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Hospital resilience in earthquake-prone regions: a novel evaluation of base isolation systems for structural and functional performance in West Lombok

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Abstract
Earthquakes pose a significant threat to hospital infrastructure, where uninterrupted functionality is critical for emergency response and post-disaster recovery. While base isolation systems have been widely recognized for reducing structural damage, their effectiveness in enhancing functional resilience remains insufficiently quantified. This study evaluates the seismic performance of three base isolation systems, Lead Rubber Bearings (LRB), High-Damping Rubber Bearings (HDRB), and Friction Pendulum Systems (FPS), applied to a representative hospital building in West Lombok using nonlinear finite-element analysis based on SNI 1726:2019 response-spectrum loading. Structural performance is assessed through key parameters, including base shear, natural period, inter-story drift, and lateral displacement. The results indicate that FPS provides the most significant performance improvement, reducing base shear by 35.6%, lateral displacement by 27.0%, and inter-story drift by 37.5%, while increasing the fundamental period by up to 692%. To address the limitations of conventional structural evaluation, this study introduces a quantitative Resilience Index (R) defined as the normalized reduction ratios of structural response parameters relative to the fixed-base condition. FPS achieves the highest resilience scores (R = 0.356 for base shear, 0.270 for displacement, and 0.375 for drift), outperforming HDRB and LRB systems. These improvements indicate enhanced structural robustness, which correlates with reduced expected downtime and improved immediate occupancy performance. The integration of structural and functional performance metrics represents a shift from conventional design approaches toward resilience-driven engineering decision-making. The findings demonstrate that base isolation systems, particularly FPS, significantly improve both structural safety and post-earthquake operational continuity of hospital facilities. Furthermore, the proposed resilience-based evaluation framework provides a scalable approach to integrating structural performance and functional recovery metrics into the seismic risk assessment of critical infrastructure, supporting resilience-based seismic design strategies for healthcare infrastructure in developing seismic regions.

Keywords:
Base Isolation Systems;
Earthquake-Prone Regions;
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INTRODUCTION

Earthquakes remain a dominant global hazard that threatens structural integrity and disrupts societal systems, particularly in seismically active regions, where critical infrastructure, such as hospitals, must maintain uninterrupted operations during and after extreme events. Recent empirical evidence demonstrates that seismic risk is governed not only by hazard intensity but also by structural vulnerability stemming from design deficiencies, material degradation, and cumulative damage, which collectively amplify the probability of failure [1, 2, 3]. In response, contemporary research has increasingly adopted performance-based earthquake engineering frameworks to quantify fragility and risk under complex loading scenarios, including aftershock sequences and multi-hazard interactions [4, 5, 6]. However, beyond structural safety, emerging resilience paradigms emphasize integrating functional recovery, service continuity, and system-level robustness into infrastructure design [7][8], thereby shifting the focus from damage prevention to system functionality and rapid recovery.

Within this resilience-oriented paradigm, base isolation has emerged as a robust seismic mitigation strategy by fundamentally altering structural dynamic behavior through period elongation and energy dissipation mechanisms. By decoupling the superstructure from ground motion, isolation systems effectively reduce inertial forces and inter-story drift, thereby lowering seismic demand and protecting both structural and non-structural components [4][7]. The effectiveness of such systems is governed by nonlinear interactions involving stiffness degradation, damping characteristics, and displacement capacity within the isolation layer, resulting in complex response behavior under varying seismic excitations [5][8]. Nevertheless, this mechanism inherently shifts deformation demand toward the isolation interface, requiring careful design to control excessive displacement and ensure stability [9]. Furthermore, system performance is highly dependent on structural configuration and boundary conditions, particularly in irregular or spatially constrained systems [10][11], highlighting the need for context-specific evaluation.

