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A Study on the Effects of Aleatory and Epistemic Uncertainties on Fragility Curves of Steel Moment Frames

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1. Introduction

In the last several earthquakes damage occurred in structures that were designed by the latest design codes. Studies showed that uncertainties in design of such structures play and important role in their seismic behavior. These can be categorized into aleatory and epistemic uncertainties. Aleatory uncertainties origin from uncertainty in earthquake phenomenon while epistemic uncertainties are due to errors and simplified assumptions in structural modeling.

IDA analysis can only model record-to-record (aleatory) uncertainties. Recently extended IDA has been introduced that can model both aleatory and epistemic uncertainties. The aim of this study was to investigate the effects of both aleatory and epistemic uncertainties on steel moment frames using extended IDA analysis.

2. Modeling and record selection

The structure used for analysis is a 5-story steel moment frame with 5m-length bays. It was located in Tehran with very high seismicity and was designed by Iranian design codes. A 2D frame of the building was modeled in OpenSees for analysis. Plastic hinges were modeled by concentrated elasticity using zero-length element. Bilin material was used to define moment-rotation behavior of the plastic hinges based on modified Ibarra-Krawinkler model. Moreover, beam and column elements were modeled by elastic Beam Column element. Forty far-field ground motions were selected for analysis. The records were selected randomly to obtain the desired dispersion in the characteristics of these records.

3. Uncertainty modeling

To model epistemic uncertainties, first a hysteresis model for plastic hinges is needed. As mentioned before, Ibarra-Krawinkler model (Figure 1) was used in this study with the statistical parameters shown in Tables 1 and 2. Based on this hysteresis model, 50 random models were generated as well as a model with mean parameters. Next, IDA analysis was conducted on these models and IDA curves were plotted (Figure 2).

To be able to interpret the results, 16%, 50% and 84% fractiles are also calculated. In the mean model, the first and the last IDA curves reach global instability at 0.6 and 2.3 g while other models collapse at 0.4 and 3.25 g levels. Also, when the structures reach high levels of spectral intensity, dispersion in IDA curves increases. Most of the 84% fractiles show a similar trend near collapse state of the structure, but a large dispersion is observed in 16% fractiles.

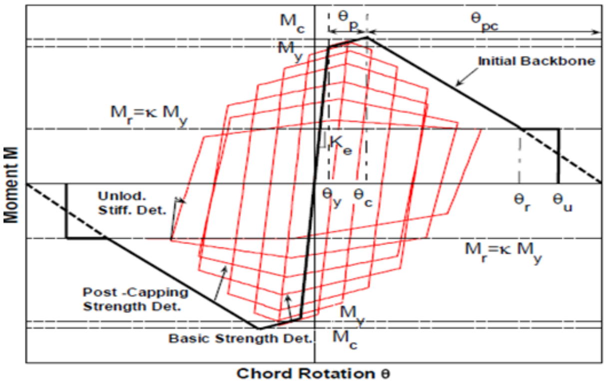

Figure 1. Ibarra-Krawinkler model for dynamic analyses

Table 1. Statistical parameters of plastic hinges

parameter	θ_p	θ_{pc}	Λ	$\frac{M_y}{M_{y,p}}$	$\frac{M_c}{M_y}$
distribution	Log-normal	Log-normal	Log-normal	normal	normal
mean	calculated	calculated	calculated	1.17	1.11
Standard dev.	0.32	0.25	0.35	0.21	0.05

Table 2. Statistical parameters of plastic hinge parameters

parameter	θ_p	θ_{pc}	Λ	$M_y / M_{y,p}$	M_c / M_y
θ_p	1.00	0.69	0.44	0	0
θ_{pc}	0.69	1.00	0.67	0	0
Λ	0.44	0.67	1.00	0	0
$M_y / M_{y,p}$	0	0	0	1.00	0
M_c / M_y	0	0	0	0	1.00

4. Fragility curves

To plot fragility curves, IO, CP, and GI limit states were defined based on FEMA350 definition. Next, the assumption of lognormal distribution of the spectral accelerations was controlled. For this reason, KS statistical test was employed and P-values were calculated. If the P-value is more than the significance level (i.e. 0.05), the assumption of lognormal distribution is confirmed.

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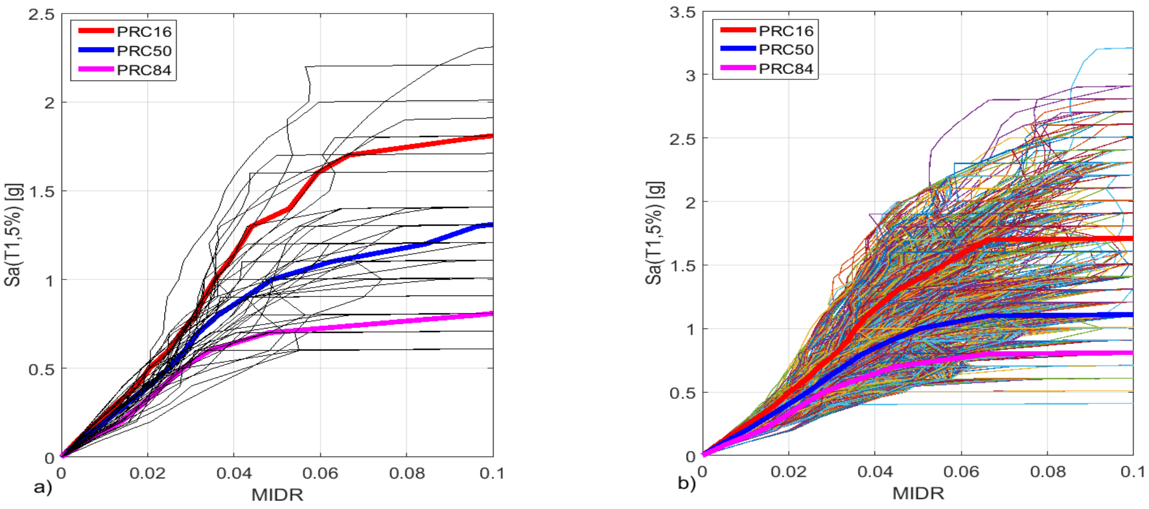

a) b)

Figure 2. IDA curves and fractiles of a) mean model b) 50 random models

According to the results, all the models showed a lognormal distribution. For IO level, the difference of fragility curves of mean of the 50 models and the mean model is significant. However, for CP and GI levels the difference is negligible which confirms the IDA results. Therefore, the effect of uncertainties cannot be neglected for IO level.

5. Conclusion

In this study, the effects of aleatory and epistemic uncertainties on a steel moment frame were investigated. Extended IDA was employed using LHS method for every random model to obtain fragility curves. From the results the following conclusions can be drawn:

1. According to the IDA, the effect of aleatory uncertainties is considerable, since for each random model seismic response of the structure is variable, especially for higher seismic demands.
2. Uncertainties due to plastic hinge parameters can highly affect the structure's response. For instance, for mean model, collapse occurs in the range of 0.6 to 2.3g, but for other models this range is 0.4 to 3.25 g.
3. Difference in fragility curves is more obvious for IO level and for the other CP and GI levels this difference is reduced. Overall, the epistemic uncertainties mostly affect the IO state of the structure. However, when the number of random models increase, the uncertainties decrease.