Structural Mechanics

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Numerical studies on the seismic performance of three structural systems

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Summary

For many years, the basic intent of the building code seismic provisions has been to provide buildings with an ability to withstand intense ground shaking without collapse, but potentially with some significant structural damage.

The damage to buildings, transportation structures and lifelines wrought by the 1989 Loma Prieta earthquake, the 1994 Northridge earthquake, and the 1999 Hanshin earthquake near Kobe, has forced structural engineers, disaster response agencies and building officials to carefully consider seismic response of the building environment in terms of performance rather than life-safety.

Civil engineering structures normally rely on their ability to dissipate energy to resist dynamic forces such as strong earthquakes. In recent years, to keep the vibration of these structures within the functional and serviceability limits and to reduce structural and architectural damage caused by extreme loads, different passive protective systems have been proposed. Addition of energy dissipation devices (EDDs) is considered one of the viable strategies for enhancing the seismic performance of building structures. For many building structures, EDDs may provide considerable performance improvement or cost saving.

This paper provides a comparison of the performance indices of a three story building with three different structural systems – moment frame, viscously damped frame and a base isolated frame. Fluid viscous damping and base isolation have the same objective of significantly decreasing the response of a structure to earthquake excitation. With both fluid viscous damping and base isolation it is possible to have a structure remain within the elastic region, so there is no permanent deformation from a seismic event. Each of the models were analyzed as linear structures and subjected to time histories for 3 different earthquakes of Vrancea type. The non-dimensional performance indices considered for the models are: Peak Drift ratio, Peak Base Shear and Peak Level Acceleration.

In summary, the viscously damped frame has the best overall relative performance of the three framing schemes. The base isolated frame is better than moment frame.

KEYWORDS: steel frames, passive control, base isolation, viscous damper, time history analysis.

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1. INTRODUCTION

Earthquakes represent one of the most damaging disasters. Repairing an area that has experienced an earthquake is an expensive and difficult process. Engineers have introduced different techniques to prevent a large amount of the damage typically caused by earthquakes. The use of passive energy dissipation devices represents a feasible alternative to improve seismic behavior of structures by reducing the structural damage resulting from environmental disturbances [1].

Damping is one of many different methods that have been proposed for allowing a structure to achieve optimal performance when is subjected to an earthquake. The level of damping in a conventional elastic structure is very low, and hence the amount of energy dissipated during transient disturbances is also very low. During strong motions, conventional structures usually deform beyond their elastic limits, and eventually fail or collapse.

The concept of supplemental dampers added to a structure assumes that much of the energy input to the structure will be absorbed by supplemental devices [2]. An ideal damper will be able to reduce both stress and deflection in the structure. Fluid viscous dampers operate on the principle of fluid flow through orifices. A stainless steel piston travels through chambers that are filled with silicone oil. The pressure difference between the two chambers cause silicon oil to flow through an orifice in the piston head and seismic energy is transformed into heat.

Seismic isolation is another alternative for protecting structures from earthquakes. The philosophy behind this method is based on minimizing the earthquake induced forces transferred to the superstructure. During the past 20 years, seismic isolation has emerged as one of the most promising retrofitting strategies for improving the seismic performance of existing buildings. It is also an attractive approach for new construction when conventional design is not suitable or economical [3], [4].

Japan, New Zealand, and a number of European countries pioneered the use of seismic isolation in civil engineering structures. More recently, the United States has begun to implement isolation technology in bridges. In the seismic isolation approach, the superstructure mass is uncoupled from seismic ground motions. This is also referred to as "superstructure" isolation. It uses special types of bearings called "seismic isolation bearings," which are placed below the superstructure and on top of the substructure (foundation). In the event of a strong earthquake, they add flexibility to the structure, by elongating its period and dissipating energy. It could also give rise to large relative displacements across the isolator interface; this can be controlled by incorporating damping elements in the bearing or by adding supplemental dampers.