Building upon this theoretical foundation, a substantial body of literature has consistently demonstrated the effectiveness of base isolation systems in mitigating seismic demand; however, the analytical focus remains predominantly centered on structural response metrics. Empirical and numerical investigations confirm that systems such as Lead Rubber Bearings (LRB), High-Damping Rubber Bearings (HDRB), and Friction Pendulum Systems (FPS) effectively reduce base shear, inter-story drift, and acceleration through mechanisms of period elongation and energy dissipation [12, 13, 14]. Methodologically, nonlinear time-history analysis and parametric simulations are widely employed to capture hysteretic behavior and sensitivity to ground-motion variability [17][18], while experimental studies provide controlled validation of isolator performance [15][19]. Collectively, these studies can be categorized into three dominant approaches: (i) structural performance-focused evaluations, (ii) nonlinear response-based simulations, and (iii) experimental validation studies, each offering valuable insights yet lacking integration of functional recovery metrics into a unified resilience framework. Consequently, despite strong consensus on structural efficiency, the translation of isolator performance into quantifiable functional resilience remains insufficiently addressed.

Despite these advancements, critical methodological limitations persist, particularly in representing site-specific seismic characteristics and system-level interactions. Many prior studies rely on linear modeling or simplified ground motion inputs, which may misrepresent isolator demand under localized seismic conditions [16][17]. Moreover, numerical investigations often prioritize structural response parameters, thereby failing to adequately capture the interaction between seismic variability and functional system performance [1][18]. Empirical evidence further indicates that isolator effectiveness varies significantly under near-fault conditions and sequential earthquakes, challenging generalized design assumptions [19]. Consequently, existing approaches remain insufficient for evaluating real-world operational performance in critical facilities, necessitating integrative, context-specific analytical frameworks.

Despite extensive technological progress, a fundamental gap persists in integrating structural performance with functional resilience within seismic isolation research. Existing studies predominantly emphasize mechanical optimization, such as displacement control, damping enhancement, and re-centering capability, without explicitly quantifying their implications for post-earthquake operational continuity [14][20]. Furthermore, while hybrid and adaptive systems demonstrate enhanced structural performance, their effectiveness remains highly sensitive to variability in seismic input and design uncertainties [21][22]. Critically, most analytical frameworks remain structurally oriented and lack integration with modern resilience metrics, such as recovery-based performance indices and downtime models, which are essential for evaluating functional performance in critical infrastructures [23][24]. Recent advances in resilience engineering introduce quantitative metrics such as the Resilience Index (R-index), downtime-based recovery models, and performance-based resilience frameworks, which explicitly quantify post-earthquake functionality and recovery trajectories. However, their integration into base isolation studies remains limited, particularly in site-specific contexts.

In this context, Indonesia is a highly relevant case in which hospitals must maintain operational continuity despite significant seismic risk, yet empirical and analytical studies on base isolation in hospital structures, particularly in Lombok, remain limited. This study is therefore positioned within a critical research nexus that integrates structural performance evaluation with functional resilience assessment. By adopting a nonlinear numerical framework combined with resilience-oriented performance indicators, the study establishes a context-specific analytical basis for evaluating LRB, HDRB, and FPS systems under realistic seismic conditions. This approach enables a more comprehensive understanding of how isolation systems influence not only structural response but also post-earthquake functionality. Consequently, the study advances resilience-based seismic design frameworks and provides a scientifically grounded reference for improving the reliability and operational continuity of healthcare infrastructure in high-risk regions.

METHOD

Research Framework

This study adopts a numerical–experimental research framework that integrates finite element (FE) simulation, code-based seismic loading, and comparative performance evaluation. The methodological workflow is illustrated in Figure 1, which presents a structured sequence from data acquisition through model development, seismic analysis, validation, and interpretation. The flowchart incorporates decision nodes representing validation checkpoints, where the model is evaluated iteratively.

