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Seismic Performance Enhancement Of Steel Structures Using Viscous Damper

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Abstract
This study explores the seismic performance enhancement of steel structures through the application of Fluid Viscous Dampers (FVDs), focusing on their impact on reducing displacement, story drift, and improving overall structural stiffness. Steel structures, which are widely used in modern construction due to their durability and ductility, are highly vulnerable to seismic forces, often resulting in excessive displacements, story drift, and potential structural failure during earthquakes. FVDs, as a passive energy dissipation system, help mitigate these effects by converting seismic energy into heat, thus reducing the amplitude of vibrations. The research examines the efficiency of various damper configurations in symmetric and unsymmetric steel frame buildings of different heights (10, 15, and 20 story), subjected to seismic loading conditions in both X and Y directions. Four damper placement schemes—No Damper, all story Dampers, Alternate Floor Dampers, and Top, Middle, Bottom Dampers—were analyzed using Response Spectrum Analysis as per IS 1893:2016 seismic design codes. The study finds that the introduction of FVDs significantly reduces displacement and drift, with the most noticeable improvements occurring in taller buildings. Among the configurations, the "All Story Dampers" strategy proved to be the most effective in mitigating seismic response, reducing displacements by 40% to 70%. However, considering cost efficiency, the "Top, Middle, Bottom Dampers" configuration was found to offer a balanced solution, providing adequate seismic mitigation while reducing costs. The results indicate that all damper configurations kept the seismic response within the permissible limits set by the IS code, ensuring both seismic safety and stability. The findings emphasize that FVDs, particularly with selective placement strategies, are an effective, cost-efficient solution for enhancing the seismic resilience of steel buildings. The research provides valuable insights for both the design and retrofitting of steel structures in earthquake-prone regions.
Keywords: *Seismic performance, Steel structures, Fluid viscous dampers, Earthquake resilience, Structural control.*

1. INTRODUCTION

The advancement of both active and passive structural control techniques has equipped structural engineers with a range of innovative solutions aimed at enhancing seismic performance[1]. Among these, viscous dampers have gained widespread acceptance and are frequently utilized in practice[2]. Despite their popularity, engineers often face challenges in properly selecting and strategically placing viscous dampers within a structure to effectively reduce seismic impacts[3]. The exceptional strength-to-weight ratio of steel structures makes them a popular choice for modern construction, ductility, and rapid construction capabilities. However, these structures are vulnerable to seismic events, especially in earthquake-prone regions[4]. Earthquake-induced ground motions cause dynamic forces that can lead to excessive displacement, story drift, torsion, and even catastrophic failure if the structures are not adequately designed or retrofitted[5]. The need for seismic resilience in steel buildings has prompted extensive research into innovative structural control methods that can mitigate seismic damage and enhance overall safety [6][7]. Among various structural control systems, viscous dampers have gained significant attention due to their ability to dissipate seismic energy effectively[8]. The impact of passive seismic energy dissipation systems utilizing fluid viscous dampers (FVD) on the maximum reactions of reinforced concrete buildings subjected to far-field ground movements in terms of accelerations, displacements, and other forms of internal forces[9].

The seismic performance of steel structures can be significantly enhanced by incorporating various systems, such as shear walls, X-bracing, and dampers[10]. Recent studies have shown that these systems, when combined, offer substantial improvements in the resilience of multi-story buildings under seismic loads[11]. Specifically, the integration of viscous dampers into steel structures has emerged as a highly effective method to reduce lateral displacements and mitigate the vibrations induced during an earthquake[12]. Viscous dampers work by dissipating the energy generated by seismic forces, which reduces the amplitude of oscillations and prevents the structure from experiencing excessive deformations[13]. Research has demonstrated that the use of such dampers, combined with other systems like shear walls or bracing, can enhance the overall seismic safety of buildings, providing significant cost savings by minimizing damage to both structural and non-structural elements[14][15].

A viscous damper, typically a fluid viscous damper (FVD), works by converting kinetic energy from structural vibrations into heat energy through fluid viscosity, thus reducing the amplitude of vibrations during seismic events[16]. The use of viscous dampers in steel buildings provides improved damping, reducing displacements and stresses without significantly altering the stiffness or mass of the structure[17]. Conversely, viscous dampers function by using a piston that travels through a conduit that has been filled with silicon and a comparable lubricant, as illustrated in Figure 1. The fluid is displaced through the numerous small openings in the piston as it moves. Viscous dampers are activated at low displacements and exhibit linear behavioral characteristics[18]. While these dampers require periodic inspection and maintenance, they are more costly compared to other dampers[19].

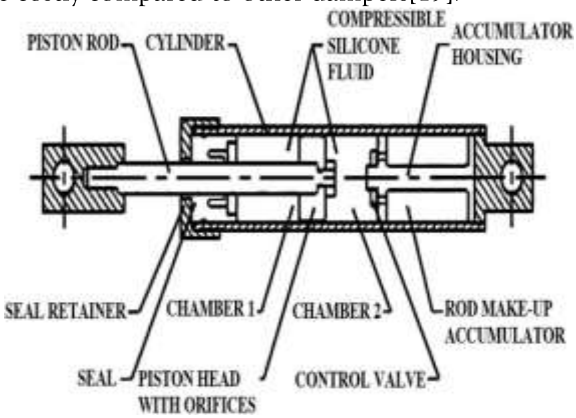

Figure 1: Viscous Damper [20]

Despite their many advantages, the use of viscous dampers is not without challenges. One of the primary limitations is the cost, both in terms of installation and maintenance. The design and manufacturing of viscous dampers can be expensive, particularly for large structures or buildings requiring high damping capacities. Additionally, the maintenance of these systems is crucial to ensuring their long-term effectiveness. Regular inspections and replacements of the damping fluid or components may be required, depending on the type of damper used[21]. Another challenge is the interaction between the damper and the structure. While viscous dampers are designed to reduce vibrations, their integration with the building's structural system must be carefully considered to avoid unintended consequences, such as changes in the natural frequency or increased stress on certain components. Although the use of viscous dampers in seismic performance enhancement is well established, there remains significant scope for further research[22]. This research investigates the seismic performance enhancement of steel structures by utilizing viscous dampers under seismic loads, specifically focusing on symmetric and unsymmetric building configurations with 10, 15, and 20 story[23]. Various damper installation schemes such as no damper, all story dampers, alternate story dampers, and dampers at top, middle, and bottom levels are evaluated[24]. This study aims to quantify the effectiveness of viscous dampers in improving structural stability and reducing seismic responses such as maximum displacement, story drift, overturning moments, base shear, and torsion[25]. Kang and Tagawa (2013) A seesaw dissipation in energy system that utilises fluid viscous dampers has been suggested as a means of improving the seismic resilience for steel structures. Subsequent system avoids brace buckling by allowing only tensile forces in braces. Nonlinear analysis on 3- and 6-story frames showed that the system effectively reduced story drift and top displacement. Compared to diagonal and chevron brace systems, the seesaw model offered better energy dissipation and response control under seismic loads[26]. Hu et al. (2020) investigated the seismic mitigation capabilities of structures that are mounted in fluid viscous dampers (FVDs) during near-fault pulse-type earthquakes. Using both SDOF and MDOF models, they found that while FVDs significantly reduced seismic responses, short-period structures showed better performance when the structural period-to-pulse period ratio (T/Tp and T1/Tp) were both less than 1. However, mid- and long-period structures still experienced large plastic deformations. The study emphasized that findings from SDOF systems may not directly apply to MDOF systems due to their complex dynamics[27]. Silwal et al. (2015) A superelastic viscosity damper (SVD) was suggested as a means of enhancing the earthquake resistance for steel moment frames by incorporating high-damped viscoelastic rubber and shape memory alloy (SMA) cables. Time history analyses that are nonlinear on a six-story steel frame under 44 ground motions showed that the SVD effectively reduced structural responses and ensured re-centering after seismic events. The hybrid device offered improved energy dissipation at varying displacement levels and maintained post-earthquake functionality better than conventional dampers[28]. De Domenico and Hajirasouliha (2021) developed a multi-level performance-based optimization method for retrofitting steel frames using nonlinear viscous dampers (NVDs)[29]. Using a Maxwell model and uniform damage distribution (UDD) strategy, they optimized the height-wise damping layout under various seismic intensities. The most effective seismic performance was achieved by drift-based UDD, as demonstrated by complex time-history analysis of frames with 3, 7, and 12 stories. This approach minimised inter-storey drift, thermoplastic rotation, or global damage. The method proved practical and effective for achieving code-compliant multi-level seismic objectives[30]. Kaleybar and Tehrani (2021) evaluated the seismic performance of an eight-story steel moment frame equipped with various passive dampers, including linear/nonlinear viscous dampers, viscoelastic, friction, and metallic (TADAS) types[31]. By employing nonlinear analysis of time history in OpenSees, they determined that nonlinear viscous dampers and toggle arrangements provided superior energy dissipation and reduced displacements. Among damper types, friction dampers showed the most effective performance, while toggle-arranged viscous dampers outperformed Chevron and Diagonal setups in reducing seismic response[32]. Ras and Boumechra (2016) A 3D nonlinear historical analysis was performed using SAP2000 to evaluate the seismic resilience of a 12-story concrete moment frame that was supplied with linear fluid viscosity dampers (FVDs) during the Boumerdes earthquake. The results indicated that FVDs significantly increased energy loss without increasing structural stiffness. Compared to unbraced and traditionally braced frames, FVD-equipped structures exhibited reduced seismic response and required less steel for stability, highlighting their efficiency in modern seismic design[33]. Hu et al. (2020) investigated the seismic mitigation capabilities of structures that had fluid viscous dampers (FVDs) in the presence of near-fault pulse-type ground movements. Using both SDOF and MDOF models, they found that FVDs improved seismic response but could still lead to plastic deformation when the The structural period-to-pulse phase ratio (T/Tp) was less than 1. MDOF systems exhibited more complex behaviour, while short-period structures benefited the most if both T/Tp and T1/Tp were below one. The study highlighted that SDOF-based conclusions may not fully apply to MDOF structures[34]. Parajuli et al. (2023) evaluated 17 models in four damper configurations or four dampening coefficient distribution methods in a comprehensive study of ten-story RC frames that resist moments in fluid viscous dampers (FVDs). The scissor-jack configuration in story shear tension energy method (SEM) demonstrated the most favourable seismic and cost performance when analyses using nonlinear time history in ETABS. While configuration significantly influenced results, changes in damping distribution had a marginal effect, emphasizing the importance of modal analysis to capture higher mode effects accurately[35]. Behnamfar and Almohammad-albakkar (2023) presented a thorough examination of steel resisting dampers, emphasizing their essential function in the reduction of structural damage and the dissipation of seismic energy. Numerous geometries in steel yielding dampers, including steel plate, pipe, curved, or slit dampers, have been implemented to enhance seismic safety across new and extant structures, over the course of five decades of development. The study underscores the prevalence of steel plate or pipe dampers in braced messages, while U-, J-, as well as S-shaped dampers are well-suited for chevron-braced frames. Among these, steel slit dampers are the most prevalent due to their superior energy dissipation and ease of application[36].

3.METHODOLOGY AND MODELLING

This study examines the use of hydraulic viscous dampers (FVDs) to improve the seismic performance of steel structures. There are two categories of steel buildings: symmetric and unsymmetric. Models of 10, 15, or 20 story are created for each type to assess the impact of building height in seismic response. The reaction Spectrum Method is employed to conduct the structural analysis in accordance with the applicable seismic codes. The steel used for all models is of grade Fe250, with columns and beams sized as ISMB 500 and ISMB 450 sections, respectively. The buildings are designed to carry various loads, including Earthquake loads in both the X and Y dimensions (EQX and EQY), wind loads in X or Y directions (such as wind X or Wind Y), dead load (D.L.), and live load (L.L).

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Four damper configurations are considered for each building model to analyze the effect of damper placement on seismic response:

- Without damper,
- Dampers installed on all stories,
- Dampers installed at Alternate stories,
- Dampers installed at top, middle, and bottom stories.

Supplementary energy dissipation devices are utilized to model the fluid viscous dampers reduce structural vibrations by converting seismic energy into heat, thus improving stability during earthquakes. The structural modeling and analysis are conducted using ETABS software, where the buildings are modeled as framed structures with integrated dampers as per the specified configurations. The Response Spectrum analysis provides dynamic responses including maximum displacement, story drift, base shear, overturning moments, and torsional effects. These performance parameters are compared across different damper configurations and building types (Symmetric and Unsymmetric) to assess the damping efficiency and overall seismic performance improvement provided by the viscous dampers.

