Seismic Risk Assessment of Residential RCC Buildings with Street Survey in Urban Areas of Developing Countries

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Abstract

Earthquake-resistant design and construction guidelines are being prepared and practiced for years in developed countries to save human lives. But, the developing nations are still underestimating the importance of earthquake-resistant construction, particularly at the gross-root level i.e. at the local contractor level. This makes the lives of many humans at high risk. An effort is needed to address this issue/aspect. The overall aim of the study program is to gather the data of seismic vulnerable RCC buildings so that emergency preparedness plan, strengthening awareness for existing buildings and earthquake-resistant awareness efforts for new buildings can be made. The specific goal of this work is to analyse the seismic risk assessment of under construction grey RCC buildings conducted through street surveys in an urban area of the developing country. A Performa is developed from the Modified Turkish Method along with some additional factors based on local conditions. The considered parameters are: soft story, heavy overhangs, short column, ponding effect, plan and vertical regularity, topographic effect, visual construction quality, safe exit, emergency stairs and beam-column joints. The buildings are classified into four categories as: “at no risk”, “at low risk”, “at moderate risk” and “at high risk”. Recommendations are made for the building authorities to ensure the earthquake-resistant construction practices in future, strengthening awareness, and emergency preparedness plan.

Keywords: Vulnerable, urban area, earthquake-resistant, RCC buildings, risk assessment.

1. INTRODUCTION:

Pakistan is located in one of the most seismically active regions of the world. The devastating Quetta earthquake of magnitude 7.4 in 1935, the Makran coast earthquake of magnitude 8.0 in 1945, the Pattan earthquake of magnitude 6.0 in 1974 and the Muzaffarabad earthquake of magnitude 7.5 in 2005 are all evidences of active seismicity in Pakistan (Bhatti et al. 2011). Kashmir earthquake 2005, with a magnitude of 7.6 on Richter's scale, is thought to be the most disastrous earthquake in the history of the country (Ali et al. 2015). The earthquake left widespread destruction in its wake, killing at least 73,000 people, severely injuring another 70,000 and leaving 2.8 million people without shelter. Furthermore, 400,000+ structures were partly or fully damaged, costing approximately $5.2 billion on rehabilitation and restoration (ADB-WB 2005). Earthquake risk assessment is comparatively growing in the uncontrolled cities of the world (Spence et al. 2007). Many lives can be saved and losses can be avoided. The importance of seismic vulnerability cannot be denied (Rehman et al. 2014).

Reinforced concrete (RC) frame structures are potentially vulnerable to earthquake-induced collapse (Liel et al. 2010). Majority of building stock in Pakistan is based on beam-column frame system. Approximately, a total of 10–15% is built of reinforced concrete. The frame structures in private societies had deficiencies that occur during design and/or construction phase due to unawareness of the design community with modern seismic design and unskilled labor (Ali et al. 2015). Even in Islamabad, the probable fact, that only Margalla Tower collapsed while no other nearby building collapsed, defined the fault in its structural design and/or construction (Bhatti et al. 2011).

Regional seismic vulnerability assessment framework is an essential tool to mitigate consequences of earthquakes (Alam et al. 2012; Tesfamariam and Saatcioglu 2008). Many methodologies have been suggested for such purpose. Albayrak et al. (2015) proposed a new rapid seismic vulnerability assessment method for Turkey. In this method, the buildings were scored according to the features and then ranked accordingly with respect to seismic risk i.e. at no risk, at low risk, at moderate risk and at high risk. The parameters investigated through street surveying to symbolize the seismic vulnerability of each building were: age of building, number of stories, existence of soft story, short column, heavy overhangs, pounding affect, topographic effects, visual building construction quality and earthquake zone where the buildings were located. The results revealed that total 218 among 1643 buildings were classified as high risk and more detailed evaluations of these buildings were recommended. Whereas, Inel et al. (2008) presented seismic risk assessment of buildings in Denizli, Turkey. A method to determine the seismic vulnerability was suggested incorporating the scoring scheme with respect to physical structure features along with the geotechnical and geological aspects. The data was used to assess the building damage, and to determine shelter needs during the M6.3 and 7.0 scenario earthquakes. In another study, Nanda et al. (2014) proposed rapid seismic vulnerability assessment of building stocks for developing countries. It helped to identify and to rank buildings that might be potentially hazardous. An in-depth review of earthquake loss estimation software packages was also provided and a comparison was made by Nanda et al. (2015). It was observed by comparison that the losses estimated by the proposed software found to be less than the losses estimated by other tools.

