

Global Fragility Evaluation of Health Care Facilities with Structural and Nonstructural Components

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Summary

A multi-dimensional definition of fragility is developed considering multiple variables such as floor acceleration and interstory drifts. The limit states which have uncertainties are defined as random variables in the calculation of fragility. A random description of the limit state has been adopted to calculate fragility and different cases have been considered. A case study of a Hospital located in California has been considered. The development of fragility for different cases show how important is a correct evaluation of the limit state for comparison of different techniques. The paper investigates how conservative or unconservative are the fragility curves when uncertainties in limit states are considered. Among the different parameters that influence fragility damping has a considerable effect in reducing displacements; Influence of such parameters is investigated.

Introduction

The knowledge of structural damage is crucial for the evaluation of the economic losses in a region that has been or might be affected by earthquakes. It should be prepared with an acceptable degree of certainty to mitigate the potential losses that depend on the seismic performances of all types of building structures typically constructed in that region. To describe the structural damage distribution over a given region two techniques can be used: the fragility curves and the damage probability matrix (DPM). They both describe the conditional probabilities of sustaining different degrees of damage at given levels of ground motion. Engineers usually make their recommendations using fragility curves or DPM that are being build using deterministic performance limit state fixed by public policies, provisions etc.. The reason of using crisp quantities derives from the large uncertainties in the earthquake loads that are larger than the uncertainties in the limit states. The goal of this paper is to show that the limit states should be properly modeled as random variables. If uncertainties in limit states are not considered the results may be non-conservative and wrong decision could be made.

Definition of Multidimensional fragility

Fragility curves are functions that represent the conditional probability that the response of a structure for various seismic excitations exceeds performance limit states. Theoretically the definition of fragility using multidimensional parameters, like for instance displacements and accelerations of a story building, can be written in mathematical form as (Reinhorn et al., 2001):

$$Fragility = P\{\Delta \geq D_{lim} \cup Z \geq A_{lim} / I\} \quad (1)$$

Where Δ is the random variable representing the displacement response, Z is the random variable representing the acceleration response, D_{lim} is the determined displacement threshold and A_{lim} is the determined acceleration threshold. The response is represented by a “bell surface” in the pseudo acceleration (PSA) - interstory drifts (SD floor) plane and the limit space in this case can be expressed (Bruneau and Reinhorn, 2004) in term of accelerations, displacements, or velocity [Fig.1]. One time the probability of exceeding the limit states is calculated (volume underneath the surface) it can be represented using fragility curves. The peak ground acceleration (PGA) is usually used to represent the intensity of the seismic ground motion in the x axis of the fragility curves even though other quantities like return period, peak ground velocity, spectral intensity can be used. In this paper both PGA and return period are used to represent the seismic intensity ground motion.

Procedure to calculate fragility

The limit state represents the level of response at which the loss of function or undesirable damage occurs in the structure, but it requires damage descriptors describing the physical conditions of the building during and after the earthquake. Definition of limit states plays an important role in the construction of fragility curves because its value directly affects on the fragility curve parameters. Damage states of structural and non structural components depend on their mechanical properties such as strength and deformability which are characterized to be uncertain; therefore a crisp description of limit states can not be performed.

