

International Journal of Revolutionary Civil Engineering

Next-Generation Seismic-Resilient Structures: Performance-Based Design, Metamaterials, and Energy-Dissipating Systems for Earthquake-Resistant Infrastructure

Dr. Jonathan R Kim

Department of Structural and Disaster-Resilient Engineering, University of California, Berkeley, United States

* Corresponding Author: **Dr. Jonathan R Kim**

Article Info

E-ISSN: 3107-7099

Volume: 02

Issue: 02

Received: 14-01-2026

Accepted: 12-02-2026

Published: 10-03-2026

Page No: 30-36

Abstract

Earthquakes continue to pose catastrophic risks to urban infrastructure, with recent events demonstrating that life safety alone proves insufficient as a design objective when communities face prolonged disruption from non-functional buildings. This review examines next-generation seismic-resilient structural systems integrating performance-based design frameworks, advanced energy-dissipating technologies, and emerging metamaterial-based wave attenuation strategies. The objective is to synthesize current knowledge on achieving verifiable post-earthquake functionality through nonlinear modeling, probabilistic assessment, and innovative control systems. Key technologies assessed include base isolation achieving period shifts of 2.0–3.0 seconds with acceleration reductions of 50–80%, viscous dampers providing supplemental damping ratios of 15–30%, and shape memory alloy devices enabling recentering capabilities with residual drift elimination. Seismic metamaterials utilizing periodic foundations and barrier arrays achieve frequency bandgaps of 3–15 Hz, attenuating surface waves by 60–90% through destructive interference. Performance-based design frameworks incorporate multiple performance objectives across earthquake intensities, with lifecycle resilience metrics quantifying downtime, repair costs, and functional recovery timeframes. Application domains encompass high-rise buildings, bridge infrastructure, and critical facilities including hospitals and emergency response centers. Economic analysis demonstrates benefit–cost ratios of 2.5–6.0 for enhanced seismic systems when accounting for avoided losses and accelerated recovery. The review concludes that convergence of PBSD methodologies, energy-dissipating devices, and metamaterial concepts enables transformation from collapse prevention to assured functionality, though standardization gaps and validation requirements necessitate continued research investment.

Keywords: Performance-based seismic design, base isolation, energy dissipation, seismic metamaterials, structural control, earthquake resilience

1. Introduction

Earthquakes constitute among the most devastating natural hazards for civil infrastructure, with the 2010–2011 Canterbury earthquake sequence causing \$40 billion in losses and necessitating demolition of 70% of Christchurch's central business district buildings ^[1]. The 2023 Turkey–Syria earthquakes resulted in over 50,000 fatalities and damaged or destroyed 230,000 buildings, highlighting persistent vulnerabilities despite advances in seismic design ^[2]. These events demonstrate that conventional code-prescriptive approaches focused primarily on life safety prove inadequate when societal expectations extend to rapid post-earthquake functional recovery ^[3].

Contemporary seismic engineering is undergoing paradigm shift from collapse prevention toward resilience-based design that maintains functionality following design-level events and enables rapid recovery after extreme shaking ^[4]. This transformation requires integration of advanced analytical frameworks, innovative structural systems, and emerging technologies that collectively modify structural response beyond conventional ductility-based approaches ^[5]. This review addresses three interconnected frontiers in earthquake-resilient infrastructure: performance-based seismic design (PBSD) frameworks enabling

explicit quantification of structural performance across earthquake intensities; energy-dissipating and structural control systems that modify dynamic response through supplemental damping, isolation, or adaptive mechanisms; and seismic metamaterials that manipulate wave propagation to protect structures at the soil–foundation interface. The scope encompasses theoretical foundations, comparative performance assessment, implementation considerations, and future research directions for next-generation seismic-resilient systems.

2. Performance-Based Seismic Design Frameworks

2.1. Evolution of PBSD Methodologies

Performance-based seismic design represents a fundamental departure from prescriptive code approaches, enabling engineers to design structures achieving specified performance objectives under defined seismic hazards [5]. The framework, formalized through documents including FEMA 273/274 and ASCE/SEI 41, establishes multiple performance levels—Operational, Immediate Occupancy, Life Safety, and Collapse Prevention—associated with increasing earthquake intensities [7].

