# Seismic Vibration Control of a MDOF Building Connected with Viscous and SAVFD Dampers

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***Abstract*****-** **V**ibrations due to natural dynamic loads generated by earthquake. The reducing of structural vibrations occurs by adding a mechanical system that is installed in a structure called Dampers .In this paper, the vibration control of multi degree of freedom (MDOF) buildings connected with selected types of dampers due to earthquake effect is studied. The application of Viscous and Semi active variable friction (SAVFD) damper for response control of seismically excited building is evaluated. Both dampers effectiveness is investigated in terms of the reduction of structural responses (displacements and accelerations) of the connected to building. The optimum number and the location of dampers are decided by the optimization procedure. The numerical study is carried out, namely (a) A MDOF building connected with viscous dampers with optimum damping coefficient (b) A MDOF buildings connected by Semi active variable friction dampers with optimum gain multiplier. Results shows that using viscous and SAVFD to connect structures can effectively reduce earthquake-induced responses of either structure but when SAVFD is used to connect buildings and results shows that SAVFD can control only displacements of structures. Further, lesser damper at appropriate locations can significantly reduce the earthquake response of the coupled system. The reduction in responses when MDOF building connected with 50% of the total dampers at appropriate locations is almost as much as when they are connected at all floors, thereby the cost of the dampers can be minimized.

***IndexTerms***- Dampers, Optimum gain multiplier, SAVFD, Vibrations, Optimum damping coefficient

## I. INTRODUCTION

In recent years due to development of design technology and material qualities in civil engineering, the structures (high rise buildings, long span bridges) have become more light and slender. This will cause the structure to develop the initial vibrations. These vibrations may lead to serious structural damage and potential to structural failure. Civil structures also fail during large seismic events, often resulting in loss of human life and damage property.

Structural vibration control, as an advanced technology in engineering, consists of implementing energy dissipating devices into structures to reduce excessive structural vibrations(due to dynamic loads), to prevent catastrophic structural failure and enhance human comfort because of natural disturbances like strong earthquakes. In early 1990s, considerable attention has been paid to research and development of structural control devices, and medium and high rise structures have begun implementing energy dissipation devices or control systems to reduce excessive structural vibrations.

Structural control is a diverse field of study. Structural control is one area of current Research that looks promising in attaining reduce structural vibrations during loading such as earthquakes and strong winds. There are three primary classes of supplemental damping devices, categorized into three corresponding control strategies. The first class of supplemental damping devices is passive. Passive devices are non-controllable and require no power. The second class of supplemental damping devices is active. Active devices are controllable, but, require significant power to operate. The third class of supplemental damping devices is semi active. Semi active devices combine the positive aspects of passive and active control devices in that they are controllable (like the active devices) but require little power to operate. In this research, an active control strategy employing acceleration feedback, and, further, semi active “smart” dampers, are proposed to connect and control building responses.

## II. PROBLEM FORMULATION

To control vibration responses of structures it is necessary to introduce additional damping to the structures. Damping can be increased in the structure by connecting dampers and making structures stable during earthquakes. Buildings with higher natural frequencies, and a short natural period, tend to suffer higher accelerations but smaller displacement. In the case of buildings with lower natural frequencies, and a long natural period, this is reversed: the buildings will experience lower accelerations but larger displacements.

### *A. Performance of Viscous Damper Connected to a MDOF Building*

A typical viscous damper (patil, 2011) consists of viscous material in the form of either liquid (silicon gel) or solid (special rubbers or acrylics). One of the types of viscous dampers is fluid viscous damper and there are essentially two categories of it based on the functioning, such as those in which, (a) energy dissipation is achieved through the deformation of viscous fluid or special solid material (i.e. through fluid viscosity) and (b) energy dissipation is achieved by the principle of flow through orifice. In a fluid viscous damper the difference of the pressure on each side of the piston head results in the damping force, and the damping constant of the damper which can be determined by adjusting the configuration of the orifice of the piston head. When it comes to pure viscous behavior, damper force and the velocity should remain in phase. When it comes to pure viscous behaviour, damper force and the velocity should remain in phase. However, for a damper setup shown in Figure 2.5, the volume for storing the fluid will change while the piston begins to move. Thus a restoring force, which is in phase with displacement rather the velocity, will be developed. Configuration of an accumulator is used to solve the problem. The ideal force out for a viscous damper is given by,

$$f_{di} = C_{md} \left| \dot{x}_{i2} - \dot{x}_{i1} \right|^{\varepsilon} \operatorname{sgn}(\dot{x}_{i2} - \dot{x}_{i1}) \dots\dots\dots 1$$

Where $C_{md}$ is coefficient of damper, $x_{i2}$-$x_{i1}$ is relative velocity between the ends of i$^{th}$ damper and ε is exponent having value between 0 and 1.The damper with $\varepsilon = 1$ is called a LVD (Linear viscous damper). The damper with ε larger than 1 have not been seen often in practical applications. The damper with ε smaller than 1 is called a nonlinear viscous damper which is effective in minimizing high velocity shocks.

