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EARTHQUAKE RISK MODELING FOR THE EVALUATION OF LOSSES TO PROPERTY OWNERS IN THE METROPOLITAN AREA OF SHIRAZ

M. Sadeghi[1], S. Hochrainer-Stigler[2], M. Ghafory-Ashtiany[3] and N. Pakdel-Lahiji[1]

ABSTRACT

Natural disasters can cause huge human and economic losses, and subsequent operation efforts in disaster relief, recovery and reconstruction by the government, the private sector stakeholders as well as international donors can significantly drain their resources from other non-disaster related pre-planned investments. As a consequence, there is now a paradigm shift for dealing with extremes from after the event approaches to more pro-active ones, the later one including risk reduction and risk financing options. However, reliable and quantitative up-to-date estimation of the underlying risks is of outmost importance towards developing effective risk management strategies as well as risk reduction activities. This is even more so the case for countries that are highly exposed to natural hazards, such as earthquake risk in Iran. This paper focuses on earthquake risk for Shiraz, the 4th largest city in Iran, located in a high seismic active hazard zone with additional high socio-economic and historical importance for the country. It is for the first time that such an assessment for the region is performed and therefore the results should shed some light on potential risks within a probability based setting which could guide current earthquake related policy processes in the region. A catastrophe modeling approach is adopted to assess risk and a detailed analysis of potential future economic losses as well as vulnerability assessments for assets within district 1 is performed. Via combining the hazard, exposure and vulnerability an Exceedance Probability (EP) curve for assets was well as human losses are constructed. The EP curve represents a powerful tool for the assessment of feasible risk reduction strategies as well as cost-benefit analysis for these strategies. An approach is suggested how this could be achieved within an integrative framework.

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Earthquake Risk Modeling For the Evaluation of Losses to Property Owners in the Metropolitan Area of Shiraz

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ABSTRACT

Natural disasters can cause huge human and economic losses, and subsequent operation efforts in disaster relief, recovery and reconstruction by the government, the private sector stakeholders as well as international donors can significantly drain their resources from other non-disaster related pre-planned investments. As a consequence, there is now a paradigm shift for dealing with extremes from after the event approaches to more pro-active ones, the later one including risk reduction and risk financing options. However, reliable and quantitative up-to-date estimation of the underlying risks is of outmost importance towards developing effective risk management strategies as well as risk reduction activities. This is even more so the case for countries that are highly exposed to natural hazards, such as earthquake risk in Iran. This paper focuses on earthquake risk for Shiraz, the 4th largest city in Iran, located in a high seismic active hazard zone with additional high socio-economic and historical importance for the country. It is for the first time that such an assessment for the region is performed and therefore the results should shed some light on potential risks within a probability based setting which could guide current earthquake related policy processes in the region. A catastrophe modeling approach is adopted to assess risk and a detailed analysis of potential future economic losses as well as vulnerability assessments for assets within district 1 is performed. Via combining the hazard, exposure and vulnerability an Exceedance Probability (EP) curve for asset and human losses was constructed. The EP curve represents a powerful tool for the assessment of feasible risk reduction strategies as well as cost-benefit analysis for these strategies. An approach is suggested how this could be achieved within an integrative framework.

Introduction

One key element for a sustainable disaster risk management strategy is the accurate assessment of potential future losses and corresponding event probabilities [1]. As experienced in the recent past, e.g. the Tohoku earthquake in 2011, in Haiti in 2010, or in China in 2008, earthquake events can be devastating, with a large number of casualties and losses. In some countries, such as Iran, the government is a key risk bearer and plays an important role in compensating losses from the private sector [2]. To assess risk on various levels and to adapt to changes in risk, iterative loss estimation plays a vital role as property values change over time, as do the costs of

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repair and replacement, also building materials, design and practice change along with new building codes. Therefore, new structures may be more or less vulnerable to catastrophe events than existing ones which has to be taken into account in future planning [3].

