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MITIGATION OF SEISMIC RESPONSE OF DUAL ECCENTRICALLY BRACED STEEL FRAMES EQUIPPED WITH FLUID VISCOUS DAMPERS

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Abstract: *Although the benefits of equipping the moment resisting frames with fluid viscous dampers have been shown by numerous studies, so far the utilization of these devices in the case of dual eccentrically braced steel frames has not been identified. A numerical investigation has been carried out in this paper considering the seismic response of a 3D five story steel structure, with perimeter dual eccentrically braced frames, situated in Iași. The structure has been analyzed in several cases: unequipped and equipped with fluid viscous dampers that provide different damping ratios. The numerical results (maximum base shears, inter-story drift ratios, lateral story accelerations and links rotations) has proven the efficiency of the fluid viscous dampers for the seismic protection of dual steel frames.*

Key words: *fluid viscous dampers, dual steel frames, damping ratios, seismic response, time-history analyses.*

1. Introduction

This paper is part of a comprehensive study undertaken by the authors which investigates numerically the mitigation of seismic response of dual eccentrically braced steel frames with short links equipped with fluid viscous dampers, situated in different seismic zones of Romania [1].

A dual eccentrically braced steel frame is a relatively new structural typology obtained by combining two structural subsystems (a moment resisting frame and an eccentrically braced frame) that work in parallel and contribute together to the resistance against lateral forces induced by earthquakes. The main benefits of the two subsystems are the high ductility in the case of moment resisting frame and high lateral stiffness in the case of eccentrically braced frame, while their main inconveniences are great relative displacements in the upper stories of the moment resisting frame and great story shears in the lower stories of the eccentrically braced frame. The dual eccentrically braced frame increases the advantages of each subsystem, while minimizing their disadvantages [2, 3, 4, 5].

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To improve the seismic behavior of dual eccentrically braced frames, the authors of the paper propose to equip them with damping devices. Linear fluid viscous dampers have been chosen due to their capacity to simultaneously reduce stresses and deflections of structures [6, 7].

Consequently, the main objectives of this paper are: (i) to investigate the seismic performance of dual steel structures designed according to P100-1 (2013) requirements; (ii) to examine the seismic response of dual eccentrically braced steel frames equipped with linear fluid viscous dampers which provide different supplemental damping ratios; (iii) to recommend the minimum supplemental damping ratio for which an adequate overall seismic performance is attained.

For these purposes, a parametric numerical study has been carried out.

2. Study Cases

A five story residential building, located in Iași, has been considered in this study. The building has a rectangular plan of 18m x 30m and is 17.5m tall. The story height equals 3.5m at all levels. The structure of the building is formed by six frames oriented along the transverse direction (X direction) and four frames along the longitudinal direction (Y direction). The spacing between all frames is 6m (Figure 1). The perimeter frames, on both directions, are eccentrically braced in the middle bays, being dual frames. The length of all links is 0.4m, being short links. The internal frames are moment resistant frames. The floors are made of composite steel decks supported by steel beams and are assumed to behave as rigid diaphragms in plane, their thickness being equal with 15cm. All connections between beams, columns, braces have been considered rigid.

The building has been designed with dissipative behaviour, ductility class high (DCH), in accordance with the Romanian seismic design code P100-1/2013 [8] and EN 1993-1-1 [9]. According to P100-1/2013, two limit states must be fulfilled by the structure: Ultimate Limit States (ULS) and Damage Limitation (DL), considering the inter-story drift ratio limit as 0.75%. The previous limit is valid for ductile non-structural members.

The seismic actions have been computed by means of modal response spectrum analysis. The essential characteristics of the response spectrum are: peak ground acceleration a_g= 0.25 g; corner period T_C=0.7 s; behaviour factor: q=6 (on both directions).

Steel grade S235 has been used for links and beams, while S355 has been used for the other structural members.

The characteristic value of dead loads for current floors is 5.0 kN/m^2, except the roof level where it is 5.5 kN/m^2. The characteristic value of live loads is 2 kN/m^2 for all floors.

The design load combinations have been established based on EN 1990.

Structural members cross sections are given in Tables 1, 2 and 3.

