Iraqi journal of civil engineering (IJCE)
P-ISSN: 1992-7428 ; E-ISSN: 2706-686X

Vol. 19 , No. 1 (2025) , pp. 68 ~ 86
DOI: 10.37650/ijce.xxxx.xxxxxx

Iraqi Journal of Civil Engineering

Journal homepage: https://ijce.uoanbar.edu.iq/

A Study of Viscous Dampers for Enhanced Seismic Performance in Reinforced Concrete Multi-Storey Building

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PAPER INFO

Paper history
Received: 14 /01/2025
Revised: 15/06/2025
Accepted: 21/06/2025

Keywords:
ETABS
Multi storey building
Fluid viscous damper
Equivalent static load
Response spectrum analysis

ABSTRACT

This study investigates the seismic performance of a nine-storey reinforced concrete building located in Seismic Zone 3, focusing on the effectiveness of viscous dampers in enhancing structural resilience. With increasing seismic risks, the integration of damping systems has become critical for mitigating vibrations and improving building safety.
The research evaluates four configurations: a fixed-base building with no dampers, buildings with corner dampers featuring uniform and varying force capacities, and a building with middle dampers. The Equivalent Static Load (ESL) and Response Spectrum study (RSA) methods are used in the ETABS 2021 research to look at important factors such the natural period, storey stiffness, storey drift, storey displacement, and overturning moments. These steps are based on the UBC 97 criteria.

The results show that viscous dampers do assist structures stay standing during earthquakes. Buildings with corner dampers that could handle different amounts of stress had a natural period that was 37.5% shorter. This means that they were stiffer and could respond to seismic shocks faster. The storey's stiffness went down by 16.7%, and the periods of overturning went down by 5.7%. This shows that the dampers did a great job of getting rid of energy. Also, the maximum storey displacement and drift were 41.6% and 48.14% lower than in the fixed-base model, respectively.

These figures show how important it is to put dampers in the right places, especially at corners where the force capacity changes, to make buildings more resistant to earthquakes. The study's conclusion is that viscous dampers make multi-story structures in moderate seismic zones much safer by making them less likely to break and improving how effectively they perform. This study gives engineers and designers important information that makes them desire to use current dampening technologies in tall buildings to make them safer during earthquakes.

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1. Introduction

The viscous damper is a typical form of damping device utilized in many engineering fields, including cushioning systems and equipment (De Domenico, Ricciardi, & Takewaki, 2019; Fahiminia & Shishegaran, 2020; Hu, Zhang, Ren, Pan, Zhang, & Li, 2022; Zhu, Guo, & Mwangilwa, 2020). The damper shows viscous damping behavior when the damping force is proportional to the first power of velocity. This resistance to movement makes sure that the damping force changes smoothly and continuously with speed, which leads to a linear connection (Riaz, Malik, Shah, Usman, & Najam, 2023; Zhou, Sebaq, & Xiao, 2022). The viscous damper is not very complicated mathematically, which is why many academics use it to solve difficult damping issues (Rohith Kumar, Satyanarayana, and Ravi Dakshina Murthy, 2023). It is extensively utilized worldwide in the design of modern multi-storey buildings and contributes significantly to enhancing the structural integrity of existing buildings (Elwardany, Jankowski, & Seleemah, 2021; Rohith Kumar et al., 2023).

Integrating viscous damping into a new building can significantly reduce seismic design intensity, potentially cutting it by half. This integration minimizes base shear by approximately one-quarter to one-third. Consequently, the structure requires smaller beams (member sections) and less reinforcement in its design. Seo et al. conducted an experiment to evaluate the collapse resistance of steel frames with and without viscous dampers. Their study revealed that energy dissipation, which enhances safety against failure, decreases as the reduction in force the building must withstand increases. However, in reinforced concrete (RC) structures, seismic design considerations extend beyond the size of structural components to include the arrangement of reinforcement bars in both horizontal and vertical orientations. These differences result in seismic performance outcomes that vary significantly from those of steel frames or composite frames made of steel and concrete (De Domenico & Hajirasouliha, 2021). The seismic response analyzes structures with various layouts, including columns, square and rectangular shapes, as well as the presence or absence of viscous fluid dampers (FVD) (Sharma, Parmar, Gautam, Choudhary, & Gohil, 2023). The study evaluates the effectiveness of FVD in enhancing structural performance under seismic loads by comparing various characteristics, such as displacement, base shear reduction, and variations in the time period, using SAP2000 software (Abdi, 2022). However, the study is limited to the application of a specific type of damper (FVD250) in the external corners of buildings, which may restrict the generalizability of the findings to other types of dampers or locations within buildings.

The study looks at how fluid viscous dampers (FVDs) may be used as passive control systems in multi-story frame structures to lessen the effects of earthquakes. It suggests that FVDs could be able to spread out seismic energy and control building vibrations without putting extra stress on the structure (Riaz et al., 2023). Buildings in areas where earthquakes are likely to happen have viscous dampers put in to reduce the shaking produced by high winds and earthquakes. In 2017, Landge and Joshi used ETABS 2015 software to look at several types of dampers (Nishanth, Swaroop, Jagarapu, & Jogi, 2020; Prajapati & Butala, 2020).

In the study, strong earthquake loads from Zone 4 are applied, and various aspects such as storey shear, storey drift, and displacement are compared. Among the different types of dampers, the viscous damper demonstrates the best performance in enhancing earthquake resilience (Prajapati & Butala, 2020).

Fluid viscous dampers are classified into two groups based on their mechanical behavior. The first group is the Maxwell rheological type, which operates by utilizing a flexible silicone liquid instead of oil (Venczel, 2023). Rather than passing through holes, the oil flows through the annular space between the piston head and the internal casing of the damper. In terms of structural implementation, viscous dampers are increasing at the fastest rate and have a high energy dissipation capacity. Despite the growing use of viscous dampers and their crucial role in improving a structure's seismic response, there is currently no consensus on the optimal placement technique for dampers along the height of a structure (Liu, Jing, Liu, Zhang, Han, Xiao, & Zhang, 2022).

Enhancing building resilience through advanced software analysis tools like ETABS and incorporating innovative seismic resilience designs, such as VFD, directly contributes to SDG 11 (Sustainable Cities and Communities) by improving urban safety and sustainability (Kynčlová, Upadhyaya, & Nice, 2020; Singh, 2023). This aligns with SDG 9 (Industry, Innovation, and Infrastructure), which emphasizes the importance of resilient infrastructure in promoting sustainable industrialization and fostering innovation (Sinha, Sengupta, & Alvarado, 2020; Sinha, Sengupta, & Saha 2020). In the construction sector, these efforts are vital for developing infrastructure that can withstand climate change and natural disasters, thereby reducing financial losses and ensuring public safety.

