Vibration Control of Adjacent Buildings Connected With Selected Types of Dampers

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Abstract— **The optimality criterion is obtained with the help of root mean square value of inter-storey drift A study is also conducted to investigate the optimum exponential coefficient of the viscous dampers and optimum gain multiplier of the SAVFD and importance of those parameters in the structural–response reduction of adjacent buildings. Results show that using viscous and SAVFD to connect the adjacent dynamically similar structures can effectively reduce earthquake-induced responses of either structure but when SAVFD is used to connect soft and stiff buildings and results shows that SAVFD can control only displacements of both structures and it can't control accelerations of soft structure. Further, lesser damper at appropriate locations can significantly reduce the earthquake response of the coupled system. The reduction in responses when two MDOF structures 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. In the initial part of the study evaluate the application of viscous and semi active variable friction (SAVFD) damper for response control of seismically excited dynamically similar and dissimilar adjacent buildings. The numerical study is carried out in four parts, namely (a) two adjacent dynamically similar MDOF buildings connected by viscous dampers with optimum damping coefficient (b) two adjacent dynamically dissimilar MDOF buildings connected by viscous dampers with optimum damping coefficient (c) two adjacent dynamically similar MDOF buildings connected by SAVFD with optimum gain multiplier. (d) Two adjacent dynamically dissimilar MDOF buildings connected by SAVFD with optimum gain multiplier. The study is conducted for the two innovative arrangements of the dampers**

Keywords— ***Optimum damper parameters; Seismic response; Similar and dissimilar adjacent buildings; Viscous damper;SAVFD***

INTRODUCTION

Earthquakes are the Earth's natural means of releasing stress. When the Earth's plates move against each other, stress is put on the lithosphere. When this stress is great enough, the lithosphere breaks or shifts. When the break occurs, the stress is released as energy which moves through the Earth in the form of waves, which can be felt and called an earthquake. There are many different types of earthquakes: tectonic, volcanic, collapse and explosion. The type of earthquake depends on the region where it occurs and the geological make-up of that region. The most common are tectonic earthquake these occur when rocks in the earth's crust break due to geological forces created by movement of tectonic plates. Another type volcanic earthquake occurs in conjunction with volcanic activity. The objectives of this study are to evaluate the application of viscous and semi active variable friction (SAVFD) damper for response control of seismically excited dynamically similar and dissimilar adjacent buildings. The numerical study is carried out in four parts, namely (a) two adjacent dynamically similar MDOF buildings connected by viscous dampers (b) two adjacent dynamically dissimilar MDOF buildings connected by viscous dampers (c) two adjacent dynamically similar MDOF buildings connected by SAVFD. (d) Two adjacent dynamically dissimilar MDOF buildings connected by SAVFD. Both dampers effectiveness is investigated in terms of the reduction of structural responses (namely, displacements and accelerations) of the connected adjacent buildings.

A. *PERFORMANCE OF VISCOUS DAMPER CONNECTE TO ADJACENT MDOF BUILDINGS*

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. The ideal force out for a viscous damper is given by,

$$f_{di} = \mathrm{C}_{\mathrm{md}} \left|\dot{x}_{i2} - \dot{x}_{i1}\right|^{\varepsilon} \operatorname{sgn}(\dot{x}_{i2} - \dot{x}_{i1})| \quad (1.1)$$

Where C_{md} is coefficient of damper, x_{i2}-x_{i1} is relative velocity between the ends of ith damper and ε is exponent having value between 0 and 1.The damper with ε =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

B. Equation Motion of Connected Structures

Let two 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 combined 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

$$\mathbf{M}\,\ddot{\mathbf{X}} + (\mathbf{C} + \mathbf{C_D})\dot{\mathbf{X}} + \mathbf{K}\,\mathbf{X} = -\mathbf{M}\,\mathbf{I}\ddot{x}_g \tag{1.2}$$

