FRAMEWORK FOR ASSESSING SEISMIC RESILIENCE OF CITIES

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Abstract

This paper focuses on a framework for the seismic resilience of cities which incorporates the quantification of the seismic losses and developing models for assessing such losses(economic and human losses). By convolution of seismic hazard curve and fragility curve, a seismic loss curve has been obtained. Also the recovery paths have been chosen for the cities situated in south Asian countries by considering the pre-defined recovery curve.A general concept of resilience in cities has been presented by combining the losses and recovery in a in a single graph showing the resilience for the required city.

Keywords: Resilience, Seismic, Hazards, Risks, Fragility, Losses, Recovery, Functionality.

I. Introduction

Disasters impact a community in different ways such as its economy has been effected by the structural losses of different buildings, similarly the downtime in businesses also imparts a vital role in such losses. Besides these, human losses are much important to keep in focus. Natural and man-made disasters produce different stressful conditions in a community, with these situations a community needs to be

prepared and less vulnerable in order to gain high resilience [II]. Resilience can be checked by comparing the performance of code complaint and non-code complaint structures for seismic events [IX].

Different authors have defined resilience in terms of technical, organizational, social and economic features[III]. Many researchers have made many attempts to define and explain the concept of resilience, but its definition is ambiguous while taking into account the terms like risk reduction and management of disasters [V]. Also, it is the fundamental ability of the system, community or society predisposed to a shock or stress to adapt and survive by changing its non-essential attributes and rebuilding itself[V].

II. Hazard Curve

The specific ground motion which belongs to an earthquake and can be calculated as an annual rate of exceedance of different ground motion levels is called as seismic hazard [IV].

For obtaining seismic hazard curve, the comprehensive procedure depicted in Fig. 1 must be followed. Based on the parameters like size of the earthquake, recurrence rate and the location, the PSHA must be carried out by including all the uncertainties in these parameters[VII].

The model presented in Equation 1 is used for the conversion of the annual rate of exceedance to probability of exceedance for specific time of exposure and considering the earthquake as a Poisson process. In Equation 1, t is the exposure time and N is an event. Fig. 2shows the seismic hazard curve.

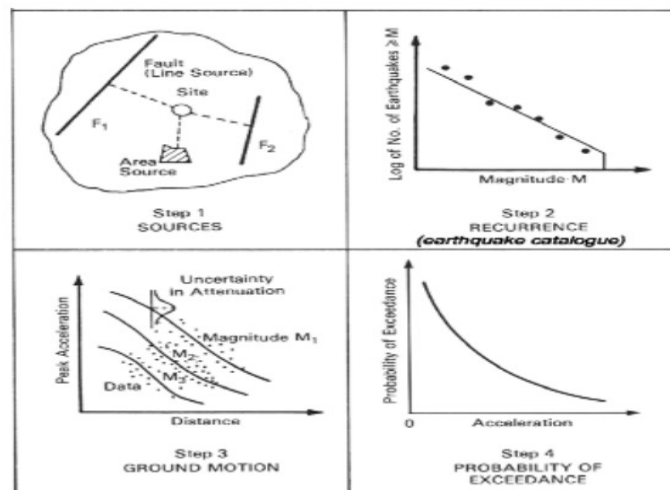$$P[N \geq 1] = 1 - \exp(-ARE \times t) \tag{1}$$
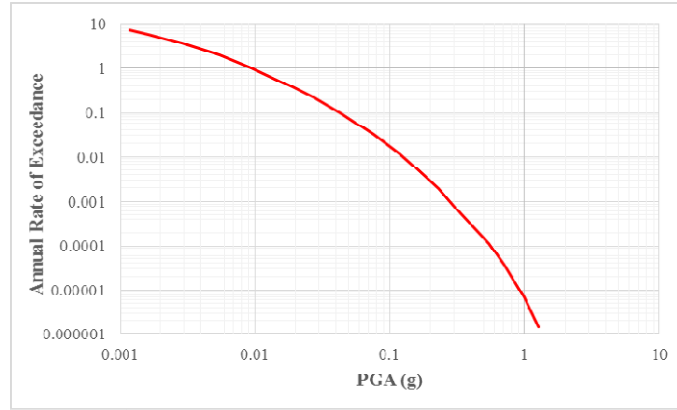

Fig.1: Steps for performing PSHA [VII]

Fig.2: Seismic Hazard Curve

III. Fragility Curve

The generation of the FCs has based on the method developed by Wen, Ellingwood, & Bracci[IX].Equation 2 has been used for thegeneration of the fragility curves for different building types.

$$P(LS_i|GMI) = 1 - \phi\left(\frac{\lambda_{CL}^i - \lambda_{(D|GMI)}}{\beta_D^2 + \beta_{LS}^2 + \beta_{CC}^2 + \beta_M^2}\right) \tag{2}$$

In Equation 2, $P(LS_i|GMI)$=probability of exceedance for a limit state at given intensity, $\phi[.]$ = standard normal cumulative distribution function, λ_{CL}^i= natural logarithm of threshold limit state, β_{LS}^2 = uncertainty in the values of limit state, β_{cc}^2 = uncertainty in the capacity curve of buildings, β_M^2 = uncertainty in the building modeling, and β_D^2 = uncertainties in the demand of earthquake.

