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Direct displacement based design approach for steel moment frames equipped with nonlinear fluid viscous damper

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ABSTRACT: The direct displacement-based design (DDBD) approach is one of the performance-based design methods that has been paid attention by designers and researchers because of its effective performance in the achievement of design performance level. In previous researches, the DDBD approach has been modified for the design of structures equipped with linear fluid viscous damper (FVD) by applying two different modification factors. These factors are applied because of higher mode effects and the difference between pseudo-spectral velocity and spectral velocity. In this study, this approach is extended for nonlinear FVD and steel moment frames with different heights of 4, 8 and 12 stories are designed using this modified method to achieve life safety performance level under seismic hazard having a probability of occurrence 10% in 50 years. The design force of FVD is also considered as 30% of the design story shear at each story. To evaluate the design method performance, steel moment frames have been simulated in OpenSees and nonlinear time-history analysis has been performed under twenty earthquake records. The results show that average peak story drift becomes close to target drift with applying modification factors in the design process and the designed structures have achieved the desirable performance level. Therefore it can be concluded that the modified DDBD is an effective method for the design of steel moment frames equipped with nonlinear FVD. To evaluate the effect of FVD nonlinearity in design results, steel moment frames have also been designed using DDBD while have been controlled by linear FVD and a comparison has been conducted between design results. The results show that the design sections of structures equipped with linear and nonlinear FVDs are almost the same, whereas the nonlinear behavior of FVD has a significant effect on the design of the damping coefficient..

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1- Introduction

A well-designed structure should be capable to achieve the design performance level under the design earthquakes. The force-based design approach is not very successful in achieving this goal [1]. In the recent years, researchers and designers have been interested in using performance-based design approaches because of their effectiveness in the achievement of design objective. DDBD is one of the most effective performance-based design approaches. This design approach was initially developed by Priestley [2] based on the theory of substitute single degree of freedom (SDOF) system and the equivalent damping. The effectiveness of DDBD has been proven in the design of different structures.

Fluid viscous damper (FVD) is an effective passive control system to protect structures against seismic loadings. DDBD has also been employed for the design of FVD. Kim and Choi [3] showed the effectiveness of DDBD in retrofitting the structures with FVD. Sullivan and Lago [4] designed a nine-story concrete frame controlled by FVD using the DDBD approach and demonstrated that the designed structure could effectively meet desirable performance level. An optimization-based approach for distributing FVDs in the DDBD method has also been proposed by Moradpour and Dehestani [5]. Noruzvand et al. [6] proposed a modified procedure of DDBD for structures controlled by linear FVD by applying two different factors because of higher mode effects and the difference between pseudo-spectral velocity and spectral velocity. Nonlinear FVD has more superior performance than linear FVD against seismic loading, so this modified DDBD is extended for the design of steel moment-resisting frames equipped with nonlinear FVD in this study. For comparison objectives, these frames have also been designed while their performances are controlled by linear FVD, too.

2- Direct displacement-based design

DDBD was initially developed by Priestley [2] based on the theory of SDOF system that more detail about this design

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approach and its design steps can be found in Priestley et al. [7]. Sullivan and Lago [4] first implemented DDBD for the design of new structures controlled by linear FVD. However, this method had led to an expensive over-design [6]. To overcome this drawback, Noruzvand et al. [6] proposed a modified version of DDBD. They developed this approach for linear FVD that in this study, this design approach is extended for steel moment-resisting frames equipped with nonlinear FVD.

Sullivan [8] showed that if β is defined as the proportion of the story shear resisted by linear FVD, damping ξVD due to FVD is determined as follow:

$$\xi_{VD} = \frac{\beta}{2} \quad (1)$$

the damping ξVD of nonlinear FVD can also be determined according to this approach as follows:

$$\xi_{VD} = \frac{\lambda}{2}\beta \quad (2)$$

It can be found that the constant Γ is applied on the damping ξVD because of the nonlinear behavior of FVD. This constant is determined as follow:

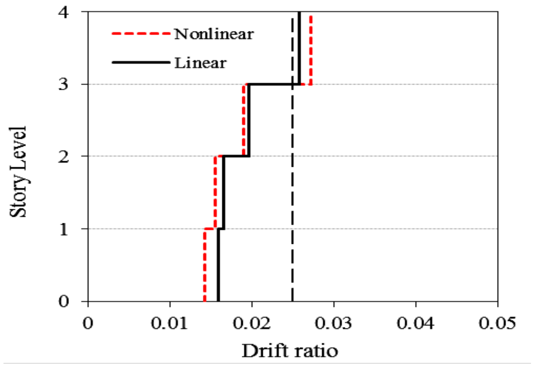
$$\lambda = \frac{2^{2+\alpha}\Gamma^2(1+\alpha/2)}{\pi\Gamma(2+\alpha)} \quad (3)$$

where Γ is the gamma function and α is a constant to simulate the nonlinear behavior of the damper. As noted, Noruzvand et al. [6] modified the DDBD approach for structures equipped with linear FVD. They determined the damping coefficient of FVD by applying two different constants of γ and η as follow:

