SEISMIC RESISTANT BUILDINGS USING DAMPERS: A COMPARATIVE STUDY

[a] Muhammad Bilal Ansari*, [b] Muhammad Yaqub

a: Department of Civil Engineering, University of Engineering and Technology Taxila, Pakistan. engr.mbilalansari@gmail.com
b: Department of Civil Engineering, University of Engineering and Technology Taxila, Pakistan.muhammad.yaqub@uettaxila.edu.pk
* Corresponding author

Abstract- This study evaluates the comparison of the seismic behavior of reinforced concrete buildings of varying heights (G+14, G+29, and G+44), both with and without the inclusion of viscous dampers. The building under consideration is situated in Islamabad and falls under seismic site class "C". It features a regular square layout and is intended for residential use. All structural components are designed in accordance with ACI 318-15 standards, while the applied loads are determined based on IBC-2023 provisions. The structural system adopted is a special reinforced concrete moment-resisting frame. For dynamic analysis, the response spectrum method has been utilized. Both the structural modeling and analysis has been performed using ETABS version 17.0.1. Given that earthquakes are among the most significant natural hazards globally, this study incorporates viscous dampers to mitigate the seismic response of the structure. The dampers are employed in high rise structures in seismic zones to minimize vibrations caused by lateral stresses. Such as strong winds and earthquakes in order to prevent such catastrophic damages. The mechanical properties of the viscous damper employed in this study include a damping coefficient Cd=320 KN/ (mm/s) and a stiffness value Kd=224 KN/mm. Key structural response parameters such as storey drift, storey shear, storey displacement, and storey stiffness are evaluated and compared.

Keywords- ETABS, Seismic Response, Storey Drift, Viscous

1. Introduction

Pakistan is a developing country and the population is growing at a very high rate. The planned building is located in Islamabad, the capital city, which is considered an area of high earthquake risk due to its closeness to a major active geological fault in the northern region. Therefore, it is important to design buildings that can safely endure moderate to strong earthquakes. Since a tall building act much like a vertical cantilever, its structural parts must be capable of handling both vertical forces due to gravity and horizontal forces caused by wind and seismic activity. Seismic design enhances the structure's resistance to earthquakes by employing shear wall-based systems or moment-resisting frames [1]. Typically, seismic design seeks to avoid damage during small earthquakes, minimize structural harm during moderate ones, and permit limited impact to both structural and non-structural components during strong earthquakes. The most dangerous aspect of an earthquake is its unpredictability in terms of time and location, which presents a significant economic and structural challenge [2]. This necessitates that building components be designed to dissipate the energy imparted by earthquakes, thereby minimizing damage [3]. To reduce the seismic effects on buildings and bridges, structural control devices are being developed. During an earthquake, seismic energy enters the structure, causing increased vibrational response. Mechanical devices such as dampers are installed throughout the height of the structure to enhance damping and, consequently, reduce the structural response by absorbing or dissipating seismic energy [4], [5].

2. Research Methodology

In this study, ETABS v17 (Extended Three-Dimensional Analysis of Building Systems) software is used for the modelling and analysis of the structures. The buildings are designed as regular square-plan reinforced concrete structures with three different heights: G+14, G+29, and G+44 storeys. Each model is analysed in two cases: with and without the use of fluid viscous dampers (FVDs).

Initially, the models without dampers are developed and analysed in ETABS. Gravity loads are assigned, and earthquake loads are aplied according to IBC-2023 provisions. The buildings are assumed to be located in seismic site class D (Islamabad), and dynamic analysis is carried out using the Response Spectrum Method (RSM), considering a 5% damping ratio and appropriate scale factors in both X and Y directions as per code requirements.

2.1 Significance of Research

This research enhances the understanding of damping systems in improving the seismic resilience of buildings by analyzing their effectiveness in mitigating earthquake-induced forces. By significantly reducing structural damage, damping systems enhance overall safety; extend the lifespan of buildings, and lower long-term maintenance and re- construction costs. Additionally, their ability to minimize material waste contributes to sustainable construction practices. The study also highlights the wide industry applications of damping technology, particularly in seismic- prone regions. Overall, this research contributes to the advance of seismic protection strategies, promoting safer, more cost-effective, and environmentally sustainable building practices.

