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МЕТОД ОПРЕДЕЛЕНИЯ ВЕТРОВЫХ НАГРУЗОК И ВОЗДЕЙСТВИЙ С ИСПОЛЬЗОВАНИЕМ ПРОГРАММНОГО ОБЕСПЕЧЕНИЯ

Аннотация. *В рамках исследования рассматривается многофункциональный жилой комплекс повышенного уровня ответственности. Исследование проводилось в рамках научно-технического сопровождения проектирования объекта строительства. Как правило результатом научно-технического сопровождения проектирования является соответствие проектной и изыскательской документации установленным требованиям.*

Методика определения ветровых нагрузок и воздействий реализована с помощью применения пакета программного обеспечения SOFiSTiK. Данное программное обеспечение способно выполнят расчет стационарных и нестационарных ветровых нагрузок.

В результате применения рассматриваемой методики были найдены аэродинамические коэффициенты лобового сопротивления и боковой силы, величины средних значений давления. Также были определены картины распространения среднего давления на поверхности фасадных систем и картины полей средних скоростей комплекса.

Keywords: *техническое обследование, ветровые нагрузки, 3D-модель.*

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METHOD OF DETERMINING WIND LOADS AND IMPACTS USING THE SOFTWARE

Abstract. *The current study considers a multifunctional high security residential complex. The study was conducted as part of the scientific and technical support for the design of the construction project. The compliance of design and survey documentation with the established requirements is usually a result of scientific and technical support of design.*

The methodology of determining wind loans and impacts is implemented with the help of a software package named SOFiSTiK. This software is capable of performing computations of stationary and non-stationary wind loans.

Aerodynamic coefficients of drag and lateral force, as well as average pressure values were found as a result of applying the methodology in question. Also, patterns of medium pressure propagation on the surface of facade systems and patterns of medium-velocity fields of the complex were determined.

Keywords:*technical survey, wind loads, 3D-model.*

Introduction

In modern practice, it is recommended to perform scientific and technical support not only during the construction stage, but during the design stage as well. Such support is aimed at satisfying safety requirements and reliability of the designed facility.

The analysis of authorization, design and survey documentation is carried out, an alternative calculation with comparative analysis of the results with the results of the main computation are performed, and the recommendations for adjusting the design and survey documentation are developed in order to achieve the set goal and solve the problems of the scientific and technical support of the design.

The result of scientific and technical support of the design is the compliance of design and survey documentation with the requirements of normative and technical documentation and technical regulations.

The determining of wind loans and impacts is one of the components of scientific and technical support for their further comparison.

A multifuncational high security residential complex planned to be designed in a city of Moscow is considered in the current study. The complex consists of three cases connected by a stylobate part. The maximum height of complex is 166.26 m.

Building 1 includes sections 1 and 2 with a height of 46 floors and section 3 with a height of 28 floors, building 2 with a height of 47 floors, building 3 includes 3 sections with a height of 47 floors, a stylobate number of floors - 3 floors, a parking number - 2 floors

Floors height as seen in the light (without accounting for floor coverings and ceiling finishing materials):

– height of the 1st floor in building 1 is 4.7m; 3.5m in buildings 2 and 3;
– height of a typical floor of high-rise buildings is 3.15m;
– height of technical space above the 1st floors of high-rise buildings is 1.78m;
– height of the -1st floor of the stylobate part – 4.7m;
– height of a typical floor of the stylobate part – up to 3.5m;
– height of the -2nd floor of the parking lot 4.9m;
– height of the -3rd floor of the parking lot 3.15m.

Dimensions as seen in the plan and the shape of the buidlings

1. Building 1 – Z-shaped, about 80m long and 18m wide;
2. Building 2 – of a rectangular shape with a ledge on one of the edges with overall dimensions (as seen in the plan) of 43.6×18.2m;
3. Building 3 – Z-shaped, about 90m long and 17m wide.

The relief on the site is of a relatively flat surface with a height difference of no more than 2 m. There are outbuildings on the territory of the construction site, almost the entire site is covered with asphalt concrete.

The surrounding buildings are represented by high-rise buildings on the south-west and south-east, as well as medium and low-rise buildings. Various engineering communications pass along the perimeter of the site; there are also large collectors.

The climatic region is moderate. The calculated value of the weight of the sega cover is 1.8 kPa, the value of the wind pressure is 0.23 kPa.

