Features of construction control in the construction of high-rise buildings

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Abstract. With the continuous development of the social economy and the relentless progress of modernization, the construction industry has greatly contributed to the rapid development of urban planning. High-rise buildings are playing an increasingly important role in Russia’s economic construction. Based on the research and analysis of the current state of high-rise building development in the world and Russia, as well as the technical characteristics of construction control, to summarize the current problems in the high-rise building construction control field in Russia and put forward the relevant control measures. Based on an extensive review of scientific literature at home and abroad, this study analyzed the following issues as high-rise building construction control in terms of development history, influencing factors, and technical characteristics of Russian high-rise buildings, where the key focus was on the historical development and technical attributes of high-rise buildings in Russia; the current shortcomings and development prospects of Russian high-rise buildings were identified, and analogies and graphical analogies were proposed. In Russia, the development of high-rise buildings is hampered by the fact that 30 years ago, there was no unified regulatory and research base on high-rise building management. Currently, the Russian Ministry of Construction is actively developing normative and methodological documents to make up for inactive and outdated records in the field of high-rise buildings.

1 Introduction

With the appearance of high-rise skyscrapers in Chicago in the late 19th century, ultra-high buildings have dramatically changed the look of major cities in various countries over the past hundred years. Every few decades, the rise of new economic systems promises another high-rise building to refresh the city’s skyline. In fact, until the mid-to-late 19th century, the highest architectural heights were still the architectural wonders of the ancient world (such as pyramids, temples, etc.). In ancient times, buildings reaching more than 100 meters were religious structures, except for palaces and tombs, where the symbolic meaning of height was more important than its actual use. Following the Industrial Revolution, when large numbers of people concentrated in cities, urbanization accelerated greatly [1]. The development of industry and commerce places ever-higher demands on building density

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and height. Rising land values in the city have contributed to upward development, becoming a more cost-effective alternative (Figure 1).

![Fig. 1. Changing patterns in global urbanization (1800–2050).](image)

With the rapid development of the construction industry, land resources are becoming less and less, construction began to pay more attention to the space field, and high-rise buildings developed rapidly. Construction management of high-rise buildings has the characteristics of general construction management of high-rise buildings, but large-scale projects and high construction complexity have revealed new challenges to construction management.

High-rise buildings in Russia began to flourish in 2000 (Figure 2). According to the World Society of Tall Buildings and Urban Habitat (CTBUH) statistics, as of 2021, Russia is home to 7 of the 10 tallest buildings in Europe (Figure 3). There are 87 high-rise buildings over 130 meters tall and 18 projects under construction, mostly concentrated in Moscow, St. Petersburg, Yekaterinburg, and other major cities [2]. The number of high-rise buildings in Russia is also growing.

![Fig. 2. Construction completion schedule.](image)
Fig. 3. Information about the top 5 best high-rise buildings in Russia

The highest building in Russia is located in the center of Lakhta, St. Petersburg [3], with a height of 462 meters – it is the highest building in Europe at present, which has won the CTBUH2021 award for Best Tall Buildings 400 meters and above, the European Excellence Award 2021 for Best Tall Buildings, the Architecture 2021 Award for Outstanding Achievement and many other awards, and it is one of the 5 most sustainable ultra-high buildings in the world.

2 Materials and methods

Based on an extensive review of scientific literature at home and abroad, this study analyzed the following issues as high-rise building construction control in terms of development history, influencing factors, and technical characteristics of Russian high-rise buildings, where the key focus was on the historical development and technical characteristics of high-rise buildings in Russia; the current shortcomings and development prospects of Russian high-rise buildings were identified, and analogies and graphical methods were proposed (Figure 4).
Fig. 4. Research Task Sequence.


Construction control, in its essence, is a set of checks, the importance of which is to ensure that the work is carried out under the requirements of regulatory documentation and control of the cost estimates and timing of work.

The purpose of construction supervision is to provide control over the quality of construction work and guarantee the use of building materials and structures that are provided by the project [6].

