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RESEARCH ARTICLE

MULTICOMPONENT SEISMIC ASSESSMENT OF A 16-STORY RC BUILDING IN ALMATY USING EUROCODE 8

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Abstract. *This study presents a numerical assessment of a 16-story cast-in-place concrete building in Almaty, Kazakhstan, under static and multi-component seismic actions in accordance with SP RK EN 1998-1:2004/2012 and SP RK 2.03-30-2017. A finite-element model was developed in LIRA-SAPR for a wall structural system with coupled shear walls on type IB soils. The analysis explicitly accounts for both horizontal and vertical earthquake components; modal responses are combined using the SRSS or CQC methods, considering more than 20 vibration modes along the X, Y, and Z axes ($a_g = 0.487$ g; $a_{vg} = 0.438$ g). The cumulative modal participation masses reach 89.8% in X and Y, indicating adequate capture of the dynamic response. Maximum interstory drifts are 5.5 mm (X) and 6.3 mm (Y), and roof displacements are 75 mm and 85 mm, respectively – within the relevant code limits. The building satisfies stability and seismic-resistance criteria; for structures higher than 12 stories in a 9-intensity seismic zone, the necessity of Special Technical Conditions (STU) is confirmed. The novelty lies in a practice-oriented implementation of Eurocode provisions adapted to Kazakhstan, with explicit treatment of the vertical component and multi-component spectral analysis, improving demand estimates and the applicability of results to high-rise design in seismically active regions.*

Keywords: *high-rise construction, seismic performance, multi-component seismic response, finite element method, LIRA-SAPR, Eurocode 8, Almaty*

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ҒЫЛЫМИ МАҚАЛА

ЕУРОКОД 8 НОРМАЛАРЫ БОЙЫНША АЛМАТЫДАҒЫ 16 ҚАБАТТЫ ТЕМІРБЕТОН ҒИМАРАТТЫ КӨПКОМПОНЕНТТІ СЕЙСМИКАЛЫҚ БАҒАЛАУ

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Аңдатпа. *Бұл зерттеуде ҚР ЕЖ EN 1998-1:2004/2012 и ҚР ЕЖ 2.03-30-2017 нормаларына сәйкес, Алматы қаласындағы 16 қабатты монолитті темірбетон ғимараттың статикалық және көпкомпонентті сейсмикалық әсерлер кезіндегі сандық бағалауы ұсынылған. IB санатындағы топырақта орналасқан, байланыстырылған қабырғалары бар қабырғалық тасымалдаушы жүйе үшін LIRA-SAPR бағдарламалық кешенінде ақырлы элементтер моделі әзірленді. Талдау барысында жер сілкінісінің көлденең және тік компоненттері нақты ескерілді; модальдық реакциялар X, Y және Z осьтері (a_g = 0.487 g; a_{vg} = 0.438 g) бойынша 20-дан астам тербеліс пішінін ескере отырып, SRSS немесе CQC әдістері арқылы біріктірілді. X және Y бағыттарындағы жиынтық модальдық массалар 89,8%-ға жетеді, бұл динамикалық реакцияның толыққанды қамтылғанын көрсетеді. Қабатаралық максималды ығысулар 5,5 мм (X) және 6,3 мм (Y) құрайды, ал шатырдың көлденең орын ауыстырулары сәйкесінше 75 мм және 85 мм-ге тең – бұл қолданыстағы нормалардың шектік талаптарынан аспайды. Ғимарат орнықтылық пен сейсмотұрақтылық критерийлерін қанағаттандырады; 9 балдық сейсмикалық аймақтағы 12 қабаттан асатын құрылыстар үшін Арнайы техникалық шарттарды (АТШ) әзірлеу қажеттілігі расталады. Зерттеудің ғылыми жаңалығы – Қазақстан жағдайына бейімделген Еурокод ережелерін практикаға бағыттап енгізуде, сондай-ақ сейсмикалық сұранысты бағалауды және нәтижелерді сейсмикалық белсенді өңірлердегі биік ғимараттарды жобалауда қолдануды жақсартатын тік компонент пен көпқұрамды спектралдық талдауды нақты ескеруінде жатыр.*

Түйін сөздер: *биік ғимарат, сейсмикалық төзімділік, көпқұрамды сейсмикалық жауап, ақырлы элементтер әдісі, LIRA-SAPR, Eurocode 8, Алматы*

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НАУЧНАЯ СТАТЬЯ

МНОГОКОМПОНЕНТНАЯ СЕЙСМИЧЕСКАЯ ОЦЕНКА 16-ЭТАЖНОГО ЖЕЛЕЗОБЕТОННОГО ЗДАНИЯ В АЛМАТЫ ПО НОРМАМ ЕВРОКОД 8

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Аннотация. *В данном исследовании представлена численная оценка 16-этажного монолитного железобетонного здания в г. Алматы при статических и многокомпонентных сейсмических воздействиях в соответствии с требованиями СП РК EN 1998-1:2004/2012 и СП РК 2.03-30-2017. В программном комплексе LIRA-SAPR разработана конечно-элементная модель стеновой несущей системы с сопряженными стенами на грунтах категории IB. В ходе анализа в явном виде учитываются как горизонтальные, так и вертикальная компоненты землетрясения; модальные реакции суммируются с использованием методов SRSS или CQC с учетом более 20 форм колебаний по осям X, Y и Z (*$a_g = 0.487$ g; $a_{vg} = 0.438$ g*). Суммарные модальные массы достигают 89,8 % в направлениях X и Y, что свидетельствует о достаточном учете динамического отклика. Максимальные межэтажные перекосы составляют 5,5 мм (X) и 6,3 мм (Y), а перемещения покрытия — 75 мм и 85 мм соответственно, что строго находится в пределах нормативных ограничений. Здание удовлетворяет критериям общей устойчивости и сейсмостойкости; при этом подтверждается необходимость разработки Специальных технических условий (СТУ) для сооружений высотой более 12 этажей в 9-балльной сейсмической зоне. Научная новизна заключается в практико-ориентированной реализации положений Еврокода, адаптированных для Казахстана, с явным учетом вертикальной компоненты и применением многокомпонентного спектрального анализа, что повышает точность оценки сейсмического спроса и надежность проектирования высотных зданий в сейсмоактивных регионах.*

Ключевые слова: *высотное строительство, сейсмостойкость, многокомпонентный сейсмический отклик, метод конечных элементов, LIRA-SAPR, Eurocode 8, Алматы*

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CONFLICT OF INTEREST

The authors state that there is no conflict of interest.

