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VISCOUS DAMPER RESPONSE ANALYSIS IN BUILDING FRAMES WITH A SIMPLIFIED METHOD

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Abstract: Use of viscous dampers in seismic applications for drift control as well as for reduction of base shear in building frames is studied using a simplified method. This study reports the results of a parametric study performed using the finite element method for multi-story building frames with a range of viscous damping values and the results are compared with a simplified analytical model developed for a single degree of freedom system for a bridge model. The results obtained from the approximation agreed very well with the finite element results. This method may be useful for designers of buildings for earthquake applications.

Keywords: Simplified Method, Viscous Damper, Drift Control, Dynamic Analysis, Time History Analysis

1. Introduction

Past earthquakes have suggested that there is room for improvement with respect to the seismic restraining devices of building frames. Specifically, after Northridge earthquake many non-ductile steel and concrete moment frame buildings were retrofitted with viscous dampers as an Energy Dissipation System (EDS) in structures for reducing seismic demands. This is an innovative way to improve seismic performance as reported by Miyamoto [1]. Popular structural engineering software such as SAP2000 and ETABS are routinely used to model viscous damping elements. This study evaluates the performance of steel moment frame structures with and without EDS subjected to earthquake time histories. The fluid viscous damper (FVD) as an EDS unit is velocity dependent, and hence the forces are out of phase with the axial loading of the columns. Also change in natural period of the building is not significant due to addition of this type of dampers. Many investigators including Charney [2] studied comparison of methods for computing viscous damping ratios for different configuration of structures. Garcia [3] studied the possible optimum configuration for dampers in structures.

The general design philosophy [4] is to design frames for strength only and EDS to provide control of drift. It is normally a trial and error solution using computer code to determine what damping values would provide the specified limits of drifts in building frames. The SAP2000 [5] finite element computer code is used in the current study for structural dynamic analysis under the seismic ground motion input time histories given by the El Centro earthquake (NS-component, May 1940; PGA=0.348g) which is shown in Figure 1.

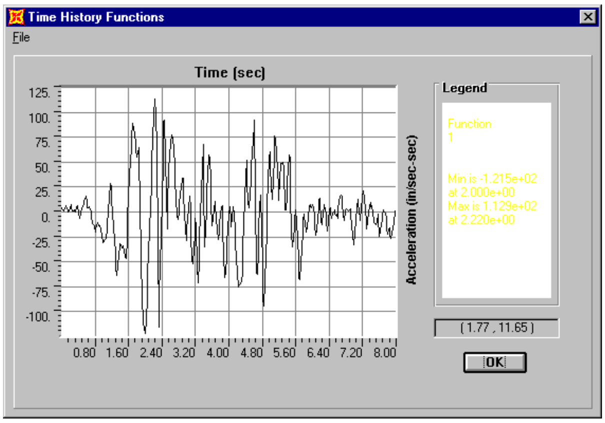

Fig. 01. El Centro earthquake (1940, NS-component) units inches/sec 2

It was found that the damping coefficient values *c* for which the viscous dampers become effective are in the range that is obtainable from the devices available in the market.

2. Methods and Analysis

Several multistory building models with one story, three story, five story and seven story steel moment resisting building frame models with and without diagonal braces with viscous dampers were subjected to the El Centro time history analysis acceleration records using SAP 2000 structural simulation program. These results were compared with the simplified formula developed by Shinozuka [6] el al.

2.1 Simplified Relationship of Peak Displacement with Damping Coefficient

The simplified formula between damping coefficient c_j and corresponding displacement $\hat{x}_j$ of a single-degree-of-freedom system subjected to a white noise was based on random vibration theory:

$$\hat{x}_j \propto \frac{1}{(\xi_{str}+\xi_d)^a} \qquad \text{Eq 1}$$

where ξ_{str} and ξ_d are respectively critical damping ratio of structure itself and viscous dampers, and a is 0.5. However, a=1.0 if the peak response at resonant frequency is considered. Assuming conservatively that the stiffness is zero, the normalized relative displacement curve for zero spring constant is given in approximation:

$$\hat{x}_j = \hat{x}_0 \Big/ \left[1+\frac{c_j}{c_1}\left\{\left(\frac{\hat{x}_0}{\hat{x}_1}\right)^{\frac{1}{a}}-1\right\}\right]^a \qquad \text{Eq 2}$$

