IOP Conf. Series: Earth and Environmental Science **61** (2017) 012093 doi:10.1088/1755-1315/61/1/012093

# Earthquake damage of self-built reinforced concrete frame structures in $M_S$ 8.1 Nepal Earthquake

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**Abstract.** An earthquake measured Ms 8.1 occurred near the Nepal Pokhara on April 25, 2015(Beijing time). As a member of China to Nepal disaster assessment team, the author conducted thorough investigation about the earthquake damage of all kinds of engineering structure in Nepal. Self-built reinforced concrete frame structure which is widely accepted by the people at all levels in Nepal and is one of the building structure forms which are widely built suffered damage by varying degrees in the strong earthquake and aftershocks. Based on the seismic damage investigation date of the earthquake and its aftershocks, the characteristics of aseismic construction are summed up, the damage characteristics and the reasons of its destruction are analyzed. The main problems in the design and construction of the structure are pointed out. The advices on the existing problem of self-built reinforced concrete frame structures are given.

## 1.Introduction

An earthquake measured $M_s$ 8.1 occurred near the Nepal Pokhara (N28.2 degrees, E84.7 degrees) at 14:11 on April 25, 2015(Beijing time ). The focal depth is 20Km. In Nepal and parts of other countries like India, Bangladesh, China and Pakistan, people could feel clearly. Some counties in Tibet,China like Nielamu County, Tingri County, Geelong County, could feel very strongly.

The author investigated self-built reinforced concrete frame structure deeply in different earthquake affected areas of Nepal. Seismic design ideas weren't considered into the construction of most self-built reinforced concrete frame structure, nor were the standardized construction methods. In the earthquake and strong aftershocks, self-built reinforced concrete frame structure were subjected to various degrees of damage. Particularly in the high intensity region, even collapse happened.

This paper will summarize the structure and disaster characteristics of reinforced concrete frame structure in Nepal. We will also analyse the weak link existing in structure and give some proposals to improve the design and construction. The research can help us understand the seismic capacity of building structure in Nepal preliminary, so that the Chinese government can help Nepal to carry out reconstruction work targeted.

## 2. Seismic Characteristics Of Self-built Reinforced Concrete Frame Structure

Self-built reinforced concrete frame structure are mainly 3-5 layers (Fig. 1).The top of general structure are ready to be followed by half layer of reinforced concrete columns and exposed steel cage(Fig. 2).Storey height is 3.0m.Layout is symmetric regularly.Column space is from 3m to 3.9m.

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The structure use independent column foundation; the size of frame column section is 230mm×230 mm ;longitudinal bar is 6A12 and stirrup is A6@120,without reinforcement of stirrup encryption in frame columns (Figure 3); the size of frame beam section is 300mm×230 mm; the majority of beam section’s size is greater than the column section’s size,violating the specification requires for a "strong column, weak beam"and component section with minimum size concept design principles of all countries in the world ; floor and roof panels use cast-in-place reinforced concrete floor slab, of which the thickness is 100mm; infilled walls use solid brick (220mm×100mm×50 mm) and mud masonry; the outer wall thickness is 220mm, the inner wall thickness is 100mm;there is no construction rachel measures between the wall and the frame column(Figure 4).

**Fig.1** Overall picture of self-built reinforced concrete frame structure

**Fig.2** Reserved reinforced concrete column and steel cage on the top floor

**Fig. 3** Reinforcement of frame column

**Fig.4** Structural Rachel measures between infilled walls and frame columns are not set

## 3.Analysis on The Characteristics And Causes Of Seismic Damage Of Self-built Reinforced Concrete Frame Structure

Self-built reinforced concrete frame structure is a better structure relatively in the earthquake affected areas of Nepal. The damage features are: the structures were virtually undamaged in the area of VI degree; slight diagonal cracks and cross cracks occurred in infilled walls in the area of VII degree; a vast of severe diagonal cracks and cross cracks occurred in the infilled walls as well as a small quantity of the stigmas of frame bottom columns was damaged seriously inVIIIdegree;the infilled walls were damaged seriously and the construction collapsed partial ;some frame bottom columns was damaged seriously andthe construction even collapsed in the area of IXdegree.

### *3.1. Damage of Infilled Walls*

In VI zone, there were no obvious damage in infilled walls. In VII zone, the bottom infilled walls run through the inclined cracks or cross cracks (Figure 5). In VIII degree, the bottom infilled walls run through the transparently inclined cracks or cross cracks (Figure 6).In IXdegree, the bottom infilled walls collapsed partially, and were damaged heavily (Figure 7).Using mud masonry in the infilled wall lead to the low level of walls' shear strength. Under the action of reciprocating horizontal earthquake, a large number of shear cracks or cross cracks happened in the infilled walls; at the same time, the infilled walls had external flash, or even collapsed in high intensity area because there were no reinforcement structure filled between the walls and the frame columns.