*Assumptions and Limitations:*

A MDOF building is having similar storey height with their symmetric planes in alignment. The problem is simplified as 2D because the excitation of ground is assumed to occur in one direction in symmetric plane of a structure. The seismic excitation is assumed to be not so severe and due to the enhanced energy absorbing capacity of the building because of the connected dampers, the building is assumed to be remain in linear elastic and hence, do not yield under the considered earthquake excitation. Structure is modelled as a linear MDOF flexible shear-type structure with lateral degree-of-freedom at their floor levels. The total plan dimensions in the direction of excitation are not large, so any effect due to spatial variations of the ground motion is neglected. Any effect due to soil–structure interaction is neglected; limit the applicability of the results to structures on stiff, firm ground and less restrictively to structures whose foundations are not massive (e.g. footing foundations). The lateral resistance of the structures is assumed to be so large that it does not have any effect on the performance of damper. The floors are rigid and the total mass is concentrated at the levels of the floors. There is no rotation of the horizontal section at the level of floors. The floors are subjected to horizontal ground acceleration, while the vertical component of the ground acceleration is neglected.

*Equation of Motion:*

Let structures having n stories, the mass, damping coefficient and shear stiffness values for the i$^{th}$ storey are $m_i$, $c_i$, $k_i$. The system will then be having a total number of degrees of freedom equal to 2n. The equations of motion for this system are expressed as,

$$M\ddot{X} + (C + C_D)\dot{X} + KX = -MI\ddot{x}_g \dots\dots\dots 2$$

Where M, C and K are the mass, damping and stiffness matrices of the structural system.$C_D$ is the additional damping matrix due to the installation of the viscous dampers but we are not considering additional damping due to installation of dampers. X is the relative displacement vector with respect to the ground, I is a vector with all its elements to unity, and $x_g$ is the ground acceleration at the foundations of the structures. The details of each matrix are given as,

$$m_{(n,n)} = \begin{bmatrix} m12 & & & \\ & m22 & & \\ & & \dots & \\ & & & mn2 \end{bmatrix} \dots\dots\dots\dots\dots\dots 3$$

$$c_{(n,n)} = \begin{bmatrix} c12 + c22 & -c22 & & \\ -c22 & c22 + c32 & -c32 & \\ & \dots & \dots & \\ & & & cn2 \end{bmatrix} \dots\dots 4$$

$$k_{(n,n)} = \begin{bmatrix} k12 + k22 & -k22 & & \\ -k22 & k22 + k32 & -k32 & \\ & \dots & \dots & \\ & & & kn2 \end{bmatrix} \dots\dots 5$$

*State Space Representation:*

$$z[k+1] = A_d z[k] + B_d u[k] + E_d w[k], \dots\dots\dots\dots\dots\dots 6$$

Where the vector z(k) represents the state of the structure, which contains the relative-to ground Velocity and displacement of each floor, [k + 1] denotes that the variable is evaluated at the (k +1)$^{th}$ time step, u(k) denotes the vector of the controllable Viscous forces provided by the viscous dampers, w(k) is the vector of ground accelerations. $A_d$ represents the discrete-time system matrix with Δt being the time interval (sampling period), while the constant coefficient matrices $B_d$ and $E_d$ are the discrete-time counterparts of the matrices B and E that may be written explicitly as

$$\left.\begin{array}{l} Bd = A^{-1}(Ad - I)\,B \\ Ed = A^{-1}(Ad - I)\,E \end{array}\right\} \dots\dots\dots\dots\dots 7$$

*Numerical Study:*

The study, MDOF structure with ten stories is considered with floor mass and inter storey stiffness is assumed to be uniform for structure. The damping ratio of 5% is considered for structure. The mass and stiffness of each floor are chosen such that the fundamental time period of structure $T_1$ yields 0.3s for structure and for case. A thorough study is conducted to arrive building responses like displacements, and accelerations for MDOF structure connected with viscous damper under modified El Centro earthquake data.

