Analysis of wind load impact on the high-rise buildings glass facade

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Abstract. This article discusses and analyzes the problem of finding the necessary appropriate parameters of glass in cases of panoramic glazing and the reasons for their destruction with a specific example. The influence of the buildings relative position on the formation of wind load on the glazing of a high-rise building is revealed. The article also identifies the reason for the glass enclosing structures deformation of the apartment under study in a residential complex in the urban area.

Introduction
It is difficult to imagine a modern city without the glass-fronting facades of high-rise buildings and huge windows of shops and restaurants reflecting the city life. Glass is widely used in the residential and public buildings design, as well as in the interiors of hotels, shops, office and public buildings. Architecture, meanwhile, continues to grow high, as well as to do the needs of the society in general and human in particular. Technologies are developing rapidly, architects create projects of increasingly fantastic skyscrapers, and engineers are forced to solve more complex structural problems to invent the new elements that will meet the requirements of the volume being created. The facades of glass have become one of the most common and popular solutions of modern architecture.

Constructive decisions of the continuous glass facades implemented using specialized systems (visible and invisible, horizontal or close to them in a vertical or close to them profiles) and planar systems (mount point) with hinged bolts. Glass installation is produced at different angles, allowing any virtual architectural concepts.

Filling window openings is performed by European technology from lightweight aluminum, metal-plastic and wooden stained-glass systems.

The maintenance of built residential and public buildings in a frame-monolithic version, revealed serious shortcomings:
1) instability in large-size insulating glass geometry;
2) image distortion;
3) the possibility of focusing sunlight into the energy beam;
4) wind load impact;
5) during the exploitation of buildings, the premises owners often redevelop the premises, indirectly affecting the operation of the structural system of the building and the building envelope, which is a new problem that will be discussed in this article.
Purpose of the study
We intend to identify the glass destruction causes.

The object of the study is a penthouse in the residential complex “Rostov-City”. An apartment owner has changed the pattern and size of glazing panoramic windows at its own discretion.

The subject of the study is the part of the panoramic glazing of the penthouse room (the floor-sized apartment on the last residential floor of a 25-storey residential building).

The aim of the study is: to develop the constructive solutions to ensure the rational sections of the glazing elements of the defined materials subject to mechanical and environmental safety.

Studies were carried out for double-glazed windows:
- Composition №1 – 32mm thickness: 6 Stopsol Supersilver Clear no.1 simple tempered +20+3.3 (triplex), dimensions width - 1125 mm, height - 2805 mm, spraying with energy saving;
- Composition №2 – 32mm thickness: 6 Stopsol Supersilver Clear no.1 simple tempered +20+3.3 (triplex), dimensions width - 910 mm, height - 2805 mm, spraying with energy saving.

In accordance with the regulatory documents, guidelines and the terms of reference for conducting the research requirements, the necessary types of work were carried out [6], including the identification of key functional-planning requirements and restrictions, followed by a calibration calculation of the enclosing structure of the investigated apartment space.

The building where the apartment is located, takes place in the historical center of Rostov-on-Don. In the considered part of the city center there are residential buildings and public buildings of medium height. The residential complex “Rostov-City”, located on the surveyed site territory is a few residential buildings of variable number of floors (17-25 floors, taking into account the technical premises). The towers are connected by utter northeastern edges with each other, forming a cascade array in plan. The apartment in which the glass fence deformations occurred is located in the South Tower - a 23-storey building with a basement and a technical floor, almost square in plan, with overall outer dimensions of 22.3х23.4 m and a height of 81.00 m to the parapet top.

On the visual inspection basis, it was established that the technical condition of the enclosing structures is in a restricted-working condition:
- there are branched cracks in the two double-glazed windows in the upper right corner in the eastern and western parts of the apartment building (almost on the same line in the plan);
- the nominal thickness of the glass, the distance between the glasses and the size of the glass in height and width comply with the technical requirements;
- there is no technical documentation for double-glazed windows - the requirement is not met.

