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BUILDING DAMAGE PATTERNS OF NON-ENGINEERED MASONRY AND REINFORCED CONCRETE BUILDINGS DURING APRIL 25, 2015 GORKHA EARTHQUAKE IN NEPAL

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Abstract

The April 25, 2015 Gorkha Earthquake of Magnitude 7.8 in Nepal damaged about seven hundred thousand buildings. The main typologies of buildings in the affected area are stone masonry with mud mortar, some buildings with stone and brick masonry with cement/sand mortar and few reinforced concrete buildings with masonry infill. Among the damaged buildings, about 96% of the buildings were masonry and about 4% reinforced concrete buildings with masonry infill.

This study conducted detail damage assessment of over one hundred fifty thousand buildings of different type of Masonry and Reinforced Concrete (RC) buildings in Nepal. First, the buildings were classified to different structural types like adobe, stone in mud, brick in mud, stone in cement, brick in cement, wood, bamboo, RC and others. Other important parameters like type of floors and roofs and occupancy of the buildings were noted before starting the detail damage assessment in structural elements.

Damage to overall building as well as to different structural/non-structural elements were categorized into four different categories mainly overall hazard, structural hazard, non-structural hazard and geotechnical hazard. The damage level to different structural/non-structural elements was assigned from insignificant damage to extreme damage in three categories considering the severity of damage like crack widths, delamination, tilting etc. In addition to the severity of damage, extent of damage to that particular element of different severity was also noted. Each type of damage with different severity was estimated in terms of extent like less than 1/3rd of the total area, 1/3rd to 2/3rd and more than 2/3rd. Considering the damage severity and extent, overall damage grade to the building was assigned. Finally, based on the damage grade and extent of damage recommendation to the building either to demolish, repair and retrofit or just repair was recommended.

This study further analyzes the main type of damage to different categories of the buildings and finds out critical factors to be considered for making them earthquake resistant. Existing traditional earthquake resistant elements like wooden bands and their effectiveness on earthquake safety of masonry buildings are further studied. It is found that, corner separation, diagonal cracking, out of plane failure, in-plane flexural failure and delamination are the main type of damage to masonry buildings while soft-story damage, joint failure, lap splice, columns shear failure, beam failure and infill walls failure are the main types of damages to non-engineered RC buildings.

Keywords: Low strength masonry, Non-engineered buildings, Damage Patterns

1 Introduction

The April 25, 2015 Gorkha Earthquake of Magnitude 7.8 in Nepal damaged about seven hundred thousands buildings. The main typologies of buildings in the affected area are stone masonry with mud mortar, some buildings with stone and brick masonry with cement/sand mortar and few reinforced concrete buildings with masonry infill. Figure 1 shows the building typology distribution in 31 districts which were affected by April 25, 2015 earthquake in Nepal. It shows that about 58% of the buildings are mud based masonry, i.e. stone in mud, adobe or brick in mud; 21% are cement based masonry either stone with cement-sand mortar or brick with cement-sand mortar and about 15% are reinforced concrete with masonry infill. There are other types of buildings that are only about 6%.

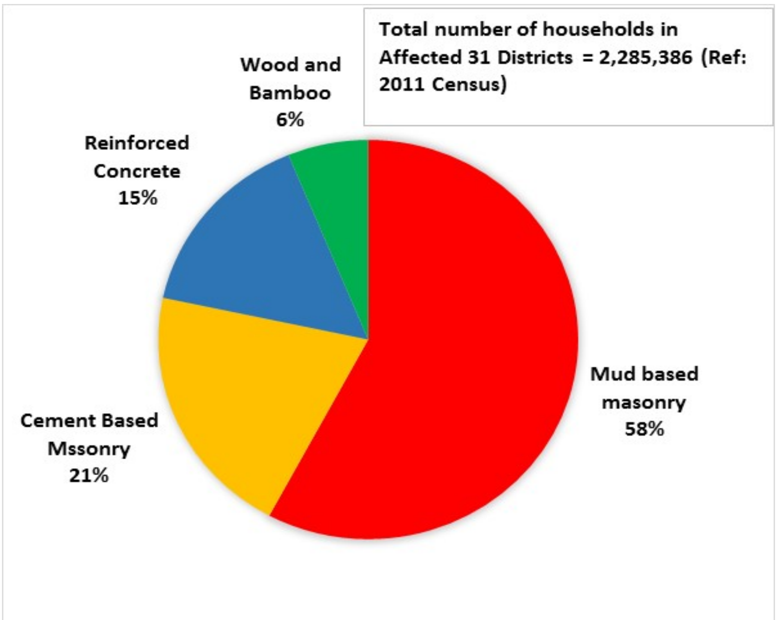

Figure 1: Overall Building Typology Distribution in the Affected Area of April 25, Nepal Earthquake [1]