*Responses of MDOF Building*

The building responses of the top floor displacements and accelerations when connected with viscous dampers at all the floors (TYPE II) are plotted as shown in Figures 3.4–3.5, respectively. These plots clearly indicate the effectiveness of viscous dampers in controlling the earthquake responses of both the structures. Viscous damper can reduce 70 to 75 % of earthquake responses when damper connecting arrangements as shown in Fig.1

*Optimization of Number of Dampers:*

To minimize the cost of dampers and number of dampers, the responses of the building are investigated by considering 50% of the total dampers and even less at different floors. As the force in viscous damper is proportional to the maximum relative velocity of the damper connected floors, to arrive at the variation of damping in the dampers, the maximum relative velocities between all dampers connecting floors, under earthquake considered are obtained. The variation of these maximum relative velocities of damper connecting floors is calculated, from which an average value for variation is obtained. The storey having maximum relative displacement and or velocity are selected to place the dampers.

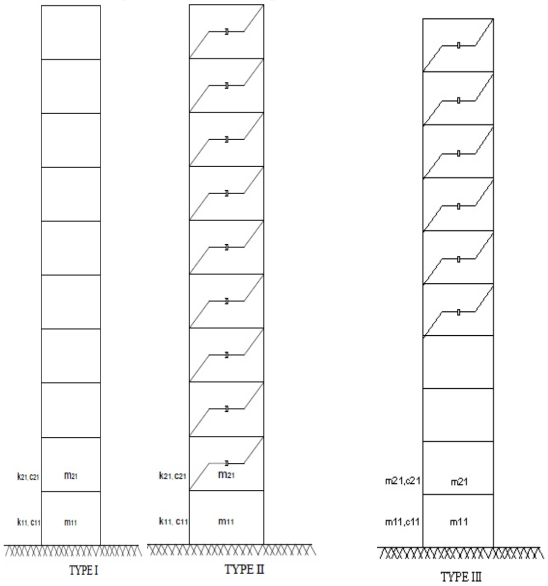


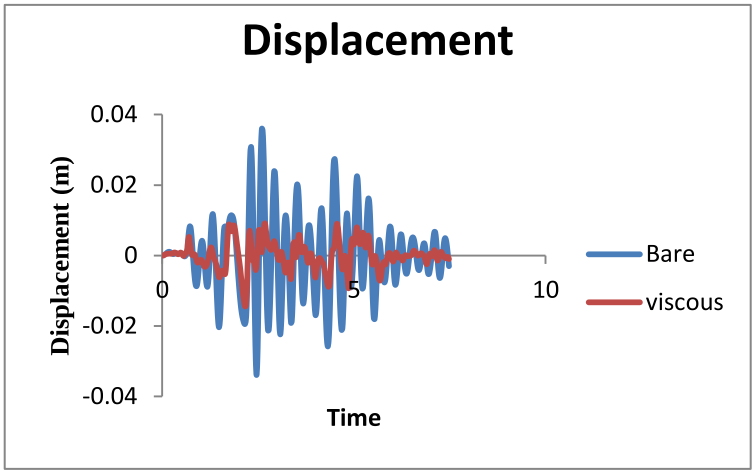
Fig1. buildings connected with viscous Dampers with Different arrangements.

*Table1. Seismic Response Of The Building Connected With Viscous Dampers ($T_1$=0.3s).*

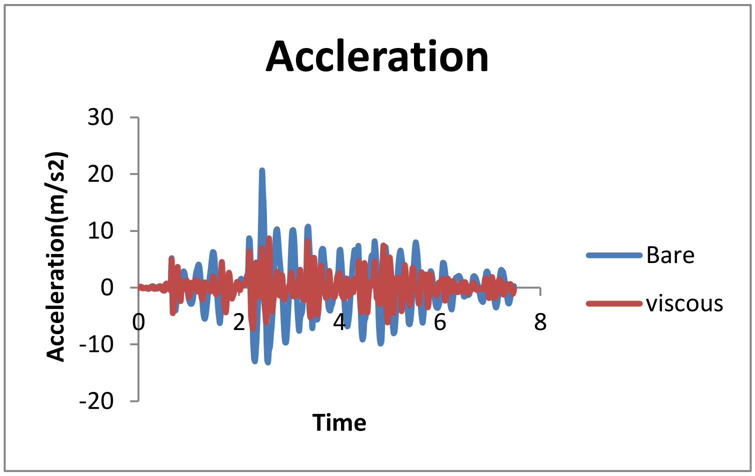
| Earthquake Imperial Valley, 1940 | Str | Peak Top floor displacement (m) | | |
|---|---|---|---|---|
| | | TYPE I | TYPE II | TYPE III |
| | 1 | 0.035988 | 0.009115<br>(74.6%)* | 0.019593<br>(45.5%)* |

| Earthquake Imperial Valley, 1940 | Str | Peak Top floor accelerations(m/$s^2$) | | |
|---|---|---|---|---|
| | | TYPE I | TYPE II | TYPE III |
| | 1 | 20.55093 | 8.657686<br>(57%)* | 13.13196<br>(36%)* |

