doi: 10.18720/MCE.83.5

The stress state of a tank shell in the group under wind load

Напряжения от ветровой нагрузки в стенке резервуара, находящегося в группе

V.P. Mushchanov*,
H.V. Zubenko,
M.N. Tsepliaev,
Donbas National Academy of Civil Engineering and Architecture, Makiyivka, Donetsk region, Ukraine

Д-р техн. наук, проректор по научной рабооте, заведующий кафедрой
В.Ф. Мущанов*,
ассистент А.В. Зубенко,
аспирант М.Н. Цепляев,
Донбасская национальная академия строительства и архитектуры, Макеевка, Донецкая область, Украина

Key words: wind tunnel; aerodynamic coefficient; vertical cylindrical tank

Ключевые слова: аэродинамическая труба; аэродинамический коэффициент; вертикальный цилиндрический резервуар

Abstract. The distribution of the wind flow has been studied and its effect on the stressed state of the shell of a steel vertical cylindrical tank. Variants of wind pressure were considered for one tank and for a group of tanks. Aerodynamic coefficients are obtained for the considered variants in the SolidWorks software package. A physical experiment on a reduced tank model in a wind tunnel was conducted to verify the coefficients obtained. The stresses in the tank shell were determined by the finite element method using the SCADOffice calculation complex. The result revealed differences normative distribution of wind pressure from the pilot for single tank and located in the band. The most unfavorable version of the distribution of wind pressure for the tank located in the group was determined. The stress-strain state of the tank shell is compared under the normative and experimental wind load for the most unfavorable variant.

Аннотация. Изучено распределение ветрового потока и его влияние на напряженное состояние стенки стального вертикального цилиндрического резервуара. Рассматривались варианты ветрового давления на один резервуар и на группу резервуаров. Аэродинамические коэффициенты для рассматриваемых вариантов получены в программном комплексе SolidWorks. Для верификации полученных коэффициентов был проведён физический эксперимент на уменьшенной модели резервуара в аэродинамической трубе. Напряжения в стенке резервуара определялись методом конечных элементов при помощи расчётного комплекса SCADOffice. В результате выявлены отличия нормативного распределения ветрового давления от экспериментального для одиночного резервуара и находящегося в группе. Определён наиболее неблагоприятный вариант распределения ветрового давления для резервуара, находящегося в группе. Проведено сравнение напряженно-деформированного состояния стенки резервуара при нормативной и экспериментальной ветровой нагрузке для наиболее невыгодного варианта.

1. Introduction

To calculate wind loading on buildings there are several ways of defining aerodynamic characteristics with the use of analytical and experimental data. Accurate analytical decisions in the constructional aerodynamics embrace very limited tasking, because it is very difficult to obtain a clear mathematical model for aerodynamic processes, and that is why in most cases for new and complicated structures the research is conducted in the wind tube. This research is a reliable remedy for the process study of airflow of buildings, structures and their complexes. The computer simulation of airflow and defining basic aerodynamic characteristics for buildings and structures must be mentioned as one of the developing methods.

The existing methods of wind load simulation on buildings and structures with the use of aerodynamic formulae were developed in the early 70-s in CNIISK named after Kucherenko on the base of works of A. Davenport and A. Vaisand realized in the SNiP II-6-74 [1]. In 1985 at publishing SNiP 2.01.07-85 [2] there were simplified the expressions describing the dynamic reaction of structures at wind effect.

Мущанов В.Ф., Зубенко А.В., Цепляев М.Н. Напряжения от ветровой нагрузки в стенке резервуара, находящегося в группе // Инженерно-строительный журнал. 2018. № 7(83). С. 49–62.

The basic theoretical information on architectural-building aerodynamics, methods of defining wind loads on buildings and structures are represented in the works of J. D. Holmes, O. I. Poddaeva, A.S. Kubenin [3, 4]. The works of Ye. V. Gorokhov, M. A. Berezin [5, 6], are devoted to defining wind effects on buildings and structures in the wind tube. The works of R.I. Kinash, Yasushi Uematsu, Y.Zhao, Y.Zhang [7–12] describe the experimental simulation of interaction between the wind flow and engineering structures in the wind tube.

The results of model experimental investigations of wind and snow loads on technically sophisticated large-span coverings with complex geometry are represented in the books of Ye.V. Gorokhov [13] and P.G. Eremeev [14]. Verification results and methods of computer simulation of wind influence on high-rise buildings are presented in the publications of S.A. Isaev, P.A. Vatin, P.A. Baranov [15–17].

The investigations of Ya. Jumpei, A. Moshida, Y. Tominaga, T. Shirasava [18–21] and others are devoted to the numerical simulation of wind effects.

In spite of numerous works in the field of design, construction and exploitation of tanks some problems connected with the estimation and tank efficiency are still unsolved. Among them it is necessary to mention the following ones:

– loads and effects on vertical cylindrical tanks for new types of roof coverings including slack membranous coverings have been understudied;

– loads and effects on vertical cylindrical tanks within a group, in spite of the fact, that in most oil storage tanks such composition is predominant, have been understudied.

2. Methods

General methods used in the performance of all problems given in the report are:

– calculus of approximations of constructional mechanics (method of finite-elements – MFE) with the use of universal program complexes “SCAD Office”;
– method of physical simulation with the use of the similarity theory;
– methods of mathematical statistics (while processing the results of experimental and numerical simulation).

Additionally used calculus of approximations of finite volumes (MFV) of simulation of turbulent flows with the use of program complex “SolidWorks Flow Simulation”.

3. Results and Discussion

Taking into account the complexity, multi-faceted essence and volatility of results of numerical simulation in the environment of SolidWorks Flow Simulation of flow-around of the wind flow of the 4 tanks group, it has been performed the experiment in the wind tube of the Donbass National Academy of Civil Engineering and Architecture MAT-1.

To define Reynolds number that is a similarity criterion during aerodynamic experiments, the test experiment has been conducted in the wind tube for the model of tank with a flat roof.

To meet the requirements of the surface area of the projection of the experimental model to the surface area of the cross section of a work part of the aerodynamic tube ratio it must not exceed 3 % [5]. To take into account the actual size of building (according to the requirements of VBN the distance between tanks must be 0.5D, so, while composing the group of 4 tanks with the volume of 20 000m^3 the total length is 100 m (see Figure) and peculiarities of the work part arrangement of the wind tube MAT- 1 DonNACEA with the width 1 м, it has been chosen the model scale M = 1:320.

According to the research plan of the wind tube MAT-1 DonNACEA the provision has been made for defining coefficients of the wind pressure (C_{pi}) in 49 supporting points on the model of the tank (Figures 1, 2). During investigations it has been defined the dependence $C_{pi}=f(\beta)$ within the limits β = 0…360˚ in increments of $\Delta\beta$ = 10˚. The results have been represented by 6 areas of activity (β = 0˚, 45˚, 90˚, 150˚, 180˚, 270˚).

Figure 1 and Figure 4 demonstrate a physical model of a tank with a rounded spherical roof for which the investigation has been performed.

In basic data of high-speed wind flow characteristics the value of Reynolds number is defined as:

$$\mathrm{Re} = \frac{L \cdot U(z_e)}{\nu}, \tag{1}$$

where L is a diameter;

ν is a kinematic air viscosity, ν = 1.5·10^{-5} m^2/s;

$U(z_e)$ is a peack height of the wind speed, $U(z_e)$ = 14.9 m/s.

