Wind impact on low-rise buildings when placing high-rises into the existing development

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Abstract. As height of new development rises, there is an increase in pressure from the windward side and in eddy flows from the leeward side of a high-rise building. This pressure affects not only neighboring high-rises, but also it has an impact on low-rise existing ones. The purpose of the study is to model wind flows to determine maximum aerodynamic wind effects on multi-storey buildings and their surroundings. It also aims at improving the expression for defining maximum wind load depending on the building height and the distance to it. In this study numerical experiments on modeling the distribution of wind flows in a virtual wind tunnel for an existing low-rise building have been carried out. Based on their results, an increasing coefficient in the expression for determining the wind load depending on the height of a multi-storey building and the distance to it is proposed. The results obtained can be used in determining wind loads during the reconstruction of low-rise buildings and their verification calculations when placing multi-storey and high-rise buildings in existing buildings.

Keywords: high-rise building, low-rise buildings, wind flow, wind load, reconstruction of five-storey buildings, numerical simulation, virtual wind tunnel.

1 Introduction

Multi-storey and high-rise buildings are the main type of buildings in urban development. It is optimal to build separate complexes of such buildings, but this is not always possible, so it is quite common to place multi-storey and high-rise administrative and residential buildings in the existing low-rise buildings, which are usually represented by "khrushchevki". Such houses with a height of 4 or 5 floors have become widespread due to the high speed of construction and the solution of the housing problem of citizens. To date, almost all flat roofs of "khrushchevki" have been reconstructed into pitched ones. From the point of view of distribution and change of wind impacts and loads, this neighborhood makes its own adjustments to the stress-strain state of existing buildings that have a certain degree of wear and the presence of many defects obtained during operation.

The main horizontal load that acts on a high-rise building is wind. The most important factor in terms of ensuring the stability and comfort of finding a person on the highest or last floors is the provision of a load-bearing system to resist wind loads. When the building height increases, wind loads increase, in addition to static ones, aeroelastic dynamic vibrations occur, the value of which can often dominate [26 - 28]. The effect of wind load on high-rise buildings is of great interest in terms of the resulting aerodynamic fluctuations, the distribution of wind pressure along the height of a building or structure, the effect of air flows on nearby buildings, and other aspects. In the works of many authors, aerodynamic vibrations for high-rise buildings are studied depending on the ratio of the length, width and height of the building and the shape in the plan [1 - 4]. Tests are performed in a wind tunnel to measure acceleration at the top of a building depending on the angle of attack and wind speed. The obtained data allow determining the coefficient of aerodynamic damping, the optimal shape of the building in height and in plan [5, 6].

Existing regulatory documents and methods do not fully reflect the specifics of accounting for wind impacts on high-rise and multi-storey buildings, primarily in conditions of their compact location. Recommendations are given for specifying wind pressure values by conducting tests in a wind tunnel, which is quite expensive and not always possible [29-32]. The paper also examines issues related to the study of changes in wind loads depending on the distance between neighboring high-rise buildings.
It is proved that the increase in wind pressure can be up to 30% in high-rise buildings. In addition, data were obtained on the screening effect during the construction of a high-rise building, and an increase in wind pressure on low-rise buildings [9]. It is noted that varying the location of high-rise buildings can change wind pressure on tall building and surrounding buildings [10, 11]. On the other hand, the norms do not provide any recommendations for reconstruction, strengthening, inspection of nearby buildings and clarification of wind load values on their elements. At the same time, the wind affecting high-rise buildings will create additional aerodynamic vibrations, such as buffeting, fluttering, galloping, resonant vortex excitation, including on existing low-rise buildings. Due to changes in climatic conditions, such phenomena as hurricanes, typhoons, and storms often occur, which lead to a significant increase in wind pressure, a change in the magnitude of instantaneous extreme impact [12, 13]. Recommendations for the use of special damping devices for regulating the force of impact are developed. The paper [14] provides data on the influence of terrain type on the value of wind load on a high-rise building, and compares real data with wind tunnel data. Similar comparisons of experimental results are given in the article. In [20], the change in the stress-strain state of a building from the impact of 14 typhoons from 2008 to 2016 is observed, in order to develop wind-resistant structures of high-rise buildings. Similar studies were conducted in [20] to increase the high-rise building's resistance to typhoon impacts. In paper [21] recommendations for a combination of wind loads depending on the shape of the building and wind direction are provided. It is interesting to note that not much attention is paid to the behavior of structures of buildings located in the zone of the redistributed wind flow. These problems are considered in [9, 10]. In [11] an optimal design solution for the roof of low-rise buildings to reduce the aerodynamic load is suggested. In [22] the analysis of wind pressure depending on the structural features of the roof, the dimensions of the building and the wind load were performed, and recommendations for the design of roofs of low-rise buildings in areas with a typhoon were proposed. The behavior of structures of low-rise buildings that fall under the influence of redistributed wind pressure and accurate determination of its value is a complex and urgent task.