Disputes occur between all participants in the construction process regarding construction control procedures and many other issues that arise because the participants interpret the provisions of Resolution of the Government of the Russian Federation No. 468 (hereinafter – the Resolution) differently.

Lack of flexibility in construction control

Following clause 12 of GOST 27751-20148 and clauses 8-10 of part 1 of Art. 1 of Article 4 No. 384-F31, in practice, construction control is not divided into levels of different types of buildings and structures following the assigned categories, classes and groups of responsibility. Construction controls for all facilities are planned and implemented similarly, not considering temporary buildings and structures of normal and elevated levels. Relying on the laws that cover the entire list of construction works, except for finishing works affecting safety, all participants in the construction process need to certify most of the works and sign all necessary acts by the customer. All of this suggests that the necessary flexibility required by standards and laws needs to be included. This flexibility is essential so that different levels of customer construction control can provide control for different types of buildings and types of work that affect safety [7].

3 Results

3.1 Specifics of control and management of the construction of high-rise buildings

3.1.1 Large scale of structures, high cross-building requirements

The scale of high-rise buildings is enormous. The overall construction planning, deployment, process, and division of construction zones must consider various influencing factors (Figure 5). At the same time, in most cases, construction is located in the city center, surrounded by a complex environment, affecting numerous industries and areas. The environmental and safety requirements are high, and the complexity is great.
3.1.2 Greater difficulty in constructing deep foundation excavations

The foundations are buried relatively deep, where the excavation depth reaches 20 m and some even 30 m, to stabilize the structures and develop underground space for high-rise buildings. The construction area of the basement is relatively large, the construction period of deep excavation is long, and the construction risk is huge. During the basement excavation phase, if the gutter curtain leaks over a large area, the excavation cannot be done according to the regulations. At the same time, the most complex difficulties to be overcome in constructing engineering piles, lateral wall pipes, sand backfill, etc., in a medium-sized foundation pit will be the difficulties in making deep foundation pits for high-rise buildings (Figure 6). The construction of deep excavations should also consider key technical measures and innovative requirements to ensure construction time and save circulating materials such as formwork.
3.1.3 Complex basic structure of high-rise buildings: ultra-high building structure of high-rise buildings, high construction technology

The peculiar shape of high-rise buildings increases the structure’s complexity and the construction’s difficulty. Firstly, the construction of the building uses high-strength concrete and an ultra-high concrete pumping height of 200 meters, increasing the complexity of concrete construction. Second, the concrete structures of high-rise buildings utilize a composite steel structure system (Figure 7). At the same time, increasing structural stability also requires high-construction technology. As a result, the frame scaffolding system and safety protection, protective layer structure, 40-m roof, the steel structure of the lightbox and installation of the translucent facade, lifting large-sized equipment to a great height, etc., make high demands on the stability of the building structure.

![Fig. 7. Plan of the integrated steel structure system.](image)

3.1.4 There are many professional sectors within the construction industry, ultra-high buildings have numerous features and complex systems

The cross-construction of professional building blocks, such as steel framing, curtain walls, hardcover finishes, elevator, and low current, has increased the complexity of general contractor organization and coordination. At the same time, a large amount of detailed design work needs to be done during the construction process, but the general contractor’s technical management tasks are important, the workload is large and coordination is difficult (Figure 8).

![Fig. 8. Features of control over the construction of high-rise buildings.](image)
3.2 Typical problems in construction management of high-rise buildings

Typical problems in construction management of high-rise buildings are shown in Figure 9.

