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Enhancing Seismic Resilience: Evaluating Buildings with Passive Energy Dissipation Strategies

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Abstract: Structures are recommended to be designed and constructed with the integration of structural health monitoring techniques to ensure that they can dissipate a large amount of energy without considerable damage when subjected to earthquakes. Hysteretic (H), friction (F), viscous (V), and viscoelastic (VE) dampers were employed in this study to observe the response of buildings using the commercially available software ETABS. The effect of different dampers along with configurations on three prototype concrete buildings (3, 5, and 10-storey) was studied by performing a time history analysis. Initially, the response of the buildings was observed in terms of storey drifts, base shear, and displacement without using dampers, while gradually increasing the damping ratio from 0 to 40%. Subsequently, the response of the buildings was evaluated in terms of displacements and base shear using various types of dampers with different configurations. The analysis results demonstrated that the effectiveness of viscous and viscoelastic dampers is higher for 3 and 5-storey buildings, while friction and hysteresis dampers are more suitable for 10-storey buildings. This information enables informed decisions regarding the performance and maintenance of dampers, contributing to the overall resilience and durability of structures in seismic events.

Keywords: buildings; dampers; distribution; seismic resilience; structural health monitoring

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1. Introduction

The historical backdrop of damaging seismic shocks overall confirms the weakness of mankind to the powers of nature. The gigantic measure of energy delivered during a seismic shock can create extraordinary damage, even in modern countries [1]. One of the main challenges in structural engineering design is to reduce the harmful effects of earthquakes by developing new design concepts and techniques [2–4]. These devices are meticulously engineered to absorb and dissipate a significant portion of the seismic energy, thereby reducing the force transmitted to the structure. International codes and standards are available that provide guidelines for the seismic rehabilitation of buildings [5], the effects of strength and stiffness degradation on the seismic response [6], improvement of nonlinear static seismic analysis procedures [7], and a pre-standard and commentary for the seismic rehabilitation of buildings [8]. Constantinou et al. studied that conventional design procedures in structural engineering are not applicable in the scenario when a structure has to stay useable after an earthquake [9]. In situations like these, it is necessary to ensure that the structure is sufficiently robust to reduce any irreversible distortions, but this approach can be quite costly. Moreover, additional precautions must be implemented in such structures to protect vital secondary systems that are essential for ongoing functionality [10]. Over the past few decades, significant advancements have been made in alternative design approaches that integrate earthquake protection systems into structures. These methods aim to prevent the conventional design approach by enabling structural elements to dissipate and absorb seismic energy, thereby, minimizing inelastic deformations. However, this strategy involves deliberately inducing cyclic deformations in specific areas, which can lead to structural damage that may render the structure irreparable over time [11–14].

Earthquake protective systems are generally termed as control devices [15]. Systems of control devices can be categorized into four groups: (1) seismic or base isolation, (2) semi-active, (3) active control, and (4) passive energy dissipation devices (PEDDs) [16–20]. Seismic or base isolation is a technology that is practically implemented in seismically active areas and is effective for both buildings and bridges [21–23]. Controllers in active and semi-active devices are utilized to decrease the structural response by processing real-time response data along with force producers that apply counteractive forces. However, the practical application of these methods is often limited, particularly for large and heavy structures, due to the substantial control forces that the structures require [17]. PEDDs are different from semi-active and active systems because they do not need an external power source to work [24]. PEDDs encompass a diverse array of devices and passive materials that augment stiffness, damping, and strength. These systems are primarily known for their ability to dissipate energy through various means, such as transferring energy between different vibration modes or converting kinetic energy into heat [25]. To enhance seismic response, the research conducted by [26] focused on the utilization of dampers in tall buildings with shear walls. This innovative retrofitting method involved incorporating viscoelastic dampers within the shear wall of the building structure. Research findings indicated that placing viscoelastic dampers in the lowest storey of a building proved to be more effective. The rationale behind this approach is that the highly damped and rigid lower portion of a multi-storey building acts as a modulator for seismic dynamic excitation, particularly during intense ground shaking. As a result, the natural time period of the structure increases, reducing the amount of seismic energy absorbed by it and decreasing the stiffness at the base of the building. Therefore, the lower storey of the building is shown to be the most effective position for installing dampers. Shao et al. argue that passive dampers are the most economical option for improving the seismic performance of a concrete building [27]. In the preliminary study, the author selected and studied several damping systems for seismic retrofit and performed linear and non-linear time-history analyses. The study demonstrated that the most favourable performance was achieved by combining nonlinear viscous dampers with additional friction devices. The friction damping system, in particular, provided significant cost savings in comparison to the viscous damping system [28]. In contrast, the combination of viscous dampers with additional friction dampers resulted in a 25% reduction in floor accelerations compared to the friction dampers [29]. The greater floor acceleration responses associated with a friction damping system could potentially lead to increased costs for tile wall strengthening.

While prior research has predominantly explored the seismic response of buildings employing one or two types of passive energy dampers (PEDs), there exists a notable gap in comprehensive studies that encompass a broad spectrum of these dampers. Addressing this lacuna, our study rigorously investigates the seismic behaviour of buildings through the application of four distinct PEDs: hysteretic, friction, viscous, and viscoelastic. This research delineates a thorough examination of the seismic responses of 3, 5, and 10-storey buildings when outfitted with these diverse PEDs. A novel aspect of our study lies in the systematic manipulation of damper properties across uniform, triangular, and reverse-triangular distributions, thereby offering an intricate understanding of the dampers' performance dynamics. Through a meticulous comparative analysis, the research underscores the relative effectiveness of each PED type, shedding light on their practical implications for enhancing seismic resilience. It is pertinent to note that our study meticulously focuses on low to medium-rise buildings situated in regions ranging from moderate to high seismic susceptibility, thereby providing targeted insights into seismic mitigation strategies for these specific structural typologies.

2. Description of the Buildings

Three prototype concrete buildings of 3, 5, and 10-storeys in height, having concrete compressive strengths of 21 MPa, were modelled on a computer using ETABS software. ETABS is a widely recognized and commercially available structural analysis and design software package. ETABS offers robust capabilities for modelling various structural systems and incorporating different types of dampers, making it the ideal choice for our research objectives. The buildings have the first storey height of 4.570 m the height of the other storeys of 3.650 m. The buildings under consideration in this study were originally designed for moderate seismic zones. However, their performance was assessed by subjecting them to seismic records associated with a high seismic zone, while incorporating various passive energy devices. This evaluation aimed to gauge the effectiveness of the different passive energy devices in enhancing the seismic performance of the buildings beyond their original design criteria. The detailed parameters of the concrete frame are shown in Table 1.

Table 1. Detailed parameters of the concrete frame.

Parameters	Three (03)-Storey	Five (05)-Storey	Ten (10)-Storey
X-direction grids/bays	3	3	3
Y-direction grids/bays	1	1	1
X-direction grid/bay width (m)	7.5	7.5	7.5
Number of storeys	3	5	10
Column size (mm)	500 × 500	600 × 600	700 × 700
Beam size (mm)	400 × 600	400 × 600	500 × 600
Fundamental Time Period (s)	0.468	0.670	1.10

The researchers applied both gravity and dynamic loadings to the building frames in the study. Gravity loading included dead and live loads, while dynamic loading used the E–W (east–west) component of the El Centro 1940 time history earthquake data in the X-direction. The El Centro earthquake record was chosen for its significance and relevance. The El Centro earthquake had a peak ground acceleration value of 0.318 g. Figure 1 shows the time acceleration graph for the E-W component.

