Seismic Vulnerability Assessment of Brick Masonry Houses with Street Survey in Developing Countries

Kainat Batool [1], Gulelalah Ayaz [2], Majid Ali [3]

1. Corresponding Author. Bachelor Student, Department of Civil Engineering, Capital University of Science and Technology, Islamabad, Pakistan.
   Email: qynishah@gmail.com

2. Bachelor Student, Department of Civil Engineering, Capital University of Science and Technology, Islamabad, Pakistan.
   Email: gulelalahayaz@gmail.com

3. Associate Professor, Department of Civil Engineering, Capital University of Science and Technology, Islamabad, Pakistan.
   Email: majid.ali@cust.edu.pk

Abstract

In recent years, a lot of efforts are being made about the awareness of earthquake-resistant houses among common people. But still, there is a need to check the effectiveness of these efforts in modern-day construction practices exercised at the implementation level i.e. by local contractors and house owners. The overall aim of the study program is to gather the data of seismic vulnerable masonry houses so that emergency preparedness plan, strengthening awareness for existing houses and earthquake-resistant awareness efforts for new houses can be made. The specific goal of this work is to analyze the seismic vulnerability assessment of newly-built masonry houses conducted through street survey in semi-private society of an urban area of the developing country. A Performa is developed from the available literature. The considered parameters are: brick bond; horizontal and vertical stiffeners at appropriate locations; percentage, width and location of openings; horizontal and vertical gaps between openings; and lintel level in load bearing walls. The houses are classified into four categories as: “at no risk”, “at low risk”, “at moderate risk” and “at high risk”. Recommendations are made for the housing authorities to ensure the earthquake-resistant construction practices in future, strengthening awareness, and emergency preparedness plan.

Keywords: Seismic risk, vulnerability, load bearing, brick masonry, assessment, preparedness plan.

1. INTRODUCTION:

Pakistan is an earthquake prone country and its capital, Islamabad, is situated close to the seismically active regions (Bhatti et al. 2011). ADB-WB (2005) reported that, on 8th October 2005, a ruinous earthquake of magnitude 7.6 hit Kashmir and Northern cities of Pakistan, leaving more than 70,000 causalities and more than 400,000 buildings partly or fully damaged. Also, it was highlighted that approximately $5.2 billion were spent on rehabilitation and restoration. In the Kashmir earthquake 2005, most of the damaged structures were built of concrete block masonry, brick masonry and stone masonry (Shahzada et al. 2012). Brick masonry structural elements are also abundant in historic buildings (Drougkas et al. 2016). The losses were due to the fall down of brick structural members during earthquakes. The reason was that these structures were usually designed for gravity loads only (Naseer et al. 2010). Vulnerability studies of urban centers should be developed with the aim of identifying structure fragilities and reducing seismic risk (Vicente et al. 2011).

Seismic vulnerability studies of ordinary masonry buildings had been conducted based on a statistical approach (Asteris et al. 2014, Achs and Adams 2012, Corsanego et al. 1986, Augusti et al. 1985). Further, it was reported that the indexed algorithms for which the crucial parameters were recognized and assigned weights were based on rudimental structural models. Mud-stone masonry structures were collapsed or heavily damaged even in small earthquakes (Doğangün et. al 2008). Different assessment techniques had been developed to check the seismic risk of structures. The vulnerability assessment based upon a hybrid approach, using statistical data of earthquake damaged unreinforced masonry structures, was performed by Kappos et al. (2006). Seismic risk assessment by survey of mostly residential non engineered structures was done in Haiti. The survey focused on the building use, methods of assembly, material quality, and structural performance (Lang et al. 2011). Flaws in the construction techniques were identified and recommendation were made. A methodology for earthquake risk assessment of structural systems was presented through case studies of masonry structures in Europe. GIS application and database management system were also used for seismic vulnerability and risk mapping. The results obtained from the assessment allowed the estimation of physical damage scenarios, economical and human losses (Vicente et al. 2014). Seismic risk assessment using an existing probabilistic seismic hazard approach by Global Earthquake Model initiative was done in different cities of Nepal (Chaulagain et al. 2015). Risk percentages of brick masonry constructions were calculated and emergency response guidelines were recommended. The assessment of unreinforced brick masonry houses by visual screening (street survey) was adopted earlier by Achs and Adam (2012). Different parameters were analysed. Based on scoring, the inspected buildings were classified into one of four vulnerability classes (i.e. at no risk, at low risk, at moderate risk and at high risk).

