SEISMIC VULNERABILITY AND CAPACITY ASSESSMENT: A CASE STUDY OF LALITPUR SUB-METROPOLITAN CITY, NEPAL

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ABSTRACT:

This is an effort to identify an appropriate method for assessment of seismic vulnerability and capacity to cope with earthquake disasters, which can be easily adopted by municipal authorities. It includes estimation of building collapse probability and casualties due to different scenario earthquakes, and measuring the capacity of local people to cope with the earthquake disaster in Lalitpur Sub-Metropolitan City (LSMC), Nepal. Building damage and collapse probabilities are estimated for individual buildings considering their conditions in addition to height, construction types and earthquake intensity using an existing damage matrix. Using an empirical relation between building collapse probability and population distribution, established by HAZUS, casualties are estimated for different earthquakes in different time of the day. The level of public awareness, preparedness and capacity are analyzed from the information received by interviewing local people.

KEYWORDS:

Earthquake vulnerability, casualty, preparedness, response, capacity

1 INRODUCTION

Nepal, a small Himalayan kingdom, is located on the southern hill-slopes of the Himalayas in-between India and China. Within its 150 km width, the country has varied climatic conditions and diverse physical features; as a result it is prone to multi-hazards. The country is known as one of the seismic prone countries in the world. It has repeatedly experienced the large-scale earthquakes. The country's high seismicity is related to the presence of active faults between tectonic plates along the Himalayas. Among the reasons for Nepal's high vulnerability to earthquake is the poor construction especially in densely populated cities like Kathmandu and Lalitpur. The current study area, LSMC, is one of the five municipalities of Kathmandu valley with a total population about 0.2 million.

Although many agencies have invested lot of efforts on earthquake risk reduction in Nepal, the earthquake risk in the country have continued to grow mainly due to haphazard urbanization resulting high vulnerability, use of inappropriate construction technology and low level of capacity to cope with earthquake risk. Therefore this research is to develop a method which can be adopted by municipal authorities in order to assess the vulnerability and level of capacity of local people.

1.1. Methodology

The population was calculated for different time periods for specific space uses by the population density factors calculated from the samples of the household survey. The information on socioeconomic condition, public awareness, response, perception and preparedness were recorded received from the field survey. An intensity-damage matrix, considering existing Nepalese building types, prepared by NSET and JICA was used applying some modifications. Once the building damage was estimated, human casualties were estimated in relation of population distribution and building damage/collapse probability. Casualty ratios related to building damage were derived from HAZUS-MH (2003). Level of public awareness, preparedness and capacity were analyzed from the information received interviewing with local people.

2 BUILDING LOSS ESTIMATION

Based on the field survey, 60% buildings were found of less than 10 years age with majority of reinforced cement concrete and 8% of 50-150 years age with load bearing walls and the rest buildings were found of mixed structure. The average height of buildings was 9-12 meters. Some of the buildings were observed with visual wall/floor cracks, dampness and differential settlements.

