Architectural and Structural Characteristics of Indigenous Newari Chhen: Study of Seismic Risk and Resilience in the Historic Urban Nucleus of Bhaktapur City, Nepal

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ABSTRACT

This paper highlights the structural and architectural properties of indigenously constructed Newari houses. This article aims to disseminate the main properties of traditionally houses in the urban center of Bhaktapur in comparison to modern earthquake resistant unreinforced masonry construction. The growing trend of modern reinforced concrete construction has overshadowed the importance of masonry construction in urban areas of Nepal, though a large fraction of buildings are unreinforced masonry structures so that their behavior during earthquakes may be important. This study highlights the features like symmetrical construction, vertical load transfer system, cantilevered load distribution, openings, structural integrity, timber bands, non-structural members, and introduction of special building components, among others. The geometrical properties of building components and their significance have been discussed in this paper so as to correlate with prevalent standards and codes. Through a detailed structural and architectural survey of 42 owner built houses, it observed several features with interest for reconstruction after the 2015 Gorkha earthquake. Culture is inseparable dimension of the society in the study area and the importance is emphasized more by the world heritage site, thus earthquake resistant construction of unreinforced masonry buildings with cultural components is must for Bhaktapur. In this regard, this paper has attempted to identify those features and associated structural sufficiency through detailed survey, phenomenological and archival study and non-structured interviews.

Keywords: *Bhaktapur city, culture, earthquake resistant construction, Newari Chhen, seismic risk, unreinforced masonry construction*

1. INTRODUCTION

Indigenous knowledge and practices in building construction have very long influence and guidance through adoption and subsequent formulation of cultural settlement localized to any geographical boundary. Afterward, such knowledge is propagated to

generations as customs. Indigenous knowledge and practices are dynamic and time variant with frequent combination of contemporary cultures, beliefs and skills.
The growing trend of reinforced concrete (RC) construction has overwhelmed the traditional construction practices globally, though unreinforced masonry structures are dominant over modern RC constructions in indigenous communities of Bhaktapur city till date. In many past earthquakes, masonry structures have shown significant resilience against the ground shaking and amplification so assessing features of masonry buildings is nowadays more pronounced. During many past earthquakes, traditional masonry buildings constructed with timber components survived significantly (e.g. Boen, 2001; Decanini et al., 2004; Gulkan and Langenbach, 2004; Bothara et al., 2007; Audefroy, 2011; Langenbach, 2010; Siswanto et al., 2013; Gautam, 2014a). In this context, the genius aspects of traditional construction practices need to be analyzed with regard to seismic response. Previous studies have figured out some earthquake resistant features in monumental buildings in Kathmandu valley (Bajracharya, 1982; Dixit et al., 2004; Shrestha et al., 2004; Sinha et al., 2004; Dixit et al., 2008; SDMC, 2008; Jigyashu, 2013; Gautam, 2014b). However, detailed assessment of residential buildings and detailing earthquake resistant features and geometrical properties have been felt more in recent dates only.

While identifying the earthquake resistant features of unreinforced masonry (URM) buildings (Newari Chhen) of Bhaktapur city, this study attempts to figure out the construction technology, technology transfer, geometric and architectural specifics, earthquake resistant features and recent trend of incorporation of indigenous knowledge in construction scenario. The features have been justified by reconnaissance immediately after the 2015 Gorkha earthquake as well.

2. SEISMIC HAZARD IN THE STUDY AREA AND NEPAL

Nepal is situated amongst the world's seismically most active region, so frequent earthquake events and associated damages are common. As Nepal lies in the convergence zone of Indian plate beneath the Eurasian plate leading the entire region one of the most seismically active region of the world. Also, Nepal is placed in the 11th place by The Bureau of Crises Prevention and Recovery of the United Nations Development Program (UNDP). Events like the earthquake of 1255, 1833 M_L 7.7, 1934 M_W 8.1, 1988 M_L 6.5 (Dixit et al., 2013) and 2015 M_W 7.8 Gorkha earthquake show the severity of impact clearly. In these events, the preponderance of the observed damage is concentrated in Kathmandu valley. Global seismic hazard map designates Nepal in Zone IV with the possible shaking of MMI-IX or above with 10% probability of exceedance in 50 years (JICA, 2002). In addition to this, the local soil condition dominates the peak spectral acceleration and amplification factor even in a small spatial variation (Chamlagain and Gautam, 2015).
The start of modern reinforced concrete construction began in the major urban centres of Nepal some thirty years back, and concentrated in the Kathmandu valley and other urban centres. However, it nevertheless supplanted the traditional URM construction practices in some of the urban nuclei, like Bhaktapur; where unreinforced masonry construction is dominant comprising of more than 90% buildings (Gautam, 2014b).

