SIVILTEK: Jurnal Teknik Sipil

Volume 1, Number 1 (2024), p. 8-15
Available online at:
https://ojs.ucp.ac.id/index.php/SIVILTEK/en/index

The Development of Performance-Based Seismic Structural Design Concepts in Indonesia: A Literature Review

Faradhiya Jinan Bastini[1]*, Abd Basit Amir[2], Fitri[3], Andi Hasri Tri Ulandari[4], Ira Suartika[5]
[1,2,3,4] **Universitas Cahaya Prima**
***Email:** faradhiyaa18@gmail.com

ARTICLE INFO
Article History
Received: 19-02-2024
Accepted: 26-02-2024

Keywords:
performance-based design, earthquake-resistant structures, nonlinear analysis, building resilience

ABSTRACT

Indonesia is situated in a region of high seismic activity; therefore, earthquake-resistant structural design constitutes a critical component of the national construction system. The conventional force-based design approach, which remains predominant in national standards, has inherent limitations in controlling damage levels and post-earthquake structural performance. In contrast, the concept of Performance-Based Seismic Design (PBSD) has evolved internationally as an approach that explicitly defines structural performance objectives. Although numerous studies in Indonesia have examined nonlinear analysis and building performance evaluation, integrated literature reviews addressing the development of PBSD concepts within the national context remain limited. This study aims to synthesize the development of performance-based seismic structural design and to identify its implications for enhancing building resilience in Indonesia. A qualitative approach was employed using a narrative literature review method covering national and international publications from 2000 to 2025, as well as relevant technical standard documents. The analysis was conducted through thematic categorization to map the evolution of conceptual frameworks, nonlinear analytical methods, and their integration into national regulations. The findings indicate that PBSD has evolved from a force-based approach toward performance- and displacement-based frameworks, supported by nonlinear analytical methods such as pushover analysis and nonlinear time history analysis. However, its implementation in Indonesia remains partial and requires strengthened regulatory frameworks as well as enhanced professional capacity. Systematic integration of PBSD has significant potential to improve safety, reduce damage risk, and strengthen the seismic resilience of building structures in the future.

INTRODUCTION

Indonesia is among the countries with the highest levels of seismic activity in the world, as it is located at the convergence of three major tectonic plates: the Indo-Australian, Eurasian, and Pacific plates. This geological setting results in a high frequency of earthquakes with the potential to cause significant damage to building infrastructure (BMKG, 2023). Data from the National Disaster Management Agency indicate that earthquakes have been among the disasters causing the greatest economic losses in Indonesia over the past decade (BNPB, 2023). Major seismic events in Aceh (2004), Yogyakarta (2006), Palu (2018), and Cianjur (2022) demonstrate that structural failure remains a serious concern within the national construction system.

In structural engineering practice in Indonesia, earthquake-resistant design generally continues to rely on force-based design principles as stipulated in SNI 1726 concerning Seismic Design Requirements for Building and Non-Building Structures (BSN, 2019). This approach emphasizes satisfying structural strength capacity against a specified design earthquake force. However, numerous studies have shown that force-based design has limitations in predicting actual structural performance during major seismic events, particularly in controlling damage levels and post-earthquake functionality (Priestley et al., 2007; Chopra, 2012).

In response to these limitations, the concept of Performance-Based Seismic Design (PBSD) has gained widespread international recognition. Recent studies further emphasize that PBSD has become a central framework in modern earthquake engineering because it enables engineers to explicitly control structural performance targets and improve infrastructure resilience under multiple hazard scenarios (Kazantzi & Vamvatsikos, 2015; Taylor et al., 2023). This approach extends beyond strength considerations by explicitly defining structural performance objectives, such as Immediate Occupancy, Life Safety, and Collapse Prevention (FEMA 356, 2000; ATC-40, 1996). Within this framework, structural performance is evaluated using nonlinear analytical methods, including pushover analysis and nonlinear time history analysis, which are increasingly applied in recent PBSD research and optimization studies (Buckley, 2025; Cheng et al., 2025).

In Indonesia, research on performance-based design has expanded over the past two decades, particularly in studies evaluating the seismic performance of existing buildings and reinforced concrete structures. For example, (Kurniawandy & Nakazawa, 2020) proposed a seismic index approach for evaluating existing buildings using pushover analysis, while several national studies have examined structural performance through nonlinear analysis methods. More recent research also highlights the growing application of nonlinear analysis in Indonesian structural engineering studies, including the evaluation of building performance using pushover and time history analysis methods (Aranta & Irawati, 2025; Rohman et al., 2025). Recent national studies also demonstrate the use of nonlinear time history analysis to evaluate seismic performance of multi-storey buildings in high seismic zones of Indonesia (Nurhidayatullah & Ardiyanto, 2025). These studies indicate that nonlinear performance evaluation is increasingly recognized as an important component of earthquake-resistant structural assessment in Indonesia.

