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Evaluating Accuracy of FEMA-356 Proposed Equation for Effective Damping Ratio for Viscous and Visco-elastic Dampers

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ABSTRACT: The use of dampers for retrofitting and reducing seismic induced vibrations of structures is rising. Among all types of dampers, viscous and visco-elastic dampers are extensively used for buildings. Adding dampers increases equivalent damping ratio of structure which decreases displacement and member stresses. FEMA-356 has proposed an equation for calculating equivalent damping ratio of shear buildings with added dampers, based on the first mode of vibration. In the present research, the goal was to study the accuracy of FEMA-356 formula for evaluating equivalent damping ratio with dampers as compared with the theoretical one. For the latter, the calculation is based on the hysteresis force-displacement response of the dampers. For obtaining hysteresis response, dynamic equation of motion of 2 to 12 stories 2D shear buildings equipped with viscous and visco-elastic dampers subjected to harmonic base excitation were solved. Both regular and mass distributed in height irregular structures with added dampers at all levels were considered. In addition to that, dampers were considered at random stories of the buildings and accuracy of equivalent damping ratios of FEMA-356 were evaluated. This study has shown that for viscous dampers, error of FEMA-356 formula in comparison with theoretical formula for viscous dampers would be in the range of 1 to 3 percent and for visco-elastic ones in which stiffness ratio of visco-elastic dampers to story shear stiffness is 10 percent, would be in the range of 1 to 17 percent. When the stiffness ratio is decreased to 5 percent, the error would decrease to 2, in the worst case. Also, it has been shown that mass irregularity in the height of the buildings increases the maximum error from 17% to 58% for viscoelastic dampers; no significant effect for viscous dampers. Moreover, addition of dampers in random stories of buildings up to six stories would increase error of FEMA-356 formula about 42 and 50 percent, respectively, for viscous and visco-elastic dampers.

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1- Introduction

In this study, fluid dampers (viscous and visco-elastic types) are investigated. The goal is to study the accuracy of FEMA-356 [1] formula for evaluating equivalent damping ratio of buildings in comparison with the evaluated theoretical formula for viscous and visco-elastic dampers added to regular and in height distributed mass irregular buildings.

2- Method of the work

FEMA-356 gives the following formula for evaluating equivalent damping ratio, $\xi_{d,F}$.

$$\xi_{d,F}=(T\sum_{i=1}^{n} C_i\cos^2\theta_i\,\phi_{ri}^{2})/(2\pi\sum_{i=1}^{n}m_i\phi_i^{2}) \quad (1)$$

In Equation 1, T is the fundamental period of rehabilitated building including stiffness of the velocity dependent dampers, C_i is the damping constant for damper i, θ_i is the angle of inclination of device i to the horizontal, ϕ_{ri} is the first mode relative amplitude between the ends of damper i in the horizontal direction, m_i is the reactive mass of the floor level i, ϕ_i is the first mode amplitude at floor level i and n is the number of stories.

For theoretical determination of equivalent damping ratio with added dampers, $\xi_{d,T}$, the confined area in the force-displacement hysteresis loop of dampers' ends is used [2-5].

$$\xi_{d,T}=(\sum_{J=1}^{nd} W_J)/(4\pi W_K) \quad (2)$$

In Equation 2, W_J is the work done by device J in one complete cycle corresponding to floor displacement, nd is number of device and W_K is the maximum strain energy in the frame.

For this investigation, 2, 4, 6, 8, 10 and 12 story braced shear buildings with lumped masses in the story levels are considered. Axial stiffness of braces, lumped masses at the story levels and damping coefficient of dampers are assumed to be 25000 kN/m, 10 tons and 400 kN.sec./m, respectively. Stiffness ratios of visco-elastic dampers to story shear stiffness of ten and five percent are considered. In numerical solution,

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shear buildings are considered equivalent with n degree of freedom systems subjected to base excitation. For irregular mass distribution in the height, two types are considered, mass increasing (type-1) and mass decreasing (type-2) with increasing the height.