The piston rod is made from high-alloy stainless steel, which is polished to enhance its durability. This polishing extends the lifespan of the seal. To prevent the seal from bending or buckling under pressure, the rod is designed to be rigid (Moreira, Furtado, Buarque, Cardoso, Merlin, & Moreira, 2019; Volokitin, Volokitina, & Panin, 2022; Volokitina, Siziakova, Fediuk, & Kolesnikov, 2022). During operation, the cylinder must be capable of withstanding pressure while holding the fluid. It is typically made from steel bars or seamless steel tubes. The cylinder is designed to endure up to 1.5 times the maximum expected pressure during an earthquake (Hehn, 2021; Ma, Xing, Ong, & Hemmingsen, 2021; Usama, Gardezi, Jalal, Rehman, Javed, Janjua, & Iqbal, 2023).

The fluid used must be durable, non-toxic, fire-resistant, and heat-stable. OSHA requires a flash point of at least 200°F (Prugh, 2009). Silicone fluid is widely used due to its high stability, safety, and a flash point exceeding 650°F (Rogovyi, Korohodskyi, & Medvediev, 2021). The seal must have a minimum lifespan of 35 years without the need for replacement, ensuring it remains free from sticking or leakage. High-strength polymers, such as nylon or Teflon, are used in its construction (Romanos, Delgado‐Ruiz, & Sculean, 2019). The cylinder is divided into two pressure chambers by the piston head, which is attached to the rod and features an aperture between them. To facilitate temperature adjustment, the piston is often made from a material different from that of the cylinder (Sener, Yangaz, & Gul, 2020). The accumulator compensates for volume changes as the rod moves by using foam, a forcing piston, and accommodating fluid expansion due to temperature variations (Yang, Zhou, Wang, Xu, Yang, & Ye, 2023).

Unlike buildings with fixed foundations, incorrect modeling of damping can lead to significant issues, even if the behavior of the structure above remains predictable. Recent studies indicate that improper use of damping in time-history analysis can considerably dampen the response of a base-isolated structure. Viscous damping has traditionally been applied to the superstructure of the building (Amanti, Muraro, Roma, Chiessi, Puzzilli, Catalano, & Tallini, 2020; Gardezi, Ikrama, Usama, Iqbal, Jalal, Hussain, & Li, 2024; Pergalani, Pagliaroli, Bourdeau, Compagnoni, Lenti, Lualdi, & Verrubbi, 2020; Usama et al., 2023; Xu, Li, Liu, & Chen, 2019).

This paper provides a comprehensive analysis of the dynamic performance of a G+8 reinforced concrete building located in seismic zone 3 (indicates a region with moderate earthquake risk, requiring structures to be designed to withstand moderate ground shaking as per local seismic codes), with a focus on the impact of viscous dampers at different locations and forces. By comparing the structural response of fixed base buildings without dampers to those equipped with dampers, the study highlights the potential benefits of incorporating damping systems to enhance earthquake resistance. When examining height-wise damper placement, it is noted that for smaller buildings, the damping strength may fluctuate and deviate from the target, particularly on certain floors (e.g., the top floor) as the process progresses. The ultimate goal is to achieve a uniform level of damping across all floors to ensure stability, with adjustments made to the damping strength as needed. The findings of this study are expected to contribute to improved design practices and promote the adoption of advanced seismic mitigation techniques in high-rise building construction.

2. Research methodology

A multi-storey RC-framed structure is taken into consideration in this study. The effects of installing viscous dampers in a multi-storey reinforced concrete (RC) framed structure located in Zone 3 of Abbottabad. To assess the structural behavior, four distinct models are considered, each representing different configurations of the viscous dampers. The methods used are the Response Spectrum Analysis (RSA) and the Equivalent Static Load (ESL) Techniques in accordance with UBC 97.

These models are as follows: -

1. Building with fixed base (no damper).
2. Building with Viscous Damper at Corner bays of each story.
3. Building with Viscous Damper of different forces at corner bays of each story.
4. Building with Viscous Damper at middle bays of each story.

In order to examine the seismic performance of each model, factors including model period, storey displacement, storey drift, storey stiffness, and maximum overturning moment are examined.

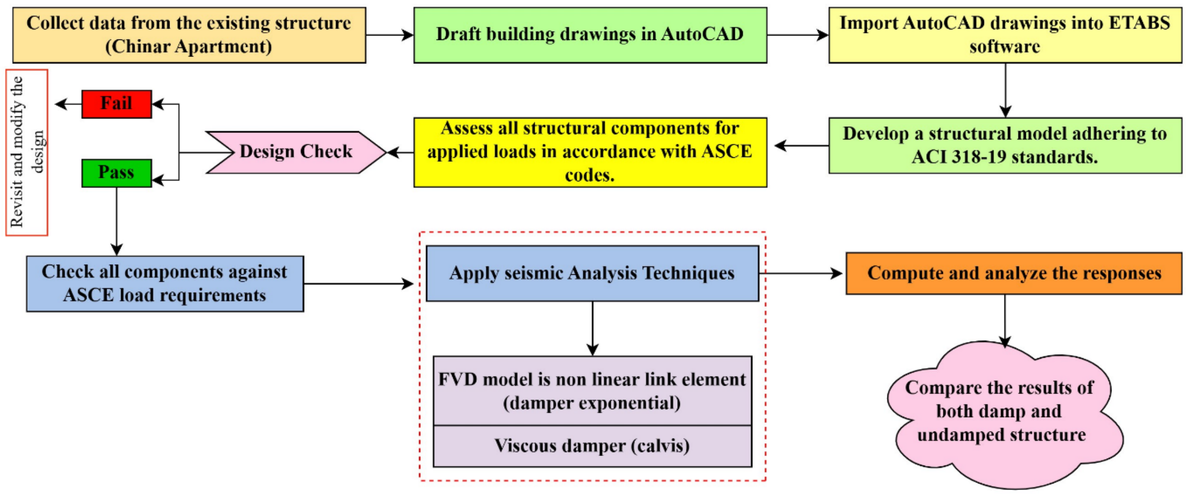

Fig.1 Research Methodology

2.1. Structural properties and modelling

This study examines a multi-storey reinforced concrete frame building. The structural properties and modelling of different parts or dimensions are shown in Table 1.

Table 1 – Structural Properties and Modelling.

