Vulnerability Assessment of the Old Brick Masonry Buildings

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Seven monuments have been registered as World Heritage properties in the cultural city, Kathmandu. They have sustained in vertical loads for years but very weak in earthquakes. In order to find out the vulnerability of the buildings and adequate strengthening measures, investigations in Durbar Square Area of Patan, one of the seven monuments zones, was done. More than two hundred buildings were surved and structural conditions were identified. All buildings are classified into different categories. 45% of the buildings are found cracked. Their finite element analyses of six sample masonry buildings were done and damage potentials were estimated.

Keywords : *Kathmandu World Heritage, brick masonry, finite element method, vulnerability assessment*

1. Introduction

Kathmandu valley, the capital city of Himalayan country Nepal, is living heritage which offers beautiful landscapes, aesthetics and architecture of structures. It was inscribed on the List of World Heritage in 1979, as a single site comprising seven best monuments. They are Durbar Squares of Hanuman Dhoka (Kathmandu), Patan and Bhaktapur, the Hindu temple of Pashupati and Changu Narayan, and the Buddhist stupas of Swayambhu and Bhuddhanath. For this study, Jhatapol area of Durbar Squares of Patan and surrounding area has been taken. All the Heritage structures are brick masonry constructed over 300 years ago. The study area of Jhatapol represents the prototype of settlements in Patan city which has become a heritage site in terms of traditional buildings and historical structures. The area and its neighborhood have their layout with a mixture of buildings of different periods, with very different levels of maintenance, from the 15th century onward. Recently a significant number of original buildings have been intervened with concrete framed buildings, usually with extension of floors making the buildings with 5 or more than 5 storeys. This has aggravated the seismic vulnerability situation with substantially greater height and small plan area. The large number of private buildings in the core area of Patan city has traditional architecture and constructed with indigenous technology. Most of the buildings are three or four stories high with floor height between 1.8 to 2.4m. Generally these buildings have a simple rectangular plan with depth about 6 m and length varying from 3 to 10 meters. The foundation is usually shallow, made out of stones or brick. The superstructure is constructed with locally available burnt clay bricks and mud-mortar. The whole structure is supported by three walls, two outside walls and one spine wall at the centre. At the upper storey the spine wall is sometimes replaced by a timber frame system so as to create a larger continuous space. The floors and roof are supported by timber joists, over which wooden boards or planks with a thick layer of mud topping is applied. The roof is usually doubly pitched covered with traditional roofing tiles made of burnt clay. The buildings are coalesced with each other forming a courtyard. At least one house in the courtyard provides access to the street through a gateway on the ground floor. This is generally due to lack of space or due to security reasons. A brief description of the most important structural components is described in the following paragraphs

2. Fragility Analysis

The seismic risk analysis in a probabilistic format is carried out to estimate the probability of failure for different values of peak ground acceleration. The building was modeled by SAP 2000 software[1]. Specific to the properties of brick masonry buildings, a failure mechanism, different from that of RC buildings is assumed. At the outset, modal analysis of the brick masonry buildings is carried out to obtain the vibration properties. From linear time history analysis, parameters like the base shear and the displacement at different storey level are determined for the rescaled PGA value of 0.45g in the ground motion acceleration time history.