Seismic risk assessment has been given importance globally. Different methodologies have been used by different nations. First level assessment technique comprising of evaluation of physical damage in relation with seismic intensity was used in Coimbra, Portugal (Vicente et al. 2011). A strategy was proposed to find damage and loss consequences for the city centre by using GIS mapping application. Through this management system, building features, survey data, and seismic vulnerability assessment along with damage and risk scenario prediction could be made. In addition upgrading and improvement of data could also be done. A study for seismic risk assessment and hazard mapping in Nepal demonstrated the effects of historical earthquake of 1934 (Chaulagain et al. 2015). Seismic hazard and risk along with corresponding economic losses was calculated using the OpenQuake-engine, the open-source platform for seismic hazard and risk assessment from the Global Earthquake Model initiative. From analysis, it was observed that 14% of buildings would experience extensive damage while 7% were limited to overall collapse. The trends of damage indicated that brick and stone masonry buildings were liable for more than 50% of losses.

The specific goal of this work is to analyze the seismic risk assessment of newly-built RCC buildings through street surveys in an urban area of Pakistan. A Performa is developed from the Modified Turkish Method along with addition of few parameters based on local construction practices. The rest of the procedure is same as that proposed by Albayrak (2015). Recommendations are made for the building authorities to promote earthquake-resistant construction practices in future and aware about strengthening and repairing of vulnerable structures.

2. PROCEDURE:

2.1. STUDY AREA

Street survey is carried out in a society of an urban area as shown in Figure 1 for assessing the grey structures. Grey structures are the RCC residential buildings in which the RCC members and partial brick work are completed i.e. before plastering. A total of 20 residential grey structures are assessed. The society is intentionally kept anonymous.

Figure 1: Anonymous Society for Seismic Risk Assessment

2.2. ASSESSMENT CRITERIA

The procedure adopted for seismic risk assessment of RCC buildings was similar to the method proposed by Albayrak et al (2015) and Sucuoglu & Yazgan (2003). A two-level seismic risk assessment procedure is implemented in this study for low to medium rise (less than 8 stories) ordinary reinforced concrete buildings. Buildings are taken from different sectors of the society in order to ensure diversity of construction practices used in a particular urban area. Building parameters that can be easily observed or measured during a systematic survey are considered in level 1, whereas calculation based analysis is made in level 2. For level-1, the parameters taken into consideration are: number of stories, presence of a soft story, presence of heavy overhangs (such as balconies with concrete parapets), apparent building quality (good, moderate or poor), presence of short columns, pounding between adjacent buildings, topographic effects and visual construction quality (Good, moderate, poor). Due to local conditions, additional parameters are included i.e. presence of safe exit, presence of emergency staircase/exit, and beam-column joints (weak or strong). During any unforeseen circumstances, presence of a safe exit allows ease in eviction. Also, the presence of emergency exit at suitable location is also essential to ensure timely evacuation in case of crises. Furthermore, visible honey combing or segregation in beam-column joints represent unskilled construction practices that reduces the strength of structure. Due to these mentioned aspects, these three parameters are added. For each building, earthquake risk scores (E.R.S) are calculated and classified into one of four risk categories i.e. high risk, moderate risk, low risk and no risk. The additional parameters have been allocated respective scores according to local construction practices. Table 1 displays the scoring with respect to risk factors. The weightage of scores i.e. -2 to -10 corresponding to different number of stories is kept same for additional parameters. Depending on the effect of these parameters on seismic behavior of buildings, scoring is assigned relative to other parameters. For level-2, a sketch of framing plan is made. Dimensions of columns, concrete and masonry walls are taken. Regularity / irregularity of plan is judged. On the basis of data and calculations, redundancy ratio and strength index are calculated. The building is categorized as strong, moderate or weak.