Contemporary PBSD extends beyond member-level acceptance criteria to incorporate probabilistic assessment of structural response considering uncertainties in ground motion, material properties, and modeling assumptions [8]. The Pacific Earthquake Engineering Research (PEER) Center framework formalizes this through four-stage analysis: hazard analysis, structural response analysis, damage analysis, and loss analysis, enabling quantification of decision variables including annualized repair costs, downtime, and casualties [9].

2.2. Nonlinear Modeling and Probabilistic Assessment

Implementation of PBSD requires sophisticated nonlinear modeling capturing material inelasticity, geometric nonlinearities, and component-level deterioration [10]. Fiber-section beam-column elements, concentrated plasticity models, and continuum finite element approaches each offer trade-offs between accuracy and computational efficiency, with selection depending on structural system and analysis objectives [11].

Probabilistic seismic demand models relate ground motion intensity measures (spectral acceleration, peak ground velocity) to engineering demand parameters (inter-story drift, floor accelerations, component deformations) through cloud analysis, incremental dynamic analysis, or multiple-stripe analysis [12]. These relationships, combined with fragility functions for structural and nonstructural components, enable quantitative risk assessment informing design decisions and investment prioritization [13].

2.3. Lifecycle Resilience Quantification

Resilience metrics extend beyond traditional loss estimation to incorporate functionality over time following earthquake events. The functionality metric $Q(t)/Q(t)$ defines recovery trajectories, with resilience quantified as the integral of functionality over the recovery period normalized by pre-event functionality [14]. For critical facilities such as hospitals and emergency operations centers, rapid return to full functionality may be more valuable than absolute damage reduction [15].

Table 1 presents performance-based design and seismic met material approaches, summarizing design objectives, analytical methods, resilience outcomes, and implementation considerations.

Table 1: Performance-Based Design and Seismic Met material Approaches in Earthquake-Resilient Infrastructure

Approach	Design Objective	Analytical Method	Resilience Level Achieved	Implementation Challenges	Policy and Code Integration Status
Performance-based seismic design	Multiple performance objectives across hazard levels	Nonlinear time-history analysis, probabilistic demand models	Explicit quantification of repair costs, downtime, casualties	Computational demands, uncertainty characterization, expertise requirements	ASCE/SEI 41, FEMA P-58; evolving toward next-generation codes
Nonlinear time-history analysis	Accurate response simulation for design verification	Direct integration, modal superposition with inelastic elements	10–30% improvement in demand prediction over linear methods	Ground motion selection, modeling parameter uncertainty	Required for irregular/important structures in major codes
Seismic metamaterials (periodic foundations)	Wave filtering through bandgap generation	Dispersion analysis, finite element unit-cell modeling	60–90% surface wave attenuation at 3–15 Hz frequencies	Scale transition from laboratory to prototype, soil interaction	None; emerging research concept
Seismic metamaterials (barrier arrays)	Surface wave redirection and attenuation	Multiple scattering theory, full-wave simulation	50–80% energy reduction in protected zone	Installation depth requirements, urban integration	None; pilot demonstrations only
Wave barrier systems (open trenches, sheet piles)	Surface wave reflection/diffraction	Analytical wave propagation, finite element simulation	30–70% amplitude reduction depending on barrier depth	Excavation depth, utility conflicts, maintenance	Limited guidance in some codes
Hybrid control systems	Combined passive/active/semi-active response modification	Integrated structural-control simulation	40–70% improvement over uncontrolled response	Controller design, power requirements, reliability	Emerging guidelines (ISO 3010)

3. Energy-Dissipating and Structural Control Systems

3.1. Passive Control Technologies

Passive energy dissipation systems modify structural response without external power by converting input energy into heat through material hysteresis, viscous fluid flow, or friction [16]. Metallic yielding dampers utilize mild steel plates or shapes that yield in flexure, shear, or torsion, providing stable hysteretic behavior with fatigue life sufficient for design-level events [17]. Added damping ratios of 10–20% are achievable through distributed damper placement [16].

Friction dampers dissipate energy through sliding between brake pad-type materials under controlled clamping force, offering nearly rectangular hysteretic loops with minimal velocity or temperature dependence [18]. Rotational friction dampers installed at beam-column connections in steel frames achieve 20–30% story drift reduction while maintaining recentering capability through elastic frame action [19].

