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Probabilistic seismic performance evaluation of the steel frame buildings controlled with lead rubber bearings (LRBs)

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ABSTRACT: The probabilistic analysis could effectively apply the effects of uncertainty in the structural analysis, where fragility curves are a well-established technique for the probabilistic evaluation of the structural performance. Notably, incremental dynamic analysis (IDA) is one of the most common analytical methods for obtaining fragility curves. In this study, the statistical and probabilistic seismic performance of 3- and 9-story steel buildings are investigated under 22 pairs of far-fault records introduced in FEMA P695. The seismic performance of both uncontrolled and controlled buildings with LRB is studied using IDA. Then, a general mathematical equation corresponding to each structure will be determined for all damage states known as the probabilistic seismic demand model (PSDM) of the structures. Using this equation, the collapse fragility curve of the structures will be determined for both uncontrolled and controlled structures with LRB. To evaluate the possible impact of different levels of seismic intensities on the performance of the isolated structure, the collapse fragility curves for three different levels of intensities of the benchmark records are presented. According to the collapse fragility curves, in addition to the effect of different levels of seismic intensity on the seismic performance of the structure, it is possible to see the positive effect of the LRB in reducing the probability of collapse. Also, the collapse margin ratio (CMR) in the 3- and 9-story buildings has increased by 100% and 81%, respectively, which indicates the better performance of the LRB isolators in low-rise structures.

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1- Introduction

Several studies have focused on evaluating the seismic performance of base isolators in controlling the basic seismic structural responses such as roof displacement, story drifts, acceleration of stories, etc. However, limited studies have been carried out based on the control of more developed responses including the aleatory uncertainty of the earthquake and the epistemic uncertainty of the structural parameters. Moreover, these studies are more limited in the discussion of the seismic performance of isolated buildings and show the need for more studies. Also, the studies that have specifically studied steel structures with different heights and under standard records with an appropriate number of records have been very limited due to the high computation costs.

Because SAC structures and FEMA-P695 records are benchmark buildings and natural ground motions respectively, the use of these buildings and records provides a more effective comparison platform with the results of other conducted research or ongoing research. The far-fault record set of FEMA-P695 contains 22 pair of natural ground motions, which can provide researchers with an adequate number of records to account for record-to-record uncertainty. Also, in this study, two 3- and 9-story steel buildings without isolator and with isolators, have been analyzed statistically and probabilistically. Therefore, in addition to deriving fragility curves for 3- and 9-story benchmark buildings, which are usually considered in the seismic risk studies, in this study, the performance of the LRB to control the seismic responses of steel buildings is evaluated based on the probable indicators. Moreover, the effect of peak ground acceleration (PGA) on the seismic probabilistic performance of both benchmark buildings has been investigated to evaluate the effect of PGA uncertainty.

2- Methodology

3. In this study, 3- and 9-story benchmark buildings of the SAC project have been modeled to assess the seismic behavior of the isolated steel buildings. Due to the symmetry and simplicity, the two-dimensional model of the buildings is analyzed for both uncontrolled and controlled buildings with LRB [1]. The LRBs are designed based on the Iranian design guide for the implementation of seismic bearing systems in buildings (standard No. 523). Consequently, the designed parameters including the cross-sectional area of the bearing, the height of the bearing, the cross-sectional area of the lead core, shear modulus, and yield stress are reported in Table 1. Also, the KikuchiAikenLRB code is used to model the LRBs in OpenSEES software [2].

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Table 1. Characteristics of the designed LRBs

	A-Rubber (m^2)	H-Rubber (m)	A-Lead (m^2)	Shear modulus (N/m^2)	Yield stress (N/m^2)
SAC - 3	0.3421	0.18	0.0093	6.4×10^5	8×10^6
SAC - 9	0.8355	0.5	0.0235	6.4×10^5	8×10^6

The records provided in the FEMA P695 i.e., 22 far-fault earthquakes with both horizontal components for each earthquake which results in 44 earthquake records are selected to assess the probabilistic seismic performance of the buildings using IDA and generating fragility curves [3].

