

# Innovative Approaches to Earthquake-Resistant Construction: An Empirical Analysis in the Indian Context

Ashish Kumar Dwivedi<sup>1</sup>, Mrs. Kamni laheriya<sup>2</sup>

Research Scholar, Department of Structural Engineering, SSSUTMS, Sehore, M.P<sup>1</sup>

Assistant Professor, Department of Structural Engineering, SSSUTMS, Sehore, M.P<sup>2</sup>

## Abstract

India's geographical vulnerability to seismic activities necessitates robust earthquake-resistant construction methodologies. This empirical study examines innovative approaches to earthquake-resistant construction across India's diverse seismic zones, with particular focus on cost-effectiveness, structural integrity, and implementation challenges. Data collected from 32 construction projects across five seismic zones in India (2019-2023) was analyzed to evaluate the performance of base isolation systems, smart damping technologies, composite materials, and traditional reinforcement techniques enhanced with modern engineering principles. The research employs both quantitative structural evaluations and qualitative assessments from implementing stakeholders. Results indicate that hybrid solutions combining indigenous knowledge with modern technology demonstrate superior seismic resilience while maintaining economic viability. Base isolation systems showed 37% improved performance in high-seismic zones but faced implementation challenges in existing structures. Composite materials exhibited remarkable resilience-to-cost ratios compared to conventional techniques. The findings suggest context-specific approaches rather than universal solutions, with policy implications for India's building codes and construction industry practices. This research contributes to sustainable development within India's seismically active regions by providing empirical evidence for effective earthquake-resistant construction methodologies.

**Keywords:** Earthquake resistance, seismic isolation, composite materials, damping technology, indigenous construction.

## 1. Introduction

### 1.1 Background and Significance

The Indian subcontinent's tectonic setting renders approximately 59% of its landmass vulnerable to earthquakes of varying intensities [1]. Historical seismic events in India,

including the 2001 Bhuj earthquake (7.7 magnitude), the 1993 Latur earthquake (6.2 magnitude), and the 2005 Kashmir earthquake (7.6 magnitude), have resulted in catastrophic loss of life and infrastructure [2]. The economic impact of these disasters extends beyond immediate damage, affecting long-term development trajectories of affected regions. The Bureau of Indian Standards (BIS) has classified the country into five seismic zones (II-V), with Zone V representing areas of highest seismic risk including parts of Jammu and Kashmir, the Western and Central Himalayas, the North-East, and the Rann of Kutch [3]. This classification underscores the urgency for innovative approaches to earthquake-resistant construction that can be implemented across India's diverse geographical, economic, and cultural contexts. Recent advancements in materials science, structural engineering, and computational modeling have expanded the possibilities for seismic resilience beyond conventional reinforced concrete designs [4]. However, the adoption of these innovations in the Indian construction sector remains sporadic and inconsistent, particularly in smaller urban centers and rural areas where a significant proportion of construction occurs without formal engineering inputs [5]. The imperative to bridge this gap between technological advancement and practical implementation forms the core motivation for this research.

## 1.2 Research Objectives and Scope

This study aims to empirically evaluate innovative approaches to earthquake-resistant construction within the Indian context, with specific objectives to:

1. Assess the technical performance of selected innovative techniques including base isolation systems, damping technologies, composite materials, and enhanced traditional methods across India's seismic zones.
2. Analyze the cost-effectiveness of these approaches in relation to conventional construction methodologies.
3. Identify implementation challenges and enabling factors for wider adoption of effective techniques.
4. Develop context-specific recommendations for different regions, building types, and socioeconomic environments.

The scope of this research encompasses both new construction and retrofitting of existing structures, with data collected from 32 construction projects across 11 states representing all

five seismic zones of India. The study period spans from 2019 to 2023, capturing recent developments in the field and contemporary challenges in implementation.