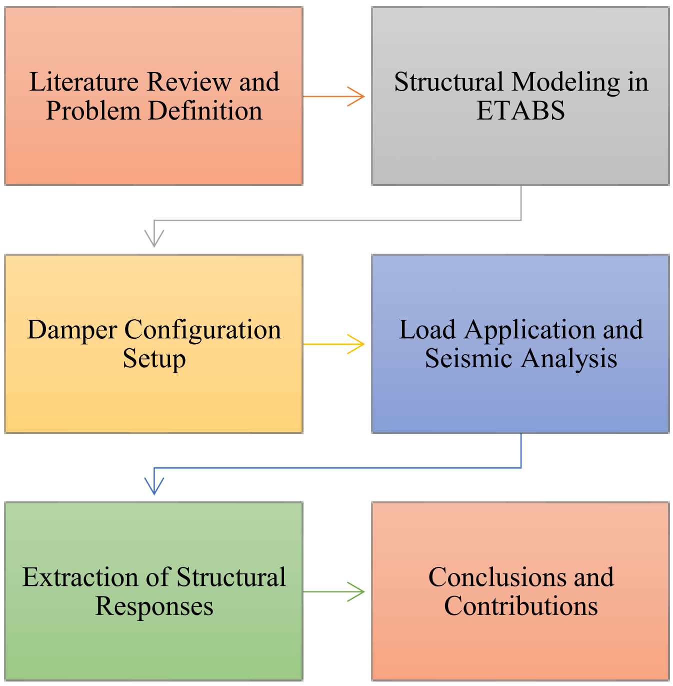

Figure 2: Flowchart Of Methodology

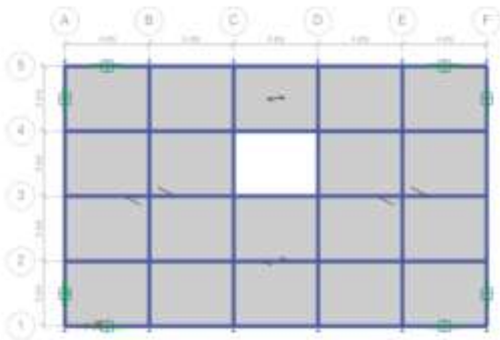

Figure 3: a) SYM plan view

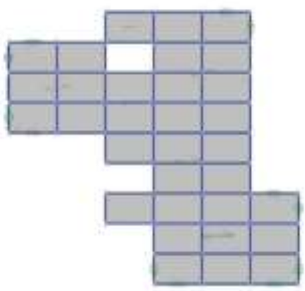

Figure 3: b) UNSYM plan view

The figures show structural plan views of two buildings: a symmetric (SYM) layout on the left and an unsymmetric (UNSYM) layout on the right. Both plans highlight column grids and load distribution patterns.

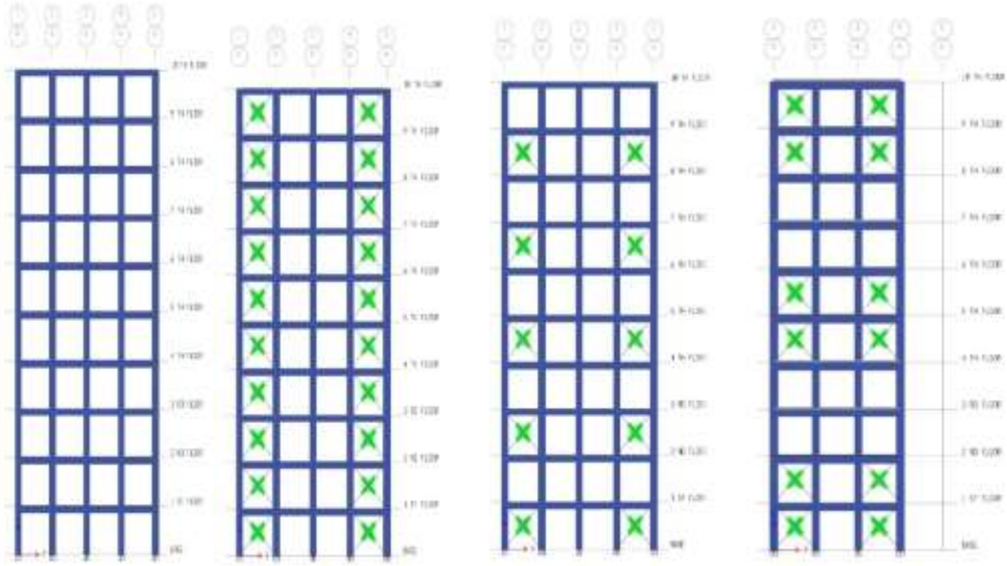

Fig.4a) Fig.4b) Fig.4c) Fig.4d)

Figure 4: Symmetrical and Unsymmetrical building of 10, 15,20 story damper placement a) Without damper b) All floor damper c) Alternate floor damper d) Top, Middle, Bottom damper

Table 1: Structure Details and Specifications

Sr. No.	Description	Specification
1	Structure Types	Symmetric, Unsymmetric
2	Number of Story	10, 15, 20
3	Steel Grade	Fe345
4	Column Size	ISMB 500
5	Beam Size	ISMB 300
6	Loads Considered	Dead Load (D.L.), Live Load (L.L.), Earthquake Loads (EQX, EQY), Wind Loads (Wind X, Wind Y)
7	Method of Analysis	Response Spectrum Method

4. Results and discussion

The seismic performance in steel structures with hydraulic viscous dampers (FVDs) has been evaluated in this study across buildings in varying heights—10, 15, or 20 story. The displacement and seismic response were analyzed under four damper placement configurations: No Damper, All story Dampers, Alternate Floor Dampers, and Top, Middle, Bottom Dampers. Displacement values were recorded in the X-direction (EQX) for each scenario, and the results were compared to evaluate the effectiveness of different FVD placements in reducing seismic-induced deformations.

For the 10-storey symmetric structure, the No Damper configuration exhibited the highest displacement, with a maximum displacement of 56.21 mm at the top story under EQX loading. In contrast, the All-story Dampers configuration significantly reduced the displacement, bringing it down to 23.83 mm. This reduction is approximately 58% and shows the effectiveness of placing dampers across all stories in controlling seismic vibrations. The Alternate Floor Dampers configuration reduced the top- story displacement to 36.34 mm, while the Top, Middle, Bottom Dampers scenario resulted in 35.50 mm of displacement, both showing substantial but lesser reductions than the All-story Dampers configuration.

For the 15-storey structure, the All-story Dampers configuration reduced displacement from 123.53 mm

(No Damper) to 40.84 mm. Similarly, for the 20-storey building, all story Dampers resulted in a reduction from 219.60 mm (No Damper) to 65.84 mm at the top story, demonstrating that the effectiveness of FVDs increases with building height. These results highlight the clear advantage of installing dampers on all story. The All-story Dampers configuration consistently provided the most effective reduction in displacement and drift across all story in both symmetric and unsymmetric building models. The other configurations, while still effective, showed relatively higher displacement values compared to the All-story Dampers placement.

Maximum displacement for Symmetric Structure EQX and EQY

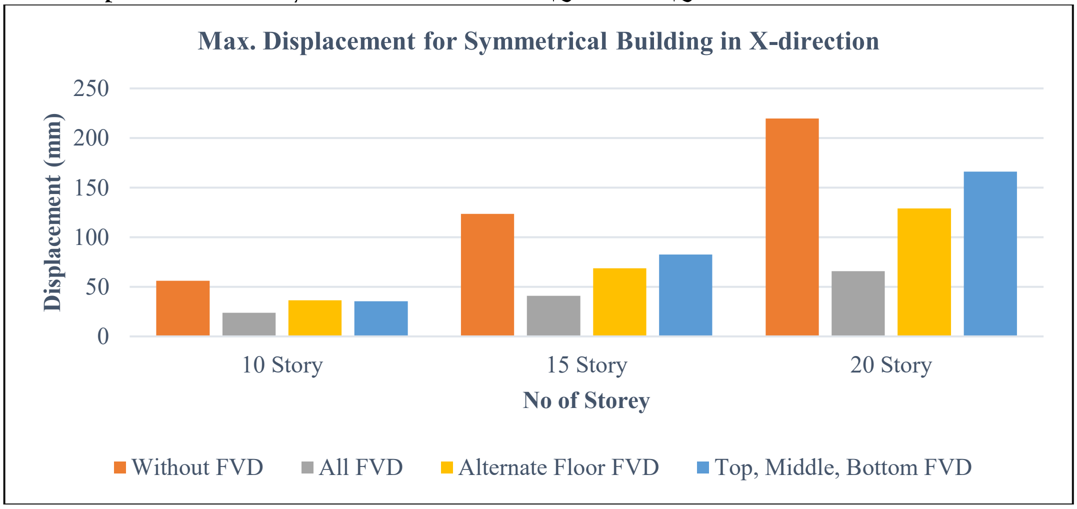

Figure 5: Maximum Displacement for SYM EQX

Figure 5 shows the variation of maximum lateral displacement across each story level for a symmetric structure. For 10 story subjected to EQX loading. It is evident that the incorporation of Fluid Viscous Dampers (FVD) significantly reduces displacement compared to the structure without FVD. The "All FVD" configuration shows the greatest effectiveness, limiting displacement at the top story to 23.83 mm, compared to 56.21 mm without FVD. The "Top, Middle, Bottom FVD" and "Alternate Floor FVD" setups also offer substantial reductions, reaching 35.50 mm and 36.34 mm respectively. The maximum displacement trend for a 15-storey symmetric building subjected to EQX seismic loading, comparing four FVD installation strategies. The structure without FVD reaches the highest displacement of 123.53 mm at the top story. The "All FVD" configuration performs best, reducing displacement to 40.84 mm, followed by "Top, Middle, Bottom FVD" at 82.62 mm, and "Alternate Floor FVD" at 68.58 mm. Significant reductions are visible from the lower story itself. This highlights that full-floor damper implementation is most effective in enhancing seismic performance, especially in taller buildings where cumulative displacement is more critical. The displacement response of a 20-storey symmetric structure under EQX seismic loading across four FVD arrangements. The structure without FVD shows the highest displacement of 219.60 mm at the top floor. The "All FVD" configuration performs best, reducing displacement drastically to 65.84 mm, followed by "Top, Middle, Bottom FVD" with 166.04 mm, and "Alternate Floor FVD" with 128.95 mm. The displacement reduction is most notable in the upper story. This demonstrates that as building height increases, the effectiveness of FVD installation becomes more pronounced, with full- story damping showing the highest performance in seismic control.

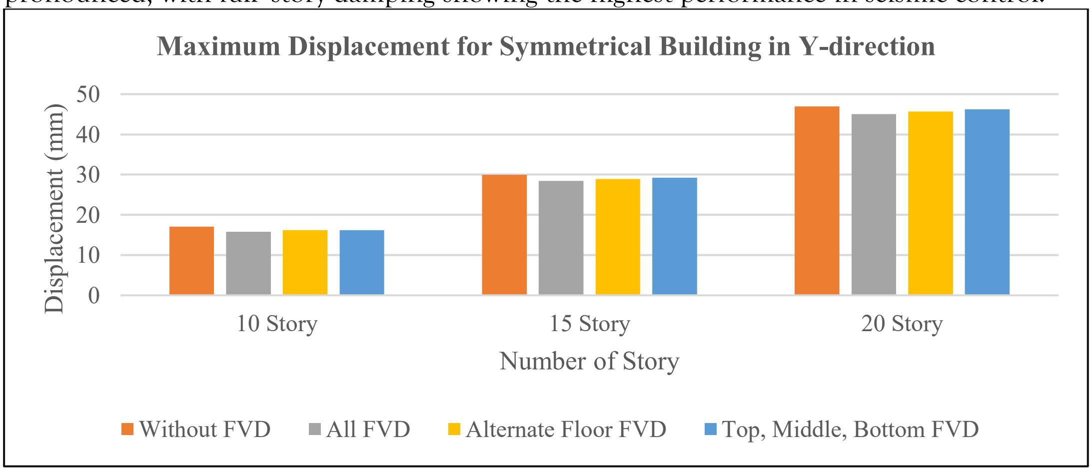

Figure 6: Maximum Displacement for SYM EQY

Figure 6 shows the comparative maximum lateral displacement response of a 10-storey symmetric structure subjected to EQY loading. As seen, the displacement progressively increases from the base to the top story across all configurations. The structure without FVD experiences the highest displacement of 17.08 mm at the 10th story. The use of FVDs significantly reduces this response, with the "All FVD" setup achieving the lowest top- story displacement of 15.82 mm. The "Top, Middle, Bottom FVD" and "Alternate Floor FVD" configurations follow closely with values of 16.20 mm and 16.19 mm respectively. Although all damping configurations are effective, the full-floor damper arrangement provides the most efficient seismic control under EQY loading.

The displacement profile of a 15-storey symmetric building under EQY seismic loading. The structure without FVD shows the highest peak displacement of 29.98 mm at the top. Among the FVD strategies, the "All FVD" configuration provides the most effective control, limiting the maximum displacement to 28.41 mm. The "Top, Middle, Bottom FVD" and "Alternate Floor FVD" configurations follow closely, with peak values of 29.21 mm and 28.93 mm, respectively. The differences are modest compared to the EQX case, indicating that FVDs are less effective under lateral loading in the EQY direction for symmetric buildings, though full-floor installation still offers optimal results. The utmost displacement in a 20-story building when it is subjected to various configurations of Floor Vibration Dampers (FVD). The displacement increases to all cases as the number in stories increases. Among the four conditions, the configuration with "Top, Middle, Bottom FVD" results in the highest displacement, followed by the "All FVD" case. The "Alternate Floor FVD" case shows a moderate displacement, while the "Without FVD" condition produces the smallest displacement.