Large numbers of the residential buildings in developing countries in seismic area are non-engineered type owner built masonry. Unreinforced stone masonry buildings are common in mountain areas in seismic countries around the world. Stone masonry has been constructed for different use starting from simple residential buildings to palaces, temples and monuments. Jitendra Bothara and Svetlana Brzev [2] have discussed different types of stone masonry buildings in earthquake prone countries and their performance during earthquakes. The performance of masonry buildings during earthquake is very poor. The breakdown of the casualties due to earthquakes in the period of 1900-1990 shows about 75% of the fatalities attributed to earthquakes are caused due to collapse of buildings and the greatest proportion of it is from the collapse of masonry buildings [3]. The performance of stone masonry buildings in different earthquakes shows random shaped stone masonry buildings are more vulnerable than other type of masonry buildings [4]. Damage to random shaped stone masonry buildings was highest in 2005 Kashmir earthquake in Pakistan [5,6].

Among the damaged buildings, about 96% of the buildings were masonry and about 4% reinforced concrete buildings with masonry infill based on preliminary analysis conducted for preliminary damage and need assessment [7].

The April 25th 2015 Gorkha Earthquake in Nepal caused 8,450 deaths and more than 700000 buildings severely damaged with significant of them get collapsed. Most of the death and injuries were caused by the collapse of buildings. Just after the earthquake, though mainly in Kathmandu valley, many organizations provided rapid visual assessment of the buildings and suggested people on possibility of continue using the buildings or evacuation is required.

However, the information on possibility of repair/retrofit or demolition was not covered by the rapid visual assessment. So, detail damage assessment of the building was necessary so that reasonable suggestions can be provided to the people in need. Further, the local governments can use the detail damage assessment information for development of reconstruction strategy within their territory. In addition, the detail damage assessment help to understand the main reason of damage to buildings and the lessons learned will be beneficial for designing future strategies for disaster risk reduction. In this context, a detail damage assessment targeting more than 200,000 buildings is conducted by National Society for Earthquake Technology-Nepal (NSET) after the April 25, 2015 Gorkha Earthquake. This paper highlights the objectives and methodology of the detail damage assessment, locations and scope of the detail damage assessment and initial findings and results of the detail damage assessment.

2. Objectives and Methodology of the Detail Damage Assessment

2.1 Objectives

The overall objective of the study was to understand the main failure mechanism of different type of the buildings so that the mitigation measures can be optimized in the longer run. However, for the immediate benefit for the reconstruction, the specific objectives were to:

- Assess and collect the building damage information in systematic way
- Provide possible solutions to the affected communities and
- Provide references for the policymakers for reconstruction planning based on the results gained from the assessments.

2.2 Methodology

The overall methodology adopted in this study is as follows:

- Development of Damage Assessment Format: The post disaster damage assessment guidelines published by Department of Urban Development & Building Construction (DUDBC), the government of Nepal was used to develop the damage assessment format. Figure 2 and Figure 3 shows the detail damage assessment form used for the study.
- Use IT Tools for Survey: Android application was developed used to collect the data.
- Train Surveyor: Training curricula was develop to enhance the skill of surveyors in technical and social understanding for the detail damage assessment of the buildings.
- Conduct the detail damage assessment and analyze the data

First, the buildings were classified to different structural types like adobe, stone in mud, brick in mud, stone in cement, brick in cement, wood, bamboo, RC and others. Other important parameters like type of floors and roofs and occupancy of the buildings were noted before starting the detail damage assessment in structural elements.
Damage to overall building as well as to different structural/non-structural elements were categorized into four different categories mainly overall hazard, structural hazard, non-structural hazard and geotechnical hazard. The damage level to different structural/non-structural elements was assigned from insignificant damage to extreme damage in three categories considering the severity of damage like crack widths, delamination, tilting etc. In addition to the severity of damage, extent of damage to that particular element of different severity was also noted. Each type of damage with different severity was estimated in terms of extent like less than 1/3rd of the total area, 1/3rd to 2/3rd and more than 2/3rd. Considering the damage severity and extent, overall damage grade to the building was assigned. Finally, based on the damage grade and extent of damage, recommendation to the building either to demolish, repair and retrofit or just repair was recommended.