3.2.1 There is a certain irrationality in the construction format

In the construction management of high-rise buildings, most of the construction work is carried out by labor subcontracting, and there are serious shortcomings in the culture level of many construction workers. Although construction personnel have been involved in construction projects for a long time and have rich experience, they are limited by their cultural level, which resulted in construction personnel failing to accurately understand the impact of new construction technologies on improving construction quality and process. Traditional construction methods are still used in construction work nowadays, resulting in many modern facilities and equipment on the construction site being idle, affecting the quality of construction and leading to serious unnecessary waste in construction costs. In addition, although some construction departments pay great attention to new technologies, the construction process is slowed down due to insufficient operation. The quality of the construction work was neglected at a late stage of the construction work to speed up the work progress. Under the influence of this vicious circle, the construction quality, construction progress, and construction safety of high-rise buildings have been seriously damaged, which has greatly affected the long-term development of high-rise building construction level.

3.2.2 Irregular categories (phenomena) existing in the construction process

In constructing high-rise buildings, the construction links are complex and intricate. Construction managers and construction operators often overlook the relevant provisions of rules and regulations during construction, so operation in violation of regulations is common. Rules and regulations formulated by construction departments are often superficial and cannot play a significant role in construction supervision and management. Building codes and regulations are the main guiding documents in the construction process of high-rise buildings. Although there is a certain degree of difference between high-rise buildings and traditional buildings at the construction level, and they have a certain degree of flexibility, the smooth development of construction work should be based on adherence to rules and regulations as a fundamental condition; construction managers and operators should strictly carry out their duties following relevant laws and regulations, and then constantly improve the construction efficiency and construction work quality and make timely contributions to the construction of high-rise buildings.

3.2.3 There are certain omissions in the collection of data in the workplace

Field studies of labor activity at the construction site are an important prerequisite for ensuring the quality of construction work. However, in the construction of high-rise buildings at this stage, many surveyors cannot carry out survey work on time per the requirements, resulting in a certain deadlock in the field survey [8]. The geological materials the relevant technical personnel provided are not perfect, and their reliability is difficult to guarantee. The spacing between boreholes is too large in actual exploration, resulting in a lack of staff understanding of the actual soil foundation condition. When the foundation surface of the construction site is undulating, it directly affects the thickness of the soil layer. The drilling depth by exploration personnel during operations is inadequate, resulting in a serious misunderstanding of underground soft ground layers, landslides, pits,
and other stratigraphic structures in situ. Thereby, it directly impacts the accuracy of the work project (WP). Under the influence of the above factors, uneven foundation settlement of high-rise buildings often occurs during the construction process, significantly reducing high-rise buildings’ stable performance. At the same time, the walls of the above-ground part of buildings are highly susceptible to cracking, collapse, and other phenomena.

Fig. 9. Typical problems in the construction management of high-rise buildings.

China began conducting research into high-rise building construction in the early twentieth century. At that time, in Shanghai, Tianjin, Guangzhou, and other places, China actively studied progressive Western high-rise construction technology and built a number of high-rise buildings according to the advanced world standards of the time. In 1976, with the completion of the 114-meter-high Baiyun Hotel in Guangzhou, China entered a phase of ultra-high building development.

After the reform and opening-up policy, the urban modernization process accelerated, and the agglomeration effect in the city’s central part became more obvious, which stimulated the demand for a large amount of office and residential space. As land prices continue to rise as a share of construction costs, buildings are also being built higher and higher. At the time, a popular concept stated: “The height of the tallest building in the city reflects the level of urban economic development and is a sign of urban modernization”.

The policy of reform and openness has not only contributed to accelerated urbanization. After many foreign companies came to China, their demand for modern office environment and equipment also led to a boom in ultra-high-rise buildings. China’s continuous economic development over the years has also objectively provided an internal driving force for developing ultra-high-rise buildings.

There are currently 2,964 buildings over 150 meters tall, of which 964 are over 200 meters tall, and 102 are over 300 meters tall [9]. Six of the ten tallest ultra-tall buildings in the world are in China. The Shanghai Central Building, completed in 2015, is the tallest ultra-high building in China in modern times, standing 632 meters tall with a total of 120 floors. Worldwide, the Shanghai Central Tower is second only to the Burj Khalifa skyscraper in Dubai, with a height of 828 meters. Among the 10 cities in the world with the
most buildings above 150 meters, Hong Kong, Shenzhen, Shanghai, Guangzhou, and Chongqing are among the top five Chinese cities (Figure 10).