To perform IDA, first, a suitable intensity measure (IM) is selected according to the characteristics and location of the structure. The IM can be peak ground acceleration, peak ground velocity and spectral acceleration corresponding to the main period of the structure, etc. Among the mentioned IMs, since the spectral acceleration of the first mode is related to the characteristics of the structure, it provides more favorable results and the dispersion of the results in this IM is less [4]. Next, the engineering demand parameter (EDP) is selected. This parameter can be the maximum rotation of plastic joints, the maximum acceleration of the roof, the maximum base shear, the maximum roof displacement ratio, the maximum inter-story drift ratio, etc. Then, a suitable algorithm is selected to implement the analysis. In this research, Hunt & Fill technique is applied to scale records of IDA. This algorithm is one of the most suitable algorithms to choose the IM-level [5]. Finally, although there are various distributions to obtain the fragility curves, the lognormal probability distribution is preferred in this study.

3- Results and Discussion

First, an IDA curve is obtained considering three different intensity levels of PGA. In this study, the spectral acceleration of the first mode and the maximum inter-story displacement ratio is selected as the IM and EDP, respectively. The IM is scaled based on the Hunt and Fill algorithm. In these graphs, each corresponding point is a step of IDA, and the values of the intensity measure corresponding to that step are plotted against the maximum story drift (EDP) during the entire analysis time. Increasing the values of the intensity measure has continued until reaching the maximum story drift which is 10%. (Figure 1). The parameters that are necessary to describe the lognormal distribution are logarithmic median (IMm) and logarithmic standard deviation (βD), which were estimated by performing the linear regression analysis of ln(DM) on ln(IM) (Figure 2).

The equation of these lines represents the probabilistic seismic demand models (PSDMs) of each structure. Using these PSDMs, it is possible to obtain the fragility curve corresponding to all damage states without performing new analyzes. In this research, the collapse fragility curve has been obtained for both isolated and non-isolated buildings for different levels of PGA intensities (Figure 3).

For the 3-story building, the spectral acceleration of the structural collapse corresponding to the 10%, 50% and 100% probability of the collapse of the structure for the case of controlled buildings with LRB has increased by 13%, 34% and 52%, respectively. Moreover, among the important parameters that can be obtained from IDA and fragility curves is the collapse margin ratio (CMR). The larger CMR means the lower the probability of the damage. This ratio is obtained by dividing the median of the spectral accelerations of the collapse with a probability of 50% by the spectral acceleration of the maximum considered earthquake (MCE).

with different PGA intensity levels

The CMR for a 3-story building without and with LRB is equal to 1.56 and 3.14, respectively. Also, for the 9-story building, the spectral acceleration corresponding to the 10%, 50% and 100% probability of structural collapse for the buildings with LRB has increased by 28%, 51% and 98%, respectively. Additionally, the CMR for the 9-story building without and with LRB is calculated as 1.52 and 2.75, respectively.

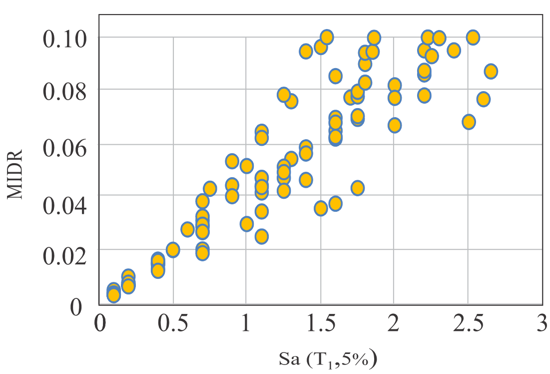

Fig. 1. IDA of the uncontrolled 3-story building under far-fault records with high PGA

