

Vibration Mitigation in Adjacent Buildings Using Selected Damper Types

Naveen Malammanavar¹, Shrikantha T², Shivaraja N³

¹senior scale lecturer, Department of civil engineering, Sri channakeshava government polytechnic guddachannapur, bankapur

²Department of civil engineering, Government Polytechnic Karatagi

³senior scale Lecturer, Department of civil engineering, Government polytechnic Hiriur

Article History

Volume 6 issue 10, July 2024

Received: 1 July, 2024

Accepted: 10 July, 2024

Published: 28 July, 2024

doi:

[10.48047/AFJBS.6.10.2024.7393-7407](https://doi.org/10.48047/AFJBS.6.10.2024.7393-7407)

ABSTRACT

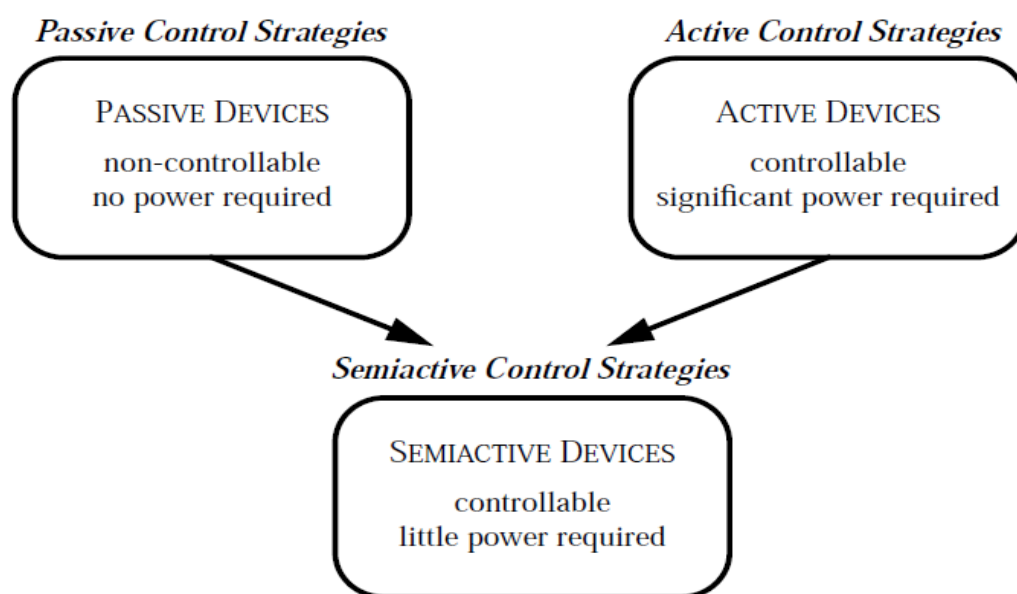
Incorporating energy dissipation devices or control systems into structures proves to be more effective in mitigating excessive vibrations caused by natural disturbances. This thesis explores vibration control in adjacent multi-degree-of-freedom (MDOF) buildings linked with selected types of dampers under earthquake conditions. The model uses Modified El Centro earthquake data, with dampers positioned between adjacent stories. The study aims to assess the effectiveness of viscous and semi-active variable friction dampers (SAVFD) in controlling the seismic response of both dynamically similar and dissimilar adjacent buildings. The equations of motion for the two adjacent MDOF structures, connected with viscous and SAVFD dampers, are formulated. The numerical analysis is divided into four parts: (a) dynamically similar MDOF buildings connected by viscous dampers with optimal damping coefficients, (b) dynamically dissimilar MDOF buildings connected by viscous dampers with optimal damping coefficients, (c) dynamically similar MDOF buildings connected by SAVFD with optimal gain multipliers, and (d) dynamically dissimilar MDOF buildings connected by SAVFD with optimal gain multipliers. The effectiveness of both dampers is evaluated based on the reduction of structural responses (displacement, acceleration, and velocity) of the connected buildings. Additionally, the study examines the optimal damper damping coefficients, exponential coefficients for viscous dampers, and gain multipliers for SAVFD, highlighting their importance in reducing structural responses in adjacent buildings. The findings indicate that connecting dynamically similar structures with viscous and SAVFD can significantly reduce earthquake-induced responses by selecting appropriate damping coefficients and gain multipliers. However, when SAVFD connects soft and stiff buildings, it effectively controls displacements but not accelerations of the soft structure. Furthermore, strategically placing fewer dampers can substantially reduce earthquake responses in the coupled system. The response reduction achieved by connecting two MDOF structures with dampers at 50% of the total locations is nearly as effective as connecting them at all floors, thus minimizing damper costs.

INTRODUCTION

In recent years, advancements in design technology and material quality in civil engineering have led to the construction of lighter and more slender structures, such as high-rise buildings and long-span bridges. These structures are more susceptible to vibrations, particularly in earthquake-prone areas, which can result in serious structural damage or even failure. Large seismic events have historically caused significant destruction, leading to substantial loss of life and property. In recent decades, earthquakes have claimed the lives of tens of thousands of people and resulted in billions of dollars in property damage.

This study aims to assess the effectiveness of viscous and semi-active variable friction dampers (SAVFD) in controlling the seismic response of adjacent buildings, both dynamically similar and dissimilar. The equations of motion for two adjacent multi-degree-of-freedom (MDOF) structures connected by these dampers are formulated. The numerical analysis is divided into four scenarios: (a) dynamically similar MDOF buildings connected by viscous dampers with optimal damping coefficients, (b) dynamically dissimilar MDOF buildings connected by viscous dampers with optimal damping coefficients, (c) dynamically similar MDOF buildings connected by SAVFD with optimal gain multipliers, and (d) dynamically dissimilar MDOF buildings connected by SAVFD with optimal gain multipliers. The effectiveness of both types of dampers is evaluated by examining reductions in structural responses such as displacement, acceleration, and velocity in the connected buildings.

