UDC 699.841:624.042.7 DOI: 10.31650/2786-6696-2025-13-80-87

SEISMIC RESISTANCE OF LARGE-PANEL BUILDINGS IN SEISMIC REGIONS. RETROSPECTIVE ANALYSIS OF REGULATORY FRAMEWORK

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Abstract. The article presents an extensive retrospective analysis of the regulatory framework governing seismic-resistant design of large-panel buildings in seismic regions of Ukraine, spanning from early Soviet documents (PSP-101-51, SN 8-57) and subsequent SNiP regulations (II-A.12-62, II-12-69, II-7-81) to contemporary DBN V.1.1-12:2006 and DBN V.1.1-12:2014. The study's relevance stems from increased design seismic intensity in numerous regions following the implementation of ZSR-2004 maps, which necessitated reassessment of seismic resistance in buildings previously constructed without appropriate anti-seismic measures. The authors systematized key regulatory criteria (maximum building height and length, minimum requirements for joints and reinforcement, calculation methods) in a comparative table to demonstrate the trends of increasing requirements and transition from general recommendations to precise numerical limitations. A comprehensive, structured approach was applied, including documentary research, thematic analysis, and systematic grouping of regulatory requirements, which enabled establishing the relationship between the construction period of a large-panel building and its degree of compliance with current standards. The study demonstrates that the development of requirements has occurred in response to accumulated experience, technological advances, and international influences, resulting in modern calculation methods (spectral, nonlinear), detailed specifications for joints and reinforcement, and possibilities for seismic isolation implementation. The obtained results provide opportunities for direct integration into the methodology of visual assessment and certification of existing residential buildings, significantly optimizing the process of identifying potentially problematic structural elements and facilitating the development of scientifically substantiated solutions for strengthening load-bearing structures by engineers. Thus, the retrospective approach serves as a valuable tool for improving the efficiency of seismic resistance assessment, optimizing resources for building reinforcement, and enhancing regulatory documents in the field of seismic-resistant construction.

Keywords: seismic resistance, large-panel buildings, retrospective analysis, regulatory framework, seismic regions.

Introduction. Ensuring the seismic resistance of buildings has become increasingly critical in Ukraine's earthquake-prone regions, where recent seismic hazard reassessments have highlighted the vulnerability of existing housing stock [1-3]. During the Soviet era, particularly in the latter half of the 20th century, large-panel buildings were constructed en masse across what is now Ukraine, often without adequate consideration of seismic requirements. This oversight occurred because contemporary building codes, specifically SNiP II-A.12-62, mandated anti-seismic measures only for areas with design seismicity of 7 points or higher (clause 1.1 SNiP). Regions with lower seismicity ratings (such as 6 points) were generally deemed not to require special seismic provisions, though subsequent code revisions (SNiP II-7-81*) did introduce exceptions for critical structures built on weak soils, even in 6-point zones. The situation changed dramatically with the adoption of the ZSR-2004 general seismic zoning maps, which upgraded the seismic intensity by one point or more for numerous regions of Ukraine [4, 5]. Consequently, a substantial portion of existing large-panel building stock now falls within zones of elevated seismic hazard (6-9 points), necessitating compliance with earthquake-resistant construction standards.

Visual assessment methods for evaluating the seismic resistance of existing structures, especially large-panel buildings, is gaining considerable attention [2-3, 6]. Comprehensive assessment criteria have been explored in detail [7]. A particularly valuable tool in this assessment process would be a retrospective analysis of building codes, which reveals what standards were applicable during construction, highlights discrepancies with current requirements, and identifies potential structural vulnerabilities.

This paper presents a thorough retrospective examination of regulatory requirements specific to large-panel buildings in Ukraine's seismic zones, tracing their evolution from early Soviet-era documents (PSP-101-51, SN 8-57) through subsequent SNiP codes (II-A.12-62, II-12-69, II-7-81) to contemporary state building standards (DBN V.1.1-12:2006 [4], DBN V.1.1-12:2014 [5]).

The scientific novelty of this work lies in its systematic compilation of regulatory criteria and requirements that have evolved over several decades, along with the identification of both constant and evolving elements within the seismic resistance regulatory framework for large-panel buildings. This approach facilitates the integration of retrospective analysis into contemporary visual assessment and certification methodologies for Soviet-era buildings that were constructed without consideration of current seismic standards. As a result, engineers can develop more accurate and well-substantiated reinforcement recommendations. Through detailed comparative analysis of documents from different periods, we demonstrate how a large-panel building's construction date can serve as a reliable indicator of potential non-compliance with modern standards.