Iran is one of the most earthquake-prone countries in the world. In the 20th century alone, 22 major earthquakes have happened and claimed over 150,000 lives. Part of the reason for the exceptional high human and economic losses in the past, include the failure of most physical structures to withstand the impact [4]. Major earthquakes in the last decades, including Manjil-Roudbar in 1990, Bam in 2003, and Azarbaijan in 2012, all of them have destroyed and damaged many buildings and caused exceptionally high losses both in human and economic terms. Table 1 summarizes the 7 major earthquake events in Iran since 1900, including the number of deaths, injuries as well as direct economic losses for each event.

Table 1. Number of deaths, injuries and direct economic losses of Iran's major earthquakes since 1900 [5].

N	Earthquake	Magnitude	Time	Human Losses		Direct Economic Loss (million $)
				Deaths	Injuries	
1	Manjil-Roudbar	7.1	1900	15000	29654	526.1
2	Bejnord	6.1	1996	90	260	98.6
3	Ardebil	5.5	1996	980	2600	145.3
4	Ghaen-Birjand	7.3	1997	1567	3500	280.3
5	Chngoore (Avaj)	6.2	2002	230	1466	79.1
6	Bam	6.5	2003	31828	17500	2049.3
7	Azarbaijan	6.4	2012	300	3000	822.1

In what follows, a catastrophe risk modeling approach is applied to one of the most important cities in Iran, namely Shiraz.

Probabilistic Earthquake Risk Modeling

Catastrophe modeling is the state-of-the-art approach to investigate probability-loss relationships of extremes, usually in the form of Exceedance probability (EP) curves [3]. Four major modules in a probabilistic earthquake risk modeling setting can be distinguished: Hazard, Exposure, Vulnerability and Loss, all of them are described in detail next.

Hazard Module

The methodology of Probabilistic Seismic Hazard Analysis (PSHA) is used for preparing the probabilistic seismic hazard curve for Shiraz's District one (from now on called district one).

In order to assess earthquake hazard risk, Iran's active faults as mapped in Hessami et al. (2003) are considered first. Figs. 1a and 1b show active faults within the radius of 200 km from the center of district one including ten line sources (labeled LS) and four area sources (labeled AS). By dividing each fault to equal sections, the distances from the center of each section to district one has been calculated.

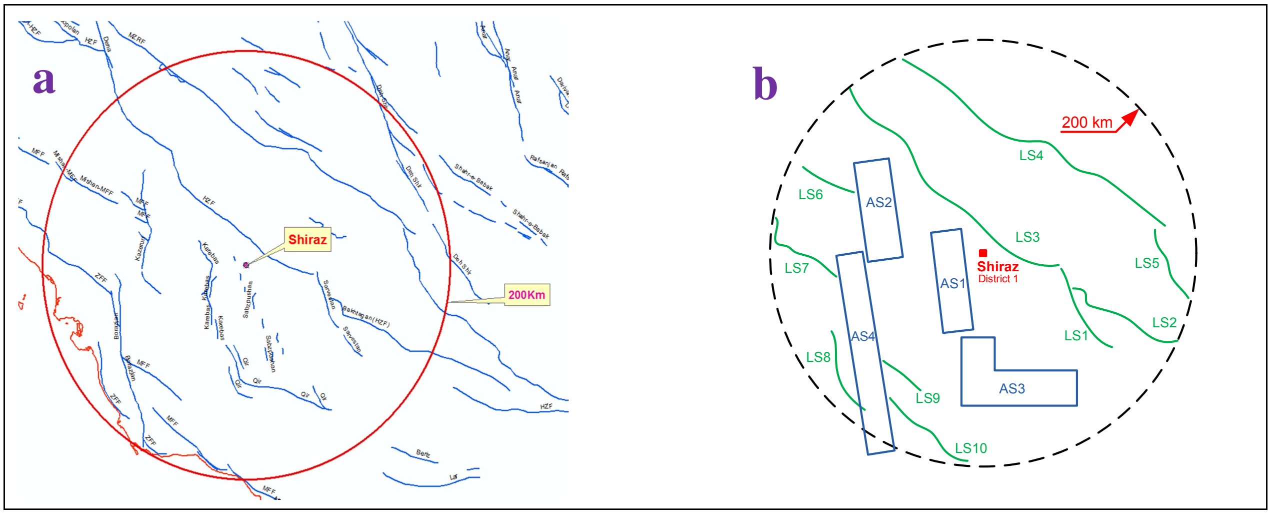


Figure 1. Active fault map with radius of 200km from Shiraz district 1 (a), Definition of area and line faults (b).

