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ADVANCED SEISMIC PROTECTION: OPTIMIZING DESIGN OF HIGH-RISE BUILDING PERFORMANCE THROUGH PASSIVE ENERGY DISSIPATION TECHNOLOGY

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ABSTRACT

In a country like Nigeria, where urban growth is rapidly reshaping cities and more multi-story buildings are going up, ensuring that these structures are safe during earthquakes no matter how rare is becoming increasingly important. This study focuses on improving the seismic performance of mid-rise buildings (between 10 and 15 stories) by using passive energy dissipation systems. These include devices such as fluid viscous dampers and tuned mass

Introduction

As Nigeria's urban centres continue to expand, the skylines of cities like Lagos, Abuja, and Port Harcourt are changing rapidly. Multi-story buildings ranging from 10 to 15 floors are becoming more common in residential, commercial, and institutional developments (Oluwabusuyi Adonis Fakanlu 2024).

dampers, which are designed to absorb and reduce the energy a building experiences during ground shaking. Using structural analysis software, we developed a realistic model of a reinforced concrete building typical of those found in Nigerian cities. The building was tested under simulated earthquake conditions using real seismic data. We analysed how different damping devices performed when installed in various configurations, focusing on how well they reduced building sway, stress at the base, and the number of shaking occupants would feel. The results showed that integrating damping systems especially base isolators and fluid viscous dampers can greatly reduce structural movement and stress during seismic events. For instance, the most effective setup reduced inter-floor drift and peak displacement by over 60%, making the building much safer without requiring major changes to its design. This research doesn't just stay in theory it offers practical advice for Nigerian engineers, architects, and city planners. It shows that even in places where earthquakes are less frequent, taking preventive steps in design can make a big difference. With the right approach, we can build safer, stronger mid-rise buildings that are better prepared for natural hazards, helping protect both people and infrastructure in the long run.

Keywords: Seismic Protection, Passive Energy Dissipation, High-Rise Buildings, Earthquake-Resistant Design, Structural Resilience, Advanced Materials, Innovative Design Approaches, Seismic Response, Building Safety, Community Resilience.

While Nigeria is not typically classified as a high-seismic region, recent global events and the increasing unpredictability of climate and geophysical patterns have underscored the need for a more proactive approach to structural resilience Spyridon Mavroulis, et al 2024). One area that remains largely underexplored in local building practices is seismic protection. Even though the likelihood of a major earthquake may be relatively low, the consequences of being unprepared can be devastating especially for densely populated, poorly reinforced buildings. Traditional structural Luqman Owamoyo, Baharak Tabibi,2023) design in Nigeria tends to focus on wind loads, dead loads, and live loads, often overlooking seismic considerations. However, with increasing globalization and the adoption of international building codes Abhiram Reddy Anireddy 2021), there is a growing need to align local construction practices with global safety standards. This study explores the use of passive energy dissipation systems as a practical and cost-effective strategy for improving the earthquake resistance of mid-rise buildings in

Nigeria. Devices like fluid viscous dampers and tuned mass dampers have been successfully applied in other parts of the world to manage seismic forces, and this research aims to evaluate their potential benefits in the Nigerian context. Using a typical 12-story reinforced concrete building as the case study, a series of simulations were conducted to assess how different damping systems (Muhammad Hamza, et al 2024), perform under earthquake conditions. Real seismic data were used to model the building's behaviour during ground motion, and various performance indicators such as inter-story drift, base shear, and floor acceleration were analysed. The study also considered how factors like material properties, damper placement, and structural configuration affect overall performance.

The goal is not only to demonstrate the technical effectiveness of these systems but also to provide practical guidance for local engineers, architects, and policymakers. By incorporating passive damping into standard building designs (Fatma S. Hafez, et al 2023), we can take an important step toward safer, more resilient infrastructure without adding excessive cost or complexity. In essence, this research bridges the gap between advanced engineering solutions and the realities of construction in developing regions. It argues for thoughtful, forward-looking design that prioritizes human safety and community resilience, even in areas where seismic events may seem unlikely today but not impossible tomorrow.

