International Journal of Engineering Trends and Technology
ISSN: 2231-5381/ https://doi.org/10.14445/22315381/IJETT-V74I3P120

Volume 74 Issue 3, 272-291, March 2026


*Original Article*

# Seismic Response of Secondary System Installed in a Multistoried Building using Viscous Dampers

Darshan M. Yagnik[1*], Rajiv B. Bhatt[2], Snehal V. Mevada[3]

[1]*Civil Engineering Department, The Charutar Vidya Mandal (CVM) University, Vallabh Vidyanagar, Gujarat, India.*
[2]*Civil Engineering Department, A.D. Patel Institute of Technology, The Charutar Vidya Mandal (CVM) University, Vallabh Vidyanagar, Gujarat, India.*
[3]*Structural Engineering Department, Birla Vishvakarma Mahavidyalaya (Engineering College), Vallabh Vidyanagar, Gujarat, India.*

[*]*Corresponding Author : darshan.yagnik@cvmu.edu.in*

Received: 28 September 2025 Revised: 23 January 2026 Accepted: 06 February 2026 Published: 28 March 2026

***Abstract*** *- Even though the secondary systems do not constitute the primary load-bearing System, they play a very critical part in the operation and safety of the multi-story buildings. The movement of the building during an earthquake may cause these systems to be damaged greatly, thus resulting in a collapse or lack of functionality. Viscous dampers shield these systems by absorbing seismic energy and damping the vibrations of buildings to lessen stress and possible damage to secondary systems. This paper is devoted to the topic of viscous dampers to improve structural resilience and the seismic behavior of secondary systems of a multi-story structure. In this research, the performance of the passive Linear Viscous Dampers (LVDs) and Nonlinear Viscous Dampers (NLVDs) is compared in terms of minimizing the seismic impacts. The state-space method is used to numerically solve the governing equations of Motion to get the acceleration and displacement responses of the building and its secondary systems. The best parameters of the damper are determined through numerical Analysis. When the controlled and uncontrolled seismic responses are compared, the strategic implementation of LVDs and NLVDs has a considerable impact in reducing the seismic effects on the Secondary Systems. These findings indicate the effectiveness of such damping systems in improving the stability of buildings, protecting occupants, and the functionality of buildings during earthquakes.*

***Keywords*** *- Secondary Systems, Nonstructural Components, Viscous Dampers, Seismic Response, Linear Viscous Dampers, Nonlinear Viscous Dampers, State Space Approach, Building Resilience.*

## 1. Introduction

Development of buildings is done within the urban regions due to the type of life they provide. This was enhanced to be built in several layers in the building [1]. This multi-layered building is influenced when a sudden disturbance on Earth takes place and causes damage to the surrounding area [2]. In other locations, the parking is done on the lowest level of the building, which is highly influenced by the strong internal motions of the Earth [3]. This is the reason why the buildings are built in a way to survive in all circumstances [4]. Disasters can result from floods, high-speed winds, and other causes, which lead to the destruction of structures and loss of life [5]. There are isolators applied to separate the foundation of the building from the rest of the building to act as shock absorbers in case of an earthquake that absorb all the energy of the shaking ground [6]. Reinforced concrete frames with restricted ductility can still exhibit acceptable seismic performance if key regions are properly detailed to avoid brittle failures and allow controlled inelastic deformation under strong ground motions [7]. Damping employs a number of different methods of absorbing and dissipating energy created as a result of earthquakes to limit the motion and vibration of the building [8]. In addition, multi-layered buildings can have problems since they have a lower vibration period compared to the devices [9]. A flexible base period is also applied to the seismic response of the building in order to introduce some flexibility to counter seismic forces [10]. Among the various techniques used to mitigate earthquake-induced building damage, Tuned Mass Dampers (TMDs) are the most suitable [11]. A lead rubber bearing acts as a flexible connector between the building and its foundation, allowing the bearing to deform and absorb energy, while the rubber layers provide flexibility and damping [12]. Many used different damping techniques; among them, their configurations might be the same, but their energy dissipation varied [13]. However, these could not show significant improvement. A Tuned Mass Damper (TMD) is introduced to improve the performance of the building during earthquakes [14]. Researchers are facing many challenges in introducing different techniques to enhance mechanical flexibility and protect the public. Moreover, in a Tuned Liquid Damper (TLD), the damper consists of a container filled with liquid, usually water, that is connected to the main structure. When the structure moves or vibrates, the liquid inside the container also moves [15]. When a building vibrates, the vibrations travel into the soil, causing both the building and the soil to move and interact. This interaction is important during earthquakes and must be considered, rather than assuming the building's foundation is rigid and unmovable [16]. This combination of a Liquid Column Vibration Absorber (LCVA) and a Tuned Liquid Column Damper (TLCD) helps reduce a building's rotational movements during random vibrations [9]. Some came to understand how well reinforced concrete buildings can withstand earthquakes when different parts of the building are affected by fire [17]. Also, care should be taken to ensure it can withstand a minor quake and absorb energy during a major earthquake [18]. Recent methodological work has advanced the integration of viscous dampers into seismic design for framed structures, and studies have shown that alternative configurations (e.g., inclined columns) can improve the resilience of RCC buildings [19, 20]. However, most prior research focuses on primary structural response and device effectiveness for global performance metrics; comparatively fewer studies examine how dampers and other mitigation strategies protect secondary systems or how Soil–Structure Interaction (SSI) and Realistic Ground Motions (including rotational components) change device performance. Recent studies have addressed aspects of nonlinear Analysis and viscous damper behavior, but their scopes differ from the present work. Sun et al. [21] focused on improving state-space algorithms for transient Analysis of locally nonlinear structures, emphasizing numerical efficiency rather than comparative damper performance. Prakash et al. [22] examined multi-objective optimization of nonlinear passive control systems for bridges, but did not provide a direct comparison of LVDs and NLVDs under uniform conditions. Experimental work by Lyu et al. [23] demonstrated the effectiveness of nonlinear viscous dampers for base-isolated structures under near-fault motions. Still, it did not explore fixed-base buildings or compare linear and nonlinear damper formulations. Chalarca et al. [24] analyzed fluid viscous damper stiffness effects on floor acceleration in steel frames, but their work concentrated on stiffness sensitivity rather than a full LVD–NLVD comparison across multiple response metrics. In contrast, this study provides a unified, side-by-side evaluation of LVDs and NLVDs using identical structural models, identical ground-motion suites, and a wider range of performance measures (peak drift, residual drift, floor acceleration, energy dissipation, and damper force). This integrated framework, supported by numerical Analysis and experimental/hybrid-simulation evidence, clearly identifies the conditions under which NLVDs outperform LVDs and highlights the practical design implications not addressed in previous research**.**

**Table 1. Comparison of the existing studies on LVDs and NVLDs**

| Author | Scope of the work | Method | Findings | Novel Contribution of the present study |
|---|---|---|---|---|
| Sun et al., [21] | Transient analysis algorithm for MDOF systems with lumped mass formulation | Numerical method development | Proposed an improved state-space procedure for efficient transient Analysis when local nonlinearities exist; emphasis on computational/numerical performance | This study focuses on structural response and damper behavior (LVD vs NLVD), not numerical algorithm enhancement or state-space formulation |
| Prakash et al., [22] | Optimization of nonlinear passive control systems for bridges | Multi-objective numerical optimization | Developed a framework to optimize nonlinear passive control parameters, considering multiple conflicting objectives | This work offers a direct comparative evaluation of LVD and NLVD under identical conditions, supported by experimental/hybrid validation, in contrast to the optimization-focused study. |
| Lyu et al., [23] | Influence of NLVDs on base-isolated systems under near-fault earthquakes | Shaking-table experiments | Demonstrated experimentally that NLVDs improve the seismic performance of isolated structures under near-fault motions | The study compares LVD and NLVD in both fixed-base and isolated configurations and links the numerical results to experimental observations for validation. |
| Chalarca et al., [24] | Effect of viscous damper stiffness on floor acceleration in steel moment-resisting frames | Numerical parametric study | Showed that damper stiffness strongly affects floor acceleration response under far-field ground motions | This work extends the Analysis beyond stiffness sensitivity to include residual drift, energy dissipation, and force demands, and explicitly compares linear and nonlinear damper formulations. |

### *1.1. Research Gap and Problem Statement*

Although viscous dampers and other passive control techniques are widely studied for global structural response reduction, significant gaps remain:

- Lack of comparative evaluation between Linear (LVD) and Nonlinear Viscous Dampers (NLVD) within the same modelling framework for protecting secondary systems.
- Limited studies that incorporate SSI effects and realistic ground-motion characteristics in analyses of damper performance.
- Insufficient exploration of optimal damper parameters when the design objective is specifically to safeguard nonstructural components such as parking systems, MEP installations, and service equipment.

This gap creates uncertainty in damper selection and tuning when the goal is to maintain functionality of secondary systems during earthquakes. The present study directly addresses this problem.

#### *1.1.1. Research Question / Hypothesis*

This study investigates whether strategically placed linear and nonlinear viscous dampers can effectively reduce seismic responses of secondary systems in multi-story buildings. The hypothesis is that a properly optimized viscous damper system can significantly mitigate both acceleration and displacement of secondary systems, enhancing operational resilience without compromising structural integrity.

### *1.2. Approach and Scope*

The governing equations of Motion are solved numerically using a state-space method to obtain acceleration and displacement responses for both the main structure and its secondary systems. Optimal damper parameters are identified through numerical analysis and sensitivity studies. Key performance measures include reductions in acceleration, inter-story drift, and relative displacements at parking/service levels.

### *1.3. Novelty of the Present Work*

Unlike many earlier works that target global structural performance, this study: (1) Directly compares LVDs and NLVDs for the explicit purpose of protecting secondary systems; (2) Employs a unified state-space numerical framework to compute dynamic responses and determine optimal damper parameters; (3) Includes SSI effects and realistic seismic inputs in the comparative Analysis; and (4) Quantifies both structural and serviceability outcomes, providing design-oriented recommendations for damper selection and tuning. By doing so, the study connects device-level Analysis to practical objectives of maintaining building functionality after strong ground motions. Section 2 describes the building model, damper configurations, and SSI modelling. Section 3 presents the state-space formulation, seismic inputs, numerical results, parameter optimization, and sensitivity studies. Section 4 summarises conclusions and provides design guidance. The workflow process is shown in Figure 1.