The Gutenberg-Richter relation (see Eq. 1) were obtained for events within the Shiraz region, starting from July 1925 to May 2013 with magnitude of 4.5 to 6.5. For hazard analysis three empirical attenuation relationships of Ambraseys 2005, Boore et al. 1997 and Ghodrati Amiri 2007 have been used [6].

$$logN = a - bM \tag{1}$$

Where, N is the number of events having a magnitude equal or greater that M; a and b are constants.

Via the consideration of all faults, a seismic hazard curve has been developed for district one which is shown in Fig. 2. From the hazard curve, Peak Ground Acceleration (PGA) for the annual exceedance probability of 10% and 2% in 50 years, or return periods of 475 and 2475 years, are 0.37g and 0.55g respectively.

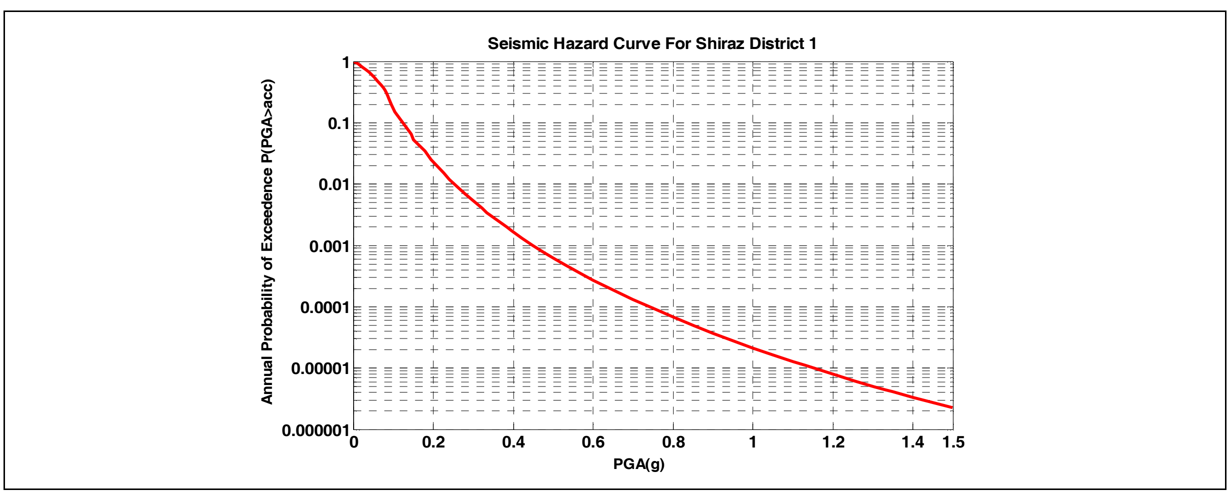


Figure 2. Seismic hazard curve for Shiraz district 1.

Exposure Module

In this module, the inventory at risk is described by performing a building taxonomy. A building taxonomy describes characteristics of individual buildings or a class of buildings with similar characteristics. In order to do a building taxonomy a GIS dataset from Shiraz municipality has been acquired and used. Part of the building taxonomy is presented in Fig. 3.

