

Technical features of the construction of high-rise buildings

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Abstract. High-rise buildings are unique construction objects, in the design and construction of which special rules and regulations apply. The purpose of the work is, through an analysis of the literature and technical documentation, to present the main features of the construction of high-rise buildings. Based on the results of the study, differences in the concept of "high-rise building" in different countries were identified, specific problems encountered in high-rise construction were described, and design features of high-rise buildings were described. Special attention is paid to additional difficulties arising in the construction of high-rise buildings, due to the specificity of loads, construction technology, operation of high-rise buildings, and other reasons.

1 Introduction

High-rise buildings are being built in connection with the growing population of cities, lack of land, as a rule, these are prestigious projects of special architectural significance, reflecting the state of the scientific and technical process, innovative technologies in construction. Tall buildings have features that significantly distinguish them from ordinary buildings. These are prestigious projects of special architectural significance, reflecting the state of scientific and technological progress, innovative technologies.

Throughout history, mankind has been striving for something more perfect, more ambitious, erecting ever higher and more refined buildings.

The first high-rise buildings were built in the USA (Chicago). The increase in land prices, technical progress in building and construction and the reliable construction of the elevator by the American engineer E. Otis led to the appearance of the first many-story houses, which were called "skyscraper".

At the turn of the 19th and 20th centuries, large volumes of office construction, as well as requirements for high concentration and building density, led to an increase in the number of storeys in buildings. At the same time, in addition to the possibility of erecting high-rise buildings on small land plots, the prestige and advertising of firms located on them played a significant role. That is why high-rise buildings are sometimes called

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“prestige buildings”, and the architecture of these buildings is called “the big business style”.

In Europe, high-rise buildings appeared only in the middle of the 20th century. At first, these were detached buildings in a historic city area: Pirelli in Milan, Montparnasse Tower in Paris, etc. Since the 1960s high-rise buildings are located mainly outside urban historical zones.

In the 1990s the most dynamically high-rise construction is developing in the countries of Southeast Asia. In 1990–2005, 445–450 m high structures were erected in Kuala Lumpur, Shanghai, and Taipei, for example. Petronas skyscraper (Kuala Lumpur, 1995), consisting of two towers (88 floors each) and recognized in 1996 as the tallest building in the world (Figure 1).



Fig. 1. Petronas Twin Tower (Kuala Lumpur, Malaysia).

The first high-rise buildings in Russia were erected in the late 1940s - early 1950s in Moscow. Seven high-rise buildings were built, the most significant of which is the main building of Moscow State University on the Sparrow Hills (Figure 2). By the beginning of the 21st century, a number of high-rise buildings were erected in Moscow, including administrative buildings (Gazprom, the central office of Sberbank) and residential complexes (Scarlet Sails, Triumph Palace, etc.).



Fig. 2. The main building of Moscow State University on the Sparrow Hills.



Fig. 3. Residential complex "Triumph Palace" (Moscow, Russia).

What is now considered a high-rise building? A high-rise building is any building with a height of more than 75 meters, that is, more than 25 floors. But such a standard is used only in Russia. In other countries, this term usually refers to buildings with a height of 35-100 m, and buildings above 100 m are considered skyscrapers. Skyscrapers above 300 meters are called superhigh.

The minimum height of the skyscraper building remains controversial. In the United States and Europe, skyscrapers are considered buildings at least 150 meters high. There is some uncertainty in the classification and ranking of high-rise buildings due to different measurement methods. The generally accepted standards are those developed by The Council on Tall buildings and Urban Habitat (CTBUH), an international organization dedicated to high-rise construction.

There are three criteria for measuring height:

1. height from the sidewalk level to the highest point of the structural elements of the building, not including television radio antennas and flagpoles;
2. to the floor level of the highest available floor of the building;
3. to the highest point (the height of the building to the tip of the antenna / spire).

At the moment, the first criterion is the main one. It is he who is used in compiling the rating of the highest buildings.

Today in the world there are more than 70 high-rise buildings, which are mainly located in the UAE, China, USA and other countries.

2 Features of the construction of high-rise buildings

High-rise buildings are construction object of high risk and engineering complexity, which indicates the need for a thorough analysis of decisions made and taking into account the results of the extensive international experience in high-rise construction.

Despite the accumulated world experience in the construction of high-rise buildings, there are currently no general regulated rules for the selection of structural solutions for load-bearing systems, enclosing structures and materials for their implementation. In each case, the design engineer makes a technical decision in accordance with the requirements established by international or national standards, design standards or other documents.