During the preparation of this manuscript, the authors used artificial intelligence tools (ChatGPT) solely for editorial assistance, such as improving phrasing and checking grammar, spelling, and punctuation. All ideas, interpretations, and conclusions are the responsibility of the authors, who take full accountability for the content of the article.

АЛҒЫС / ҚАРЖЫЛАНДЫРУ КӨЗІ

Зерттеу Қазақстан Республикасы Ғылым және жоғары білім министрлігі Ғылым комитетінің № BR24992865 гранттық қаржыландыруы шеңберінде жүргізілді.

МҮДДЕЛЕР ҚАҚТЫҒЫСЫ

Авторлар мүдделер қақтығысы жоқ деп мәлімдейді.

Мақаланы дайындау барысында авторлар жасанды интеллект құралдарын (ChatGPT) тек редакциялық көмек мақсатында пайдаланды: тұжырымдарды жетілдіру, грамматикалық, орфографиялық және тыныс белгілеріндегі қателерді тексеру үшін. Барлық идеялар, интерпретациялар мен қорытындылар авторларға тиесілі, және олар мақаланың мазмұнына толық жауапты.

БЛАГОДАРНОСТИ/ИСТОЧНИК ФИНАНСИРОВАНИЯ

Исследование выполнено в рамках грантового финансирования Комитета науки Министерства науки и высшего образования Республики Казахстан (грант № BR24992865).

КОНФЛИКТ ИНТЕРЕСОВ

Авторы заявляют, что конфликта интересов нет.

При подготовке данной рукописи авторы использовали инструменты искусственного интеллекта (ChatGPT) исключительно для редакторской помощи, такой как улучшение формулировок и проверка грамматики, орфографии и пунктуации. Все идеи, интерпретации и выводы являются ответственностью авторов, которые несут полную ответственность за содержание статьи.

1 INTRODUCTION

A sequence of high-impact earthquakes since 2020 has exposed persistent vulnerabilities in the global building stock and reinforced the need for modern, model-based seismic design. The 6 February 2023 Türkiye-Syria earthquakes revealed systemic weaknesses–soft/weak stories, poor confinement and joint detailing, irregularities, and unsecured nonstructural components–while also providing counter-examples where contemporary engineering and quality control delivered robust performance (Earthquake Engineering Research Institute [EERI] & Geotechnical Extreme Events Reconnaissance [GEER], 2023; U.S. Geological Survey, 2023). Reconnaissance syntheses documented strong shaking, widespread geotechnical effects (liquefaction, landslides), and highly variable building performance, including in critical facilities **(EERI & GEER, 2023).**

In 2024, the M7.4 Hualien (Taiwan) event again showed how updated codes, construction control, and preparedness can limit collapses and speed restoration despite landslides and infrastructure disruption **(EERI, 2024; National Center for Research on Earthquake Engineering [NCREE], 2024)**. The 8 September 2023 Al-Haouz (Morocco) earthquake further highlighted disproportionate risk for adobe/earthen and unreinforced masonry typologies with weak diaphragms and connections, underscoring the need for targeted retrofit strategies in heritage and rural contexts **(EERI, 2023; OCHA, 2023)**.

In parallel, standards and guidance have evolved. FEMA P-2090/NIST SP-1254 introduced the functional-recovery objective–moving beyond life-safety toward timely reoccupancy and continuity of key functions–and emphasized explicit treatment of multi-component shaking and nonstructural systems **(FEMA & NIST, 2021)**. ASCE 7-22 updated provisions for vertical ground motion, cementing practice where three-component input, rational spectrum matching, and expanded performance checks are expected for taller, irregular, or risk-critical buildings **(ASCE, 2022; Structural Engineers Association of Utah, 2024)**. Europe is rolling out the second-generation Eurocodes; EN 1998-1-1:2024 (EC8) refreshes the framework for seismic action, analysis methods, and nationally determined parameters, with complementary parts forthcoming **(British Standards Institution, 2024; Joint Research Centre, 2025)**. These shifts align with recent research on near-fault directivity, vertical motion effects, and validated selection/scaling protocols that can materially alter drifts, shear demands, and nonstructural performance in high-rise wall systems.

Evidence from the 2023 Türkiye events also informs expectations for critical facilities: multiple base-isolated hospitals (primarily using friction-pendulum bearings) generally remained functional or rapidly functional, contrasting with damage-impaired operation in some fixed-base facilities; this pattern supports wider adoption of isolation/damping for essential buildings in high-hazard regions **(Qu et al., 2023; Galasso et al., 2024; EERI Lifelines Program, 2023).**

Against this global backdrop, Almaty's design seismicity (up to MSK-64 intensity 9) and the growing share of high-rise construction require verifiable, conservative modeling. In this study, we adopt a practice-oriented strategy for a 16-story cast-in-place wall system: three-component input (including vertical motion), modal sufficiency checks, SRSS/CQC spectral combinations, and results are interpreted against both ultimate limit states and serviceability/functional targets, consistent with the guidance above.

The regulatory framework for construction in Kazakhstan is currently undergoing significant modernization. The newly developed Draft Construction Code aims to consolidate existing regulatory acts, implement digital platforms (such as "single-window" systems), and, most importantly, enhance structural safety requirements for buildings in seismically active zones. **(Government of the Republic of Kazakhstan, 2025; Zakon.kz, 2025)**. We recommend that the implementing rules: (i) harmonize with second-generation EC8 on multi-component analysis, vertical seismic effects, and limit-state criteria; (ii) incorporate functional-recovery objectives for higher-importance facilities (by analogy with FEMA/NIST); (iii) require explicit modeling and anchorage of nonstructural components; (iv) set clear triggers for three-component nonlinear response history analysis and soil – structure interaction in intensity-9 regions and for irregular/tall buildings; and (v) formalize pathways that incentivize seismic isolation and supplemental damping in essential infrastructure. Novelty and contributions. This study advances the regional state of practice for high-rise RC buildings in Almaty by moving beyond conventional horizontal-only, linear-elastic, spectrum-based checks toward a fully three-component, practice-oriented dynamic assessment with explicit treatment of vertical ground motion, torsional irregularity, P-Δ effects. In contrast to earlier local works that typically (i) apply modal response spectrum analysis with horizontal components only, (ii) do not report floor accelerations governing nonstructural performance, and (iii) focus solely on life-safety criteria, our framework introduces functional-recovery–relevant response metrics (interstory drift, residual drift, and floor acceleration proxies), and aligns the interpretation of demands with the second-generation Eurocode 8 and current international guidance.