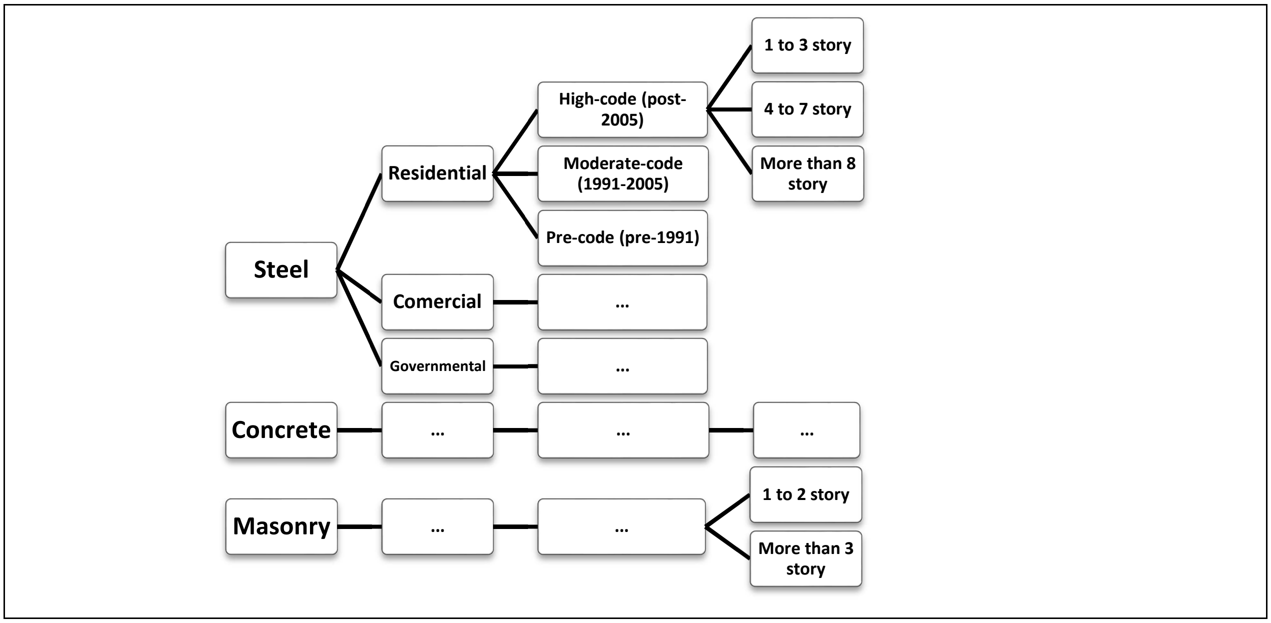


Figure 3. Building taxonomy of Shiraz city.

In more detail, buildings have been classified by structural types in three main groups: Steel, concrete and masonry. Steel buildings include different steel frames such as: moment, braced, light and unreinforced masonry infill walls. Concrete buildings are similar to steel frame buildings except that the frames are reinforced concrete. The concrete-frame buildings include concrete moment, shear walls and unreinforced masonry infill walls. Masonry buildings have perimeter bearing walls of reinforced brick or concrete-block masonry. These buildings have been defined in three groups: reinforced masonry bearing walls with metal and concrete deck diaphragms and unreinforced masonry bearing walls [7].

Three types of occupancies such as residential, commercial and governmental are identified in our application. Residential buildings are single family dwellings; commercials are retail and wholesale trade, personal or repair services, professional or technical services, shopping malls and hotels; finally, government buildings include hospitals, clinics, schools, universities, officials and mosques.

Additionally, related to several editions of Iranian's seismic codes, three time periods for building codes have been considered. High-code, moderate-code and pre-code which are related to the buildings built after 2005, 1991 to 2005 and before 1991, respectively. Steel and concrete structures have been classified by 1 to 3, 4 to 7 and more than 8 story buildings. Masonry structures have been classified by 1 to 2 and more than 3 story buildings. Regarding to these classifications, 53 classes are identified. Fig. 4 shows a 3D distribution of buildings in district 1.

