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Comparative Seismic Performance Evaluation of Base-Isolated and Damper-Equipped Reinforced Concrete Buildings

Prof. Vidya B. Dhawle[1], Bhakti S. Dharpale[2], Nikita B. Ghodke[3], Archana J. Rathod[4], Nikita R. Joshi[5], Gayatri D. Surashe[6]

[1,2,3,4,5,6]Civil Engineering Department, CSMSS, Chh. Shahu College of Engineering, Chh. Sambhajinagar

ABSTRACT

Earthquake-induced damage to reinforced concrete buildings remains a major concern in seismic regions, necessitating the adoption of advanced vibration control techniques beyond conventional strength-based design. Among these techniques, base isolation and seismic dampers represent two fundamentally different approaches to mitigating seismic demand. This study presents a comprehensive comparative case analysis of base isolation systems and column-installed seismic dampers to evaluate their effectiveness in improving structural seismic performance. A multi-storey reinforced concrete frame is analytically modelled and subjected to seismic loading using response spectrum and time-history analysis methods. Key response parameters including fundamental time period, base shear, storey displacement, inter-storey drift, floor acceleration, and energy dissipation are systematically examined. The results demonstrate that base isolation significantly lengthens the structural time period and achieves substantial reduction in base shear and floor accelerations, making it particularly suitable for acceleration-sensitive structures. In contrast, seismic dampers installed in columns exhibit superior control over inter-storey drift and internal force demand by dissipating seismic energy through hysteretic behavior. The comparative assessment highlights that while both systems considerably enhance seismic resilience, their effectiveness is strongly influenced by building height, functional requirements, soil conditions, and retrofitting feasibility. The study provides practical insights and design-oriented guidance for selecting appropriate seismic protection strategies in performance-based earthquake-resistant design.

Keywords: Base Isolation, Seismic Dampers, Earthquake Engineering, Storey Drift, Base Shear, Response Spectrum Analysis.

1. INTRODUCTION

Earthquakes impose severe dynamic forces on buildings, often leading to excessive displacement, damage to structural members, and loss of functionality. Conventional earthquake-resistant design primarily relies on strength and ductility to resist these forces; however, such approaches frequently result in significant structural and non-structural damage during strong seismic events. To overcome these limitations, modern seismic design philosophies emphasize reducing seismic demand through vibration control and energy dissipation mechanisms rather than merely increasing member strength.

Among the advanced seismic protection techniques, **base isolation** and **seismic dampers installed in columns** have gained wide acceptance due to their proven effectiveness and practical applicability. Base isolation works by decoupling the superstructure from ground motion through flexible bearings, thereby increasing the natural time period of the structure and significantly reducing the transmission of seismic forces. This system is particularly effective in minimizing base shear and floor accelerations, making it suitable for important and acceleration-sensitive structures.

In contrast, seismic dampers enhance structural performance by dissipating seismic energy within the structural system itself. When installed in columns, these dampers reduce inter-storey drift and internal force demands by converting seismic energy into hysteretic or viscous energy dissipation, without significantly altering the global stiffness or mass of the building. Such systems are especially effective for retrofitting existing buildings and controlling damage in multi-storey reinforced concrete frames.

Although both techniques improve seismic performance, their effectiveness varies depending on building height, functional requirements, soil conditions, and design objectives. Therefore, a comparative evaluation of base isolation and column-installed seismic dampers is essential for selecting an appropriate seismic protection strategy. This study aims to systematically compare the seismic response of buildings equipped with base isolation and seismic dampers, focusing on key performance parameters such as displacement, inter-storey drift, base shear, acceleration, and energy dissipation.

2. LITERATURE REVIEW

Seismic response control has evolved from conventional strength-based design toward energy-based and performance-oriented approaches aimed at reducing earthquake-induced demand on structures. Early theoretical work by Housner (1959, 1963) established that structural damage during earthquakes is closely related to cumulative energy input rather than peak forces alone. His findings emphasized the importance of incorporating mechanisms capable of dissipating seismic energy, which later became the foundation for seismic isolation and supplemental damping technologies.