3. METHODOLOGY

In order to identify the genius features of traditional Newari houses of Bhaktapur city, 42 owner built URM houses from 14 different wards (three houses from each ward) of the municipality were selected. While selecting the sample houses, at least throughout timber band(s) was assured. Due to difficulty in identifying the housing components in row houses, isolated houses were chosen. The number of isolated houses is very less throughout the city; so three houses constructed at least 40 years before were selected for study. Structural integrity, ductile connections, load concentration and distribution, roofs, overhangs and other commonly noticed defects of masonry buildings were checked on field with a checklist. Some geometrical features were also measured in field as well. The findings are presented in terms of weight distribution, plan and elevation symmetry/asymmetry, provisions of bands, roofing materials, binding materials, projections, load path continuity, building proximity, openings, foundation site condition and plinth, wall dimensions and number of stories, non-structural members, geometrical and architectural specifics, among others. Phenomenological studies across the city were also conducted for identifying and validating the buildings features incorporated during field survey. Non-structured interviews, library and archive consultations were also performed for identifying and formulating the seismic risk, resilience and structural as well as non-structural preparedness technologies adopted locally.

4. RESULTS AND DISCUSSION VIS-À-VIS SEISMIC RISK AND RESILIENCE

Most of the studied *Newari chhens* were found to be composed of three storied houses consisting of *chheli* (ground floor), *matan* (first floor), *chota* (second floor) and sometimes *buigal* (terrace). Exterior walls were usually found to be constructed as thick layers up to the third storey and subsequently reduced in upper storey. The upper storey is constructed of similar type of material. As per the utility; *chheli* is commonly used for storage and occupational purposes/activities and *matan* is used for living, sitting and bed room purposes. *Chota* is used for kitchen, dining and worshipping purpose (as *pooja* room). Geometrical properties of studied buildings in terms of wall thickness, storey height, building dimensions, opening dimensions have been presented in table 1. At the meantime, other findings have been disseminated in detail under following heads.

Table 1: Geometrical properties of various components of *Newari chhen*

Building components	Mean (m)	Standard deviation
Wall thickness	0.42	0.08
Storey height	1.84	0.05
Length of building	10.28	0.12
Width of building	6.85	0.09
Height of khapa	1.35	0.10
Length of khapa	0.65	0.06
Height of jhya	0.71	0.05
Length of jhya	0.36	0.06
Average building height	8.05	0.08
No. of storeys	3.5	0.03

4.1 Bands at various levels

Plinth band was found placed immediately above the plinth using a wooden flake throughout the wall. Such bands usually contribute in bearing the differential settlements. The foundation soil below plinth is soft due to prevalence of loose fluvio-lacustrine soil. Though purpose of such band was not justified while incorporating as a construction component, it has positive influence upon seismic performance of buildings. During reconnaissance immediately after the 2015 earthquake, houses with plinth/sill/lintel bands were found to be more resilient than those without plinth and wooden plinth bands. Wooden bands are found to be extensively used in every *chhen* and are contributing in integrity of structure and resistance to out of plane wall bending. The level of openings is usually found incorporated with lintel bands. Moreover, lintel band and the gable band, performing similar function like that of the lintel band, also effectively incorporate prevention of roof collapse.

4.2 Building configuration and dimensions

A rectangular configuration walls restricting any re-entrant corners usually compose URM houses. At the meantime, buildings are typically constructed as row houses joining walls and other components throughout the city. Due to this procedure, storey heights were found constant. This practice usually prevents the pounding effect in the aggregate. The average length of wall is about 10.3m with the standard deviation of 0.12; whereas the average width is 6.85m at the standard deviation of 0.09 (Table 1). This suggests length to width ratio to be less than 2, which is well within the limit of 3 as per Nepal Building Code (NBC 205) (NBC, 1994). Lower value of this ratio justifies most of the modern URM construction practices and codes as well; however there was no any prevalent code of practice during construction of studied houses.
All the studied buildings were found to be simple rectangular in configuration (Fig. 1); with a proper configuration in accordance with modern construction practices.

