A COMPREHENSIVE REVIEW ON BASE ISOLATION METHODS FOR SEISMIC PROTECTION OF STRUCTURES

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Abstract

Earthquakes are a major factor that endangers the structural safety, especially in areas where there is a lot seismic activity and thus there is a need to come up with sophisticated mitigation measures. The conventional design methods mainly use the strength and ductility but can readily accommodate substantial structural and non-structural damages. Here, one of the methods that have been proven to be of use in minimizing seismic demand is base isolation, which decouples the structure to ground motion. This review paper is a comprehensive evaluation of base isolation techniques and its application in improving seismic performance. It reviews important isolation systems, such as elastomeric bearings, lead rubber bearings, high damping rubber bearings as well as friction-based systems such as friction pendulum mechanisms. It also discusses performance evaluation, design, and implementation in buildings, bridges, hospitals, and heritage buildings. The review also discusses smart materials, hybrid control systems, and adaptive isolation technologies. In general, base isolation devices may reduce seismic forces, structural acceleration, and damage and improve safety and post-earthquake functionality. Researchers, engineers, and politicians can apply this study to improve earthquake resistance utilizing isolation strategies.

Keywords: Base Isolation, Seismic Protection, Earthquake Engineering, Structural Dynamics, Elastomeric Bearings, Friction Pendulum System.

1. INTRODUCTION

Earthquakes are considered to be the most devastating natural hazards which are a great danger to human life, infrastructure and economic stability everywhere in the world. The high rate of urbanization, population density, and the growth of infrastructure in the seismically active areas have only increased the risks of the impact of the seismic events. The traditional structural design methods are mainly aimed at increasing strength, stiffening, and ductility to absorb the forces of earthquakes [1]. Although these techniques will avoid collapsing, they usually allow a lot of structural and non-structural damage resulting in expensive repairs, functional impairment, and in some extreme cases, loss of vital services.

To counter these drawbacks, contemporary earthquake engineering has changed to innovative approaches that not only strive to counter seismic forces but also minimize the demand placed on structures [2]. Base isolation has also become one of the most successful and common methods of seismic protection among these methods. The basic basis of base isolation is to provide flexibility in between the foundation and the superstructure and thus decouples the structure to the ground vibrations. This strategy changes the dynamic nature of the structure by raising the natural period and introducing energy dissipation mechanisms that in combination, decrease transmission of seismic forces [3].

Base isolation systems have proved to be incredibly successful in reducing the structural acceleration, base shear and inter-storey drift leading to the increased structural safety and better performance during earthquakes. Base-isolated structures are provided to stay mostly on the elastic range unlike traditional systems which can only dissipate the energy through inelastic deformation, this ensures less damage and post-earthquake functionality [4]. This renders base isolation especially effective in facilities that are critical like hospitals, emergency response center, bridges, and heritage buildings, where constant operation and conservation are paramount to their survival.

The last few decades have seen a lot of progress in terms of the evolution of different base isolation methods such as elastomeric bearings, friction-based systems and hybrid methods of isolation. Their designs, material composition and energy dissipation capabilities vary and provide a broad selection of solutions that meet the particular structural and seismic needs [5]. There are also new technologies that have been introduced in the recent past such as incorporating smart material, adaptive systems, and performance-based design technology, which has improved the efficiency and applicability of the base isolation technology.

Although it has been proven to be effective, the choice of proper base isolation systems as well as their deployment necessitates a thorough knowledge of the behaviour, strengths, weaknesses and appropriateness of the various systems in different conditions [6]. Thus, systematic review of the existing base isolation techniques is needed to summarize the existing knowledge, to determine the gaps in research, and to stimulate future advancement of the given field.

1.1. Objectives of the Review

- To critically analyze and synthesize existing base isolation techniques for enhancing the seismic performance of structures
- To evaluate the principles, types, performance, and design considerations of base isolation systems in different structural applications

2. PRINCIPLES OF BASE ISOLATION

Base isolation systems are another innovation in earthquake engineering in that it alters the dynamic behavior of structures when subjected to seismic excitation. Base isolation takes a more innovative approach compared to the traditional methods of structural design that rely largely on the strength, stiffness and ductility to withstand earthquake forces but instead controls and minimizes the seismic demand itself [7]. This is done through the implementation of flexible interface between the structure and the foundation, hence changing the manner in which seismic energy is conveyed. The operation of base isolation systems is regulated by three fundamental principles period shift, energy dissipation and structural decoupling, which have a contribution to each in improving seismic performance.