$Re \approx 1.28 \cdot 10^5$. is a Reynolds number

To estimate the drag of high-speed flow of wind it has been done the expulsion: 1) a model with a flat roof for a physical model with drain ports (Figure 2a); 2) for a model fixed on the triple-component aerodynamic tensometric balance (Figure 2b, 2c [22]); 3) the numerical simulation in SolidWorks Flow Simulation (Figure 2d).

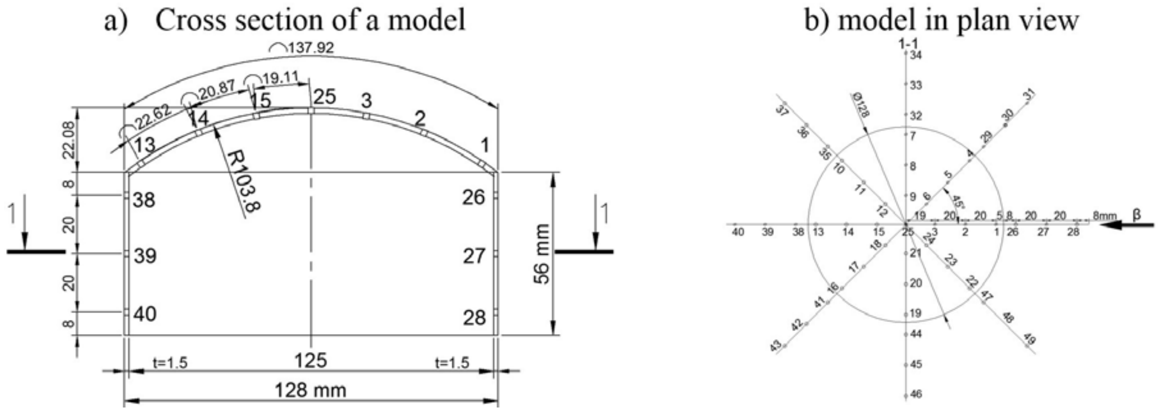


Figure 1. Scheme of the Tested Model of VCT with the Arrangements of the Horizontal Points

a) test physical model with drain ports and flat roof

b) physical model on the triple-component aerodynamic tensometric balance

c) triple-component aerodynamic tensometric balance

d) scheme for numerical experiment

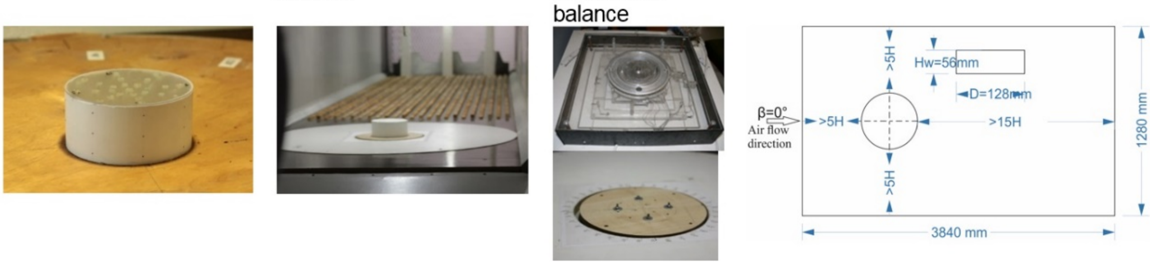


Figure 2. Scheme of a Test Physical Model of VCT with a Flat Roof at Determining the Drag Coefficient

Based on the research results for the model with a flat roof according to three techniques a graph of variation of drag coefficient with Reynolds number is made.

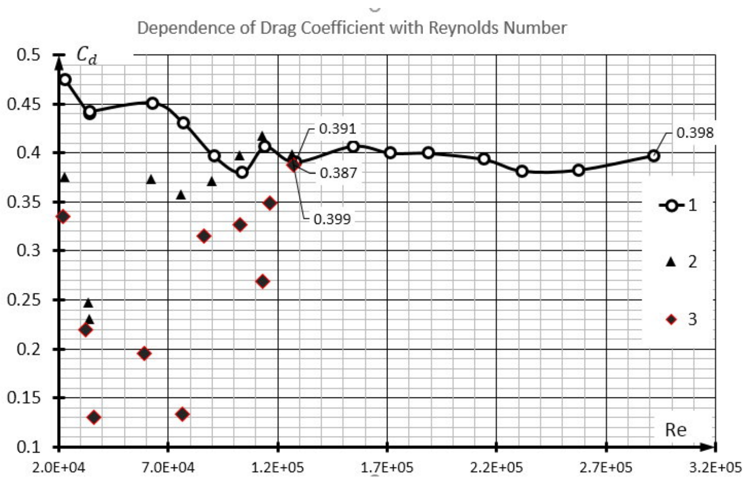


Figure 3. Dependence of Drag Coefficient with Reynolds Number

Based on the results obtained by 3 techniques it was decided to conduct further experiment at Reynolds numbers ($Re \approx 1.28 \cdot 10^5$)

where 1is a graph made on the values obtained in numerical simulation.

2 is a graph made on the values obtained in experimental simulation in wind tunnel for the test drained model with a flat roof

3 is a graph made on the values obtained in experimental simulations in wind tunnel for the test model with a flat roof set on the aerodynamic tensometric balance.

In Figure 4 the scheme with sizes of arrangement and models installations on turntable with calibration is shown.

Each cycle of the experimental purge (the given angle of attack, speed of wind flow) consisted of the following stages: start of wind wheel with the sixty-second normalization of speed of wind flow, measurement of static air pressure, its transformation to an electric signal, processing and display of the received results with the use of automatic highly productive information technology system “SCADA”. It consists of a pneumatic commutator with pressure units, the high-performance computer with the system of transformation of an analog signal in digital and also the corresponding switching equipment and electrical power supply. One polling cycle takes 1sec. During the cycle of measurements each of drainage points was read twelve times. In further processing the corresponding primary signals on each drainage point were averaged. After each turn of the examined model on $\Delta\beta$ = 10 ° the inquiry of the signal from each drainage point at zero speed of airflow was made, the so-called "0" was maintained, then the wind tunnel was started, and the speed of air was brought up to speed about 15 m/s, then speed was maintained not less than 60 s and drainage points were also read.

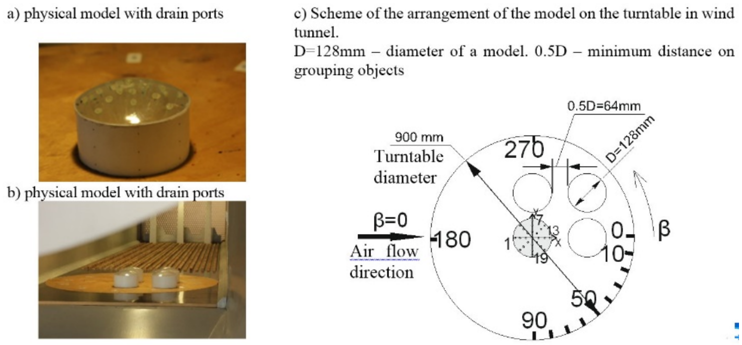


Figure 4. Arrangement of the Group of Vertical Cylindrical Tanks

Distribution of the aerodynamic coefficients on the shell of the VCT model for a single VCT with a spherical convex up roof, consisting of the group of 4 objects. The values for the 25 mm mark from the bottom of the model are given.

