

Seismic Vulnerability Assessment of Existing Public and Private Buildings in Kathmandu

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SUMMARY

Various study reports on the seismic vulnerability of Nepal have revealed that more than 60% of the buildings in Kathmandu valley are unsafe and extremely vulnerable to the large impending earthquake. In recent years, National Society for Earthquake Technology-Nepal (NSET) has been involved in earthquake vulnerability assessments of hundreds of private and public buildings in Nepal, including both load bearing masonry and reinforced concrete moment resisting frame buildings with masonry infill. Two types of assessment methodologies, qualitative and quantitative, were used in the study of both public and private buildings.

Assessment results show that masonry buildings are abundantly non-compliant to construction standards with seismic consideration. Similarly, more than 60% of RC frame buildings assessed were also found non-compliant as the buildings of both construction techniques lack strength and ductility. This paper highlights the process, methodology, and results of the assessment carried out in over 100 buildings in Kathmandu.

Keywords: Vulnerability assessment, Earthquake resistant, Non-engineered buildings, Qualitative method

1. INTRODUCTION

Past seismic records of Nepal show that many destructive earthquakes have occurred throughout the country, claiming thousands of lives and property. In 1934AD, a strong earthquake shook the Kathmandu Valley, destroying 20 percent and damaging 40 percent of the buildings in the valley. Many earthquakes have since followed causing further damage to the buildings of Kathmandu Valley, warranting the fact that future destructive earthquakes are unavoidable. (KVERMP, 1998)

Through development and rapid urbanization, the seismic vulnerability of Kathmandu valley has increased a great deal over the past century. With an increase in population to about 1 1/2 million, construction of new buildings and infrastructure has increased at an extremely fast rate. The majority of this new infrastructure, especially that with buildings of poor construction, does not meet basic seismic requirements, hence increasing the seismic vulnerability of Kathmandu. If an earthquake of similar intensity to that of 1934AD were to occur in modern day Kathmandu Valley, the lost estimate study of the valley reveals that as many as 60 percent of all buildings in the Valley are likely to be damaged heavily, many beyond repair. (KVERMP, 1998)

Past records of earthquakes, both in Nepal and around the world, show that the major cause of loss of life and property in earthquakes is due to the damage and collapse of buildings. Seismic Vulnerability assessments of buildings has become an urgent need, to know the reliability of the buildings under different intensity earthquakes, to find out the deficiencies in the buildings, and to adopt the proper mitigation methods to ensure safety in upcoming big earthquakes. In recent years, National Society for Earthquake Technology-Nepal (NSET) has been involved in earthquake vulnerability assessments of hundreds of private and public buildings in Nepal, including both load bearing masonry buildings and reinforced concrete moment resisting frame buildings with masonry infill. The buildings assessed were mostly residential buildings, followed by a number of school buildings. This paper is about the buildings assessed in the Kathmandu valley. It presents the methodologies used in the assessment, the

key findings of the assessment, and recommendations for the buildings assessed.

2. METHODOLOGY

The methodologies of assessment are based on FEMA 310 and IITK Guidelines for Seismic Evaluation and Strengthening of Existing Buildings. The assessments were done in two phases, the first phase a Qualitative assessment and the second a Quantitative assessment. The Qualitative assessment is a general seismic vulnerability assessment method, based on a qualitative approach to identify the seismic deficiencies in the building and the retrofiting options. It determines whether the building, in its existing condition, has the desired seismic performance capability. If the first phase study finds seismic deficiencies in the building and expected seismic performance is not up to the acceptable level/criteria, it either recommends second phase assessment or concludes the evaluation and states the potential deficiencies identified. The Quantitative assessment involves a more detailed seismic evaluation with a complete analysis of the building, proposing seismic strengthening measures and modifications to correct/reduce seismic deficiencies identified during the evaluation procedure in the first phase. (Seismic Vulnerability Evaluation of Private and Public buildings. Part 1: Pre disaster, 2009)

Among the hundreds of buildings assessed in Kathmandu, most were assessed based on the Qualitative assessment. Quantitative assessments were done in some special cases, usually for the more complex building types that could not be judged from the Qualitative assessment alone, and in cases where retrofitting of the building has been requested by the building owners.