Where M, C and K are the mass, damping and stiffness matrices of the combined 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 xg is the ground acceleration at the foundations of the structures. The details of each matrix are given as,

$$\mathbf{M} = \begin{bmatrix} \mathbf{m}_{(n,n)} & \mathbf{0}_{(n,n+m)} \\ \mathbf{0}_{(n+m,n)} & \mathbf{m}_{(n+m,n+m)} \end{bmatrix}; \quad \mathbf{C} = \begin{bmatrix} \mathbf{c}_{(n,n)} & \mathbf{0}_{(n,n+m)} \\ \mathbf{0}_{(n+m,n)} & \mathbf{c}_{(n+m,n+m)} \end{bmatrix}; \quad \mathbf{K} = \begin{bmatrix} \mathbf{k}_{(n,n)} & \mathbf{0}_{(n,n+m)} \\ \mathbf{0}_{(n+m,n)} & \mathbf{k}_{(n+m,n+m)} \end{bmatrix}, \tag{1.3}$$

$$\mathbf{m}_{(n,n)} = \begin{bmatrix} m_{12} & & & \\ & m_{22} & & \\ & & \cdots & \\ & & & m_{n2} \end{bmatrix}$$

$$\mathbf{m}_{(n+m,n+m)} = \begin{bmatrix} m_{11} & & & \\ & m_{21} & & \\ & & \cdots & \\ & & & m_{n+m,1} \end{bmatrix}, \tag{1.5}$$

$$\mathbf{c}_{(n,n)} = \begin{bmatrix} c_{12} + c_{22} & -c_{22} & & \\ -c_{22} & c_{22} + c_{32} & -c_{32} & \\ & \cdots & \cdots & \\ & & & c_{n2} \end{bmatrix};$$

$$\mathbf{c}_{(n+m,n+m)} = \begin{bmatrix} c_{11} + c_{21} & -c_{21} & & \\ -c_{21} & c_{21} + c_{31} & -c_{31} & \\ & \cdots & \cdots & \\ & & & c_{n+m,1} \end{bmatrix} \tag{1.6}$$

$$\mathbf{k}_{(n,n)} = \begin{bmatrix} k_{12} + k_{22} & -k_{22} & & \\ -k_{22} & k_{22} + k_{32} & -k_{32} & \\ & \cdots & \cdots & \\ & & & k_{n2} \end{bmatrix};$$

$$\mathbf{k}_{(n+m,n+m)} = \begin{bmatrix} k_{11} + k_{21} & -k_{21} & & \\ -k_{21} & k_{21} + k_{31} & -k_{31} & \\ & \cdots & \cdots & \\ & & & k_{n+m,1} \end{bmatrix} \tag{1.7}$$

‘0’ is the null matrix .Equation (3.1) can be further transformed to state–space representation as follows

C. State Space Representation

$$z\,[k+1] = A_d z[k] + B_d u[k] + E_d w[k] \tag{1.8}$$

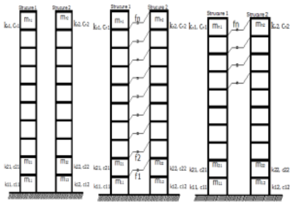
Where the vector z(k) represents the state of the structure, which contains the relative-to ground Velocity and displacement of each floor, [k + 1] denotes that the variable is evaluated at the $(k+1)^{th}$ time step, u(k) denotes the vector of the controllable Viscous forces provided by the viscous 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

$$Bd = A^{-1}\,(Ad - I)\,B \tag{1.9}$$

$$Ed = A^{-1}\,(Ad - I)\,E \tag{2.0}$$

D.Numerical Study

The study, two adjacent MDOF structures with ten stories are considered with floor mass and inter storey stiffness is assumed to be uniform for both structures. The damping ratio of 5% is considered for both structures. For case (i)The mass and stiffness of each floor are chosen such that the fundamental time period of structures T_1 yield 0.4s (similar buildings) for both structures and for case (ii) The mass and stiffness of each floor are chosen such that the fundamental time period of structure 1 and structure 2 yield 1.2 s(soft structure) and 0.4 s (stiff structure)respectively A thorough study is conducted to arrive earthquake responses like displacements, and accelerations for MDOF adjacent structures connected with viscous damper under modified El Centro earthquake data.



