The Effect of Capacity Uncertainty on the Seismic Hazard Demand Curve Estimation of Steel-Moment Resisting Frames

B. Shokrollahi-Yancheshmeh [1], A. Mohebkhah*[1], M. Mahdavi-Adeli[2]

[1] Department of Civil Engineering, Malayer University, Malayer, Iran
[2] Department of Civil Engineering, Shoushtar Branch, Islamic Azad University, Shoushtar, Iran

ABSTRACT: Probabilistic seismic demand assessment of steel moment-resisting frames is associated with uncertainty. The most important factors of uncertainty include the inherent uncertainty caused by the record-to-record variability, as well as the epistemic capacity uncertainty due to the model parameters. The first uncertainty can be applied in the form of using an acceptable number of different ground motion records. Capacity uncertainty arises due to the approximate nature of the parameters used to define the structural model behavior which is based on the experimental relationships derived from laboratory results. In the present study, a 20-story steel moment-resisting frame in two cases of uncertain and base model has been investigated with and without considering the capacity uncertainty, respectively. The method of applying such uncertainty has been done by generating random variables in the defined range by Monte Carlo simulation. Based on the results of the incremental dynamic analysis performed for both base and uncertain models, the seismic hazard demand curves for the entire range of demand parameters including limit states of immediate occupancy and collapse prevention has been extracted and compared. Also, in order to evaluate the influence of the fragility and seismic hazard curves parameters on the variation of the mean annual frequency of limit state of the uncertain model, sensitivity analysis based on the above-mentioned quantities has been done. The results indicate the significant effect of capacity uncertainty on increasing the mean annual frequency at the collapse prevention limit state.

1- Introduction

Probabilistic estimation of seismic demand for steel flexural frames, which include various uncertainties, is one of the most challenging performance-based design issues in earthquake engineering. In a general classification of sources of uncertainty in estimating the seismic demand of such structures can be related to the inherent uncertainty due to the use of different earthquake records and the systemic capacity uncertainty. In 2014, Vamvatsikos studied the seismic performance of a 9-story steel moment frame through IDA[1] [1] with progressive accelerogram-wise Latin hypercube sampling [2]. This method is an effective algorithm in order to consider the uncertainties of the behavioral model by random sampling with a smaller number of samples compared to previous conventional methods. The convergence rate of the model is high and with a smaller number of sampling, the capacity uncertainty can be investigated. In 2020 Barbagallo et al. [3] investigated the impact of using variable or invariable set of accelerograms on the fragility and mean annual frequency of exceeding of limit states. They used a large set of one degree of freedom models by two different methods of analysis and validated the results by means of some multi-story models. In the first method, a multiple stripe analysis was done using a set of earthquake records characterized by intensity measure dependent ground motion duration and the shape of the median response spectrum, whereas in the second method, the accelerograms were considered invariable for the whole range of intensity measures. They concluded that using invariable spectral shapes for SDOF systems having low periods of vibration (less than 0.4 s) led to a conservative analysis. On the other hand, for moderate and large periods of vibration SDOF systems, the results were underestimated especially for systems having high ductility demand and degradation and pinching models, but the maximum error was limited to 25%.

In this study, a 20-story steel moment frame including capacity uncertainty at two limit states and using different seismic hazard curves have been investigated. Also, the effect of capacity uncertainty on the estimation of the fragility curves and the mean annual frequency at different limit states are evaluated.

2- Methodology

In the present study, a 20-story steel moment-resisting frame considering the effect of capacity uncertainty

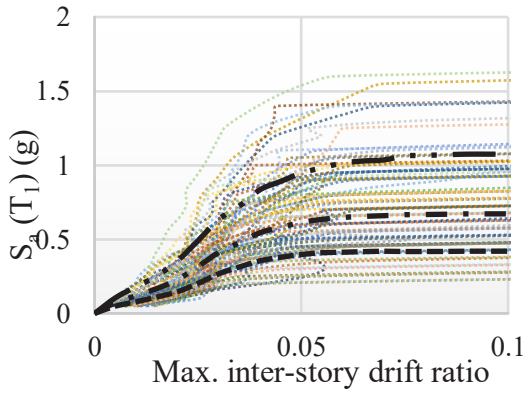*Corresponding author's email: amoheb2001@yahoo.com

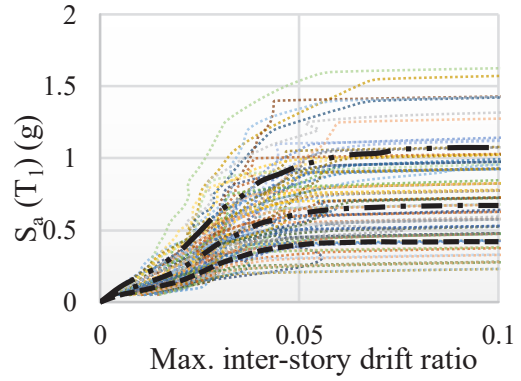**Fig. 1. IDA curves for the base model**