Many trials are carried out to arrive at the optimal placement of the dampers, among which Figures shows the variation of the displacement and accelerations respectively, in all the floors for Five different cases, such as case (i) TYPE I arrangement case (ii) TYPE II arrangement (iii) TYPE III arrangement and It is found from the plots 1.1 and 1.2 that the dampers are more effective when building are connected with optimum dampers and responses in all the stories are reduced almost as much as when they are connected at all floors(TYPE II). The reduction in the peak top floor displacement, peak top floor acceleration and velocities of the structures, for without dampers, connected with dampers at all floors and connected with only 50% of total viscous damper are shown in Table 1. It is observed form the table that reduction in the responses when structures connected at all the floors are as much as when connected with 50% of total dampers Thus, it can be concluded that providing the dampers at all the floor need not be the optimum solution and even few dampers may results in the same performance.

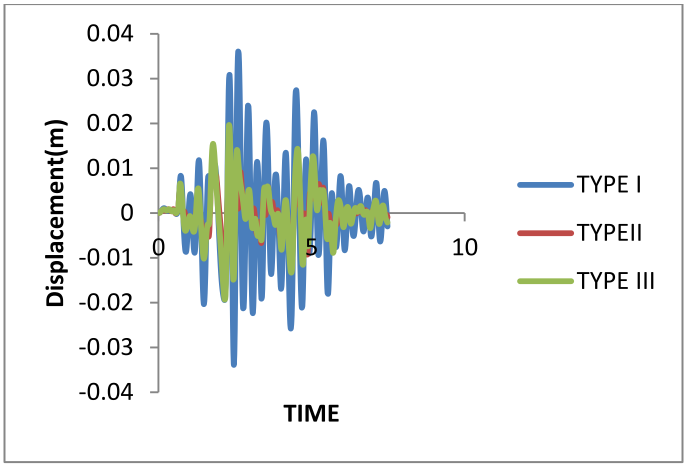


Plot 1.1(a)

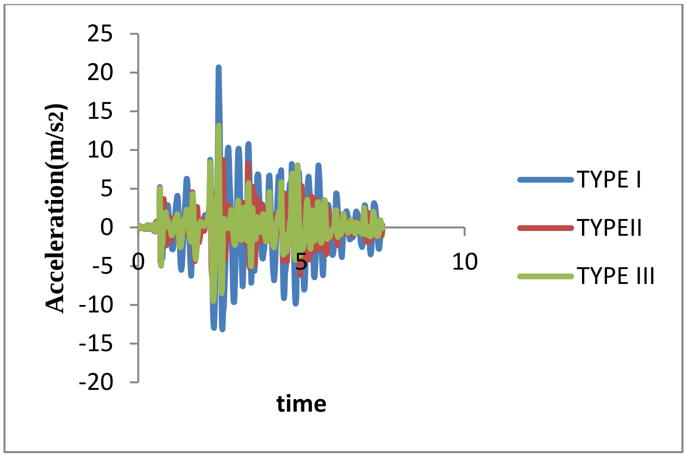


Plot 1.1(b)

Graph 1.1 Top Floor displacements for type I and type II building (a) Displacement (b) Acceleration with T=0.3 s

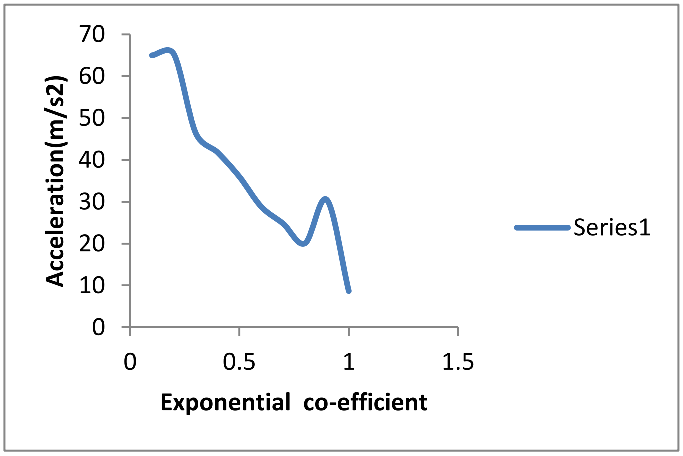


Plot 1.2(a)