Although the body of literature on performance-based design continues to grow, most studies are case-specific, focusing on particular building types such as reinforced concrete high-rise buildings or steel structures—without developing a comprehensive conceptual synthesis of PBSD evolution in Indonesia. Moreover, a considerable portion of the research emphasizes numerical analysis while overlooking regulatory dimensions, industry readiness, and implementation challenges within the national context. There remains a lack of studies that systematically summarize the conceptual, methodological, and implementation trajectories of performance-based design within a comprehensive literature review framework.

This condition reveals a gap in Indonesian civil engineering literature, underscoring the need for an integrated narrative review on the development of performance-based earthquake-resistant structural design concepts. Unlike previous studies that concentrate on a single case study or analytical method, this research develops a cross-study synthesis to identify conceptual evolution, analytical approaches, and their implications for the advancement of national design standards.

Accordingly, this study seeks to address the following questions: How has the concept of performance-based seismic structural design evolved within the civil engineering literature? How has this approach been applied in research and regulatory contexts in Indonesia? And what are its implications for enhancing the future resilience of building structures? The objective of this research is to develop a narrative synthesis of PBSD development in Indonesia and to formulate a conceptual framework that supports the strengthening of more adaptive and performance-oriented earthquake-resistant structural planning.

The novelty of this study lies in the development of a comprehensive synthesis of performance-based design concepts within the Indonesian context, integrating theoretical, methodological, and regulatory dimensions into a systematic analytical framework.

METHOD

This study employed a qualitative approach using a narrative literature review method to identify, analyze, and synthesize the development of Performance-Based Seismic Design (PBSD) concepts within the Indonesian context. This approach was selected because the research seeks to construct an integrated conceptual understanding of the evolution of PBSD theory, analytical methods, and regulatory implementation without undertaking direct field data collection. A narrative review enables a comprehensive exploration of the development of ideas and design practices within the civil engineering literature (Snyder, 2019).

The literature search was conducted up to December 2025 through national and international scientific databases, including Scopus, ScienceDirect, Google Scholar, as well as the Garuda and SINTA portals for accredited national journals. In addition, standard and regulatory documents such as SNI 1726:2019, FEMA 356 guidelines, ATC-40, and other technical references were examined as primary sources for understanding the performance-based design framework. The keywords employed included "performance-based seismic design," "pushover analysis," "nonlinear analysis," "desain berbasis kinerja," "struktur tahan gempa," and "SNI 1726." The search process utilized Boolean operators (AND, OR) to obtain relevant and up-to-date literature (Kitchenham, 2004).

The reviewed literature was limited to publications from 2000 to 2025 in order to capture the historical development of PBSD since its broader introduction through ATC-40 and FEMA 356, as well as its subsequent application in national research. The inclusion criteria comprised: (1) nationally and internationally indexed journal articles addressing performance-based seismic design; (2) books and technical guidelines serving as primary references for PBSD; (3) studies evaluating the application of nonlinear analyses such as pushover analysis and nonlinear time history analysis; and (4) publications in Indonesian and English. Articles that did not directly address structural performance evaluation or that focused solely on conventional elastic analysis were excluded from the selection process.

The selection procedure involved initial identification of literature, screening based on titles and abstracts, and comprehensive full-text review. Eligible sources were analyzed to identify patterns in conceptual development, analytical approaches employed, and their integration into regulatory frameworks and engineering practice in Indonesia. This process was undertaken to ensure the relevance and consistency of sources supporting the comprehensive conceptual synthesis.

Data analysis was conducted using thematic analysis by categorizing the literature into several principal themes, including the evolution of PBSD concepts, nonlinear analytical methods, integration into national standards, and implementation challenges in Indonesia (Thomas & Harden, 2008). The selected studies were grouped into these thematic categories based on their primary research focus, methodological approach, and contribution to PBSD development, enabling a systematic mapping of conceptual evolution and relationships among themes within the performance-based seismic design framework.

To enhance the credibility of the review, source triangulation was performed by comparing findings from international and national literature and by examining the consistency between theoretical concepts and regulatory practices in Indonesia. Interpretation was conducted reflectively and analytically to produce a synthesis that is not only descriptive but also critically evaluative of PBSD development within the national context.

Through this methodology, the study is expected to provide a comprehensive overview of the development of performance-based seismic structural design in Indonesia and to offer a conceptual foundation for strengthening future structural design standards and engineering practice.

