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ANALYSIS OF THE INFLUENCE OF EXTERNAL FACTORS ON THE DEFORMATION OF HIGH-RISE BUILDINGS IN THE PROCESS OF THEIR CONSTRUCTION AND OPERATION

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During the construction and operation of high-rise buildings, their vertical axis changes its position in space. The higher the building, the greater the amplitude of oscillation. It causes problems of geodetic construction support and the need to monitor deformations during the operation of high-rise buildings. The article examined and analyzed the influence of external forces of the change in the geometry of a high-rise building and focuses on solving the scientific problem of geodetic support for the construction and operation of modern high-rise buildings under dynamic loads.
Keywords: high-rise construction, vertical axis of the structure, deformations of the high-rise structure, subsidence, tilt, bending, wind force, solar radiation, temperature deformations.

Introduction. In the modern conditions of the megacities development, the construction of high-rise buildings is widely used for public needs. A modern city should have its own unique face, one ofthe elements of which is modern architecture, which no longer exists without high-rise buildings.

Modern high-rise buildings reach a height of hundreds of meters. As they are erected, and in thesubsequent operation, the structure is affected by temperature fluctuations, which arise as a result ofuneven heating of the structures by the sunlight rays and the force of the wind, which, as a result,cause the vertical axis of the high-rise structure to deviate from the vertical line along which the forceof gravity acts. The study of the influence of external factors on the geometry of a high-rise buildingwill allow solving the scientific problem of geodetic support for the construction and operation ofhigh-rise buildings. Therefore, the development of modern technologies and methods of geodeticsupport for construction and monitoring of deformation processes that may occur during theoperation of high-rise buildings is urgent.

Analysis of research and publications. According to [1], the classification of high-rise buildings used in the world is given, in addition, types of tower buildings and their structural features are given in [2]. It should be noted that in [3] there are absolutely no high-rise buildings, the so-called "skyscrapers". The author has considered in detail the influence of external factors on the change in the geometry of tower structures, formulas from theoretical mechanics for modeling the change in their geometry have been given, but, unfortunately, not enough attention has been paid to modern methods and technologies of geodetic support during the construction and monitoring of geometric parameters of high-rise buildings, namely technologies using electronic total stations and GNCC. The author mentions only methods of geometric leveling to determine subsidence and angular measurements using theodolites.The occurrence of defects building structures is a common phenomenon in the operation of vertical structures. Such defects can occur both at the beginning of the operation of the vertical structures, which may be associated with a violation of the manufacture conditions or the installation procedures of the elements and during operation. [4, 5].

Setting objectives. Traditionally, during construction, a high-rise building was considered a static object, and when it came to the deviation of the geometry of the building from the design values, they meant the deviations caused by errors in the execution of geodetic works, the accuracy of construction manufacturing, and the accuracy of installation work. But high-rise buildings and structures are dynamic objects that, under the influence of external forces such as solar radiation (temperature fluctuations) and wind loads, change their position in space, that is, their vertical axis deviates from the vertical line along which the force of gravity is directed. Thus, a high-rise building has not only the tilt that was traditionally defined, but also the bending of the vertical axis of the building and torsion. These deformations are in no way related to errors in geodetic or installation work. Therefore, both at the stage of construction and at the stage of operation, it is necessary to know all changes in the geometry of the structure, to understand the reasons for their occurrence and their nature.

The main part. High-rise buildings or buildings are free-standing structures fixed at the base by means of their own foundation. A feature of such buildings is that their height is significantly higher than the dimensions in the plan.

Any structures, in the process of operation, are exposed to external forces that cause their deformation. As a rule, if we are talking about buildings or structures that are not high-rise, then the main deformations are associated with a change in position in height or in plan, the consequence of which is the appearance of cracks in building structures.

For a better understanding of the process of deformation caused by the action of forces, it is necessary to give a definition of this physical quantity and give a list of forces that can act on a high-rise building and cause its deformation.