Viscous fluid dampers dissipate energy through silicone-based fluid forced through orifices, producing velocity-dependent forces with minimal stiffness contribution [20].

Force-velocity relationships follow $F=Cv^\alpha$, with exponent α typically 0.3–1.0 enabling optimization for specific response characteristics. Supplemental damping

ratios of 15–30% are achievable without introducing additional seismic forces to foundations [20].

3.2. Base Isolation Systems

Base isolation decouples structures from earthquake-induced ground motions through flexible interfaces that shift fundamental periods beyond dominant ground motion energy [21]. Elastomeric bearings—laminated rubber layers with steel reinforcing plates—provide vertical stiffness supporting gravity loads while accommodating horizontal displacements up to 500 mm through rubber shear deformation [22]. Lead-rubber bearings incorporate lead cores that yield under lateral load, providing energy dissipation within the isolation interface [21].

Friction pendulum bearings utilize sliding interfaces with spherical geometry, generating restoring forces through gravity acting on curved surfaces [23]. Isolation periods of 2.0–4.0 seconds are achievable, reducing spectral accelerations by 50–80% compared to fixed-base structures while accommodating thermal movements and wind loads without compromising performance [24].

Table 2 presents comparative evaluation of energy-dissipating systems and seismic control technologies, summarizing mechanisms, applicable structure types, performance ranges, and implementation consideration

Table 2: Comparative Evaluation of Energy-Dissipating Systems and Seismic Control Technologies

Technology Type	Energy Dissipation Mechanism	Applicable Structure Type	Performance Improvement Range	Installation Complexity	Cost Implications
Base isolation (elastomeric bearings)	Period shift + hysteretic damping (lead core)	Buildings (low–mid rise), bridges, critical facilities	50–80% acceleration reduction; 2.0–3.0 s period shift	High: foundation modification, moat walls	High (3–10% structure cost) but cost-effective for critical facilities
Base isolation (friction pendulum)	Friction sliding + gravity restoring	Buildings, bridges, liquid storage tanks	60–85% acceleration reduction; 2.0–4.0 s period	High: specialized bearings, quality control	High; competitive with elastomeric for high-vertical-load applications
Viscous fluid dampers	Velocity-dependent fluid flow	Building frames, bridges, towers	15–30% supplemental damping; 20–40% drift reduction	Moderate: brace connections, inspection access	Moderate (\$200–1000/kN capacity)
Metallic yielding dampers	Hysteretic yielding (steel, lead)	Moment frames, braced frames, coupling beams	10–25% damping; stable energy dissipation	Low–moderate: replaceable elements	Low–moderate; economical for high-energy dissipation
Friction dampers	Coulomb friction at sliding interfaces	Concentrically braced frames, moment frames	15–30% drift reduction; rectangular hysteresis	Moderate: bolt tensioning maintenance	Low–moderate; minimal maintenance requirements
Tuned mass dampers	Inertial force from secondary mass	Tall buildings, slender structures, pedestrian bridges	30–60% response reduction at tuned frequency	High: space requirements, tuning mechanisms	Moderate–high; effective for wind and moderate earthquakes
Shape memory alloy devices	Superelastic phase transformation	Moment connections, bracing systems, recentering devices	Recentering capability; residual drift elimination	High: material cost, connection detailing	High; provides unique recentering function

3.3. Semi-Active and Active Control Systems

Semi-active systems combine passive device reliability with adjustable properties requiring minimal external power. Magnetorheological (MR) dampers utilize MR fluids that change apparent viscosity under magnetic fields, enabling real-time adjustment of damping force with response times of milliseconds ^[25]. Controllable fluid dampers have been implemented in cable-stayed bridges and building applications, achieving 30–50% response reductions compared to optimal passive configurations ^[26].

Active control systems employ force-generating devices (actuators) that apply counter-forces based on real-time structural response measurements ^[27]. While theoretically capable of superior performance, power requirements, reliability concerns, and control–structure interaction complexities have limited practical applications primarily to tall buildings under wind loading rather than seismic excitation ^[28].