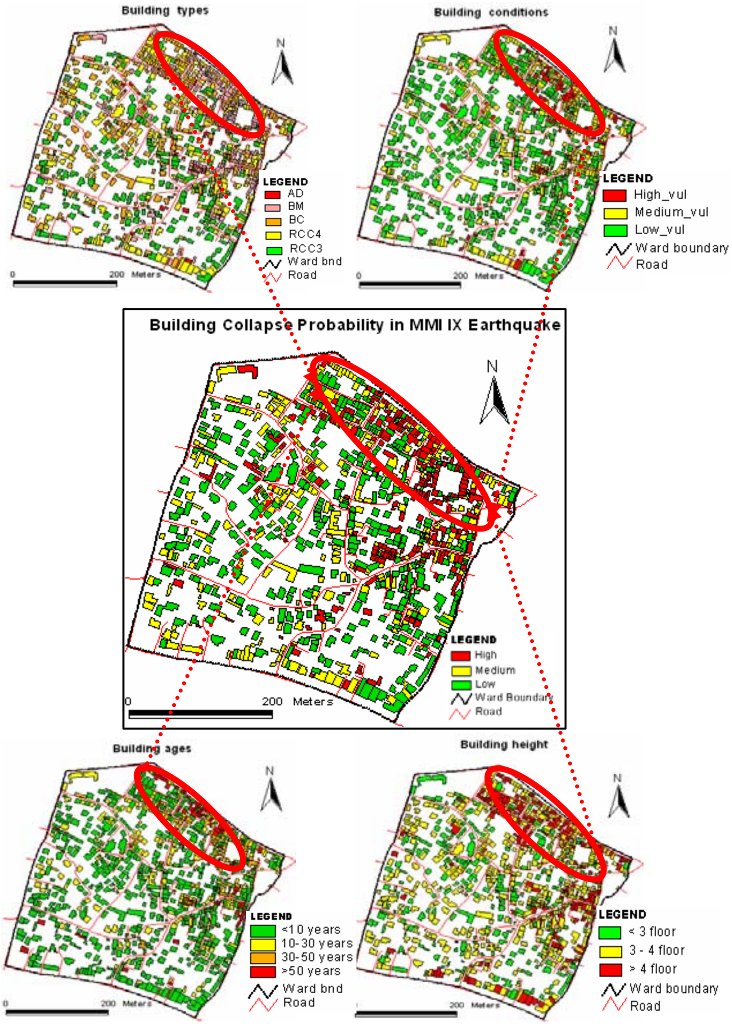
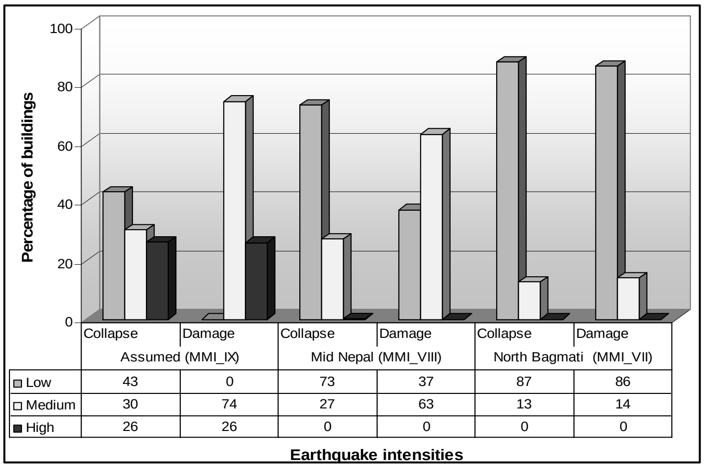


Figure 1: Building Collapse Probability in Scenario Earthquake

Depending on the earthquake intensity and the building strength, a building may suffer damage during an earthquake ranging from fine cracks in plaster to the completely collapse of the building. When the earthquake intensity is considered constant, the damage grade is then directly related to the strength of a building, which is related to the material and construction type (JICA, 2002). For this study the relation of maximum and minimum probability of an individual building damaged or collapse for different earthquake intensities (MMI) for different building types has been derived from NSET and JICA considering the fragility curves prepared during the building code project with some modifications based on the damage pattern observed in the 1988 earthquake in Nepal. However, this damage matrix addressed only the building height, types and earthquake intensity, and indicates a range of values which indicate the percentage of buildings within the given class that might be damaged or collapsed. These values may differ considerably, as there may be different quality buildings within the same class. Therefore in this study these percentage values are used to indicate the probability of damage and/or collapse of individual buildings. The damage matrix was further interpreted as the maximum, minimum and average probability of damage/collapse of individual building in different intensity of earthquakes. For an individual building this probability might be closer to the minimum or the maximum value, depending on the characteristics of that particular building such as geometry, age, building condition, etc.



	Collapse	Damage	Collapse	Damage	Collapse	Damage
	Assumed (MMI_IX)		Mid Nepal (MMI_VIII)		North Bagmati (MMI_VII)	
▨ Low	43	0	73	37	87	86
☐ Medium	30	74	27	63	13	14
■ High	26	26	0	0	0	0

Figure 2: Building Damage/Collapse Probability in Scenario

The present study assigned the weights to the building characteristics according to their contribution for vulnerability using a pair-wise method. Finally the result was used to define the probability of damage or collapse of an individual building in reference of building damage probability matrix. For the comparison between parameters no engineering analysis was carried out so the comparative weight values between parameters may be different by other researches.

None of the studies carried out so far (SLARIM 2004-2006, JICA, 2002, and NSET, 1998) have pointed out the potentiality of liquefaction in the current study area, therefore it is not considered for the current study as well. Based on the earthquake scenarios used by SLARIM, derived from JICA, the study area falls in intensity zone VIII. However, the losses are estimated assuming different level of intensities.

As shown in the figure, if the study area experiences an earthquake with intensity IX, 26 % buildings have the high probability of collapsing and more than 26 % buildings have high probability of being damaged. No buildings are found with low probability of being damaged in the study area. Most of the buildings with high probability of collapse are from northeast part of the study area (Figure 1). It was because, the buildings in this area are found relatively higher, old and have poor existing conditions. Likewise the building damage/collapse probabilities were estimated for different earthquake scenarios (Figure 2).