2. THE STRUCTURE, DAMPERS, BASE ISOLATORS, LOADS

2.1. The structure

Because the majority of buildings in Romania are less than three stories in height, a three story steel frame was selected as a reference frame. The structure was designed as a conventional SMRF (Figure 1) to provide a benchmark for seismic performance comparison with passive control systems. The following design parameters according to P100-1/2006 were used to design SMRF [5]:

- importance class II γ=1,2
- design ground acceleration a_g=0,24cm/sec^2
- T_C=1,6 sec
- behavior factor q=6

All connections between beams and columns are assumed rigid connections.

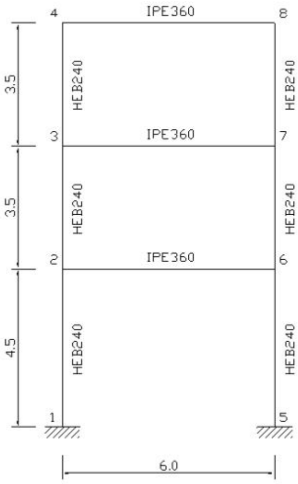

Figure 1. 3 Storey Moment Frame

The structure was then modified by the addition of fluid viscous dampers (Figure 2) or base isolators (Figure 3) to improve the seismic performance, with no attempt made to redesign the main frame elements.

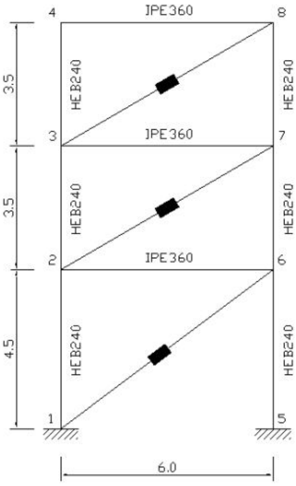

Figure 2. 3 Storey Frame with Linear Viscous Dampers

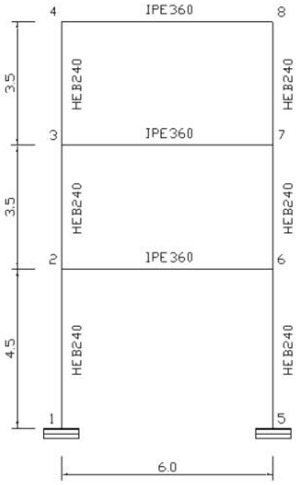

Figure 3. 3 Storey Frame with Base Isolators

2.2. The dampers

The linear viscous dampers (Figure 4) will be installed with a diagonal 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 designated at 20% of critical.

The damping cofficient used for all dampers is c=245kN-sec/m. In this example, the linear effective stiffness is set to zero so that pure damping behavior is achieved.

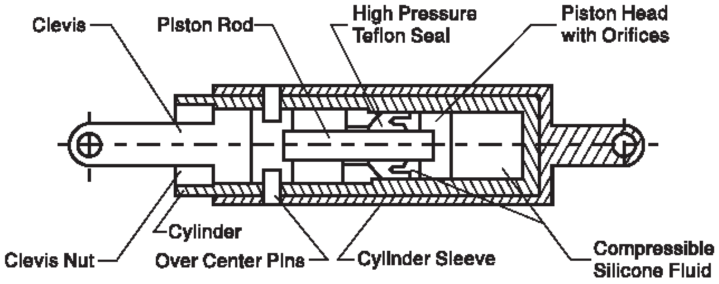

Figure 4. TAYLOR DEVICES Viscous Damper

2.3. The base isolators

The isolators are of elastomeric type (Figure 5) and have been chosen from FIP INDUSTRIALE catalog, according to the vertical reactions requirements [6].