Building Damage Assessment Form

Inspection

Inspector ID: ____________ Organization: ____________ Inspection date and time: ____________
Day/Month/Year: hh/mm

Building Description

Building ID ____________ District ____________ Municipality/VDC ____________
House owner/Org. Name: ____________ Tole ____________ Ward No ____________
Contact number: ____________

Building Existing Condition: ☐ Site Clearance/Demolish ☐ No Interventions ☐ Repair/Retrofitting
Approx. "Footprint area" (sq. ft.) ____________ Age of Building ____________ Number of Story ____________

Slope of Ground: ☐ Flat ☐ Moderate Slope ☐ Steep Slope

Type of Construction
☐ Adobe ☐ Stone in mud ☐ Stone in cement ☐ Dry Stone ☐ Timber frame ☐ Bamboo
☐ RC Frame ☐ Brick/Block in mud ☐ Brick/Block in cement ☐ Mix: ____________ ☐ Others: ____________

Type of Floor Construction
☐ Soil overlain on timber/ bamboo structure
☐ RC/RB/RBC slab

Type of Roof
☐ Light metal roof on timber/ bamboo structure
☐ Heavy roofing on timber/ bamboo structure
☐ RC/ RB/ RBC slab

Position of Building Block:
☐ Detached Building
☐ Adjoining Building in one side
☐ Adjoining Building in two side
☐ Adjoining Building in three side

Primary Occupancy:
☐ Residential ☐ Hospital ☐ Government office ☐ Police station
☐ Educational ☐ Industry ☐ Office Institute ☐ Mix ____________
☐ Commercial ☐ Assembly ☐ Hotel/Restaurant ☐ Others____________

Building Foot Print:
☐ Square ☐ E-shape
☐ Rectangular ☐ H-shape
☐ T-shape ☐ Multi Projected
☐ L-shape ☐ Building with Central Courtyard
☐ U-shape ☐ Others: ____________

Vertical Structural Irregularity:
☐ Regular ☐ Irregular

If Irregular:
☐ Soft Storey
☐ Narrow and Tall
☐ Setbacks
☐ Heavy Overhang

Evaluation Investigate the building for the condition below and check the appropriate column.

	Damage Levels									
	Extreme			Moderate-Heavy			Insignificant-Light			None
	>2/3	1/3-2/3	<1/3	>2/3	1/3-2/3	<1/3	>2/3	1/3-2/3	<1/3	
Overall Hazards										
➢Collapse	☐	☐	☐							☐
➢Building or storey leaning	☐			☐			☐			☐
➢Other ____	☐			☐			☐			☐
Structural Hazards										
➢Foundation	☐			☐			☐			☐
➢Roofs/floors	☐			☐			☐			☐
For Masonry Buildings										
➢Corner separation	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
➢Diagonal cracking	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
➢Out of plane failure	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
➢Delamination	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
➢Gabel Wall	☐			☐			☐			☐
For Frame Buildings										
➢Joint	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
➢Columns	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
➢Beams	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
➢Infill/Partition/Interior Walls	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Nonstructural Hazards										
➢Parapets	☐			☐			☐			☐
➢Cladding, glazing	☐			☐			☐			☐

General Comments:
____

Geotechnical hazards ☐ None ☐ Settlement ☐ Slope movement ☐ Liquefaction
☐ Ground fissures ☐ Rockfalls ☐ Others........................

Figure 2: Detail Damage Assessment Form (1/2)

Building Damage Assessment Form Page 2

Estimated Building Damage: Estimate building damage (repair cost ÷ replacement cost)
☐ None ☐ 0-1% ☐ 1-10% ☐ 10-30% ☐ 30-60% ☐ 60-100% ☐ 100%

Damage Grade
☐ Grade 1 ☐ Grade 2 ☐ Grade 3 ☐ Grade 4 ☐ Grade 5

Recommendations
☐ Repair ☐ Retrofit ☐ Demolish ☐ None ☐ Further Evaluation

Areas inspected: ☐ Exterior ☐ Ground Story ☐ 1st Story ☐ Other Stories ....

Number of family members ? ------------------------------

Who is the head of household ? ☐ Male ☐ Female

Does anyone in your household have a disability ? ☐ Yes ☐ No

What is the highest level of education by any members in your household ?
☐ No School ☐ Some Secondary School ☐ University/College Graduate
☐ Some Primary School ☐ SLC ☐ Don't Know
☐ Completed Primary School ☐ Some University/College

What is the main source of your income ?
☐ Agriculture ☐ Services/Government ☐ Livestock
☐ Remittance ☐ Businesses Owner ☐ Other

What is the current condition of living ?
☐ Living on own house ☐ Temporary Shelter ☐ Living in the house of relatives/friends
☐ Tent ☐ Rebuilding new house ☐ Other

Was anyone from your household injured by the earthquake ?
☐ Yes ☐ No

Was anyone from your household killed by the earthquake ?
☐ Yes ☐ No

Citizenship ID number of house owner: --

Photo: 1. Citizenship Card 2. Front view 3. Right Side View 4. Back Side View 3. Left Side View 4. Others

G.P.S -- **Survey End Time:** hh/mm ------------------------

Figure 3: Detail Damage Assessment Form (2/2)

3. Study Area and Scope

Figure 4 shows the targeted locations for the detail damage assessment. This paper presents the preliminary result of about 80,000 buildings that already surveyed and analyzed. The number of buildings surveyed and analyzed in different locations is given in Table 1.