- ✓ **Period Shift:** Simply adding the structure's inherent time period is Period Shift. Resonant behavior with earthquake ground oscillation frequencies is more likely in fixed-base structures due to their short natural periods. However, an isolation system increases base flexibility and structure lifespan. The structural response shifts from the high-energy seismic response spectrum to the low-energy section, reducing acceleration demand. It reduces structure forces, improving safety and performance.
- ✓ **Energy Dissipation:** The second principle, energy dissipation, plays a crucial role in controlling structural vibrations. Damping solutions for base isolation systems include lead cores, high-damping rubber, and sliding components. They store and release seismic energy by hysteretic action or frictional resistance. These dampening systems reduce energy passed to the superstructure, minimizing excessive displacements and structural damage. Increased energy dissipation reduces residual deformations, ensuring structure functionality after a seismic event.
- ✓ **Structural Decoupling:** Decoupling effect, the third principle, partially separates the superstructure from ground motion [8]. Classic fixed-base systems transmit ground acceleration directly through the structure, causing large inertial forces. Instead, base isolation technologies allow controlled horizontal movement at the base and disconnect the structure from the ground. This will significantly reduce acceleration in the building's upper levels. Thus, partitions, ceilings, and equipment are barely damaged while structural integrity is maintained.

Besides the above main mechanisms, the base isolation systems enhance structural stability and serviceability with less inter-storey drift and comfort of the occupants during seismic events. The slowdown of the acceleration is especially advantageous to delicate structures like hospitals, laboratories, and data centers where it matters greatly to safeguard the apparatus and continue operating.

3. TYPES OF BASE ISOLATION SYSTEMS

The three main categories of base isolation systems can be categorized into three broad categories on the basis of their working principles namely: elastomeric bearing systems, sliding isolation systems and hybrid isolation systems. All categories vary in relation to design, energy dissipation method, stiffness property and their applicability to various types of structures. The choice of the proper isolation system is based on the seismic conditions, structural design, economic factors, and performance goals.

3.1. Elastomeric Bearing Systems

One of the most used base isolation devices in the current earthquake engineering is the elastomeric bearing systems [9]. These systems comprise alternate layers of natural or synthetic rubber and thin steel plates that are vulcanized or joined to come up with a composite structure. The plates of steel give it vertical stability and the ability to carry a load; whereas the rubber layers give it horizontal flexibility, enabling it to move laterally during an earthquake.

The main benefit of elastomeric bearings is their capability to support heavy vertical loads and at the same time have lateral flexibility, effectively isolating the structure against ground movement. The energy dissipation is also facilitated by these systems, based on the material composition and other components.

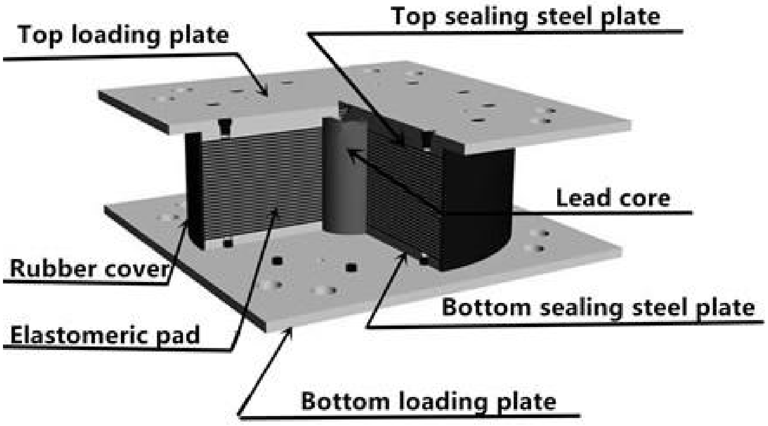

Figure 1: Elastomeric Bearing Systems [10]

There are two typical ones:

a) **Lead Rubber Bearings (LRB):** LRBs have lead core in between the rubber-steel layers. The lead is then subjected to plastic deformation during seismic activity which gives a lot of energy dissipation. These bearings are very effective in minimizing the structural displacement and acceleration and have been applied in bridges and high-rise constructions. Nonetheless, they can be affected by a deterioration in performance when repeatedly loaded and also sensitive to changes in temperature.
b) **High Damping Rubber Bearings (HDRB):** HDRBs are made by specially formulated rubber which has an intrinsic damping characteristic and hence no lead core is required. They are eco-friendly, low maintenance and stable in performance. They typically offer less damping than LRBs, however, and might need larger displacements to be effective.