Additionally, the study investigates the optimal parameters for the dampers, including the damping coefficients for viscous dampers, the gain multipliers for SAVFD, and the exponential coefficients for viscous dampers, highlighting their significance in reducing structural responses in adjacent buildings. The results demonstrate that connecting dynamically similar structures with viscous and SAVFD dampers can effectively mitigate earthquake-induced responses by selecting appropriate damping coefficients and gain multipliers. However, when SAVFD dampers connect dynamically dissimilar buildings, they can only control displacements and not the accelerations of the softer structure. Furthermore, strategically placing fewer dampers can significantly reduce earthquake responses in the coupled system. The reduction in structural responses when two MDOF structures are connected with dampers at 50% of the total locations is almost as effective as connecting them at all floors, thus reducing the overall cost of the dampers.



Bhaskararao and Jangid[5] examined the dynamic behavior of two adjacent single-degree-of-freedom (SDOF) structures linked by a viscous damper under base acceleration. Their study

focused on determining the optimal damper damping, revealing that a viscous damper significantly reduces the dynamic responses of adjacent structures and identifying an optimal damping coefficient for minimizing responses.

Patel and Jangid[14] analyzed the responses of two adjacent structures connected by semi-active variable friction dampers (SAVFD) during various earthquake excitations. They also investigated the optimal gain multiplier value and its critical role in reducing structural responses. To cut costs, their study employed only 50 percent of the total dampers placed at optimal locations. While a higher gain multiplier results in a greater control force, the optimum gain multiplier provides superior efficiency and energy dissipation.

Dong-dong et al.[8] conducted a dynamic response analysis of damper-connected adjacent multi-story structures with uncertain parameters. They selected the mean square random responses of structural displacement and story drift as optimization objectives. Their detailed analysis covered the variations in mean square responses of top-floor displacements and bottom-story drifts in neighboring structures relative to damper stiffness and damping coefficient.

Bharti and Shrimali[6] proposed a control scheme for coupled buildings using variable friction (VF) dampers. Their numerical example involved two adjacent buildings of twenty and ten stories, respectively. They also examined the influence of the VF damper gain multiplier on the control strategy's performance, concluding that VF dampers are effective for seismic response control in coupled buildings, with the control scheme's performance significantly impacted by the VF damper gain multiplier. Their findings suggested that response control is more effective for shorter buildings.

Bharti et al.[6] explored the use of MR dampers for mitigating seismic responses in adjacent multistory buildings within a coupled building control scheme, incorporating passive-off, passive-on, and semi-active control strategies. They concluded that energy dissipation devices are highly effective in reducing excessive structural vibrations caused by natural disturbances.

Their work involved studying the structural responses of two buildings with different fundamental frequencies, connected by various dampers (SAVFD, viscous, Maxwell, and passive friction dampers) under different types of earthquake ground motions. They highlighted the advantages and disadvantages of each damper under various building conditions and assessed their suitability.

PERFORMANCE OF VISCOUS DAMPER CONNECTED TO ADJACENT MDOF BUILDINGS

Formulation of Equation Motion of Connected Structures

$$\mathbf{M} \ddot{\mathbf{X}} + (\mathbf{C} + \mathbf{C}_D) \dot{\mathbf{X}} + \mathbf{K} \mathbf{X} = -\mathbf{M} \mathbf{I} \ddot{x}_g$$

$$\mathbf{M} = \begin{bmatrix} \mathbf{m}_{(n,n)} & \mathbf{0}_{(n,n+m)} \\ \mathbf{0}_{(n+m,n)} & \mathbf{m}_{(n+m,n+m)} \end{bmatrix};$$

$$\mathbf{C} = \begin{bmatrix} \mathbf{c}_{(n,n)} & \mathbf{0}_{(n,n+m)} \\ \mathbf{0}_{(n+m,n)} & \mathbf{c}_{(n+m,n+m)} \end{bmatrix};$$

$$\mathbf{K} = \begin{bmatrix} \mathbf{k}_{(n,n)} & \mathbf{0}_{(n,n+m)} \\ \mathbf{0}_{(n+m,n)} & \mathbf{k}_{(n+m,n+m)} \end{bmatrix},$$

State Space Representation

$$z [k + 1] = A_d z[k] + B_d u[k] + E_d w[k]$$

$$B_d = A^{-1} (A_d - I) B$$

$$E_d = A^{-1} (A_d - I) E$$

Viscous Damper Force

The force exerted by a viscous fluid damper primarily depends on the relative velocities between floors, the damping coefficient, and the exponential coefficient. The following formulation (4.9) explicitly shows the parameters that influence the viscous fluid damper force.

$$F = C_d (V_2 - V_1)^{\eta}$$

Numerical Study

An extensive study is conducted to determine earthquake responses such as displacements, velocities, and accelerations at the optimal damping coefficient for dampers in multi-degree-of-freedom (MDOF) adjacent structures subjected to modified El Centro earthquake time histories. When adjacent structures are connected as depicted in Fig 1(b) with identical damping in all dampers, the displacement and acceleration responses initially decrease with an increase in damper damping. However, after a certain point, further increases in damper damping cause the responses to rise again.

For this study, two adjacent MDOF structures with ten stories each are considered, assuming uniform floor mass and inter-story stiffness for both buildings. A damping ratio of 5% is applied to both structures. The mass and stiffness of each floor are selected to achieve a fundamental time period (T1) of 0.4 seconds for both structures, representing similar buildings. Additionally, the study examines a scenario where the first structure (soft) has a time period of 1.2 seconds and the second structure (stiff) has a time period of 0.4 seconds, as illustrated in Fig. 4.3(b).