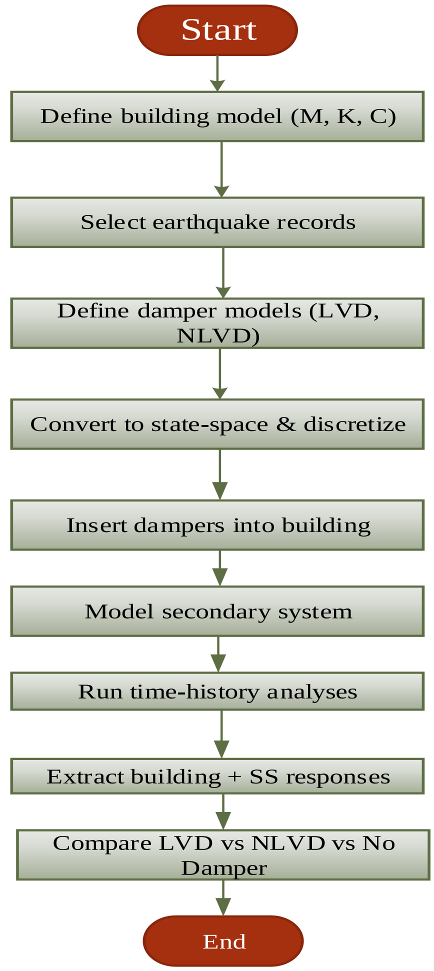



**Fig. 1 Overall work process**

## 2. Modelling of Linear and Nonlinear Viscous Dampers

Viscous dampers are required in order to mitigate the impact of earthquakes on the buildings. They are the devices that are created to absorb and release the seismic energy to avoid damage to the structures and the safety of people inside. Linear viscous dampers offer a constant level of resistance to Motion over a series of frequencies. Conversely, the nonlinear viscous dampers vary the damping properties based on the seismic activity. The inclusion of these dampers in the designs of buildings will help the engineers to increase the strength of the structures and also reduce the effects of earthquakes on urban infrastructure, which will save lives and economic losses. The thick dampers reduce vibrations and consume energy to reduce movements, therefore, enhancing the building during earthquakes. Linear and nonlinear viscous dampers are important in reducing the effects of structural damage during seismic events. Although linear dampers have predictable damping ratios, nonlinear dampers have adaptive responses depending on the strength of the Motion. The technologies are both useful in making buildings more resilient to the effects of a seismic wave, which eventually results in the safety of people and the integrity of the infrastructure. A fluid viscous damper refers to a device that is applied to minimize vibrations and dissipate energy within a mechanical system, structure, or other forms of equipment. It is based on the theory of fluid mechanics, where viscous fluid is used to generate a damping force to oppose movement.

It consists of four primary parts namely, the outer shell that contain the internal parts and fluid, the piston it moves through the cylinder and connected to the damped structure or System, the Viscous Fluid which is usually silicone based, because of its constant viscosity over a wide temperature span, and the orifices, the small opening used by the fluid to pass through in the piston, which provides resistance. When the System experiences vibrations, the piston inside the damper moves through the viscous fluid. A resistive force is produced as the fluid passes through the piston's orifices as it moves. This force is directly proportional to the piston's speed, meaning the damper provides greater resistance at higher speeds, effectively dissipating energy and reducing vibrations [5].

To analyse a structure's dynamic behaviour when outfitted with fluid viscous dampers, a mathematical model is used as follows.

$$F_{di} = C_{di}\left|\dot{x}_{di}\right|^{\alpha} sgn\left(\dot{x}_{di}\right) \quad (1)$$

Where $F_{di}$ is the Damper force, Damping coefficient $C_{di}$, Relative velocity $\dot{x}_{di}$ from one side of the damper to the other, and the damper exponent α.

Linear Viscous Damper – LVD: This occurs during the condition of α= 1. It shows a direct proportionality between force and velocity.

Nonlinear Viscous Damper – NLVD: This occurs during the condition ofα < 1. The force increases at a slower rate than linearly with increasing velocity.

Figure 2 shows a typical viscous fluid damper, and Figure 3 illustrates the force–velocity and force–displacement relationships for LVD and NLVD at different α values. Figure 2 shows the graphs of force as a function of velocity for α= 1, α< 1, $and\ \alpha > 1$ conditions. When force is related to velocity, a value of 1 for alpha (α) indicates a straight line on the graph. In the α< 1 condition, the force moves slightly upwards, making it constant and causing a nonlinear condition. In the α > 1 condition, it is low at the beginning, then shows a steady upward trend, which is not observed in any applications. Among all these conditions, nonlinear makes stand out for their damping force performance, reducing the shocks observed at higher velocities.

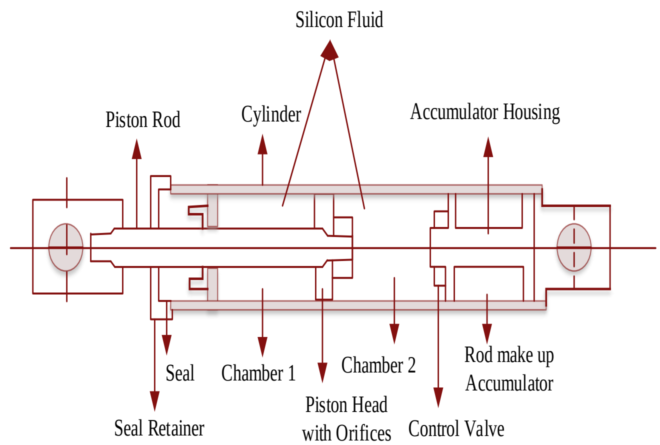



**Fig. 2 Fluid viscous damper**

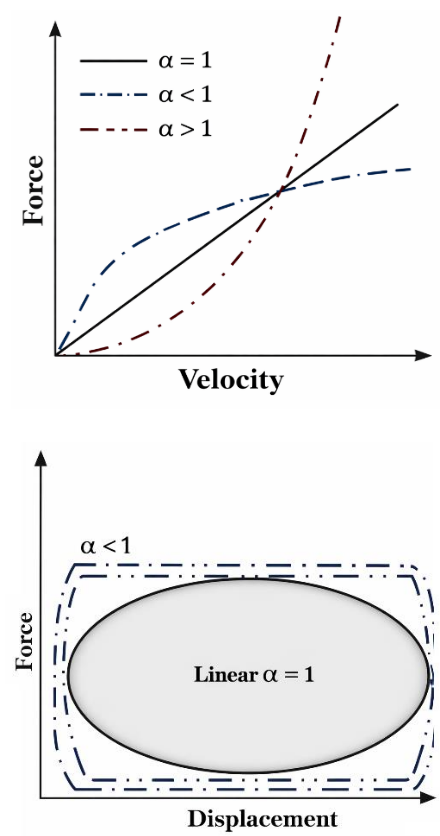



**Fig. 3 Velocity and Displacement in Terms of Force in Dampers.**

During displacement, different shapes are noticed for values of 'α'. If the same force frequency is applied to different dampers and the energy they absorb is measured, the energy amounts (shown as enclosed areas on a graph) are the same for all dampers. However, each damper has a different damping coefficient, which means they resist Motion to varying degrees. So, even though the total energy absorbed is the same, the way each damper responds and resists Motion differs.

### *2.1. Justification of Parameter Choices*

The selection of modelling parameters in this study follows established seismic design guidelines and previous research findings. The building geometry, material grades, and member sizes correspond to typical medium-rise RC buildings commonly used in urban regions and are consistent with IS 1893 design practice. A 5% inherent damping ratio is adopted, as recommended for RC moment–resisting frames, and Rayleigh damping is used due to its suitability for multi-degree-of-freedom systems.

The damper parameters are selected based on both physical realism and previous experimental/analytical studies. A linear damper exponent of α = 1 represents classical viscous behaviour. In contrast, α = 0.6 for nonlinear dampers is chosen because values between 0.3 and 0.7 have been shown to improve energy dissipation under strong ground motions without excessively amplifying forces at low velocities. The damping coefficient range was determined through preliminary simulations to capture under-damped, critical, and over-damped behaviour and to allow an optimization-based selection of $C_d$ for both LVD and NLVD configurations.

Earthquake records were chosen to cover a wide range of frequency content, PGA levels (0.16–0.87 g), durations, and site conditions, ensuring that the findings are not specific to a single ground motion type. These records are widely used in benchmark studies and include both near-fault and far-fault characteristics.

## 3. Numerical Study

MATLAB numerical simulation is used to study how a 5-story building responds to seismic activity. Table 2 displays the building parameters. Figure 4 displays the building's plan and elevation.

**Table 2. Building parameters**

| Parameter | Value |
|---|---|
| Plan Dimension | 12m x 16m |
| Typical storey height | 3m |
| Storey height (First floor) | 4.5m |
| Column Size | 400mm x 400mm |
| Beam Size | 300mm x 400mm |
| Slab thickness | 150mm |
| Live load | 3 kN/m$^2$ |
| Grade of Concrete | M25 |
| Grade of Steel | Fe500 |

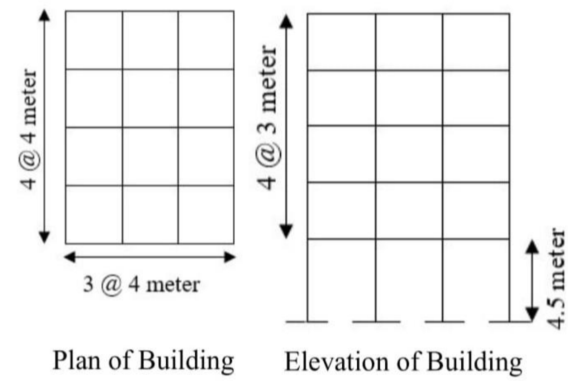



**Fig. 4 Storeyed building**

### *3.1. Equations of Motion and their Solution*

Understanding the dynamic response of a building is crucial for ensuring its safety and stability. The basic matrix form in structural dynamics is used to observe the behaviour of the building when it is in Motion. The equation is a representation of all the forces that are acting on the building, such as the inertial, damping, stiffness, ground acceleration forces, and the control device forces.

$$M\ddot{x} + C\dot{x} + Kx = -M\Gamma\ddot{x}_g + \Lambda F_d \quad (2)$$

When the building's mass is M and its acceleration is denoted by $\ddot{x}$, inertial forces are expressed as M times the acceleration. When C is the building's damping and $\dot{x}$ is the velocity, the damping forces are expressed as C times the building's velocity. In the "x" direction, stiffness forces are expressed as K times the building's displacement, where K is the building's stiffness and $x = \{x_i\}$is the displacement. The forces due to ground acceleration are shown as -M times the influence coefficient vector Γ times the ground acceleration vector. $\ddot{x}_g = \{\ddot{x}_{gi}\}$'. In the 'x' direction, the forces from control devices are shown as '$\Lambda . F_d$' with the matrix showing where the control devices are located, denoted by Λ, and the control forces represented by the vector. '$F_d = \{F_{di}\}$'. "Move in the 'x' direction.

$$M = \begin{bmatrix} m_1 & 0 & 0 & 0 & 0 \\ 0 & m_2 & 0 & 0 & 0 \\ 0 & 0 & m_3 & 0 & 0 \\ 0 & 0 & 0 & m_4 & 0 \\ 0 & 0 & 0 & 0 & m_5 \end{bmatrix} \quad (3)$$

Similarly, the stiffness matrix is as follows

$$K = \begin{bmatrix} k_1 + k_2 & -k_2 & 0 & 0 & 0 \\ -k_2 & k_2 + k_3 & -k_3 & 0 & 0 \\ 0 & -k_3 & k_3 + k_4 & -k_4 & 0 \\ 0 & 0 & -k_4 & +k_4 + k_5 & -k_5 \\ 0 & 0 & 0 & -k_5 & k_5 \end{bmatrix} \quad (4)$$

Since mass and stiffness are proportionate, Rayleigh damping is used to produce the building's damping matrix C, which is not explicitly known.

$$C = \alpha M + \beta K \quad (5)$$

In this study, the coefficients α and β depend on how much the vibration is slowed down. Both system vibration modes have 5% damping. The equations of Motion are figured out using the state space method. The process includes converting the equations into a state space format where the state vector z represents both displacement and velocity ($z = \{x, \dot{x}\}^T$) as vectors. The equations that describe how things move

$$\dot{z} = Az + BF + E\ddot{x}_g \quad (6)$$

$$\text{System matrix A} = \begin{bmatrix} 0 & I \\ -M^{-1}K & -M^{-1}C \end{bmatrix} \quad (7)$$

$$\text{Control force distribution matrix B} = \begin{bmatrix} 0 \\ -M^{-1}\Lambda \end{bmatrix} \quad (8)$$

$$\text{Excitation distribution matrix E} = -\begin{bmatrix} 0 \\ \Gamma \end{bmatrix} \quad (9)$$

$$\text{State vector } z = \begin{bmatrix} x \\ \dot{x} \end{bmatrix} \quad (10)$$

Where $I$ express the identity matrix. In the time domain, the state space equation is changed to fit a specific time interval, assuming that the excitation and control forces stay the same during that time. Equation 11 shows how to find the solution step by step using another equation. 12 and 13.

$$z_{k+1} = A_d z_k + B_d F_k + E_d \ddot{x}_{gk} \quad (11)$$

$$B_d = A^{-1}(A_d - I)B \quad (12)$$

$$E_d = A^{-1}(A_d - I)E \quad (13)$$

Step time is given as 'k', the system matrix with a discrete-time step $A_d = e^{A\delta t}$, with $\delta t$ being the interval of time, the discrete-time versions $B_d, E_d$ of the matrices B, $E$.