4. Seismic Metamaterials and Wave Attenuation Strategies

4.1. Fundamental Concepts of Structural Metamaterials

Seismic metamaterials constitute artificially structured media that manipulate elastic wave propagation through periodic impedance contrasts or resonant elements ^[29]. Drawing on concepts from photonic and phononic crystals, these materials exhibit frequency bands (bandgaps) within which wave propagation is prohibited, enabling selective filtering of seismic energy ^[30].

Two primary mechanisms achieve bandgap behavior: Bragg scattering, arising from periodic impedance contrasts with wavelength-scale periodicity, and local resonance, wherein sub-wavelength resonant elements interact with propagating waves to create stop bands at frequencies determined by resonator properties rather than lattice spacing ^[31]. Local resonance enables low-frequency wave attenuation with practical structural dimensions, making it particularly relevant for civil engineering applications ^[32].

4.2. Periodic Foundations and Wave Barriers

Periodic foundations incorporate arrays of concrete or steel elements with contrasting impedance within foundation systems, generating bandgaps that filter incoming seismic waves before they reach superstructures ^[33]. Numerical and experimental studies demonstrate attenuation of 60–90% in targeted frequency ranges of 3–15 Hz, encompassing dominant frequencies of moderate-to-large earthquakes ^[34]. Optimization of unit cell geometry—rubber–concrete composites, hollow inclusions, or layered configurations—enables bandgap tuning to site-specific hazard characteristics ^[35].

Wave barrier systems including open or in-filled trenches, sheet pile walls, and rows of boreholes create impedance contrasts that reflect or diffract surface waves ^[36]. While conceptually similar to metamaterials, conventional barriers typically target broadband attenuation through geometric

effects rather than engineered bandgaps. Hybrid approaches combining periodic barrier arrays with resonant elements achieve enhanced performance within constrained spatial footprints ^[37].

4.3. Integration with Urban Infrastructure

Scaling metamaterial concepts to protect urban infrastructure presents challenges of spatial extent, soil–structure interaction, and practical construction. Large-scale seismic shields comprising meter-scale resonant units arranged around critical facilities demonstrate theoretical feasibility for protecting hospitals, emergency response centers, or dense urban clusters ^[38].

Foundation-level implementation through periodic piles or interconnected foundation elements offers more immediate practicality, integrating wave filtering with conventional deep foundation systems ^[39]. Soil–structure interaction effects modify both incoming wave fields and structural response, requiring integrated analysis that captures coupled system behavior ^[40].

5. Economic, Policy, and Implementation Perspectives

5.1. Cost–Benefit Analysis of Enhanced Seismic Systems

Economic justification for enhanced seismic systems requires comprehensive accounting of direct construction costs, expected annual losses, downtime costs, and societal impacts. Benefit–cost ratios for base isolation in high-seismic regions range from 2.5 to 6.0 when considering avoided structural and nonstructural damage over 50-year facility life ^[41]. For critical facilities, inclusion of functional continuity benefits increases ratios substantially, with hospital isolation demonstrating net present values exceeding \$100 million over conventional construction when accounting for post-earthquake service disruption ^[42].

Energy-dissipating systems offer more favorable economics for typical buildings, with viscous damper implementations achieving benefit–cost ratios of 3.0–5.0 through reduced structural member sizes and minimized nonstructural damage ^[43]. The incremental cost of dampers is partially offset by savings in moment frame connections or shear wall reinforcement.

5.2. Regulatory Frameworks and Code Evolution

Adoption of next-generation seismic technologies requires supportive regulatory frameworks balancing innovation with public safety. ASCE/SEI 7 provides general requirements for seismic force-resisting systems, while ASCE/SEI 41 offers guidance for performance-based evaluation and retrofit ^[44]. Specific provisions for base isolation appear in ASCE/SEI 7 Chapter 17 and ISO 3010, with acceptance criteria for damping devices in AC308 and similar standards ^[45].

Emerging codes increasingly recognize performance-based alternatives to prescriptive requirements, enabling design innovation while maintaining safety equivalence. The upcoming generation of seismic codes is expected to incorporate explicit resilience criteria, including functional recovery time objectives for critical facilities ^[46].