Due to the high height, the layout, design and technical equipment of high-rise buildings are qualitatively different from buildings with lower floors. The design of each high-rise

building is unique, because it solves the specific problems that arise during high-rise construction:

- strong influence of environmental factors (wind, noise, air temperature drops);
- providing fire protection and safe evacuation of people in an emergency;
- difficulties in the design of ventilation systems, heat supply and heating;
- a large concentration of cable equipment and pipelines stretched in mines to a huge height;
- the need for continuous monitoring of the main load-bearing structures of the building and base soils, etc.

Architectural and planning decisions of internal premises should take into account the psychological aspects associated with a person staying at a height.

Tall buildings have their own specifics, which are significantly different from traditional buildings. These features should be considered when choosing materials, structural solutions of high-rise buildings, as well as in the design of load-bearing structures, foundations.

2.1. Materials

Currently, tall buildings are increasingly preferred to be made of reinforced concrete, since this material has the highest fire resistance, and its strength characteristics are close to the strength of steel. The requirements for concrete as a structural building material for high-rise buildings have become especially stringent. Therefore, without modern technologies for the modification of monolithic concrete, which provide the necessary frost resistance, fire resistance, impact resistance and durability under aggressive influence, high-rise buildings cannot do. Concrete grades B80 and B100 were created and used, while the lower grades B60 and B70, high-strength concrete, are used in a wide range of construction practices.

2.2. Building foundation

A huge load is placed on the foundation of the building, because the specific pressure reaches 500-800 kPa or more. The depth of foundation can be 15-25 m. Nowadays, three types of foundations have been widely used in the design and construction of high-rise buildings: pile, slab and pile-slab. Massive slab foundations are the simplest and most economical design solution.

2.3. Structural schemes of high-rise buildings

With the development of high-rise buildings, several design solutions for these buildings have been developed:

1. frameless structure with parallel bearing walls;
2. core structure with bearing walls;
3. box-shaped structure;
4. frame structure with cantilever slabs in the level of each floor;
5. frame structure with girderless floor slab panels;
6. structure with storey high cantilevers in the level of each second floor;
7. structure with suspended storeys;
8. structure with storey high staggered trusses;
9. framed-and-ledged structure;
10. frame-core structure;
11. frame structure with lattice diaphragms;

12. frame structure with lattice horizontal gird and lattice core;
13. box-shaped core structure (pipe-in-pipe system);
14. multisectional box-shaped structure.

The choice of a specific design decision depends on many factors: the height of the building, construction conditions, architectural and planning requirements.

Constructive versions of the load-bearing enclosures of multi-storey buildings (box systems). In boxed systems, the outer bearing shells can be made in the form of beveled gratings made of steel or reinforced concrete. The drap-free grille does not create difficulties when placing a translucent fence on the facade of a high-rise building, but is inferior to the diagonal in terms of ensuring structural rigidity.

2.4. Bearing elements of structural systems of high-rise buildings

Shelf frame systems-columns, pylons and other similar elements are constructed using the so-called high-strength (HSC) and high-quality (HQC) concrete, the compressive strength of which reaches 100 MPa and higher. The overall dimensions of the columns and the number of service valves are determined by many factors. In case of insufficient bearing capacity, rigidity or longitudinal stability of the frame, reinforced concrete columns with an external steel cover or internal rigid reinforcement are used. This solution allows to increase the fire resistance of the structure.

The design of the columns located around the perimeter of the building with a barrel supporting system, largely determines its ability to resist existing loads. To suppress accelerations and reduce the amplitude of oscillations of the upper floors, columns with damping properties are arranged in these places, which help to limit the swing of the structure.

2.5. Walls

The walls of high-rise buildings are made of less durable concrete compared to the concrete used for the construction of columns. In high-rise buildings, the system of load-bearing walls has a monolithic concrete arrangement. This is due to the need to give the frame the maximum possible rigidity, which is technically difficult to provide with prefabricated versions.

Facades that are subject to significant energy and temperature and climate impacts during construction and operation are designed taking into account the structural systems of high-rise buildings. In frame systems and their varieties with columns located around the perimeter, chain structures with a canopy are used.

