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The role of damping systems in protecting buildings from seismic risk

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Abstract

Most often, energy-absorbing passive damping devices are used to regulate the vibration response of tall structures during seismic occurrences. Manufactured dampers come in many different forms and materials, which in turn allows for many different amounts of damping and stiffness The efficiency We measured the damped and undamped responses of the building at each level in terms of accelerations and deflections to assess the effectiveness of the damping system in reducing the seismic response using a direct integration dynamic analysis Various seismic loadings were applied to a number of Constructions of medium and high-rise buildings include integrated dampers in a range of configurations and locations. The impact of damper type, quality, arrangement, and location was the target of an investigation. Using a range of excitations, including cases where the primary seismic frequencies coincide with the structure's inherent frequency, the technique is shown to effectively mitigate seismic effects on these structures show that the technique can reduce tip deflection and acceleration in several circumstances.

Keywords: Seismic, high-rise, buildings, damping, acceleration and deflection

Introduction

Modern urban architecture is characterized by high-rise structures, which represent technical and economic progress. Nevertheless, building them is no easy task, especially in areas that are prone to earthquakes. Rigid analysis and design approaches are required to guarantee resilience, since the safety and stability of these buildings during earthquakes are of utmost importance. In this work, we utilize STAAD Pro, a top structural analysis and design program, to compare the seismic performance of G+16 buildings, which are high-rise structures with 16 stories above ground. Because of their height and the dynamic properties that affect their reaction to ground motion, high-rise structures are particularly susceptible to seismic forces. In order to find the best solutions for reducing seismic hazards, the research will compare various structural systems and layouts.

Building geometry, material characteristics, load distribution, and damping mechanisms are some of the aspects that will be taken into account in the study. The project aims to find ways to make high-rise construction safer by simulating earthquakes and seeing how the structures react. The goal is to improve seismic performance. The results of this comparative research are especially pertinent in light of the rising population density and globalization of cities. Maintaining the structural integrity of tall structures in the face of seismic activity is an important part of city planning and public safety measures, especially as cities keep becoming taller. Design and regulation of high-rise structures in seismically active locations would benefit greatly from the insights provided by this study for engineers, architects, and legislators.

Tall buildings have altered the size and look of contemporary cities and serve as iconic representations of modern urban communities; they also encourage creativity and national pride. A kilometer-tall building is now within reach, thanks to contemporary auxiliary frames and materials. This means that structural engineers can do anything. The lateral strains caused by wind and earthquakes may be particularly damaging to tall buildings. Side loading serviceability is achieved by the use of bracing, shear walls, and dampers. A major metropolis would be severely lacking in skyscrapers. As a whole, skyscrapers have altered the size and look of the modern metropolis while simultaneously inspiring faith in innovation and national pride.

Literature review

Kitayama, Shoma & Constantinou, Michael. (2018) [1]. Using ASCE/SEI 7-16 as a guide, this study analyses the seismic performance of buildings using fluid viscous damping systems. The study covers a lot of ground, including the following: the required strength of the brace-damper-connection system; the base shear force for the frame design without the damping system; the quantity of damping; the displacement capacity of the dampers; and the type of damping, which includes the use of fluidic self-cantering devices. Over the course of a 50-year lifespan, for a particular site, the results are assessed by determining the likelihood of collapse and surpassing predefined residual drifts of0.2,0.5,1.0, and 2.0% of story height for varying seismic intensities, up to the maximum permitted earthquake. In order to reduce the danger of collapse and residual story-drift ratio surpassing the essential thresholds of 0.5 and 1%, the most crucial factors, according to the results, are the design base shear force, brace-damper-connection strength, and damping quantity.

Xiao, Congzhen & Li, Jianhui & Li, Yinbin & Qiao, Baojuan & Sun, Chao & Wei, Yue & Jiannan, Ding. (2023) [2]. Engineers often use seismic performance-based design methodologies. In this study, we survey the current landscape of high-rise seismic performance-based design approaches in China and summarizes recent advances in this field. It specifically discusses design methods that are based on member ductility requirements and methods that are based on predetermined yield modes. Lastly, we look forward to the future of seismic performance-based design for tall structures.