Structural components	Dimensions
Building Type	Commercial Building
Building Location	Abbottabad KPK, Pakistan
Seismic Zone	Zone 3 (moderate seismic risk)
Plan dimensions	23.88mx31.39m
No of floors	9
X- axis length	23.88m
Y- axis length	31.39m
Floor height	3.66m
Total height of building	32.92m
Thickness of slab	0.1524 m
Size of Column	0.4572m x 0.4572 m
Size of Beam	0.3048 m x 0.4572 m
Zone	3
Importance factor(I)	1
Response Reduction Factor (R)	8.5 for SMRF
Type of Soil	(Very dense soil and soft rock)
Concrete in (Beam and Column)	20.684 MPa
Concrete in (Slab)	20.684 MPa

Grade of reinforcement	Grade 60, Yield Strength: 415 MPa
Poisson's Ratio (Steel)	0.3
Density (Concrete)	2400 kg/m³
Modulus of Elasticity (Concrete)	25 GPa
Modulus of Elasticity (Steel)	GPa

2.1.1. Material Models and Analysis

The materials and analysis types used in this study are crucial to accurately simulating the seismic performance of the reinforced concrete building. The concrete used for beams, columns, and slabs is modeled with a compressive strength of 20.684 MPa, exhibiting linear elastic behavior under low-stress conditions and transitioning to nonlinear inelastic behavior under higher seismic loads. The steel reinforcement bars, with a yield strength of 60 ksi, are represented using a bilinear stress-strain curve to account for strain hardening and ductile failure under seismic force

2.2. Modelling of dampers

- The dampers used to mimic these structures are manufactured in the USA by Taylor Devices Inc. A fluid viscous damper is a mechanical device used to dissipate energy in systems experiencing vibrations, shocks, or dynamic forces. It works by using the resistance created when a viscous fluid (such as silicone oil) flows through an orifice or narrow passage inside the damper. The manufacturer provides two types of fluid viscous damper (FVD) performance data, which can be utilized for structural modeling in ETABS 2021 (Extended Three-dimensional Analysis of Building Systems). The dampers used to mimic these structures are manufactured in the USA by Taylor Devices Inc. They provide two types of Fluid viscous dampers FVD with data-hat may be utilized for structural modeling in ETABS 2021. Fluid viscous dampers and lock-up devices clevis – clevis configuration.
- Fluid viscous dampers and lock-up devices – base plate configuration.

Below are the specifics of the clevis—base plate layout for fluid viscous dampers and lock-up devices.

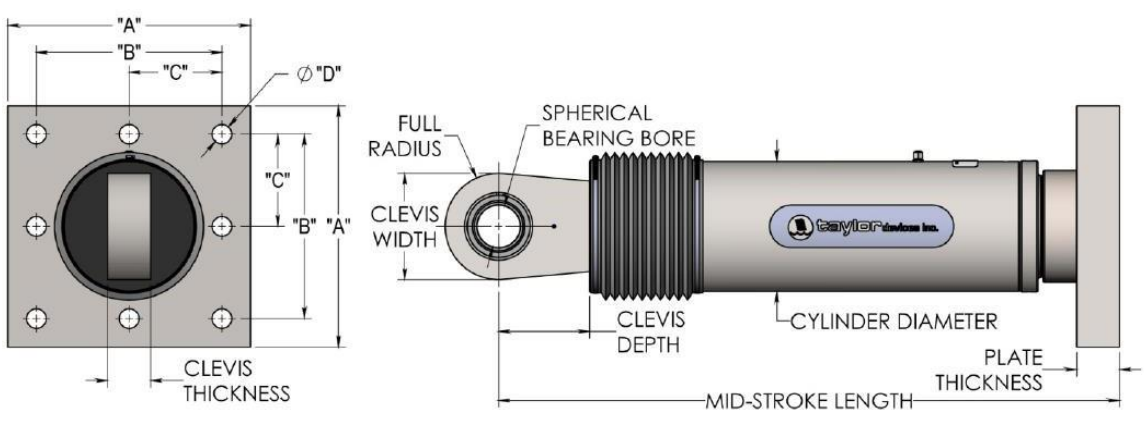

Fig. 2 Fluid viscous dampers & lock-up devices clevis – base plate configuration

Table 2 – FVD with Different Capacities Force (KN) (Scozzese, Gioiella, Dall'Asta, Ragni, & Tubaldi, 2021; Wang, Zhang, Chen, Hua, & Feng, 2024).

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)	Maximum cylinder diameter	Weight (kg)
250	17120	38.1	787	±75	43	100	83	33	114	44
500	17130	50.8	997	±100	55	127	102	44	150	98
750	17140	57.15	1016	±100	59	155	129	50	184	168
1000	17150	69.85	1105	±125	71	185	150	61	241	254
1500	17160	76.2	1205	±125	77	205	162	67	286	306
2000	17170	88.9	1346	±125	91	230	191	78	350	500
3000	17180	101.6	1441	±125	117	290	203	89	425	800
4000	17190	120.65	1645	±125	142	325	273	111	515	1088
6500	17200	152.4	1752	±125	154	350	305	121	515	1930
8000	17210	177.8	1867	±125	178	415	317	135	565	2625

Different buildings can benefit from using fluid viscous dampers with varying forces. "Forces" refer to the maximum force that the damper can generate during operation, representing its ability to resist motion and dissipate energy by producing force when subjected to relative velocity between its ends. This is not synonymous with structural strength or material properties but rather describes the damper's capacity to handle dynamic loads. Different buildings or structures require dampers with varying force capacities based on factors such as weight, height, and the intensity of seismic or wind forces they are designed to mitigate, ensuring the damper can meet the demands of the specific application. Smaller devices were utilized to initiate the analysis for the low-height structure being modeled. The program can receive this tabular data, which is presented above in Table 2. To incorporate an FVD into the structure, a new Damper-Exponential is added to the Link Property Data by defining it in Link properties (Scozzese, Gioiella, Dall'Asta, Ragni, & Tubaldi, 2021; Wang, Zhang, Chen, Hua, & Feng, 2024).

2.3. Properties of the viscous damper

The behavior of fluid viscous dampers is governed by a fundamental law that relates the damping force to the velocity of structural deformation. Mathematically, this is expressed as $Fd=Cv\alpha$, where Fd is the damping force, C is the damping coefficient, v is the relative velocity between the damper ends, and α is the velocity exponent. The velocity exponent α typically ranges between 0.3 and 1.0, depending on the damper's nonlinearity; a value of 1.0 indicates a linear viscous behavior. This relationship shows that the damping force increases proportionally to the velocity raised to the power α, allowing the damper to effectively dissipate energy during seismic events. By absorbing and dissipating kinetic energy, the damper reduces vibrations, thereby minimizing the stress and displacement experienced by the structure. The dampers used in this study exhibit near-linear viscous behavior and are designed to meet the performance requirements of seismic zone 3. Their ability to provide consistent energy dissipation significantly enhances the seismic resilience of the analyzed reinforced concrete buildings.