Methods

The SOFiSTiK software package, capable of performing computations of stationary and non-stationary wind loans was used for the determining of wind loans and impacts. The mathematical model is a system of Reynolds averaged Navier-Stokes equations for a viscous incompressible fluid, supplemented by equations for turbulent characteristics. As the latter, the differential equations of the semi-empirical model of shear stress transfer SST were chosen, which is preferred when calculating vortex and separated flows. [1-5]

A three-dimensional non-stationary problem in the framework of discretization of the Reynolds-averaged Navier-Stokes equations is solved in this paper. The solution of the problem occurs in a dimensional form. If we take the characteristic width of the complex, which is b=44 m, as the characteristic linear size, and choose the incident velocity V_0 equal to 20 m/s as the characteristic speed, then the Reynolds number calculated for a speed of 6 m/s will be R_e=1.25·10^7.

Therefore, for any velocity greater than 6m/s, the flow pattern is identical, and the flow characteristics can be recalculated using the values obtained in this work. [6-9]

The calculation is performed up to a time when the value corresponding to the output of the integral average loads settle at steady-state values.

The following thermodynamic air parameters are used in the computation:

- environmental pressure 101325 Pa;
- environmental temperature 288.15° K;
- environmental density 1.2248 kg/m^3.

An approach should be used in which the pulsation component is determined depending on the average component of the wind effect to obtain the pulsation component. This approach is implemented in certified software systems used for structural analysis (LIRA-SAPR, STARK ES, SCAD, MICRO FE and others). [10-13]

The complex was divided into blocks, for which the average component of wind pressure was determined, in order to achieve the numerical values in tabular form and prepare recommendations for assigning aerodynamic pressure coefficients. [14]

Results and Discussion

Figure 1 shows the graph of the establishment of the drag force at a residential complex depending on the number of accumulated time steps.

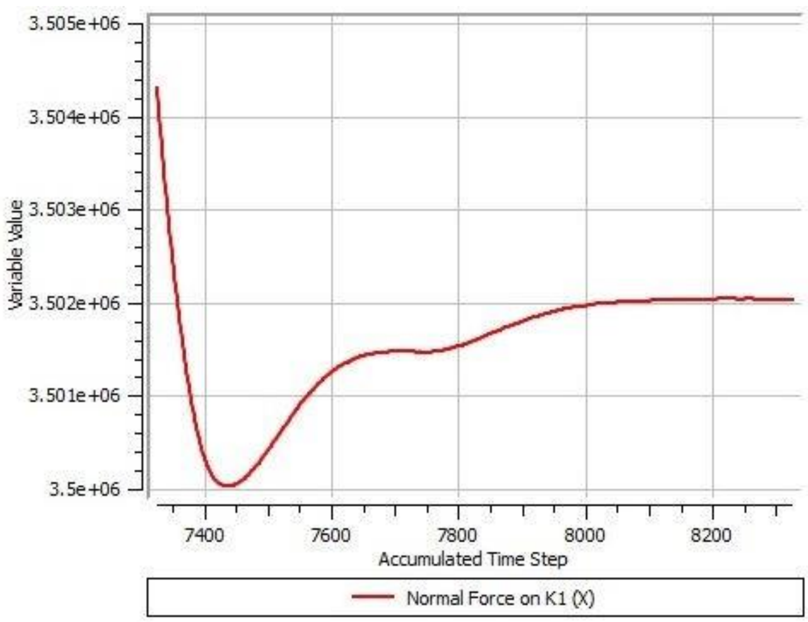

Figure 1 – Graph showing the establishment of the drag force

A 3D model was formed based on the analysis of the surrounding buildings. Buildings that could affect the aerodynamic of the complex in question were chosen for the task. The geometry of surrounding buildings was simplified to the point where it can no longer affect the aerodynamic characteristics of the complex under study (see figure 2). [15-20]

Figure 2 – The 3D model of the complex and buildings surrounding it

The calculation considered natural values of surrounding buildings and the complex under study.

The design grid consists of three blocks: the main block, the block with the surrounding buildings, the external block. The blocks are connected in the solver by an interface to transfer data between each other.

The main block includes the studied geometry of the complex. The block is broken up by an unstructured mesh with a prismatic sublayer. For basic calculations, the mesh is built with the height of the first element from the wall being no more than 1cm.

The block with the surrounding buildings includes the geometry of the surrounding buildings of the studied complex. The choice of the geometries of the surrounding buildings included in the calculation area is made by the method of expert assessment (but at a distance of less than three characteristic dimensions of the complex under study).

