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EFFECTIVENESS OF VISCOUS DAMPING SYSTEM IN ENHANCING SEISMIC PERFORMANCE: CASE STUDY IN ISLAMABAD

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Abstract – With the escalating seismic risks in Islamabad, enhancing the earthquake resilience of existing buildings is becoming increasingly vital. This study delves into the efficacy of viscous dampers as a retrofitting strategy, focusing on a 10-story structure located in Gulberg Greens, Islamabad. Although the benefits of viscous dampers are well recognized, there remains a gap in research specific to their implementation in the seismic context and architectural norms of Islamabad. This study seeks to fill this void by employing numerical modeling to evaluate how viscous dampers can decrease seismic vulnerabilities in the selected building. A detailed numerical model of the building is constructed with viscous dampers incorporated into diagonal braces. The study thoroughly examines the seismic responses measuring displacements, accelerations, and in-ternal forces of the building both with and without dampers. The results of this comparative analysis highlight the significant role of viscous dampers in reducing seismic loads and improving the overall structural performance. By providing essential insights into the practical use of viscous dampers for seismic retrofitting in Islamabad, this research aims to guide engineers and inform policy decisions, thereby fostering more robust building practices and enhancing public safety in regions susceptible to earthquakes.

Keywords – Fluid Viscous dampers, story shear, maximum displacement, structural response.

I. INTRODUCTION

Earthquakes remain a significant threat to structures, necessitating continuous advancements in seismic mitigation strategies. Damper systems have emerged as a prominent technology for enhancing seismic performance [1,2,3]. This study examines the retrofitting process of the already existing buildings to endure major earthquakes and maximize the load capacity. Moreover, to enhance the energy dissipation of buildings using viscous dampers. The emphasis will be on implementation of new methodologies and technologies in structural engineering to create technology-driven retrofitting strategies and energy dissipation techniques. Structure retrofitting involves altering an existing building to protect it from flooding, high winds, and earthquakes [4, 5, 6]. Structural members encounter a range of challenges that require attention.

Islamabad, prone to seismic activity, experienced earthquakes in 2024 (6.4 magnitude) and 2023 (5.8 magnitude) originating near Jurm, Badakhshan, Afghanistan. Earthquakes pose a significant threat to structures, driving the continuous evolution of seismic mitigation strategies. Damper systems have emerged as prominent technologies for enhancing seismic performance, particularly in retrofitting existing buildings to endure major earthquakes and maximize load capacity [7,8,9,10]. This study focuses on implementing new methodologies and technologies in structural engineering to create technology-driven retrofitting strategies and energy dissipation techniques, with a specific emphasis on using viscous dampers.

Our major analysis of this research is the Study of finite element analysis models of old buildings reinforced with modern techniques like viscous dampers. Despite the strong features of E-Tabs, several challenges need to be addressed including the correct representation of the complex damper behavior, nonlinear materials under various earthquake scenarios, and the efficient interpretation of the big data volume. While the opportunity exists for advanced modelling features to be used, the possibility of calibration with physical tests and cost-benefit analysis can be provided for giving the right methodological decision. A comprehensive research methodology that combines sophisticated E-Tabs based modeling with analytical expertise to reliably evaluate the performance of this advanced renovation techniques.

The effectiveness of fluid viscous damping systems in enhancing seismic performance has been investigated extensively, highlighting their ability to dissipate energy and improve structural response during earthquakes. Studies show that these dampers significantly reduce displacement and velocity, particularly in low-rise buildings and under far-fault earthquake conditions, with reductions of up to 59% and 53%, respectively [11]. Additionally, viscous dampers combined with steel yielding dampers have proven effective even with challenges such as oil leakage, maintaining reliable performance in seismic mitigation [12]. Another study highlights the challenge of wave-passage effects on such systems in long-span bridges, emphasizing the need for specialized configurations to manage delayed activations and ensure effective mitigation [13].

The effectiveness of fluid viscous damping systems in seismic performance enhancement is widely studied, reflecting the importance of optimizing damper configurations and placement for structural resilience. Gobbo et al. [14] focused on using linear fluid viscous dampers (FVDs) to enhance building seismic performance while considering repair costs. They proposed an improved method for calculating damper coefficients, showing that the ideal damping level should be between 25% and 45% to minimize repair costs—a shift from the previously suggested 20-25%. The implementation of FVDs significantly reduced damage caused by drift and acceleration, demonstrating their role in maintaining building functionality after earthquakes [14].

