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Analytical Study on the Use of Dampers Retrofitted in Buildings to Enhance Their Seismic Resilience

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Abstract

Even during minor seismic events, buildings and towering structures are destroyed by earthquakes. For structures to withstand seismic vibration, they must be strengthened to the greatest extent feasible. Seismic retrofitting refers to the process of enhancing the earthquake resistance of buildings with external connections. Traditional seismic retrofitting techniques are frequently inefficient and costly. The phrase "energy dissipation" is commonly used. Significant advances have been made in the field of energy dissipating devices. New retrofitting techniques and dampers have emerged in recent years. Dampers are retrofitted devices that both increase a structure's resistance to seismic vibrations and dissipate energy. In this investigation, a building model was fitted with three distinct types of dampers and then subjected to seismic loading. To determine the most effective attenuation configuration, the responses and outcomes of all cases were recorded and compared. A model of a thirty-story building was constructed in SAP software, and all specified loads were applied to it. Accelerogram were obtained following an analysis of time history without dampers. Different responses, including storey displacements, drifts, and pseudo spectral accelerations, were obtained using the same retrofitting procedure on the same structure. Responses for three distinct damping configurations were obtained. Time history analysis was repeated for each of the three configurations. Comparing the retrofitted structure to the unmodified structure, the seismic response was drastically reduced. The analysis revealed that seismic responses were substantially reduced by retrofitting.

Keywords
Dampers, energy, retrofitting, seismic, structural modeling, vibration.

1. Introduction
Earthquakes are destructive to structures and cause significant damage. Recent earthquakes around the world have made people worry about the stability of buildings, especially tall ones. The structural safety of these buildings is very important. Buildings that weren't built with earthquakes in mind are more likely to get damaged during an earthquake.

This is very risky. Seismic retrofitting is the process of making a building resistant to shaking from earthquakes. We all know that no building can be totally safe from earthquakes. Instead, buildings must be able to stand up to vibrations to reduce damage and loss. Before 1970, there were no seismic rules, so buildings weren't made with earthquakes in mind. Many studies and research have been done all over the world to try to solve this problem (Abdeddaim et al 2017)

The term "seismic retrofitting" refers to the process of making changes to buildings or structures that are already there or are on the list. Retrofitting makes a building more resistant to earthquake and seismic vibrations. Retrofitting is becoming more common because of the state of the world and the number of earthquakes. Because earthquakes cause a lot of damage to both people and things, it is important to reduce the risk of earthquakes. So, reducing the damage as much as possible is very important. Structures built before seismic load provisions were added to design rules are not made to withstand earthquakes. These buildings could be damaged in an earthquake. Seismic retrofitting is the process of putting things on the outside of a building to make it more resistant to earthquake shocks. It should be mentioned, though, that a structure can only be built to be as resistant to earthquakes as possible; no structure can be built to be earthquake proof (Mortezaei et al 2010). The significance of retrofitting buildings with dampers lies in its ability to address critical issues in structural engineering and construction. Here are some of the key elements that make such a study unique and significant:

1. Enhanced Structural Resilience.
2. Sustainability and Environmental Impacts.
3. Long Term Performance Monitoring.

The potential benefits of retrofitting buildings with dampers include the ability to advance structural engineering practices, improve building resilience, promote sustainability, and address real-world challenges in preserving and enhancing the built environment (Wilkinson et al 2006).
Types of dampers used the study are as follows:

Diagonal Dampers: diagonal dampers, also known as diagonal braces or diagonal bracing systems, are structural elements used in construction and engineering to provide stability and reduce lateral movement in buildings and structures. They are typically diagonal members (such as rods or beams) that connect different parts of a structure in a diagonal fashion, forming a crisscross pattern. These dampers are commonly used in tall buildings and other structures to withstand various forces, including wind loads and seismic forces (Wang and Hsin 2011). Major functions of diagonal dampers:

1. Structural Stability: Diagonal dampers help distribute and transfer lateral forces, such as wind or seismic loads, from one part of the structure to another, reducing the overall sway and movement of the building. This enhances the building's stability and structural integrity.
2. Energy Dissipation: In the event of an earthquake or strong wind, diagonal dampers absorb and dissipate energy, reducing the structural impact of these forces. This protects the structure and its occupants from damage or discomfort.
3. Vibration Control: Diagonal dampers can also be used to control vibrations in buildings, which is especially important in high-rise structures. These dampers improve occupant comfort and safety by reducing excessive sway and movement.
4. Reducing Dynamic Amplification: In seismic design, diagonal dampers can help mitigate the dynamic amplification of forces that can occur during an earthquake, preventing excessive motion and structural damage.

The specific design and placement of diagonal dampers depends on the structural requirements of a building or structure as well as the anticipated loads. Viscous dampers, friction dampers, and tuned mass dampers are common types of diagonal dampers, each with its own mechanism for dissipating energy and controlling lateral movement (Monir et al 2013).