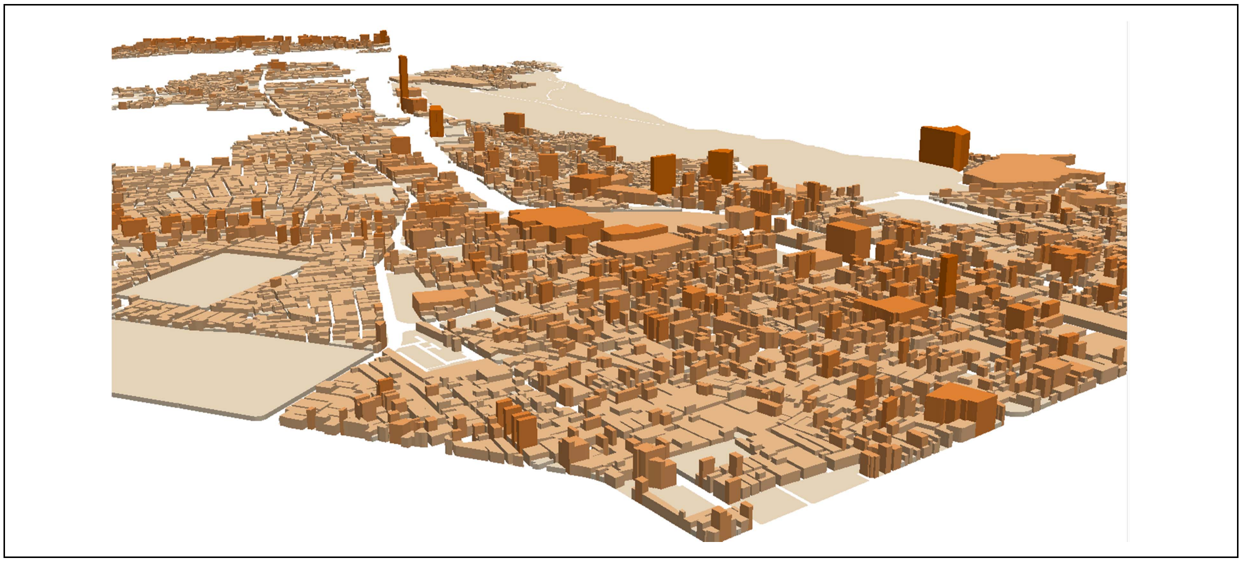


Figure 4. 3-D distribution of buildings in Shiraz district 1.

Vulnerability Module

The vulnerability component deals with the potential of the hazard to damage structures and their contents. It estimates the probability that building damage would exceed various levels as a result of ground motion [8]. For many types of structures, damageability may be defined in terms of fragility, which in turn is defined as the probability that some limit states are exceeded, conditioned on an input level of demand. A graph of this relationship is represented as a fragility function.

There are no classified fragility functions for Iranian buildings and instead HAZUS fragility curves have been used to define building vulnerabilities. The HAZUS model classifies structure as being in a Slight, Moderate, Extensive, or Complete damage state and fragility curves are presented in term of building types, height, seismic codes and occupancies.

We use these fragility curves as proxies to the building inventory for Iran. Based on a literature review and expert opinions it was concluded that the curves are viable first order approximations but should be updated if new information arrives.

Loss Module

The last module links the ground motion levels with inventories and corresponding fragility functions and one output is the aforementioned EP curve which shows the probabilities that given monetary losses are exceeded. Structural loss is defined as repair and/or replacement cost of a structure. Regarding the importance of assessment of human losses for earthquake risks [9], calculations are performed for night with high probability of occupancy in residential buildings, and i.e. it is assumed that 100% of people are at home during the night. Moreover loss calculations are performed under the Iranian official dollar exchange rate of August 2013.

Structural losses are calculated using Eq. 2 and human losses are calculated only for residential buildings using Eq. 3, as follows:

$$\mathrm{SL}_{ds,i} = \sum_{ds=1}^{4} \left\{ R_{C,i} \times \sum_{i=1}^{n} P_{ds,i} \times R_{r,i} \right\} \quad (2)$$

$$\mathrm{HL}_{ds,i} = \sum_{ds=1}^{4} \sum_{i=1}^{n} \{ (P_{ds,i} \times R_{r,i}) \times N_{i\times} \times A_i \times O_i \} \quad (3)$$

where

$\mathrm{CS}_{ds,i}$: Cost of structural damage (repair and replacement costs) for damage state ds and occupancy i.