The process followed in the qualitative assessment is shown in the Fig. 2.1.

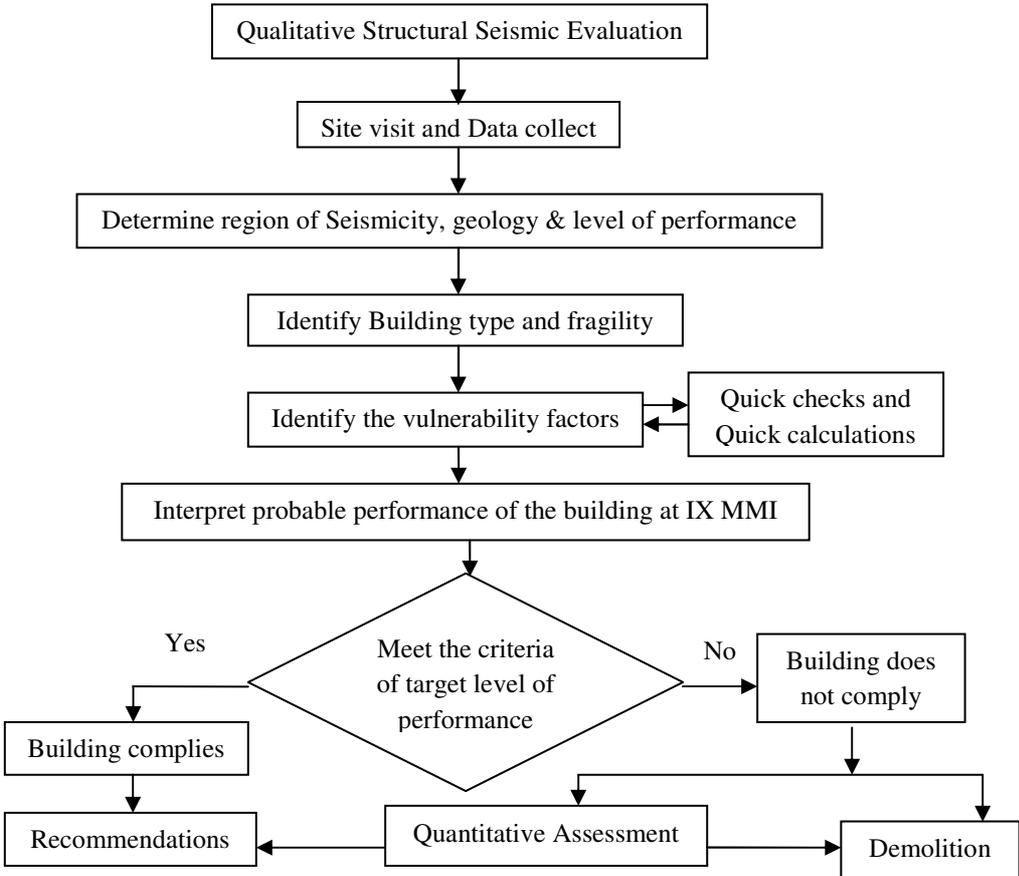


Figure 2.1. Qualitative Seismic evaluation process

2.1. Site visit and Data collection

Architectural and structural drawings were collected from the house owners where possible. In many cases, only the architectural drawings were available as most of the buildings were non-engineered, hence no structural drawings and in many cases, a limited capability for detail assessment. The data was verified from site visits. Interviews with the building owner and designer were conducted wherever possible. Structural drawings were verified through rebar detection tests using bar scanners at the site. Additional missing data and other data such as the condition of the building and the site, building typology, terrain type, pounding effects etc., were also collected.



Figure 2.1.1. Use of Rebar Detector for Verification of Reinforcement Details

2.2. Identification of Seismicity of the region

The probable level of earthquake shaking that each building may face was determined by identifying the location of the building on the seismic hazard map. The zone map of Nepal is provided in Nepal National Building Code NBC 105: 1994 in which the zone factor for Kathmandu is 1.0. The intensity of ground shaking for this zone factor is intensity IX. As per IS 1893(Part1):2002, Nepal lies in zone V. On this basis, the intensity of ground shaking in terms of MMI Scale is Intensity IX. Hence all the buildings in Kathmandu valley were assessed for intensity IX shaking, as predicted for the large impending earthquake.