Cross Dampers or X Shaped Dampers: Cross-shaped or X-shaped dampers are a type of structural bracing used in construction and engineering to improve the stability and strength of buildings and structures. They are also known as X-braces or X-bracing systems. These dampers are typically made up of diagonal members that intersect to form a "X." They are strategically placed within a structure to provide lateral force resistance against wind loads and seismic forces (Zhou et al 2015). Major functions of Cross or X Shaped Dampers include the following:

1. Lateral Force Resistance: By providing diagonal bracing in multiple directions, cross-shaped dampers help distribute and counteract lateral forces such as those caused by wind or seismic activity. This helps to keep the building or structure from swaying and moving too much.
2. Structural Stiffness: X-bracing systems increase the overall stiffness of the structure, which improves its ability to withstand different types of loads without deforming or collapsing.
3. Reducing Dynamic Amplification: In seismic design, X-bracing systems can help reduce dynamic amplification effects that can cause structural damage during an earthquake. They help to mitigate this effect by providing additional lateral support.
4. Increasing Structural Integrity: These dampers contribute to a building's overall structural integrity and safety by increasing its resistance to lateral movements, protecting both the structure and its occupants.

The design and placement of cross-shaped dampers are determined by the specific needs of the building or structure, as well as the anticipated loads. Engineers can use a variety of materials and configurations for X-bracing systems to optimize their performance in a variety of situations (Di et al 2021).

Inverted V-Shaped Dampers: Inverted V-shaped dampers, also known as inverted V-braces or inverted V-bracing systems, are a type of structural bracing used in construction and engineering to improve building and structure stability and resistance to lateral forces such as wind loads and seismic forces. These dampers are made up of diagonal members that meet in the shape of an inverted "V," which looks like an upside-down letter "V" (Di et al 2021).

Major Functions of inverted V shaped Dampers:

1. Lateral Force Resistance: Inverted V-shaped dampers are strategically placed within a structure to distribute and counteract lateral forces like wind or seismic activity. They offer diagonal bracing in multiple directions, assisting in the prevention of excessive sway and movement of the building or structure.
2. Structural stiffness: These dampers increase the overall stiffness of the structure, which improves its ability to withstand different types of loads without deformation or structural failure.
3. Reducing Dynamic Amplification: Inverted V-shaped dampers in seismic design can help mitigate the dynamic amplification effects that occur during an earthquake, lowering the risk of structural damage.
4. Enhancing Structural Integrity: Inverted V-shaped dampers contribute to the overall structural integrity and safety of a building by increasing resistance to lateral movements, protecting both the structure and its occupants.

The specific design, material selection, and placement of inverted V-shaped dampers are determined by the structural requirements of the building or structure as well as the expected loads. Engineers can optimize the performance of inverted V-bracing systems by using different configurations and sizes (Di et al 2021).

2. Objectives

The main objective of this study is to find the effectiveness of various damper configurations with the aim of reducing the seismic responses of existing buildings with the help of seismic retrofitting. This study aims towards comparing the performances of three types of dampers (diagonal, cross-shaped and inverted V-shaped) and analyzing the impact on the storey displacement, drift and pseudo spectral acceleration under seismic load. A thirty storey building is designed using SAP software. The designed building is then fitted with the different types of dampers and subjected to different loading conditions to achieve the most effective damping configuration by reducing structural vibrations to enhance the resilience of building to improve structural stability and safety.

3. Literature Review

Concerns have been made about how stable structures and buildings are during quakes because the safety of the people inside depends on how stable these structures are. In the event of an earthquake, buildings that don't follow seismic rules can be very dangerous. Both people and things are in danger from these. Structures that were built without following the seismic code must be strengthened so they can survive future earthquakes. Seismic modification is the process of making a building less likely to shake during an earthquake. Buildings that were made before 1970 have to be fixed up because there were no earthquake rules in place at the time. As these can do a lot of damage to people and things during an earthquake. Structures, especially ones that weren't built according to the seismic code, need to be made stronger so they can stand up to future shocks (Li et al 1995).

The main goals of retrofitting are to make buildings stronger against earthquake vibrations and forces, to make buildings more flexible against earthquake vibrations and forces, and to mix all these things (Villaverde and Roberto 2009).

Retrofitting Using Dampers: Linear viscous dampers work by letting fluid run through specially shaped orifices to create damping forces that are proportional to the speed. When compared to how the same structure responded without dampers, adding dampers to a steel model structure cut interstorey drifts, floor accelerations, and storey shear forces by two to three times. Both standard and new ways were used to make changes to RCC structures. Base isolators and techniques for getting rid of energy were some of the newer ways. Modern methods were found to be successful at lowering the vibrations caused by earthquakes. Several retrofitting methods based on the way dampers are set up have been made and tried. There are four different kinds of dampers (Villaverde and Roberto 2009). The 4 types are discussed below.

Viscoelastic Dampers: These were made by the 3M Company, and they are made of layers of viscoelastic plastics that are stuck together. At first, these were used to stop the wind from making noise. The shear viscoelastic layers control how these viscoelastic dampers work (Wang et al). With the help of viscoelastic dampers, a five-story steel-framed building was put through vibration tests. Results were better than expected. It was found that more damping ratios were needed to bring down the structure's maximum reaction to the level that was wanted. On the full-size model, it was found that the dampers placed in the structure cut down vibrations to the level that was wanted (Li et al 1995). These made the brace stiffer when the frequency was low, and the brace was already stiff (Rüdinger 2007). The reactions from viscoelastic dampers were used to study and test the reliability of passive devices that get rid of energy (Mortezaei et al 2010).

