POST EARTHQUAKE QUICK DAMAGE INSPECTION OF BUILDINGS IN NEPAL

Sunil Kumar THAKUR* **Supervisor: Taiki SAITO****
MEE06017

ABSTRACT

This study focuses on the post earthquake quick damage inspection of buildings in Nepal. A post earthquake quick damage inspection system for the typical building typology of Nepal has been proposed after a thorough analysis of various aspects of vulnerability of building typologies prevalent in Nepal based on standard professional engineering practice. The paper, firstly, presents damage grade classification of individual elements of building structure, index of stability in terms of drift angle and resistance and, details of system of inspection including quick inspection sheet and posting placard for building usability as developed in this study. Later, it outlines a proposal to establish the system in the country with implementation plan of operation, organizational structure, necessary qualification and training system required for inspectors. The study is expected to provide a basis for post-earthquake risk management of damaged buildings in Nepal.

Key words: Quick inspection, Failure mechanism, Seismic resistance, Damage grade, Inspection system

INTRODUCTION

Nepal is a highly earthquake prone country. It is at high seismic risk owing to large stock of vulnerable non-engineered masonry and lightly reinforced concrete buildings. The JICA study on earthquake disaster mitigation of Kathmandu Valley (JICA2002) shows that a scenario earthquake of magnitude greater than 8 in Richter scale in vicinity of Kathmandu causes partial or heavy damage of more than 50% of buildings in the city and building damage would be the most serious part of disaster. Considering the fact that there is, so far, no system in place for post earthquake building damage inspection in the country, development of a simple and effective system of such inspection is deemed necessary so that its implementation would reduce the secondary disaster caused by damaged buildings due to potential aftershocks after a big earthquake.

The objective of this study is to develop a methodology for post earthquake quick damage inspection of buildings typology of Nepal. The methodology includes criteria of damage grade classification of building elements and safety rating of overall building, standard inspection survey sheet and posting placards. The study also proposes a formal mechanism for inspection system and a long term plan for capacity building to effectively implement the quick inspection system in Nepal considering socio-political characteristics, building construction culture and availability of resource.

Post earthquake quick damage inspection of buildings is the first essential step immediately after a major earthquake to mitigate the disaster caused by aftershocks. The purpose of this inspection is to quickly inspect and judge the risk of collapse of damaged buildings or falling of building components due to after shocks and to inform the habitants about the safety of their houses as soon as possible to prevent secondary disaster due to after shocks. The result of quick inspection also provides

* Engineer, Department of Urban Development and Building Construction (DUDBC), Ministry of Physical Planning and Works, Government of Nepal.
** Chief Researcher, International institute of seismology and Earthquake Engineering, Building Researcher Institute, Tsukuba, Japan.

the basic information to estimate the number of temporary houses and refuge centers necessary for the displaced people. It helps the people of the affected area gradually return to their normal way of life and to minimize the loss of economic activity. This operation of quick damage inspection and safety declaration is completed in a very limited period on the basis of visual observation of damaged elements of the buildings. Since post earthquake quick inspection process may demand large number of buildings to be inspected in a short period, a different method and approach than that for the assessment of residual strength of an individual building is applied for this purpose. These factors are considered in the development of the methodology for Nepal in this study and hence reflected in the proposed system of quick inspection.

In case of big earthquake, a large number of work forces with various levels of knowledge and experience are required for inspection purpose. However, the damage evaluation of buildings must be uniform across the inspection area and should be as objective as possible to avoid gross effect of variation in statistical ground. In order to meet this condition, it is imperative to have a simple procedure and uniform damage inspection criteria so that two different individuals examining the same building should arrive, essentially, at the same conclusion regarding the structural safety and potential hazard category to aftershocks. The study attempts to achieve this objective with due consideration of context in Nepal in developing damage grade classification criteria for typical masonry building, in preparing quick inspection sheet for those buildings and in setting criteria for declaration of safety by posting placards.

