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Research Paper

Earthquake Resistant Assessment of Building Construction Technique in the Nayagaun Settlement of Kavre before Gorkha Earthquake

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ABSTRACT

The major earthquake on April 25, 2015 (7.8 Mw) and the aftershock on May 12, 2015 (7.3 Mw) caused severe damages on the Nayagaun settlement of Dhulikhel Municipality, Kavre, Nepal. This study proposes to highlight the extent of damages in the buildings due to the absence of the earthquake resistant components. In this study, the suitability of the building construction techniques in the study area has been addressed after knowing the consequences faced due to the absence of the earthquake resistant components in the buildings. This study provides idea on the earthquake resistant components and its significance in the residential buildings during the earthquake period. In this study, the types of the buildings damaged are tabulated according to the typology of the buildings whereas the type of damages incurred are categorized based on the grade of damages (partially damaged or fully collapsed). Some mitigating measures are identified throughout the study to overcome the future earthquakes.

1. Introduction

This is a case study for earthquake resistant assessment of building construction techniques in Nayagaun settlement of Kavre before Gorkha earthquake 2015. The settlement lies in ward no. 3 of Dhulikhel municipality, Kavre, Nepal as shown in **Fig 1.** The strong earthquake on April 25, 2015 (7.8Mw moment magnitude) originated at Barpak, Gorkha District and the largest aftershock with the magnitude of 7.3 Mw (United States Geological Survey) affected the buildings in Nayagaun settlement to great extent leading to the failure in structural and non-structural components of the buildings.

Fig. 1. View of Ward no. 3, Nayagaun
(Source: https://www.google.com/maps/place/Dhulikhel)

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There were 77 households in this area. This settlement consists of population of 329. Out of 329 population, 174 people are male and 155 are female (CFLG Household survey, 2016).

The Gorkha earthquake has significantly affected the livelihood of people and overall economy in the country, causing huge damages of property and human lives in many districts. Among the 14 severely affected districts, the touristic destination district Kavrepalanchowk was also affected because of the ancient settlement of improperly maintained majority of mud mortar buildings. Since earthquake is unpreventable and unpredictable, design of buildings should be earthquake resistant so that it can withstand earthquake forces without much damage to the life and properties of its inhabitants (Bothara *et al*, 2002). The reason behind the cause of the extent of damage was carried in this study. Hence, this study is aimed to assess the earthquake resistant building components in the Nayagaun settlement, identify the extent of damages due to the absence of the earthquake resistant components of the building and address the suitability of the building construction techniques in the study area.

2. Earthquake Disaster in Nepal

The people of Nepal have been living with the vulnerability of earthquake from many generations. The locations of slip during Gorkha earthquake and its main aftershock ruptures are shown in **Fig 2.** Nepal is one of the most vulnerable countries to the impact of the disasters and ranked 11th in the earthquake-prone country in the world (MOHA, 2017). The entire territory of Nepal lies in high seismic hazard zone. It lies in between the Indian and Tibetan plates, along which a relative shear strain of about 2 cm per year has been estimated and the Indian plate is also subducting at a rate assumed to be 3 cm per year (Theeng, 2016).

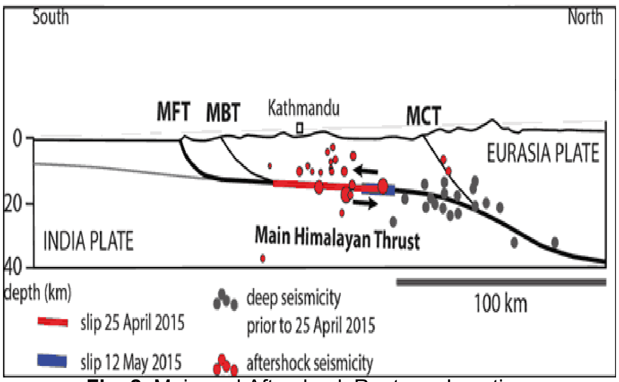

Fig. 2. Main and Aftershock Ruptures Locations.
(Source: USGS, 2015)