Therefore, force is a measure of the interaction of two bodies. In our case, we take a high-rise building as the first body, and the second body is the external environment.

Let's look at a high-rise building through the prism of theoretical mechanics. If a high-rise building is taken as a solid body, and according to the mechanics of solid bodies, solid bodies are bodies that do not change their size and shape, then such a building should not change its size and shape. But absolutely solid bodies do not exist in nature, therefore deformations occur in bodies under the action of force. Depending on the direction of force action and the point of its application, we have changes in the geometric parameters of these structures.

Traditionally, in geodesy, we associated the deviation of the geometry of buildings from the design dimensions with the accuracy of geodetic marking works, installation works and the accuracy of manufacturing structures. But this system lacks the influence of external forces such as wind and temperature. Which significantly affect the change in the geometric parameters of high-rise buildings when the height is increased.

Therefore, it is necessary to analyze the forces and deformations that arise in high-rise buildings under their influence. Deformation is the movement of body points in space. According to [2], in construction mechanics, displacement is understood as linear deviations of points of the structure, angles of rotation of sections and their combinations under the influence of force loads. That is, the displacement is a vector that connects the position of the point at the beginning and at the end of the displacement during a certain time interval, the direction of which coincides with the chord of the trajectory of the point.

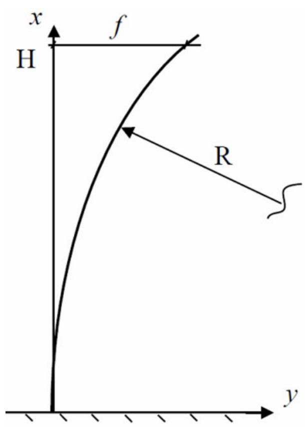

Fig. 1. Deflection of the axis of a high-rise building without tilt

Our task is to divide the concept of "deviation" into two components, namely:

the first is a deviation during the construction of structures that are related to accuracy, which was mentioned above, the second is the influence of external forces.

Thus, if we imagine that the structure is being built with absolute precision, then it will not have any deviations, but during the construction process, the structure will be affected by, for example, the force of the wind, which will cause the axis of the structure to deviate from the vertical, which cannot be ignored during the execution of detailed marking works.

Therefore, it is important to study and analyze in detail the external forces acting on the structure in the process of both its construction and operation in order to determine the deformations in order to prevent emergency situations and the destruction of high-rise buildings.

Traditionally, in relation to high-rise buildings, when determining their deformations, we talked about subsidence and roll. Sedimentation could be uniform or uneven. The result of uneven settlement is tilt. That is, in this case we are talking about the behavior of an absolutely solid body, but, as was mentioned earlier, there are no absolutely solid bodies in nature, therefore, in addition, a deflection of the axis of the structure may occur in the structure.

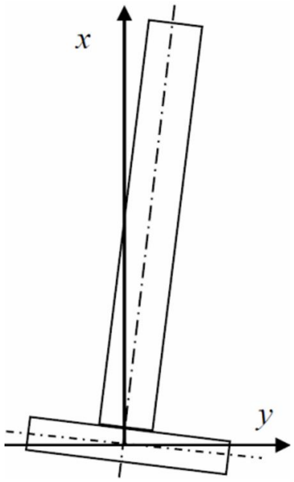

Fig. 2. The tilt of a high-rise building

Under these conditions, we separate the concepts of tilt and deflection of a high-rise building. By roll we understand the process of deformation of the ground base caused by the uneven settlement of the foundations, and as a result of the inclination of the vertical axis of the structure (Fig. 2).

So, as we can see, the external forces acting on the structure cause various types of deformations. Thus, we highlight the following main forces that must be taken into account during the construction and operation of high-rise buildings to determine their deformation:

- temperature;
- wind force;
- gravity.