REVIEW OF RELATED LITERATURE

Seismic protection has made significant strides over the last few decades, especially with the rise of passive energy dissipation systems as a dependable strategy for minimizing structural damage during earthquakes. Devices such as fluid viscous dampers (FVDs), tuned mass dampers (TMDs), and base isolators have been thoroughly studied and implemented in earthquake-prone nations like Japan, the United States, and New Zealand (Chopra, 2017; Skinner et al., 1993). These systems work by dissipating or redirecting energy during seismic events, thereby reducing the internal stresses experienced by building components.

Research led by Housner et al. (1997) under the Structural Control Research Initiative established that energy dissipation mechanisms could drastically reduce seismic response, primarily by converting vibrational energy into heat. Supporting this, Lu et al. (2019) carried out a numerical study on high-rise buildings with dampers and found that FVD-equipped structures experienced up to 60% less inter-story drift, while TMDs significantly reduced peak roof displacements during earthquake simulations. Similarly, Lin and Tsai (2021) demonstrated improved seismic resilience in mid-rise buildings when using hybrid damping systems in high-intensity shaking zones.

However, in sub-Saharan Africa, including Nigeria, the integration of these technologies remains limited. Building regulations in Nigeria (e.g., the National Building Code, 2006) prioritize wind loads and cost efficiency, with minimal emphasis on seismic safety. This oversight persists despite studies that confirm Nigeria's exposure to minor seismic activity. Ajakaiye (1989) provided early documentation of seismic events in the country, and more recently, Adepelumi et al. (2013) recorded low to moderate magnitude tremors in regions such as Kaduna, Ijebu-Ode, and Abuja, suggesting the presence of underlying fault lines and a need for seismic risk awareness.

Further concern arises with Nigeria's rapidly growing urban centres, where mid-rise buildings (5–15 stories) are becoming increasingly common. According to Nwachukwu and Okonkwo (2016), the rise of these buildings often constructed with cost-driven designs and minimal structural redundancy demands a revaluation of current engineering practices. Their findings indicate that even moderate ground motion could critically affect buildings that lack energy-dissipating features or proper reinforcement.

Despite the global validation of damping technologies, barriers such as high initial costs, lack of local expertise, and limited indigenous research have slowed their uptake in Nigeria. Oyenuga and Babalola (2020) highlighted that seismic design is rarely included in Nigerian architectural and civil engineering curricula, leading to a skills gap in both design and construction practices.

This study, therefore, aims to bridge this gap by simulating the performance of passive damping systems in a typical Nigerian mid-rise structure, using locally available materials, regional loading conditions, and practical seismic input scenarios. The results will contribute to a better understanding of how passive seismic protection can be adapted for the Nigerian built environment laying the groundwork for future policy and code development.

Figure 1 uses a striking visual metaphor a small house caught inside a steel bear trap to represent the ever-present danger of earthquakes for inadequately protected buildings. This image doesn't show an actual seismic event, but it speaks volumes about the hidden risks lurking beneath the surface. Just like the trap, earthquakes can strike suddenly and without warning, leaving devastation in their wake. The house appears ordinary, familiar even, which makes the message more personal: any home, anywhere, could be at risk if seismic resilience is not prioritized. The imagery reminds us that without the proper safeguards such as flexible foundations, energy-dissipating components, or reinforced structure

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seven the most well-built homes remain exposed. This symbolic representation brings urgency to the conversation around seismic protection and the importance of forward-thinking design in both policy and practice.

Figure 1: Freepik (2020) Seismic protection of a Metaphor for Seismic Vulnerability

Figure 2 shows two high-rise buildings under construction, set against the backdrop of a growing city. These towers are a clear sign of urban expansion and modern architectural ambition. As cities grow upward rather than outward, these tall structures become more common but with height comes added complexity, especially when it comes to structural stability in earthquake-prone areas. The buildings in this image reflect the need for thoughtful engineering that takes into account both function and safety. Passive energy dissipation systems like dampers or base isolation units aren't just technical add-ons; they're essential parts of ensuring that these buildings can endure seismic forces. This photo speaks to the balance between innovation and responsibility in construction, reminding us that progress must also mean protection, especially in environments where the earth itself can become a threat.

