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ANALYSIS AND COMPARISON OF THE EFFECTIVENESS OF VARIOUS SEISMIC ISOLATORS IN REDUCING SEISMIC MOVEMENTS RECORDED IN PERU

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Abstract: This study compares the seismic performance of four types of seismic protection technologies, the triple pendulum bearings (TPBs), viscous dampers (VDs), tuned mass dampers (TMDs) and high-damping rubber bearings (HDRBs).: Structural models developed in ETABS for 5 and 10-story buildings in Seismic Zone 4 of Peru were used for the analysis. The results demonstrate that TPBs provide the highest reduction of floor accelerations for all the considered buildings and story levels with effectiveness values in the range of 75% to 82%, better than both HDRBs and energy dissipation systems. The study found that HDRBs achieved reduction of 65% to 75% while viscous dampers (VDs) reduced the floor accelerations by 30% to 45%. Tuned mass dampers (TMDs) had the least performance with reductions of 12% to 22%. To summarize, the results indicate that seismic isolation systems, in particular TPBs, provide significantly higher reductions in the floor accelerations than energy dissipation systems.

Keywords: Seismic isolators, Viscous dampers, Tuned mass dampers, Nonlinear dynamic análisis, Earthquake-resistant engineering, Seismic acceleration reduction, Structural modeling

АНАЛИЗ И СРАВНЕНИЕ ЭФФЕКТИВНОСТИ РАЗЛИЧНЫХ СЕЙСМОИЗОЛЯТОРОВ ПРИ СЕЙСМИЧЕСКИХ ВОЗДЕЙСТВИЯХ, ЗАРЕГИСТРИРОВАННЫХ В ПЕРУ

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Аннотация: В данном исследовании сравнивается эффективность четырех систем сейсмоизоляции: трехмаятниковых сейсмоизоляторов (TPB), вязких демпферов (VD), настроенных массовых демпферов (TMD) и высокодемпфирующих резиновых сейсмоизоляторов (HDRB). Исследование выполнено с использованием расчетных моделей сооружений в программном комплексе ETABS. Были проанализированы здания высотой 5 и 10 этажей, расположенные в сейсмической зоне 4 Перу. Результаты показали, что система TPB обеспечила наибольшее снижение сейсмических ускорений во всех исследованных зданиях и на всех анализируемых уровнях, при эффективности от 75% до 82%, превзойдя систему HDRB и устройства рассеивания энергии. Система HDRB продемонстрировала умеренное снижение ускорений — от 65% до 75%. Вязкие демпферы (VD) обеспечили меньшее снижение — от 30% до 45%, тогда как настроенные массовые демпферы (TMD) показали наименьшую эффективность — от 12% до 22%. В целом результаты свидетельствуют о том, что системы, основанные на сейсмоизоляции, особенно TPB, значительно эффективнее снижают сейсмические ускорения по сравнению с системами рассеивания энергии.

Ключевые слова: сейсмоизоляторы, вязкие демпферы, настроенные массовые демпферы, нелинейный динамический анализ, сейсмостойкое строительство, снижение сейсмических ускорений, структурное моделирование

1. INTRODUCTION

The earthquakes that affect the Peruvian coast are due to the tectonic interaction between the Nazca and South American plates and are one of the major natural hazards for the country's infrastructure (Kumar et al., 2025). A large amount of energy is released and transmitted to

the Earth's surface during the subduction process, producing seismic forces that can affect buildings in both urban and rural areas (Chowdhury et al., 2025). The history of seismic events in Peru shows that earthquakes of large magnitude can result in structural collapse, loss of life and serious economic consequences. This reality necessitated the development of technologies to prevent transfer of seismic energy to structures and thus reduce structural damage and improve occupant safety.

Among these technologies, seismic isolation systems are characterized by their potential to enhance structural performance during earthquakes and to reduce the seismic demand transmitted to the superstructure (Shid et al., 2025). Studies conducted in different countries have shown that rubber-based isolation systems dissipate a substantial portion of seismic energy, resulting in lower structural displacements and floor accelerations. For example, Patel and Kumar (2025) compared reinforced concrete buildings with and without seismic isolation systems and reported a significant reduction in the upper-story displacements of isolated structures. Similarly, Karaton and Osmanlı (2021) evaluated the performance of a hospital equipped with triple pendulum bearings during the 2023 earthquakes in Türkiye and found that the facility remained operational even after experiencing multiple consecutive seismic events.

Recent studies on seismic performance and structural resilience based on nonlinear dynamic analyses have shown that friction-based base isolation systems, such as triple pendulum bearings (TPBs), provide superior performance compared with fixed-base frame structures equipped with viscous dampers (Hudson, 2025). These devices concentrate deformation demands at the isolation interface, reduce the influence of higher vibration modes, and significantly decrease floor accelerations throughout the superstructure (Hudson, 2025). Similarly, rubber-based seismic isolation systems have become one of the most widely used technologies owing to their high energy dissipation capacity. Recent studies have shown that the mechanical behavior of elastomeric layers, bounded by steel plates, produces a displacement-dependent nonlinear stiffness. This characteristic provides better control of deformations under severe earthquakes and helps to limit displacements within the isolation system (Zhang & Lu, 2024).