Effect of temperature. According to the molecular-kinetic theory of the structure of substances, any substance consists of molecules that are at a certain distance from each other. Molecules are in chaotic motion (thermal motion) and constantly interact with each other, attracting and repelling each other. The higher the temperature of the body, the faster the molecules move, thereby increasing the average distance between them and, accordingly, the volume of the body increases. Conversely, with a decrease in body temperature, the movement of particles becomes slower, the intermolecular spaces decrease and, accordingly, the volume of the body decreases. Thus, we have the dependence of the size of bodies on the change in temperature.

Now we should analyze how the change in temperature affects the change in the geometric dimensions of the high-rise building. If a high-rise building is modeled in the form of a rectangle, then when the temperature changes, its dimensions will change proportionally, both vertically and in plan (Fig. 3)

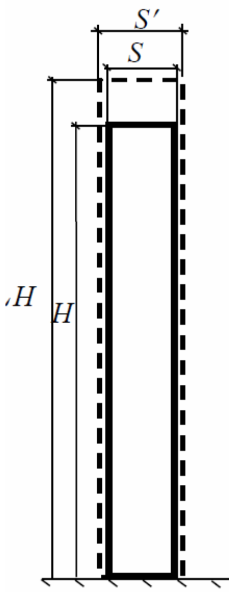

Fig. 3. Changes in the size of the building when temperatures change

$$\Delta h = H' - H = a_t \cdot H \cdot \Delta t, \quad (1)$$

$$\Delta s = S' - S = a_t \cdot S \cdot \Delta t, \quad (2)$$

where $\Delta h, \Delta s$ – changing the dimensions of the building in height and plan, a_t – proportionality factor (thermal expansion coefficient of the material), $\Delta t = t_2 - t_1$ – the difference between initial and final temperatures.

During the construction of high-rise buildings, the load-bearing structures are mainly made of reinforced concrete.

According to the table of values of coefficients of thermal expansion of some materials, we have:

- concrete $a_t = 12 \cdot 10^{-6}\,°\mathrm{C}^{-1}$;
- iron $a_t = 11.1 \cdot 10^{-6}\,°\mathrm{C}^{-1}$.

As you can see, the coefficients of thermal expansion for iron and concrete are almost equal. Therefore, we will calculate the thermal expansion of a high-rise building made of reinforced concrete structures in accordance with formulas (1) and (2) and place the data in table 1 and present it in the form of a graph (Fig. 4).

Table 1

Type	α_t, °C^{-1}	t_2, °C	t_1, °C	H, m	Dh, mm
Reinforced concrete	1.20E-05	50	20	100	36
	1.20E-05	50	20	200	72
	1.20E-05	50	20	300	108
	1.20E-05	50	20	400	144
	1.20E-05	50	20	500	180

When calculating the temperature expansion, $t_2 = 50°\text{C}$, $t_1 = 20°\text{C}$ was taken, which is quite realistic from the point of view of the operating conditions of the building.

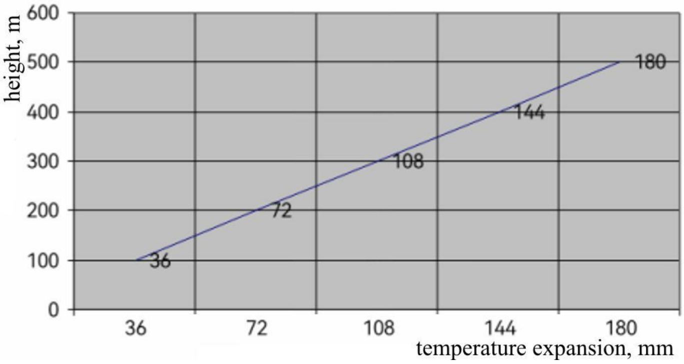

Fig. 4. Temperature expansion of reinforced concrete depending on the height

From the calculations, it can be seen that at a building height of 100 m with a temperature difference of 30°C, the thermal expansion will be 36 mm, and at a building height of 500 m, the thermal expansion will be 180 mm, which significantly exceeds the permissible accuracy of transferring the mark to the installation horizon according to DBN B.1.3-2:2010 "Geodesic works in construction", which for the first class of accuracy of structures is

$$m = (2 + 10H)\text{mm} = 2 + 10 \cdot 1 = 12\text{mm}$$

for a height of 100 m and 52 mm for a height of 500 m.