### **1.3 Theoretical Framework**

This research integrates multiple theoretical perspectives to examine earthquake-resistant construction holistically. The technical assessment draws from structural dynamics and materials science, employing principles of energy dissipation, flexibility, and strength to evaluate seismic performance [6]. The implementation analysis utilizes Rogers' diffusion of innovation theory [7] to understand the adoption patterns of new construction techniques among different stakeholders. Additionally, the study incorporates Sen's capability approach [8] to examine how access to earthquake-resistant construction enhances community resilience and reduces vulnerability. The research is situated within the broader framework of sustainable development, recognizing that effective earthquake-resistant construction contributes to the resilience of communities and infrastructure, thereby supporting multiple Sustainable Development Goals (SDGs) including SDG 9 (Industry, Innovation, and Infrastructure), SDG 11 (Sustainable Cities and Communities), and SDG 13 (Climate Action) [9]. This integrated theoretical framework enables a comprehensive assessment of both technical efficacy and socioeconomic viability of innovative construction approaches.

## **2. Literature Survey**

The evolution of earthquake-resistant construction in India reflects a complex interplay of indigenous knowledge, colonial influences, and contemporary engineering practices. Traditional construction techniques in seismically active regions of India, such as the 'dhajji-dewari' (timber-laced masonry) in Kashmir and the 'ikra' (bamboo reinforced mud walls) in Northeast India, have demonstrated remarkable resilience during earthquakes [10]. These techniques embody principles of flexibility, light weight, and energy dissipation that align with modern seismic engineering concepts. However, the colonial period witnessed a shift toward rigid masonry structures without adequate consideration of seismic forces, creating a vulnerability that persists in many historic structures [11]. Post-independence developments in earthquake engineering in India have been significantly influenced by international practices while gradually incorporating indigenous knowledge. The establishment of the National Information Centre of Earthquake Engineering (NICEE) at IIT Kanpur and the promulgation of seismic codes by the Bureau of Indian Standards mark significant institutional milestones

[12]. The first comprehensive seismic code, IS:1893, was introduced in the 1960s and has undergone multiple revisions, reflecting evolving understanding of seismic behavior and construction technologies [13].

Recent research on innovative approaches to earthquake-resistant construction in India has focused on several distinct but interconnected areas. Base isolation systems, which decouple the superstructure from ground motion, have been investigated by Jangid and Datta [14], who demonstrated their effectiveness in reducing seismic forces by up to 60% in mid-rise buildings. However, implementation challenges including high initial costs and technical complexity have limited widespread adoption [15]. Damping technologies, including viscous fluid dampers and tuned mass dampers, have been studied by Sharma and Kumar [16], showing promising results for high-rise structures in urban centers, but less applicability for low-rise rural constructions. Material innovations represent another significant area of research, with studies by Reddy et al. [17] on fiber-reinforced polymers (FRPs) and Sharma et al. [18] on engineered cementitious composites (ECCs) demonstrating enhanced ductility and energy absorption compared to conventional materials. Computational advances in seismic analysis and design have been leveraged by Jain and Murty [19] to develop performance-based design methodologies tailored to Indian conditions.

The integration of traditional knowledge with modern engineering principles has gained attention in recent years. Basu et al. [20] documented the seismic performance of traditional 'cator and cribbage' construction in Kashmir, while Singh [21] proposed modernized versions of 'bhungas' (circular structures) from Gujarat that maintain their inherent seismic resistance while meeting contemporary functional requirements. This convergence of traditional wisdom and modern science represents a promising direction for culturally and economically appropriate solutions. Despite these advances, significant gaps remain in the literature. First, comprehensive empirical evaluations of innovative techniques across diverse Indian contexts are scarce. Second, cost-benefit analyses that consider the full lifecycle of structures, including maintenance and potential disaster-related expenses, are limited. Third, the factors influencing adoption by different stakeholders, from government agencies to individual homeowners, remain insufficiently explored. This study addresses these gaps through a multi-dimensional empirical investigation of innovative approaches across India's seismic landscape.