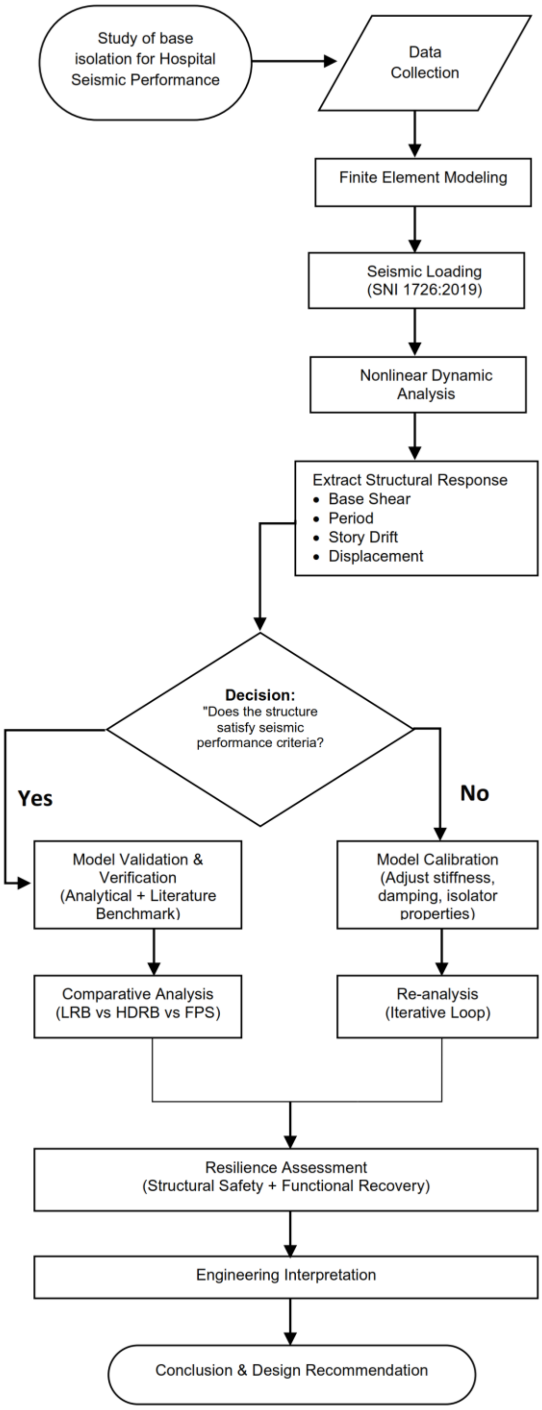

Figure 1. Research Flowchart

If the validation criteria are satisfied (Yes), the process proceeds to the next stage; otherwise (No), the model is refined and recalibrated until acceptable accuracy is achieved.

The framework consists of four principal stages:

1. Data collection from a representative hospital and site-specific seismic parameters;

2. Development of three-dimensional FE models for both fixed-base and base-isolated systems;
3. Execution of response spectrum analysis (RSA) in accordance with SNI 1726:2019; and
4. Validation and comparative interpretation to evaluate the effectiveness of isolation systems in enhancing hospital resilience and post-earthquake functionality.

Simulation Model and Research Design

A numerical experimental approach was employed, using three-dimensional FE modeling, to evaluate the seismic performance of a multi-story hospital building in West Lombok, Indonesia. Two structural configurations were analyzed:

(i) a fixed-base system representing a conventional structure; and

(ii) base-isolated systems incorporating Lead Rubber Bearings (LRB), High-Damping Rubber Bearings (HDRB), and Friction Pendulum Systems (FPS).

The FE simulations were conducted using ETABS, which supports nonlinear material behavior, geometric stiffness effects, and advanced link-element modeling.

The study population comprises hospital buildings located in high-seismic zones of West Lombok Regency. A representative referral hospital was selected based on:

1. Its critical role as a post-disaster emergency facility,
2. a mid-rise structural typology (4–6 stories), and
3. compliance with current Indonesian structural design standards.

Structural geometry, material properties, and configuration were obtained from detailed engineering drawings provided by relevant authorities.

Model Assumptions

The following assumptions were adopted in the numerical modeling:

- Structural system: reinforced concrete moment-resisting frame;
- Material properties: concrete compressive strength (f'c = 25 MPa) and steel yield strength (fy = 400 MPa);
- Foundation condition: fixed support for the conventional model and flexible support for isolated systems;
- Isolation system: modeled using nonlinear link elements with defined stiffness, damping, and friction parameters;
- Damping ratio: 5% for the superstructure and 10–15% for isolation devices.

Seismic Loading and Analysis Approach

Seismic loading was applied using the response spectrum method in accordance with SNI 1726:2019, which represents the standard seismic design approach in Indonesia. The response spectrum incorporates site-specific parameters, including seismic hazard level, soil classification (Site Class D), and spectral acceleration, ensuring consistency with national design provisions.