3- Results and Discussion

In Tables 1 to 3, equivalent damping ratios calculated by FEMA-356 and theoretical formulas for viscous and visco-elastic dampers for regular and two types of irregular 2- to 12-story buildings are shown. In these tables error percent of equivalent damping ratios calculated by FEMA-356 formula, as defined by Equation 3 are also shown.

$$error\%=ABS((\xi_{d,T}-\xi_{d,F})/(\xi_{d,T}))\times 100 \quad (3)$$

Table 1. Comparison of damping ratio of FEMA-356 and theoretical formula for 2- to 12-story regular buildings

Story numbers	T (period), Sec.	FEMA damping ratio	Viscous damper		Visco-elastic damper	
			Theoretical damping ratio	Error (%)	Theoretical damping ratio	Error (%)
2	0.2033	0.2472	0.2402	2.9142	0.2452	0.8157
4	0.3618	0.1389	0.1371	1.3129	0.1431	2.9350
6	0.5213	0.0964	0.0953	1.1542	0.1022	5.6751
8	0.681	0.0738	0.0731	0.9576	0.0813	9.2251
10	0.8408	0.0598	0.0593	0.8432	0.0688	13.0814
12	1.0007	0.0502	0.0499	0.6012	0.0607	17.2982

Table 2. Comparison of damping ratio of FEMA-356 and theoretical formula for 2- to 12-story type-1 irregular buildings

Story numbers	T (period), Sec.	FEMA damping ratio	Viscous damper		Visco-elastic damper	
			Theoretical damping ratio	Error (%)	Theoretical damping ratio	Error (%)
2	0.2191	0.2294	0.2261	1.4595	0.232	1.1207
4	0.4079	0.1232	0.1216	1.3158	0.1279	3.6747
6	0.5977	0.0841	0.0832	1.0817	0.0907	7.2767
8	0.7879	0.0638	0.0633	0.7899	0.0723	11.7566
10	0.9782	0.0514	0.0511	0.5871	0.0616	16.5584
12	1.1686	0.043	0.0428	0.4673	0.0549	21.6758

Table 3. Comparison of damping ratio of FEMA-356 and theoretical formula for 2- to 12-story type-2 irregular buildings

Story numbers	T (period), Sec.	FEMA damping ratio	Viscous damper		Visco-elastic damper	
			Theoretical damping ratio	Error (%)	Theoretical damping ratio	Error (%)
2	0.1896	0.2651	0.2627	0.9136	0.2689	1.4132
4	0.5999	0.0838	0.0828	1.2077	0.0902	7.0953
6	1.1304	0.0445	0.0443	0.4515	0.0561	20.6774
8	1.7597	0.0286	0.0286	0.0000	0.0444	35.5856
10	2.4746	0.0203	0.0204	0.4902	0.0395	48.6076
12	3.2658	0.0154	0.0155	0.6452	0.0371	58.4906

4- Conclusions

The error of FEMA-356 formula for evaluating equivalent damping ratio for viscous and viscous-elastic dampers in braced shear buildings is studied. Results of the analyses have shown that:

1. Accuracy of FEMA-356 formula used for viscous dampers is much more than that for visco-elastic dampers.
2. For viscous dampers regularity or mass irregularity in height does not have significant effects on the accuracy of evaluated FEMA-356 formula but for visco-elastic dampers, accuracy of FEMA-356 formula decrease in comparison with theoretical evaluation considerably.
3. Decreasing the stiffness ratio of visco-elastic dampers to story shear, increases considerably the accuracy of FEMA-356 formula.
4. Generally, increasing number of stories increases and decreases the accuracy of FEMA-356 formula for viscous and visco-elastic dampers, respectively.
5. In the case that dampers are installed at random stories of the building, accuracy of FEMA-356 formula decreases considerably.

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