Comparison between the visco-elastic dampers And Magnetorheological dampers and study the Effect of temperature on the damping properties

A.Q. Bhatti
National University of Sciences and Technology (NUST), Islamabad, Pakistan

H.Varum
University of Aveiro, Portugal

SUMMARY

A number of studies have been carried out to investigate the performance of visco-elastic dampers (VEDs) and Magnetorheological dampers (MRDs) in controlling the seismic response of buildings but very few studies regarding the effect of temperature on the behavior of those dampers. As the energy absorption properties of the VEDs are dependent on the ambient temperature, excitation frequency and strain amplitude. Several mathematical models have been investigated for reproducing the experimental behavior of single degree of freedom VEDs and MEDs. Of these, only the fractional derivative model can reflect the influence of temperature which is, however, so complex that it is difficult to apply in structural analysis. In order to verify the effect of temperature we took two case studies of structural element been damped once using VED and once using MRD. Kelvin-Voigt mathematical model applied and after analyzing the results, the force vs. displacement showed that MRD achieved a high force capacity and better performance than VED. Furthermore, the effect of temperature in case of VED observed via plotting the dissipated energy hysteresis at different temperature. Those results validate the effect of temperature as the lower the temperature the more viscous the dashpot element becomes and hence improved damping, but this is up to a specific low temperature .

Keywords: *Visco-elastic damper, Magnetorheological damper, dissipated energy.*

1. INTRODUCTION

Any infrastructural building may undergo free vibrations or may be subjected to forced vibrations due to seismic loadings. The vibrations could be damped when friction forces are present and un-damped otherwise. The basic model representing a damping system could be made essentially of a spring and a shock absorber, e.g. Maxwell model, Voigt-Kelvin model or other advanced model, which will cause the body subjected to vibrations to undergo damping forces against those vibrations (John C. Dixon. 1999). Due to the unwanted additional stresses and the related energy losses, vibrations are regarded as not good for the health of buildings. (T.K. Datta, 2010). They should therefore be eliminated or reduced as much as possible by appropriate design. The analysis of structures under vibrations and designing appropriate damping systems have become increasingly important in recent years owing to the current trend toward higher buildings and lighter structures.

In earthquake engineering, vibration control is a set of technical means aimed to mitigate seismic impacts in building and non-building structures. In general, all seismic vibration control devices may be classified as passive, active or hybrid (semi-active).

1.1 Visco-elastic Dampers

Visco-elastic dampers (VEDs) are passive control devices that can be incorporated in building frames with relative ease compared with other passive control devices. VEDs are good alternatives to base isolation in retrofitting damaged or old buildings. They are especially attractive for buildings made of steel frames (Michael D. Symans & Michael C. Constantinou, 1999). Moreover, VEDs are considered to be an ideal shock absorption device because of their cost-effectiveness, high reliability and efficient energy dissipaters for building structures against dynamic loads such as earthquakes and wind loads. Figure 1 shows a schematic diagram of the shape of a VED and a structure installed with a VED. The damper dissipates vibrational energy through shear-type deformation of visco-elastic material which retains both elasticity and viscosity (Zhao-Dong Xu , 2007)

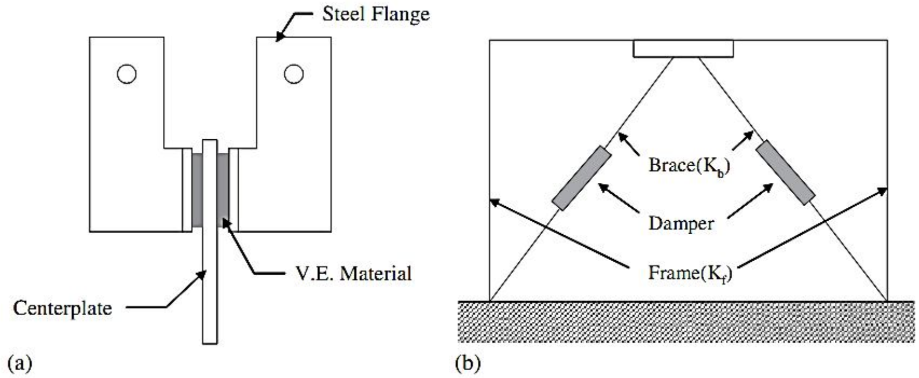

Figure 1. Schematic diagram of the shape of a VED and a frame with a VED: (a) VED; and (b) frame segment.