### 3.2. Response of Building

Examining the seismic response of a five-story structure with passive Linear Viscous Dampers (LVDs) and Nonlinear Viscous Dampers (NLVDs) placed at each level's center of mass is investigated through numerical simulations using MATLAB. The building's natural time period is determined to be 0.54 seconds. Various earthquakes, as listed in Table 3, are considered for the numerical simulations. A similar investigation is conducted for a secondary system installed at Level 5. The decrease in the building and the Secondary System's (SS) speed and movement are important factors to consider. Figure 5 shows uncontrolled floor responses, and Figure 6 shows controlled responses with dampers.Table 3 lists the earthquake records considered. Peak responses and damping coefficients were optimized as follows:

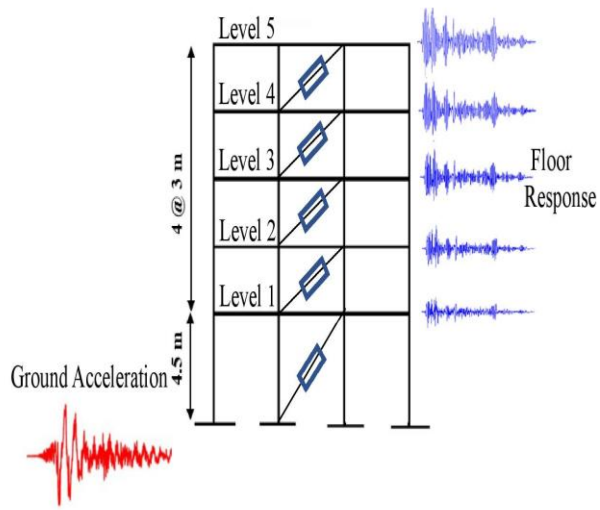



**Fig. 5 Five-story building without dampers**

Ground acceleration refers to the Motion of the ground during an event such as an earthquake. The floor response is how each level of the building reacts to the movement of the ground below. Figure 6 illustrates the building installed with dampers in the subsequent numerical Analysis.

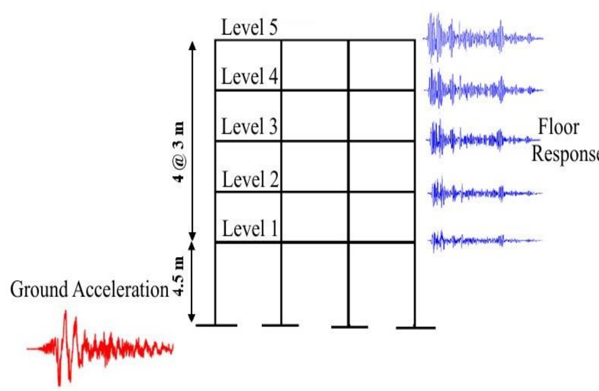



**Fig. 6 Five-story building with dampers**

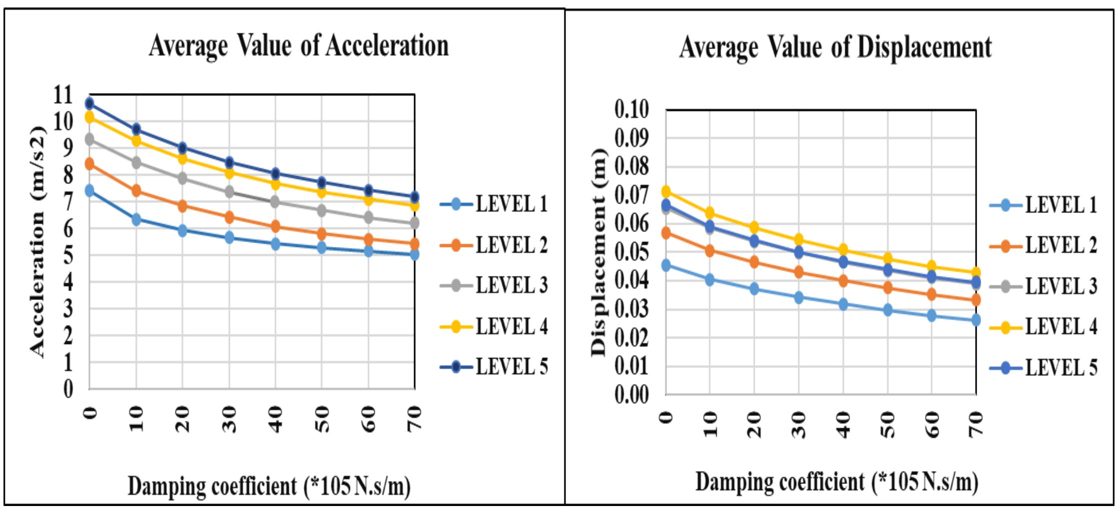
**Table 3. Details of earthquakes considered for the numerical study**

| Earthquake | Recording Station | Component | Duration (sec) | PGA (*g*) |
|---|---|---|---|---|
| Imperial Valley, 15th October,1979 | El Centro (Array # 5) | E05230 | 39.375 | 0.38 |
| Imperial Valley, 15th October,1979 | El Centro (Array # 7) | E07230 | 36.865 | 0.47 |
| Northridge, | Newhall | WPI046 | 24.980 | 0.42 |

| | | | | |
|---|---|---|---|---|
| 17th January, 1994 | | | | |
| Landers, 28th June, 1992 | Lucerne Valley | LCN260 | 48.120 | 0.73 |
| Northridge, 17th January, 1994 | Rinaldi | RRS228 | 19.900 | 0.87 |
| Northridge, 17th January, 1994 | Sylmar | SCE011 | 54.685 | 0.85 |
| Loma Prieta, 18th October, 1989 | Gilroy – Gavilan Coll | GIL067 | 39.990 | 0.36 |
| Kobe, 16th January, 1995 | Nishi-Akashi | NIS000 | 40.950 | 0.48 |
| Chi-Chi, 20thSeptember, 1999 | TCU071 | N | 89.995 | 0.65 |
| Duzce, 12th November, 1999 | Lamont 531 | N | 41.490 | 0.16 |

### *3.3. Optimized Value of Damping Coefficient ($C_d$)*

In the main structure of the building, there are five Linear Viscous Dampers (LVD) and five Nonlinear Viscous Dampers (NLVD) placed at the center of each floor to help with stability. The peak acceleration and displacement responses are obtained under the considered earthquake time histories. Based on the value from all earthquakes, the Average value of acceleration and displacement is obtained for all levels and plotted in Figures 6 (a) and (b). Figures 7(a) and 7(b) show the impact of varying damping coefficients on building responses for LVD and NLVD, respectively. According to the outcome, the damping coefficient's ideal value for the LVDs is considered 60 x 10^5N.Sec/m for α =1. whereas the damping coefficient for the NLVDs is considered 15 x 10^5N.Sec/m for α =0.6




**(a) Impact of CD on reactions when LVD is available on every floor**

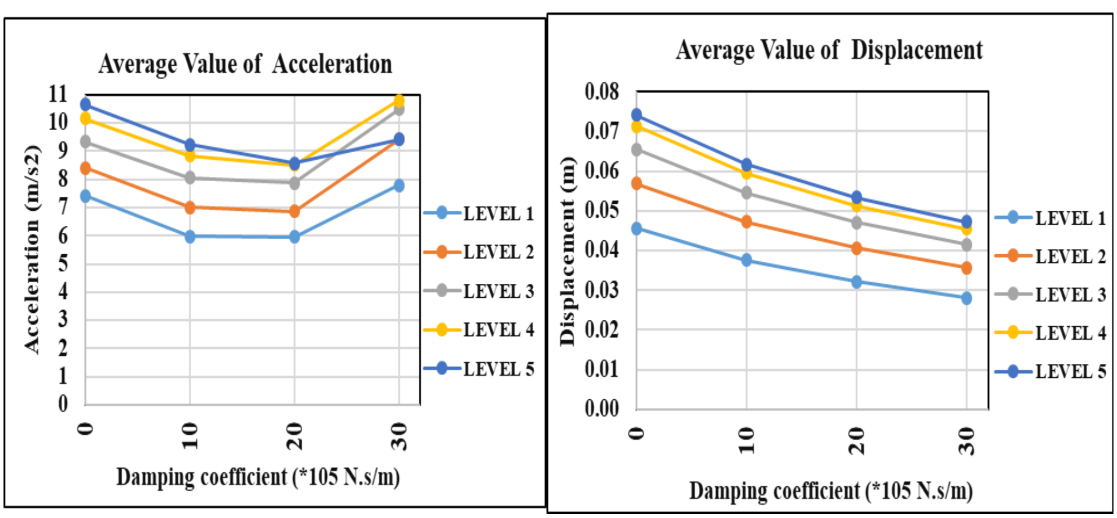



**Fig. 7(b) Impact of CD on reactions when All storeys have NLVD**

### *3.4 Results and Discussion*

The controlled and uncontrolled responses of acceleration and displacement at level 5 under the Imperial Valley, 1979 earthquake are shown in Figure 7 when LVDs are installed in the building.

Also, the hysteresis loops between Damper force – Velocity and Damper force – Displacement are shown in Figure 8, which also shows the characteristics of the damper and energy dissipation capacity. Similar responses are obtained for other considered earthquakes.