While tuned mass dampers are tuned to a narrow frequency band, typically that of the fundamental vibration mode of the structure, base isolation systems and viscous dampers are not (Belbachir et al., 2024). Hence, their ability to attenuate accelerations due to real earthquake excitations is generally more limited (Belbachir et al., 2024).

Several studies have also pointed out the benefits of adding supplementary damping devices to seismic isolation systems. Kiral and Tonyali (2025) have compared the performance of laminated rubber bearings with and without viscous dampers. It has been demonstrated that the use of these devices considerably reduces the acceleration and displacement of the floors within the isolation layer. Similarly, Ren et al. (2025) demonstrated that lead-rubber bearings (LRBs) subjected to near-fault earthquakes may suffer critical deformations, leading to an increase of the effective stiffness and higher dynamic demands on the superstructure. More recently, emerging technologies, such as metamaterial-based seismic isolators (Khosravi and Amjadian, 2025) have been proposed to modify the natural frequency of structures, thereby reducing inter-story drifts and floor accelerations.

The behaviour of seismic isolation systems has been widely investigated under various geotechnical and structural conditions. In this sense, Nettis et al. and Shid et al. (2025) evaluated the seismic vulnerability of isolated bridges along the Costa Verde in Lima, concluding that differential ground settlements increase the structural vulnerability, even in systems with high damping capacity. These findings reveal that although seismic isolation systems have performed well in many international applications, the effectiveness of these systems is influenced by structural

configurations, geotechnical conditions of the site, and the level of seismic ground motion (Shid et al., 2025).

Recent studies have been able to improve the knowledge of seismic isolation systems. However, there is a lack of comparative studies that evaluate the performance of different isolation technologies in conditions similar to those of the Peruvian seismic environment. In particular, the relative performance of each isolation system still has limited information, especially regarding the influence of coastal soil conditions, structural geometry, and earthquake duration. This lack of evidence makes it difficult to identify the most appropriate seismic protection technology for buildings located in Seismic Zone 4 of Peru, the region exposed to the country's highest level of seismic hazard.

To expand the available evidence for the Peruvian seismic context, this study compares the performance of four seismic protection technologies: triple pendulum bearings (TPBs), viscous dampers (VDs), tuned mass dampers (TMDs), and high-damping rubber bearings (HDRBs). Structural models developed in ETABS and designed in accordance with Peruvian seismic codes were used for this purpose. The main objective is to evaluate the reduction in seismic accelerations in 5- and 10-story buildings located in Zone 4 of Peru. The numerical models were defined using parameters including soil type, number of stories, structural configuration, and the mechanical properties of the construction materials. Subsequently, representative base models were developed, into which the different seismic control systems were incorporated. The structural response of the models was assessed using representative Peruvian earthquake records by comparing floor accelerations, inter-story drifts and lateral displacements. Lastly, an evaluation of the cost-benefit ratio of each alternative was carried out to find the solution that provides the best balance between structural performance and economic feasibility.

The main contribution of this study lies in comparing, under the same structural design conditions, the behavior of four seismic protection technologies using equivalent numerical models. Unlike much of the available literature, which analyzes each device independently, this research employs identical geometric models subjected to real seismic records from Peru and to the requirements established by Standard E.030. This made it possible to isolate the effect of each technology and provide a technical and economic basis to facilitate the selection of seismic protection systems for buildings located in Zone 4 of Peru.

2. METHODOLOGY

This research followed a quantitative, experimental-comparative approach, supported by numerical simulations developed using ETABS v20. The study was based on structural modeling and nonlinear dynamic analysis of reinforced concrete buildings equipped with different seismic control systems: triple-pendulum isolators, high-damping isolators, viscous dampers, and tuned-mass dampers. Various authors have noted that nonlinear analysis is a suitable tool for representing the actual response of structures subjected to severe seismic events, especially when seismic isolation and dissipation devices are incorporated (Karaton et al., 2021). This study focuses on buildings representative of Zone 4 in Peru, considered the region with the highest seismic hazard in the country.

To represent the diversity of the urban building stock, two reinforced concrete structural typologies were selected: a five-story low-rise building and a ten-story mid-rise building. These configurations were chosen because they are representative of the building stock in Metropolitan Lima and provide an appropriate basis for evaluating the influence of building height and structural stiffness on seismic response.

