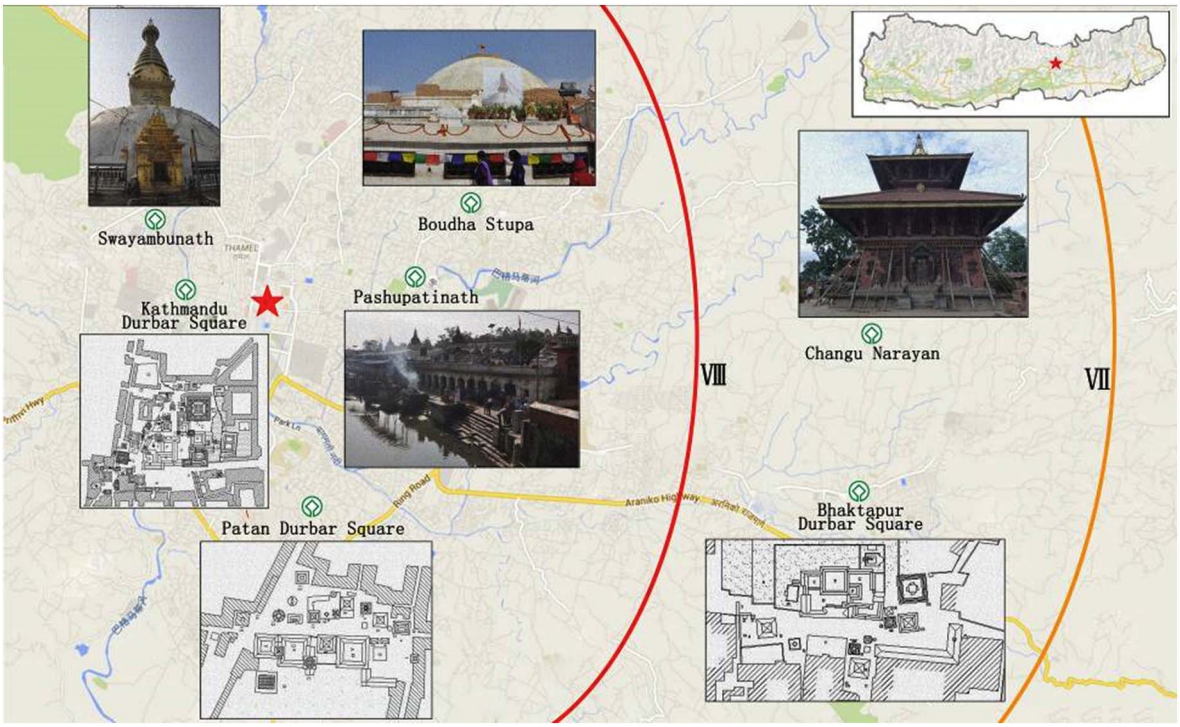

Fig. 1. Intensity for the cultural heritage buildings in the Kathmandu Valley.

consideration of modern seismic design rules, the structures experienced different degrees of damages during the earthquakes in history. Most research on the Nepalese cultural heritage buildings in recent years focused on the historic, artistic, and cultural aspects [2–4]. However, relatively little has been done to address the seismic performance and safety issues of these buildings. Shakya performed parametric analyses on three Nepalese Pagoda temples using finite element modeling to understand the influence of structural component fragility on the seismic vulnerability of the whole structure [5]. The results showed that damage or degradation of the masonry walls contributed most to the reduction of the overall stiffness of the temple structures. Jaishi conducted finite element analysis on ten typical multi-tiered temples in Nepal and obtained the dynamic properties [6]. Ambient vibration testing was done on three of the ten temples to validate the finite element models. The seismic performance of the temples was evaluated using response spectrum method. Ranjitkar reported different types of seismic damages of some monuments based on the photographic record of the great 1934 Nepal earthquake [7]. They summarized the weaknesses of the historic temple structures and proposed suggestions for seismic retrofitting of heritage buildings. To date, the research on the seismic performance of Nepalese cultural heritage buildings is limited to masonry-timber structures; no masonry structures have been studied. Furthermore, there are very few field data for a thorough seismic damage assessment for the cultural heritage buildings in Nepal.

This research is based on field investigations which forced on the cultural heritage buildings in the three Durbar Squares after the 2015 Gorkha (Nepal) earthquake. This study is by not only analyzing the seismic damage patterns, but also classifying the damage levels of the structures. Moreover, seismic retrofit strategies were proposed at the end of the paper, serving as a reference for the preservation of Nepalese cultural heritage buildings.

2. Damage to structures

2.1. Structural details

There are two structures types which dominates the cultural heritage buildings in the three Durbar Squares, such as masonry-timber structures and masonry structures.

Masonry-timber structures, which are composed of brick and timber frame. Among these structures, such as the Chowks, usually two- or three-story high adopted a closed plan layout. The multi-tiered temples typically had one, two, three, or five roofs. They can be categorized into four types depending on the bottom wall systems (Fig. 2 shows): (a) single wall with one side open, (b) single wall with three sides open, (c) double walls with four sides open and walkway between the walls and (d) inner wall and outer colonnade with walkway in between [8].

The masonry-timber structures consist of brick walls and timber components (such as columns, beams, brackets and struts). The brick walls serve as the main structural member to resist the vertical and lateral loads. The wall was usually built with three layers [9], the exterior surface and interior surface were made of fired bricks and sun-dried bricks respectively, and the middle core filled