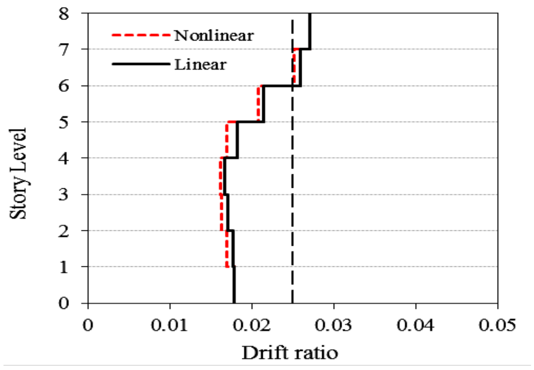
$$C_i = \frac{\gamma T_e F_{d,i}}{2\pi\eta_i\Delta_{d,i}} \quad (4)$$

where Fd,i and Δ d,i are the force and displacement of FVD at ith floor, respectively; Te is fundamental period of system; γ is ratio of pseudo-spectral velocity to spectral velocity; and the constant η represents higher mode effects. In this study, this approach is developed for nonlinear FVD. Therefore, the damping coefficient of nonlinear FVD is determined as follow:

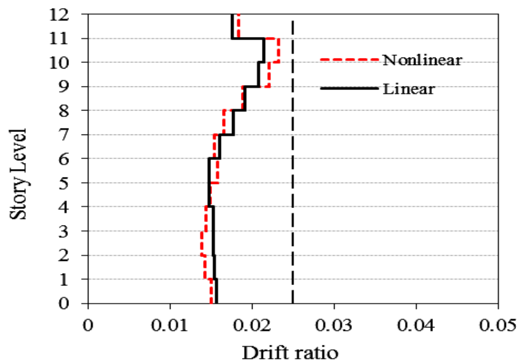
$$C_i = \frac{F_{d,i}(\gamma T_e)^{\alpha}}{(2\pi\eta_i\Delta_{d,i})^{a}} \quad (5)$$



(a): 4-story building



(b): 8-story building



(c): 12-story building

Fig. 1. Average peak story drift ratio of frames under test earthquakes

3- Numerical example

To validate the effectiveness of the developed DDBD approach, three multi-story (4, 8 and 12 stories) steel moment frames are designed based on this design procedure. In this case study, the design objective is defined to achieve life safety under a seismic hazard level with a probability of exceedance of 10% in 50 years. The seismic performance of designed frames has been evaluated under twenty earthquakes proposed in SAC steel project for the Los Angeles region.

The proportion of story design shear resisted by FVD has been selected as β=0.3 and its nonlinearity constant has been assumed equal to α=0.35. For comparison objectives, steel moment frames have also been designed while their performances are controlled by linear FVD. The average peak story drift ratio of the designed frames under test earthquakes is presented in Figure 1. As shown in this figure, the peak drift ratio is generally less than the target drift limit and the designed frames have effectively achieved design performance level. Therefore the modified DDBD approach can be introduced as an effective design method for structures equipped with both linear and nonlinear FVDs.

4- Conclusions

In this paper, steel moment-resisting frames equipped with nonlinear FVD are designed using the modified version of DDBD by applying two different modification factors in the design process because of higher mode effects and the difference between pseudo-spectral velocity and spectral velocity. The effectiveness of this modified method has been shown for linear FVD in previous researches that in this study, this method is extended for nonlinear FVD. Steel moment frames with different heights of 4, 8 and 12 stories have been designed based on this design approach, while the design objective has been defined to achieve life safety under a seismic hazard level with a probability of occurrence 10% in 50 years. To validate the effectiveness of the developed DDBD approach, these frames have been subjected to twenty earthquakes proposed in SAC steel project. For comparison objectives, these frames have also been designed while their performances are controlled by linear FVD. The results show that average peak story drift under test earthquakes is generally less than the target drift limit and the designed frames have effectively achieved design performance level. Therefore the modified DDBD approach can be introduced as an effective design method for structures equipped with both linear and nonlinear FVDs.

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