where $\hat{x}_0$ is the peak relative displacement of structure without dampers, and $\hat{x}_1$ is peak relative displacement of the structure with damping value of c_1 and zero stiffness for the dampers. Equation (2) can be rewritten for determining the value of damping coefficient c_{req} required to suppress the relative displacement within allowable value $\hat{x}_{all}$ as:

$$c_{req} = c_1 \left\{\left(\frac{\hat{x}_0}{\hat{x}_{all}}\right)^{\frac{1}{a}} - 1\right\} \Big/ \left\{\left(\frac{\hat{x}_0}{\hat{x}_1}\right)^{\frac{1}{a}} - 1\right\} \qquad \text{Eq 3}$$

Therefore, equation (2) shows the normalized relative displacement as a function of c ($=c_{req}$) when k=0, while equation (3) represents the required damping coefficient as a function of allowable relative displacement at joint ($\hat{x}_{all}$). The comparison between the results obtained with the simplified method and the detailed structural simulation are documented.

2.2 Seismic response analysis of building frames with viscous dampers

2.2.1 Example Frames

The building frame models considered in this study are one story (Frame A), three story (Frame B), five story (Frame C) and seven story (Frame D) building frames as follows:

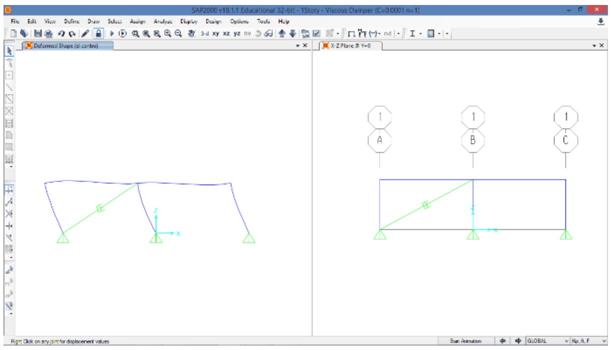

Fig. 2(a). Model A: Two bay (26 feet each) and one story (14 feet high) moment frame.

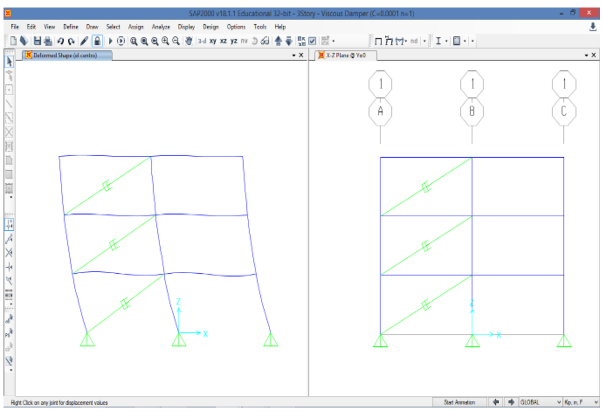

Fig. 2(b). Model B: Two bay (26 feet each) and three story (14 feet each story) moment frame.

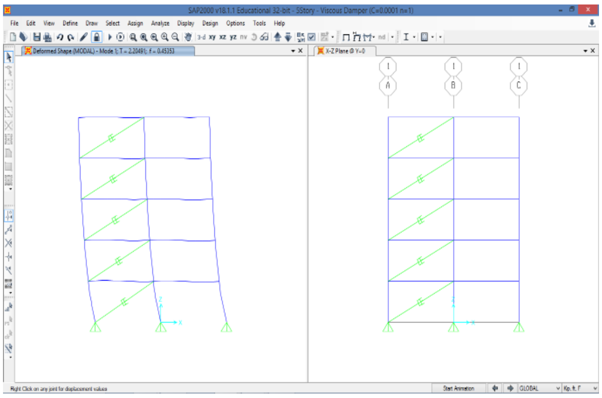

Fig. 2(c). Model C: Two bay (26 feet each) and five story (14 feet each story) moment frame

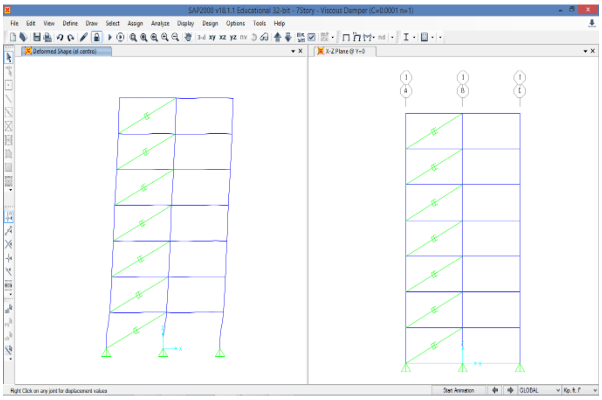

Fig. 2(d). Model D: Two bay (26 feet each) and seven story (14 feet each story) moment frame

The frames were modeled as moment frames with pin bottoms. The diagonal viscous dampers connect between each floors as shown. The material and cross-sectional properties of the models are listed in Table 1.

