2014 International Conference on Geological and Civil Engineering
IPCBEE vol.62 (2014) © (2014) IACSIT Press, Singapore
DOI: 10.7763/IPCBEE. 2014. V62. 4

Dissipative Capacity Analysis of Steel Building Using Viscous bracing Device

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Abstract. This study is focussed on Energy dissipation system provided by Fluid Viscous Dampers (FVD). A 3D numerical investigation is done considering the seismic response of a twelve-story steel building moment frame with diagonal FVD that have linear force versus velocity behavior. The time history of Boumerdes earthquake (Algeria, May 2003) is considered for analysis and carried out using SAP2000 software and comparisons between the unbraced, braced and damped structure are shown in a tabulated and graphical format. The results of the various systems are studied to compare the structural response with and without this device of the energy dissipation thus obtained were discussed. The conclusions showed an increase of the structure potential with supplemental dampers to improve its dissipative capacities without increasing the stiffness. It is contributing significantly to reduce the displacements and efforts generated by the seismic loads, which consequently decreases the quantity of steel necessary for its overall stability.

Keywords: Steel structure, bracing, energy dissipation, viscous fluid damper, finite element method

1. Introduction

For many engineers, the most conventional approach to protect structures from earthquakes effects is to increase stiffness. This approach is not always effective, especially for an environment that promotes resonance and amplifies seismic forces. Thus, earthquake engineering has made significant inroads catalyzed by developing computational techniques and powerful testing facilities. This has favoured the emergence of several innovative technologies such as the introduction of special damping devices in the structure. This approach is commonly known as the "energy dissipation" and has the capacity to absorb significant efforts without damaging the structure [1]. Among the energy dissipation devices (Fig. 1), there is the FVD which are seen as passive control systems. They have the ability to transmit developed forces according to the request of the structural response. Because of their great ability to return a building to its original position after an earthquake, they are increasingly used in the bracing structures in steel high-rise structures. The additional cost of the damper is typically offset by the savings in the steel weight and foundation concrete volume [2]. Effects of this device on the seismic structure response are the subject of this study.

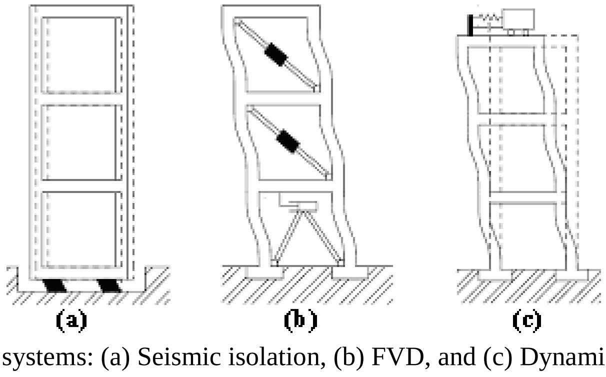

Fig. 1: Passive control systems: (a) Seismic isolation, (b) FVD, and (c) Dynamic vibration absorber [3].

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2. Fluid Viscous Damper

FVD were initially used in the military and aerospace industry. They were integrated in structural engineering in the late 1980's and early 1990's. FVD (Fig. 2) typically consist of a piston head with orifices contained in a cylinder filled with a highly viscous fluid. Energy is dissipated in the damper by fluid orificing when the piston head moves through the fluid. The fluid in the cylinder is nearly incompressible, and when the damper is subjected to a compressive force, the fluid's volume decreases as a result of the piston rod area movement. A decrease in volume results in a restoring force. This undesirable force is prevented by using an accumulator. An accumulator works by collecting the volume of fluid that is displaced by the piston rod and storing it in the make-up area. As the rod retreats, a vacuum that has been created will draw the fluid out.

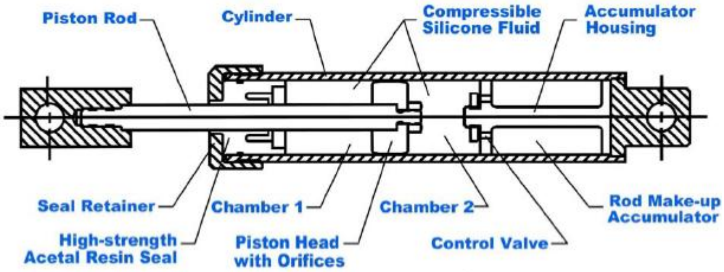


Fig. 2: Fluid Viscous Dampers [4].