FAILURE MECHANISM AND SEISMIC RESISTANCE VERIFICATION OF WALL

Failure mechanism of masonry wall

The principal failure mechanism and failure mode of masonry walls when subjected to seismic loads can be divided in two types: I. Out of Plane failure, and II. In Plane failure. According to the results of earthquake damage analysis and subsequent experiments, three types of mechanism and failure modes define the seismic behavior of structural masonry walls when subjected to in plane seismic loads (Miha Tomazevic, 1999). These are: 1. Sliding failure 2. Shear failure and 3. Flexural failure. The mechanism depends on the geometry of the wall (aspect ratio, h/l) and quality of materials, as well as boundary restraints and load acting on the wall. In terms of damage level and its severity to structural stability in masonry buildings, the typical damages can be classified into two categories.

1. Non-structural damage: The non-structural damage does not affect the strength and stability of the building and it is limited to non structural elements of the building like parapet, chimney etc. Such damage occurs often even under moderate earthquake. Some of the common types of non structural damage are: Cracking and overturning of parapets, chimney, and balconies, cracking and falling of glass panes, cracking and overturning of partition walls, falling of loose plaster from walls and ceiling, falling of cladding, cracking and failing of ceilings, failing of loosely placed objects, overturning of cupboards, etc.

2. Structural damage: The structural damage is related to loss of strength and stability of building system due to damage in structural member of the buildings like wall, roof etc. It is observed in the past earthquake that typical structural damage is generally found in vertical load carrying element such as wall and column. In plain masonry building, elements susceptible to heavy damage are solid wall, weak piers, and weak spandrel depending upon the mode of inelastic behaviors. The damage grade classification of member of masonry building is generally based on prevalence of either in-plane damage or out-of-plane damage or combination of both. The majority of failure modes relate to in-plane damage but out of plane damage can occur as well often in combination with in plane damage. The most common type of failure in plain masonry buildings is shear cracking of wall piers but flexural failure is also evident.

Similarly, the confined masonry building elements that are damaged in case of earthquake are typically infill wall panels held in between reinforced concrete frames or confinement elements like columns. The confined walls can crack diagonally or perpendicular to the wall plane. The confinement element can crack due to tension, compression or combined effect due to the cracking of infill wall in side the frame.

Verification of seismic resistance of plain masonry and confined masonry wall

The type and extent of damage and failure occurred in building elements depend on its resistance against seismic forces. The seismic resistance and corresponding displacement of plain masonry and confined masonry walls can be estimated at three characteristics points (elastic limits) by standard theoretical equation (Miha Tomazevic, 1999). On the basis of these equations, the lateral resistance and corresponding value of displacement has been calculated in terms of drift (%) for typical plain masonry and confined masonry wall of residential building in Nepal in this study. The table 1 provides the values of lateral resistance and rotation at characteristic limit points for typical size of masonry wall derived from these equations.

Table 1 Values of lateral resistance (H) and rotation (R) for typical wall at characteristic limit states

Calculated parameters for typical masonry wall in Nepal (Size of wall - 4000X3000X230mm)								
Masonry Type	Plain masonry				Confined masonry			
Limit state	H (KN)	K (KN/mm)	d(mm)	Rotation (R%)	H (KN)	K (KN/mm)	d(mm)	Rotation (R%)
Elastic limit	262.34	87.12	2.11	0.07	221.68	98.16	2.26	0.07
Max. Resistance	183.64	44.43	5.90	0.20	353.31	42.59	8.30	0.30
Ultimate state	209.87	13.71	15.30	0.50	247.32	1.93	128.15	4.00

The value of lateral resistance and corresponding rotation angle for plain and confined masonry wall given by the results of various experiments (M. Tomazevic & I. Kelmenc, 1997 and others) were considered in this study where the average values are proposed for the judgment of degree of risk due to inclination of the building due to differential settlement in earthquake. As these values have been proposed based on the study of limited experimental results carried out in other countries and corresponding theoretical calculation based on above equation for a typical wall in Nepal, further research study with experiment on typical Nepalese building is suggested for verification of these values. The values of rotation R, observed in various experiment and proposed value for Nepal are presented in table 2.