A number of studies have been carried out to investigate the performance of VEDs in controlling the seismic response of buildings. These studies dealt with (i) the mechanical behavior of dampers; (ii) analysis, both exact and approximate, of framed structures fitted with VEDs; and (iii) optimal placement of VEDs in building frames (Lee et al., 2004)**.** An introduction of VEDs in the frames makes the systems non-classically damped.

1.2 Magneto Rheological Dampers (MR)

There are three main applications of an MR fluid. The anticipated application of a damper determines in which way MR damper has to be designed. The said ways of operation/design are known as Squeeze Mode, Shear Mode and Valve mode as shown in Figure 2 and Figure 3.

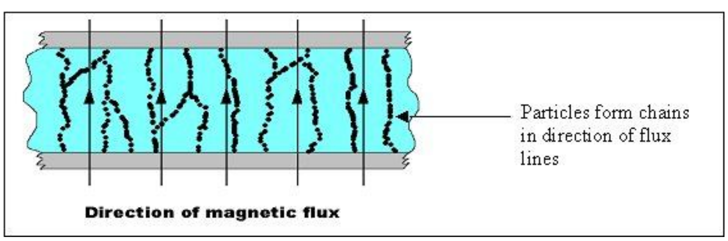

Figure 2 MR Fluid in "ON" state

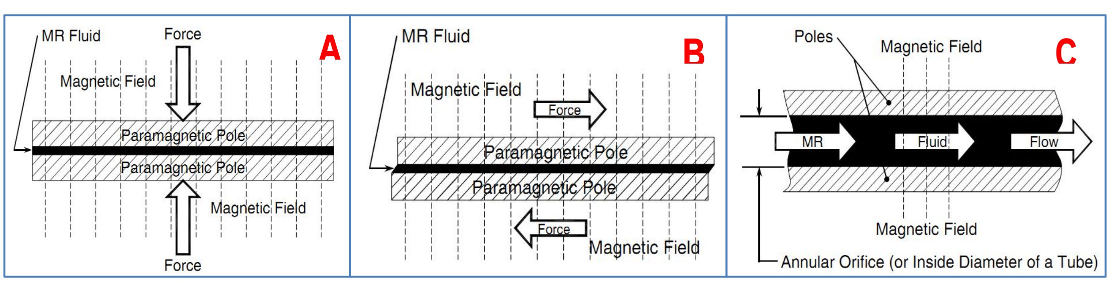

Figure 3. MR fluid used in (A) squeeze mode, (B) shear mode, and (C) valve mode.

An MR device is said to operate in valve mode when the MR fluid is used to impede the flow of MR fluid from one reservoir to another. One of the challenges in the application of the MR dampers is to develop an effective control strategy that can fully exploit the capabilities of the MR dampers.

2 THEORITICAL TREATMENT

2.1 Modeling VEDs

2.1.1 Kelvin Element

The main disadvantage of Kelvin model (Figure 4), in modeling the visco-elastic material, is that it differentiates a loss modulus linearly dependent on the frequency and a storage modulus independent of frequency that is not an accurate representation for most materials and, in particular, for polymers or rubbers.

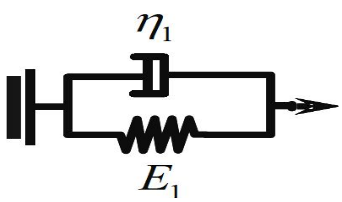

Figure 4. Kelvin Model

The Kelvin model of VED (element) consists of a linear spring in parallel with a viscous damper. The response behavior of the Kelvin-Voigt model satisfies:

$$\sigma_t = \eta_1 \dot{\varepsilon}_t + E_1 \varepsilon_t \tag{1}$$

$$E'' = \eta_1 \omega \tag{2}$$

The dissipation of energy per cycle in harmonic deformation is linearly proportional to the deformation frequency:

$$W_{(locp)} = \pi \varepsilon_o^2 [\eta_1 \omega] \tag{3}$$

2.1.2 Maxwell element

The storage modulus and the loss modulus for the Maxwell model may easily be obtained. Using a Maxwell model, the mechanical behavior of the visco-elastic damper can be modeled with much more accuracy as both storage modulus and loss modulus are fully dependent on the excitation frequency. The frequency-dependent behavior of visco-elastic dampers is typically obtained via harmonic testing. In this test, a harmonic displacement at a given frequency is imposed on the damper and the force required to impose the motion is measured. (Alexis Lagarde, 2000) **.** Due to the velocity-dependence of the damper, the measured force is out-of-phase with respect to the displacement. The elastic force is proportional to displacement, the damping force is proportional to velocity, and the measured (or total) force is related to both displacement and velocity. For visco-elastic materials, the behavior is typically presented in terms of stresses and strains rather than forces and displacements.

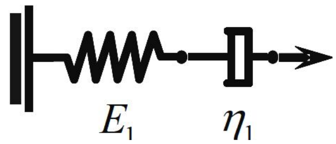

Figure 5. Maxwell Model

A Maxwell element consists of a linear spring with constant E in series with a linear viscous dashpot, with constant $\eta = \tau E$. This model satisfies the following differential equation.

$$W_{(loop)} = \delta_{max} E\pi \left[\frac{\omega\tau}{(1+(\omega\tau)^2)}\right] \tag{4}$$

Which shows that the energy dissipated in a cycle in this model increases with frequency for frequencies less than $1/\tau$ and monotonically decreases with frequency for frequencies greater than $1/\tau$.

2.2. Modeling MR Dampers

The behavior of MR fluids when in the "OFF" state is also non-Newtonian and temperature dependent, however it deviates little enough for the fluid to be ultimately considered as a Bingham plastic for a simple analysis. Thus our model of MR fluid behavior becomes:

$$\tau = \tau_y(H) + \eta \frac{dv}{dz}\ , \ \tau > \tau_y \tag{5}$$

Where τ = shear stress; τy = yield stress; H = Magnetic field intensity η = Newtonian viscosity; dv/dz is the velocity gradient in the z-direction. If we consider Kelvin-Voigt model and state the equation of motion

$$m\ddot{x} + c\dot{x} + kx = c\dot{y} + ky \tag{6}$$

For the equation of motion in differential equation form, its transfer function can be found through Laplace transform and its state space form also can be written down as following. So, Transfer function: Laplace transform both sides of previous equation

$$ms^2X + csX + kX = csY + kY \tag{7}$$

$$\frac{X}{Y} = \frac{cs+k}{ms^2+cs+k} \tag{8}$$

3. RESULTS AND DISCUSSION

To investigate the performance of (VEDs) and Magneto-rheological dampers (MRDs) in controlling the seismic response of buildings, a synthesis signal generated and applied once to a VED and once on a MRD. The response of the damper recorded and analyzed to compare the performance of both of them. In case of VED the effect of temperature has also been investigated by testing the performance under different ambient temperatures from 0 to 180°C. The case of seismically excited structure using VE damper will be simulated using PCANSR.

3.1. Magneto-rheological Damper

As what we mentioned before, Kelvin-Voigt element main disadvantage in modeling the visco-elastic material is that it defines a loss modulus linearly dependent on the frequency and a storage modulus independent of frequency that is not an accurate representation for most visco-elastic materials. However, Kelvin-Voigt model is used in modeling the MR dampers for many reasons including that the MR dampers at low frequency, low voltage, is independent on frequency while at high frequencies it becomes to be dependent. Another reason is the simplicity of modeling using Kelvin-Voigt. Hence for the purpose of MR dampers, we will use Kelvin-Voigt model, where the seismically excited structure using MR dampers will be simulated using MATLAB Simulink toolbox.
In our simulation we took the time and acceleration to be:

$$\mathrm{time} = [0{:}\,0.02{:}\,6000] \tag{9}$$

$$\mathrm{acceleration} = \cos(2t) + 5\sin(t^2 + 5t) \tag{10}$$

We assumed that the modal mass m=1000, and then computed the string stiffness form the equation:

$$k = m(1 + 2\pi)^2 \tag{11}$$

In addition, we assumed that the damping factor zeta to be 1%; $\zeta = 0.01$. Hence, the amount of damping is given by:

$$c = (2m\omega) * \zeta \text{ , where } \omega = \sqrt{\frac{k}{m}} \tag{12}$$

From here on we are ready to compute A , B, C, and D as input parameters. And the output of the simulation will be the displacement *x*, the velocity $\dot{x}$, the acceleration $\ddot{x}$, the controlling voltage and force. Our results based on comparison of the controlled and uncontrolled condition were as follow. Semi-active dampers vary from two-state (on/off) to continuously variable.

In the said test, shaker is steered using a signal with stochastic sinusoidal frequency. The applied voltage can be varied according to the force. Five sets of experimental simulated data are obtained, each one of them having displacement, velocity, acceleration, voltage and damping force. The responses of the MR damper subject to the stochastic converging sinusoidal signal are shown in Figures 6 for controlled and uncontrolled conditions. Four parameters were obtained against time; displacement, velocity, acceleration, voltage and force; in addition to force against displacement. We can observe that with the application of MR damper the displacement, velocity, acceleration and force amplitude decreased in a good deal. It can be observed that voltage increases with an increase in force.

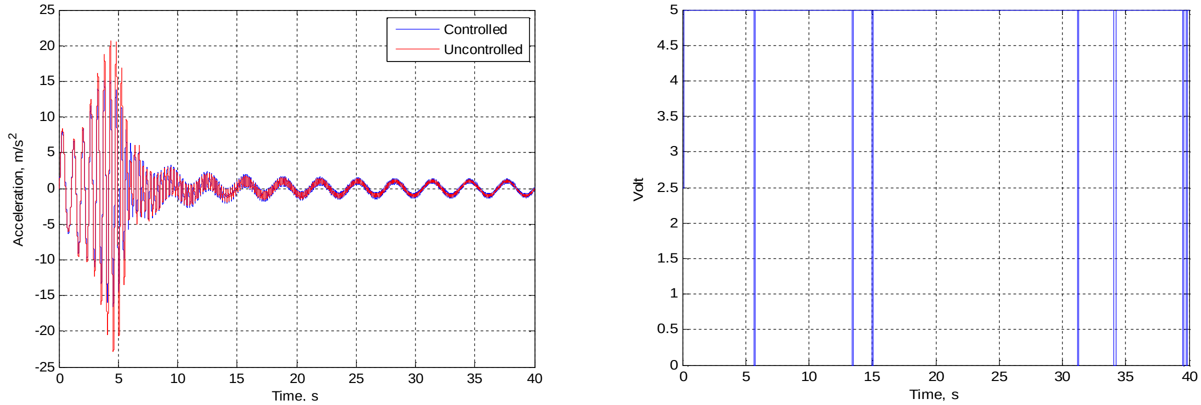

Figure 6. Controlled and Uncontrolled Of MRD, Acceleration And Voltage Vs. Time

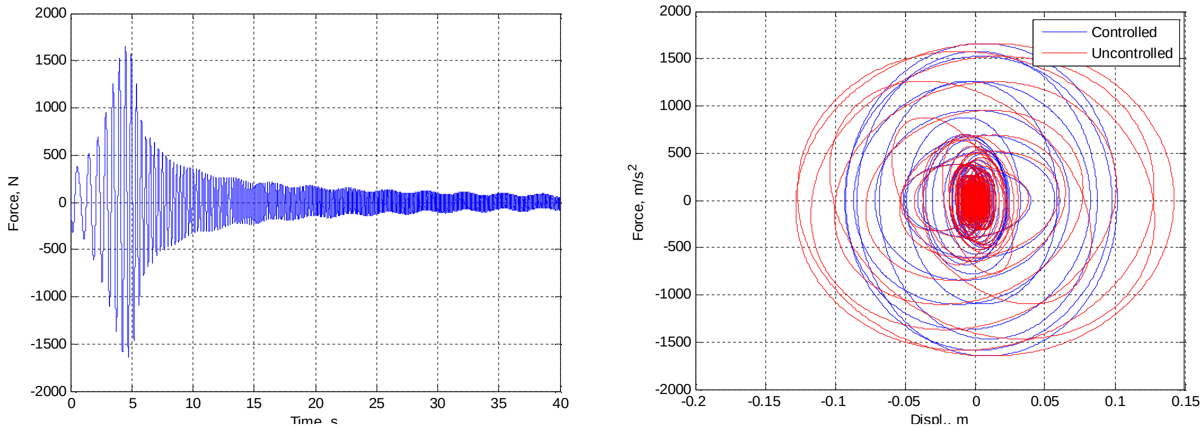

Figure 7. Controlled and uncontrolled of MRD, force vs. time and force vs. displacement

From the force-displacement graph, Figure 7, it is obvious that the MR damper can achieve substantial reduction of force and displacement and hence substantial increase in damping properties. The results clearly indicate that the semi-active control method is the optimum robust solution in terms of human comfort if we apply those kind of dampers in structural construction or in car design.

