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SEISMIC PERFORMANCE OF STEEL FRAME STRUCTURES WITH PASSIVE CONTROL SYSTEMS

H. A. MOCIRAN[1]

Abstract: *The aim of the paper is to evaluate the efficiency of using two passive control systems (fluid viscous dampers and base isolators) for earthquake protection of steel frame structures. The paper presents a numerical comparative study of seismic performance (base shears, inter-storey drifts and storey accelerations) of a 3D five storey steel frame building with and without the aforementioned control systems. The unequipped and equipped structures are located in Iași and have been subjected to nonlinear time history analyses for seven different semiartificial earthquakes of Vrancea 1977 type. The analyses show that the seismic performance of the structure equipped with fluid viscous dampers significantly exceeds that of the base isolated structure.*

Key words: *passive control systems, fluid viscous dampers, base isolators, seismic performance.*

1. Introduction

In the classical seismic design, an important part of earthquake input energy is dissipated by the structure through inelastic deformations. Inelastic behaviour occurs in plastic hinges at beam-column joints and column bases. The amount of inelastic deformations is related to structural damage.

An innovative approach for protecting the buildings from earthquakes consists of adding fluid viscous dampers to the structure. The aim of these dampers is to consume a significant part of the seismic input energy, reducing the energy dissipated by the structure itself and thus minimizing structural and non-structural damage. A fluid viscous damper consists of a closed cylinder filled with silicone oil and a stainless steel piston with a bronze head with specially shaped small holes [5].

Other innovative approach of improving the seismic response of buildings consists of adding base isolators to the structure. The fundamental principle of seismic isolation is to minimize the earthquake induced forces in a structure by elongating its fundamental period away from the dominant period of ground motion, or by adding damping to the structure, or both. The paper focuses on elastomeric isolators, which consist of alternate layers of rubber and vulcanized reinforcement steel plates [4].

[1] Faculty of Civil Engineering, Technical University of Cluj-Napoca.

2. Description of Structure, Fluid Viscous Dampers, Base Isolators and Input Ground Motions

2.1. Description of Structure

A five storey residential building with a squared plan (Figure 1), located in Iași, was chosen in this study. The structure of the building is formed by six moment resisting frames (MRFs) along X direction (1 to 6) and six MRFs along Y direction (A to F).