TYPEI TYPEII TYPEIII

Fig.1 Structural Models of Two MDOF Adjacent Structures Connected With Viscous Dampers with Different Arrangements

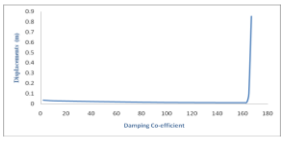


fig.1a

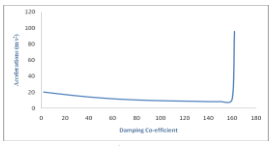


fig1b

Variations of Top Floor (1a) Displacements (1b) Accelerations With Damping Coefficient of viscous damper

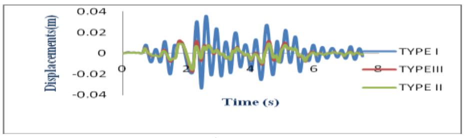


fig4a

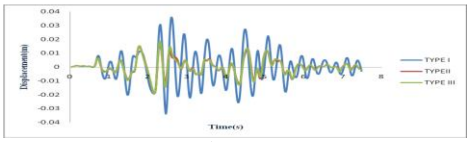


fig4b

Top Floor displacements for type I, type II and type III structures 4a Structure 1 With 1.2 s and 4b Structure 2 With T_1=0.4 s

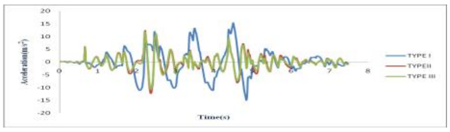


fig4c

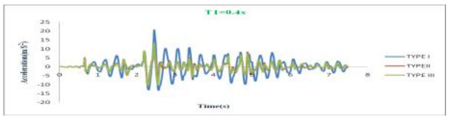


fig4d

Top Floor Accelerations for type I, type II and type III structures 4c Structure 1 with T1=1.2 s and 4d (b) Structure 2 With T_1=0.4s

Seismic Response Of The Two Dynamically Similar Adjacent Structures Connected With Viscous Dampers (T_1=0.4s).table1

Earthquake Imperial Valley, 1940	structure	Peak Top floor displacement (m)		
		TYPE I	TYPE II	TYPE III
	1	0.035988	0.009876(72.5%)*	0.0125(65.2%)*
	2	0.035988	0.00783(78.23%)*	0.0084(27.5%)*
Earthquake Imperial Valley, 1940	**structure**	**Peak Top floor accelerations(m/s^2)**		
		TYPE I	TYPE II	TYPE III
	1	20.55093	8.24163(59.89%)*	9.6222(53.17%)*
	2	20.55093	7.2091(64.92%)*	7.53771(63.32%)*

*Percentage of reduction compared to TYPE I structure

Seismic Response of Two Adjacent dynamically dissimilar Structures
Connected with Viscous Dampers(table2)

Earthquake Imperial Valley, 1940	Structure	Peak Top floor displacement (m)		
		TYPE I	TYPE II	TYPE III
	1(T_1=1.2s)	0.254048	0.0352(86.12%)*	0.0329(87%)*
	2(T_1=0.4s)	0.035988	0.01734(51.80%)*	0.01856(48.5%)*
Earthquake Imperial Valley, 1940	**Structure**	**Peak Top floor accelerations(m/s^2)**		
		TYPE I	TYPE II	TYPE III
	1(T_1=1.2s)	15.35189	12.3233(20%)*	11.8786(22.62%)*
	2(T_1=0.4s)	20.55093	11.9096(42.5%)*	13.1882(36%)*

E.PERFORMANCE OF SEMI ACTIVE VARIABLE FRICTION DAMPER CONNECTED TO ADJACENT MDOF BUILDINGS

The present study is aimed to investigate the effectiveness of semi active variable friction damper (SAVFD) in mitigating the seismic response of the dynamically similar and dissimilar adjacent coupled structures under modified El Centro earthquake ground motions. The specific objectives of the study are

- To study the earthquake responses like displacements and accelerations of adjacent MDOF buildings
- 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.To examine the effect of considering different building parameters.