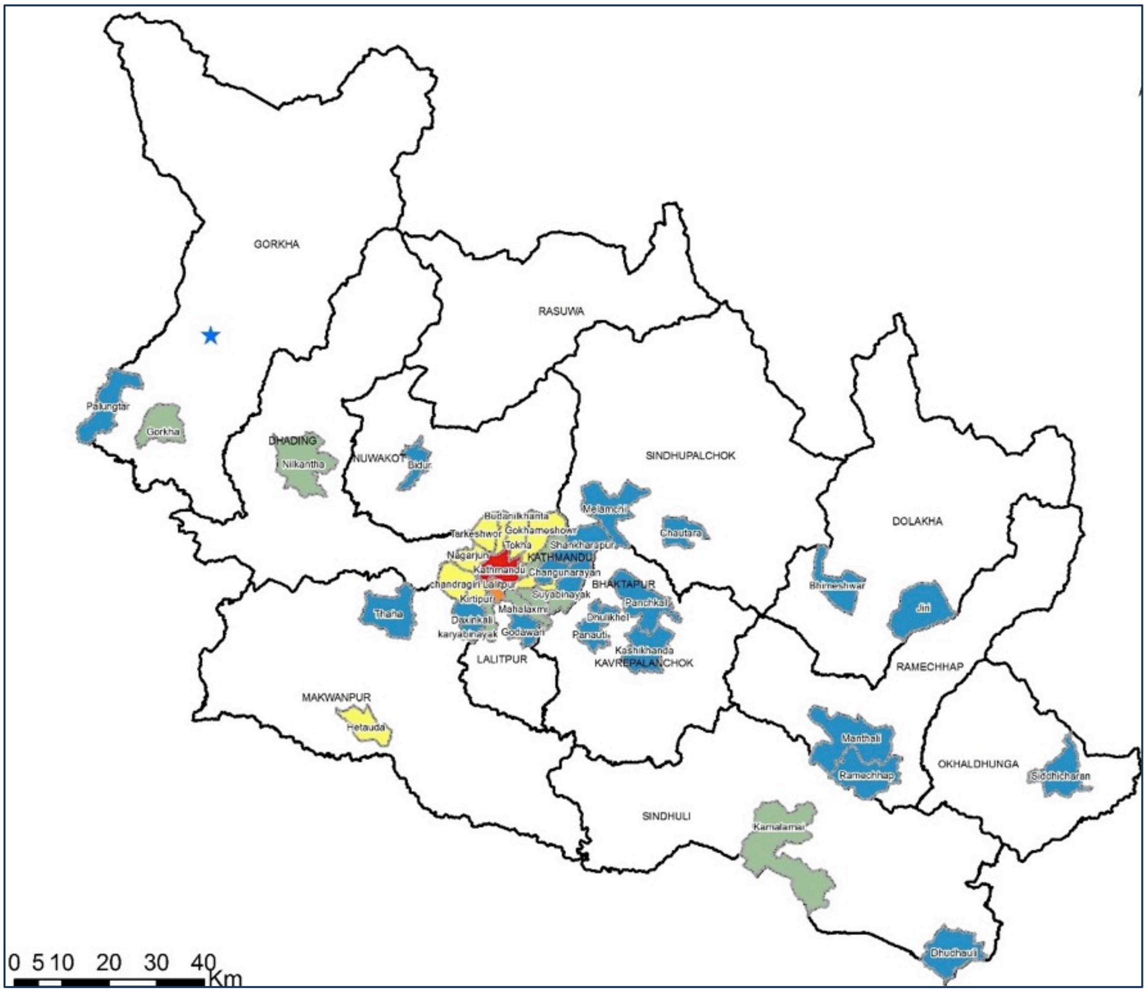

Figure 4: Locations of the area surveyed for buildings damage assessment

Table 1: Location and number of buildings surveyed and analyzed

Location	Number of Buildings	Location	Number of Buildings
Chautara	4308	Jiri	3997
Kamalamai	8575	Panauti	6928
Thosey	754	Manthali	8295
Bidur	6760	Kathmandu	8216
Lalitpur	6630	Bhimeshor	6035
Budhanilkantha	12723	Besisahar	5597
Total Buildings Analyzed: 78918			

4. Preliminary Results

This section highlights the preliminary findings of the analysis of the damage assessment results.