![Skyscrapers of the 21st century](image)

Fig. 10. Global information about high-rise buildings in the 21st century.

3.3 Construction site management of a high-rise building

Technology of observation of construction settlement of high-rise buildings

According to the characteristics of high accuracy of building settlement observation, it is generally stipulated that the measurement error should be less than 1/10-1/20 of the deformation value to reflect the foundation settlement under constant load accurately. For this reason, it is required that a high-precision aluminum alloy leveling rod be used when observing settlement, which is less affected by environmental changes and temperature differences. If an aluminum alloy leveling rod is unavailable, an ordinary tower ruler and the first rod can be used as often as possible.

3.3.1 Control of the “three lines” of high-rise buildings

The axis, height, and verticality are similar to the meridians of a building. For high-rise buildings, due to the wide range of aspects involved and the complexity of operation, displacements or inaccurate phenomena often occur. Controlling the “three lines” is a major difficulty in high-rise buildings.
Verticality control. Verticality control is the basis of quality assurance for high-rise buildings and one of its key links. To control the verticality of the building, firstly, the position of the four corner columns of the building should be determined according to the location of the building column network [10]. In setting up the formwork of the four corner columns, draw a thickness line along the outer layer of the column, set up the formwork, add support, and use the plumb line method to measure the verticality of the column. After achieving 100% verticality, align the outer edge of the formwork with the reinforcement of the support and pour concrete [11].

After removing the quadrangular column, the remaining columns use it as a baseline and string a steel wire to control the uniformity and verticality of the façade. The verticality control uses a laser device and a heavy hammer for a double comparison test, which can improve the verticality accuracy [12]. At the same time, the external double inspection can minimize the vertical measurement error of high-rise buildings.

Axis control. Axis changes. In the construction of high-rise buildings, the scaffolding is lifted in synchronization with the construction layer; as a result, it is not possible to load from some anchor points. For this reason, after checking the correctness of the axis of the structure ± 0.00, several pieces of 200*200*8 mm steel plates are inserted in the longest vertical and horizontal direction according to the floor, and the reference axis or reference points of the main axis are marked on the steel plate. During the construction of the second floor and above, a 200 * 200 mm square hole is left in the corresponding position of each floor based on the first floor, and a large linear hammer is used to determine the reference points of the lower floor. A theodolite and steel tape measure are then used to calibrate and release each layer’s axis and dimension lines.

Reference line control. At least four holes in the pre-monitored axis of each floor (generally, the elevation should point upward from 3 locations) to determine the elevation, supplemented by a review of the sum of the layered elevations and then supplemented by a leveling level to verify that the four points are in the same horizontal plane to ensure the accuracy of the elevation [13].

Crack control during construction. If there is insufficient space for deformation, measures are taken to prevent crack formation – “unblocking” measures: installing permanent expansion joints, leaving separation joints at appropriate locations on the exterior wall, etc. “Anti-measures”: avoid stress concentration caused by structural changes in cross-section, and pay attention to the configuration of structural steel bars. For lightweight walls such as small concrete hollow blocks, add structural columns at > 3 m intervals and a concrete belt beam 120 mm thick and the same width as the wall at the mid-height of the wall of each floor. Add load-bearing columns at the free end of masonry; reinforce the reserved door and window openings with reinforced concrete frames. Reinforce armored door and window openings with reinforced concrete frames. Steel wire mesh (150 mm lap length on all sides) is used at the junction of two different substrates for processing. Rationally, place a vapor barrier, roof insulation layer, etc. The “release” and “resistance” measures are reasonable installation of the tape after pouring, the use of appropriate technology to compensate for concrete shrinkage, and the addition of large amounts of cellulose to the concrete, etc.

