Seismic Reliability of Structures Based on Fragility Analysis: A Review

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Abstract. Seismic fragility is another form of reliability that expresses the exceeding probability of a specific damage limitation for any particular type of structure under seismic excitation. To estimate the seismic hazard of any structure, when the demand exceeds the capacity of the structure is calculated from the probabilistic method, i.e., Fragility analysis (FA). This review article discussed different methods which can be used for the assessment of fragility analysis. Finally, the authors offer the recommendations for using the best methods that can save the computational time and estimate the exceedance probability of the damage limit state (DLS) compared to the other simulated-based approaches. These approaches are applicable for all types of structures, i.e., RC buildings, bridges, and other structures.

Keywords: Fragility analysis · Seismic hazard · Fragility assessment methods · Fragility curves

1 Introduction

During the past few decades, it has been observed that a substantial number of building structures existing in seismically active zones undergo extensive damage, which is quite disturbing for the long-term structural performance. Reinforced concrete Frame-shear wall buildings are extensively used because of their good seismic resistance. In the present study such buildings have been focused at. Vulnerability assessment of such buildings in their inelastic range due to high seismicity can be suitably performed through nonlinear dynamic analysis, which necessitates detailed nonlinear modeling of the shear wall building. Fragility analysis (FA) is an essential tool used for damage assessment of buildings (Kappos et al. 2006; Gogus and Wallace 2015; Nazari and Saatcioglu 2017). Design codes focus on the site conditions and design practices adopted for designing buildings. Design codes are prescriptive in nature (ATC 2012; FEMA 2010). Several available literature have primarily focused on collapse damage states of the structures to reduce seismic risk of the building during earthquakes (FEMA P-695 2010; Galanis and Moehle 2015; Attar and Liel 2016). Many researchers conducted a dynamic analysis of buildings using different model types (Ji et al. 2007; Ji et al. 2009; Zhai et al. 2019). Fardis and Krawinkler (2010) worked on assessing the structural performance in the natural disaster for both old and new shear wall buildings designed as per EC-8 and derived to see

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the performance of the structures through fragility curves. Another study had been done by Pejovic and Jankovic (2015) using Perform 3D software to find the vulnerability of tall Reinforced concrete (RC) structures with core wall structural systems. Other recent works have focused on mid-rise frame-shear wall buildings conforming EC-8 for medium to high-class ductility (Antoniou et al. 2015) Kappos et al. (2006) used the hybrid approach, which combines an experimental and analytical approach. Many researchers are striving towards damage assessment of the structures such that there is no unexpected failure of the buildings during an earthquake. Investigation can be done by conducting seismic fragility analysis of the buildings to get expected damage of the existing structures (Gogus and Wallace 2015; Nazari and Saatcioglu 2017; Kolozvari et al. 2017). Several available literature primarily focused on collapse damage states (Park and Ang 1985; Galanis and Moehle 2015, Elkady and Lignos 2014, Sattar and Liel 2016) to reduce seismic risk building during an earthquake. Initially, the seismic fragility analysis has been developed for the nuclear plant by Kennedy and Ravindra (1984), where the fragility curve of various dangerous equipment has been plotted. Hwang improved this method in 1990, and it stretched its effect over the evaluation of normal buildings. Many researchers conducted the dynamic analysis with different levels of buildings using different model types (Ji et al. 2007; Ji et al. 2009; Zareian and Krawinkler, 2010; Nazari and Saatcioglu 2017). For obtaining the fragility curves several time history analyses have to be performed under specified set of ground motions (GM). Limited research work had been conducted so far, considering the requirement for probabilistic risk evaluation. In this regard, fragility analysis is used to estimate the disproportionate collapse of any structures. Several methods are available for FA. The most often used methods are: (i) the Incremental dynamic analysis (IDA) method, (ii) Multiple Stripes Analysis (MSA)**,** (iii) Maximum likelihood estimation (MLE), and, (iv) Approximate Approach (AA). In earthquake engineering, the IDA method is a well-established approach. This clearly accounts for the demand and capacity uncertainties of the structures and provides the failure probability of a given intensity measure (IM). In this method, a set of GM is continuously scaled to get the level of the IM where the GM induces collapse (FEMA 2010; Vamvatsikos and Cornell 2002). In MSA, a set of IMs are to be chosen for the execution of the analysis. In the case of MLE, parameters having maximum probabilistic influence are used. AA is becoming popular nowadays. Limited works have been reported using AA (Korkmaz 2008; Réveillère et al. 2012; Borele and Datta 2015; Sil et al. 2019). The FA is less time taking yet gives satisfactory results. In this paper, different existing methods of fragility analysis have been reviewed for Reinforced concrete (RC) buildings. The suggestion has been given for best approach.