3.2 Visco-Elastic Damper

In the following analysis, the effect of temperature in case of VED observed via plotting the dissipated energy hysteresis at different temperature, namely 0, 20, 50, and 180. Those results validate the effect of temperature, as the lower the temperature the more viscous the dashpot element becomes and hence improved damping, but this is up to a specific low temperature, around ambient, where beyond that the dashpot acts more like solid not liquid anymore and hence we observed no damping force or displacement detected. In addition, the higher the temperature, the lower the damping as the dashpot acts like water, hence as we increase the temperature the damping properties will become lower and lower till it reach the damping value of water where the damping properties still constant beyond this value. Figures 8 summarize the effect of temperature.

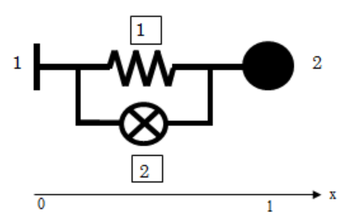

Figure 8. Model Figure

The model figure is shown with the following defined parameters in Table 1-3:

Table 1 Mass Table

node	Mass (kN.s^2/cm)
2	1.0

Table 2 Analysis Conditions

Input File	Ve. (in)
Input EQ	$cos(2t) + 5sin(t^2 + 5t)$
Dt	0.02(sec)
Newmark b Method	0.25

Table 3 Material Properties

No	ELEM	A(c^2)	E (kN/cm^2)	Eh/E	Np (kN/cm^2) Tensile	Np (kN/cm^2) Compressive	L (c)	K kN/cm	C(kN*s/cm)
1	G2	56.4	1.0	0.0001	1.0E+13	1.0E+13	1.0	56.4	2.99E-01

No	Elem	α	G(kN/cm^2)	aref	bref	θref (℃)	θ (℃)	p1	p2	sρ (kN/cm^2/℃)	H (cm)	As cm^2
2	G7	0.558	3.92E-03	5.60E-05	2.1	20.0	20.0	14.06	97.32	999999	1.0	607.1

From Figure 9 to Figure 12 are shown the behavior of visco-elastic dampers in terms of its Force Vs Displacement curves, at a given Time Period.

