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A configuration of seismic energy dissipation system for stiff structures

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Summary

The aim of the paper is to assess the efficiency of viscous fluid dampers with toggle bracing mechanism in reducing the seismic response of rigid steel frame structures.

A five story, three bay rigid steel frame was chosen for this study as a reference frame. The structure was then equipped with linear fluid viscous dampers, installed with the toggle brace configuration in the central bay of the building.

The dampers were sized to provide 15%, 25% and 35% of critical damping in the fundamental mode.

The numerical results (peak story shear, peak interstory drift and peak lateral floor acceleration) show that the proposed device is usefulness in enhancing the seismic response of stiff structure.

KEYWORDS: toggle brace system, viscous damper, damping ratio, time history.

1. INTRODUCTION

Conventionally, structures have been designed to resist seismic excitations through a combination of strength, deformability, and energy absorbtion. These structures may deform well beyond the elastic limit in a severe earthquake. They may remain intact only due to their ability to deform inelastically, as this deformation results in increased flexibility and energy dissipation. Unfortunately, this deformation also results in local damage to the structure, as the structure itself must absorb much of the earthquake input energy. It is ironic that the prevention of the devastating effects from earthquakes, including structural damage, is frequently attained by allowing certain structural damage.

Damping is one of many methods that have been proposed for allowing a structure to achieve optimal performance when is subjected to an earthquake [1], [2]. The level of damping in a conventional elastic structure is very low, and hence the amount of enrgy dissipated during transient disturbances is also very low.

Viscous dampers are often placed in diagonal or chevron configuration, however such geometric configurations leads to device displacements that are less or equal

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to the interstory drift [3], [4]. Interstory displacements are small in the case of stiff structure. Small device displacement involves large damper force and expensive damper [5]. Viscous dampers are ideally suited for flexible structures. The toggle brace system overcomes this problem by using the lever principle to amplify interstory drift at damper level and consequently reduced the damper force (reduced damper size and cost) [6].

2. DESCRIPTION OF STRUCTURE, VISCOUS DAMPERS AND INPUT GROUND MOTION

2.1. The structures

A five story, three bay steel frame building was chosen for this investigation as a reference frame. The structure was then modified by the addition of fluid viscous dampers (Figure 1) to improve the seismic performance, with no attempt made to redesign the main frame elements.

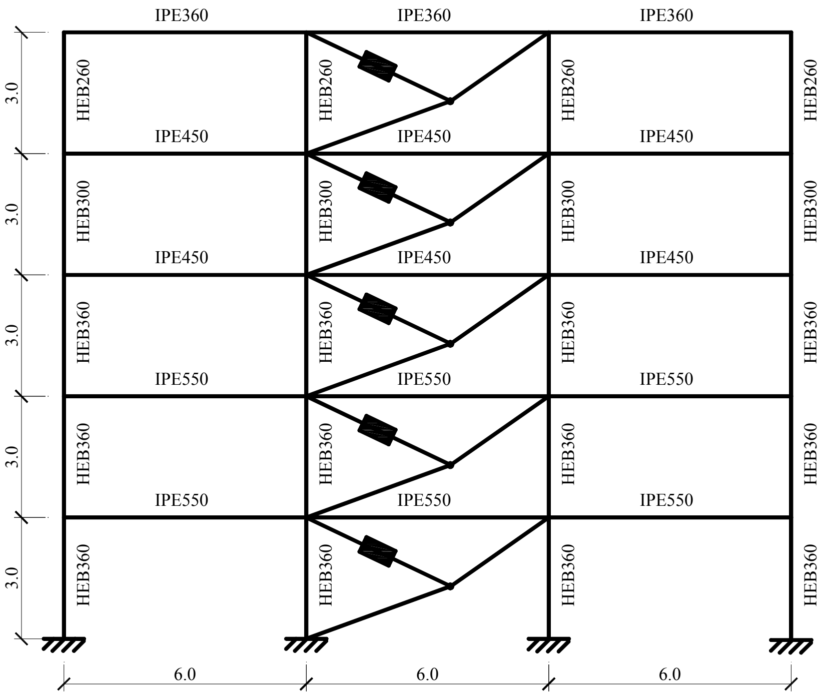

Figure 1. Elevation view of steel frame with viscous dampers

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2.2. The viscous dampers

Five linear viscous dampers (Figure 2) will be installed in the central bay of the building. It is assumed that all dampers have identical properties. The dampers will be installed with a toggle brace configuration. The inherent damping ratio of the structure is assumed to be 5%, and the total effective damping ratio of the whole system is designed as equivalent to 15%, 25% and 35% of critical damping for the first mode.