2.2 Methods of Analysis

There are various methods available for conducting seismic analysis of buildings, aimed at determining the internal forces and deformations caused by earthquake excitations. The choice of analysis method primarily depends on the structural configuration, material properties, and the external seismic inputs applied.

2.2.1 Equivalent Static Method

Also known as, the Equivalent Lateral Force Method, this approach is a simplified procedure used in seismic analysis. It assumes that the horizontal seismic load can be represented by an equivalent static force, simulating the effects of dynamic ground motion. Unlike more advanced dynamic methods, it typically does not require consideration of higher vibration modes, focusing only on the fundamental mode, which simplifies the analysis.

The method starts by calculating the total base shear based on the building's mass, the fundamental period of vibration, and its modal shape. This base shear is then distributed along the height of the structure. At each floor level, the resulting lateral force is further allocated to the structural elements. Due to its simplicity, the Equivalent Static Method is most appropriate for low- to mid-rise buildings that have regular geometry and mass distribution.

2.2.2 Response Spectrum Method

Also referred to as the Modal or Mode Superposition Method, the Response Spectrum Method is a dynamic analysis technique widely used in seismic design? It is especially suitable for structures where modes beyond the fundamental mode significantly influence the seismic response, such as in buildings with irregular mass or stiffness distributions.

This method evaluates the peak structural response by referencing an earthquake design response spectrum, which reflects the maximum expected response of a single-degree-of-freedom (SDOF) system subjected to ground motion. Each mode of vibration is analyzed independently. The resulting modal responses are then combined using techniques like the Square Root of the Sum of the Squares (SRSS) or the Complete Quadratic Combination (CQC) to determine the total structural response. The Response Spectrum Method yields accurate results that are suitable for designing high-rise and complex structures under seismic loading.

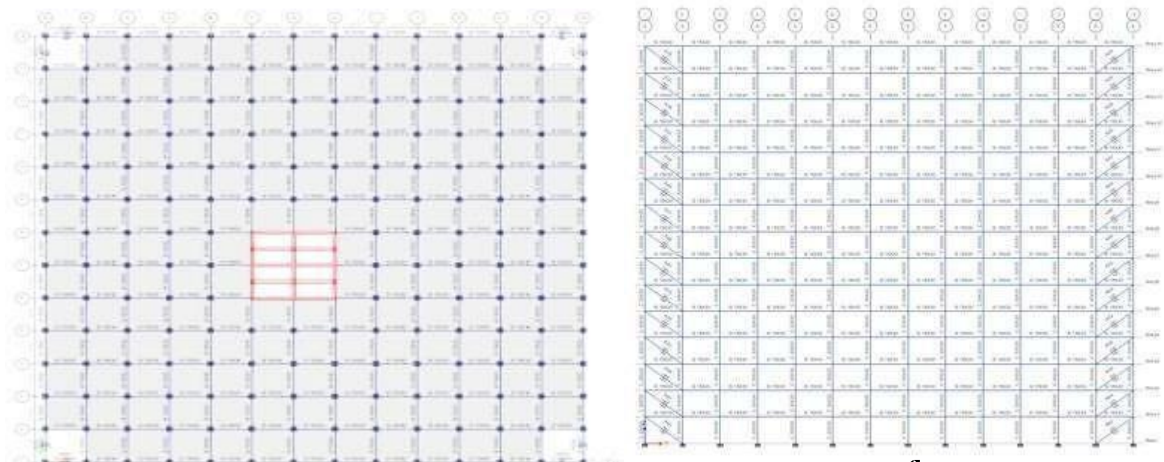
2.3 Model and Analysis

In this study, three different high-rise reinforced concrete building models are considered: G+14 (15 storeys), G+29 (30 storeys), and G+44 (45 storeys). All buildings are modelled with the same plan dimensions and structural layout, ensuring consistency in comparison. The structures are assumed to be residential buildings located in seismic zone D (Islamabad, Pakistan). Each model is analyzed both with and without fluid viscous dampers (FVDs).