Friction Dampers: Friction dampers take in the energy that comes from earthquake waves and use friction to get rid of it. This is put in place where the cross braces meet. When a seismic stress is put on the structure, the compression braces buckle, which causes the friction joints to slip. When the four links are moved, the compression brace moves. This is what it means for energy to be lost. The only time friction dampers work is when there is stress (Al Ansari 2011). RCC structures with lightly reinforced concrete exterior and inner walls showed that when a thin wall was exposed to lateral seismic load, it behaved more like a double curve than a cantilever (Mortezaei et al 2010). How buildings react to earthquakes when dampers are put in the cutout parts of the walls. With finite elements, the time history analysis was used. It was seen that this method could make a building better at handling earthquakes (De La Llera 2005).

Tuned Mass Dampers: TMDs, which stand for "tuned mass dampers," are springs with weights that can move. These are mostly used to stop tall, light buildings from drifting in the wind. Tall buildings with 8 to 10 stories or more use a similar design to stop shaking from earthquakes. Because these buildings are often damaged by vibrations caused by earthquakes (Filiatraut and Andre 2013). The FEMA 273 suggestions for dampers are an example of a structure that worked well and responded well to earthquake vibrations when it was flexible (Sladek 1983).

Fluid Viscous Dampers: Fluid viscous dampers (FVD) are made of viscous fluids that soak up earthquake energy and release it as heat. An experiment and a detailed study were done on how buildings with FVD react to a quake. It was found that different methods for getting rid of energy had very different effects. The purpose of the project was to find out how structures with dampers work. By modelling earthquake vibrations on the models, mathematical models were made and tested. With the help of an active control system, it was found that FVD were more effective at getting the benefits (Wang and Hsin 2011, Narkhede et al 2014). Using both linear and nonlinear FVD, the seismic reactions of asymmetric structures were investigated. In this study, it was found that nonlinear dampers had lower peak forces than linear dampers. This made the corresponding damping lower at speeds much higher than the design speed (Obaidat et al 2011, Banerji et al 2011). To show frame drift, a dynamic study of FVD and its effects on steel moment was done. The research was done on models of multi-story buildings that were made with the goal of getting rid of seismic vibrations so that the dampers could be tested. In each floor's bay, dampers were put in place. With these, damping with critical ratios of 5%, 10%, 20%, and 30% could be made. There were turn ground motions and a gradual dynamic analysis done on these models. Between-story drift was found to be well controlled by FVD in steel moment frames (Divleli 2007). More research showed that some of these movements can be stopped by adding dampers to structures that are already there.

4. Methodology

A 30 storey building was designed for the study. The study's methodology has been developed with definite loadings that are applied to the structure. A variety of set-ups and loading situations have been used. The basic structure and its variations were subjected to a time history analysis. For various accelerations and deflections, different results were obtained. The results were obtained in cases, with and without dampers. The structure's planned design was to retrofit it with various types of dampers and test damping ratios. The results attained for the retrofitted structure show a significant reduction in drifts and accelerations when compared to the structure that was not fitted with dampers. The findings also show that seismic responses have decreased to a great extent. It was also discovered that the use of dampers reduced the damping coefficient. Three cases were created and researched. SAP software was used to create a multi-story building model. A variety of loads were assigned to the structure, including earthquakes. One model was left alone, while the others were fitted with types of dampers and subjected to a time history analysis.

The structure was modelled with various damper configuration scenarios in mind. Loads, including dead load, live load, and earthquake loads, were applied to it, as well as self-weight. Loads were applied along the X axis and Z axis at storey level. Following that, a time history analysis was done on all 3 cases, and an accelerogram was obtained for all. The first was for a structure not fitted dampers, followed by structures that were fitted dampers. Time history analysis was performed for all cases, and a comparison of the obtained responses such as pseudo spectral acceleration, storey drift, and so on, between the retrofitted and non-retrofitted structures was done. The best result was discovered after examining three different configuration options. Everything was done in accordance with the Euro Code.

Table 1. Design details of the building models.

Total height of the building	90 m
Each floor-to-floor height	3m
Grade of concrete	C30
Grade of steel	500
Live load on the slab	3 KN/m^2

All loads were applied, including dead, live, and earthquake loads. At the storey level, loads were applied along the X and Z axes. Figure 1 shows a 3D view of the plan and elevation of the building model created using SAP, where each story is 3 meters tall.