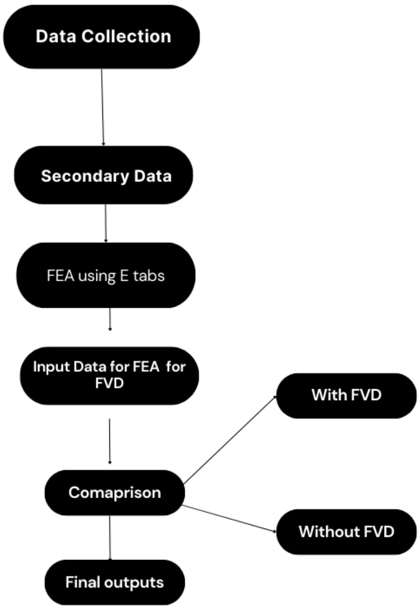
Kookalani and Shen [15] conducted a comparative study on a retrofitted seven-story steel frame with fluid viscous dampers, examining different damping parameters. Their results indicated that the installation of a longitudinal nonlinear fluid viscous damper can significantly decrease the seismic response of structures, which can be optimized through careful selection of cost-effective damping parameters such as stiffness and damping coefficients [15].

Tiwari et al. [16] explored the seismic response of different types of standard buildings in Nepal using non-linear fluid viscous dampers. Comparing models of bare frames with those incorporating dampers, the study highlighted that dampers significantly improve seismic performance across various parameters including dis-placement and drift, particularly under conditions simulating both Design Basis and Maximum Considered Earthquakes [16].

Damper systems offer a promising approach for enhancing the seismic performance of buildings. Their effectiveness in dissipating energy, reducing seismic demands, and improving damage resistance makes them a valuable tool in earthquake engineering [17], [18], [19]. Further research on optimal design for specific scenarios, the integration of damper systems with other seismic protection technologies, and cost-effectiveness analysis will guide the wider adoption of dampers for both new and existing structures in earthquake-prone regions. The research gap which was found from the literature is about the modelling and comparison of conventional buildings with FVDs installed building using E- tabs. In this research, further analysis of FVDs installed buildings would be utilized for comparison for seismic events. It focuses on the role of damping systems in influencing the dynamics of structures and the distribution of loads. By employing a synergy of numerical simulations, the research serves to provide a holistic comprehension of the pros and cons of damping systems in earthquake-proofing for a practical use in the engineering and research community.

II. MATERIALS AND METHOD

This research investigates the effectiveness of fluid viscous damping (FVD) systems in enhancing the seismic performance of a 10-story building located in Islamabad, Pakistan. The seismic zone of Islamabad is 2B. The research methodology employs a finite element analysis (FEA) approach using the software E-Tabs. Data will be collected from secondary sources such as existing research papers and seismic hazard maps for Islamabad.



Secondary data will be collected for the analysis in the E tabs. Fluid viscous dampers including their working principles, design parameters, and effectiveness in seismic mitigation (reference existing research papers). Seismic hazard maps for Islamabad to determine the appropriate ground motion for the FEA model (reference building codes and seismic hazard maps). Case study selection: A real-world example of a building retrofit project in the Islamabad region will be studied to gain insights into practical applications of FVD systems. Using both the realistic properties of Fluid Viscous Dampers (spring stiffness, damping coefficient) as input manufacturers provide as shown in the table [20] below. The FVD with 500 KN has been utilized in the E-Tabs as shown in table 1 below.

A meticulous 3D FEA model of the 10-story building will be built in E-Tabs software. This model will accurately capture the building's geometry, material properties (concrete and steel), member sections (beam and column sizes), and existing connections. Realistic properties of a specific 500 KN FVD system, including spring stiffness and damping coefficient from manufacturer data, will be integrated into the model for a comprehensive evaluation of its impact on the building's seismic performance. This methodology aims to rigorously evaluate how Fluid Viscous Damping systems can enhance the seismic resilience of structures, potentially leading to more effective building practices in earthquake-prone regions.