The uncertainties should be taken as 30 % based on the variation in material properties investigated. The same uncertain values were used in the development of FCs for different types of masonry buildings by Thomas Michael Frankie[VIII].

The other parameters are given by equation 3 and 4. And the values of constants a_1, a_2 in Equation 3 are estimated by linear regression.

$$\lambda_{D|GMI} = \ln a_1 + a_2 \ln(GMI) \tag{3}$$

$$\beta_D = \sqrt{\sum_{k=1}^{n}\left[\ln(GMI_{kD}) - \lambda_{D|GMI}(GMI_k)\right]^2 * 1/n - 2} \tag{4}$$
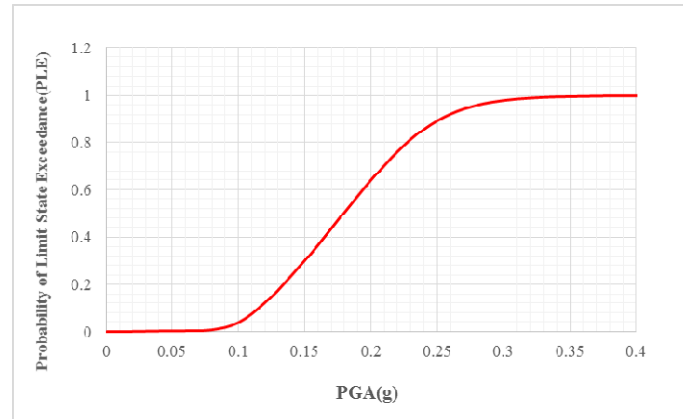
Fig.3: Seismic Fragility Curve

IV. Seismic Losses

Seismic hazard curve is convoluted with the fragility or vulnerability functions of the building to get the seismic risk/loss. Equation 5 represents the seismic loss model for the required region.

$$Seismic\ Risk/Loss\ =\ Seismic\ Hazard\ x\ (Vulnerability\ or\ Fragility) \qquad (5)$$

Equation 5 can be used for obtaining the seismic loss by continuous functions multiplication. The annual rate of exceedance of different ground motion levels is plotted with the related fragility of the specific structural system for a given time of exposure is called damage exceedance curve or limit state exceedancecurve [IV]. Fig. 4 shows the limit state exceedance curve for a single class of structural system for a given exposure time.
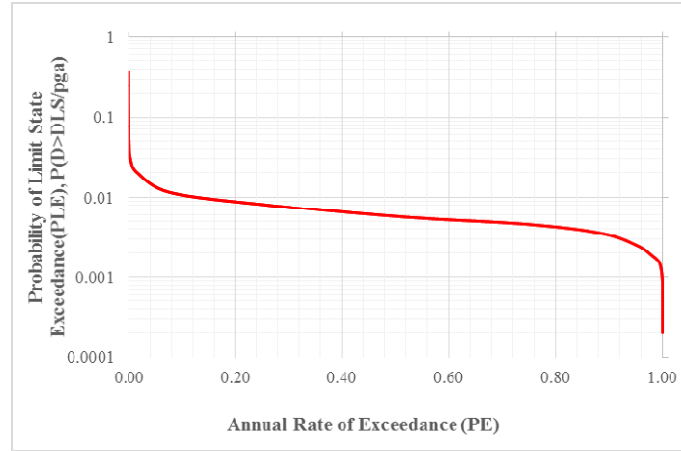
Fig.4: Seismic Loss Curve

V. Economic Losses

Seismic loss includes the economic loss as one of the two prime parameters which may be specific or total economic loss. The economic loss is estimated by the summing the multiplications of seismic risk/loss with the specific and separate cost of each limit state. Ratio between the costs of repair to the replacement is called specific cost for specified limit state, which includes the cost of demolition. Equation 6 and Equation 7 are used for estimating specific and total economic losses respectively [IV].

$$\text{SEL}_i = \sum_{j=1}^{m} Seismic\ Hazard \times Vulnerability_{ij} \times Exposure_i \times Specific\ Cost_{ij} \quad (6)$$

$$\text{TEL}_i = \sum_{j=1}^{m}\sum_{i=1}^{n} Seismic\ Hazard \times Vulnerability_{ij} \times Exposure_i \times Specific\ Cost_{ij} \quad (7)$$