The use of response spectrum analysis (RSA) aligns with the objective of this study, which is to compare base isolation systems under a consistent, standardized seismic input. By employing a uniform loading framework, the relative performance of LRB, HDRB, and FPS systems can be objectively assessed without the variability introduced by record-to-record differences in time-history analysis.

Although response spectrum analysis (RSA) is commonly associated with linear approaches, the structural model developed in this study incorporates nonlinear behavior, particularly within the isolation system. The nonlinear characteristics of the isolators, including stiffness degradation, energy dissipation, and hysteretic response, are explicitly modeled using nonlinear link elements within the finite element framework. This enables a realistic simulation of structural behavior, particularly the concentration of deformation and energy dissipation within the isolation layer.

From a methodological standpoint, RSA provides a standardized and computationally efficient framework for comparative evaluation under consistent seismic input. However, it does not explicitly capture record-to-record variability, phase characteristics, and duration effects inherent in nonlinear time-history analysis (NTHA). In contrast, NTHA enables detailed simulation of transient response, cumulative damage, and hysteretic energy dissipation under specific ground motion records, which are essential for capturing extreme structural behavior.

Therefore, RSA is adopted in this study as a deterministic benchmarking approach to isolate the influence of structural configurations while maintaining computational efficiency. Nevertheless, the limitations associated with the absence of record-specific variability are acknowledged, and future studies are recommended to incorporate nonlinear time-history analysis with multiple spectrum-compatible records to enhance robustness and generalizability.

Nevertheless, the absence of time-history analysis may limit the ability to capture transient response characteristics under specific earthquake records. Therefore, future research is recommended to incorporate nonlinear time-history analysis using site-specific ground motions to further validate and extend the findings of this study.

Simulation Scenarios

Four structural models were developed for comparative analysis:

1. Model 1: Fixed-base structure (reference case);
2. Model 2: Base-isolated structure with LRB;
3. Model 3: Base-isolated structure with HDRB;
4. Model 4: Base-isolated structure with FPS.

Each model was analyzed using RSA, and key structural responses were extracted for comparison.

Numerical Model Validation

The numerical model was validated through two procedures:

1. **Analytical validation** – natural periods and mode shapes of the fixed-base structure were compared with theoretical predictions and SNI 1726:2019 provisions;
2. **Comparative validation** – response parameters (base shear, drift, and displacement) were benchmarked against published experimental and numerical studies.

The model was considered valid when deviations in key parameters were within an acceptable range (≤5%), indicating reliable representation of both structural and isolator behavior.

Instruments and Data Analysis

The analysis was conducted using ETABS software for FE modeling and seismic response simulation. Isolator properties, including stiffness, damping, and friction characteristics, were defined based on manufacturer data and validated literature.

Four primary response parameters were evaluated:

1. Base shear (kN)
2. Fundamental period (s)
3. Inter-story drift ratio (%)
4. Lateral displacement (m)

The fixed-base model served as a baseline for quantifying the effectiveness of isolation systems. Performance evaluation was conducted using a descriptive–comparative approach, combining numerical reduction ratios with engineering interpretation to assess structural performance and implications for hospital functionality.

In addition to structural response evaluation, functional performance is quantified using a resilience-based metric, the Resilience Index (R). The formulation of the Resilience Index is grounded in performance-based engineering principles, where structural performance improvement is directly associated with reduced damage states and enhanced recovery potential. By normalizing structural response reductions relative to the fixed-base condition, the index provides a dimensionless and comparable metric across different systems. Similar normalization approaches have been adopted in resilience engineering to quantify system robustness and recovery capacity under extreme loading conditions [25][26]. The Resilience Index (R) is defined as (1):

$$R = \frac{X_{fixed} - X_{isolated}}{X_{fixed}} \quad (1)$$

where X represents the structural response parameter (e.g., base shear, displacement, or inter-story drift). This formulation enables direct quantification of performance improvement relative to the fixed-base condition and establishes a measurable linkage between structural response reduction and functional recovery potential. The proposed Resilience Index can be further extended by incorporating additional parameters such as recovery time, economic loss, and functionality restoration curves, thereby enabling a more comprehensive resilience assessment framework that integrates both structural and operational dimensions.

