Earthquake Risk Assessment using PSHA in ArcGIS for developing countries - An easy and quick approach

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Abstract

Risk assessment and risk mitigation techniques are useful to prevent structural damage from natural disasters e.g. earthquakes. Damage caused by natural hazards is comparatively larger in developing countries because of the congested buildings and bad construction practices. In a previous study, seismic vulnerability assessment of typical reinforced concrete (RC) hypothetical structures in Pakistan, without and with CFRP retrofitting technique, was carried out. The vulnerability curves of retrofitted and un-retrofitted structures were developed. In this work, an easy and quick approach to determine seismic risk for developing countries is presented. Seismic risk in terms of monetary loss, fatalities and injuries using Probabilistic Seismic Hazard Analysis (PSHA) in ArcGIS is focussed. A total of 1757 RC real structures in 16 union councils of a district (in seismic zone 3) are studied. It is found out that almost half of the RC structures in the region can be improved to resist the structural collapse against the considered vulnerability curves and hazard level. The average reduction in monetary loss, fatalities and injuries was 65%, 48% and 49%, respectively, using CFRP retrofitting technique in that district. This rapid method of risk assessment can help building authorities of developing countries to plan for risk mitigation techniques.

Keywords: seismic risk, Kashmir earthquake, seismic vulnerability, seismic hazard

1. INTRODUCTION

Earthquakes are one of most devastating events caused by the natural forces. Risk assessment and risk mitigation techniques can prevent human and financial loss due to structural damage from natural events like earthquakes. Damage caused because of natural hazards is comparatively larger in Pakistan being a developing country because of the congested buildings and bad construction practices (Khan and Siddique, 2014; Ali *et al.*, 2015). Furthermore, high seismic vulnerability of existing structures against these hazard increases the risk (Maqsood and Schwarz, 2008), resulting in loss of lives and property. The Kashmir earthquake 2005 had taken approximately 100,000 lives and 400,153 buildings were devastated. The total economic loss was almost $5.2 billion (Durrani and Kim, 2005). The devastation of this natural hazard could have been reduced to a larger extent with proper planning by building authorities for implementation of required construction practices and knowledge. Building code of Pakistan was developed in 2007 to include seismic provisions increasing the ductility of structures for new construction but existing building still poses threat. This research is conducted to evaluate the seismic risk of Mansehra district of Pakistan during the Kashmir earthquake. It was observed that poor detailing and low quality concrete make structures brittle and heavy, attracting more seismic loads with poor drift capacities. Carbon fiber reinforced polymers were selected to improve seismic performance of existing structures as they do not add extra weight to the structure and are efficient in enhancing ductility. The study focusses on the probable reduction in monetary loss, fatalities and injuries that could have achieved if CFRP retrofitting techniques would have been applied in the region prior to earthquake event. Haseeb et al. (2011) recommended ductile joints to prevent structural collapse of reinforced concrete buildings since most of the failures in the study region were concentrated in beam column joints due to lack of detailing. CFRPs were used around beam-column joints to improve joint ductility, hence improving overall structural performance against seismic hazard. Joints were wrapped according to FEMA 547 (2006) recommendations i.e. at distance 1.5D where D is the depth of the beam or column. Total area per square feet of retrofit material was calculated and reasonable estimation of the cost was made.

2. PROCEDURE

2.1. Background

According to the 1998 census, Mansehra had a population of 1153,839 with the annual growth rate of 2.4%, containing an average of 6.7 persons per house. The map of Mansehra district showing union councils along with the bifurcation of areas based on detailed evaluation and extended prediction is shown in Figure 1. A total of 16 union councils are evaluated and in detail. The predictions are extended for the rest of the area.