2.3. Building typology identification

Building typology was identified from the classification of building types in Kathmandu valley. The common building types in Kathmandu valley are given in Table 2.2.1.

Table 2.2.1. Building typology in Kathmandu valley

No.	Building Types in Kathmandu Valley	Description
1	Adobe, stone in mud, brick-in-mud (Low Strength Masonry).	Adobe Buildings: These are buildings constructed in sun-dried bricks (earthen) with mud mortar for the construction of structural walls. The walls are usually more than 350 mm. Stone in Mud: These are stone-masonry buildings constructed using dressed or undressed stones with mud mortar. These types of buildings have generally flexible floors and roof. Brick in Mud: These are the brick masonry buildings with fired bricks in mud mortar
2	Brick in Cement, Stone in Cement	These are the brick masonry buildings with fired bricks in cement or lime mortar and stone-masonry buildings using dressed or undressed stones with

		cement mortar.
3	Non-engineered Reinforced Concrete Moment-Resisting-Frame Buildings	These are the buildings with reinforced concrete frames and unreinforced brick masonry infill in cement mortar. The thickness of infill walls is 230mm (9") or even 115mm (4 1/2") and column size is predominantly 9"x 9". The prevalent practice of most urban areas of Nepal for the construction of residential and commercial complexes is generally of this type. These Buildings are not structurally designed and supervised by engineers during construction. This category also includes the buildings that have architectural drawings prepared by engineers.
4	Engineered Reinforced Concrete Moment-Resisting-Frame Buildings	These buildings consist of a frame assembly of cast-in-place concrete beams and columns. Floor and roof framing consists of cast-in-place concrete slabs. Lateral forces are resisted by concrete moment frames that develop their stiffness through monolithic beam-column connections. These are engineered buildings with structural design and construction supervision by engineers. Some of the newly constructed reinforced concrete buildings are of this type.
5	Others	Wooden buildings, Mixed buildings like Stone and Adobe, Stone and Brick in Mud, Brick in Mud and Brick in cement etc. are other building types found in Kathmandu valley and other parts of the country.

The buildings assessed were of three major types, namely unreinforced load bearing masonry (brick in cement), non engineered reinforced concrete moment resisting frame buildings with masonry infill, and engineered reinforced concrete moment resisting frame buildings with masonry infill, as shown in fig. 2.2.1, 2.2.2, 2.2.3



Figure 2.2.1. Load bearing masonry Building (Brick in Cement)



Figure 2.2.2. Non Engineered Reinforced Concrete Moment Resisting Frame Building



Fig 2.2.3. Engineered Reinforced Concrete Moment Resisting Frame Building

2.4. Level of performance

The basic earthquake resistant criteria, as specified in Building Code, are “Structures should be able to resist moderate earthquakes without significant damage” and “Structures should be able to resist major earthquakes without collapse”. The buildings were assessed for the Life Safety Performance level. Life Safety Performance Level is the level of building performance that allows for significant damage to both structural and non-structural components through predicted earthquake intensities, within limits preventing either partial or total structural collapse. Injuries may occur, but the level of risk for life-threatening injury and entrapment is low.

2.5. Fragility of the building

The fragility, or the seismic vulnerability, of a building is the predicted reaction of the building to probable levels of earthquake shaking. NSET has extracted the damage grades of different building typologies through different intensity earthquakes from fragility functions available in “The Development of Alternative Building Materials and Technologies for Nepal and Appendix-C: Vulnerability Assessment, UNDP/UNCHS 1994” and the definitions used as per “European Macro-seismic Scale (EMS 98)” as shown in tables 2.5.1, 2.5.2, 2.5.3.