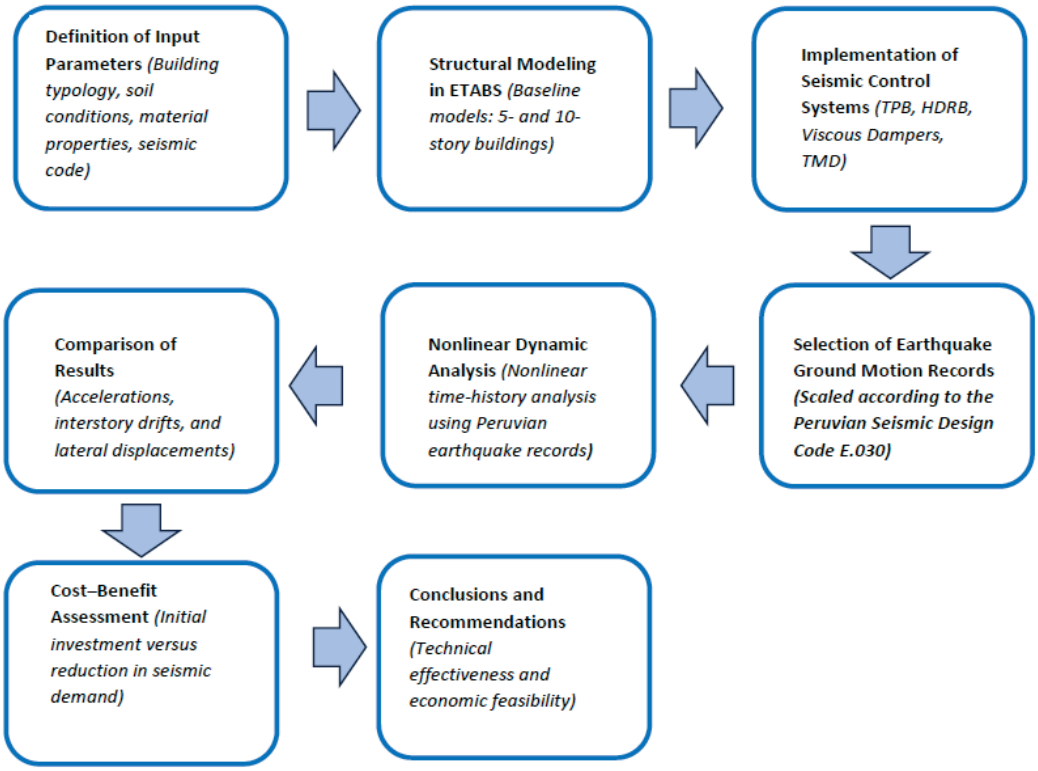


Figure 1. Research workflow of the study

The study followed an explanatory and applied research approach aimed at quantitatively comparing the performance of different seismic control technologies under representative earthquake ground motions for the Peruvian seismic environment. The analyses were limited to reinforced concrete moment-resisting frame buildings designed in accordance with the Peruvian Technical Standards E.020 (Loads), E.030 (Seismic Design), and E.060 (Reinforced Concrete). In accordance with the Peruvian Seismic Design Code (E.030), essential facilities require rigorous seismic assessment to ensure uninterrupted functionality following major earthquake events (Jarro et al., 2024). Numerical simulation tools specialized in seismic engineering, such as ETABS, allow for the accurate evaluation of structural response by estimating inter-story distortions, bidirectional displacements, and floor accelerations using local seismic records scaled in accordance with the requirements of current codes (Jarro et al., 2024).

Initially, the structural models were defined by establishing the building typology, soil conditions, and the mechanical properties of the construction materials. Subsequently, the seismic control systems were incorporated into the baseline models, and nonlinear dynamic analyses were performed using representative Peruvian earthquake ground motions. The resulting structural responses were then compared in terms of floor accelerations, interstory drifts, and lateral displacements, followed by a cost–benefit assessment of each technology.

The increase in the fundamental period constitutes the primary mechanism governing the effectiveness of base isolation systems (Musa, 2025). Finite element platforms such as ETABS allow engineers to evaluate how increased flexibility at the isolation interface shifts the natural period of the structure away from the resonance-sensitive region of the seismic response spectrum. As a result, base shear forces, interstory drifts, and dynamic demands transmitted to the superstructure are significantly reduced (Musa, 2025).