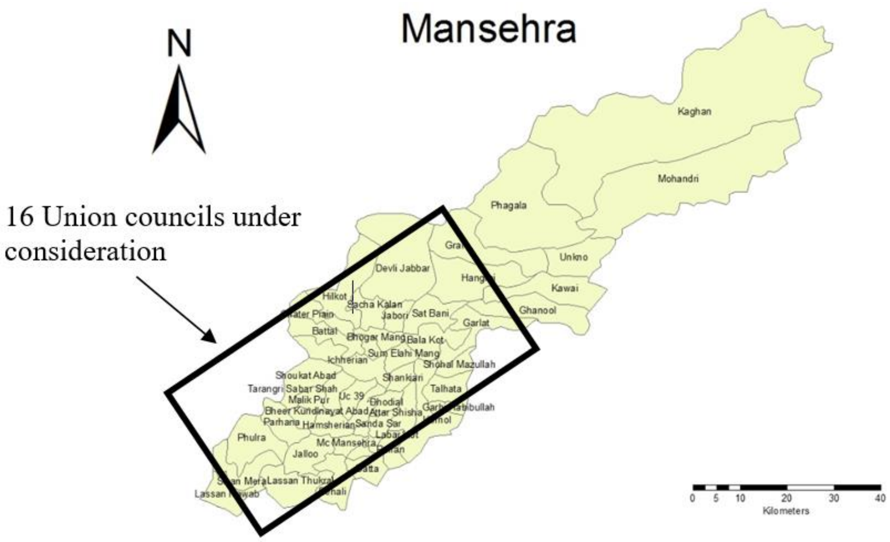

Figure 1. Union Councils of Mansehra

2.2. Risk assessment parameters

2.2.1. Vulnerability

For determination of seismic risk for Mansehra district, vulnerability for the moment resisting frame structures, without and with CFRP, developed in Anwar et al. (2016) are used in this study. Reinforced concrete frame structures in Pakistan showed high seismic vulnerabilities because they were usually designed under gravity loads only. Lack of proper confinement, insufficient lap length, strong beam-weak column and soft story were main cause of high damage index. Absence of nationally accepted building code resulted in poorly designed and detailed buildings. Concrete compressive strengths determined using Schmidt hammer test rarely exceeded 13.75 MPa during a reconnaissance survey (Naseer et al. 2010). Nonlinear static analysis procedure from FEMA440 (2005) was used to develop vulnerability curves using capacity spectrum method which gave a PGA value at structural collapse i.e. 100% damage index. Nonlinear cyclic pushover analysis was carried out to calculate the capacity curves for performance evaluation.

2.2.2. Hazard

Seismic hazard gives probability of occurrence of an earthquake and is calculated in terms of peak ground accelerations using Probabilistic Seismic Hazard Analysis. ArcGIS software is used for seismic hazard distribution input for Mansehra district. Historic catalogue of earthquake 2005 is used for the seismic hazard data since it was a rare earthquake event of 7.6 M_w.

2.2.3. Value

Value is a worth of the structural components of a building. The worth of a structure is reasonably estimated in PKR.

2.3. Considered seismic risk

Seismic risk assessment in terms of monetary loss, fatalities and injuries is determined considering vulnerability, hazard and value.

2.3.1. Monetary loss assessment

Number of building collapsed per union council is determined using structural vulnerability and seismic hazard. Monetary loss is calculated using reasonably estimated value of structures collapsed.

2.3.2. Fatalities assessment

Fatalities per union council are calculated by multiplying the "expected average deaths per collapsed structure" with "total number of collapsed buildings per union council."

2.3.3. Injuries assessment

Injuries in a union council are calculated by multiplying the "expected average survivals per collapsed structure" with "total number of collapsed buildings per union council."

3. ANALYSIS AND RESULTS

3.1. Evaluation of risk assessment parameters

3.1.1. Evaluation of vulnerability

The vulnerability curves developed in Anwar et al. (2016) are given in Figure 2. Existing reinforced concrete structures designed under gravity loads exhibit poor structural performance under lateral loads with 100% damage index at around 0.43g whereas retrofitting beam-column joints with CFRP wraps can improve the ductility and seismic performance of sub-standard reinforced concrete frame structures considerably as shown in vulnerability curve with CFRP retrofitting where structure has a 100% damage index around 0.65g.

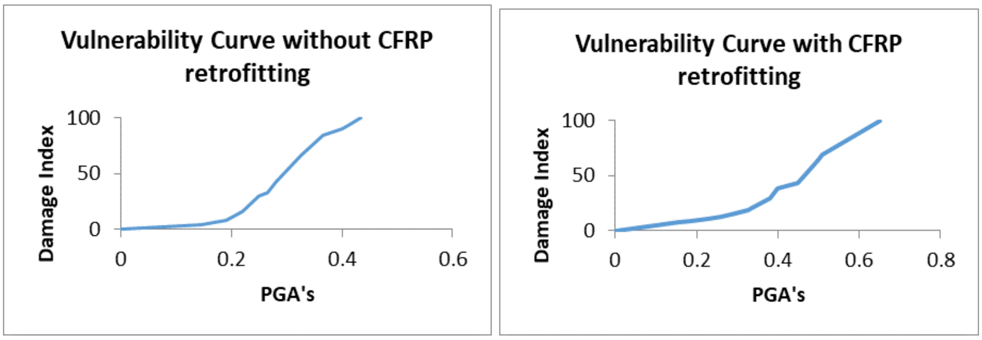

Figure 2. Vulnerability curves Anwar et al. (2016)

