

Performance-Based Seismic Design

Elide Nastri ^{1,*}  and Alessandro Pisapia ² ¹ Department of Civil Engineering, University of Salerno, 84084 Fisciano, Italy² Department of Engineering, Pegaso Telematic University, 80143 Napoli, Italy; alessandro.pisapia@unipegaso.it

* Correspondence: enastri@unisa.it

1. Introduction

The increasing complexity of modern structures, combined with the pressing demand for resilient and sustainable structures, has driven significant advancements in earthquake engineering. In this evolving landscape, Performance-Based Seismic Design (PBSD) has emerged as a pivotal methodology, allowing engineers to design structures based on targeted performance objectives rather than solely adhering to prescriptive code provisions. By leveraging advanced numerical simulations, experimental validations, and probabilistic assessments, PBSD provides a more refined evaluation of structural behavior under seismic loading, ensuring both safety and economic efficiency. This approach, now recognized in seismic design standards such as Eurocode 8 [1] and FEMA P-695 [2], provides a refined assessment of structural behaviors under earthquake loading, ensuring both safety and economic efficiency.

Unlike conventional force-based design approaches, which primarily focus on global strength and stiffness requirements, PBSD explicitly considers structural responses at various performance levels, such as immediate occupancy, life safety, and collapse prevention [3–8]. This approach enables engineers to optimize solutions based on specific project requirements, striking a balance between performance, cost-effectiveness, and resilience against seismic hazards. Over the past few decades, PBSD has been successfully applied to new constructions, the retrofitting of existing buildings, and various structural typologies, including reinforced concrete (RC) structures, steel moment-resisting frames (MRFs), masonry buildings, and hybrid systems [9–29]. The rapid advancements in nonlinear dynamic analysis, probabilistic methods, and innovative seismic protection technologies have expanded the applicability of PBSD across different structural systems and geographical regions [30–36]. Key innovations include the integration of energy dissipation devices, base isolation systems, advanced material modeling, and data-driven optimization techniques, all contributing to more reliable and adaptive seismic designs. Despite these advancements, significant challenges remain, particularly regarding the standardization of methodologies, computational efficiency, and the incorporation of uncertainties in seismic hazard assessments and structural modeling [37–40].

This Special Issue brings together contributions from researchers across the globe, offering a truly international perspective on the latest developments in PBSD. The authors, hailing from different research institutions and engineering firms worldwide, present new methodologies, computational techniques, and case studies that highlight the effectiveness of PBSD in improving seismic resilience. The published works address innovative seismic retrofitting strategies, the role of damping and energy dissipation mechanisms, the optimization of structural configurations, and the calibration of simplified design procedures. Through a combination of theoretical advancements and practical applications, this



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collection of studies offers valuable insights into the current state of performance-based seismic engineering and outlines future directions for research and implementation on a global scale.

2. An Overview of Published Papers

The contributions gathered in this Special Issue reflect the growing interest in Performance-Based Seismic Design (PBSD) as a comprehensive and adaptable approach to earthquake-resistant construction. The published studies showcase innovative methodologies, advanced numerical modeling, and experimental validations, with a focus on optimizing both new and existing structures to achieve predefined seismic performance levels. Covering a range of structural typologies—including reinforced concrete (RC) frames, steel moment-resisting frames (MRFs), hybrid systems, and cold-formed steel structures—these studies offer valuable insights into seismic retrofitting strategies, energy dissipation mechanisms, and the calibration of simplified design procedures.

A recurring theme across these contributions is the need for the seismic performance enhancement of existing buildings, particularly in highly seismic regions where outdated structures pose significant risks. Addressing this challenge, Meglio and Formisano propose an innovative cold-formed steel exoskeleton system as a lightweight yet highly effective retrofitting solution for RC multi-story buildings [41]. Their study introduces the Resisto 5.9 Tube system, which not only improves the seismic safety of vulnerable structures but also enhances their energy efficiency by integrating thermal insulation into the exoskeleton. Through nonlinear static analyses, the authors demonstrate a substantial increase in seismic performance, highlighting how external reinforcement strategies can provide cost-effective and minimally invasive retrofit solutions. This integrated approach aligns with contemporary trends in sustainable engineering, where seismic resilience and energy efficiency are pursued simultaneously.

Another significant research focus within this Special Issue is the development of advanced energy dissipation mechanisms. Bosco et al. introduce a refined design procedure for steel frames equipped with viscoelastic dampers, addressing a critical gap in the current literature [42]. While previous studies have established the efficacy of these passive control devices, their interaction with higher-mode vibrations has often been overlooked. The proposed methodology accounts for these effects, offering a more accurate prediction of internal forces in bracing systems. By validating their approach through nonlinear dynamic analysis, the authors provide a practical framework for improving the seismic response of steel moment-resisting frames (MRFs), ensuring both damage mitigation and post-earthquake functionality.

The simplification of PBSD methodologies is another key aspect explored in this collection of studies. Montuori et al. present a performance-based assessment framework aimed at streamlining seismic vulnerability evaluations for steel moment-resisting frames [43]. Their method leverages a trilinear non-dimensional pushover curve, allowing engineers to quickly assess the structural capacity without the need for computationally expensive nonlinear dynamic analyses. By validating their approach through comparisons with Incremental Dynamic Analysis (IDA) and Eurocode-based provisions, the authors highlight the high reliability and practical applicability of this simplified procedure. Such developments are crucial for large-scale seismic risk assessment, particularly in urban areas where the rapid screening of vulnerable structures is a priority.