Table 1 presents the geometric and material properties used in all three models.

Table 1: Description of Building Model

Particulars	**Model -01**	**Model-02**	**Model-03**
Plan dimension	200ft X 200ft	200ft X 200ft	200ft X 200ft
Area	40,000 sft	40,000 sft	40,000 sft
No of story	15	30	45
Height of each story	11 ft	11 ft	11 ft
Total height	165 ft	330 ft	495 ft
Size of column	15"x30"	15"x30"	15"x30"
Slab thickness	30"x30"	30"x30"	30"x30"
Dead load	6 in	6 in	6 in
Live load	40 psf	40 psf	40 psf
Roof live load	40 psf	40 psf	40 psf
Partition wall load	40 psf	40 psf	40 psf
Parapet wall load	180 lb/ft	180 lb/ft	180 lb/ft
Wind load	80 mph	80 mph	80 mph
Compressive strength of concrete for (beam and slab)	5000 psi	5000 psi	5000 psi
Compressive strength of concrete for column	6000 psi	6000 psi	6000 psi
Grade of reinforcing steel	Gr-60	Gr-60	Gr-60
Code	IBC-2023	IBC-2023	IBC-2023
Density of concrete	150 lb/cft	150 lb/cft	150 lb/cft
Damping ratio	0.05%	0.05%	0.05%
Soil type	SD	SD	SD
Spectral Acc Sc	1.22	1.22	1.22
Spectral Acc S1	0.37	0.37	0.37
Site class	D	D	D
Response modification (R)	5	5	5
Over strength omega	3	3	3
Deflection amplification (Cd)	4.5	4.5	4.5
Occupancy importance (I)	1.25	1.25	1.25



(a (b

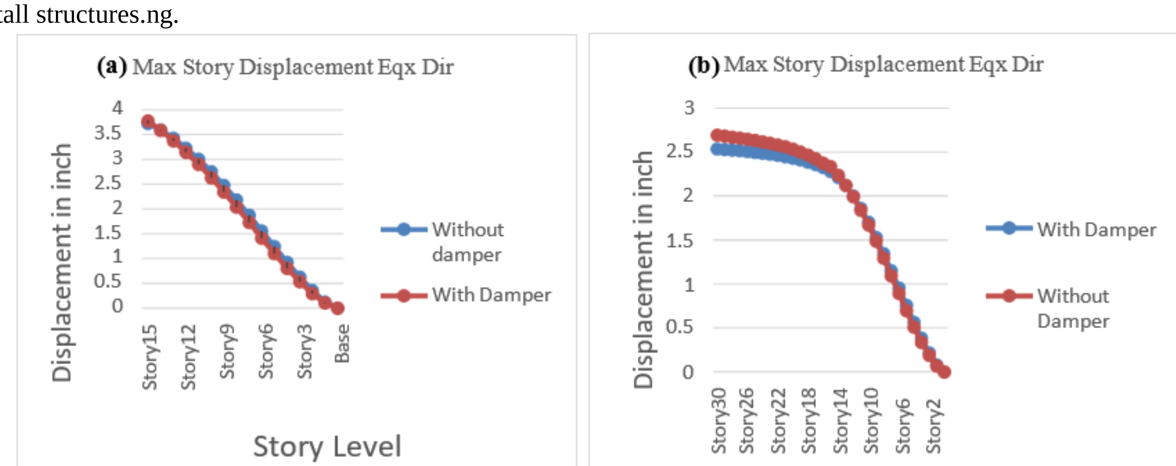
Figure 1: (a) Plan view of building with FVD in ETABS and (b) FVD at exterior corner elevation in YZ plane

3. Results

This section presents the comparison of seismic responses for three building configurations (G+14, G+29, and G+44 storeys), analyzed with and without fluid viscous dampers (FVDs). The analyses were performed using both the Equivalent Static Method (ESM) and the Response Spectrum Method (RSM). The key parameters considered include storey displacements, storey drifts, base shear, and modal time periods.