RESULT AND DISCUSSION

The synthesis of the literature indicates that the development of Performance-Based Seismic Design (PBSD) has undergone significant evolution since its introduction in the late 1990s through the ATC-40 and FEMA 356 documents. The concept emerged in response to the limitations of conventional force-based design, which primarily ensures minimum strength capacity without explicitly controlling post-earthquake structural damage levels. International literature emphasizes that PBSD offers a more rational framework by explicitly defining measurable structural performance objectives under varying levels of seismic intensity (Priestley et al., 2007; Chopra, 2012).

In Indonesia, the development of this concept has become evident in academic research and the evaluation of existing buildings, particularly in reinforced concrete and mid- to high-rise structures. However, its implementation in national engineering practice remains largely confined to research contexts and has not yet been fully integrated into prevailing structural design standards.

Evolution of the Performance-Based Design Concept

The literature demonstrates that conventional force-based design exhibits limitations in predicting post-elastic structural behavior during major seismic events. PBSD addresses this shortcoming by defining explicit performance levels—such as Immediate Occupancy, Life Safety, and Collapse Prevention—associated with deformation limits or specific damage states of structural components (FEMA 356, 2000).

Subsequent developments reveal a shift toward displacement-based design approaches, which more accurately represent the inelastic response of structures (Priestley et al., 2007). This approach prioritizes deformation control rather than force control, thereby providing a more realistic assessment of structural ductility capacity. In the Indonesian context, several studies indicate that displacement-based approaches can produce more efficient and better-controlled designs compared to conventional methods, particularly for medium- to high-rise reinforced concrete buildings.

This conceptual evolution underscores that PBSD is not merely an analytical method, but a paradigm shift in defining the objectives of earthquake-resistant structural design—namely, minimizing losses and ensuring occupant safety.

Development of Nonlinear Analytical Methods

The implementation of PBSD is highly dependent on nonlinear analytical methods to realistically evaluate structural response. The literature identifies two primary methods widely employed: pushover analysis and nonlinear time history analysis. In Indonesia, pushover analysis has become the most commonly adopted approach in academic research due to its relative simplicity and computational efficiency.

The review findings indicate that pushover analysis is effective in identifying plastic hinge distribution and assessing global ductility capacity. However, it has limitations in representing complex dynamic responses. Consequently, nonlinear time history analysis is regarded as more accurate, as it simulates structural response using actual ground motion records, although it requires substantially greater computational resources (Chopra & Goel, 2002).

In Indonesia, the use of software platforms such as ETABS and SAP2000 for nonlinear analysis has become increasingly prevalent in academic settings. Nevertheless, the application of these methods in professional design practice remains limited due to constraints related to time, cost, and analytical complexity.

Integration into Regulation and Practice in Indonesia

Indonesia’s national standard, particularly SNI 1726:2019, continues to adopt a force-based design approach utilizing a response modification factor (R-factor) to approximate inelastic structural behavior (BSN, 2019). However, performance evaluation concepts have begun to be introduced through provisions for the assessment of existing buildings and the application of nonlinear analysis for essential facilities or high-risk structures.

The literature suggests that the integration of PBSD into national regulations remains partial and has not yet become the primary design framework for building structures. Key challenges include the lack of detailed technical guidelines, limited human resource readiness, and the need for harmonization with international best practices. This condition highlights a gap between conceptual developments at the academic level and regulatory implementation in professional engineering practice in Indonesia.

Implementation Challenges and Conceptual Synthesis

The synthesis reveals several challenges in implementing performance-based design in Indonesia, including limited availability of representative local ground motion records, the complexity of nonlinear analysis, and insufficient integration of PBSD into academic curricula and professional training. Additionally, higher analytical costs and extended design timelines often pose obstacles in commercially driven construction projects.

Conceptually, the development of PBSD in Indonesia can be understood as a transitional process from a force-based paradigm toward a more comprehensive performance-based framework. This transition requires integration across theoretical, methodological, and regulatory dimensions. The conceptual dimension reflects a shift in design philosophy; the methodological dimension involves the application of nonlinear analysis; and the regulatory dimension concerns the strengthening of national standards.

This synthesis affirms that performance-based earthquake-resistant structural design holds substantial potential to enhance building resilience in Indonesia. However, its successful implementation depends on more explicit regulatory support, strengthened professional capacity, and closer alignment between academic research and construction industry practice.

CONCLUSION

Based on the findings of the literature review, the development of performance-based seismic design concepts reflects a paradigm shift from force-based design approaches toward frameworks oriented to the achievement of explicit structural performance objectives. This concept has evolved through the establishment of defined performance levels such as Immediate Occupancy, Life Safety, and Collapse Prevention supported by displacement-based approaches and nonlinear analytical methods to more realistically represent inelastic structural behavior. This progression signifies a fundamental transformation in the objectives of earthquake-resistant structural planning: not merely ensuring minimum strength capacity, but also controlling damage levels and post-earthquake performance.