Plot 1.2(b)

Plot1.2 Top Floor displacements for type I, II, III building (a) Displacement (b) Acceleration with T=0.3 s

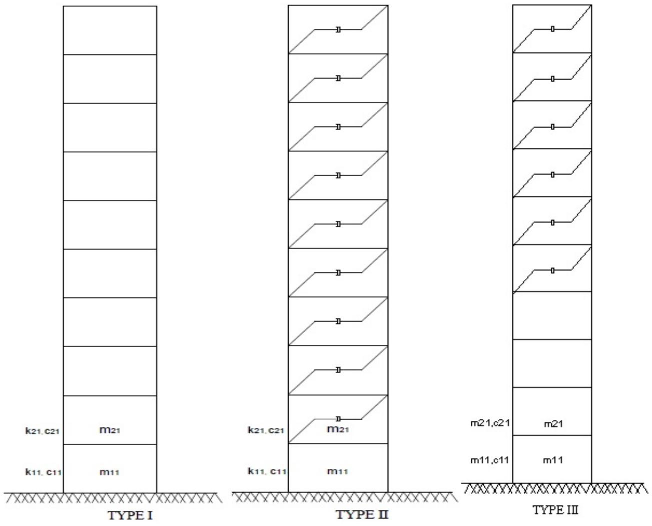


Plot 1.3 Responses of floor (a) Displacement (b) Accelerations with Exponential co-efficient

*B. PERFORMANCE OF SEMI ACTIVE VARIABLE FRICTION DAMPER CONNECTED TO MDOF BUILDING*

A semi–active system combines the features of active and passive systems. They utilize the response of a structure to develop control actions through the adjustment of damping or stiffness characteristics of the system. A variety of semi–active devices have been considered for seismic applications, including variable orifice dampers; variable friction devices; adjustable, tuned liquid dampers; controllable fluid dampers and variable stiffness dampers. Because of their relatively high performance and low energy requirement, a numbers of different devices have been proposed for the practical implementation of semi– active control systems, and more research has focused on improving semi–active control devices or control laws to enhance its performance. A friction damper is a displacement–dependent energy dissipation device, and the damper force is independent of the velocity and the frequency–content of excitation. The present study is aimed to investigate the effectiveness of semi active variable friction damper (SAVFD) in mitigating the seismic response of the structure under modified El Centro earthquake ground motions. The specific objectives of the study are

- To study the earthquake responses like displacements and accelerations of a MDOF building.
- To investigate the optimal placement of the dampers instead of providing them at all the floors for optimum the cost of the damper.
- To ascertain the optimum value of gain multiplier of the dampers.



TypeI (a) TypeII (a) TypeIII (a)

Fig.2 Structural Models of a MDOF Building Connected With SAVFD Dampers with Arrangements

*Equation of Motion:*

$$M\ddot{x} + C\dot{x} + Kx + \Delta F = -M I \ddot{x}_g \quad \ldots\ldots\ldots\ldots 7$$

Where M, C and K are the mass, damping, and stiffness matrices of the combined structure system, respectively; x is the relative–displacement vector with respect to the ground, $F = [f_{d1}, f_{d2} \ldots\ldots f_{dn}]^T$ is control–force vector, Δ is a matrix of zeros and 1s, where 1 will indicate where the damper force is being applied. I is a vector with all its element equal to unity; and $\ddot{x}_g$ is the ground acceleration at the foundations of the structures.

*Semi Active Variable Friction Damper Force:*

By keeping the adjustable slip force of a semi-active friction damper slightly lower than the critical friction force, the method allows the damper to remain in its slip state throughout an earthquake of arbitrary intensity, so the energy dissipation capacity of the damper can be improved.

$$f[k] = \alpha\,(G_z\, z[k-1] + G_u\, u[k-1] + G_w\, w[k-1]) \ldots\ldots 8$$

Where Gz ,Gu and Gw are given in Equation (9). After being multiplied by the factor α, these matrices may also be treated as the control gains. It is obvious in Equation (8) that the parameter α plays an important role in the proposed control law. A larger value of α will lead to a higher control force, but this does not necessarily guarantee better energy dissipation capacity. [Lu, 2004]

$$\left.\begin{aligned} G_z &= K_b\, D(A_d - I) \\ G_u &= K_b\, D\,(B_d + I) \\ G_w &= K_b\, D\, E_d \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots 9$$