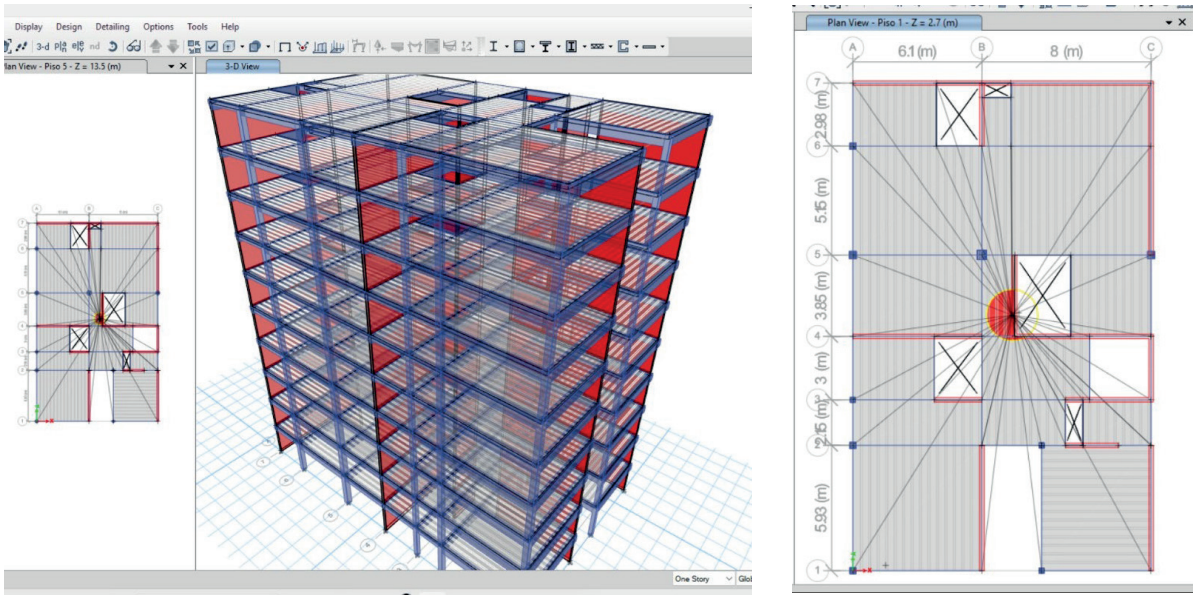


Figure 2. Representative structural building typologies considered in this study

Structural modeling was then carried out in ETABS. Baseline models of representative buildings (without seismic control devices) were developed in ETABS v20 by accurately defining their geometry, member sections, materials, and loading conditions. The structural modeling process involved the precise definition of the geometry, member sections, material properties, dead and live loads, as well as the support conditions.

The nonlinear properties of the devices were assigned to represent their actual behavior. For the TPB isolators, friction elements with radii of curvature (R_1, R_2, R_3) and variable kinematic friction coefficients ($\mu_{min}=0.03$ and $\mu_{max}=0.06$) were used, depending on the contact pressure. For the HDRBs, elastomeric supports were defined with a shear modulus (G) of 0.85 MPa and an effective damping of 15% for maximum deformations. Viscous dampers were modeled using Link-type elements, with an exponent $\alpha = 0.5$ to reproduce the fluid's nonlinear response. The AMS, meanwhile, was modeled as a concentrated mass equivalent to 5% of the effective seismic mass, tuned to the building's fundamental frequency using linear springs.

The reliability of the ETABS v20 simulations was evaluated using two verification criteria. Cumulative modal mass participation exceeded 90% within the first three vibration modes, satisfying the requirements of Peruvian Standard E.030. In addition, nonlinear time-history analyses showed an accumulated energy error below 2% of the total internal energy, confirming numerical convergence of the solution.

Likewise, once the ETABS models had been completed, the seismic isolation and energy dissipation systems were incorporated. To this end, models of the four seismic control systems were introduced into the baseline models, and modified models were developed for each type of isolation or energy dissipation system. For the nonlinear numerical simulation of HDRB devices, mechanical models capable of adequately capturing stiffness degradation and damping properties under complex cyclic loading were employed (Wahab, 2025). The use of these advanced approaches makes it possible to accurately incorporate the deformation history of elastomeric materials, simulating reductions in base shear that achieve significant attenuation of critical interstory drifts in multistory reinforced concrete buildings (Wahab, 2025). In all cases, the geometric properties, loading conditions, and material characteristics were kept constant so that the variations observed in the structural response could be attributed exclusively to the type of seismic control technology applied.