Khan and Ali (2017) highlighted requirements, limitations and practical issues for earthquake-resistant brick masonry houses and their convenient solutions were recommended. Emphasis was made on features like opening percentages with respect to wall lengths, lintel levels, openings width and their locations, horizontal and vertical gaps between openings. The guidelines on these parameters can be used to assess the seismic risk of load bearing structures by conducting street survey. The reality "Earthquake don’t kill people, buildings do" reflects the mal practices of the construction at delivering end, that leads to loss of human lives and finance during the tremendous earthquakes. Seismic resistance is considered in design standards but the more important thing is the implementation of these standards at the gross root level.

The capital territory, Islamabad, is located over the fault line of Margalla hills which is not active yet. In case, the fault line gets active, whether the construction of most planned city of the country will be able to sustain the tremors or not. So there is a need to check the current construction practices. The overall purpose of this project is to carry out the seismic vulnerability evaluation of brick masonry houses. This can help making recommendations about strengthening and earthquake disaster preparedness plan. The project mainly focuses on seismic risk assessment of under-construction (grey) brick masonry houses by conducting street survey in an urban area of Pakistan .

2. PROCEDURE:

2.1 STUDY AREA:

Figure 1 shows the society of an urban area taken for street survey. The society has a scattered spread of different plot sizes throughout the sectors. 10 Marla and 20 Marla houses are taken for seismic vulnerability assessment. This pilot study is limited to visual observations of under-construction houses using street survey (i.e. level 1 of seismic risk assessment) only. There can be further levels of risk assessment like inspection of building from inside, material testing, modelling and strengthening guidelines. These four levels are outside the scope of work but are recommended for future researches. For this pilot study, a total of 40 houses are assessed. Grey structures with minimum two stories have been chosen for assessment. A minimum of 50% critical walls have been assessed. Grey structures are the houses under-construction in which structural members are completed. The society is intentionally kept anonymous. Only brick masonry houses with cement sand mortar are assessed.

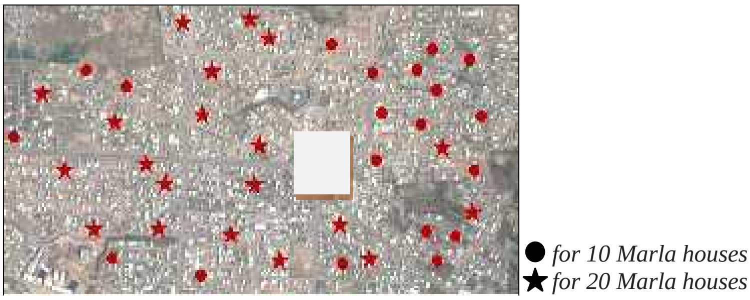

Figure 1: Anonymous society for seismic risk assessment of brick masonry structures

2.2 ASSESSMENT CRITERIA:

A seismic risk assessment Performa is developed based upon earthquake resistant brick construction guidelines from Khan and Ali (2017), Arya et al. (2012), EERI and IAEE (2011). The Performa consists of certain parameters upon which evaluation of structures is carried out. The parameters include opening width, its percentage in a particular wall, its horizontal and vertical gaps with other openings. Also, lintel levels, provision of vertical and horizontal stiffeners, plan and elevation dimensions according to brick size are included as the assessment parameters.

