ABSTRACT

For the dissertation for the degree of Doctor of Philosophy (PhD)
Educational Program: 8D07321 – "Construction"
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Topic: «Seismic resistance of high-rise buildings made of monolithic reinforced concrete for the conditions of the city of Almaty»

In recent years, there has been a significant increase in the height of buildings constructed in Almaty, which is located in a high seismicity zone with a rating of 9 on the seismic scale. This trend is driven by modern urban planning requirements and the acute shortage of available land in major cities, a phenomenon typical not only for Almaty but for many metropolitan areas worldwide. At the end of the 20th century, the tallest building in 9-point seismic zones in the CIS was the 25-story Kazakhstan Hotel. However, since 2005, dozens of high-rise buildings ranging from 20 to 37 stories have been constructed in Almaty, posing new challenges for designers and builders.

Relevance of the research topic. Considering the nature and characteristics of seismic effects, experimental studies are the most preferable, as they allow for the creation of seismic-type dynamic impacts. Such experiments provide objective information on the effectiveness of adopted structural solutions for buildings or their individual elements, which have not previously been tested under real earthquake conditions, as well as on the reliability of calculation models used to justify the seismic resistance of structural systems. Given the ongoing construction of high-rise buildings in seismically active regions of Kazakhstan, these studies are crucial for enhancing the safety and seismic resistance of new buildings, making this topic particularly relevant and in demand.

Object of study: High-rise monolithic buildings in Almaty subjected to seismic loads in a high seismicity zone (9 points).
Subject of study: Experimental studies of high-rise buildings, exemplified by 22- and 35-story residential buildings in Almaty.

Research objective: To provide a comprehensive solution to the scientific and technical problem of designing and constructing seismic-resistant high-rise buildings in zones of high seismic hazard for Almaty. The research aims to develop a calculation methodology for frame-wall high-rise buildings that accounts for dynamic characteristics obtained through experimental studies, and to formulate recommendations for using more accurate calculation models to ensure the seismic resistance of these systems.

The objective of the study is to provide a comprehensive solution to the scientific and technical problem of designing and constructing earthquake-resistant high-rise buildings in areas of high seismic hazard, specifically for the conditions of the city of Almaty. It also involves developing a methodology for the analysis of high-rise buildings with frame–wall structural systems that accounts for dynamic characteristics obtained through experimental research, and, on this basis, formulating recommendations for the use of more accurate analytical models to ensure the seismic resistance of these systems.

Research tasks:

1. Determine the main natural dynamic characteristics of a high-rise building, such as vibration periods, damping decrements, and mode shapes.
2. Analyze the dissipative properties of high-rise buildings under seismic loads.
3. Evaluate the ability of floor diaphragms to distribute horizontal seismic forces among vertical elements.
4. Compare experimentally obtained natural dynamic parameters with calculated values.
5. Assess the correspondence between calculated and experimental results for the designed structural system.
6. Verify that the actual material properties match the design specifications.
7. Calculate maximum displacements of the studied high-rise buildings using instrumental accelerogram datasets (spectral-time method) and compare with spectral method results.
8. Perform calculations in accordance with the requirements of SNiP and regulatory technical guidelines (RTG) for SP RK EN 1998-1:2004/2012, refining key parameters such as height coefficient and material safety factors.
9. Based on experimental and theoretical results, develop recommendations for the design and calculation of frame-wall high-rise monolithic buildings in seismic zones under the conditions of Almaty.

Research methods.

The study employed experimental methods including tests of high-rise buildings using inertial vibration machines (type B3) and the “load-drop” method. Concrete properties were determined using non-destructive testing with IPS-MG4.03 (impact pulse method). The mechanical properties of reinforcement steel were evaluated according to the European standard ST RK ISO 6892-1-2010. Calculations were performed using the software packages LIRA-SAPR 2019(R1) (License No. 1475, ID key 747656825) and ETAPS.

Scientific novelty.