The country's high seismicity is related to the movement of tectonic plates along the Himalayas that has caused several active faults. Nepal, because of its location in the boundary of two active tectonic plates moving against each other, is in high earthquake hazard zone. After 82 years since 1990 it faced a major earthquake which the experts declare to have been occurred due to the tectonic collision of Tibetan and Indian plates (Pradhan *et al*, 2016a). Nepal has a regular interval of occurrence of earthquakes along the major active faults in east-west alignment. Historical data and seismological studies have indicated that the entire region of Nepal is prone to earthquake and it lies in the active seismic zone V. Evidence shows that the seismic pattern is geographically divided into three clusters of events that are western, central and eastern Nepal. Historical data has shown that the country witnessed three major earthquakes in the 20th century, namely Bihar-Nepal 1934 earthquake, Bajhang 1980 earthquake and Udayapur 1988 earthquake. A total of 92 active faults has been mapped throughout the country. In 1934 AD earthquake produced strong shaking in Kathmandu Valley, and destroyed 20 percent and damaged 40 percent of the valley's building stock. Gorkha earthquake damaged lot of non- engineered buildings.

Fig. 3. Collapse of stone masonry in mud mortar building in the study area due to Gorkha Earthquake
(Source: Santosh Lama, ward 3 beneficiary)

Fig. 4. Collapse of residential buildings in Nayagaun settlement
(Source: Santosh Lama, ward 3 beneficiary)

Unreinforced masonry buildings are found in most of the areas in Nepal. The condition of Nayagaun settlement after Gorkha earthquake can be observed in **Fig.3 and Fig.4.** Most of the buildings were of stone masonry constructed without the earthquake resistant components. More than 98% of the buildings in Nepal are being built by owner-builders who follow the advice of local mason (Dixit, 2004). The majority of buildings were built without modern construction codes. The construction and structural deficiencies were the major causes of failure of the buildings.

2.1 Factors responsible for the damage of the buildings

The damage patterns of existing houses were observed during site investigation in the study area. However, most of the buildings were flattened to the ground surface. So, to get an idea about the damage pattern, questionnaires were prepared and necessary information was collected from house owners. Based on the site investigation and questionnaire survey, the major factors for the damage of buildings are mainly due to:

a. Construction method
b. Materials used
c. Building configuration in plan and in elevation
d. Age of the building
e. Number of storey
f. Size of the building

2.2 Factors responsible for increasing risk of buildings by earthquake hazard

Earthquake results in loss of human life and property. So, the design of buildings should be earthquake resistant. Following are the factors which are responsible for increasing the risk of buildings by earthquake hazard.

a. Structural system (frame structure, load bearing structure, dual structure),
b. Structural bands (plinth band, lintel band, roof band, and gable band),
c. Building shape, building height, building separation distance and building materials.

Structural system enhances the building seismic capacity. Structural elements like: plinth band, lintel band, roof band, sill band, gable band, etc play great roles in a building to resist the earthquake force during earthquake period. Vulnerability of any structure to earthquake risk can be reduced by consideration of lateral forces during design. Proper load path should be defined and irregularities should be avoided (Pradhan *et al*, 2016b). Likewise, the shape of building, height of building, the distance between two buildings, the type of materials used in construction of a building also matters a lot in the seismic capacity of the building.

3. Methodology

For determining the extent of damage in the buildings, site investigation and questionnaire survey method were carried out. In this study, two methods were used for the methods of data collection.