Specific input data for FEA is prepared focusing on buildings equipped with Fluid Viscous Dampers [21]. This data is crucial for analyzing how these dampers influence the seismic performance of structures.

Table 1:This table displays the specifications of Fluid Viscous Dampers (FVD) with different force capacities ranging from 250 KN to 8000 KN. The table serves as a reference for selecting appropriate FVDs based on required force capacities and other dimensional.

Force (kN)	**Taylor Devices Model Number**	**Spherical Bearing Bore Diameter (mm)**	**Mid-Stroke Length (mm)**	**Stroke (mm)**	**Clevis Thickness (mm)**	**Maximum Clevis Width (mm)**	**Clevis Depth (mm)**	**Bearing Thickness (mm)**
250	17120	38.1	787	±75	43	100	83	33
500	17130	50.8	997	±100	55	127	102	44
750	17140	57.15	1016	±100	65	160	131	55
1000	17150	69.85	1048	±100	71	185	150	67
1500	17160	76.2	1105	±100	77	205	162	76
2000	17170	88.9	1346	±125	91	230	191	87
3000	17180	101.6	1499	±125	117	325	273	111
4000	17190	127	1645	±125	154	350	305	121
5000	17200	152.4	1752	±125	154	350	305	121
6000	17210	177.8	1667	±125	178	415	317	135

Table 2: Input data utilized for FEA Analysis in E-Tabs. The values are taken from UBC-97.

Parameter	**Values**	**Table**
Zone	0.20	Table -16-I
Seismic Source Type	B	Table -16-U
Soil Profile	SD	Table -16-J
Seismic Importance Factor (I)	1.00	Table -16-K
Seismic Coefficients (Cv)	0.4	Table -16-R
Seismic Coefficients (Ca)	0.28	Table -16-Q
Over Strength Factor (R)	5.5	Table -16-O

III. RESULTS

The deformed shapes after analysis in the E-Tabs is given below in fig. 1 and fig. 2. From both figures as shown it can be seen that more deformation can be observed in the case of conventional building in comparison to FVDs. The effectiveness of FVDs in absorbing and dissipating seismic energy reduces the stress and strain on the building's structural components. This results in less deformation compared to conventional buildings that lack such damping systems. In conventional buildings, the energy from seismic activity directly impacts the structure, causing greater deflections and deformations, which can lead to structural damage or failure.

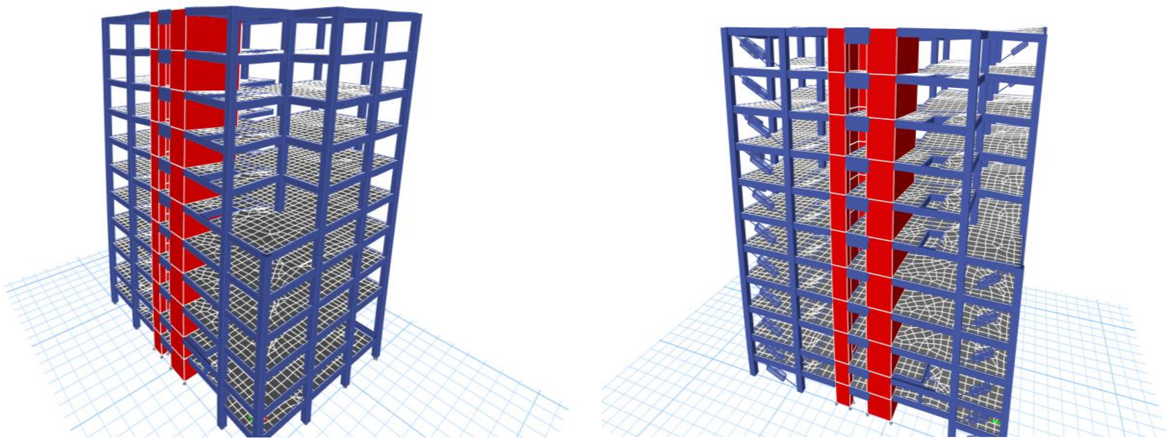


Figure 1: Deformed shape after analysis with(left) and without FVDs(right).