In this work:

– new experimental data were obtained on the natural dynamic characteristics (vibration periods, damping decrements, mode shapes, etc.) from tests of 22- and 35-story monolithic residential buildings in Almaty with similar structural systems;

– it is recommended that logarithmic damping decrements for seismic load calculations be taken within 0.12–0.18 (ξ = 2–3%);

– key calculation parameters, including height coefficients and material safety factors (concrete and reinforcement), were refined and corrected. These results will be used to update the National Annexes to SP RK EN 1998–1:2004/2012;

– a formula for practical application was proposed to determine vibration periods of high-rise buildings: $T = \alpha \cdot N$, where N is the number of floors and $\alpha = 0.045$;

– based on experimental and calculated data, recommendations were developed for the design and calculation of frame-wall high-rise monolithic buildings in seismic zones for Almaty.

Key findings submitted for defense

1. Application of a parametric calculation methodology to analyze experimental data using spectral and spectral-time seismic models.
2. Results of full-scale dynamic tests confirmed by calculations for a 35-story monolithic building in Almaty.
3. Load-drop experimental tests on a 22-story building with a similar structural system, validated by calculations.
4. Identification of significant changes in dynamic characteristics and dissipative properties of frame-wall systems with increasing building height.
5. Established relationship between vibration period and number of floors; proposed formula for practical determination.
6. Calculation methodology and design recommendations for seismic-resistant frame-wall high-rise buildings.

Practical significance

Recommendations were developed for the design of seismic-resistant frame-wall high-rise buildings in Almaty, ensuring enhanced seismic safety. Quantitative relationships were established between dynamic parameters and building configurations, allowing designers to accurately determine dynamic characteristics for buildings of different heights. Results have been implemented in design practice (LLP "Menessa").

Publication and approbation of the work: Five publications have been issued on the topic of the dissertation, including two articles in scientific and scientific-practical journals included in the list recommended by the Committee for Quality Assurance in Science and Higher Education of the Ministry of Science and Higher Education of the Republic of Kazakhstan, and one article published in a journal indexed in the Scopus database with a percentile of 39 in the field of "Building Construction." In addition, two articles have been published in other outlets.

Structure of the work:

The dissertation consists of an introduction, five chapters, a conclusion, and appendices (138 pages, 25 tables, 43 figures, 121 references, and 3 appendices).

Substantively:

In the first chapter:

– the main approaches to improving the seismic resistance of buildings, including high-rise structures; a review of studies on enhancing building seismic resistance;

– the phenomenon of earthquakes and earthquakes with epicenters within the city of Almaty;

– structural systems of monolithic high-rise buildings constructed in both conventional and seismic regions; methods for assessing the seismic resistance of buildings and an analysis of the design provisions of current standards in CIS countries and the Republic of Kazakhstan.

In the second chapter:

– experimental studies of a 35-story monolithic high-rise residential building using a V-3 type vibration machine;

– testing methodology for high-rise buildings, including dynamic impacts, sensors, and recording equipment; description of the test object; verification of the strength of concrete and reinforcement;

– method for generating dynamic loads on the test object; testing procedures and recording instrumentation;

– dynamic parameters and deformation characteristics of the structure during testing;

– results of visual inspection; analysis of instrumental data obtained from vibration testing of the experimental object.

In the third chapter:

– Experimental studies of a 22-story monolithic high-rise residential building using cable pulling with subsequent instantaneous release of the statically applied load;

– description of the test object; testing methodology; test results;

– engineering analysis.

In the fourth chapter:

Response of a 22-story building based on instrumental acceleration records (spectral time method); objects and methods; results.

In the fifth chapter:

Comparative analysis of the parameters of design provisions in current standards.

Final conclusions:

1. Full-scale testing of 35-story buildings determined natural vibration parameters, showing good agreement between experimental and calculated periods.

2. The 35-story building exhibits long-period dynamic behavior with low energy dissipation; recommended logarithmic damping decrements are 0.12–0.18 (ξ = 2–3%).

3. Horizontal floor deformations did not exceed 3% of interstory displacements.

4. Load-drop tests on a 22-story building determined natural vibration periods of 0.88–0.94 s and damping decrements of 0.11–0.27 (1.6–2.9% of critical).

5. Recommended formula $T = \alpha \cdot N$ for wall-type systems with $\alpha = 0.045$ for Almaty conditions.

6. High correspondence found between calculated and experimental horizontal displacements. Proposed multimodal coefficient $\gamma\_Ih = 1.5$ for designing high-rise buildings, considering building height and responsibility class.