Concretely, the contributions are:

Explicit vertical-motion demand in a high-rise wall system for Almaty. We quantify how including the Z-component alters drifts, shear forces, and floor accelerations relative to horizontal only models – an aspect rarely treated in regional case studies but critical for slab-column systems and nonstructural components.

The analysis employs a transparent, reproducible workflow (selection, scaling, SRSS/CQC combinations, modal mass participation targets), providing an auditable bridge between design verification and performance evaluation for tall buildings in a 9-intensity zone.

Functional-performance perspective for essential occupancy. Beyond ultimate limit states, we report serviceability/operational indicators (story-drift envelopes, peak floor accelerations as NSC proxies, qualitative residual-drift checks), enabling discussion of rapid reoccupancy and continuity of service scenarios that prior local works do not address.

Sensitivity to near-fault pulse-like effects and torsion. We document how pulse-period compatibility and plan-irregularity/torsional participation influence response concentration in a coupled-wall system – extending earlier regional analyses that did not interrogate these drivers in multi-component input.

Regulatory integration specific to Kazakhstan. The results are interpreted against the Kazakhstan adaptations of Eurocodes and the current Draft Construction Code trajectory, with actionable thresholds (e.g., triggers for NLTHA, soil-structure interaction, and consideration of isolation/damping for critical facilities) tailored to Almaty’s 9-intensity context.

Transparent reproducibility and design implications. We provide a clearly specified analysis stack (software versioning, model idealizations, boundary conditions, load cases, and acceptance checks) so that practitioners can replicate the workflow and adopt it as a verification layer in high-rise projects.

How this differs from prior works. Prior regional studies predominantly: (a) rely on horizontal-only response-spectrum analysis; (b) omit vertical-motion effects and do not report floor accelerations linked to nonstructural damage/operability; (c) evaluate solely life-safety; and (d) do not align results with the emerging second-generation EC8 and functional-recovery agenda. Our work addresses all four gaps in a single, reproducible framework and demonstrates their design significance for a representative 16-story RC wall system in Almaty.

2 MATERIALS AND METHODS

Modern seismic design of reinforced concrete (RC) buildings increasingly emphasizes performance-based workflows and the explicit consideration of multi-component ground motions. The transition to the second-generation Eurocodes (EN 1998-1-1:2024) and updated international standards (ASCE 7-22) mandates a more rigorous analysis of vertical ground motion (VGM) and near-fault effects, particularly for high-rise and irregular structures.

Recent international research highlights the criticality of these factors. It has been demonstrated that VGM significantly amplifies axial forces in vertical elements and floor accelerations, which are often underestimated in conventional horizontal-only analyses **(Tian et al., 2020; Xiang et al., 2022)**. Furthermore, comparative assessments have shown that near-field pulse-like motions can shift the plastic hinge formation mechanism in high-rise buildings **(Wang et al., 2024; Zhang et al., 2025)**, necessitating advanced spectral scaling methods **(Hasanoğlu et al., 2024).**

In the specific context of Kazakhstan and the seismically active Almaty region, the adoption of Eurocode-aligned standards has prompted a comprehensive re-evaluation of design practices. An analysis of the correlation between the number of storeys and seismic resistance in Almaty's monolithic buildings emphasized the non-linear increase in seismic demand for structures exceeding 12 floors **(Tuleyev et al., 2024)**. The dynamic characteristics of such frames under the localized adaptation of Eurocodes were further investigated, identifying discrepancies between normative periods and numerical model results that suggest the need for more refined stiffness assumptions in regional models **(Abakarov et al., 2017)**.

The geotechnical complexity of Almaty, particularly on Type IB soils, requires robust soil-structure interaction modeling. A comparison of Mohr-Coulomb and Hardening Soil Small (HSS) models concluded that advanced soil constitutive models are essential for accurate deformation prediction in this region **(Shadkam et al., 2024)**. This aligns with findings regarding foundation design features for high-rise structures in thick sedimentary basins **(Kuanyshbay & Aubakirova, 2024)**.

Additionally, the importance of precise deformation control during the operational phase is underscored by long-term monitoring studies in seismic regions **(Kirgizbayeva et al., 2025)**. Despite this progress, few studies have integrated these local findings with a full multi-component spectral analysis for high-rise wall systems. This paper addresses this deficit by modeling a 16-story building with explicit consideration of vertical excitation (Z-component) and determining the necessity of Special Technical Conditions (STU) for such projects.

3 MATERIALS AND METHODS

3.1 Initial Data and Computational Model

The LIRA-SAPR software package was used for modeling, as it is one of the most precise tools for performing calculations using the finite element method (FEM). Numerical analysis was performed with LIRA-SAPR (LIRALAND Group, Kyiv, Ukraine). Copyright © LIRALAND Group; official copyright certificates are available online (LIRALAND Group, 2024). The finite element method allows for a detailed analysis of structural behavior by breaking it down into multiple small elements, significantly improving the accuracy of deformation and stress calculations.