FVD are characterized by a resistance force F. It depends on the velocity of movement, the fluid viscosity and the orifices size of the piston. The value of F given by the relationship:

$$F = Cp.V^{\alpha}.\text{sgn}\ (V) \tag{1}$$

Where; V is the velocity between two ends of the damper, Cp is the damping constant and, α is a exponent which depends on the viscosity properties of the fluid and the piston.

FVD allow very significant energy dissipation where the stress - strains diagram show a hysteretic loop approaching an ellipse for a pure viscous linear behaviour. The absence of storage stiffness make the structure's natural frequency incorporated with the damper remains the same. This advantage will simplify the design procedure with supplemental viscous devices. However if the damper develops restoring force, the loop will be changer from Fig. 3a to Fig. 3c. It turns from viscous behaviour to viscoelastic behaviour.

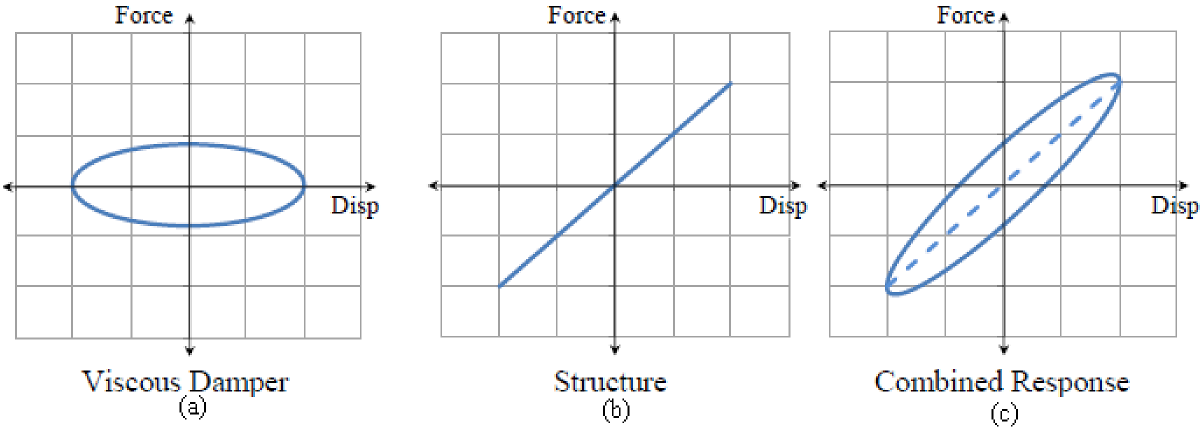


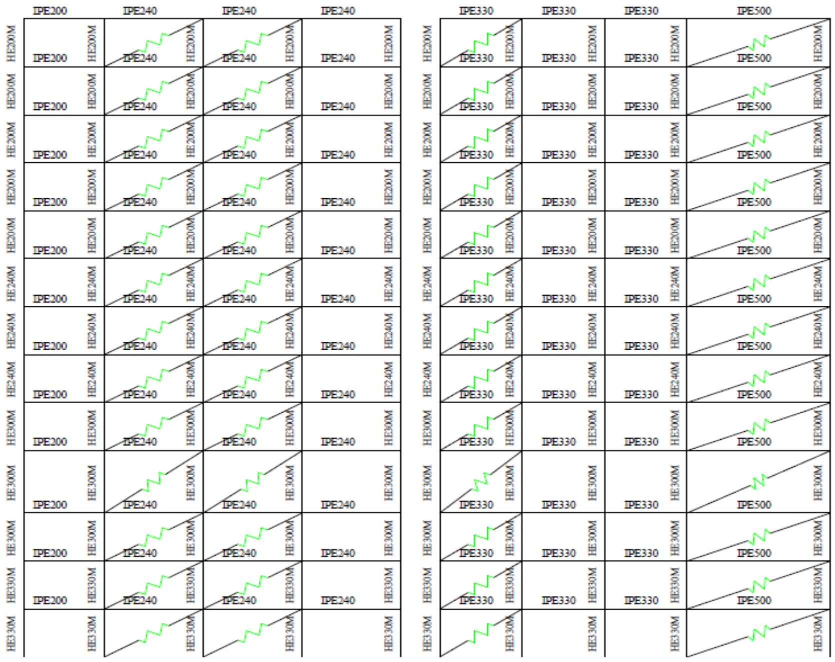
Fig. 3: Hysteretic curve of FVD [5].

3. Case study

3.1. Structure's characteristics

A twelve-story steel building modelled as 3D moment resisting frame is analyzed with and without viscous dampers using the SAP2000 computer software [6]. The properties of the building and related information are shown in Fig. 4.

The damper stiffness inserted into the SAP2000 model is equal to one diagonal of L120x13 profile. The lateral dynamic load applied to the structure was simulated by linear time history of the Boumerdes earthquake (Algeria May 2003). The results were summarized in the following sub-section.