Model Numbers 17120 and 17130: Weight: 44 kg; 98kg; Force: 250 kg; 500 kg. (All FVD data from Taylor Devices Inc., a US-based company).

3. Models taken in the analysis

The 4 models taken in the analysis are as follows.

3.1. Building with fixed base (no damper)

The structure comprises eight columns of slab panels oriented along the Y-axis and five rows of slab panels oriented along the X-axis, as shown in Figure 3. It does not include a damper. The design features a total of 48 square panels. Figure 3 illustrates the connection between beams and columns. As depicted in Figure 3, the building consists of eight stories, with a 12-foot gap between each story. A 3D model showing all the connected structural elements is also available for reference. Gridlines 1–9 run parallel to the X-axis, while gridline A is parallel to the Y-axis.

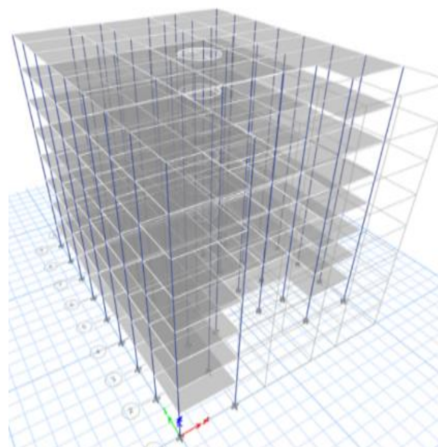

Fig. 3 Building with fixed base (no damper)

3.2. Building with viscous damper of same forces at corner bays of each story

As seen in Figure 4, this building has a damper made up of 48 square-shaped columns joined by beams, five rows of slab panels oriented in the X direction, and eight columns of slab panels oriented in the Y direction. According to the figure, the building has eight stories, each of which is 12 feet tall from the floor next to it. Every floor has a fluid viscous damper fitted at the corner with a 250KN capacity. The 3D perspective of every connecting structural part is also included in Figure 4. The Y axis is parallel to the A gridlines, while the X axis is parallel to the 1–9 gridlines.

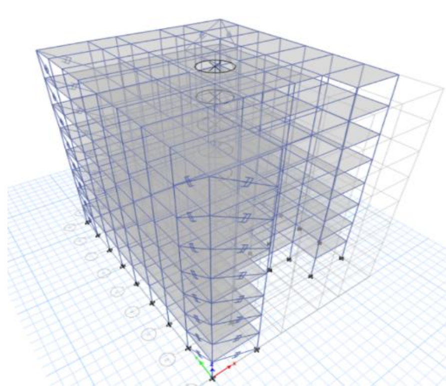

Fig.4 Building with viscous damper of same forces at corner bays of each story.

3.3. Building with viscous damper of different forces at corner bays of each story

The structure has a damper with eight columns of slab panels pointing in the Y direction and five rows of slab panels pointing in the X direction. The damper is supported by 48 square-shaped columns connected with beams, as illustrated in the figure. The building is eight storeys tall, with a 12-foot height difference between each floor. A fluid viscous damper (FVD) with varying capacities is installed at every floor-level corner. The damper's capacity in the first storey is set at 500KN, while the capacity is reduced to 250KN in the subsequent stories. With gridlines, the figure 5 displays a three-dimensional picture of every connected structural part. Parallels 1–9 to the X-axis and A to the Y-axis.

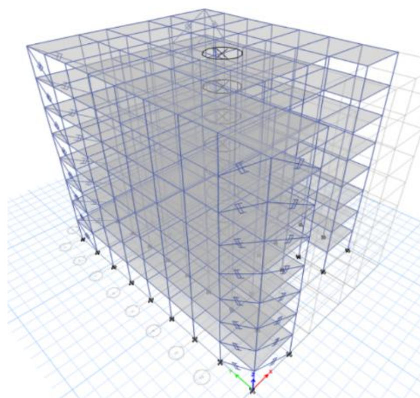

Fig. 5 Building with Viscous Damper of different forces at corner bays of each story

3.4. Building with viscous damper at middle bays of each story

This structure features a damper made up of 48 square columns joined by beams, with five rows of slab panels oriented in the X direction and eight columns of slab panels oriented in the Y direction. The structure of the building is raised for eight floors with a 3.66 m gap between each floor. The fluid viscous damper (FVD), shown in Figure 6, is positioned at the center of each floor level and has different capacities. The capacity for the first storey is 500 kN, while it is reduced to 250 kN for subsequent stories. Figure 6 also displays a three-dimensional perspective of all the connected structural elements. Gridlines A and 1–9, in turn, run parallel to the Y and X axes, respectively.

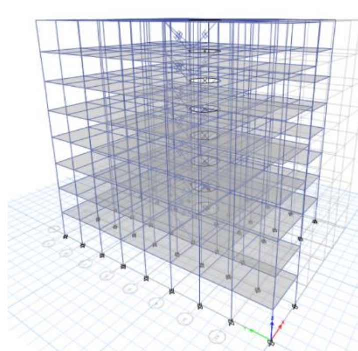

Fig. 6 Building with Viscous Damper of different forces at middle bays of each story

4. Results and Analysis

ETABS 2021 is used to conduct Equivalent Static Load (ESL) and Response Spectrum Analysis (RSA) in accordance with UBC 97 code. The graphs depicting the building's response integrate the following factors: time periods, storey drift, storey displacement, storey stiffness, and maximum overturning values. These are analyzed for different damper configurations, including a damper at the center, a damper at the corner with varying forces, a damper at the corner, and the scenario with no damper.

4.1. Equivalent Static Load (ESL)

Equivalent Static Load (ESL) is a simplified method used in structural engineering to account for the dynamic effects of seismic forces on a building. Instead of analyzing the complex and time-consuming behavior of a structure during an earthquake, ESL represents the earthquake's impact using a static load. This static load is calculated based on the building's characteristics, such as its height, mass, and stiffness, which influence how it would respond to seismic forces.

ESL is often used when more detailed analysis methods, like Response Spectrum Analysis (RSA), are not necessary or practical. RSA is a dynamic method that calculates how a building will respond to different ground motions by considering the building's natural vibrations (frequencies and mode shapes). However, in many cases, a simplified approach using ESL is sufficient to ensure the building's safety.

To substitute different ground motions with ESL or RSA, engineers typically apply a factor based on the expected intensity of the earthquake and the building's structural properties. This allows them to represent the earthquake's effects as a static load, making the analysis simpler and faster, but still effective for ensuring the structure's resilience in an earthquake.

4.2. Natural period

Table 3 – Maximum natural periods.