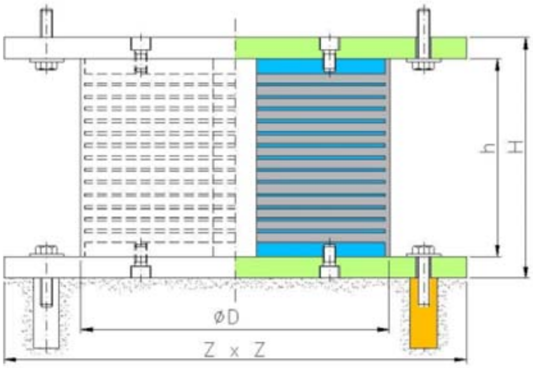

Figure 5. FIP INDUSTRIALE Base Isolator

The selected isolators SI-S 400/78, have the following specifications:

Mechanical properties: Vertical load V=570kN; Horizontal stiffness=0.64kN/mm.

Geometrical characteristics: Diameter D= 400mm; Total height Z=450mm.

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2.4. The loads

The seismic performance of these structural systems was studied using linear response-history analysis. Three scaled artificial earthquakes of Vrancea type, that matched on average a P100-1/2006 Provisions response spectrum were used for analysis.

3. NUMERICAL RESULTS

The results of the time history analyses are presented and discussed. Comparisons are made of estimated base shear, interstory drift and floor acceleration.

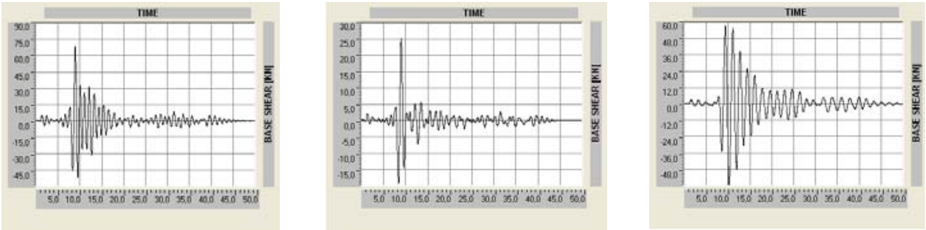

Figure 6. Base Shear for Vrancea type earthquake

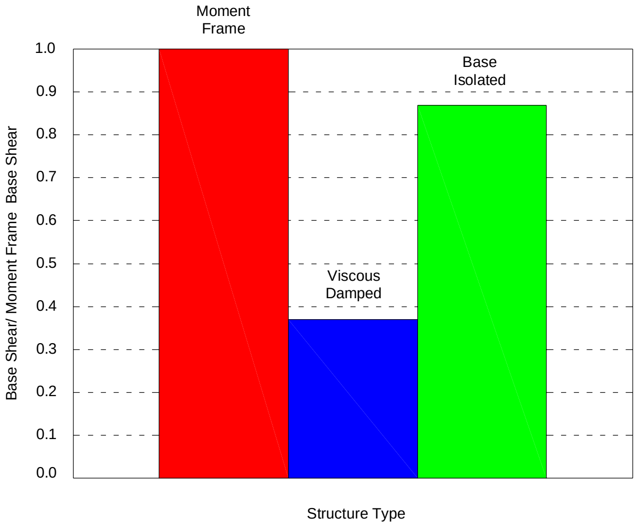

Figure 7. Normalized Maximum Value of Base Shear

3.1. Base shear

Figures 6 and 7 show a comparisons of base shears for the three structural schemes that were studied. Viscous dampers are extremely effective in reducing the base shear of the frame, whereas the addition of base isolators results in a modest reduction in base shear.

3.2. Interstory drift

This is a code design parameter and is something most engineers focus upon during the design process. From a damageability perspective, it is a measure that impacts damage to the framing system, building façade and windows, piping, ductwork and partitions.