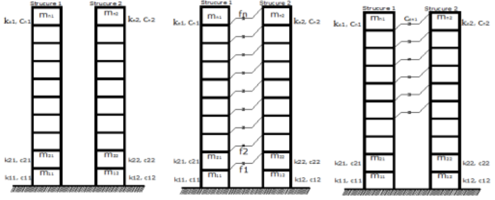
Mathematical Formulation of Damper Connected Structures

$$\mathbf{M}\ddot{\mathbf{x}} + \mathbf{C}\dot{\mathbf{x}} + \mathbf{K}\mathbf{x} + \mathbf{\Lambda F} = -\mathbf{MI}\ddot{x}_g \tag{1.9}$$

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.

Numerical Study

The study is carried out with two adjacent MDOF structures with ten stories are considered with floor mass and inter storey stiffness is assumed to be uniform for both structures. The damping ratio of 5% is considered for both structures. For case (i)The mass and stiffness of each floor are chosen such that the fundamental time period of structures T_1 yield 0.4s (similar buildings) for both structures and for case (ii) The mass and stiffness of each floor are chosen such that the fundamental time period of structure 1 and structure 2 yield 1.2 s(soft structure) and 0.4 s (stiff structure)respectively A thorough study is conducted to arrive earthquake responses like displacements, and accelerations for MDOF adjacent structures connected with semi active variable friction damper under modified El Centro earthquake data.



TYPE I TYPE IIa TYPE IV

Fig.2 Structural Models of Two MDOF Adjacent Structures Connected With SAVFD Dampers with Different Arrangements

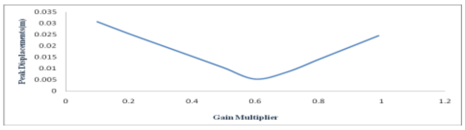


fig2a

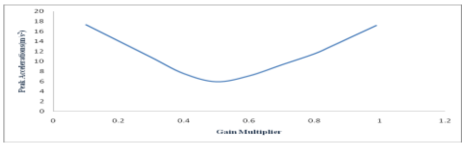


fig2b

Variations of Top Floor (2a)Displacements (2b)Accelerations with Gain Multiplier

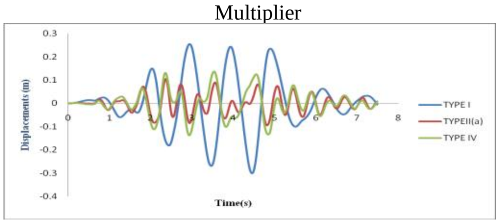


fig5a

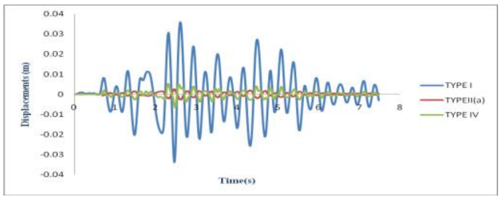


fig5b

Top Floor Displacements for type I, type II(a) and type IV structures 5a Structure 1 with T_1=1.2 s and 5b Structure 2 With T_1=0.4 s

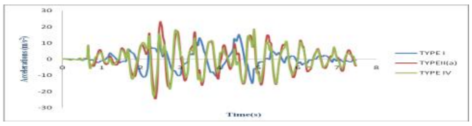


fig5c

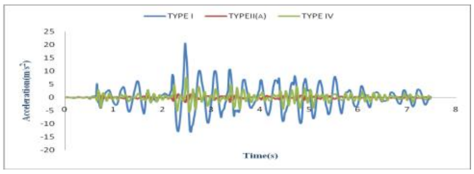


fig5d

Top Floor Accelerations for type I, type II(a) and type IV structures 5c (a) Structure 1 with T_1=1.2s and 5d (b) Structure 2 With T_1=0.4s

Table 3. Seismic Response Of The Two Dynamically Similar Adjacent Structures Connected With SAVFD (T_1=0.4s).