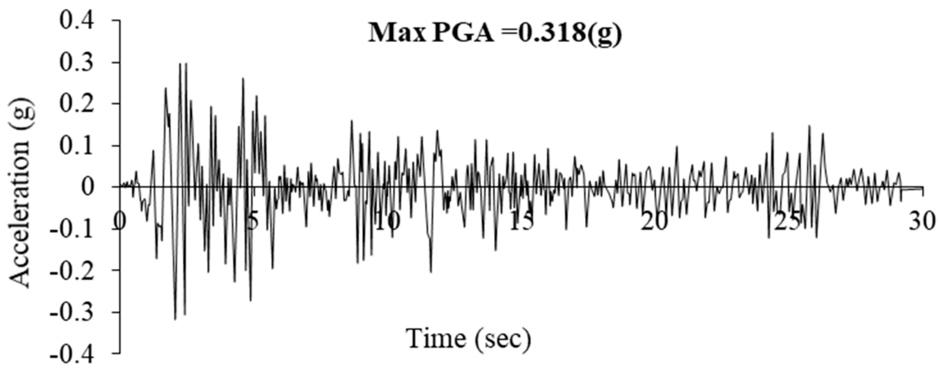


Figure 1. Time Acceleration Graph of the El Centro Earthquake in the E–W Direction.

2.1. Damper Characteristics

Four types of dampers were utilized in the study: hysteretic, friction, viscous, and viscoelastic, and installed in the central bay of the building frames. A schematic diagram of the dampers is shown in Figure 2a–d. The types and properties of the dampers are specified in Table 2, whereas the characteristics of the dampers are defined as follows,

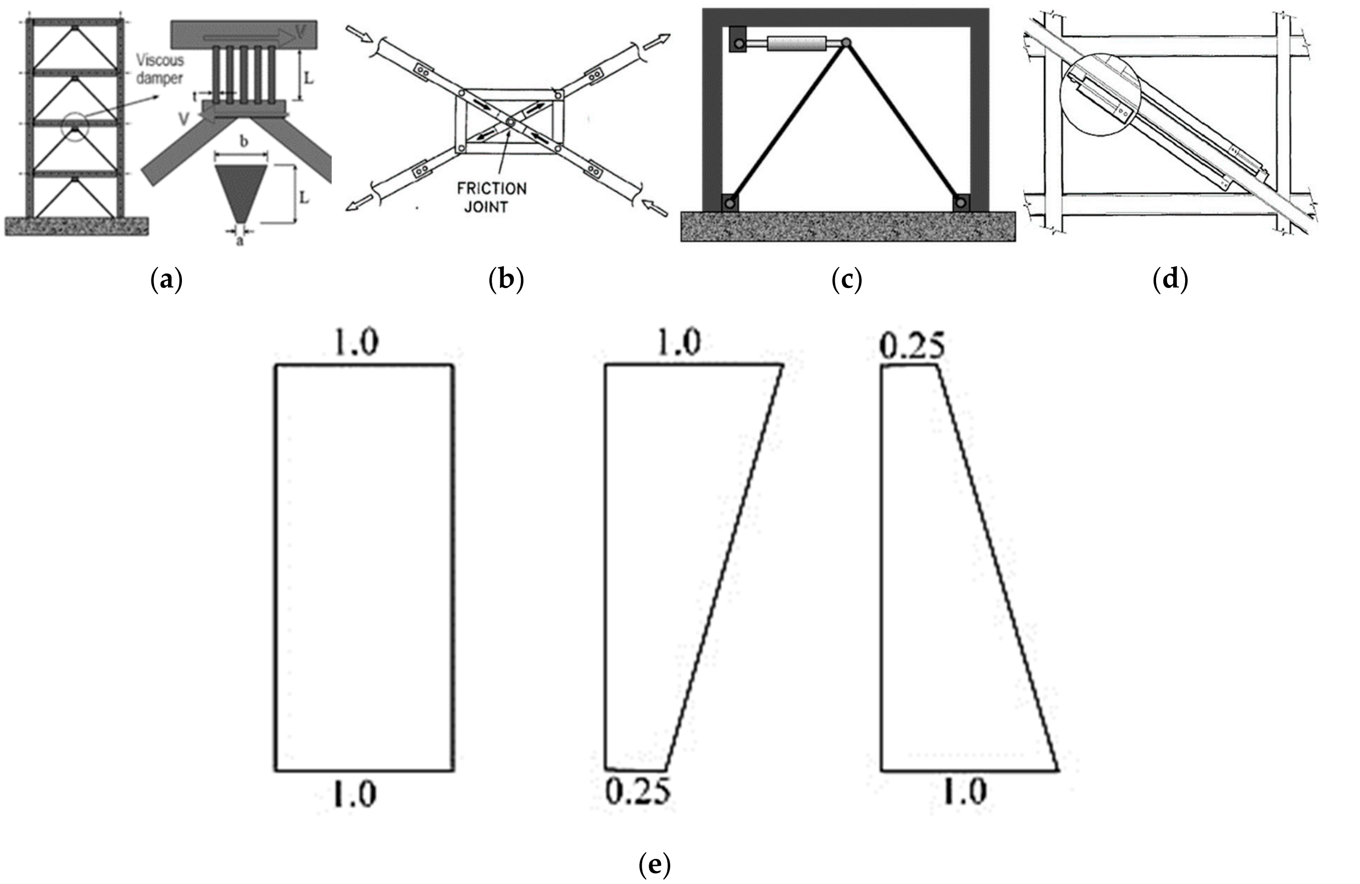


Figure 2. Dampers: (**a**) hysteretic, (**b**) friction, (**c**) viscous, and (**d**) viscoelastic; (**e**) parameter variations: uniform, reverse triangular, and triangular.

Table 2. Damper properties.

Case No.	Damper Types				
	Hysteretic or Friction Dampers			Viscous Dampers	Viscoelastic Dampers
	10-Storey	5-Storey	3-Storey	All Buildings	All Buildings
	P_y (kN) for Hysteretic Dampers or F_y (kN) for Friction Dampers			Damping Coefficient C (kN-s/m)	Effective Stiffness K_{EFF} (kN/m)
1	0	0	0	0	0
2	100	50	30	1000	2000
3	200	100	60	2000	4000
4	300	150	90	3000	6000
5	400	200	120	4000	8000
6	500	250	150	5000	10,000
7	600	300	180	6000	12,000
8	700	350	210	7000	14,000
9	800	400	240	8000	16,000
10	900	450	270	9000	18,000
11	1000	500	300	10,000	20,000

The hysteretic damper was modelled as a plastic-wen element with a max. yield force (P_y) equal to 1000 kN.

The friction damper was also modelled as a plastic-wen element. The values of the friction force (F_y) were similar to the yield force (P_y) in the hysteretic damper, whereas the stiffness was increased by a factor of 10 as compared to the hysteretic damper.

The viscous damper that was used was diagonally linked to the adjacent floors. The values of the damping coefficient are listed in Table 2, whereas the value of the exponent was assumed to be 1.0 for all types of analyses. The viscous damper is generally described by Equation (1) [5,8]:

$$F_D = C\,|\dot{u}|_{\alpha}\mathrm{sgn}\,(\dot{u}) \tag{1}$$

where, C is the damping ratio and $\dot{u}$ is the velocity of the piston, α is a constant parameter controlled by orifice shape to alter flow characteristics with fluid speed. For seismic protection, α is designed to be typically in the range of 0.3 to 1.0.

A viscoelastic damper having damping coefficient similar to the viscous damper and an effective stiffness "K_{EFF}" equal to *t* times the damping coefficient was used. The effective stiffness refers to the ratio of the modulus loss to the storage modulus in smaller frequency responses, indicating a reasonable level of stiffness.

The force in the viscoelastic damper is expressed by Equation (2) [5,8].

$$F_D = k_{eff}\,\Delta + C\,|u|_{\alpha}\mathrm{sgn}\,(\dot{u}) \tag{2}$$

where, Δ is the relative displacement between each end of the device.