$R_{C,i}$: Building replacement cost of occupancy i.

$P_{ds,i}$: Probability of occupancy i being in structural damage state ds.

$R_{r,i}$: Structural repair and replacement ratio for occupancy i in damage state ds (HAZUS).

$\mathrm{CH}_{ds,i}$: Cost of structural damage (repair and replacement costs) for damage state ds and occupancy i.

N_i: Number of examined building of occupancy i.

A_i: Average number of people living in each building of occupancy i.

O_i: Occupancy probability of death upon collapse in building of occupancy i.

n: Number of building in occupancy i [7] [10].

By developing event loss tables and combining information on frequency and severity of losses, the probabilistic catastrophe model generates the distribution of the expected losses associated with all possible scenarios of earthquakes. Regarding the hazard curve, losses related to each event has been calculated by the annual probability of occurrence P_i and its related loss L_i. The expected loss for a given event is defined as:

$$E[L] = P_i L_i \quad (4)$$

The overall expected loss for the entire set of events, denoted as the Average Annual Loss (AAL) is the sum of the expected losses of each individual event for a given year [3] and is given by:

$$AAL = \sum_{i=1}^{n} P_i L_i \quad (5)$$

The Exceedance Probability (EP) curves have been derived for all types of buildings and regarding to Eq. 5 the area under the EP curve is the AAL.

Results

Figs. 5, 6, and 7, illustrate selected structural EP curves for three selected groups of buildings. Structural loss related to a 475 year event for steel structures, high code with 4 to 7 story is about \$97 million. For concrete structures, moderate code with 1 to 3 story, the structural loss is 83\$ million. The value for pre-code, masonry buildings with 1 to 2 story, is about 900\$ million. The last group of buildings has the largest share in terms of building stock and residents (about 40% of total) for district one and the highest level of loss. An important result for policy makers who wish to decrease structural losses the most for the more poorer areas or to address issues about increase of safety levels via structural mitigation measures.

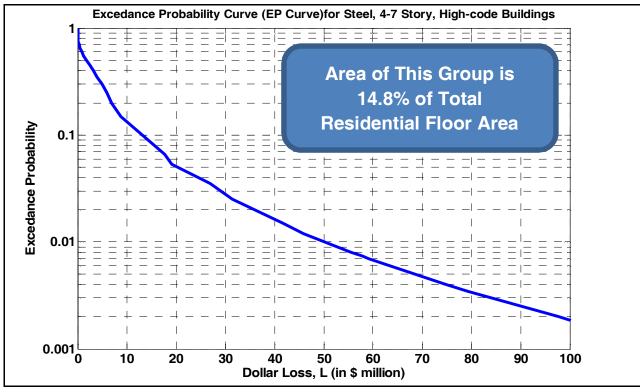


Figure 5. Structural EP curve for steel, high code and 4 to 7 story buildings.

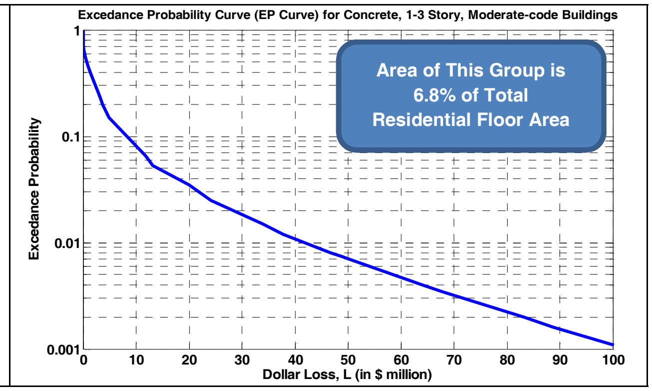


Figure 6. Structural EP curve for concrete, moderate code and 1 to 3 story buildings.