4.1 Building Typology and Number of Story

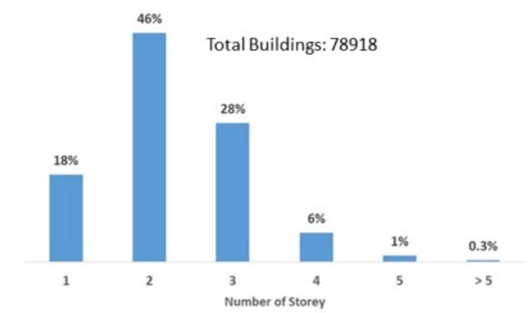

Figure 5: Distribution of buildings with number of stories

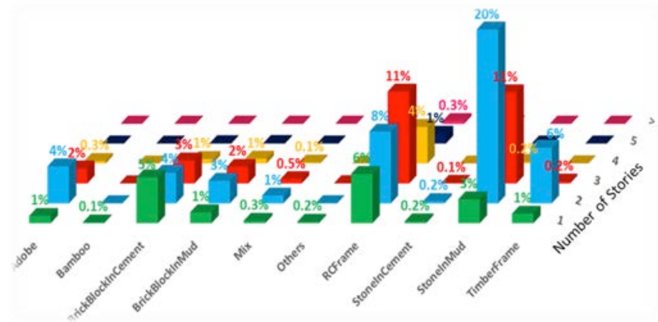

Figure 6: Building typology vs number of stories

Figure 5 shows the distribution of buildings with number of stories. The surveyed area was mainly municipalities even then more than 92% of the buildings are less than 3 stories. This clearly indicates any strategy for risk reduction should be focused on low rise buildings to solve the majority of the problem.

Figure 6 shows building typology versus number of stories distribution. The interesting fact is 2 stories stone in mud buildings are found highest in number. Among the total of about 80,000 buildings surveyed 36% are stone in mud and 20% of the total are 2 stories stone in mud buildings. So, in one hand it is clear that the earthquake risk reduction should focus on low rise buildings and on the other hand a solution for safety of two stories stone in mud buildings need to be developed.

The other important findings is existing stone in cement buildings are less than 1% in total. The study area was in municipalities, if the survey is conducted in rural area, the ratio of use of cement would be less than this.

4.2 Building Typology and Age Distribution

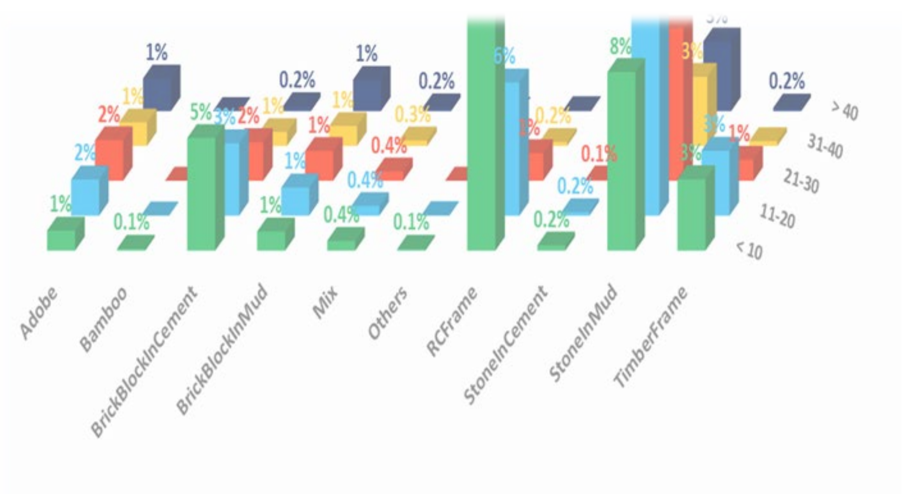

Figure 7: Building Typology vs Age Distribution

Figure 7 shows the building typology vs number of stories. The reinforced concrete buildings very clearly shows that these buildings are new and percentage distribution is more for recent buildings with age less than 10 years. However, stone in mud buildings shows almost uniform distribution among the age with less than 10 years, 10-20 years and 20-30 years. This fact also indicates that people are still constructing stone in mud buildings with very little change to other building types in overall.

4.3 Overall Building Damage

Figure 8 shows the overall damage grade distribution of the buildings assessed. While as the Figure 9 shows the damage grades versus the building typology distribution. From the Grade 5 damage, which is 15% of the total building stock, 11% is stone in mud buildings which is about 75% of the total collapsed buildings. Other major damaged categories are brick in mud and adobe.