3.3.2 A smart construction site system

It is a safety management system for the life cycle of construction projects extended based on the smart concept [14, 15]. A smart construction site system has the characteristics of professional and efficient digital platformization and application integration. It can effectively enhance the construction site control and management level and improve
construction quality, environmental management, personnel safety, and economic benefits, leading to widespread use in the construction industry.

Highly efficient industry.

Smart construction site system is based on the production activities of construction sites, which truly realizes a high degree of integration between the construction stage and information technology; integrates and manages construction information resources; provides it with professional management and decision-making support, and effectively solves the business problems of the construction site.

Digital platformization. The smart construction platform system digitizes all elements and processes of the construction site, creates a virtual digital space, seamlessly integrates it with the site, forms mapping relationships, accumulates a large amount of data and information resources, and effectively solves management and technical problems in engineering construction projects through in-depth analysis of information processing results [16, 17]. The smart system has established a robust data collection and processing platform to effectively enable real-time information collection and sharing and enhance the ability of different departments to work together [18].

Practical integration. Smart construction site system fulfills the main purposes of various functional integration of information technology, realizes the optimal allocation and linkage of resources, meets the needs of engineering construction, and ensures the implementation and efficiency of the information management system [19].

4 Discussion

There are only 87 buildings over 130 m high in Russia; 18 objects are under construction, and 28 projects still need to be realized. Compared to countries such as the US and China, the number of high-rise buildings is significantly different. However, Russian construction technologies, improvement of construction materials, engineering solutions, and other aspects are developing at a high speed.

In Russia, the development of high-rise buildings has also slowed down since 30 years ago, there was no unified regulatory and research base for high-rise construction management: each project had its documents formulated and approved, which, in turn, hindered the popularization and widespread development of high-rise buildings.

However, the rapid development of high-rise buildings in China after entering the 21st century. There are 2,964 buildings over 150 meters high in China, of which 964 are over 200 meters high, and 102 are over 300 meters high. Six of the ten tallest ultra-high buildings in the world are in China. The Shanghai Central Building, completed in 2015, is the tallest ultra-high building in China in modern times, standing 632 meters tall with 120 floors. Worldwide, the Shanghai Central Tower is second only to the Burj Khalifa skyscraper in Dubai, with a height of 828 meters. Hong Kong, Shenzhen, Shanghai, Guangzhou, and Chongqing are among the top 10 Chinese cities in the world with the most buildings above 150 meters. This provides a great experience for Russian high-rise buildings; in recent years, the Russian government’s introduction of several new regulatory legal acts has actively contributed to the rapid development of the construction sector. The Forum “100+ Russian High-Rise Buildings”, one of the organizers of which is the Ministry of Construction of Russia, serves as an effective official exchange platform for sharing experiences and solving problems in high-rise construction in the country and abroad.

Today, the Russian Ministry of Construction is actively developing normative and methodological documents to replenish inactive and outdated documents in the field of high-rise buildings. Due to the large number of floors, large building area, and long construction cycle, high-rise buildings require huge capital investment. For this reason,
lowering the construction cost is important for saving project investment. At the same time, the judicious use of building controls will contribute to the sustainable development goals of green buildings and structures.

5 Conclusion

The history of high-rise construction development in Russia has a long history and rich experience. However, given the complex technical characteristics of high-rise buildings and the problems encountered during construction, the need to improve construction control has been proven. Russia is currently facing a conflict between new construction technologies and materials and the lack of a modern construction supervision system. At the same time, the Russian Ministry of Construction is actively clarifying regulatory and methodological documents to compensate for inefficient and outdated high-rise buildings. However, on the construction and owner side, improving construction progress control, optimizing construction technology, and improving management are also important. Based on the experience of high-rise construction in China and its wisdom, it is necessary to study the management technology of high-rise buildings. The construction site system, which combines building management and a digital information platform, enhances the ability of construction units and departments to work together, improves the work efficiency and quality of high-rise construction projects, and is the main research direction in the future.

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