Maximum displacement for UnSymmetric Structure EQX and EQY

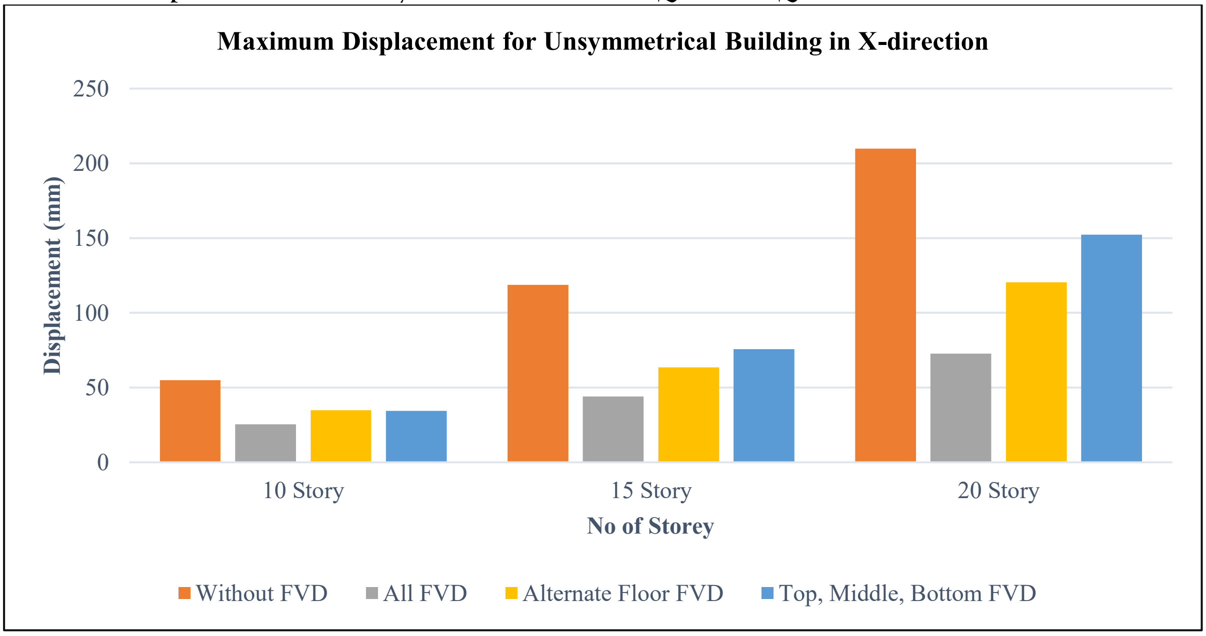

Figure 5: Maximum Displacement for UNSYM EQX

Figure 5 Shows the structure without FVD records the maximum displacement of 54.97 mm at the top story. Installing dampers across all story achieves the greatest reduction, limiting displacement to 25.51 mm. The "Top, Middle, Bottom FVD" configuration follows with 34.44 mm, and "Alternate Floor FVD" with 34.94 mm. The results highlight that although all FVD layouts help control displacement, full- story damping yields the most effective mitigation, particularly beneficial in unsymmetric configurations where torsional effects can amplify seismic response. Figure 17 presents the lateral displacement profile of a 15-storey unsymmetric building subjected to EQX seismic loading. The structure without FVD exhibits the highest top-storey displacement of 118.70 mm. Among the damping strategies, the "All FVD" configuration is most effective, reducing displacement to 44.03 mm, followed by "Alternate Floor FVD" at 63.54 mm and "Top, Middle, Bottom FVD" at 75.70 mm. Figure 19 displays the displacement pattern for a 20-storey unsymmetric building under EQX loading. The structure without FVD records the highest top-storey displacement at 209.87 mm. Among the damping strategies, the "All FVD" configuration performs best, reducing the peak displacement to 72.74 mm. This is followed by "Alternate Floor FVD" at 120.45 mm, and "Top, Middle, Bottom FVD" at 152.38 mm.

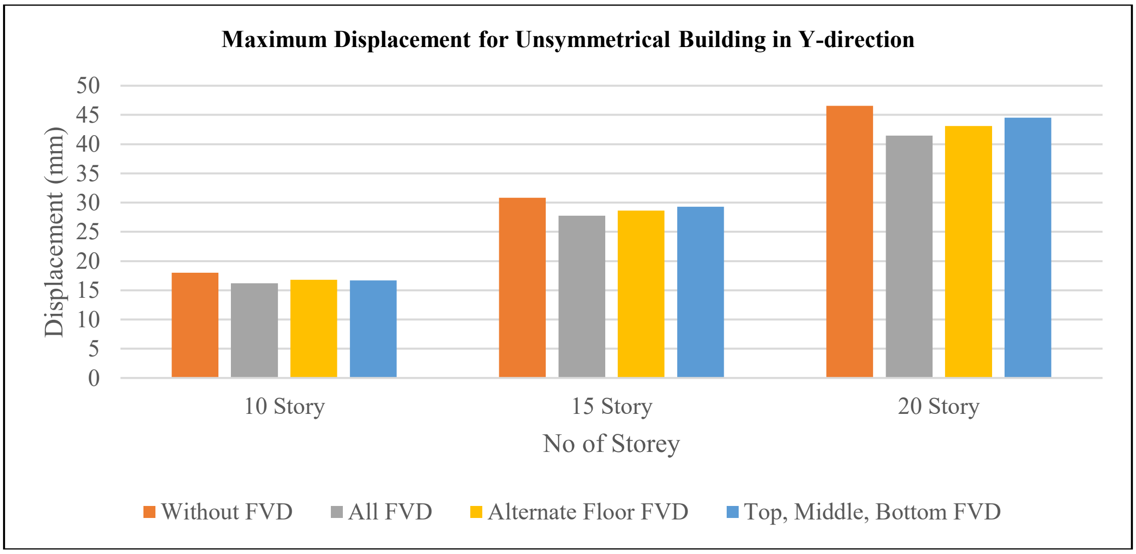

Figure 6: Maximum Displacement for UNSYM EQY

Figure 6 shows the displacement variation of an unsymmetric 10-storey building under EQY loading. The structure without FVD exhibits the highest displacement of 18.01 mm at the top floor. The "All FVD" configuration achieves the best control, reducing displacement to 16.17 mm, followed closely by "Top, Middle, Bottom FVD" at 16.69 mm, and "Alternate Floor FVD" at 16.79 mm. While the differences are marginal, all FVD arrangements consistently reduce displacement across story, indicating their effectiveness even in story layouts under lateral seismic loads.

Figure 18 shows the displacement trend of a 15-storey unsymmetric structure subjected to EQY loading across different FVD arrangements. The structure without FVD shows a peak displacement of 30.85 mm at the top floor. Among the damping strategies, the "All FVD" configuration performs best with 27.77 mm, followed by "Top, Middle, Bottom FVD" (29.31 mm) and "Alternate Floor FVD" (28.62 mm). Figure 19 displays the displacement pattern for a 20-storey unsymmetric building under EQX loading. The structure without FVD records the highest top- story displacement at 46.558 mm. Among the damping strategies, the "All FVD" configuration performs best, reducing the peak displacement to 41.481 mm. This is followed by "Alternate Floor FVD" at 43.121 mm, and "Top, Middle, Bottom FVD" at 44.545 mm.

Maximum Story Drift for Symmetric Structure EQX and EQY

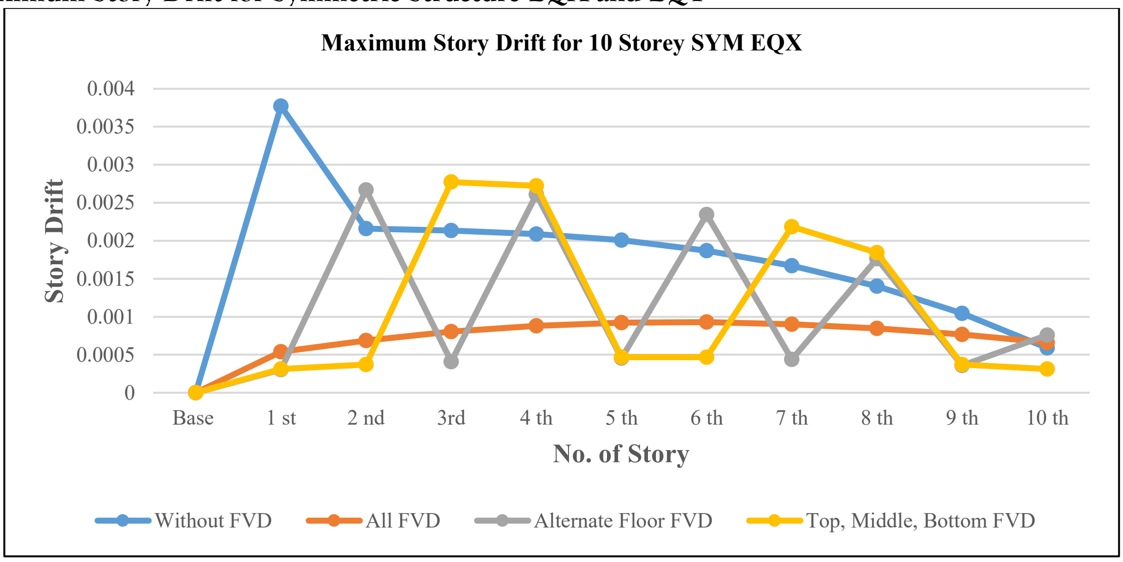

Figure 7: Maximum Story Drift for 10 Story SYM EQX

Figure 7 shows Story drift values in a 10-story symmetric skyscraper under EQX loading are depicted in the figure. The 1st story exhibits the highest drift when FVD is absent, with a value in 0.003772, which progressively decreases as the story ascend. All FVD configurations significantly reduce drift across all story, with the "All FVD" configuration achieving the lowest maximum drift of 0.000663 at the top story. The "Top, Middle, Bottom FVD" and "Alternate Floor FVD" configurations also reduce drift effectively, but with slightly higher values compared to the full-floor dampers.

Figure 8 display maximum story drift for the 10-storey building decreases significantly when viscous fluid dampers (FVD) are used. The highest drift occurs near the lower floors without dampers. Installing dampers on all floors or alternate floors reduces drift the most, providing better seismic control. Dampers placed only at the top, middle, and bottom floors also reduce drift but less effectively. Overall, FVDs improve building stability by minimizing lateral displacements during earthquakes.

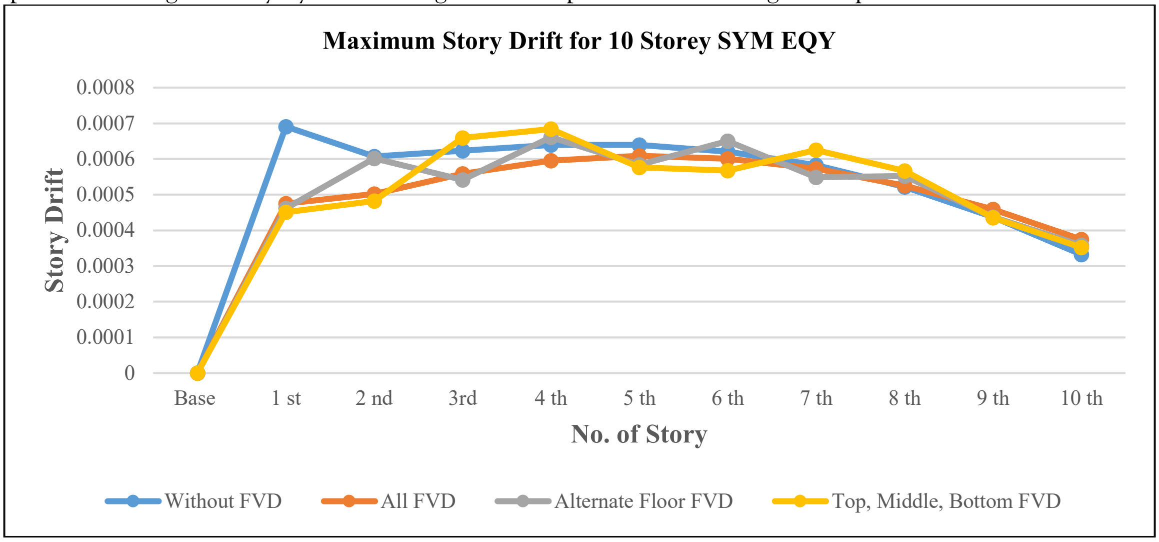

Figure 8: Maximum Story Drift for 10 Story SYM EQY

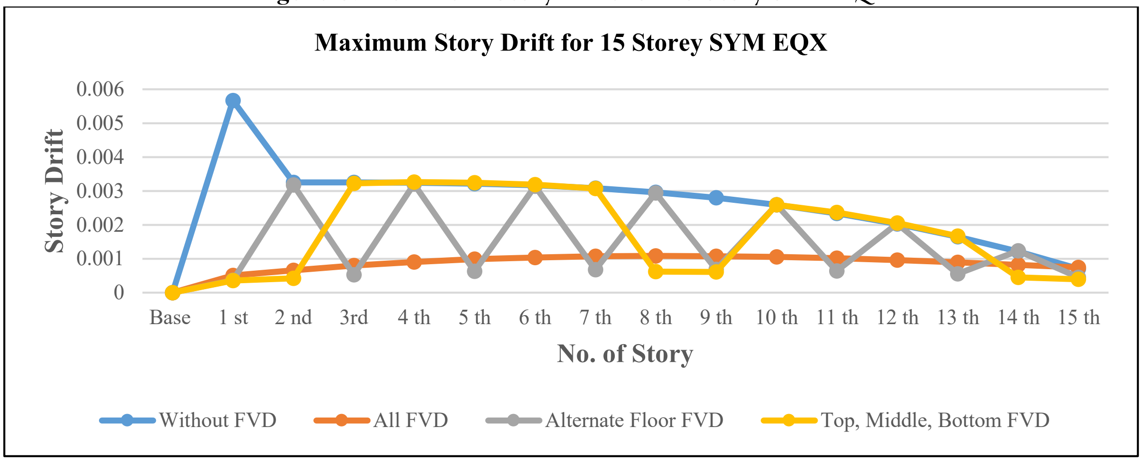

Figure 9: Maximum Story Drift for 15 Story SYM EQX

Figure 9 display maximum story drift is highest without any dampers, especially at the 1st floor. Using dampers on all floors greatly reduces drift uniformly across the building. Dampers placed on alternate floors or only at top, middle, and bottom reduce drift compared to no dampers but cause fluctuations in drift values between floors. Overall, installing dampers on every floor provides the best control of building displacement under seismic loading.