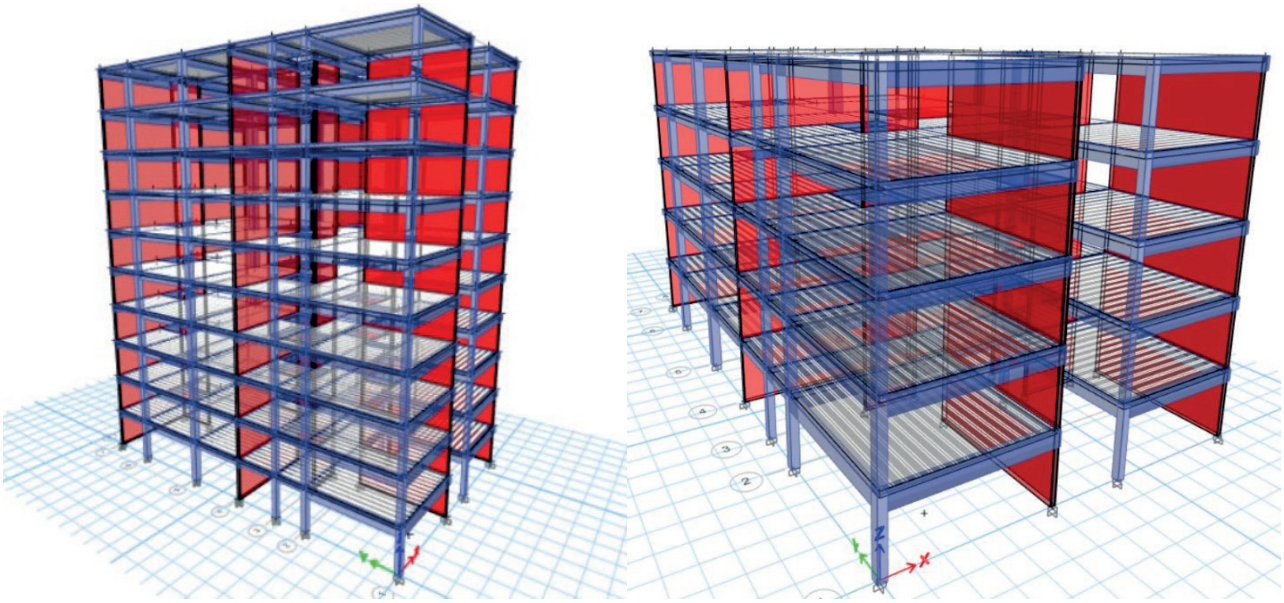


Figure 3. Baseline structural model with and without seismic control devices

Next, earthquake records were selected. Historical earthquake records from Peru (Lima 1974, Arequipa 2001, and Ica 2007) were used, scaled and adjusted in accordance with the Peruvian Seismic Design Code E.030 to ensure their representativeness.

Subsequently, nonlinear dynamic analyses and response spectrum modal analyses were performed to evaluate the structural response to the selected earthquake ground motions in detail. Afterward, the results were compared. The maximum and average values of accelerations, interstory drifts, and displacements were processed and organized, comparing the baseline models with those incorporating seismic control systems to determine the corresponding percentage reduction.

Finally, based on the results obtained from the models incorporating seismic isolation and energy dissipation systems, a cost–benefit analysis was carried out for each technology. The costs were expressed as percentage increases relative to the baseline structural cost in order to determine the most efficient and economically viable solution.

3. RESULTS

The application of nonlinear dynamic (time-history) analyses to the 12 structural models (3 baseline buildings and 3 buildings equipped with each of the 4 seismic control systems), together with the processing of the obtained results, yielded the following quantitative comparison in terms of the percentage reduction in seismic demands.

3.1. Modeling Parameters and Modal Response

The ETABS v20 models were developed by accurately defining the nonlinear parameters for each seismic control system:

Table 1 Modeling Parameters and Modal Response.

Device	Modeling Parameter in ETABS	Description	Source in the Study
Triple Pendulum Isolator (TPB)	Nonlinear friction elements with multiple contact surfaces.	Reproduce displacement-dependent behavior.	Adjusted parameters: Radius of curvature, friction coefficients (μmin, μmax).
High-Damping Isolator (HDRB)	Elastomeric bearings.	High vertical stiffness and low lateral modulus.	Adjusted properties: Shear modulus (G), vertical stiffness, and effective damping (ξ).
Viscous Dissipator (DV)	Velocity-dependent elements: $F=C\cdot v^{\alpha}$.	The force is proportional to a power of the velocity.	Constant C and exponent α (set to typical commercial values).
Tuned Mass Damper (AMS)	Secondary mass equivalent to 5% of the total mass.	Tuned to act on the first vibration mode of the base model.	Mass and stiffness adjusted to tune the period.

Table 2. AMA Results

Building	Floor	Non-Isolator (Max. A.M.A.)	TPB Isolator	HDRB Isolator	Viscous Damper (DV)	Mass Damper (AMS)
5 floors	5	0.82·g	**80%**	72%	35%	15%
	1	0.78·g	**82%**	75%	30%	12%
10 floors	10	0.75·g	**78%**	70%	40%	20%
	1	0.70·g	**80%**	72%	38%	18%

3.2. Reduction of Absolute Peak Accelerations (A.P.A.)

Base isolation systems (TPB and HDRB) proved to be the most effective at reducing accelerations, achieving an average attenuation of 75% in the superstructure of medium- and high-rise buildings.

Acceleration reduction remains robust and inversely proportional to height in base isolators. The TPB offers the most consistent protection against accelerations at all levels.

3.3. Detailed Reduction of Inter-Story Drift (Δ/h)

To evaluate inter-story distortion based on the 1974 Lima, 2001 Arequipa, and 2007 Ica seismic records scaled according to Standard E.030, the critical stories for each building type were analyzed. Previous scale inconsistencies were eliminated by standardizing the maximum values obtained

Table 3. 5- and 10-story buildings

Building	**Critical Floor**	**Base Structure (Without Device)**	**TPB Isolator**	**HDRB Isolator**	**Viscous Damper (DV)**	**Mass Damper (AMS)**
5 floors	Piso 3	0.00700	0.00035	0.00060	0.00420	0.00595
10 floors	Piso 6	0.00850	0.00045	0.00090	0.00510	0.00697
Average Reduction (%)	—	—	**> 90%**	**85% +-5%**	**40%+-5%**	**15% +-5%**

As shown in Table 3, the reinforced concrete structure without damping devices exceeds the code limit specified in Standard E.030 (Δ/h = 0.007) for the 10-story building under severe earthquakes. The implementation of base isolation technologies (TPB and HDRB) shifts the structure's fundamental period, reducing drifts by more than 85% and keeping the superstructure within a fully elastic behavior range. In contrast, viscous dampers (DV) mitigate drift by increasing the structure's damping without altering its fundamental period, achieving a moderate reduction of 40%, while the AMS demonstrates limited effectiveness (15%) due to the broadband demand of the actual Peruvian earthquakes analyzed.