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Figure 2: High-Rise Buildings, Growth and the Challenge of Seismic Safety

RESEARCH QUESTION

- How do different passive energy dissipation systems affect the seismic performance of a typical Nigerian mid-rise building?
- What levels of improvement can be achieved in terms of inter-story drift, roof displacement, and base shear?
- Which damper type and configuration offers the best trade-off between effectiveness and cost in a local construction context?
- How do local factors like building height, stiffness, and seismic load levels influence the overall effectiveness of these damping systems?
- Can passive damping technologies be realistically integrated into Nigerian building designs without significantly increasing construction complexity or cost?

STATEMENT OF PROBLEM

Nigeria's rapid urban growth has led to an increase in the construction of mid-rise buildings, especially in densely populated cities. While these buildings are designed to withstand conventional loads like gravity and wind, they often lack

provisions for seismic resistance. Given the country's limited but real seismic activity, this oversight poses a potential risk to life and infrastructure.
There is a pressing need for research that evaluates practical and locally adaptable strategies for seismic protection. Existing global studies on passive energy dissipation are promising, but few have examined how these technologies would perform in the specific conditions of Nigeria considering its building materials, construction practices, and urban layouts. Without this contextual understanding, there is a risk of continuing to build structures that are vulnerable to even moderate seismic events.

RESEARCH OBJECTIVE

Table 1: This table outlines the core aims of the study, which focus on modelling a realistic Nigerian mid-rise building and analysing the effectiveness of various passive energy dissipation systems.

S/N	Objective
1	To model a typical Nigerian mid-rise (10–15 story) building and simulate its seismic behaviour.
2	To investigate the performance of different passive energy dissipation systems (FVDs, TMDs, isolators).
3	To evaluate the impact of damper placement and configuration on building performance indicators.
4	To assess how local design parameters such as building height, material stiffness, and foundation type affect damper effectiveness.
5	To optimize the damper setup for best performance using simulation and algorithm-based techniques.
6	To provide recommendations for integrating damping technologies into standard Nigerian building practices.

Types of Dampers

Dampers are classified based on their performance of friction, metal (flowing), viscous, viscoelastic; shape memory alloys (SMA) and mass dampers. Among the advantages of using dampers we can infer to high energy absorbance, easy to install and replace them as well as coordination to other structure members. (journal,2006).

- Friction Dampers:
- Viscoelastic Dampers (VEDs)
- Yielding Dampers (Metallic Dampers)
- Magnetorheological Dampers (MRDs)

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- Electrorheological Dampers (ERDs)
- Tuned Liquid Dampers (TLDs)
- Tuned Liquid Column Dampers (TLCDs)
- Active Mass Dampers (AMDs)
- Hybrid Dampers
- Tuned Mass Dampers (TMDs)
- Fluid Viscous Dampers (FVDs)

Fluid Viscous Dampers

It is another type of friction damper and due to ease to installation, is one of the most widely used dampers in structures (Warn,2004). PVD damper can be used to create necessary damping for flexible structures, such as bending steel frame or to provide effective damping to relative stiffness of structures (Naeim,1995). PVD damper is designed to installation where displacement can generate necessary damping such as installation of metal skeleton brace or concrete moment frame.

Tuned mass dampers

A TMD is based on a spring-mass system. The spring is calibrated to the eigenfrequency of the structure and the required mass is designed depending on the modal mass of the structure. Decisions, for example with regard to form, mass, frequency or damping, are made in close collaboration with the specifier Maurer (Magazine 07 2025). Bridges may be prone to vibrations induced by traffic loads, wind, people and earthquakes due to their often-slim construction and their low inherent damping. This can lead to fatigue fractures or even collapse of the bridge due to galloping and flutter vibrations induced by movement. The spring stiffness of the secondary mass is chosen in such a way that an optimum tuning of the main system is achieved. MAURER tuned mass dampers are custom-designed for each structure. Among the various devices listed to control structural movement in tall buildings during earthquakes, this research focuses on two specific types: Tuned Mass Dampers (TMDs) and Fluid Viscous Dampers (FVDs). These devices were chosen because they have proven effective in real-world applications and are commonly used in high-rise structures.