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

Story	Exterior columns	Interior columns	Current beams	Middle bay beams	Braces
1-3	HE 200M	HE 240M	IPE 330	IPE 500	HE 220B

4-5	HE 200M	HE 240M	IPE 300	IPE 360	HE 200B

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

Story	Exterior columns	Interior columns	Beams
1-3	HE 200 M	HE 260 M	IPE 330
4-5	HE 200 M	HE 260 M	IPE 300

Members cross sections for frames from axes A and D Table 3

Story	Current columns	Middle bay columns	Current beams	Middle bay beams	Braces
1-3	HE 200M	HE 240M	IPE 330	IPE 500	HE 220B
4-5	HE 200M	HE 240M	IPE 300	IPE 360	HE 200B

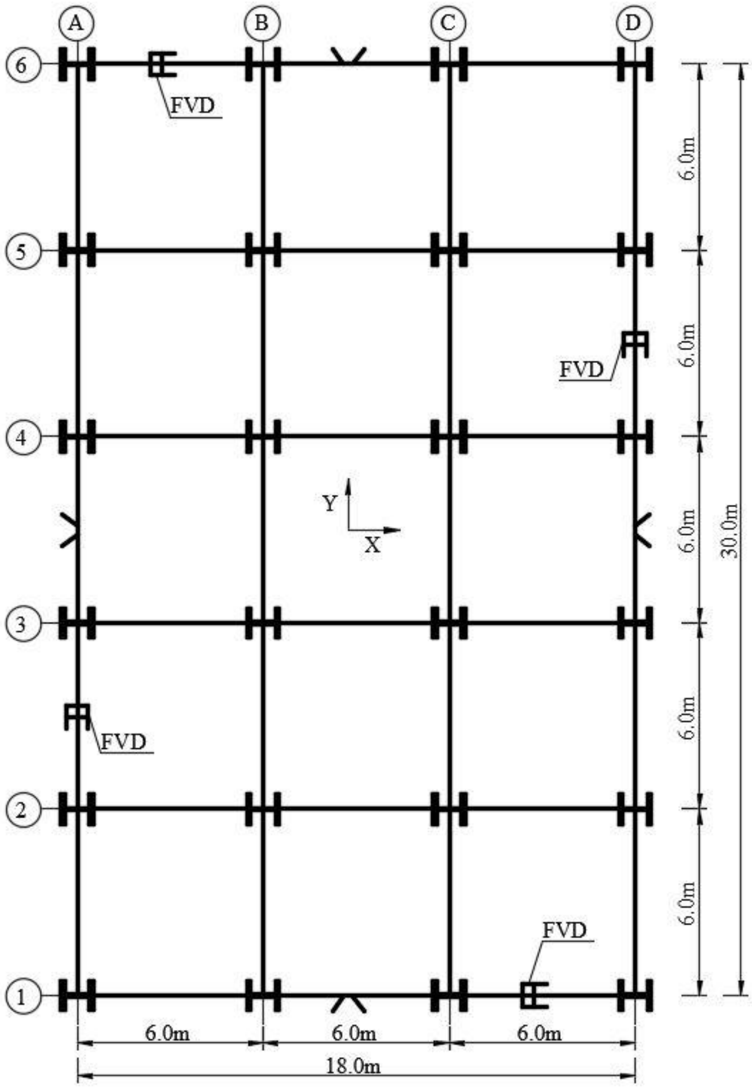

Fig. 1. *Plan view of the building*

Then, the structure has been equipped with linear fluid viscous dampers that provide three supplemental damping ratios (10%, 15% and 20%), without redesigning its members, with the purpose of controlling the seismic response (Figures 1 and 2). The inherent damping ratio of the bare structure has been considered 5%. The dampers have been installed with a diagonal configuration at each story of an external bay of perimeter frames (one damper/story).

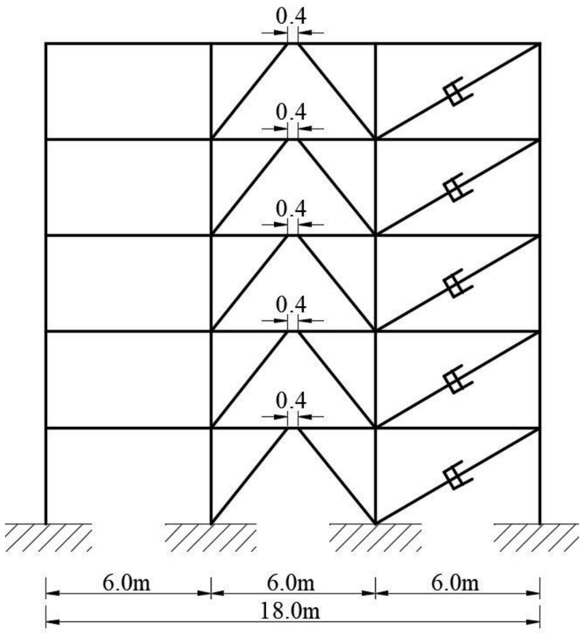

Fig. 2. *Elevation view of a perimeter dual frame equipped with fluid viscous dampers*