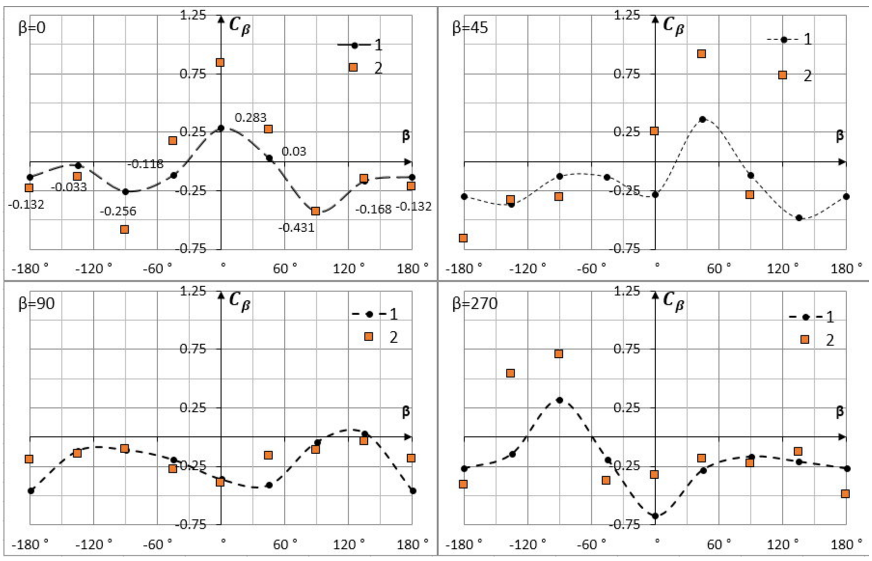


Figure 5. Comparison of Distribution of Aerodynamic Coefficients on the Tank Shell in the Group with a Convex up Roof (an angle of attack of wind flow β=0-270 °)

where 1– the values obtained during the experiment in wind tunnel;

2 – the values obtained in numerical simulation in SolidWorks Flow Simulation.

Analyzing the obtained values we can conclude that the obtained results are qualitatively convergent.

According to the obtained data of the comparative analysis of experimental, analytical and normative data the analytical model for calculation for single and VTC groups in Solid Works Flow Simulation for numerical simulation of aerodynamic processes was created. The main feature of this procedure was the determination of the size of the computer simulation of the component. A methodical approach providing a correct display of the physical processes of flow around the tank shell by wind flow (comparison of the results of experimental data and numerical studies ensure convergence within 15% for the main design cross-sections) is proposed.

3.1. Statement of a Problem of Numerical Experiment:

– to obtain the values of the aerodynamic coefficients for the separately standing vertical cylindrical tank represented as a circular cylinder with given initial geometric and thermodynamic parameters on a scale of 1:1 and compare it with the current normative documents, namely Eurocode [23];

– according to the obtained results in the form of coefficients of wind pressure on the shell of the vertical cylindrical tank to compare with the experimental data given in [22];

– to make final element model in the program complex SCAD Office c and to analyze stressed state for the isolated tank at wind load determined by a technique Eurocodes [23] and the load received as a result of numerical simulation in the program complex SolidWorks Flow Simulation

– providing admissible convergence within 10-15% to execute calculation for the group of 4 vertical cylindrical tanks, to analyze stressed state for the tank which is affected by the most adverse load in the group.

To solve the problems formulated above, verification calculation for a VCT model in the SolidWorks Flow Simulations software package was performed, the results of which are given in the article.

Before determining the wind effect by means of computer simulation it is necessary to define all the variables which satisfy the purposes of this calculation which can be compared with the experiment.

3.2. The Size of the Computational Domain

From the experience of the research in wind tunnels it is considered that a structure with height H affects the distance to almost 10H. And as the test calculations of the Japanese Institute of Architecture show [18, 20, 24, 25], the size of the computational vertical area for isolated structures should be at least 5H. When examining a group of objects, it is recommended to use a factor blocking, which is equal to the cross-sectional area ratio of the structure to the cross-sectional area of the computational area, the coefficient should not exceed 3 %. In our case, for the group with building height of 24.89 m ≈ 25 the percentage of blocking is 2.09 %. Width of the calculated area must also be set so that the blocking factor is less than 3 %. The distance along the flow to the structure must be at least 5H. And the distance behind the structure should be ≥ 15H. The following figure shows the domain scheme.

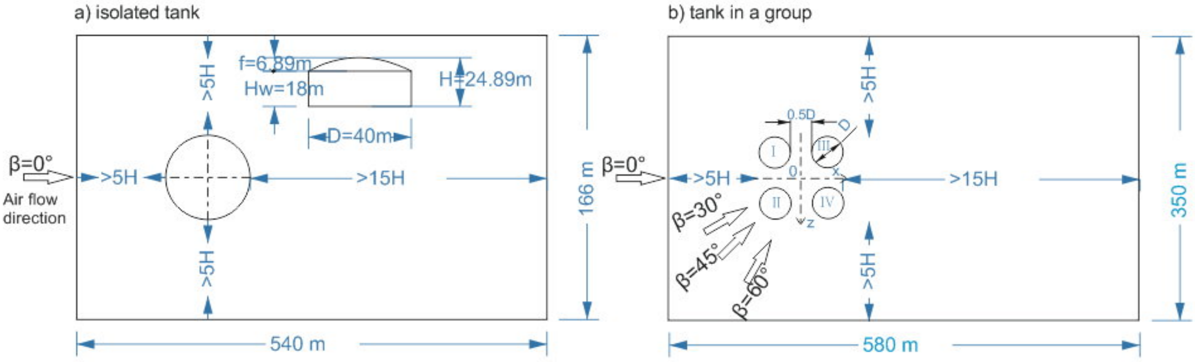


Figure 6. Size of the Calculated Area for the Isolated Tank and in the Group of 4 Objects

3.3. The Choice of Boundary and Initial Conditions

The profile of the average speed on the input is usually obtained in accordance with the requirements of normative documents. For our research, we took the profile of the average velocity $v_m(z)$, the turbulence intensity $I_v(z)$, the integral turbulence scale $L\ (z)$ according to formulas (8, 7, 12) according to Eurocode standards, because of the norms of Ukraine [26] and Russia [27], the energy of velocity pulsations is described by the Davenport spectrum, which does not take into account the dependence of the energy of turbulent wind pulsations on height and the integral longitudinal scale of turbulence assumes a constant value $L_u(z)$ = 1200 m, the intensity does not appear explicitly in turbulence.

We have followed the recommendations of A. Moshida, Y. Tominaga [18] from the Japanese Institute of Architecture when specifying the sizes of the finite elements mesh to solve the CFD tasks. The FE mesh resolution should be 1/10 from the lower structure in the group (approximately 0.5- 5m).

The FE meshes ratio for sequential mesh systems should not exceed 3.4 [28].

The verification analysis in three-dimensional view of a test model (Figure 1) for Reynolds number based on the wind-tunnel testing has been made to determine the mesh size in CFD.