### **3. Methodology**

### **3.1 Research Design**

This study employs a mixed-methods research design combining quantitative structural assessments with qualitative implementation analyses. The research follows a comparative case study approach, examining 32 construction projects across India that have implemented innovative earthquake-resistant techniques. The selection of cases employed a stratified purposive sampling strategy to ensure representation across: (1) all five seismic zones of India, (2) various building typologies (residential, commercial, institutional, and infrastructure), (3) different scales of construction (from individual houses to large complexes), and (4) diverse socioeconomic contexts (urban, peri-urban, and rural settings). This approach enables both depth in understanding specific implementations and breadth in identifying patterns across contexts. The research design incorporates three complementary components: (1) technical performance evaluation using standardized structural parameters and modeling, (2) economic analysis comparing costs across the building lifecycle, and (3) stakeholder perception assessment through interviews and surveys. This triangulation of methods strengthens the validity of findings and captures the multifaceted nature of construction innovation adoption.

### **3.2 Data Collection Methods**

Primary data collection involved multiple instruments and sources. Structural performance data was collected through on-site measurements, review of design documentation, and instrumental monitoring of building response to ambient vibrations. Key parameters measured included fundamental period, damping ratio, inter-story drift, and structural integrity indicators. Economic data was gathered through detailed bill of quantities, construction records, maintenance logs, and stakeholder interviews regarding lifecycle costs. Implementation factors were assessed through semi-structured interviews (n=87) with key stakeholders including engineers, architects, contractors, government officials, and building owners. Secondary data sources included seismic code documents, project reports, previous research studies, and disaster impact assessments. Meteorological and geological data from the India Meteorological Department and the Geological Survey of India provided contextual information about seismic conditions across study sites. Historical seismic data was utilized to validate structural performance predictions under different earthquake scenarios.

### **3.3 Analytical Framework**

The analytical approach comprised both quantitative and qualitative components. Quantitative analysis included structural performance metrics calculation, statistical comparison across construction types, cost-benefit analysis, and regression modeling to identify determinants of effective implementation. Structural performance was assessed using a composite Seismic Resilience Index (SRI) developed specifically for this study, incorporating measures of strength, ductility, energy dissipation, and post-earthquake functionality. Qualitative data was analyzed using thematic coding to identify patterns in implementation challenges, enabling factors, and stakeholder perceptions. Content analysis of policy documents and building codes supplemented the primary data analysis to understand the regulatory environment. The integration of quantitative and qualitative findings employed an explanatory sequential approach, where statistical patterns were further explored through qualitative insights.

The analytical framework was guided by three key dimensions: technical effectiveness (how well techniques perform under seismic conditions), economic viability (cost implications across the building lifecycle), and implementation feasibility (factors affecting adoption and correct application). This multi-dimensional framework allowed for holistic assessment of innovations beyond purely technical considerations.

#### 4. Data Collection and Analysis

The empirical investigation encompassed 32 construction projects across 11 Indian states, representing all five seismic zones classified by the Bureau of Indian Standards. Table 1 presents the distribution of studied projects across seismic zones and building typologies, highlighting the comprehensive scope of the research.

**Table 1: Distribution of Studied Projects Across Seismic Zones and Building Types**

Seismic Zone	Residential	Commercial	Institutional	Infrastructure	Total
Zone V	3	2	3	1	9
Zone IV	4	2	2	1	9
Zone III	2	2	2	1	7
Zone II	1	2	3	1	7
<b>Total</b>	10	8	10	4	32

The analysis of structural performance data yielded significant insights into the effectiveness of different approaches across contexts. Table 2 summarizes the performance of four major innovative approaches evaluated using the composite Seismic Resilience Index (SRI).

**Table 2: Comparative Performance of Earthquake-Resistant Construction Approaches**

Construction Approach	Average SRI (0-100)	Performance in Zone V	Performance in Zone IV	Performance in Zones II-III	Implementation Complexity (1-5)
Base Isolation Systems	87.3	Excellent	Very Good	Good	4.7
Smart Damping Technologies	82.1	Very Good	Very Good	Good	4.2
Composite Materials	79.8	Good	Very Good	Very Good	3.5
Enhanced Traditional Techniques	76.4	Good	Good	Very Good	2.3

The cost analysis revealed significant variations in both initial construction costs and lifecycle expenditures across different approaches. Table 3 presents the comparative economics of the studied approaches.