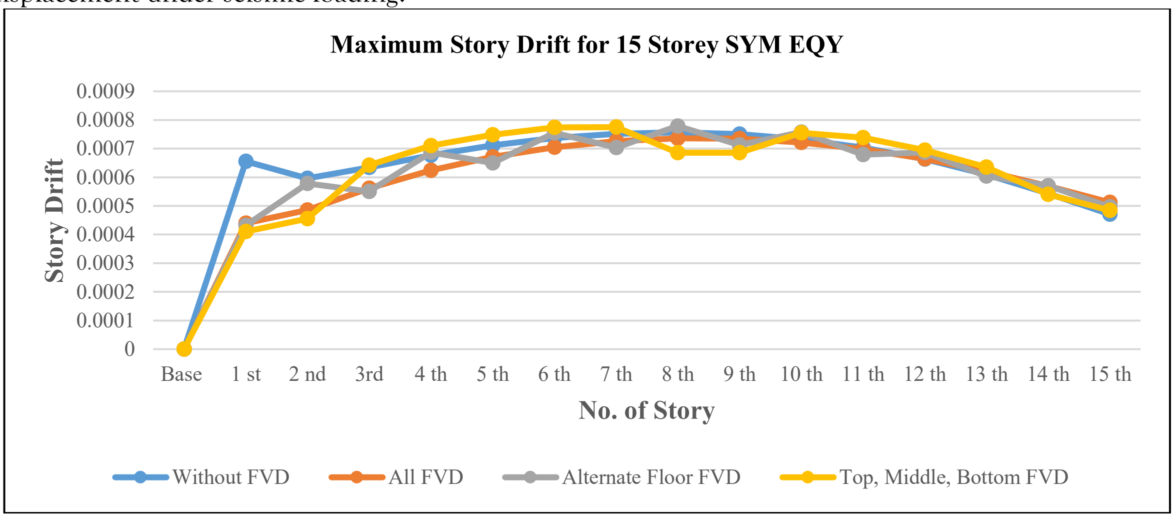

Figure 10: Maximum Story Drift for 15 Story SYM EQY

Figure 10 illustrates the maximum story drift for a 15-storey building subjected to seismic loading in the EQY direction. The drift is highest in the "Without FVD" scenario, progressively decreasing with the inclusion of FVD systems. The "All FVD" system shows the lowest drift, indicating effective lateral displacement control. The "Alternate Floor FVD" and "Top, Middle, Bottom FVD" systems provide intermediate results, with the latter being the most effective in minimizing story drift across all floors.
Figure 11 shows that the story drift increases initially with the first few stories, especially without any FVD system. As FVD systems are introduced, the drift decreases significantly, with the "Top, Middle, Bottom FVD" showing the lowest drift across all stories. The "Alternate Floor FVD" shows a moderate reduction, while "All FVD" provides a substantial reduction in story drift, especially for the higher floors.
Figure 12 demonstrates a similar pattern of maximum story drift. The drift remains comparatively lower for all FVD systems, with "Top, Middle, Bottom FVD" showing the most effective reduction. "Alternate Floor FVD" and "All FVD" follow a similar trend, though the overall drift is lower than in Figure 25, reflecting a different earthquake load scenario (EQY).

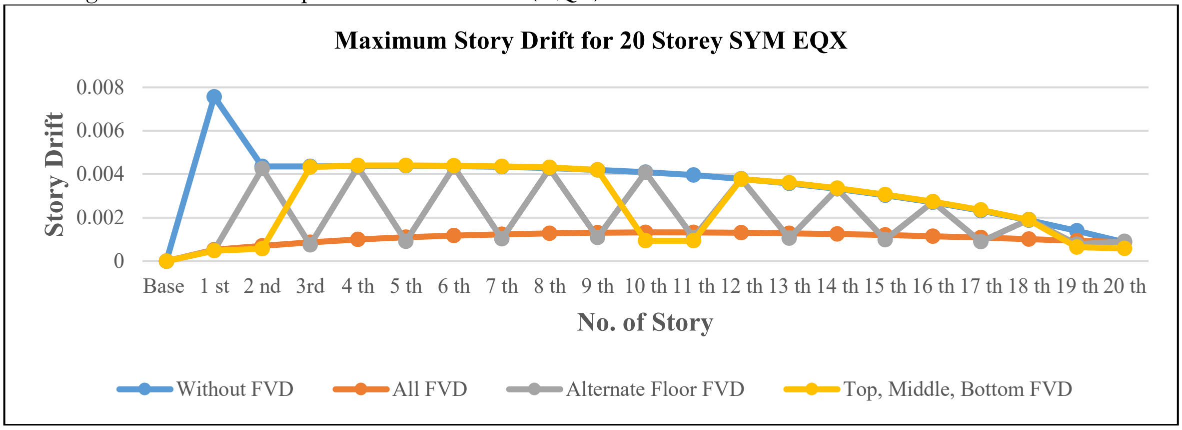

Figure 11: Maximum Story Drift for 20 Story SYM EQX

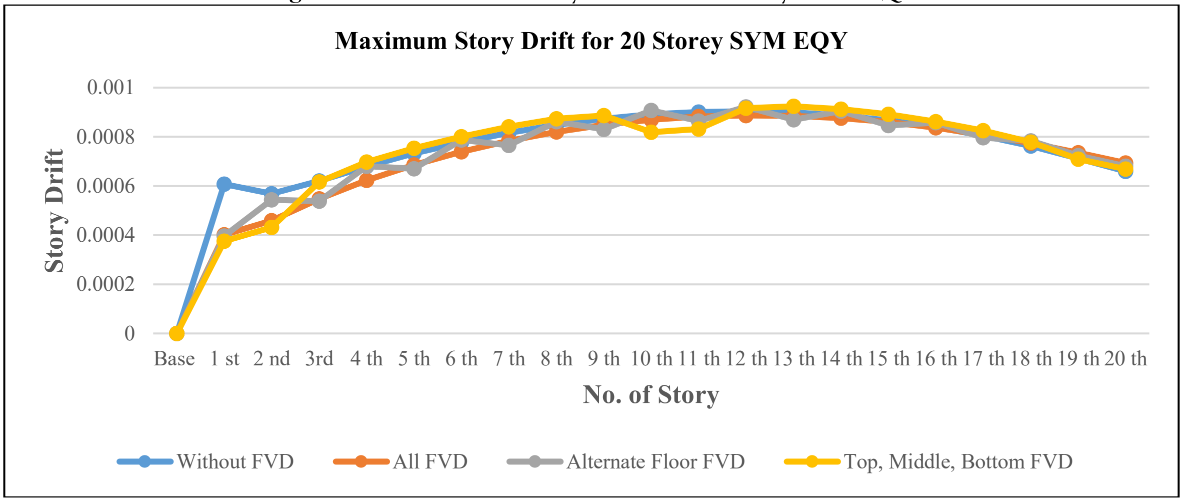

Figure 12: Maximum Story Drift for 20 Story SYM EQY

Maximum Story Drift for unsymmetric Structure EQX and EQY

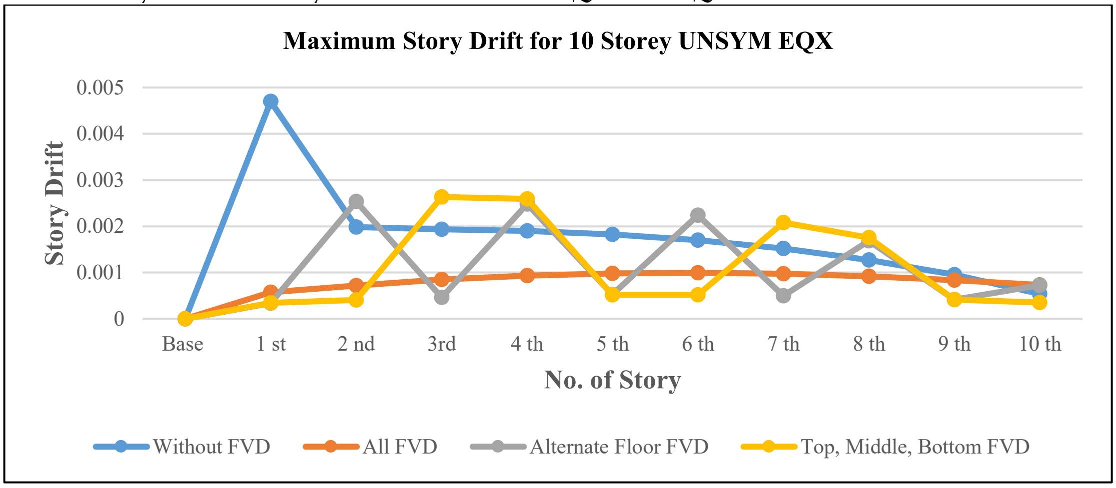

Figure 13: Maximum Story Drift for 10 Story UNSYM EQX

Figure 13 shows maximum story drift peaking at the 1st floor (~0.0047) without dampers, with a sharp decline in higher stories. “All FVD” greatly reduces drift, maintaining values below 0.001. Alternate floor and top-middle-bottom damper placements lower drift but create fluctuations in drift between floors, showing less uniform control. This suggests that while partial damper configurations reduce drift, installing dampers on all floors offers superior seismic displacement mitigation in 10-storey symmetric buildings under EQX loading.

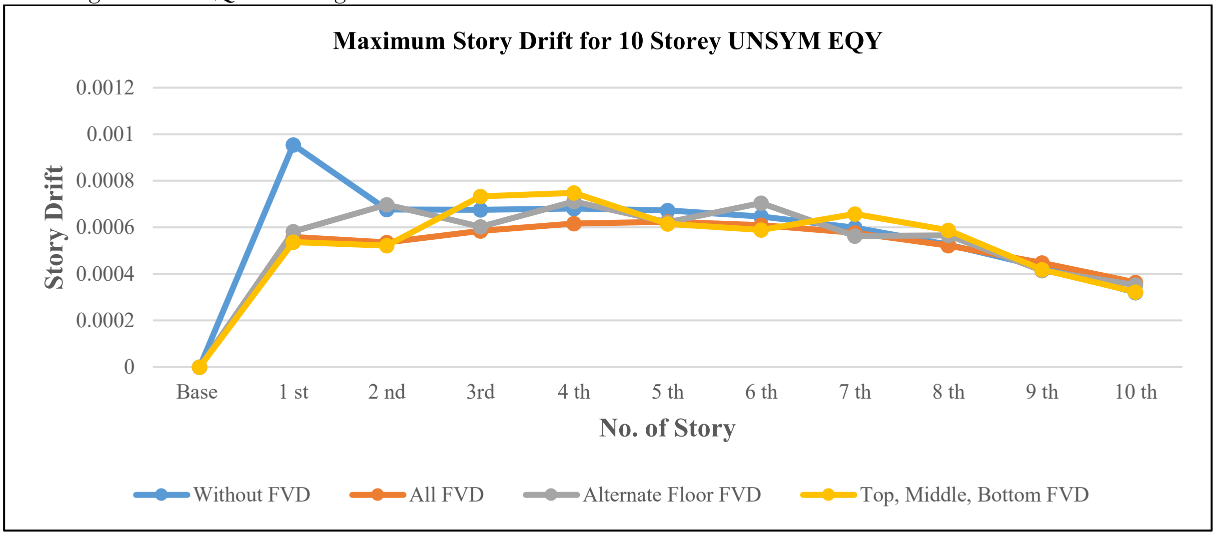

Figure 14: Maximum Story Drift for 10 Story UNSYM EQY

Figure 14 shows maximum story drift under symmetric and unsymmetric earthquake loading for a 10-storey building. The Without FVD case exhibits the highest drifts, particularly at the lower stories, indicating greater structural displacement. The All FVD configuration significantly reduces drift uniformly across all floors, demonstrating optimal damping performance. The Alternate Floor FVD and Top, Middle, Bottom FVD setups also reduce drift but with minor variations at mid-level stories

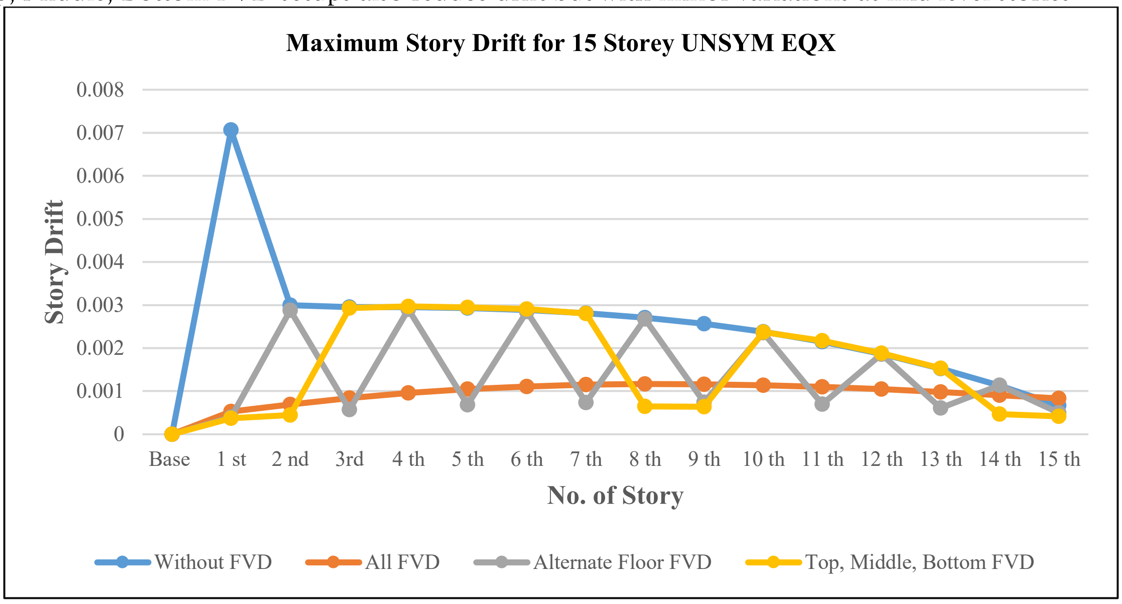

Figure 15: Maximum Story Drift for 15 Story UNSYM EQX

Figure 15 shows maximum story drift for a 15-storey building under symmetric and unsymmetric earthquakes. The Without FVD condition records very high drifts at the first floor, signaling higher vulnerability. The All FVD case effectively minimizes drifts uniformly throughout the height, reflecting superior vibration control. The Alternate Floor FVD and Top, Middle, Bottom FVD configurations reduce drift but with oscillations across floors, indicating less consistent damping. FVD devices overall play a critical role in improving seismic resilience by controlling story displacements effectively.