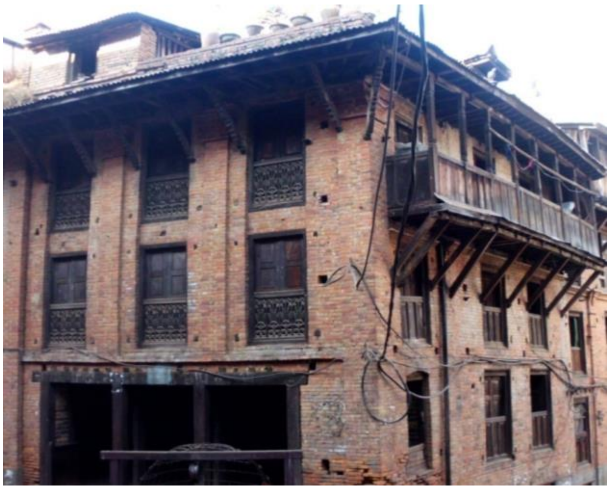

Fig. 1 Symmetrical matchbox construction practice at Bhaktapur

Most of the houses were constructed at least four decades earlier than introduction of earthquake resistant building construction practice in Nepal in 1994. A matchbox type-building configuration was found to be prevalent in studied buildings and throughout the city in the field survey.
Openings in *Newari Chhen* were found in the form of windows and doors; at the meantime their construction mainly dominates typical cultural forms of windows.

These forms are *tiki:jhya* (lattice window), *sa: jhya* (relatively larger opening in *chota*), *ga: jhya* (depressed window) and *khapa* (door with smaller dimensions). In case of openings, all of these were heartwood timber elements tied properly with the structural wall systems. Moreover, in case of openings, smaller openings are preferred instead of larger ones and avoiding the arches above openings.

4.3 Elevation and stories of buildings

Average height of houses is found to be 8.05m at the standard deviation of 0.08 and average stories of houses are depicted to be 3.5 (Table 1). Figure 2 represents the frequency of buildings in terms of their storey heights separately. Each of the *chheli, matan, chota* and *baiga* has different heights as per the purpose of utility and mobility. However, such difference is height is not large and primarily low storied houses are found throughout the city.

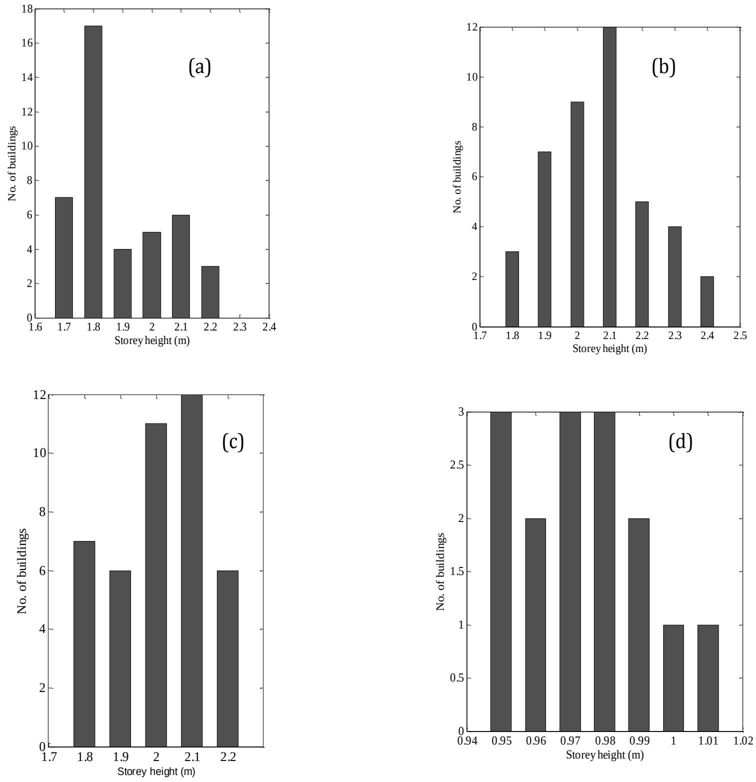

Fig. 2 Height distribution of (a) *Chheli* (b) *Matan* (c) *Chota* and (d) *Buigal*