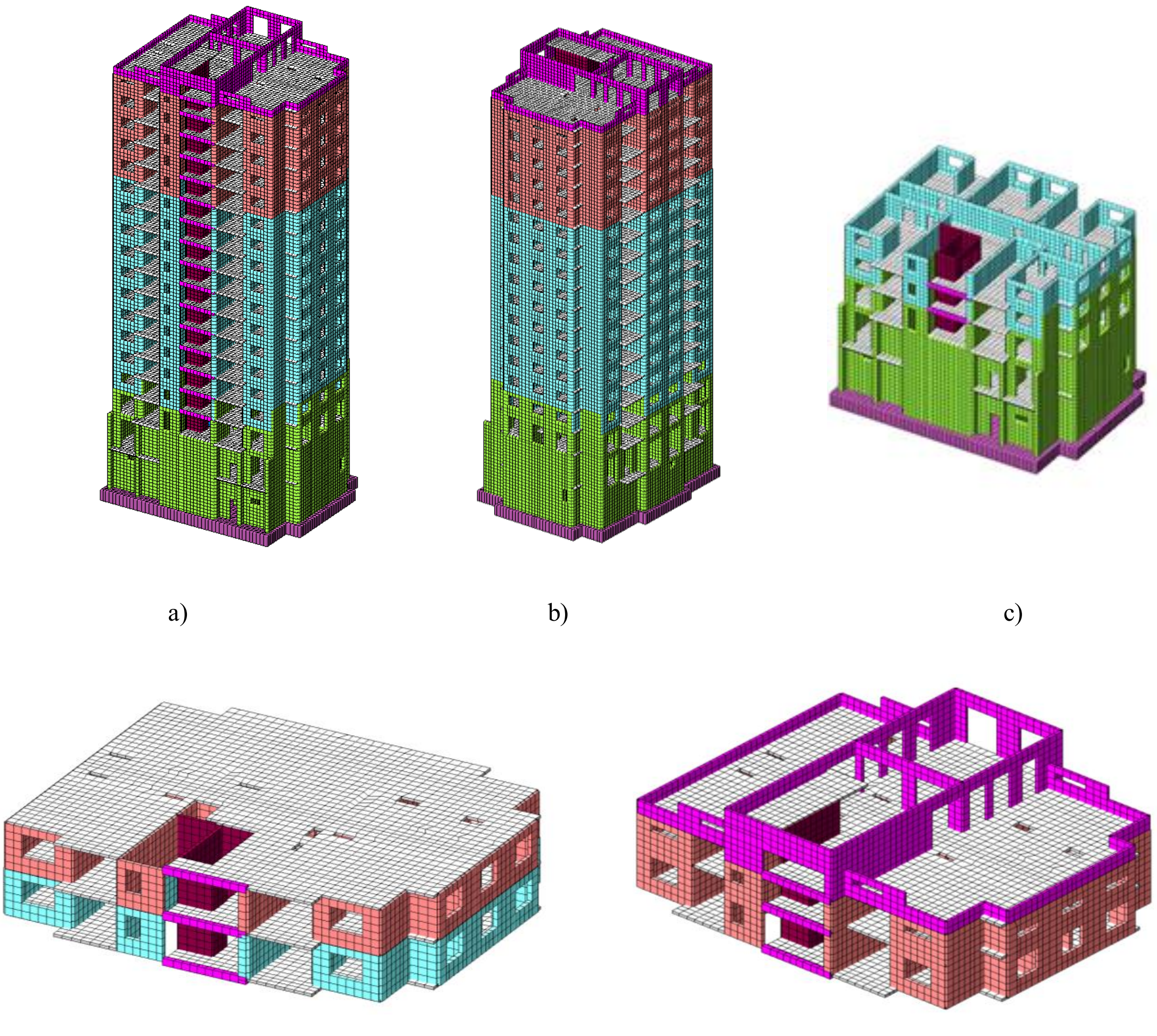
For this study, a computational model of a multi-story building was created. The building is a 16-story monolithic reinforced concrete frame structure with plan dimensions of 20.4 × 25.6 meters. The height of a standard floor is 3.3 meters, which is a typical height for residential buildings. The first floor, designated for commercial use, has a height of 5.4 meters. The structural scheme includes columns, slabs, beams, and walls, which were modeled as individual finite elements.

In the LIRA-SAPR computational model, the load-bearing monolithic walls and floor slabs were represented as finite flat plate elements. This allowed for a detailed distribution of loads across all structural elements, as well as the consideration of their interaction.

The computational mesh was constructed with consideration of all geometric and structural features of the building. The mesh step was selected to ensure sufficient accuracy in deformation modeling without significantly increasing computation time. For wall and slab elements, an optimal mesh step was used to account for local deformations that may arise under static and dynamic loads.

According to NTP RK 08-01.3-2012, the structural system of the studied building is classified as a wall system, formed predominantly by coupled walls in both primary directions. The structural system of the studied building was classified according to the definitions and provisions of SP RK EN 1998-1:2004/2012. Based on this standard, a wall system is defined as a structural system in which vertical and horizontal loads are primarily resisted by vertical coupled or uncoupled walls, provided that their shear resistance at the base exceeds 65% of the total shear resistance of the entire structural system. Within this context, a coupled wall refers to an element consisting of two or more walls connected into a single unit by sufficiently ductile coupling beams. These beams must be capable of reducing the total bending moment at the base by at least 25% compared to the separate, independent action of these walls. If the majority of the total wall shear resistance is provided by coupled walls, the entire structural system can be considered a coupled wall system.

As shown in **Figure 1** (a-e), the developed 3D computational model accurately captures the spatial geometry and load-bearing layout of the structure. Specifically, Figure 1 (a, b) illustrates the full elevation of the building, highlighting the vertical continuity of the shear walls across different height zones. Furthermore, the detailed structural cutaway views presented in Figure 1 (c, d, e) demonstrate the internal arrangement of the floor slabs, structural openings, and the central stiffening core, which provides the primary lateral rigidity of the building under seismic actions.



a) b) c)

d) e)

Figure 1 – General Views of the Computational Model (a, b, c, d, e) (author's material)

3.2 Load Assignment

The calculation considered permanent and variable loads, as well as seismic impacts, applied using a multicomponent analysis. Permanent loads included the self-weight of the building, the weight of engineering systems, partitions, and finishing materials, all of which were modeled as uniformly distributed across the structural elements. Variable actions, specifically climatic snow and wind loads, were defined in accordance with SP RK EN 1991-1-3 /-1-4 and the National Annex NTP RK 01-01-3.1(4.1)-2017. For snow loads, Almaty falls within Snow Region II, corresponding to a characteristic ground snow load of sk = 1.20 kPa. Regarding wind actions, the site is classified under

Wind Region II, which is characterized by a basic wind velocity vb = 25 m/s and a normative wind pressure of $w_0 \approx 0.39$ at a height of 10 meters.

These values are consistent with the Kazakh implementation of Eurocode 1 and are explicitly documented in approved project materials for Almaty **(CEN, 2003; CEN, 2005; Republic of Kazakhstan, 2017; CYPE, 2024; MOST Project LLP, 2022)**. Accordingly, this study adopts $s_k = 1.20$ kPa and $w_0 \approx 0.39$ kPa for the numerical model.