3.1 Primary Data

Primary data were collected by Focused Group Discussion (FGD) and Key Informant Interviews (KII) with local residents and municipal staff. Damages of buildings were identified by the questionnaire survey techniques with the affected local people. Site investigation was done to know the condition of the buildings in the settlement area and the scenario of the damage incurred due to the earthquake. For the convenience of the study purpose, buildings were categorized as follows:

a. Stone Masonry in Mud Mortar (SMM)

The structures constructed with stone masonry and those structures which had purely mud mortar were taken on this category. Generally, these types of structures were found mostly in the site. This type of buildings in Nayagaun had generally 1 to 3 storeys including attic. Galvanized iron sheets were mostly used for roofing and in only few houses, tiles were used as a roofing material. We can find wall thickness of 18 inches to 24 inches. The seismic capacity of this type of structures was found to be very low due to lack of the lack of elements tying the structural component.

b. Brick Masonry in Mud Mortar (BMM)

The structures constructed with brick masonry with mud mortar fall under this category. The floor and roof were found with flexible as well as rigid diaphragms. The structural elements were also not adequate on this typology.

c. Reinforced Cement Concrete Frame (RCC Frame)

The structures constructed with frames consisting of concrete and reinforcement fall under this typology. Masonry partition and infill walls (brick, block or stone masonry) were other non-structural components. Infill walls were not tied to the frame and the floor and slab consist of reinforced concrete in these structures. In the site during questionnaire survey, the respondents answered that the infill wall was stone with mud mortar as its binding material. This is the main reason that during the earthquake the infill wall were collapsed.

3.2 Secondary Data

Secondary data were collected through books, journals, aerial photographs, maps, newspaper, articles, research papers, thesis reports, internets, etc.

3.3 Data Analysis

All data were scrutinized carefully to eliminate the irrelevant elements. Relevant and useful data are sorted and organized in such a way to simplify data analysis. The information obtained from the primary and secondary data are categorized as per the construction types, materials, structural bands, storey distribution and age of the building. The data are then presented on chart, graph, table, diagram etc.

For the study purpose, damage evaluations were categorized under the following two observed conditions:

a. Fully Collapsed or Beyond Repairs
b. Partially damaged or can be repaired/retrofitted

Buildings typology found in the site area during field survey were categorized in different sections depending upon the nature of damage. The reasons for the damage of those buildings in the field were identified and then listed out. The outcomes were interpreted and presented in graphs, bar charts to find out the damages of the buildings attributes typology.

4. Results and Discussion

4.1 Building Typology

In this study, it is found that Nayagaun area of Ward No.3 were vulnerable due to the absence of the earthquake resistant elements in the buildings and poor workmanship. During the site visit, it was found that most of the areas where buildings suffered damage were not subjected to enforcement of the Building Code and Standards. Most of the buildings that suffered damage were old buildings constructed of weaker materials (i.e. stone, adobe and mud), buildings constructed with deficient construction practices and non-engineered buildings. There were no trained masons in the construction of the buildings. The people in Nayagaun have adopted owner driven approach for the construction of their house. The majority of structures were of stone mud mortar joint type which were more vulnerable to earthquakes. Bricks in mud mortar joint were also found relatively whereas earthquake resistant RC frame structures were seen lesser in aggregate. Building typology in the Nayagaun settlement before Gorkha earthquake is shown in **Table 1.**

The buildings were categorized as follows as per:

a. Construction Types
b. Construction Materials
c. Structural Bands
d. Storey distribution
e. Age of the building

Table 1 Building typology in Nayagaun before Gorkha Earthquake

S.N.	No. of Type	In %	Typology
a. As per Construction Types			
1	47	96%	Stone Mud Masonry
2	1	2%	Brick Mud Masonry
3	1	2%	Reinforced Concrete Frame
b. As per Construction Materials			
Wall Materials			
4	48	98%	Stone
5	1	2%	Brick
Roof Materials			
6	47	96%	CGI Sheet
7	1	2%	Tiles
8	1	2%	RCC Flat Roof
c. As per Structural Bands			
9	34	70%	Absence of Structural Band
10	15	30%	Presence of Structural Band
d. As per Storey Distribution			
11	35	71%	Two Storey
12	14	29%	One Storey
e. As per Age of the building			
13	11	22%	0-5 year
14	10	20%	6-10 year
15	12	24%	11-15 year
16	16	34%	16-20 year