Figure 16 displays story stiffness distribution along the height of a 15-storey symmetric building under EQY. Stiffness peaks sharply at the 1st and 2nd stories, then gradually decreases with height. Installing all dampers or top-middle-bottom FVDs significantly increases stiffness across all stories compared to no dampers. Alternate floor FVD also improves stiffness but with more variability. The results highlight that viscous dampers enhance structural rigidity, particularly in lower stories, contributing to improved seismic performance

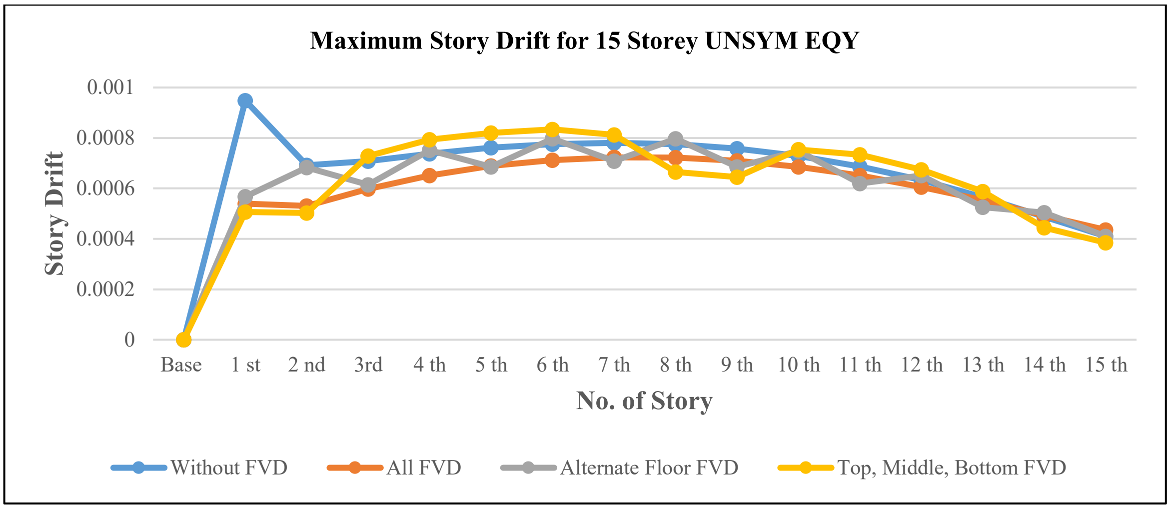

Figure 16: Maximum Story Drift for 15 Story UNSYM EQY

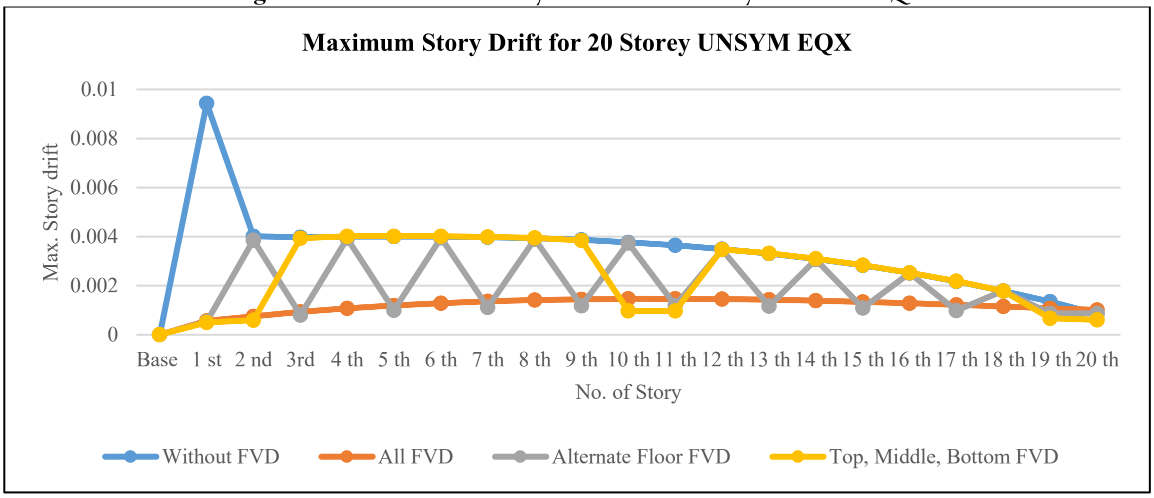

Figure 17: Maximum Story Drift for 20 Story UNSYM EQX

Figure 17 shows maximum story drift in a 20-story symmetric building in EQX seismic load is depicted in the figure, comparing different viscous fluid damper (FVD) configurations. The "Without FVD" case exhibits the highest drift, peaking sharply at the 1st story (~0.0094), indicating significant displacement without dampers. The "All FVD" configuration consistently shows the lowest drift values, demonstrating effective drift reduction. Alternate Floor FVD and Top, Middle, Bottom FVD configurations reduce drift but exhibit fluctuating values across stories

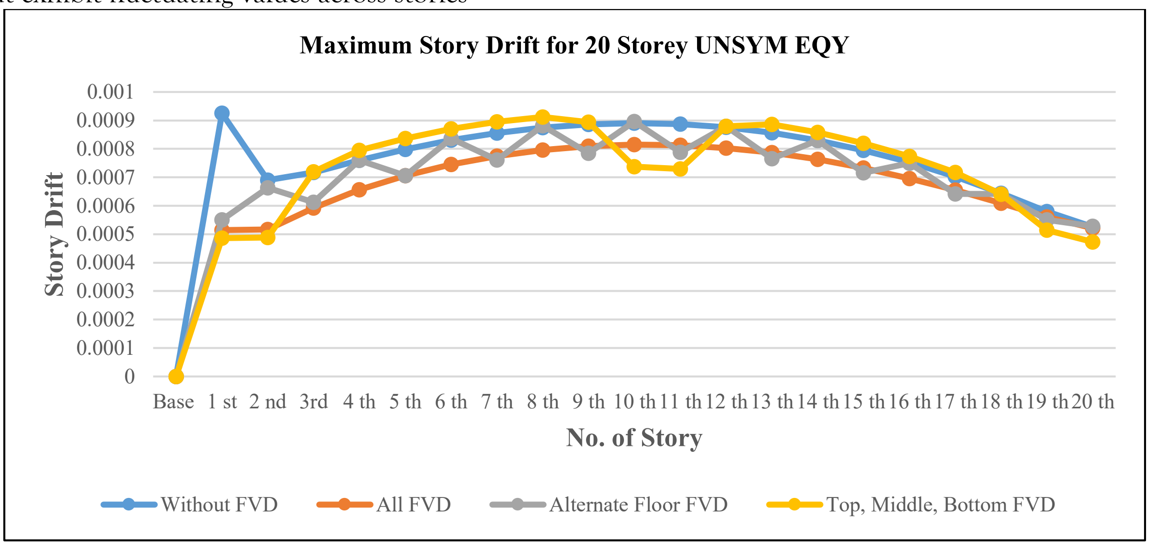

Figure 18: Maximum Story Drift for 20 Story UNSYM EQY

This figure 18 quantifies maximum story drift under EQX for a 20-storey asymmetric structure with different FVD arrangements. Drift is highest without dampers, especially at lower stories, with values decreasing from 0.009431 at the 1st story to 0.000851 at the 20th. Using "All FVD" drastically reduces drift, mostly below 0.0015 across stories. Alternate Floor FVD and Top, Middle, Bottom FVD show intermediate performance, with some stories showing larger drift spikes. These results verify that the most effective method of drift reduction is the implementation of a full damper, while selective damping placements result in a less consistent reduction in drift.

Maximum Story Stiffness Symmetric Structure EQX and EQY

The figure 19 shows story stiffness for a 10-storey symmetric building under seismic load, comparing configurations with and without fluid viscous dampers (FVD). Without FVD, stiffness remains steady around 40,000 units. Installing FVD on all floors greatly increases stiffness, peaking near 373,000 units at the first floor and tapering upward. Alternate floor dampers cause fluctuating stiffness, with high values on damped floors and low on others. Dampers at top, middle, and bottom floors also show varied stiffness but maintain higher values at these key levels. Overall, dampers substantially enhance structural stiffness, improving seismic resistance.

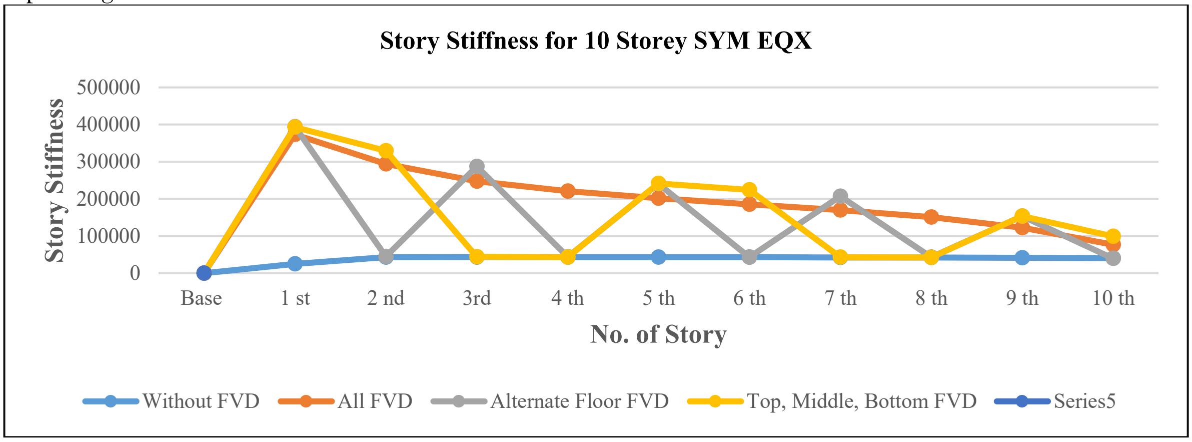

Figure 19: Story Stiffness for 10 Story SYM EQX

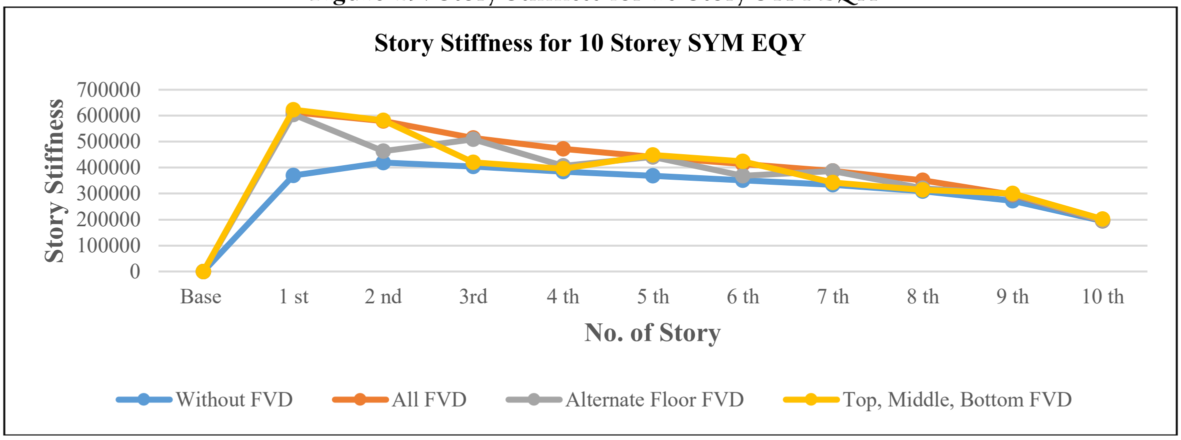

Figure 20: Story Stiffness for 10 Story SYM EQY

figure 20 presents story stiffness with higher magnitude values for the same building. Without dampers, stiffness rises sharply to about 370,000 units at the first floor and decreases gradually to 195,000 units at the top. Installing FVD on all floors increases stiffness significantly, reaching over 610,000 units at the base and diminishing upwards. Alternate floor dampers produce similarly high but fluctuating stiffness values. Dampers placed at top, middle, and bottom floors maintain stiffness close to alternate floors but slightly higher at the ends. Comprehensive FVD use clearly strengthens seismic performance.