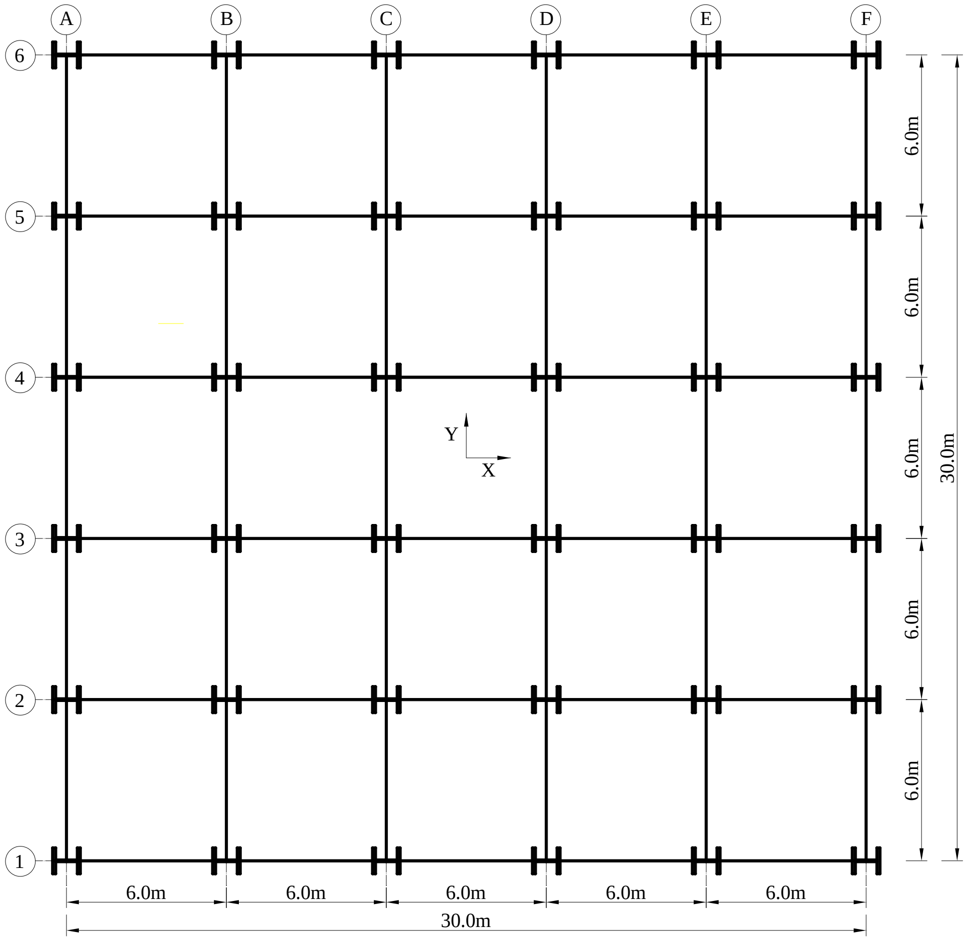

Fig. 1. *Plan view of the building*

The storey height equals 3.5 m at all levels. The floors are assumed to behave as rigid diaphragms in plane, their thickness being equal with 15 cm.

The columns are considered fixed at the base.

The characteristic value of the dead load for the typical floors is 5 kN/m^2 and 5.5 kN/m^2 at the roof level. The characteristic value of the live load is 2 kN/m^2 for all stories.

The structure has been designed with dissipative behaviour, ductility class high (DCH), according to the Romanian seismic design code P100-1/2013 and EN 1993-1-1, for Ultimate Limit State (ULS) [6], [7].

The seismic actions have been computed by means of modal response analysis.

The main features of the design spectrum are: peak ground acceleration: a_g=0.25g, corner period: T_c=0.7 s, behaviour factor: q=6.5 for multi-storey steel MRFs.

The overstrength of the structural system, $1.1\gamma_{ov}\Omega=3$, has been used for the design of columns. According to P100-1/2013, γ_{ov} represents the material overstrength factor and is equal with 1.40 for S235, and Ω represents the overstrength factor.

Steel grade S235 has been used for beams, while S355 has been used for columns.

Structural members cross sections are given in Tables 1 and 2.

Members cross sections for frames from axes 1 and 6 Table 1

Storey	Exterior columns	Interior columns	Beams
4-5	HE 200 M	HE 240 M	IPE 240
1-3	HE 240 M	HE 300 M	IPE 220 O

Members cross sections for frames from axes 2 to 5 Table 2

Storey	Exterior columns	Interior columns	Beams
4-5	HE 200 M	HE 240 M	IPE 330
1-3	HE 240 M	HE 300 M	IPE 300

Then, the building has been equipped with fluid viscous dampers or base isolators, without redesigning its structural members, with the purpose of fulfilling P100-1/2013 requirement regarding the Serviceability Limit State (SLS). For SLS, the inter-storey drift limit is 0.075 times storey height for an earthquake with a reference return period of 40 years [6].