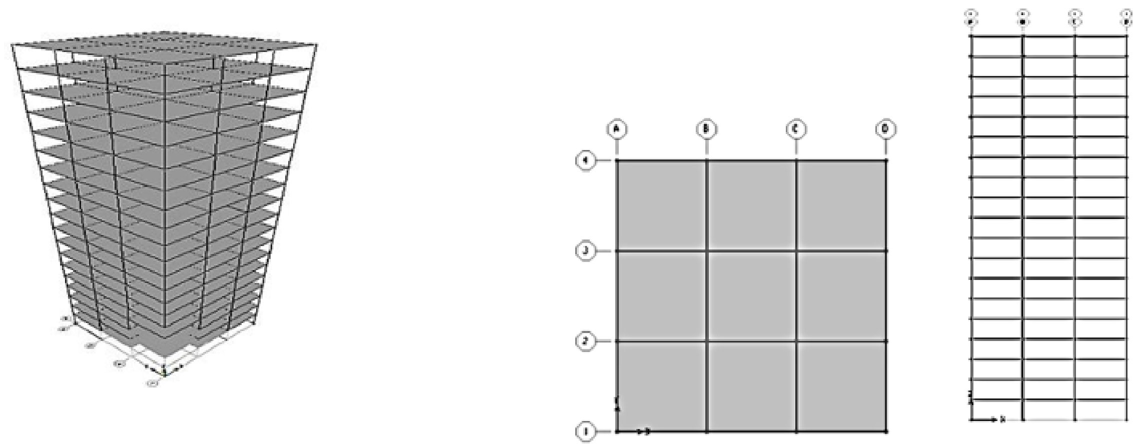

Figure 1. 3D view plan and elevation of the building model created using SAP

The modelled building was examined in three ways: dynamically, in terms of time, and in terms of how it moves on the ground. The building was dynamically analyzed using seismic design force and distributions at various storey heights and lateral load resisting parts. A time history study was performed using the principles of dynamics and the appropriate ground motion data. The mathematical model was subjected to various loads and speeds. The use of extra passive energy dissipation exposed a structure or part of a structure that was directly linked to ground-to-ground motion and its response, as required by the code. Ground motion is a major cause of building collapse. The structural parts of the building comply with EN 1998-1:2004 €, 3.2.3.1. This demonstrates how the material behaves when loaded and unloaded elastically. The study employs three types of dampers. Dampers shaped like a vertical, a cross, or a K (Chevron K dampers). A damper's shape is influenced by several factors inside the damper. The geometrical limits are the storey height, bay width, connecting link length, and angle between the links and the members. Figure 2 shows the diagonal dampers, cross dampers, and inverted V dampers used for damper configurations.

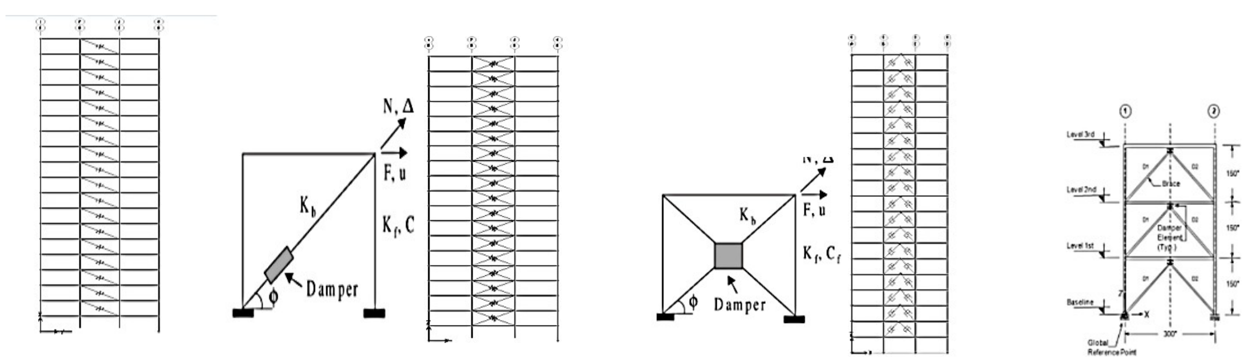

Figure 2. Diagonal dampers, cross dampers and inverted V dampers used for damper configurations.

For the load that is put on the building, the lateral stiffness distribution factor and deflection for each storey are found. To get the lateral stiffness, divide the displacement by the point load (Saaed et al 2015). The coefficient of damping is thought to be 0.35. Then, the time span was worked out. When the trial period and the damping period are the same, that number is used to figure out the damping coefficient. All loads are put on the structure in line with EC 7. The dampers are put in specific places on each floor of the outside walls of the building. The following are the assumptions considered in this study:

- The designed RCC structure is strong enough to withstand all loads placed on it.
- Linear dampers are used.
- Bending deformations are assumed to be absent in dampers.
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5. Results and Discussion

For the 30-storey symmetrical building, three different types of dampers were fitted to achieve the best configuration. Three distinct loading scenarios were investigated. All dampers are mounted on the exterior. For all retrofitting cases involving all loads, the linear static and response spectrums were examined. Dampers were then introduced at chosen locations on all floors with trial stiffness of k0tr. After obtaining these values the analysis is performed. Figure 3 shows the steps used for the analysis:

5.1 Numerical Results

Figure 3 illustrates the steps that were used to obtain the lateral stiffness distribution and damping coefficient of the structure that was fitted with Fluid Viscous Dampers (FVD). The lateral stiffness is calculated by dividing the deflection by the point load. The 0.05 damping ratio considered inherent for RCC structures. As a result, remaining damping ratio and coefficient of 0.35 is given by: $\xi = \xi_x + \xi_v$ i.e., 0.35 (35%) of the critical.

Time period was calculated by: $T_o = T / \sqrt{}\ (2\xi_v + 1)$

Where, T = Time period of unbraced building and Td= Time period of braced building. Damping coefficient = 9073.52.