Moving beyond traditional seismic-resistant systems, Tartaglia et al. explore the seismic performance of hybrid moment-resisting–eccentrically braced dual frames (MRF–EBF) equipped with detachable links [44]. By integrating dissipative fuses, these systems are designed to sustain severe earthquakes while facilitating post-earthquake reparability.

Through extensive pushover analyses, the study demonstrates how hybrid configurations enhance energy dissipation and structural redundancy, significantly reducing the likelihood of progressive collapse. The findings underscore the importance of modular and replaceable components in modern seismic engineering, reinforcing the concept of damage-tolerant structural design.

Finally, Sato and Kitagawa push the boundaries of cold-formed steel (CFS) structures, proposing a seismic design procedure for low-rise cold-formed steel special bolted moment frames (CFS-SBMFs) [45]. Their research addresses a long-standing limitation of CFS systems, traditionally restricted to single-story applications. By introducing a new moment connection detail and validating its seismic performance through full-scale cyclic testing, the authors expand the applicability of CFS-SBMFs to multi-story low-rise buildings. The study further employs FEMA P-695 methodologies to evaluate seismic design factors, ensuring compliance with international standards. The results provide compelling evidence for the potential of CFS structures in earthquake-resistant construction, particularly in industrial and lightweight residential applications.

The growing interest in Performance-Based Seismic Design (PBSD) is reflected in the increasing number of studies addressing its challenges and advancements. The research contributions gathered in this Special Issue demonstrate the relevance of this topic within the scientific community, as well as its critical role in shaping the future of earthquake engineering. The broad engagement of international researchers and the diversity of approaches confirm that PBSD remains an active and rapidly evolving field, with continuous developments in seismic assessment methodologies, innovative retrofitting solutions, and structural optimization techniques.

To ensure that this Editorial maintains a balanced and objective synthesis of the research presented, journal self-citations and author self-citations have been carefully monitored and kept within the strict 15% threshold recommended by COPE and indexing databases. The fact that these limitations have been met further underscores the wide-ranging interest in PBSD, as the referenced literature extends beyond the works included in this Special Issue, drawing from a broader global discourse on seismic resilience. This reinforces the notion that PBSD is not only a specialized research niche but rather a core subject of modern structural engineering, with direct implications for both academia and industry.

Collectively, these studies illustrate the versatility and effectiveness of PBSD across different structural systems and design scenarios. The integration of innovative retrofitting techniques, enhanced energy dissipation mechanisms, and streamlined performance assessment tools represents a significant step forward in earthquake engineering. Moreover, the international scope of these contributions highlights how PBSD principles are being adapted to diverse seismic contexts, construction practices, and regulatory frameworks worldwide. As the field continues to evolve, future research should focus on bridging the gap between numerical modeling and real-world implementation, refining uncertainty quantification techniques, and enhancing the resilience and sustainability of the built environment.

3. Conclusions and Future Perspectives

The research presented in this Special Issue underscores the fundamental role of Performance-Based Seismic Design (PBSD) in modern earthquake engineering, demonstrating its capacity to enhance structural resilience and optimize seismic safety strategies. The diversity of approaches explored—ranging from advanced retrofitting techniques to innovative energy dissipation systems and streamlined performance assessment methodologies—

reflects the increasing adoption of PBSD as a cornerstone in the design and evaluation of earthquake-resistant structures.

A critical aspect emerging from the studies included in this collection is the growing emphasis on probabilistic methodologies to account for the inherent uncertainties in seismic input and structural response. While deterministic approaches remain widely used, integrating risk-based assessment frameworks allows for a more precise evaluation of performance expectations under varying conditions, ultimately leading to more robust and reliable design solutions. Alongside this, the advancement of seismic retrofitting strategies is shaping new perspectives in structural resilience. The effectiveness of steel exoskeletons, viscoelastic dampers, and hybrid systems, as demonstrated in several contributions, highlights the importance of developing cost-effective, minimally invasive, and scalable intervention techniques that can be applied across different structural typologies, particularly in highly seismic regions where existing buildings often lack adequate protection.

Another promising research direction revolves around the optimization of dissipative connections and energy dissipation mechanisms. The introduction of detachable links and bolted moment connections represents a significant step forward in damage-tolerant design, enabling enhanced reparability and reduced post-earthquake downtime. These solutions, aimed at ensuring both structural integrity and ease of repair, align with contemporary trends in seismic engineering, where functionality and resilience must be balanced against cost-effectiveness and practicality.

As PBSD methodologies continue to evolve, the integration of experimental validation and advanced numerical simulations remains a crucial aspect of research. The combination of full-scale laboratory testing and high-fidelity computational modeling allows for the refinement and validation of innovative design strategies, bridging the gap between theoretical developments and real-world implementation. Future studies should further explore this synergy, leveraging multi-disciplinary collaboration to refine design frameworks and improve their applicability in engineering practice.

The findings presented in this Special Issue mark a significant step forward in the understanding and application of Performance-Based Seismic Design. By integrating innovative technologies, refined assessment methods, and enhanced computational tools, PBSD continues to solidify its role as a key approach in modern seismic engineering. The research contributions gathered here provide a valuable foundation for further investigations and practical applications, ultimately contributing to the development of a more resilient and sustainable built environment in the face of future seismic challenges.

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