2.2. Description of Fluid Viscous Dampers

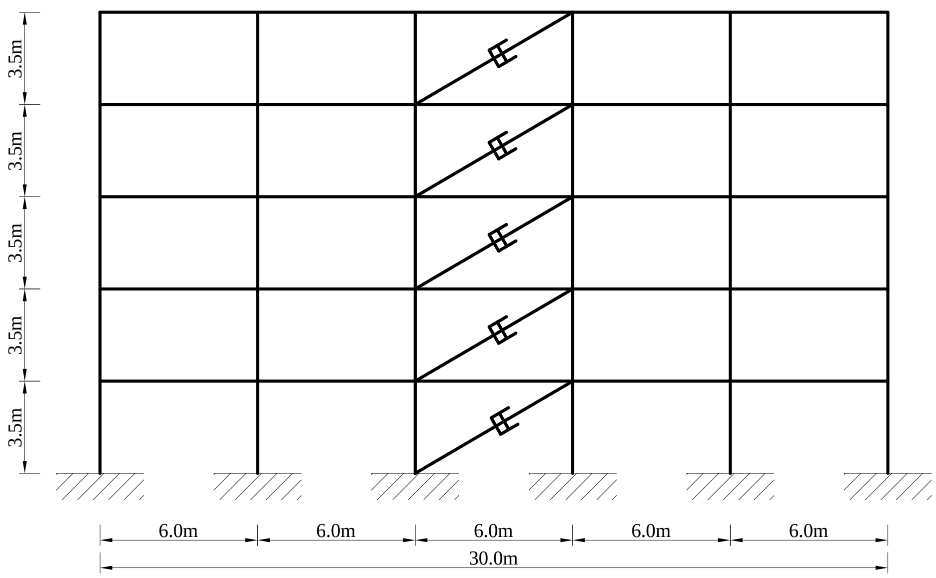

Fig. 2. *Elevation view of o a perimeter MRF equipped with dampers*

Fluid viscous dampers, of Taylor Devices type, have been installed with a diagonal configuration in the central bay of all perimeter frames, at each story (Figure 2).

The inherent damping ratio of the unequipped structure is assumed 5%.

Two usual supplemental damping ratios (ξ_{supl}=15% and ξ_{supl}=20%) of the first two modes of vibrations have been considered in this research [2].

The values of the damping constants, considered equal at all storeys on each direction, have been obtained by using the formula proposed by Hwang [1].

2.3. Description of Base Isolators

The elastomeric isolators, of *FIP Industriale* type, have been chosen from catalogue, for a maximum displacement of 100 mm [4].

The main characteristics of the selected isolators SI-H 350/50 are:

- V=700 kN – maximum vertical load at load combinations including the seismic action;
- F_{zd}=3510 kN – maximum vertical load at non-seismic load combinations, at ULS;
- K_e=2.69 kN/mm – effective horizontal stiffness;
- K_v=1550 kN/mm – vertical stiffness.

2.4. Description of Input Ground Motions

The seismic performance of the equipped structures has been investigated by nonlinear time history analyses.

A set of seven semiartificial earthquakes of Vrancea 1977 type, on NS and EW directions, compatible with the elastic response spectrum for Iași, generated with SeismoMatch program, have been used for analyses.

3. Numerical Results and Discussions

The results of the time history analyses are presented and discussed. Comparisons have been made between the equipped and unequipped structure for the following parameters: maximum base shears; maximum inter-storey drifts, which are related to degradation of non-structural drift sensitive components; and maximum absolute storey accelerations, which are related to degradation of non-structural acceleration sensitive components [3].

3.1. Maximum Base Shears

Figures 3 and 4 show the average value (of the seven time history analyses) of the maximum values of the base shears of the structures with and without passive control systems, under the Vrancea 1977 type earthquakes, components NS and EW.

It can be seen that by equipping the structure with passive control systems, the values of the maximum base shear have been significantly reduced in all cases. The reductions are higher on the Y direction of the structure. Best seismic performance has been achieved in the case of viscously damped structure with a supplementary damping ratio of 20%. In this case, compared to the unequipped structure, the base shear has been reduced by 41.71% on the X direction of structure and by 54.72% on the Y direction of structure.