The concept of base isolation gained prominence with advancements in structural dynamics and response spectrum analysis. Newmark and Hall (1982) demonstrated that increasing the natural period and damping of a structure can significantly reduce seismic acceleration and force demand. Building on this principle, Kelly (1997) and Naeim and Kelly (1999) developed comprehensive analytical formulations and design guidelines for base-isolated structures, supported by global case studies. Their research showed that isolation systems such as lead–rubber bearings and friction pendulum bearings effectively decouple the superstructure from ground motion, resulting in substantial reductions in base shear and floor acceleration. Experimental investigations by Grant et al. (2004) and Providakis (2010) further validated the effectiveness of elastomeric isolators, reporting acceleration and force reductions of up to 70% in low- to mid-rise buildings.

In parallel, extensive research has been conducted on seismic dampers as passive energy dissipation devices. Constantinou and Symans (1998, 1999) carried out experimental and analytical studies on viscous, friction, and metallic dampers, concluding that these devices significantly enhance effective damping and reduce displacement and base shear without increasing structural stiffness. Murty (2005) highlighted the practical relevance of seismic dampers in reinforced concrete buildings, particularly in Indian seismic zones, where they are effective in controlling inter-storey drift and minimizing structural and non-structural damage.

Accurate modeling of damper behavior under cyclic loading has been addressed by several researchers. Iwan (1966) proposed distributed-yield hysteresis models, while Wen (1976) developed the Bouc–Wen hysteresis formulation, both of which are widely used to represent nonlinear damper and isolator behavior. Park and Ang (1985), later extended by Ang (1990), introduced damage indices linking deformation and hysteretic energy to expected structural damage, enabling performance-based evaluation of damping systems. Chopra (2012) synthesized these modeling approaches into practical procedures for analyzing multi-degree-of-freedom structures equipped with isolation or damping devices.

More recent studies have focused on the comparative performance and optimization of damping systems. Singh and Moreschi (2001) demonstrated the effectiveness of tuned mass dampers in reducing acceleration response in tall buildings. Patil and Jangid (2014) and Kumar and Singh (2018) showed that friction and viscous dampers can reduce displacement and acceleration demands by approximately 50–60% in reinforced concrete frames. Takewaki (2009) emphasized that damper placement plays a critical role in seismic effectiveness, showing that strategically located dampers can achieve superior performance with fewer devices.

Advancements in semi-active and smart control systems have further expanded seismic protection strategies. Spencer and Dyke (1997), Dyke (1998), and Carlson (1996) developed and experimentally validated magnetorheological dampers capable of adapting to varying seismic demands, achieving performance close to active control systems while maintaining fail-safe characteristics. Filiatrault (2000) provided large-scale experimental evidence supporting the reliability and durability of various damping devices, contributing to their inclusion in seismic design guidelines.

Overall, existing literature clearly demonstrates that both base isolation and seismic dampers significantly enhance structural seismic performance through different mechanisms—period shifting and energy dissipation, respectively. However, most studies examine these systems independently, and direct comparative evaluations under consistent modeling assumptions and performance criteria remain limited. The present study addresses this gap by providing a systematic comparison of base isolation and column-installed seismic dampers, focusing on key response parameters relevant to performance-based seismic design.

3. METHODOLOGY

The present study adopts a structured comparative methodology to evaluate the seismic performance of base isolation systems and column-installed seismic dampers under identical structural and seismic conditions. The methodology is specifically designed to ensure that the observed differences in response are solely due to the seismic control strategy employed, thereby strengthening the validity of the comparative assessment.