Table 2.5.1. Building Fragility: Brick in Mud (Well Built) + Brick in Cement (Ordinary)

Shaking Intensity (MMI)		VI	VII	VIII	IX
PGA (%g)		5-10	10-20	20-35	>35
Damage Grade for different classes of buildings	Weak	DG2	DG3	DG4	DG5
	Average	DG1	DG2	DG3	DG4
	Good	-	DG1	DG2	DG3

Table 2.5.2. Building Fragility: Non-Engineered Reinforced Concrete Frame Buildings (≥ 4 story)

Shaking Intensity (MMI)		VI	VII	VIII	IX
PGA (%g)		5-10	10-20	20-35	>35
Damage Grade for different classes of buildings	Weak	DG1	DG2	DG4	DG5
	Average	-	DG1	DG3	DG4
	Good	-	DG1	DG2	DG3

Table 2.5.3. Building Fragility: Non-Engineered Reinforced Concrete Frame Buildings (≤ 3 story) + Engineered Reinforced Concrete Buildings + Reinforced Masonry Buildings

Shaking Intensity (MMI)		VI	VII	VIII	IX
PGA (%g)		5-10	10-20	20-35	>35
Damage Grade for different classes of buildings	Weak	DG1	DG2	DG3	DG4
	Average	-	DG1	DG2	DG3
	Good	-	-	DG1	DG2

Damage Grades of buildings:

This classification of damage grade of buildings has been taken from European Macro-seismic Scale (EMS 98)

Damage Grade 1 (DG1): No Structural damage and slight non-structural damage

Damage Grade 2 (DG2): Slight Structural damage and moderate non-structural damage

Damage Grade 3 (DG3): Moderate Structural damage and heavy non-structural damage

Damage Grade 4 (DG4): Heavy Structural damage and very heavy non-structural damage

Damage Grade 5 (DG5): Very heavy Structural damage

2.6. Identification of vulnerability factors

Different Vulnerability factors associated with the particular types of building were then checked with a set of appropriate checklists from FEMA 310, "Handbook for the Seismic Evaluation of Buildings"

and “IS Guidelines for Seismic Evaluation and Strengthening of Existing Buildings” to identify potential links with structures that have been observed in past significant earthquakes. The basic vulnerability factors related to the building system, lateral force resisting system, connections, and diaphragms were evaluated based on visual inspection and review of drawings. Some quick checks and some supplementary checks were done for RCC buildings, such as shear checks, ductility related checks like ‘strong column weak beam’, and checks for torsion. Based on this, the "Influence of Different Vulnerability Factors to the Building" table was then completed to evaluate the final influence of different vulnerability factors on the fragility of the building.

An example of the vulnerability factors defined in the checklist is as follows:

C NC N/A NK LOAD PATH: The structure shall contain at least one rational and complete load path for seismic forces from any horizontal direction so that they can transfer all inertial forces in the building to the foundation.

2.7. Interpret probable performance of the building

After thorough analysis and interpretation of vulnerability factors, the building is then categorized by building typology into overall weak, average or good construction. The probable performance of the building is then determined at different intensity earthquakes in terms of damage grades at intensities VII, VIII and IX. If the damage grade of the assessed building is within DG3 at intensity IX earthquake, then the building meets the Life Safety Performance Level.

For complex buildings that could not be judged from the Qualitative assessment alone, a non-linear pushover analysis was done using SAP software to find the predicted performance level of the building.

3. KEY FINDINGS

The residential buildings assessed were for diplomat organisations, NGO's and INGO's, and were therefore among the better-constructed buildings in Kathmandu. About 80% of them were reinforced concrete moment resisting frame buildings with masonry infill and the remaining 20% were load bearing masonry buildings built of brick in cement. The reinforced concrete moment resisting frame buildings with masonry infill were of two types, engineered (85%) and non-engineered (15%). Table 3.1. and 3.2 show the major vulnerabilities found in the assessed load bearing masonry buildings and RC moment resisting frame buildings respectively, and their influence on them.