2.2. Damper Variations

In this study, each damper was modelled with three different types of distributions, namely, uniform (U), triangular (T) and reverse triangular (R) distributions, as shown in Figure 2e. The uniform distribution represents the same damper property at each storey level. For triangular and reverse triangular distributions, the dampers at the top and bottom floor, respectively, were assigned ¼th of the value used on the opposite floor. The linear interpolation method was used for damper values at the intermediate storey level. A typical variation in damper properties for a 10-storey building is shown in Figure 3, where DP is the "Damper Parameter" in either yield force, friction force, or damper coefficient.

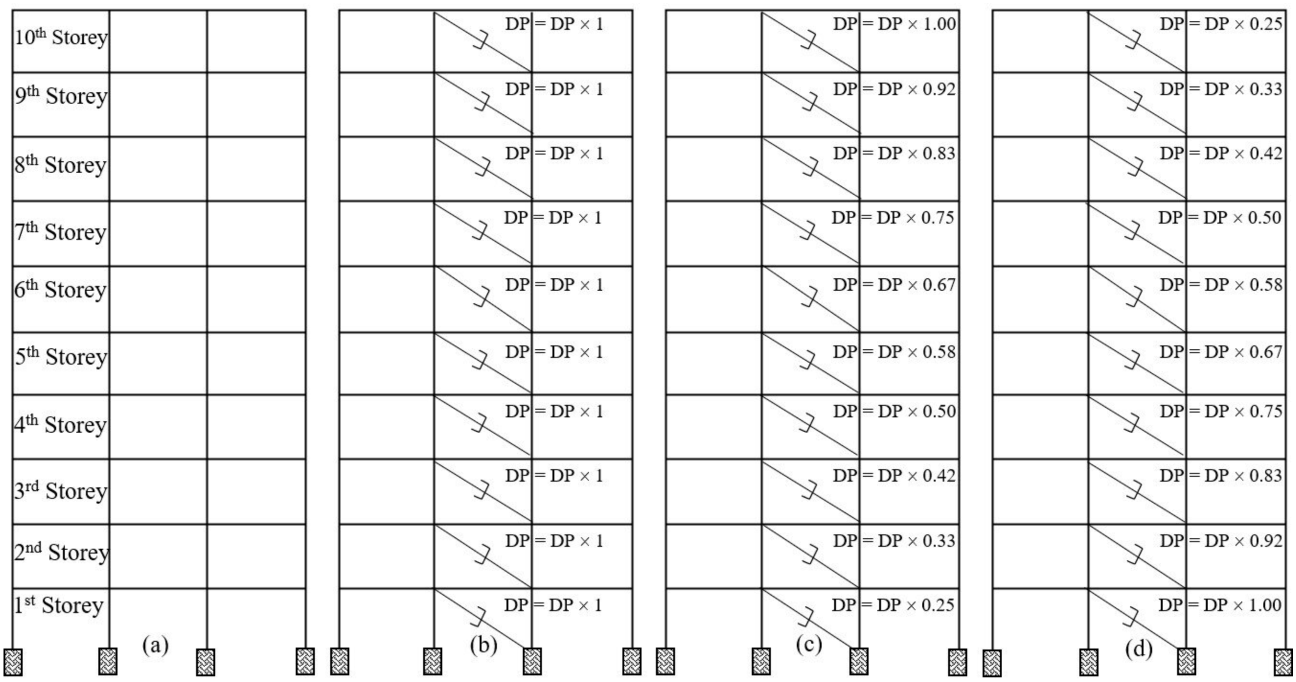


Figure 3. Damper parameter variation distribution with building height, (**a**) without dampers, (**b**) uniform, (**c**) triangular, and (**d**) reverse triangular.

2.3. Limitations of the Study

This study primarily focuses on buildings of moderate height, which implies that the findings might not accurately reflect the behaviour of exceptionally tall structures. Furthermore, the study bases its predictions on the behaviour of buildings using seismic data from a single earthquake event. While the use of computer models offers valuable predictions about how buildings would respond during an earthquake, the study does not incorporate real-life structural modelling, which could provide a more comprehensive understanding of the buildings' seismic performance.

3. Results and Discussion

3.1. Building Behaviour without Installing Dampers

In this study, prototype buildings were modelled with and without various types of dampers, allowing for a comparison of the structural response between different models. The seismic behaviour of the buildings was analysed using free vibration and time history analyses. To understand the behaviour of the buildings, the response of the original design was examined by gradually increasing the level of viscous damping from 0% to 40%. The effect of increasing the damping value was evaluated in terms of storey drift and base shear. Figure 4 illustrates the impact of increasing viscous damping on storey drift and base shear. As shown in Figure 4a, the maximum storey drift in all three prototype buildings decreased as the viscous damping increased from 0% to 40%. On the other hand, the effect of viscous damping on base shear, as depicted in Figure 4b, showed less variation compared to the drifts.

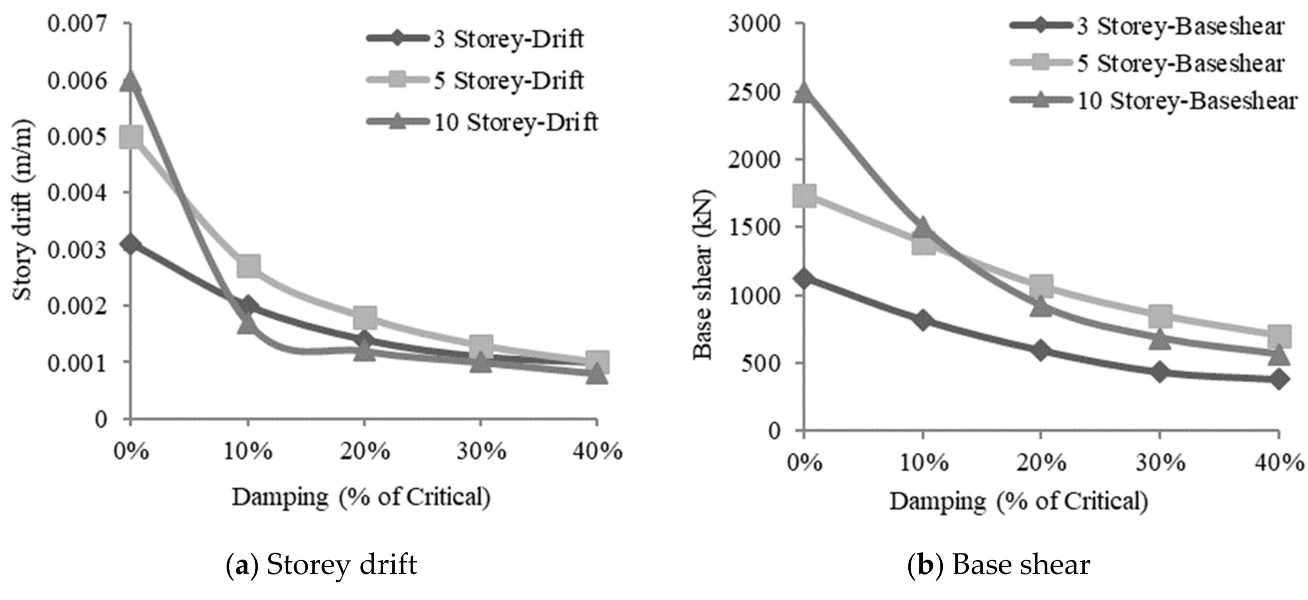


Figure 4. Effect of increases in the damping ratio: (**a**) storey drift, (**b**) base shear.