Solution to the problem
- search for compliance with configuration parameters that do not contradict the requirements of technical regulations in terms of mechanical strength;
- calculated search for configuration parameters that do not contradict the requirements of technical regulations in terms of deformability;
- analysis of the urban situation regarding the location of the object in terms of height and other parameters.

After analyzing the geometry of the cracks in the glass, the specialists (the authors of the article) concluded that this is not a “thermal shock”, but the result of the wind load impact. In accordance with the contract, there were made calculations of the existing glass product composition, taking into account the need for: ensuring mechanical safety and security from external factors causing a change in its stress-strain state; ensuring normal operating conditions; ensuring the microclimate of the room.

The elements of the enclosing structure of the apartment building were calculated using the kinematic method of maximum equilibrium at a given average pressure of the wind load. The following features of the glass unit were taken into account in the calculation formulas: the presence of elements of different thickness and properties, inelastic properties of glass, the effect of long-term load on the rigidity of the element in its ultimate state. The calculations were performed using approved methods.
in accordance with regulatory documents with the introduction of existing coefficients of working conditions.

Particular attention in this study was paid to wind load, since the wind impact on the building is dynamic and is determined by such important environmental factors as the shape of the territory, the location of neighboring buildings, flexibility and features of the facade of the building itself, as well as the speed, direction and nature of the wind.

**The method of calculation**

At present, calculations of wind currents and impacts are reduced to the numerical solution of three-dimensional non-stationary non-linear hydrodynamic equations in the Navier-Stokes formulation. In addition, the continuity equations (mass conservation) and states must be satisfied.

Creating a design model of a structure is the initial and most difficult stage of constructive calculation. As the technical base and software component was created and improved, the computing unit began to allow more and more complex and complicated calculations, in which both mathematical specialists and professionals of various technical specialties, including designers, were interested [2].

Like all tools, depending significantly on the method of their application, modeling the design system of the design object can give either very good or very bad results; it can also be misleading. Therefore, it is important that the calculator and the design engineer, which will use the results of the calculation, could imagine the meaning of the introduced assumptions, strengths and weaknesses of the method, its advantages and subtleties [1].

When searching for the optimal solution, the method of mathematical programming was applied without using a low-control search. The quality of the decision was characterized by an objective function depending on the parameters of the system:

$$ C = c(x_1, \ldots, x_n) $$

To solve the described problem, the objective function is simplified by linearizing it (restricting inequalities).

Thus, according to the recommendations for the refined dynamic calculation of buildings and structures for the effect of the pulsation component of the wind load [10], when calculating the wind load, a simplification is introduced that wind flows are assumed to be incompressible and isothermal, the mass forces are disregarded. Therefore, in modern computational practice, a semi-empirical approach dominates, based on decomposing speed into time-averaged and pulsation components:

$$ u_i(t) = \bar{u}_i + u'_i(t) $$

and passing to solving the so-called Navier-Stokes equations averaged by Reynolds.

It is known that the wind is an irregular, turbulent movement of air and, therefore, in solving most applied problems, including problems of construction dynamics, the wind speed is considered as a random vector process, which, as usual, is described by its spatial and temporal statistical characteristics: average value, variance, auto- and mutual spectral and correlation functions. With this approach, the effect of wind $w(t,x)$ on buildings and structures can also be considered as a random function of time $t$ and spatial coordinate $x = (x_1, x_2, x_3)$. At the same time, $w(t,x)$ is rather naturally divided into the middle ($w_m$) and pulsation ($w_p$) components, that is [10]:

$$ w(t,x) = w_m(x) + w_p(t,x) $$

The results of calculations performed by the specialists of "AGC Flat Glass Clean" (AGC GLASS UNLIMITED) using the software based on SL Mepla v.3.5.9 (SJ Software GmbH) are presented in table1:
Table 1. The results of calculations performed by the specialists of "AGC Flat Glass Clean" (AGC GLASS UNLIMITED)

| Mount type | Dimensions, [mm] | Load, [kPa] | Double glazing composition | Permissible deflection, [mm] | Deflection, [mm] | Voltage value, [MPa] |
|------------|-----------------|-------------|-----------------------------|-----------------------------|----------------|---------------------|
| the perimeter | 2750x1100 | wind 1130 (SLS) 1590 (ULS) | composition №3 6ESG/20/33.1VSG | 4.4 | 7.43 | 11.84 |
| the perimeter | 2750x1100 | wind 1130 (SLS) 1590 (ULS) | composition №4 6ESG/16/44.2VSG | 4.4 | 3.57 | 11.84 |
| the perimeter | 2750x650 | wind 1130 (SLS) 1590 (ULS) | composition №5 6ESG/14/4ESG | 2.6 | 1.53 | 10.64 |