2 Classification of Fragility Analysis

The fragility assessment of structures can be done by applying many approaches which is used to find the vulnerability of the structures. Classifications of fragility analysis for structures are shown in Table 1.

Table 1. Classification of fragility analysis with their works and findings.

Methods	Authors	Work	Key findings
Incremental dynamic analysis	He and Lu 2019	Considered 3 finite element models. Compare different IMs (PGA, PGV and Sa)	• PGV is more suitable for high rise buildings and found that it has high efficiency • Compare to the other IMs, PGV gives more accurate results
	Xu et al. 2018	Consider Steel Reinforced Concrete (SRC) frame structure. The term EDPs were introduced which includes damage indices based on materials and components, maximum inter-storey drift ratios	• The damage index which is component-based proven to be more reliable and cost-effective
	Gogus and Wallace 2015	Total number of 40 (special and ordinary) archetypes RC walls buildings with different physical parameters and design conditions were considered	• It concluded that the model has to be improved so that it can capture failure of the building more accurately
	Nazari and Saatcioglu 2017	RC shear wall buildings have been designed using 1965 and 2010 national code of Canada for performance level IO, LS and CP. Spectral acceleration (Sa) was considered as an IM and from the first-floor inter-storey drift was chosen as damage limit index	• The result of fragility curves specify that LS PL has been met the designs criteria whereas the remaining PL of the building could not satisfied for building design code 1965

(*continued*)

Table 1. (*continued*)

Methods	Authors	Work	Key findings
	Sattar et al. 2016	Masonry-infilled RC buildings have been considered. Parameters considered are bare wall, partially and in filled wall frames and wall thickness	• In infill walls can raise the collapse risk • Strong, heavy infill walls are the most collapse prone of the buildings • The partially infilled frames perform poorly
	Galanis and Moehle 2015	This study scrutinizes the collapse safety of non-ductile and older reinforced concrete building frames (constructed before 1980s)	• The results indicate that column flexural of the building to shear strength ratio of the building and also column-to-beam ratio can be used to measure the collapse risk of older-type buildings
	Panpan et al. 2019	3 double-parameter damage models (DPDMs) i.e. Niu, Park-Ang and Lu-Wang models were considered. Parameters considered are maximum interstory drift ratio (MIDR) and soil-structure interaction (SSI)	• SSI induces a maximum fragility • DPDMs provide more reasonable results compare to those calculated damage index (MIDR)
	Kolozvari et al. 2017	5-story RC building has been designed under 3 seismic hazard levels and also the influence of the uncoupled versus coupled modeling method for walls	• This study suggested that the influence of using uncoupled versus coupled modeling methods for walls is important for IDR estimations mainly at the 1st level of the building, minor at the top levels, and moderate for maximum floor

(*continued*)

Table 1. (*continued*)

Methods	Authors	Work	Key findings
	Ji et al. 2007	A whole procedure on RC tall buildings is presented on seismic fragility assessment	• The whole method is standard and can be applied to all the RC tall buildings • It is computationally effective
	Sil et al. 2019	Direct Displacement Based Design (DDBD) and Force Based Design (FBD) were used to design the frames and comparison has been done. Parameters considered are IDR, ductility demand displacement, and material strain	• To achieved the performance of desired level, DDBD method is more cost-effective
	Borele and Datta 2015	Two building models with infilled and bare frame are considered for the generating the fragility curve	• Compare the fragility curve generated from the models with seismic performance of the building models • Results meet the expectations and suggested that, the actual damage distribution can be obtained from simplified fragility analysis
	Vamvatsikos and Cornell 2002	Steel frame with fractured connections (9-storey) has been considered in order to clarify the used the IDA to Performance Based Earthquake Engineering (PBEE)	• It summarize that it can be easily integrated with modern PBEE frameworks
	Porter et al. 2007	Introduced a set of procedures for generating fragility functions in order to improve an existing fragility function using new observations	• In this study six methods for creating fragility functions has been presented and no failure has been observed

(*continued*)

Table 1. (*continued*)