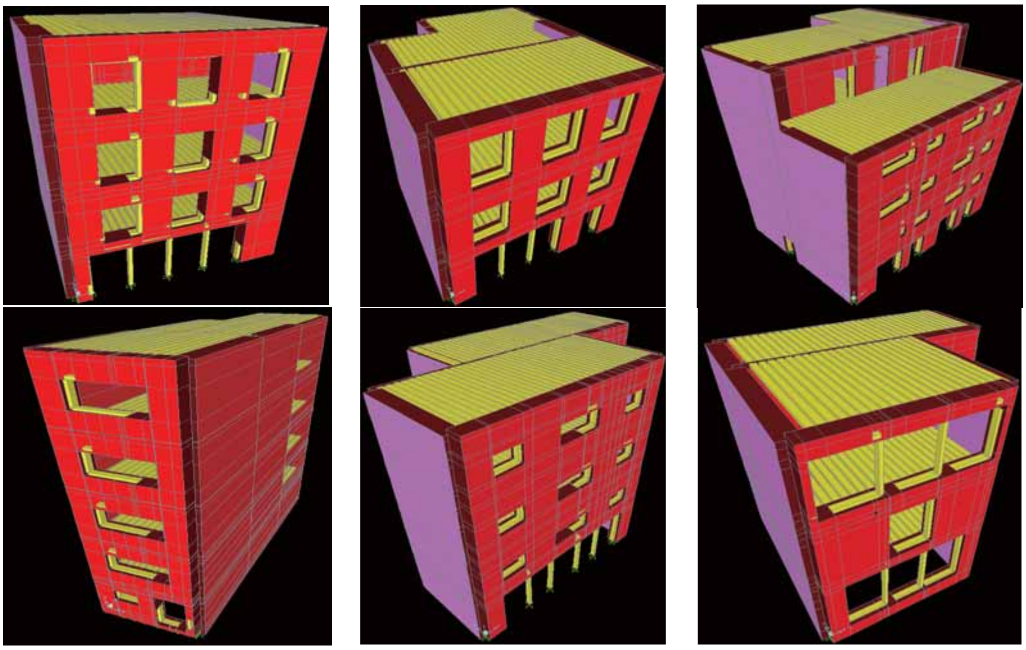

Fig. 1 Finite models of sample masonry buildings

The simulated ground motion acceleration time history with a PGA of 0.45g is used as the seismic input. The shear capacity of the brick masonry building is found out by manual calculation to develop fragility curve. The finite element modeling for masonry building is not that simple compared to that of reinforced concrete buildings. The masonry buildings consist of walls of 45-60cm thickness reduced in upper floors, and with wooden usually doubly framed, door and windows. The floor is made of timber joists with planks or boards overlaid with mud or clay materials, and hence flexible floors. There is no actual data showing or proving exact percentage of fixity of flexibility of these floors which poses difficulties in modeling. In this analysis, wooden purlins are modeled as beam members and end moments are released then it act like hinge member. Six models considered for the building are shown in the Fig. 1. The buildings are A48, A04, B47, C75, B15 and C26 respectively. The prefixes A, B and C stand for three blocks of the study area. Though survey has been done in three areas, only B block's result has been shown in this study. The response of the brick masonry buildings are the stresses in the walls due to earthquake ground motion, where as the failure mechanism is assumed to the shear failure in the wall, which is the usual reason for the serious damage , if not complete collapse. The calculation for the development of the fragility curves of the masonry buildings is presented in Table 1. The fragility curves for the six types of the masonry buildings classes are presented in Figs. 2-7. The details procedure are given in reference 3.

Table 1 Development of Fragility Curve for Brick Masonry Building

PGA(g)	**Shear capacity N/mm^2, (S_c)**	**Sear demand N/mm^2, (S_d)**	**log normal distribution, ln(S_d/S_c)/0.64**	**Probability of failure**
0	0.3	-0.00006	0	0
0.05	0.3	0.0867	-1.939576	0.02621562
0.1	0.3	0.17346	-0.855993	0.19600086
0.15	0.3	0.26022	-0.222274	0.41205049
0.2	0.3	0.34698	0.2273198	0.58991246
0.25	0.3	0.43374	0.5760356	0.71770445
0.3	0.3	0.5205	0.8609491	0.80536696
0.35	0.3	0.60726	1.1018353	0.86473335
0.4	0.3	0.69402	1.3104973	0.90498618
0.45	0.3	0.78078	1.4945484	0.93248382
0.5	0.3	0.86754	1.6591862	0.95146086
0.55	0.3	0.9543	1.8081181	0.96470594
0.6	0.3	1.04106	1.9440816	0.97405719
0.65	0.3	1.12782	2.0691553	0.98073424
0.7	0.3	1.21458	2.1849549	0.98555392
0.75	0.3	1.30134	2.2927614	0.98906913
0.8	0.3	1.3881	2.3936074	0.9916582
0.85	0.3	1.47486	2.4883373	0.9935829
0.9	0.3	1.56162	2.5776509	0.99502628
0.95	0.3	1.64838	2.662134	0.99611765
1	0.3	1.73514	2.7422827	0.99694931

The probability of failure of the brick masonry buildings obtained for the value of peak ground acceleration 0.45g determined from the fragility curves is presented in Table 2. They were calculated based upon first order second moment equation.