Climate Change Considerations (2025–2035): While current design maps remain the governing standard, the analysis considers long-term climatic trends. IPCC AR6 assessments indicate a continuing decline in seasonal snow duration across much of Asia and decreases in mean surface wind speeds over Central and Northern Asia, alongside increases in heavy precipitation events **(IPCC, 2021; IPCC, 2022)**. On a decadal horizon to ~2035, differences among emissions pathways are comparatively modest for these metrics. While Kazakhstan's Strategy on Achieving Carbon Neutrality by 2060 represents an important mitigation pathway **(Government of the Republic of Kazakhstan, 2024)**, it does not currently necessitate a revision of design maps. Therefore, current normative snow and wind maps remain governing until formally updated. However, engineering practice should incorporate robust sensitivity checks – e.g., wet-snow/rain-on-snow episodes, exceptional snow drifts at roof discontinuities, and site-specific wind evaluations for tall/irregular buildings. Recent regional studies documenting declining snow depth in Central Asia (~20% over multi-decadal periods) reinforce the validity of using current code values as a conservative baseline **(Fallah et al., 2024; Global Cryosphere Watch, 2024)**.

Seismic Impact Parameters. The computational model incorporated 20 vibration modes in each orthogonal direction (X, Y, Z) to fully account for multi-component seismic effects. The design parameters were defined as follows:

- Design Horizontal Acceleration: $a_g = 0.487g$.
- Design Vertical Acceleration: $a_{vg} = 0.438g$.
- Seismic Hazard: The construction site is located in a zone with a seismic intensity of 9 points on the MSK-64(K) scale. According to the probabilistic seismic hazard maps (OSZ-1-475 and OSZ-1-2475) referenced in Appendices A and B of NTP RK 08-01.1-2017, the reference peak ground accelerations on rock are a_{gR} (475) = 0.38g and a_{gR} (2475) = 0.73g.
- Soil Conditions: The site soil is classified as Type IB according to Table 3.1 of NTP RK 08-01.1-2017.

Given these complex soil conditions, proper foundation design is crucial for high-rise stability, necessitating specific calculation methods adapted for Almaty's geology **(Kuanyshbay & Aubakirova, 2024).** Furthermore, to accurately capture soil-structure interaction, advanced constitutive models (such as Hardening Soil Small) are increasingly preferred over traditional Mohr-Coulomb models to predict seismic deformations more reliably **(Shadkam et al., 2024)**.

For construction sites with Type IB soil, the design horizontal acceleration ag (in fractions of g) should be no less than $a_g = 0.487$ (see Appendix B of NTP RK 08-01.1-2017), and the design vertical acceleration avg (in fractions of g) should be no less than avg = 0.438 (where avg = 0.9·ag, see Table 4.7 of NTP RK 08-01.1-2017).

The design load combinations were generated in accordance with the provisions of SP RK EN 1990:2002+A1:2005/2011 «Basis of Structural Design» taking into account the National Annex.

For the analysis of Ultimate Limit States (ULS), the fundamental combination of actions was defined using expression (6.10b), with specific partial factors adopted for different types of actions. A factor of 1.35 was applied to permanent actions, which included the self-weight of structural members, the weight of finishing layers, and lateral earth pressure. Meanwhile, a factor of 1.50 was used for variable actions, encompassing imposed loads for Category A (residential areas) and Category H (roofs), as well as snow loads. Seismic actions along the X, Y, and Z axes, including torsion, were considered as reversible (sign-variable) loads with a partial factor of 1.0 within the seismic design situations. In the formation of seismic combinations, variable loads were reduced using quasi-permanent combination factors in compliance with Eurocode 8 requirements. The importance factor for the structure was set to 1.0 for all combination types.

3.3 Modal Analysis

Modal analysis allows for the determination of the natural frequencies and mode shapes of a structure. These frequencies are essential for assessing the dynamic behavior of a building, as they indicate how the structure will respond to seismic loads. The components of the horizontal design seismic impact are applied along the two principal horizontal directions of the buildings. For buildings whose load-bearing structures are oriented in orthogonal horizontal directions and whose mode shapes correspond to these directions, these two directions should be considered as the principal ones.

In this study, more than 20 vibration modes were analyzed for each direction, providing a comprehensive understanding of the building's dynamic behavior during an earthquake (Figure 2). As illustrated in **Figure 2**, the visualization of the model in the oscillation state demonstrates the global sway mechanism of the structural system. The deformed shapes confirm that the fundamental vibration modes are predominantly translational along the principal orthogonal axes. This indicates a regular distribution of mass and stiffness throughout the building's height, effectively minimizing adverse torsional effects during the initial stages of seismic excitation.

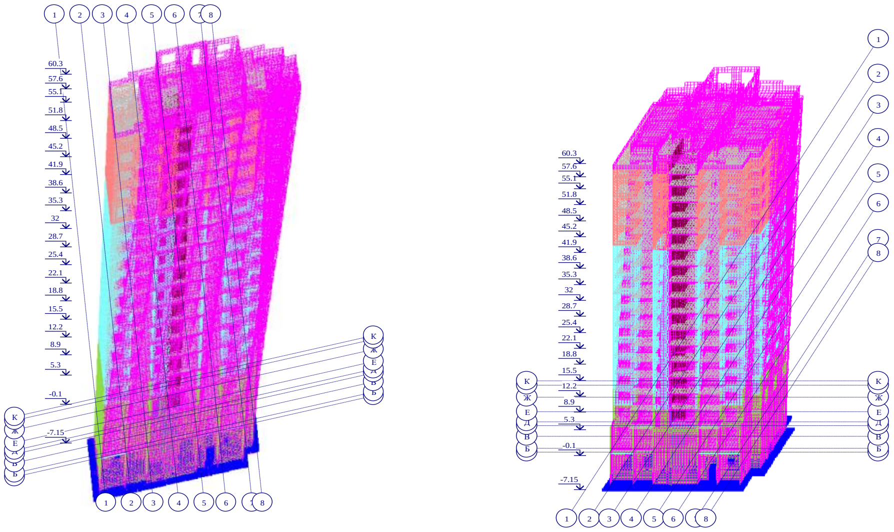


Figure 2 - Visualization of the model in the oscillation state (author's material)

In accordance with the provisions of SP RK 2.03-30-2017*, the examined 16-story building falls under responsibility class II by functional designation and responsibility class IV by the number of floors (high-rise buildings).

To determine the horizontal design seismic load F_{ik} using the spectral method in the selected direction, the following equation (from SP RK 2.03-30-2017) is applied:

$$F_{ik} = \gamma_{I,h} * S_d(T_i) * m_{ik} * \eta_{ik} \tag{1}$$

Where:

F_{ik} - seismic load on the building or structure in the considered horizontal direction for the i-th mode shape, applied at point k.

$\gamma_{I,h}$ - importance factor accounting for the responsibility of the building or structure in determining horizontal seismic loads (assumed as 1.72 for this calculation).

$S_d(T_i)$ - design spectral response acceleration at period T_i, determined in accordance with section 7.5.2.

