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Effects of structural uncertainties on seismic performance of steel moment resisting frames

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ABSTRACT

Prediction of structural response to seismic loads is a complex problem with many parameters involved that some of them can behave highly uncertain. Nonetheless, it is needed to have a clear understanding of how these uncertainties affect seismic structural performance. In this matter, it is convenient to separate uncertainties into two categories: aleatory (due to variability of strong ground motions) and epistemic (related to numerical model of structure).

This paper aims to investigate effects of structural uncertainties on seismic performance of steel moment resisting frames, through extended IDA of two sample 5-story frames. In this regard, damping, mass, yield strength and ultimate strength of structural steel have been considered as probabilistic variables. Latin Hypercube Sampling (LHS) has been used to create random realizations of structures.

With the aid of reliability methods, different sources of uncertainty and their ranges of influence on seismic performance have been disaggregated. Two steel moment frames, despite having the same geometry, have been designed with different levels of ductility. This can give an idea about how the ductility of structure affects different aspects of probabilistic performance evaluations.

Considering the results, it can be seen that uncertainties in selected parameters have important effects on seismic performance. In other words, capacity and demand estimations based only on deterministic procedures may ignore some substantial points. Including these uncertainties in performance calculations can considerably change, at some levels, the probability of achieving desired performance. Also, a clear superiority in performance capacities can be seen for special moment frame.

1. Introduction

For structures designed based on the current codes, performance of structure subjected to different levels of earthquake is a key issue. In fact, it is needed to have a level of confidence that in an earthquake event desirable performance will be achieved and damages occurred to structure will remain in an acceptable range. Of course, in order to achieve this desired confidence, an essential matter is to deal with uncertainties involved in the process of calculation of seismic capacity and demand.

In this context, a convenient procedure is to separate these uncertainties into two independent categories, namely aleatory and epistemic, each of which relates to a different origin. Aleatory uncertainties relate to the random nature of ground motions and epistemic uncertainties relate to our lack of knowledge in modeling structures perfectly [1].

Incremental dynamic analysis (IDA) is nowadays a widely used tool to study seismic performance of structures, as discussed in many researches and technical reports [2,3]. Using this method is usually based on a deterministic numerical model of structure, which is affected only by aleatory uncertainties (known as record to record effect). But in a more developed method, which is named extended IDA; it is possible to perform IDAs with a probabilistic description of structural model. In such a case, results will contain both aleatory and epistemic uncertainties.

Extended IDA has been subject for many researches in recent decade. Dolsek [4] studied effects of epistemic uncertainties on seismic capacity of a 4-story concrete moment resisting frame (MRF), selecting a set of various structural modeling parameters as probabilistic variables. Zareian and Krawinkler [1] suggested a probabilistic-based methodology for quantifying the collapse potential of structural systems, based on different sources of uncertainty and for desired levels of confidence.

Shafei et al. [5] proposed a simplified methodology for predicting the median and dispersion of collapse capacity of MRF and shear wall structural systems subjected to seismic excitations. For this purpose, they developed some closed-form equations, based on a comprehensive database of collapse fragilities and pushover curves generated for generic structural models. Vamvatsikos and Fragiadakis [6] employed parameterized moment-rotation relationships with non-deterministic

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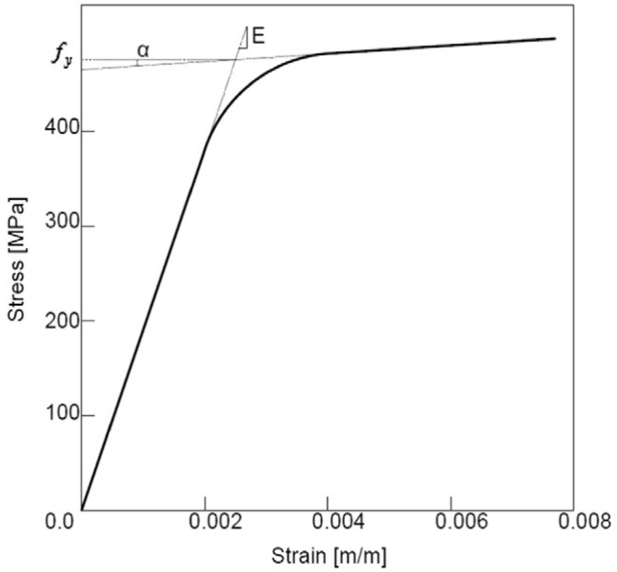

Fig. 1. Monotonic behavior of material Steel02.

quadrilinear backbones for beam plastic-hinges. They studied effect of these uncertainties on seismic performance of a 9-story steel MRF, using various statistical tools.