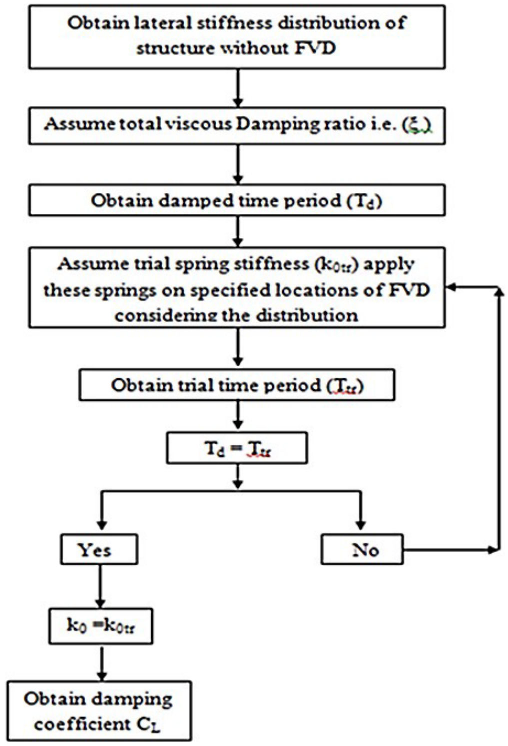


Figure 3. Determining Lateral Stiffness Distribution and Damping Coefficient in Structures with Fluid Viscous Dampers (FVDs)

5.2 Graphical Results

The graphical results are illustrated in Figures 4, 5, 6, 7and 8. Figure 4 shows the story drift without and with dampers (single diagonal) retrofitted for 3 different earthquake records, while Figure 5 illustrates the story drift with and without dampers (inverted V) retrofitted for 3 different earthquake records and Figure 6 illustrates the storey drift of the structure with and without dampers (X- cross diagonal).

Figure 4 compares the storey drift of the building without dampers and the storey drift of the building after retrofitting it with single diagonal dampers under three different earthquake loading conditions (TH003, TH006 and TH0014). It was observed that the storey drift analysis results for the structure without dampers (represented by the blue line) had larger storey drift, compared to the results of the single diagonal damper (represented by the red line). The addition of the single diagonal damper effectively minimized storey drifts indicating that the damper effectively absorbs seismic energy lowering the lateral displacement of the structure. The storey drift reductions were more noticeable in the upper floors. This shows that the diagonal damper is more effective in controlling vibrations at higher levels of the structure.

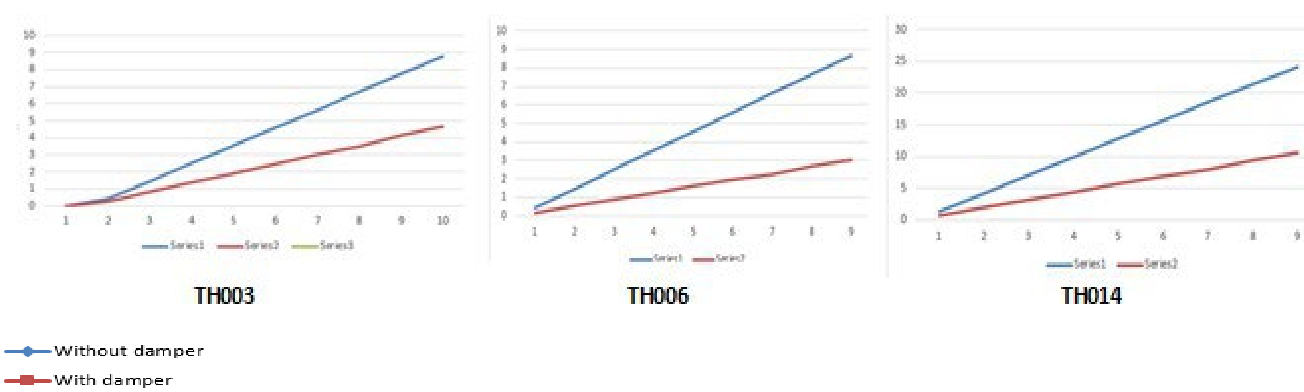


Figure 4. Storey drift without and with dampers (Single diagonal) retrofitted for 3 different earthquake records

Figure 5 shows the storey drift of the structure with and without dampers (inverted V) under three different earthquake loading conditions (TH003, TH006 and TH0014). Similar to figure 4, the storey drift of the building was compared without dampers and with inverted V-shaped dampers. It was observed that for all the three loading scenarios, the inverted V-shaped dampers (represented by the red line) minimized the storey drift greatly when compared to the results of the structure without dampers (represented by blue line). In this case as well, the reduction of storey drift was more noticeable on the upper floors. This shows that the inverted V-shaped dampers are also effective at regulating lateral displacement at higher levels of the structure. The inverted V-shaped dampers showed better performance than single diagonal dampers, with storey drifts reduced across all levels of the structure.