It is important to state here that the approach which was followed is only an assumption, and has clear drawbacks. The behaviour of individual buildings under an earthquake is a highly complicated matter. In fact a series of detailed vulnerability curves should be made for many more different typical buildings, based on finite element modelling. Each of the individual building then should be classified in one of the tested building classes. However, this approach is very time consuming and requires technical expertise which is out of the scope of this study.

3 CASUALTY ESTIMATION

The casualties are estimated in different severity levels for different time periods of the day using an empirical relationship, developed by HAZUS, between population distribution and building damage or collapse probability due to different earthquake intensities. However, this study estimates only the casualties that occur indoors as a result of building collapse or damage. For the current study, the term casualty refers to human injuries, from slight injury (severity level 1) to highest fatality that is instant death (severity level 4). Table 1 provides a straight casualty rates used by a previous study (Islam, 2005) that have derived from HAZUS-MH (2003).

Table 1: Relation between building damage/collapse and level of severity

Building Damage Level	Injury Level (in %)			
Injury Level (in %)	Severity 1	Severity 2	Severity 3	Severity 4
Partial Damage	1	0.1	0.001	0.001
Complete Damage	40	20	5	10

Thus, the casualties due to different earthquake intensities depend on the damage/collapse probability of the building and the number of persons present in that building following the injury ratios, which can be expressed in the following formula:

$$C=PBd*Pop*Irt$$

Where,
C= Casualties (in each building),
PBd= Probability of building damage or collapse in a given earthquake intensity,
Pop= Population present in the building at a given time (morning, day, evening or night),
Irt= Injury ratios in different severity levels

3.1. Casualties Due to Different Earthquake Scenarios

Two cases of building losses were taken i.e. building collapse and damage for casualty estimation. Calculated casualties were more in case of building collapse then in building damage. The logic behind this is, there is less chance to escape from the building in case of the complete collapse of the building where the victim living in, then in case of damage. In general the casualties of all severity levels by all scenario earthquakes were smaller during the day than in the morning, evening and night respectively (Figure 3). It was due to different number of people present in different time according to the use of buildings. The majority of the buildings were found of residential types in the study area which were found highly occupied in the morning, evening and night then at day time. Moreover there are more people in the morning and evening because more people are work/studying outside in the day time. The reason for a lower population at night than in the morning and evening would be the people from other wards working in the commercial shops, who would go to their place after closing the shops i.e. in late evening and open early morning. In average the total population of the study area was calculated 15,646.

The figure 4 shows the calculated casualties assuming different possible earthquakes in the study area in different time periods of a day. As buildings are occupied in the morning, the highest numbers of casualties (about 12%) of severity level 1 were calculated in the morning due to intensity IX earthquake. However, for the same intensity in day could time make only 10% casualties of same level. Similarly there could be more than 3% casualties of severity level 4 by the same level earthquake. It was found that a high number of casualties in day time were from the school/college buildings, where the day-classes are running (marked with circles). Some of the school buildings have possibilities to have about 50 casualties of severity 1 and 10-20 of severity 4 alone. The other non-residential buildings also suffer much higher casualties during day than in night-time. At night most of the residential buildings including residential school/hostels were found to have more casualties. Similarly the casualties were also calculated for other earthquake scenarios with intensity VIII, VII and VI, where the rate of casualties was decreased as the scenario earthquakes are comparatively with lower intensities than the previous ones.

During the study it was remarkably noted that the use of building was the most important factor for the casualty estimation. Therefore only the number of the buildings and earthquake intensity would not be the best way for the estimation of casualties.