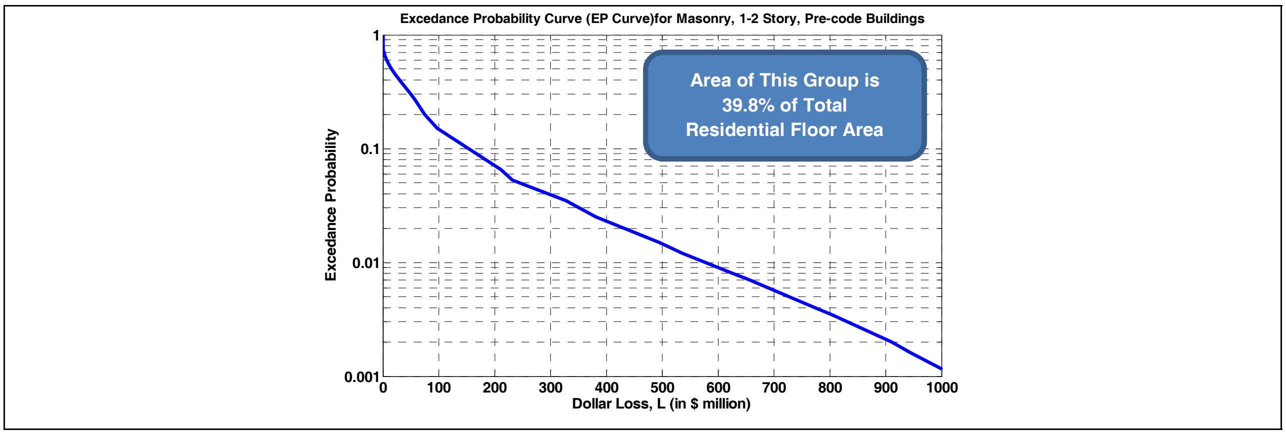
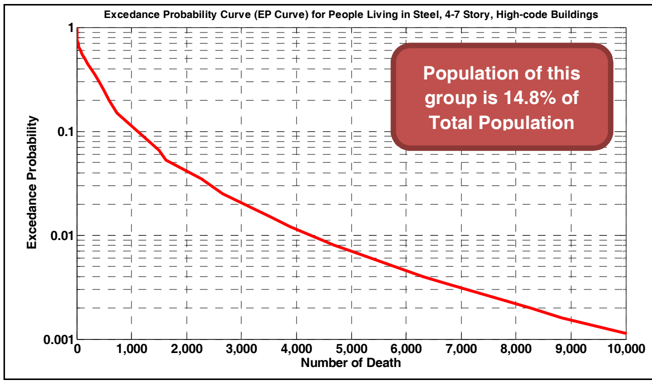


Figure 7. Structural EP curve for masonry, pre code and 1 to 2 story buildings.

Preliminary results shows that based on structural losses in commercial and governmental buildings for a 475 year event, which have been derived from EP curves, results show that moderate code steel structures with 4 to 7 story, have 9.8$ and 10$ million losses, respectively. The structural loss for moderate code concrete structures with 1 to 3 story are 10$ and 17$ million, respectively and for pre code, masonry buildings with 1 to 2 story are 188$ and 155$ million, respectively.

In order to compare structural losses with human casualties, EP curves of human losses have been developed for the three mentioned groups of buildings. Fig. 8 shows human casualties for steel structures, high code with 4 to 7 story and is estimated to 8,200 casualties for the 475 year event. Number of deaths for concrete structures, moderate code with 1 to 3 story is 8,100 people (see Fig. 9). In Fig. 10 the EP curve for human casualties for pre code, masonry buildings with 1 to 2 story shows 98,000 casualties for a 475 year event. Also here, these results are important for decision makers (such as the government which wants, for example, to provide some subsidies for structural mitigation efforts in the private sectors) as loss of life can drastically be reduced if focus is on pre-code structures. However, this could also be achieved, in principle, if in the future better building codes are implemented.