An external block is a block on the boundaries of which the boundary aerodynamic conditions are set. The size of the outer block is about three characteristic diameters of the block from the surrounding building upstream relative to the studied complex, about 10 characteristic diameters backward, about three characteristic diameters on the sides and about 5 characteristic diameters upstream. Concentration of elements is done towards the surface of the earth and towards the interface between the blocks. Towards the edges of the area, the size of the mesh elements is purposefully increased in order to damp the numerical oscillations during the calculation.

The internal criterion for assessing the quality of the mesh "Quality" gives the following result for the constructed mesh:

– minimal value of 0.0009756;
– maximal value of 1;
– mean value of 0.7141.

The dimensions of the studied area are as follows:

– height of 5 km;
– distance from the complex up to the front border 7 km;
– distance from the complex up to the back border 27 km;
– distance from the complex up to the side border 6.5 km;

The total volume of the computational grid for preliminary calculations is about 2.6 million cells, and about 22 million cells for a detailed aerodynamic calculation.

The calculation was performed for the constructed three-dimensional model of the complex of buildings and the surrounding buildings. Preliminary calculations were carried out on a coarse grid with a step of 15° in wind directions in the range of 360°. Aerodynamic coefficients of drag

(c_x) and lateral (c_y) force were obtained in the entire range of angles under consideration after the verification of design scheme. Based on the results acquired, the representative set of wind directions is formed, for which the following wind directions were chosen: 0°, 45°, 135°, 210°, 330°. Then the calculations on the representative set of wind directions were performed on a mesh grid. The aerodynamic coefficients c_x and c_y were refined. Pressure values on facades of the complex under study were acquired both in the form of pressure distributions over facades and in the form of average values for blocks. Furthermore, velocity fields and vectors used to rate the comfort in the pedestrian areas of the complex.

A complete picture of the velocity and pressure fields in the flow was obtained based on the calculation results for a representative set of wind directions:

– overwiew of wind pressure on the facades of the complex;

– pressure fields, velocity fields and velocity vectors for heights +100 and +150m;

– pressure fields, velocity fields and velocity vectors for pedestrian zones at elevations of +1.5 m and +7.2 m.

Analysis of the wind patterns of the pressure distribution on the building surface allows us to highlight the following characteristic features of the tear-off flow around the building:

– it is possible to draw qualitative conslusions about the absence of clearly characteristic stagnant zones in their area, which indicated satisfactory “ventilation”;

– windward zones are characterized by the level of average loading and the pressure of p ~ 300÷350 Pa in the area of flow inhibition zones;

– the leeward zones of the inhibited flow are characterized by pressure level p ~ -150÷-50 Pa.

– there are narrow zones of intense stalling of the flow localized near the sharp edges of the bodies with peak values p ~ -1400 ÷ -1000 Pa;

– on the parapets of the buildings' roofs, intense separated flows with p ~ -1400 ÷ -1000 Pa also manifest.

Conclusions

The calculated dimensionless characteristics of the fields of the wind flow around the complex are full-scale and independent of the speed of the oncoming wind.

The long-term practice of parallel computational and experimental work shows that even problem-oriented, validated and verified by the results of the experiment, computational technologists of the Navier-Stokes level give differences from the experiment in numbers in the range of 10-30%, depending on the configuration of the object and the type of characteristics obtained. The "hierarchy" of calculation accuracy is as follows:

– velocity field

– pressure field on the surface

– integral forces.

Thus, the data on the pressure distribution on the facade surfaces and the integral averaged loads is indicative and can be used to assess design solutions, and is also used when processing the configuration of the model complex on the situational plan and optimizing the process of testing models in a wind tunnel.

The aerodynamic characteristics of the building are characterized by the traditional level of resistance (force along the flow) and, importantly, the lateral "lifting" force commensurate with the drag force (across the flow), which must be taken into account in the design.

When making structural decisions for facades, it is advisable to take into account the increased level of local loads in areas where sharp corners are present.

As a result of applying the methodology of determining wind loans and impacts using SOFiSTiK software package and performing the calculations, the following results were achieved:

1. Aerodynamic coefficients of drag (c_x) and lateral force (c_y) were obtained.

2. Average pressure values were obtained.

3. Patterns of medium pressure propagation on the surface of facade systems were determined.

4. Patterns of medium-velocity fields of the complex were determined in order to identify possible flow patterns in the area of pedestrial zones.

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3. The leeward zones of the inhibited flow are characterized by pressure level *p* ~ -150÷-50 Pa.