VI. Human Losses

Seismic loss is convoluted with the exposure of people and the loss ratio to obtain human losses for each limit state. Loss ratio is the ratio between the injured plus dead people and total people present in the building. Equation 8 and Equation 9 are used for estimating the specific and total human loss respectively [IV].

$$Specific\ Human\ Loss\text{i} = \sum_{j=1}^{m} Seismic\ Hazard \times Vulnerability_{ij} \times Exposure_i \times Loss\ Ratio\text{ij} \quad (8)$$

$$\text{Total Human Lossi} = \sum_{j=1}^{m}\sum_{i=1}^{n} Seismic\ Hazard\ \times Vulnerability_{ij} \times$$
$$Exposure_i \times Loss\ Ratio_{ij} \quad (9)$$

It is considered that total human losses are important for making policies and plans for rescue operations. Specific human losses are essential for sharing the social and economic impacts of seismic risk/loss to the community openly, while telling them the losses produced by different building classes.

VII. Recovery

For recovery model for any city in south Asia, a trigonometric recovery function is used which was based in the conceptual model represented byChang &Shinozuka [VI]. When the community is not well prepared for such seismic events or there are less resources then trigonometric recovery function is best suitable function for that community. At the initial stage of recovery (just after the event) the rapidity of the recovery doesn't increase very fast, this is because of the response of the society which totally depends in the organization and resources. But with the passage of time the rapidity increases as different communities help the affected one, so it organizes itself and starts recovering rapidly.

$$f_{rec}(t) = 0.5 * \left\{ 1 + \cos\left[\frac{\pi(t - t_{0E})}{T_{RE}} \right] \right\}; \quad (10)$$

In Equation 10, t_{0E} is the timeframe in which the building has to recover its functionality while t is the time at the moment. Total recovery time can be set by the government or policy makers which is based on the resources of that community. The values of T_{RE}should be adopted from HAZUS®-MH 2.1Technical Manual[I].

VIII. Resilience

The evaluation of resilience is based on the Multidisciplinary Center for Earthquake Engineering Research (MCEER)approach as shown in Fig. 5. In this approach, the quantification of resilience is done by estimating different parameters. Step-by-step procedure is given below to clarify the methodology. Fig. 6 is depicting the trigonometric recovery curves based on Equation (10).
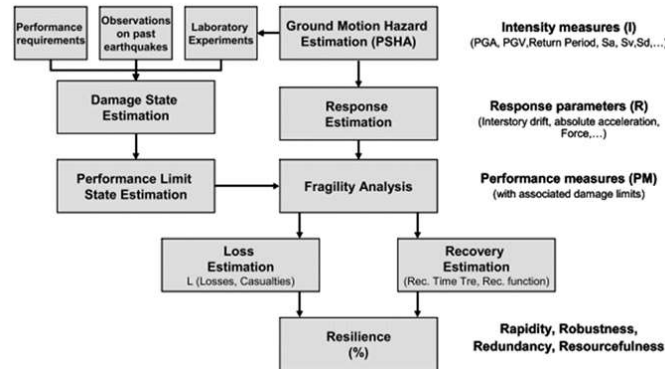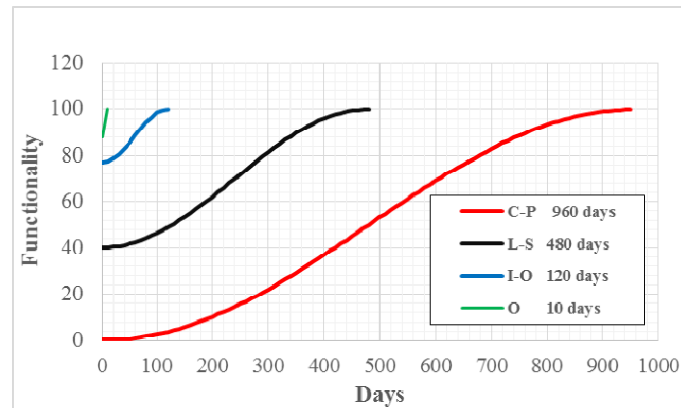
Fig.5: MCEER Approach for Resilience

Fig.6: Recovery Curve for a Building

IX. Conclusions

The resilience of a city is a vast term that includes the information of many fields like technical and organizational. It also imparts the specialized technical fields like seismology, earthquake engineering with the amalgamation of economic and social science. Since the definition of the resilience contains many assumptions and uncertainties. But the aim of this research is to provide a framework for finding a resilience which is related to a city that has been subjected to a seismic events. This also presents the generalized form of resilience in terms of seismic losses that have been estimated from different procedures as mentioned in paper and also the recovery curves which defines the time as well as the path of recovery of a city which was affected by an earthquake. The importance of the finding the resilience is to predetermine the preparedness of a community or a city for events that will have to occur in the future. This paper provides the guideline for a decision maker for planning the emergency response for a city according to the economic and human losses. To ensure the rescue for the injured people.

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