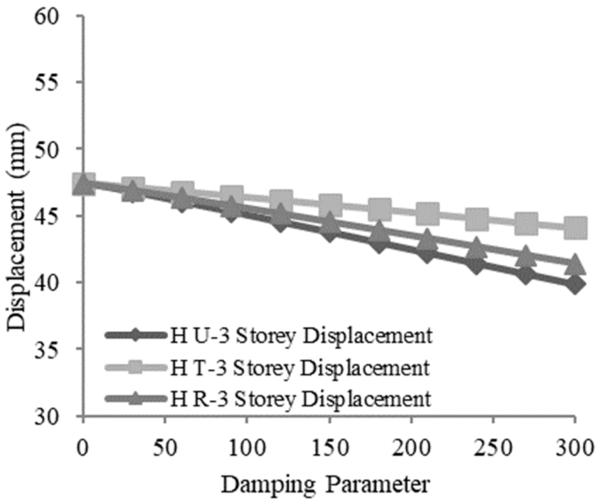
3.2. Response of Buildings with Dampers

3.2.1. Effect of Variation in Damping Parameters on Displacement

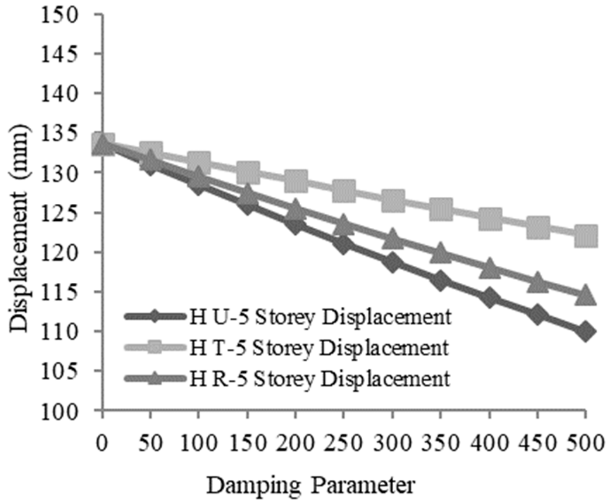
In this section, the effect of variation in the damping parameters of hysteretic, friction, viscous, and viscoelastic dampers on the displacement of the 3, 5, and 10-storey buildings are studied and discussed.

Hysteretic Damper

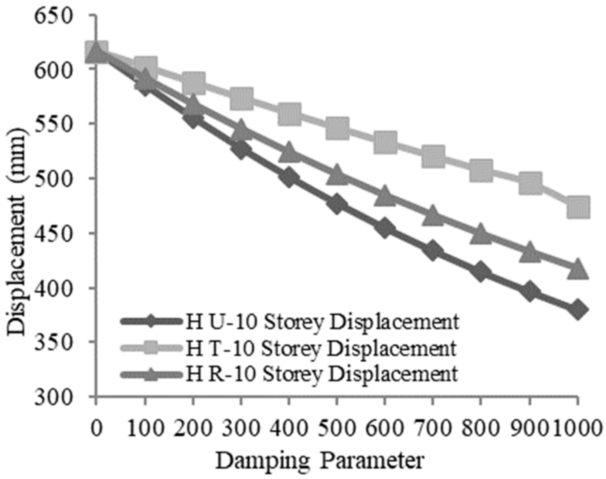
The researchers installed hysteretic dampers in the buildings to dissipate more energy than the strength and added stiffness. Some hysteretic dampers, such as the yielding brace, acted as structural members because they were indistinguishable from them. The effect of variation in the damping parameter in all types of buildings is shown in Figure 5. The figure shows that displacement increased with the building height; however, installing a hysteretic damper significantly reduced the building's displacement. Hysteretic dampers are typically designed to yield or deform before the existing structure in order to absorb and dissipate seismic energy. This intentional yielding behaviour allows the dampers to protect the main structural elements by absorbing and dissipating a significant portion of the seismic forces, thereby reducing the overall demand on the primary structure. For the 3-storey building, the displacement was reduced by 16.0% for the uniform, 7.0% for the triangular, and 12.5% for the reverse-triangular distributions. Similarly, for the 5-storey building, the displacement was reduced by 17.5% for the uniform, 8.5% for the triangular, and 14.5% for the reverse-triangular distributions. In the case of the 10-storey building, hysteretic dampers were determined to be the most effective, resulting in a reduction of displacement by 38.7% for the uniform distribution, 23.0% for the triangular distribution, and 32.0% for the reverse-triangular distribution. Across all types of buildings, the triangular distribution of dampers demonstrated greater effectiveness compared to the uniform and reverse-triangular distributions.



(**a**) Three (03)-Storey Frame



(**b**) Five (05)-Storey Frame



(**c**) Ten (10)-Storey Frame

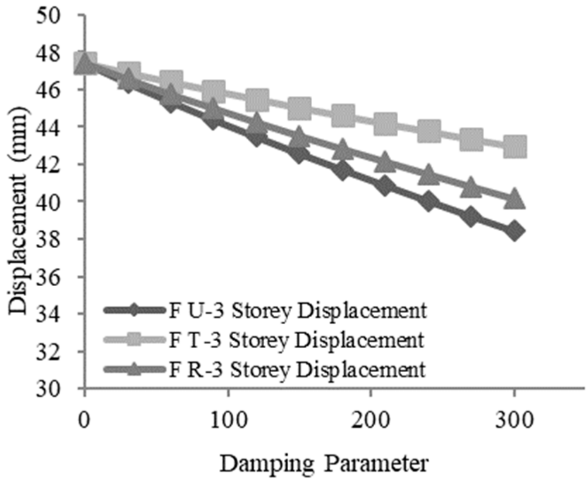
Storey	**Distribution**		
	U	**T**	**R**
3	15.9%	6.94%	12.61%
5	17.73%	8.68%	14.29%
10	38.36%	22.95%	32.20%

(**d**) Summary of the results

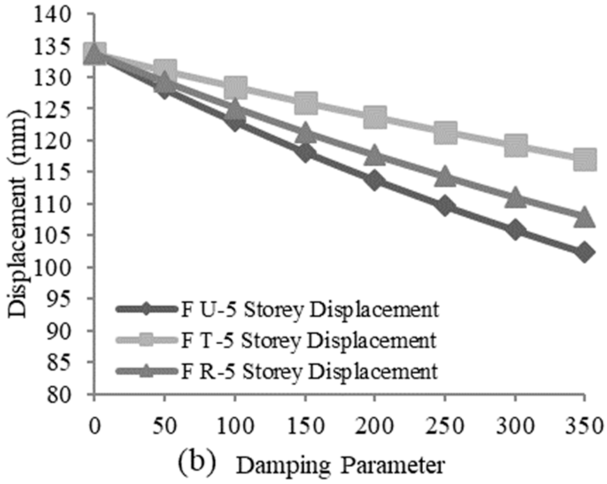
Figure 5. Effect of variation in hysteretic damper parameters on the displacement of (**a**) three, (**b**) five, and (**c**) ten-storey frames, and (**d**) a summary of the results.

Friction Damper

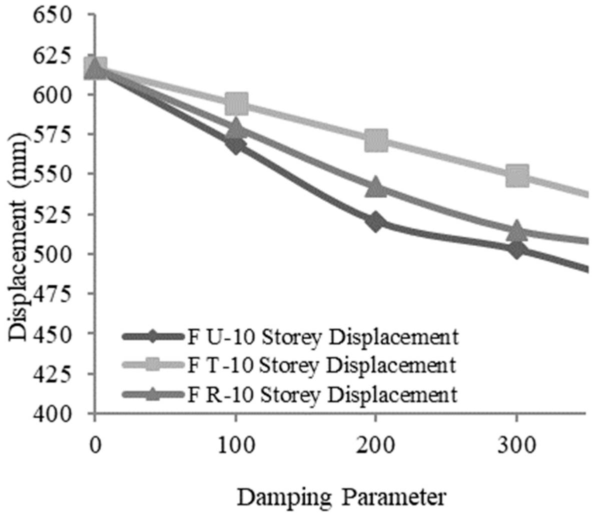
Friction dampers are commonly installed in the diagonal braces of buildings. Certain friction devices are designed to generate stable rectangular hysteresis loops, while others are configured to produce self-centring force and generate non-rectangular hysteresis loops. These different configurations allow friction dampers to provide specific performance characteristics and address different structural response requirements. The effect of variation in friction dampers damping parameters in all types of buildings is shown in Figure 6. For the 3-storey building, the displacement was reduced by 19.0% for the uniform, 9.5% for the triangular, and 15.0% for the reverse-triangular distributions. Unlike hysteretic dampers, friction dampers were more effective for the 5-storey and 10-storey buildings. For the 5-storey building, the displacement was reduced by 30.5% for the uniform, 17.0% for the triangular, and 25.5% for the reverse-triangular distributions. The displacement of the 10-storey building decreased by 44.0% with the uniform distribution, 28.0% with the triangular distribution, and 38.30% with the reverse-triangular distribution. The triangular distribution proved to be more effective than the other two types of distribution for all kinds of buildings.