T_i - vibration period of the building for the i-th mode in the considered horizontal direction.

m_{ik} - effective modal mass assigned to point k, corresponding to the i-th mode shape.

η_{ik} - distribution coefficient dependent on the mode shape of the building in its natural oscillations for the i-th mode, the location of the load (determined in section 7.3.2), and the direction of the seismic impact.

Similarly, to determine the vertical design seismic load $F_{ik,v}$ using the spectral method, Equation 7.5 from the code is applied:

$$F_{ik,v} = \gamma_{I,v} * S_{vd}\left(T_{v,i}\right) * m_{ik} * \eta_{ik,v} \tag{2}$$

Where $\gamma_{I,v}$ is the vertical importance factor (assumed as 1.48), and S_{vd} is the vertical design spectrum.

3.4 Spectral Method Analysis Of Design Seismic Loads

In accordance with the provisions of SP RK 2.03-30-2017*, the examined 16-story building falls under responsibility class II by functional designation and responsibility class IV by the number of floors (high-rise buildings). To determine the horizontal design seismic load F_{ik} using the spectral method in the selected direction, equation (7.1) from SP RK 2.03-30-2017 is applied. In this equation, F_{ik} represents the seismic load on the building or structure in the considered horizontal direction for the i-th mode shape, applied at point k. The parameter γIh is the coefficient accounting for the responsibility of the building or structure in determining horizontal seismic loads, assumed as 1.72 for the calculation. Furthermore, S_d(Ti) denotes the spectral response acceleration at period Ti, determined in accordance with section 7.5.2, while Ti is the vibration period of the building or structure for the i-th mode in the considered horizontal direction. The effective modal mass assigned to point k, corresponding to the i-th mode shape, is denoted by mik and is determined using equation (7.2). This calculation involves ηik, a coefficient dependent on the deformation mode of the building or structure in its natural oscillations for the i-th mode, the location of the load (determined in section 7.3.2), and the direction of the seismic impact.

To determine the vertical design seismic load F_{ikv} using the spectral method, equation (7.5) is applied. Here, F_{ikv} represents the calculated seismic load in the vertical direction for the i-th mode shape, applied at point k. The parameter γIv is the coefficient accounting for the responsibility of buildings and structures in determining vertical seismic loads, assumed as 1.48. Additionally, $S_{dv}(T_{vi})$ is the spectral response acceleration at period Tvi, determined in accordance with section 7.5.2, and T_{vi} corresponds to the vibration period of the building or structure for the i-th mode in the vertical direction.

Horizontal seismic impact is described by two orthogonal components, considered independent and characterized by identical response spectra. For the horizontal components of the seismic impact considered in the calculation of buildings, the response spectrum Sd(T) is determined by specific expressions where Sd(T) characterizes the horizontal component of the seismic impact. The parameter T represents the vibration period of a single-degree-of-freedom linear system in the horizontal direction, expressed in seconds. The design acceleration at the construction site, ag, is taken as 0.487 g based on Appendix B of NTP RK 08-01.1-2017. The periods TB and TC define the constant section of the spectral acceleration graph, with TB representing the minimum period value taken as 0.15 s and TC representing the maximum period value taken as 0.44 s, both referenced from Table 4.1 of NTP RK 08-01.1-2017. Additionally, β acts as the lower boundary coefficient of the response spectrum for horizontal components, taken as 0.2, while the behavior factor q is taken as 4.2 for wall systems with coupled walls.

For the vertical component of seismic impacts, the response spectrum Svd(T) is determined by corresponding expressions where Svd(T) represents the response spectrum for the vertical component. In this context, Tv is the vibration period of a single-degree-of-freedom linear system in the vertical direction in seconds, and avg denotes the calculated ground acceleration in the vertical direction, equal to 0.438 g. The constant section of the spectral acceleration graph for the vertical component is bounded by a minimum period value TBv of 0.05 s and a maximum period value TCv of 0.2 s, while the absolute maximum period value on the graph, TDv, is taken as 2.0 s. Furthermore, the exponent factor k is taken as 0.6, and the behavior factor q is established at 1.5.

The building responses corresponding to two mode shapes i and j (including translational and torsional modes) can be considered independent if their periods Tk and Tk+1 satisfy a specific condition for Tk+1 ≤ Tk. If all significant modal responses in determining the effects of seismic impact can be considered independent, then the maximum magnitude EE of the seismic impact effect can be taken as the Square Root of the Sum of the Squares (SRSS). In this approach, EE represents the effect of the considered seismic impact, such as force or displacement, and EEi denotes the value of the seismic impact effect for the i-th mode shape. However, if the first condition regarding period independence is not met, more precise procedures should be used for the combination of modal maxima, such as the Complete Quadratic Combination (CQC) method. The expression for summing modal maxima using the CQC procedure incorporates ξ, which represents the damping coefficient expressed as a fraction of the critical damping.

4 RESULTS AND DISCUSSION

The calculations confirm that the building complies with regulatory requirements for stability and seismic resistance according to SP RK 2.03-30-2017. The analysis of the building’s dynamic characteristics using modal analysis showed that the modal masses in the X and Y directions account for 89.8%, which is sufficient to consider all possible vibration modes of the building under seismic impact.

The global spatial behavior of the building under seismic excitation is analytically visualized through displacement isolines and mosaics. As shown in **Figure 3**, the displacement isolines along the X-axis indicate a uniform and controlled increase in lateral drift toward the upper floors, culminating in a maximum overall displacement of 75 mm. To further examine the dynamic response, **Figure 4** illustrates the deformed shape of the floor slab at the top elevation (+67.800) for the second vibration mode under X-axis seismic action. This visualization is critical as it highlights the limited torsional response of the slab, confirming that the floor acts as a rigid diaphragm without excessive twisting. Similarly, the structural response in the orthogonal direction is presented in **Figure 5**. The displacement isolines along the Y-axis indicate a maximum roof displacement of 85 mm, with uniform contour gradients confirming global stability even under extreme lateral impacts. Furthermore, **Figure 6** displays the displacement mosaic along the Y-axis, which captures the vertical deformations of the structural system and underscores the necessity of explicitly modeling the vertical seismic component to capture local stress concentrations.