(Source: Field Survey)

4.1.1 Construction Types

The structures of the buildings in the past were predominantly load bearing type (LBW) with stone walls and mud mortar. Load bearing structures with cement mortar and reinforced concrete frame with masonry infill walls became popular after May 25, 2015 Gorkha earthquake. These are the most popular construction types these days. Before the earthquake, 96% of the buildings in Nayagaun were load bearing wall type construction (Stone mud masonry), 2% were of Brick mud masonry and 2% were Reinforced Concrete type construction. The rest of them were load bearing wall type of construction as shown in **Fig 5.**

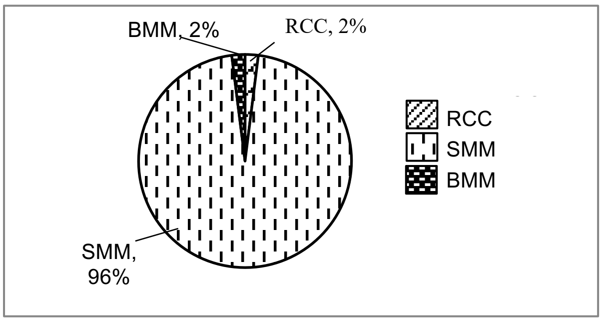

Fig. 5 Buildings by Structure Type

4.1.2 Construction materials

Stones are the predominant wall materials used in the buildings as it is locally available material in the site during construction. Sun dried bricks were also used in few houses as the wall materials in Nayagaun. The floor of the buildings in the past was constructed with mud and wood. 98% houses were constructed with stone and 2% houses were constructed with bricks as shown in **Fig 6.**

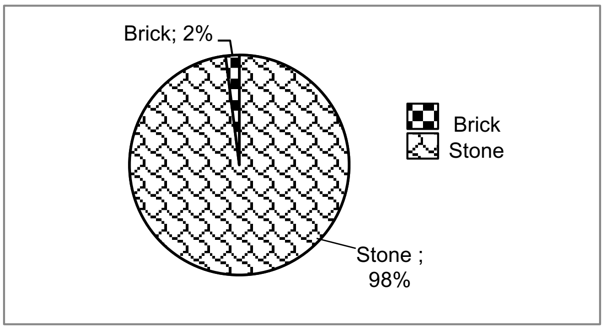

Fig. 6. Types of Wall Materials used in the study area

Most of the buildings on the site have corrugated iron sheet (CGI) as a roofing material. Only few buildings have tiles and flat reinforced concrete (RCC) roofs. 96% houses have CGI sheet, 2% houses have tiles and rest 2% houses have RCC Flat roof as roofing materials as shown in **Fig 7**.

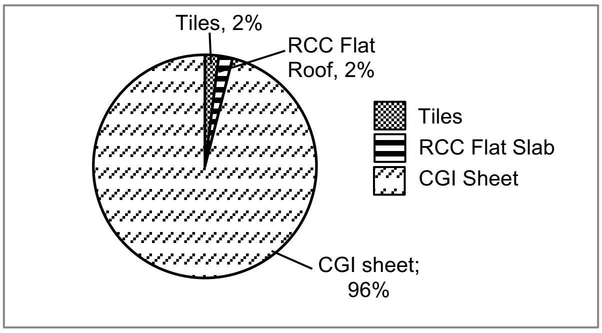

Fig. 7. Types of Roof materials used in buildings in the study area

4.1.3 Structural Bands

Structural Bands are the most important elements that can greatly contribute to reduce the possibility of different failure mechanisms. The presence of sill bands, lintel bands and roof bands are recorded during field work. The field study revealed that most of the buildings do not have presence of such structural bands. 70% of the buildings have lacked structural bands which are shown in **Fig 8.** Only 30% of the buildings have used structural bands. Timber and woods were used as structural bands in the buildings.