Model	Natural Time Period (in Seconds)
Building with No damper	1.514
Building with Corner damper	1.153
Building with Corner damper with Different force	1.003
Building With Middle Damper	1.335

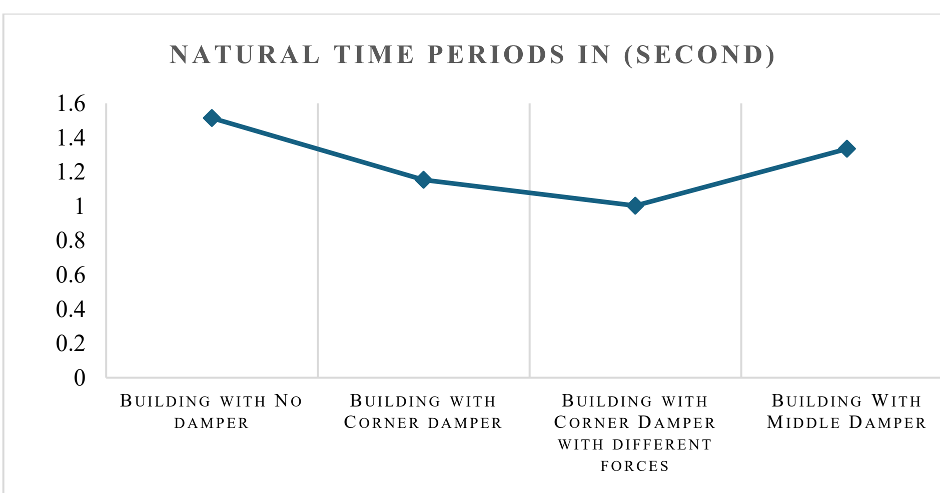

Fig. 7 Natural periods of different models

The maximum natural time periods for buildings without dampers, buildings with dampers at corners, buildings with dampers at corners subjected to varying forces, and buildings with dampers at the center subjected to varying forces are shown in the Figure 7. It suggests that buildings with corner dampers with varying forces are superior and have a lower failure rate than those without them. A smaller natural period indicates a quicker response to dynamic forces, typically associated with higher stiffness and better resistance to oscillationsFigure 7 demonstrates that buildings with corner dampers that are impacted by different forces have a shorter natural period. This makes them more stable and lowers the strength of the vibrations. These structures are less likely to fail because they can handle shifting loads better than buildings without dampers. Dampers make the structure operate better and survive longer.

4.3. Maximum storey displacement

Table 4 shows the most movement that may happen in the storey when an equivalent static load (ESL) is applied in the X and Y dimensions. It looks at a building without dampers, one with dampers at the corners, one with corner dampers that are pushed by various forces, and one with center dampers that are pushed by different forces. The study shows that buildings with corner dampers that are put under different forms of stress work far better and are less likely to break than structures without dampers.

Table 4 – Maximum storey displacement due to ESLx and ESLy.

Model	Maximum Storey Displacement (m)
Building with No damper	0.045724
Building with Corner damper	0.0317
Building with Corner damper with Different Forces	0.026
Building with Middle damper	0.035

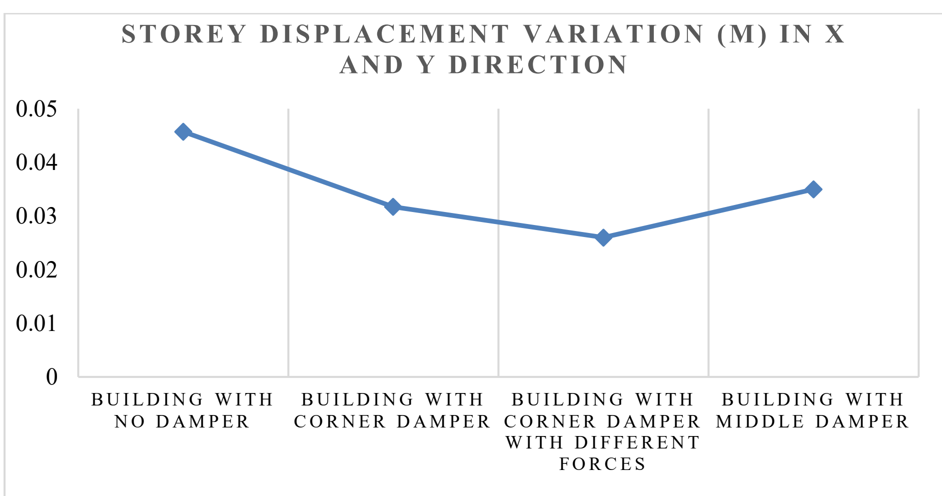

Fig. 8 Maximum storey displacement of different models

Figure 8 shows the most storey movement between buildings without dampers, buildings with dampers at the corners, buildings with dampers at the corners with different capacities, and buildings with dampers at the center with different forces when an equivalent static load (ESL) is applied in the X and Y directions. It shows that buildings with dampers at the corner with different forces are much better and have less chances of failure as compared to buildings without dampers.

4.4. Maximum storey drift

Table 5 – Maximum storey drift due to ESLx and ESLy.

Model	Maximum Storey Drift (m)
Building with no damper	0.000685
Building with corner damper	0.00040
Building with corner damper with different forces	0.000355
Building with middle damper	0.00044

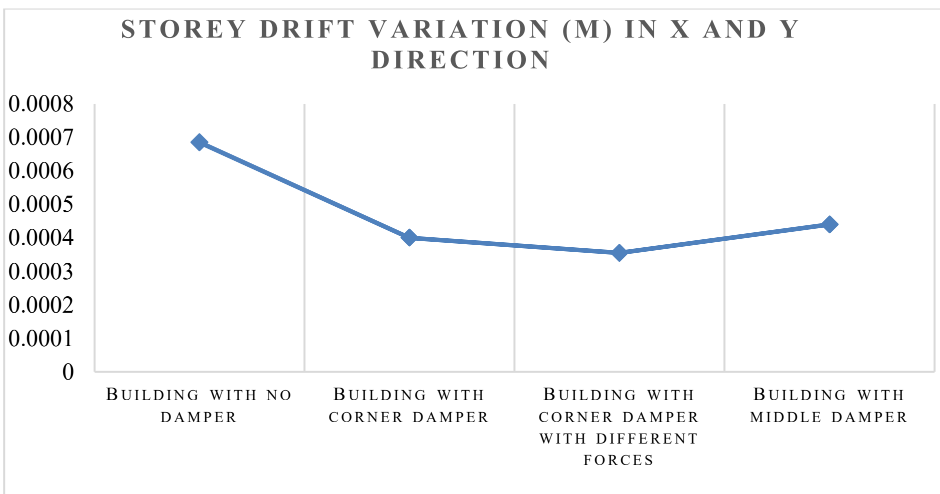

Fig. 9 Maximum storey drift of different models

When a structure is under stress, as from wind or earthquakes, it might shift sideways. This is called drift. When drift gets too high, it might generate too much distortion, which makes the building's structure weaker and makes it more prone to fail. Dampers help keep the building from moving by managing drift and storing and releasing energy. Dampers put in key spots, like the corners or the center of the building, let it stand up to these stresses better, which keeps it from bending too much.