Table 01. Material and Cross-Sectional Properties of Analysis Models

Example Building	Structural Component (AISC designation)	Moment of Inertia (in ^{4})	Cross-Sectional Area (in^2)
A (One Story)	Beams W16x31	375	9.31
	Columns W14x30	291	8.85
B (Three Story)	Beams W16x67	954	19.6
	Columns W14x90	999	26.5
C (Five Story)	Beams W21x68	1480	20.0
	Columns W14x120	1380	35.3
D (Seven Story)	Beams W21x68	1480	20.0
	Columns - 1 to 4 Story: W14x74	795	21.8
	Columns - 5 to 9 Story: W14x77	1380	35.3

2.2.2 Structural Simulation Results by SAP2000

The effectiveness of the viscous dampers in reducing the relative displacements and base shear are primary interest of this study. Also it is desirable to know whether story displacements can be predicted by a simplified formula than extensive computer analysis. Table 2 shows the natural period and mass participation factors of dominant modes for horizontal motion of analysis models considered. Tables 3(a)-3(e) show comparison of displacements obtained from SAP2000 with the Simplified Formula for different models considered.

Table 02. Building Natural Periods and Mass-Participation Factors

Example Frame	Period (Secs)	Mass Participation %
A (1 Story)	Mode 1 -0.214	99
B (3 Story)	Mode 1 -0.356	88
	Mode 2 - 0.12	10
C (5 Story)	Mode 1 – 2.204	82.5
	Mode 2 – 0.638	13.8
D (7 Story)	Mode 1 – 2.705	79.33
	Mode 2 – 0.849	15.25

Table 03(a). Comparison of Simulation Results with Simplified Method for Frame A

Damping Coefficient (kip-sec/in)	Roof Displacement (inches)		Base Shear (kips)
	SAP2000	Simplified Formula	
No damper	2.33		20.7
0.5	2.079		19.148
1	1.873	1.8768	18.375
1.5	1.6941	1.7105	17.98
2	1.538	1.5712	17.72
2.5	1.403	1.4529	17.51
3	1.2858	1.3512	18.96
3.5	1.185	1.2628	20.4
4	1.11	1.1852	21.75
4.5	1.0483	1.1167	22.98

Table 03(b). Comparison of Simulation Resultswith Simplified Formula for Frame B

Damping Co-efficient (kip-sec/in)	Displacement (inches)		Base Shear (kips)
	SAP2000	Simplified Formula	
No damper	4.77		54.098
0.5	4.5474		50.835
1	4.337	4.3446	48.23
1.5	4.14	4.1592	46.73
2	3.956	3.9889	46.205
2.5	3.785	3.8321	45.936
3	3.626	3.6871	45.83
3.5	3.4787	3.5527	45.827
4	3.412	3.4277	45.9
4.5	3.26	3.3112	46.04

Table 03(c). Comparison of Simulation Results with Simplified Method for Frame C

Damping Co-efficient (kip-sec/in)	Displacement (inches)		Base Shear (kips)
	SAP2000	Simplified Formula	
No damper	6.874344		97.533
0.5	6.648756		95.451
1	6.43758	6.4375	93.459
1.5	6.239592	6.2393	91.552
2	6.053556	6.0529	89.707
2.5	5.878368	5.8773	87.925
3	5.713068	5.7116	86.206
3.5	5.557104	5.5550	84.572
4	5.40954	5.4068	83.007
4.5	5.269584	5.2662	82.258

Table 03(d). Comparison of Simulation Results with Simplified Formula for Frame D