(**a**) Three (03)-Storey Frame



(**b**) Five (05)-Storey Frame



(**c**) Ten (10)-Storey Frame

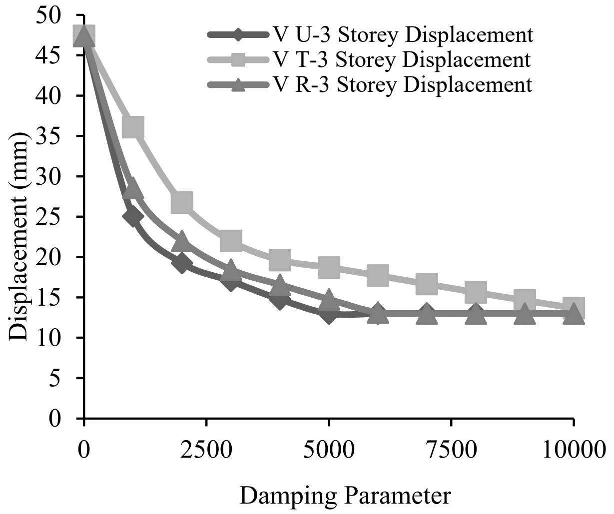
Storey	**Distribution**		
	U	**T**	**R**
3	19.0%	9.5%	15.0%
5	30.5%	17.0%	25.5%
10	44.0%	28.0%	38.30%

(**d**) Summary of the results

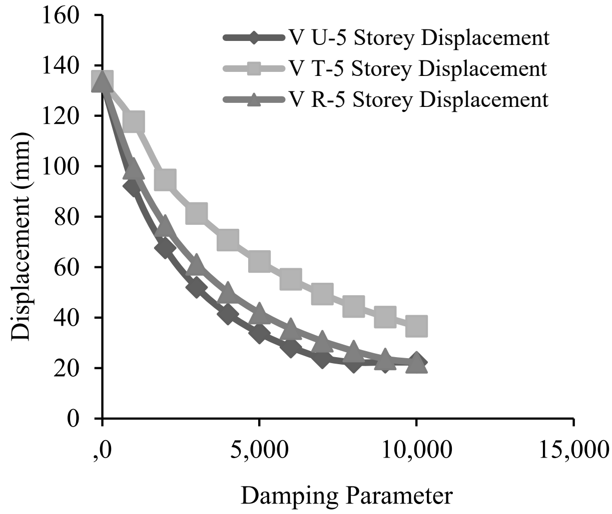
Figure 6. Effect of variation in friction damper parameters on the displacement of (**a**) three, (**b**) five, and (**c**) ten-storey frames, and (**d**) a summary of the results.

Viscous Damper

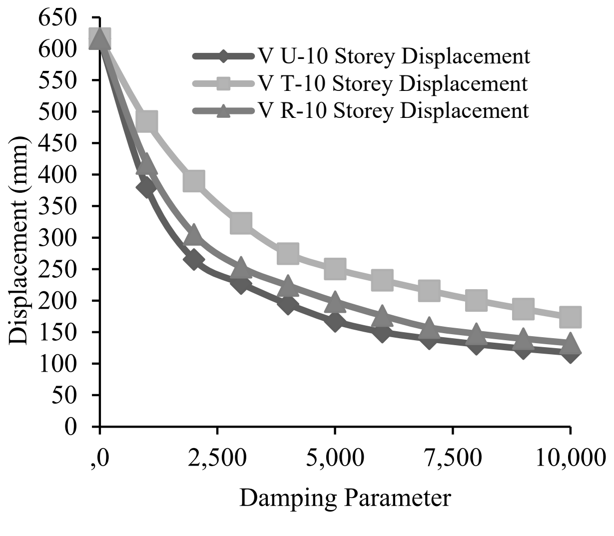
Viscous dampers typically exert an opposing force that is directly proportional to the velocity of the applied displacement, rather than being dependent on the displacement itself. This characteristic allows viscous dampers to provide damping forces that are proportional to the rate of motion, helping to dissipate energy and reduce the structural response to dynamic loads. The effect of variation in viscous damper damping parameters in all types of buildings is shown in Figure 7. Viscous dampers exhibit low resistance to deformation when loads are gradually applied, but this resistance increases as the speed at which the deformations are applied is accelerated. For the 3-storey building, the displacement was reduced by 75.60% for the uniform, 71.10% for the triangular, and 72.60% for the reverse-triangular distributions. For the 5-storey building, the displacement was reduced by 83.35% for the uniform, 72.60% for the triangular, and 83.30% for the reverse-triangular distributions. Similarly, for the 10-storey building, the displacement was reduced by 80.95% for the uniform, 71.80% for the triangular, and 78.45% for the reverse-triangular distributions. The triangular distribution proved to be more effective than the uniform and reverse-triangular distributions for all types of buildings.



(**a**) Three (03)-Storey Frame



(**b**) Five (05)-Storey Frame



(**c**) Ten (10)-Storey Frame

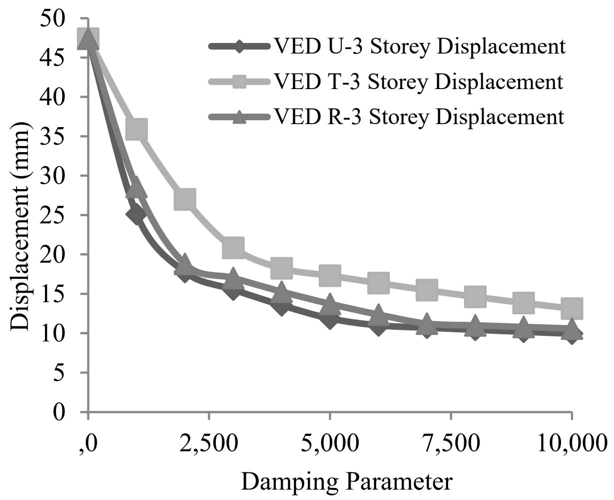
Storey	Distribution		
	U	T	R
3	75.60%	71.120%	72.60%
5	83.35%	72.60%	83.30%
10	80.95%	71.80%	78.45%

(**d**) Summary of the results

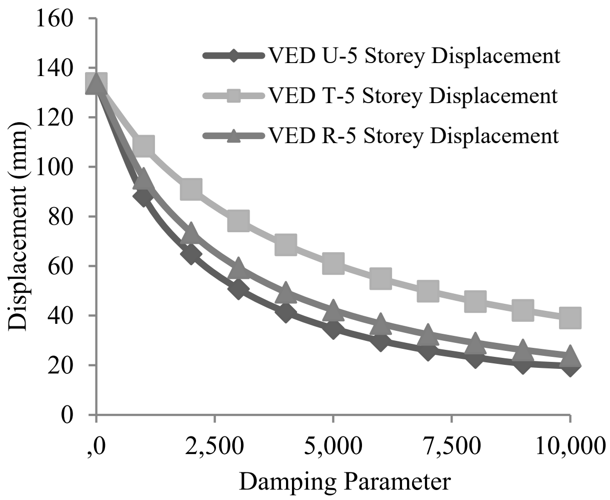
Figure 7. Effect of variation in viscous damper parameters on the displacement of (**a**) three, (**b**) five, and (**c**) ten-storey frames, and (**d**) a summary of the results.