3.2. Sliding Isolation Systems

Sliding isolation systems operate on the principle of non-random sliding between surfaces thereby minimizing the transmission of seismic forces to the structure. Such systems are based on frictional resistance that enables the movement to take place in the horizontal direction during earthquakes.

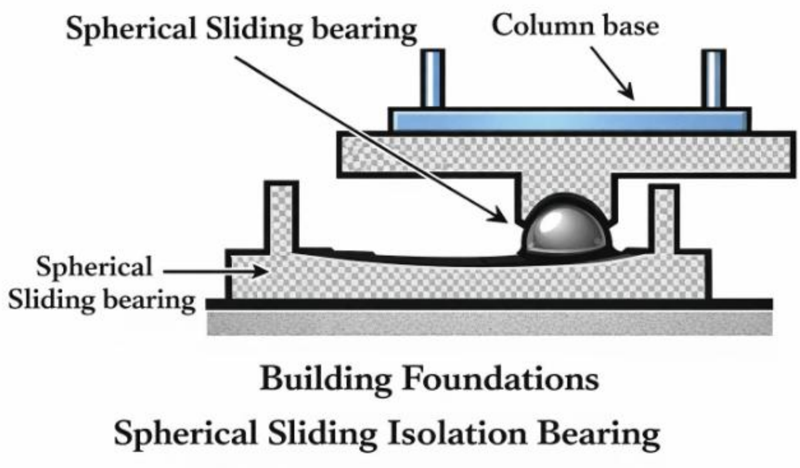

Figure 2: Spherical Sliding Isolation Bearing [11]

Sliding systems, in contrast to elastomeric systems, are especially practical when large movements must be accommodated, and are considered in the construction of structures where flexibility and re-centering properties are important.

a) **Friction Pendulum System (FPS):** FPS employs a curved sliding surface, which means that the structure of the system is free to move similar to a pendulum. This offers a restoring force which assists the structure to back to its original position. It works well at different seismic levels but relies on stable friction qualities and must be well maintained.

b) **Flat Sliding Bearings:** These bearings have low-friction materials like PTFE to allow sliding. They are cheap, easy to install, but have no self-centering ability, thus leading to irreversible displacement following an earthquake.

3.3. Hybrid Isolation Systems

Hybrid systems are built by using elastomeric and sliding mechanisms to perform better. They offer greater flexibility, energy dissipation and stability in varying seismic conditions. They combine several mechanisms to surmount the shortcomings of single systems.Nevertheless, hybrid systems are more expensive, require more complicated design, and require more engineering skills.

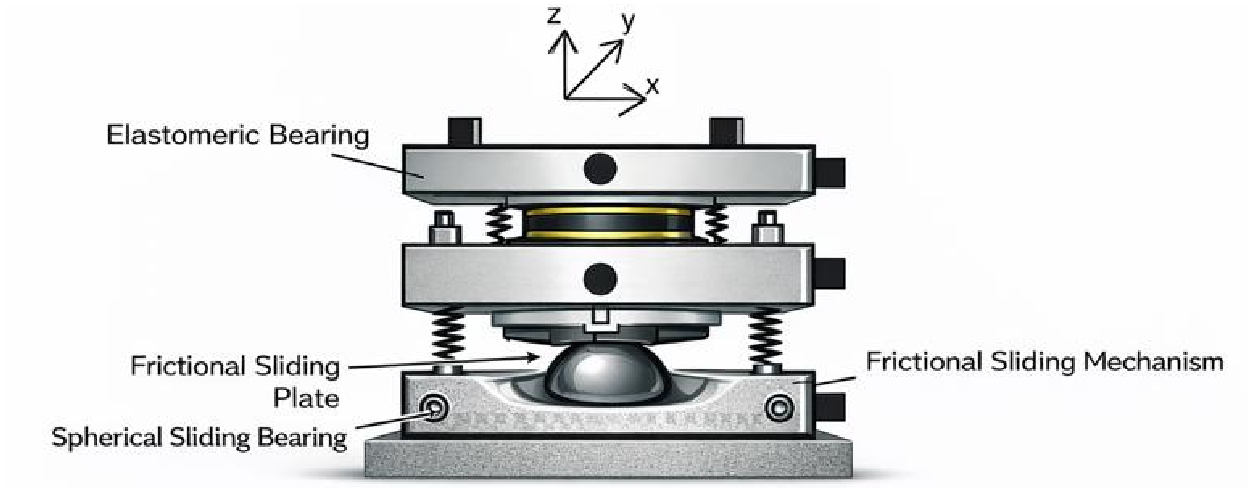

Figure 3: Hybrid Isolation Systems [12]