At the same time, all of the above refers to the uniform temperature expansion of the entire building, which causes its uniform increase in size.

And now, the influence of temperature should be looked at from the point of view of real conditions of operation or construction, in which uneven heating of building structures occurs. That is, part of the structures will be in the shade and their temperature will be lower than the structures that will be under the influence of solar radiation, the temperature of which will be much higher. Thus, the structure will be deformed as a result of uneven thermal expansion, that is, it will bend (Fig. 5).

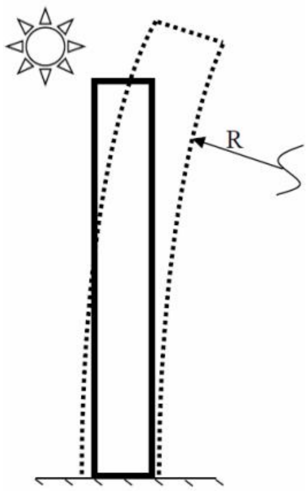

Fig. 5. Deflection of the structure as a result of uneven thermal expansion

Thus, it can be concluded that during geodetic support of the construction and operation of high-rise buildings, changes in the temperature regime of building structures should be taken into account in connection with significant absolute values of changes in the geometric dimensions of the building as a result of thermal expansion, which significantly exceed the accuracy regulated by the regulatory document.

Effect of wind force. Similarly to the influence of solar radiation on a high-rise building, the force of the wind will also act, which will also cause the axis of the building to bend. As you know, the force of the wind compared to the temperature effect will have a much greater effect on the structure.

Under the influence of the force of the wind, the axis of the building will have a deflection, the absolute value of which will depend on the speed of the wind, the height and shape of the building on which it will act, causing pressure on its surface.

A table with the Beaufort scale is given in [2]. The wind speed is determined at a height of 10 m, which is used for construction purposes.

Table 2

The nature of the wind	A distinction sign	Wind strength in points	Pressure, Pa	Wind speed, m/s
Calm	Smoke rises vertically	0	0	0
Quiet	Smoke rises at a slight angle	1	0,61	0,6-1,7
Light	The movement of the wind is felt by the face	2	2,5-5,6	1,8-3,3
Weak	Tree leaves move	3	10-15	3,4-5,2
Moderate	Thin tree branches move	4	22-40	5,3-7,4
Fresh	Mediumtree branches sway	5	50-62	7,5-9,8
Strong	Large tree branches sway	6	75-105	9,9-14,4
Sturdy	The trunks of small trees sway	7	123-180	14,5-15,2
Very strong	Wind breaks branches, delays people	8	200-250	15,3-18,2
Storm	Wind tears the roof off, breaks trees	9	276-306	18,3-21,5

According to [2], the wind speed changes with height, so up to a height of 500-800 m it increases by 70-100% relative to the wind speed directly near the surface of the earth. In addition, its direction also changes.

Formulas from theoretical mechanics are given in [2] for calculating the movement of the free end of a tower structure (in general, a cantilever rod) due to wind load. In this case, the given formulas allow you to determine the deflection of the axis of a high-rise building due to wind load, thereby demonstrating that a high-rise building is not a completely rigid body and has several degrees of freedom. Thus, both during the construction and during the operation of such structures, this factor must be taken into account, and not limited only to settlement and tilt. At the same time, the author, talking about the complex of geodetic works to determine the spatial position of the axis of the building, mentions only the complex of angular measurements.