Figures 7 and 8 illustrate the comparison graphs of aerodynamic factors for the shell of both an isolated tank and a tank in the group.

a) distribution of aerodynamic factors b) velocity fields

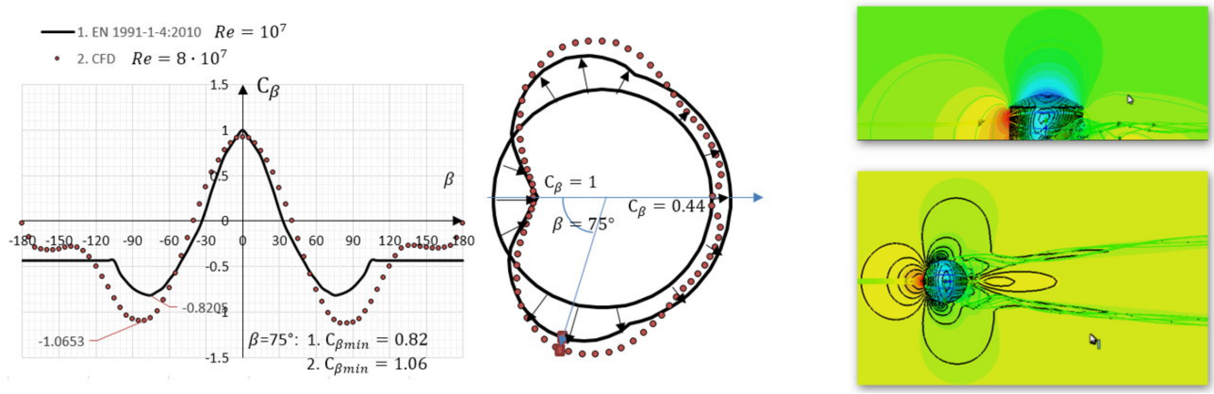


Figure 7. Comparison of Aerodynamic Factors Graphs for an Isolated Tank

a) for β=0 b) for β=15 c) for β=30 d) for β=45

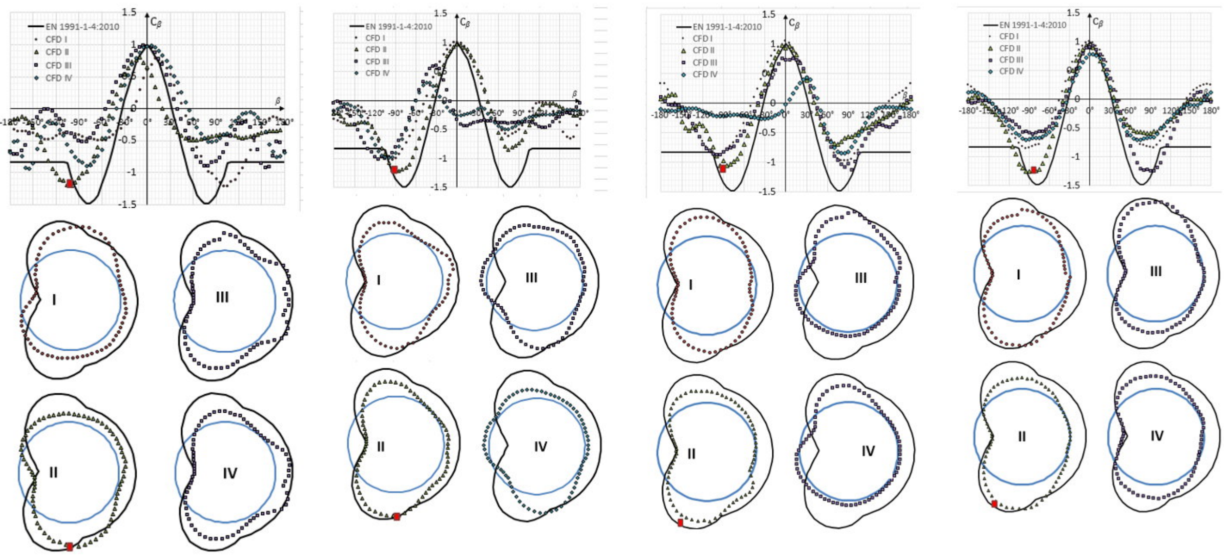


Figure 8. Comparison of Aerodynamic Factors Graphs for a Tank in the Group

The comparison of the obtained values of aerodynamic factors for an isolated vertical cylindrical tank presented in the form of a circular cylinder with preset initial geometrical and thermal properties in full scale (Eurocodes norms) has shown that they differ greatly in negative pressure environment by 50 %.

The analysis of the obtained aerodynamic factors for a tank in the group has revealed the most negative effect of the wind flow at the angle of attack of 45° for tank number II (see Figure 6).

3.4. Simulation of Finite Elements Model of a Tank in SCAD Office

The values of the wind load on the isolated tank and the tanks in the group are determined by means of SolidWorks Flow Simulation. Nevertheless, it is not available to assess the strain-stress state of the tanks resulting from the wind load by means of this program. It is a good practice to apply the finite elements method to assess the strain-stress state of the tanks. So far as there is little scope for a designer to use some program, this paper presents the setting of an actual wind load distribution by means of SCAD Office, the most available software system in CIS states.

We shall consider the wind load distribution on the shell of a vertical cylindrical tank in the following instances:

- the actual wind load distribution profile according to Eurocodes [23];
- the wind load on the isolated tank and the tanks in group based on the results of numerical simulation.

3.5. Parameters of a Tank FE Model

In numerical simulation in SolidWorks Flow Simulation the dimensions of tanks have been assumed according to the type design No. 704-1-70 in the volume of 20 000 m^3 [29]. Therefore, the finite element model of a tank conforming to the type design dimensions has been made. The bottom is fixed rigidly in the entire area, the shell of the tank is hinged to the bottom, the support ring of the roof is assigned in parameters in the form of a rod having computed characteristics, the elements of a ribbed and circular dome are also assigned by the rods. The thickness of rings of the shells, bottom and plate are preset according to the type design [29]. The size of the finite element is set to 250 x 250 mm. With the further size reduction of FE the accuracy increases insignificantly, whereas both the complexity of designing and load setting increase greatly. Thus, the shell of a tank is to consist of 36072 finite elements.

It is impossible to set non-linear load variations on a curved surface by means of the known quantity of load values for different points in SCAD system. It means that in order to set the wind load on tank's curved surface, we have to calculate manually and set the load on each finite element separately. So far as the tank model consists of more than 96000 FE, it could take a few days to specify the wind load. The method of load specifying by means of a text file can be used as an alternative. The procedure for specifying the actual profile of wind load on the similar tank is described in the paper [30], for this reason we shall use the excerpts from it in the given paper, the process will not be detailed.

3.6. Determining the Design Load Based on the Results of Numerical Simulation

Profiles of wind load on the isolated tank and the tank within the group obtained by means of SolidWorks Flow Simulation have a complicated form. To transfer the given load on each FE, the table of load values on vertical cylindrical tank shells depending on design point location over the height and length of the circle has been formed. The vertical pitch equals 1m, the circumference pitch is 2° (0.696 m). Intermediate values are determined by double linear interpolation in MS Office Excel by means of macros. An example of the table for an isolated tank is given below (Table 1).