Table 2 Values of rotation (R) for typical wall in at characteristic limit states

	Values of R for plain masonry		Values of R for confined masonry	
	Observed value	Proposed value	Observed value	Proposed value
At elastic limit	0.07% to 0.09%	**0.08%**	0.07% to 0.12%	**0.09%**
At max. Resistance	0.20% to 0.26%	**0.25%**	0.30% to 0.83%	**0.50%**
At ultimate State	0.46% to 0.66%	**O.50%**	1.61% to 4.17%	**1.5%**

PROPOSAL FOR QUICK INSPECTION PROCEDURE OF BUILDINGS IN NEPAL

Damage grade classification of individual elements of plain and confined masonry buildings

For effective quick damage inspection system, the procedure should be simple and criteria of damage grade classification should be uniform. The characteristics are to be maintained for consistency in field observation and safety judgment. This ensures that different building inspectors examining the same building reach at the same conclusion about the structural safety and potential hazard category to aftershocks. The major factors to judge the risk of total or partial collapse of a building is residual strength, stiffness and ductility of the load resisting walls. The factors are estimated by inspecting the failure or damage occurred in load resisting walls for masonry building. The extensive shear cracks in piers and separation of walls from corner are some of the key sign for the evaluation of residual strength and stiffness of the element. When the load bearing wall does not exhibit any damage due to main shocks, it is supposed that the member has not exceeded the elastic limit. In this case the probability of collapse or damage caused by the aftershocks is supposed to be insignificant. If the load bearing wall suffers damage, it shows that the elastic limit has exceeded and the resistance of the elements to seismic force has been reduced by the main shock. Damaged structural members can be divided into three damage levels: Damage Grade I (Slight damage), Damage Grade II (Moderate damage) and Damage Grade III (Heavy or severe Damage) based on the resistance envelope i.e. lateral resistance and displacement relationship of masonry walls. The typical relationship between the lateral resistance and displacement in masonry building is schematically shown in the figure 1. This illustrates the load carrying capacity, load deflection curve, member damage grade and building performance level.