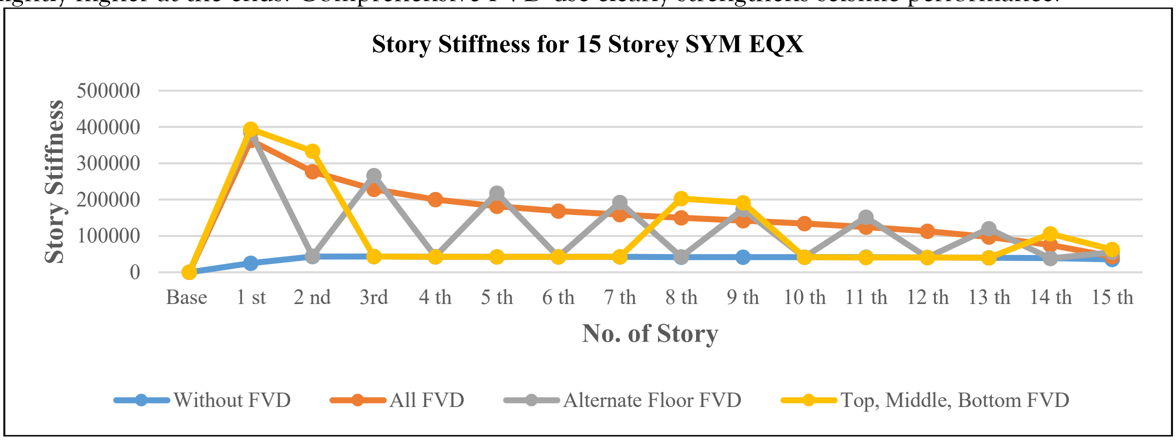

Figure 21: Story Stiffness for 15 Story SYM EQX

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Figure 21 shows story stiffness for a 15-storey symmetric building subjected to earthquake loading within the direction of X (EQX). Subsequent "Without FVD" curve indicates relatively low and stable stiffness values across all stories. The "All FVD" line displays much higher stiffness at lower floors that gradually decreases towards the top. The "Alternate Floor FVD" pattern produces significant fluctuations with stiffness peaks at alternating floors, while the "Top, Middle, Bottom FVD" curve reveals stiffness concentrated at these specific floors with low values in others. This highlights the impact of damper placement on stiffness distribution and seismic response.

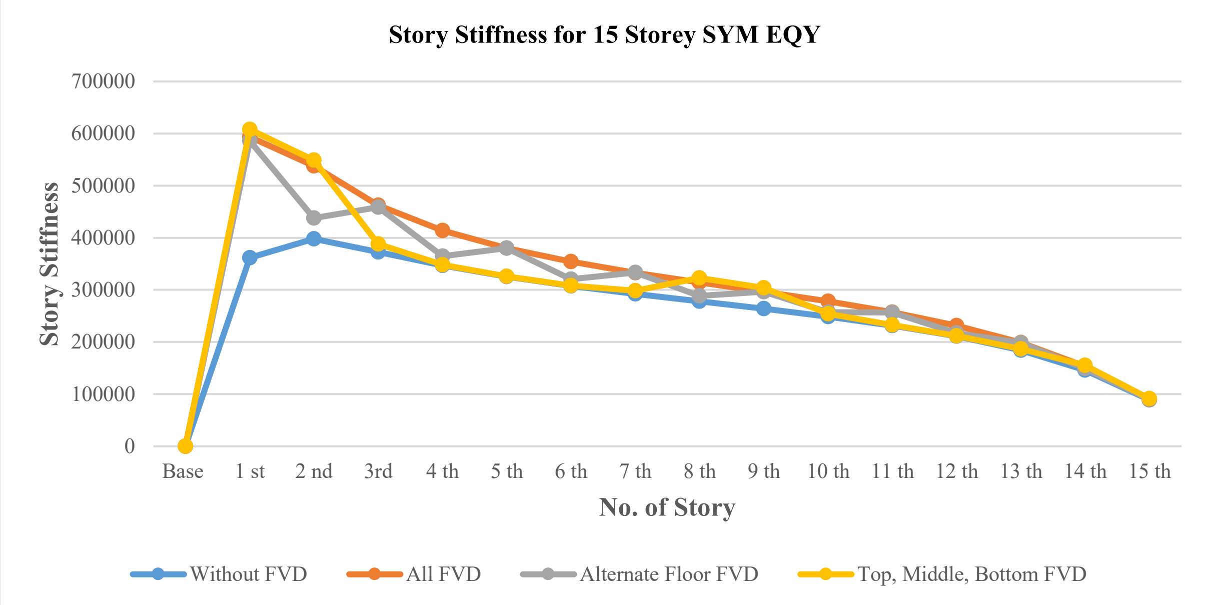

Figure 22: Story Stiffness for 15 Story SYM EQY

Figure 22 shows story stiffness for the same 15- a multi-story structure that is subject to earthquake impact in the Y direction (EQY). Stiffness values are generally higher than the EQX direction. Both "All FVD" and "Top, Middle, Bottom FVD" show a gradual reduction in stiffness from base to top, while "Alternate Floor FVD" exhibits moderate fluctuations. The "Without FVD" case shows the lowest stiffness across stories, emphasizing how fluid viscous dampers (FVD) improve overall structural stiffness under EQY loading.

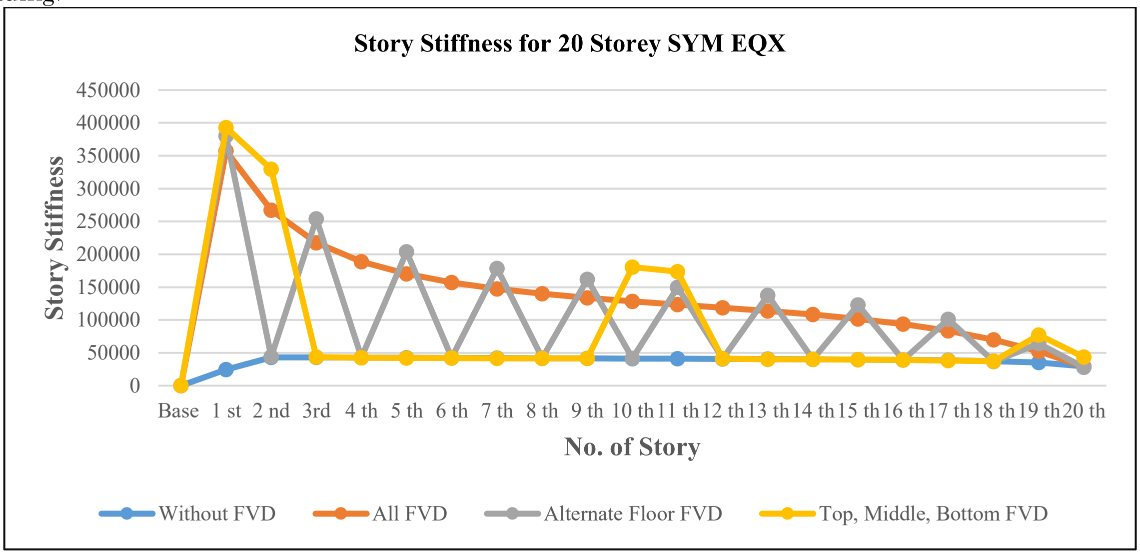

Figure 23: Story Stiffness for 20 Story SYM EQX

Figure 23 shows story stiffness distribution for a 20-storey symmetric building under EQX loading. The "Without FVD" line remains low and fairly constant. The "All FVD" and "Top, Middle, Bottom FVD" lines present high stiffness at lower stories, gradually decreasing with height. The "Alternate Floor FVD" pattern exhibits notable oscillations with peaks at alternating floors.

The figure 24 shows story stiffness values for the 20-storey building under earthquake loading in the Y direction (EQY). The "All FVD" and "Top, Middle, Bottom FVD" cases exhibit smooth, gradual stiffness reduction from base to top, with higher overall values than EQX. The "Alternate Floor FVD" line has smaller fluctuations. The "Without FVD" curve consistently shows the lowest stiffness, reinforcing that FVD installations significantly enhance building stiffness and seismic resilience in the Y direction.

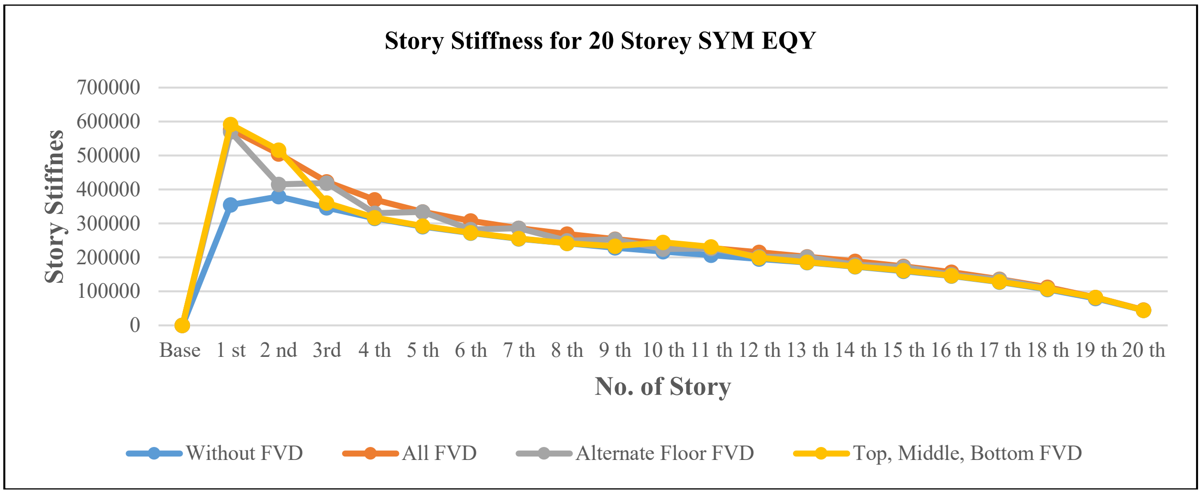

Figure 24: Story Stiffness for 20 Story SYM EQY

Story Stiffness for 10 Story UNSYM EQX

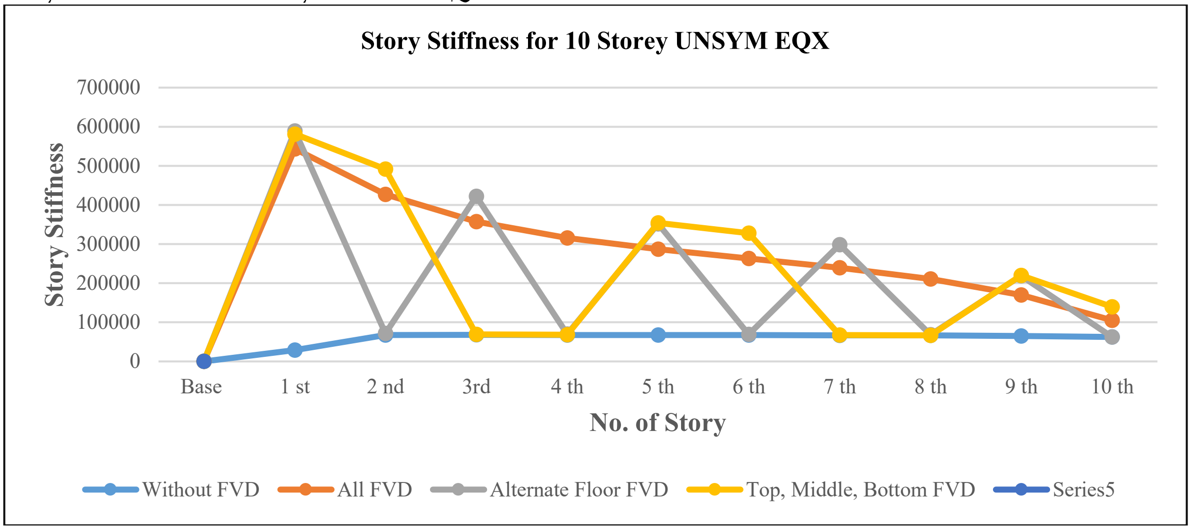

Figure 25: Story Stiffness for 10 Story UNSYM EQX

Figure 25 shows the variation in story stiffness across different floors for a 10-storey building under the UNSYM EQX seismic condition. The stiffness is highest at the base and gradually decreases as you move upwards. The "Without FVD" case exhibits the least stiffness, while "All FVD" shows the highest stiffness at the lower floors, with a more stable reduction across the stories. The "Alternate Floor FVD" and "Top, Middle, Bottom FVD" cases show intermediate stiffness values, indicating the influence of different Floor Vibration Damping (FVD) strategies.

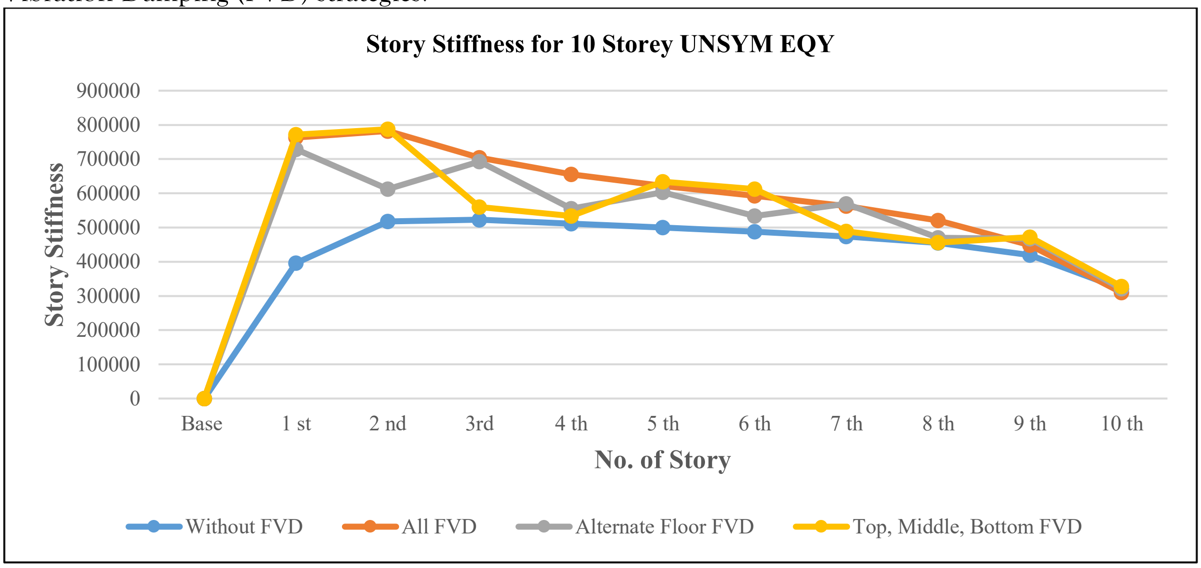

Figure 26: Story Stiffness for 10 Story UNSYM EQY

Figure 26 depicts the story stiffness for the same 10-storey building under the UNSYM EQY seismic condition. The stiffness distribution shows a similar trend as in Figure 39, but with a steeper drop-off as you move upward in the building. The "All FVD" configuration demonstrates a more uniform stiffness distribution across the stories, while "Without FVD" shows the largest variation between the lower and upper floors.