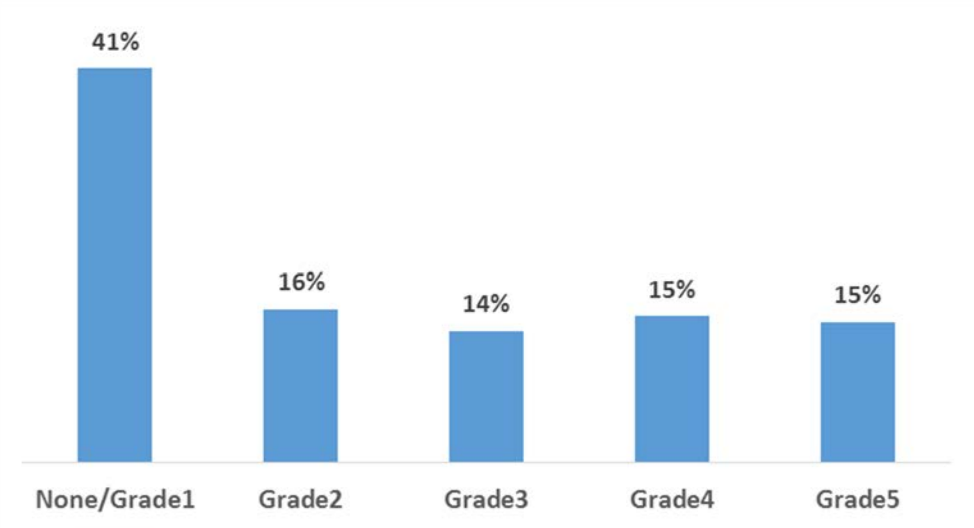

Figure 8: Overall Damage Grade Distribution vs Building Typology

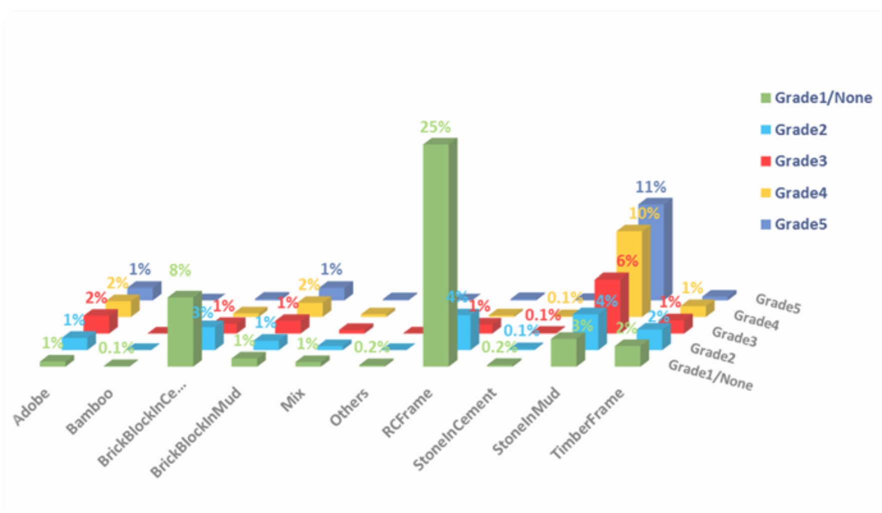

Figure 9: Overall Damage Grade Distribution vs Building Typology

Very little damage to reinforced concrete buildings is clearly seen. Stone in cement and brick in cement masonry buildings are also found less suffered in comparison to mud based construction

4.3 Overall Building Damage

Figure 10 and Figure 11 shows the comparison of different type of damage to stone in mud and brick in cement buildings. In stone in mud buildings, diagonal cracking and corner separation are found the major type of damage. Though, the delamination is generally considered one of the major problem in stone masonry buildings, standing buildings with delamination was relatively small. This might be due to the reason that the delaminated buildings either got partial to complete collapse or had out of plane failure.

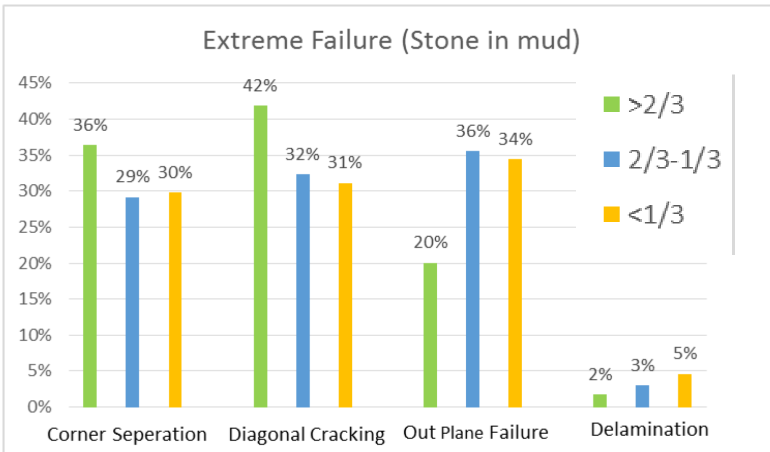

Figure 10: Different type of Damages in Stone in Mud Buildings

In the brick in cement buildings, corner separation and diagonal cracking are the major damages in the standing damaged buildings. Out of plane failure is relatively small and delamination is negligible for this category of the building.