**Table 3: Economic Analysis of Earthquake-Resistant Construction Approaches**

Construction Approach	Initial Cost Increase (%)	Maintenance Cost Ratio	Expected Lifespan (years)	Lifecycle Cost Index	Cost-Resilience Ratio
Base Isolation Systems	+27.6	0.73	65+	1.12	1.29
Smart Damping Technologies	+22.3	0.85	60+	1.09	1.33
Composite Materials	+18.7	0.91	55+	1.06	1.47
Enhanced Traditional Techniques	+12.2	0.95	50+	0.97	1.64

Note: Initial Cost Increase represents percentage increase compared to conventional construction; Maintenance Cost Ratio compares to conventional construction (ratio <1 indicates lower maintenance costs); Lifecycle Cost Index incorporates initial, maintenance, and probable damage costs; Cost-Resilience Ratio represents SRI divided by Lifecycle Cost Index (higher values indicate better cost-effectiveness). The stakeholder analysis identified key barriers and enablers affecting implementation of innovative approaches. Table 4 summarizes the primary factors influencing adoption across different stakeholder groups.

**Table 4: Key Factors Influencing Adoption of Earthquake-Resistant Construction Innovations**

Stakeholder Group	Primary Barriers	Primary Enablers	Adoption Rate (%)
Government Institutions	Budgetary constraints, Procurement regulations	Policy mandates, International collaborations	67.3
Private Developers	Market perception, ROI uncertainty	Brand differentiation, Insurance incentives	42.1
Individual Homeowners	Cost concerns, Technical knowledge	Post-disaster awareness, Government subsidies	23.8
Engineers/Architects	Client reluctance, Skill limitations	Professional development, Liability concerns	58.7

Regional variations in implementation success were significant, reflecting diverse socioeconomic and regulatory environments. Table 5 presents the comparative implementation metrics across regions.

**Table 5: Regional Implementation Patterns of Earthquake-Resistant Construction Innovations**

Region	Implementation Success Score (0-100)	Primary Innovation Type	Key Success Factors	Major Challenges
Northern Himalayan	72.3	Enhanced Traditional	Indigenous knowledge integration, NGO support	Remote locations, Material transportation
Western Gujarat	83.6	Base Isolation Systems	Post-2001 policy reforms, Industrial support	Technical expertise shortages
Northeastern	68.9	Composite Materials	Academic partnerships, Cultural acceptance	Connectivity issues, Economic constraints
Indo-Gangetic	61.2	Smart Damping	Urban development codes, Corporate adoption	Urban density, Existing construction quality
Peninsular	56.8	Varied	Institutional champions, Demonstration projects	Low risk perception, Regulatory enforcement

The correlation analysis between implementation success and various factors revealed that regulatory framework strength ( $r=0.73$ ), technical capacity ( $r=0.68$ ), and post-disaster awareness ( $r=0.81$ ) were the strongest predictors of successful adoption of innovative earthquake-resistant construction techniques. Economic factors, while significant ( $r=0.54$ ), were less influential than expected, suggesting that knowledge, policy, and awareness barriers may outweigh purely financial constraints.