*Numerical Study:*

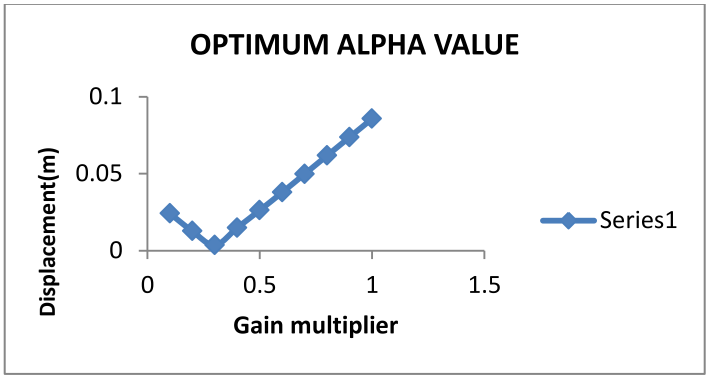
The study, MDOF structure with ten stories is considered with floor mass and inters storey stiffness is assumed to be uniform for structure. The damping ratio of 5% is considered for structure. The mass and stiffness of each floor are chosen such that the fundamental time period of structure $T_1$ yields 0.3s for structure and for case. A thorough study is conducted to arrive building responses like displacements, and accelerations for MDOF structure connected with SAVFD damper under modified El Centro earthquake data.

*Optimum Gain Multiplier Of Semi Active Variable Friction Damper:*

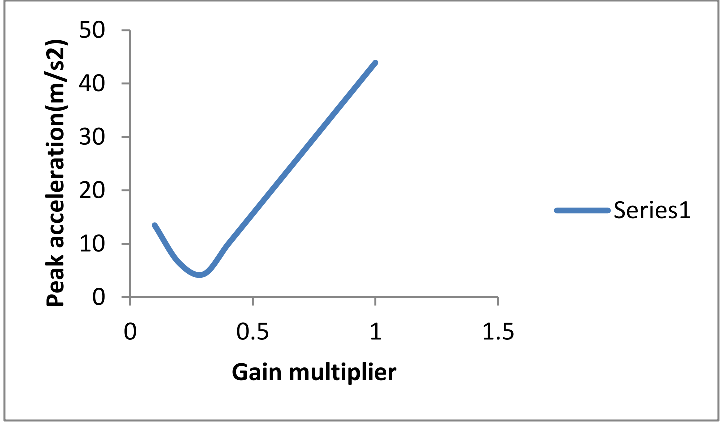
To arrive at the optimum gain multiplier of the SAVFD connected as shown in TYPE II structure .The variation of the top–floor displacements and accelerations of structure are shown in the Fig.4.3. It shows the influence of the gain multiplier on the peak responses under earthquake ground motions. It is observed that the responses of structures (displacements and accelerations) are reduced when value of gain multiplier will be in the range of 0.2 to 0.4 and after this there will be increase of responses with higher value of gain multiplier. Thus, it is concluded that the optimum gain–multiplier value exists to yield the lowest responses of building. For the gain multiplier of a different value, the performance of the dampers is significantly reduced.

*Responses Of MDOF Structure:*

The earthquake responses of the top floor displacements and accelerations connected with SAVFD at all the floors (TYPE II (a)) are plotted as shown in plot 1.5a–1.5b, respectively. These figures clearly indicate the effectiveness of Semi active variable friction dampers can reduce 70 to 80 % of earthquake responses when damper connecting arrangement is shown in Fig. 1(TYPE II (a)).

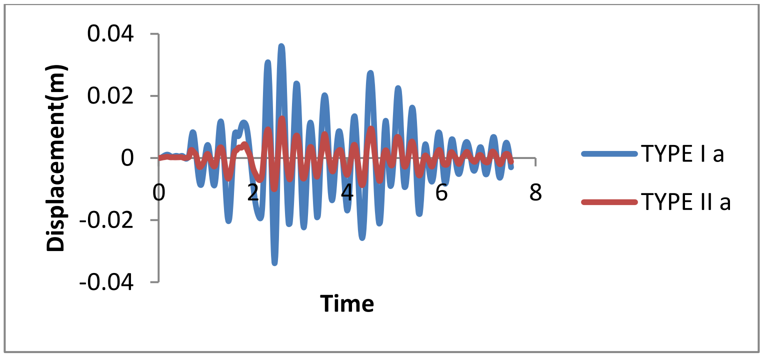


Plot 1.4(a)