Table 5 and Figure 9 illustrate that buildings with corner dampers that are exposed to varied forces fare a lot better than buildings without dampers. These damped constructions have lower drift values, which implies that the parts of the structure are under less stress and are less prone to break, for example, via cracks or joint failures. Buildings with dampers are less prone to fail because they stop drift. This demonstrates how vital dampers are for keeping structures stable while they are under dynamic pressures.

4.5. Storey stiffness

Storey stiffness is a measure of a building's ability to resist deformation, such as bending or swaying when it is withstood against the external forces like wind or earthquakes. A building with higher stiffness is more rigid and resists movement, reducing the chance of structural failure. Conversely, lower stiffness allows more movement, increasing the risk of failure under dynamic loads. In this context, buildings with higher stiffness, such as those with corner dampers, perform better by absorbing energy from external forces, reducing excessive movement, and lowering the risk of failure. Therefore, more stiffness (from dampers) translates to better stability and a lower probability of structural damage.

Table 6 – Maximum Storey Stiffness due to ESLx and ESLy.

Model	Storey Stiffness (N/m)
Building with No damper	6.10×10^{8}
Building with Corner damper	5.725×10^{8}
Building with Corner damper with Different Forces	5.018×10^{8}
Building with Middle damper	5.315×10^{8}

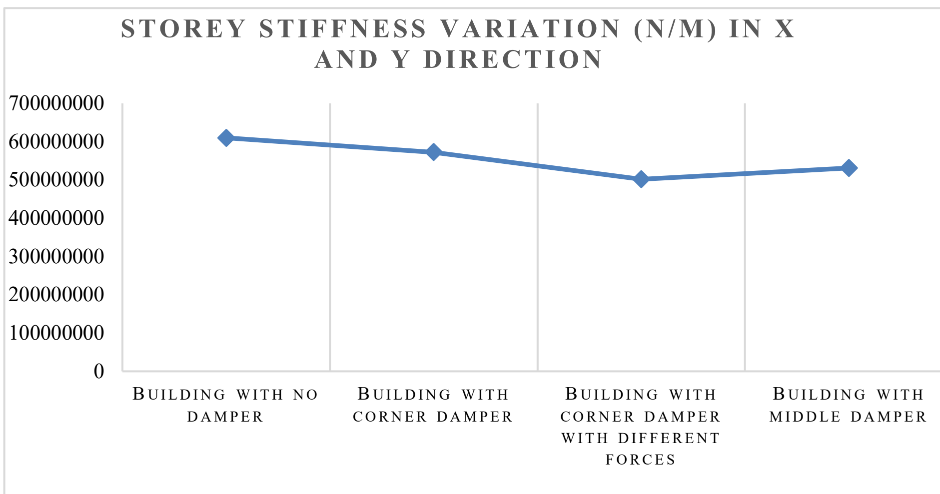

Fig. 10 Storey stiffness of different models

Table 6 illustrates the storey stiffness resulting from the application of an equivalent static load (ESL) in both the X and Y directions. Storey stiffness refers to the building's resistance to deformation under external forces. A higher stiffness reduces the likelihood of swaying or bending, while lower stiffness makes the building more susceptible to movement. The table compares buildings without dampers, with corner dampers, with corner dampers subjected to varying forces, and with center dampers under varying forces. The analysis shows that buildings with corner dampers subjected to varying forces perform significantly better, with a reduced risk of failure. The dampers help absorb and dissipate energy from external forces, thus reducing excessive movement and minimizing the potential for structural damage.

Figure 10 displays the maximum storey stiffness for ESL application in the X and Y directions for these building configurations. It shows that buildings with dampers at the corners, especially when subjected to varying forces, exhibit higher stiffness and lower chances of failure compared to those without dampers.

4.6. Overturning moment

The greatest overturning moment brought on by applying an equivalent static load (ESL) in the X and Y directions is shown in the Table 7. It looks at a building without dampers, one with dampers at the corners, one with corner dampers that are influenced by different forces, and one with center dampers that are impacted by different forces. The study demonstrates that buildings with corner dampers that are under different kinds of stress do far better and are less likely to fail than buildings without dampers.

Table 7 – Maximum Overturning Moment due to ESLx and ESLy.

Model	Overturning Moment (N/m)
Building with No damper	1.405×10^9
Building with Corner damper	1.3715×10^9
Building with Corner damper with Different Forces	1.347×10^9
Building with Middle damper	1.360×10^9

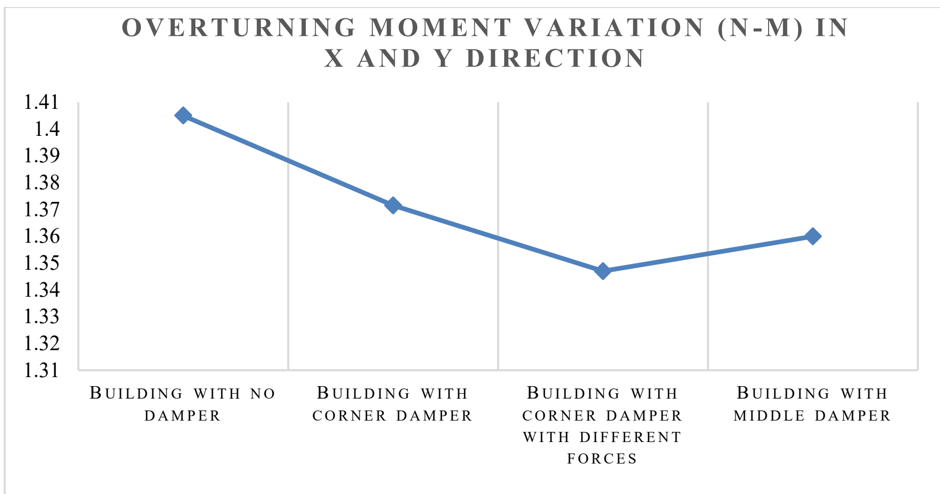

Fig. 11 Overturning moment of different models

Buildings without dampers, buildings with dampers at corners, buildings with dampers at corners with varying forces, and buildings with dampers at the center with varying forces are shown in the Figure 11 as having the greatest overturning moment while applying equivalent static load (ESL) in the X and Y directions. It indicates that buildings with dampers at the corner with different forces have more moments as compared to buildings without dampers.