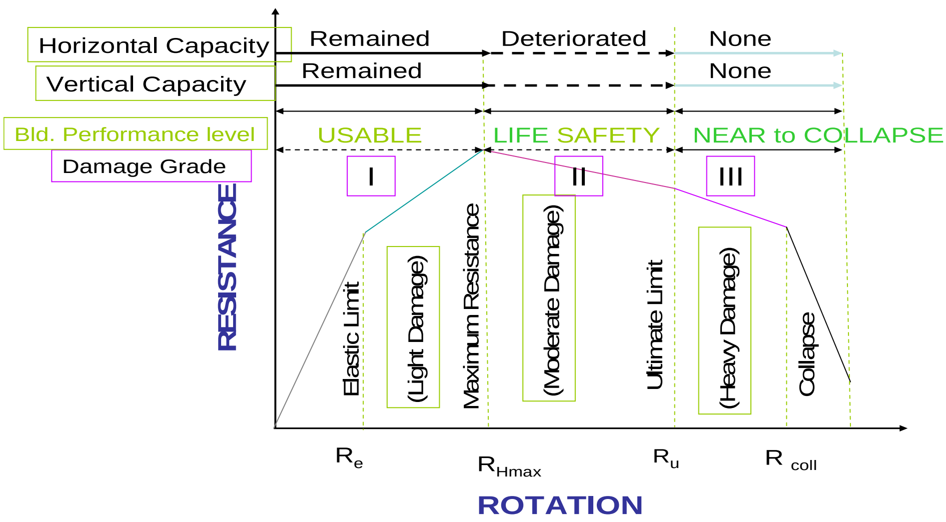

Figure 1 Strength deflection relation ship for masonry building

A building is not considered as damaged before it attains the elastic limit. The first cracks that changes the stiffness but do not influence the usability of the building, occurs in the range between the elastic limit and maximum resistance limit state. Horizontal and vertical load carrying capacities of the structure do not change up to maximum resistance limit and structure does not suffer permanent drift. Only very limited minor structural damage can occur in this range. The risk of life threatening injuries as a result of structural damage is very low up to this limit. Although some minor structural repairs may be appropriate but these would generally not be required prior to re-occupancy. The damage occurred in the structure before the stage of attainment of maximum resistance is classified as light damage and ranked as damage Grade I.

After the attainment of maximum resistance the load carrying capacity is deteriorated but the structure remains safe until the ultimate limit state. In this stage, some significant damage and some permanent drift occurs to the structure but some residual strength and stiffness remains against either partial or total structural collapse of the structure. Gravity load bearing elements still function to make the building withstand the normal load. Overall risk of life threatening injury as result of structural damage is expected low up to this stage but injuries may occur during after shocks. The structure can be repaired, however sometimes it may not be practical due to economic reason. Although the damaged structure is not at imminent collapse risk but it would be prudent to implement structural repairs or install temporary bracing prior to re-occupancy. Damage occurred in the range of maximum resistance level and ultimate limit is classified as moderate damage and ranked as damage Grade II.

Horizontal and vertical load carrying capacity of the structure no more remain after the ultimate limit state. Load bearing members seem apparently function as a very little residual stiffness and strength remains. Large permanent drift occurs and structure is on the verge of partial or total collapse. The past experimental results shows that the structure enters the actual state of collapse long after the ultimate state but the deformation capacity beyond this point is not taken in account because of heavy damage that occurs to the structural walls. In this stage the structure is unsafe for re-occupancy as aftershock may induce collapse. The damage occurred after the ultimate limit is classified as heavy/severe damage and ranked as damage Grade III. The detail damage grade classification for each type of element for different behavior mode has been taken in account mainly based on FEMA documents (ATC 43, 1998).

PROPOSAL FOR POST EARTHQUAKE QUICK INSPECTION SYSTEM IN NEPAL

Steps of Quick Inspection Procedure

A standard quick inspection sheet for typical masonry buildings in Nepal and colored posting placard have been developed in this study. The post earthquake quick damage inspection of buildings can be performed according to this sheet. The procedure has six steps as designated by Step-0 to Step-5. The main parts of the inspections include three steps from step-1 to step-3.

Step-0 is related with the general information about the inspection and the inspected building such as date, address of building and name of inspectors etc. Step-1 is related with the general inspection of the entire building. Here the degree of danger is judged from the general inspection of entire building by visual inspection from out side. If the building is found obviously danger due to either 1) total or partial collapse and fallen floors of the building or 2) significant damage to superstructure or remarkable offset of superstructure from foundation or 3) significant inclination of entire building or individual storey, the building is judged as unsafe.

Step-2 is about the structural safety judgment. At this stage, the degree of danger is judged from the hazard from adjacent buildings, surrounding ground, settlement of building due to ground failure, inclination of building due to differential settlement. These items include inspections of structural safety as a whole building. The next part of structural safety is related with the damage to structural elements i.e. load bearing walls. The most seriously damaged story is inspected and the length of wall suffered from damage Grade II and damage Grade III is taken into account. Then the ratio of damage Grade II is calculated by dividing the length of walls suffered from damage Grade II by total length of inspected walls. Similarly the ratio of damage Grade III is calculated by dividing the length of walls suffered from damage Grade III by total length of inspected walls. Judgment of the structural safety is classified as "INSPECTED" if all items are given Rank-A, "LIMITED ENTRY" if Rank-B is greater than or equal to 1 but not Rank-C and "UNSAFE" if Rank-C is equal to or greater than 1 or if Rank-B is equal to or greater than 2. Structural safety from step-2 is judged as per given criteria in the sheet and building is classified as INSPECTED, LIMITED ENTRY or UNSAFE.