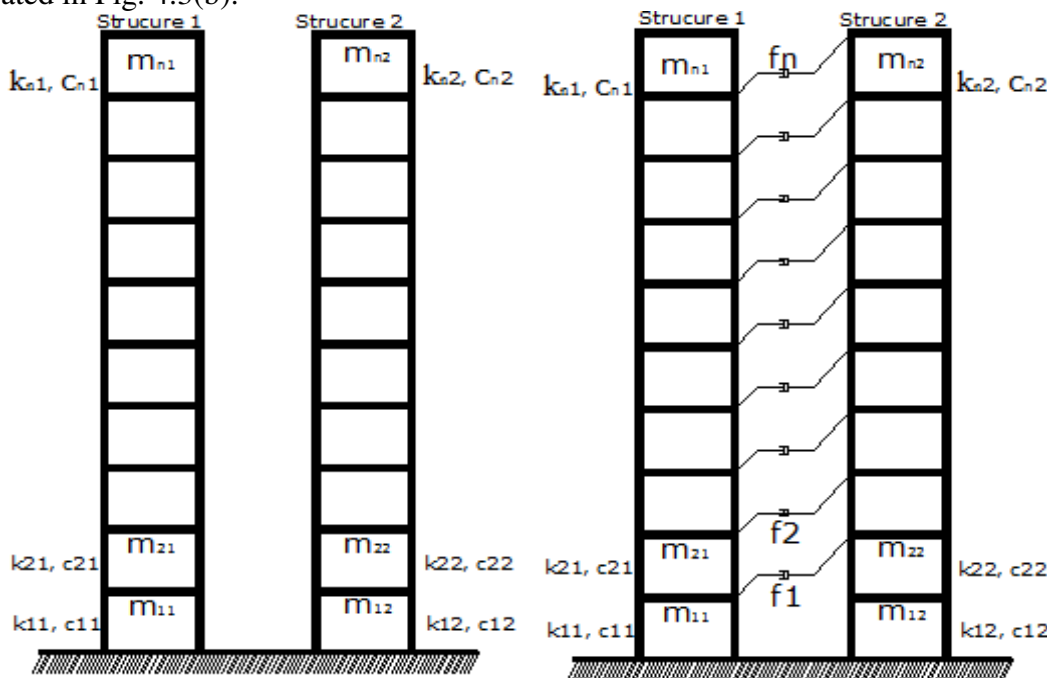


Fig 1 (a)

Fig 1(b)

Figure shows that the responses of displacement, acceleration, and velocities decrease as damper damping increases, but this reduction only occurs up to a certain point. Beyond this point, further increases in damper damping cause the responses to rise again, indicating the presence of an optimal damping coefficient. At very high damping coefficients, the two structures behave as if they are rigidly connected, resulting in minimal relative displacements

and velocities between the connected floors, rendering the damper ineffective. Conversely, if the damping coefficient is reduced to zero, the structures revert to an unconnected state. To minimize damper costs, the study investigates the responses of the structures using only 50% of the total dampers with the optimal damping coefficient. Since the force in a viscous damper is proportional to the maximum relative velocity of the connected floors, the maximum relative velocities between all dampers under the considered earthquake are obtained to determine the variation in damping. The table shows that the reduction in responses when structures are connected at all floors is nearly the same as when connected with only 50% of the total dampers. Thus, providing dampers on every floor is not necessarily the optimal solution, and even a few dampers can achieve similar performance. This study also considers two adjacent MDOF structures with ten stories, assuming different floor masses and inter-story stiffness for each structure.

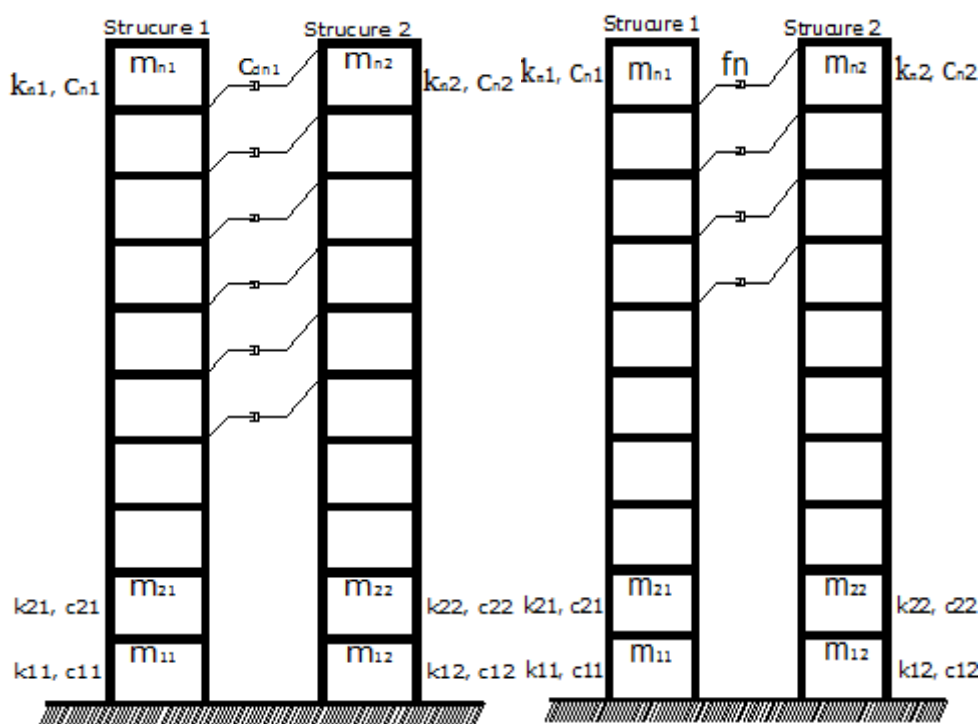
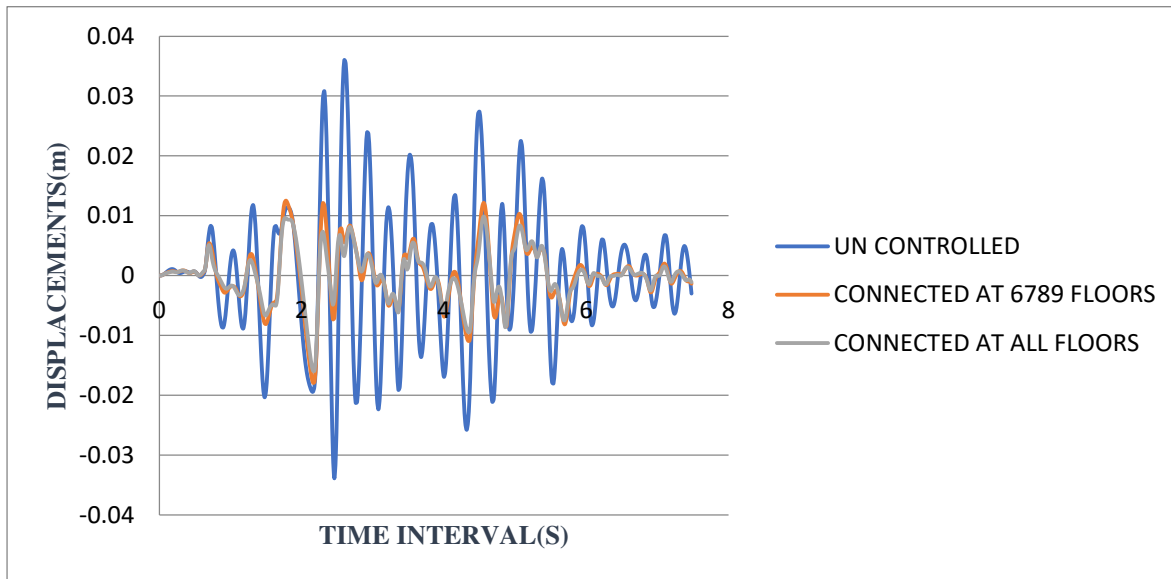