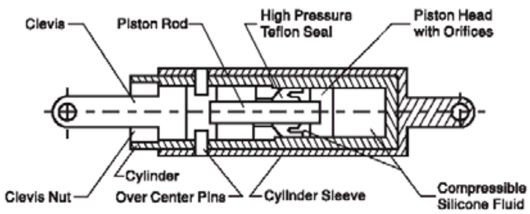

Figure 2. TAYLOR DEVICES Viscous Damper

The damping cofficient of each damper is c=97.51kN-sec/m for the case of a damping ratio of 15%, c=195.02kN-sec/m for a damping ratio of 25% and c=292.53kN-sec/m for a damping ratio of 30%. In this example, the linear effective stiffness is set to zero so that pure damping behavior is achieved.

2.3. Input ground motion

The nonlinear time history analysis was performed using the 1977 Vrancea earthquake record (N-S component) with the maximum peak acceleration of 0,198g (Figure 3).

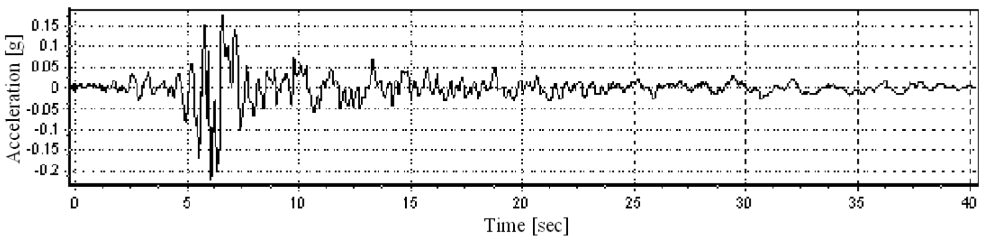

Figure 3. Ground acceleration for 1977 Vrancea Earthquake

3. NUMERICAL RESULTS AND DISCUSSIONS

The time history results are presented and discussed. Comparisons are made of estimated peak story shear, peak interstory drift and peak floor acceleration.

3.1. Peak story shear

The peak story shear $(F_{\max})$ are given as a fraction of the total frame weight $(W = 2589.84kN)$. Table 1 compares the values obtained for the four cases.

As expected, best performance is achieved for a damping ratio of 35%, although the case of 25% damping ratio produces important response reduction. It should be mentioned that these results apply for an elastic structural system.

Peak story shear profiles are presented in Figure 4.