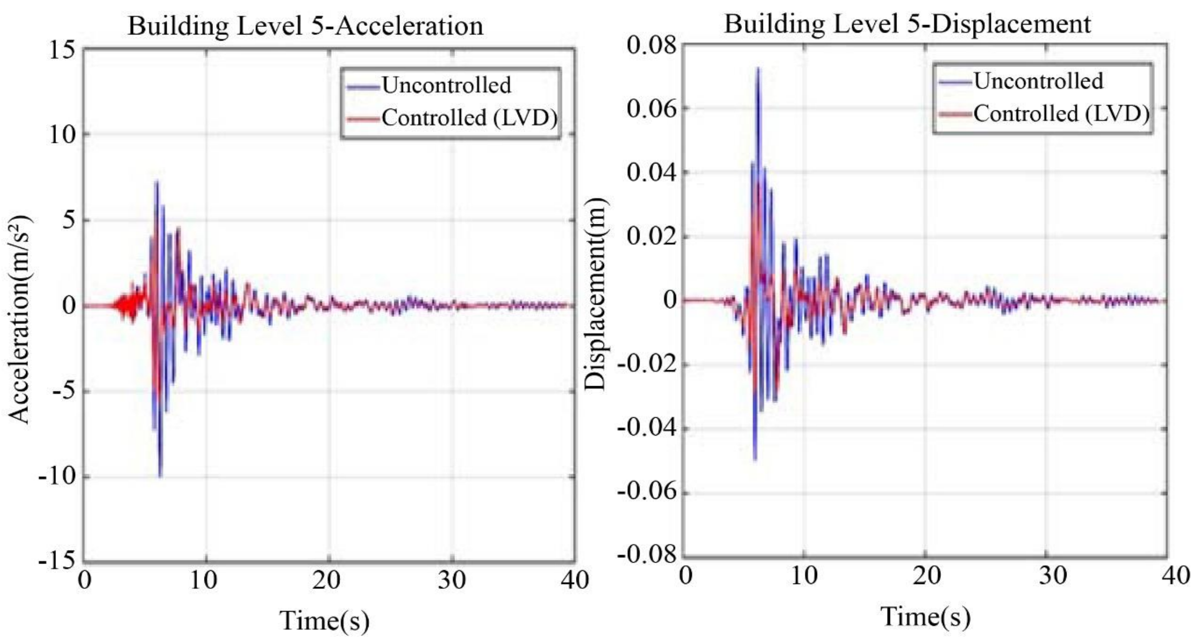



**Fig. 8 Time history for controlled and uncontrolled acceleration & displacement responses at level 5 under imperial valley, 1979 earthquake (LVD installed at all storeys)**

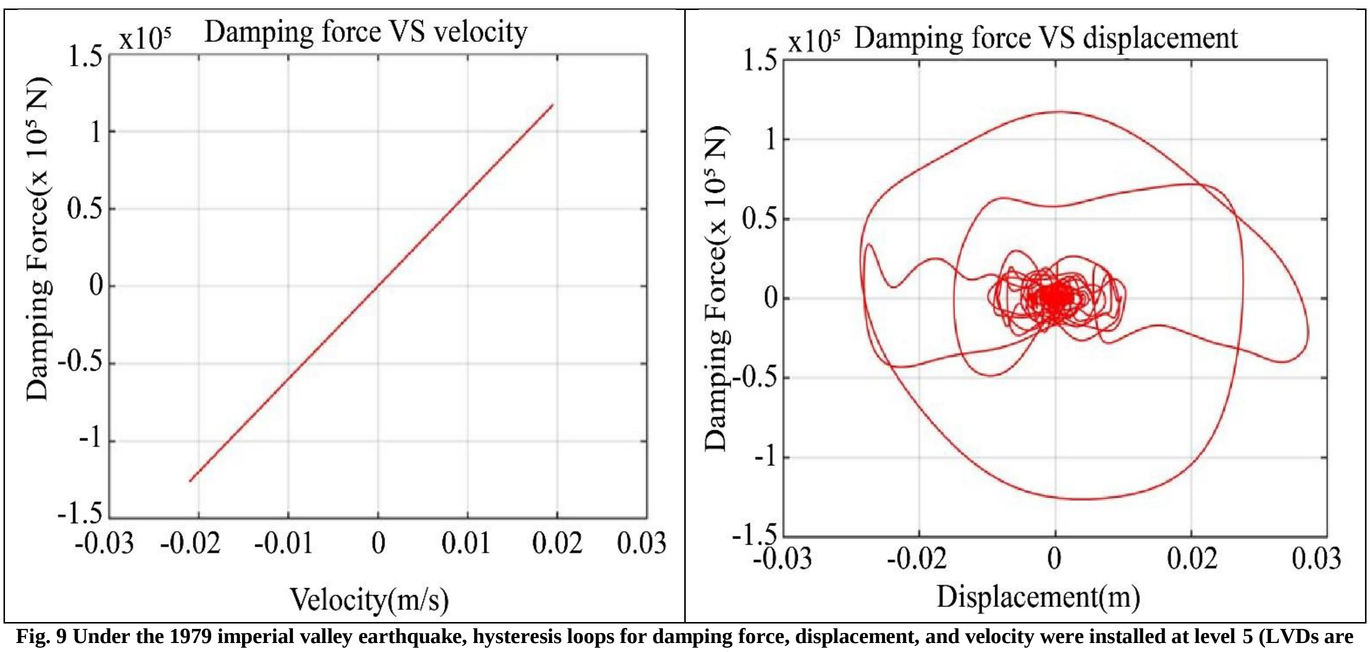



**Fig. 9 Under the 1979 imperial valley earthquake, hysteresis loops for damping force, displacement, and velocity were installed at level 5 (LVDs are installed at all floors)**

Similarly, the controlled and uncontrolled responses of acceleration and displacement at level 5 in Imperial Valley, 1979 earthquake are shown in Figure 9 when NLVD are installed in the building. Also, the hysteresis loops between Damper force – Velocity and Damper force – Displacement are shown in Figure 10, which also shows the characteristics of the damper and energy dissipation capacity. Similar responses are obtained for other considered earthquakes.

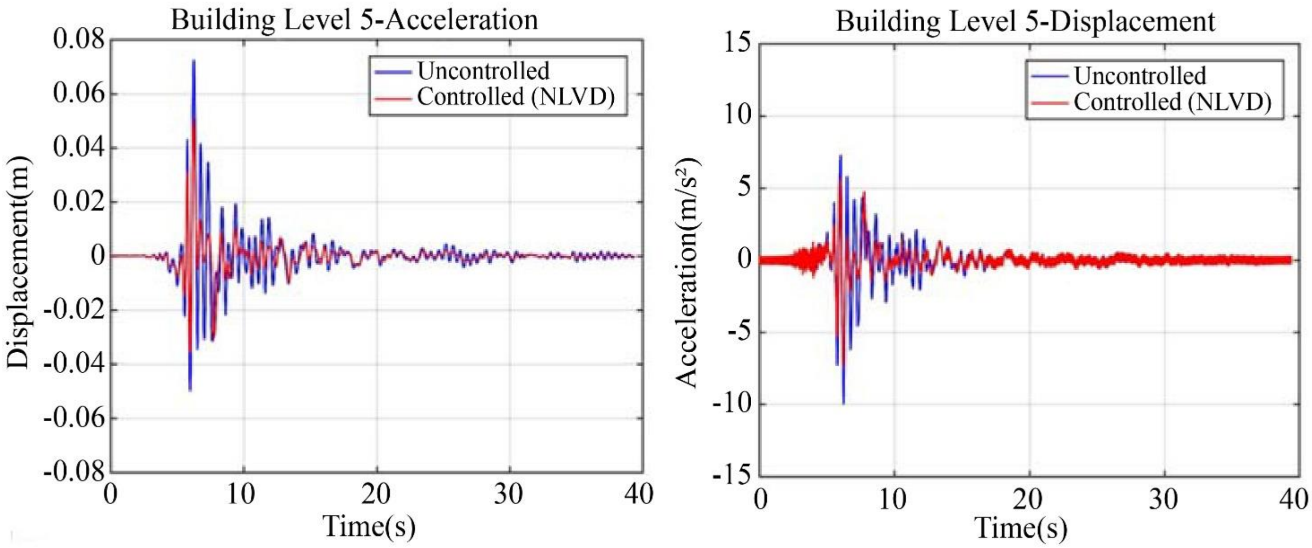



**Fig. 10 History of controlled and uncontrolled in time for acceleration & displacement responses at level 5 under imperial valley, 1979 earthquake (NLVD installed at all storeys)**

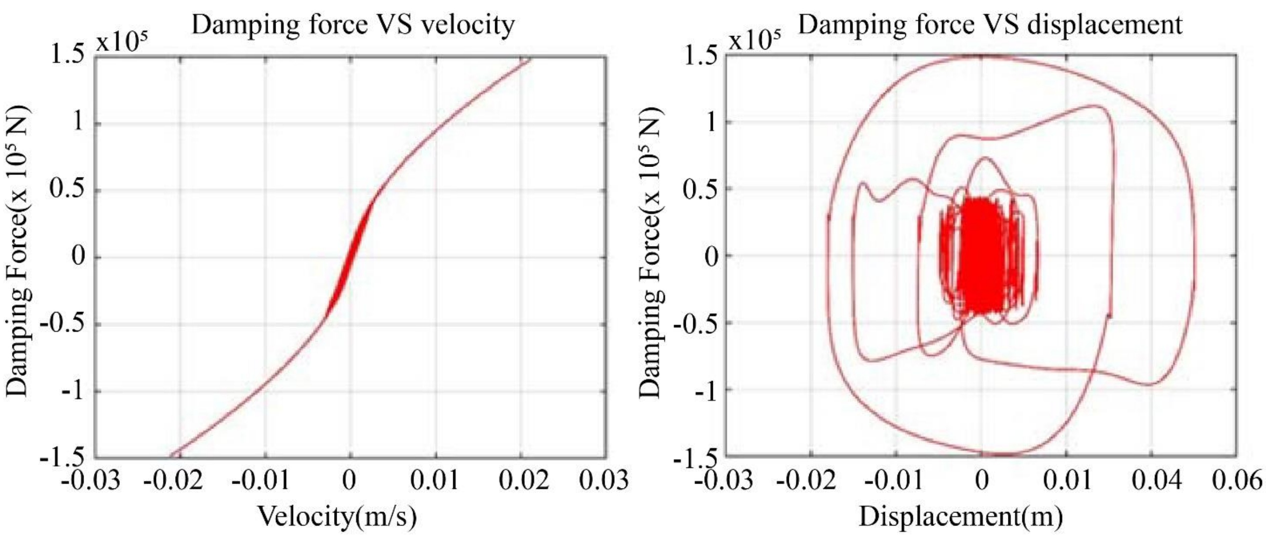



**Fig. 11 Under the 1979 imperial valley earthquake, hysteresis loops for damping force-displacement and damping force-velocity at level 5 (NLVD are placed at all storeys)**

Table 4 Summarizes the Maximum Displacement and Accelerations at Level 5, Highlighting Percentage Reductions Compared to Uncontrolled Cases. LVD Reduces Average Displacement by 37%-30% and acceleration by 30%.83%, while NLVD reduces displacement by 25.60% and acceleration by 19.21%

**Table 4. Maximum response quantities at level 5 of the building**

| Sr No | Earthquake Name | Uncontrolled Response | | With LVD | | With NLVD | |
|---|---|---|---|---|---|---|---|
| | | Displacement (m) | Acceleration ($m/s^2$) | Displacement (m) | Acceleration ($m/s^2$) | Displacement (m) | Acceleration ($m/s^2$) |
| 1 | Imperial Valley, 15th October,1979 (Array # 5) | 0.0726 | 10.0084 | 0.0372 (48.76%) | 5.7352 (42.70%) | 0.0501 (30.99%) | 7.3628 (26.43%) |
| 2 | Imperial Valley, 15th October,1979 (Array # 7) | 0.0673 | 8.7003 | 0.0523 (22.29%) | 7.3129 (15.95%) | 0.0589 (12.48%) | 8.0724 (7.22%) |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 3 | Northridge, 17th January, 1994 (Newhall) | 0.0626 | 7.8352 | 0.0445 (28.91%) | 5.9874 (23.58%) | 0.0489 (21.88%) | 6.5441 (16.48%) |
| 4 | Landers, 28th June, 1992 (Lucerne Valley) | 0.0395 | 7.9376 | 0.0330 (16.46%) | 6.2963 (20.68%) | 0.0368 (6.84%) | 6.7155 (15.40%) |
| 5 | Northridge, 17th January, 1994 (Rinaldi) | 0.1402 | 18.8053 | 0.1058 (25.54%) | 15.5201 (17.47%) | 0.1286 (8.27%) | 17.7364 (5.68%) |
| 6 | Northridge, 17th January, 1994 (Sylmar) | 0.1010 | 14.7782 | 0.0693 (31.39%) | 11.7442 (20.53%) | 0.0823 (18.51%) | 13.7023 (7.28%) |
| 7 | Loma Prieta, 18th October, 1989 (Gilroy – Gavilan Coll) | 0.0431 | 6.6198 | 0.0234 (45.71%) | 4.4083 (33.41%) | 0.0276 (35.96%) | 5.0130 (24.27%) |
| 8 | Kobe, 16th January, 1995 (Nishi-Akashi) | 0.1251 | 18.2020 | 0.0584 (53.32%) | 9.3820 (48.46%) | 0.0880 (29.66%) | 13.2736 (27.08%) |
| 9 | Chi-Chi, 20th September, 1999 (TCU071) | 0.0672 | 10.3309 | 0.0349 (48.07%) | 6.0607 (41.33%) | 0.0397 (40.92%) | 6.5945 (36.17%) |
| 10 | Duzce, 12th November, 1999 (Lamont 531) | 0.0222 | 3.3826 | 0.0103 (53.60%) | 1.8864 (44.23%) | 0.0110 (50.45%) | 2.4993 (26.11%) |
| | | Average Reduction (%) | | 37.30 % | 30.83 % | 25.60 % | 19.21 % |

*(Note: The values written in brackets indicate the percentage reduction with respect to the uncontrolled response)*

Table 3 Provides a comparison of maximum acceleration and displacement values of the building with and without LVD and NLVD. It also indicates the average percentage reduction in acceleration and displacement between LVD and NLVD. For Level 5, LVD reduces average displacement by 37.30% and acceleration by 30.83%, whereas NLVD reduces average displacement by 25.60% and acceleration by 19.21%. Overall, both LVD and NLVD significantly reduce the displacement and acceleration. The performance of both dampers is relatively consistent across different levels, with slightly higher effectiveness observed in LVD compared to NLVD.