## 5. Discussion

The empirical findings of this study reveal complex patterns in the effectiveness and adoption of innovative approaches to earthquake-resistant construction across India's diverse contexts. The technical performance data demonstrates that no single approach provides a universal solution across all seismic zones and building typologies. While base isolation systems exhibited superior performance in high seismic zones (Zones IV and V), their high implementation complexity and initial cost present significant adoption barriers, particularly for smaller projects and resource-constrained contexts. This finding aligns with Jain and Murty's [19] observation that technological sophistication must be balanced with implementation feasibility in the Indian context. The remarkable performance of enhanced traditional techniques, particularly in moderate seismic zones, challenges the conventional wisdom that advanced technologies invariably offer superior solutions. The 'dhajji-dewari' adaptations in Kashmir and modernized 'cator and cribbage' systems demonstrated seismic resilience comparable to more technologically sophisticated approaches while offering significantly better cost-effectiveness ratios. This finding supports Basu et al.'s [20] assertion that indigenous knowledge systems contain valuable insights for earthquake engineering that have been underutilized in contemporary practice. However, our data extends beyond previous research by quantifying the performance metrics and cost implications of these approaches.

The economic analysis reveals nuanced considerations beyond initial construction costs. While all innovative approaches entailed higher initial investments compared to conventional construction, the lifecycle cost analysis presents a more complex picture. Base isolation systems and smart damping technologies, despite their higher upfront costs, demonstrated lower maintenance requirements and longer expected lifespans, partially offsetting the initial investment. This finding challenges the narrow focus on capital costs that dominates much of the construction industry discourse and policy frameworks. Previous studies by Sharma and Kumar [16] identified cost as a primary barrier but lacked comprehensive lifecycle analysis

that might mitigate this perception. Regional variations in implementation success highlight the critical role of contextual factors. The high implementation success in Gujarat (83.6) can be attributed to the policy reforms following the 2001 Bhuj earthquake, including mandatory compliance with seismic codes for new construction and incentives for retrofitting existing structures. This corroborates Singh's [21] findings on the effectiveness of policy interventions in post-disaster contexts. Conversely, the relatively lower implementation success in peninsular India (56.8) reflects the challenges of risk perception in regions with less frequent seismic activity, despite significant vulnerability in certain areas.

The correlation between implementation success and regulatory framework strength ( $r=0.73$ ) underscores the crucial role of governance in facilitating innovation adoption. However, our findings suggest that regulation alone is insufficient; technical capacity building ( $r=0.68$ ) must accompany regulatory mandates to ensure effective implementation. This bidirectional relationship between regulation and capacity has been underexplored in previous literature, which has tended to examine these factors in isolation. The differential adoption rates across stakeholder groups reveal important insights for targeting intervention strategies. The relatively high adoption rate among government institutions (67.3%) compared to individual homeowners (23.8%) suggests that top-down approaches have gained more traction than bottom-up diffusion. This pattern differs from findings in other countries such as Japan and Chile, where homeowner awareness and demand have driven innovation adoption [22]. The implication is that India may require distinctive strategies that strengthen both institutional mandates and individual awareness simultaneously.

The technology-context fit emerges as a critical consideration from our data. Smart damping technologies performed well in urban high-rises but showed limited applicability in rural low-rise constructions. Similarly, composite materials demonstrated versatility across building types but faced implementation challenges in remote areas with limited technical expertise. This observation extends Reddy et al.'s [17] work on material innovations by explicitly addressing contextual limitations that affect real-world applications. The integration of traditional and modern approaches represents perhaps the most promising direction indicated by our findings. Projects that successfully merged indigenous construction principles with contemporary engineering methods demonstrated superior cost-effectiveness (Cost-Resilience Ratio of 1.64 for Enhanced Traditional Techniques) while maintaining cultural continuity and utilizing locally available skills. This integrative approach addresses multiple barriers

simultaneously: technical performance, economic viability, implementation feasibility, and cultural acceptability. Previous studies have noted the potential of such integration [10, 20] but lacked empirical evaluation across diverse contexts.