Table 3.1. Major vulnerabilities and their influence on Load bearing masonry buildings

Vulnerability Factors		% of buildings with vulnerabilities			
		Load bearing masonry building			
		High	Medium	Low	Not known
Configuration / Building System	Shape	19	50	31	0
	Proportion in Plan	13	6	81	0
	Number of Storey	0	6	94	0
	Opening in walls	19	69	13	0
	Position of Opening	6	75	19	0
	Load Path	13	25	63	0
	Redundancy	6	19	75	0
	Weak Storey	0	0	100	0
	Soft Storey	0	0	100	0
	Vertical Discontinuities	13	25	63	0
	Mass irregularity	0	25	75	0
	Torsion	6	56	38	0
Adjacent Buildings	0	31	69	0	
Lateral load	Shear Strength	50	31	19	0

resisting system	Height of walls	6	75	19	0
	Diaphragm opening	6	13	81	0
	Lack of Vertical Reinforcement	81	19	0	0
	Lack of Horizontal Bands	88	13	0	0
	Transfer to shear walls	13	38	44	6

Table 3.2. Major vulnerabilities and their influence on RC moment resisting frame buildings

Vulnerability Factors		% of buildings with vulnerabilities							
		Engineered RC moment Resisting Frame				Non engineered RC moment Resisting Frame			
		High	Medium	Low	Not known	High	Medium	Low	Not known
Building System	Load Path	14	46	41	0	11	22	67	0
	Adjacent Buildings	2	2	97	0	0	11	89	0
Plan irregularities	Torsion	8	31	61	0	11	78	11	0
	Diaphragm continuity	7	10	81	2	0	22	78	0
Vertical irregularities	Weak storey	0	3	95	2	0	0	100	0
	Soft storey	0	3	97	0	0	0	100	0
	Mass irregularity	5	32	63	0	0	67	33	0
	Vertical geometric irregularity	8	32	59	0	0	56	44	0
	Vertical discontinuities	3	12	83	2	0	11	89	0
Lateral load resisting system	Redundancy	0	5	93	2	0	11	89	0
	Shear stress	19	34	47	0	56	33	11	0
	Short columns	27	39	32	2	0	67	33	0
	Strong column – Weak beam	54	27	8	10	56	0	0	44
	Shear Failures	7	7	32	54	0	11	44	44
	Column tie spacing	19	22	54	5	67	22	11	0
	Beam Stirrup spacing	3	8	83	5	33	33	11	22
	Joint eccentricity	2	25	69	3	0	33	67	0
Wall connection	88	10	2	0	78	11	11	0	

3.1. Major vulnerabilities in load bearing masonry buildings

As per Table 3.1, the major vulnerabilities found in masonry buildings are shape, load path, size and position of openings, shear capacity of walls and vertical and horizontal reinforcement.

- Vulnerability due to shape is due to irregular shapes of buildings, mostly L, U, and C shapes, that add torsion to the building.
- Load path problems are due to improper distribution of walls in different storeys. The main load bearing walls were not in the same location in all storeys.
- Opening size and position related vulnerabilities are due to windows placed at the corners and junctions of the walls, inhibiting critical wall to wall connections, and very large size of openings, decreasing the shear capacity of the walls.
- Vulnerability related to shear capacity of walls is mainly due to insufficient size and numbers of shear walls.
- Reinforcement related vulnerability is due to a lack of sill bands and lintel bands, vertical reinforcement, and proper connection between walls and floors.

3.2. Major vulnerabilities found in RC moment resisting frame buildings

As per Table 3.2, the major vulnerabilities found in RC moment resisting frame buildings are load

path, shear capacity, ductile detailing, strong column weak beam, short columns and wall connections.

- Load path problems found in RC frame buildings are due to columns placed not in proper grid line, secondary beams resting on main beams, and walls built on cantilever slabs.
- Insufficient shear capacity of the buildings is due to lean columns, usually 9"x9" or 9"x12" columns in most of the non-engineered buildings.
- Ductile detailing is not sufficient in non-engineered buildings, column ties are found far spaced, usually, 6" to 8" throughout the column with no confining reinforcement at column ends.
- Strong column weak beam criteria are not met as beams are found with more reinforcement than columns.
- The infill walls are often not connected to the buildings' main structure.
- Short column effects were due to openings positioned very close to columns, and staircase landings resting on beams connected to the column at mid height.