3.1 Comparative Research Framework

A uniform reinforced concrete (RC) building configuration is used as the baseline model for all analyses. Three structural configurations are developed from this baseline: a fixed-base structure, a base-isolated structure, and a structure equipped with seismic dampers in columns. All models share identical geometry, mass distribution, material properties, gravity loading, and boundary conditions, ensuring a fair and direct comparison between seismic protection systems.

The selected building is modeled as a multi-degree-of-freedom (MDOF) system with lumped masses at floor levels. The superstructure is assumed to remain elastic so that the influence of base isolation and damping devices on global response parameters can be clearly isolated. This assumption allows the study to focus on **demand reduction mechanisms** rather than damage progression, which is consistent with performance-based seismic design objectives.

3.3 Definition of Comparative Models

Three analytical models are developed:

- **Model A – Fixed-Base Reference Model:** Serves as the control case representing conventional earthquake-resistant design without supplemental protection.
- **Model B – Base Isolated Model:** Incorporates an isolation layer at foundation level using lead–rubber bearings or friction pendulum systems. The isolators are designed to shift the fundamental period of the structure and introduce additional equivalent damping.
- **Model C – Damper-Equipped Model:** Incorporates seismic dampers installed in selected columns at critical storeys. Dampers are designed to dissipate energy through nonlinear hysteretic behavior while maintaining the original stiffness characteristics of the frame.

The comparison among these models enables evaluation of **period-shifting effects (isolation)** versus **energy-dissipation effects (dampers)**.

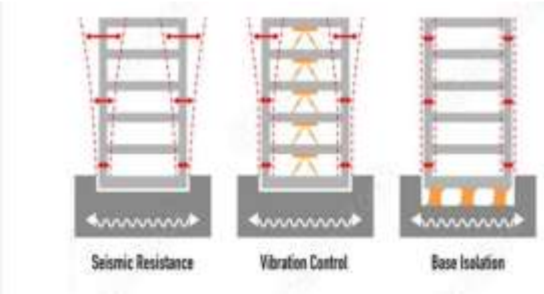

Fig.No. 3.1 Earthquake Resistant Building

This figure presents a conceptual comparison between conventional earthquake-resistant design, vibration control using seismic dampers, and base isolation systems. It illustrates how seismic forces are either resisted by structural members, dissipated through damping devices, or filtered at the foundation level using isolation bearings.

Fig. No. 3.2 Base Isolation System in Building

The figure shows a typical base isolation arrangement where isolation bearings are installed between the foundation and the superstructure. These bearings increase structural flexibility and damping, thereby reducing the transfer of seismic forces, base shear, and floor accelerations to the building.

Fig. No. 3.3 Metallic Seismic Dampers in RC Columns

This figure illustrates the installation of metallic seismic dampers within reinforced concrete columns at critical locations. The dampers dissipate seismic energy through controlled hysteretic deformation, reducing inter-storey drift and protecting primary structural members from excessive damage.

3.4 Normalization of Design Parameters

To ensure equivalence in comparison, design parameters such as target displacement capacity, equivalent damping ratio, and device strength are normalized across models. For example, isolation bearings and dampers are proportioned to achieve comparable performance objectives under design-level seismic loading. This normalization avoids bias toward any particular system and allows a meaningful performance-based comparison.

3.5 Seismic Input and Analysis Consistency

Identical seismic input is applied to all three models. Response spectrum analysis is used for preliminary evaluation, followed by linear and nonlinear time-history analyses for detailed response assessment. Ground motion records are scaled to the same peak ground acceleration and spectral compatibility, ensuring consistency in seismic demand across models.

3.6 Comparative Performance Metrics

The effectiveness of each seismic protection strategy is evaluated using consistent and quantifiable performance indicators, including:

- Change in fundamental time period
- Percentage reduction in base shear relative to fixed-base model
- Maximum storey displacement and roof drift
- Inter-storey drift ratio profiles along building height
- Peak floor acceleration at different levels
- Energy dissipated through isolation bearings and dampers

These metrics allow direct comparison of **force reduction**, **deformation control**, and **vibration mitigation** capabilities.