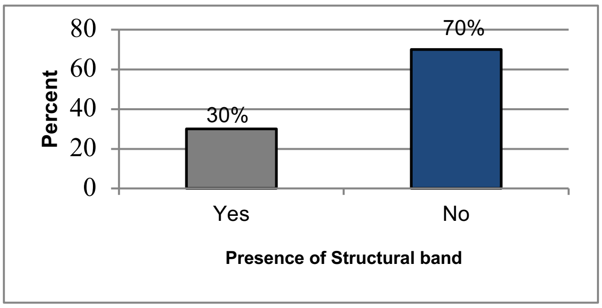

Fig. 8. Percentage of Presence of sill band, lintel band and roof band

4.1.4 Number of Storeys

The number of storeys in a building consists of all storeys that are primarily above ground level and in which there are habitable rooms or office space or other space conforming to the intended use of the building. If the number of storeys varies in different parts of the building, the number usually refers to the largest number of storeys in the building.

Generally, the buildings on the site were 1 to 3 storeys including attic. More than 70% of the houses were 2 storeys including attic and few of them were 1 storey including attic as shown in **Fig 9.**

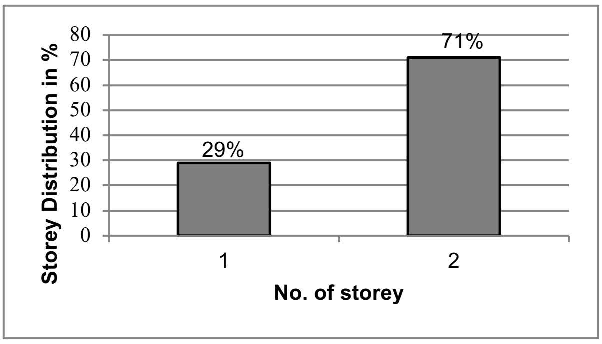

Fig. 9. Storey Distribution in percentage

4.1.5 Age of the buildings

22% of the buildings on the site were of age group 0-5 years, 20% of the buildings were of age group 6-10 years, 24% of the buildings were of age group 10-15 years and 34% of the buildings were of age group 15-20 years as shown in **Fig 10.**

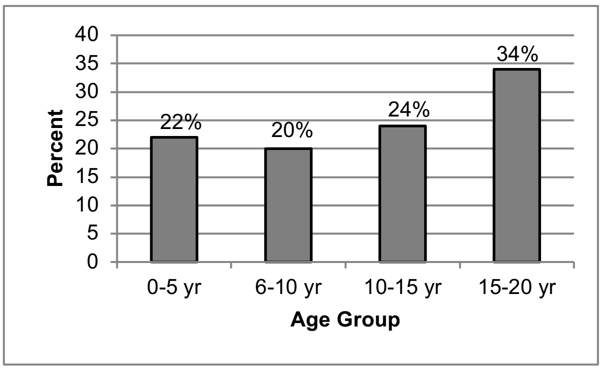

Fig. 10. Age of building

4.2 Types of Building Damages

Damaged buildings have been categorized into 3 different types considering the ratio from census data and the ratio of possible collapse and partial damage derived from fragility functions for different earthquake shaking intensities. Building typologies and damage are shown in **Table 2**.

Table 2. Building Typologies and Damage

S.N.	Typology of Buildings	Fully Collapsed or Beyond Repairs		Partially Damaged (can be repaired/ retrofitted)	
		No.	In %	No.	In %
1	Stone Mud Masonry	46	94	1	2
2	Brick Mud Masonry	1	2	–	–
3	Reinforced Concrete Frame	–	–	1	2

(Source: Field Survey)

In the field survey, among 49 households, it was found that 46 houses of stone mud masonry category was fully collapsed which indicates that 94% of houses were totally collapsed and could not be repaired. Similarly, only one house was found of brick mud masonry which indicates 2% of house was fully collapsed and could not be repaired. No any reinforced concrete frame structure was fully collapsed.