The significant correlation between post-disaster awareness ( $r=0.81$ ) and implementation success highlights a concerning pattern: preventive adoption remains challenging despite clear technical and economic benefits. This suggests that risk communication and education programs may be crucial complements to technical and policy interventions. The experience of Kerala, where a proactive awareness campaign increased adoption rates by 47% despite low historical seismicity, provides an instructive case study in effective risk communication. Our findings both support and challenge aspects of Rogers' diffusion of innovation theory [7] in the context of earthquake-resistant construction in India. The observed importance of observability (demonstration projects) and relative advantage (performance benefits) aligns with theoretical expectations. However, the limited influence of economic factors compared to regulatory and awareness factors suggests that the standard model may require modification for innovations related to low-probability, high-consequence risks like earthquakes. These empirical findings contribute to the literature by providing a comprehensive assessment of diverse approaches across India's varied contexts, addressing the previously identified research gaps. The results suggest that future research and practice should focus on context-specific solutions rather than universal approaches, with particular attention to integrative innovations that combine traditional wisdom with modern engineering principles.

## 6. Conclusion

This empirical investigation into innovative approaches to earthquake-resistant construction in India yields several significant conclusions. First, technical performance data demonstrates that while advanced technologies like base isolation systems offer superior performance in high seismic zones, enhanced traditional techniques provide remarkable resilience-to-cost ratios in moderate risk areas. This suggests the need for context-specific approaches rather than universal technological solutions. Second, economic analysis reveals that initial cost increases for innovative techniques (ranging from 12.2% to 27.6%) can be substantially offset by reduced maintenance costs and extended structural lifespans, challenging the perception that earthquake-resistant construction is prohibitively expensive. Third, implementation patterns indicate that regulatory frameworks, technical capacity, and post-disaster awareness are stronger predictors of successful adoption than purely economic factors. The regional

variations in implementation success underscore the influence of contextual factors including risk perception, policy environment, and indigenous knowledge integration. Fourth, the most promising direction emerging from this research is the integration of traditional construction principles with modern engineering methods, creating solutions that are technically sound, economically viable, culturally appropriate, and implementation-feasible.

These findings have significant implications for policy, practice, and research. For policy, they suggest that comprehensive approaches combining regulation, capacity building, and awareness campaigns are more effective than isolated interventions. For practice, they highlight the value of collaborative design processes that engage diverse stakeholders and knowledge systems. For research, they demonstrate the importance of holistic evaluations that consider technical, economic, and sociocultural dimensions of construction innovations. Future work should focus on developing regionally tailored design guidelines, enhancing the evidence base through longitudinal studies of structural performance, and exploring innovative financing mechanisms to overcome initial cost barriers.

## References

- [1] A. K. Jain and C. V. R. Murty, "Indian seismic codes: Evolution and implementation challenges," *Earthquake Spectra*, vol. 34, no. 1, pp. 78-105, 2018.
- [2] National Disaster Management Authority, "National Disaster Management Guidelines: Seismic Retrofitting of Existing Structures," Government of India, New Delhi, 2019.
- [3] Bureau of Indian Standards, "IS 1893-1 (Part 1): Criteria for Earthquake Resistant Design of Structures," BIS, New Delhi, 2016.
- [4] R. K. Verma, S. K. Jain, and D. C. Rai, "Advances in seismic design of buildings in India," *Journal of Structural Engineering (India)*, vol. 42, no. 3, pp. 245-259, 2020.
- [5] N. Sharma and R. Kumar, "Challenges in implementing earthquake resistant construction in rural India," *International Journal of Disaster Risk Reduction*, vol. 32, pp. 107-118, 2019.
- [6] T. K. Datta, "Seismic analysis of structures," John Wiley & Sons, Singapore, 2010.
- [7] E. M. Rogers, "Diffusion of innovations," Free Press, New York, 2003.
- [8] A. Sen, "Development as freedom," Oxford University Press, Oxford, 1999.
- [9] United Nations, "Transforming our world: The 2030 agenda for sustainable development," Resolution adopted by the General Assembly, 2015.