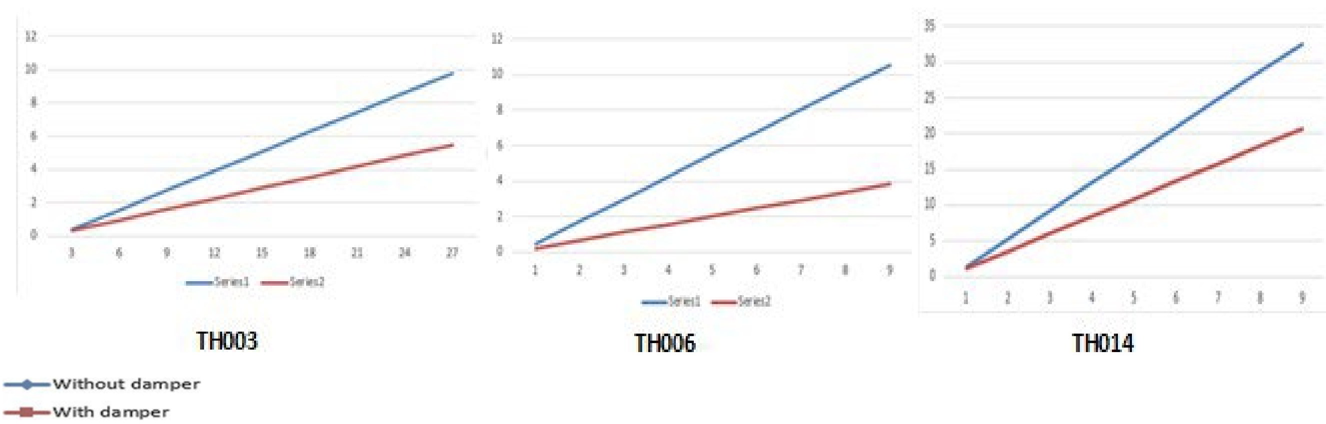


Figure 5. Storey drift without and with dampers (inverted V) retrofitted for 3 different earthquake records

Figure 6 shows a comparison of storey drift of the designed building without and with dampers (Cross Diagonal) retrofitted and tested for three different earthquake records. It was observed that for all the three cases of seismic loading, the cross shaped dampers (represented by red line) reduced the storey drift of the structure significantly compared to the building without dampers (represented by blue line). In this case the reduction in storey drift was found to be uniform across all the floors. This shows that the cross shaped dampers are found to be most effective amongst the three selected configurations. The cross shaped dampers showed the greatest reduction in storey drift across all levels and under all the three loading scenarios.

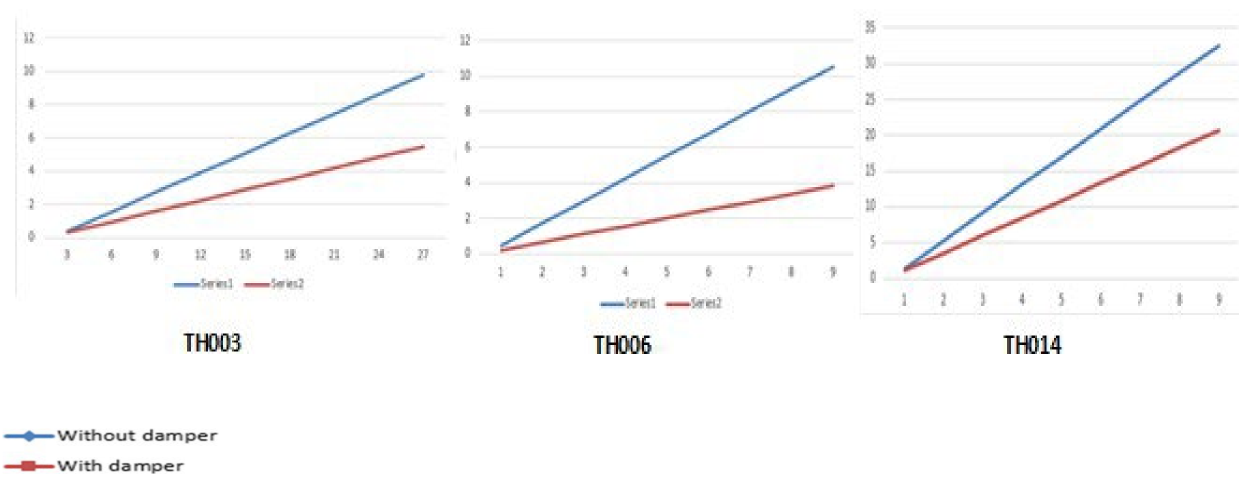


Figure 6. Storey drift without and with dampers (cross diagonal) retrofitted for 3 different earthquake records

When compared to the non-retrofitted structure, the retrofitted structure had a much lower response to storey drift. There was a significant reduction in storey drift. The X type damper proved to be the most effective and demonstrated the greatest reduction in storey drift. On average, a reduction of 50% to 70% was observed.

The results of the time history analysis of joint displacement performed on the modeled structure after applying specific loads without retrofitting is illustrated in Figure 7. The key observations from the results of time history analysis of the building without retrofitting indicate that the structure has high displacement values, making it vulnerable to seismic loads. This reduces the structure's ability to absorb and dissipate seismic energy resulting in larger joint displacement. In an event of earthquake, the structure would face potential damage.