- **Tuned Mass Dampers (TMDs)**

  TMDs are particularly useful for reducing swaying motion in tall and slender buildings that are prone to oscillations caused by wind or earthquakes. A TMD consists of an additional mass connected to the main structure through a system of springs and dampers. This mass is carefully tuned to

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vibrate in opposition to the building's natural frequency, resulting in reduced movement when both systems resonate together.

For this research, TMDs are particularly suitable because of their:

- High efficiency in controlling resonance and sway in high-rise buildings.
- Minimal intrusion into the structural layout.
- Well-documented analytical models, enabling precise simulation and optimization.
- **Fluid Viscous Dampers (FVDs)**

  FVDs work by dissipating energy through the controlled movement of a piston within a viscous fluid. Unlike TMDs, which primarily target specific vibration modes, FVDs can handle both small and large displacements effectively. They are designed to perform well under various dynamic loading conditions, including seismic events.

  Incorporating FVDs into this research is justified by their:
- Excellent energy dissipation capacity during earthquakes.
- Velocity-dependent response that complements the frequency-based performance of TMDs.
- Proven success in real-world applications, such as retrofitting existing buildings to withstand seismic forces.

Rationale for Combined these two Dampers

By combining TMDs and FVDs in our analysis, we can gain a more comprehensive understanding of how these devices interact with each other during seismic events. This approach allows us to explore both frequency- and velocity-dependent damping behaviours, which is crucial for minimizing structural responses across different intensities and frequencies of earthquakes.

The insights gained from this study will have practical implications for designing modern high-rise buildings that can better withstand seismic forces. Additionally, our focus on these two specific damping devices will enable us to conduct more realistic simulations of energy dissipation scenarios and support our optimization goals throughout the research process.

Research Methodology

Research Design

This study adopts a simulation-based analytical approach to evaluate how passive energy dissipation devices can improve the seismic performance of typical Nigerian mid-rise buildings. Rather than working with physical prototypes, the research relies on structural modelling and dynamic analysis, which allows for

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controlled testing of multiple variables without the constraints of real-world construction costs or safety risks.

Model Description

A 12-story reinforced concrete building was selected as the case study, reflecting common structural designs found in urban areas of Nigeria. The building was designed according to both Nigerian building codes and elements of international standards (such as Eurocode 8) to ensure realism and relevance. The structural model includes beams, columns, slabs, shear walls, and a foundation system representative of common local practices.

Software Tools

Two advanced engineering software programs were used for modelling and analysis:

ETABS: For 3D structural modelling, load definition, and static/dynamic response analysis.

SAP2000: For detailed time history analysis and fine-tuning of damping configurations.

These tools are widely accepted in the engineering field and offer reliable platforms for simulating seismic behaviour under different conditions.

SEISMIC INPUT DATA

To assess the building's behaviour under earthquake loading, this study utilized ground motion records from two well-documented seismic events: the 1995 Kobe Earthquake in Japan and the 1994 Northridge Earthquake in California, USA. These events were selected not only because of their severity but also due to the quality and completeness of their seismic datasets, which have been widely referenced in earthquake engineering research (Kawashima, 2000; USGS, 1995).

Although Nigeria is not traditionally known for high seismic activity, minor tremors have been recorded in regions like Kaduna, Ijebu-Ode, and Abuja. Given the absence of locally recorded strong-motion data, it was essential to adopt a conservative modelling approach that reflects a safety-first mindset. The selected records were therefore scaled and adapted to simulate moderate seismic events that could plausibly affect Nigerian mid-rise buildings (Somerville et al., 1997).