3. Numerical Analyses and Discussions

To evaluate the effects of fluid viscous dampers on seismic response mitigation of dual eccentrically braced frames with short links, nonlinear time history analyses have been conducted. A set of seven semi-artificial accelerograms of Vrancea 1977 type (NS and EW components) generated with SeismoMatch program to match the elastic response spectrum for Iași, has been used as input ground motions.

The average peak response of the unequipped and equipped structure has been analyzed in terms of: base shears, which represent the maximum lateral force that occur at the base of the structure due to seismic motion; inter-story drift ratios, which are closely related with structural stability, damages to nonstructural components and human comfort; lateral story accelerations which are related to damages to nonstructural components; and links rotations, which are one of the main characteristic in the seismic analysis of eccentrically braced frame [10].

Since the perimeter dual frames in the two directions are similar, for space considerations, only the graphs for Y direction will be presented. The comments about the analyzed parameters refer to both directions.

3.1. Base shears

The base shears at ULS, for the unequipped and equipped structures, in Y direction is displayed in Figure 1.

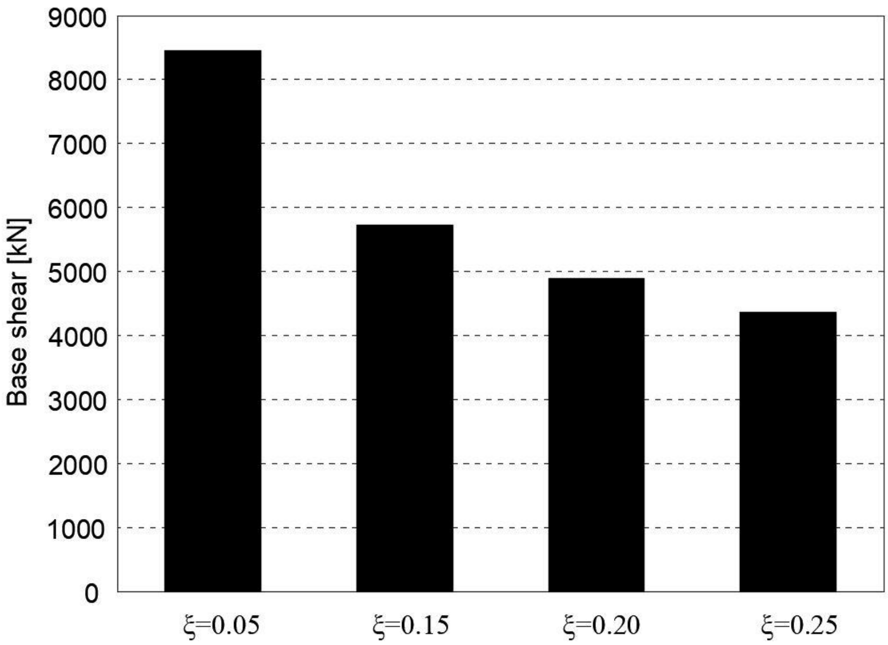

Fig. 3. *Base shears at ULS in Y direction*

In all equipped structures, there is a significant reduction of base shear, compared to that of the bare structure. Thus, the base shear has been diminished by 32.18-32.38% in the case of the structure with a total damping ratio ξ=0.15, by 40.89-42.20% in the case of the structure with ξ=0.20 and by 46.97-48.35%, for the structure with ξ=0.25. Note, however, that an increased of the total damping ratio over ξ=0.20 has much less influence on the base shear.

3.2. Inter-story drift ratios

The distribution of inter-story drift ratios on the height of the structure at SLS, for the unequipped and equipped perimeter dual eccentrically braced frames, in Y direction, is plotted in Figure 4.