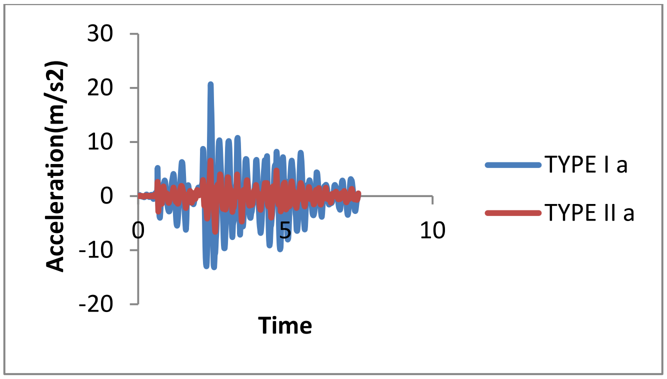


Plot 1.4(b)

Plot 1.4 Variations of Top Floor (a) Displacements (b) Accelerations with Gain Multiplier

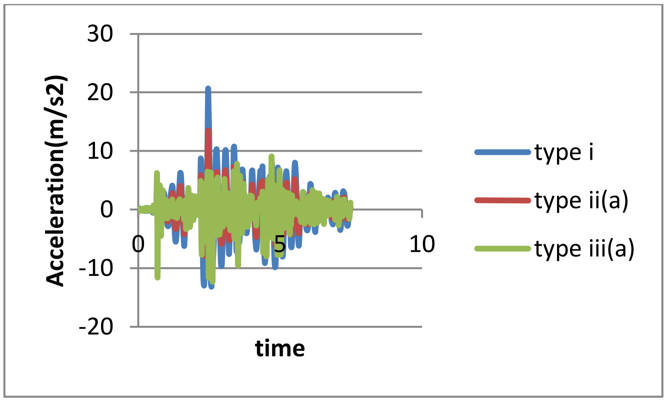


Plot 1.5(a)

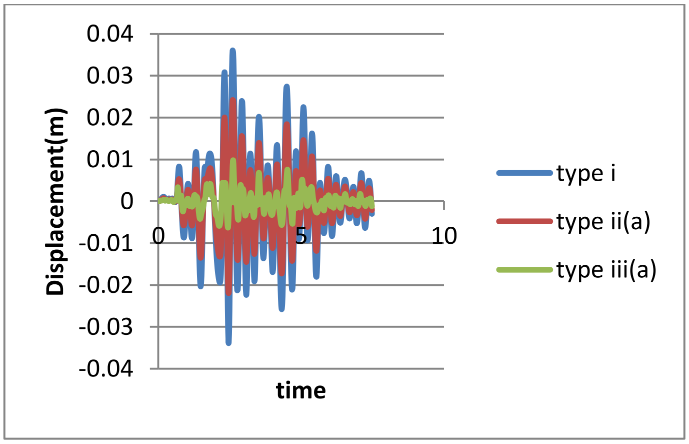


Plot 1.5(b)

Plot 1.5 Top Floor displacement and acceleration for type I (a) and type II(a) 1.5(a) Displacement 1.5(b) Acceleration



Plot 1.6(a)



Plot 1.6(b)

Plot 1.6 Top Floor displacements and acceleration for type I (a) and type II (a) type III (a) 1.6(a) Displacement 1.6(b) Acceleration

*Table 2. Seismic Response Of The Building Connected With SAVFD ($T_1$=0.3s).*
*Percentage of reduction compared to TYPE I structure

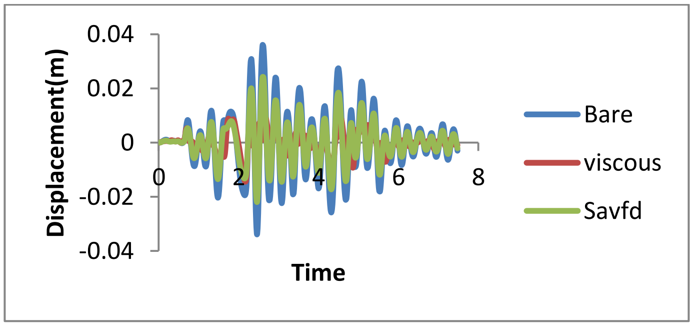
| Earthquake | str | Peak Top floor displacement (m) | | |
|---|---|---|---|---|
| Imperial Valley, 1940 | | TYPE I | TYPE II(a) | TYPE III(a) |
| | 1 | 0.035988 | 0.012706(64.69%)* | 0.0175616(51.20%)* |
| Earthquake | str | Peak Top floor accelerations(m/s$^2$) | | |
| Imperial Valley, 1940 | | TYPE I | TYPE II(a) | TYPE III(a) |
| | 1 | 20.55093 | 6.411074(68.8%)* | 9.089983(55.75%)* |