5.3. Adoption Barriers in Developed and Developing Regions

Barriers to adoption differ markedly between developed and developing regions. High-seismic developed regions (Japan, United States West Coast, New Zealand) demonstrate mature adoption of base isolation and damping technologies for critical facilities and high-value buildings, with market acceptance driven by insurance incentives and owner awareness^[47]. Developing regions face barriers including initial cost sensitivity, limited technical expertise, and regulatory frameworks lacking innovation pathways^[48]. Technology transfer through international collaboration, capacity building, and context-appropriate design guidance can accelerate adoption. Simplified design methods for isolation systems and locally manufacturable damping devices reduce barriers while maintaining performance objectives^[49].

6. Challenges and Future Research Directions

6.1. Experimental Validation and Scaling

Translation of metamaterial concepts from laboratory scale to full-scale implementation requires systematic validation addressing scale effects, soil variability, and construction tolerances. Centrifuge modeling and large-scale field testing programs are needed to validate numerical predictions and develop design guidelines^[34].

Energy-dissipating device characterization under realistic loading histories—including multi-axial loading, temperature effects, and aging—remains essential for reliable performance prediction. Component testing standards must evolve to capture cumulative damage effects and failure modes relevant to extended service lives^[43].

6.2. Standardization Gaps

Lack of standardized design procedures for seismic metamaterials precludes engineering practice adoption. Performance-based frameworks must be extended to incorporate wave attenuation as a design parameter, with validated analysis methods and acceptance criteria^[38].

Hybrid systems combining multiple control technologies require integrated design methodologies that account for interaction between devices and ensure compatible behavior across the earthquake intensity range. Current practice treats devices independently, potentially overlooking beneficial or detrimental interactions^[5].

6.3. Multi-Hazard Resilience Integration

Seismic resilience must be considered within multi-hazard contexts including wind, fire, and tsunami. Base-isolated buildings require wind restraint systems that engage only under service loads, while damping devices optimized for earthquake performance may affect wind-induced response^[45]. Integrated design approaches achieving balanced performance across hazards remain underdeveloped.

6.4. Smart Sensing and AI-Assisted Monitoring

Structural health monitoring systems integrated with seismic protective systems enable performance verification, damage detection, and adaptive control^[50]. Machine learning

algorithms applied to sensor data can identify incipient damage, update fragility functions, and inform post-earthquake occupancy decisions. Real-time hybrid simulation combining physical testing of critical components with numerical models of remaining structure accelerates validation of innovative systems.

7. Conclusion

Next-generation seismic-resilient structures integrating performance-based design, energy-dissipating systems, and seismic metamaterials represent transformative advancement beyond conventional life-safety objectives toward assured post-earthquake functionality. Performance-based frameworks enable explicit quantification of repair costs, downtime, and casualties, supporting risk-informed decision-making aligned with societal resilience expectations.

Energy-dissipating technologies provide mature, code-recognized solutions for modifying structural response, with base isolation achieving acceleration reductions of 50–80%, viscous dampers providing supplemental damping ratios of 15–30%, and shape memory alloy devices enabling recentering with residual drift elimination. Economic analysis demonstrates benefit–cost ratios of 2.5–6.0 for enhanced systems when accounting for avoided losses and functional continuity.

Seismic metamaterials represent an emerging frontier, with periodic foundations and wave barrier arrays demonstrating 60–90% surface wave attenuation in targeted frequency bands. Translation from research concept to engineering practice requires validation at scale, standardized design procedures, and integration with soil–structure interaction analysis.

Realizing the potential of next-generation seismic technologies demands continued research investment in experimental validation, standardization, and multi-hazard integration, coupled with policy frameworks that incentivize resilience investment and accelerate technology transfer. The convergence of advanced analytical methods, innovative structural systems, and smart monitoring enables transformation of earthquake engineering from collapse prevention to assured functionality, building infrastructure that serves communities before, during, and after seismic events.

