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RESEARCH ARTICLE

EFFECT OF THE NUMBER OF STOREYS ON SEISMIC RESISTANCE OF HIGH-RISE MONOLITHIC BUILDINGS IN ALMATY

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Abstract: *The article considers the issues of the construction of high-rise monolithic buildings in Almaty. High-rise construction has received significant development in the territory of the metropolis - more than several dozen buildings more than 20 stories high have been built. Experimental studies of the proper dynamic characteristics of high-rise buildings (periods and forms of natural oscillations, oscillation decrement) and verification of the correctness of the calculation assumptions adopted during their design are relevant. The influence of height on the proper dynamic characteristics of high-rise monolithic buildings constructed in Almaty is analyzed. Data are provided on determining the dynamic characteristics of a 22-storey monolithic building using the building pull-out method with the subsequent abrupt release of the applied load. The results are compared with the data on the proper dynamic characteristics of four high-rise buildings (more than 20 stories high) obtained as a result of vibration tests: - 25-storey Kazakhstan Hotel; - 35-storey building on Al Farabi Street (Nurly-Tau district); - 22-storey building of the Stolichny Tsentr residential complex; -26-storey building of the residential complex "Megatowers". The results of the work can be used in the design of high-rise monolithic buildings.*

Keywords: *high-rise monolithic building, concrete, reinforcement, full-scale testing, testing methods, dynamic characteristics of the building.*

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ҒЫЛЫМИ МАҚАЛА

АЛМАТЫ ҚАЛАСЫНДАҒЫ БИІК МОНОЛИТТІ ҒИМАРАТТАРДЫҢ СЕЙСМИКАЛЫҚ ТӨЗІМДІЛІГІНЕ ҚАБАТТЫЛЫҚТЫҢ ӘСЕРІ

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Аңдатпа. *Алматы қаласында биік монолитті ғимараттар салу мәселелері қарастырылуда. Биіктік құрылысы мегаполис аумағында айтарлықтай дамыды-биіктігі 20 қабаттан асатын бірнеше ондаған ғимараттар салынды. Биік ғимараттардың өзіндік динамикалық сипаттамаларын эксперименттік зерттеу (меншікті тербелістердің кезеңдері мен формалары, тербелістердің декреті) және оларды жобалау кезінде қабылданған есептік алғышарттардың дұрыстығын тексеру өзекті болып табылады. Алматы қаласында салынған биік монолитті ғимараттардың өзіндік динамикалық сипаттамаларына биіктіктің әсері талданады. 22 қабатты монолитті ғимараттың динамикалық сипаттамаларын ғимаратты тарту әдісімен анықтау, содан кейін қолданылатын жүктемені күрт босату туралы мәліметтер келтірілген. Нәтижелер дірілді сынау нәтижесінде алынған төрт биік ғимараттың (биіктігі 20 қабаттан асатын) өзіндік динамикалық сипаттамаларының деректерімен салыстырылады: - "Қазақстан" 25 қабатты қонақ үйі; - Әл-Фараби көшесі бойындағы 35 қабатты ғимарат ("Нұрлы - Тау" ауданы); - "Астаналық орталық" ТК 22 қабатты ғимараты; - "Мегатауэрс"ТК 26 қабатты ғимараты. Жұмыс нәтижелерін көп қабатты монолитті ғимараттарды жобалау кезінде пайдалануға болады.*

Түйін сөздер: *көп қабатты монолитті ғимарат, бетон, арматура, табиғи сынақ, сынақ әдістері, ғимараттың динамикалық сипаттамалары.*