From the presented data it is clear that, the composition №3 of the glass unit has a deflection equal to 7.43 mm with an allowance of 4.4 mm, which is unacceptable (moreover, the calculation of the wind load acting on the glazing was made without taking into account the corner zone of the facade for the type of terrain “B”).

The authors of the article made an updated calculation of the wind load, taking into account the corner zone of the facade of the building, and calculated the strength of the compositions of glass packs №1 and №2 “manually” with the determination of intermediate values from the nomogram of instructions for the design of glass packs. The calculation showed that the voltage in the double-glazed windows is greater than the allowable design resistance of the glass [6]:

$$\sigma = 200\text{kPa} > R = 150\text{kPa}$$ (4)

Analyzing the urban planning solution of the “Rostov-City” residential complex, taking into account that all the towers are connected by extreme northeastern edges with each other, forming a cascade array in the plan (Figure. 1), it is revealed that the “South Tower” is in the most disadvantageous position in terms of wind exposure:

- lower vacuum zone (up to 17 floors, the eastern wind load is closed by the building of the business center “League of Nations”);
- from the north-east and from the south powerful suction wind load.

When considering the residential complex as a whole, the edge areas of up to 10m in size are in the worst position, which led to the deformation of the double-glazed windows.

Thus, it was established that during the deformation of the enclosing structures, along with the magnitude of the dynamic effect, the factor of its duration is of great importance. The increase in the time of action leads to a decrease in the rate of deformation, and, consequently, to a decrease in the tensile strength and yield strength.

When designing buildings with a curved glass facade, there is a possibility of focusing sunlight into an energy beam, which can lead to the burning of objects around or included in the volume. An example of this is the building of the “Gorizont” cinema. The asphalt surface of the parking lot is very hot near the concave part of the facade. At the close located park the car suffered. To prevent the
effect of overheating, calculations and research are needed to simulate the actual working conditions of the glass facade. [11].

When using glass as a material for the walls, not only the decorative qualities are important, but also the carrying capacity of the glass, as well as the thermal properties [13].

![Diagram](image-url)

**Figure 1.** Analysis of the urban planning solution of the residential complex "Rostov-City"

**Conclusions and recommendations**

The revealed defects in the apartment under study are partial weakening of the enclosing structure, which do not cause a breach of its stability and do not threaten the integrity of the building, but over time lead to a decrease in serviceability. The reason for these cracks appearance and their further development is the discrepancy between the thickness of the glass in the glass unit and the allowable values of deformations under actual wind load conditions.

At the design stage, no studies of facade structures of high-rise structures were carried out according to the "wind load-structure" interaction criterion.

**Summary**

The complex real nature of the impact of wind on high-rise buildings in our region is just in the beginning of the investigation. In order to make the right decisions for these particularly important problems, the designers must:

1. Use the results of aerodynamic tests on models to obtain complete information about the nature of wind and wind loads.
2. Use computational fluid dynamics - a versatile and cost-effective tool for studying the effects of wind loads on buildings. Various complex situations can be effectively modeled using mathematical methods of fluid dynamics, to better understand the nature of the interaction of buildings and wind flows. In addition to researching wind loads, computational fluid dynamics methods can be used in the development of solutions for improving the wind characteristics of buildings.
3. Develop analytical expressions and formulas for the use of test results both experimentally in a wind tunnel, and when modeling situations in a computer program.
4. To solve the problems of facade glazing by searching for the relevant parameters to consistent configuration requirements in terms of technical regulations of mechanical strength, thermal properties and in part of nearby buildings and structures.

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