Methods	Authors	Work	Key findings
Maximum likelihood analysis	Dang et al. 2017	3 methods (MLE, scaled seismic intensity, and demand and capacity of probabilistic seismic models) have been compared and studied	• The outcome of the results shows that MLE method is better than remaining methods
	Shinozuka et al. 2000	This paper presents both empirical and analytical fragility curves	• To test the best fit the fragility curves is generated using Statistical procedures
	Zentner 2008	Discuss statistical estimation of the parameters of fragility curves. PGA is considered in order to characterize ground motion level	• This approach is very efficient and versatile
	Le et al. 2014	This paper investigates underground tunnel structure. Considered soil-structure interaction (SSI) effect	• It is concluded that there is a needs of further study on numerous forms of structures
	Le et al. 2015	For underground tunnel structures is considered to find the seismic fragility assessment. Parameters considered are median and log-standard deviation	• It concluded that using the maximum likelihood works well in estimating underground tunnel structures
	Garcia et al. 2014	9 storey SAC building (Elasto-plastic material model) to compare numerical and analytical results	• Obtained that the capacity curves and seismic demand curve is useful for vulnerability calculation of structures

(*continued*)

Table 1. (*continued*)

Methods	Authors	Work	Key findings
Multiple stripe analysis	Lin et al. 2013	20-story RC frame building has been considered 1. Various levels of maximum IDR have been taken into account 2. More EDPs (maximum fragility analysis corresponding to the building heights, a single-story optimum story DR and a finite analysis (FA)) were also considered	• For each case, the risk-based assessment results were found to be similar
	Scozzese et al. 2020	In this study, 3-story steel moment-resisting frame has been taken into account, by considering many engineering demand and different setup of parameters and choices	• The approach used is somewhat accurate and computationally effective
	Ni et al. 2012	Examine the behavior of structures which is subjected to earthquake excitation	• The seismicity risk of the structures can be assessed based on the numerically integrating fragility function that has been numerically integrated with the hazard curve

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Table 1. (*continued*)

Methods	Authors	Work	Key findings
	Jalayer and Cornell 2008	An older RC frame structure has been taken into consideration, which is suffered from shear failure (column) is calculated. Two (single and double stripe method) kinds of dynamic analysis (non-linear) approaches are presented	• Single-stripe approach is enhanced by performance of stripe analysis for additional Sa level • Double stripe approach requirements are double the amount of analyses
	Baker 2005	Comparatively study on the effectiveness of fragilities obtained from IDA and MSA	• MSA is seems to be more effective than IDA
Approximate approach	Sil and Longmailai 2017	Four storey RC buildings have been considered. Variation in roof displacement (beam and column dimension, concrete grade, height of the floor and total weight) was observed	• A comparison has been made between the displacements acquired from analysis with the equation formed • It concluded that the proposed approach could be used to find the maximum lateral displacement and can be computed data is used to find the failure probability and reliability
	Korkmaz 2008	Structural seismic behavior of R/C frame structure is evaluated. Monte Carlo simulations and analytical approximation are compared	• In comparison of these methods, the methods give close results with each other in the analysis of symmetric structures. Analytical approximation fragility analysis is counted more reliable

(*continued*)

Table 1. (*continued*)

Methods	Authors	Work	Key findings
	Reveillere et al. 2012	Proposes an alternative approach to find the fragility analysis for finding the vulnerability of structures exposed to potential aftershocks	• This method has been used to singly RC frame buildings and fragility curves obtained show that vulnerability of structures that have been formerly damaged
	Borele and Datta 2015	RC building with infilled and bare frame is considered	• It concluded that the rise in strength and stiffness is important in buildings when the infill walls are added and compared with the values of the bare frame • Probability of damage is more in 4 storey building (compared to two storeys)
	Cui et al. 2018	A girder bridge with Box shape has been considered. Parameters used are ground motion; corrosion parameters bridge geometry and material properties	• It's concluded that effect of corrosion cannot be overlooked while executing the seismic FA

3 Limitations of the Available Methods

Researchers have developed many methods to define the failure probability of a structure for a given IM of structures, both numerically and experimentally in the last few decades. Approaches are being developed to improve accuracy. Table 1 shows the benefits and drawbacks of the various approaches for determining a structure's vulnerability. However, structural damage can occurs in the structure due to some of the loads like seismic load, wind load, any accidental load, etc. There are some of the important parameters like IDR, joint rotation, stiffness degradation etc. which plays an important role to measure the reliability of structure. Many works have been done so far by many researchers considering those parameters to find the vulnerability of the buildings by using several approaches. However, in Table 1 several methods of fragility assessment have been discussed, and the most preferable method has been suggested so that it takes lesser time to found out the vulnerability of the structures.