Step-3 describes about the non-structural safety. In this step of inspection non structural hazards like falling and overturning hazards to occupants, users and the general public are taken into consideration. Judgment of non-structural safety is classified as "INSPECTED" if there is only Rank-A and / or Rank-B is present. If Rank-C, is equal to or greater than one then it is classified as "LIMITED ENTRY" as defined in the sheet.

Step-4 is sub-summary on structural safety and non-structural safety. An overall rating is defined according to the highest rating among step-2 and step-3. Step-5 is the overall summary of the inspections. The inspected building is classified as Inspected, Limited Entry or Unsafe according to the above results. Final result of inspection is informed to building users and each building is posted with one of the colored placards (UNSAFE: RED / LIMITED ENTRY: YELLOW / INSPECTED: GREEN). Placards are posted in such a way that general public can be easily aware of the results.

Quick inspection operation plan

Another important and critical aspect of post earthquake quick inspection is its successful implementation in a short time. This can be achieved only when if the system is well planned in advance. A well prepared post earthquake strategy including quick damage inspection as well as pre-event preparedness is critically important to be in place beforehand so that the inspection system would be all set and ready for the immediate application after a big earthquake disaster. For this purpose, establishment of an appropriate organizing scheme before the earthquake is necessary. A quick inspection operation plan with organizational structure, necessary training system and qualification required for inspectors has been proposed in this study to address this aspect of preparedness. The quick damage inspection requires large number of technical man power. Therefore, it is necessary to develop an appropriate organizational scheme prior to the earthquake. Organization structure proposed in this study is based on the administrative structure of the country and the availability of technical manpower. Department of urban development and building construction has been proposed as a leading organization for conducting training and quick inspection operation with cooperation of public, private and academia.

CONCLUSIONS AND FUTURE RESEARCH

The outline of post earthquake quick damage inspection system applicable for typical building typology in Nepal as suggested in this study is intended to provide basic and unified tool for damage evaluation and safety declaration of damaged building in case of earthquake. The proposed quick inspection system will play significant role in assuring the immediate safety of the inhabitants after a big earthquake and also in alerting the inhabitants to take further action towards the retrofitting of their damaged houses. Also, it would help as basic document to develop detail manual of post earthquake quick damage assessment of buildings for the country. It is expected that if this quick damage inspection operation system is established beforehand, the emergency damage assessment of building can be successfully made immediately after the great earthquake disaster. The study would be, thus, a meaningful step contributing towards disaster risk management, particularly, in the field of post earthquake emergency risk mitigation in Nepal.

Damage grades classification criteria of individual elements described in the study are mainly based on the literature surveys of various countries like, Japan, US and Colombia. The criteria are developed through theoretical analysis and judgment. Hence, further experimental researches, field verification and calibrations are needed to accurately set the criteria for buildings in Nepal. This requires further study and research based on field.

ACKNOWLEDGEMENT

I would like to thank Mr. Bishnu Hari Pandey, researcher of UNCRD for his kind support, valuable suggestions.

REFERENCES

ATC 20, 1989, Procedures for post–earthquake safety evaluation of buildings by ATC.
ATC 43,1998, FEMA-306, Evaluation of EQ Damaged Concrete and Masonry Buildings.
BRI, 2002, Guidelines for Damage Survey Methods of EQ Disaster Related with Blds and Houses.
Guido Magenes and Gain Michele Calvi (1997), Earthquake Engng. Struct. Dyn., 26, 1091-1112.
Miha Tomazevic (1999), Earthquake-Resistanat Design of Masonry buildings.
Miha Tomazevic and Iztock Kelemenc (1997), Earthquake Engng. Struct. Dyn., 26, 1059-1071.