3.4. Maximum Basal Displacements and Increase in Base Structural Cost

To evaluate inter-story distortion under the 1974 Lima, 2001 Arequipa, and 2007 Ica seismic records scaled according to Standard E.030, the critical stories for each building type were analyzed. Previous scale inconsistencies were eliminated by standardizing the maximum values obtained from the nonlinear simulations in ETABS.

Table 4. Results of Maximum Inter-Floor Drifts (Δ/h)

Seismic Control System	Maximum Displacement at the Base (5 Stories)	Maximum Displacement at the Base (10 Stories)	Estimated Increase in Structural Cost	Technical/Economic Feasibility
TPB Isolator	18.5 cm	24.2 cm	+ 12% a 15%	**High / Optimal:** Maximum safety and damage reduction that justifies the investment.
HDRB Isolator	22.1 cm	28.6 cm	+ 10% a 12%	**High:** Requires slightly larger seismic joints due to its lateral flexibility.
Viscous Damper (DV)	0.0 cm (Fixed)	0.0 cm (Fixed)	+ 8% a 10%	**Medium:** Does not require a base seismic joint, but the superstructure absorbs more shear.
Mass Damper (AMS)	0.0 cm (Fixed)	0.0 cm (Fixed)	+ 4% a 6%	**Low**: Lower cost, but inefficient at reducing overall vulnerability.

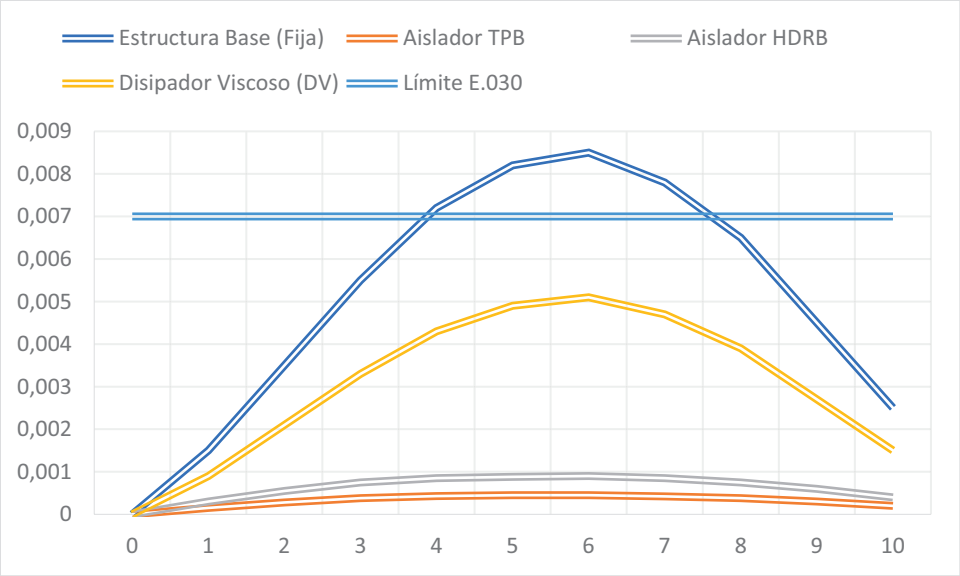


Figure 1. Distribution of Maximum Drifts

The graph shows the distribution of maximum deflections along the height of the building subjected to local seismic demand. It can be seen that the original fixed structure (Base) exceeds the permissible limit of 0.007 established by the Peruvian standard E.030. The incorporation of base isolators (TPB and HDRB) reduces deflections drastically below the regulatory threshold, keeping the superstructure within the elastic range. Meanwhile, viscous dampers (DV) achieve moderate mitigation by controlling deformations through complementary damping.