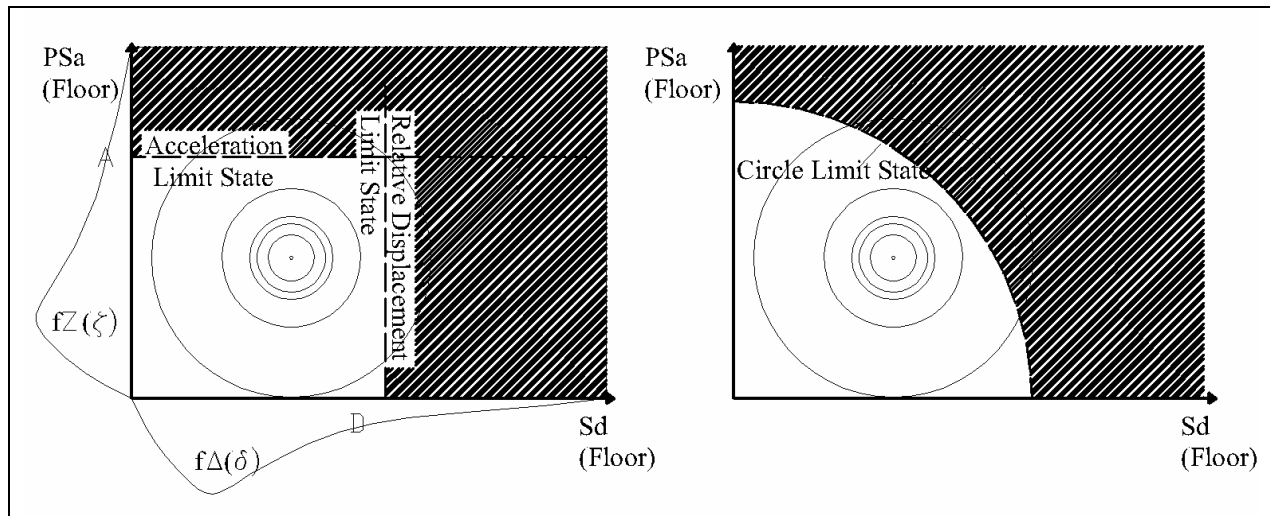


Figure 1. Probability of two random variables of exceeding two deterministic limit states
(a) uncorrelated or (b) related

The limit states should be properly modeled as random variables. In this study the limit states are considered as random variables and defined in term of interstory drift and accelerations. Five different cases have been considered to calculate the probability of exceeding a certain limit state assuming that the considered limit states are randomly distributed as the response of the structure and considering two different types of responses: displacements and accelerations. Both the response of the structure in term of displacements and accelerations are considered lognormal

distributed. This assumption is reasonable, because we are considering the maximum of the response that is always positive. For each case the linear case has been separated from the non linear case and various assumptions have been made regarding the random variables considered. In figure 1 limit states are represented by straight lines, and by a circle curve, but it is also possible to define different curves limit state like ellipses and so on.

Case study: West coast Hospital W70

A non linear MDOF model and SDOF model equivalent to the Hospital W70 located in the West coast of California has been used. The model is used by multiple research teams at MCEER for evaluation of various aspects of hospital seismic issues. The non linear MDOF model has been developed in the computer platform IDARC2D 6.0 (Reinhorn et al., 2004) and non linear springs have been used in all hinge connections of the non moment resisting frames. The SDOF system is modeled as elastic perfectly plastic with a yield shear strength equal to $V_y = 0.62 \cdot W$ that have been calculated by non linear static pushover analysis of the hospital. Different deterministic limit states related to the interstory drift have been considered according to FEMA 356 (0.7% - 2.5% - 5% of interstory drift) and SEAOC (0.2% - 0.5% - 1.5% - 2.5% of interstory drift).

Characterization of ground motion for SDOF and MDOF system

In this study three different families of accelerograms have been used.