Figure 27 illustrates the story stiffness for a 15-storey building under the UNSYM EQX seismic condition. As in the 10-storey case, the base stiffness is the highest, and the stiffness decreases with increasing height. The "Without FVD" configuration shows the least stiffness, particularly noticeable in the lower floors. "All FVD" exhibits a more consistent stiffness distribution, and the "Alternate Floor FVD" and "Top, Middle, Bottom FVD" configurations show intermediate behavior, providing better control over the stiffness reduction in the upper floors.

Figure 28 illustrate story stiffness for a 15-storey unsymmetrical building under earthquake loading in the X-direction with varying FVD placements. Stiffness values are highest at the 1st story, then generally decrease upward. The 'Without FVD' scenario shows relatively low stiffness throughout, while 'All FVD' and 'Alternate Floor FVD' configurations have significantly higher stiffness at the lower stories but gradually decrease. The 'Top, Middle, Bottom FVD' case shows localized stiffness peaks, particularly at the 2nd and 8th stories, indicating the effectiveness of damping placement in mitigating structural flexibility at specific levels.

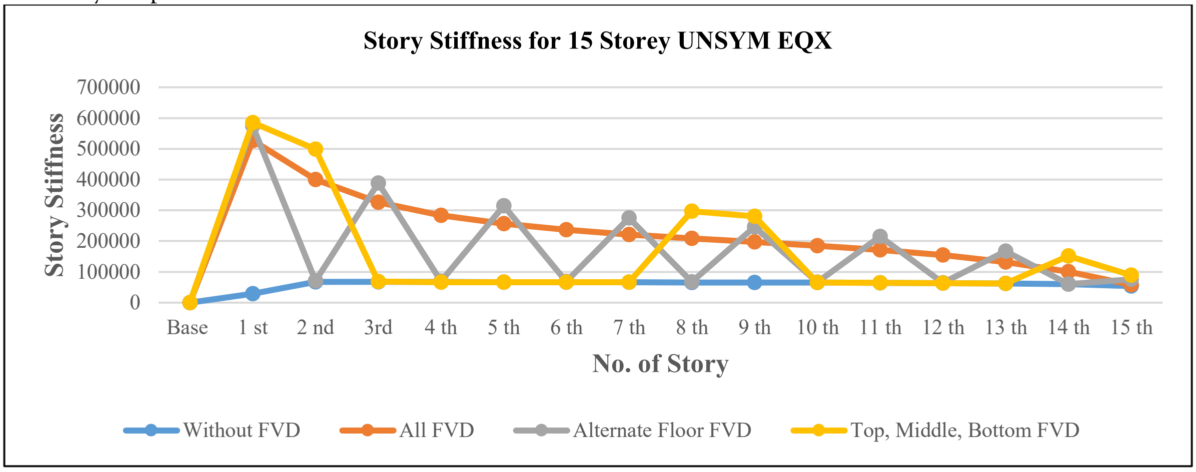

Figure 27: Story Stiffness for 15 Story UNSYM EQX

The figure 29 shows story stiffness distribution for a 20-storey symmetric building under EQX loading. The "Without FVD" line remains low and fairly constant. The "All FVD" and "Top, Middle, Bottom FVD" lines present high stiffness at lower stories, gradually decreasing with height. The "Alternate Floor FVD" pattern exhibits notable oscillations with peaks at alternating floors.

Figure 30 shows story stiffness values for the 20-storey building under earthquake loading in the Y direction (EQY). The "All FVD" and "Top, Middle, Bottom FVD" cases exhibit smooth, gradual stiffness reduction from base to top, with higher overall values than EQX. The "Alternate Floor FVD" line has smaller fluctuations. The "Without FVD" curve consistently shows the lowest stiffness, reinforcing that FVD installations significantly enhance building stiffness and seismic resilience in the Y direction.

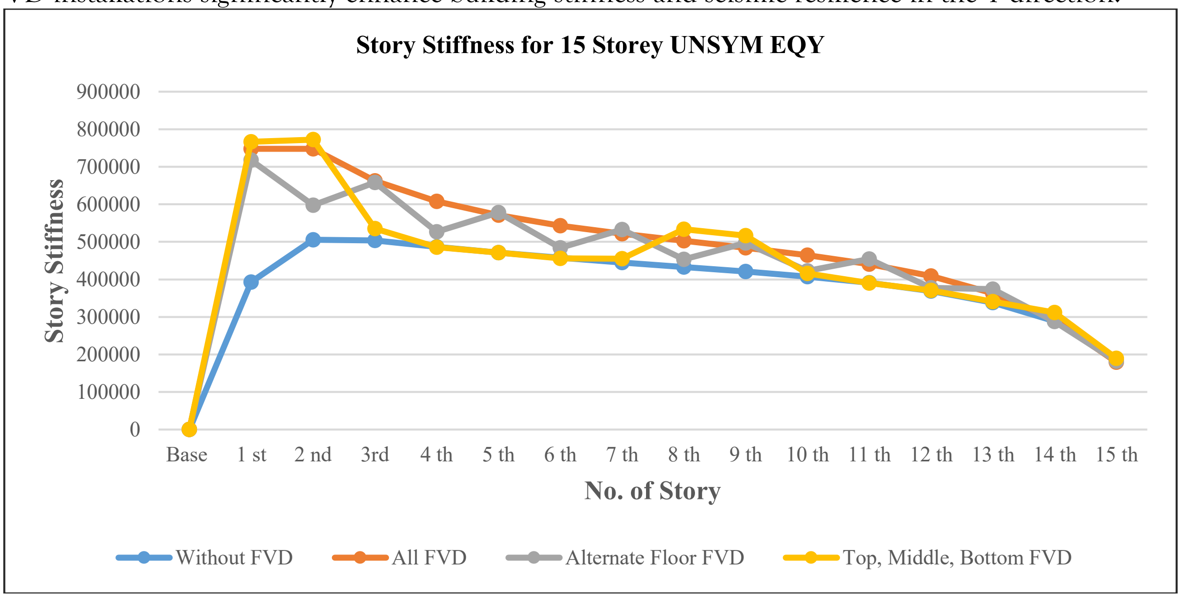

Figure 28: Story Stiffness for 15 Story UNSYM EQY

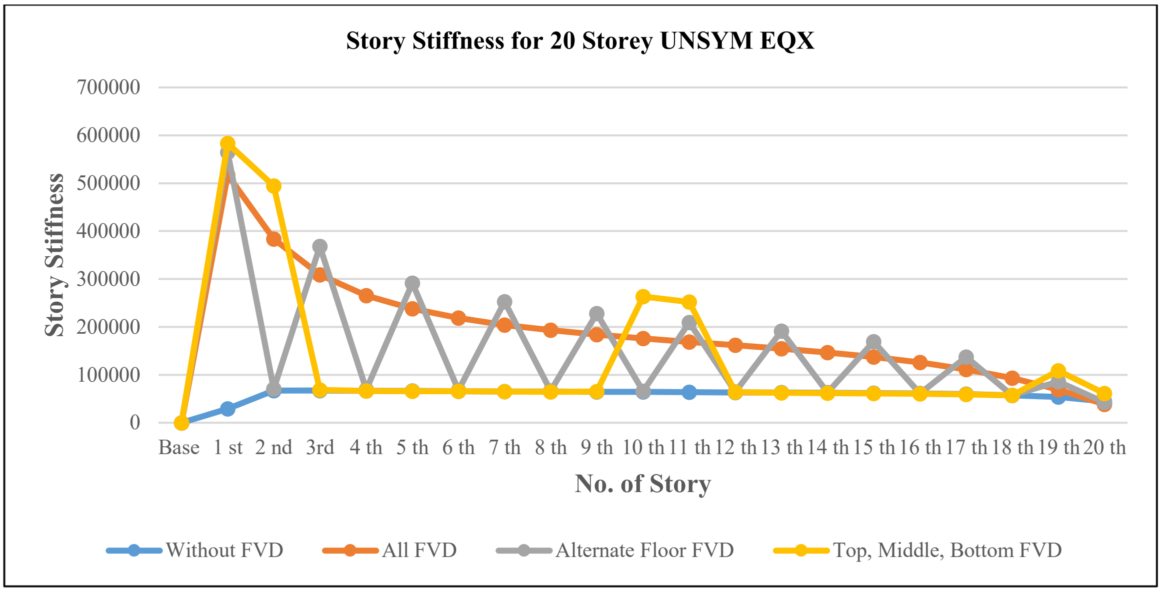

Figure 29: Story Stiffness for 20 Story UNSYM EQX

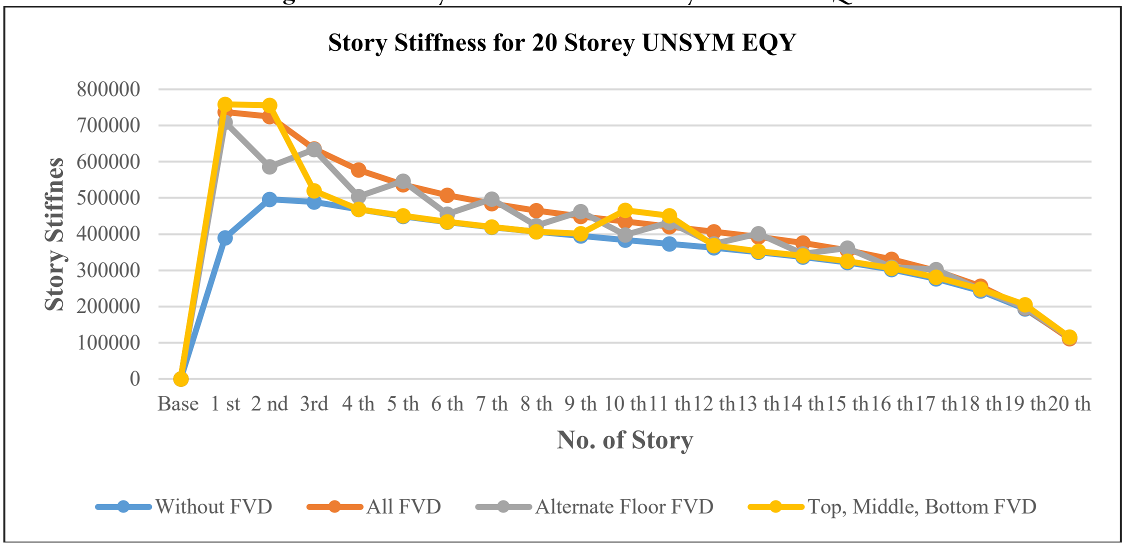

Figure 30: Story Stiffness for 20 Story UNSYM EQY

Story Shear for SYM EQX

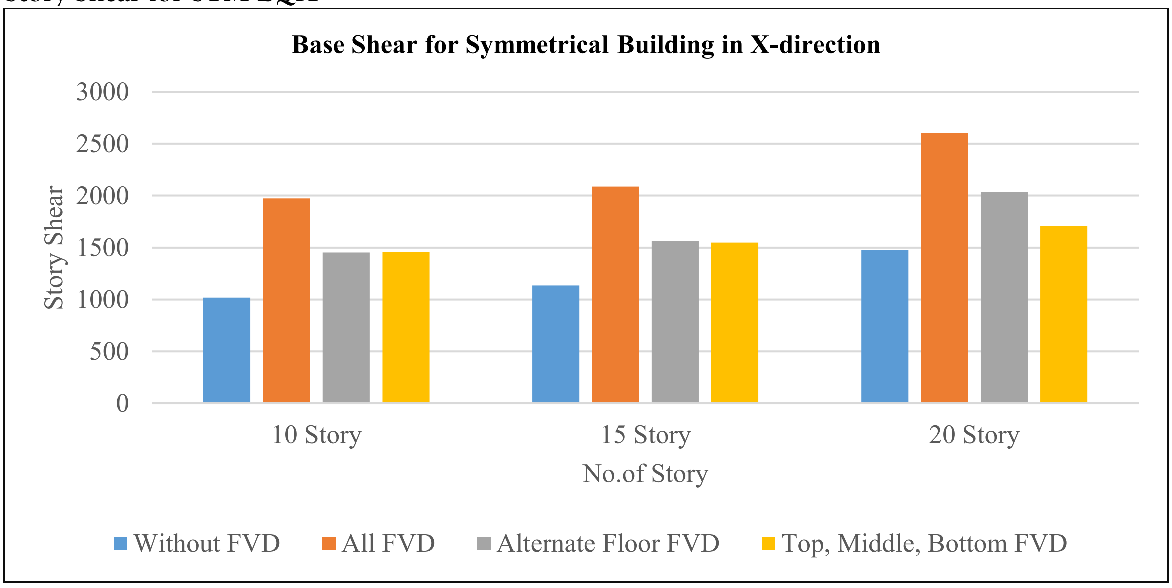

Figure 31: Base Shear for Symmetrical Building in X-direction

Figure 31 shows the base shear values for a symmetrical building in the X-direction. As the number of story increases from 10 to 20, base shear values rise. FVDs reduce base shear, with the "All FVD" configuration showing the greatest reduction across all story heights: 1019.23 KN (10 stories), 1135.38 KN (15 stories), and 1476.38 KN (20 stories).