The presence of obstacles to the effects of wind in the form of multi-story buildings leads to an increase in the effect of ventilation and contributes to the formation of stagnant phenomena, the so-called "wind shadow". It leads to discomfort for people in pedestrian areas experiencing high wind speeds and swirls formed by it. The analysis of influence and redistribution of wind flows taking into account the actual development is a little-studied and complex task. When the wind affects the side surface of the building, the wind pressure is transmitted to it. In this case, in general, the windward side of the building is stretched, and the leeward side is compressed. Therefore, the horizontal wind load causes the high-rise building to bend according to the cantilever scheme.

In accordance with regulatory documents, the amount of wind load is determined by the wind speed, air flow density, and type of terrain, height of the building, its configuration, and climatic features of the construction area. When solving calculation and design problems related to buildings of complex shapes, tasks related to determining the current loads on reconstructed or modernized buildings of the existing development, it is difficult to determine the aerodynamic coefficients for cases that are not provided for by the norms.

The effect of wind on buildings and structures and the reverse effect of urban development on wind flows is an interdependent process. Despite the fact that the atmosphere is a turbulent environment, subject to the influence of numerous external factors, the influence of terrain, as an obstacle that constantly affects on the flow, is considered the same. High obstacles in the form of buildings deform the air flow, its direction and speed, thereby becoming the cause of aerodynamic vibrations and mechanical effects. So it is important to be able to predict what changes the wind undergoes in the conditions of development and places where there will be increased wind speeds. There are four types of air flow perturbations over an obstacle: laminar flow, standing vortex flow, wave flow movement, and rotor flow. The main aeroelastic phenomena, recommended to the calculation of regulatory documents include the flutter and buffeting as the most frequently occurring. However, in relation to the effects on structures, it is necessary to consider vortex excitation, galloping across the air flow,
divergence and parametric resonance. All these impacts are unacceptable for load-bearing systems of buildings.

For buildings and structures of complex shape, it is recommended to determine the aerodynamic coefficients by testing in a wind tunnel, which is quite accurate, but expensive. It is not possible to determine wind impacts based on the experience of designing buildings of low and medium height, since they are mainly considered simple forms, so the methods on this basis become inapplicable. However, the necessary information about the distribution of wind loads on high-rise structures of complex configuration and surrounding buildings can be obtained quite adequately using mathematical (computer) modeling methods [29, 30, 33, 34]. This is also reflected in the work of Kupriyanov V. N., Altapova S. R. on modeling wind impacts by changing the shape of a building.

2 Methods

To clarify the nature of wind flow distribution, determine the maximum aerodynamic effects on high-rise buildings and their surrounding buildings, a numerical study was conducted in the virtual wind tunnel simulation program for air flow visualization-Autodesk «Flow Design» and analysis of changes in wind pressure depending on the direction of wind load and its values. Building a model for purging is performed in the software package for modeling three-dimensional objects «SketchUp». Similar research was conducted by K. A. Fabrichnaya, N. S. Abdurakhimova, S. R. Altapov when modeling building framework, taking into account the compliance of nodes pair under wind influences.

Dangerous meteorological phenomena on the territory of the Republic of Tatarstan include weather phenomena that, by their intensity, duration and time of occurrence, pose a threat to the safety of people, and can also cause significant damage to economic sectors. The list and criteria of dangerous phenomena and climate phenomena were approved by the order of the Federal state budgetary institution «FGBU of the Republic of Tatarstan» No. 98 dated 17.10.2014. To determine possible negative impacts on buildings, the standard wind pressure was calculated based on the hurricane speed of 25 m/s. The results of determining the maximum wind speed are shown in Table1.

| Height h(z_0), m | 15  | 20  | 30  | 40  | 50  | 60  | 77.5 | 80  | 90  | 100 | 120 |
|------------------|-----|-----|-----|-----|-----|-----|------|-----|-----|-----|-----|
| V_{max} SR 20.13330 | 18.2 | 19.3 | 21.6 | 23.1 | 24.6 | 25.6 | 26.6 | 27.9 | 29.2 | 29.9 | 30.6 |
| V_{max} «Flow design» | 36.6 | 35.9 | 36.6 | 37.2 | 37.7 | 44.2 | 50.2 | 58.3 | 57.5 | 59.3 | 60.6 |
| V_{max} Hurricane | 29.3 | 30.1 | 32.5 | 35.4 | 37.5 | 39.5 | 42.0 | 42.9 | 43.3 | 44.2 | 46.3 |

The object of research is the existing building on Pavlyukhina street, Kazan and the residential complex "Golden horseshoe", consisting of three 23-storey towers, 77.5 m high. The existing buildings are represented by five-storey buildings of the 1-446C series, built from 1958 to 1964, with a flat roof replaced by a pitched roof during reconstruction.