IV. DISCUSSION

The figure 2 illustrates the results of an E-tabs analysis showing the maximum story displacement of a multi-story building subjected to seismic forces, where no dampers are installed. The x-axis represents the displacement in inches, while the y-axis lists the building floors from the base to the roof. The displacements in the X-direction (blue line) indicate a gradual and consistent increase from the base upwards, peaking at the roof. Conversely, the displacements in the Y-direction (red line) show a sharply lower magnitude across all floors, suggesting more uniform behaviour in this direction. This disparity highlights the building's anisotropic response to seismic forces, potentially due to differing stiffness or mass distribution along the two directions. Such data is critical for assessing the building’s structural performance and vulnerability in seismic events, indicating areas that might benefit from retrofitting or the implementation of control systems like dampers to mitigate such displacements.

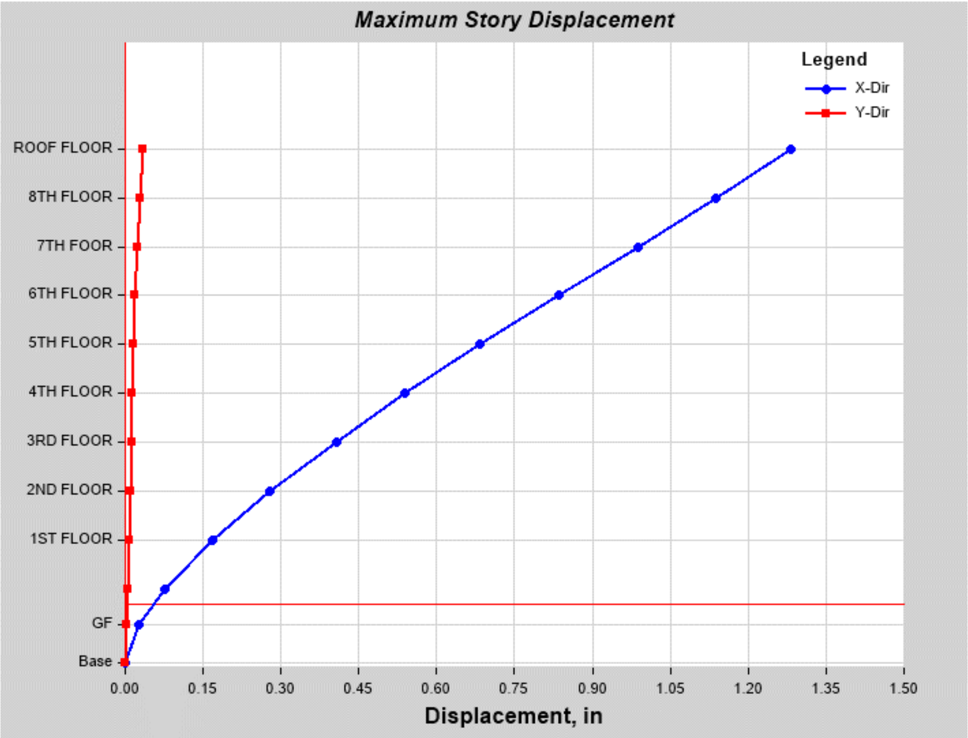


Figure 2: Max Story Displacement without dampers.

The graph in figure 3 depicts the maximum story displacement of a multi-story building equipped with dampers, analysed using E-tabs. In this analysis, the Y-direction shows significantly reduced displacements compared to the X-direction, which demonstrates the effectiveness of dampers in controlling displacements across different axes of the building. The dampers' installation likely contributes to this differential reduction by more effectively mitigating seismic energy along the direction where they have the most impact, potentially aligned with the principal direction of seismic activity or building design that favors damping in this direction. The displacements in the X-direction, while still showing a linear increase from the ground floor to the roof, are noticeably lower across all floors compared to a similar structure without dampers (as observed in the previous scenario provided without damper). This pattern indicates that the dampers are functioning effectively to reduce the overall motion of the building, which is essential for minimizing structural stress and potential damage during seismic events. Overall, the installation of dampers has resulted in a marked improvement in the building's seismic response, as evidenced by the reduced displacements, thereby enhancing the safety and stability of the structure during earthquakes.