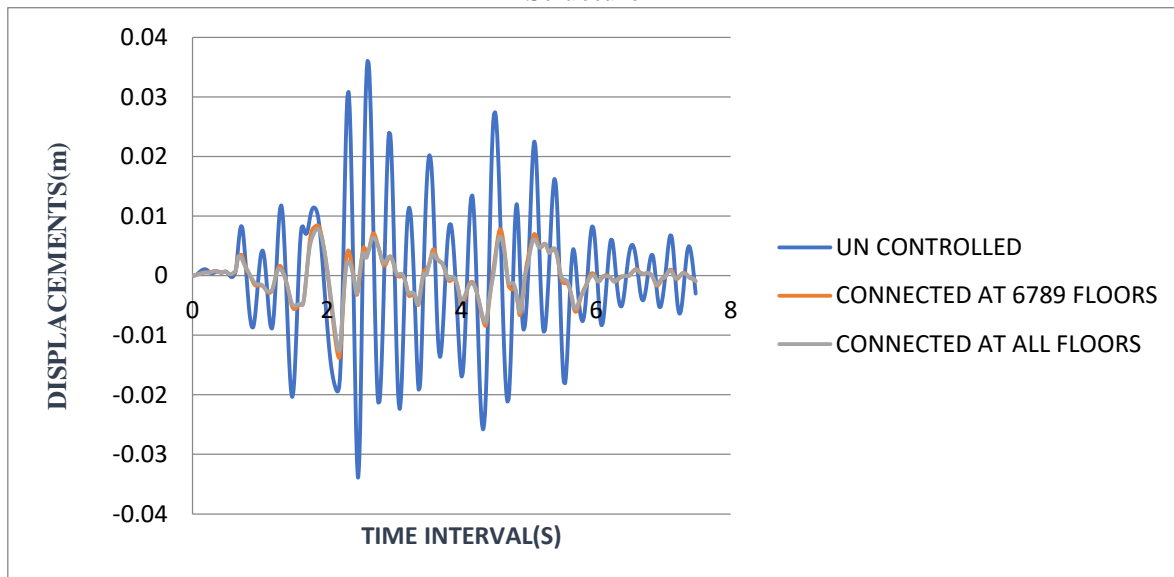
Fig 1(c)

Fig 1(d)

Fig.2.Structural Models of Two MDOF Adjacent Structures Connected With Viscous Dampers, And SAVFD Arrangements