The influence of wind on the complex of buildings and its influence on the distribution of wind flows on the surrounding buildings are observed. The maximum speed and pressure were considered for the calculated wind load according to Sanitary Rules (SR, i.e. rus. SP) 20.13330.2016 "Loads and impacts" and for the hurricane load determined from statistical data.
Figure 1a. Distribution of wind flows to existing buildings during the construction of multi-storey and high-rise buildings at a height of 77.5 m

Figure 1b. Distribution of wind flows to existing buildings during the construction of multi-storey and high-rise buildings at a height of 100 m

The wind direction was taken in accordance with the wind rose and considered in the most characteristic directions. To identify the most adverse wind impacts on existing low-rise buildings, depending on the height of the buildings being constructed, the building was modeled at a height of 77.5, 85, 100 and 120 meters. At the next stage, hurricane wind impacts were simulated in a virtual wind tunnel to identify maximum pressures.

3 Results and Discussion

At a building height of 77.5 meters, there is a standing vortex that occurs at average wind values. A whirlwind is formed on the leeward side of the building, almost parallel to the ground, and an area of shadow of the wind appears behind the building. This is the area of occurrence and intensive movement of vortices, which puts pressure on the existing low-rise buildings. At a height of 85 meters, there is a wave movement of the flow that occurs when strong winds increase with height, when a stationary vortex on the leeward side seems to break up into a system of vortices, exerting even more pressure on a low-rise existing building. When modeling a high-rise building at a height of 100 and 120 meters, the rotor flow is observed. Strong winds form swirls, at close distances both to each other and to the obstacle, the movement of streams becomes disordered.

With increasing height, there is an increase in pressure from the windward side and an increase in eddy flows from the leeward side of a high-rise building, which affect not only high-rise buildings, but also low-rise existing buildings [35]. At the same time, the maximum wind speed in the wind tunnel is 1.5 – 2 times higher than the calculated maximum wind speed for the joint venture. As a result of
calculations, it is obtained that the impact of hurricane wind on the existing building is about 1.5 times higher than the wind speed according to Sanitary Rules 20.13330.2016 "Load and impact"; when modeling with the account of aerodynamics, the impact is 1.3 times greater than the hurricane wind speed. At the next stage, hurricane wind impacts were simulated in a virtual wind tunnel to identify maximum pressures. The nature of the distribution of light flow from high-rise buildings to existing low-rise buildings is determined.

During the operation of buildings, not only the technical condition of structural elements changes due to the appearance of defects and damage, but also the regulatory and design loads on these elements, in particular when the regulatory framework changes. When determining wind loads on buildings and structures, statistical data are used to determine the values of these loads. However, for many reasons, this data are changing, and the requirements that were used at the time of the design and construction of buildings in the last century cannot be applied today. Due to the increase in standard loads, the perception of their existing load-bearing system may be different. In particular, this may lead to a redistribution of forces in the elements and a change in the stress-strain state as a whole [34]. Based on this, the work compares the wind pressure according to the standards of 1962 and the current code of practice, as well as their comparison with possible adverse effects and the results of purging in a virtual wind tunnel. The results are presented in Table 2.

Numerical experiments have shown that the wind pressure in the simulation, taking into account the aerodynamics, is 1.8-2 times greater than the wind pressure obtained by SNiP II-A.11-62 "Load and impact", which was in effect at the time of construction. It should be noted that before the construction of the multi-storey complex, the wind pressure was approximately 2 times less and 2.5 times less than when modeling with the account of aerodynamics.

| H, м | SNiP II–A.11–62, kPa | SR 20.13330.2016, kPa | As a result of the "Flow Design" experiment, taking into account multi-storey buildings, kPa | As a result of the experiment in "Flow Design" without multi-storey buildings, kPa |
|------|---------------------|-----------------------|--------------------------------------------------------------------------------|--------------------------------------------------------------------------------|
| 2.70 | 0.21                | 0.26                  | 0.28                                                                           | 0.083                                                                           |
| 5.40 | 0.225               | 0.26                  | 0.28                                                                           | 0.098                                                                           |
| 8.10 | 0.225               | 0.26                  | 0.33                                                                           | 0.11                                                                            |
| 10.80| 0.23                | 0.27                  | 0.37                                                                           | 0.13                                                                            |
| 13.50| 0.25                | 0.29                  | 0.42                                                                           | 0.15                                                                            |
| 17.50| 0.27                | 0.33                  | 0.46                                                                           | 0.17                                                                            |