3.1.2. Evaluation of Hazard

The hazard distribution plotted in ArcGIS is shown in Figure 3. Legend showing dark areas have high seismic hazard as compared to the light areas which can be due to many reasons involving attenuation factors, soil surface interactions, type of soil, topography, etc. The figure shows horizontal peak ground accelerations averaged per union council for Kashmir earthquake 2005 event. A single earthquake catalogue is used to determine horizontal PGAs shown below. Regions with darker shades have a high peak ground acceleration values than regions with lighter shades.

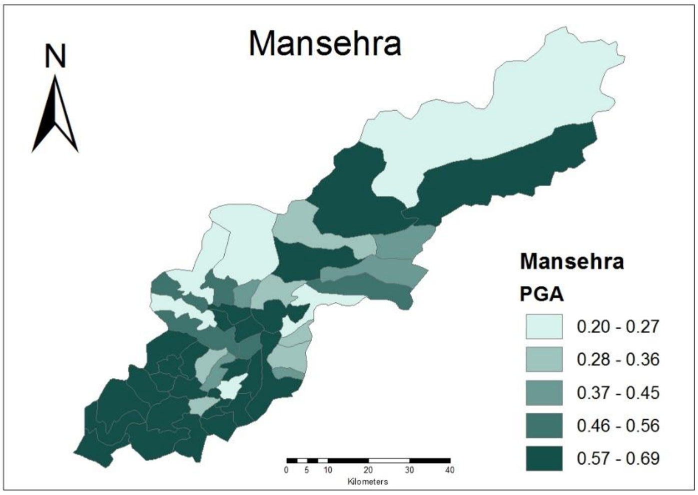

Figure 3. Hazard Map of Mansehra

3.1.3. Evaluation of Value

The distribution of the reinforced concrete structures scattered over the study area is collected from National Engineering Services Pakistan (NESPAK). Worth of a grey structure is reasonably approximated around 40, 00,000 Pakistani Rupees.

3.2. Estimation of seismic risk

Probabilistic seismic hazard analysis integrated with ArcGIS is used to determine the seismic risk for un-retrofitted and retrofitted structures. The vulnerability and spatial distribution of RC frame structures is used as an input for plotting the seismic risk of Mansehra considering historic catalogue of Kashmir earthquake 2005.

3.2.1. Monetary loss assessment

For the monetary loss assessment average risk per building for different unions is generated for unconfined and confined RC structures using vulnerability curves developed in Anwar et al. (2016), hazard assessment and reasonably estimated worth of a structure. Figure 4 shows the map generated in ArcGIS for un-retrofitted and retrofitted frames after the seismic risk analysis. The areas having high hazard and high vulnerability have high seismic risk. The figure 4. shows monetary loss in percentage of the replacement cost for un-retrofitted and retrofitted structures. Seismic risk is reduced in some regions of moderate peak ground acceleration values after CFRP retrofit.