This method aligns with international engineering best practices, where foreign ground motion records are often adapted for regions with limited seismic data, ensuring the structural design remains resilient under unpredictable conditions (Bertero & Bertero, 2002; BSSC, 2001). By incorporating these records into the

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simulation, the study aims to produce realistic yet cautious performance insights essential for guiding future updates to Nigeria's building codes.

Passive Energy Dissipation Devices Studied

Three types of devices were tested:

- Fluid Viscous Dampers (FVDs) –Installed between floors to dissipate kinetic energy.
- Tuned Mass Dampers (TMDs) – Placed at the top of the building to counteract sway.
- Base Isolators – Positioned beneath the foundation to absorb seismic ground motion.

Each system was tested under various installation configurations to examine its individual and combined effects on performance.

Performance Parameters Assessed

The simulations measured:

- Inter-story drift ratio
- Roof displacement
- Base shear force
- Peak floor acceleration
- Energy dissipation rate

These indicators provide insight into how much movement the building experiences and how well the dampers reduce seismic stress.

Optimization Approach

To identify the best configuration of dampers, a Genetic Algorithm (GA) was used. This method mimics natural selection, gradually improving designs by evaluating many combinations and selecting the most efficient in terms of drift reduction and material use.

Assumptions and Limitations

The study assumes ideal material behaviour and excludes long-term degradation or construction defects.

Soil-structure interaction is simplified due to limited regional geotechnical data.

Cost analysis was not deeply explored but is acknowledged for future research.

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Table 2: Seismic input parameters used for simulation, including selected historical earthquake events with varying intensities. The scaling factors were applied to adapt the ground motions to site-specific conditions, supporting performance evaluation under both severe and moderate seismic scenarios.

Table 2: Seismic Input Data Used for Simulation

Earthquake Event	Peak Ground Acceleration (g)	Magnitude (Mw)	Distance to Fault (km)	Scaling Factor Applied	Purpose
1995 Kobe (Japan)	0.82	6.9	4.7	Yes	Represents severe seismic activity for conservative modeling
1994 Northridge (California)	0.84	6.7	5.3	Yes	Used to simulate moderate seismic activity in Nigerian context

Table 3 outline build characteristics, analysis method, software tools, passive control devices considered, and the performance metrics evaluated to assess seismic response and efficiency of damping systems.

Table3: Key Simulation Parameters

Key simulation Parameters	
Parameter	**Description**
Building Height	Approximately 36 meters
Number of Stories	12
Structural Material	Reinforced Concrete
Seismic Analysis Type	Time History Analysis
Software Used	ETABS and SAP2000
Passive Devices Tested	Fluid Viscous Dampers (FVDs), Tuned Mass Dampers (TMDs), Base Isolators
Performance Metrics	Drift, Roof Displacement, Base Shear, Acceleration, Energy Dissipation

Table 4: Comparative Performance of Passive Energy Dissipation Devices

The table compares various passive energy dissipation devices based on key seismic response parameters. It demonstrates how each device type, both individually and in hybrid form, reduces maximum drift, roof displacement, base shear, and top floor acceleration compared to a structure without damping systems.

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Table 4: Performance Summary by Passive Energy Dissipation

Device Type	Max Drift Reduction (%)	Roof Displacement (mm)	Base Shear Reduction (%)	Top Floor Acceleration Reduction (%)
None (Baseline)	0	128	0	0
FVDs	65	58	40	40
TMDs	30	49	10	50
Base Isolators	75	45	72	60
Hybrid (FVD + TMD)	70	42	55	55

Result and Discussion

Overview of Simulation Outcomes

After running several earthquake simulations on the 12-story reinforced concrete building model, both with and without damping systems, a clear difference in structural behaviour was observed. Buildings equipped with passive energy dissipation devices consistently performed better under seismic loads compared to the conventional design model.

Performance Without Dampers (Baseline Model)

In the baseline scenario where no dampers were installed the structure experienced:

High inter-story drift, particularly between the 6th and 9th floors, indicating potential points of failure during real seismic events.

A roof displacement of 128 mm, which suggests considerable building sway.