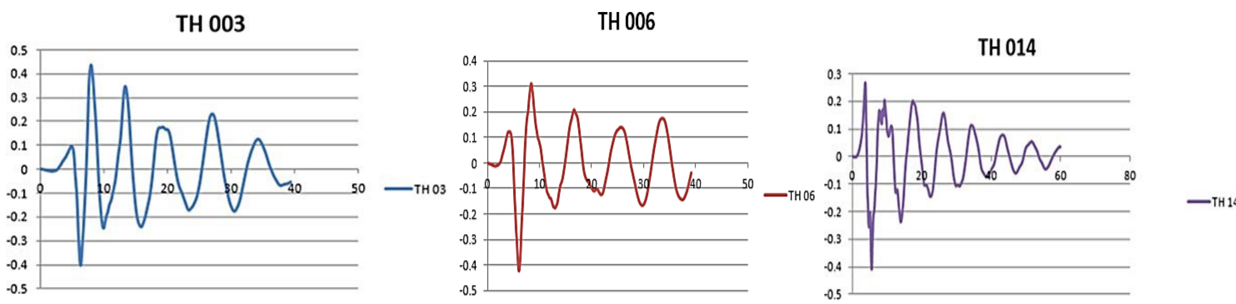


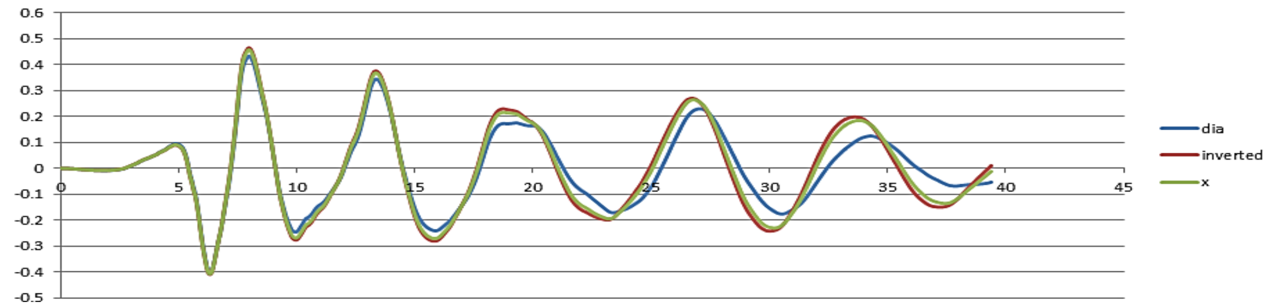
Figure 7. Time history analysis of displacement of the building without retrofitting

On the other hand, Figure 8 shows the results of roof joint displacement of the retrofitted structures for earthquake load cases 1 (TH003), 2 (TH006), and 3 (TH0014), and for all the three configurations (the results of single diagonal damper is shown in blue, result of inverted V-shaped damper is shown in red and the results for the X-shaped damper is shown in green). It was observed that the results obtained from the building after it was retrofitted with dampers showed significantly lower displacement values indicating towards an increase in seismic performance. The X-shaped and V-shaped dampers showed the best results as they had the least amount of displacement across all the three loading conditions. This implies that these two are more effective than the single diagonal damper towards improving structural stability.

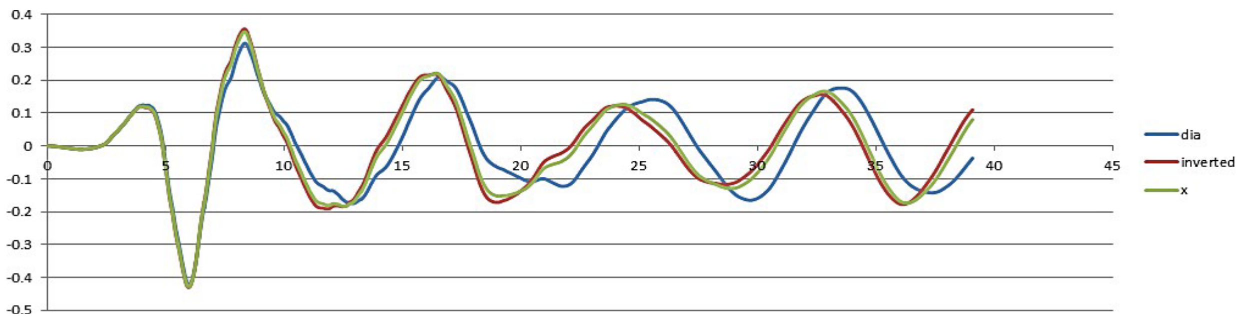
As shown in the graphs of the figure, the X and inverted V configurations had the lowest displacement values. The type of damper configuration and damper location had a significant influence on the joint displacement results. The single diagonal type, on the other hand, demonstrated the most displacement. It was observed that the use of X type dampers would aid in structural stabilization in the event of a seismic event.

In addition, Figure 8 provides a comparative analysis of how each configuration responds under different earthquake load cases. Specifically, it visually highlights the displacements recorded at the roof joint of a retrofitted building, assessed for three earthquake load cases: TH003, TH006, and TH0014. Each of these load cases represents varying intensities or characteristics of seismic forces applied to the structure. The positioning of the dampers within the structure, in addition to their shape, plays a crucial role in the building's response to seismic activity. Figure 8 underscores the importance of strategic placement and shape selection for maximum structural support. The X-shaped damper consistently resulted in the lowest displacement values, suggesting that its configuration offers the most efficient transfer and dissipation of seismic forces through the structure. This indicates that, under seismic loads, the X configuration is likely the most effective option for structural stability. Across all configurations, the presence of dampers substantially reduced roof joint displacement compared to the non-retrofitted building, confirming an improvement in seismic performance. The notably low displacements for the X-shaped and inverted V-shaped dampers suggest these configurations not only help in minimizing damage but also ensure structural integrity and occupant safety during seismic events.