Table 1. Values of Wind Load on the Shell of an Isolated Tank

		Height of the Design Point, m							
		0.01	**1**	**2**	**…**	**15**	**16**	**17**	**17.9**
Circumference Pitch 2° =0.696 м	**0**	−336.985	602.378	554.547	…	847.6	791	628.4	−824
	0.696	−256.211	602.428	552.147	…	853.8	798.3	636.5	−820
	1.392	−266.838	602.342	544.477	…	847.6	792.9	644.5	−815
	…	…	…	…	…	…	…	…	…
	123.17	123.86	−537.288	602.8	…	834.11	779.53	632.56	−811.146
	123.86	124.56	−442.437	602.8	…	847.756	793.048	644.333	−815.617
	124.56	125.54	−336.985	602.4	…	853.772	798.247	636.201	−820.177
	125.35	123.86	−537.288	602.8	…	847.609	790.968	628.39	−823.84

Similar tables have been made for either of four tanks in the group at different angles of attack. For further strain-stress state analysis of tanks in the group the vertical cylindrical tank No. 2 (Figure 6) at the angles of attack of 0 and 45 degrees has been chosen based on comparison results of the tables. At these angles the wall of the vertical cylindrical tank No. 2 is affected by the most distinct wind load profile in comparison to that one affecting the isolated tank.

Further on, three tables for determining the wind load on each finite element are made in MS Office Excel for the next task in SCAD:

– the wind load on the isolated tank;

– the wind load on tank No. 2 in the group (angle of attack is 0°);

– the wind load on tank No. 2 in the group (angle of attack is 45°).

Since the concept for such tables is absolutely identical, below is given an example of a table segment for one of the cases – the wind load on the isolated tank (Table 2).

Table 2. Determining the Wind Load on each FE of the Shell of the Isolated VCT

No. of element	z, m	$C_{e(}z)$	Arc length, m	W_e, kN/m^2	W_e* $C_{e(}z)$, kN/m^2	Type of load	Direction		Load value: No. of element		
1	2	3	4	5	6	7	8	9	10	11	12
1	0.25	0.974	0.125	−0.207	−0.201	6	3		−0.201:1		/
2	0.25	0.974	0.376	−1.813	−0.177	6	3		−0.177:2		/
…	…	…	…	…	…	…	…	…	…	…	…
36071	17.88	3.32	125.29	−0.783	−2.598	6	3		−2.598:36071		/
36072	17.88	3.32	125.54	−0.784	−2.6	6	3		−2.6:36072		/

Notes to the Table:

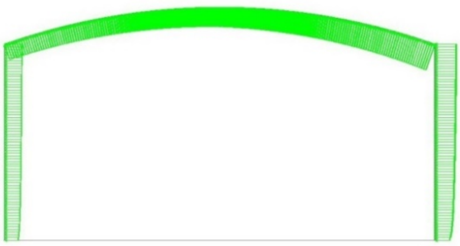
column 4 – the length of an arc from the 1-st FE till the design one over the circle length, m;

column 5 – the value of wind load regardless of $C_{e(}z)$ factor, being defined by means of double interpolation according to Table 5inMSOfficeExcel;

column 6 – the design value of wind load.

3.7. Specifying the Load by Means of a Text File

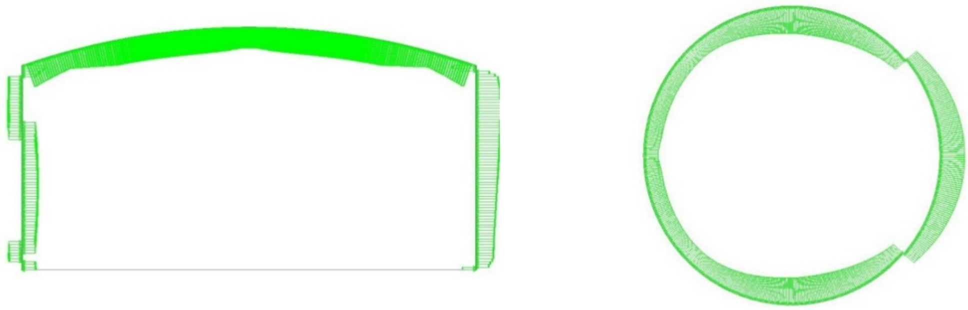
Wind loading procedure by means of a text file is described in full detail in the paper [30]. The principle of method consists in editing the file of a tank model, created in SCAD and saved in the form of a text. In a text file the designation of the load is entered manually, the parameters and values of the load for each element are copied. Thus, columns 7-12 and lines 1-36072 of Table 3 are used for the wind load on the isolated tank. To display the results of specifying the actual wind load profile, below are given two typical cross-sections of the wall (stacked to the bottom and the roof) made transversely (in the middle of the wall height) and length wise for four design diagrams under consideration (Figure 9–12):



a) longitudinal cross-section along the height of the vertical steel tank

b) transverse cross-section along the height of the vertical steel tank

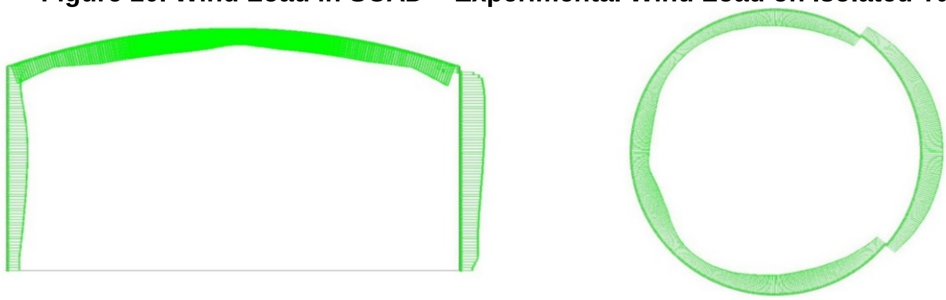
Figure 9. Wind Load in SCAD – Wind Load according to Eurocodes



a) longitudinal cross-section along the height of the vertical steel tank

b) transverse cross-section along the height of the vertical steel tank

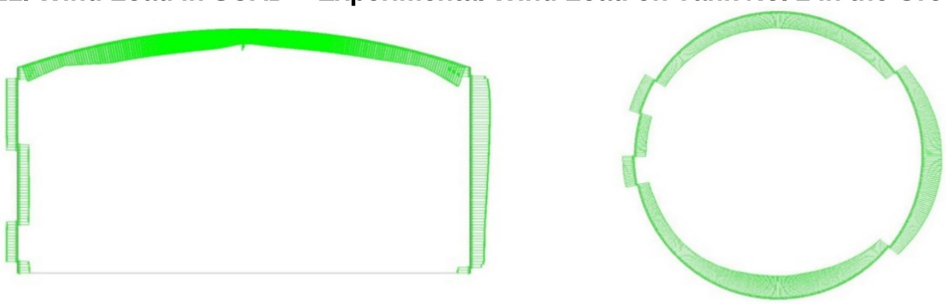
Figure 10. Wind Load in SCAD – Experimental Wind Load on Isolated Tank



a) longitudinal cross-section along the height of the vertical steel tank

b) transverse cross-section along the height of the vertical steel tank

Figure 11. Wind Load in SCAD – Experimental Wind Load on Tank No. 2 in the Group (Wind 0°)



a) longitudinal cross-section along the height of the vertical steel tank

b) transverse cross-section along the height of the vertical steel tank

Figure 12. Wind Load in SCAD – Experimental Wind Load on Tank No. 2 in the Group (Wind 45°)

So far as the wind load on the vertical cylindrical tank in the group has less peak values at the angle of attack of 0° than at the angle of 45° and coincides greatly with the wind load on the isolated tank, we shall use three design situations to make a strain-stress state analysis of the tanks:

– the wind load according to Eurocodes [23];

– the wind load on the isolated tank based on the results of numerical simulation;

– the wind load on tank No. 2 from the group of four tanks at the angle of 45°.