Forcellini, Davide & Kalfas, Konstantinos. (2023) [3]. The fundamental benefit of inter-story seismic isolation is the interruption of the energy transfer across floors, which is a crucial factor to think about in multi-story structures with varying seismic performance needs due to their various purposes. Adding isolation layers at varying building heights may improve the seismic behaviour of the system by reducing the inertial forces transmitted to the superstructure. Examining a 20-story building with many inter-story designs that position the isolation layer at different heights, this research aims to determine the ideal location throughout the structure's height and provide an explanation of each model's performance. The models' robust non-linearities are calculated using Open Sees, which additionally considers the interaction between horizontal and vertical forces. Our analysis takes into account accelerations, drifts, and shear forces to determine the various responses, showing how inter-story isolation might be used to isolate bases.

Lago, Alberto & moghadasi faridani, Hadi & Trabucco, Dario. (2022) [4]. This project aims to investigate several approaches to damper-based building motion control. There are three primary types of devices available for this purpose: "passive," "active," and "base isolation." This article provides a comprehensive overview of the most popular solutions used by the tall building industry, discussing them in light of design principles, building system interactions, testing, inspection, and maintenance. The extensive use of these technologies and their potential future notable uses are shown by a study of the tall structures above 250 meters developed worldwide.

Dasari, Hima & Bhalkikar, Aniket & Ramancharla, Pradeep. (2024) [5]. When a structure can dampen the effects of dynamic loads like earthquakes and winds, it shows that it can lessen the amplitude of vibrations. Throughout a structure's lifespan, it aids in making sure occupants are comfortable under wind loads, and during intense earthquake shaking, it measures how much energy a building can dissipate. Despite damping's critical significance in building design, identifying it is difficult because of its intrinsic complexity caused by various causes. This work aims to address this difficulty by quantifying the damping of reinforced concrete (RC) tall structures in India using ambient vibration. To do this, 37 RC structures with heights between 5 and 150 meters are subjected to an ambient vibration test, and the damping ratio is estimated using the famous Frequency Domain Decomposition (FDD). We compare an existing model for RC tall structures in Asia, the Americas, and Europe with a new one that is designed specifically for tall buildings in India in terms of damping prediction.

Research methodology

This study uses Finite Element (FE) methods to model and analyze the effects of six damping devices on seismic response in Australian multi-story building construction. The numerical analysis was conducted using ABAQUS Standard Version 6.3, and MSC/PATRAN 2003 was used to produce the model's geometry, element mesh, boundary conditions, and loading conditions. The concrete used in the models was reinforced concrete with a density of 2500 kg/m3, a Poisson's ratio of 0.2, and a Young's modulus of 30,000 MPa. The study aimed to develop a model that faithfully represents the operation of friction dampers using a model of the interaction between two sliding tubes. The shear wall (W0) was used to test the method's viability, and four different damping sites were examined to see how location impacts the seismic response of these models.

Results

The shear wall structure's seismic reactions at a height of 96 meters

Measuring the total impact of seismic reaction may be done in a number of ways; one of them is by computing tip deflection. To "average out It is possible to trace the seismic effects of varying wall accelerations from their respective base shear and moment moments all the way back to the tip deflection. As a result, lowering the total seismic design force is beneficial. The findings demonstrate that the significance of tip deflection reduction is influenced by the intricate features of the time histories that are used for evaluation. Therefore, it is only fair to do the analysis over a series of time histories in order to fairly analyses the advantages.

In order to evaluate the shear wall's impact construction implanted with five different types of dampers, this research built a model of an undammed shear wall. dampening mechanisms. Table 1 displays the findings of the structure's tip acceleration and deflection measured under five different seismic excitations.

Table 1: Acceleration and deflection of the undammed structure's tips

	El Centro	Hachinohe	Kobe	Northridge	S. Fernando
Deflection (m)	0.161	0.356	0.168	0.143	0.141
Acceleration (m/s^2)	4.87	5.33	5.96	5.57	4.42

Below you can see the outcomes of all the shear wall structural models that were developed using data from each of the five earthquake records.

In contrast to the undamped structure, which has its damper at the top, structural model W1 shows the tips' displacement and acceleration in Figs. 1-5 as a result of the El Centro earthquake excitations. Incorporating the dampers into the structure reduced the peak values of tip deflections and accelerations for all five seismic loads, as shown by the data. The performance of the designed dampers, however, varied significantly under different excitations. While the chevron bracing friction damper was the poorest at decreasing tip deflection, the diagonal VE damper was the best overall. The hybrid friction-VE damper exhibited the smallest reduction in tip acceleration, whereas the diagonal VE damper once again had the greatest performance.