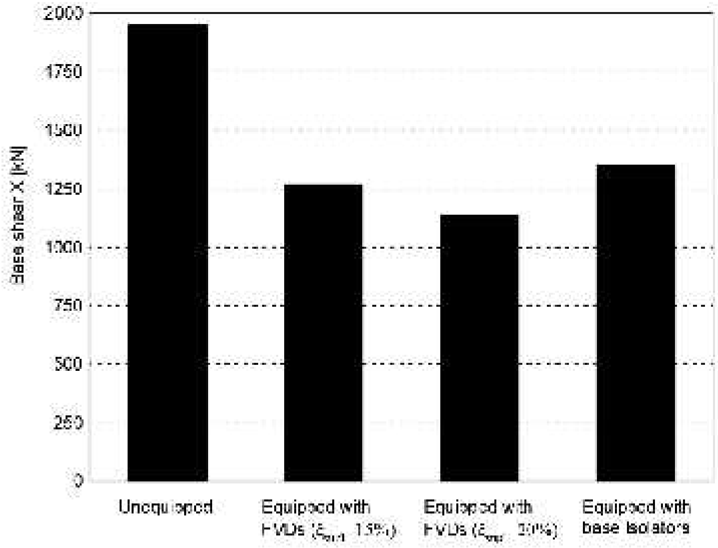

Fig. 3. *Maximum base shears at ULS, on the X direction of the structure*

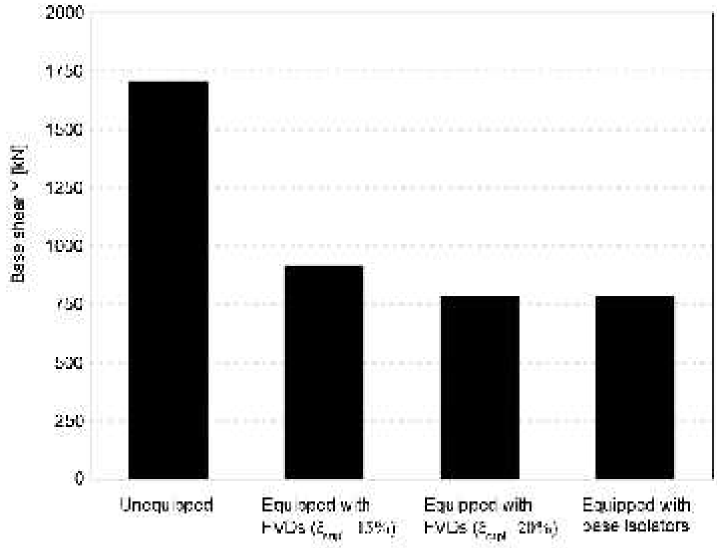

Fig. 4. *Maximum base shears at ULS, on the Y direction of the structure*

3.2. Maximum Inter-Storey Drifts

Figures 5 and 6 show the average value (of the seven time history analyses) of the maximum values of the inter-storey drifts over the story height of the structures with and without passive control systems, under the Vrancea 1977 type earthquakes, components NS and EW.

These figures indicate significant inter-storey drifts reductions in all cases, when passive control systems have been used. Again, higher reductions have been obtained on the Y direction of the structure. Best seismic performance has been achieved in the case of viscously damped structure with a supplementary damping ratio of 20%. In this case, compared to the unequipped structure, the inter-storey drifts have been reduced by 37.55% to 41.74% on the X direction of structure and by 43.11% to 54.77% on the Y direction of structure. Notice that in the case of viscously damped structures, higher reductions of the inter-storey drifts have occurred at the lower storeys, while for the base isolated structure higher reductions have occurred at the upper storeys

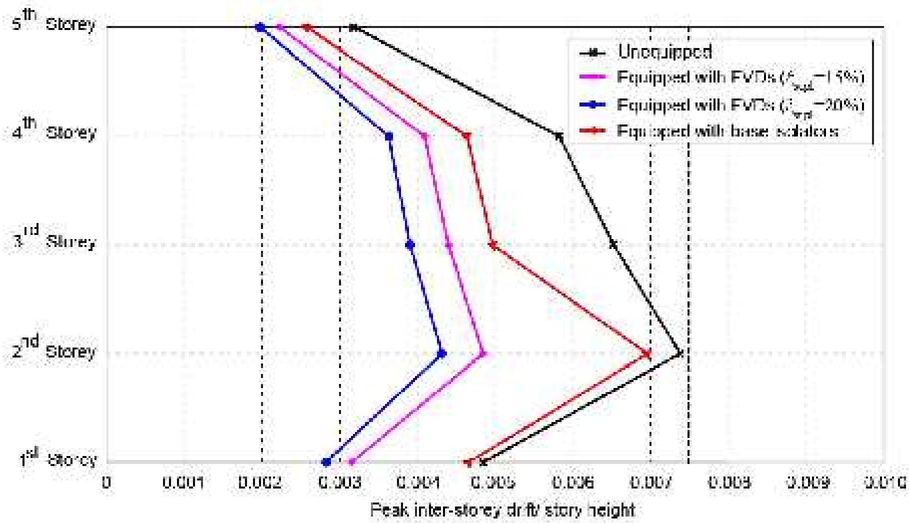

Fig. 5. *Inter-storey drift/storey height profile, on the X direction of the structure, at SLS*