Earthquake	structure	Peak Top floor displacement (m)		
		TYPE I	TYPE II(a)	TYPE IV
Imperial Valley, 1940	1	0.035988	0.010314(71.3%)*	0.00523(85.44) *
	2	0.035988	0.00375(89.55%)*	0.00170(95.25%)*
Earthquake	**structure**	**Peak Top floor accelerations(m/s^2)**		
		TYPE I	TYPE II(a)	TYPE IV
Imperial Valley, 1940	1	20.55093	5.928538(71.2%)*	3.777883(81.6%)*
	2	20.55093	1.78312(91.32%)*	4.31608(79%)*

*Percentage of reduction compared to TYPE I structure

Table 4.Seismic Response Of The Two Adjacent Structures Connected With SAVFD

Earthquake Imperial Valley,	structure	Peak Top floor displacement (m)		
		TYPE I	TYPE II(a)	TYPE IV

1940	1(T_1=1.2s)	0.254048	0.10551(58.46%)*	0.13738(45.98%)*
	2(T_1=0.4s)	0.035988	0.00252(92.98%)*	0.00519(85.55%)*
Earthquake Imperial Valley, 1940	structure	Peak Top floor accelerations(m/s^2)		
		TYPE I	TYPE II(a)	TYPE IV
	1(T_1=1.2s)	15.35189	23.354(-52.1%)*	18.572(-20.9%)*
	2(T_1=0.4s)	20.55093	1.92135(90.64%)*	7.45512(63.72%)*

*Percentage of reduction compared to TYPE I structure

F.COMPARATIVE STUDY ON ADJACENT BUILDINGS WHEN CONNECTED WITH SAVFD AND VISCOUS FLUID DAMPER

The comparative responses of two adjacent MDOF buildings connected with semi–active variable friction dampers (SAVFD) and viscous fluid damper under El Centro earthquake excitations investigated .For the present study, two adjacent structures with 10 stories with uniform floor mass and inter–story stiffness were considered for case (i) and two adjacent structures with 10 stories with different floor masses and inter–story stiffness were considered for case (ii). The damping ratio in each structure was taken as 5 percent for both the cases. For case (i) The stiffness of each floor of the structures was chosen so they would yield fundamental time periods of 0.4 sec for both the structures and . For case (ii) the stiffness of each floor of the structures was chosen so they would yield fundamental time periods of 1.2 sec and 0.4 sec for Structure 1 and Structure 2, respectively. Thus, Structure 1 may be considered a soft structure and Structure 2, a stiff structure in case (ii).for comparative study when adjacent buildings are connected with viscous damper we are considering maximum optimum damping coefficient and maximum optimum exponential coefficient. In the same way when adjacent buildings connected with SAVFD we are considering maximum optimum gain multiplier.

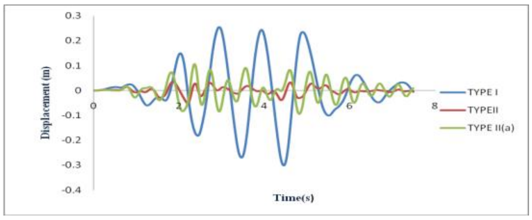
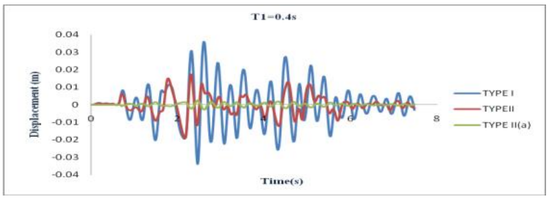
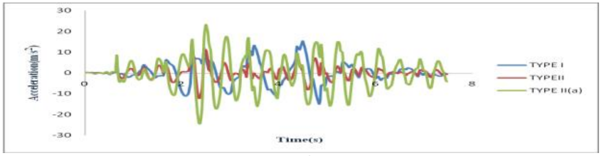