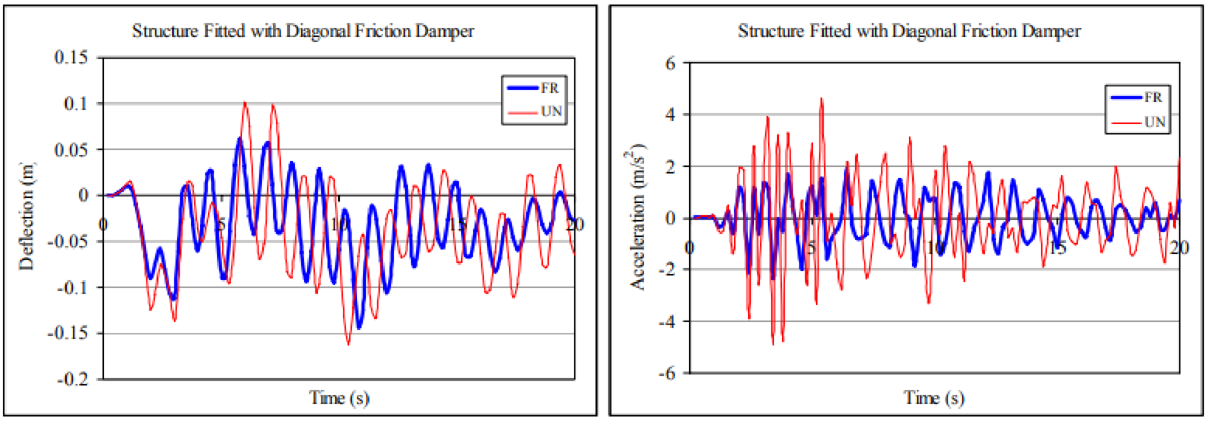

Fig 1: Response of the undammed and damped structures to the El Centro earthquake in terms of tip acceleration and deflection

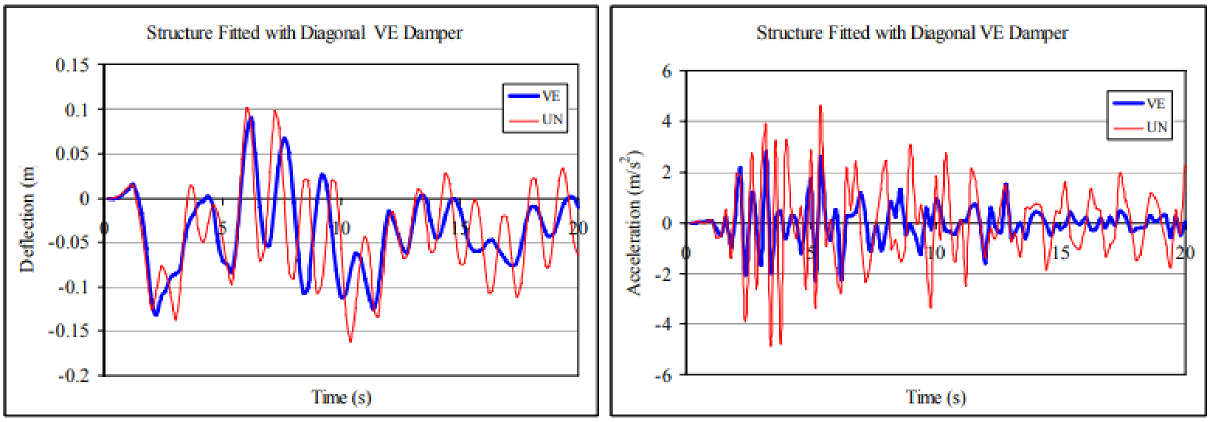

Fig 2: The reaction of the undammed and damped structures to the El Centro earthquake in terms of tip acceleration and deflection