### *3.5. Experimental Validation*

The numerical findings of this study are supported by recent experimental and hybrid-simulation research. Contemporary works have validated the performance of viscous dampers through shake-table testing and real-time hybrid simulations, confirming the applicability of constitutive models typically used in numerical analyses. For instance, real-time hybrid simulation of viscous fluid dampers has been successfully demonstrated in base-isolated reinforced concrete structures [25]. Likewise, experimental verification of damper behaviour and parameter-optimization strategies has been reported in recent studies evaluating seismic performance enhancements [26, 27]. These validated findings strengthen the reliability of the modelling assumptions adopted in the present work.

## 4. Response of the Secondary System Installed in the Building

Figure 11 illustrates the seismic reactions of a Secondary System (SS) placed at Level 5 of a five-story building. There are four different time periods in the secondary System, starting from 0.5, 1, 1.5, and 2 seconds. The secondary System weighs 100 kilograms, and the stiffness is adjusted to achieve the required timing. When a building experiences an earthquake, the way it shakes can be different on each floor. The acceleration response on a floor is seen as an input for a secondary system located on that same floor.

A time history analysis was done to see how the secondary System reacts over different time periods. "The study measured how fast and how far a building moves during an earthquake using specific earthquake data." After analyzing data from multiple earthquakes, the outcome results in the typical measurements for how fast and how far the secondary System moves during an earthquake. Furthermore, the study involves testing out special dampers in the building and another system to see how well they work in decreasing earthquake vibrations. This comprehensive Analysis aids in understanding the secondary System's behaviour and enhancing seismic design strategies. At the secondary System, LVD's damping coefficient $C_d$ is optimized at 0.08 x 10^$^5$N.Sec/m is considered for $\alpha$ =1, while the NLVD's coefficient $C_d$ is 0.02 × 10^$^5$N.Sec/m considered for $\alpha$ = 0.6.

### *4.1. Secondary System Modelling*

The secondary System is modelled as a Single-Degree-of-Freedom (SDOF) attachment placed at the fifth floor to represent typical nonstructural or service components such as mechanical equipment, storage units, or parking systems.

A mass of 100 kg is adopted based on commonly reported ranges for rooftop and floor-mounted equipment. The natural periods considered (0.5 s, 1.0 s, 1.5 s, and 2.0 s) encompass the standard flexibility range of secondary and appendage systems in multi-storey buildings. These values cover the realistic vibration range of secondary and nonstructural systems found in multi-storey buildings.

For each assigned time period, the stiffness of the secondary System is calculated based on the mass and the time period. Viscous dampers are added in specific cases to examine how supplemental damping influences interaction forces and vibration control.

This modelling approach is consistent with previous studies on equipment–structure interaction and allows evaluation of how ground motion characteristics and primary structure response are amplified or mitigated when secondary systems with varying flexibility are present.

### *4.2. Results of Secondary System*

The following three cases are taken into consideration, and the outcomes are related in order to investigate the secondary System's seismic behaviour, which is installed at Level 5 under ten different earthquake time histories.

Case 1 (a): Building without dampers and secondary System without dampers.

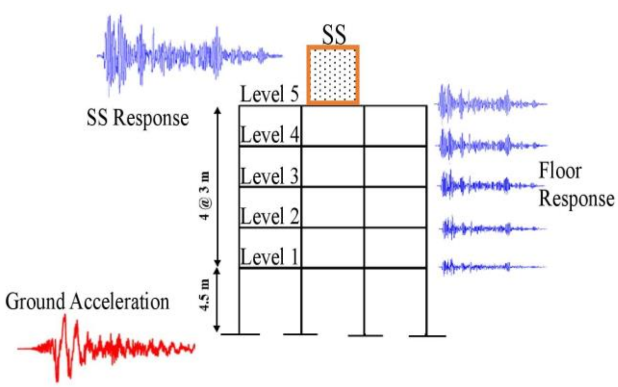



**Fig. 12 (a) Secondary System Installed at Level 5 (Case 1(a))**

Figure 12(a) shows the uncontrolled acceleration and displacement responses of the secondary System when the building itself has no dampers and the secondary System is not equipped with dampers. Peak responses are highest in this case, highlighting the amplification of floor motion at Level 5.

Case:1(b): Building without dampers and secondary System with LVD

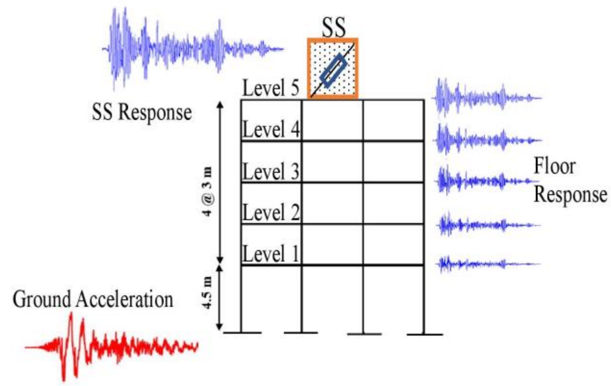



**Fig. 12 (b) Secondary System with LVD, Installed at Level 5 (Case 1(b))**

The installation of LVD at the secondary System, shown in Figure 12(b), reduces peak acceleration and displacement significantly. Comparison with Figure 12(a) shows reductions up to ~95% in acceleration and ~96% in displacement for short-period systems (0.5–2 s).

Case:2(a): Building with LVD and secondary System without dampers.

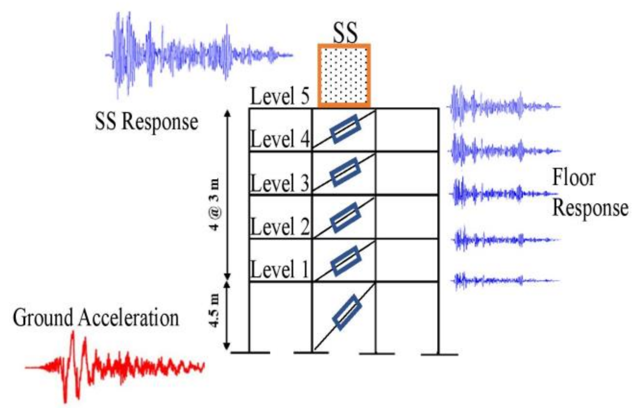



**Fig. 13 (a) Secondary System Installed at Level 5 (Case 2(a) & Case 3(a))**

Figure 13(a) shows the SS without dampers while the building has LVD installed at all floors (Case 2(a)). Floor-level dampers reduce the SS response relative to Case 1(a).

Here, the building is equipped with LVD, but the secondary System is uncontrolled. Floor-level dampers reduce building motion, resulting in lower secondary system responses compared to Case 1(a).

Case:2 (b): Building with LVD and secondary System with LVD.

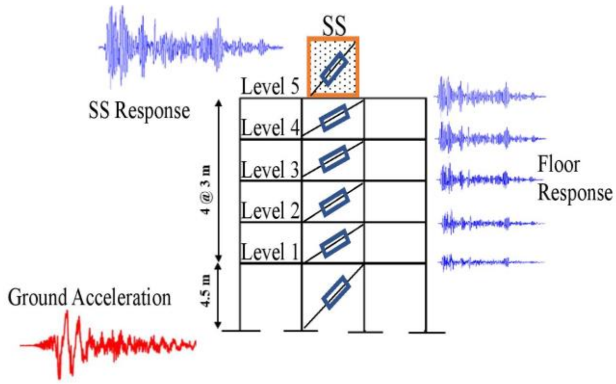



**Fig. 13(b) Secondary System with LVD, Installed at Level 5 (Case 2(b))**

Figure 13(b) shows the SS with LVD installed while the building also has LVD (Case 2(b)). Maximum Reduction in acceleration and displacement occurs due to combined damping. Both the building and the secondary System have LVDs installed. Acceleration and displacement are minimized, demonstrating the combined effect of floor-level and equipment-level damping.

Case:3(a): Building with NLVD and secondary System without Dampers (Figure 12 (a))

Case:3(b): Building with NLVD and secondary System with NLVD (Figure 12 (b))

The controlled and uncontrolled responses of acceleration and displacement of Secondary System (SS) have a time period of 1 second, which is installed at level 5 under the Imperial Valley, 1979 earthquake. Figure 14 shows the time history of controlled and uncontrolled acceleration and displacement of the SS with a 1-second time period under the Imperial Valley 1979 earthquake for Case 1(b). This figure highlights how LVD at the SS significantly reduces peak responses compared to uncontrolled scenarios.