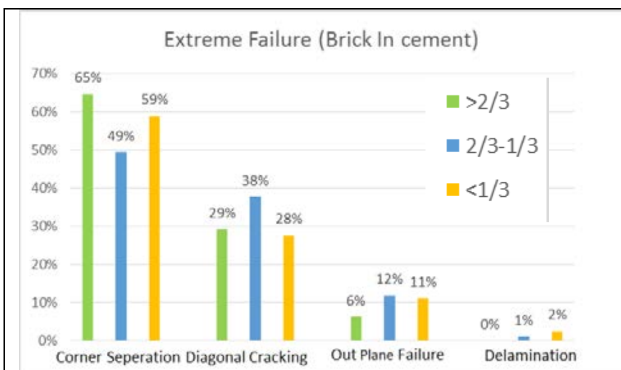

Figure 11: Different type of Damages in Brick in Cement Buildings

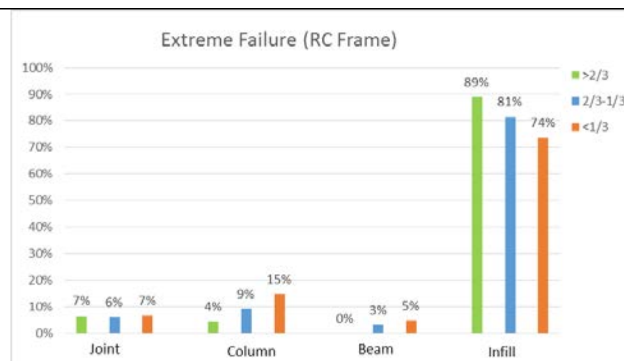

Figure 12: Different type of Damages in Brick in RC Buildings

Figure 12 shows different type of damages to reinforced concrete buildings. Damage to infill walls is the highest, however, this damage can be categorized as the non-structural damage. In the remaining damages, damages to column and joints is found the major damage. While, damage to beams is relatively small.

4.3 Comparison of Damages to Previous Studies

Fragility functions for different type of masonry buildings in Nepal is conducted by Guragain, R. [8]. The Gorkha Earthquake 2016 accelerometer records only at Kathmandu [9]. So, it was possible to compare the ratio of different grade of damage only in Kathmandu Valley. The average peak ground acceleration in Kathmandu Valley is about 0.2g. Figure 12 gives different level of damages to Brick in Mud Buildings in Karyabinayak Municipality in Kathmandu Valley and Figure 13 gives the fragility functions for brick in mud buildings by Guragain, R. [8] with ratio of damage obtained from field survey. The fragility function shows 50% of complete damage, which includes the partial collapse and the fully collapsed buildings, at 0.2g while as the damage ratio obtained from field survey is 56% for complete damage. For the moderate damage, it is 25% in the fragility function and 22% from the field survey. Similarly, it is 25% and 21% for the slight damage case. This comparison shows the fragility functions by Guragain, R. [8] are near to the damage ratio obtained from the field. The damage grade definition are as: DG1- slight structural damage, DG2-moderate structural damage, DG3-significant structural damage, DG4- partial collapse and DG5-collapse of the building. The case 1 and case 2 in the figure 13 represents both the numerical simulation results, case 1 represents simulation results using only the average mortar strengths while as case 2 represents simulation results including very poor mortar strength and very strong mortar strengths as well.

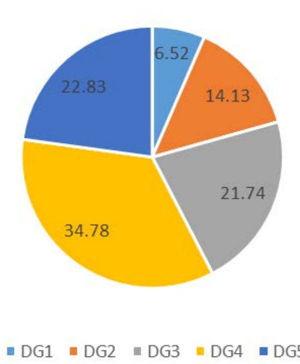

Figure 12: Percentage of Brick in Mud Buildings with Damage Grades in Karyabinayak Municipality

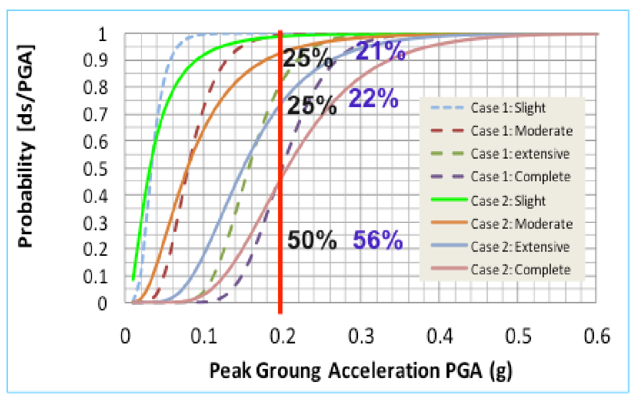

Figure 13: Fragility Function of Brick in Mud Buildings by Guragain, R. [8] with ratio of damage obtained from field survey at 0.2g

The percentage value with black fonts are from numerical simulation and the blue fonts are from field survey.