3.7 Energy-Based Comparative Assessment

An energy-based evaluation framework is adopted to further strengthen the comparison. The total seismic input energy is decomposed into elastic strain energy, kinetic energy, viscous damping energy, and hysteretic energy. The relative contribution of isolation systems and dampers in dissipating seismic energy is quantified and compared, providing deeper insight into their effectiveness under cyclic loading.

3.8 Sensitivity and Practical Applicability Assessment

A parametric comparison is conducted by varying key parameters such as damping ratio, isolator stiffness, and damper placement levels. This assessment highlights the sensitivity of structural response to device characteristics and identifies conditions under which one system outperforms the other. Practical considerations including constructability, retrofitting feasibility, and suitability for different building heights are also qualitatively evaluated.

3.9 Validation and Comparative Interpretation

The trends observed in the comparative analysis are validated against established experimental and analytical results reported in the literature. Emphasis is placed on identifying consistent patterns rather than exact numerical agreement. The final comparison provides design-oriented insights into the selection of base isolation or seismic dampers for specific performance objectives.

4. RESULTS AND DISCUSSION

The seismic response of the reinforced concrete building is evaluated for three structural configurations: fixed-base structure, base-isolated structure, and structure equipped with seismic dampers in columns. The comparison is carried out using identical seismic input and modeling assumptions to ensure consistency. The results are discussed in terms of response parameters relevant to performance-based seismic design.

4.1 Comparative Results

Response Parameter	**Fixed-Base Structure**	**Base-Isolated Structure**	**Structure with Seismic Dampers**
Fundamental Time Period	Low	Significantly Increased	Moderately Increased
Base Shear	Highest	Reduced by ~60–70%	Reduced by ~35–50%
Roof Displacement	Moderate	Higher (within isolator limits)	Reduced
Inter-Storey Drift	High	Moderate	Lowest
Peak Floor Acceleration	High	Lowest	Moderate
Energy Dissipation	Minimal (structural yielding)	High (isolation layer)	Very High (damper hysteresis)
Damage Concentration	Structural members	Isolation bearings	Replaceable dampers

Table 4.1 Comparative Seismic Response of Structural Models

4.2 Discussion of Comparative Seismic Response

4.2.1 Time Period and Base Shear Response

The base-isolated structure exhibits a substantial increase in fundamental time period compared to the fixed-base structure, resulting in a significant reduction in seismic force demand. This period-shifting mechanism effectively moves the structure away from dominant earthquake frequencies, leading to base shear reductions of approximately 60–70%. In contrast, the damper-equipped structure shows a moderate increase in time period, with base shear reduction primarily achieved through energy dissipation rather than stiffness modification.

4.2.2 Displacement and Inter-Storey Drift Control

While the base-isolated structure experiences larger total displacement due to flexibility at the isolation level, inter-storey drift within the superstructure remains controlled. However, the structure with seismic dampers demonstrates superior control over inter-storey drift along the building height. The dampers effectively dissipate seismic energy, reducing relative floor displacements and limiting deformation demand on columns and beams, which is particularly beneficial for multi-storey and retrofit applications.

4.2.3 Floor Acceleration Response

Floor acceleration is a critical parameter for protecting non-structural components and sensitive equipment. The base-isolated structure shows the lowest peak floor accelerations due to reduced transmission of ground motion. The damper-equipped structure also achieves noticeable acceleration reduction compared to the fixed-base structure, although not as effectively as base isolation. This indicates that base isolation is more suitable for acceleration-sensitive structures such as hospitals and emergency facilities.

4.2.4 Energy Dissipation Characteristics

Energy-based evaluation reveals that the fixed-base structure dissipates seismic energy mainly through structural deformation, which can lead to damage. In contrast, the base-isolated structure dissipates a significant portion of seismic energy at the isolation interface. The structure equipped with seismic dampers shows the highest hysteretic energy dissipation within the dampers themselves, effectively protecting primary structural members by concentrating damage in replaceable devices.