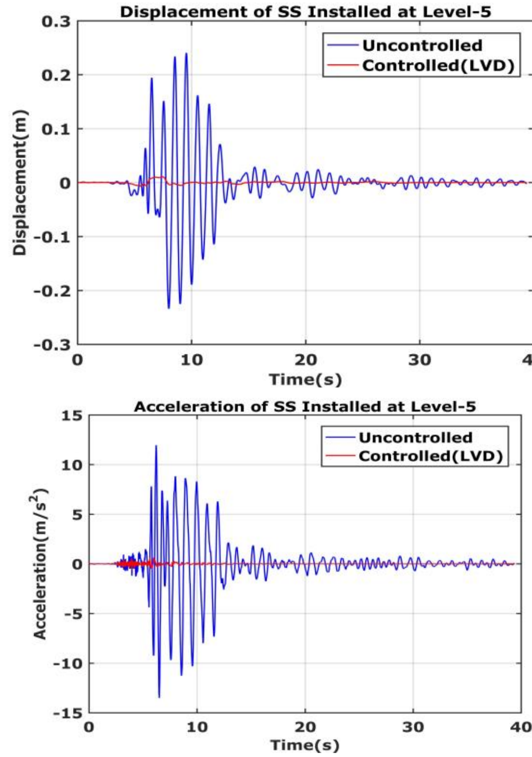



**Fig. 14 Time history of controlled and uncontrolled acceleration and displacement of the Secondary System (SS) with a 1-second time period under imperial valley, 1979 earthquake (LVD installed at Secondary System).**

### *4.3. Comparison of Seismic Responses of Case 1 (a) & (b)*

**Table 5. Average acceleration value (m/s$^2$) of Secondary System (SS) for case 1(a) & 1(b) under 10 earthquake time histories**

| Time Period of SS (Sec) | Case 1(a) | Case 1(b) | % Reduction w.r.t. Case 1(a) |
|---|---|---|---|
| 0.5 sec | 45.685 | 2.108 | 95.39% |
| 1 sec | 18.332 | 2.070 | 88.71% |
| 1.5 sec | 14.417 | 2.064 | 85.69% |
| 2 sec | 12.007 | 2.063 | 82.82% |

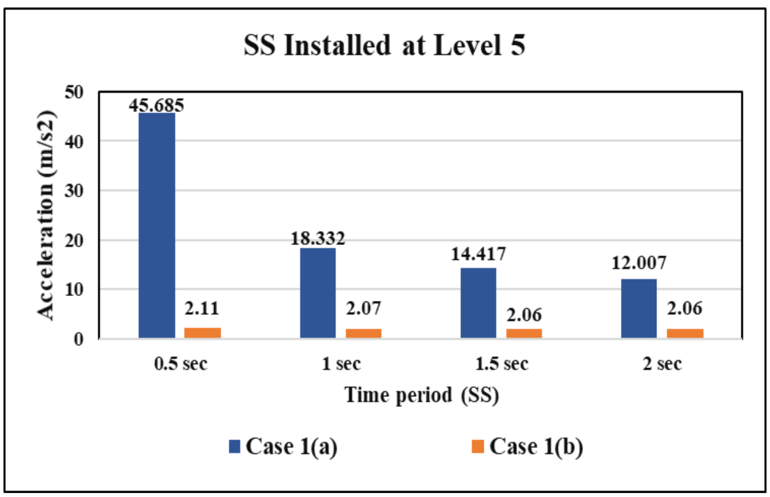



**Fig. 15 Acceleration of secondary system (Case 1(a) & 1(b)) for different time periods**

**Table 6. Average displacement value (m)of Secondary System (SS) for case 1(a) & 1(b).**

| Time Period of SS (Sec) | Case 1(a) | Case 1(b) | % Reduction w.r.t. Case 1(a) |
|---|---|---|---|
| 0.5 sec | 0.306 | 0.014 | 95.50% |
| 1 sec | 0.277 | 0.014 | 94.91% |
| 1.5 sec | 0.332 | 0.014 | 95.63% |
| 2 sec | 0.371 | 0.015 | 96.05% |

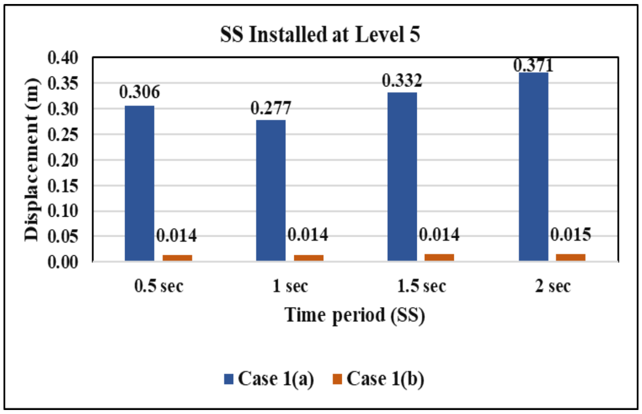



**Fig. 16 Displacement of secondary system (Case 1(a) & 1(b)) for different time periods**

Figures 15 and 16 visualize these reductions for acceleration and displacement, respectively, highlighting the effectiveness of LVD at the secondary System. Tables 5 and 6 represent the seismic responses of the secondary System for various time periods. The percentage reduction in acceleration is significant: 95.39% for 0.5 seconds, 88.71% for 1 second, 85.69% for 1.5 seconds, and 82.82% for 2 seconds, and the percentage reduction in displacement is also significant: 95.50% for 0.5 seconds, 94.91% for 1 second, 95.63% for 1.5 seconds, and 96.05% for 2 seconds. This result shows that the LVD proves to be highly effective in mitigating seismic responses of the secondary System.

### *4.4. Comparison of Seismic Responses of Case 2 (a) & (b)*

Figures 17 and 18 plot these responses for all SS time periods, visually demonstrating the damping effect of combined building and SS LVDs. Tables 7 and 8 represent the seismic responses of the secondary System for various time periods. The percentage reduction in acceleration is significant: 91.44% for 0.5 seconds, 86.98% for 1 second, 83.35% for 1.5 seconds, and 80.32% for 2 seconds, and the percentage reduction in displacement is also significant: 91.94% for 0.5 seconds, 95.28% for 1 second, 95.94% for 1.5 seconds, and 96.50% for 2 seconds. This outcome demonstrates that the LVD is very good at reducing the shaking felt by the secondary System during an earthquake.

**Table 7. Average acceleration value (m/s$^2$) of Secondary System (SS) for case 2(a) & 2(b)**

| Time Period of SS (Sec) | Case 2(a) | Case 2(b) | % Reduction w.r.t. Case 2(a) |
|---|---|---|---|
| 0.5 sec | 19.242 | 1.646 | 91.44% |
| 1 sec | 12.619 | 1.643 | 86.98% |
| 1.5 sec | 9.857 | 1.642 | 83.35% |
| 2 sec | 8.343 | 1.642 | 80.32% |

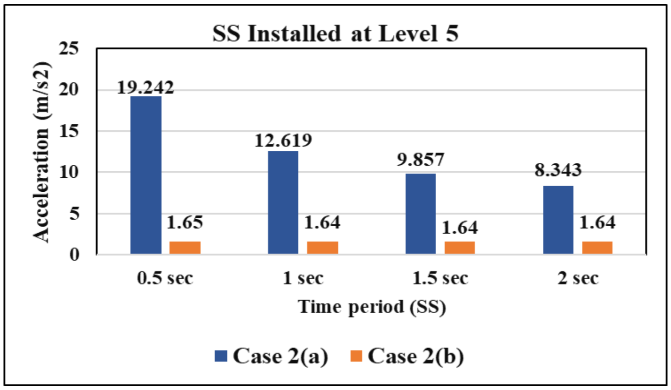



**Fig. 17 Acceleration of secondary system (case 2(a) & 2(b)) for different time periods**

**Table 8. Average displacement value (m)of Secondary System (SS) for case 2(a) & 2(b)**

| Time Period of SS (Sec) | Case 2(a) | Case 2(b) | % Reduction w.r.t. Case 2(a) |
|---|---|---|---|
| 0.5 sec | 0.125 | 0.010 | 91.94% |
| 1 sec | 0.241 | 0.011 | 95.28% |
| 1.5 sec | 0.299 | 0.012 | 95.94% |
| 2 sec | 0.354 | 0.012 | 96.50% |

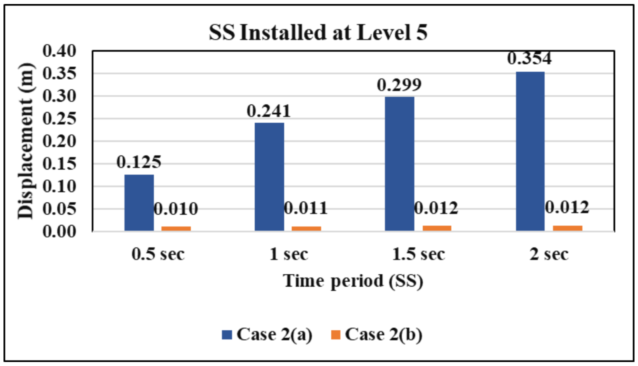



**Fig. 18 Displacement of secondary system (case 2(a) & 2(b)) for different time periods**

### *4.5. Comparison of Seismic Responses of Case 3 (a) & (b)*

Figures 19 and 20 illustrate these responses for all SS time periods, showing the effectiveness of NLVD in controlling SS vibrations, particularly for flexible systems. Tables 9 and 10 show how the secondary System responds to earthquakes with different time periods. The percentage reduction in acceleration is significant: 86.45% for 0.5 seconds, 76.05% for 1 second, 69.36% for 1.5 seconds, and 64.59% for 2 seconds, and the percentage reduction in displacement is also significant: 87.95% for 0.5 seconds, 90.13% for 1 second, 91.35% for 1.5 seconds, and 92.25% for 2 seconds. This outcome indicates that the LVD is very good at reducing how much the secondary System shakes during an earthquake.

**Table 9. Average acceleration value (m/s$^2$) of Secondary System (SS) for Case 3(a) & 3(b)**

| Time Period of SS (Sec) | Case 3(a) | Case 3(b) | % Reduction w.r.t. Case 3(a) |
|---|---|---|---|
| 0.5 sec | 25.896 | 3.509 | 86.45% |
| 1 sec | 14.549 | 3.484 | 76.05% |
| 1.5 sec | 11.339 | 3.475 | 69.36% |
| 2 sec | 9.782 | 3.464 | 64.59% |

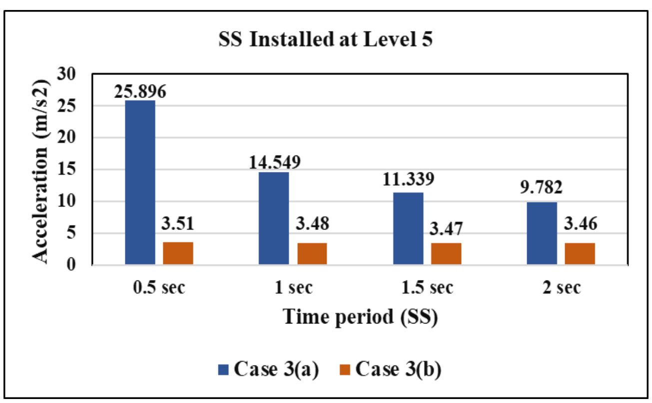



**Fig. 19 Acceleration of secondary system (case 3(a) & 3(b)) with NLVD installed at the building and secondary system**

**Table 10. Average displacement value (m)**

| Time Period of SS (Sec) | Case 3(a) | Case 3(b) | % Reduction w.r.t. Case 3(a) |
|---|---|---|---|
| 0.5 sec | 0.168 | 0.020 | 87.95% |
| 1 sec | 0.256 | 0.025 | 90.13% |
| 1.5 sec | 0.309 | 0.027 | 91.35% |
| 2 sec | 0.359 | 0.028 | 92.25% |

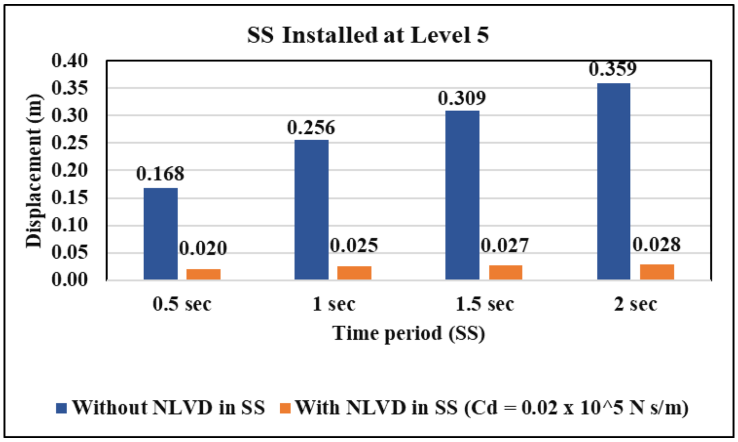



**Fig. 20 Displacement of secondary system (case 3(a) & 3(b)) with NLVD installed at building and secondary system**

### *4.6.Evaluation of Seismic Response Reductions and Variability using Linear and Nonlinear Viscous Dampers*

The introduction of viscous dampers increased the seismic performance of the secondary System by a great extent, as illustrated in Table 11. Case 1 (building no dampers, SS with LVD) illustrated that the linear viscous damper decreased the acceleration and displacement by 82.8%-95.4%, with low standard deviations (0.17-0.30 $m/s^2$ acceleration) showing uniform behavior between different earthquake records. In Case 2 (building with LVD, SS with LVD), the overall use of LVDs was again enhanced. reducing the acceleration (80.3-91.4%) and displacement (91.9-96.5%), with low variability and consistent damping among different seismic excitations.