In the Indonesian context, the implementation of performance-based design remains gradual and is more extensively applied in academic research than in professional practice. National standards, including SNI 1726:2019, continue to be predominantly grounded in force-based design principles, although nonlinear analysis has begun to be introduced for the evaluation of specific building categories. The gap between international conceptual advancements and national regulatory frameworks highlights the need for strengthened technical guidelines, enhanced professional capacity, and closer harmonization between academic research and construction industry practice.

The implications of adopting performance-based design for the resilience of building structures in Indonesia are substantial. This approach enables more effective control of inelastic deformations, reduces the risk of collapse, and minimizes both structural and non-structural damage during major seismic events. With stronger integration into regulatory frameworks and design practice, performance-based design has the potential to enhance safety levels, reduce economic losses, and sustain building functionality after earthquakes. Therefore, the systematic development and implementation of PBSD represent a strategic step toward strengthening the resilience of building infrastructure in Indonesia.

REFERENCES

Applied Technology Council. (1996). ATC-40: Seismic evaluation and retrofit of concrete buildings. Applied Technology Council.

Aranta, S. D., & Irawati, I. S. (2025). Evaluasi Kinerja Struktur Pada Desain Struktural Gedung Rumah Sakit Dengan Metode Pushover. *Jurnal Permukiman*, *20*(1), 11–21. https://doi.org/10.31815/jp.2025.20.11-21

Badan Meteorologi, Klimatologi, dan Geofisika. (2023). Katalog gempa bumi signifikan dan merusak di Indonesia. BMKG.

Badan Nasional Penanggulangan Bencana. (2023). Data dan informasi bencana Indonesia 2022–2023. BNPB.

Badan Standardisasi Nasional. (2019). SNI 1726:2019 tata cara perencanaan ketahanan gempa untuk struktur bangunan gedung dan non gedung. BSN.

Buckley, N. W. (2025). Research on seismic structural optimization design based on performance-based design methods. *Ingegneria Sismica*, *42*, 1–18. https://doi.org/10.65102/is202511

Cheng, Y., Chen, Q., & Pang, W. (2025). Robust multi-objective optimization framework for performance-based seismic design of steel frame with energy dissipation system. *Frontiers in Built Environment*, *11*, 1617542. https://doi.org/10.3389/fbuil.2025.1617542

Chopra, A. K. (2012). Dynamics of structures: Theory and applications to earthquake engineering (4th ed.). Pearson Education.

Chopra, A. K., & Goel, R. K. (2002). A modal pushover analysis procedure for estimating seismic demands for buildings. Earthquake Engineering & Structural Dynamics, 31(3), 561–582. https://doi.org/10.1002/eqe.144

Federal Emergency Management Agency. (2000). FEMA 356: Prestandard and commentary for the seismic rehabilitation of buildings. FEMA.

Kazantzi, A. K., & Vamvatsikos, D. (2015). Intensity measure selection for vulnerability studies of building classes. *Earthquake Engineering & Structural Dynamics*, *44*(15), 2677–2694. https://doi.org/10.1002/eqe.2603

Kitchenham, B. (2004). Procedures for performing systematic reviews. Keele University Technical Report.

Kurniawandy, A., & Nakazawa, S. (2020). A Proposal of Seismic Index for Existing Buildings in Indonesia using Pushover Analysis. *Journal of Engineering & Technological Sciences*, *52*(3). https://doi.org/10.5614/j.eng.technol.sci.2020.52.3.2

Nurhidayatullah, E. F., & Ardiyanto, D. (2025). Seismic Performance Study of Multi-storey Building Structures with Nonlinear Time History Analysis Method. *Journal Of Civil Engineering Building And Transportation*, *9*(1), 62–79.

Priestley, M. J. N., Calvi, G. M., & Kowalsky, M. J. (2007). Displacement-based seismic design of structures. IUSS Press.

Rohman, R. K., Wibowo, R. G., & Afrianto, A. (2025). Seismic Evaluation of the Magetan DPRD Building in East Java, Indonesia Using Pushover Analysis. *Engineering, Technology & Applied Science Research*, *15*(5), 26423–26429.

Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. Journal of Business Research, 104, 333–339. https://doi.org/10.48084/etasr.12106

Taylor, M., Ridgley, N., & Clayton, P. (2023). Performance-based design in earthquake geotechnical engineering. I: Implementing Performance Based Design. *Proc. 2023 Australia and New Zealand Conference on Geomechanics*.

Thomas, J., & Harden, A. (2008). Methods for the thematic synthesis of qualitative research in systematic reviews. BMC Medical Research Methodology, 8(45), 1–10. https://doi.org/10.1186/1471-2288-8-45