Likewise, among 49 households, it was found that only 1 house of stone mud masonry category was partially damaged. This partially damaged structure can be repaired and retrofitted and the structure can be strengthened. Similarly, only 1 house of reinforced concrete frame structure was partially damaged and this partially damaged structure can be repaired and retrofitting can be done to strengthen the structure.

Based on the field observation, the main types of the damages were identified as follows:

- Parapet and gable wall toppling
- Delamination of low strength masonry walls
- Out of plane toppling of walls
- Corner separation of walls
- Various types of wall failures under in-plane loading such as diagonal cracks, sliding cracks, crushing of piers, failure of spandrels
- Collapse of floor and roof due to loss of vertical load bearing elements such as walls.

The overall result shows that building with Adobe and Mud joint had exhibited more damage characteristics than the other building typology. Adobe and Mud joint buildings have mud mortars which has weak bonding nature than other mortar. The seismic resilient capacity of this type of structures is low due to lack of integrity of structural components, the strength of the wall and the lack of elements tying the structural component. The main reason for the damages of buildings were due to lack of knowledge about earthquake resistant components (like: Vertical rebar, sill and lintel bands, etc.) in the buildings, no technical supervision, lack of quality and workmanship of masons were observed. According to the respondents, if the old buildings were timely retrofitted and maintained, the damages would have been reduced.

Lack of integrity between different structural members and inherent weak properties of the materials was the main cause of failures in masonry buildings. Poor quality mud or cement mortar caused in the disintegration of masonry units and loss of support to floors. Especially, mud-stone masonry structures collapsed or were heavily damaged even in small earthquakes due to poor mud mortar and insufficient anchorage between mud and stone. Many people and animals have lost their lives under debris of these structures. So, this structural system should not be constructed in the earthquake zones or some wood structural elements should be inserted in this system adequately to prevent total collapse.

Many masonry buildings subjected to destructive earthquakes collapsed and were severely damaged due to some unsuitable designs. Few new reinforced concrete structures were built at the same location, despite that they were damaged or collapsed as they were non-engineered. Thus, if masonry buildings are designed to be resistant against earthquake and constructed with good quality materials, they would survive during the earthquakes. No proper use of header stone in the corner and vertical rebar in the corner position has led to the corner separation of walls. Vertical confining elements should be located at the end of the load-bearing walls, at the both sides of the doors and windows opening to prevent from the possible damages during the earthquake.

Another failure can be the formation of vertical cracks at the corners of an unconfined masonry building in which the wall begins to form a hinge from the swaying. Failures and cracks at the corners occurred because of the insufficient connections between the walls and floors. If there were vertical confining elements at the corners, these elements would have contributed to the earthquake resistance of the wall.

Unreinforced masonry buildings are the most vulnerable to flexural out-of-plane failure. If the connection between the walls and floors is not adequately restrained, the whole wall panel or of a significant portion of it will overturn due to seismic excitation in the perpendicular direction to the wall plane. Added vertical R/C confining elements contribute to earthquake resistance of the wall; in this manner, out-of-plane failure does not easily occur.

Only a building constructed on 2050 B.S was not much damaged by the earthquake shown in **Fig 11.** The reason was that the building was constructed including all the earthquake resistant elements like: sill and lintel bands, proper opening size was maintained and all the roofing members are connected properly with each other. Almost all buildings were of Mud mortar and foundations were generally about 1- 2 feet and hardly up to 3 feet. The integral components of the masonry building as shown in **Fig 12** helped the building to survive during Gorkha earthquake.

With comparison to the nearby village "Nayabasti", the house in Nayagaun has been completely damaged due to the absence of the earthquake resistant components (like: Vertical rebar, sill and lintel bands, etc.) in the buildings. Some people have built their house in the steep slope area where there is a great chance of facing landslide after the earthquake. Houses in Nayabasti are not completely destroyed by the Gorkha Earthquake. The instability due to geometry, design, or material choice was also one of the main reasons that cause the structure to fail from fatigue or corrosion.