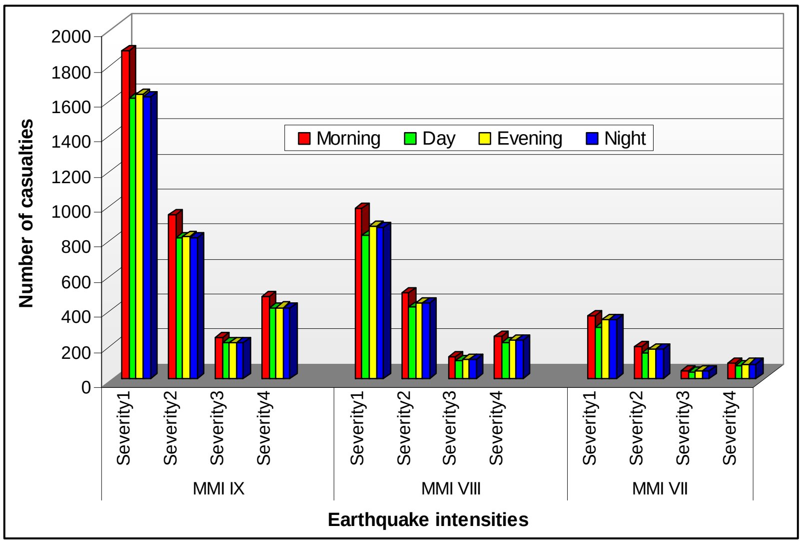


Figure 3: Casualties due to different earthquake intensities

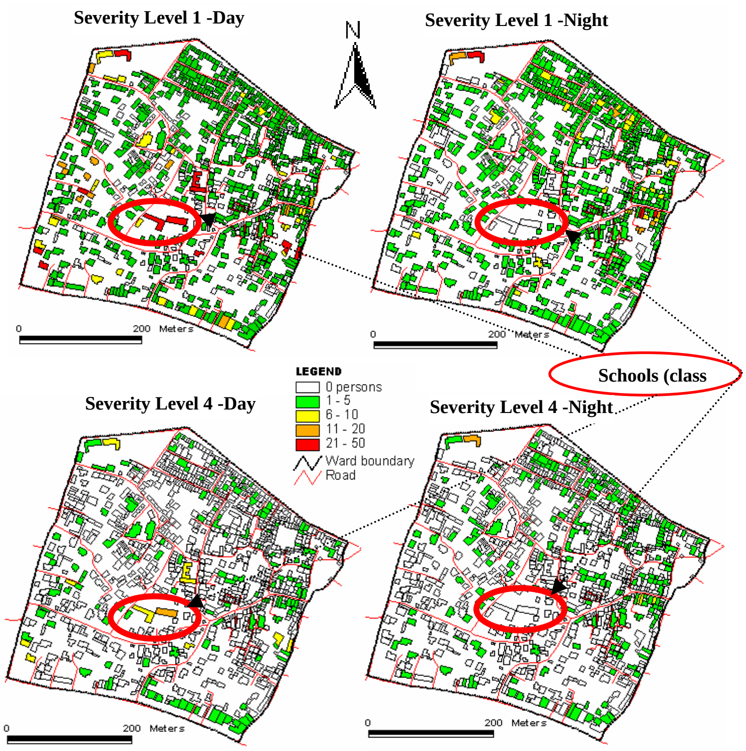


Figure 4: Casualties due to different earthquake intensities

4 AWARENESS, PREPAREDNESS AND CAPACITY OF LOCAL PEOPLE

Earthquakes can strike without warning that may cause a large amount of losses in a very short period. It is a disaster beyond human control therefore only way to reduce the risk is increasing the capacity of potential victims to cope with its impact. In general term the capacity is the capability of individuals or communities to reduce the impact during an earthquake, which comes through awareness and preparedness. For this study, the information about the existing capacity was received from a field survey conducted for sampled buildings. It was found about 50% respondents know about building code, 47% know about the annual Earthquake Safety Day program in Nepal, about 95% could indicate the nearest hospital and police station and about 64% could locate the open space.

Regarding the response during an earthquake, 50% respondents preferred to search for a safe place if they were on the upper floor of a building; about 27-44 % argued using stairs and 2-5 % argued to jump through the window. About 54-65 % would use a flash light and the rest would use electricity, gas lighter and kerosene lamp to make a light during an earthquake. Likewise, about 94% mentioned open spaces as a safe place and rest preferred under a bridge and near an electric pole.

The risk perception may influence the attitude/response of people during an emergency caused by a disaster like an earthquake; and for the long-term it leads the level and pace of preparedness. If people don't perceive that they are living at risk, they don't think there is a need to be prepared. During the survey, it was found that 73-80 % realized that they were living at risk. Similarly, 22-25 % thought that old buildings also could be made earthquake resistant (retrofitting).

Community preparedness is vital for reducing the earthquake risk. The preparedness of individuals is highly controlled by their knowledge, perception and resources. Regarding the preparedness, 30-56 % respondents were found identifying safe places inside their building, 38-47 % discussing about possible earthquake disasters; 30-35 % have prepared an emergency kit; and 16-25 % have properly fixed the non-structural elements. Only 11-19 % mentioned that they have used earthquake safety measures in their buildings.

4.1. Development of Indices for Awareness, Preparedness and Capacity

The information received from the household survey were grouped as main components i.e. awareness and preparedness, and then summed to get the overall capacity. Weights were assigned to all fields within the components, and the sub-components using a range from 0 to 1, according to their importance in the context of earthquake awareness, preparedness and capacity.