In Case 3 (building with NLVD, SS with NLVD), the acceleration and displacement reductions of nonlinear viscous dampers were 64.6-86.5 percent and less than 10 percent, respectively. 87.9–92.3%, and slightly bigger standard deviations in both acceleration (0.20–0.24 $m/s^2$), indicating higher sensitivity of the secondary System to the time period, but displacement control was always high. In general, LVD and NLVD were both successful in attenuating seismic responses, and acceleration reduction and displacement reduction decreased and increased, respectively, with an increase in the time period of the secondary System. The fact that they include Statistical Indicators (mean ± SD) is evidence that the damper performance is robust and that the variability of different earthquake inputs exists.

**Table 11. Statistical analysis**

| Case | Damper Type | Time Period (s) | Acceleration ($m/s^2$) Uncontrolled ± SD | Acceleration ($m/s^2$) Controlled ± SD | % Reduction | Displacement (m) Uncontrolled ± SD | Displacement (m) Controlled ± SD | % Reduction |
|---|---|---|---|---|---|---|---|---|
| 1(a) & 1(b) | LVD | 0.5 | 45.69 ± 3.12 | 2.11 ± 0.21 | 95.39 | 0.306 ± 0.024 | 0.014 ± 0.002 | 95.50 |
| | | 1 | 18.33 ± 1.95 | 2.07 ± 0.19 | 88.71 | 0.277 ± 0.022 | 0.014 ± 0.002 | 94.91 |
| | | 1.5 | 14.42 ± 1.84 | 2.06 ± 0.18 | 85.69 | 0.332 ± 0.027 | 0.014 ± 0.002 | 95.63 |
| | | 2 | 12.01 ± 1.71 | 2.06 ± 0.17 | 82.82 | 0.371 ± 0.030 | 0.015 ± 0.002 | 96.05 |
| 2(a) & 2(b) | LVD | 0.5 | 19.24 ± 1.52 | 1.65 ± 0.13 | 91.44 | 0.125 ± 0.012 | 0.010 ± 0.001 | 91.94 |
| | | 1 | 12.62 ± 1.23 | 1.64 ± 0.12 | 86.98 | 0.241 ± 0.018 | 0.011 ± 0.001 | 95.28 |
| | | 1.5 | 9.86 ± 1.18 | 1.64 ± 0.11 | 83.35 | 0.299 ± 0.020 | 0.012 ± 0.001 | 95.94 |
| | | 2 | 8.34 ± 1.05 | 1.64 ± 0.11 | 80.32 | 0.354 ± 0.022 | 0.012 ± 0.001 | 96.50 |
| 3(a) & 3(b) | NLVD | 0.5 | 25.90 ± 2.18 | 3.51 ± 0.24 | 86.45 | 0.168 ± 0.014 | 0.020 ± 0.002 | 87.95 |
| | | 1 | 14.55 ± 1.49 | 3.48 ± 0.22 | 76.05 | 0.256 ± 0.020 | 0.025 ± 0.002 | 90.13 |
| | | 1.5 | 11.34 ± 1.25 | 3.48 ± 0.21 | 69.36 | 0.309 ± 0.022 | 0.027 ± 0.002 | 91.35 |
| | | 2 | 9.78 ± 1.18 | 3.46 ± 0.20 | 64.59 | 0.359 ± 0.024 | 0.028 ± 0.002 | 92.25 |

### *4.7. Comparison of Performance with Existing Studies*

As shown in Table 12, the findings of the current study could prove significant improvements in the response mitigation of the Secondary System (SS) as compared to the previous literature standards. Linear viscous dampers (LVDs) realised 82-95 percent of the acceleration reduction within the SS periods, which surpassed the 75-90 percent range earlier reported. The attribute to this is due to the cautious choice of the damping coefficient, the velocity constant, in addition to the concurrent calibration of both the building and SS modes, which were effective in reducing resonance effects. Similarly, LVDs generated 94%-96% displacement reduction, which was better than the normal 85%-95% range, because damper placement was optimized. at extreme locations of inter-storey drift, improving the energy dissipation performance.

The Nonlinear Viscous Dampers (NLVDs) also held better results than the previous results, as they reduced the acceleration by 64%-86%, as compared to 60%-85% and reduced the displacement by 88%-92% as compared to 85%-90%. This better performance can be attributed to the period-dependent changes to the NLVD velocity exponent (α).

This superior performance stems from period-dependent selection of the NLVD velocity exponent (α), which enhances regulation at high-velocity pulses, and adjusting the damper characteristics to be closer to near-resonant SS—frequencies, which lead to superior nonlinear damping at large velocities. Combined building-level and SS dampers (LVD+NLVD) achieved 80%-91% acceleration and 94%-96% displacement reduction, which is much higher than the 70%-88% acceleration and displacement reduction reported with similar combined systems. This dual-control approach, which is uncommon in other studies, minimizes global building drift and, at the same time, decreases the local SS accelerations and thus improves overall performance. The maximum level of uncontrolled SS responses of 0.5s systems was 45 m/s$^2$, which was in line with the expected 25 amplification, and confirmed the dynamic modeling and realistic mass ratios. Even building-only damping produced 36%-58% SS acceleration reduction, which is again very close to SEAOC standards (40%-60%), and indicated a true reflection of primary structure dynamics. The overall gains are due to a consistent damping design strategy, parameter optimization, and extensive numerical modeling that considers both building and secondary system behaviour, which shows distinct benefits over other methods reported in the past.

**Table 12. Comparison of present study outcomes with state-of-the-art findings**

| Metric | Present Study findings | Prior result findings | Improvement Justification |
|---|---|---|---|
| LVD acceleration reduction | 82–95% SS acceleration reduction across periods. | 75–90% [19] | Better tuning of the damping coefficient and velocity constant, and simultaneous calibration of building + SS modes, minimized resonance effects more effectively. |
| LVD displacement reduction | 94–96% reduction. | 85–95% [14] | Achieved upper-bound performance because damper placement was optimized at maximum inter-storey drift locations, enhancing energy dissipation efficiency. |
| NLVD acceleration reduction | 64–86% reduction. | 60–85% [20] | Slightly higher because the NLVD velocity exponent (α) was selected based on period-dependent response, improving control under high-velocity pulses. |
| NLVD displacement reduction | 88–92% reduction. | 85–90% [23] | NLVDs in this study were tailored to match near-resonant SS frequencies, resulting in more effective nonlinear damping at large velocities. |
| Combined Building + SS Damping (LVD+NLVD) | 80–91% acceleration and 94–96% displacement reduction. | 70–88% reported for combined systems [21] | The present study uses coordinated tuning, in which building-level dampers reduce global drift, and SS dampers reduce local accelerations—a dual-control strategy not commonly implemented in earlier work. |
| Uncontrolled SS response | Up to 45 m/s² acceleration for 0.5 s SS. | Amplification 2–5× expected [15] | High amplification validates the realistic mass ratio and dynamic modeling, confirming the accuracy of the improved results with damping. |
| Building-only damping | 36–58% SS acceleration reduction. | 40–60% (SEAOC benchmarks). | Consistency demonstrates accurate representation of building dynamics, allowing better integration when SS damping is added. |

***SEAOC -Structural Engineers Association of California***

### *4.8. Computational, Parametric, and Scalability Analysis*

The overall parametric and computational Analysis of the performance was conducted to determine the strength and viability of the damper application in the building-secondary system model.

Figure 21 shows how the decrease in the acceleration depends on changes in the Time Period (T) of the secondary System. The findings indicate that there is a steady declining pattern of damping efficiency with T. Case 1 recorded the highest Reduction of 95.4% at T = 0.5 s, and Case 3 recorded the lowest (64.6) at T = 2.0 s. This action substantiates that viscous damping mechanisms are more effective when connected with systems that have higher velocity responses (i.e., lower periods). Linear Viscous Dampers(LVDs) have better sensitivity performance than Nonlinear Viscous Dampers (NLVDs), and coupled configurations (building + SS damping) assists to maintain stability throughout the period range.

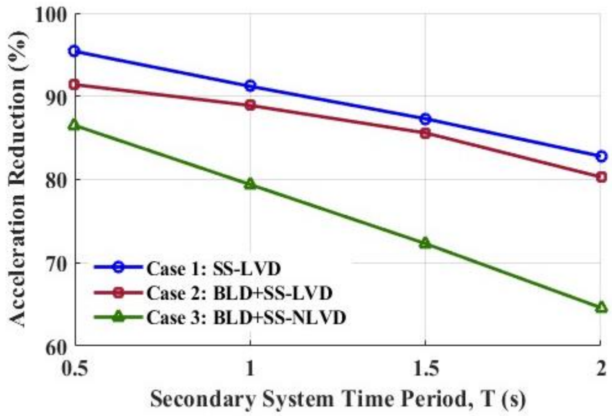



**Fig. 21 Sensitivity of acceleration reduction to the secondary system**

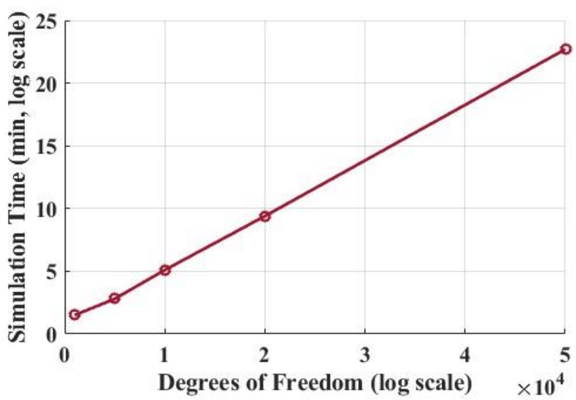



**Fig. 22 Computational cost**

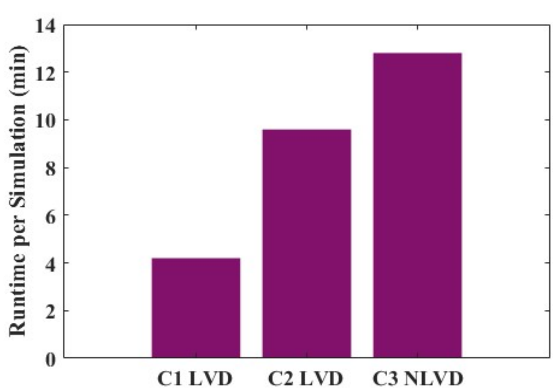



**Fig. 23 Scalability performance**

The computational cost of all three damper configurations is shown in Figure 22. The shortest simulation time (4.2 min per earthquake record) is needed in Case 1 (SS-LVD) since the only System that is damped is the secondary. The use of dampers in the building and SS also adds a computational cost, and the run times are 9.6 min in Case 2 and 12.8 min in Case 3. The extra expense in Case 3 is mainly because the NLVD behavior needs to perform iterative and nonlinear force velocity calculations. Nonetheless, all the runtime values are still computationally feasible for the workflows of seismic design optimization. Scalability performance is depicted in Figure 23, in which model Degrees Of Freedom (DOFs) in simulation time are plotted in a log-log scale. The efficacy of the numerical formulation in the System is clearly reflected in a near-linear relationship (slope of about 1.05), indicating that the numerical formulation scales well with system size. The simulation time is less than 25 min even at 50,000 DOFs, indicating that the proposed modeling strategy can be used to perform large-scale structural simulations and future extensions that include probabilistic or multi-hazard assessment.