Fig. 11. House in Nayagaun that survived after Gorkha Earthquake
(Source: Field survey)

Fig. 12. Proper joint connections in the house that help to prevent the building from collapse
(Source: Field survey)

5. Conclusions and Suggestions

Damage degrees in all categories show that masonry buildings with mud mortar as binding materials were found to be much damaged than other typologies. RC Frame structures were less vulnerable compared to masonry structures.

From the study it was concluded that more than 95% of the buildings were of stone and mud joint typology whereas 2% were Brick in mud mortar and other few were RC frame structures according to average building typology. Damage degrees in all categories show that stone and mud joint buildings were found higher than other typologies. For RC frame structures, the damage degree was found not more than 2%. It was concluded from research that the flexible floors were damaged, 10 times more than that of rigid floors.

The main cause of failures in masonry buildings was due to lack of integrity between different structural members and inherent weak properties of the materials. Poor quality mud or cement mortar caused in the disintegration of masonry units and loss of support to floors. Especially, mud-stone masonry structures collapsed and heavily damaged even in small earthquakes due to poor mud mortar and insufficient anchorage between mud and stone. This results in heavy loss of human life and properties as well. So, this structural system should not be constructed in the earthquake zones or some earthquake resistant elements should be inserted in this system adequately to prevent total collapse.

Awareness levels in building construction to the locals were found to be increased due to the recent earthquake. Residents of municipality focused more on RC frame buildings to minimize the losses. Positive attitudes on proper engineering design, supervision, quality construction materials, column size, foundation depth, stories limitation and following building bylaws and building codes were found in the minds of local residents.

Strict implementation of modified building bylaws and proper application of building codes in a proactive way must be adhered to and if not followed, reactive ways must be put up in the municipality policy like: penalties.

It is a known fact that heavy loss of life and property during earthquakes is mainly due to collapse of weak buildings and lack of earthquake preparedness. Although National Building Code has been formulated in 1994, dissemination of the codal and bylaws requirements has not been effective in most of the rural part of Nepal. Further, due to economic constraints, owner driven construction and ineffective codal implementation, the houses in the study area are observed to be low earthquake resilient. Therefore, the followings are the recommendations:

a. Building permit process should be strictly followed and timely monitoring of the constructed houses should be done by the municipal engineers to know the condition of building at site.

b. The municipality has to organize the training program regularly to engineers, masons, and other stakeholders to alert about bylaws, code and the building permit process.

c. Dimensions in the building should be strictly adhered to the authorized codes or guidelines. If not followed, necessary structural analysis should be checked to ensure whether the structure to be built is safe or not. Only structurally safe building design should be followed.

d. The structural elements should be placed in the buildings in proper manner following the authorized building codes.

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Abbreviations

AD	Anno Domini
BMM	Brick Masonry in Mud Mortar
BS	Bikram Sambat
CFLG	Child Friendly Local Governance
CGI	Corrugated Galvanized Iron
DUDBC	Department of Urban Development and Building Construction
FGD	Focus Group Discussion
GoN	Government of Nepal
KII	Key Informant Interview
LBW	Load Bearing Wall
MBT	Main Boundary Thrust
MCT	Main Central Thrust
MFT	Main Frontal Thrust
MMI	Modified Mercalli Intensity
MOHA	Ministry of Home Affairs
NSC	National Seismological Centre
NSET	National Society for Earthquake Technology
PU	Pokhara University
RC	Reinforced Concrete
RCC	Reinforced Cement Concrete
SMM	Stone Masonry in Mud Mortar
TU	Tribhuvan University
TV	Television
UNDP	United Nations Development Programme
USA	United States of America
USGS	United States Geological Survey
VDC	Village Development Committee