4.7. Response spectrum analysis

Response Spectrum Analysis (RSA) is a method used to predict how a structure will respond to seismic forces during an earthquake. Ground motion during an earthquake involves vibrations at various frequencies, which affect a building differently depending on its natural frequencies. RSA simplifies this by breaking down the ground motion into frequencies and analyzing the building's response to each one. The result is a Response Spectrum, a graph that shows the maximum structural response at each frequency.

Engineers use Equivalent Static Load (ESL) or RSA to apply seismic forces. ESL replaces seismic forces with a static load corresponding to the peak response predicted by the response spectrum, typically for low-seismic regions or simple structures. RSA substitutes different ground motions, decomposed into spectral components, to evaluate the structure's response under various seismic conditions.

4.8. Maximum storey displacement

Table 8 – Maximum storey displacement due to RSAx and RSAy.

Model	Maximum Storey displacement (m)
Building with no damper	0.057
Building with corner damper	0.046
Building with Corner damper with different forces	0.036
Building with middle damper	0.039

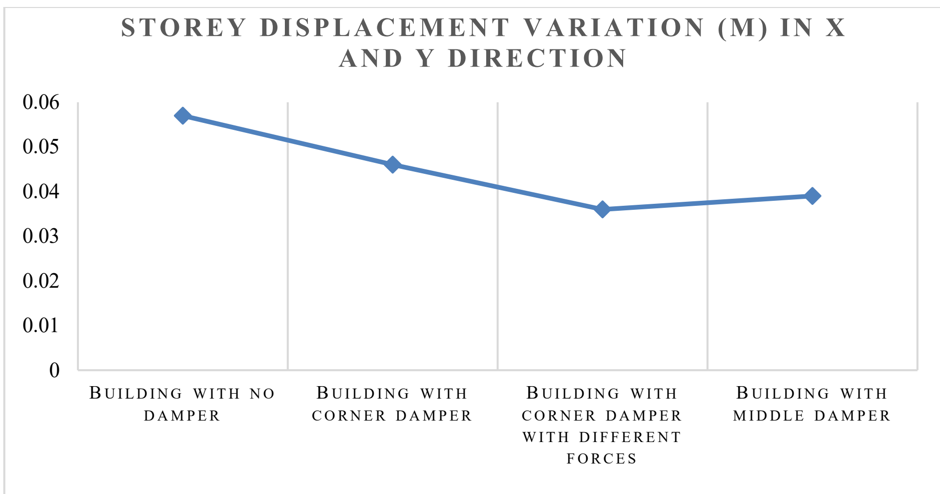

Fig. 12 Maximum storey displacement of different models

Table 8 illustrates the maximum storey displacement from a Response Spectrum Analysis (RSA) in the X and Y directions, comparing buildings with and without dampers. It evaluates buildings with dampers at the corners, buildings with dampers at the corners subjected to varying forces, and buildings with center dampers under different forces. The analysis shows that buildings with corner dampers, especially under varying forces, perform significantly better, with a reduced risk of failure compared to buildings without dampers, as also depicted in Figure 12.

4.9. Maximum storey drift

Table 9 – Maximum storey drift due to RSAx and RSAy.

Model	Maximum Storey Drift (m)
Building with no damper	0.12
Building with corner damper	0.077
Building with corner camper with different forces	0.071
Building With middle damper	0.080

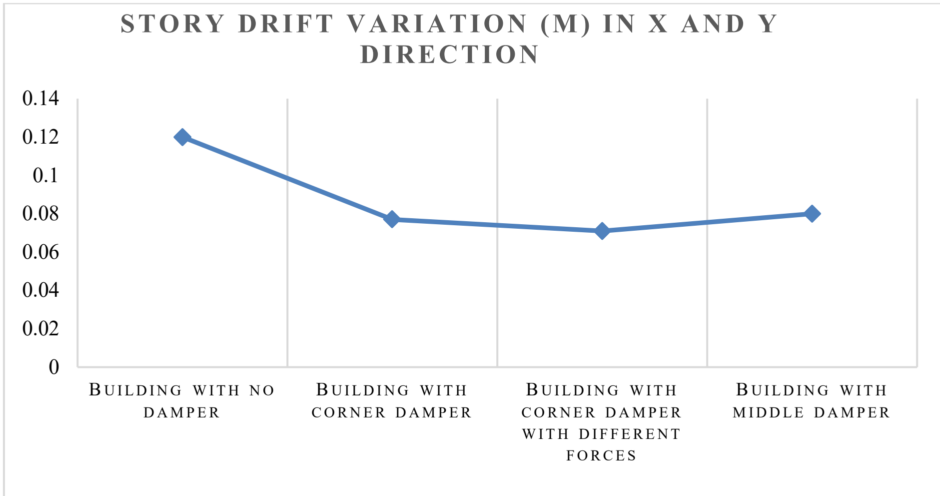

Fig. 13 Maximum storey drift of different models

Table 9 illustrates the maximum storey drift under the Response Spectrum Analysis (RSA) in the X and Y directions. It compares buildings with different damper configurations: without dampers, with corner dampers, with corner dampers subjected to varying forces, and with center dampers under varying forces. The analysis shows that buildings with corner dampers subjected to varying forces perform significantly better, exhibiting a lower risk of failure compared to buildings without dampers. The corresponding results are also presented in Figure 13.

4.10. Storey stiffness

Table 10 – Maximum storey stiffness due to RSAx and RSAy

Model	Storey Stiffness (N/m)
Building with no damper	6.157×10^{8}
Building with corner damper	4.387×10^{8}
Building with corner camper with different forces	4.404×10^{8}
Building With middle damper	5.156×10^{8}