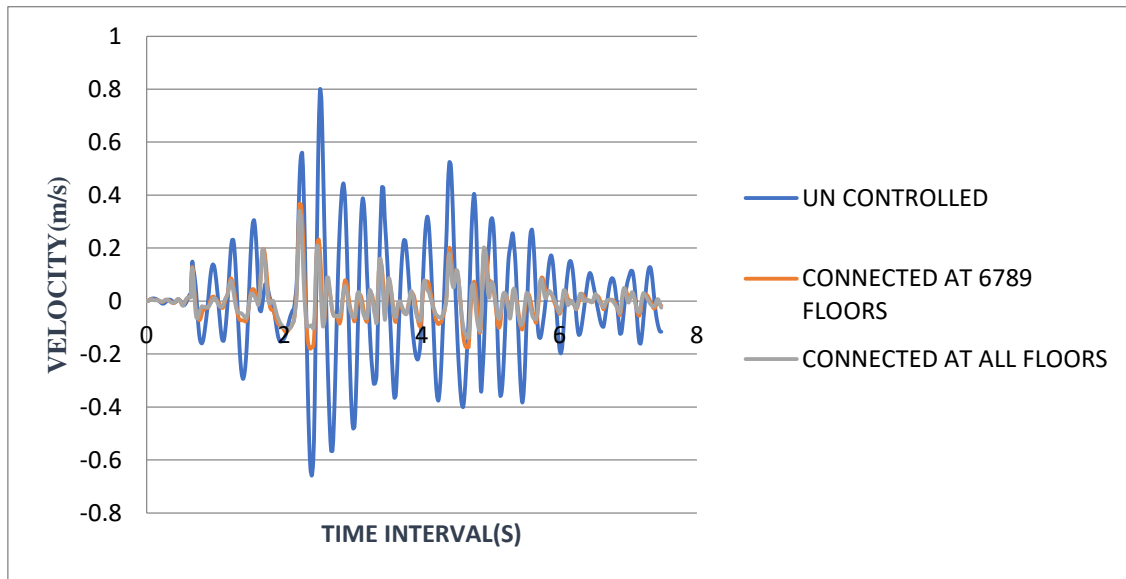


Structure 1

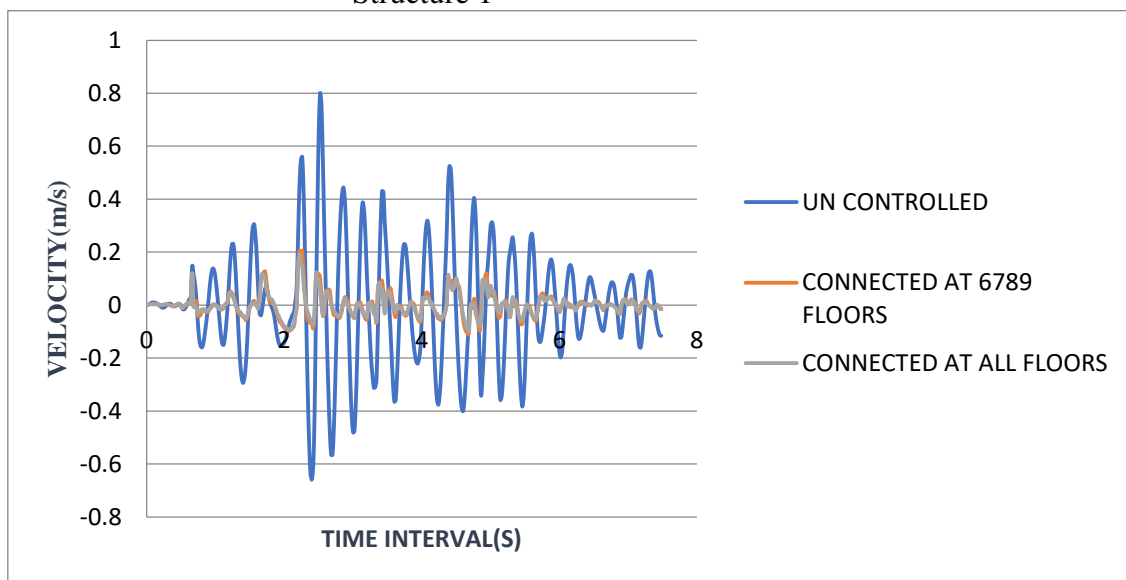


Structure 2

Fig.3. Time Histories of Top Floor Accelerations of Two MDOF Structures (a) Structure 1 (b) Structure 2 with $T_1=0.4s$

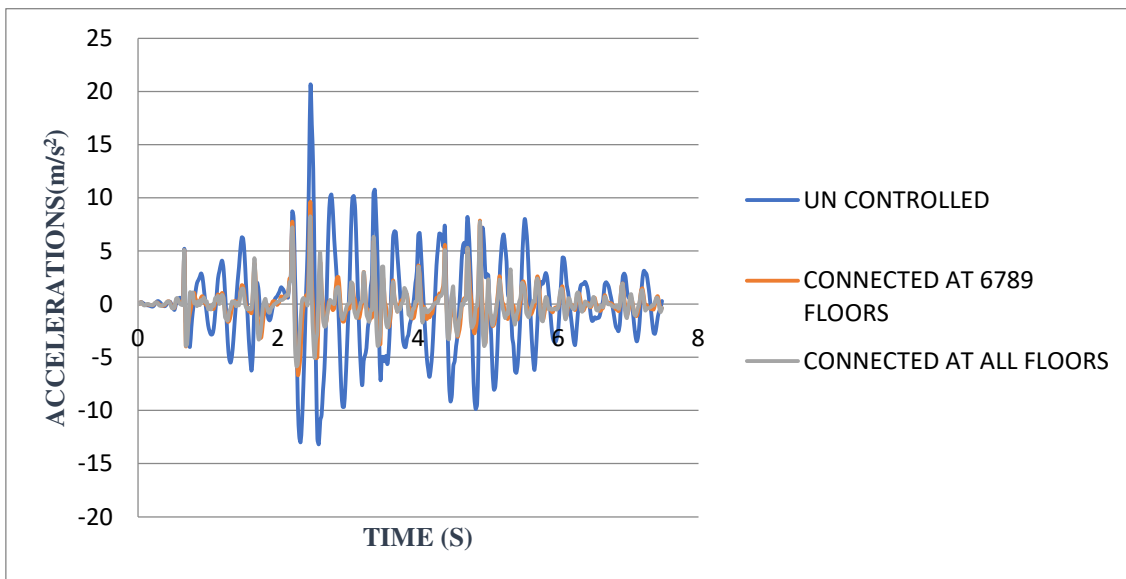


Structure 1

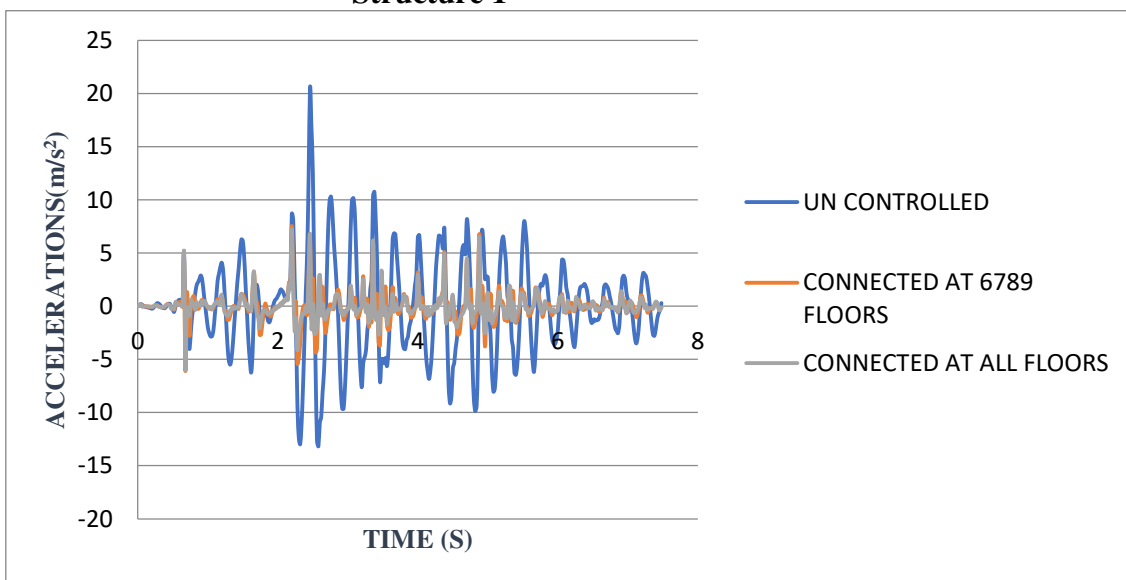


Structure 1

Fig.4. Time Histories of Top Floor Accelerations Of Two MDOF Structures (a) Structure 1(b) Structure 2 With $T_1=0.4s$