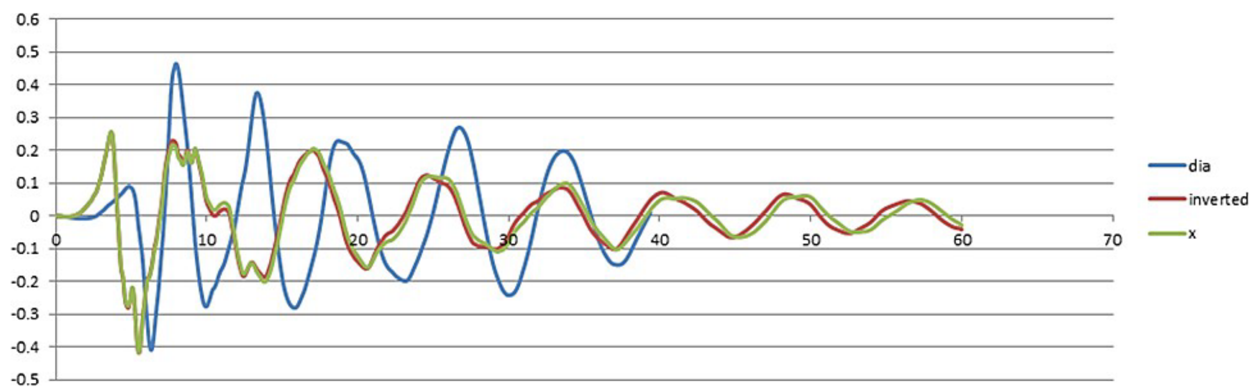
In summary, Figure 8 emphasizes the role of damper design and configuration in seismic retrofitting, highlighting the X-shaped and inverted V-shaped dampers as the most effective for enhancing structural stability under earthquake load cases. This insight is valuable for selecting damper types for seismic retrofitting projects, ensuring both optimal performance and safety.



Case 1: Earthquake load 1 (TH003)



Case 2: Earthquake load 2 (TH006)



Case 3: Earthquake load 3 (TH0014)

Figure 8. Results of roof joint displacement of the retrofitted structures for all the 3 loading cases and all the 3 configurations

5.3 Practical Implementation Challenges

Some practical implication challenges are associated with the different damper configurations. For example, single diagonal dampers are efficient in reducing storey drift, mainly on the upper floors and this factor may have sone practical issues. Secondly, the placement and orientation of these dampers must be cautiously assessed to ensure they are integrated into the structure without the need for any major design or structural changes. For effective dissipation of seismic energy proper load transfer between the diagonal dampers and building frames must be ensured. Additionally, the interface with existing building elements like doors and windows may hinder diagonal damper installations in specific building layouts.

In the case of inverted V-shaped dampers, the seismic load is effectively distributed limiting storey drift. However, the installation of inverted V-shaped dampers is comparatively difficult, especially in buildings which are shaped irregularly or structures where space is tight. Retrofitting of buildings using inverted V-shaped dampers might require structural changes like reinforcing of connections. This can be expensive.

X-shaped dampers are high performing and provide excellent displacement control along with energy dissipation making them ideal for application in earthquake prone areas. However, the are complex and have a very sophisticated design. X-shaped dampers require large spaces and strong anchor points. While retrofitting old structures with X- shaped dampers, often requires the addition on structural components like beams and columns. This adds to cost and complexity. Each damper has its own unique advantage, but the design selected must consider the structural arrangement of the building, seismic needs and cost implications.

5.4 Proposed Improvements

To enhance the effectiveness of seismic retrofitting innovative materials like smart dampers and shape memory alloys could be incorporated to enhance energy dissipation. The positioning of dampers within the structures in irregular and asymmetrical structures could further help in dissipating energy. Hybrid retrofitting techniques could be used to tune mass dampers and base isolation in addition to the mentioned use of dampers to improve structural performance. Dynamic soil-structure interaction can be used to create real scenarios to assess the effect of retrofitting along with coupling wind and seismic loads. The research can be expanded to include more damper configurations along with cyclic loading effects. This would provide a more comprehensive evaluation of the functions of dampers under different seismic circumstances. Additionally, extending the analysis to buildings of different heights can provide more insight into understanding the productivity and usefulness of better damper configurations, as height variations can drastically alter the performance and application of different damper designs.

5.5 Validation

To test the performance of the mentioned dampers configurations ANOVA or t-tests could be used to check the significant statistical changes in reducing seismic responses. A paired t-test could be used to check the performance of the structures before and after retrofitting. Damper site optimization can be assessed by regression analysis such as Chi-square test and the results could be assessed over a range of seismic intensities. To check the consistency of the dampers over time and through multiple seismic activities repeated-measures ANOVA can be used. These tests can provide statistical validation of the retrofitting techniques to support the identification of the most effective solution.

6. Conclusion

By increasing stiffness, decreasing ductile properties and time period, and decreasing torsion, retrofitting a structure improves its overall performance. The base shear was found to be greatest when the links within the storey were connected. The single diagonal link provided the best storey shear control and increased ductility. The least amount of storey displacement was shown by cross links. If the dampers were connected via a cross link, storey drift was also minimal. When dampers or links are present in both the X and Y directions, they control storey displacement. Cross links exhibited the least amount of drift. The diagonal link was more rigid than the bare frame. As the connection between stories grows, so does the stiffness. The inverted V links were incredibly stiff. The X type links, on the other hand, had the highest stiffness. When the number of links within the storey increases, eccentricity and the torsion effect decrease. Torsion and eccentricity were best controlled by the diagonal links/dampers. The structure's inertia was reduced as the peak accelerations were reduced using dampers, which increased its stability and helped it resist seismic vibrations.

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