3.1 Storey Displacement

Storey displacement refers to the lateral movement of each storey during seismic excitation. It was observed that displacement values increase with the height of the structure. However, the inclusion of viscous dampers significantly reduced the overall displacement for all models. For instance, in the G+44 storey model, the maximum top storey displacement without dampers was significantly higher compared to the model with FVDs. The dampers effectively absorbed seismic energy, leading to a reduction in peak displacement by up to 24% in tall structures.ng.



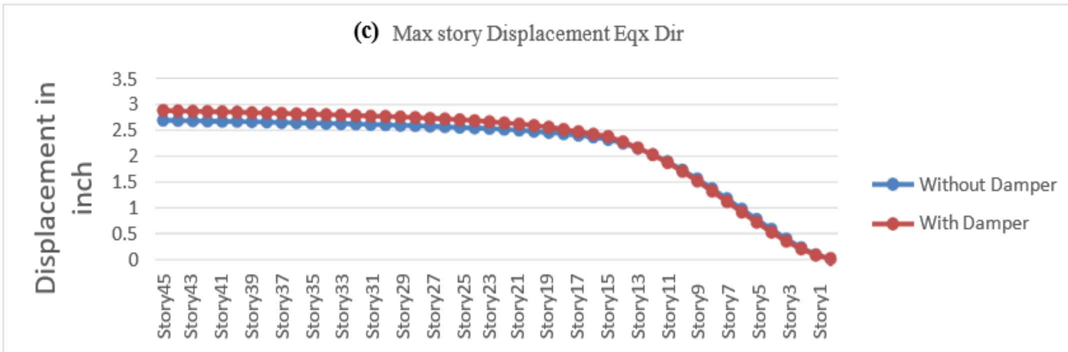


Figure 2: a. Maximum Storey Displacement a.15 storey, b.30 storey and c. 45 storey

3.2 Storey Drifts

Inter-storey drift is the relative displacement between adjacent floors and is a critical factor for seismic design. The maximum drift values were observed near the mid-height of the buildings. The drift increased with building height but was notably lower in all damped models.

The G+29 and G+44 models exhibited the most pronounced improvements, with inter-storey drift reductions reaching up to 28% when FVDs is used. This confirms that the use of dampers not only enhances performance but also helps meet code-based drift limits more effectively