Usually *matan*, which is used for living purpose is found to be having the greatest height upto 2.07m in average; however all other stories are found to be having smaller height than that of the *matan*. *Baiga*, which accommodates roof, either thatched with *jhingati* (roof tile) or even the corrugated sheets, is found to be having its height less than 1m. Immediately after the 2015 Gorkha earthquake, field reconnaissance was performed and hence the majority of damage is found to be concentrated in upper stories.

4.4 Wall system

Building materials were identified as *appa* (sun dried clay bricks) or *si appa* (non-burnt clay brick), though compressive strength of such bricks was nevertheless verified. However, Japanese specialists during the study on earthquake disaster mitigation in Kathmandu valley experimentally verified that the traditional bricks were stronger than expected and prohibit the pancake destruction unlike the RC construction (JICA, 2002) leading a strong evidence of resilience of such structures during many past earthquakes like 1934 Bihar-Nepal earthquake, 1988 Udyapur earthquake, 2011 Sikkim-Nepal border earthquake and 2015 Gorkha earthquake. While at the level of *chota*, the wall thickness decreased and above this storey, usually smaller wall thickness is provided. Projections were not observed frequently on walls though some projections in terms of wooden *ga:jhya* were observed with struts supported beneath it.

4.5 Other building features

Struts are observed to be connecting the roof to the lower stories usually the *chota*, and sometimes used for aesthetic purpose in the form of *tudals* (struts with carved appearance within the timber element) as well. Struts are significant in transferring the cantilevered load to the continuous and regular load path, thus during vibration, detachment of cantilevered portion is usually prevented. Beside the architectural purpose, struts help to reduce the problem of vertical deformation in case of cantilevered load leading to improvement building behaviour during earthquakes. Without struts, even minor vertical earthquake may cause damage in the houses.

In traditional buildings, vertical transportation system is provided by *sona* (moveable timber ladder) of low weight within a staircase opening found in corners of buildings. Use of such timber ladder has reduced the load of non-structural members in greater extent as most of modern constructions are experiencing wider damage in non-structural members. Ladders are assembled with small pieces of wooden flakes having low weight.

Newars are gregarious culturally and they establish settlements as row housing. Beside construction of row housing, height of every storey is found to be almost similar as most of such houses were built by the similar technology and craftsmanship.

During this study, some of additional features of houses are identified, which have significant contribution during earthquakes like; vertical corner post, wooden pegs at various levels, and double boxing of openings.

5. CONCLUSION

Indigenous housing technology has been significantly playing an important role in the survivability and sustainability of unreinforced and traditionally built houses in seismic zones. During past events, many of such buildings survived significantly. People usually develop unique coping mechanism through unrelenting trials and errors and experiences. Such knowledge system is reflected in prevalent construction technology and institutionalized as a custom for the built environment. While analysing the indigenous knowledge of housing construction in the world heritage site and vicinity in historic urban nucleus of Bhaktapur city, it has been concluded that some excellent features regarding earthquake resistant constructions were introduced into the *Newari chhens*. Based on detailed survey of 42 houses and other phenomenological studies and non-structured interviews, the features like structural integrity, wall system, smaller

openings, subsequent load reduction in upper stories, provision of bands at various levels, horizontal diaphragm, struts, proper rectangular configuration with low length to width ratio, opening dimensions, among others have been identified in residential buildings of Bhaktapur city. These features are widely accepted in terms of structural performance and reduction of damage level worldwide.
In the National Building Code of India, indigenous knowledge of building construction has been provisioned for encouragement and blending with the modern technologies. Moreover this code has kept indigenous knowledge as an approach to sustainability (BIS, 2012). Till date Indian code is widely followed in Nepal. In this regard, assuring cultural reconstruction may be pivotal in city sustainability. Likewise, in Dhajji construction guideline has been prepared and practiced in Pakistan with special reference and promotion of indigenous constructions (UN Habitat and National Disaster Management Authority, Pakistan, 2009). Regional paradigm from these two evidences could be replicated in Nepal National Building Codes through sustainability approach.

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