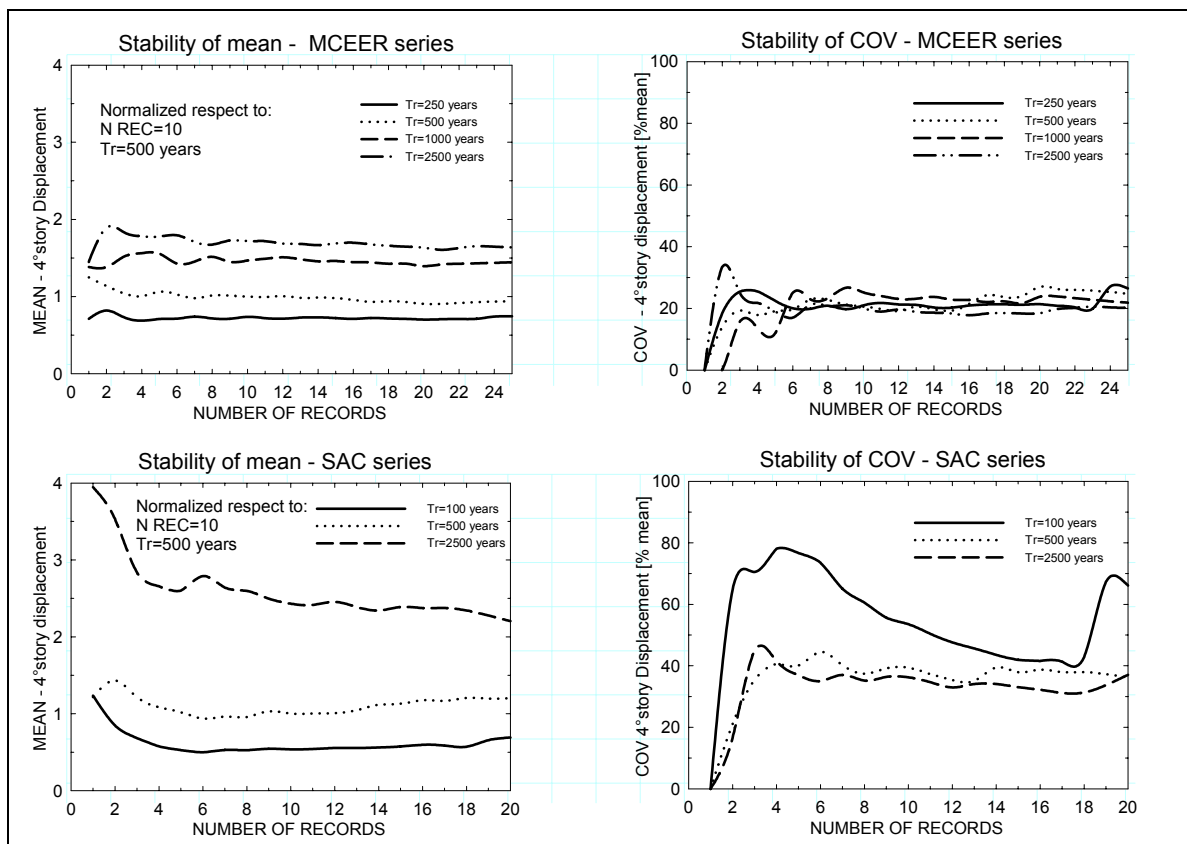


Figure 2. Stability of Mean and of CoV for MCEER and SAC series.

For the SDOF model the accelerograms used have been derived by the frequency content of the modified Kanai-Tajimi spectral density function (Clough and Penzien, 1993). The selected parameters for the model are the following: $\omega_g = 15.0 \text{ rad/s}$; $\zeta_g = 0.6$; $\omega_k = 1.5 \text{ rad/s}$ and $\zeta_k = 0.6$. These parameters have been used to reflect firm-soil conditions. of some literature (Heredia-Zavoni and Vanmarcke, 1994). For the MDOF system two series of accelerograms related to different return period have been used: the MCEER series and the SAC series [Fig. 2].

Influence of structural parameters on fragility

Fragility curves can be used for decisions to strength buildings that are at high risk of being damaged and for this purpose it is necessary to know the effects of different structural parameters such as strength, stiffness, and damping on fragility. The following figure describes the influence of stiffness on fragility and it shows how the increments of stiffness reduce fragility. This is due to reduction in displacements obtained when we increase the stiffness of the structure.

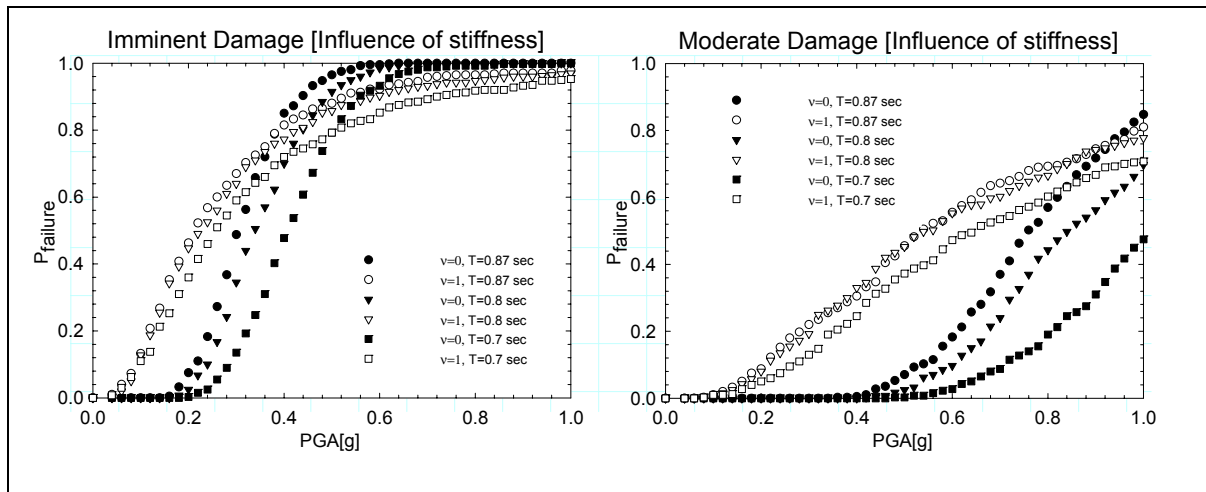


Figure 3. Comparison between different values of dispersion of limit state and different values of stiffness.