There are not any accelerometer records outside Kathamndu Valley. So, the damage ratio could not be compared. Insted, peak ground acceleration was estimated considering the ratio damage grades of stone in mud buildings at different locations. Table 2 gives the ratio of different damage grade for stone in mud buildings at different municipalities.

Table 2: Ratio of different Damage Grade for Stone in Mud Buildings at different Municipalities

Municipality	Damage Grades			
	Slight or more	Moderate or more	Heavy or more	Complete
Bhimeshwor	99%	97%	91%	67%
Bidur	99%	97%	94%	84%
Kamalamai	100%	81%	53%	38%
Chautara	100%	99%	97%	96%
Manthali	99%	92%	68%	34%
Beshisashr	81%	43%	18%	7%

Figure 14 shows the fragility function for stone in mud buildings proposed by Guragain, R. [8] and the estimated peak ground acceleration at different locations. The stone in mud buildings are similar in configuration, construction techniques and number of stories in different geographical locations in Nepal. So it is logical to assume that the stone in mud buildings have similar level of vulnerabilities broadly. Thus, for this research purpose it is assumed that the vulnerabilities of stone in mud buildings in different location in Nepal is similar. Anyway, the numerical simulation results already covers different type of configuration and material properties. With this assumption, the comparison shows that there might have the low peak ground acceleration of about 0.1g at Besisahar municipality and high acceleration of 0.34g at Chautara municipality based on the damage ratio obtained. However, once the more reliable acceleration distribution map is obtained, the damage ratio can be compared and the proposed fragility functions may need to update accordingly.

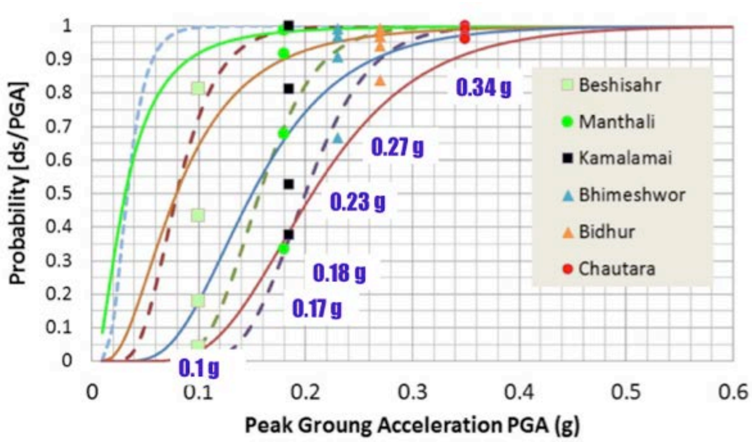

Figure 14: Estimation of Peak Ground Acceleration based on the Fragility Function

5. Conclusions

Detail damage assessment of over one hundred fifty thousand buildings of different type of Masonry and Reinforced Concrete (RC) buildings damaged by April 25, 2015 Gorkha earthquake in Nepal is conducted and analysis of about 80,000 buildings are presented in this paper.

This study further analyze the main type of damage to different categories of the buildings and finds out critical factors to be considered for making them earthquake resistant. It is found that, corner separation, diagonal cracking, out of plane failure, in-plane flexural failure and delamination are the main type of damage to masonry buildings while joint failure, columns shear failure, beam failure and infill walls failure are the main types of damages to non-engineered RC buildings.

Analyzing the building typology and age of the buildings it is found that the mud bases construction, specially stone in mud is uniformly distributed among the different categories of ages which shows the importance of considering development of earthquake safety measures for making safe to the stone in mud buildings. The number of stories distribution indicates the focus should in low rise buildings while as in the development of earthquake safety measures for 2-3 stories stone masonry buildings with mud mortar need to be given the highest priority if the existing construction practices and life style of the people is given the importance.

Comparison of the ratio of different damage grades for brick in mud buildings in Kathmandu Valley shows similar results to the fragility function developped earlier to earthquake through analytical methods. The study also proposed peak ground acceleration at different locations considering the fragility function of stone in mud buildings and the damage ratio obtained for stone in mud buildings at different municipalities.

6. References

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