3. RESULTS AND ANALYSIS:

3.1 OBSERVATION OF BRICK MASONRY HOUSES:

The summary of construction practices observed for the load bearing structures during the street survey is shown in Table 1. The trend of provision of stiffeners at critical locations decreases from no risk houses to high risk houses. Also, the diversity of focused features in assessed houses can be noted; for example, opening width and their percentages varies for different risk levels. Inappropriate plan and elevation dimensions can also be seen in high risk houses. Risk assessment of historical masonry structures was done earlier by Asteris et al. (2014). The data of different damage stages of historical masonry structures was compiled, while in this project the susceptibility of risk in latest construction practices is accomplished. Through analysis, it is found that the construction practices still have flaws. If the guidelines of seismic resistant brick masonry construction are followed properly, it can reduce the future risk of damage due to earthquake. The results of current study show that, in plot size of 10 Marla, 15% of houses are at "no risk", 45% of houses are at "low risk", 30% houses are at "moderate risk", and 10% houses lies in "high risk" level. Similarly, in 20 Marla plot sizes, 10% of houses are marked as "no risk", 40% of houses are at "low risk", 45% of houses are marked as "moderate risk", and only 5% houses are at " high risk".

Table 1: Summary of observations for brick masonry houses during street survey

Level of risk	**No. of Houses**		**% opening and lintel level**	**Opening width and location**	**Horizontal and vertical gaps**	**Brick bond and dimensions**	**Vertical and horizontal stiffeners**	**Remarks**
	10 Marla	**20 Marla**						
No risk	3	2	• Proper % opening • Same lintel level • Lintel band provided	• Opening width ≤ 4’ • Openings centrally located	• Sufficient horizontal and vertical gaps	• Appropriate plan and elevation dimensions • Proper English bond	• Stiffeners given at proper locations	• Overall good construction • Few stiffeners at uncritical (i.e. doors/ windows, sill) locations are missing
Low risk	9	8	• % opening is not in limits (i.e. 42% for two stories) • Same lintel level	• Most opening widths of about 4.5' to 5' (≤4’ opening recommend ed) • Location is fine	• Horizontal and vertical gaps are just ok	• Appropriate plan and elevation dimensions • Proper English bond	• Most of the stiffeners given at proper locations	• Few stiffeners are missing at uncritical locations • Mortar filling is not good • Overall appearance is good
Moderate risk	6	9	• % opening slightly greater than 42% • Same lintel level	• Opening widths of 6' to 8' • Location is in limits (1/4H≥2)	• Horizontal gaps are not in limits (i.e. 1/2H≥2) • Vertical gaps are fine	• Appropriate plan and elevation dimensions • English bond is not followed	• Few stiffeners are missing at critical location (i.e. junctions)	• Substandard facade walls • Broken bricks are used
High risk	2	1	• 80% of openings on the external walls • Same lintel level	• Opening widths of about 8' to 10' • Location is fine	• Horizontal gaps are not in limits • Vertical gaps are not in limits (i.e. 1/2W≥ 2)	• Inappropriate plan, elevation dimensions and English bond	• Many stiffeners are missing at critical locations (i.e. corners and junctions)	• Corner stiffeners missing • Large openings without special considerations

3.2 CONFIGURATION OF EXTERNAL WALLS:

The construction trends of external walls of brick masonry houses of 10 Marla are shown in Figure 2. It can be seen that opening widths and percentages are properly given in "no risk" houses. Only few vertical stiffeners are missing at some uncritical locations like doors and windows. In the external walls of "low risk" houses, vertical stiffeners are provided only at corners and junctions. The vertical gaps between openings are appropriate. The opening widths are within limits and openings are centrally located. There is diversity seen in external walls of "moderate risk" houses with no special measures, even corner stiffeners are missing. Plan and elevation dimensions are in accordance to the nominal brick size used in English bond (see Figure 2c). In "high risk" houses, there are many openings in external walls with no special measures. Stiffeners at two of the four corners are missing. If the larger openings are provided without vertical stiffeners at their edges then it can cause diagonal cracking in brick walls. The horizontal and vertical gaps between openings are also not properly given. In high risk houses, there are brick masonry columns beside large openings (see Figure 2d)