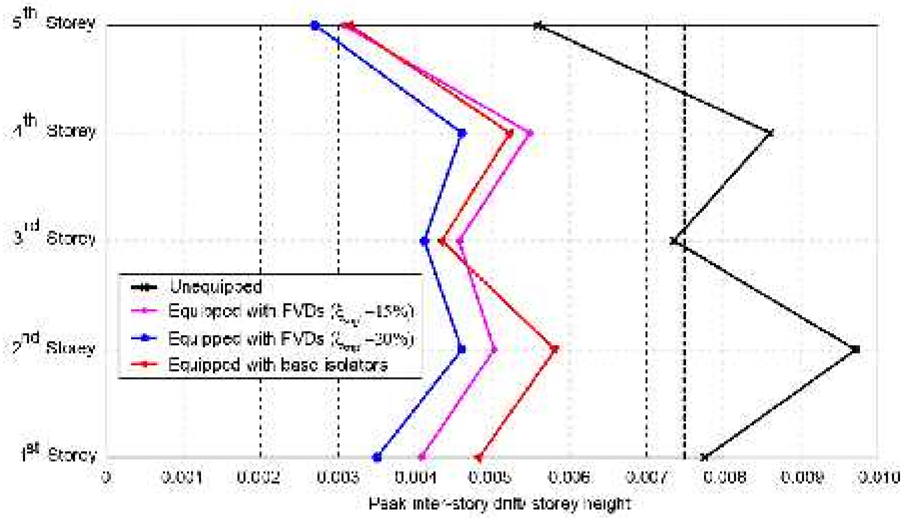

Fig. 6. *Inter-storey drift/storey height profile, on the Y direction of the structure, at SLS*

3.3. Maximum Storey Accelerations

Figures 7 and 8 show the average value (of the seven time history analyses) of the maximum values of the absolute accelerations of the structures with and without passive control systems, under the Vrancea 1977 type earthquakes, components NS and EW.

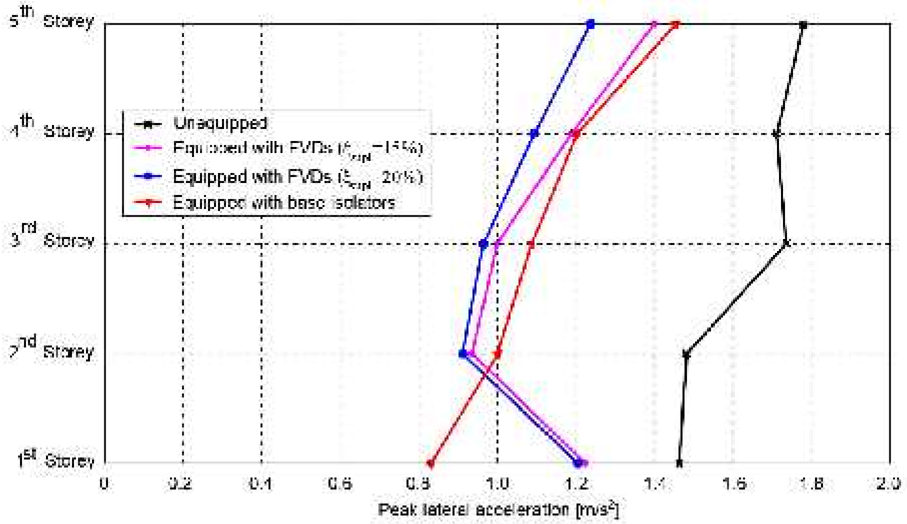

Fig. 7. *Maximum storey accelerations profile, on the X direction of the structure, at SLS*