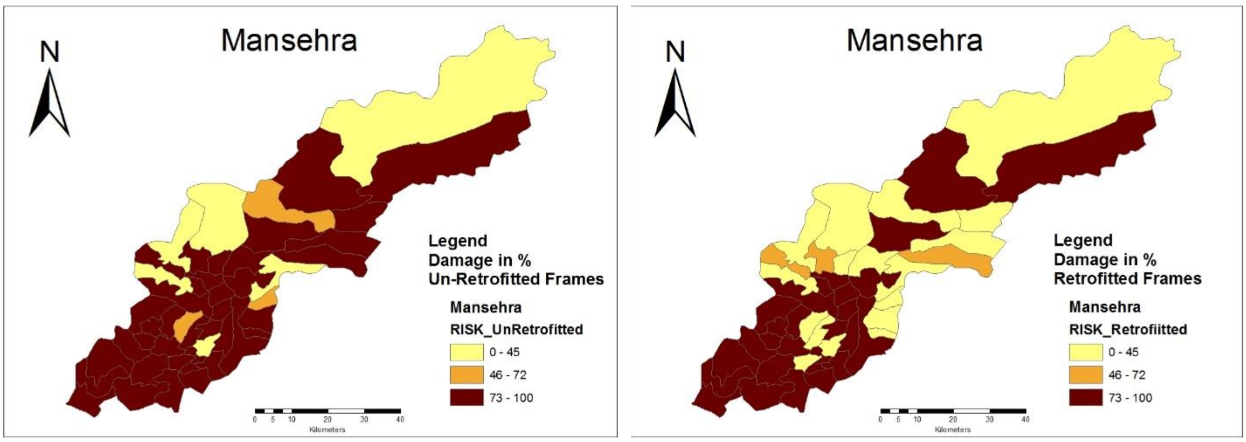

Figure 4. Risk Map of Mansehra

3.2.2. Fatalities assessment

Fatalities are determined by calculating total number of structures collapsed per union council using seismic hazard and vulnerability studies. Mansehra district document (ERRA, 2007) states average 6.7 persons per apartment in a reinforced concrete structure during the earthquake 2005. The average number of apartments per building are reasonably estimated around 6, making total number of people per structure equal to 40.

Incorporating this data, number of deaths are calculated. Figure 5 shows ArcGIS plots of fatalities for retrofitted and un-retrofitted frame structures in study region. Number of fatalities recorded per union council are shown in the legends. The fatalities are reduced in each union council after retrofit showing the efficiency of CFRP technique in reducing fatalities.

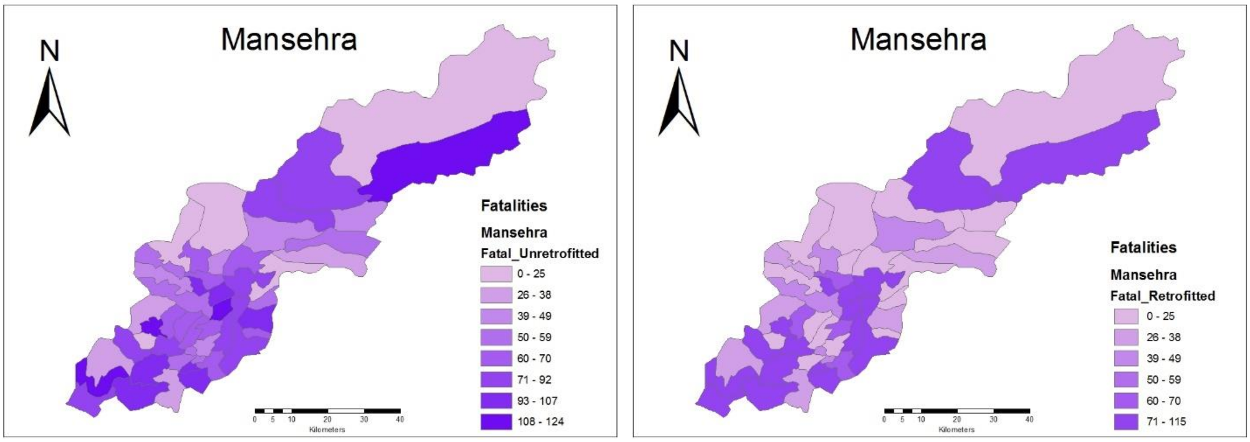

Figure 5. Fatalities Map of Mansehra

3.2.3. Injuries Assessment

For the injuries assessment, same procedure is followed. All the data is plotted in the ArcGIS using PSHA calculating the number of buildings collapsed during the earthquake 2005. Trapped survivors can be determined from total fatalities and average number of people living per building. Figure 6 shows injuries for un-retrofitted and retrofitted structures per union council. Number of persons injured are considerably reduced by increasing performance of structures using CFRP wraps around beam column joints.