fig6a

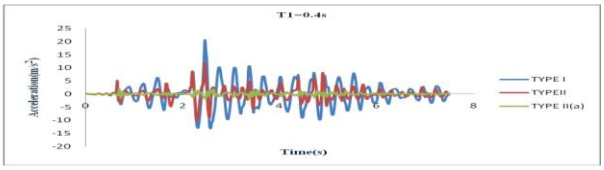


Figb

Top Floor Displacements for type I, type II(a) and type II(a) structures 6a Structure 1 with T_1=1.2s and 6b Structure 2 With T_1=0.4s



figc



figd

Top Floor Accelerations for type I, type II(a) and type II(a) structures 6c Structure 1 with T_1=1.2s and 5.4 6d Structure 2 With T_1=0.4s

Table 5 Seismic Response Of The Two Dynamically Similar Adjacent Structures Connected With Viscous (TYPE II) and SAVFD (TYPE II (a))

Earthquake Imperial Valley, 1940	structure	Peak Top floor displacement (m)		
		TYPE I	TYPE II	TYPE II(a)
	1	0.035988	0.00987(72.55%)*	0.01031(71.34%)*
	2	0.035988	0.00783(78.23%)*	0.00375(89.55%)*
Earthquake Imperial Valley, 1940	structure	Peak Top floor accelerations(m/s2)		
		TYPE I	TYPE II	TYPE II(a)
	1	20.55093	8.241633(59.89%)	0.062473(99.6%)
	2	20.55093	7.20919(64.9%)	1.783125(91.3%)

*Percentage of reduction compared to TYPE I structure

Table 6.Seismic Response Of The Two Dynamically Similar Adjacent Structures Connected With Viscous (TYPE II) and SAVFD (TYPE II (a))

Earthquake Imperial Valley, 1940	structure	Peak Top floor displacement (m)		
		TYPE I	TYPE II	TYPE II(a)
	1(T1=1.2s)	0.254088	0.03525(86.12%)*	0.105517(58.6%)*
	2(T1=0.4s)	0.035988	0.01734(51.80%)*	0.00252(92.98%)*
Earthquake Imperial Valley, 1940	**Structure**	**Peak Top floor accelerations(m/s2)**		
		TYPE I	TYPE II	TYPE II(a)
	1(T1=1.2s)	15.35189	12.3334(20%)*	23.35421(-52%)*
	2(T1=0.4s)	20.55093	11.90963(42%)*	1.9213(90.65%)*

*Percentage of reduction compared to TYPE I structure

CONCLUSIONS

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 thesis presented the vibration control of adjacent multi degree of freedom buildings connected with selected types of dampers (viscous and semi active variable friction damper) due to earthquake effect. The model is subjected to Modified El Centro earthquake data. Dampers are placed between the adjacent stories. Viscous damper mainly depends on damper damping coefficient and exponential coefficient similarly semi-active damper also depends on a parameter α and 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.
- 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.
- The viscous damper is found to be very effective to control the earthquake responses of the dynamically similar (stiff-stiff) and dissimilar (soft-stiff) adjacent connected structures.
- 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 coupled structures.
- 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 dynamically similar (stiff-stiff) structure and when SAVFD is connected to softer adjacent structures it will reducing displacements of the building but it will increase instead of reducing the acceleration responses of building. Hence SAVFD is very effective for stiffer structures compared to viscous damper.

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