4.3 Comparative Chart Interpretation (Explanation Only)

The comparative response plots of base shear, storey displacement, inter-storey drift, and floor acceleration clearly illustrate distinct behavioral trends. Base-isolated models show flattened response curves for base shear and acceleration, indicating effective force filtering at the foundation level. Damper-equipped models display reduced drift profiles along the height, confirming efficient control of deformation demand. Fixed-base structures consistently exhibit higher response values across all parameters, validating the need for supplemental seismic protection systems.

5. CONCLUSION

This comparative study demonstrates that both base isolation and seismic dampers significantly enhance the seismic performance of reinforced concrete buildings when compared to conventional fixed-base systems. Base isolation proves highly effective in reducing base shear and floor acceleration by approximately 60–70%, making it an ideal solution for acceleration-sensitive and low- to mid-rise structures. However, it introduces larger displacements at the isolation level, which must be accommodated in design.

Seismic dampers installed in columns offer superior control of inter-storey drift and internal force demand, achieving drift reductions of approximately 40–60% relative to the fixed-base structure. By dissipating seismic energy through hysteretic behavior, dampers protect primary structural elements and localize damage within replaceable components, making them particularly suitable for retrofitting existing buildings and high-rise structures.

The energy-based assessment confirms that base isolation primarily reduces seismic demand through period shifting, whereas seismic dampers enhance performance through direct energy dissipation. The selection between these systems should therefore be guided by building height, functional requirements, soil conditions, and retrofit feasibility.

Overall, the study provides a clear comparative framework and practical design guidance for selecting appropriate seismic protection strategies within a performance-based seismic design approach.

6. FUTURE SCOPE

The present study provides a comparative analytical assessment of base isolation and column-installed seismic dampers for improving seismic performance of reinforced concrete buildings. However, several research directions can be explored to further enhance understanding and practical implementation of seismic protection systems.

- **Hybrid Seismic Protection Systems** Future studies can investigate hybrid configurations combining base isolation with seismic dampers to simultaneously achieve period shifting and enhanced energy dissipation, particularly for high-rise and irregular structures.
- **Extension to Nonlinear Structural Behavior** The current work assumes elastic behavior of the superstructure. Future research may incorporate nonlinear material behavior and damage progression in beams and columns to evaluate structural performance under severe and near-fault earthquake excitations.
- **Application to Irregular and Tall Buildings** The methodology can be extended to buildings with plan irregularity, vertical stiffness irregularity, and soft-storey configurations, where seismic response control is more challenging and critical.
- **Soil–Structure Interaction Effects** Inclusion of different soil conditions and soil–structure interaction effects would provide a more realistic assessment of base isolation and damper performance, especially for soft soil sites.
- **Smart and Semi-Active Damping Devices** Advanced damping technologies such as magnetorheological, shape memory alloy, and adaptive viscous dampers may be explored to develop real-time response control systems capable of adjusting to varying seismic intensities.
- **Performance-Based and Multi-Hazard Design** Future work may adopt a performance-based seismic design framework considering multiple performance levels and integrate other hazards such as wind and blast loading to evaluate overall structural resilience.
- **Life-Cycle Cost and Sustainability Analysis** Comprehensive life-cycle cost assessment including installation, maintenance, and replacement costs can be conducted to evaluate the economic and sustainability benefits of seismic protection systems.
- **Experimental Validation and Field Implementation** Shaking-table experiments and real-time monitoring of damper- and isolation-equipped buildings can be undertaken to validate analytical findings and improve confidence in practical implementation.
- **Code Development and Design Guidelines** The outcomes of future comparative studies can contribute to the refinement of seismic design codes and development of simplified design guidelines for base isolation and seismic dampers.

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