4. PERFORMANCE EVALUATION OF BASE ISOLATION SYSTEMS

Base isolation systems performance evaluation is an important area of earthquake engineering since it will determine how effective the systems are in minimizing seismic vulnerability and improving structural resilience [13]. Contrary to the traditional fixed-base structures, the base-isolated structures are designed to reduce the seismic demand and as a consequence, structural response during earthquake loading is markedly different to that of the conventional fixed-base structure.

The decrease in base shear is one of the important measures of performance that shows the overall lateral force that is passed on to the structure. As a consequence of the greater flexibility provided at the base, base-isolated buildings have a significant decrease in spectral acceleration leading to a significantly reduced base shear. This minimization lowers internal stresses in structural components thus reducing any damage. The other significant parameter is the decrease in structural acceleration, especially at higher levels. Base isolation systems are very effective in eliminating high-frequency ground vibrations resulting in reduced floor accelerations. This is particularly useful in safeguarding non-structural components and delicate equipment to maintain operations in vital facilities.

The efficiency of base isolation systems is also brought to the fore by the control of inter-storey drift. These systems permit a more uniform displacement profile with height of the structure by permitting controlled movement at the bottom [14]. This minimizes the ability of the floors to move in and out between floors and eliminates localized destruction. Besides, base isolation is important to occupant safety and comfort levels which limit the level of vibration and sudden movement in seismic events. This helps to achieve better psychological stability and less risk of injuries, in case of an earthquake. These advantages are well depicted in Table 1, which is a comparative study of fixed-base and base-isolated structures. The table shows that base isolation causes significant decreases in base shear, acceleration, and structural damage and at the same time an increase in occupant comfort and post-earthquake functionality. These comparative observations support the excellence of the base isolation systems in the contemporary seismic design.

Table 1: Comparative Performance of Fixed-Base and Base-Isolated Structures [15]

Performance Parameter	Fixed-Base Structure	Base-Isolated Structure
Base Shear	High	Significantly Reduced (up to 60–80%)
Structural Acceleration	High	Low
Inter-storey Drift	Uneven and High	Uniform and Controlled
Energy Dissipation	Limited	High (through isolators)
Structural Damage	Moderate to Severe	Minimal
Non-structural Damage	Significant	Negligible
Post-earthquake Functionality	Often compromised	Largely maintained
Occupant Comfort	Low	High

These findings are further supported by empirical studies which have stated that base isolation systems have the potential to suppress seismic forces by about 60-80% depending on the structural conditions and the seismic conditions.

5. DESIGN CONSIDERATIONS

Base isolation system design must be done in an integrated manner taking into consideration structural dynamics, geotechnical, and economic feasibility. An effective system should be designed to have the best performance, safety, and reliability over the seismic loading. Among the most important is the evaluation of the soil conditions and seismic hazard. The amplification and frequency properties of ground motion are greatly affected by the soil properties. As an example, the seismic waves can be magnified by the soft soils so that higher damping capacity isolators are needed. Proper design parameters can thus only be established with seismic hazard analysis.

The structural weight and configuration are also important [16]. The heavier structures demand isolators with higher load-bearing capacity and irregular geometries can bring about torsional effects which must be well addressed. Isolators have to be distributed properly to provide a balanced seismic response and stability of the structures. Of equal importance is the stiffness and damping properties of the isolation system. The amount of period shift is determined by stiffness, and the amount of energy dissipation is determined by damping. There should be an optimal balance to prevent over displacement and to achieve good vibration control.