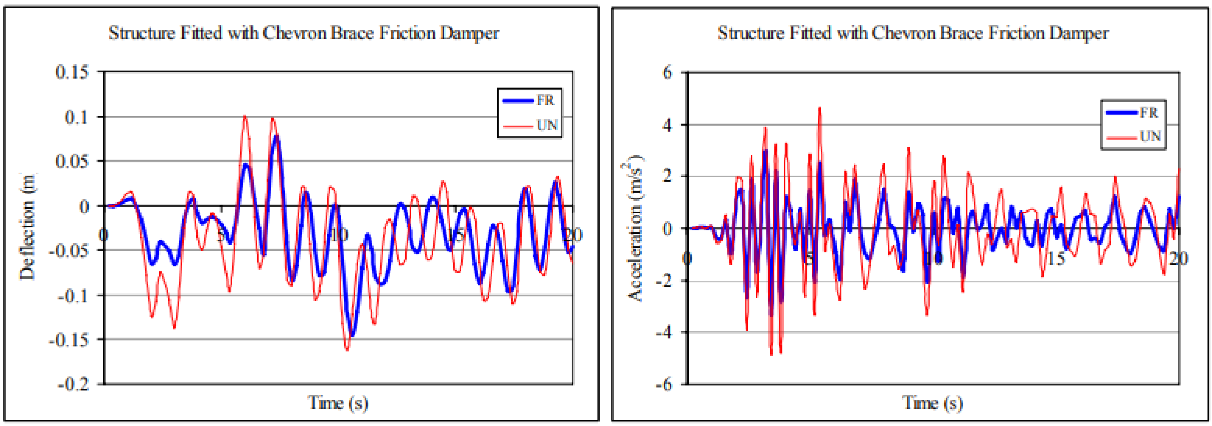

Fig 3: The reaction of the undammed and chevron brace friction-damped structures to the El Centro earthquake in terms of tip acceleration and deflection

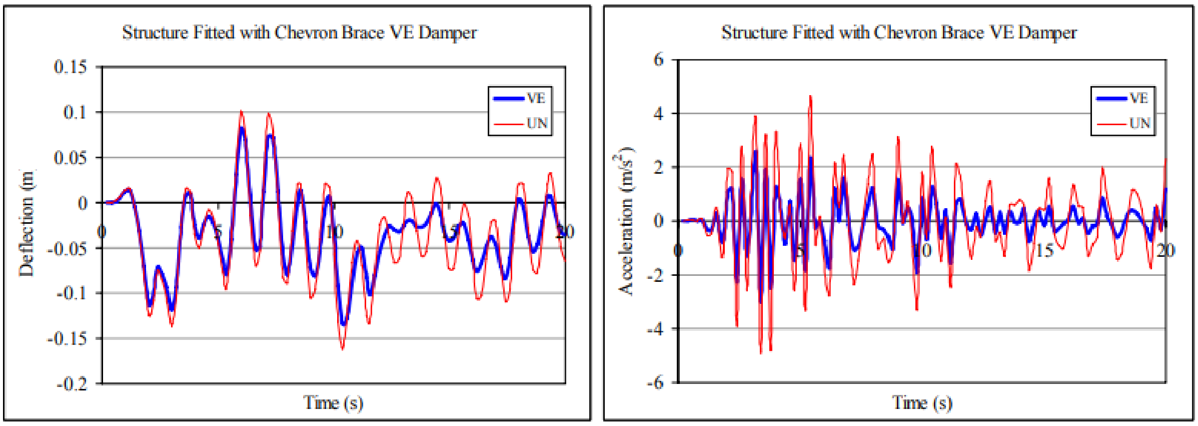

Fig 4: During the El Centro earthquake, the undammed structure and the one with the chevron brace VE damper implanted both experienced tip acceleration and deflection.

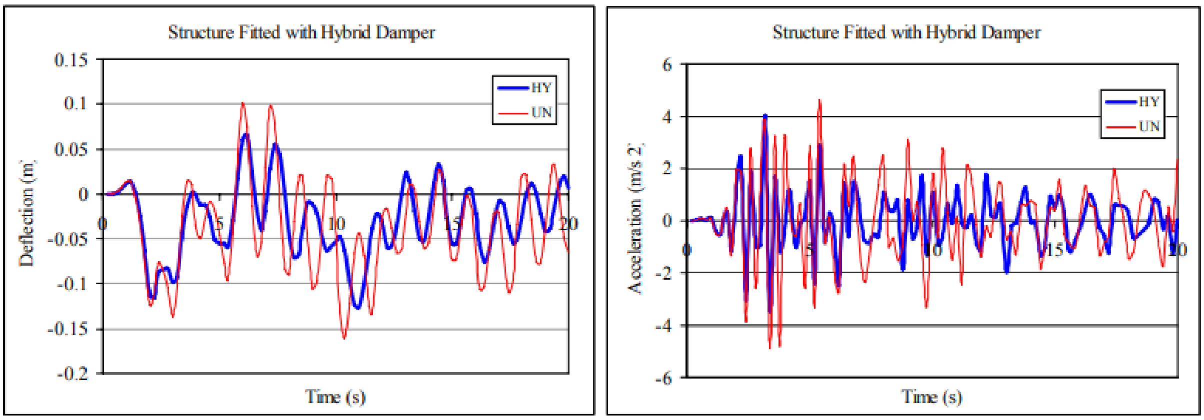

Fig 5: Effects of the El Centro earthquake on the undammed and dampened structures' tip deflection and acceleration responses