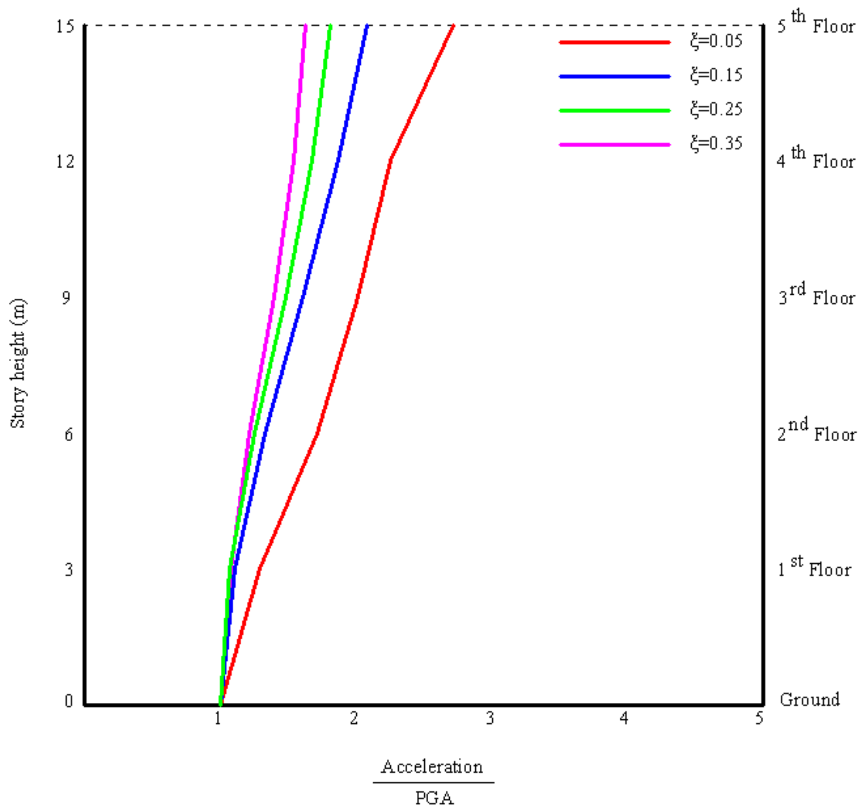

Figure 4. Peak story shear/total weight profile for Vrancea 1977 earthquake

Table 1. Peak story shear/weight results

Floor	$\xi = 0.05$	$\xi = 0.15$		$\xi = 0.25$		$\xi = 0.35$	
	$\frac{F_{max}}{W}$	$\frac{F_{max}}{W}$	Reduction ratio (%)	$\frac{F_{max}}{W}$	Reduction ratio (%)	$\frac{F_{max}}{W}$	Reduction ratio (%)
5	0.106	0.066	37.736	0.059	44.339	0.054	49.057
4	0.192	0.132	31.250	0.118	38.542	0.108	43.750
3	0.263	0.197	25.095	0.177	32.670	0.163	38.023
2	0.325	0.263	19.076	0.236	27.385	0.217	33.231
1	0.375	0.329	12.267	0.295	21.333	0.271	27.733

3.2. Peak interstory drift

A comparison of peak interstory drift $\left(d_r^{max}\right)$ responses of the frame structure with and without viscous dampers is shown in Table 2. The obtained results indicate that the maximum interstory drift values were reduced in proportion to the amount of damping supplied in the structure.

Figure 5 shows peak interstory drift profiles for the analysed cases.

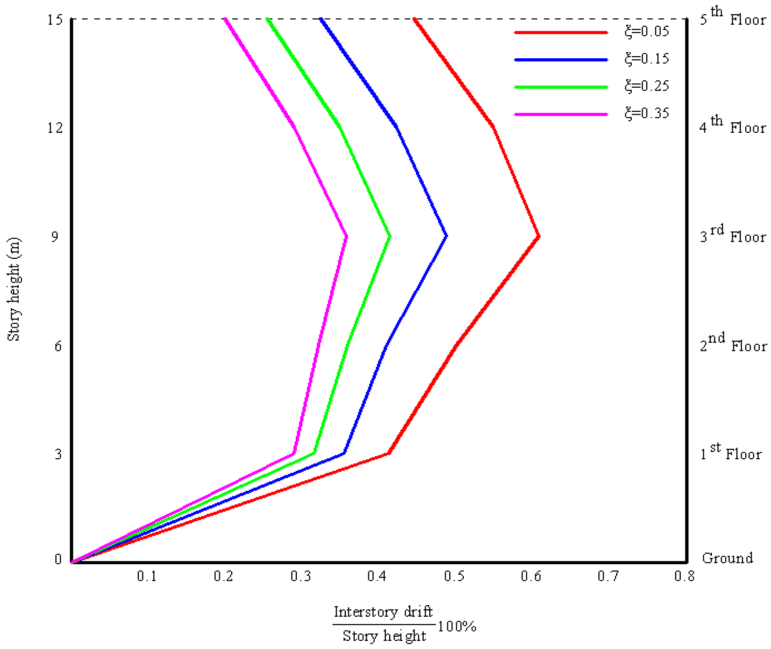

Figure 5. Peak interstory drift/height for Vrancea 1977 earthquake

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Table 2. Peak interstory drift/height results

Floor	$\xi = 0.05$	$\xi = 0.15$		$\xi = 0.25$		$\xi = 0.35$	
	$\frac{d_r^{max}}{h}$	$\frac{d_r^{max}}{h}$	Reduction ratio (%)	$\frac{d_r^{max}}{h}$	Reduction ratio (%)	$\frac{d_r^{max}}{h}$	Reduction ratio (%)
5	0.768	0.373	51.432	0.282	63.281	0.206	73.177
4	0.705	0.482	31.631	0.396	43.830	0.317	55.035
3	0.621	0.547	11.916	0.471	24.155	0.398	35.910
2	0.513	0.448	12.670	0.405	21.053	0.362	29.435
1	0.420	0.387	7.857	0.359	14.524	0.333	20.714

3.3. Peak lateral floor acceleration

This parameter is almost never taking into account in the design process, because it requires a time history analyses to obtain it. From the damageability perspective it is the measure that impacts damage to the ceiling and lights, electrical and mechanical equipment, elevators and the building contents.