Analysis of research and publications. Retrospective regulatory analysis has proven valuable both internationally (FEMA 154 [8-13]) and domestically [1-3, 6]. Within the former USSR and modern Ukraine, building code evolution spans from the 1950s to today. The progression from PSP-101-51 and SN 8-57 through SNiP II-A.12-62, II-12-69, and II-7-81 to current standards DBN V.1.1-12:2006 [4] and DBN V.1.1-12:2014 [5] reveals a clear shift from broad guidelines to precise computational requirements. This evolution includes the introduction of seismic zoning maps and increasingly sophisticated analytical methods, including nonlinear static (pushover) and direct dynamic analyses. Similar retrospective studies have already been conducted for masonry structures [14-15].

Purpose of the study. This research aims to provide a comprehensive retrospective analysis of regulatory requirements for large-panel buildings in seismic zones, identify trends in requirement intensification, document changes in regional seismic classifications, and establish a methodological foundation for preliminary seismic resistance assessments of existing buildings.

Materials and research methodology. We identified and analyzed key regulatory documents (PSP-101-51, SN 8-57, SNiP II-A.12-62, SNiP II-12-69, SNiP II-7-81, DBN V.1.1-12:2006 [4], DBN V.1.1-12:2014 [5]) that governed large-panel building design in seismic regions. Using content analysis techniques, we extracted critical provisions from each document regarding large-panel buildings, including requirements for maximum height (story limits), building length, joint design and reinforcement, and calculation methods. We conducted targeted searches using relevant keywords and their parts ("large-panel", "panel walls", "prefabricated elements", "panel joints", etc.) to ensure comprehensive coverage. The findings were organized into a comparative table (Table 1). Subsequently, we analyzed evolutionary trends in regulatory requirements, examining which provisions became more detailed, which remained unchanged, and how these changes corresponded with the introduction of new analytical methods and updated seismic zoning maps.

Historical development of the regulatory framework. The evolution of seismic resistance requirements throughout the 20th and into the 21st century represents a continuous refinement process. Ukraine's regulatory framework developed within the Soviet system, drawing on construction experience from various seismically active USSR regions including the Caucasus, Central Asia, and the Far East. Initial anti-seismic construction rules emerged in the 1930s, prompted by earthquakes of 7-9 point intensity that drove the search for protective building solutions [3]. These early documents prioritized symmetrical floor plans and rigid horizontal and vertical connections, though computational methods remained rudimentary due to technological limitations.

The 1950s marked the introduction of systematic seismic design standards (PSP-101-51, SN 8-57). These underwent progressive refinement in subsequent SNiP codes, particularly II-A 12-62, II-A 12-69, and II-7-81, which increasingly incorporated international best practices and research institute findings. Following independence in 1991, Ukraine began adapting Soviet standards to national conditions, accounting for local geological characteristics. Current standards DBN V.1.1-12:2006 and V.1.1-12:2014 [4-5] incorporate the ZSR-2004 maps, which significantly increased seismic intensity ratings across large areas. This change has necessitated widespread reassessment of existing buildings, particularly large-panel structures.

Our analysis focused on key requirements including:

– Maximum height (story limits) for various seismic intensities.
– Maximum building length restrictions.
– Embedded element spacing in joints and minimum reinforcement cross-sections.
– Structural requirements for joints, anti-seismic belts, and reinforcement.
– Calculation methodologies.

It should be noted that this analysis specifically addresses codes applicable to Ukrainian territory (including the Soviet period) to develop a national methodology for visual seismic assessment. International standards are not explicitly addressed.

Research Results.

Maximum building height (large-panel walls):

●PSP-101-51 (~1951). This document established no specific height restrictions for large-panel buildings, as seismic design practices for panel construction remained undeveloped. The code emphasized general structural solutions and plan symmetry but stopped short of specifying formal story limits.

●SN 8-57 (1957). For 7-8 point seismicity zones, the code permitted large-panel buildings to reach heights comparable to those in non-seismic regions, imposing no direct restrictions. However, buildings in these zones still required reinforced joint grouting and adequate embedded hardware. In contrast, 9-point zones faced a recommended height limit of approximately 30 m (roughly 9-10 stories), with mandatory emphasis on joint reinforcement and increased building rigidity per clause 66 of SN 8-57.

●SNiP II-A.12-62 (1962). These standards maintained the permissive approach, imposing no additional height restrictions for large-panel buildings in 7, 8, or 9-point zones, effectively treating them like non-seismic areas in terms of height. Nevertheless, the code mandated enhanced monolithic joint behavior and vibration resistance, prioritizing calculation-based justification and verified connection strength over prescriptive height limits.