Structure 1



Structure 2

Fig.5. Time Histories Of Top Floor Accelerations Of Two MDOF Structures (a) Structure 1 (b) Structure 2 With $T_1=0.4s$.

Table 1. Seismic Response Of The Two Dynamically Similar Adjacent Structures Connected With Viscous Dampers ($T_1=0.4s$).

Earthquake Imperial Valley, 1940	structure	Peak Top floor displacement (m)		
		Un controlled	Connected at all floors	Connected at 6789
	1	0.035988	0.009876(72.5%)	0.012523(65.20%)
2	0.035988	0.007831(78.23%)	0.008417(27.5%)	

Earthquake Imperial Valley, 1940	structure	Peak Top floor velocity(m/s)		
		Un controlled	Connected at all floors	Connected at 6789
	1	0.799748	0.338009(57.7%)	0.366085(54%)
	2	0.799748	0.192907(75.87%)	0.2053(75%)
Earthquake Imperial Valley, 1940	structure	Peak Top floor accelerations(m/s ²)		
		Un controlled	Connected at all floors	Connected at 6789
	1	20.55093	8.241633(59.89%)	9.62229(53.17%)
	2	20.55093	7.20919(64.92%)	7.537712(63.32%)

Table 2.
Seismic Response of Two Adjacent Structures Connected With Viscous Dampers

Earthquake Imperial Valley, 1940	structure	Peak Top floor displacement (m)		
		Un controlled	Connected at all floors	Connected at 6789
	1(T1=1.2s)	0.254048	0.03525(86.12%)	0.03298(87%)
	2(T1=0.4s)	0.035988	0.017345(51.80%)	0.018566(48.5%)
Earthquake Imperial Valley, 1940	structure	Peak Top floor velocity(m/s)		
		Un controlled	Connected at all floors	Connected at 6789
	1(T1=1.2s)	1.939959	0.722818(62.74%)	0.598138(70%)
	2(T1=0.4s)	0.799748	0.441986(44.73%)	0.448171(44%)
Earthquake Imperial Valley, 1940	structure	Peak Top floor accelerations(m/s ²)		
		Un controlled	Connected at all floors	Connected at 6789
	1(T1=1.2s)	15.35189	12.32334(20%)	11.87863(22.62%)
	2(T1=0.4s)	20.55093	11.90963(42.5%)	13.18827(36%)

Table3.Variation of RMS Inter Storey Drifts of Displacements with Optimum Damping and Exponential Co-Efficient For Structure1 and Structure2 When T1=0.4s for Both the Structures

Floor number	Un connected	Connected to all floors	Connected to 6789 floors
1	0.074574	0.03584(51.94%)	0.00479(94.5%)
2	0.00275	0.0001179(95.71%)	0.00055(80%)
3	0.197256	0.009175(96.35%)	0.010262(94.7%)
4	0.200905	0.009394(95.32%)	0.010531(94%)
5	0.002354	0.00013888(94.1%)	0.000264(88.7%)
6	0.277195	0.012909(95.34%)	0.014152(94.89%)
7	0.287519	0.013357(95.35%)	0.014673(94.8%)
8	0.01645	0.0001828(98%)	0.000232(98.58%)
9	0.295364	0.013956(95.27%)	0.015108(94.88%)

Fig 1 (a)

Floor number	Un connected	Connected to all floors	Connected to 6789 floors
1	0.074574	0.003121(95.81%)	0.003284(95.55%)
2	0.00275	0.0000910(96.69%)	0.0000202(99.26%)
3	0.197256	0.007715(96.00%)	0.007695(96.1%)
4	0.200905	0.007924(96.05%)	0.008009(96.01%)
5	0.002354	0.000163(93.07%)	0.0000906(96.15%)
6	0.277195	0.010544(96.19%)	0.010159(96.33%)
7	0.287519	0.010918(96.20%)	0.010535(96.4%)
8	0.01645	0.000255(98.44%)	0.000401(97.56%)
9	0.295364	0.011015(96.27%)	0.010512(96.44%)

Fig 1(b)

Table4.Variation of RMS Inter Storey Drifts of Velocities with Optimum Damping and Exponential Co-Efficient For Structure1 and Structure2.When T1=0.4s for Both the Structures

Floor number	Un connected	Connected to all floors	Connected to 6789 floors
1	0.498165	0.046107(90.74%)	0.047(90.565%)
2	0.0296	0.00444(85%)	0.00196(93.37%)
3	1.309416	0.114182(91.27%)	0.1325(89.88%)
4	1.331652	0.115465(91.32%)	0.1256(90.56%)
5	0.0826	0.00626(92.42%)	0.0048(94.14%)
6	1.864232	0.173079(90.71%)	0.1863(90%)
7	1.930	0.174475(90.95%)	0.1969(89.79%)
8	0.00563	0.004347(22.78%)	0.00546(30%)
9	2.004315	0.204422(89.8%)	0.220165(89%)

Floor number	Un connected	Connected to all floors	Connected to 6789 floors
1	0.498165	0.043395(91.28%)	0.051415(89.67%)
2	0.0296	0.003084(89.58%)	0.00194(93.44%)
3	1.309416	0.093831(92.83%)	0.0956(92.69%)
4	1.331652	0.099942(92.49%)	0.13442(89.90%)
5	0.0826	0.006452(92.18%)	0.00272(96.70%)
6	1.864232	0.127399(93.6%)	0.150(92.16%)
7	1.930	0.133877(93.06%)	0.14753(92.35%)
8	0.00563	0.004665(17.14%)	0.0034(28.95%)
9	2.004315	0.133025(93.36%)	0.01413(98%)