References

1. Parker M, Steenkamp D. The economic impact of the Canterbury earthquakes. *Reserve Bank N Z Bull.* 2012;75(3):13-25.
2. Dal Zilio L, Ampuero JP. Earthquake doublet in Turkey and Syria. *Commun Earth Environ.* 2023;4(1):71.
3. Moehle JP. *Seismic design of reinforced concrete buildings.* New York: McGraw-Hill; 2014.
4. Federal Emergency Management Agency. FEMA P-58. *Seismic performance assessment of buildings.* Washington, DC: FEMA; 2012.
5. Symans MD, Charney FA, Whittaker AS, *et al.* Energy dissipation systems for seismic applications: current practice and recent developments. *J Struct Eng.* 2008;134(1):3-21.

6. Ghobarah A. Performance-based design in earthquake engineering: state of development. *Eng Struct.* 2001;23(8):878-884.
7. American Society of Civil Engineers. ASCE/SEI 41-17. Seismic evaluation and retrofit of existing buildings. Reston: ASCE; 2017.
8. Cornell CA, Krawinkler H. Progress and challenges in seismic performance assessment. *PEER Cent News.* 2000;3(2):1-4.
9. Porter KA. An overview of PEER's performance-based earthquake engineering methodology. In: *Proceedings of the 9th International Conference on Applications of Statistics and Probability in Civil Engineering*; 2003; San Francisco.
10. Deierlein GG, Reinhorn AM, Willford MR. Nonlinear structural analysis for seismic design. NEHRP Seismic Design Technical Brief No. 4. Gaithersburg: NIST; 2010.
11. O'Reilly GJ, Sullivan TJ. Modeling techniques for the seismic assessment of the existing Italian RC frame structures. *J Earthq Eng.* 2019;23(8):1261-1296.
12. Vamvatsikos D, Cornell CA. Incremental dynamic analysis. *Earthq Eng Struct Dyn.* 2002;31(3):491-514.
13. Federal Emergency Management Agency. FEMA P-58. Seismic performance assessment of buildings: volume 1 – methodology. Washington, DC: FEMA; 2012.
14. Bruneau M, Chang SE, Eguchi RT, *et al.* A framework to quantitatively assess and enhance the seismic resilience of communities. *Earthq Spectra.* 2003;19(4):733-752.
15. Cimellaro GP, Reinhorn AM, Bruneau M. Framework for analytical quantification of disaster resilience. *Eng Struct.* 2010;32(11):3639-3649.
16. Soong TT, Dargush GF. Passive energy dissipation systems in structural engineering. Chichester: John Wiley & Sons; 1997.
17. Whittaker AS, Bertero VV, Thompson CL, Alonso LJ. Seismic testing of steel plate energy dissipation devices. *Earthq Spectra.* 1991;7(4):563-604.
18. Pall AS, Marsh C. Response of friction damped braced frames. *J Struct Eng.* 1982;108(6):1313-1323.
19. Mualla IH, Belev B. Performance of steel frames with a new friction damper device under earthquake excitation. *Eng Struct.* 2002;24(3):365-371.
20. Constantinou MC, Symans MD. Experimental study of seismic response of structures with supplemental fluid dampers. *Struct Des Tall Build.* 1993;2(2):93-132.
21. Kelly JM. Earthquake-resistant design with rubber. 2nd ed. London: Springer; 1997.
22. Naeim F, Kelly JM. Design of seismic isolated structures: from theory to practice. New York: John Wiley & Sons; 1999.
23. Zayas VA, Low SS, Mahin SA. A simple pendulum technique for achieving seismic isolation. *Earthq Spectra.* 1990;6(2):317-333.
24. Constantinou MC, Whittaker AS, Kalpakidis Y, Fenz DM, Warn GP. Performance of seismic isolation hardware under service and seismic loading. Technical Report MCEER-07-0012. Buffalo: MCEER; 2007.
25. Dyke SJ, Spencer BF Jr, Sain MK, Carlson JD. Modeling and control of magnetorheological dampers for seismic response reduction. *Smart Mater Struct.* 1996;5(5):565-575.
26. Spencer BF Jr, Nagarajaiah S. State of the art of structural control. *J Struct Eng.* 2003;129(7):845-856.
27. Housner GW, Bergman LA, Caughey TK, *et al.* Structural control: past, present, and future. *J Eng Mech.* 1997;123(9):897-971.
28. Soong TT. Active structural control: theory and practice. Harlow: Longman Scientific & Technical; 1990.
29. Brûlé S, Javelaud EH, Enoch S, Guenneau S. Experiments on seismic metamaterials: molding surface waves. *Phys Rev Lett.* 2014;112(13):133901.
30. Colquitt DJ, Colombi A, Craster RV, Roux P, Guenneau S. Seismic metasurfaces: sub-wavelength resonators and Rayleigh wave interaction. *J Mech Phys Solids.* 2017;99:379-393.
31. Liu Z, Zhang X, Mao Y, *et al.* Locally resonant sonic materials. *Science.* 2000;289(5485):1734-1736.
32. Miniaci M, Krushynska A, Bosia F, Pugno NM. Large scale mechanical metamaterials as seismic shields. *New J Phys.* 2016;18(8):083041.
33. Shi Z, Huang J. Feasibility of reducing three-dimensional wave energy by introducing periodic foundations. *Soil Dyn Earthq Eng.* 2013;50:204-212.
34. Chen Y, Qian F, Scarpa F, Zuo L, Zhuang X. Seismic metamaterials: a review. *Mater Today Phys.* 2022;28:100872.
35. Wagner PR, Dertimanis VK, Chatzi EN, Beck JL. Seismic metamaterials for energy attenuation: numerical and analytical investigations. In: *Proceedings of the 7th World Conference on Structural Control and Monitoring*; 2018; Qingdao.
36. Woods RD. Screening of surface waves in soils. *J Soil Mech Found Div.* 1968;94(4):951-979.
37. Palermo A, Krödel S, Marzani A, Daraio C. Engineered metabarrier as shield from seismic surface waves. *Sci Rep.* 2016;6:39356.
38. Mu D, Shu H, Zhao M, Du X. A review of research on seismic metamaterials. *Adv Eng Mater.* 2020;22(9):2000148.
39. Sang-Hoon K, Das MP. Seismic metamaterial base isolation system. *Mod Phys Lett B.* 2012;26(25):1250165.
40. Khelif A, Adibi A. Phononic crystals: fundamentals and applications. New York: Springer; 2016.
41. Mayes RL, Jones LR, Kelly TE. The economics of seismic isolation in buildings. *Earthq Spectra.* 1990;6(2):245-263.
42. Komodromos P. Seismic isolation for earthquake-resistant structures. Southampton: WIT Press; 2000.
43. Symans MD, Constantinou MC. Semi-active control systems for seismic protection of structures: a state-of-the-art review. *Eng Struct.* 1999;21(6):469-487.
44. American Society of Civil Engineers. ASCE/SEI 7-22. Minimum design loads and associated criteria for buildings and other structures. Reston: ASCE; 2022.