The study compares the performance of an undammed structure to a dampened one during five earthquake recordings, analyzing the decreases in tip deflection and tip acceleration for each damper type, design, and location. The study found that both diagonal VE and diagonal friction dampers exert nearly the same amount of damping force. The study found that the combined damping forces of diagonal VE dampers and chevron brace friction dampers in the hybrid friction-VE damper were 52% and 33%, respectively. The diagonal dampers' damping force was 67%, represented by the characteristics of chevron brace friction dampers and chevron brace VE dampers. All five types of damping devices showed excellent performance, with hybrid friction-VE dampers having the greatest overall decrease of 22.2%. Chevron brace friction dampers installed in shear wall structures achieved the second-highest decrease. Constructions with diagonal VE dampers and diagonal friction performed similarly. The buildings equipped with chevron brace VE dampers had the worst performance, with a 12.3% decrease in average tip deflection.

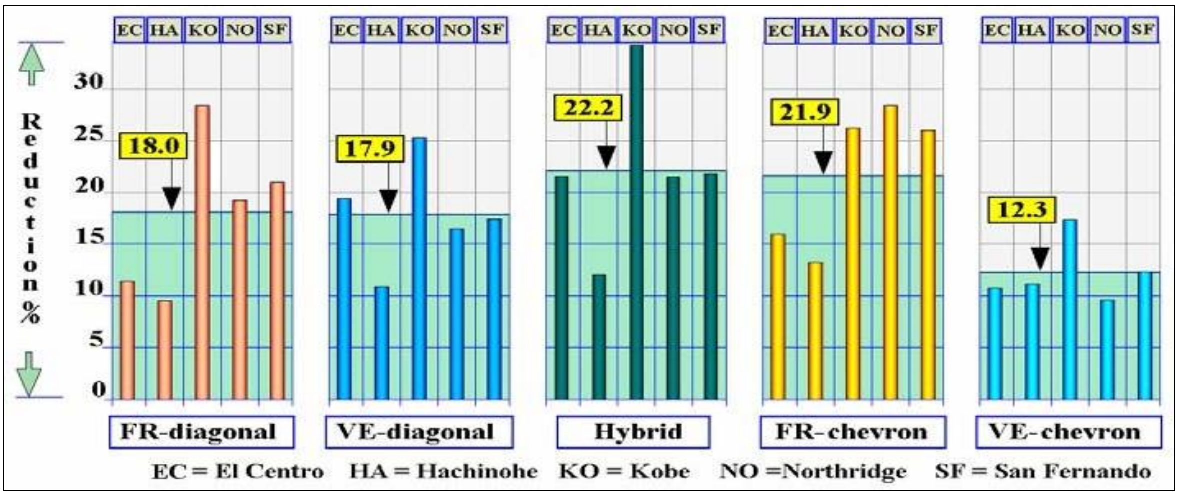

Fig 6: Deflective indices of five different damping systems averaged out.

When The results show that shear wall structures with VE dampers regularly perform better than those without them in the lower and middle parts of the structure, and that the latter is clearly superior in the higher and overall portions of the structure. In terms of performance and reliability, the hybrid damping system stood head and shoulders above the competition.

With regard to the positions of the dampers, Fig. 7 shows the average % decrease in tip deflection for the models.

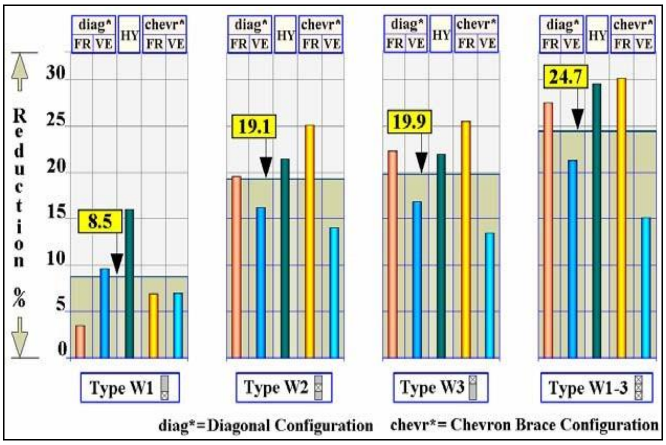

Fig 7: Deflection reductions at the tips of objects subjected to five earthquakes evaluated at various damper sites