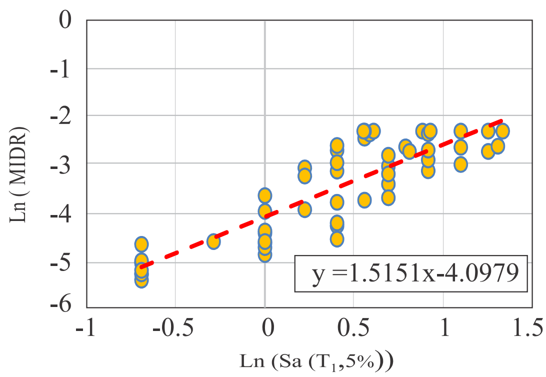

Fig. 2. Logarithmic curve of PSDM for 3-story building with LRB under far-fault records with high PGA

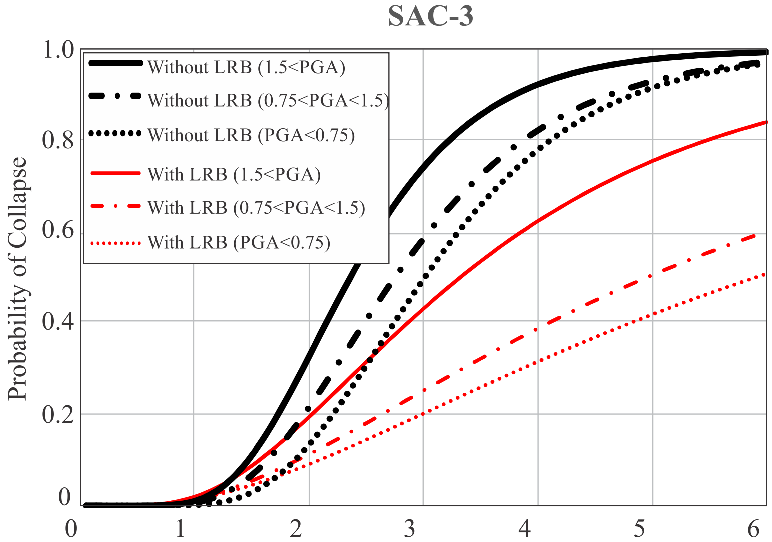

Fig. 3. Collapse fragility curve of uncontrolled & controlled 3-story building under far-fault records with different PGA intensity levels

4- Conclusions

According to the results obtained from the response history analysis performed on the 3 (9) story building, the roof displacement of the building with LRB compared to the building without LRB has decreased on average 73% (45%) with a standard deviation of 9 % (16%). The maximum and minimum response reduction values of the roof of the 3 (9) story building with LRB compared to the building without LRB are 88% (69%) and 41% (11%), respectively under the set of investigated records. The reduction of the roof displacement of the building is due to the reduction of seismic demand and the increase of damping of the building. Notably, both in terms of reducing the average displacement of the roof and in terms of reducing the uncertainty of the record-to-record, the LRB has performed better in the 3-story building, which is due to the lower period of the 3-story building and the greater effect of the LRB in the low rise structures. Also, the LRB causes the vibration amplitude to decrease faster over time and the building to enter the nonlinear region less, which has reduced the residual displacement in the buildings by reducing the seismic demand and increasing the damping.

According to the results of the fragility curve, the LRB has reduced the damage to both 3- and 9-story buildings by reducing the seismic demand and as a result, the story drift. According to the analysis, the spectral acceleration of the 10%, 50% and 100% probability of the collapse for the 3- (9) story isolated building has increased 13%, 34% and 52% (28%, 51% and 98%). It should be noted that the period of the building with LRB changes differently for the building without LRB for 3- and 9-story building and as a result the percentage of the seismic demand reduction is also different. Therefore, the comparison of the percentage increase in the spectral acceleration of the structural collapse obtained from the fragility curve of these two buildings cannot be a suitable criterion to compare the seismic performance of the controlled buildings with LRB in the two 3- and 9-story buildings. For this purpose, the local index of CMR, has also been compared for both 3- and 9-story buildings and in both cases of controlled buildings without and with LRB.

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