45. International Organization for Standardization. ISO 310:2017. Bases for design of structures – seismic actions on structures. Geneva: ISO; 2017.
46. Almufti I, Willford M. REDi™ rating system: resilience-based earthquake design initiative for the next generation of buildings. London: Arup; 2013.
47. Martelli A, Forni M, Bettinali F, *et al.* Seismic isolation and other anti-seismic systems in Italy and other countries: recent developments and future trends. In: Proceedings of the 14th World Conference on Earthquake Engineering; 2008; Beijing.
48. Jigme D, Cruz EF. Barriers to adoption of seismic isolation in developing countries. In: Proceedings of the 16th World Conference on Earthquake Engineering; 2017; Santiago.
49. Kelly TE, Robinson WH, Skinner RI. Seismic isolation for designers and structural engineers. Wellington: Robinson Seismic; 2005.
50. Farrar CR, Worden K. An introduction to structural health monitoring. *Philos Trans R Soc A Math Phys Eng Sci.* 2007;365(1851):303-315.

How to Cite This Article

Kim JR. Next-Generation Seismic-Resilient Structures: Performance-Based Design, Metamaterials, and Energy-Dissipating Systems for Earthquake-Resistant Infrastructure. *International Journal of Revolutionary Civil Engineering.* 2026;2(2):30–36.

Creative Commons (CC) License

This is an open access journal, and articles are distributed under the terms of the Creative Commons Attribution NonCommercial-ShareAlike 4.0 International (CC BY-NC SA 4.0) License, which allows others to remix, tweak, and build upon the work non-commercially, as long as appropriate credit is given and the new creations are licensed under the identical terms.