With dampers installed in all three sections of the W1-3 shear wall construction, the greatest performance was achieved, resulting in a decrease of 24.7%. Type W3 shear walls with dampers installed in the top section of the structure had surprisingly good performance, resulting in a total decrease nearly 20%. After that, a total reduction of 19.1% was obtained using shear wall type W2 with dampers positioned in the middle of the structure. The base-mounted dampers, denoted by shear wall type W1, achieved the least overall tip deflection reduction, at 8.5%. Figure 8 shows the outcomes of the damping systems' evaluations effectiveness under different seismic loadings.

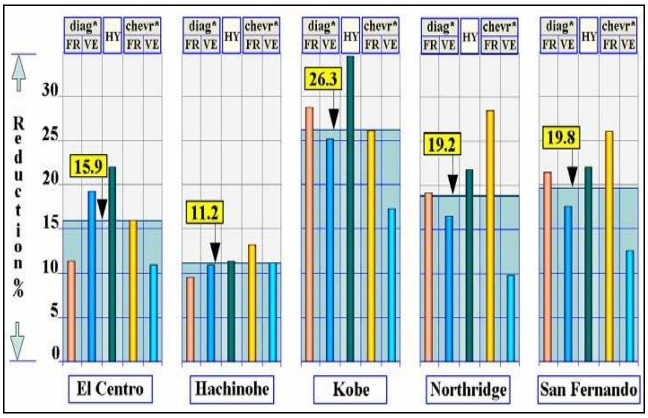

Fig 8: The average decrease in tip deflection under various seismic excitations for five distinct kinds of damping systems.

The study examines the performance of shear wall structures during earthquakes, focusing on the Kobe earthquake excitation. The study found that the Kobe earthquake had a narrow frequency range, resulting in a 26.3% average decrease in tip deflection. The San Fernando earthquake had a wider frequency range, resulting in a 19.8% decrease. The shear wall structure's performance was 19.2% worse during the Northridge earthquake, with a narrow frequency range. The El Centro earthquake had a 15.9% decrease, and the Hachinohe earthquake had a 11.2% decrease. The study found that the damping systems had excellent results, with the structure integrated with diagonal friction dampers having the greatest overall performance. Shear wall structures implanted with chevron brace VE dampers and hybrid friction-VE dampers had the second biggest reductions. The bottom and middle sections of the structure with VE dampers reduced tip acceleration the most, while the upper and throughout sections with friction dampers reduced tip deflection the least.

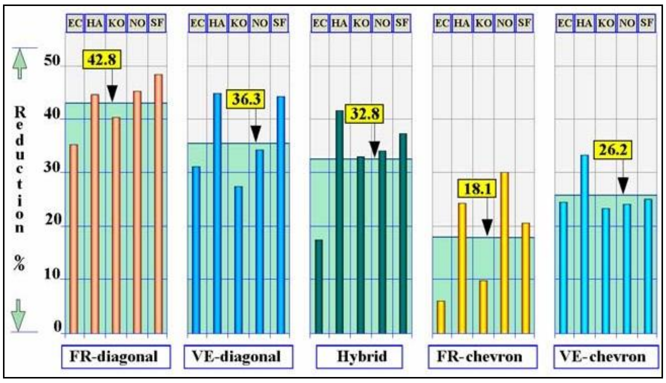

Fig 9: Average tip acceleration decreases for five kinds of dampening devices.

When comparing models with different locations of dampers, the one with the lowest placement had the greatest results (Fig. 10), resulting in a 42.5% reduction in total tip acceleration. A 36.1% decrease was seen in Type W1-3, which had dampers installed in all three structural sections. The lowest overall performance was achieved by structure type W3, which featured dampers, located in the top section of the structure and reduced tip acceleration by 16.4%. A much lower total decrease of 27.1% was obtained by shear wall construction type W2, which has dampers positioned in the center.