Table 3 compares maximum lateral floor accelerations (a_{max}) normalized by peak ground acceleration (PGA) for the analyzed cases. Reductions of up to 39.92% and 33.32% in the peak values of accelerations were obtained for damping ratios of 35% and 25% (Figure 6).

Table 3. Peak lateral acceleration/PGA results

Floor	$\xi = 0.05$	$\xi = 0.15$		$\xi = 0.25$		$\xi = 0.35$	
	$\frac{a_{max}}{PGA}$	$\frac{a_{max}}{PGA}$	Reduction ratio (%)	$\frac{a_{max}}{PGA}$	Reduction ratio (%)	$\frac{a_{max}}{PGA}$	Reduction ratio (%)
5	2.713	2.082	23.258	1.809	33.321	1.630	39.919
4	2.260	1.864	17.522	1.677	25.796	1.545	31.637
3	2.017	1.604	20.476	1.482	26.524	1.400	30.590
2	1.715	1.325	22.740	1.254	26.880	1.212	29.329
1	1.294	1.102	14.838	1.071	17.233	1.075	16.924

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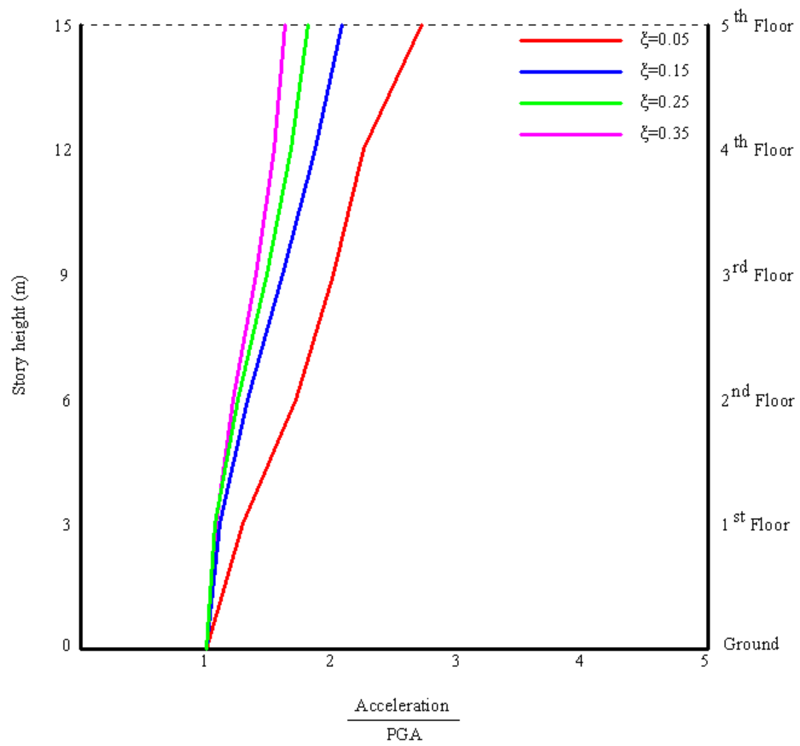

Figure 6. Peak lateral acceleration/PGA profile for Vrancea 1977 earthquake

4. CONCLUSIONS

The paper studies the seismic response of stiff frame structure fitted with viscous dampers installed in a toggle brace configuration, for different damping ratios. The toggle brace system utilizes the lever principle to magnify frame interstory drifts at the damper level and consequently reduce the required damper force.

The time history results show that story shears, interstory drifts and lateraral floor accelerations were reduced significantly in proportion to the amount of damping supplied in the structure [7].

The toggle brace system will facilitate the use of viscous dampers in stiff frame structures.

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