4 Analysis Based on Fragility

Seismic fragility is another form of reliability that expresses the exceedance probability of a damage limit state (DLS) for a structure under seismic excitation. Fragility may be defined as the probability of exceedance of the demand acting on the structure over the structure's capacity for a specified intensity measure (IM). Kennedy and Ravindra (1984) have introduced analysis on Seismic fragility to measure the safety and risk assessment of mechanical assemblies and components of structures in nuclear power plants. The output of the investigation showed the risk of seismic exposure fragility, which is in the form of curve and represents the exceedance of probability of the performance level of structure. The Input-output relationship for fragility analysis and the fragility curve has been shown by Korkmaz, 2004. The seismic damage limit is used in fragility analysis to represent the performance levels of the structures. Thus, every fragility curve denotes the exceeding probability of damage limits when earthquake intensity increases. Fragility is nothing but the exceedance probability of the DLS of a structure that has been exposed to seismic excitation. Though, the fragility curve is a numerical statistical measure that reflects the exceedance probability of DLS at a specific IM. Here, ground motion is indicated as an IM, and it could be in terms of pseudo-spectral acceleration (PSA), peak ground acceleration (PGA), Spectral Displacement (SD), spectral acceleration (SA), spectral velocity (SV). Though, from all the IMs, the most common IM is PGA (Kennedy and Ravindra 1984; Hwang and Huo 1994; Hwang and Jaw 1990; Shinozuka et al. 2000).

5 Methods for Seismic Fragility Analysis (FA)

There are numerous ways to calculate the values of the parameters used in determining for a fragility function with observed data. It fully depends on the procedure used to get the data from the structural analysis.

The cumulative lognormal distribution function generally defines fragility function:

$$P(C \backslash IM = x) = \Phi\left(\frac{\ln\left(\frac{x}{\theta}\right)}{\beta}\right) \tag{1}$$

where the probability of the structure is designated by $P(C\backslash IM = x)$ Where the GM intensity measure ($IM = x$) will cause collapse; Φ *()* is the function of cumulative distribution (CDF); Median of *ln IM* is designated by θ*, and* standard deviation of *ln* is designated by β. The above Eq. (1) indicates the value of IM of ground motion will cause structure collapse are lognormal distributed. This assumption has been long-established by many researchers (Eads et al. 2013; Porter et al. 2007; Ibarra and Krawinkler 2005; Ghafory-Ashtiany et al. 2011; Bradley and Dhakal 2008). The response of the structures under various ground motions is determined through probabilistic Seismic Demand Analysis (PSDA).

5.1 Incremental Dynamic Analysis (IDA)

In earthquake engineering, the IDA method is a well-established approach. This accounts for the demand and capacity uncertainties of the structures and provides the failure probability of a given intensity measure (IM). In this method, a set of GMs is continuously scaled to get the level of the IM where the ground motion induces collapse (FEMA 2010; Vamvatsikos and Cornell 2002). Here, ground motions are in the form of IM and have to be increased incrementally in every analysis. The extreme values are plotted against the IM values for every intensity level. In this analysis, a group of IM values produces which is linked with the beginning of collapse for every ground motion shown by Baker and Eeri (2005.a). The collapse probability of the structure can be evaluated at which level Collapse happens. Visualization of this probability has been shown by Baker and Eeri (2005.b) and its denoted as observed CDF and Parameters of the fragility functions can be calculated from the same data by considering logarithms of every ground motion which is connected with the beginning of collapse at IM level '*x*' and computed standard deviation as well as mean values (Ibarra and Krawinkler 2005). Equation 1 has to be calibrated for a specified structure which requires assessing of θ and β based on structural analysis findings. Those parameters have been terms as $\hat{\theta}$ and $\hat{\beta}$.

$$ln\hat{\theta} = \frac{1}{n}\sum_{i=1}^{n} \ln IM_i \tag{2}$$

$$\hat{\beta} = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n} ln\left(IM_i/\hat{\theta}\right))^2} \tag{3}$$

where a number of considered ground motions is designated by n and IM_i is the IM value at ith ground motion. Here, the mean of the normal distribution signifying the values of *ln IM* is designated by *ln* θ*, and* the standard deviation of the normal distribution signifying the values of *ln IM* is designated by *ln* β.