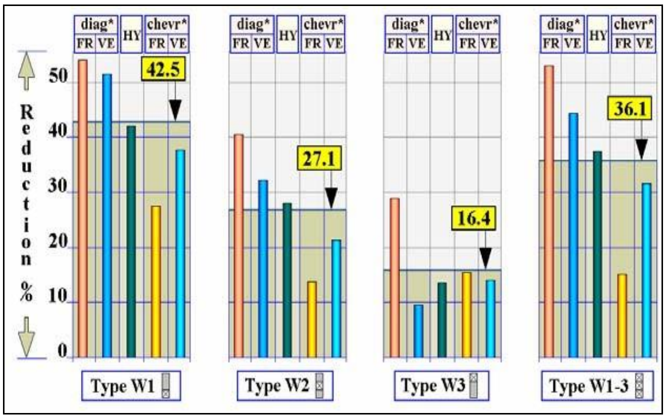

Fig 10: Modifications to average tip acceleration (subject to five earthquakes) at various damper sites

In Figure 11, we can see how well the damping devices mitigate the acceleration of the tips subjected to distinct earthquake loads.

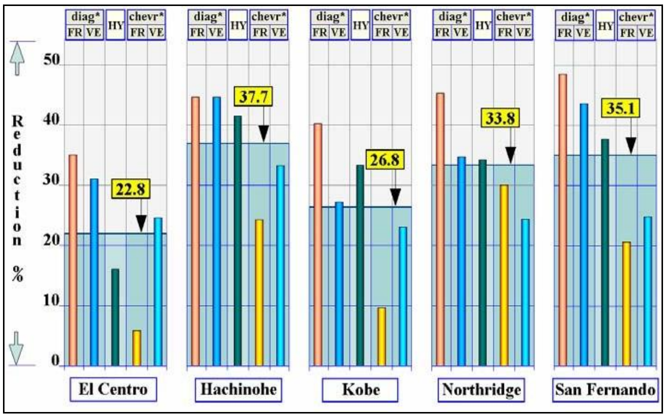

Fig 11: Typical decreases in tip acceleration (for five distinct damping system types) in response to varying seismic stimulus.

The Hachinohe earthquake excitation led to a 37.7% decrease in tip acceleration, while the San Fernando earthquake resulted in a 35.1% reduction. The Northridge earthquake resulted in a 33.8% reduction, the Kobe earthquake 26.8%, and the El Centro earthquake had the lowest drop at 22.8%. Researchers simulated and evaluated shear wall constructions using three damping mechanisms: velocity-elastomer (VE), friction, and a mix of the two. They found that all three types significantly reduced the structure's deflection and acceleration in every configuration and place.

Dampers positioned at the top worked best in reducing tip deflection, while those at the bottom reduced extreme levels of tip acceleration. VE dampers performed better in the middle and lower parts of the structures, while friction dampers were superior in higher sections and throughout. Hybrid dampers were the best in terms of efficiency and stability.

The majority of shear wall structural models had natural frequencies falling within the seismic modes most prevalent. This research shows that a suitable dampening system could potentially reduce the seismic response of structures. The data for shear wall constructions is provided in Tables 2 and 3, as well as Figures 12 and 13.