Kazantzi et al. [7] presented a quantification of the model parameter uncertainty effects on the seismic performance for a 4-story steel MRF. They examined variability in strength and plastic deformation properties of frame members and considered three construction quality levels (very good, average and low). Kazantzi et al. [8] also quantified the effect of joint ductility and failure on structural response, through seismic fragility analysis of a mid-rise steel frame.

Calderoni et al. [9] obtained statistical samples of parameters characterizing the inelastic behavior of steel MRF, assuming five different probability density functions for material yield strength. They examined the requirements for the quality control and acceptance of structural steel. Moreover, Calderoni et al. [10], studied the influence of structural overstrength on the seismic behavior of steel MRF. They used different schemes and design criteria for these frames and performed a statistical analysis on their dynamic inelastic response gathered from significant number of time history analyses.

Finally, Calderoni and Rinaldi [11] evaluated the structural seismic behavior of steel MRF proportioned by adopting different capacity design criteria. They particularly considered damage level and the structure's ability to withstand a strong earthquake, in the framework of performance-based design and on the basis of the results obtained by both dynamic time histories and push-over analyses.

About the purpose of this study, it can be said that although in case of steel MRF there have been diverse studies conducted to quantify the effect of uncertainty in moment-rotation characteristics of members, evaluation of other modeling parameters like seismic efficient mass, equivalent viscous damping and mechanical properties of steel has not been of particular interest yet. So results of new studies in this area can create a new viewpoint about effects of epistemic uncertainties on seismic performance.

Also, comparing frames designed with different levels of ductility and global inelastic response capability in a probabilistic framework, may bring some new aspects in performance evaluations. In addition, with proper assumptions made, performance capabilities of structures can be considered in a more meaningful way and then compared to what is expected by governing codes and standards based on deterministic procedures.

2. Methodology used for probabilistic performance evaluations

In order to separate between epistemic and aleatory sources of uncertainty, it is needed to analyze structures in their deterministic form as well as probabilistic form. So in the first phase, for a selected set of earthquake records, structures are analyzed through IDA with their parameters set to central values (which will be named as *base structure* hereafter).

Since previous studies have reported that majority of uncertainty effects are due to modeling of strong ground motion [6,12], the set of records are selected such that they cover as wide as possible range of variation in intrinsic properties of ground motions. Results of this phase include solely uncertainty due to record to record effect.

In the next phase, assuming damping, mass, yield strength and ultimate strength of steel as probabilistic variables, a sufficient number of different realizations of structural models are generated. Then, every single realization of structures is subjected to IDA for selected records. Results of this phase include effects of both aleatory and epistemic uncertainties.

Having the results of these two phases, and utilizing reliability methods, it will be feasible to separate between different sources of uncertainty and to define the extent to which each of them has affected seismic performance.

In order to optimize the procedure of generating random realizations of structures, here Latin Hypercube Sampling (LHS) method [13] has been used. This technique uses a constrained sampling scheme instead of random sampling utilized by direct Monte Carlo method, and consequently will need significantly fewer simulations to cover desired probability space [4,14]. This can become very helpful to decrease high computational costs usually involved in uncertainty studies.

An important point in this part, is the parameter used for intensity measure (IM) in each single IDA: It has been suggested that even in presence of mass and stiffness uncertainties, still it would be appropriate to use the spectral acceleration corresponding to fundamental period of *base structure* as IM parameter [6].

Taking a different approach in this part (i.e. calculation of spectral acceleration based on uncertain value of fundamental period or using vector-valued parameters) can possibly have important effects on final results and may be subject to further studies. Nevertheless, here IM parameter has been treated deterministically and taken equal to spectral acceleration corresponding to structure's fundamental period.

According to definitions existing in FEMA-350 [2], performance limit states can be defined for steel MRF. Particularly, three limit states namely immediate occupancy (IO), collapse prevention (CP) and global instability (GI) are of prime interest. After gathering pair values of intensity and demand measures from multi-record IDA curves, statistical characteristics of their distribution can be calculated for any performance level. Central values (median or mean) represent structural capacity at performance levels and dispersion values (standard deviation) represent the limit of uncertainty effects.

Also, with assignment of a proper statistical distribution to pair values of demand and intensity, a cumulative distribution function will be available that can be employed to define the fragility function of structure for every desired performance level. In this matter, a convenient and widely-accepted assumption is using lognormal distribution [5,15].With this procedure done, the probability of exceeding a specific performance level given seismic intensity, can be calculated.

Table 1
Statistics of material yield strength from flange coupon tests [22].

Mean F_y (Mpa)	σ_{Fy} (Mpa)	Mean F_u (Mpa)	σ_{Fu} (Mpa)	$\rho_{Fu,Fy}$
310.3	35.8	455.7	29.6	0.851