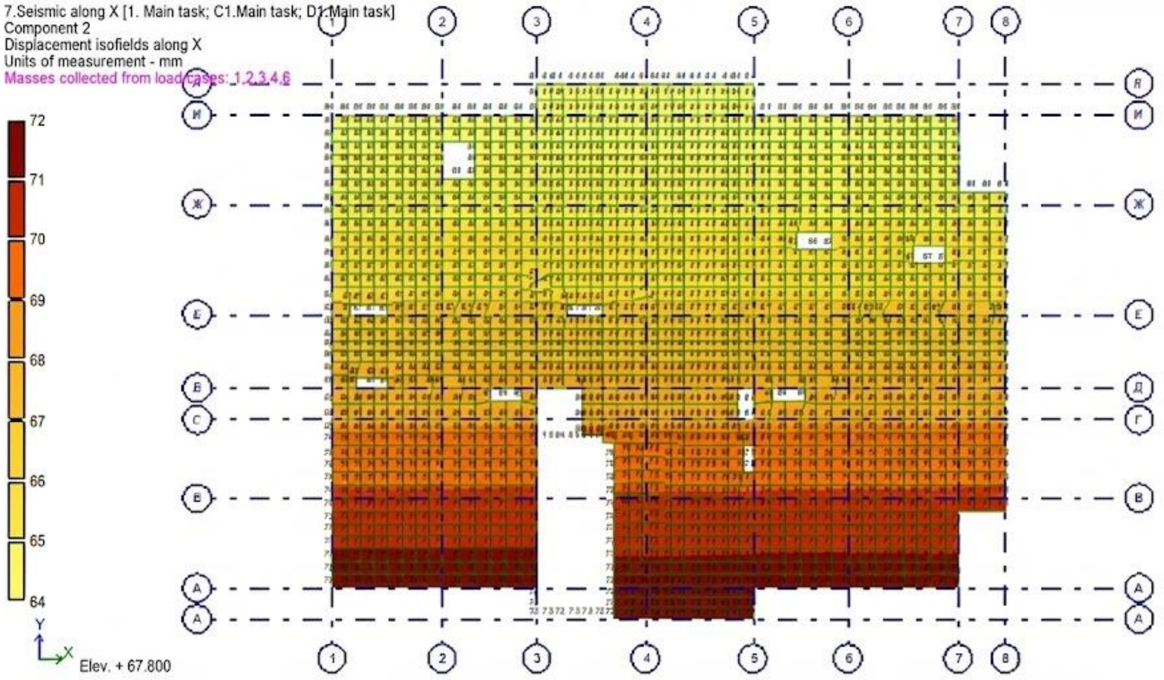


Figure 3 - Isolines of displacements along the X-axis (author's material)

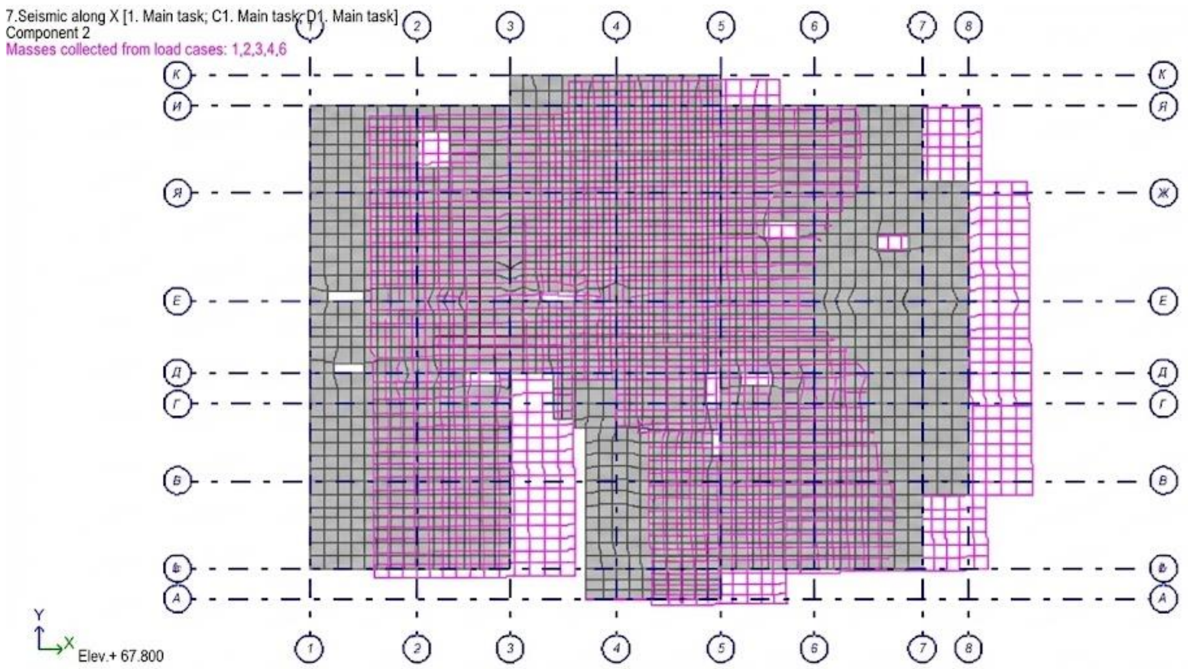


Figure 4 - Deformed shape of the floor slab at elevation +67.800 for the second vibration mode (Component 2) under seismic action along the X-axis (author's material)