3.8. Finite Element Analysis of the Shell Strain-Stress State at the Wind Load on Isolated Vertical Cylindrical Tank According to Eurocodes and Numerical Simulation Results

The combination of the wind load and own weight with unity combination factors (1 x Wind + 1 x Own Weight) has been used to compare the strain-stress state of the tank at the wind load obtained according to Eurocodes and the load obtained by numerical simulation results. To give an outline of the strain-stress state of the vertical cylindrical tank's shell resulting from the given loads, below is given the distribution of equivalent stresses in the tank's shell according to maximum distortion energy theory (Figures 13, 14):

a) distribution of stresses b) values of stresses

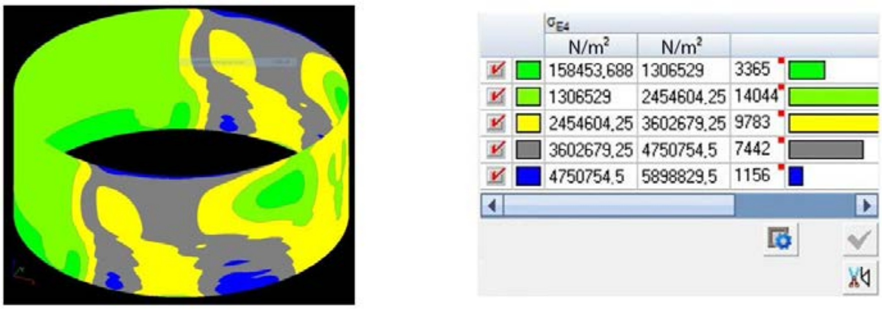


Figure 13. Equivalent Stresses in the Tank's Shell at Wind Load according to Maximum Distortion Energy Theory Computed by Eurocodes

a) distribution of stresses b) values of stresses

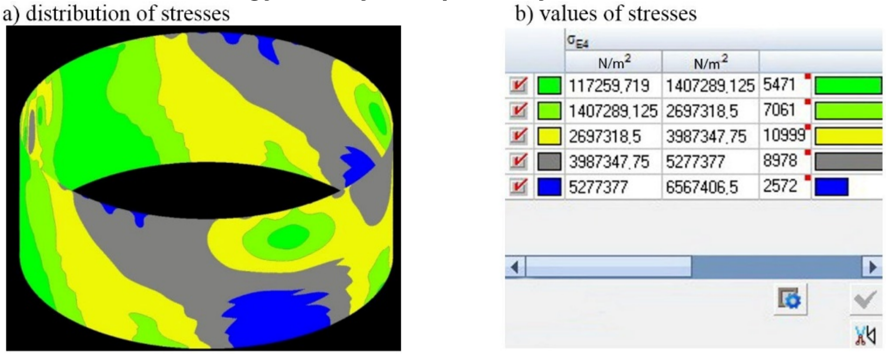


Figure 14. Equivalent Stresses in the Isolated Tank's Shell at Wind Load according to Maximum Distortion Energy Theory Computed by SolidWorks Flow

For strain-stress state analysis two rings of vertical cylindrical tank No. 5 (half the height of the wall) and No. 8 (2/3 of the wall height) have been singled out. Since edge effects have little influence on the strain values in these rings, heavy wind loads are brought about. It is more relevant to present the comparison results in the form of a table (Table 3).

Table3. The Strain-Stress State of the Isolated Vertical Cylindrical Tank

No. of Tank Rings	Design Load	Ny= σ_1 (+), MPa	Ny= σ_1 (−), MPa	Nx=σ_2 (+), MPa	Nx=σ_2 (−), MPa	σ_{e4}(maximum distortion energy theory), MPa
5	According to Eurocodes	1.872	2.863	4.400	2.947	3.967
	Numerical Simulation	2.166	3.173	5.138	3.149	4.148
Variation%		15.74	10.84	16.79	6.86	4.57
8	According to Eurocodes	2.086	2.744	4.690	3.000	4.322
	Numerical Simulation	3.385	5.104	5.695	5.000	5.154
Variation %		62.23	86.02	21.42	66.65	19.2

Thus, according to the results of numerical simulation the largest deviation had been recorded in the upper ring of VCT of the shell. Minimum deviation is 21 %, maximum one is 108 %, in both cases stresses were great because of the wind load obtained by numerical simulation in Solid Works Flow. Considerable difference in upper rings can be explained by the disarrangement of wind flow in the area of roof joint with the shell, thus some part of the upper ring is under the influence of "breaking off wind load".

3.9. Finite Element Analysis of Strain-Stress State of the Shell at Unfavorable Wind Load on VCT, Consisting of a Group of 4 Objects

As it was mentioned earlier, VCT No. 2 will be examined at the angle of wind of 45° as the most unfavorable one. As a whole the distribution of equivalent stresses according to the 4th maximum distortion energy theory is given in figure 15.

a) the distribution of stress

b) values of stresses

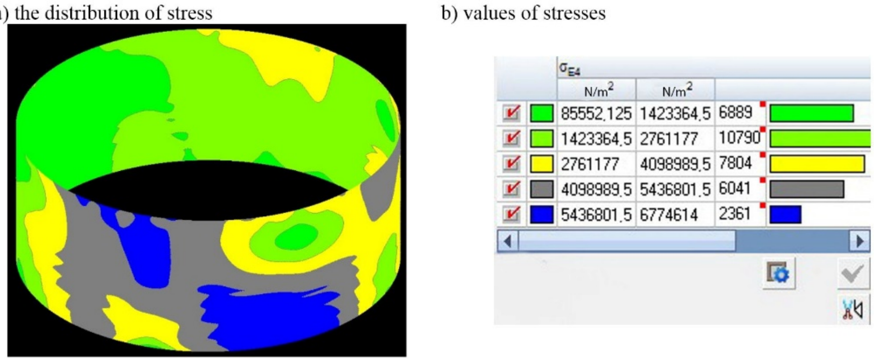


Figure 15 Equivalent Stresses according to the 4th Maximum Distortion Energy Theory on the Shell of VCT in the Group of Tanks Depending on the Load Obtained in SolidWorks Flow

Below are given the values of occurring stresses in the 5th and 8th rings of the tank and the percentage-based comparison of these stresses deviations from the wind load according to the codes of the European Union and stresses occurring in an isolated tank under the influence of wind pressure obtained as a result of numerical simulation (Table 5).

Table 5.Stress and Strain State of VCT Shell in the Group

No. of tank ring	Design load	Ny= σ_1 (+), MPa	Ny= σ_1 (−), MPa	Nx=σ_2 (+), MPa	Nx=σ_2 (−), MPa	σ_{e4}(The 4th maximum distoration energy theory), MPa
5	VCT in group	1.922	1.026	5.705	4.147	5.870
	Difference from European code, %	2.67	179.04	29.67	40.73	47.97
	Difference from wind on 1 VCT, %	12.73	209.27	11.02	31.69	41.51
8	VCT in group	2.485	1.120	6.082	5.024	6.199
	Difference from European code, %	19.11	145.05	29.68	67.46	43.41
	Difference from wind on 1 VCT, %	36.20	355.83	6.8	0.49	20.27

The analysis of comparative table shows, that stress and strain state of the shell of tank which is in the group differs greatly from stress and strain state of the shell of an isolated VCT. Thus maximum deviation of stresses makes 356%. In this case maximum stresses occur exactly in the case of wind load on VCT in group, though most part of the shell undergoes less stress than in two other examined cases.