2.6. Interfloor overlappings

Overlapping high-rise buildings are decided depending on the adopted span. In the USA, the depth of the premises under natural light conditions is allowed 16 meters. To ensure a free layout of the floor, they also usually have a span of 16 m. In this case, beam stands with main and secondary beams are used, and the former are made of steel, both solid and lattice. Reinforced concrete beams are solid. For the device of the slab part of the ceilings, a monolithic reinforced concrete slab is widely used. In Europe, where the depth of the premises in buildings is limited to 8 meters, mainly flat monolithic reinforced concrete slabs with a thickness of 250 mm are mainly used. A feature of the floors of high-rise buildings is the fact that suspended ceilings are used to accommodate numerous engineering systems (ventilation, heating, air conditioning, power supply, etc.) and communications (computer, signal, video surveillance, automation, etc.). The total height of

suspended ceilings and technological floors can reach 900 mm, therefore, with a floor height of 3.6 m, the height of the room can be 2.7 m.

2.7. Staircase elevator structures

Staircase elevator structures of buildings play a special role in ensuring communication between floors and evacuation of people in case of emergency. Staircase elevator structures can combine the functions of communication lines and evacuation or can be performed separately. In both cases, their technical equipment is subject to certain requirements related to ensuring safety parameters.

Typically, staircase elevator structures are located in the central part of high-rise buildings. As a rule, they are located within the central trunk of structures with load-bearing systems. The fire resistance limit of staircase elevator structures is adopted according to national design standards.

2.8. Additional difficulties

The specificity of the loads, the technology of construction, operation of high-rise buildings causes a number of additional difficulties.

2.8.1 Fire safety, evacuation

Tall buildings, unlike buildings of normal number of storeys, have a high fire hazard due to their specificity.

For those who are in skyscrapers, the fire hazard increases due to the fact that there are difficulties in evacuation and rescue. Overlapping evacuation routes with products of combustion and fire is the main cause of the tragic consequences. Combustion products block emergency exits, elevator shafts and stairs. The spread of smoke and toxic gases can reach tens of meters per minute. After a few minutes, the building will be filled with smoke, and it will be impossible to stay indoors without respiratory protection. The smoke of the upper floors, where reconnaissance, rescue and supply of fire extinguishing agents are most difficult, is most intense. In addition, in the event of a fire, elevator equipment and fire protection systems often fail.

Analysis of the consequences of fires in high-rise buildings and structures that were built at the end of the last century, revealed the following causes of the tragic consequences:

- Low fire resistance of building structures and engineering equipment, especially metal beams and trusses;
- Large internal volume without fire barriers
- Lack of a sufficient number of stairs and their necessary width for evacuation;
- The presence of numerous holes in the walls and ceiling for the use of air conditioners, electrical equipment and other technological needs;
- Lack of evacuation plans in the event of an accident or fire;
- The presence of false ceilings;
- A large number of combustible equipment, furniture and cladding.

2.8.2 Wind loads

Skyscrapers sway under gusts of wind, and often these fluctuations cause great discomfort at the top. The wind blows through the buildings, creating whirlwinds - "mini-tornadoes" that pose a danger to the building.

Increasing the resistance of tall buildings to wind loads can be achieved in several ways

The first of them: the circular shape of the building is most suitable in relation to the effects of wind. A little inferior to its oval shape, square then. In this regard, many high-rise buildings have the shape of a circle or oval.

Rational forms of buildings:

- a triangular prism;
- elliptical cylinder
- vertical shell;
- shape narrowed up;
- a pyramid;
- round cylinder.

An increase in rigidity can also be achieved by giving the high-rise buildings a certain taper, as well as the use of a multi-section box version of the system. In the latter case, horizontal loads, in addition to the outer shell, can also be perceived by the internal transverse walls and the presence of core rigidity, the projections of the building divide the wind flow and weaken it.

The second method: a special mechanism that damps the vibrations of tall buildings, so there is no resonance. One way is to install a vibration muffler on top. He hesitates with the building, but is so heavy that he does not keep up with the vibrations of the building and dampens them due to inertia. The role of the damper is sometimes performed by a water tank, which can be used to extinguish fires.

2.8.3 Seismic load

Speaking about the design of high-rise buildings, designed for the impact of seismic loads, it should be borne in mind that earthquakes of up to 4 points at the level of the earth's surface lead to the appearance on the upper floors of effects corresponding to impacts of 6, 7 or more points.

Earthquake protection can be carried out in various ways, for example, various types of damper and supports, multi-frequency vibration damper, etc.

In addition, sometimes they use special systems that protect skyscrapers from falling - for example, in Japan, where earthquakes often occur, or in San Francisco, an American city that stands on the edge of a tectonic plate.

3 Resume

With increasing concentration of the population, the demand for high-rise buildings also grows, as if humanity is beginning to grow upward, filling itself with vertical space. But high-rise buildings carry not only practical meaning, but also aesthetically-architectural, and even sports, because the race for heights is still ongoing.