<u>T = 0</u>

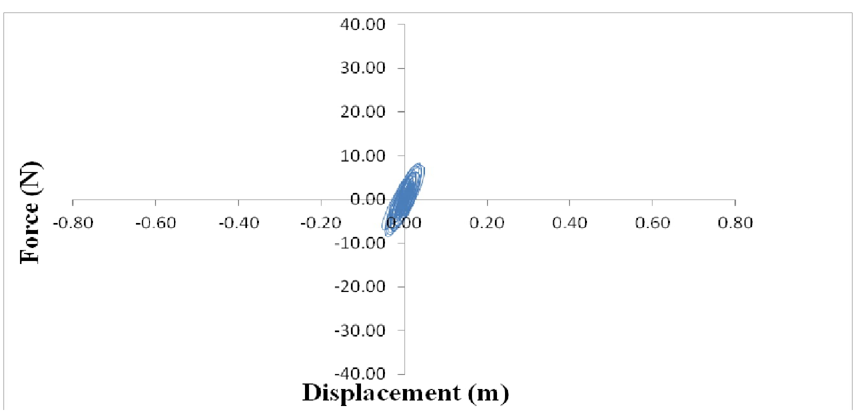

Figure 9. VED force vs. displacement at T=0

T= 20

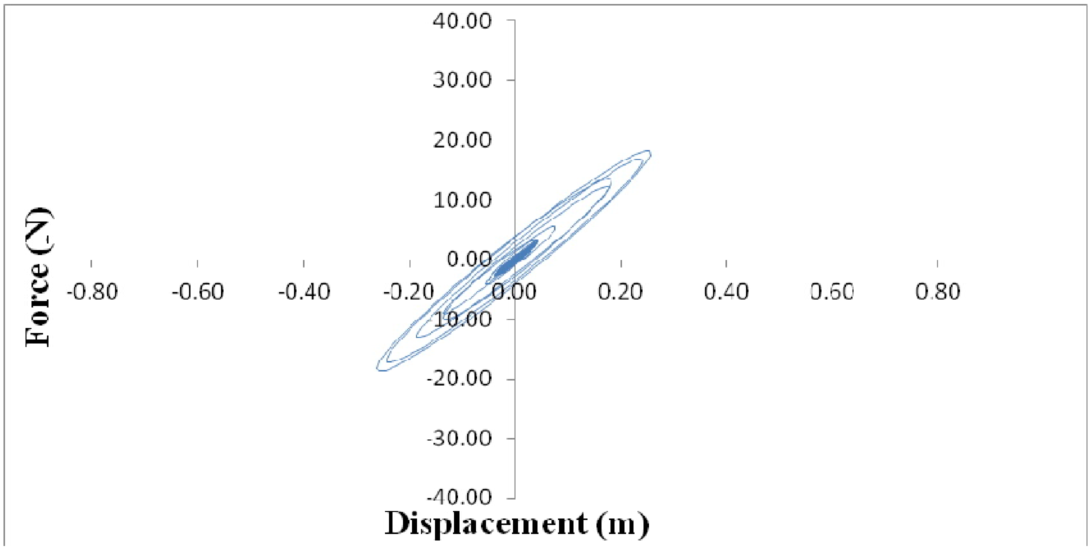

Figure 10. VED Force vs. Displacement at T=20

T= 50

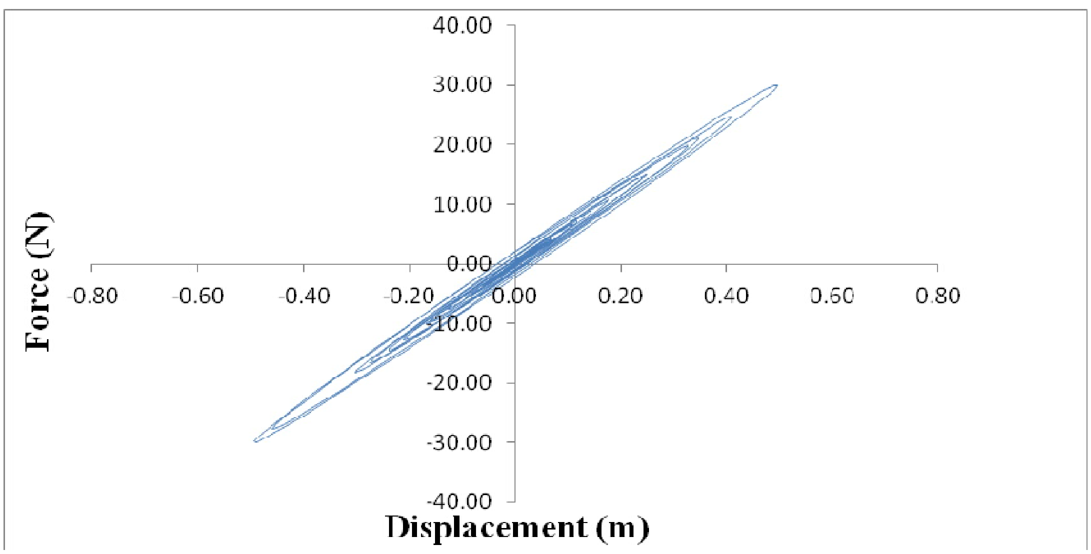

Figure 11. VED force vs. displacement at T=50

T= 180

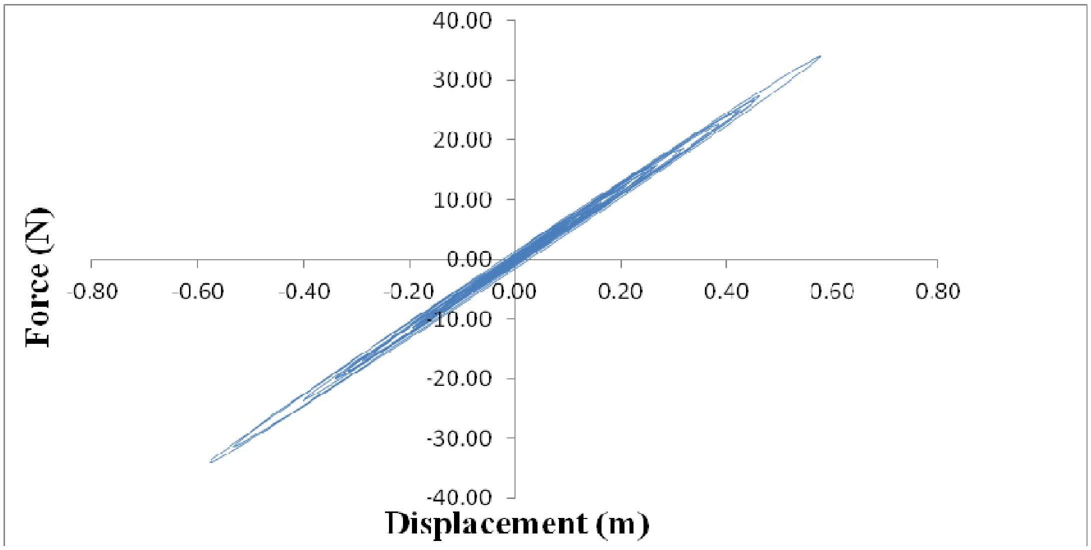

Figure 12. VED force vs. displacement at T=180

4. CONCLUSION

The application of the VE and MR damper for the vibration control of an SDOF system is studied. First, the characteristics of the different vibration types studied. Then, a mathematical model of the VE and MR damper is adopted. Also, the relative displacement, velocity, acceleration, voltage and force with respect to time in addition to force with respect to displacement were quantized and comparison made between the controlled and uncontrolled system. Furthermore, different states of the Semi-active dampers, two-state (on/off) to continuously variable, were studied and compared. Some interesting observations are obtained and their physical insights are explained. In addition, the performance of the VE damper system studied and evaluated at different