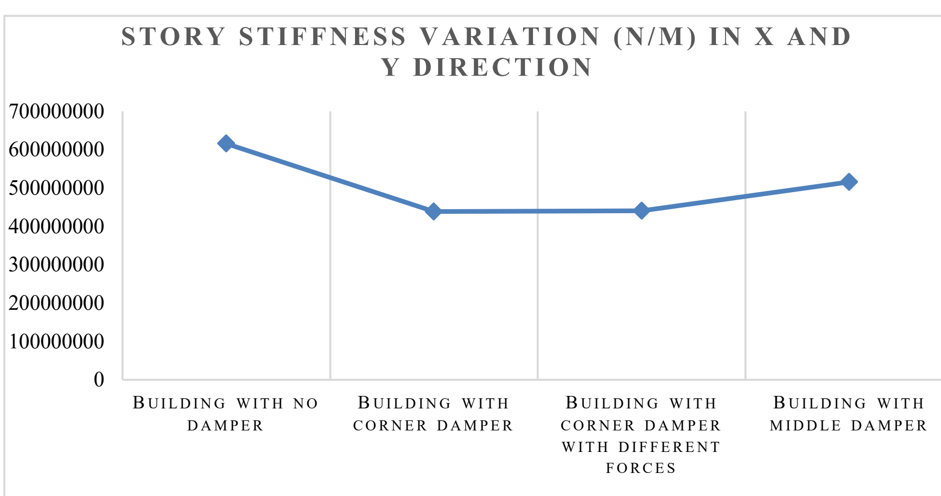

Fig. 14 Storey stiffness variation of different models

Table 10 and Figure 14 illustrate how rigid the storey of buildings that were examined with Response Spectrum Analysis (RSA) was in the X and Y axes. The research looks at four different situations: a structure with no dampers, a building with dampers at the corners, a building with corner dampers that change forces, and a building with center dampers that change forces. The results show that buildings with corner dampers work far better than buildings without dampers, especially when they are put under diverse kinds of stress. They are more rigid and less likely to break.

4.11. Overturning moment

Table 11 – Maximum overturning moment due to RSAx and RSAy

Model	Overturning Moment (N/m)
Building with no damper	1.405×109
Building with corner damper	1.361×109
Building with corner camper with different forces	1.33187×109
Building With middle damper	1.341×109

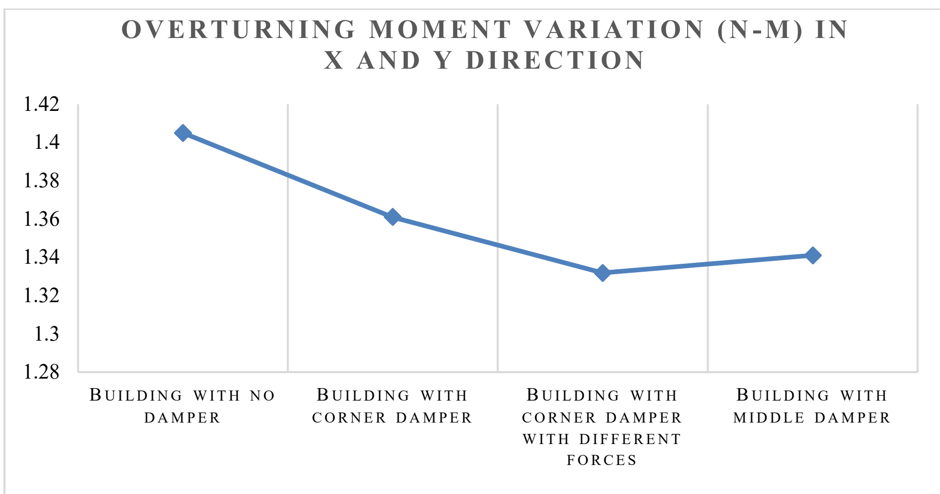

Fig. 15 Overturning moments of different models

The Response Spectrum Analysis (RSA) in both the X and Y directions looks at different building layouts, such as those with and without dampers, those with corner dampers that are affected by different forces, and those with center dampers that are influenced by different forces. The study indicated that buildings with corner dampers that are exposed to varied loads fare much better and are less likely to fail than buildings without dampers. Figure 14 illustrates the greatest moment of overturning for a few different configurations. It indicates that buildings with corner dampers under different loads have more moments than ones without dampers.

4.12 Comparison with other analysis methods

The major ways this study meets UBC 97 standards are Equivalent Static Load (ESL) and Response Spectrum Analysis (RSA). But it's important to talk about how these methods are like other popular ones, such adaptive pushover, non-adaptive pushover, and nonlinear time-history analysis, so we can have a clearer grasp of the whole picture.

Adaptive pushover analysis changes the load patterns in real time during the study to take into account how the structure's stiffness and forces change when it bends in a way that isn't straight. This method is ideal for watching how viscous dampers change multi-story reinforced concrete (RC) structures over time. Non-adaptive pushover analysis, on the other hand, thinks that the load pattern stays the same the whole time. This makes things straightforward, but it doesn't help you understand how forces change when the structure gets stiffer or when dampers are added.

When it comes to earthquakes, nonlinear time-history analysis gives the most thorough picture of how a building reacts by modeling how ground vibrations vary over time. This approach is fantastic for working out how dampers modify energy dissipation and dynamic behavior, but it takes a lot of computing power and very accurate input data, including recordings of ground motion and damping characteristics.

This study uses ESL and RSA to quickly look into how different damper settings affect seismic performance measures such storey drift, displacement, stiffness, and overturning moments. These methods strike a balance between computational efficiency and accuracy, making them suitable for analyzing a nine-storey RC-framed structure under moderate seismic risk (Zone 3). While adaptive pushover and time-history analyses could provide deeper insights into nonlinear behavior and damper optimization, the selected methods are sufficient for demonstrating the enhanced seismic performance provided by viscous dampers in terms of reducing drifts, displacements, and natural periods.

5. Conclusion

The study compared the outcomes of Equivalent Static Load (ESL) and Response Spectrum Analysis (RSA) for buildings in Abbottabad (zone '3') using different damper configurations. The findings are summarized as follows:

- Buildings without dampers have a longer natural period compared to damped models. Viscous dampers reduce the natural period by 37.5%, improving seismic response, particularly in terms of reducing vibration and structural movement.
- The ESL and RSA techniques showed that buildings with corner dampers at varying force Capacities locations had significantly lower storey drifts 48.14% reduction, and 41.45% safer than those without dampers.
- Dampers placed at corner locations with different forces capacities reduced displacement by approximately 41.6% and 35.5%, proving effective under seismic conditions.
- Buildings with corner dampers also experienced lower storey stiffness and overturning moments, with reductions of 16.7% and 24.7% in stiffness, and 4.7% to 5.7% in overturning moments, compared to those without dampers.

Practical Implementation

Implementing viscous dampers in reinforced concrete multi-storey buildings requires excellent care. To begin with, research and analysis must be conducted to comprehend the distinctive challenges and requirements of the building and to select appropriate dampers. Then, trained experts install the chosen dampers and test them a lot. After that, they are watched over and taken care of to make sure they stay healthy. This process makes the building stronger and safer, which protects people and objects safe from possible dangers.

Acknowledgments

Grateful to Almighty Allah for His grace enabling this work, we sincerely thank our supervisor Engr. M. Jamal Butt for his pivotal guidance, the evaluation committee for their invaluable feedback, and our family for their constant support and encouragement.

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