In the case of bare structures, the magnitude of the inter-story drift ratios is approximately constant at the intermediate floors, the minimum values being recorded at the first and top floor. It is interesting to note that regardless of the supplemental damping ratio, the reductions of inter-story drift ratios slightly increased on the height of the building from the first to the last level. The recorded reductions in comparisons with the bare structures have been in the range of 32.14-38.82% for structure with a total damping ratio ξ=0.15, 42.67-49.41% for structure with ξ=0.20 and 48.67-57.06% for structure with ξ=0.25, respectively.

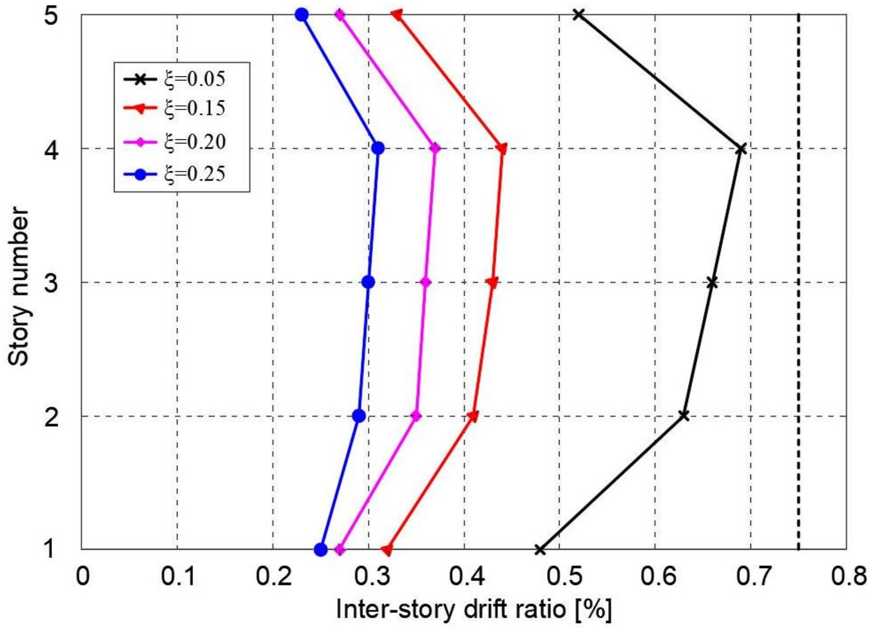

Fig. 4. *Distribution over the structure height of inter-story drift ratio at DL in Y direction*

3.3. Lateral story accelerations

The variation of the lateral story accelerations on the height of the building at ULS, for the unequipped and equipped perimeter dual eccentrically braced frames, in Y direction, is presented in Figure 5.