temperatures. As a conclusion, semi-active control is the best choice because the results of computer simulations indicate major improvements in building displacement and force damping.

REFERENCES

John C. Dixon. Wiley 1999, The Shock Absorber Handbook (1st Edition), ISBN-10: 0768000505

Alexis Lagarde. Springer 2000, IUTAM Symposium on Advanced Optical Methods and Applications in Solid Mechanics, 1 edition, p266, ISBN-10: 0792366042

Michael D. Symans, Michael C. Constantinou, Semi-active control systems for seismic protection of structures: a state-of-the-art review, Engineering Structures, Volume 21, Issue 6, June 1999, Pages 469-487, ISSN 0141-0296, DOI: 10.1016/S0141-0296(97)00225-3.

T. K. Datta , Seismic Analysis of Structures. Wiley 2010, p411, ISBN: 978-0-470-82461-0.

Lee, S.-H., Son, D.-I., Kim, J. and Min, K.-W. (2004), Optimal design of visco-elastic dampers using eigenvalue assignment. Earthquake Engineering & Structural Dynamics, 33: 521–542. doi: 10.1002/eqe.364

Zhao-Dong Xu, Earthquake Mitigation Study on Visco-elastic Dampers for Reinforced Concrete Structures, Journal of Vibration and Control January 2007 13: 29-43, doi:10.1177/1077546306068058