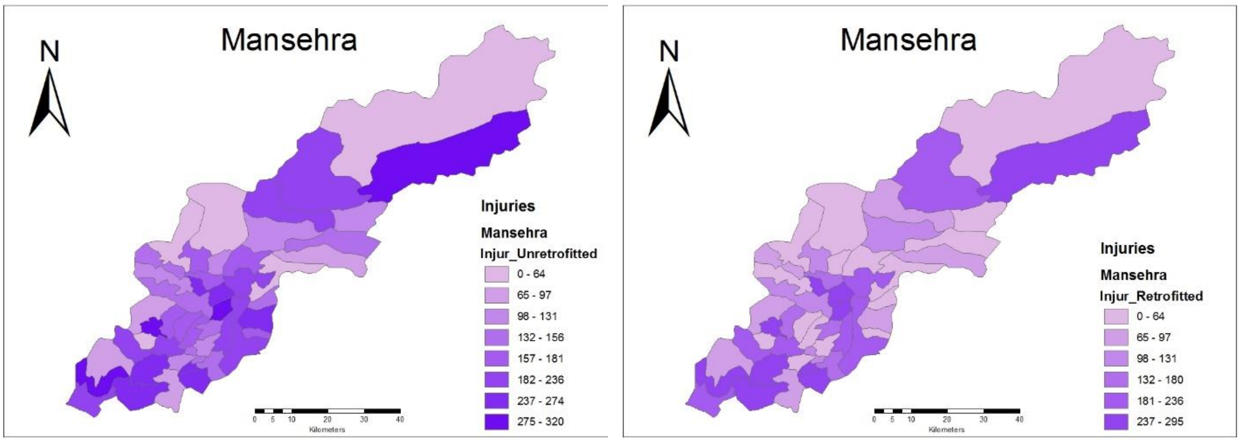

Figure 6. Injuries Map of Mansehra

4. DISCUSSION

Seismic risk is calculated for both confined and unconfined reinforced concrete frame structures. Study indicates the reduced seismic risk in terms of monetary loss, fatalities and injuries. Figure 7 shows the percentage reduction in monetary risk calculated for RC frame structures achieved after CFRP retrofitting. Around 60% reduction is risk is observed using beam-column CRFP retrofitting technique in the study region.

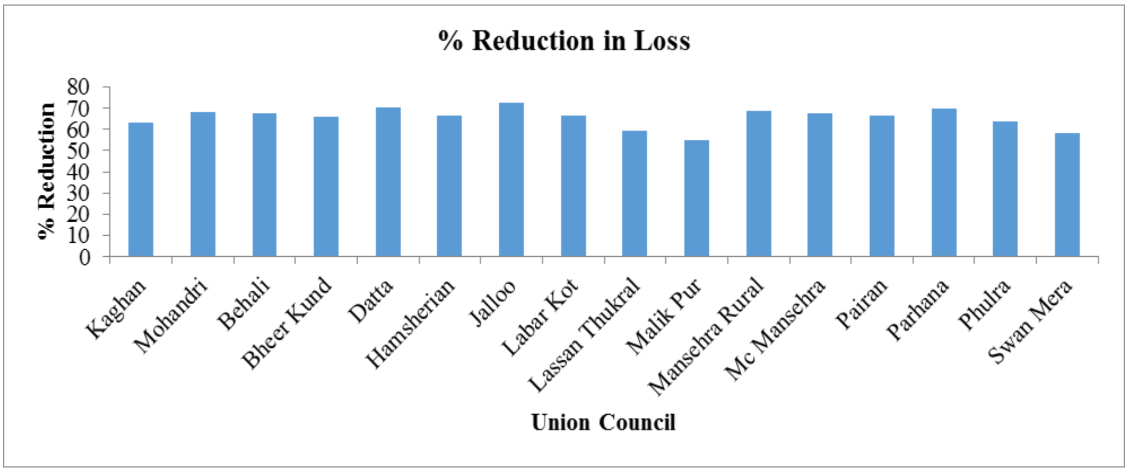

Figure 7. Percentage reduction in seismic risk in terms of monetary loss

The approach presented in this paper can be used for seismic risk assessment of developing countries with limited resources. This easy and quick approach focusses on PSHA developed in VBA utilizing structural vulnerability to calculate seismic risk. Significant cost savings can be achieved utilizing this approach. Furthermore, this approach can help in risk mitigation strategies, saving lives and important facilities.

5. CONCLUSIONS

Following conclusions can be made from earthquake risk assessment of Mansehra.

- The reduction in seismic risk in terms of monetary loss could have been 65% by confining the structures with CFRP's in the study region.
- The lives of 48% people could have been saved and almost 49% reduction in injuries could have been made possible using CFRP confinement in reinforced concrete frame structures in Mansehra before Kashmir earthquake 2005.

6. RECOMMENDATIONS

An easy and quick approach is utilized on RC frame structures for the determination of monetary loss, fatalities and injuries for the study region against single seismic hazard catalogue. This approach can be used to determine risk assessment of reinforced concrete frame structures for future earthquakes by using records with probability of occurrence of a major event in different regions. Future studies are recommended to verify the accuracy of this approach. Furthermore, it can also be extended to masonry and other structural systems to include wider structural configurations for better estimate of seismic risk involved.

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