Total length	23.70 m
Total Width	22.92 m
Total Height	45.82 m
Height of floors	3.40 m
Height of 3 rd floor	4.42 m
Modulus of Elasticity	200 GPa
Weight per unit volume	7698 KN/m3

Fig. 4: The twelve-story building model connected to FVD.

3.2. Results and interpretation

To maximize the performance of the dampers, upstream optimization study on the diagonal steel bracing elements positions was conducted on twelve variants. The best one was compared with the non-braced and damped models (Table 1). Note that the condition of 90% of mass participation (M.P.) required by the Algerian seismic code [7], have been satisfied in the case of the braced alternative at the mode N °8.

Table 1: Results comparison of the three models.

Un-braced structure		Braced structure (cross)		Damped structure (FVD)	
Period (s)	M. P. (%)	Period (s)	M .P. (%)	Period (s)	M .P. (%)
$T_1 = 7.47$	76.36	$T_1 = 2.02$	73.13	$T_1 = 2.32$	77.87
$T_2 = 4.84$	75.50	$T_2 = 1.87$	76.21	$T_2 = 2.31$	75.00
$T_3 = 3.95$	76.13	$T_3 = 1.33$	77.77	$T_3 = 1.67$	79.15

As expected, the fundamental period of vibration for the braced structure decreases due to the increased stiffness. In the third case, the period decreases due to the added stiffness resulting from the use of dampers. It should be noted that the number of diagonals used in the third case is reduced by half compared to the second case however the values of the periods remain close.

The time history analysis of top displacement and acceleration in the three models (Fig. 5) shows a significant response decrease for the structure equipped with FVD, when compared to the unbraced case. When the top displacement of the cross braced structure reach maximum, the one corresponding to the damped structure decreases by 54%. It is also seen that the acceleration response between the two cases, braced and self-supporting is almost the same unlike the case with FVD which decreases at the peak by 25%. This can lead to reduce the unpleasant effects of acceleration for occupants of these structures but also for non-structural parts, pipes, false ceilings, etc.

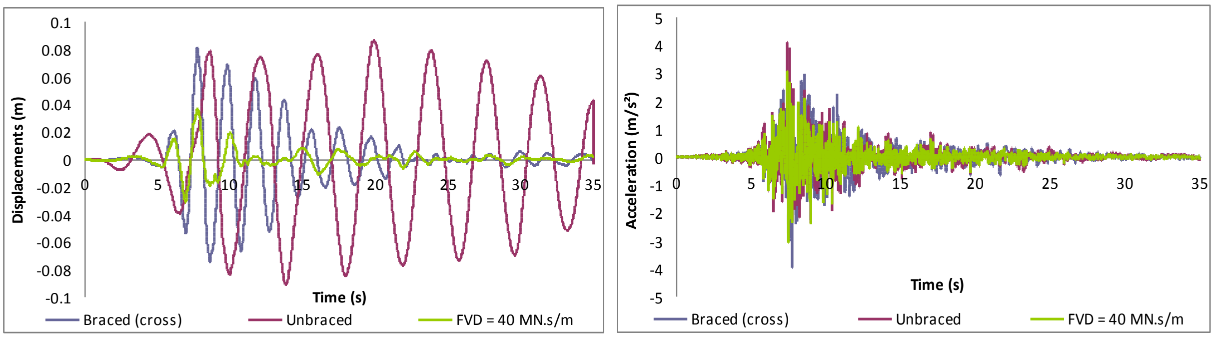


Fig. 5: Time history displacement and acceleration response (Cross braced, unbraced and structure with AFV).

The of structural members' stability is checked in combinations including earthquake (as requested by the Algerian regulations), however a time history analysis of the top axial (N), shear (V) forces and moment (M) resulting of the seismic loading has been carried out (Fig. 6). The results showed a decrease values for reinforced cross brace and FVD models with a net benefit to the dissipative device model. This decrease is due to the additional stiffness provided by the reinforcing elements but it is also due to the increase of damping rate for the FVD model. It is also important to note that in the braced structure, the cross diagonals transmit a very important axial force, valued at 85 times the ones of the damped model.