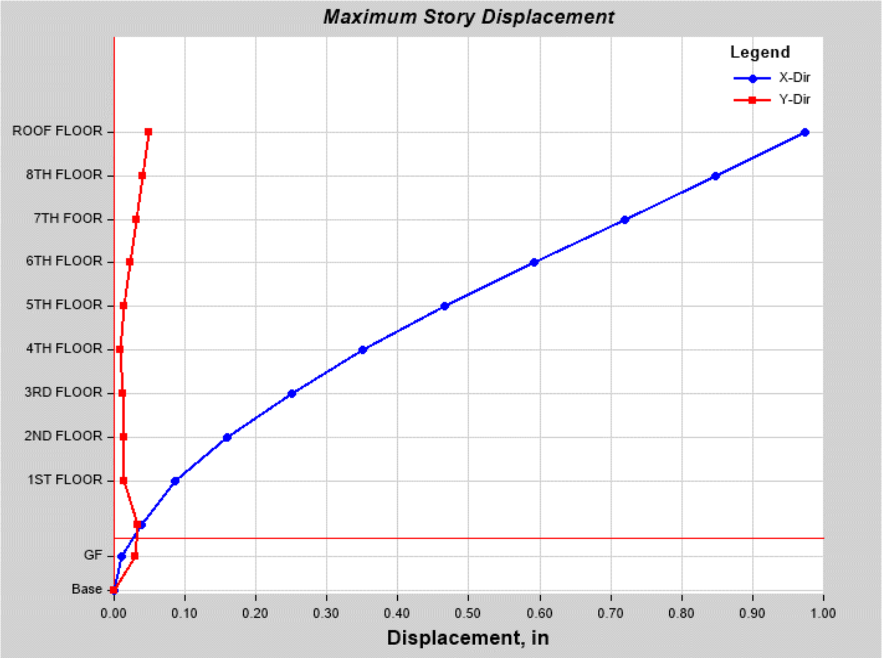


Figure 3: Max Story Displacement with dampers.

The figure 4 illustrate the maximum story drifts for a multi-story building both with and without FVDs.. These plots are crucial in assessing the impact of dampers on the building's response to seismic forces. The X-direction exhibits a significant increase in drift as you move from the base to the roof, indicating a larger displacement at the higher floors. This pattern suggests that the building is less rigid and more susceptible to swaying under seismic stress in the X-direction. The drift in the Y-direction is relatively smaller, reflecting perhaps a different structural configuration or stiffness in that direction. The presence of dampers has a noticeable impact on the drifts, especially evident in the Y-direction where the drift is drastically reduced across all floors as seen in right graph of FVDs installed building. This reduction indicates that the dampers are highly effective in mitigating seismic energy in this direction, likely due to optimal placement or the inherent characteristics of the building that favor damping in the Y-direction. The drift in the X-direction is also reduced, though the overall trend of increasing drift towards the roof remains. This suggests that while dampers improve stability, the X-direction might still be more susceptible to seismic forces, possibly due to higher story heights or less effective damper action in that orientation. The comparison clearly illustrates the effectiveness of dampers in reducing story drifts, which are critical for preventing structural damage and failure during earthquakes.