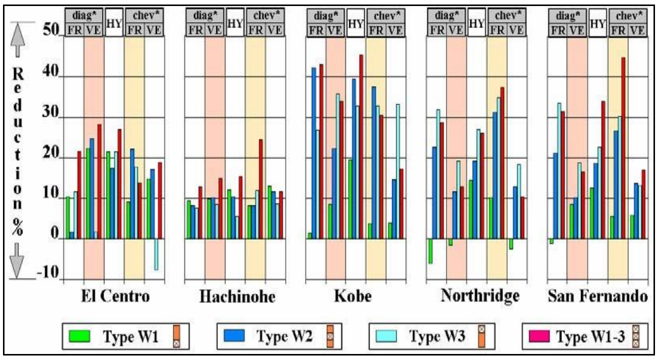

Fig 12: Reduced tip deflection percentages for all shear wall systems

Table 2: Deflective bending of all models as a percentage

Records	Configurations	Devices	Wall W1	Wall W2	Wall W3	Wall W1-3
El Centro	Diagonal	Friction	10.5	1.7	11.7	21.6
		VE	22.4	24.8	1.7	28.3
	Hybrid		21.5	17.5	21.5	26.9
	Chevron	Friction	9.7	22.2	17.8	13.9
		VE	14.8	17.2	-7.6	19.0
Hachinohe	Diagonal	Friction	9.4	8.3	7.6	12.8
		VE	9.9	10.2	8.6	14.9
	Hybrid		12.1	12.4	5.6	15.4
	Chevron	Friction	8.2	8.2	11.9	24.5
		VE	13.0	11.6	7.7	11.6
Kobe	Diagonal	Friction	1.4	42.2	26.8	43.0
		VE	8.6	22.4	35.7	33.9
	Hybrid		19.5	39.4	32.7	45.4
	Chevron	Friction	10.1	31.2	34.8	37.3
		VE	-2.5	12.9	18.3	10.4
S. Fernando	Diagonal	Friction	-1.1	21.2	33.5	31.4
		VE	8.5	10.1	18.8	16.6
	Hybrid		12.6	18.6	22.6	33.9
	Chevron	Friction	2.5	26.6	30.2	44.8
		VE	5.8	13.7	13.1	17.0

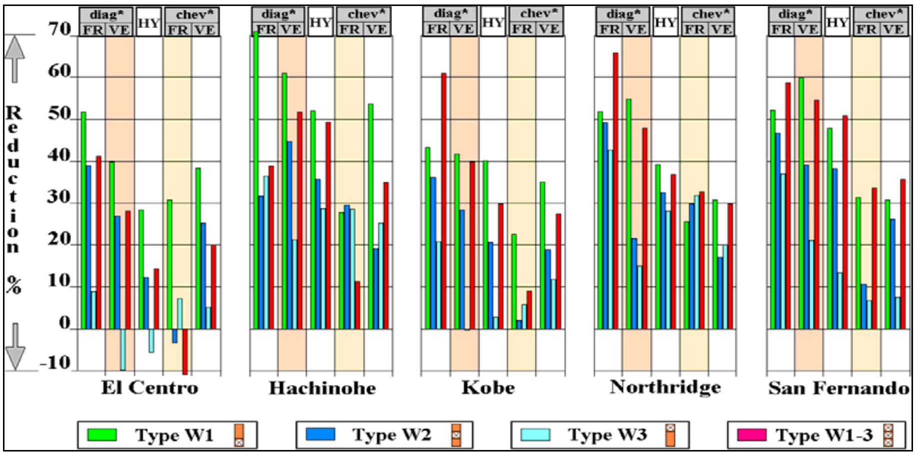

Fig 13: Minimization of tip acceleration across all shear wall constructions as a percentage

Table 3: Lowering the maximum tip acceleration of each model by a certain percentage

Records	Configurations	Devices	Wall W1	Wall W2	Wall W3	Wall W1-3
El Centro	Diagonal	Friction	51.7	39.0	8.8	41.1
		VE	39.8	26.9	-9.9	28.1
	Hybrid		28.3	12.3	-5.6	14.4
	Chevron	Friction	30.7	-3.3	7.2	-10.9
		VE	38.3	25.2	5.1	30.1
Hachinohe	Diagonal	Friction	71.7	31.7	36.4	38.8
		VE	61.0	44.8	21.2	51.8
	Hybrid		52.0	35.6	28.7	49.3
	Chevron	Friction	27.8	29.5	28.5	11.3
		VE	53.7	19.1	25.3	34.9
Kobe	Diagonal	Friction	43.3	36.1	20.8	60.9
		VE	41.8	28.4	-0.3	39.8
	Hybrid		40.1	20.6	2.7	29.9
	Chevron	Friction	25.6	29.8	31.8	32.7
		VE	30.8	17.1	20.1	29.8
S.Fernando	Diagonal	Friction	52.1	46.7	37	58.7
		VE	59.9	39.1	21.0	54.5
	Hybrid		47.9	38.2	13.4	50.9
	Chevron	Friction	31.4	10.8	6.8	33.5
		VE	30.7	26.2	7.5	35.6

Conclusion

high-rise buildings with six dampening technologies under five distinct earthquake records. When handled in various buildings, the performance of these damping systems varied greatly and was unique for each. Nevertheless, a few distinct characteristics are discernible. The friction dampers were superior than the VE dampers in most cases when it comes to minimizing the severity of the initial hard strikes. An inferior toggle VE damper failed to all other dampening devices in terms of performance and dependability. To get a full knowledge of the efficiency and location of the dampers, several evaluations were conducted on various structure types that were equipped with different damping systems and subjected to varied seismic excitations. The structural reaction was examined in this research regardless of whether the prevailing seismic frequencies were in sync with the structure's inherent frequency or not. Evidence suggests that seismic reduction is feasible for all earthquake excitations with the use of certain kinds of dampers placed correctly inside the building.

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