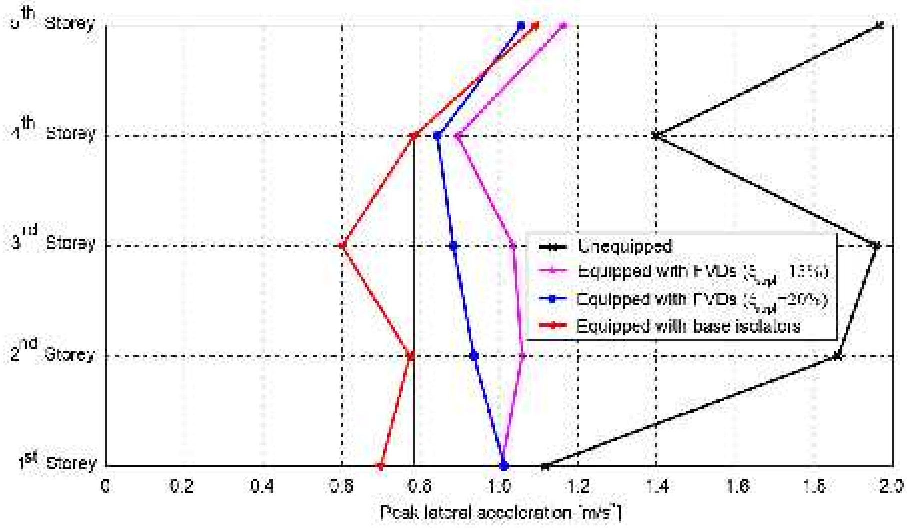

Fig. 8. *Maximum storey accelerations profile, on the Y direction of the structure, at SLS*

These figures indicate significant storey accelerations reductions in all cases, when passive control systems have been used. Higher reductions have been obtained on the Y direction of the structure. Best seismic performance has been achieved on the X direction of the structure in the case of viscously damped structure with a supplementary damping ratio of 20%, while on the Y direction of the structure in the case of base isolated structure. In the case of viscously damped structure with a supplementary damping ratio of 20%, compared to the unequipped structure, the maximum storey accelerations have been reduced by 17.62% to 44.47% on the X direction of structure and by 9.31% to

54.87% on the Y direction of structure. In the case of viscously damped structures, the maximum reductions in both directions have occurred at the mid-height of the building (third storey). In the case of base isolated structure, compared to the unequipped structure, the maximum storey accelerations have been reduced by 18.21% to 43.24% on the X direction of structure and by 22.36% to 69.32% on the Y direction of structure.

4. Conclusions

The main objective of this paper has been to assess the seismic performance of 3D steel moment resisting frame structure equipped with two passive control systems (fluid viscous dampers and base isolators). For this purpose, a 3D six storey steel structure, located in Iași, has been designed according to P100-1/2013 and EN1993-1-1, in order to fulfill the ULS requirement. Then, the building has been equipped with passive control systems, in 3 different cases (with fluid viscous dampers that provide a supplemental ratio of 15% and 20%, respectively with base isolators) with the aim of fulfilling P100-1/2013 requirement regarding the SLS. The equipped and unequipped structures have been subjected to a set of seven semi-artificial accelerograms of Vrancea 1977 type, compatible with the response spectrum for Iași. The seismic performance has been quantified by comparisons between equipped and non-equipped structures for the following response parameters: maximum base shears, maximum inter-storey drifts and maximum absolute storey accelerations.

All these control systems have improved the seismic performance of the unequipped structure. Best seismic performance has been achieved for all these parameters in the case of viscously damped structure with a supplemental damping ratio of 20%. In this case, compared to the unequipped structure, the maximum base shears have been reduced by at least 41.71%, the maximum inter-storey drifts by at least 37.55% and the maximum storey acceleration by at least 9.31%.

The response parameters indicate that structural and non-structural damages are significantly diminished or eliminated in case of viscously damped structure with supplemental damping ratio of 20%.

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