**Fig.5** Destruction of infilled walls in the region of VII degrees

**Fig.6** Destruction of infilled walls in the region of VIII degrees

**Fig.7** Destruction of infilled walls in the region of IX degrees

*3.2. Damage of Frame Column*

In VIII degree area, shear failure occurred at the top of a small quantity of frame bottom columns (Figure 8); In IX degree area, shear failure occurred at the top of some frame bottom columns, shear failure occurred at the middle of a small quantity of frame bottom columns (Figure 9). In self-built reinforced concrete frame structure, the size of beam section is generally greater than that of the column section and the reinforcement of reinforced beams are often stronger than the column, resulting in the formation of "strong beam weak column" mode in the structure [1-3].At the same time, the lack of joint hoop reinforcement near the beam and column node area [4-6] lead to less reinforcement brittle damage on the top of column more easily. At the same time, there is an inherent weak link in the top of the column because most of the frame columns were poured directly to the bottom of the beam during construction. It increased the destruction of the top of the column under the horizontal earthquake reciprocating action, eventually leading to shear failure occurred on the top of the column.

**Fig.8** Destruction of the top of the underlying columns in the region of VIII degrees


**Fig.9** Destruction in the middle of the bottom frame columns

*3.3. Collapse of Self-built Reinforced Concrete Frame Structure*

In IXdegree, the disappearance of bottom layer occurred on parts of self-built reinforced concrete frame structure.The research found that most of the bottom columns suffered severe shear failure in the main shock. In the following 3larger aftershocks,the damage on the top of columns continued to increase until the underlying structure disappeared(Figure 10).

**Fig.10 Collapse of the self-built reinforced concrete frame structure**

*3.4. Damage Caused by Collision*

Due to the limited land resources, the density of buildings in Nepal's towns is extremely high and the spacing between adjacent buildings is extremely small. And the design and construction of self-built reinforced concrete frame structure has not been effectively supervised by the government. The above two reasons lead to obvious differences of dynamic performance of adjacent structures, adjacent buildings collide and the structure is damaged in the earthquake. (Figure 11)

Parts of the self-built reinforced concrete structure were built along the road. Structure were close to the road subgrade or connected by rigid connection with the road subgrade. Because the dynamic performance of the structure and subgrade is different, the two collide with each other in the earthquake, resulting in serious structural damage and even collapse. (Figure 12).

**Fig.11** Collision damage to adjacent structures

**Fig.12** Collision damage between self-built reinforced concrete frame structure and highway roadbed

**4.Some Points of View**

The paper summarize the characteristics of earthquake damage and aseismatic construction of reinforced concrete frame structure built by themselves based on the investigation of 8.1 earthquake in Nepal. The paper indicates the following things:

(1) Self-built reinforced concrete frame structure is one of the housing structures which are widely recognized and built by all sectors of the Nepalese people. Due to the nature of private land ownership and the lack of local government supervision, the ideas of aseismic design has not been considered and the normative construction methods have not been used in self-built reinforced concrete frame structure.

(2) Self-built reinforced concrete frame structure suffered destruction in different degrees in the earthquake and strong aftershock. The structures are virtually undamaged in the area of VI degree and slight diagonal cracks and cross cracks occurred in infilled walls when in the area of VII degree. A vast of severe diagonal cracks and cross cracks occurred in infilled walls as well as a small quantity of the stigmas of frame bottom columns was damaged seriously in the VIIIdegree. The infilled walls were damaged seriously and the construction collapsed partial as well as some of the stigmas of frame bottom columns was damaged seriously and the even the construction collapsed in the area of IXdegree.

(3) The primary design problems existed in Self-built reinforced concrete frame structure in Nepal are followings. The size of beam section is generally greater than that of the column section and the reinforcement of reinforced beams are often stronger than the column resulting in the formation of "strong beam weak column" mode in the structure. Under this mode, destroy occurs in the frame column before frame beam under large earthquake. The lack of joint hoop reinforcement near the beam and column node area leads to shear failure on the top of column more easily.

(4) The primary problems of constructions existed in Self-built reinforced concrete frame structure in Nepal are followings. The concrete was cast to the bottom of the beam when the frame column was constructed which lead to congenital aseismatic defects at the top of the column. Using mud masonry in the infilled wall leads to the low level of walls' shear strength and integrality of structure. Under the action of the earthquake there is the possibility that the wall are pulled off from the main structure, external flashed or collapsed because there were no reinforcement structure filled between the walls and the frame columns.

(5) In view of the existing problems of self-built reinforced concrete frame structure, it is proposed to strengthen the supervision and review of the new reinforced concrete frame structure by the government departments of Nepal.The cross-sectional area of the frame column should be strictly ensured in the structural design, and enough stirrups encryption area should be set up in the beam - column joint area at the same time. We should ensure that the self-built frame structure is a "strong column and weak beam" ductile structure, and the frame column should not be poured directly to the

bottom of the beam during construction.Cement mortar masonry should be used in the infilled wall. And at the same time, enough construction rachel measures should be ensured between the infilled wall and the main structure.

**Acknowledgments**
Yan Li (1982) male, Ph.D., associate professor, mainly engaged in structural seismic and disaster research, Sun Baitao (1961) male, PhD, researcher, mainly engaged in structural seismic and disaster research. Fund project: supported by Scientific Research Fund of Institute of Engineering Mechanics, China Earthquake Administration（Grant No. 2014B11）, the National Natural Science Foundation of China (Grant No. 51508531) and Program for Innovative Research Team in China Earthquake Administration

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