3.10. Discussion

In this work, new results were obtained on the distribution of wind loads on the wall of a tank that is in a group of 4 reservoirs, which is not taken into account by the current design standards. The need for such an account is confirmed by the data of subsection 3.9.

At the same time, these data are subject to discussion and can be considered as primary, to be clarified before introduction into the relevant regulatory documents, due to the following reasons, in our opinion:

- the need to conduct a physical experiment on large models,
- the need to conduct a numerical experiment with a larger range of tanks, ranging from 100 to 30 000 m^3;
- the need to obtain generalized expressions for rationing the wind load on a group of tanks with varying parameters of the geometrical dimensions of the tanks, the shape of the roof, the distance between the tanks.

4. Conclusion

1. In the shell of an isolated tank affected by the wind load according to the results of numerical simulation, in the middle and low rings the equivalent stresses differ not more than by 5 % from those according to Eurocode, in the upper tanks – by 20 %. The difference of upper ring stress and strain state has been caused by the fact that diagram of wind pressure according to the Eurocode for examined standard size of the tank because of the small values of occurring stresses, did not take into account break up lifting wind pressure in the area of roof and shell joint.

2. Maximum values of stresses in the shell all of VCT in all examined cases of loadings, occur in tank No. 2 at wind attack angle of 45°.

3. Stress and strain state of the shell under the effect of unfavorable wind load on VCT, which is in the group of 4 objects differs greatly from the stresses occurring in the shell of isolated VCT. On the whole peace loads of equivalent stresses differ by 48 % as compared to isolated VCT according to the Eurocode and by more than 41 % in comparison with isolated VCT according to the results of numerical simulation. Thus objects situated nearby influence greatly stress and strain state of the shell of VCT and it requires the development of the technique taking this fact into account.

References

1. SNiP II-6-74. Nagruzki i vozdeystviya [SNiP II-6-74. Loads and effects]. Moscow : Stroyizdat, 1976. 58 p. (rus)
2. SNiP 2.01.07-85*. Nagruzki i vozdeystviya [SNiP 2.01.07-85*. Loads and effects]. Moscow : FGUP TsPP, 2005. 44 p. (rus)
3. Holmes, J.D. Wind loading of structures. Boca Raton, FL : CRC press, 2015. 412 p.
4. Lawson, T. Building aerodynamics. London: Imperial College Press, 2001. 286 p.
5. Gorokhov, Ye.V., Kuznetsov, S.G. Eksperimentalnye metody opredeleniya vetrovykh nagruzok na zdaniya i sooruzheniya [Experimental methods of determination of wind load on buildings and constructions]. Donetsk: Nord-Press, 2009. 169 p. (rus)
6. Berezin, M.A., Katyushin, V.V. Atlas aerodinamicheskikh kharakteristik stroitelnykh konstruktsiy [Aerodynamic characteristics atlas of engineering constructions]. Novosibirsk : Oldenpoligrafiya, 2003. 140 p. (rus)
7. Kinash, R.I., Kopylov, A.Ye. Bulletin of Lviv Polytechnic National University. Series: Theory and Practice in Construction. 2004. No. 495. Pp. 88–92. (rus)
8. Kinash, R.I., Kopylov, A.Ye. Proceeding of the Donbas National Academy of Civil Engineering and Architecture. 2007. No. 2007-6(68). Pp. 32–40. (rus)
9. Uematsu, Y., Koo, C., Kondo, K. Wind loads on open-topped oil storage tanks. BBAA VI International Colloquium on Bluff Bodies Aerodynamics and Applications, Milano, Italy, July, 20-24 2008. Milano, 2008. Pp. 1–15.
10. Zha, Y., Lin, Y., Shen, Y.-B. Wind loads on large cylindrical open-topped tanks in group. Thin-Walled Structures. 2014. No. 78. Pp. 108–120.
11. Zhang, Y. Study of microburst-like wind and its loading effects on structures using impinging-jet and cooling-source approaches. Ames, Iowa: Iowa State University, 2013. 235 p.
12. Zhang, Y., Hu, H., Sarkar, P.P. Comparison of microburst-wind loads on low-rise structures of various geometric shapes. Journal of Wind Engineering and Industrial Aerodynamics. 2014. No. 133. Pp. 181–190.
13. Gorokhov, Ye.V., Mushchanov, V.F., Kinash, R.I., Shimanovskiy, A.V., Lebedich, I.N. Konstruktsiyi statsionarnykh pokrytiy nad tribunami stadionov [Construction of fixed-site coverings over terraces]. Makeyevka : RIO DonNASEA, 2008. 405 p. (rus)
14. Yeremeyev, P.G. Sovremennye stalnye konstruktsiyi bolsheproletnykh pokrytiy unikalnykh zdaniy i sooruzheniy [Current steel constructions of large-span shell of one-off buildings and constructions]. Moscow: ASV, 2009. 336 p. (rus)

Литература

1. СНиП II-6-74. Нагрузки и воздействия. – Взамен СНиП II-А.11-62; СН 318-65; СН 355-66 ; вед. 01.09.1974. М: Стройиздат, 1976. 58 с.
2. СНиП 2.01.07-85*. Нагрузки и воздействия. – Взамен главы СНиП II-6-74 ; введ. 01-01-1987. М: ФГУП ЦПП, 2005. 44 с. (Строительные нормы и правила).
3. Holmes J.D. Wind loading of structures. Boca Raton, FL : CRC press, 2015. 412 p.
4. Lawson T. Building aerodynamics. London: Imperial College Press, 2001. 286 p.
5. Горохов Е.В., Кузнецов С.Г. Экспериментальные методы определения ветровых нагрузок на здания и сооружения. Донецк : Норд-Пресс, 2009. 169 с.
6. Березин М.А., Катюшин В.В. Атлас аэродинамических характеристик строительных конструкций. Новосибирск : Олденполиграфия, 2003. 140 с.
7. Кинаш Р.И., Копылов А.Е. Аэродинамические исследования четырех круглых цилиндров // Вісник Національного університету “Львівська політехніка”. Серія: Теорія і практика будівництва. 2004. № 495. С. 88–92.
8. Кинаш Р.И., Копылов А.Е. Исследование аэродинамических параметров системы из двух круговых цилиндров // Вестник Донбасской национальной академия строительства и архитектуры. 2007. №. 2007-6(68). С. 32–40.
9. Uematsu Y., Koo C., Kondo K. Wind loads on open-topped oil storage tanks // BBAA VI International Colloquium on Bluff Bodies Aerodynamics and Applications, Milano, Italy, July, 20-24 2008. Milano, 2008. Pp. 1–15.
10. Zhao Y., Lin Y., Shen Y.-B. Wind loads on large cylindrical open-topped tanks in group // Thin-Walled Structures. 2014. № 78. Pp. 108–120.
11. Zhang Y. Study of microburst-like wind and its loading effects on structures using impinging-jet and cooling-source approaches. Ames, Iowa : Iowa State University, 2013. 235 p.
12. Zhang Y., Hu H., Sarkar P.P. Comparison of microburst-wind loads on low-rise structures of various geometric shapes // Journal of Wind Engineering and Industrial Aerodynamics. 2014. No. 133. Pp. 181–190.
13. Горохов Е.В., Мущанов В.Ф., Кинаш Р.И. [и др.]. Конструкции стационарных покрытий над трибунами стадионов. Макеевка : РИО ДонНАСА, 2008. 405 с.
14. Еремеев П.Г. Современные стальные конструкции большепролетных покрытий уникальных зданий и сооружений: монография. М: АСВ, 2009. 336 с.
15. Исаев С.А., Ватин Н.И., Баранов П.А., Судаков А.Г., Усачов А.Е., Егоров В.В. Разработка и верификация