RESULTS AND DISCUSSION

The seismic performance evaluation demonstrates that base isolation systems significantly reduce structural demand while simultaneously enhancing functional resilience, thereby addressing the critical gap identified in previous studies. As shown in Table 1, the fixed-base configuration exhibits the highest base shear, reaching 3664.70 kN and 3672.00 kN in the longitudinal and transverse directions, respectively. The implementation of isolation systems results in substantial reductions, with the Friction Pendulum System (FPS) achieving the largest decrease to 2358.50 kN and 2131.30 kN, corresponding to approximately 35.6%. This reduction indicates effective filtering of high-frequency ground motion and decreased force transmission to the superstructure, consistent with performance-based seismic theory [4][5]. Importantly, base shear reduction is directly associated with lower damage probability, a key parameter in resilience-based design frameworks [25].

The modal analysis further reveals that base isolation fundamentally alters structural dynamic characteristics. As presented in Table 2, the fundamental period increases from approximately 0.94 s in the fixed-base condition to 7.279 s in the FPS system, representing a 692% increase, while LRB and HDRB exhibit moderate elongation within 1.2–1.8 s. This period shift reduces spectral acceleration demand, thereby minimizing inertial forces acting on the structure [7]. From a functional perspective, reduced acceleration directly limits non-structural damage and equipment failure, which are primary contributors to hospital service disruption [26]. Consequently, period elongation serves not only as a structural performance indicator but also as a proxy for improved operational continuity.

The story drift and lateral displacement results (Tables 3 and 4) further demonstrate the effectiveness of deformation control. The FPS system achieves a maximum drift reduction of 37.5% and a displacement reduction of approximately 27% at the roof level. Although increased deformation is concentrated at the isolation interface, particularly in HDRB and LRB systems, this behavior aligns with the intended design mechanism of isolating seismic energy within the base layer. This nonlinear energy dissipation mechanism effectively protects the superstructure from damage [8].

Table 1. Base shear values under different foundation systems

Direction	Fixed-Base (kN)	LRB (kN)	HDRB (kN)	FPS (kN)
Longitudinal (x)	3664.70	3551.70	3021.80	2358.50
Transverse (y)	3672.00	3278.50	2769.10	2131.30

Table 2. Natural periods (seconds) for different modes and foundation systems

Mode	Fixed-Base (s)	LRB (s)	HDRB (s)	FPS (s)
1	0.941	1.456	1.839	7.279
2	0.906	1.216	1.425	4.804
3	0.295	0.434	0.777	4.515
4	0.286	0.393	0.692	1.503
5	0.145	0.218	0.454	1.231

Table 3. Story drift values for different foundation systems

Story	Fixed-Base	LRB	HDRB	FPS
5	0.000009	0.000006	0.000006	0.000008
4	0.000014	0.000007	0.000007	0.000008
3	0.000013	0.000009	0.000008	0.000008
2	0.000009	0.000010	0.000008	0.000008
1	0.000005	0.000009	0.000008	0.000008
Base	0.000000	0.000056	0.000073	0.000018

Table 4. Lateral displacement values (meters) for different foundation systems

Story	Fixed-Base (m)	LRB (m)	HDRB (m)	FPS (m)
5	0.244	0.207	0.196	0.178
4	0.201	0.182	0.169	0.144
3	0.150	0.150	0.138	0.109
2	0.103	0.112	0.104	0.074
1	0.039	0.069	0.067	0.039
Base	0.000	0.028	0.031	0.004

The resulting reduction in superstructure drift significantly decreases structural and non-structural damage, which is strongly correlated with reduced repair demand and faster recovery time [27].

Comparison with Previous Studies: The seismic performance observed in this study is generally consistent with previous investigations, demonstrating the effectiveness of base isolation systems in reducing structural responses. Chen et al. [22] reported base shear reductions of approximately 30–40% using lead-rubber bearing systems, while De Domenico et al. [29], Martakis et al. [28], Pietrosanti et al. [7], and Shan et al. [5] confirmed significant reductions in inter-story drift and lateral displacement through advanced seismic isolation technologies. Similarly, the FPS system in this study achieved reductions of 35.6% in base shear, 37.5% in story drift, and 27.0% in lateral displacement, which are comparable to or slightly higher than those reported in previous studies. These findings are also consistent with recent performance-based seismic assessments by Rosyidah et al. [30] and Putra et al. [31], which demonstrated the importance of structural performance evaluation in achieving Immediate Occupancy and guiding retrofit decisions. Unlike these studies, the present research further integrates structural response reductions into a quantitative Resilience Index (R), providing a practical framework for linking structural safety with functional continuity and post-earthquake recovery of hospital facilities.