### *C. COMPARATIVE STUDY ON BUILDING WHEN CONNECTED WITH SAVFD AND VISCOUS DAMPER*

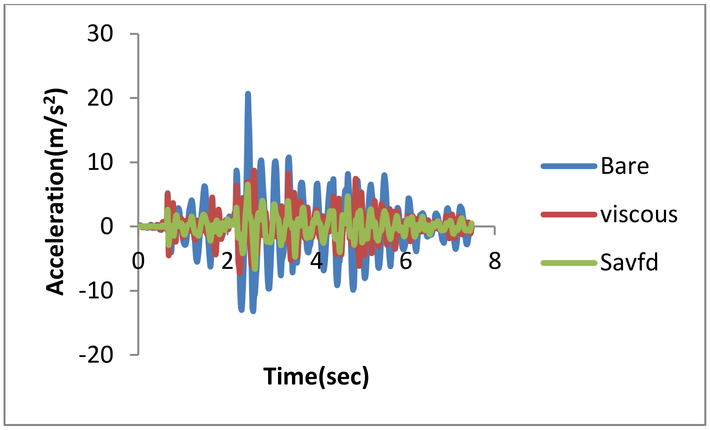
In this study, the comparative responses of MDOF building connected with semi–active variable friction dampers (SAVFD) and viscous fluid damper under El Centro earthquake excitations investigated. As we know from both dampers (SAVFD and VISCOUS FLUID DAMPER) mitigating the earthquake responses at some extent when we considering their optimum parameters but there will be some advantages and disadvantages in both damper performances hence we are giving comparison.

*Responses Of a MDOF Building:*

For the present study, building with 10 stories with uniform floor mass (i) the damping ratio in building was taken as 5 percent. For case (ii) The stiffness of each floor of the building was chosen so they would yield fundamental time periods of 0.3 sec for building and .(ii) for comparative study when building is connected with viscous damper we are considering maximum optimum damping coefficient and maximum optimum exponential coefficient. In the same way when building connected with SAVFD we are considering maximum optimum gain multiplier. Same damper locations are considered for both the dampers. Comparative responses of top floor displacements and accelerations are shown in Plot 1.7... Results are tabulated in Table 3



Plot 1.7(a)



Plot 1.7(b)

Plot 1.7 Top Floor Displacement and accelerations for type I, type II and type II(a) buildings With $T_1$=0.3s

*Table.3 Seismic Response of the Building Connected With Viscous (TYPE II) and SAVFD (TYPE II (a))*

| Earthquake Imperial Valley, 1940 | Str | Peak Top floor displacement (m) | | |
|---|---|---|---|---|
| | | TYPE I | TYPE II | TYPE II(a) |
| | 1 | 0.035988 | 0.009115(74.6%)* | 0.012706 (64.69%)* |
| Earthquake Imperial Valley, 1940 | Str | Peak Top floor accelerations($m/s^2$) | | |
| | | TYPE I | TYPE II | TYPE II(a) |
| | 1 | 20.55093 | 8.657686(57%)* | 6.411074(68.8%)* |

## III. CONCLUSION

Structural control by implementing energy dissipation devices or control systems into structures is more effective in reducing excessive structural vibrations because of natural disturbances. This study presents the vibration control of multi degree of freedom building connected with viscous and semi active variable friction damper types of dampers due to earthquake effect. The model is subjected to Modified El Centro earthquake data. Dampers are placed diagonally in-between stories. Viscous damper mainly depends on damper damping coefficient and exponential coefficient similarly semi-active damper also depends on stiffness of the damper and that can be preselected by the control designer. Some of important conclusions are mentioned below

- To control vibration responses of structures it is necessary to introduce additional damping to the structures. Damping can be increased in the structure by connecting dampers and making structures stable during earthquakes.
- The viscous damper is found to be very effective to control the earthquake responses of the connected structures for this building viscous damper reduces 74% of displacement and 57% of acceleration.
- There exists an optimum damper damping and optimum exponential coefficient of the viscous damper also there will be existing optimum gain multiplier of SAVFD for minimum earthquake response of the building.
- A larger value of a gain multiplier leads to higher control force, but higher efficiency and better energy dissipation is obtained through the optimum gain multiplier
- Lesser dampers at appropriate location can significantly reduce the earthquake responses of the connected structures and reduces the cost of the dampers by 50 percent.

The SAVFD is also found to be very effective to control the earthquake responses of the structures. For this building results shows that Semi active variable friction damper reduces 65% 0f displacement and 69% accelerations. Hence SAVFD is very effective for this building compared to viscous damper as it reduces both displacement and acceleration considerably.

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