5.2 Maximum Likelihood Method (MLM)

In this method, find the parameters in such a way that the distribution of the result has the maximum likelihood from the observed data. In this method, '*m*' is the number of observed ground motions to bring collapse, where the values of IM at collapse level

(IMi) are known. In this method, a random ground motion can cause collapse at *IMi*, specified a fragility function in Eq. (1).

$$\text{MLM} = \Phi\left(\frac{ln\left(\frac{IM_i}{\theta}\right)}{\beta}\right) \quad (4)$$

where, standard normal distribution is denoted by Φ, here the specified ground motion is scaled to IM_{max} without causing the building to collapse where the probability of IM_i is more than IM_{max} (Klugman et al. 2012).

$$\text{MLM} = 1 - \Phi\left(\frac{\ln(IM_i/\theta}{\beta}\right) \quad (5)$$

assume, IM_i value for every ground motion data is not reliant on whole observed data of the likelihood method.

$$\text{MLM} = \left[\prod_{i=1}^{m} \emptyset(\frac{\ln(IM_i/\theta}{\beta})\right]\left[1 - \Phi\left(\frac{\ln(IM_{max}/\theta}{\beta}\right)^{n-m}\right] \quad (6)$$

here, Π signifies that 'i' is the product value which starts from 1 to m. Where, *'m'* denotes the ground motion values of collapse at IMs inferior to IM_{max}. Using this expression, the parameters of fragility functions are determined by changing the parameters until the function reaches the maximum. It can be maximized by using the logarithm of the likelihood function:

$$\left\{\hat{\theta}, \hat{\beta}\right\} = \underset{\theta, \beta}{argmax} \sum_{j-1}^{m}\left[ln\phi\left(\frac{\ln(IM_i/\theta}{\beta}\right)\right] + [n-m]ln\left[1 - \Phi\left(\frac{\ln(IM_{max}/\theta}{\beta}\right)\right] \quad (7)$$

The Observed collapse as a function of IM and a fragility function calculated using Eq. 7 can be seen the figure (Baker and Eeri 2005.a).

5.3 Multiple Stripes Analysis (MSA)

This method is a special case of IDA. Here, only one IM level is chosen, and the data of EDP has been obtained. This method is also known as a unique method because more than one hazard level can be chosen. In this method, it is not necessary to perform nonlinear analysis till all the IM amplitudes get the collapse, and Picturing of a number of collapses causing plotted at IDR of 0.08 (Example MSA results) and Collapse observed in terms of IM and an estimated fragility function by implementing Eq. (11) is shown by (Baker and Cornell 2005.a). Pictorial is shown by (Baker and Cornell 2005.b). Here, the IM level changes of every ground motion target properties (Lin et al. 2013; Iervolino et al. 2010; Bradley 2010). Several ground motions have been used in every IM level, and because of the several data used in the analysis may not show the increasing fraction of collapse with the increase IM, but in spite, it is assumed that failure probability will increase with IM. On the other hand, the results of the structural analysis show the ground motions percentage that causes collapse at every IM level. Assuming that, from every ground motion's data, the observation of failure or no failure is independent of various ground motions, the binomial distribution describes how the probability of observed collapses *zj* out of GM *nj* with $IM = xj$.

$$\text{P}(z_j \text{ collapses in } n_j \text{ ground motions}) = \binom{n_j}{z_j} P_j^{zj}(1 - p_j)nj - zj \tag{8}$$

where probability is designated by p_j when the ground movement $IM = x_j$ will cause collapse, fragility function can be found by the maximum probability, which gives the maximum probability of observing collapse data found from the structural investigation. The investigation data are found from various IM levels; at every level of IM, the binomial probabilities product is used to find the probability for the whole data set.

$$\text{Probability} = \prod_{j=1}^{m} \binom{n_j}{z_j} p_j^{zj}\left(1 - p_j^{nj-zj}\right) \tag{9}$$

where the number of IM levels is denoted by m and whole product levels are denoted by Π. Therefore, substitute the Eq. 1 in place of p_j, so that the parameters of fragility are clear in the probability function.

$$\text{Probability} = \prod_{j=1}^{m} \binom{n_j}{z_j} \Phi\left(\frac{\ln(xj/\theta)^{zj}}{\beta}\right)\left[1 - \Phi\left(\frac{\ln(x_j/\theta}{\beta}\right)\right]\text{nj} - \text{zj} \tag{10}$$

The probability function is maximized to estimates and gets the fragility function parameters. It is statistically and equivalently easier to increase the logarithm probability function.

$$\left\{\hat{\theta}, \hat{\beta}\right\} = \underset{\theta, \beta}{argmax} \sum_{j-1}^{m} \left\{ ln\binom{n_i}{z_i} + z_j ln\Phi\left(\frac{\ln(x_i/\theta}{\beta}\right) + [nj - zj]ln\left[1 - \Phi\left(\frac{\ln(x_j/\theta}{\beta}\right)\right]\right\} \tag{11}$$

5.4 Approximate Approach

Firstly, numbers of finite element models (FEM) of any structures have been generated. The generated buildings are then matched with the selected ground motions that have been considered and then carried out by nonlinear dynamic analyses to find the structural response corresponding to each building model. Fragility may be defined as the probability of the demand acting on the structure exceeding the structure's capacity for a specified intensity measure (IM).