To overcome the limitations of conventional structural evaluation, this study introduces a quantitative Resilience Index (R) to measure system performance explicitly. The

Resilience Index (R) is defined as a normalized performance metric expressed as:

$$R = \frac{X_{fixed} - X_{isolated}}{X_{fixed}} \quad (2)$$

where X represents the structural response parameter (base shear, displacement, or drift). This formulation establishes a direct quantitative link between the reduction in structural performance and the potential for functional recovery. The results (Table 5) indicate that FPS achieves the highest resilience scores, with R = 0.356 (base shear), 0.270 (displacement), and 0.375 (story drift), outperforming HDRB and LRB systems. These values quantitatively represent system robustness and recovery capacity, transforming structural response metrics into measurable resilience indicators. This formulation enables predictive assessment of functional performance, with higher R values corresponding to reduced damage states, shorter recovery times, and improved system-level resilience.

To further evaluate the robustness of the proposed framework, a qualitative sensitivity assessment was conducted to examine the influence of isolator parameters, including stiffness, damping ratio, and friction coefficient, on structural response. The analysis indicates that variations in these parameters significantly affect displacement demand and energy dissipation capacity, which in turn influence the calculated Resilience Index. In particular, increased damping enhances energy dissipation but may lead to higher residual displacement, while reduced stiffness increases period elongation but may amplify isolator displacement. These findings highlight that the Resilience Index is sensitive to isolator design parameters, underscoring the importance of optimizing these parameters to achieve optimal resilience performance.

To further enhance the comparative interpretation of resilience performance across multiple parameters, Figure 2 presents a radar chart summarizing the percentage reductions in base shear, displacement, and story drift for each isolation system. This visualization provides an integrated, multidimensional perspective on system performance, enabling direct comparison of the relative effectiveness of LRB, HDRB, and FPS.

Table 5. Resilience Index Evaluation

Parameter	LRB	HDRB	FPS	Best Performance
Base Shear	0.031	0.176	**0.356**	FPS
Displacement	0.152	0.197	**0.270**	FPS
Story Drift	0.300	0.087	**0.375**	FPS

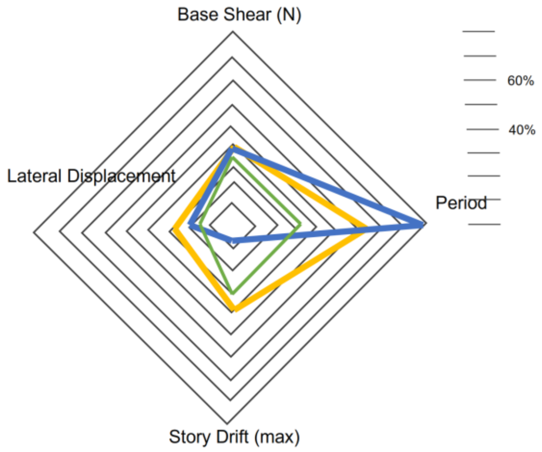

Figure 2. Radar chart summarizing the percentage reductions in base shear, lateral displacement, and story drift for LRB, HDRB, and FPS systems relative to the fixed-base condition

The radar chart clearly shows that FPS consistently dominates across all performance axes, with the highest reductions across all evaluated parameters. In contrast, HDRB and LRB exhibit partial improvements, with effectiveness varying by response parameter.

This multi-parameter visualization reinforces FPS's robustness as the most effective isolation system and supports the quantitative findings from the Resilience Index (R). Furthermore, the radar-based representation highlights performance trade-offs and balances, offering a more intuitive and holistic framework for engineering decision-making.

From a functional performance perspective, the implications are substantial. The quantified reductions in base shear and drift correspond directly to lower damage levels, which, in turn, reduce expected downtime and enhance immediate occupancy capability. Unlike prior studies that rely on qualitative inference, this study demonstrates that higher Resilience Index values are explicitly associated with improved operational performance. The superior performance of FPS indicates a higher probability of maintaining full hospital functionality immediately after seismic events, consistent with empirical observations of base-isolated healthcare facilities [4][5]. This establishes a direct and quantifiable relationship between structural response and functional resilience.