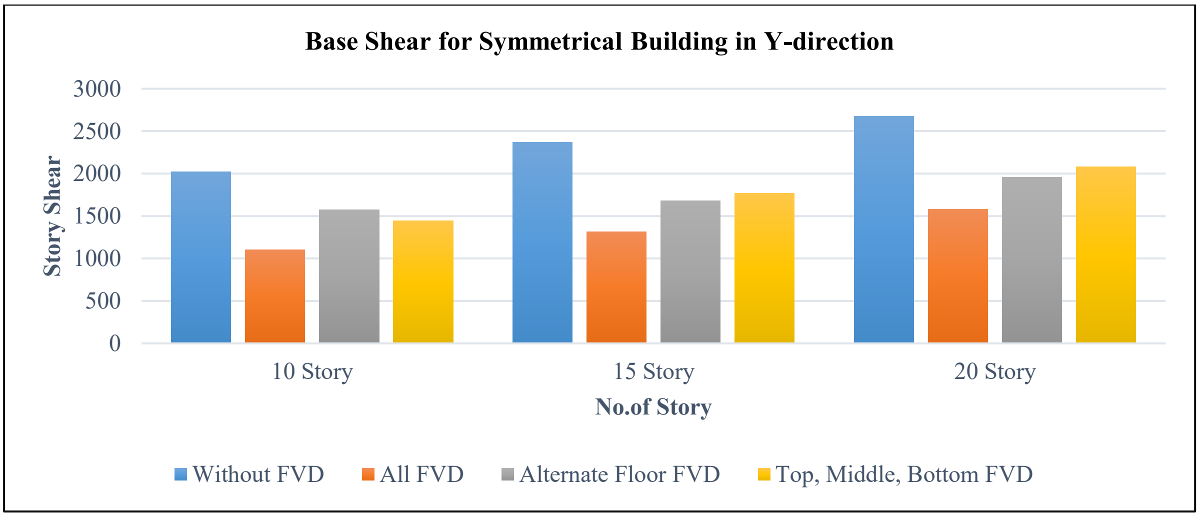

Figure 32: Base Shear for Symmetrical Building in X-direction

Figure 32 shows the base shear values for a symmetrical building in the Y-direction. As the number of story increases, base shear also increases. The "All FVD" configuration results in the greatest reduction, with values of 1103.72 KN (10 stories), 1314.54 KN (15 stories), and 1578.19 KN (20 stories), compared to the base shear without FVD.

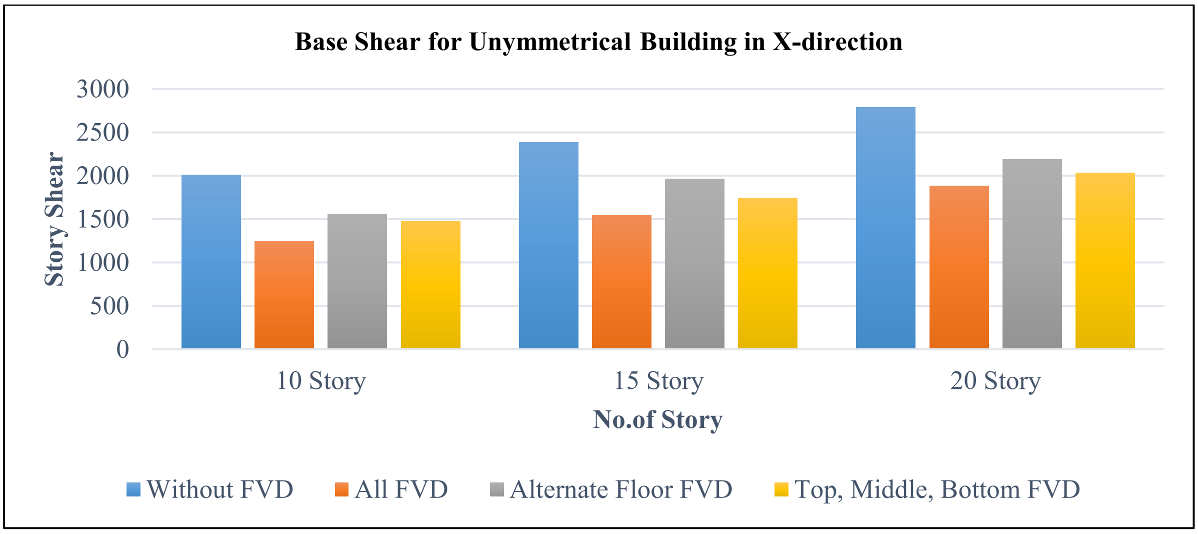

Figure 33: Base Shear for Symmetrical Building in X-direction

Figure 33 shows the base shear values for an unsymmetrical building in the X-direction. The "All FVD" configuration results in the greatest reduction: 1240.41 KN (10 stories), 1541.92 KN (15 stories), and 1879.88 KN (20 stories), compared to the base shear without FVD.

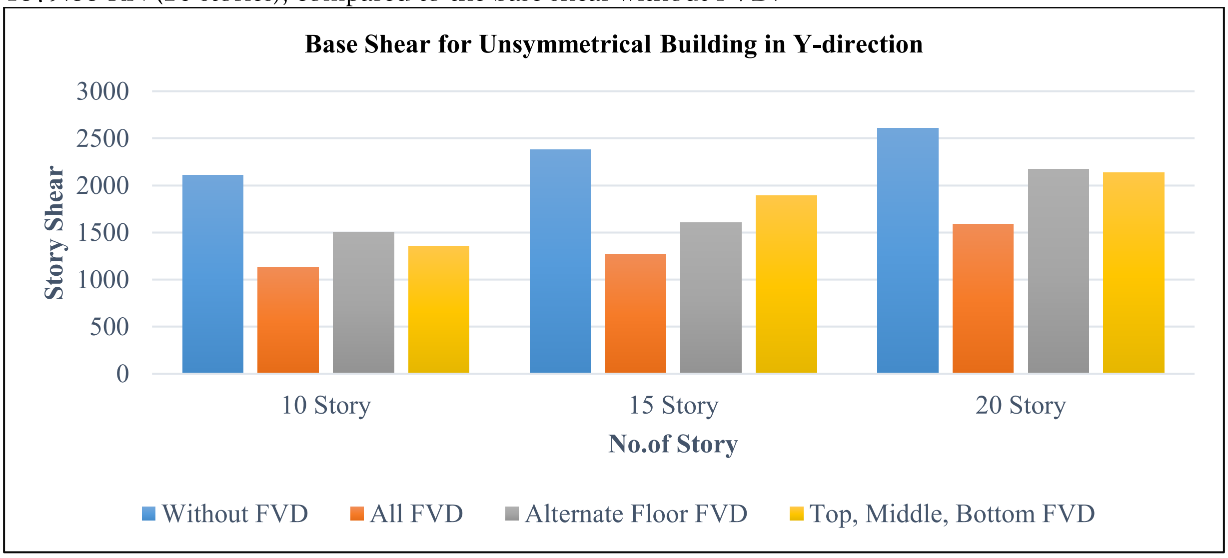

Figure 34: Base Shear for Symmetrical Building in X-direction

Figure 34 shows the base shear values for an unsymmetrical building in the Y-direction. The "All FVD" configuration results in the greatest reduction: 1135.60 KN (10 stories), 1272.07 KN (15 stories), and 1591.85 KN (20 stories), compared to the base shear without FVD.

4.CONCLUSION

This comprehensive study investigates the effectiveness of Fluid Viscous Dampers (FVDs) in improving the seismic performance of steel structures by analyzing key response parameters such as lateral displacement, story drift, story stiffness, and story shear. Using advanced Response Spectrum Analysis as per IS 1893:2016 guidelines, the study evaluates various damper placement configurations across 10, 15, and 20-storey symmetric and unsymmetric buildings. The insights drawn from this investigation offer both technical and practical implications for structural engineers, architects, and policymakers focusing on seismic safety, cost-efficiency, and retrofit strategies. The findings clearly demonstrate that incorporating FVDs significantly enhances the overall seismic behavior of steel buildings. The most striking improvements were observed in terms of reduced lateral displacements and story drifts across all structural configurations and building heights. In 10-storey buildings, for instance, the maximum top-story displacement was brought down from 56.21 mm (no dampers) to just 23.83 mm using the "All Story Dampers" configuration—an impressive reduction of 58%. Likewise, the 15-storey and 20-storey buildings recorded similar improvements, with displacements reduced from 123.53 mm to 40.84 mm and from 219.60 mm to 65.84 mm respectively, using full-floor dampers. These reductions are critical in mitigating structural damage during seismic events and preventing catastrophic failures.

However, while the "All story Dampers" configuration offered the best performance in all cases, it is also the most expensive due to the need for numerous damping devices. Therefore, alternative configurations like "Top, Middle, Bottom Dampers" were explored as more cost-effective solutions. These provided substantial reductions in displacement—35.50 mm for 10-storey, 82.62 mm for 15-storey, and 166.04 mm for 20-storey buildings—making them a viable trade-off between performance and cost. Particularly for mid-rise and shorter buildings, this configuration is economically appealing while still ensuring structural resilience. An essential aspect of this research is the evaluation of story drift; a parameter closely monitored in seismic design as it affects both structural and non-structural elements. According to IS 1893:2016 Part 1, the permissible story drift limit for buildings below 40 meters in height is 0.004 times the story height. In this study, even the configurations without dampers-maintained drift values within permissible limits (e.g., 0.00377 for 10-storey buildings). However, the introduction of FVDs significantly improved performance, lowering drift values to as little as 0.00066 in some configurations. This not only validates compliance with code provisions but also reinforces the effectiveness of FVDs in reducing relative lateral movement between adjacent floors, thereby protecting interior partitions, façade elements, and elevators.

The story stiffness analysis is another vital contribution of this study. Stiffness determines a structure's resistance to deformation under lateral seismic loads and is directly correlated with both story drift and overall displacement. Story stiffness is particularly crucial in identifying soft- story behavior—a common failure mode during past earthquakes. In the "Without FVD" scenario, story stiffness remained relatively low and exhibited a sharp decline in upper floors, highlighting vulnerabilities, especially in taller buildings. Also, FVDs significantly reduce base shear across all building configurations. For example, in the 10-story symmetrical building, base shear decreases from 1973.32 KN to 1019.23 KN, and in the 20-story unsymmetrical building, it drops from 2608.89 KN to 1591.85 KN.

In contrast, buildings equipped with "All Story Dampers" exhibited significantly enhanced stiffness, particularly at lower levels. For instance, in 10-storey symmetric buildings under EQX loading, the story stiffness at the first floor increased from approximately 40,000 units (without dampers) to over 370,000 units with full FVD installation. This substantial improvement demonstrates the damper's ability to effectively augment the lateral load-resisting capability of the structure. Even the "Top, Middle, Bottom Dampers" and "Alternate Floor Dampers" configurations showed meaningful improvements, albeit with variations depending on damper location. Importantly, story stiffness was observed to gradually decrease from base to top in all configurations, a desirable distribution that helps absorb and dissipate seismic forces effectively. In buildings with "Alternate Floor Dampers," stiffness patterns showed fluctuations, resulting in inconsistent damping performance and less reliable structural behavior. On the other hand, the "Top, Middle, Bottom" configuration showed stiffness concentration at strategic levels, offering targeted seismic control where it is most needed.

For unsymmetric buildings, the role of FVDs in regulating story stiffness became even more pronounced due to the presence of torsional irregularities. Here, the stiffness was found to be highest at the base and declined more steeply without dampers. FVD-equipped structures, particularly those with all- story dampers, showed better uniformity in stiffness distribution and improved overall torsional stability. Collectively, the insights on story stiffness underscore the significance of using FVDs not just for displacement and drift reduction but also for enhancing the dynamic rigidity of steel buildings. An increase in story stiffness leads to better load redistribution, minimizes the risk of resonance with ground motion frequencies, and contributes to the overall structural robustness against earthquakes. From a practical standpoint, this study provides a decision matrix for designers and policymakers. Where budget constraints exist, the "Top, Middle, Bottom" strategy emerges as a cost-efficient and performance-balanced solution. For critical infrastructure and high-importance buildings, full- story damping remains the gold standard. The modular nature of damper placement also lends itself to phased retrofitting strategies, enabling gradual upgrades in existing structures without major disruptions.

This research validates the pivotal role of Fluid Viscous Dampers in enhancing the seismic performance of steel buildings. By systematically examining displacement, story drift, and story stiffness across a spectrum of building heights and damper layouts, the study offers actionable insights for design optimization and retrofit planning. The results align with current seismic code requirements and extend beyond by offering performance-based comparisons tailored to different design goals—safety, cost, or resilience. As earthquake risks continue to rise in urbanizing regions, the integration of passive energy dissipation systems like FVDs becomes not only a design enhancement but a necessity. The findings here in provide a solid foundation for adopting these systems in new constructions and retrofitting existing vulnerable buildings, paving the way for more resilient and economically optimized urban environments.

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