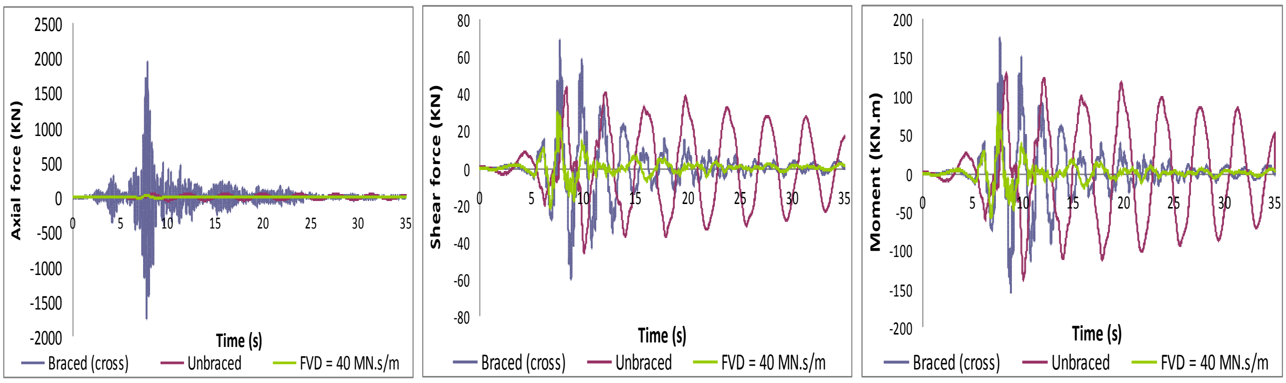


Fig. 6: Time history variation of N, T and M in the most loaded column

The Fig. 7 illustrates the variation of the axial force (N) according to the FVD damping constant Cp, for X and Y directions of earthquake. The curves have shown an exponential pace that can be compared to two straight lines. The first line shows a decreasing force versus to an increasing of damping constant until the intersection with the second line where the values become almost constant. We can conclude that for Cp = 40MN.s/m, the damped structure can fully absorb the input energy of the seismic signal and supplement damping will not affect the system which will be already completely dissipated. This conclusion was confirmed by the curves of Fig. 8, where the variation of the input and the modal damping energies of the system were compared for the values of Cp = 0 (a) and Cp = 40MN.sec / m (b). Curve (Fig. 8b) shows clearly that the energy of the seismic signal is completely dissipated by the dampers installed in the structure.

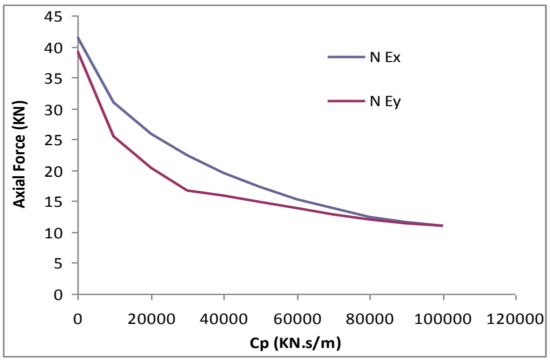
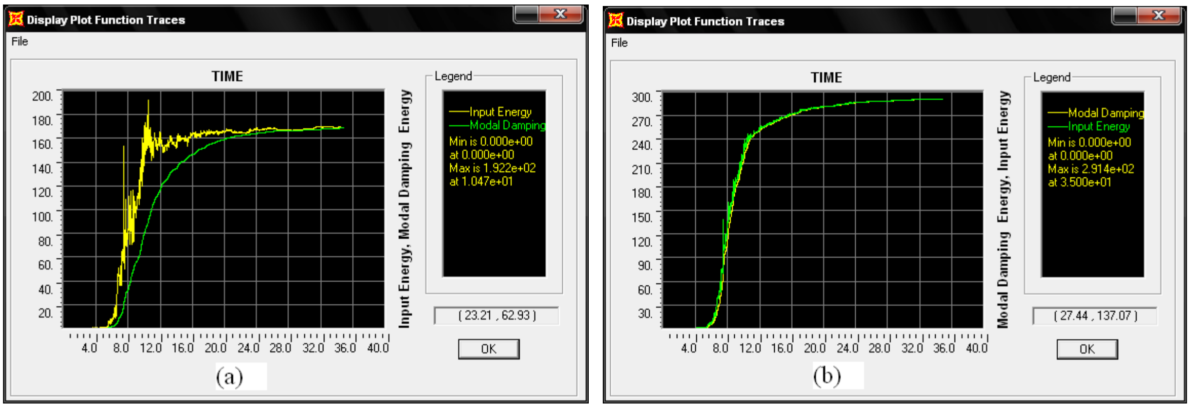


Fig. 7: Variation of Axial Force versus



Min is 0.000e+00
at 0.000e+00
Max is 1.922e+02
at 1.047e+01

(23.21 , 62.93)

(a)

Min is 0.000e+00
at 0.000e+00
Max is 2.914e+02
at 3.500e+01

(27.44 , 137.07)