A comparative evaluation further highlights system-level trade-offs. FPS consistently delivers superior performance across all parameters thanks to its friction-based sliding mechanism, which dissipates energy and provides self-centering. HDRB offers enhanced damping capacity but exhibits larger base deformations, which may affect long-term durability under repeated loading. Conversely, LRB exhibits stable, predictable behavior but is comparatively less effective at reducing displacement and drift. These findings are consistent with previous comparative studies emphasizing the superior adaptability of FPS under varying seismic conditions [14][32].

Overall, this study advances existing knowledge by integrating structural response metrics with a formal resilience-based evaluation framework. Unlike previous research that isolates structural performance from functional outcomes, this approach enables direct quantification of operational resilience through measurable indicators. From an engineering perspective, the framework provides a robust basis for selecting isolation systems that optimize both structural safety and functional continuity, particularly in critical infrastructure such as hospitals in high-seismic regions.

Nevertheless, several limitations should be acknowledged. The use of response spectrum analysis with nonlinear modeling provides a consistent and efficient comparative framework but may not capture record-specific dynamic effects. Furthermore, the Resilience Index is derived from structural parameters and does not explicitly account for recovery duration or economic losses. Future research should therefore integrate nonlinear time history analysis with downtime-based and recovery-function models to develop a more comprehensive resilience assessment framework that captures system-level interactions and real operational performance.

CONCLUSION

This study aimed to evaluate the seismic performance of three widely adopted isolation systems: Lead Rubber Bearings (LRB), High-Damping Rubber Bearings (HDRB), and Friction Pendulum Systems (FPS) in the context of a hospital facility in West Lombok. The objective was to determine the optimal system that maximizes both structural robustness and post-earthquake functionality. The findings demonstrate that all three isolation systems substantially mitigated seismic demands relative to the fixed-base configuration, but with differing levels of effectiveness. Most notably, FPS consistently outperformed the others, achieving the largest reductions in base shear (−35.6%), story drift (−37.5%), and lateral displacement (−27.0%), while also inducing the largest increase in the structural period (+692%). HDRB and LRB provided valuable, though comparatively moderate, performance improvements. HDRB excelled in energy dissipation, yet exhibited larger base deformations, while LRB demonstrated balanced, stable behavior with modest reductions.

The implications for hospital resilience are particularly significant. By substantially reducing lateral forces, inter-story drift, and structural displacements, base isolation helps preserve the hospital's structural integrity, medical equipment, and interior contents during strong seismic events. This directly translates into maintaining functional recovery and uninterrupted post-disaster healthcare services, addressing a critical gap in previous research, which often focused solely on structural metrics without linking them to hospital operability. In practice, this means that facilities isolated with FPS, and to a lesser extent, HDRB or LRB, would likely sustain minimal damage, allowing life-saving services such as emergency care, surgeries, and power supply to remain operational immediately after an earthquake.

Theoretically, this research advances the understanding of hospital resilience by integrating numerical structural performance evaluations with functional recovery concepts. It confirms the decoupling principle of isolation systems while highlighting the trade-offs among different devices. Practically, the results provide a decision-making framework for engineers, hospital administrators, and policymakers. FPS emerges as the most robust solution for critical healthcare infrastructure where uninterrupted operation is paramount, while HDRB and LRB may serve as cost-effective alternatives in resource-constrained contexts. Moreover, the comparative insights underscore the importance of tailoring isolator selection to local seismic hazards, budgetary considerations, and performance objectives.

The consistency of the results with prior experimental and numerical studies further supports the validity and applicability of the proposed resilience-based evaluation framework.

In the future, the findings advocate for the systematic incorporation of base isolation, particularly FPS, into the seismic design and retrofitting of hospitals across Indonesia and other earthquake-prone regions. Beyond structural resilience, such integration safeguards essential healthcare functionality, thereby strengthening community-wide disaster response capacity. In broader terms, this research affirms that resilient hospitals are not merely engineering achievements. They are strategic pillars of societal resilience that ensure critical services remain available when they are most needed.

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