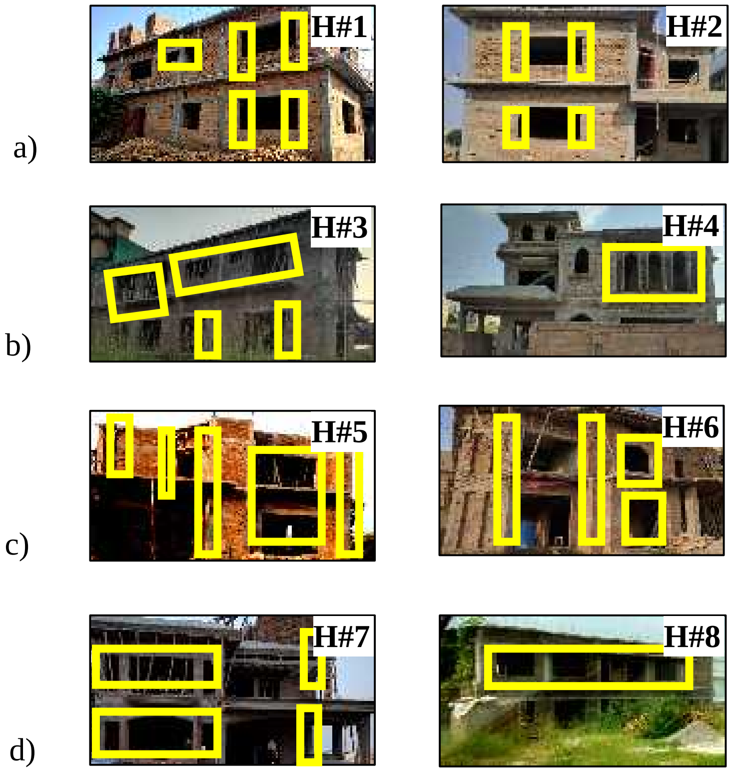

Figure 2: Brick masonry houses of 10 Marla: (a) H#1 and H#2 at no risk, (b) H#3 and H#4 at low risk, (c) H#5 and H#6 at moderate risk, and (d) H#7 and H#8 at high risk

The construction practices of 20 Marla brick masonry houses are shown in Figure 3. In the walls of "no risk" houses, lintel band can be observed which is running throughout the wall. Vertical stiffeners at critical locations are given. Limits for opening widths are followed. The percentage opening of "low risk " houses seems to be fine. One vertical stiffener at critical location (i.e. corner) is missing. Also, stiffeners at uncritical locations are missing. In " moderate risk " houses, stiffeners at some critical locations are not provided. Limits for percentage opening is also not followed in moderate risk houses. Missing vertical stiffeners at corners and other critical locations creates poor connection between two right angled load bearing walls which can cause fractional or full collapse of walls. Also, if lintel bands are not provided properly, then it can cause out-plane failure of load bearing walls. All of the four corner stiffeners are missing in "high risk" house. Also larger openings without any special measures are provided on all external walls. Achs and Adams (2012) developed the rapid visual screening method to categorize structures based on several parameters to capture the effects of possible damages under earthquake loading. Furthermore, the outcome of the proposed methodology supplied a good prediction of the damage distribution within the pilot area considered. But, in this project, risk evaluation study is carried out by conducting street survey of grey structures which have focused entirely on the flawed construction practices being followed.