Viscoelastic Damper

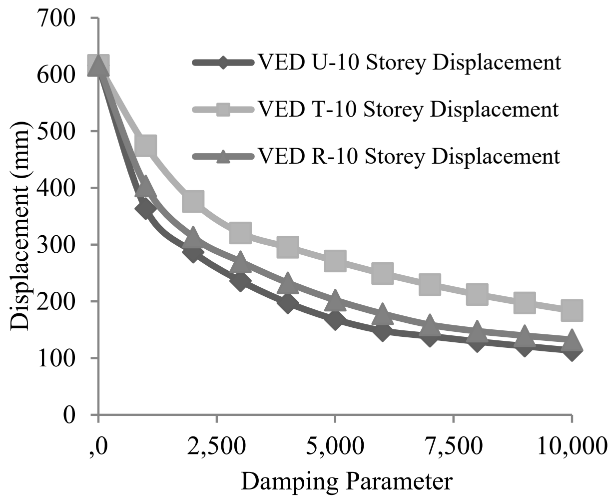
The effect of variation in the viscoelastic damper damping parameters in all types of buildings is shown in Figure 8. For the 3-storey building, the displacement was reduced by 79.01% for the uniform, 72.31% for the triangular, and 77.66% for the reverse-triangular distributions. For the 5-storey building, the displacement was reduced by 85.31% for the uniform distribution, 70.78% for the triangular distribution, and 82.16% for the reverse-triangular distribution. In the case of the 10-storey building, the displacement was reduced by 81.59% for the uniform distribution, 70.13% for the triangular distribution, and 78.51% for the reverse-triangular distribution. Similar to the previous findings, the triangular distribution was found to be more effective than the uniform and reverse-triangular distributions for all types of buildings.



(**a**) Three (03)-Storey Frame



(**b**) Five (05)-Storey Frame



(**c**) Ten (10)-Storey Frame

Storey	**Distribution**		
	U	**T**	**R**
3	79.01%	72.31%	77.66%
5	85.31%	70.78%	82.16%
10	81.59%	70.13%	78.51%

(**d**) Summary of the results

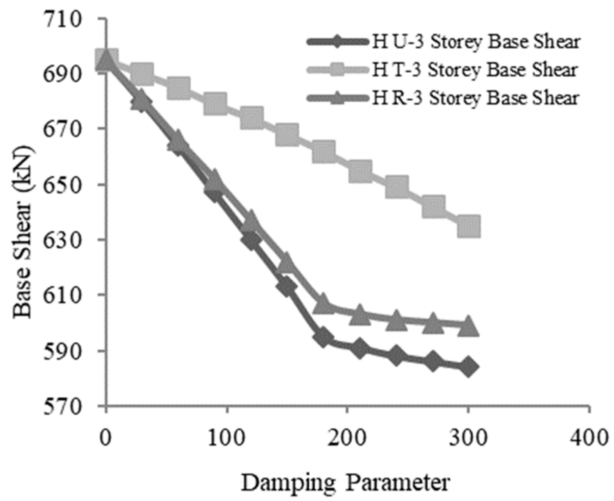
Figure 8. Effect of variation in viscoelastic damper parameters on the displacement of (**a**) three, (**b**) five, and (**c**) ten-storey frames, and (**d**) a summary of the results.

3.2.2. Effect of Variation in Damping Parameters on Base Shear

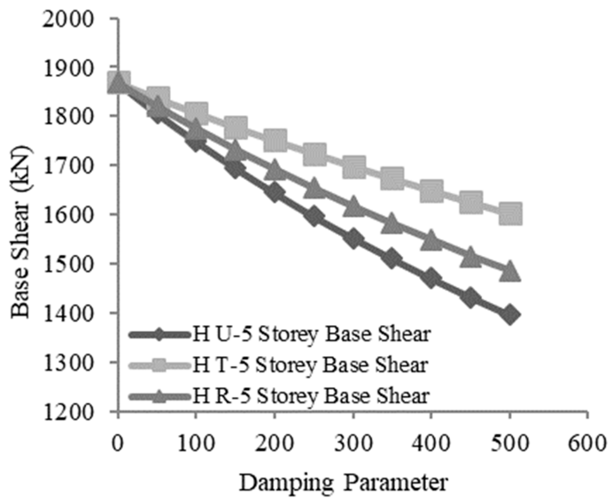
The base shear is one of the most important aspects to be considered when designing structures to withstand earthquakes. This section shows the effect of using different types of dampers on the total base shear of the structure.

Hysteretic Damper

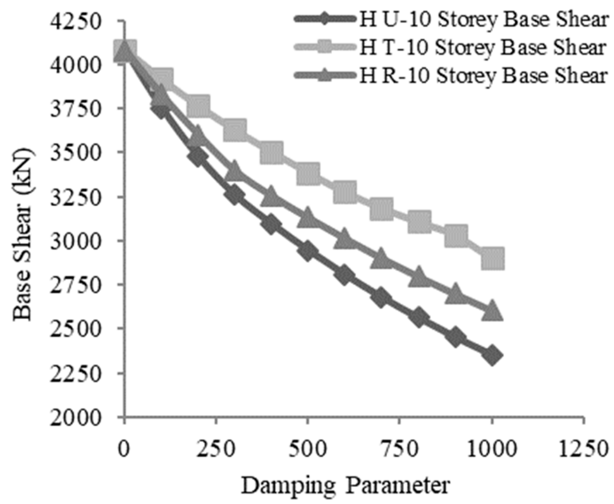
The effect of variation in the damping parameter in all types of buildings is shown in Figure 9. For the 3-storey building, the base shear was reduced by 16.0% for uniform, 8.70% for triangular, and 13.80% for reverse-triangular distribution. Similarly, for the 5-storey building, the base shear was reduced by 25.25% for the uniform, 14.23% for the triangular, and 20.50% for the reverse-triangular distributions. For the 10-storey building, hysteretic dampers were identified as the most effective, resulting in a reduction of base shear by 42.33% for the uniform distribution, 28.91% for the triangular distribution, and 36.61% for the reverse-triangular distribution. Consistently with the previous observations, the triangular distribution exhibited greater effectiveness compared to the uniform and reverse-triangular distributions for all types of buildings.



(**a**) Three (03)-Storey Frame



(**b**) Five (05)-Storey Frame



(**c**) Ten (10)-Storey Frame

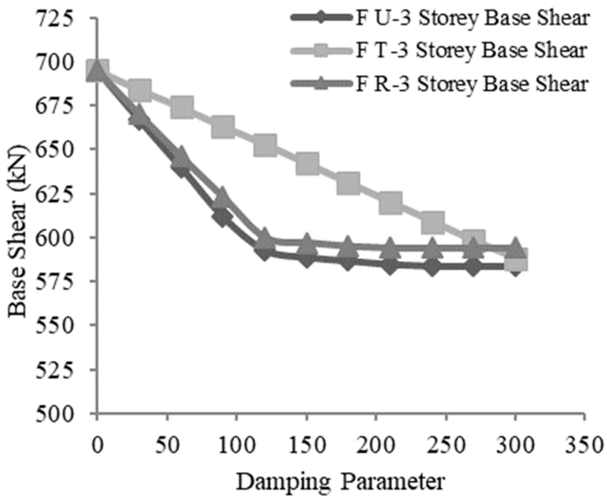
Storey	**Distribution**		
	U	**T**	**R**
3	16.0%	8.70%	13.80%
5	25.25%	14.23%	20.50%
10	42.33%	28.91%	36.61%

(**d**) Summary of the results

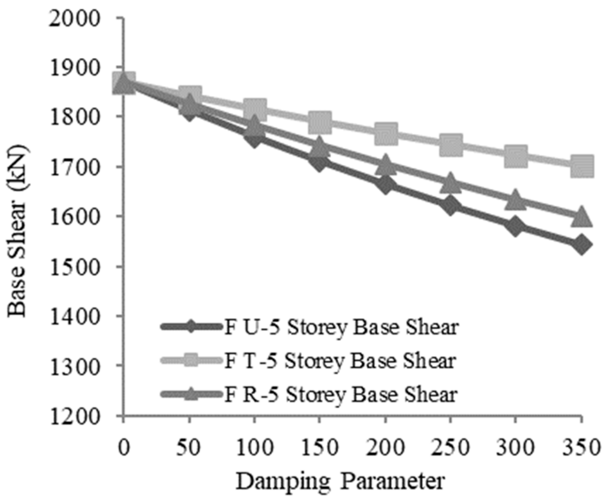
Figure 9. Effect of variation in hysteretic damper parameters on the base shear of (**a**) three, (**b**) five, and (**c**) ten-storey frames, and (**d**) a summary of the results.