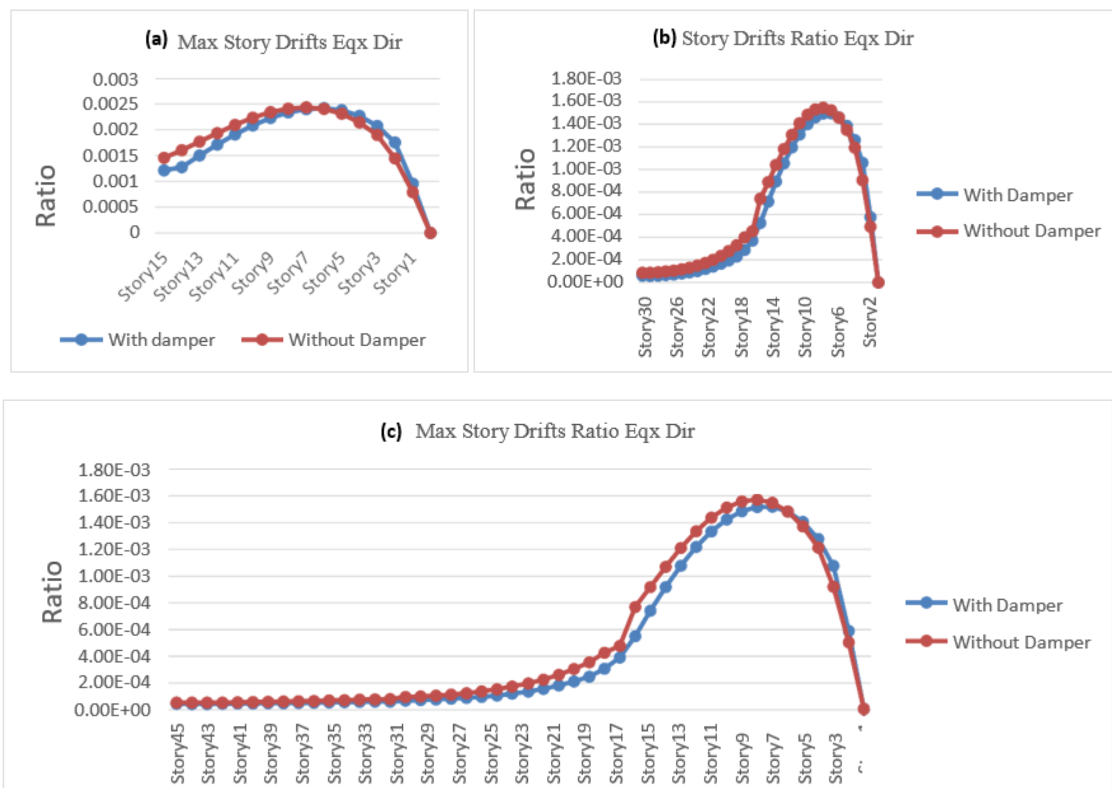


Figure 3: a. Maximum Storey Drifts a.15 storey, b.30 storey and c. 45 storey

3.3 Modal Time Periods

Modal time periods reflect the natural vibration characteristics of a structure. It was found that models without dampers had slightly higher fundamental time periods due to reduced stiffness and lack of energy dissipation mechanisms. The incorporation of dampers resulted in lower time periods and more stable dynamic response. This confirms that dampers contribute not only to deformation control but also to improved structural stability under dynamic excitation.