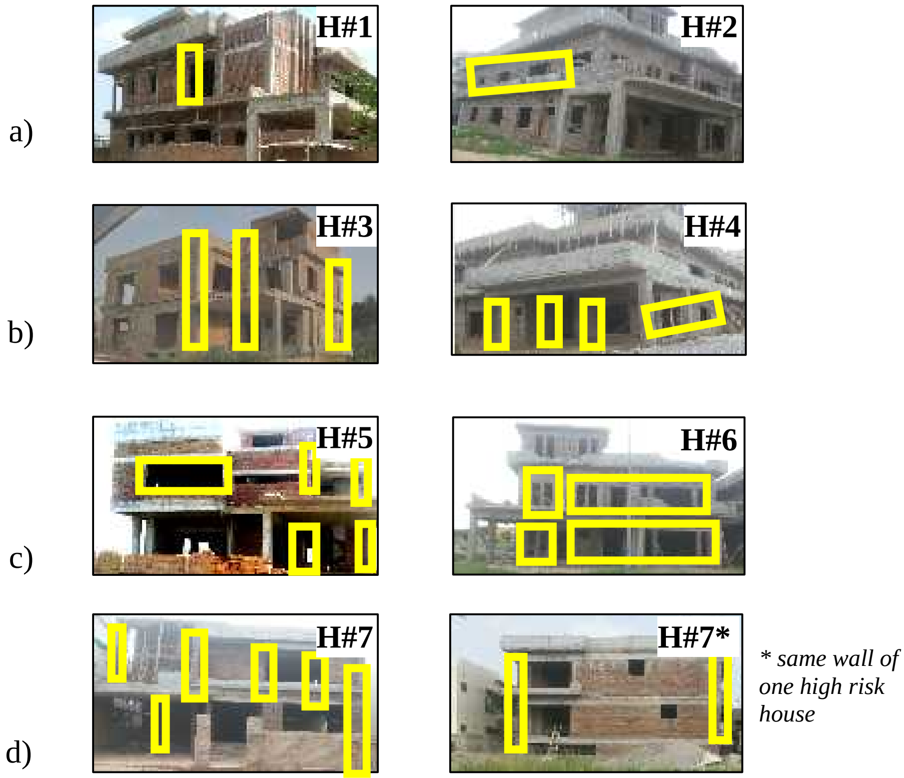

Figure 3: Brick masonry houses of 20 Marla: (a) H#1 and H#2 at no risk, (b) H#3 and H#4 at low risk, (c) H#5 and H#6 at moderate risk, and (d) H#7 at high risk

4. DISSCUSSION

Seismic vulnerability assessment of brick masonry houses (that are under-construction) is carried out to evaluate the risk resilience of the structure. From the detailed analysis of data, the trend of larger openings is observed mostly in the under-construction houses. In the current construction practices, negligence towards provision of vertical stiffeners is observed at a higher rate. Larger openings with minute horizontal gaps are observed. Also, larger openings are not centrally located and are without vertical stiffeners at their edges which enhance the risk factor. Vertical stiffeners are the most crucial constraint for earthquake resistant design. The provision of the stiffeners at the critical locations is ignored.

For under-construction houses, following strengthening techniques can be applied: (i) polypropylene bands (arranged in a mesh fashion and embedded in a mortar overlay) can be used to reduce the risk level, (ii) angle sections and steel plates can be used at the connection of perpendicular masonry walls to enhance the seismic performance, and (iii) using rebars in masonry (i.e. making it reinforced masonry) to compensate the provision of vertical stiffeners can be applied to reduce the risk level.

The study area lies in a seismic prone region which is located near to seismic fault line. In future, if this fault line gets active, the study area will be in low to moderate risk zone (this is concluded based on this limited pilot study). Accordingly, the building authorities should plan their strategies in order to spread awareness about retrofitting of existing houses and to make emergency preparedness plans so that the risk can be minimised. The future construction practices should be made in line with earthquake resistant brick masonry construction guidelines. To the best of author's knowledge, there is no such legal document of seismic guidelines/standards for load bearing structures in Pakistan. National standards and guidelines for brick masonry construction should be prepared in Pakistan to avoid damage cases in future.

5. CONCLUSIONS AND RECOMMENDATIONS:

Street survey of a semi-private society of an urban area has been conducted. The survey helps to carry out the seismic vulnerability assessment of brick masonry houses. Under-construction forty houses have been assessed on the basis of which following conclusions about whole society have been made:

- Through data collected, it is estimated that 12½% of the houses are at "no risk", 42½% of the houses are at "low risk", 37½% of the houses are at "moderate risk" and 7½% of houses are at "high risk".
- Vertical stiffeners at critical locations and percentage openings are crucial features which should be greatly considered and focused in construction practices to avoid any kind of fiscal and human loss during future hazards.

Special measures for strengthening awareness should be taken by the concerned building authorities on the urgent basis to lessen the amount of future loss. The authorities should also make policies to develop an emergency preparedness plan to be followed in time of earthquake disaster. Street survey at large scale should be conducted for seismic risk assessment of the whole urban area. Testing of materials (bricks, mortar, concrete and steel) is also necessary to have deep insight.

ACKNOWLEDGMENT:

The authors would like to thank every person who helped thorough out the project. The careful review and valuable recommendations by the anonymous reviewers are appreciatively acknowledged.

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