REFERENCES

1. Airapetov A.B., Vishinskii V.V., Katunin A.V. Raschetnie i experemental’nii issledovaniya obtekaniya v usloviyah gorodskoi zastroiki. Proceedings of MIPT. 2017. Vol. 9, No 2. Pp. 5–12. (rus)
2. E. Kuzina, V. Rimshin and A. Neverov Residual resource of power resistance during building structures deformation E3S Web of Conferences Vol. 135 (2019) ITESE-2019
3. Rimshin, V., Aralov, R. Sustainable regeneration of urban areas (using the example of Moscow renovation program) E3S Web of Conferences 110,01011. 2019
4. Airapetov A.B. Methodical principles of high-rise buildings aerodynamics simulation in the wind tunnel. Modern high-rise building. 2007. Pp. 292–294. (rus)
5. E. Kuzina, V. Rimshin and A. Neverov Reserves and exposure assessment of reinforced concrete structures safety while reducing its power resistance E3S Web of Conferences Vol. 135 (2019) ITESE-2019
6. V. Rimshin, P. Truntov Determination of carbonation degree of existing reinforced concrete structures and their restoration E3S Web of Conferences Vol. 135 (2019) ITESE-2019
7. Vyshinsky V.V., Sudakov G.G. Application of computation methods in aerodynamic design problem. Moscow: TsAGI. 2007.
8. V.Rimshin and P. Truntov An integrated approach to the use of composite materials for the restoration of reinforced concrete structures E3S Web of Conferences Vol. 135 (2019) ITESE-2019
9. Kuzina, E., Rimshin, V., Kurbatov, V. The Reliability of Building Structures Against Power and Environmental Degradation Effects. IOP Conference Series: Materials Science and Engineering, 463(4),042009. 2018
10. Karpenko, N.I., Eryshev, V.A., Rimshin, V.I. The Limiting Values of Moments and Deformations Ratio in Strength Calculations Using Specified Material Diagrams. IOP Conference Series: Materials Science and Engineering 463(3),032024. 2018.
11. Airpetov A.B. New aspects of wind loaded aerodinamics of hight-rise duilings in metropolis, new approaches and methodical investigation principals. Academia. 2010. No 3. Pp. 585-584.
12. Telichenko, V., Rimshin, V., Eremeev, V., Kurbatov, V. Mathematical modeling of groundwaters pressure distribution in the underground structures by cylindrical form zone. MATEC Web of Conferences 196,02025. 2018
13. Krishan A.L., Rimshin V.I., Chernyshova E.P., Astafeva M.A., Chernyshov V.E. Calculation of strength resistance of load-bearing structures of architectural object of cultural heritage. Heritage for planet Earth Proceedings of the international symposium heritage for planet Earth 2018. 2018. Pp. 280-284.
14. Churin P., Poddaeva O. Aerodynamic Testing of Bridge Structures // Applied Mechanics and Materials. 2014. V. 467. Pp.404-409.
15. Egorychev O. O., Guvernyuk S. V., Isaev S. A., Poddaeva O. I., Kornev N. V., Usachov A. E. Numerical and physical modeling of wind effects on a group of high-rise buildings. Vestnik MGSU. 2011. No. 3. vol. 1. Pp. 185–191. (rus)
16. V. Rimshin, E. Kuzina, and A. Neverov Residual resource of force resistance to deformation E3S Web of Conferences Vol. 135 (2019) ITESE-2019
17. Poddaeva O. I. Physical study of architectural-construction aerodynamics for sustainable design in construction industry. Promyshlennoe i grazhdanskoe stroitel'stvo. 2013. No 9. Pp. 35–38. (rus)
18. S. Merkulov, N. Polyakova, V. Rimshin, E. Kuzina, and A. Neverov Construction building systems protection under emergency exposure *E3S Web of Conferences* Vol. **135** (2019) ITESE-2019

19. Egorychev O. O., Orekhov G. V., Kovalchuk O. A., Doroshenko S. A. Studyng the desing of wind tunnel for aerodynamic and aeroacoustic tests of building structures. Scientific Herald of the Voronezh State University of Architecture and Civil Engineering. Construction and Architecture. 2012. No. 4. Pp. 7–12.