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НАУЧНАЯ СТАТЬЯ

ВЛИЯНИЕ ЭТАЖНОСТИ НА СЕЙСМОСТОЙКОСТЬ ВЫСОТНЫХ МОНОЛИТНЫХ ЗДАНИЙ В АЛМАТЫ

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Аннотация. *Рассматриваются вопросы строительства в городе Алматы высотных монолитных зданий. Высотное строительство получило значительное развитие на территории мегаполиса - построено свыше нескольких десятков зданий высотой более 20 этажей. Актуальными являются экспериментальные исследования собственных динамических характеристик высотных зданий (периоды и формы собственных колебаний, декремент колебаний) и проверка корректности расчетных предпосылок, принятых при их проектировании. Анализируется влияния высоты на собственные динамические характеристики высотных монолитных зданий, построенных в г. Алматы. Приводятся данные по определению динамических характеристик 22-этажного монолитного здания методом оттяжки здания с последующим резким сбросом приложенной нагрузки. Результаты сравниваются с данными собственных динамических характеристик четырех высотных зданий (высотой более 20 этажей), полученных в результате вибрационных испытаний: - 25 этажная гостиница «Казахстан»; - 35 этажное здание по улице Аль Фараби (район «Нурлы - Тау»); - 22 этажного здания ЖК «Столичный центр»; -26-ти этажное здание ЖК «Мегатауэрс». Результаты работы могут быть использованы при проектировании высотных монолитных зданий*

Ключевые слова: *высотное монолитное здание, бетон, арматура, натурное испытание, способы испытаний, динамические характеристики здания*

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1 INTRODUCTION

Currently, Almaty tends to sharply increase the height (number of floors) of buildings erected in conditions of high seismicity **(Yerzhanov et al., 2020)**. This trend is due to two main factors: modern urban planning requirements and an acute shortage of free territory in large cities. This trend is inherent in many large cities around the world.

If at the end of the twentieth century, the tallest building located in the 9-point districts of the CIS countries was the 25-story hotel "Kazakhstan", built in Almaty, then starting in 2005, Kazakhstani and foreign construction companies began to erect dozens of 20–35-story high-rise monolithic buildings in Almaty **(Yerzhanov et al., 2020)**.

The design and construction of high-rise buildings in seismic areas is a complex engineering task, the correct solution of which is possible only if there is an appropriate regulatory framework, as well as special logistical and technological support **(Farzaliyev & Guluzadeh, 2022).**

During the certification of 2023-2024, 32 houses with several floors above 18 floors were identified out of 1777 surveyed houses. Among the 322 (approximately 2,100 houses) multi-story residential complexes built over the past 15-20 years, high-rise buildings (over 18 floors) account for about 3%.

The building regulations of the Republic of Kazakhstan, as well as similar norms of other CIS countries, do not contain provisions regulating the rules and construction of high-rise buildings in due volume.

Therefore, there is a significant amount of experimental research devoted to the study of the dynamic characteristics of high-rise buildings, and comparing their results with computational studies. Numerous experimental data and classification of high-rise buildings in regulatory documents of various countries **(Farzaliyev, 2018)**.

Numerous studies **(Farzaliyev & Pahomov, 2022)** have noted the effects of building configuration on seismic resistance (plan dimensions, height, flexibility, symmetry, etc.) **(Gaidzhurov & Volodin, 2023).**

At first glance, an increase in building height may seem equivalent to a rise in the span of a cantilever beam. But this is not the case. With an increase in a building's height, the value of its period of natural vibrations usually increases, and a change in the period of vibrations means a change (in the upper or lower level) in the building's responses and the magnitude of the corresponding efforts **(Ereiz et al., 2021)**.

It is unlikely that an earthquake can cause intense ground movements with high acceleration and a period of basic vibrations equal to 2 seconds; usually, for observed earthquakes, this value was no more than 0.5 seconds. Under high-intensity seismic effects, high-frequency ground vibrations are predicted for the city of Almaty.

Therefore, a building with a height of more than 20 floors with a main oscillation period of more than 1 s will experience less mass acceleration than a building with a height of 5-10 floors with a period of 0.5 s.