●SNiP II-12-69 (1969). This document marked a turning point by introducing explicit height limits: 39 m for 7-point zones, 30 m for 8-point zones, and 24 m for 9-point zones for large-panel buildings.

●SNiP II-7-81 (1981). The code further refined these restrictions, establishing height limits of 45 m (~14 stories) for 7-point zones, 39 m (~12 stories) for 8-point zones, and 30 m (~9 stories) for 9-point zones. These specifications not only provided greater clarity than previous standards but also coupled height restrictions with enhanced requirements for structural rigidity and joint monolithic behavior.

●DBN V.1.1-12:2006 (2006). Reflecting advances in construction technology and analysis methods, this code substantially increased allowable heights: 20 stories for 7-point zones, 16 stories for 8-point zones, and 10 stories for 9-point zones. Significantly, it also introduced provisions for exceeding these limits, provided projects included additional justification, experimental research, and scientific oversight.

●DBN V.1.1-12:2014 (2014). This revision retained the 2006 height restrictions unchanged: 20 stories for 7-point zones, 16 stories for 8-point zones, and 10 stories for 9-point zones, while maintaining flexibility for exceeding these limits under experimental construction programs.

Maximum building length:

●PSP-101-51 (~1951). The code imposed no specific length restrictions for large-panel buildings, treating this parameter as unregulated.

●SN 8-57 (1957) - SNiP II-A.12-62 (1962). Both codes maintained this permissive stance, allowing large-panel buildings to extend to lengths comparable to those in non-seismic regions without direct limitations. Instead of prescriptive length limits, these codes relied on ensuring adequate spatial structural behavior through proper spacing of embedded elements and comprehensive joint grouting.

●SNiP II-12-69 (1969). While continuing to allow lengths similar to non-seismic buildings, this code introduced the first absolute limit: structures could not exceed 150 m without being divided into separate sections, marking the beginning of length-based seismic design considerations.

●SNiP II-7-81 (1981), DBN V.1.1-12:2006 (2006), DBN V.1.1-12:2014 (2014). These later codes converged on more restrictive requirements, establishing maximum recommended lengths of 80 m for 7-8 point zones and 60 m for 9-point zones. This significant reduction from the earlier 150 m limit may reflect growing understanding that longer buildings experienced excessive horizontal deformations during earthquakes.

Frequency/minimum cross-section of joint connections:

●PSP-101-51 (~1951). The code remained silent on specific requirements for minimum cross-sections or embedded element frequency in large-panel building joints, providing only general anti-seismic guidance without addressing panel joint details.

●SN 8-57 (1957). This code introduced the first quantitative requirements: embedded elements in vertical and horizontal joints had to be spaced no more than 2 m apart for 7-8 point zones, with this spacing tightening to 1 m maximum for 9-point zones (clause 66, SN 8-57).

●SNiP II-A.12-62 (1962). Rather than specifying numerical requirements for embedded element frequency or connection cross-sections, this code took a performance-based approach, emphasizing joint monolithic behavior and minimization of weak joints to enhance overall seismic resistance.

●SNiP II-12-69 (1969). A critical advancement came with the introduction of minimum connection cross-section requirements: all seismic regions now required at least 1 cm^2/m of reinforcement area.

●SNiP II-7-81 (1981). The code introduced differentiated requirements based on building height and seismic intensity: buildings up to 5 stories in 7-8 point zones could use a reduced minimum of 0.5 cm^2/m, while all other configurations required the full 1 cm^2/m standard.

●DBN V.1.1-12:2006 (2006) – DBN V.1.1-12:2014 (2014). Both modern codes standardized requirements across all high-seismic zones, mandating a uniform minimum of 1 cm^2/m for 7, 8, and 9-point seismicity areas. This universal approach simplified design procedures while ensuring adequate reinforcement levels regardless of specific seismic intensity.

Structural requirements (panels, joints, diaphragms):

●PSP-101-51 (~1951). With panel construction in seismic regions still in its infancy, this code lacked specific requirements for large-panel systems and their joints. Design guidance focused solely on general anti-seismic principles: structural symmetry, rigidity, and spatial behavior.

●SN 8-57 (1957). The code began recommending specific construction practices: use of large panels combined with thoroughly grouted joints and embedded elements to achieve rigid connections between structural elements.

●SNiP II-A.12-62 (1962). This iteration prioritized achieving maximum joint monolithic behavior by minimizing the number of joints and increasing individual panel dimensions. This strategy effectively reduced stress concentrations at connections and improved structural reliability during seismic vibrations.

●SNiP II-12-69 (1969). The code introduced differentiated reinforcement requirements based on risk level: buildings up to 5 stories in 7-point zones could employ single reinforcement, while all other configurations, whether due to height or higher seismicity, required double reinforcement to ensure adequate spatial rigidity.