The other crucial factor is the maximum permissible displacement. Base-isolated buildings are intended to move laterally a lot during an earthquake; as such, sufficient seismic separation should be given to avoid collisions with other buildings. Elasticity of utilities to movement has to be also provided. Economic factors such as initial cost, maintenance, and lifecycle benefits are some of the factors that determine isolation systems. The initial investment is sometimes more, but base isolation saves much in terms of repair and downtime following an earthquake, and is economically justified in the long-term. The importance of these design parameters is summarized in Table 2 which indicates the impact of each factor on the performance and effectiveness of base isolation systems. The table highlights the fact that a balance between the requirements of the structure, the environment and the economy is essential in successful implementation.

Table 2: Key Design Parameters and Their Influence on Base Isolation Performance [17]

Design Parameter	Influence on Performance
Soil Conditions	Affects ground motion amplification and frequency content
Seismic Hazard Level	Determines design forces and isolation requirements
Structural Mass	Influences isolator stiffness and load capacity
Isolation Stiffness	Controls period shift and flexibility
Damping Ratio	Determines energy dissipation and vibration control
Maximum Displacement	Defines required clearance and safety margins
Structural Configuration	Affects distribution of forces and torsional behavior
Cost and Maintenance	Impacts feasibility and long-term sustainability

Practically, the design and assessment of base isolation systems have to be studied through repeated analysis and optimization to reach the intended performance goals. Combining cutting edge computational tools and experimental validation methods has greatly enhanced the accuracy and reliability of these systems. Consequently, base isolation is becoming the standard procedure of seismic protection in new buildings as well as in retrofitting projects.

6. APPLICATIONS OF BASE ISOLATION

Base isolation systems have become widely embraced all over the world because they have been found to be effective in promoting seismic resilience. They are popular in many types of buildings and in particular in the buildings where the life safety, continuity of functionality, and preservation of assets have the highest meaning [18]. The use of base isolation technology has proven to be an extremely adaptable instrument in earthquake engineering because it can be applied not only to new constructions but also to the rehabilitation of the old constructions owing to the adaptability of the base isolation technology.

One of the most significant applications of base isolation is, perhaps, residential or commercial buildings, especially in the seismic active regions. Base isolation is very useful in these structures to minimize structural and non-structural damages by curbing seismic vibrations. This guarantees the security of the occupants as well as reducing losses incurred economically due to repairs and downtime. The high-rise buildings, office complexes, residential apartments have low levels of vibration, enhanced stability and enhanced utilization following the earthquake.

Base isolation systems are important in structural integrity and serviceability of bridges and flyovers in the event of seismic events. Earthquakes in particular are highly susceptible to bridges due to long spans, flexibility and due to subjecting the bridge to dynamic loading conditions. With the use of elastomeric bearings and sliding isolation system, the total displacement is controllable, and stress concentrations within piers, abutments and foundations will be reduced. This greatly reduces chances of structural failure and guarantees its survival following an earthquake.

Hospitals and emergency facilities are one of the most challenging areas of use of base isolation technology [19]. These constructions should not be affected by seismic events thus they should be fully operational even after the seismic. Base isolation can reduce the acceleration levels at the floor hence protecting delicate medical equipment and health care is not interrupted. This has led to base isolation systems being a common component of the design of most contemporary earthquake prone hospitals to offer immediate performance levels of occupancy. The other notable application is in regards to the conservation of heritage and historical structures which are generally highly vulnerable to seismic losses, due to deteriorating structures and lack of modern structural planning. Base isolation is an efficient retrofitting option which can be used to increase seismic resistance without affecting the architectural authenticity. The cultural and historical value can be preserved in the structure, which is isolated against ground motion, in addition to making the structure much safer.

The sheer diversity of the applications underscores the fact that the base isolation principle is similar, although the performance needs vary, depending on the nature and importance of the structure. In residential buildings, protection of life and damages are the primary issues yet in commercial buildings, one of the primary issues is business continuity [20]. The constant working process in the key infrastructures such as hospitals is a must but in the old buildings, the emphasis should be laid on the preservation of authenticity. Base isolation systems have seen successful applications in the real world in countries such as Japan and the United States where it is highly prone to seismic activity and high degree of engineering practice is involved. These locations have proven to have base-isolated hospitals, government structures, and bridges that are very effective in the event of a big earthquake, which demonstrates the effectiveness and safety of the technology.