The period of natural oscillations **(Furtado et al., 2023)** of buildings is a function not only of height but also of flexibility, floor height, type of structural system, building material used, and mass distribution. Therefore, a change in the size of a building can simultaneously cause a change in the periods of its oscillations, which accordingly contributes to an increase or decrease in the magnitude of seismic loads.

2 LITERATURE REVIEW

Earthquake resistance of buildings is one of the key tasks of modern construction, especially in earthquake-prone regions. High-rise monolithic buildings, as a rule, have characteristics that affect their resistance to earthquakes. This review examines the main aspects of the influence of several stories on the seismic resistance of such structures **(Gioffrè et al., 2022)**.

The seismic resistance of buildings is determined by the ability of the structure to withstand dynamic loads arising from earthquakes. The main factors affecting earthquake resistance include:

Geometric characteristics (height, shape);

Materials and their properties;

Structural elements (frame, stiffness systems);

Basic calculation and design methods.

The aim was to determine the main dynamic characteristics of a high-rise monolithic building in Almaty of a frame-wall structural system and verify the correctness of the design assumptions adopted during its design, and the reliability of the results obtained during computational studies. However, numerous studies show that often the experimental oscillation period does not coincide with the calculated value of the specified parameter **(Pascua et al., 2023)**.

Therefore, the purpose of the work is to:

- by pulling off the building and relieving the load, determine the value of the oscillation period along two orthogonal axes oriented in longitudinal and transverse directions;
- to determine the characteristics of energy dissipation during free vibrations of the building. This is the logarithmic decrement of the oscillation;
- to compare the results of determining the dynamic characteristics of the building by calculation with their experimental values;
- analysis of the effect of height on the intrinsic dynamic characteristics of high-rise monolithic buildings constructed and subjected to vibration tests in Almaty.

3 MATERIALS AND METHODS

The dynamic characteristics of a 22-storey building are investigated. The building was erected on a site with a seismicity of 9 points. The category of soils according to seismic properties is I. The conditions complicating the seismological or engineering-geological conditions of the construction site have not been identified. The building is designed with 3 underground floors, one basement, 21 above-ground residential floors, and an upper technical floor.

The basic design spatial planning and structural solutions of the test object are shown in Figure 1-2. The building has a Y-shaped shape in plan and is separated from adjacent objects by antiseismic seams. The design height of the building from the top of the foundation plate to the top of the monolithic coating is about 85.700 m.

Figure 1 - General view of the building (author's materials)

Figure 2 - Object plan (author's materials)

Structurally, the object under study **(Polimeno et al., 2018)** is a spatial frame-wall system. The cellar, basement, and 21 above-ground floors of the building are made of reinforced concrete structures, and the technical floor is made of steel structures. The thickness of the main reinforced concrete walls of the building in question is assumed to be variable in height – from 600...500mm in the levels of the lower floors to 400mm in the levels of the upper floors. In case of horizontal impacts, the joint work of reinforced concrete walls is ensured by horizontal floor discs. The floors of the building are made of monolithic reinforced concrete and have a thickness of 200 mm. The foundation plate has a thickness of 2000mm. The design strength of the concrete foundation plate is accepted in 25, walls: to m. 11,450m – B45, from m. 11,450 to 31,250 – B40, from m. 31,250 to m. 51.050 – B35, from m. 51.050 to m. 70,850 – B30. The walls of the basement, elevator shafts, and floor slabs are made of concrete B25.

The test was carried out using the method of pulling off the building, followed by a sharp release of the applied load resulting in free vibrations. The length of the cable was approximately 90 meters. The point of application of the load is the floor slab of the 20th floor. The vibrations were recorded by the RSM digital measuring complex, equipped with AT1105 digital accelerometers and SM-3 seismic receivers. Seismic receivers were installed **(Wang et al., 2022)** on the floor slabs on the 9th, 15th, and 17th and on the core of the 19th floor. The accelerometers AT1105 c are phased relative to each other. Figure 3-4 shows digital accelerometers, as well as a photo of a digital instrumentation and measurement system.