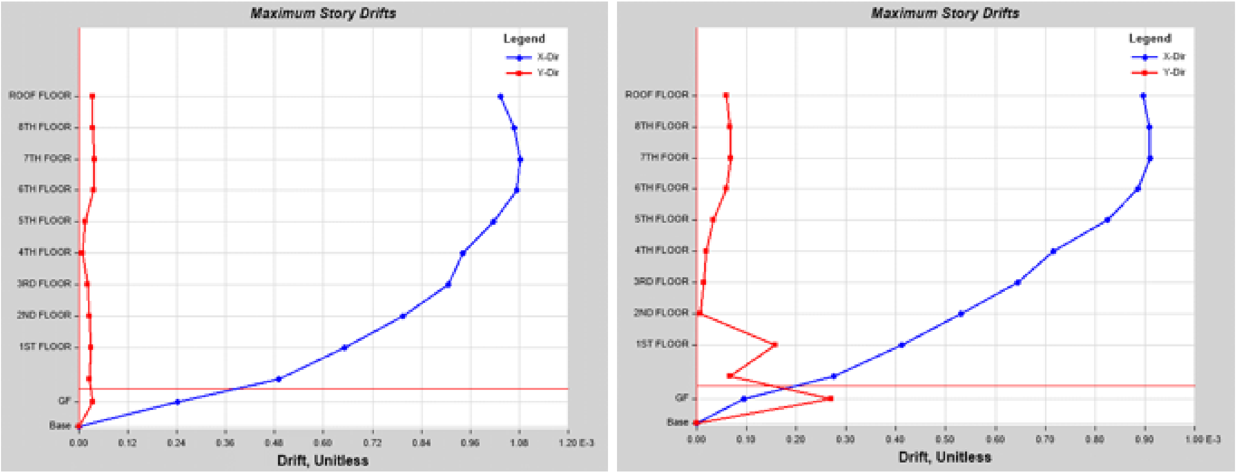


Figure 4: left graph (without FVDs) and right (With FVDs) for maximum story drift.

The figure 5 depicts the story shears in a multi-story building, comparing conditions with and without FVDs. This increase is particularly notable in the X-direction, suggesting that the lateral seismic forces are more pronounced in this orientation. The steep rise in force, especially on the upper floors, underscores the high demand placed on the building's structural system, which could lead to greater vulnerability to seismic damage. With the inclusion of dampers, there is a marked reduction in the story shear across all floors in both directions. Notably, the Y-direction (red line) shows a dramatic reduction, almost flattening out, indicating that the dampers are highly effective in mitigating lateral forces in this orientation. The X-direction also shows a reduced shear force but maintains a more pronounced gradient compared to the Y-direction. This suggests that while dampers have significantly improved the building's ability to resist lateral forces, the X-direction still experiences relatively higher shear forces, which may require further attention or additional damping capacity. The considerable reduction in story shear also means less deformation and potential damage to the building, contributing to a safer environment for occupants and a longer structural lifespan. The residual forces in the X-direction, despite the presence of dampers, might indicate a need for optimizing damper distribution or exploring additional structural enhancements to further balance the shear forces across the building.

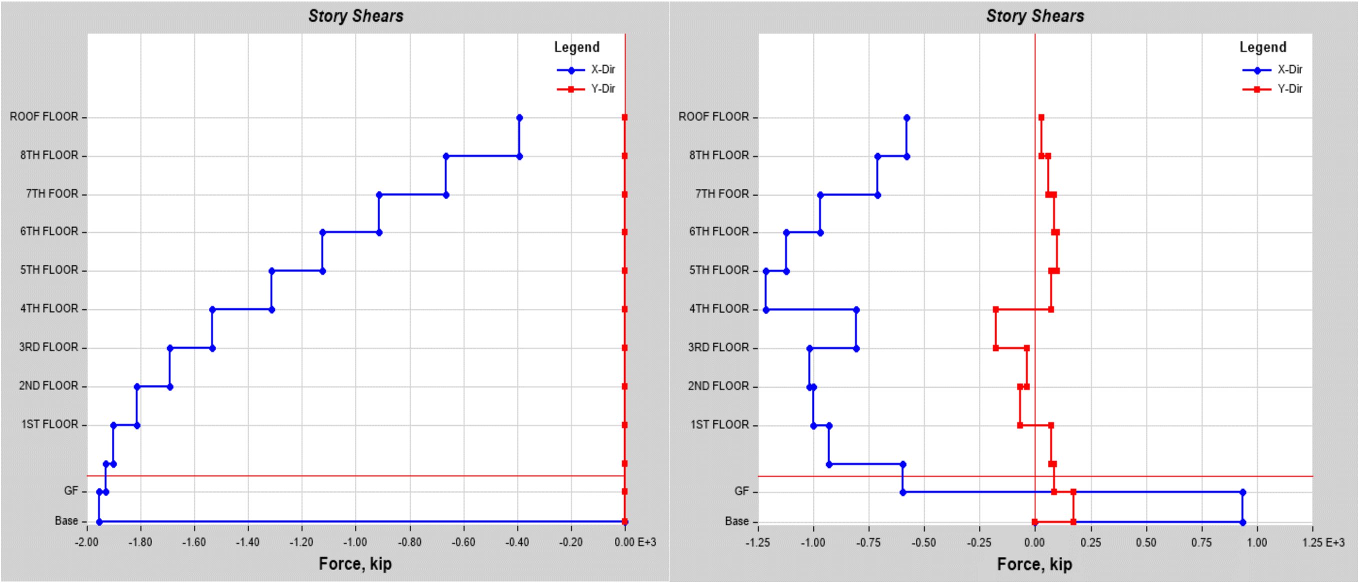


Figure 5: left graph (without FVDs) and right (With FVDs) for maximum story shear.