7. RECENT ADVANCES IN BASE ISOLATION TECHNOLOGY

The recent development of the base isolation technology has greatly enhanced its performance, flexibility and efficiency. Base isolation has transformed a passive method into an intelligent and adaptive seismic protection system with the introduction of innovative materials, smart systems and innovative design techniques. The use of smart materials, including shape memory alloys (SMAs) and magnetorheological (MR) dampers is one of the most important developments. SMAs allow self-centrifugal ability to restore to original shape following deformation whereas MR dampers allow the control of energy dissipation in real time through changes in the magnetic field. These materials increase the structure resilience and minimize residual deformations. The second significant development is the emergence of hybrid control systems that are a combination of passive, active, and semi-active systems. In contrast to the traditional systems, the hybrid systems are operated by sensors and control algorithms that dynamically modify the structural response, to achieve better performance in the changing seismic conditions.

Adaptive isolation systems enhance seismic protection even more as they enable the real-time moderation of stiffness and damping in response to received seismic data. Such systems maximize the structural response in times of earthquakes, reducing damages and enhancing safety. Also there have been performance-based design solutions that have acquired significance and they aim at meeting certain performance targets including instant occupancy and safety of life in various seismic magnitudes. Such designs have been increased in accuracy due to advanced computational tools and simulations.

Table 3: Literature-Based Advances in Base Isolation Technology

Author(s) & Year	Focus of Study	Key Contribution	Relevance to Recent Advances
Prakash et al. (2026) [21]	Soil-structure interaction in base isolation	Comprehensive review of how soil conditions influence isolation performance	Supports adaptive and performance-based design approaches
Patel et al. (2024) [22]	Sustainable base isolation techniques	Focus on eco-friendly materials and resilience under extreme events	Highlights advancement toward sustainable and smart materials
De Luca & Guidi (2019) [23]	Evolution of base isolation design worldwide	Overview of global trends and technological developments	Provides foundation for hybrid and advanced isolation systems
Nanda et al. (2016) [24]	Low-cost base isolation systems	Development of economical solutions for rural applications	Emphasizes accessibility and practical implementation
Habieb et al. (2019) [25]	Numerical evaluation of isolation systems	Comparative analysis of different isolators for masonry structures	Supports performance optimization and system selection

These technological innovations are contributing to the shift towards resilient and intelligent infrastructure systems where buildings are not just engineered to survive an earthquake but also change and recover rapidly. In the coming years, even more technological revolutions are likely to happen in the sphere of base isolation technology through the integration of digital monitoring systems, artificial intelligence and advanced materials.

8. CONCLUSION

Base isolation has become an innovative technique in earthquake engineering and is a very effective way of improving the seismic performance of buildings to minimize the transmission of ground-induced forces. This review has extensively discussed the principles, types, performance evaluation criteria, design considerations, uses and latest developments in the base isolation technology. It has been shown that base isolation systems, such as elastomeric bearings, sliding systems, and hybrid systems, can be very helpful in minimizing important response parameters, including base shear, structural acceleration and inter-storey drift, which minimizes structural and non-structural damage. Moreover, their use in a variety of buildings of various types and purposes, such as residential buildings as well as infrastructure and heritage monuments, emphasize their versatility and usefulness. Recent advances with smart materials, adaptive systems and performance-based design solutions have also increased the efficiency and versatility of these systems. Although there are obstacles like initial expenses and the design complexity involved, the long-term returns on safety, functionality and economic savings of base isolation make base isolation a very feasible solution to earthquake-resilient construction. Overall, this paper highlights the need to conduct further research and technology development in order to streamline the base isolation systems and encourage their use in the seismic prone areas.

REFERENCES

1. Cancellara, D., & De Angelis, F. (2016). A base isolation system for structures subject to extreme seismic events characterized by anomalous values of intensity and frequency content. *Composite Structures*, *157*, 285-302.
2. Zhang, R., & Phillips, B. M. (2016). Performance and protection of base-isolated structures under blast loading. *Journal of Engineering Mechanics*, *142*(1), 04015063.
3. Nakamura, Y., & Okada, K. (2019). Review on seismic isolation and response control methods of buildings in Japan. *Geoenvironmental Disasters*, *6*(1), 7.
4. Mazza, F., Mazza, M., & Vulcano, A. (2018). Base-isolation systems for the seismic retrofitting of rc framed buildings with soft-storey subjected to near-fault earthquakes. *Soil Dynamics and Earthquake Engineering*, *109*, 209-221.
5. Mazza, F. (2019). Effects of the long-term behaviour of isolation devices on the seismic response of base-isolated buildings. *Structural Control and Health Monitoring*, *26*(4), e2331.
6. Peng, Y., Ma, Y., Huang, T., & De Domenico, D. (2021). Reliability-based design optimization of adaptive sliding base isolation system for improving seismic performance of structures. *Reliability Engineering & System Safety*, *205*, 107167.