3.3. Comparison of major vulnerabilities for different types of buildings

3.3.1. Comparison between load bearing masonry and RC moment resisting frame buildings

Load path: Though load path problems exist in both the masonry and RC frame buildings, it is found to be more vulnerable in the RC frame buildings than in the masonry buildings.

3.3.2. Comparison between engineered and non-engineered RC moment resisting frame buildings

Load path: Vulnerability due to insufficient load paths is more common in engineered buildings than non-engineered. Columns and beams in non-engineered buildings are found more often in proper grid line than that of engineered buildings.

Shear stress: Regarding shear capacity of columns, engineered buildings are found to have higher capacity than non-engineered. As explained earlier, this is due to a general use of very lean columns in non-engineered buildings.

Strong column weak beam: In non-engineered buildings, only 56% of the buildings had structural drawings, thus strong column weak beam criteria was checked for only 56% of the buildings. All the checked buildings did not meet this criteria, because of small column sizes with insufficient reinforcement. In engineered buildings, though designed by engineers, this criteria was still not met in about 80% of the assessed buildings. Beams are often made stronger than the columns in engineered buildings.

Ductility: There is significant improvement in column tie spacing in engineered buildings, mostly in those newly constructed, as compared to the non-engineered buildings. In non-engineered buildings, column tie spacing were at 6"-8" throughout the column, but in engineered buildings, they are found mostly 4" at ends and 6" at mid.

3.4. Expected damage levels

The expected damage levels in masonry buildings and RC frame moment resisting buildings is shown in fig. 3.4.1 and fig. 3.4.2. respectively.

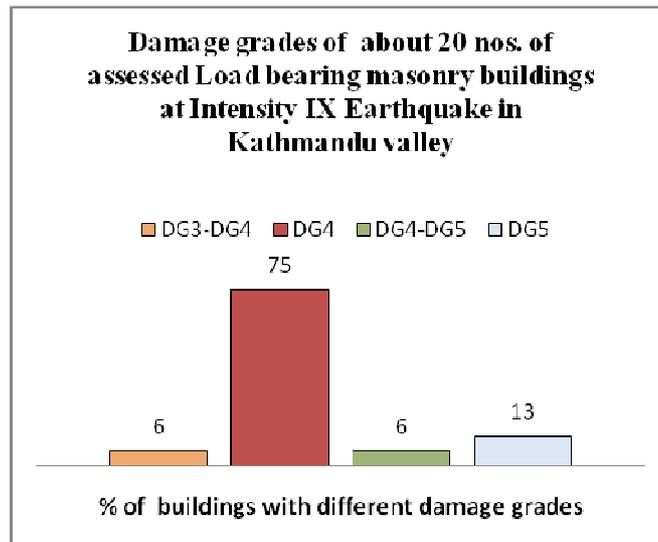


Figure 3.4.1. Damage grades of assessed unreinforced masonry buildings in Kathmandu valley