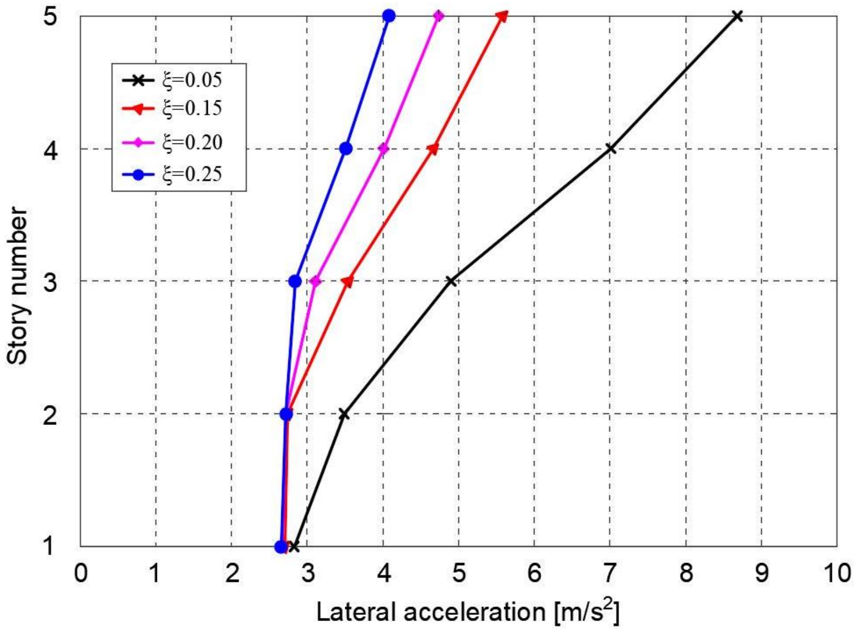

Fig. 5. *Lateral story accelerations at ULS in Y direction*

In the case of bare structures, it can be seen an increase of this parameter from the lower floors to the upper floors. For the equipped structures a reduction lateral story acceleration can be observed at all levels and for all supplemental damping ratios. For all damping ratios a beneficial effect has been met: greater reductions at the upper levels, where the magnitude of this parameter is high. In a comparison to the response of the unequipped structure, the addition of dampers resulted in lateral floor accelerations reductions by 4.59-38.52% for the structure with a total damping ratio ξ=0.15, by 5.65-47.97% for the structure with ξ=0.20 and by 6.71-54.98% for the structure with ξ=0.25.

3.4. Links rotations

The variation of links rotation on the height of the building at ULS, for the unequipped and equipped perimeter dual eccentrically braced frames in Y direction, is presented in Figure 6.

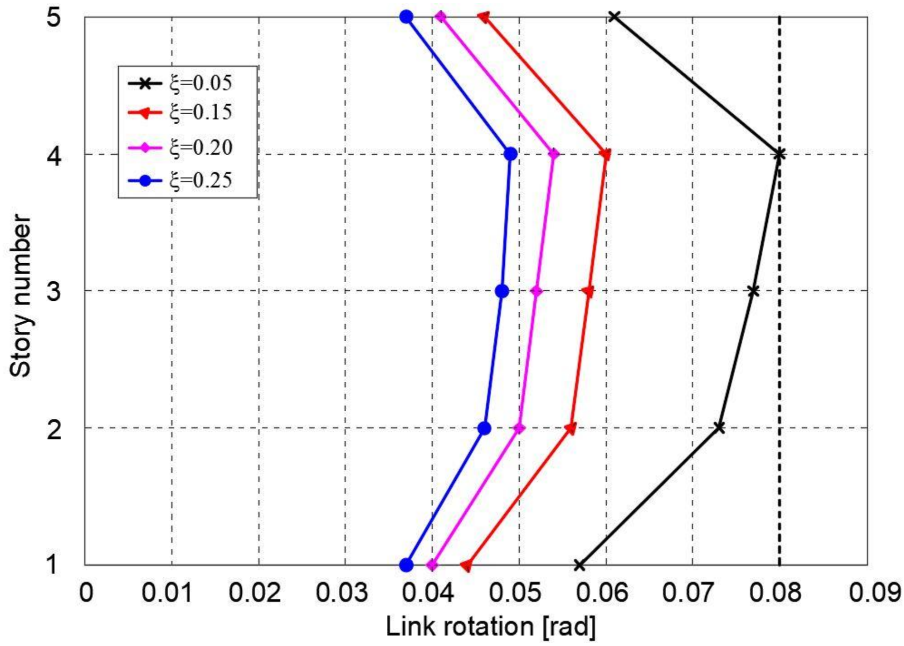

Fig. 6. *Variation over the structure height of links rotation at ULS in Y direction*

In the case of unequipped structure, it can be distinguished two groups of approximately equal magnitude of links rotation: the first and top floor, and intermediate floors, respectively. It has been found that by adding dampers to the structure, for a given damping ratio and a chosen direction (X or Y), in a comparison to the unequipped structure, the variation of links rotations reductions on the height of the building has been negligible. As in the case of all other analyzed parameters, higher reductions have been obtained for greater damping ratios. Thus, the reductions have been between 22.81-26.92% for the structure with a total damping ratio ξ=0.15, between 29.82-35.14% for the structure with ξ=0.20, and between 35.09-40.38% for the structure with ξ=0.25.

4. Conclusions

The following conclusions can be drawn from the present numerical study:

- the seismic behavior of the unequipped dual eccentrically braced steel frames designed in accordance to Romanian seismic design code P100-1/2013 has been adequate;
- the addition of fluid viscous dampers to the considered structure has resulted in significant reductions in all relevant parameters for engineering practice (base shears, inter-story drift ratios, lateral story accelerations and links rotations);
- greater reductions have been obtained for higher supplemental damping ratios;
- the equipped structures with supplemental damping ratio equal or greater than 15% have remained in the elastic range, minimizing the potential damages.

The obtained results demonstrate the efficiency of fluid viscous dampers in alleviating the seismic response of dual eccentrically braced steel frames.

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