Friction Damper

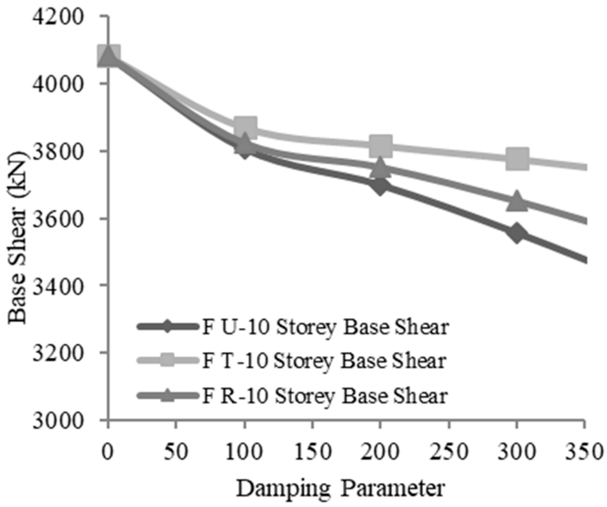
Figure 10 shows the effect of variation in the friction damping parameters on the base shear in all types of buildings. For the 3-storey building, the base shear was reduced by 15.97% for the uniform, 15.4% for the triangular, and 14.53% for the reverse-triangular distributions. Similarly, for the 5-storey building, the base shear was reduced by 25.85% for the uniform, 12.09% for the triangular, and 19.21% for the reverse-triangular distributions. Hysteretic dampers were found to be the most effective for the 10-storey building, resulting in a reduction in base shear of 33.46% for the uniform distribution, 18.23% for the triangular distribution, and 32.58% for the reverse-triangular distribution. This indicates that the use of hysteretic dampers provided significant improvements in reducing the base shear response compared to other distribution patterns. Friction dampers were found to be the most effective for the 10-storey building, where the reduction of base shear was 33.46%.



(**a**) Three (03)-Storey Frame



(**b**) Five (05)-Storey Frame



(**c**) Ten (10)-Storey Frame

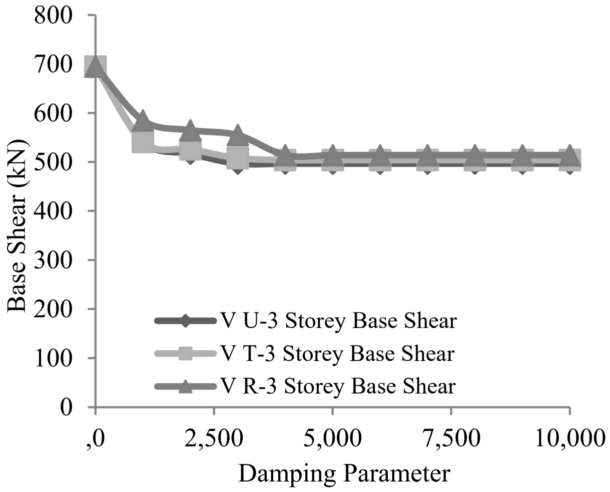
Storey	Distribution		
	U	T	R
3	15.97%	15.4%	14.53%
5	22.85%	12.09%	19.21%
10	33.46%	18.23%	32.58%

(**d**) Summary of the results

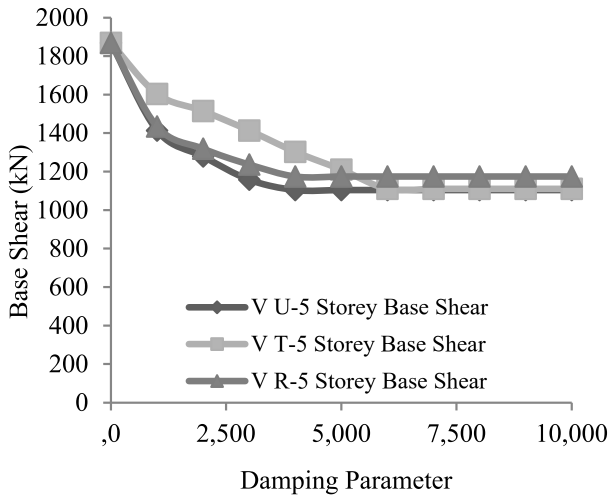
Figure 10. Effect of variation in friction damper parameters on the base shear of (**a**) three, (**b**) five, and (**c**) ten-storey frames, and (**d**) a summary of the results.

Viscous Damper

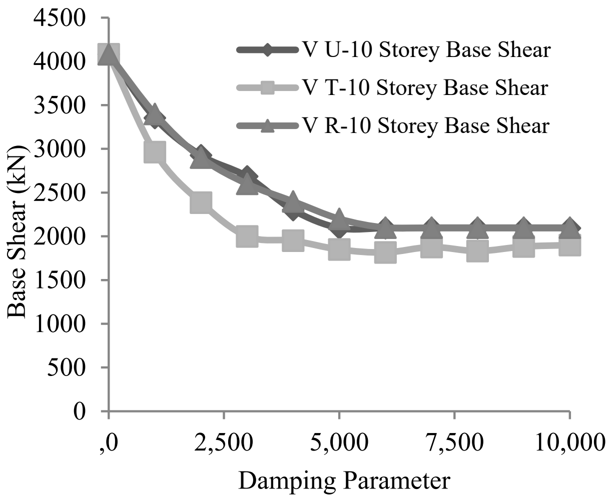
Figure 11 shows the effect of variation in viscous damper damping parameters on the base shear in all types of buildings. For the 3-storey building, the base shear was reduced by 28.49%, 27.8%, and 26.04% for the uniform, triangular, and reverse-triangular distributions, respectively. Hysteretic dampers were the most effective for the 5 and 10-storey buildings. In the case of the 5-storey building, the base shear was reduced by 40.9% for the uniform distribution, 40.58% for the triangular distribution, and 37.15% for the reverse-triangular distribution. This demonstrates that all three distribution patterns of dampers were effective in reducing the base shear response of the building, with the uniform and triangular distributions showing slightly higher reductions compared to the reverse-triangular distribution. Similarly, for the 10-storey building, the base shear was reduced by 48.69% for the uniform, 53.45% for the triangular and 48.55% for the reverse-triangular distributions. The results show that viscous dampers were the most effective for the 5 and 10-storey buildings, where the reduction of base shear was 40.9% and 53.45%, respectively.