Table 5. Variation of RMS Inter Storey Drifts of Accelerations with Optimum Damping and Exponential Co-Efficient For Structure1 and Structure2 (b)] When T1=0.4s for Both the Structures

Floor number	Un connected	Connected to all floors	Connected to 6789 floors
1	5.6277	1.475879(73.87%)	1.544(73%)
2	2.1135	0.854789(59.55%)	0.595(71.84%)
3	11.05895	3.413103(69.13%)	3.311(70.11%)
4	11.82192	3.3577(71.6%)	3.089112(73.86%)
5	10.325	1.185(88.52%)	1.269(87.70%)
6	15.82491	4.839918(69.40%)	5.02(68.26%)
7	15.95	4.8284(69.78%)	4.937(70%)
8	16.23	1.1611(92.84%)	3.011(81.44%)
9	16.41145	5.165(68.52%)	5.3044(67.70%)

Floor number	Un connected	Connected to all floors	Connected to 6789 floors
1	5.6277	1.471921(73.8%)	1.5284(72.84%)
2	2.1135	1.423299(32.65%)	1.645((23%)
3	11.05895	2.947199(68.62%)	3.4859(68.5%)
4	11.82192	2.867938(74.75%)	3.39(71.3%)
5	10.325	2.186901(78.81%)	2.742(73.5%)
6	15.82491	2.971478(81.24%)	2.91(81.6%)
7	15.95	3.771052(76.36%)	4.610(72%)
8	16.23	1.99874(87.6%)	1.738(89.29%)
9	16.41145	3.387854(79.35%)	3.8734(76.39%)

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

A semi-active system integrates elements of both active and passive systems. These systems respond to a structure's behavior by adjusting their damping or stiffness properties to create control actions. Various semi-active devices, such as variable orifice dampers, have been explored for use in seismic applications.

Mathematical Formulation of Damper Connected Structures

$$M\ddot{x} + C\dot{x} + Kx + \Lambda F = -MI\ddot{x}_g$$

Semi active variable friction Damper Force

By maintaining the adjustable slip force of a semi-active friction damper just below the critical friction force, this method ensures that the damper stays in its slip state throughout earthquakes of any intensity. This approach enhances the damper's energy dissipation capacity.

$$f[k]=\alpha(G_{zz}[k - 1] + G_u u[k - 1] + G_w w[k - 1])$$

where $G_z=KbD(A_d- I)$

$G_u=KbDBd + I$

$G_w=KbDEd$

Table 6. Seismic Response of the Two Dynamically Similar Adjacent Structures Connected With SAVFD (T1=0.4s).

Earthquake Imperial Valley, 1940	structure	Peak Top floor displacement (m)		
		Un controlled	Connected at all floors	Connected at 456789
	1	0.035988	0.010314(71.3%)	0.005239(85.44)%
	2	0.035988	0.003759(89.55%)	0.001709(95.25%)
Earthquake Imperial Valley, 1940	structure	Peak Top floor velocity(m/s)		
		Un controlled	Connected at all floors	Connected at 456789
	1	0.799748	0.17723(77.83%)	0.142472(82.18%)
	2	0.799748	0.062473(73.72%)	0.076212(90.47%)
Earthquake Imperial Valley, 1940	structure	Peak Top floor accelerations(m/s ²)		
		Un controlled	Connected at all floors	Connected at 456789
	1	20.55093	5.928538(71.2%)	3.777883(81.6%)
	2	20.55093	1.783123(91.32%)	4.31608(79%)

Table 7. Seismic Response Of The Two Adjacent Structures Connected With SAVFD.

Earthquake Imperial Valley, 1940	structure	Peak Top floor displacement (m)		
		Un controlled	Connected at all floors	Connected at 456789
	1(T1=1.2s)	0.254048	0.105517(58.46%)	0.137383(45.98%)
	2(T1=0.4s)	0.035988	0.002525(92.98%)	0.005198(85.55%)
Earthquake Imperial Valley, 1940	structure	Peak Top floor velocity(m/s)		
		Un controlled	Connected at all floors	Connected at 456789

	1(T1=1.2s)	1.939959	1.374592(30%)	1.649154(15%)
	2(T1=0.4s)	0.799748	0.054374(93.2%)	0.221647(72.28%)
Earthquake Imperial Valley, 1940	structure	Peak Top floor accelerations(m/s ²)		
		Un controlled	Connected at all floors	Connected at 456789
	1(T1=1.2s)	15.35189	23.35421(-52.1%)	18.57239(-20.9%)
	2(T1=0.4s)	20.55093	1.921354(90.64%)	7.455128(63.72%)

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

The comparative responses of two adjacent MDOF buildings connected with SAVFD and viscous fluid damper under modified El Centro earthquake excitations are investigated.

Table.8.Seismic Response Of Two Dynamically Similar Adjacent Structures Connected With Viscous And SAVFD (T1=0.4s).