(b)

Fig. 8: Variation of the input and the modal damping energies of the system

Fig. 9 gives a particularly interesting reflection on the ability of FVD to reduce the base shear force. Note that it becomes very important in the cross braced case. It is due to the decrease of the fundamental period (T=2.02sec) which makes greater acceleration but this forces decrease rapidly over time due to the stiffness of the system. Unlike to the unbraced model where the base shear force is not very important (T=7.47sec) but remains constant throughout the duration of the signal. In the third model, forces are also low (T = 2.32sec) and they disappear quickly and completely after 15sec. This is due to the capacity of FVD to produce passive control system by balancing quickly the load forces to the resistance and damping forces. An analysis of inter-story drift curve according on the height of building was carried out also for the three models (Fig. 10). The variation curve of the damped structure with FVD almost looks like a vertical line whose values are almost constant. This shows that the structure have one's block behaviour.

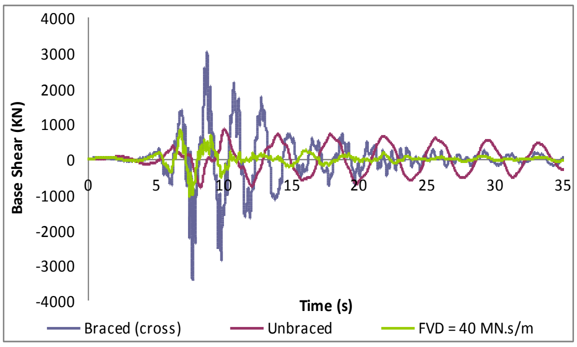


Fig. 9: Time history variation of base shear force

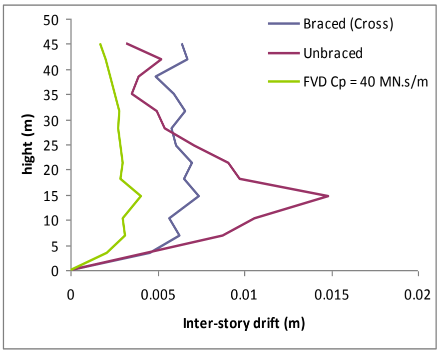


Fig. 10: Inter-story drift variation according to building height

4. Conclusions

This study permitted to analyse different steel structure behaviour, with and without viscous damper fluid for seismic loading. Numerical model of 12-story building was analysed and the results show that the use of the FVD in buildings generates a very significant reduction of the structural response compared to the unbraced ones. These devices are generally inexpensive and effective reinforcement of buildings subjected to dynamic excitations. The main conclusions are:

- The fundamental period decreases by 220% compared to the unbraced structure;
- The maximum displacements decrease of 54% compared to the cross-braced structure;
- Reduction of the maximum acceleration is 25%, which reduces base shear values and its time loading;
- Reducing efforts by more than 55% in bending moment and shear force in the most loaded member;
- With the damping energy dissipation, the diagonals do not transmit any undesirable axial forces;
- Beyond Cp = 40 MN.sec/m, FVD cannot dissipate a supplement seismic energy in the structure;
- The inter-storey drift become, almost zero, which generates block behaviour of the structure and reducing the effects of shear forces.

5. References

[1] N. Ouali, *Effets des Dispositifs D'amortissement sur les Déplacements, Vitesses et Accélérations des Structures*, Magister of civil engineering University of Science and technology Houari Boumediene, Algiers, Algeria (2009).

[2] H. K. Miyamoto, A S. Gilani, and S. Wada, State of the art design of steel moment frame buildings with dampers, The 14th World conference of earthquake engineering, October 12-17, 2008, Beijing, China.

[3] L. M. Moreschi, Seismic design of Energy Dissipation Systems for Optimal Structural Performance, Doctor of Philosophy in Engineering Mechanics, Blacksburg, Virginia, US, 2000.

[4] M. G. Oesterle, Use of Incremental Dynamic Analysis to Assess the Performance of Steel Moment-Resisting Frames with Fluid Viscous Dampers, Master of Science Thesis, Virginia, USA, 2003.

[5] C. Labise, G. W. Rodgers, G. A. MacRae and J. G. Chase, Viscous and hysteretic damping – impact of capacity design violating in augmented structural systems, Journal of University of Canterbury, New Zealand, pp 23-30.

[6] Nonlinear Structural Analysis Program, SAP2000 User Manual, 2009, Computer and Structure, Inc, Berkeley, CA

[7] RPA99/2003 Algerian seismic code, technical paper DTR B C 2 48, Algiers, Algeria 2003.