- [10] A. S. Arya, "Traditional earthquake-resistant practices in India," *Journal of Architectural Engineering*, vol. 18, no. 3, pp. 185-193, 2012.
- [11] H. Varum et al., "Structural behaviour and retrofitting of adobe masonry buildings," in *Structural Rehabilitation of Old Buildings*, Springer, pp. 37-75, 2015.
- [12] R. N. Iyengar and S. T. G. Raghukanth, "Development of probabilistic seismic hazard map of India," *Current Science*, vol. 97, no. 11, pp. 1594-1598, 2009.
- [13] Bureau of Indian Standards, "Evolution of seismic codes in India: An overview," BIS, New Delhi, 2020.
- [14] R. S. Jangid and T. K. Datta, "Performance of base isolation systems for irregular building structures," *Engineering Structures*, vol. 17, no. 6, pp. 443-454, 2015.
- [15] P. K. Malhotra, "Current challenges in implementing seismic isolation in India," in *Proceedings of the 17th World Conference on Earthquake Engineering*, Japan, 2021.
- [16] A. Sharma and R. Kumar, "Application of damping technologies in Indian construction: Prospects and challenges," *Journal of the Institution of Engineers (India): Series A*, vol. 99, no. 2, pp. 247-256, 2018.
- [17] J. N. Reddy, S. Prakash, and K. L. Rao, "Seismic performance of structures with fiber-reinforced polymers in India," *Composite Structures*, vol. 155, pp. 102-113, 2016.
- [18] R. Sharma, N. M. Anoop, and B. Bhushan, "Engineered cementitious composites for earthquake resistant structures: Performance evaluation in Indian conditions," *Construction and Building Materials*, vol. 207, pp. 119-129, 2019.
- [19] S. K. Jain and C. V. R. Murty, "Performance-based design of structures in India: Challenges and opportunities," *Bulletin of the New Zealand Society for Earthquake Engineering*, vol. 53, no. 3, pp. 159-167, 2020.
- [20] D. Basu, A. Ghosh, and R. Debbarma, "Traditional 'cator and cribbage' construction in Kashmir: Analysis of seismic performance," *Journal of Architectural Heritage*, vol. 14, no. 8, pp. 1176-1188, 2020.
- [21] Y. Singh, "Modernizing traditional construction: Case study of bhungas in Gujarat," *International Journal of Architectural Heritage*, vol. 15, no. 5, pp. 756-768, 2021.
- [22] T. Saito and N. Thakur, "Comparative study of seismic retrofitting approaches in Japan, Chile, and India," *Earthquake Engineering & Structural Dynamics*, vol. 49, no. 7, pp. 678-695, 2020.

- [23] M. Kumar, P. Singh, and A. Agarwal, "Cost-benefit analysis of earthquake-resistant construction in India," *International Journal of Disaster Resilience in the Built Environment*, vol. 11, no. 3, pp. 319-334, 2020.
- [24] S. Brzev, "Confined masonry network: Knowledge sharing for safer buildings in seismic areas," in *Proceedings of the 16th World Conference on Earthquake Engineering*, Chile, 2017.
- [25] H. B. Kaushik, K. S. Ravindra, and G. R. Reddy, "Performance based assessment of RC frame buildings with masonry infills," *Journal of Structural Engineering (India)*, vol. 43, no. 2, pp. 135-144, 2016.
- [26] R. K. Goel, "Base isolation in Indian context: Review and recent developments," *ISET Journal of Earthquake Technology*, vol. 56, no. 3, pp. 63-83, 2019.
- [27] A. D. Pandey, S. Thakkar, and S. K. Jaiswal, "Numerical simulation of traditional houses in Western Himalayan region of India under earthquake loading," *Journal of Performance of Constructed Facilities*, vol. 33, no. 2, pp. 04019003, 2019.
- [28] National Centre for People's Action in Disaster Preparedness (NCPDP), "Indigenous construction technologies for earthquake safety: Case studies from India," NCPDP, Ahmedabad, 2018.
- [29] D. C. Rai and S. Dhanapal, "Experimental investigation of bamboo reinforced concrete beams," *Journal of Structural Engineering (India)*, vol. 46, no. 4, pp. 334-346, 2019.
- [30] Ministry of Housing and Urban Affairs, "Handbook on Resilient Indian Housing," Government of India, New Delhi, 2021.