Earthquake Imperial Valley, 1940	structure	Peak Top floor displacement (m)		
		Un controlled	Connected at all floors(viscous damper)	Connected at all floors(SAVFD)
	1	0.035988	0.009876(72.55%)	0.010314(71.34%)
	2	0.035988	0.007831(78.23%)	0.003759(89.55%)
Earthquake Imperial Valley, 1940	structure	Peak Top floor accelerations(m/s ²)		
		Un controlled	Connected at all floors	Connected at all floors(SAVFD)
	1	20.55093	8.241633(59.89%)	0.062473(99.6%)
	2	20.55093	7.20919(64.9%)	1.783125(91.3%)

Table 9.Seismic Response of Two Adjacent Structures Connected With Viscous and SAVFD

Earthquake Imperial Valley, 1940	structure	Peak Top floor displacement (m)		
		Un controlled	Connected at all floors	Connected at all floors(SAVFD)
	1(T1=1.2s)	0.254088	0.03525(86.12%)	0.105517(58.6%)
	2(T1=0.4s)	0.035988	0.017345(51.80%)	0.002525(92.98%)

Earthquake Imperial Valley, 1940	structure	Peak Top floor accelerations(m/s^2)		
		Un controlled	Connected at all floors	Connected at all floors(SAVFD)
	1($T_1=1.2s$)	15.35189	12.3334(20%)	23.35421(-52%)
2($T_1=0.4s$)	20.55093	11.90963(42%)	1.921354(90.65%)	

CONCLUSIONS

- Buildings with higher natural frequencies and shorter natural periods typically experience higher accelerations but smaller displacements. In contrast, buildings with lower natural frequencies and longer natural periods tend to experience lower accelerations but larger displacements.
- Viscous dampers are highly effective in controlling earthquake responses in both dynamically similar (stiff-stiff) and dissimilar (soft-stiff) adjacent connected structures.
- There is an optimal damper damping and exponential coefficient for viscous dampers, as well as an optimal gain multiplier for SAVFD, to minimize earthquake responses in coupled structures.
- A higher gain multiplier results in a stronger control force, but the best efficiency and energy dissipation are achieved with the optimal gain multiplier.
- Strategically placing fewer dampers can significantly reduce earthquake responses in connected structures, cutting damper costs by 50 percent.
- SAVFD is also very effective in controlling earthquake responses in dynamically similar (stiff-stiff) structures. When connected to softer adjacent structures, SAVFD reduces displacements but increases acceleration responses. Therefore, SAVFD is more effective for stiffer structures compared to viscous dampers.

REFERENCES

- 1) Akira, N, Yoshihiro, N. and Yoji, I. "Structural Control Based On Semi-Active Variable Friction Dampers", Advanced Research Institute for Science and Engineering, (2000).
- 2) ALY, M. A. "A thesis on vibration control in structure due to earthquake effects using MR dampers", Alexandria University Faculty of Engineering.(2005)
- 3) Bhaskararao, A. V. and Jangid, R.S. "Harmonic response of adjacent structures connected with a friction damper", Journal of Sound and Vibration, 292 710–725, (2006).
- 4) Bhaskararao, A. V. and Jangid, R.S. "Seismic Response Of Adjacent Buildings Connected With Dampers", 13th World Conference on Earthquake Engineering, 3143, (2004).
- 5) Bhaskararao, A. V. and Jangid, R.S. "Optimum viscous damper for connecting adjacent SDOF structures for harmonic and stationary white-noise random excitations", Earthquake Engineering and Structural Dynamics, 36, 563–571, (2007).
- 6) Bharti, S. D, Dumne, S.M. and Shrimali, M.K. "Seismic response analysis of adjacent buildings connected with MR dampers", Engineering Structures, 32, 2122-2133 (2010).

- 7) Bharti, S. D. and Shrimali, M.K. “Earthquake Performance of Coupled Building by VF Damper”, The 14th World Conference on Earthquake Engineering, (2008), Beijing, China.
- 8) Dong-Dong, GE, Hong-Ping ZHU. And Dan-Sheng, WANG. “Seismic Response Analysis of Damper-Connected Adjacent Structures With Stochastic Parameters”, Journal of Zhejiang University,11(6), 402-414, (2010).
- 9) Huangsheng, S. and Linuo, C. “Connecting Parameter Study on Adjacent Structures Linked by Dampers”, Advanced Materials Research, 243-249, 3832-3838, (2011).
- 10) Lu, L. Y. “Predictive control of seismic structures with semi active friction dampers”, Earthquake Engineering and Structural Dynamics, 33 (5), 647–668, (2004).
- 11) Michael, D. S and Michael C. C. “Semi-active control systems for seismic protection of structures”,Engineering Structures21 469–487, (1999).
- 12) Ng, C.L. and Xu, Y.L. “Semi-active control of a building complex with variable friction dampers”, Engineering Structures, 29 1209–1225, (2007).
- 13) Patel, C.C. and Jangid, R.S. “Seismic response of dynamically similar adjacent structures connected with viscous dampers”, The IES Journal of Civil & Structural Engineering, 3, (1), 1–13, February (2010).
- 14) Patel, C. C. and Jangid, R. S. “Seismic Response Of Adjacent Structures Connected With Maxwell Dampers”, Asian Journal of Civil Engineering, 11 (5), 585-603, (2010).
- 15) Patel, C. C. and Jangid, R. S. “Seismic Response of Adjacent Structures Connected with Semi-Active Variable Friction Dampers”, International Journal of Acoustics and Vibration, 15 (1), 39-46, 2010.
- 16) Richard, E. and Christenson, B.S. “Thesis on Semi active Control of Civil Structures For Natural Hazard Mitigation Analytical and Experimental Studies”, The Graduate School of the University of Notre Dame.(2001).
- 17) Xu, Y. L.and Ng, C. L. “Seismic Protection of a Building Complex Using Variable Friction Damper: Experimental Investigation”, Journal of Engineering Mechanics, 637-648, August (2008).
- 18) XU, Y. L, Zhan, S. and Zhang, W. S. “Experimental Investigation of Adjacent Buildings Connected By Fluid Damper”, Earthquake Engineering and Structural Dynamics, 28, 609-631, (1999).
- 19) Xu, Y.L, He, Q. and Ko, J.M. “Dynamic response of damper-connected adjacent buildings under earthquake excitation”,Engineering Structures21, 135–148, (1999).
- 20) Yang, Z, Xu, W.L and Lu,X.L. “Experimental Seismic Study of Adjacent Buildings with Fluid Dampers”, Journal Of Structural Engineering,197-205,(2003)
- 21) Zhang, W.S. and Xu,Y.L, “Dynamic Characteristics And Seismic Response Of Adjacent Buildings Linked By Discrete Dampers”, Earthquake Engineering And Structural Dynamics, 28, 1163-1185 (1999)