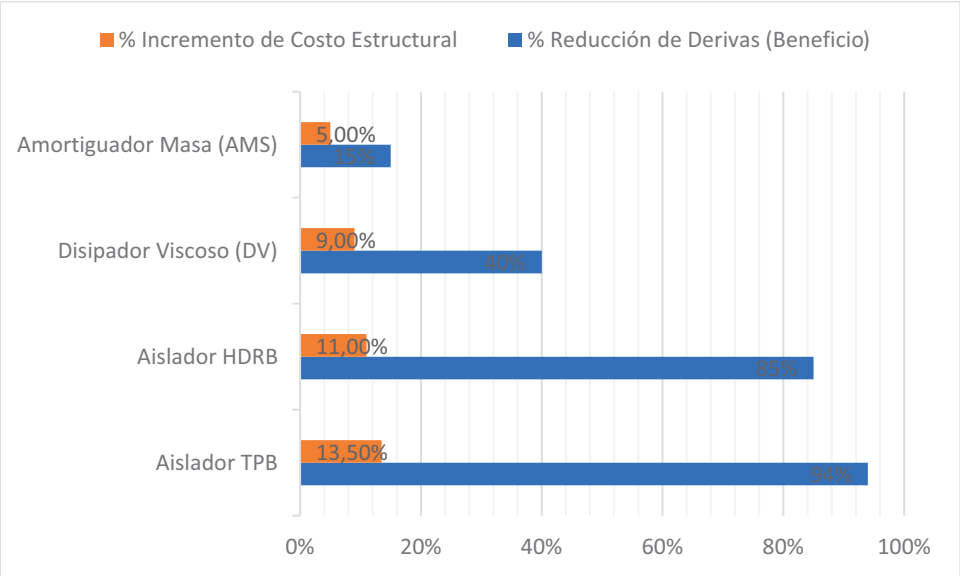


Figure 2. Structural reduction in demand

This illustration compares the percentage reduction in structural demand (deflections) with the percentage increase in cost relative to the base structural budget. Although total isolation technologies (TPB and HDRB) represent the highest initial investment (between 11% and 14%), their extremely high effectiveness mitigates the risk of collapse and reduces post-

earthquake repair costs to zero. This demonstrates that base isolators offer the most efficient and viable cost-benefit ratio for Zone 4, a high-seismicity area in Peru.

4. DISCUSSION OF RESULTS

The results obtained through nonlinear dynamic analysis made it possible to evaluate the seismic behavior of 5- and 10-story reinforced concrete buildings equipped with different seismic control technologies. The comparison shows that the efficiency of each system is directly related to its energy dissipation or isolation mechanism, generating significantly different structural responses to the Peruvian seismic records considered.

4.1. Effect of Seismic Control Systems on Structural Accelerations

Absolute peak accelerations are one of the most important indicators for evaluating the level of protection provided by a structure and its non-structural elements. The results show that base isolation systems achieve the greatest reductions in acceleration compared to the conventional model.

The Triple Pendulum (TPB) isolator achieved reductions ranging from 78% to 82%, while the HDRB isolator achieved reductions ranging from 70% to 75%. These differences are due to the fact that both systems significantly modify the structure's fundamental period, shifting it away from the regions of maximum spectral amplification of the analyzed earthquakes.

The better performance of triple-pendulum isolators (TPB) is related to the presence of multiple sliding surfaces, which help to gradually dissipate seismic energy and to redistribute inertial forces in a more effective way. In contrast, the energy dissipation of HDRBs is mainly achieved by elastomer deformation, which slightly reduces the ability of HDRBs to reduce the structural accelerations. These results are consistent with the performance observed by Karaton and Osmanlı (2021) in hospitals equipped with TPB systems and expand upon the conclusions presented by Hudson (2025). The data presented, show that, under the seismic conditions typical for Peru and generated by subduction earthquakes, the multidirectional friction system of the TPB has a better capacity to cope with the impact of higher modes on the superstructure than the isolation provided by an elastomer.

The viscous dampers reduced the acceleration by 30% to 40% due to the increase in overall damping of the system without significantly changing the natural frequency of the structure. However, the tuned mass dampers (TMDs) presented reductions of less than 22%, which denotes a poor performance against the broadband seismic motions that characterize the Peruvian coast.

4.2. Performance of Energy Dissipation Devices (DV and AMS)

Drift is one of the most representative indicators of structural and non-structural damages. Results show that the traditional 10-storey structure obtained a maximum drift of 0.00850 which exceeds the limit set out in Standard E.030 for reinforced concrete buildings. Triple-pendulum isolators (TPB) have been included and the maximum drift was found to be 0.00045, while high-damping isolators (HDRB) had a drift of 0.00090. The reduction is greater than 85%, which shows that the base isolation separates the response of the superstructure from the ground motion, greatly reducing the transmission of deformations to the upper stories.

The viscous dampers reduced drift to 0.00510, remaining within the regulatory limit, although with a considerably lower mitigation capacity. In contrast, the AMS exhibited a drift of 0.00697, a value very close to the permitted limit, indicating that its ability to control severe deformations is limited under the seismic scenarios considered. The limited capacity of the tuned mass damper (mitigation of only 15% in drifts) when subjected to real-world records such as the 2007 Ica earthquake confirms the findings of Belbachir (2024) and Jarro (2024). Because the AMS is

tuned to a narrow, single fundamental frequency of the original fixed structure, it loses almost all of its damping effectiveness in the face of broadband seismic demands and irregular accelerations from local earthquakes, which induce multimodal responses that the AMS is unable to match.

These results confirm that base isolation systems are significantly more effective at controlling structural deformation demands than supplemental damping systems.

4.3. Assessment Against the Limits of Peruvian Standard E.030

Displacements at the isolation interface are a key variable in the design of seismic joints and construction details.