Damping Co-efficient (kip-sec/in)	Displacement (inches)		Base Shear (kips)
	SAP2000	Simplified Formula	
No damper	8.368		109.7
0.5	8.134		106.37
1	7.9188	7.9127	103.59
1.5	7.716	7.7032	101.32
2	7.527	7.5044	99.704
2.5	7.348	7.3157	98.428
3	7.1815	7.1362	97.43
3.5	7.0229	6.9653	96.54
4	6.873	6.8024	95.73
4.5	6.731	6.6470	94.99

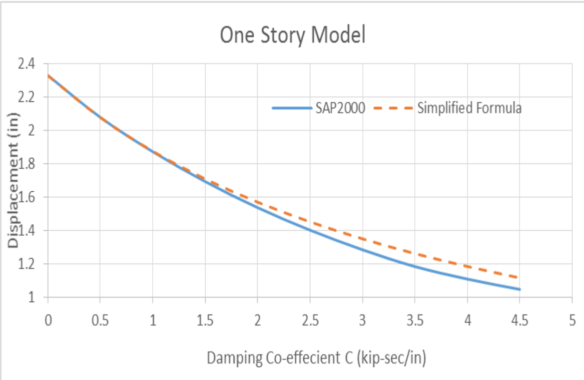

Fig. 03(a). Comparison of Simulation Results with Simplified Method for Frame A

(Damping Coefficient vs. Roof Displacement)

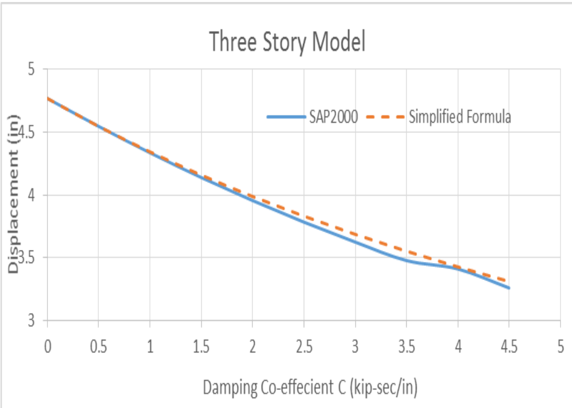

Fig. 03(b). Comparison of Simulation Results with Simplified Method for Frame B

(Damping Coefficient vs. Roof Displacement)

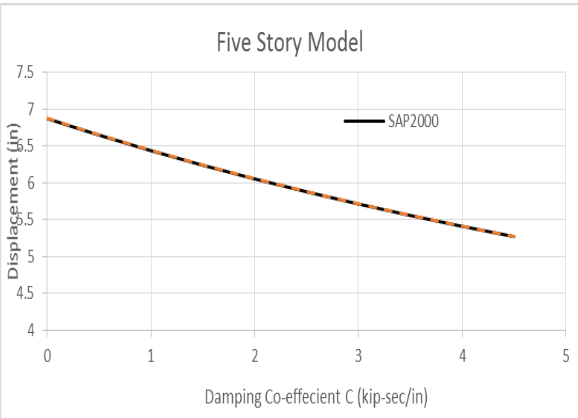

Fig 3(c): Comparison of Simulation Results with Simplified Method for Frame C

(Damping Coefficient vs. Roof Displacement)

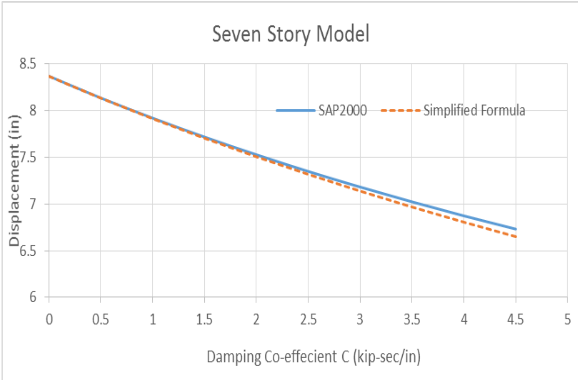

Fig 3(d): Comparison of Simulation Results with Simplified Method for Frame D

(Damping Coefficient vs. Roof Displacement)

The comparison shows good agreement of simulation results of SAP 2000 with the simplified method for multistory buildings studied up to seven story buildings even though the simplified method was developed for a single degree of freedom model.

3. Summary

This study presents a simple analysis technique using two-dimensional finite element model of building frames for displacement control. The numerical results of SAP2000 computer code correlates well with simplified method in predicting displacements for various damping values. The simplified analysis method presented is very useful for design of building structures.

Acknowledgments

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