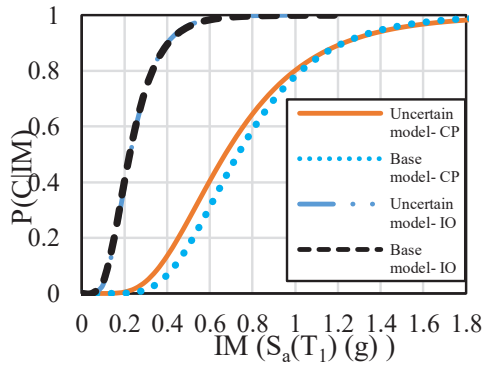**Fig. 2. IDA curves for the uncertain model**

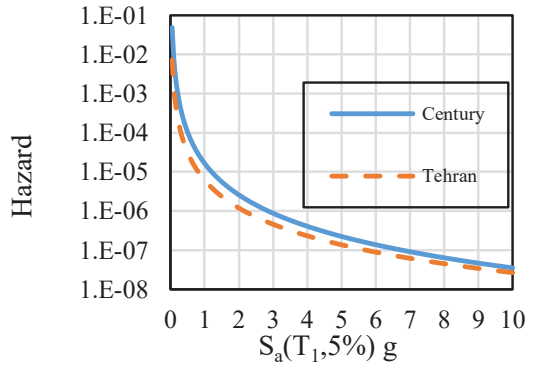**Fig. 3. Fragility curves (base and uncertain model)**

Fig. 4. Century & Tehran seismic hazard curves [4, 5]

based on the immediate occupancy (IO) and collapse prevention (CP) limit states defined in the performance-based design method is studied for two seismic hazard curves of Century and Tehran cities [4, 5]. Modified Ibarra-Medina-Krawinkler deterioration model has been used to investigate the nonlinear behavior of the structure [6]. Knowing that the equations provided to define the model parameters are based on a limited number of laboratory samples and statistical calculations, the use of these quantities is associated with uncertainty. Capacity uncertainty is applied through Latin hypercube sampling (LHS) with progressive accelerometers [2]. Incremental dynamic analysis (IDA) using a suite of 80 ground motion records are performed in two cases of the base model which only is influenced by the inherent uncertainty due to the use of different earthquake records and the uncertain model considering the combined effect of records uncertainty and the systematic capacity uncertainty. Fragility curves have been extracted and the mean annual frequency (MAF) is evaluated at defined limit states for both models and for the Century and the Tehran cities. In order to generalize the results, seismic drift hazard curves for the base and the uncertain models have been calculated and compared with

each other. This comparison makes it possible to study the impact of capacity uncertainty over the entire range of the demand parameter. Also, the usual method of using the base model' median for the uncertain model and its effect on the estimation of MAF has been reviewed.

3- Results

IDA analysis was performed for 80 earthquake records and the results for the base and the uncertain models are given in Figures 1 and 2. Fragility curves are calculated for the IO and CP limit states (Figure 3). As can be seen, at the IO limit state, the mean and standard deviation values of the base and uncertain models are very close to each other. In contrast, at the CP limit state, the mean of the uncertain model decreases and its standard deviation increases. The mean annual frequency of both models using the seismic hazard curve of the Century and Tehran cities (Figure 4) is calculated. Summary of the results for fragility curves and MAF are given in Table 1. The results show that the effect of capacity uncertainty for the IO limit state is negligible. But in the CP limit state, a significant increase of 55% and 44% in the mean annual frequency of the uncertain model for the Century and the Tehran cities has occurred.

Table. 1.The base and the uncertain model parameters (Century & Tehran cities)

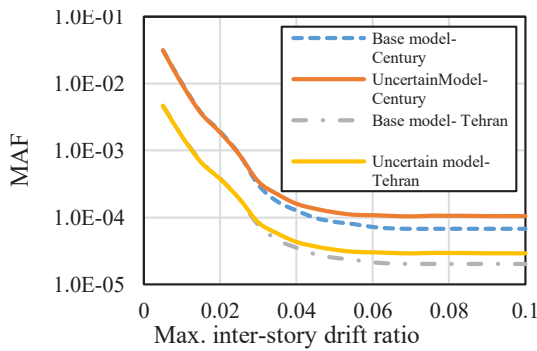| Limit state		Base Model		Uncertain Model	
		IO	CP	IO	CP
Median μ		0.224	0.732	0.225	0.671
Dispersion β		0.463	0.403	0.455	0.469
MAF λ_{LS}	Century	1.92e-3	6.76e-5	1.86e-3	9.81 e-5
	Tehran	3.82e-4	2.02e-5	3.74e-4	2.76e-5