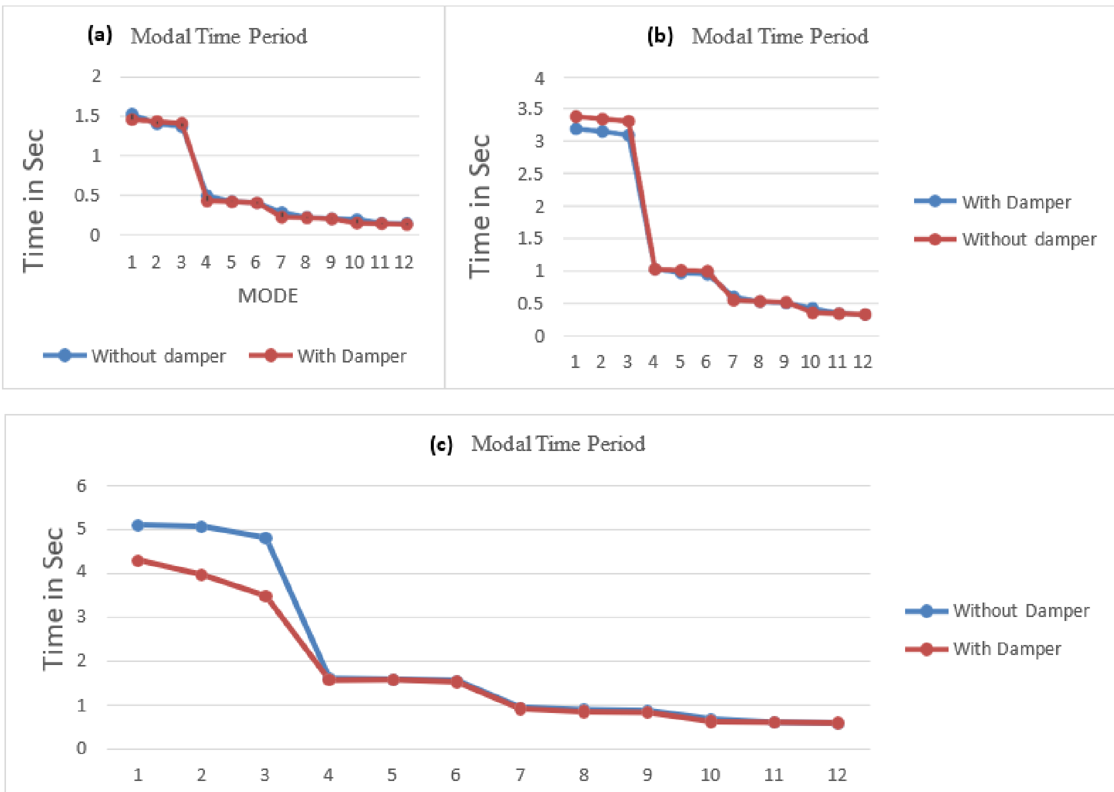


Figure 4: Instrumentation of interlocking structure on shake table, a. schematic diagram, and b. test set up

4. Practical Implementation

The use of fluid viscous dampers (FVDs) in high-rise buildings provides a practical and effective way to reduce seismic effects, especially in earthquake-prone areas like Islamabad. These dampers can be installed between beams and columns or in bracing systems to absorb and dissipate seismic energy, reducing storey displacements and inter-storey drifts. Although they may increase the initial construction cost, FVDs help minimize structural damage and repair needs after earthquakes, making them a cost-effective solution in the long run. Their application is especially beneficial in critical or tall buildings where safety and stability during seismic events are essential. With growing acceptance in modern design codes, FVDs are becoming a practical part of earthquake-resistant building design.

5. Conclusion

This study confirms that fluid viscous dampers (FVDs) are effective in reducing the seismic response of reinforced concrete high-rise buildings. A series of dynamic analyses was carried out on G+14, G+29, and G+44 storey structures to evaluate the impact of dampers on key response parameters. The findings highlight the following:

1. The installation of dampers led to a reduction in maximum storey displacement by up to 24%. As expected, storey displacement increases with building height.

2. Maximum inter-storey drift was reduced by up to 28% in buildings equipped with dampers. Similar to displacement, drift values were higher in taller structures.

3. The inclusion of dampers improved storey stiffness by up to 10%. However, as building height increased, the overall lateral stiffness naturally decreased.

These results indicate that incorporating FVDs significantly enhances the seismic performance of tall RC buildings by controlling lateral movement and improving structural stability.

Acknowledgment

The author gratefully acknowledges the Department of Civil Engineering, UET Taxila, for their support during this research. Special thanks to Prof. Dr. Muhammad Yaqub for his valuable supervision.

References

[1] H.-N. Li and G. Li, "Earthquake-resistant design of RC frame with „dual functions" metallic dampers," *Proc. ASME Pressure Vessels and Piping Conf.*, vol. PVP2007-26450, pp. 43–53, 2009.

[2] R. K. Mohammad, M. H. El Naggar, and H. Moghaddam, "Optimum strength distribution for seismic resistant shear buildings," *Int. J. Solids Struct.*, vol. 41, no. 22–23, pp. 6597–6612, 2004.

[3] G. Xu, T. Guo, A. Li, S. Wang, R. Zhang, R. Zhu, and J. Xu, "Review on self-centering damper for seismic resilient building structures," *Structures*, vol. 54, pp. 58–77, 2023.

[4] F. Paolacci, "An energy-based design for seismic resistant structures with viscoelastic dampers," *Earthq. Struct.*, vol. 4, no. 2, pp. 219–239, 2013.

[5] J. Wang and H. Zhao, "High-performance damage-resistant seismic resistant structural systems for sustainable and resilient city: A review," *Adv. Civ. Eng.*, 2018. [Online]. Available: doi.org/10.1155/2018/8703697