The construction of high-rise buildings has many features and trifles, which increase both the cost and complexity of construction. Huge loads from all sides and environmental conditions compel designers, architects and builders to look for new modern solutions that will allow them to create even larger projects and with unremitting curiosity to conquer new heights.

Based on the results of the study, one can determine the following:

- with an increase in the urban population, the number of storeys (height) of residential buildings and office buildings increases;
- the race for the construction of the tallest building in the world will only continue and, judging by the trend, it will include more and more new countries and cities;
- the main thing that needs to be taken into account when designing and constructing high-rise buildings is a strong, correctly selected frame and a reliable foundation, as well as solving other issues related to the features of high-rise construction.

When constructing high-rise buildings, in addition to technical features, it is important to consider the preservation of the existing urban infrastructure. It is necessary to comply with existing standards and architectural requirements for high-rise buildings in force in a particular city. Do not forget about the problems associated with the exterior design of high-rise buildings.

References

1. M.V. Gravit, D. Serdjuk, et al., Magazine of Civil Engineering, **1 (85)**, 92-106, Peter the Great St.Petersburg Polytechnic University (2019) DOI: 10.18720/MCE.85.8
2. O. Gamayunova, T. Musorina, and A.D. Ishkov, E3S Web of Conferences, 02045 (2018) DOI: <https://doi.org/10.1051/e3sconf/20183302045>
3. V.V. Lalin, and V.A. Rybakov, Magazine of Civil Engineering, **8 (26)**, 69-80, Peter the Great St.Petersburg Polytechnic University (2011) DOI: 10.5862/MCE.26.11
4. V.A. Rybakov, I.A. Ananeva, et al., Magazine of Civil Engineering Engineering, **6 (74)**, 161-174, Peter the Great St.Petersburg Polytechnic University (2017) DOI: 10.18720/MCE.74.13
5. N.I. Vatin, A.Y. Ivanov, et al., Magazine of Civil Engineering, **8 (76)**, 67-83, Peter the Great St.Petersburg Polytechnic University (2017) DOI: 10.18720/MCE.76.7
6. Z.Q. Liu, J. Zhang, et al., Magazine of Civil Engineering, **7(91)**, 121–128, Peter the Great St.Petersburg Polytechnic University (2019) DOI:10.18720/MCE.91.11
7. T.A. Musorina, O.S. Gamayunova, and M.R. Petrichenko, Vestnik MGSU, **13, 8 (119)**, 935-943, Moscow State University of Civil Engineering, Moscow (2018) DOI: 10.22227/1997-0935.2018.8.935-943
8. O. Gamayunova, E. Gumerova, and N. Miloradova, E3S Web of Conferences, 02046, D. Safarik, Y. Tabunschikov, and V. Murgul (eds.) (2018) DOI: <https://doi.org/10.1051/e3sconf/20183302046>
9. S.A. Isaev, N.I. Vatin, et al., High Temperature, **53 (6)**, 873-876 (2015) DOI: 10.1134/S0018151X15040136
10. M.V. Gravit, O.V. Nedryshkin, and O.T. Ogidan, Magazine of Civil Engineering, **1 (77)**, 38-46, Peter the Great St.Petersburg Polytechnic University (2018) DOI: 10.18720/MCE.77.4
11. M.R. Petrichenko, E.V. Kotov, et al., Magazine of Civil Engineering, **1 (77)**, 130-140, Peter the Great St.Petersburg Polytechnic University (2018) DOI: 10.18720/MCE.77.12
12. M.V. Gravit, E.V. Golub, et al., Magazine of Civil Engineering, **8 (84)**, 75-85, Peter the Great St.Petersburg Polytechnic University (2018) DOI: 10.18720/MCE.84.8
13. O. Gamayunova, M. Petrichenko, et al., MATEC Web of Conferences, 06006 (2018) DOI: 10.1051/matecconf/201824506006

14. O. Tsareva, and F. Portnov, E3S Web of Conferences, 01056 (2019) DOI: 10.1051/e3sconf/201911001056
15. M.V. Gravit, D. Serdjuks, et al., Magazine of Civil Engineering, **1 (85)**, 92-106, Peter the Great St.Petersburg Polytechnic University (2019) DOI: 10.18720/MCE.85.8
16. M.V. Gravit, M.D. Terekh, et al., IOP Conference Series: Materials Science and Engineering, 012016 (2018) DOI:10.1088/1757-899X/456/1/012016