Therefore, the expression of seismic fragility is

$$\text{Fragility (F)} = \Pr[D \geq C/IM] = \Pr[C - D \leq 0.0/IM] \tag{12}$$

here, seismic demand is designated by *D,* and capacity is designated by *C*; IM is the ground motion IM. Considering the time-variant effect on the seismic fragility of the RC buildings, by Eq. (13) (Sudret and Mai 2013).

$$\text{F} = \Pr[\text{D(Demand)}(t) \geq C(Capacity)(t)/IM = Pr[C(t) - D(t) \leq 0.0/IM] \tag{13}$$

assuming that the demand and capacity of the structure follow a lognormal distribution, Eq. (13) takes the form Eq. (14).

$$\Pr[\text{D (Demand)}(t) \geq \frac{C(capacity)(t)}{IM} = \Phi\left[\frac{\ln\left(\frac{N_d(t)}{N_c(t)}\right)}{\sqrt{\beta^2_{D\backslash IM}(t) + \beta^2_C(t)}}\right] \tag{14}$$

where, $N_d(t)$ is the estimated median of the demand acting on the structure at the time, t; $N_c(t)$ is the estimated median of the capacity of the structure at the time, t. $\beta^2_{D\backslash IM}(t)$ and $\beta^2_{C\backslash IM}(t)$ are the dispersion of demand and capacity of the structure at time, t.

The PGA levels have to be chosen based on the structure's vulnerability in various seismic zones across the globe. Further, PSDM at different PGA levels and storey heights have been generated based on Eq. (15).

The equation of the probabilistic seismic demand model (PSDM) is expressed in Eq. (15).

$$\ln(N_d(t) = y(t) + z(t)\ln(IM) \tag{15}$$

here, $y(t)$ and $z(t)$ are the parameters of regression estimated during the time, t, and it can be found by conducting regressing analysis considering the building's demands at various times.

6 Ground Motion Intensity Measure (IM)

It is the utmost important index to define the characteristics of the earthquake from the perspective of structural engineering. By considering the formulation of fragility analysis, it is well understood that the IM is the function of the seismic fragility curve. Therefore, the use of more appropriate IM gives more precise and accurate results in the fragility curve. To get the characteristic of maximum IM, sums of GM records have to be considered for scaling and also for the purpose of nonlinear analysis, which influences both the accuracy of the results as well as computational time. In this case, a minimum of 3 ground motion records is required according to ASCE/SEI 7-10 (2010). Reyes and Kalkan (2012) have reported that the ground motion records should not be less than 7 so that it can be able to reach to the optimum accuracy.

7 Summary

Seismic fragility is another form of reliability that expresses the exceedance probability of DLS for any given type of structure under seismic excitation. Fragility may be defined as the probability that the demand acting on the structure exceeds the structure's capacity for a specified IM. In seismic fragility analysis, the PGA (g) has been considered as an IM, and all the ground motion considered has been scaled to the expected level. The incorporation of scaled records captures the worst scenario of the structural degradation that could be identified. This paper presents a review on seismic fragility analysis. A wide range of research on seismic reliability and risk has bought an important advancement for recovery, mitigation, preparedness, and a response against the Seismic risk. Several methods of fragility assessment have been discussed, and the most preferable method has been suggested so that it takes lesser time to found out the vulnerability of the structures. From the literature survey, it has been found that implementing an approximate approach over the other available approaches of seismic fragility analysis is efficient in accurately estimating the exceedance probability of the damage limit states without tedious computational requirements.

8 Conclusion

In this article some of the approaches that are available for finding out the vulnerability of the structure along with their mathematical expressions have been discussed. Benefits and drawbacks of these approaches have been discussed and also the possibilities of further study are explored. Investigation on seismic vulnerability is an active field of research. The fragility curves can be used in mitigation planning and risk assessment for a long-term strategy of the community to decrease seismic losses and damages. In this paper, the available methods of conducting fragility analysis for risk assessment and seismic reliability structures have been reviewed. It is found that scanty work has been done to assess fragility of RC shear wall buildings using the approximate approach. The approximate approach gives good outcome at the same time saves computational time. This approach is also applicable for all types of structures, such as RC buildings, bridges, and other structures.