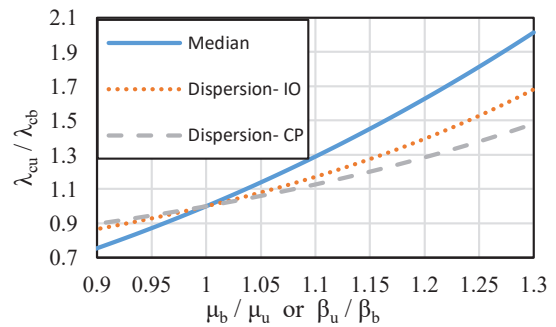**Fig. 5. Century & Tehran seismic drift hazard curves**

Fig. 6. MAF Sensitivity analysis (Century city)

According to the seismic drift hazard curves (Figure 5), it can be seen that in the range of drift ratio values less than 3%, the effect of capacity uncertainty can be ignored. In contrast, the MAF uncertain model (compared to the base model) has increased at higher drift ratio values. Also, according to the sensitivity analysis performed on the median and the standard deviation of the fragility curve, it was found that the impact of the median changes is more than the standard deviation changes on increasing the mean annual frequency of the uncertain model (Figure 6).

4- Conclusions

The seismic behavior of steel moment-resisting frames is always faced with uncertainty. A significant part of the mentioned uncertainty is due to the random nature of earthquake records. Capacity uncertainty is another important factor that should be considered. The present study investigates the effect of capacity uncertainty due to the model parameters of a 20-story steel moment-resisting frame. To apply this uncertainty, model parameters are considered as random variables within the defined range of variation for each parameter. Incremental dynamic analysis for both the base and the uncertain models (with capacity uncertainty) under 80 earthquake records have been performed and fragility curves are extracted for the immediate occupancy (IO) and collapse prevention (CP) limit states. Comparing the results of the two models, it was found that at the IO limit state, the effect of capacity uncertainty is negligible. On the other hand,

for the CP limit state, the median of the uncertain model was decreased by 8.3% and its standard deviation was increased by 16.4%. In order to investigate the effect of the fragility curve parameters on the estimation of seismic demand assessment of the 20-story frame, by using seismic hazard curves of two different cities (Century and Tehran), the mean annual frequency (MAF) of both models for the IO and CP limit states has been calculated and compared. In that comparison, it was found that for the IO limit state, the capacity uncertainty can be ignored, while at the CP limit state, the MAF of the uncertain model has increased (compared to the base model) significantly by 55% and 44% for the Century and Tehran cities respectively. According to seismic drift hazard curves, it was found that for the demand parameter (maximum inter-story drift ratio) values less than 3%, the effect of capacity uncertainty is not significant and can be ignored. On the other hand, for demand values greater than 3% the capacity uncertainty causes a significant increase in the MAF of the uncertain model. Also, for demand values above 3%, the median spectral acceleration decreases, and the standard deviation increases, which both factors will increase the MAF of the uncertain model. To investigate the impact of the fragility curve parameters on the variation of the mean annual frequency of the frame under study, a sensitivity analysis was performed based on independent changes of dimensionless median and dispersion ratio parameters (μ_b /μ_u and β_b /β_u).

The results of the present study are summarized as follows:

- Capacity uncertainty due to the model parameters has influenced fragility curve parameters, especially at the limit states leading to a structural failure (CP limit state).

- For large values of demand parameter (greater than 3%), capacity uncertainty reduces the median and increases the dispersion of the fragility curve resulted in increasing the mean annual frequency of the uncertain model.

- Reduction in the median spectral acceleration at a higher rate (compared to increasing the dispersion) will increase the mean annual frequency of the uncertain model.

- For small values of the demand parameter (IO limit state), the effect of capacity uncertainty can be ignored.

- Ignoring the effect of capacity uncertainty leads to the underestimation of the mean annual frequency at the CP limit state.

However, this research is limited to a relatively high-rise 20-story steel moment-resisting frame, and further studies are needed to generalize the results to medium or low-rise steel moment-resisting frames.

References

[1] D. Vamvatsikos, C.A. Cornell, Incremental dynamic analysis, Earthquake engineering & structural dynamics, 31(3) (2002) 491-514.

[2] D. Vamvatsikos, Seismic performance uncertainty estimation via IDA with progressive accelerogram-wise latin hypercube sampling, Journal of Structural Engineering, 140(8) (2014) A4014015.

[3] F. Barbagallo, M. Bosco, E. Marino, P. Rossi, Variable vs. invariable elastic response spectrum shapes: impact on the mean annual frequency of exceedance of limit states, Engineering Structures, 214 (2020) 110620.

[4] A. Mathiasson, R.A. Medina, Seismic collapse assessment of a 20-story steel moment-resisting frame structure, Buildings, 4(4) (2014) 806-822.

[5] M. Mahdavi Adeli, Determination of site uniform hazard and design spectra Amirkabir University, Iran 2004.(in Persian).

[6] L.F. Ibarra, R.A. Medina, H. Krawinkler, Hysteretic models that incorporate strength and stiffness deterioration, Earthquake engineering & structural dynamics, 34(12) (2005) 1489-1511.