●SNiP II-7-81 (1981). Technical specifications became more detailed, recommending room-sized panels paired with ribbed joint surfaces, welded embedded elements, and monolithic seams, designed to maximize inter-element bonding strength.

● DBN V.1.1-12:2006 (2006) – DBN V.1.1-12:2014 (2014). Modern codes mandate comprehensive reinforcement strategies: double-sided wall panel reinforcement at minimum 0.025%, ribbed joint surfaces for improved bonding, grouting with reinforcement outlets, and strategic vertical reinforcement at corners and opening edges. This last requirement ensures optimal force distribution while preventing crack formation at stress concentration points.

Joint and panel connection reinforcement. Throughout the entire evolution of Soviet and Ukrainian building codes, detailed additional requirements specifically for corner reinforcement in seismic large-panel buildings never emerged. Consequently, general large-panel building design requirements governed these details across all periods. Early documents like SN 8-57 addressed corner reinforcement primarily in the context of masonry construction, offering only general joint grouting recommendations for large-panel structures. All subsequent codes – SNiP II-A.12-62, SNiP II-12-69, SNiP II-7-81, DBN V.1.1-12:2006, and DBN V.1.1-12:2014 – continued this pattern, treating corner reinforcement not as a distinct design element but as part of the broader goal of ensuring overall joint monolithic behavior and rigidity.

Calculation methods. The sophistication of analytical approaches evolved dramatically over the decades. Early regulatory documents (PSP-101-51, SN 8-57, SNiP II-12-69, SNiP II-7-81) relied exclusively on simplified static assessments, lacking the computational tools for complex dynamic modeling. As technology advanced, later codes progressively incorporated dynamic methods. Today's DBN standards (2006, 2014) represent the culmination of this evolution, mandating spectral, direct dynamic, and nonlinear static (pushover) calculation methods while requiring consideration of multiple earthquake intensity scenarios. These key developments are summarized in Table 1.

Analysis of obtained results. The evolutionary trajectory of the regulatory framework reveals a consistent pattern of progressive refinement and increasing specificity in seismic construction requirements. Early regulatory documents offered broad guidelines that granted engineers considerable interpretive flexibility, a necessity given limited computational capabilities and earthquake engineering knowledge.

The subsequent shift toward detailed, prescriptive requirements arose from three converging factors: accumulated field experience from actual earthquakes, implementation of sophisticated seismic zoning maps (particularly ZSR-2004), and dramatic advances in computational technology. This evolution fundamentally transformed how engineers approach seismic design.

The transformation of building height requirements exemplifies this progression perfectly. The 1950s documents offered only general recommendations without quantitative limits. By the 1980s, the codes established precise, numerically defined height restrictions directly tied to site-specific seismicity levels. This same evolutionary pattern characterizes structural requirements: vague recommendations for joint arrangements and connections gradually crystallized into exact technical specifications, including precise minimum reinforcement cross-sections and maximum embedded element spacing.

These regulatory changes directly reflected lessons learned from devastating earthquakes worldwide and the integration of international best practices in seismic construction. The adoption of spectral and nonlinear calculation methods demonstrates the profession's commitment to achieving more accurate predictions of structural behavior during seismic events. For large-panel buildings specifically, these advanced methods finally enabled engineers to conduct detailed analyses of joint behavior, panel interactions, and complex vibration modes accounting for three-dimensional structural response – capabilities that were simply unavailable to earlier generations of engineers. This historical perspective on regulatory evolution provides the essential context for evaluating the technical condition and certifying the seismic resistance of Ukraine's existing large-panel building inventory.

Table 1 – Comparative table of large-panel building design requirements.