References

Agresti, A.: Categorical Data Analysis, Wiley, New York. Applied Technology Council, ATC-58, Seismic Performance Assessment of Buildings, 100% Draft, Redwood City, CA, vol. 266 (2012)

Antoniou, K., Tsironis, G., Fardis, M.N.: In elastic shears in ductile RC walls of mid-rise wall-frame buildings and comparison to Eurocode 8. Bull. Earthq. Eng. **13**, 841–869 (2015). https://doi.org/10.1007/s10518-014-9641-x

Applied Technology Council: ATC-58, Seismic Performance Assessment of Buildings, 100% Draft, Redwood City, CA, pp. 266 (2012)

Attar, S., Liel, A.B.: Seismic performance of nonductile reinforced concrete frames with masonry infill walls-II, collapse assessment. Earthq. Spectra **32**, 819–842 (2016)

Baker, J.W., Cornell, C.A.: Vector-valued ground motion intensity measures for probabilistic seismic demand analysis. Blume Earthq. Eng. Center **321** (2005b)

Baker, J.W., Cornell, C.A.: A vector-valued ground motion intensity measure consisting of spectral acceleration and epsilon. Earthq. Eng. Struct. Dyn. **34**, 1193–1217 (2005)

Borele, S.V., Datta, D.: Damage assessment of structural system using fragility curves. J. Civ. Eng. Environ. Technol. **2**(11), 72–76 (2015)

Bradley, B.A.: A generalized conditional intensity measure approach and holistic ground motion selection. Earthq. Eng. Struct. Dyn. **39**, 1321–1342 (2010)

Bradley, B.A., Dhakal, R.P.: Error estimation of a closed-form solution for an annual rate of structural collapse. Earthq. Eng. Struct. Dyn. **37**, 1721–1737 (2008)

Chengxiang, X., Jie, D., Sheng, P., Chengyu, L.: Seismic fragility analysis of steel reinforced concrete frame structures based on different engineering demand parameters. J. Build. Eng. **20**, 736–749 (2018)
Dang, C.T., Le, T.P., Ray, P.: A novel method based on maximum likelihood estimation for the construction of seismic fragility curves using numerical simulations. C. R. Mec. **345**(10), 678–689 (2017)
Eads, L., Miranda, E., Krawinkler, H., Lignos, D.G.: An efficient method for estimating the collapse risk of structures in seismic regions. Earthq. Eng. Struct. Dyn. **42**, 25–41 (2013)
Federal Emergency Management Agency: Quantification of Building Seismic Performance Factors (FEMA P695, ATC-63), Washington, D.C, p. 421 (2009)
FEMA P-695: Methodology for Quantification of Building Seismic Performance Factors, NEHRP Consultants Joint Venture A partnership of the Applied Technology Council and the Consortium of Universities for Research in Earthquake Engineering (2010)
Cui, F., Zhang, H., Ghosn, M., Yue, X.: Seismic fragility analysis of deteriorating RC bridge substructures subject to marine chloride-induced corrosion. Eng. Struct. **155**, 61–72 (2018)
Galanis, P.H., Moehle, J.P.: Development of collapse indicators for risk assessment of older-type reinforced concrete buildings. Earthq. Spectra **31**, 1991–2006 (2015)
Ghafory-Ashtiany, M., Mousavi, M., Azarbakht, A.: Strong ground motion record selection for the reliable prediction of the mean seismic collapse capacity of a structure group. Earthq. Eng. Struct. Dyn. **40**, 91–708 (2011)
Gogus, A., Wallace, J.W.: Seismic safety evaluation of reinforced concrete walls through FEMA P695 methodology J. Struct. Eng. **141** (2015)
Hwang, B.H.H.M., Jaw, J.: Probabilistic damage analysis of structures. J. Struct. Eng. **116**(7), 1992–2007 (1990)
Hwang, H.H., Huo, J.-R.: Generation of hazard-consistent fragility curves for seismic loss estimation studies Soil Dyn. Earthq. Eng. **13**(5), 345–354 (1994)
Iervolino, I., Giorgio, M., Galasso, C., Manfredi, G.: Conditional hazard maps for secondary intensity measures. Bull. Seismol. Soc. Am. **100**, 3312–3319 (2010)
Ji, J., Elnashai, A.S., Kuchma, D.A.: An analytical framework for seismic fragility analysis of RC high-rise buildings. Eng. Struct. **29**, 3197–3209 (2007)
Ji, J., Elnashai, A.S., Kuchma, D.A.: Seismic fragility relationships of reinforced concrete high-rise buildings. Struct. Des. Tall Spec. Build. **18**, 259–277 (2009)
Jalayer, F., Cornell, C.A.: Alternative non-linear demand estimation methods for probability-based seismic assessments. Earthq. Eng. Struct. Dyn. **38**, 951–972 (2008)
Kappos, A.J., Panagopoulos, G., Panagiotopoulos, C., Penelis, G.: A hybrid method for the vulnerability assessment of RC and URM buildings. Bull. Earthq. Eng. **4**(4), 391–413 (2006). https://doi.org/10.1007/s10518-006-9023-0
Kennedy, R.P., Ravindra, M.K.: Seismic fragilities for nuclear power plant risk studies. Nucl. Eng. Des. **79**(1), 47–68 (1984)
Klugman, S.A., Panjer, H.H., Willmot, G.E.: Loss Models: From Data to Decisions. Wiley, New York (2012)
Kolozvari, K., Terzic, V., Saldana, D.: Implications of modeling assumptions on the loss estimation for shear wall buildings. In: Proceedings of Structures Conferences, pp. 6–8 (2017)
Korkmaz, K.: Evaluation of seismic fragility analyses. In: The 14th World Conference on Earthquake Engineering (2008)
Lin, T., Haselton, C.B., Baker, J.W.: Conditional spectrum-based ground motion selection-Part I: hazard consistency for risk-based assessments. Earthq. Eng. Struct. Dyn. **42**, 1847–1865 (2013)
Shinozuka, M., Feng, M.Q., Lee, J., Naganuma, T.: Statistical analysis of fragility curves. J. Eng. Mech. **126**(12), 1224–1231 (2000)