If we plot in the same figure the effect of stiffening the structure together with the effect of uncertainties of limit state, we can clearly see that the randomness of limit states generate bigger increases in the probability of exceeding the limit state if compared with the reduction of the probability of exceed the l.s. due to the stiffening of the structure. This show important is a correct evaluation of the l.s. for a comparison among different retrofit techniques. One of the advanced technologies studied by the MCEER for retrofitting structures consists in adding damping for displacement reduction; therefore it is desirable to know the effect of added damping to fragility (Barron, 2000; Reinhorn et al., 2001). In the following figure the fragility curves are plotted for the Imminent Damage State and for the Moderate Damage State for three different values of damping ratios [5%, 15% and 25%]. It can be seen that a considerable reduction of fragility is obtained when damping is added. However this reduction is not proportional. From the second figure we can see that the reduction is more significant for low values of damping ratio [$\zeta = 15\%$] than for high values of damping ratio [$\zeta = 25\%$]. Also in this case from the first figure one can see do not consider dispersion of limit state it can be unconservative for values of PGA below a range that varies between 0.4g and 0.6g, depending on the kind of damping considered, and conservative for

upper values of PGA, while for the second limit state do not consider the randomness of the limit state is always not conservative for every value of damping considered and PGA. Other parameters like strength have been considered, but increments of strength do not produce significant improvements on fragility and this is due to the fact that changes in strength do not affect displacement in the inelastic range.

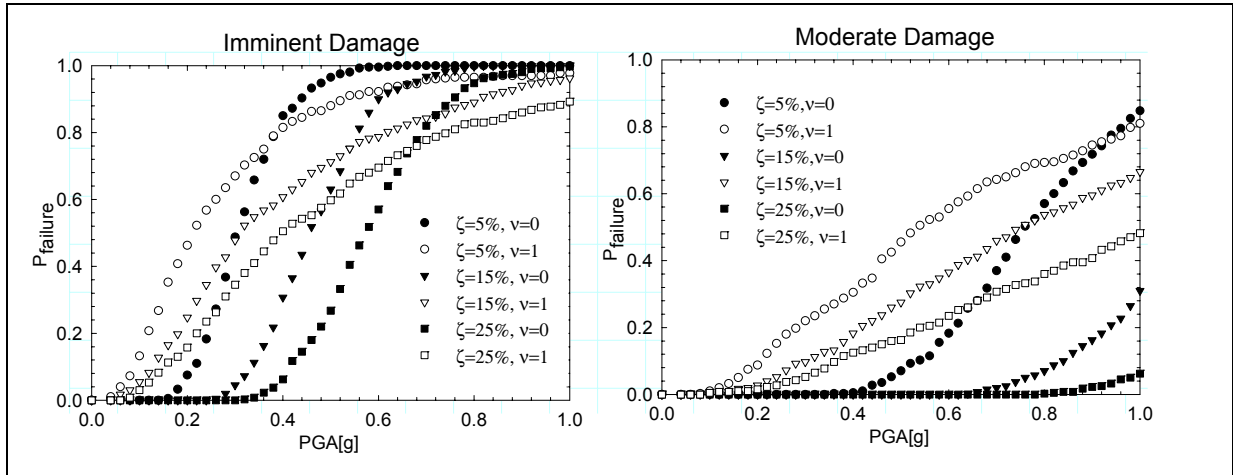


Figure 4. Comparison between different values of dispersion of limit state and different values of Damping.

Influence of acceleration threshold on fragility

In figure 5 is reported the fragility curve related to the 4^o story for the limit state of immediate occupancy according to FEMA 356, calculated using the MCEER series as input.

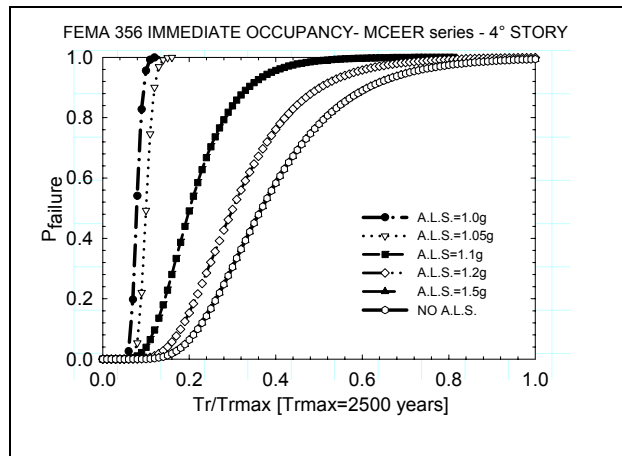


Figure 5. Influence of acceleration threshold on fragility calculated using two random variables.

In the x axis instead of PGA is used the return period, normalized respect to the maximum return period. Different values of acceleration limit state have been considered from 1 to 1.5g. It can be clearly see that the probability of exceed the limit increases quickly with small increasing value of acceleration. So fragility curves show to be really sensitive to acceleration limit state.

Concluding Remarks

A random description of the limit state has been adopted in this paper to calculate fragility and different cases have been considered. The development of fragility for different cases show how important is a correct evaluation of the limit state for comparison of different techniques. Besides to not consider randomness of the limit state can develop not conservative results. Among the different parameters that influence fragility damping has a considerable effect in reducing displacements; therefore it clearly produces changes in fragility.

Acknowledgements

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