For the calculation of a Capacity Index (CI), as the very first step, all the scores of the sub-component were calculated summing the obtained scores of fields multiplied with weights, and dividing by the sum of possible maximum scores multiplied with respective maximum weights.

$$S'score = \frac{\sum (Of'score * Wf)}{\sum (Max(Of'score) * Max(Wf))} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{(i)}$$

Where,
S'score- Score of the sub-component,
Of'score- Obtained score of the field,
Max(Of'score) Maximum possible score of the field,
Wf- Weight assigned,
Max(Wf)-Maximum possible weight

After calculation of scores for the sub-components, the index for main component of capacity i.e. awareness and preparedness were calculated summing the total scores of the sub-components multiplied with weights, and dividing by the sum of maximum score multiplied with weights. Thus applying the equation (i) an Awareness Index (AI) and Preparedness Index (PI) were calculated. Then finally the Capacity Index (CI) was calculated from the awareness index and preparedness index applying the following equation:

$$CI = \frac{[(AI * Wa) + (PI * Wp)]}{[(MaxAI * Wa) + (MaxPI * Wp)]} \quad \ldots\ldots\ldots\ldots\ldots\text{(ii)}$$

Where,
CI- Capacity Index,
AI – Awareness index,
PI- Preparedness index,
MaxAI- Maximum possible score for awareness

MaxPI- Maximum possible score for preparedness,
Wa- Weight for awareness,
Wp- Weight for preparedness
The calculated indices and followed procedures for the individual components are treated in the next sections.

4.1.1. Measuring Awareness

For the preparation of an overall index for public awareness, first of all the answers for the individual questions received from the respondents were given the scores 0 (wrong) and 1 (correct) considering from an earthquake risk reduction point of view. Then the all questions (fields) were again assigned the weights ranging from 0-1 (less to highly important). After assigning the weights for fields, the sub-components of awareness (response, knowledge, perception and level of information) were assigned ranging from 0 to 1. Then the scores for the sub-components of awareness were calculated applying the equation (i) and finally AI applying equation (ii). The final score of awareness and its components then categorized in three levels i.e. high, medium and low. By doing so, 100 % score was considered as "high", if less than 50 % then "low" otherwise "medium".

Table 2: Summary of AI for residential and non-residential respondents

	Components	Residential		Non-residential	
Awareness	Response	0.74	Medium	0.70	Medium
	Knowledge	0.54	Medium	0.58	Medium
	Perception	0.56	Medium	0.65	Medium
	Information	0.71	Medium	0.74	Medium
	Overall awareness	0.64	Medium	0.67	Medium

4.1.2. Measuring preparedness

In this study the existing level of earthquake preparedness is measured on the basis of preparation, insurance, involvement in related organizations and related trainings received. The same method of AI was applied for PI then categorized in three classes. As shown in table 3, the overall level of earthquake preparedness was found very low (0.11).

Table 3: Summary of PI for residential and non-residential respondents

	Subcomponent	Residential		Non-residential	
Preparedness	Preparation	0.35	Low	0.28	Low
	Insurance	0.01	Low		
	Membership	0.01	Low	0.01	Low
	Training	0.01	Low	0.01	Low
	Overall preparedness	0.11	Low	0.11	Low

4.1.3. Measuring capacity

The capacity to cope with earthquake risk was calculated from the awareness and preparedness calculated above. Thus two components i.e. awareness and preparedness were assigned different weights. As preparedness reflects that something is already initiated or implemented for an earthquake risk reduction, it was considered as more important component of capacity comparing to awareness. Thus for the calculation of overall capacity the weights 1 and 0.9 were assigned for the preparedness and awareness respectively and applied equation (ii).

Table 4: Summary of CI for residential and non-residential respondents

	Components	Residential		Non-residential	
Capacity	Awareness	0.64	Medium	0.67	Medium
	Preparedness	0.11	Low	0.11	Low
	Overall capacity	0.36	Low	0.38	Low

Table 4 shows that awareness in both, residential and non-residential respondents is medium level but the preparedness level is very low. As the preparedness is very important component for the capacity, it was assigned high weight therefore the low score of the preparedness finally reduced the capacity as a whole.

5 CONCLUSIONS

Nepal as a whole lies in one of the high seismic prone zones of the world. The Kathmandu valley including Lalitpur is more prone because of its geological condition. Moreover, improper technology of construction in the valley has increased the high probability of building damage/collapse resulting high number of casualties. Further the low level of capacity of local people to cope with earthquake risk is found to increase more risk in LSMC.

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