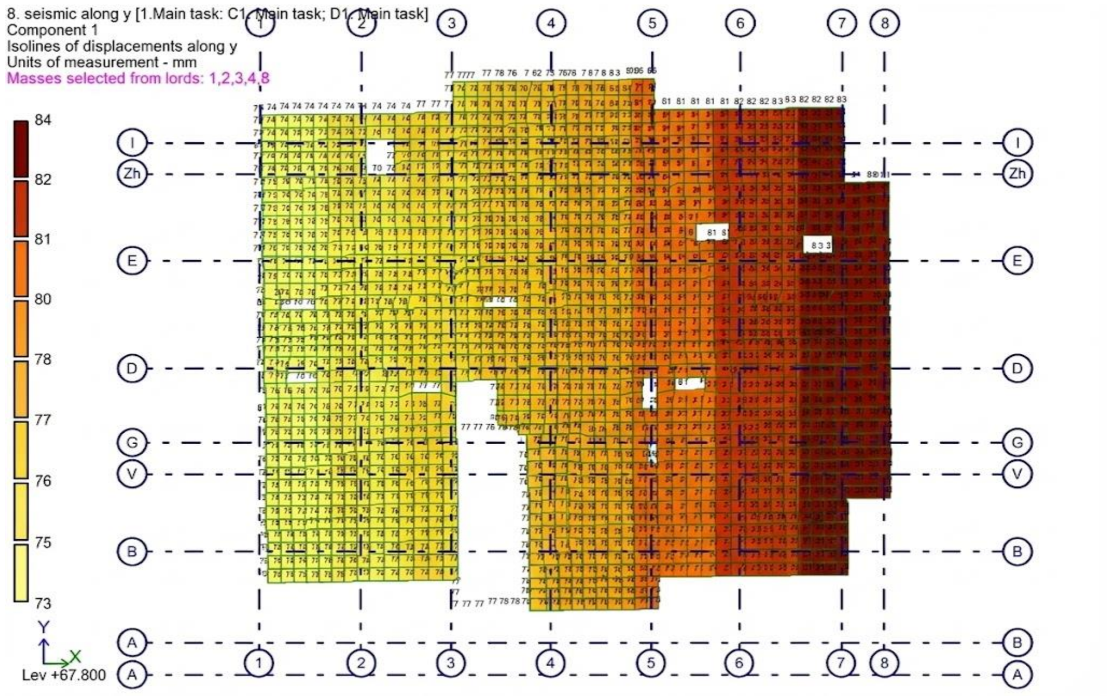


Figure 5 - Isolines of displacements along the Y-axis (author's material)

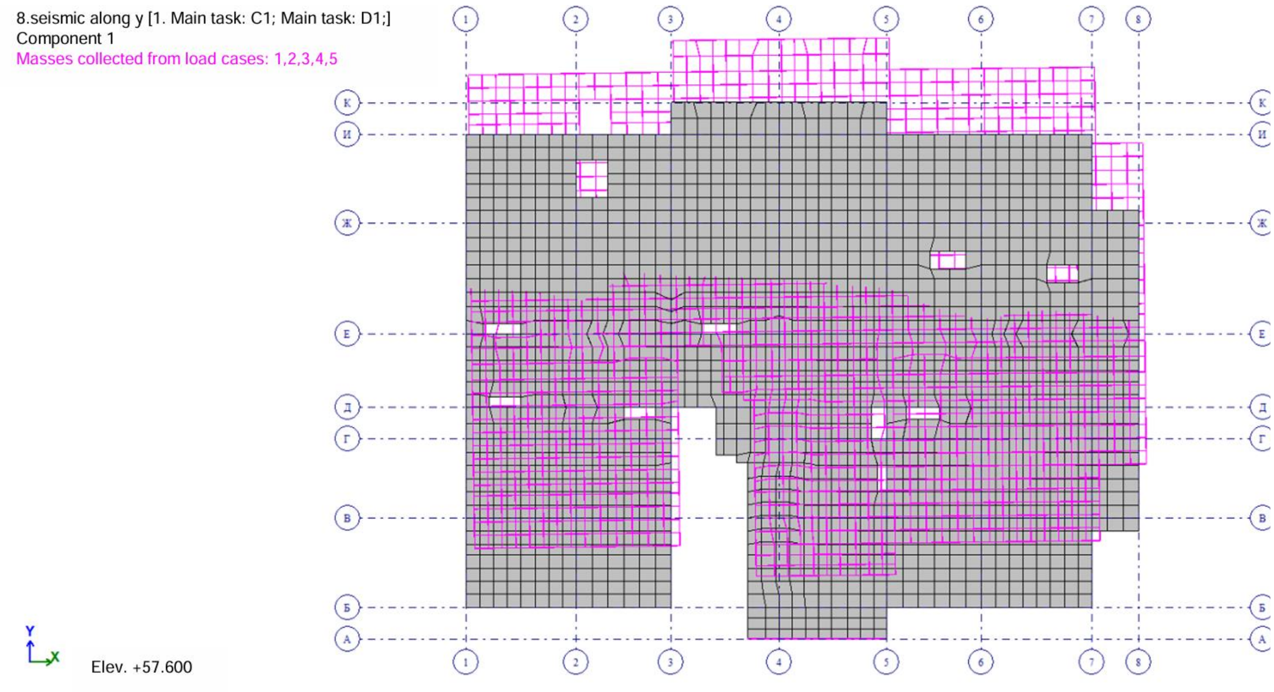


Figure 6 - Displacement mosaic along the Y -axis (author's material)

To assess the torsional and translational uniformity of the building, the relative structural deviations were evaluated based on the extreme nodal displacements. The calculations demonstrate that the maximum relative deviation constitutes 4.86% in the X direction and 6.54% in the Y direction. These low percentage values physically indicate that the floor diaphragms displace almost uniformly, confirming the high spatial rigidity of the structural system. Consequently, adverse torsional effects are negligible, and the building fully satisfies the code requirements for regular structures under multi-component seismic actions.

The results of the study demonstrate that the structure of the 16-story building exhibits high stability and reliability under seismic and static loads. The modeling was conducted in compliance with modern standards of SP RK EN 1998-5:2004/2012, ensuring an accurate representation of the seismic characteristics of the region. The settlement and story drift values of the building fully meet the requirements of regulatory documents. The application of multicomponent analysis in calculations enhanced the accuracy of the modeling, which is particularly significant for seismically active zones, where miscalculations can lead to substantial risks.

5 CONCLUSIONS

This study presented a comprehensive numerical assessment of a 16-story cast-in-place reinforced concrete building in Almaty, utilizing a multi-component spectral analysis. Based on the finite element modeling, the following conclusions are drawn:

1. The modal analysis confirmed the regularity of the structural system. Over 20 vibration modes were utilized, achieving a cumulative effective modal mass of 89.8% in both principal directions, which satisfies the regulatory thresholds and adequately captures high-order mode effects.
2. The building exhibits adequate global lateral stiffness. The calculated interstory drifts and roof displacements under the design seismic action strictly satisfy the Damage Limitation (SLS) requirements and code limits for buildings with brittle non-structural elements.
3. Explicit modeling of the vertical seismic component ($a_{vg} = 0.438$ g) revealed non-negligible variations in axial forces in the lower-story vertical members. This confirms that for high-rise construction in near-fault zones (9-intensity), omitting the Z-component leads to an underestimation of structural demands.
4. The study validates the regulatory requirement that buildings exceeding 12 stories in 9-point seismic intensity zones mandate the development of site-specific Special Technical Conditions (STU). Furthermore, adopting Eurocode principles with explicit multi-component spectral analysis provides a more reliable safety margin and is recommended as a benchmark for high-rise developments in the region.

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