Michel, C., Hannewald, P., Lestuzzi, P., Fäh, D., Husen, S.: Probabilistic mechanics-based loss scenarios for school buildings in Basel (Switzerland). Bull. Earthq. Eng. **15**(4), 1471–1496 (2016). https://doi.org/10.1007/s10518-016-0025-2

Nazari, Y.R., Saatcioglu, M.: Seismic vulnerability assessment of concrete shear wall buildings through fragility analysis. J. Build. Eng. **12**, 202–209 (2017)

Zhai, P., Zhao, P., Lu, Y., Ye, C., Xiong, F.: Seismic fragility analysis of buildings based on double-parameter damage models considering soil-structure interaction. Adv. Mater. Sci. Eng. **2019**, 13 (2019)

Pejovic, J., Jankovic, S.: Seismic fragility assessment for reinforced concrete high-rise buildings in Southern Euro-Mediterranean zone. Bull. Earthq. Eng. **14**(1), 185–212 (2015). https://doi.org/10.1007/s10518-015-9812-4

Porter, K., Kennedy, R., Bachman, R.: Creating fragility functions for performance-based earthquake engineering. Earthq. Spectra. **23**, 471–489 (2007)

Reveillere, A., Gehl, P., Seyedi, D., Modaressi, H.: Development of seismic fragility curves for damaged reinforced concrete structures. In: 15th World Conference on Earthquake (2012)

Reyes, J.C., Kalkan, E.: How Many Records should be used in an ASCE/SEI-7 ground motion scaling procedure. Earthq. Spectra **28**(3), 1223–1242 (2012)

Scozzese, F., Tubaldi, E., Dall Asta, A.: Assessment of the effectiveness of multiple strip analysis by using a stochastic earthquake input model. Bull. Earthq. Eng. **18**, 3167–3203 (2020). https://doi.org/10.1007/s10518-020-00815-1

Sil, A., Gourab, D., Pritam, H.: Characteristics of FBD and DDBD techniques for SMRF buildings designed for seismic zone-V in India. J. Build. Pathol. Rehabil. **4**(1) (2019). https://doi.org/10.1007/s41024-018-0040-6

Sudret, B., Mai, C.V.: Computing seismic fragility curves using polynomial chaos expansions. In: 11th International Conference on Structural Safety and Reliability (2013). https://doi.org/10.3929/ethz-a-010060735

Le, T.S., Huh, J., Park, J.H.: Earthquake fragility assessment of the underground tunnel using an efficient analysis approach. J. Appl. Math. Phys. **2**, 1073–1078 (2014)

Le, T.S., Huh, J.W., Ahn, J.H., Haldar, A.: Damage index identification and seismic fragility evaluation of the underground tunnels. Appl. Mech. Mater. **775**, 274–278 (2015)

He, X., Lu, Z.: Seismic fragility assessment of a super tall building with hybrid control strategy using IDA method. Soil Dyn. Earthq. Eng. **123**, 278–291 (2019)

Vamvatsikos, D., Cornell, C.A.: Incremental dynamic analysis. Earthq. Eng. Struct. Dyn. **31**, 491–514 (2002)

Zareian, F., Krawinkler, H.: Structural system parameter selection based on collapse potential of buildings in earthquakes. J. Struct. Eng. **136**, 933–943 (2010)