The figure 6 compares the natural time periods of a building across various vibration modes, with the left graph representing the building without dampers and the right graph representing the building with Fluid Viscous Dampers (FVDs). The time is a measure of how long it takes for a structure to complete one cycle of oscillation naturally and is an essential factor in understanding a building's seismic response. In the left graph, the first mode shows a significantly higher period compared to the subsequent modes. The period decreases sharply from the first to the second mode and continues to decrease more gradually for higher modes. A high time in the first mode indicates that the building is relatively flexible, which can result in larger displacements during seismic events. The steep gradient between the first few modes and subsequent ones suggests different stiffness characteristics across the structure. The introduction of dampers significantly reduces the time periods for all modes, especially noticeable in the first and second modes. The reduction in time periods indicates an increase in the building's overall stiffness and damping characteristics. The presence of dampers modifies the dynamic properties of the building, making it less prone to resonate with earthquake frequencies, which is a critical factor in reducing seismic damage. The dampers effectively reduce the natural time periods of the building across all modes. This reduction is beneficial as it typically results in a structure that is less likely to enter resonance with seismic waves, thereby mitigating potential structural damage.

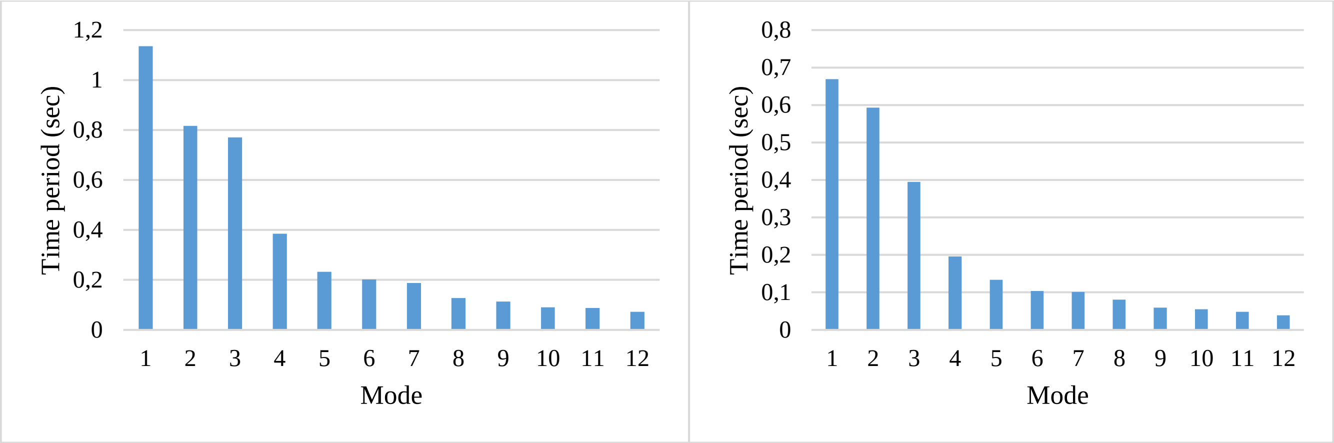


Figure 6: Time period with(right) and without dampers(left).

V. CONCLUSION

The introduction of FVDs results in a noticeable reduction in the natural periods of vibration across all modes, particularly in the lower modes. This reduction in time periods signifies a stiffer system, which is less likely to resonate with earthquake-induced ground motions, thereby reducing the risk of structural failure during seismic events. Buildings equipped with FVDs exhibit significantly lower story shear forces compared to those without dampers. This reduction is critical as it directly correlates to the ability of the structure to withstand seismic forces without undergoing severe damage or failure. In the absence of dampers, buildings show considerably higher story drifts, especially in the upper floors, indicating more significant displacements and potential for damage under seismic loading. The presence of FVDs contributes to increased structural stiffness. With the installation of FVDs, there is a marked decrease in story displacements across the building. This outcome underscores the dampers' effectiveness in controlling both vertical and horizontal movements induced by seismic forces, which helps in maintaining structural alignment and integrity during earthquakes.

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