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Reliability-based Sensitivity Analysis of Shear Frame Equipped with Nonlinear Viscous Damper

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ABSTRACT: Recently, nonlinear viscous dampers have been widely used to improve the seismic performance of structures. These dampers dissipate the kinetic energy caused by the earthquake by producing a damping force. These dampers are designed in such a way that the force is proportional to the velocity. The Maxwell model is the most common model for modeling the behavior of nonlinear viscous dampers. In this model, the damping coefficient, the velocity exponent and the axial stiffness of the dampers are the key parameters. In most previous studies, the uncertainty of the underlying parameters in the behavior of viscous dampers has been ignored while it can has a significant effect on the seismic response of structures. In this study, first, the reliability analysis of a shear frame equipped with a nonlinear viscous damper was performed using the Monte Carlo sampling method. The results show that increasing the maximum drift from 0.015 to 0.02 reduces the probability of failure by 72%. Then, a reliability-based sensitivity analysis of the studied frame was performed in order to determine the most effective random variable on the reliability of the frame. The results show that the velocity exponent is the most effective random variable on the reliability of the frame. Also, results indicate that the importance of random variables depends on the used limit state function in the reliability analysis. For example, the importance value of the damping coefficient is 59% and 9.5% less than the velocity exponent with respect to the maximum drift of 0.015 and 0.025, respectively.

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1- Introduction

The safety of building structures and the life safety of residents are the ultimate goal of designing structures under earthquakes. Structural control systems in earthquake engineering are used to protect structures against the destructive effects of earthquakes. In particular, the use of viscous dampers as a subset of passive control systems in buildings has increased significantly because these devices have the ability to reduce the structural response at a lower cost than other methods [1, 2]. Viscous dampers have the advantage that the forces created in them are generally out of phase with the forces due to the internal displacement of the building frames under earthquake load [3]. Recent earthquakes have proven the effectiveness of viscous dampers in modifying the response of buildings to control damage to structural and non-structural members [4, 5].

The performance of building frames equipped with viscous dampers has been extensively studied. In preliminary studies, a deterministic approach to this problem has been chosen and the uncertainty of the parameters involved in the behavior of structures equipped with viscous dampers has been ignored [6, 7]. However, due to the uncertainty in the seismic loads on the structure and also the characteristics of the structure equipped with viscous dampers, the use of a probabilistic approach to evaluate the performance of this type of structure is necessary and has been addressed in several studies [8-12].

In this research, sampling-based reliability sensitivity analysis [13] of structure equipped with nonlinear viscous damper has been performed, in order to identify random variables that have the greatest impact on the seismic reliability of the structure. Due to the deterioration of the nonlinear viscous damper during the structural service life [14], three parameters of damping coefficient, velocity exponent and axial stiffness have been considered as random variables in reliability analysis. Also, in order to better address the uncertainties in selected ground motion records, the conditional mean spectrum method [15] has been used.

2- Methodology

In this study, a one-story shear frame equipped with a non-linear viscous damper is considered a case study (Figure 1). Characteristics of the non-linear viscous damper consisting of damping coefficient (C_d), axial stiffness (K_d), and velocity exponent (α) are considered as random variables. It

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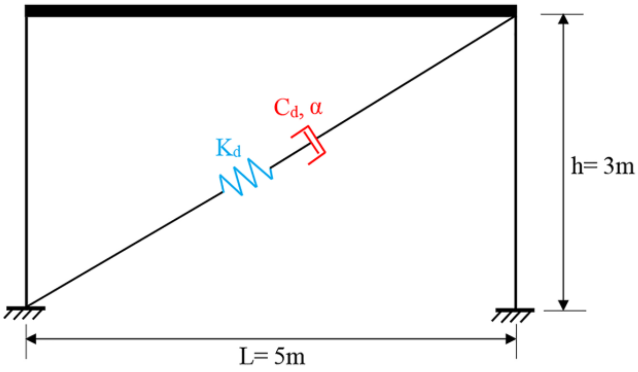