Base shear values peaked above 3000 kN, putting excessive stress on the foundation and lower columns.

Notable acceleration levels on upper floors, which could compromise occupant safety and cause damage to non-structural elements like partitions and ceilings.

Performance with Fluid Viscous Dampers (FVDs)

When FVDs were installed between selected floors (particularly between levels 4–8), the following improvements were observed:

Inter-story drift reduced by approximately 65%, especially in the middle zone where it was highest.

Roof displacement dropped to 58 mm, indicating much more controlled sway.

Base shear was reduced by 40%, which could lead to less damage to structural supports during an actual earthquake.

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FVDs were found to be highly effective in minimizing sudden movements and absorbing energy rapidly, making them suitable for buildings in urban areas with moderate seismic potential.

Performance with Tuned Mass Dampers (TMDs)

A TMD placed at the roof level reduced peak acceleration and controlled roof displacement more efficiently:

Roof displacement was brought down to 49 mm even lower than with FVDs.

Acceleration on the top three floors decreased by nearly 50%, reducing the likelihood of damage to internal finishes and suspended systems.

However, TMDs had less impact on base shear and lower-floor drifts, suggesting they are better suited for controlling sway rather than base response.

Performance with Base Isolators

Base isolators delivered significant performance improvements:

Inter-story drift across all floors was minimized to safe thresholds.

Base shear dropped by more than 70%, showcasing their strong energy absorption at the ground interface.

Overall movement was smoother and more uniform throughout the structure.

While base isolators proved the most effective overall, they are also the most expensive and technically demanding to implement especially in regions where construction skills and supply chains are still developing.

Optimized System

Through simulation-driven optimization, the best performance came from a hybrid setup using FVDs in the middle floors combined with a roof-mounted TMD. This configuration offered the best balance of drift control, cost efficiency, and ease of installation, especially within the Nigerian construction context.

CONCLUSION

This study set out to investigate how passive energy dissipation systems can improve the earthquake resistance of mid-rise buildings in Nigeria. By simulating the behaviour of a typical 12-story structure under seismic loading, we found clear evidence that devices like fluid viscous dampers, tuned mass dampers, and base isolators significantly improve structural performance reducing displacement, drift, and overall stress.

Among the three technologies, base isolators provided the best results but may pose challenges in terms of cost and construction complexity. On the other hand, fluid viscous dampers emerged as a more practical and effective solution, particularly when installed in the middle floors where the highest drift occurs. The hybrid combination with a TMD further enhanced performance without drastically increasing cost or construction difficulty.

For Nigeria where seismic activity is relatively rare but not impossible this research offers a forward-looking approach to structural safety. As cities grow taller and denser, there is a real need to start embedding these types of systems into standard building practices. This study not only confirms their effectiveness but also provides a pathway for their integration into local design and construction methods.

Ultimately, making buildings safer is not just an engineering challenge it's a social responsibility. With thoughtful design and the right technology, we can build a future where communities are better protected, even in the face of unexpected natural events.

Recommendation

The research findings strongly suggest integrating passive energy dissipation systems into the design and construction of high-rise buildings in seismic-prone regions. Tuned Mass Dampers (TMDs) and Fluid Viscous Dampers (FVDs) have proven highly effective in reducing structural responses to dynamic loads, particularly during seismic events. These technologies, which minimize inter-story drift, control acceleration, and enhance stability, should be considered essential rather than optional in modern high-rise design. Structural engineers and architects are advised to incorporate these dampers from the initial design phase, ensuring proper tuning and strategic placement for optimal performance.

Updating building codes and urban planning policies to enforce or incentivize the use of passive damping technologies in tall buildings, especially in rapidly growing cities, is crucial. This proactive approach will not only protect occupants and investments but also enhance post-disaster functionality and shorten recovery time for critical infrastructure. Furthermore, interdisciplinary studies merging structural engineering, materials science, and computational modelling are recommended to enhance damper configurations, improve cost efficiency, and ensure the long-term durability of damping systems across various climates and geological conditions.

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