The instantaneous discharge was created by the breakage of special inserts made of class A240 reinforcing steel with a diameter of 6 and 8mm with a force of 1.5-2.5 tc. The insert connected a cable fixed at the bottom level of the last floor (covering) of the building to the power plant (car) shown in Figure 5-6.

Figure 3- Photo of digital sensors (author's materials)

Figure 4 - Photo of the digital instrument panel-measuring system (author's materials)

Figure 5 - Cable attachment to building structures (author's materials)

Figure 6 - Insertion of a cable connection with a power plant (car) (author's materials)

4 RESULTS AND DISCUSSIONS

The table shows **(Table 1-2)** the dynamic characteristics of the building during the drawback tests.

Table 1
Initial dynamic parameters of high-rise monolithic buildings (author's materials)

№ in order	Name of the objects	Test methods	Experimental periods of free oscillations, s	Estimated periods of free fluctuations, s
			in the longitudinal direction along the Y axis	in the longitudinal direction along the Y axis
1	2	3	4	5
1	in the longitudinal direction along the Y axis, a 22-storey residential building in Almaty	By means of a cable tie	0,9	1,08

Table 2
Initial dynamic parameters of high-rise monolithic buildings (author's materials)

№ in order	Name of the objects	Test methods	Experimental logarithmic decrements of oscillations	Coefficient ξ (in % of critical value)
			in the longitudinal direction along the Y axis	in the longitudinal direction along the Y axis
1	2	3	4	5
2	22-storey residential building in Almaty	By means of a cable tie	0,114–0,268	1,82-4,27

Theoretical estimates of the oscillation periods of the building were carried out using a computer complex. The periods of natural oscillations in the first form, determined by calculation (T_1= 1.08 s), the differences in the calculated and experimental oscillation periods are due to the failure to consider partitions and other non-constructive elements in the work of the building structures.

In general, the calculated and experimental measurement results are not contradictory.

4.1 ENGINEERING ANALYSIS OF THE EFFECT OF HEIGHT ON THE INTRINSIC DYNAMIC CHARACTERISTICS OF HIGH-RISE MONOLITHIC BUILDINGS CONSTRUCTED AND SUBJECTED TO VIBRATION TESTS IN ALMATY

Structural solutions of high-rise monolithic buildings **(Table 3)** represent a complex engineering task that requires taking into account many factors such as seismicity, wind loads, geological conditions, etc. The choice of the optimal design depends on the specific construction conditions and building requirements.

Table 3
The main design solutions of the considered high-rise monolithic buildings constructed and subjected to vibration tests in Almaty (author's materials)

№ in order	The purpose of the object	Floor	The design scheme	The shape in the plan	Foundation, walls and ceilings	Partitions	External wall fences
1	2	3	4	5	6	7	8
1	Office Complex «Nurly-Tau»	22	Frame and wall	Y	Monolithic, reinforced concrete	Thermal blocks	Stained glass windows
2	Office Complex «Nurly-Tau»	35	Frame and wall	Y	Monolithic, reinforced concrete	Thermal blocks	Stained glass windows

3	Residential complex « Stolichny Tsentr »	22	Frame and wall	Y	Monolithic, reinforced concrete	Thermal blocks	Stained glass windows
4	Residential complex «Mega Towers»	26	The wall	Rectangular	Monolithic, reinforced concrete	Thermal blocks	Stained glass windows
5	Hotel «Kazakhstan»	25	Barrel-diaphragm	Ellipsoid	Monolithic, reinforced concrete	-	Stained glass windows

An assessment of the dynamic characteristics of high-rise monolithic buildings **(Table 4)** is a prerequisite for ensuring their safety and reliability.