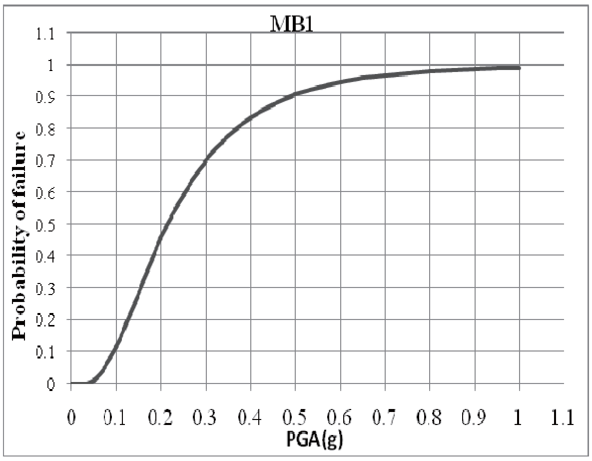

Fig. 2 Fragility curve for A48

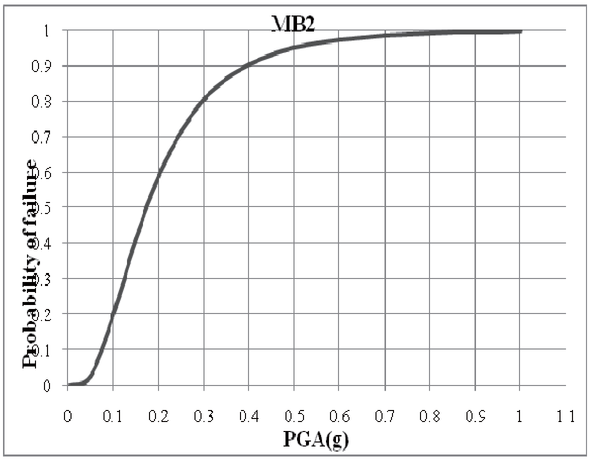

Fig. 3 Fragility curve for A04

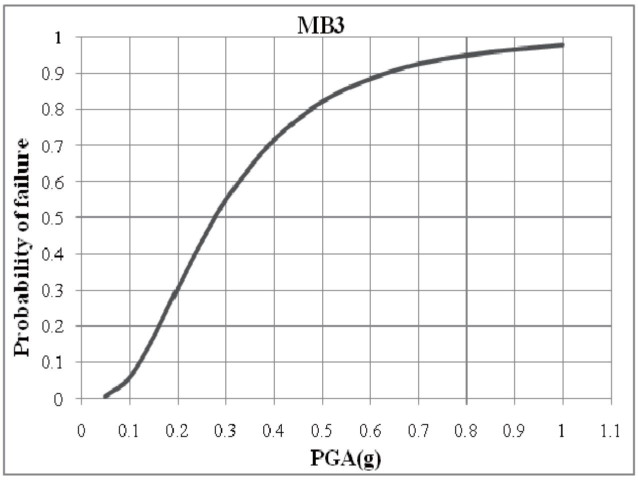

Fig. 4 Fragility curve for B47

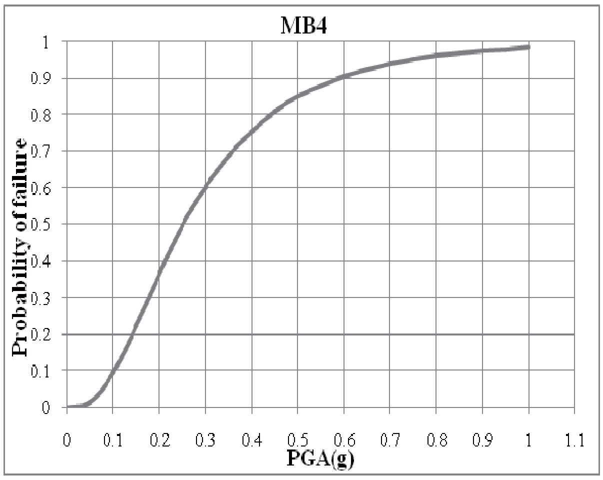

Fig. 5 Fragility curve for B75

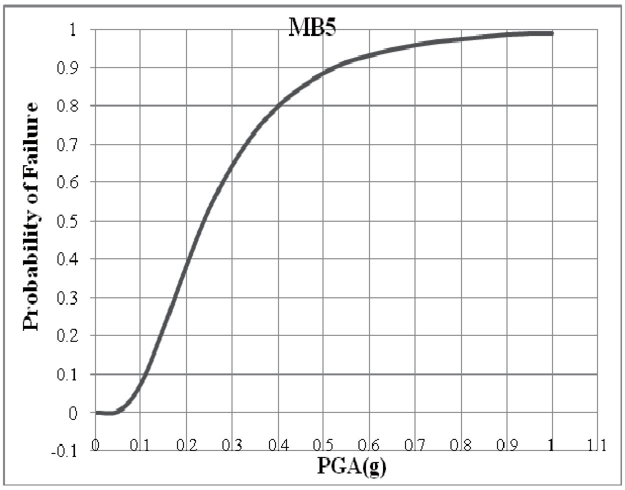

Fig. 6 Fragility curve for B15

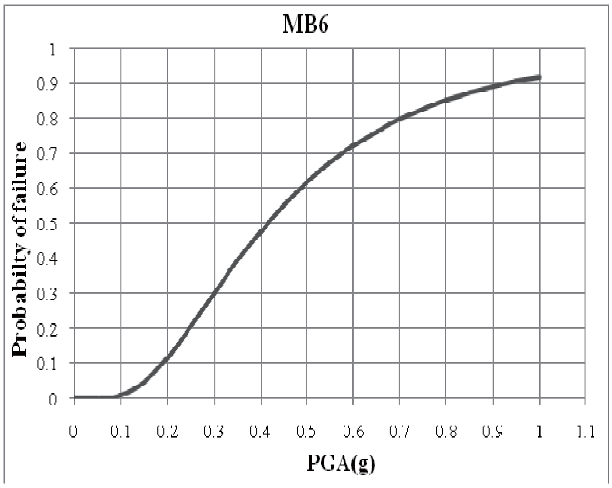

Fig. 7 Fragility curve for C26

Table 2 Probability of Failure of the buildings for PGA =0.45g

Building Class	Damage state	Location	Crushing state	Probability of failure (%)
MB1	Heavy damage	Top right corner of door at ground floor 1st floor	Crushing of masonry panel at bottom far end	88
MB2	Heavy damage	Around the door opening at ground floor	No	93
MB3	Heavy damage	Top right corner of door at ground floor and wall opening at 1st and 2nd floor	Crushing of masonry panel at bottom far end	77
MB4	Heavy damage	Around the door opening at ground floor	Crushing failure	81
MB5	Heavy damage	Around the small window opening at ground floor	Crushing of masonry panel at bottom far end	85
MB6	No damage		Crushing of masonry panel at bottom far end	55

In the table 2, damage states are defined based upon the visul inspection and stress patterns of the masonry wall panel.

Crushing of masonry brick panel are defined based upon stresses reached at that locations.

3. Vulnerability in the line of EMS-98

The vulnerability of the buildings, brick masonry buildings as well as the RC buildings are also studied for their seismic vulnerability in the line of the world accepted European Macroseismic Scale - EMS-98[2]. In this method vulnerability index values are given based on the vulnerability classes for different building typologies were calculated [2]. As the vulnerability (in the EMS-98) depends also on other factors such as: quality of workmanship, state of preservation, regularity, ductility, position, strengthening, and earthquake resistant design level; the methodology suggests the following definition of the vulnerability index (eqn. 1).

$$V_I = V_{I^*} + \Delta V_R + \Delta V_m \quad (1)$$