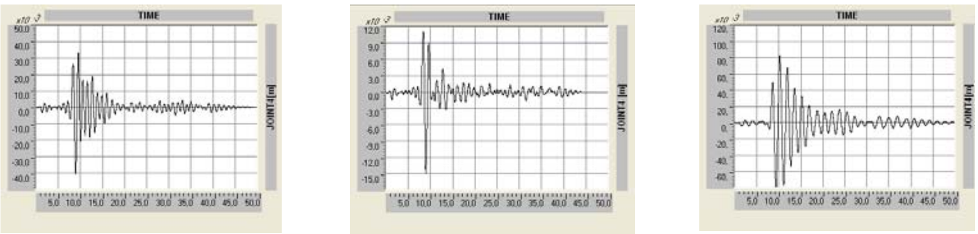

Figure 8 Top floor displacements

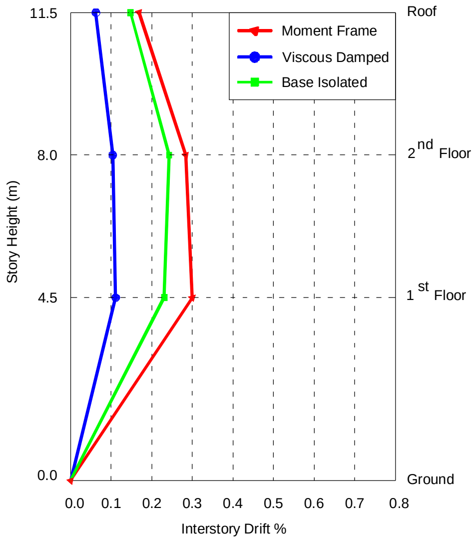

Figure 9 Interstory Drift

Results proved that control methods were successful in reducing the floor displacements of the structure (Figure 8). The viscously damped frame reduced the maximum drift by 63.30%, whereas the base isolated frame reduced the maximum drift by 23.90%. Figure 10 shows a comparison of maximum values of interstory drift for all framing schemes, normalized to the moment frame.

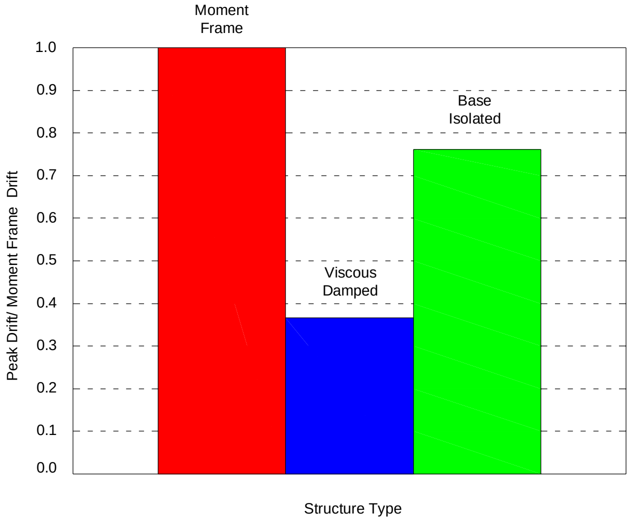

Figure 10 Normalized Maximum Value of Interstory Drifts

3.3. Floor accelerations

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.

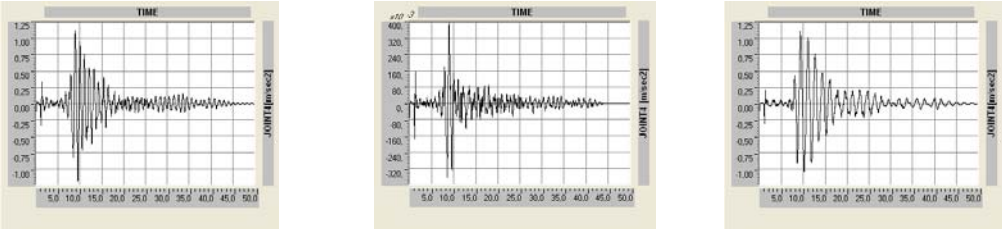

Figure 11 Top floor accelerations

In assessing the acceleration performance, the viscously damped frame has the best performance (Figure 11). The viscously damped frame reduced the maximum floor

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acceleration by 66.90%, whereas the base isolated frame reduced the maximum floor acceleration by 9.20% (Figure 12).