Table 1: Risk factor of Albayrak (2015) along with additional parameters

No. of stories	Base Score		Risk Factors						Additional Parameters		
			Soft Story *	Heavy Overhang *	Short Column *	Pounding Effect*	Topographic Effect *	Visual Construction Quality**	Safe Exit*	Emergency Stairs*	Beam-column Joints***
1-2-3	130	Score Reduction Values	-5	-5	-5	0	0	-5	-2	-2	-2
4-5	120		-10	-10	-5	-2	0	-5	-3	-3	-3
6	110		-15	-15	-5	-3	0	-10	-5	-5	-5
7	10		-20	-15	-10	-5	-2	-10	-7	-7	-7
8 or more	90		-25	-20	-10	-5	-2	-15	-10	-10	-10

*V.P.M =1 if the risk factor exists; otherwise 0. **V.P.M= 2 if the visual construction quality is “poor”, V.P.M =1 if it is “moderate”, V.P.M = 0 for “good” condition. ***V.P.M= 0 if beam-column joints are strong whereas V.P.M=1 if beam-column joints are weak.

3. RESULTS AND ANALYSIS:

3.1. OBSERVATION FROM STREET

Table 2 represents the summary of street survey. The number of stories assessed varies from four (B+G+2) to seven (B+G+5). It is observed that the number of stories and the construction quality are the most significant parameters in identifying the seismic vulnerability of R.C. buildings. Heavy overhangs are present in most buildings that increase seismic lateral forces and overturning moments during earthquakes. Buildings with soft stories are also observed with weak basement and ground floor. In few cases, pounding effect due to variation in floor levels of adjacent buildings is detected. Furthermore, the presence of emergency exits is ignored in all structures assessed. The results of level 1 assessment reveal that the percentage of buildings at no, low, moderate and high risk are 20%, 40%, 30% and 10%, respectively.

Table 2: Summary of observations during street survey

Sr. No.	Level -1 Risk Status	No. of Buildings	No. of Stories	Soft Story	Heavy Overhang	Short Column	Pounding Effect	Topographic Effect	Safe Exit	Emergency Stairs	Construction Quality	Beam-Column Joints	Overall Remarks
1	**No Risk**	4	B+G+2 (2) B+G+3 (1) B+G+4 (1)	Y (0) N (4)	Y (4) N (0)	Y (4) N (0)	Y (3) N (1)	Y (0) N (4)	Y (4) N (0)	Y (0) N (4)	G (4) M (0) P (0)	W (0) S (4)	• Good Construction • Strong beam-column joints
2	**Low Risk**	8	B+G+3 (5) B+G+4 (2) B+G+5 (1)	Y (3) N (5)	Y (7) N (1)	Y (6) N (2)	Y (6) N (2)	Y (0) N (8)	Y (6) N (2)	Y (0) N (8)	G (5) M (3) P (0)	W (3) S (5)	• Moderate construction • Short column • Heavy overhang
3	**Moderate Risk**	6	B+G+2 (1) B+G+3 (4) B+G+4 (1)	Y (2) N (4)	Y (5) N (1)	Y (4) N (2)	Y (4) N (2)	Y (0) N (6)	Y (2) N (4)	Y (0) N (6)	G (2) M (3) P (1)	W (2) S (4)	• Moderate or Poor construction • Soft story • Pounding effect
4	**High Risk**	2	B+G+3 (1) B+G+5 (1)	Y (1) N (1)	Y (2) N (0)	Y (2) N (0)	Y (2) N (0)	Y (0) N (2)	Y (1) N (1)	Y (0) N (2)	G (0) M (0) P (2)	W (1) S (1)	• Poor Construction • Weak beam-column joints • Absence of safe exit

Note: Numbers in bracket shows the number of structures. Symbols are: Y=Yes, N= No, G=Good, M=Moderate, P=Poor, W=Weak, S=Strong

Figure 2 represents the four types of buildings observed i.e. at no, low, moderate and high risk. The common parameter observed in all four types is presence of heavy overhang. Low risk structures (Figure 2a) depicts good construction quality with strong beam-column joints.