Where, V_I* is a Typological Vulnerability Index, ΔV_R is a Regional Vulnerability Factor, and ΔV_m is a Behavior Modifier Factor. The scoring for the vulnerability factors, the attribution of vulnerability classes and vulnerability Index values for different building typologies, scores for the vulnerability factors for masonry buildings were assigned and vulnerability indices for all the buildings were obtained [3]. The damage indices for each of the buildings are obtained by combining all the scores obtained from Vulnerability Index, Probability of failure from Fragility analysis, Vulnerability Class and Visual Inspection. Using the expert opinion, the weightage for each of the method in the calculation of Damage Index is as follows;

Vulnerability Index	10%
Probability of failure	60%
Vulnerability Class	10%
Visual Inspection	20%

The damage indices of the buildings are calculated and presented in Fig. 8. For detail DMUCH 2012[3] is referred.

Fig. 8 Damage indices

4. Conclusion

The damage indices obtained for the B block are shown in the Fig. 8 with different level of values. The dark black color shows higher damage potential and the light color shows lower damage potential. It is seen from the figure that the buildings: B15, B17, B18, B30, B39, B48, B65 and B88 are having the maximum damage index in the range of 0.71 – 0.75, calling for the need of strengthening of the buildings. The high value of the damage index is attributed to the high score for visual screening condition and the probability of failure as output of the detailed structural analysis for the possible seismic hazard at the site. The minimum damage index is in the range of 0.34 – 0.40, indicating basically the need for restoration, that is, reinstatement of the strength of the structural members at part with their original state, and necessary repairs.

References

1) CSI, Computer and Structures 2000.
2) Grunthal, G.: *European Macroseismic Scale 1998; EMS-9*8, Cahiers du Centre de European de Geodynamique et de Seismologie 15. Luxembourg: European Seimological Commission, Sub commission on Engineering Seismology, Working Group Macroseismic Scales, 1998.
3) Research Center for Disaster Mitigation of Urban Cultural Heritage, (DMUCH) Ritsumeikan University, Kyoto, Japan and Institute of Engineering, Tribhuvan University, Kathmandu, Nepal, *Disaster Risk Management for the Historic City of Patan, Nepal*, Final research of the Kathmandu Research Project, March 2012.