Fig. 1. Studied shear frame

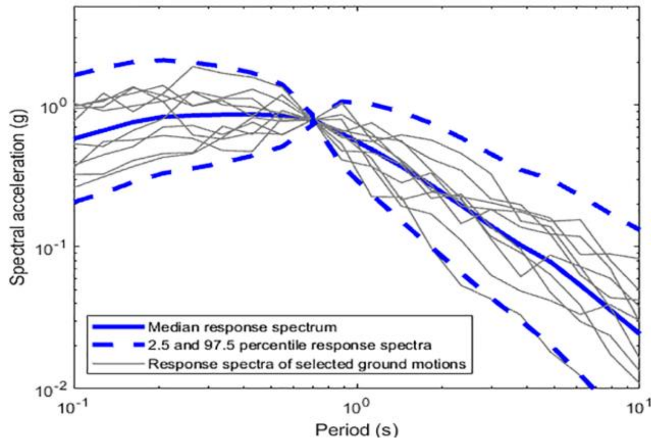

Fig. 2. Response spectra of selected ground motions

is assumed that all of these random variables have a normal distribution with 10% coefficient of variation. The mean values of C_d, K_d, and α are 20.745 kN.(s/mm)$^{0.35}$, 25 kN/mm and 0.35, respectively.

Using the mean spectrum method [14], 10 ground motion records were selected from the PEER database. The response spectra of selected records with median and 2.5 and 97.5 percentiles are shown in Figure 2.

The following limit state function is used in the reliability analysis:

$$g(\mathbf{x}) = \mathrm{Drift}_{max} - \mathrm{Drift}(\mathbf{x}) \qquad (1)$$

where $\mathrm{Drift}(\mathbf{x})$ is the drift of the frame, $\mathbf{x}$ is the vector of random variables and Drift_{max} is the code-defined allowable drift (0.015, 0.02 and 0.025 for $g_1(\mathbf{x})$, $g_2(\mathbf{x})$ and $g_3(\mathbf{x})$, respectively).

3- Results

Results of reliability analysis using the Monte Carlo sampling method are reported in Table 1. According to sampling-based reliability sensitivity analysis results, the obtained importance vectors **ä** and **ç** of random variables with respect to different limit states are shown in Figures 3 and 4, respectively.

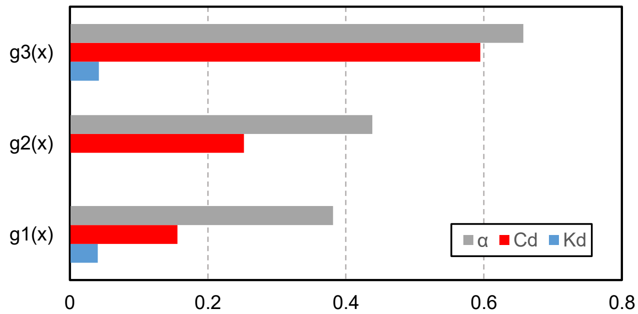

Fig. 3. importance vector

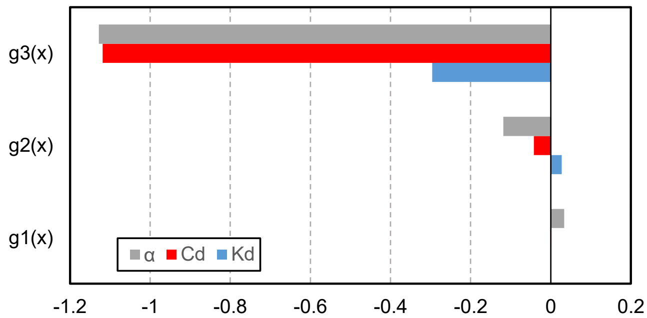

Fig. 4. importance vector

Table 1. Results of sampling analysis

Limit state function	Exceedance probability	Coefficient of variation
$g_1(\mathbf{x})$	0.5363	0.0199
$g_2(\mathbf{x})$	0.1517	0.0236
$g_3(\mathbf{x})$	0.000622	0.0486

4- Conclusions

The obtained results of sampling-based reliability sensitivity analysis of the shear frame equipped with nonlinear viscous damper indicate that:

Velocity exponent and axial stiffness are the most and least effective random variables on the seismic reliability of the frame, respectively.

The importance of random variables depends on the used limit state function in the reliability analysis. For example, the importance value of the damping coefficient is 59% and 9.5% less than the velocity exponent with respect to the maximum drift of 0.015 and 0.025, respectively.

All of the random variables (velocity exponent, axial stiffness, and damping coefficient) are the resistance parameters. So, increasing these parameters leads to an increase in the seismic reliability of the studied shear frame.

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