Table 4
Initial dynamic parameters of high-rise monolithic buildings (author's materials)

№ in order	Name of the objects	Test methods	Experimental periods of free oscillations, s	Estimated periods of free fluctuations, s
			in the longitudinal direction along the Y axis	in the longitudinal direction along the Y axis
1	2	3	4	5
1	Office Complex «Nurly-Tau»	The drawback method	0,85-0,95	1,08
2	Office Complex «Nurly-Tau»	Vibration test	1,31/1,48	1,38
3	Residential complex «Stolichny Tsentr»	Vibration test	0,944/1,152	1,510
4	Residential complex «Mega Towers»	Vibration test	1,03/1,18	1,55
5	Hotel «Kazakhstan»	Vibration test	1,05/1,10	1,55

Note – The experimental values of the oscillation periods given in the numerator correspond to the initial stages of the tests and in the denominator to the final stage of the tests.

The dynamic characteristics of high-rise monolithic buildings **(Table 5)** are the most important factor determining their resistance to various types of impacts, such as seismic vibrations, wind, and other dynamic loads.

Table 5
Initial dynamic parameters of high-rise monolithic buildings (author's materials)

№ in order	Name of the objects	Test methods	Experimental logarithmic decrements of oscillations	Coefficient ξ (in % of critical value)
			in the longitudinal direction along the Y axis	in the longitudinal direction along the Y axis
1	2	3	4	5
1	Office Complex «Nurly-Tau»	The drawback method	0,114-0,268	1,82-4,27
2	Office Complex «Nurly-Tau»	Vibration test	0,08	1,27
3	Residential complex « Stolichny Tsentr »	Vibration test	0,09	1,43
4	Residential complex «Mega Towers»	Vibration test	0,11	1.75
5	Hotel «Kazakhstan»	Vibration test	0,10	1.59

The period of natural vibrations of a building depends on: the dimensions in the plan, height, area, and mechanical properties of the walls, the characteristics of the foundation soils, the supporting structure of the structure, and others **(Atabekyan et al., 2022)**. In the practice of designing earthquake-resistant buildings with a rigid structural scheme, empirical formulas are usually used to determine the value of the period T, the first form of natural oscillations:

$$T = \alpha \cdot n$$

where

n - the number of floors;

α - a coefficient depending on the structures of buildings and the type of foundation α = 0.04....0.09.

Research experience has shown that in many cases such a simplified approach without proper analysis **(Nemchinov et al., 2015)** of a specific situation can lead to serious errors, which, however, go into "reserve" **(Khalikova et al., 2021)**. They may underestimate the assessment of the condition of a completely sound building, but not vice versa. Therefore, it is more reliable in modern conditions to analyze and compare the natural oscillation frequencies of real objects and their ideal model **(Khazov, 2022)**. In this regard, experimental studies of facilities built in the city of Almaty with load-bearing walls made of monolithic reinforced concrete with the same types of soil conditions (I-first) and seismicity of the construction site (9 points) make it possible to clarify the empirical dependence of the value of the period T, the first form of natural oscillations on the number of floors of high-rise buildings.

Based on the statistical processing of the data obtained from the tests, the coefficient α in the empirical formula (1) is recommended to be equal to 0.04.

5 CONCLUSIONS

1. The value of the oscillation period of a 22-storey residential building of a frame-wall structural system fluctuates within 0.87 – 0.95 seconds.
2. The value of the logarithmic decrement of oscillations varies between 0.11-0.27 (1.8-4.27% of the critical value).
3. Based on the analysis of experimental tests, the coefficient α – coefficient (formula 1), equal to 0.04 for wall structural systems with types of ground conditions (I-first) and seismicity of the construction site, has been clarified and recommended (9 points) for the conditions of Almaty.
4. The difference between the experimental and calculated values of the oscillation period in the first form is up to 27%. The reason is the lack of consideration of non-structural elements of the building (for example, partitions) and enclosing structures.
5. Testing at home by the method of load relief (drawback) is quite informative. The method allows you to accurately determine the period of its oscillations in the basic form and the initial decrement of the oscillation.

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