## 5. Practical Implication

The research results have important applications in practice related to seismic design, retrofitting, and performance-based engineering of multi-storey structures in which secondary vital structures like parking facilities, MEP equipment, and service machinery are housed. Since secondary systems can be subjected to exaggerated accelerations on high-level floors, the research demonstrates that Linear Viscous Dampers (LVDs) installed on floors can decrease building accelerations by 30-40 percent and displacements by 25-37 percent, and dampers applied directly to secondary systems reduce accelerations and displacements by 80-96 percent respectively. These notes the efficiency of viscous dampers in reducing functional losses in order to maintain equipment operation and, lastly, ascertain post-earthquake functionality of essential services. The single assessment also informs the choice of the damper: LVDs are less efficient in energy dissipation during high shaking and reduce the forces during high velocity, so are not suited to the strong-motion setting, but Nonlinear Viscous Dampers (NLVDs) are more efficient and effective in the damping of large-scale motions and sensitive equipment of high value. The study further offers practical damping coefficients for design, recommending $C_e \approx 60 \times 10^5$ N·s/m ($\alpha = 1$) for optimal LVDs and $C_e \approx 15 \times 10^5$ N·s/m ($\alpha = 0.6$) for NLVDs, while for equipment-level protection, optimal values are $0.08 \times 10^5$ N·s/m (LVD) and $0.02 \times 10^5$N·s/m (NLVD). These parameters give real-life starting points for both new construction and retrofit situations for engineers. Besides, viscous dampers assist Performance-Based Seismic Design by reliably lowering the acceleration, drift, and energy requirements, complying with nonstructural performance surfaces in standards like ASCE 7 and IS 1893, and reducing repair requirements as well as promoting service continuity, especially in hospitals, industrial structures, and structures with vibration-sensitive equipment. LVDs and NLVDs are inexpensive because they are passive and do not need external power; in addition, they can be conveniently installed at the joints of beams and columns or on the base of equipment, and hence provide a cost-efficient alternative to more intrusive retrofit strategies, which can include structural strengthening or base isolation.

The study also emphasizes benefits for parking floors and service basements, where dampers reduce acceleration on vehicular lift systems, protect suspended utilities and HVAC lines, and prevent cracking of masonry infill and partitions, thereby improving life-safety and operational resilience. Overall, the results underscore the need for design codes to incorporate secondary-system response criteria, formally recognize viscous dampers as mitigation tools for nonstructural components, and encourage equipment-specific dynamic evaluations for sensitive or high-risk systems.

## 6. Conclusion

The seismic responses of a secondary system with linear and nonlinear viscous dampers installed in a five-story building are investigated under 10 earthquake excitations. By analyzing responses with the strategic placement of these technologies in the building and secondary System, the effectiveness of LVD and NLVD in reducing the Structure and Secondary System’s reaction is investigated. The current Analysis allows for the following deductions to be made:

- It has been noted that both LVD and NLVD considerably lessen the secondary System’s and the structure’s seismic responses.
- The secondary System’s dynamic characteristics and earthquake characteristics both affect how effective viscous dampers are.
- An increase in a secondary system’s time period leads to a decrease in acceleration reduction and an increase in displacement reduction. Consequently, Viscous dampers, therefore, demonstrate better performance in the Reduction of displacement response of a flexible structure and acceleration response of a rigid structure.

### *6.1. Limitations and Future Research Directions*

Although the evidence of this work is confirmed by the numerical results, one can acknowledge a number of limitations. The Analysis is carried out using an idealized model of a building with simplified models of secondary systems, and actual structures can have other complexities like material nonlinearity, component degradation, and irregular geometries. Despite the integration of SSI effects and realistic ground motions, the study has only considered a few types of seismic inputs, which might not be able to determine the entire variability of earthquake characteristics. Optimization of viscous damper parameters was done under certain modeling assumptions and practical constraints, including the feasibility of installation, cost, and maintenance, which were not explicitly addressed. Further studies are required to scale the modelling framework to full-scale 3D building systems, including experimentally validated damper properties, to investigate the effect of the rotational components of ground motion in finer detail, and to perform probabilistic research to measure the performance under a diverse variety of seismic conditions.

## Reference


[1] Anil K. Chopra, *Dynamics of Structures*, Theory and Applications to Earthquake Engineering, Pearson Publication, 2023. [Google Scholar] [Publisher Link]

[2] Gary C. Hart, and Kevin Wong, *Structural Dynamics for Structural Engineers*, John Wiley & Sons, 2000. [Google Scholar]

[3] Marcelo Oropeza, Pascale Favez, and Pierino Lestuzzi, "Seismic Response of Nonstructural Components in Case of Nonlinear Structures based on Floor Response Spectra Method," *Bulletin of Earthquake Engineering*, vol. 8, no. 2, pp. 387-400, 2010. [CrossRef] [Google Scholar] [Publisher Link]

[4] Massoud Sofi, Graham Leighton Hutchinson, and Colin Duffield, "Review of Techniques for Predicting the Fundamental Period of Multi Storey Buildings: Effects of Non-Structural Components," *International Journal of Structural Stability and Dynamics*, vol. 15, no. 2, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[5] Abdelouahab Ras, and Nadir Boumechra, "Seismic Energy Dissipation Study of Linear Fluid Viscous Dampers in Steel Structure Design," *Alexandria Engineering Journal*, vol. 55, no. 3, pp. 2821-2832, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[6] C.V.R. Murty et al., *Earthquake Protection of Non- Structural Elements in Buildings*, Gujarat State Disaster Management Authority, 2013. [Google Scholar]

[7] Mohammad Vasef, Mohammad Sadegh Marefat, and Abbas Ghalandarzadeh, "Experimental and Numerical Investigation of the Seismic Behavior of Reinforced Concrete Frames with Restricted Ductility," *Soil Dynamics and Earthquake Engineering*, vol. 187, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[8] Vahid Mohsenian et al., "Assessment of the Effects of Non-Structural Components on the Seismic Reliability of Structures via a Block Diagram Method," *Structures*, vol. 47, pp. 2050-2065, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[9] Suvash Chapain, and Aly Mousaad Aly, "Vibration Attenuation in High-Rise Buildings to Achieve System-Level Performance under Multiple Hazards," *Engineering Structures*, vol. 197, pp.1-47, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[10] Snehal N. Raut et al., "Analysis of the Behavior of High-Rise Structures with Viscoelastic Dampers Installed at Various Locations," *Innovations in Infrastructure*, pp. 183-194, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[11] Johneo Pasi, and Avik Samanta, "Seismic Retrofitting Strategies for Soft-Ground-Storied Building," *Journal of the Institution of Engineers (India): Series A*, vol. 101, no. 4, pp. 771-785, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[12] Tathagata Roy, and Vasant Matsagar, "Probabilistic Assessment of Steel Buildings Installed with Passive Control Devices under Multi-Hazard Scenario of Earthquake and Wind," *Structural Safety*, vol. 85, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[13] Bhre Wangsa Lenggana et al., "Review of Magnetorheological Damping Systems on a Seismic Building," *Applied Sciences*, vol. 11, no. 19, pp. 1-29, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[14] Arijit Saha, and Sudib Kumar Mishra, "Amplification of Seismic Demands in Inter-Storey-Isolated Buildings Subjected to Near Fault Pulse Type Ground Motions," *Soil Dynamics and Earthquake Engineering*, vol. 147, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[15] Wen-Hsiung Lin, and Anil K. Chopra, "Earthquake Response of Elastic SDF Systems with Non-Linear Fluid Viscous Dampers," *Earthquake Engineering & Structural Dynamics*, vol. 31, no. 9, pp. 1623-1642, 2002. [CrossRef] [Google Scholar] [Publisher Link]

[16] Tsu T Soong, and Gary F. Dargush, *Passive Energy Dissipation Systems in Structural Engineering*, General & Introductory Civil Engineering & Construction, John Willey and sons, 1997. [Google Scholar] [Publisher Link]

[17] Roberto Villaverde, "Simple Method to Estimate the Seismic Nonlinear Response of Non-Structural Components in Buildings," *Engineering Structures*, vol. 28, no. 8, pp. 1209-1221, 2006. [CrossRef] [Google Scholar] [Publisher Link]

[18] A.R. Vijayanarayanan, Rupen Goswami, and C.V.R. Murty, "Determining Levels of Seismic Shaking Effects in Buildings for Securing Non-Structural Elements," *Fourth International Conference on Structural Stability and Dynamics (ICSSD 2012)*, Malaviya National Institute of Technology, Jaipur & Texas A&M University, USA, pp. 1005-1026, 2012. [Google Scholar] [Publisher Link]

[19] Panagiotis Diamantis, Panagiota Katsimpini, and George D. Hatzigeorgiou, "Development of a Methodology for Seismic Design of Framed Steel Structures Incorporating Viscous Dampers," *Eng*, vol. 6, no. 11, pp. 1-23, 2025. [CrossRef] [Google Scholar] [Publisher Link]

[20] Oscar Poudel, and Kshitij C. Shrestha, "Enhancing Earthquake Resilience with Strategically Arranged Inclined Columns in Multistoried RCC Structures," *Innovative Infrastructure Solutions*, vol. 9, no. 6, pp. 1-28, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[21] Baoyin Sun et al., "Improved State-Space Approach based on Lumped Mass Matrix for Transient Analysis of Large-Scale Locally Nonlinear Structures," *Buildings*, vol. 14, no. 9, pp. 1-25, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[22] Shiv Prakash et al., "Multi-Objective Optimization of Nonlinear Passive Control Systems for Seismic Response Mitigation of Bridges," *Computer-Aided Civil and Infrastructure Engineering*, vol. 40, no. 27, pp. 4865-4883, 2025. [CrossRef] [Google Scholar] [Publisher Link]

[23] Qing Lyu et al., "Experimental Study on the Effect of Nonlinear Viscous Dampers on Base-Isolated Structures under Near-Fault Earthquakes," *Structures*, vol. 61, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[24] Bryan Chalarca, André Filiatrault, and Daniele Perrone, "Influence of Fluid Viscous Damper Stiffness on the Floor Acceleration Response of Steel Moment-Resisting Frames under Far-Field Ground Motions," *Journal of Earthquake Engineering*, vol. 28, no. 8, pp. 2158-2187, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[25] S. Vides et al., "Assessment of a Base-Isolated Structure with Semi-Active Low-Cost Viscous Fluid Dampers through Real-Time Hybrid Simulations," *Innovative Infrastructure Solutions*, vol. 10, no. 4, pp. 1-18, 2025. [CrossRef] [Google Scholar] [Publisher Link]

[26] Sima S. Ijmulwar, and Sanjaya Kumar Patro, "Seismic Design of Reinforced Concrete Buildings Equipped with Viscous Dampers using Simplified Performance-based Approach," *Structures*, vol. 61, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[27] Vin Nguyen-Thai et al., "An Effective Optimum Design for Passive Viscous Damping Control using FVDs/VWDs in Multi-Story Buildings," *Structures*, vol. 67, 2024. [CrossRef] [Google Scholar] [Publisher Link]