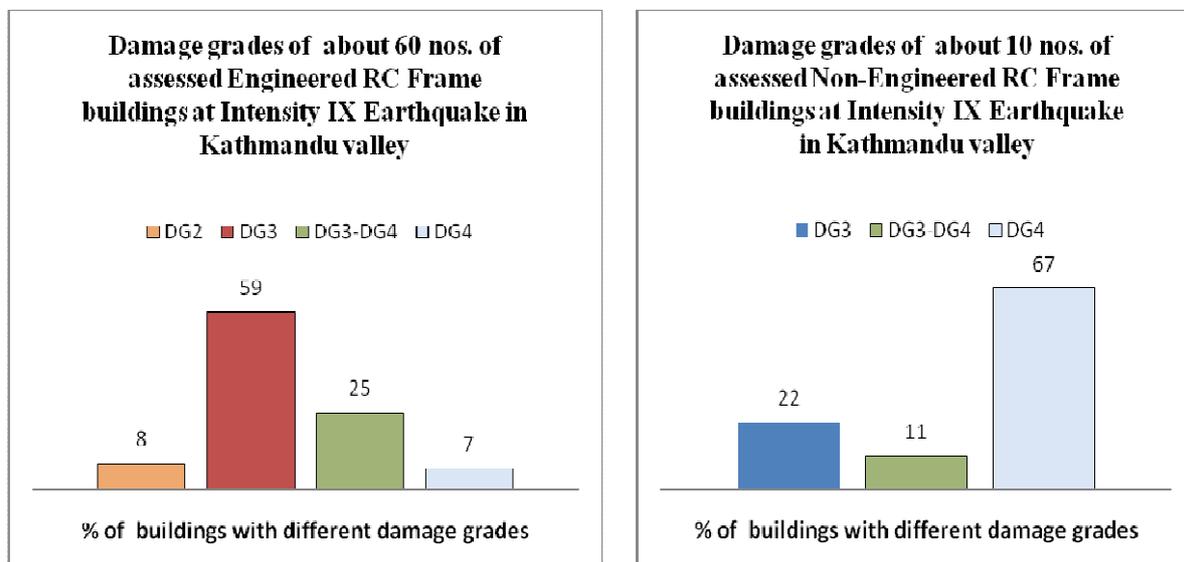


Figure 3.4.2. Damage grades of assessed RC Frame buildings in Kathmandu valley

The possible damage grade at intensity IX earthquake for almost all of the masonry buildings, about 30% of engineered RC moment resisting frame buildings, and about 80% of the non-engineered moment resisting frame buildings assessed in Kathmandu valley, is greater than DG3.

4. CONCLUSIONS AND RECOMMENDATIONS

4.1. Conclusions

The buildings were assessed for a Life Safety performance level through the largest predicted Earthquake intensity for Kathmandu valley, intensity IX: "Structures should be able to resist moderate earthquakes without significant damage" and "Structures should be able to resist major earthquakes without collapse". This performance level is achieved only if the structural damage grade of the building is within DG3. Due to the vulnerabilities and deficiencies prevalent in the buildings as detailed above, almost all of the masonry buildings, about 30% of engineered RC moment resisting frame buildings, and about 80% of the non-engineered moment resisting frame buildings assessed in

Kathmandu valley, have damage grades greater than DG3 at intensity IX earthquake. Hence they do not meet the life safety performance level, risking mass casualties and property loss through the impending large earthquake.

4.2. Recommendations

The major deficiencies found in the assessed buildings are the irregular shape of the buildings and the lack of strength and ductility. New building construction can be improved and made earthquake resistant by eliminating these deficiencies. These deficiencies can be overcome using the following construction practices:

- Always adopt regular building shapes, square or rectangular. If irregular shaped buildings are to be constructed, separate the building structure into necessary parts to make it a regular shape.
- Increase the size of the columns, with a minimum of 12"x12" columns for residential two to three storey buildings.
- Improve the ductility of the building by providing sufficient reinforcement in the columns with shear stirrups placed closely, as per Nepal Building Codes and as per design. Make columns stronger than beams. Avoid joint eccentricities at beam column joint.
- Distribute the walls properly in the buildings and Tie all masonry infill walls to the building's main structure.
- Avoid short column effects, place the windows at sufficient distances from columns and separate the staircase from the main building structure.
- In load bearing masonry buildings, use horizontal and vertical reinforcements at appropriate positions and use small opening sizes.

REFERENCES

- NBC105. (1994), Seismic design of buildings in Nepal, Government of Nepal, Ministry of Housing and Physical Planning, Department of Buildings Nepal, Kathmandu.
- The Kathmandu valley earthquake risk management action plan (KVERMP). (1998), National Society for Earthquake Technology-Nepal (NSET), Geo Hazards International, USA (GHI)
- FEMA310. (1999), Handbook for the Seismic Evaluation of Buildings-1998 A prestandard, Federal Emergency Management Agency (FEMA), Washington D.C.
- IS 1893(Part 1). (2002), Criteria for earthquake resistant design of structures, Bureau of Indian Standards, New Delhi, India.
- IITK-GSDMA. (2005), Seismic evaluation and Strengthening of existing Buildings, Indian Institute of Technology, Kanpur, India.
- Seismic Vulnerability Evaluation of Private and Public buildings. Part 1: Pre disaster. (2009), National Society for Earthquake Technology-Nepal (NSET), Department of Urban Development and Building Construction-Nepal(DUDBC)