20. Dunichkin I. V., Zhukov D. A., Zolotarev A. A. Influence of aerodynamic parameters of high-rise development on microclimate and aeration of urban environment. Promyshlennoe i grazhdanskoe stroitel'stvo, 2013, No. 9. Pp. 39–41. (rus)

СПИСОК ЛИТЕРАТУРЫ

1. Айрапетов А.Б., Вишинский В.В., Катунин А.В. Расчет и экспериментальные исследования обтекания в условиях городской застройки // Труды МФТИ. 2017. Т. 9, № 2. С. 5–12.

2. E. Kuzina, V. Rimshin and A. Neverov Residual resource of power resistance during building structures deformation // E3S Web of Conferences Vol. 135 (2019) ITESE-2019

3. Rimshin, V., Aralov, R. Sustainable regeneration of urban areas (using the example of Moscow renovation program) // E3S Web of Conferences 110,01011. 2019

4. Айрапетов А.Б. Методические основы моделирования аэродинамики высотных зданий в аэродинамической трубе // Современное высотное строительство. 2007. С. 292–294.

5. E. Kuzina, V. Rimshin and A. Neverov Reserves and exposure assessment of reinforced concrete structures safety while reducing its power resistance // E3S Web of Conferences Vol. 135 (2019) ITESE-2019

6. V. Rimshin, P. Truntov Determination of carbonation degree of existing reinforced concrete structures and their restoration // E3S Web of Conferences Vol. 135 (2019) ITESE-2019

7. Вышинский В.В., Судаков Г.Г. Применение вычислительных методов в задачах аэродинамического проектирования. Москва: ЦАГИ. 2007 г.

8. V.Rimshin and P. Truntov An integrated approach to the use of composite materials for the restoration of reinforced concrete structures // E3S Web of Conferences Vol. 135 (2019) ITESE-2019

9. Kuzina, E., Rimshin, V., Kurbatov, V. The Reliability of Building Structures Against Power and Environmental Degradation Effects // IOP Conference Series: Materials Science and Engineering, 463(4),042009. 2018

10. Karpenko, N.I., Eryshev, V.A., Rimshin, V.I. The Limiting Values of Moments and Deformations Ratio in Strength Calculations Using Specified Material Diagrams // IOP Conference Series: Materials Science and Engineering 463(3),032024. 2018.

11. Аирпетов А.Б. Новые аспекты ветровой аэродинамики высотных сооружений мегаполиса, новые подходы и принципы методических исследований // Academia. 2010. № 3. Стр. 585-584.

12. Telichenko, V., Rimshin, V., Eremeev, V., Kurbatov, V. Mathematical modeling of groundwaters pressure distribution in the underground structures by cylindrical form zone // MATEC Web of Conferences 196,02025. 2018

13. Krishan A.L., Rimshin V.I., Chernyshova E.P., Astafeva M.A., Chernyshov V.E. Calculation of strength resistance of load-bearing structures of architectural object of cultural heritage // Heritage for planet Earth Proceedings of the international symposium heritage for planet Earth 2018. 2018. Pp. 280-284.

14. Churin P., Poddaeva O. Aerodynamic Testing of Bridge Structures // Applied Mechanics and Materials. 2014. V. 467. Pp.404-409.

15. Егорычев О.О., Гувернюк С.В., Исаев С.А., Поддаева О.И., Корнев Н.В., Усачев А.Е. Численное и физическое моделирование ветрового воздействия на группу высотных зданий // Вестник МГСУ. 2011. № 3. Т. 1. Стр. 185–191.

16. V. Rimshin, E. Kuzina, and A. Neverov Residual resource of force resistance to deformation // E3S Web of Conferences Vol. 135 (2019) ITESE-2019

17. Поддаева О. И. Физические исследования архитектурно-строительной аэродинамики для устойчивого проектирования в строительстве // Промышленное и гражданское строительство. 2013. № 9. С. 35–38.

18. S. Merkulov, N. Polyakova, V. Rimshin, E. Kuzina, and A. Neverov Construction building systems protection under emergency exposure // *E3S Web of Conferences* Vol. **135** (2019) ITESE-2019

19. Егорычев О.О., Орехов Г.В., Ковальчук О.А., Дорошенко С.А. Исследование конструкции аэродинамической трубы для аэродинамических и аэроакустических испытаний строительных конструкций // Научный вестник Воронежского государственного архитектурно-строительного университета. Строительство и архитектура. 2012. № 4. С. 7–12.

20. Дуничкин И. В., Жуков Д. А., Золотарев А. А. Влияние аэродинамических параметров высотной застройки на микроклимат и аэрацию городской среды // Промышленное и гражданское строительство, 2013, № 9. С. 39–41.

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