(**a**) Three (03)-Storey Frame



(**b**) Five (05)-Storey Frame



(**c**) Ten (10)-Storey Frame

Storey	Distribution		
	U	T	R
3	28.49%	27.8%	26.04%
5	40.90%	40.58%	37.15%
10	48.69%	53.45%	48.55%

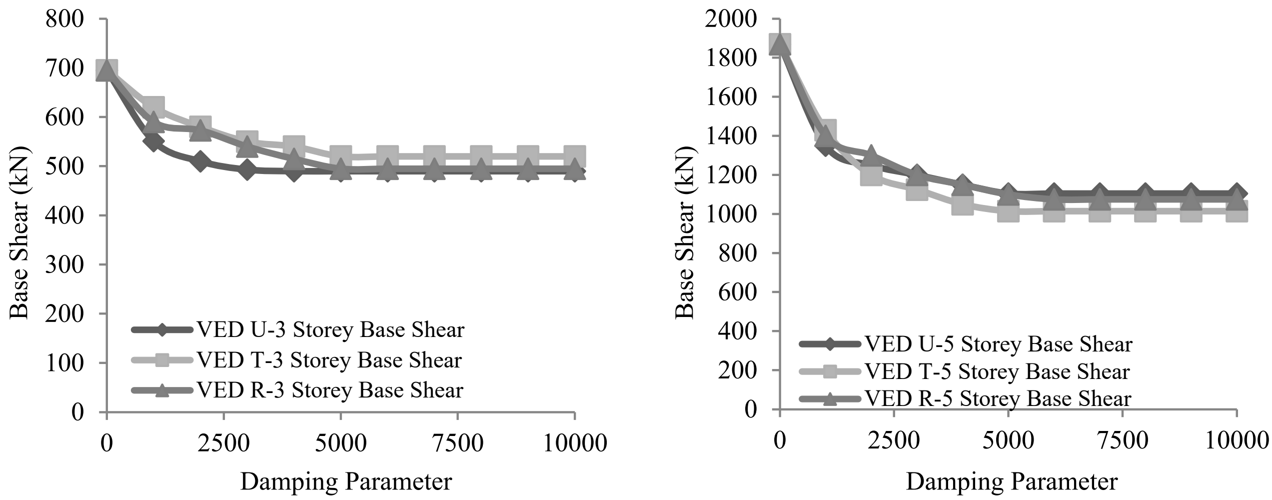
(**d**) Summary of the results

Figure 11. Effect of variation in viscous damper parameters on the base shear of (**a**) three, (**b**) five, and (**c**) ten-storey frames, and (**d**) a summary of the results.

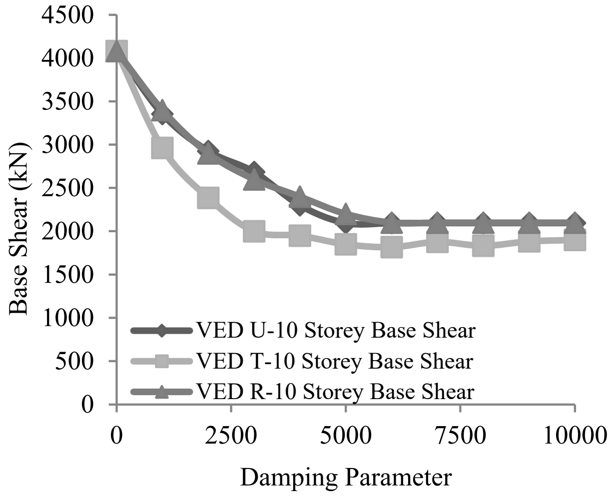
It is evident that the base shear values were consistently reduced for damping coefficient values ranging from 5000 to 6000 kN/cm across all distributions. However, beyond this range, the base shear values reached a plateau and remained relatively constant. This behaviour can be attributed to the fact that the introduction of dampers increased the total force within the structure, but the additional shear forces were effectively resisted by the dampers. As a result, the presence of the dampers generally did not lead to an increase in shear forces within the structural system. Furthermore, in terms of effectiveness, the triangular distribution consistently outperformed the uniform and reverse-triangular distributions for all types of buildings.

Viscoelastic Damper

Figure 12 show shows the effect of variation in viscoelastic damper parameters on the base shear in all types of buildings. For the 3-storey building, the base shear was reduced by 29.50% for the uniform distribution, 25.18% for the triangular distribution, and 28.78% for the reverse-triangular distribution. Viscoelastic dampers were found to be the most effective for both the 5 and 10-storey buildings. The base shear of the 5-storey building decreased by 40.88% with the uniform distribution, 45.69% with the triangular distribution, and 42.48% with the reverse-triangular distribution. Similarly, for the 10-storey building, the base shear was reduced by 56.45% for the uniform distribution, 57.29% for the triangular distribution, and 55.72% for the reverse-triangular distribution.



(**a**) Three (03)-Storey Frame (**b**) Five (05)-Storey Frame



(**c**) Ten (10)-Storey Frame

Storey	Distribution		
	U	T	R
3	29.50%	25.18%	28.78%
5	40.88%	45.69%	42.48%
10	56.45%	57.29%	55.72%

(**d**) Summary of the results

Figure 12. Effect of variation in viscoelastic damper parameters on the base shear of (**a**) three, (**b**) five, and (**c**) ten-storey frames, and (**d**) a summary of the results.

Moreover, regardless of the distribution pattern and building type, it was observed that the base shear values decreased up to damping coefficient values of 5000 to 6000 kN/cm, after which the values remained unchanged. This suggests that the introduction of dampers did not enhance the shear forces within the structure beyond this range. Consistently with the previous findings, the triangular distribution was identified as the most effective distribution pattern for all types of buildings, surpassing the uniform and reverse-triangular distributions.

4. Discussion

In this study, the effectiveness of various dampers was assessed in buildings of different heights. This research stands out for its comprehensive analysis across multiple damper types and building structures. Comparatively, studies like [9,24,29] focused mainly on the behaviour of viscous dampers in seismic scenarios. The current study's findings, highlighting the superior performance of viscous and viscoelastic dampers in lower buildings and friction and hysteresis dampers in taller buildings, add valuable insights, especially when contrasted with the singular focus of earlier works. These comparisons offer a nuanced understanding of damper effectiveness across varying architectural forms, contributing significantly to the field of seismic resilience.

5. Conclusions

In this study, different passive control devices were considered to investigate their effect on the response of structures using the finite element modelling software ETABS. These devices include hysteretic, friction, viscous, and viscoelastic dampers. Three reinforced concrete buildings (3, 5, and 10-storey buildings) with the same configuration were selected. Different configurations of dampers were considered and time history analyses were conducted using the El Centro earthquake. First, the response of the buildings was observed in terms of storey drifts, base shear, and displacement without using dampers, by increasing the damping ratio from 0 to 40%. Then, the response of the buildings was observed in terms of displacements and base shear using different types of dampers with different variations.

The following conclusions were obtained:

Viscoelastic and viscous dampers with a damping coefficient of 5000 kN-sec/m or more were the best dampers for the 3-storey building. They used reverse-triangular or uniform distribution. These parameters resulted in the lowest values of base shear and displacement.

PEDDs that are highly effective for 3-storey buildings are also considered optimal for 5-storey buildings. The performance and effectiveness of these devices is carried over from smaller-scale structures to larger ones. Therefore, the same PEDDs that prove effective for 3-storey buildings can be confidently applied to 5-storey buildings to achieve the desired damping and energy dissipation benefits.

Friction dampers were identified as the most effective for the 10-storey building. Specifically, high slip-force friction dampers demonstrated significant effectiveness in reducing shear forces and displacement within the structure. These dampers have the capability to dissipate energy and mitigate the response of the building to seismic forces, resulting in reduced shear forces and displacement.

In general, when considering different types of dampers, reverse-triangular distributions tend to be more effective for controlling base shears, while uniform distributions are typically more effective for controlling displacement. This implies that the choice of distribution pattern can influence the performance of the dampers in terms of specific objectives such as reducing base shears or controlling displacement. By selecting the appropriate distribution pattern based on the desired outcome, the effectiveness of the dampers can be optimized for the specific response parameters of the structure.

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Abbreviations

DP	Damping parameter
ETABS	Extended tall analysis of buildings and structures
F	Friction
g	Gravitational acceleration
H	Hysteretic
PEDD	Passive energy dissipation devices
PGA	Peak ground acceleration
R	Reverse-triangular distribution
T	Triangular distribution
U	Uniform distribution
V	Viscous
VE	Viscoelastic

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