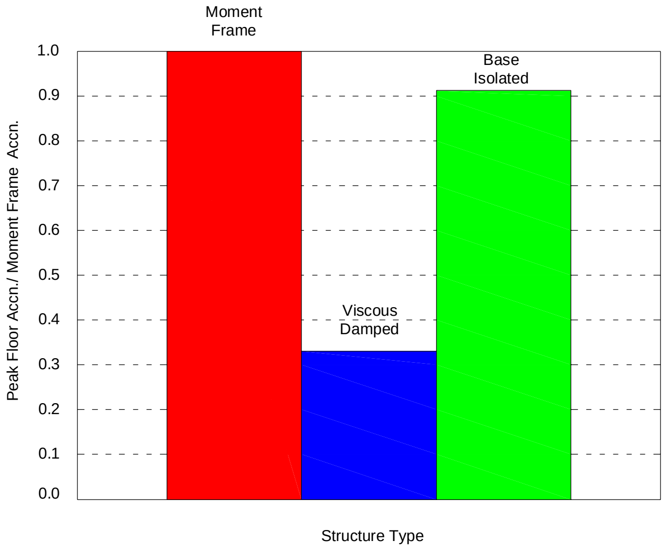

Figure 11 Normalized Peak Floor Accelerations

3.4. Performance indexes

For each control approach considered (i.e. viscous damper and base isolation), the uncontrolled response of the structure was compared with the controlled response [7].

The non-dimensional performance indexes considered in this study are Peak Base Shear (PI_1), Peak Drift ratio (PI_2), Peak Level Acceleration (PI_3).

They are defined as follows: $PI_1 = \frac{F_{b,c}^{\max}}{F_{b,u}^{\max}}$; $PI_2 = \frac{\delta_c^{\max}}{\delta_u^{\max}}$; $PI_3 = \frac{\ddot{x}_c^{\max}}{\ddot{x}_u^{\max}}$; where:

$F_{b,u}^{\max}; F_{b,c}^{\max}$ - the maximum base shear of the uncontrolled/controlled frame;

$\delta_u^{\max}; \delta_c^{\max}$ - the maximum inter storey drift ratio of the uncontrolled/controlled frame;

$\ddot{x}_u^{\max}; \ddot{x}_c^{\max}$ - the maximum absolute floor acceleration of the uncontrolled/controlled frame.

The results presented in Table 1 show that the viscouly damped frame was the most effective in reducing the building's response.

Table 1. Performance index for peak base shear, peak drift and peak acceleration

Cases	Performance Index			% Reduction		
	PI_1	PI_2	PI_3	Base Shear	Story Drift	Acc
Viscous Damped	0.367	0.367	0.331	63.30	63.30	66.90
Base Isolated	0.869	0.761	0.908	13.10	23.90	9.20

4. CONCLUDING REMARKS

The objective of the paper is to evaluate the efficiency of two passive control systems. This paper has presented a comparative study of seismic performance (base shear, interstory drift and floor acceleration) of a three story steel building. The three story moment resisting frame was designed according to P100-1/2006 Provisions and than retrofitted with viscous dampers and base isolators. The structure was subjected to linear time history analyses for different earthquakes of Vrancea type.

The above numerical results presented for the three story one bay frame can not be generalized. The analyses show that the seismic performance of the viscously damped frame significantly exceeds that of the other framing schemes. The three story base isolated frame had better performance than the three moment frame.

These parameters indicate that structural and non-structural damages are significantly reduced in the case of viscously damped frame.

The results emphasis that seismic performances of the building depend upon the structural framing scheme chosen for that building.

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