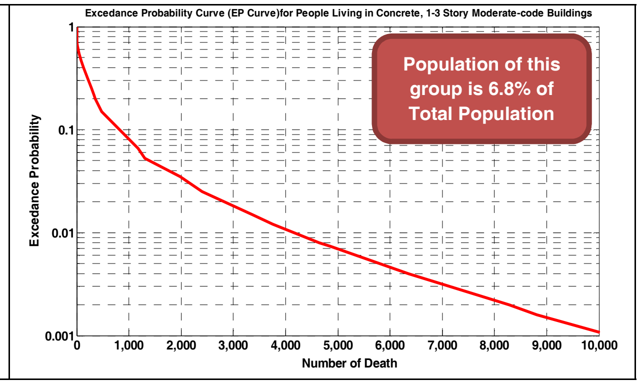


Figure 8. Human casualty EP curves for steel, high code and 4 to 7 story buildings

Figure 9. Human casualty EP curves for concrete, moderate code and 1 to 3 story buildings.

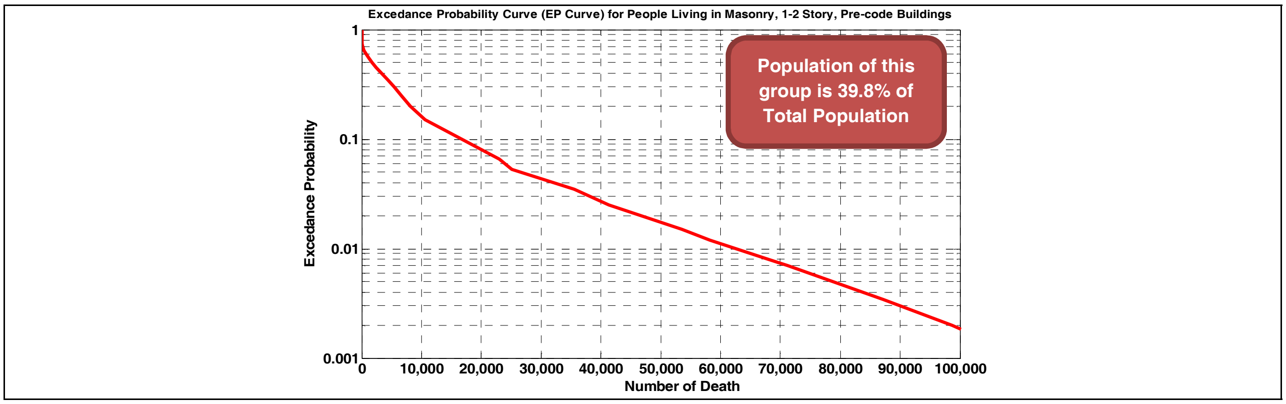


Figure 10. Human casualty EP curves for masonry, pre code and 1 to 2 story buildings.

Regarding the various types of buildings in district one, results could be seen as a representative sample of other districts in Shiraz city. Moreover, performance of "Shiraz Organization for Engineering Order of Building" is one of the most effective in Iran, so the current study may overestimate losses if applied in other cities in Iran.

Conclusion

Based on a catastrophe modeling approach, earthquake risk has been estimated for Shiraz's city district one. The implemented methodology addressed structural losses to residential, governmental and commercial buildings as well as human losses for residential buildings and provides Exceedance probability curves in the necessary detail for all possible risk bearers. Due to the large number of EP curves, the results are presented only for some groups with the largest floor area within steel, concrete and masonry structures.

Summarizing, our results show that pre code masonry structures in all residential, governmental and commercial buildings with 1 to 2 story, are the most populated ones and also have the largest share of buildings in district one, which therefore should be the focus to perform effective mitigation measures such as rehabilitations or to provide affordable insurance systems to reduce and spread economic losses among property owners.

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