Regulatory document	Max. height/stories				Max. building length	Frequency/min. cross-section of joint connections	Structural requirements (panels, joints)
PSP-101-51	Not specified for LP*				Not specified	Not mentioned	Not mentioned
SN 8-57	7-8 points			9 pts	ns	7-8 pts: embedded ≤2 m; 9 pts: ≤1 m	Use of large panels, grouted joints
	ns			30 m			
SNiP II-A 12-62	ns				ns	Not directly regulated, emphasis on monolithic behavior	Emphasis on monolithic behavior, minimum joints, increased panel size
SNiP II-A 12-69	7 pts	8 pts		9 pts	up to 150 m (for 7-8 points)	Introduced min. connection cross-section ≥ 1 cm^2/m	Double panel reinforcement (certain conditions for 7 points)
	39 m	30 m		24 m			
SNiP II-7-81	7 pts	8 pts		9 pts	Recommended ≤80 m at 7-8 pts ≤60 m at 9 pts	At ≤5 stories (7-8 points): ≥0.5 cm^2/m; other cases ≥1 cm^2/m	Room-sized panels, ribbed joint surfaces, welded embedded elements, monolithic seams
	45 m	39 m		30 m			
DBN V.1.1-12:2006	6 pts	7 pts	8 pts	9 pts	7-8 pts: ≤80 m; 9 pts: ≤60 m	Minimum 1 cm^2/m for 7,8,9 points	Double-sided reinforcement (≥0.025%), ribbed joints, vertical reinforcement at corners and opening edges
	ns	20 st.	16 st.	10 st.			
DBN V.1.1-12:2014	6 pts	7 pts	8 pts	9 pts	Same as DBN 2006: 7-8 pts ≤80 m, 9 pts ≤60 m	No change from 2006	Similar requirements plus emphasis on structural ductility, possibility of seismic isolation and nonlinear calculations
	ns	20 st.	16 st.	10 st.			

Note: ns – not specified for LP; st. – stories.

Conclusions.

1. This comprehensive retrospective analysis has systematically examined the evolution of regulatory requirements governing seismic resistance of large-panel buildings across Ukrainian territory, revealing a clear progression from general principles to specific, quantitative standards.

2. The research identifies consistent strengthening trends in regulatory requirements over seven

decades, with the most pronounced changes occurring in height and length restrictions, joint detailing specifications, and reinforcement requirements – each responding to accumulated earthquake damage observations and advances in structural engineering knowledge.

3. The analysis demonstrates that a building's construction year serves as a reliable proxy for its likely compliance with current seismic standards: structures built under early codes predictably exhibit specific deficiencies when evaluated against modern requirements, enabling targeted assessment and retrofit strategies.

4. These findings offer immediate practical value for structural engineers conducting seismic assessments and certifications of existing housing stock, while simultaneously establishing a methodological framework for developing more sophisticated seismic resistance evaluation protocols for Soviet-era large-panel buildings.

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СЕЙСМОСТІЙКІСТЬ ВЕЛИКОПАНЕЛЬНИХ БУДИНКІВ У СЕЙСМІЧНИХ РАЙОНАХ. РЕТРОСПЕКТИВНИЙ АНАЛІЗ НОРМАТИВНОЇ БАЗИ

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Анотація. У статті представлено розширений ретроспективний аналіз нормативної бази, що стосується обмежень до великопанельних будинків у сейсмічних районах України, починаючи від перших радянських документів (ПСП-101-51, СН 8-57) та подальших СНіП (II-А.12-62, II-12-69, II-7-81), до сучасних ДБН В.1.1-12:2006 і ДБН В.1.1-12:2014. Актуальність дослідження зумовлена підвищенням розрахункової сейсмічності значної кількості регіонів внаслідок впровадження карт ЗСР-2004, що призвело до необхідності оцінювання сейсмостійкості будинків, зведених без урахування відповідних антисейсмічних заходів. Систематизовано ключові критерії норм (максимальна висота та довжина будинку, мінімальні вимоги до стиків і армування, розрахункові методи), що розміщені у порівняльній таблиці, аби продемонструвати тенденції зміни вимог та переходу від загальних рекомендацій до точних кількісних обмежень. Застосовано підхід, що включає документальний пошук, аналіз та групування нормативних вимог, що дало змогу встановити залежність між датою будівництва великопанельного будинку та ступенем його відповідності чинним нормам. Продемонстровано, що тенденція розвитку вимог є реакцією на накопичений досвід, технологічний прогрес та міжнародний досвід, у результаті чого з'явилися сучасні методи розрахунку (нелінійний статичний, прямий динамічний), деталізовані обмеження до стиків та армування, а також можливості застосування сейсмоізоляції. Отримані результати надають можливість інтеграції у методологію візуального оцінювання та паспортизації існуючого житлового фонду, що суттєво спрощує процес ідентифікації потенційного дефіциту сейсмостійкості, як окремих конструктивних елементів, так і будівель в цілому, а також сприяє розробці рішень щодо їхнього підсилення. Таким чином, виконаний ретроспективний аналіз слугує корисним інструментом для підвищення ефективності оцінювання сейсмостійкості та є наступним кроком у розвитку нормативних документів у напрямку сейсмостійкого будівництва.

Ключові слова: сейсмостійкість, великопанельні будинки, ретроспективний аналіз, нормативна база, сейсмічні райони.

Стаття надійшла до редакції 11.07.2025
Стаття прийнята до друку 30.07.2025
Дата публікації статті 24.09.2025