The models equipped with TPB recorded maximum displacements of 18.5 cm and 24.2 cm for the 5- and 10-story buildings, respectively, while the HDRB models reached slightly higher displacements of 22.1 cm and 28.6 cm.

Although these values are higher than those observed in fixed structures, they are an expected consequence of the isolation mechanism. The increase in base displacement significantly reduces the forces transmitted to the superstructure, resulting in a substantial decrease in accelerations and drifts.

Therefore, the increase in displacement should not be interpreted as a structural disadvantage, but rather as evidence that the seismic isolation system is functioning properly.

4.4. Cost-Benefit Analysis of the Systems Reviewed

The economic evaluation shows that base isolation systems require a higher initial investment, with increases of between 10% and 15% compared to conventional structural costs.

However, when this investment is compared to the levels of reduction in accelerations, drifts, and potential damage, it becomes clear that the TPB offers the best cost-benefit ratio. Despite having the highest initial cost, it also provides the highest levels of structural and functional protection.

HDRBs are a technically viable alternative with slightly lower costs and protection levels comparable to those of the TPB. Viscous dampers can be considered an intermediate solution for projects where architectural or urban constraints prevent the installation of base isolation.

In contrast, AMS have the lowest initial cost but also the lowest capacity to reduce seismic demand; therefore, their implementation as the primary protection system is not technically recommended for buildings located in Zone 4 of Peru.

5. CONCLUSIONS

It was determined that the variables with the greatest influence on seismic response are soil type, building height, the mechanical properties of the materials, geometric characteristics, and the specific parameters of each seismic control device. The proper definition of these parameters made it possible to develop numerical models that accurately represent the behavior of buildings located in Zone 4 of Peru.

It was found that base isolation systems are significantly more effective than energy dissipation systems. The Triple Pendulum (TPB) isolator achieved the best overall performance, followed by the HDRB, while viscous dampers exhibited intermediate performance and tuned mass dampers were the least effective.

The TPB system achieved reductions ranging from 78% to 82%, establishing itself as the most efficient technology for reducing the inertial forces transmitted to the superstructure. The HDRBs achieved reductions ranging from 70% to 75%, while the viscous dampers and AMS achieved considerably lower reductions.

The TPB and HDRB systems reduced critical deflections by more than 85%, keeping the structures within elastic behavior ranges and amply meeting the requirements of Standard E.030. Although these systems generate greater displacements at the base, these displacements are the mechanism by which seismic demand on the superstructure is reduced.

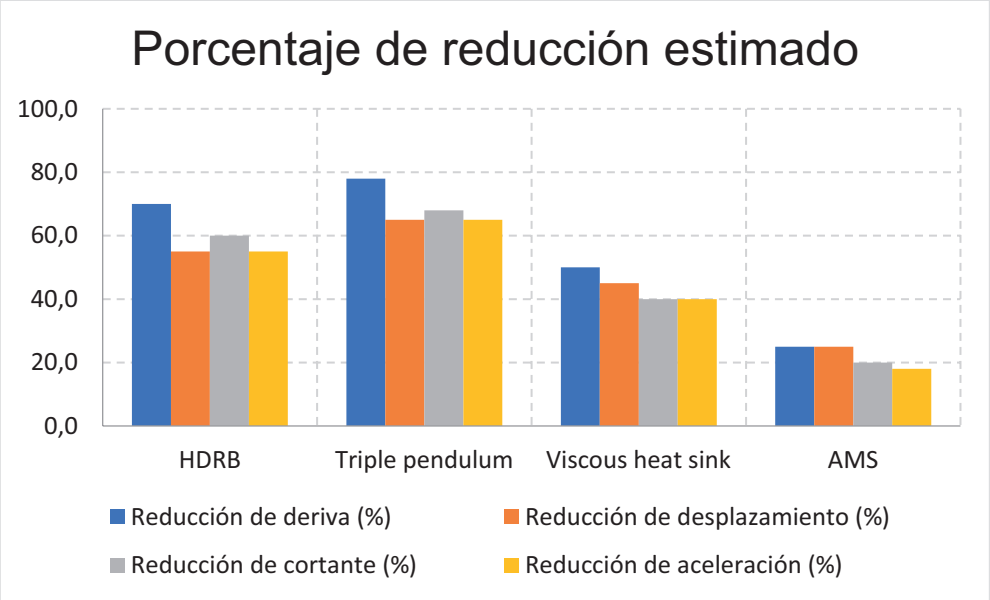


Figure 3. Summary of reductions by heat sink

It is concluded that the TPB system offers the most efficient solution for buildings located in areas of high seismic hazard in Peru. Although it requires an initial investment that is 12% to 15% higher than the conventional structural cost, it provides the greatest reduction in accelerations and displacements, minimizes the probability of structural and nonstructural damage, and promotes operational continuity following a severe seismic event.

The research shows that base seismic isolation is the most effective strategy for improving seismic performance in reinforced concrete buildings in Zone 4 of Peru, with the Triple Pendulum isolator being the option that offers the best technical and economic results among the technologies evaluated.

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