Figure 2: RCC Structures: a) at no risk, b) at low risk, c) at moderate risk, and d) at high risk

Semi-buried basements and mid-story beams around stairway shafts lead to the formation of short columns in most concrete buildings which is observed in mostly moderate and high risk structures (Figures 2c and 2d). In high risk structures poor construction quality and weak beam-column joints are observed. The proper location and width of safe exit is ignored in moderate and high risk buildings. It is also noted that there is absence of emergency exit in all grey structures. However, there is a chance that a steel staircase may be provided after completion of civil works.

3.2. MEASUREMENT AT GROUND FLOOR AND BASEMENT

Table 3 represents the summary of level 2 assessment. It is observed that strong structures have better construction quality than the other two. Also, deviations from plan regularity are observed in structures of moderate and weak category. Critical beam-column joints are also observed in weak category buildings. Furthermore, irregularity in framing plan causing unequal distribution of load make structures weak. The results reveal that 33% R.C.C buildings lie in strong category, whereas 57% lie in moderate and 10% lie in weak category.

Table 3: Summary of Level-2 assessment

Sr. No.	Level -2 Risk Status	No. of Buildings	Observations
1	**Strong**	7	Good construction quality, Regularity in plan
2	**Moderate**	11	Moderate construction quality, Irregularity in plan
3	**Weak**	2	Poor construction quality, Irregularity in Plan, Weak beam-column joints, Unequal distribution of load

4. DISCUSSION:

The vulnerability risk statuses of buildings assessed are obtained from two level assessment. The results reflect the trend of construction practices in urban sectors because grey structures are assessed. Most buildings have overhanging cantilever spans and short columns. Pounding effect is also observed in some structures of the society. Construction quality is better in no and low risk category buildings as compared to moderate and high risk structures. Figure 3 gives a comparison of both level assessments of the selected RCC buildings. No risk buildings of level-1 are potentially strong in level-2. Moderate of level-2 can be equally divided into moderate-1 (light yellow color) and moderate-2 (dark yellow color). Whereas, low risk structures of level-1 can be divided into two categories of level-2 i.e. strong and moderate-1. Low risk and strong category structures are due to plan regularity. However, moderate and high risk buildings of level-1 assessment are potentially moderate-2 and weak, respectively in level-2. No or low risk structures may not require strengthening whereas a moderate and high risk buildings may require strengthening. Building authorities should make promising efforts for further evaluation and strengthening of such structures.

<table>
<tr><td rowspan="2">Level-1</td><td>No Risk</td><td colspan="2">Low Risk</td><td>Moderate Risk</td><td>High Risk</td></tr>
<tr><td>20%</td><td colspan="2">40%</td><td>30%</td><td>10%</td></tr>
<tr><td rowspan="2">Level-2</td><td colspan="2">Strong</td><td colspan="2">ModErate</td><td>Weak</td></tr>
<tr><td colspan="2">33%</td><td colspan="2">57%</td><td>10%</td></tr>
</table>

Figure 3: Comparison of Level-1 and Level-2 assessment

5. CONCLUSION AND RECOMMENDATION:

Two level seismic risk assessment technique is implemented to assess under construction grey RCC structures of the urban society. Based on local conditions, additional parameters are added to improve seismic assessment. The results can be concluded as follows:

- Level -1 assessment shows that, out of all structures assessed, percentage of buildings at no, low, moderate and high risk are 20%, 40%, 30% and 10%, respectively. Whereas, in level-2, 33% structures are found to be strong whereas, 57% are moderate and 10% are weak.
- Additional parameters (i.e. safe exit, emergency stairs and beam-column joints) along with number of stories and construction quality are controlling factors in defining seismic vulnerability of RCC structures. These factors should not be compromised in any case.

Based on this study, the building authorities should address the need of strengthening requirements and its implementation. Also, emergency preparedness plan and improvement in building construction practices should be encouraged to minimize possible losses during future earthquake. Furthermore, keeping in view the seismic vulnerability of structures and local conditions, survey data should be enhanced.

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