Numerical modeling in the program "Flow Design" has shown that when the wind from the side of the air flow is directed at the wall and roof of the building. There is a swirl of the flow along the wall, and then the flow partially rushes down to the foundation, partially rises up, hitting the eaves of the roof. The wind stream that falls on the roof slope moves tangentially to the roof ridge, picks up calm air from the leeward side and moves further away from the building. It is found that three forces occur simultaneously – two tangents on the windward side and a lifting force formed by the difference in air pressure, on the leeward side, which can lead to its failure and capsizing. At right angles to the slope, another force acts, exerting pressure on the roof slope. Depending on the angle of inclination of the roof, normal and tangential forces can change their value. With a greater slope, normal forces are more important, with a decrease in the angle, tangents increase which contribute to an increase in lift from the leeward side.
Figure 2a. Distribution of wind flows taking into account a multi-storey building.

The development in a wind tunnel at a standard pressure of $w_0 = 0.3$ kPa has been modeled. The results are the following: taking into account the aerodynamics the wind pressure on a low-rise building is 0.46 kPa; with a hurricane wind speed of $v = 25$ m/s it is 0.7 kPa; with a hurricane wind speed modeled in a wind tunnel it is 1.2 kPa.

Figure 2b. Distribution of wind flows without a multi-storey building
It should be noted that the aerodynamic instability causes additional forces in the elements of existing low-rise buildings, calculated according to the standards of 1962. It can negatively affect the elements of the roof and the load-bearing system as a whole. The calculation of the roof lift, when the hurricane wind speed affects the existing building, taking into account the erected multi-storey buildings, has shown that the lifting force of the roof is greater than the roof’s own weight $G$, with a difference of 254.1 kN. It can lead to the roof damage of five-storey buildings when the wind load is exceeded.

According to the wind tunnel simulation of wind impact on newly erected high-rise and existing buildings wind pressure and maximum wind speed is about 2 times higher than the values calculated by Sanitary Rules 20.13330 "Loads and impacts". Wind flow disruption to the nearby low-rise buildings with a vortex of excitation and aerodynamic instability of the buffeting type is observed. Wind loads on a low-rise building in the simulation, taking into account aerodynamics, is 1.8-2 times higher than the wind load according to SNiP II – A. II-62 «Loads and impacts».

Thus, it is established that the construction of high-rise and multi-storey buildings in the current development can negatively affect existing buildings and their individual structural elements. The maximum load on the roof of a five-storey building in the considered version of the residential complex occurs when a hurricane wind is modeled taking into account the actual conditions of the location in the wind tunnel. It was determined that the wind load on low-rise buildings varies depending on the speed of the wind impact and the distance from the high-rise building. In Table 3 an increasing coefficient to the calculated wind load is proposed, depending on the height of the building and the distance to it.

### Table 3. Raising factor $k_{v,max}$

| Distance $S_1$, м | Building height $H$, м | $75$ | $85$ | $100$ | $110$ | $120$ |
|------------------|------------------------|------|------|-------|-------|-------|
| $10$             |                        |      |      |       |       |       |
|                  |                        |      |      | $1.1$ |       | $1.21$|
| $30$             |                        |      |      | $1.2$ | $1.28$| $1.41$|
| $50$             | $1.27$                 | $1.5$| $1.72$|       |       |       |
|                  | $1.0$                  |      |      |       |       |       |
| $100$            | $1.17$                 | $1.47$| $1.75$|       | $2.02$|
| $120$            | $1.224$                | $1.55$| $1.83$|       | $2.13$|
|                  | $1.33$                 | $1.67$| $1.99$|       | $2.29$|
| $150$            | $1.22$                 |      |      |       |       |       |

According to the results of the study it is suggested to average the main component of the wind load $w_m$, to enter the extension factor $k_{v,max}$, to account for hurricane wind depending on the height of newly constructed buildings and distance:

$$w_m = w_0 \cdot k(z_e) \cdot c \cdot k_{v,max}$$

where $w_0$ – standard value of wind pressure;
$k(z_e)$ – factor that takes into account the change in wind pressure for height $z_e$;
$c$ – aerodynamic factor;
$k_{v,max}$ – factor for hurricane impact of wind, determined by table 3.

### 4 Conclusion

Numerical experiments conducted to study the influence of high-rise and multi-storey buildings on existing buildings under the influence of wind proved that the redistribution of wind flows causes aeroelastic fluctuations and significantly increases the wind pressure on the existing building. As a result, it is proposed to take into account the increasing coefficient when determining wind loads during verification calculations and reconstruction of low-rise buildings. The increasing coefficient depends on the height of the newly constructed building and the distance between it and the existing
one. The value of the average component of the wind load is proposed to be determined by the expression Eq. (1). Further research can be aimed at clarifying the stress-strain state of structural elements of low-rise buildings and their connections under increased wind load, as well as the combination of wind influences depending on the angle of attack.

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