7. Xu, G., Guo, T., Ni, X. Y., Zhi, G. L., Zhang, H. Y., & Dang, L. J. (2026). Breakthroughs in seismic isolation technologies for engineering structures. *International Journal of Structural Stability and Dynamics*, *26*(09), 2650062.
8. Clemente, P. (2017). Seismic isolation: past, present and the importance of SHM for the future. *Journal of Civil Structural Health Monitoring*, *7*(2), 217-231.
9. Wang, B., Chen, P., Zhu, S., & Dai, K. (2023). Seismic performance of buildings with novel self-centering base isolation system for earthquake resilience. *Earthquake Engineering & Structural Dynamics*, *52*(5), 1360-1380.
10. Mohebbi, M., & Dadkhah, H. (2019). Optimal smart base isolation system for multiple earthquakes. *Int. J. Optim. Civil Eng*, *9*(1), 19-37.
11. Chimamphant, S., & Kasai, K. (2016). Comparative response and performance of base-isolated and fixed-base structures. *Earthquake engineering & structural dynamics*, *45*(1), 5-27.
12. Losanno, D., Ravichandran, N., Parisi, F., Calabrese, A., & Serino, G. (2021). Seismic performance of a Low-Cost base isolation system for unreinforced brick Masonry buildings in developing countries. *Soil Dynamics and Earthquake Engineering*, *141*, 106501.
13. Castaldo, P., Palazzo, B., & Della Vecchia, P. (2015). Seismic reliability of base-isolated structures with friction pendulum bearings. *Engineering Structures*, *95*, 80-93.
14. Chen, P., Wang, B., Dai, K., & Li, T. (2022). Analytical and numerical investigations of base isolation system with negative stiffness devices. *Engineering Structures*, *268*, 114799.
15. Cancellara, D., & De Angelis, F. (2016). Nonlinear dynamic analysis for multi-storey RC structures with hybrid base isolation systems in presence of bi-directional ground motions. *Composite Structures*, *154*, 464-492.
16. Makris, N. (2019). Seismic isolation: Early history. *Earthquake Engineering & Structural Dynamics*, *48*(2), 269-283.
17. Liu, Y., Li, J., & Lin, G. (2023). Seismic performance of advanced three-dimensional base-isolated nuclear structures in complex-layered sites. *Engineering Structures*, *289*, 116247.
18. Ugalde, D., Almazán, J. L., Santa María, H., & Guindos, P. (2019). Seismic protection technologies for timber structures: a review. *European journal of wood and wood products*, *77*(2), 173-194.
19. Naderpour, H., Naji, N., Burkacki, D., & Jankowski, R. (2019). Seismic response of high-rise buildings equipped with base isolation and non-traditional tuned mass dampers. *Applied Sciences*, *9*(6), 1201.
20. Yan, Y., Cheng, Z., Menq, F., Mo, Y. L., Tang, Y., & Shi, Z. (2015). Three-dimensional periodic foundations for base seismic isolation. *Smart Materials and Structures*, *24*(7), 075006.
21. Prakash, K. K., Mahalakshmi, J., & Rathod, D. (2026). Response of soil and structure to base isolation: a state-of-the-art-review. *Indian Geotechnical Journal*, *56*(3), 1492-1513.
22. Patel, D., Pandey, G., Mourya, V. K., & Kumar, R. (2024). Sustainable base isolation: a review of techniques, implementation, and extreme events. *Sādhanā*, *49*(2), 173.
23. De Luca, A., & Guidi, L. G. (2019). State of art in the worldwide evolution of base isolation design. *Soil Dynamics and Earthquake Engineering*, *125*, 105722.
24. Nanda, R. P., Shrikhande, M., & Agarwal, P. (2016). Low-cost base-isolation system for seismic protection of rural buildings. *Practice Periodical on Structural Design and Construction*, *21*(1), 04015001.
25. Habieb, A. B., Valente, M., & Milani, G. (2019). Effectiveness of different base isolation systems for seismic protection: Numerical insights into an existing masonry bell tower. *Soil Dynamics and Earthquake Engineering*, *125*, 105752.