Conclusions. Modern trends in the development of megacities require the use of non-standard architectural and technical solutions in the design and construction of buildings and structures. High-rise buildings and structures are an integral part of a modern city. The height of hundreds of meters and the influence of external forces cause changes in the geometry of high-rise buildings, which complicates construction technologies and makes it impossible to use classical methods of geodetic support for their erection. Therefore, it is relevant to study the factors that influence changes in the geometry of high-rise buildings and the development of modern technologies and methods of geodetic control, which will allow solving the scientific problem of geodetic support for the construction of high-rise buildings in modern conditions.

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Дем'яненко Р.А., Анненков А.О., Бондар С.А., Кузьмич О.Й., Лапицький І.В.

АНАЛІЗ ВПЛИВУ ЗОВНІШНІХ ФАКТОРІВ НА ДЕФОРМАЦІЮ ВИСОТНИХ СПОРУД У ПРОЦЕСІ ЇХ БУДІВНИЦТВА ТА ЕКСПЛУАТАЦІЇ

Під час будівництва та експлуатації висотних будинків їх вертикальна вісь змінює своє положення в просторі. Чим більше висота конструкції, тим більше амплітуда коливань. Це викликає проблеми геодезичного забезпечення будівництва та необхідність моніторингу деформацій під час експлуатації висотних споруд. В реальних умовах частина конструкцій буде знаходитись в тіні і їх температура буде нижча за конструкції, які будуть знаходитись під впливом сонячного опромінення, температура яких буде значно вищою. Таким чином, споруда буде деформуватись в результаті нерівномірного теплового розширення, тобто буде вигинатись.Розраховано, що у висотних спорудах теплове розширення значно перевищує допустиму точність передачі відмітки на монтажний горизонт згідно з ДБН В.1.3-2:2010 «Геодезичні роботи в будівництві».То ж при геодезичному забезпеченні будівництва та експлуатації висотних споруд слід враховувати зміни температурного режиму будівельних конструкцій в зв'язку із значними абсолютними величинами змін геометричних розмірів споруди в результаті теплового розширення, які значно перевищують точність регламентовану нормативним документом.У статті досліджено та проаналізовано вплив зовнішніх сил на зміну геометрії висотних споруд та зосереджено увагу на вирішенні наукової проблеми геодезичного забезпечення будівництва та експлуатації сучасних висотних споруд в умовах динамічних навантажень.

Ключові слова: висотне будівництво, вертикальна вісь споруди, деформація висотної конструкції, осідання, нахил, вигин, сила вітру, сонячна радіація, температурні деформації.

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During the construction and operation of high-rise buildings, their vertical axis changes its position in space. The greater the height of the structure, the greater the amplitude of oscillations. This causes problems of geodetic construction support and the need to monitor deformations during the operation of high-rise structures. In real conditions, part of the structures will be in the shade and their temperature will be lower than the structures that will be under the influence of solar radiation, the temperature of which will be much higher. Thus, the building will deform as a result of uneven thermal expansion, that is, it will bend. From DBN B.1.3-2:2010 "Geodesic works in construction". Also, during the geodetic provision of the construction and operation of high-rise buildings, changes in the temperature regime of building structures should be taken into account in connection with significant absolute values of changes in the geometric dimensions of the building as a result of thermal expansion, which significantly exceed the accuracy regulated by the regulatory document. The article examines and analyzes the influence of external forces on changes in the geometry of high-rise structures and focuses attention on solving the scientific problem of geodetic support for the construction and operation of modern high-rise structures under dynamic loads.

Keywords: high-rise construction, vertical axis of the structure, deformation of the high-rise structure, subsidence, tilt, bending, wind force, solar radiation, temperature deformations.

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Дем'яненко Р.А., Анненков А.О., Бондар С.А., Кузьмич О.Й., Лапицький І.В. **Аналіз впливу зовнішніх факторів на деформацію висотних споруд у процесі їх будівництва та експлуатації** // Опір матеріалів і споруд: наук.-тех. збірн. – К.: КНУБА. 2024. – Вип. 112. – С. 222-228.
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Табл. 2. Іл. 5. Бібліогр. 5 назв.

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Tab.2. Fig. 5. Ref. 5.

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