15. Isaev, S.A., Vatin, N.I., Baranov, P.A., Sudakov, A.G., Usachov, A.Ye., Yegorov, V.V. Development and verification of multiblock computational technologies for solution of unsteady problems of high building aerodynamics in the framework of URANS approach. Magazine of Civil Engineering. 2013. 36(1). Pp. 103–109.
16. Isaev, S.A., Baranov, P.A., Vatin, N.I., Zhukova, Y.V., Sudakov, A.G. Suppression of the Karman vortex street and reduction in the frontal drag of a circular cylinder with two vortex cells. Technical Physics Letters. 2014. No. 40(8). Pp. 653–656.
17. Isaev, S.A., Vatin, N.I., Lebiga, V.A., Zinoviev, V.N., Chang, K.-C., Miau, J.-J. Problems and methods of numerical and experimental investigation of high rise constructions' aerodynamics in the coastal region "sea-land". Magazine of Civil Engineering. 2013. 37(2). Pp. 54–61; Pp. 118-120.
18. Mochida, A., Tominaga, Y., Murakami, S., Yoshie, R., Ishihara, T., Ooka, R. Comparison of various k-ε models and DSM applied to flow around a high-rise building — Report on AIJ cooperative project for CFD prediction of wind environment. Wind and Structures. 2002. No. 5 (2–4). Pp. 227–244.
19. Tominaga, Y., Mochida, A., Yoshie, R., Kataoka, H., Nozu, T., Yoshikawa, M., Shirasawa, T. AIJ guidelines for practical applications of CFD to pedestrian wind environment around buildings. Journal of Wind Engineering and Industrial Aerodynamics. 2008. No. 96(10). Pp. 1749–1761.
20. Shirasawa, T., Tominaga, T., Yoshie, R. Mochida, A., Yoshino, H., Kataoka, H., Nozu, T. Development of CFD Method for Predicting Wind Environment around a High-Rise Building: Part 2: The cross comparison of CFD results using various k-ε models for the flowfield around a building model with 4:4:1 shape (Environmental Engineering). AIJ Journal of Technology and Design. 2003. Vol. 9. No. 18. Pp. 169–174.
21. Yasunaga, J., Koo, C., Uematsu, Y. Kondo, K., Yamamoto, M. Wind loads on two or three open-topped oil-storage tanks in various arrangements. Proceedings of the 2012 World Congress on Advances in Civil, Environmental, and Materials Research (ACEM'12). Seoul. 2012. Pp. 2339–2352.
22. Zubenko, H., Drozdov, A. Model'nyye ispytaniya vertikal'nykh uglovykh rezervuarov [Model tests of vertical cylindrical tanks and verification of numerical studies]. Metal Constructions. 2016. Vol. 22. No. 2. Pp. 91–97. (rus)
23. DSTU-N B EN 1991-1-4:2010. Yevrokod 1. Dii na konstruktsii. Chastyna 1-4. Zagalni dii. Vitrovi navantazhennya (EN 1991-1-4:2005, IDT) [Eurocode 1. Actions on structures – Part 1-4. General actions – Wind actions (EN 1991-1-4:2005, IDT)]. Kyiv : Ministry of Regional Development of Ukraine, 2012. 165 p. (ukr)
24. Tominaga, Y., Mochida, A., Shirasawa, T., Yoshie, R., Kataoka, H., Harimoto, K., Nozu, T. Cross comparisons of CFD results of wind environment at pedestrian level around a high-rise building and within a building complex. Journal of Asian Architecture and Building Engineering. 2004. Vol. 3. Pp. 63–70.
25. DBN V.1.2-2:2006. Derzhavni budivelni normy. Systema zabezpechennya nadiynosti ta bezpeky budivelnikh obyektiv. Navantazhennya i vplyvy. Normy proektuvannya [National Structural Rules and Regulations. The system of reliability and safety provision of constructional projects. Loads and effects]. Kyiv: Ministry of Regional Development of Ukraine, 2006. 61 p. (ukr)
26. SP 20.13330.2011. Nagruzki i vozdeystviya. Aktualizirovannaya redaktsiya SNiP 2.01.07-85* [Loads and effects. Updated reaction. SNiP 2.01.07-85*].

многоблочных вычислительных технологий для решения нестационарных задач строительной аэродинамики высотных зданий в рамках подхода URANS // Инженерно-строительный журнал. 2013. № 1(36). С. 103–109.
16. Isaev S.A., Baranov P.A., Vatin N.I. [et al.] Suppression of the Karman vortex street and reduction in the frontal drag of a circular cylinder with two vortex cells // Technical Physics Letters. 2014. № 40(8). Pp. 653–656.
17. Исаев С.А., Ватин Н.И., Лебига В.А., Зиновьев В.Н., Кэ-Чин Чан, Цзюн-Цзи Мяу. Задачи и методы численного и физического исследования аэродинамики высотных зданий в прибрежной зоне «море-суша» // Инженерно-строительный журнал. 2013. №2(37). С. 54–61.
18. Mochida A., Tominaga Y., Murakami S. [et al.] Comparison of various k-ε models and DSM applied to flow around a high-rise building — Report on AIJ cooperative project for CFD prediction of wind environment // Wind and Structures. 2002. № 5(2-4). Pp. 227-244.
19. Tominaga Y., Mochida A., Yoshie R. [et al.] AIJ guidelines for practical applications of CFD to pedestrian wind environment around buildings // Journal of Wind Engineering and Industrial Aerodynamics. 2008. № 96(10). Pp. 1749–1761.
20. Shirasawa T., Tominaga T., Yoshie R. [et al.] Development of CFD Method for Predicting Wind Environment around a High-Rise Building : Part 2 : The cross comparison of CFD results using various k-ε models for the flowfield around a building model with 4:4:1 shape (Environmental Engineering) // AIJ Journal of Technology and Design. 2003. Vol. 9. № 18. Pp. 169–174.
21. Yasunaga J., Koo C., Uematsu Y. [et al.] Wind loads on two or three open-topped oil-storage tanks in various arrangements // Proceedings of the 2012 World Congress on Advances in Civil, Environmental, and Materials Research (ACEM'12). Seoul, 2012. Pp. 2339–2352.
22. Зубенко А.В., Дроздов А.А. Модельные испытания вертикальных цилиндрических резервуаров и верификация численных исследований // Металлические конструкции. 2016. Т. 22. № 2. С. 91–97.
23. ДСТУ-Н Б EN 1991-1-4:2010. Єврокод 1. Дії на конструкції [Text]. Частина 1-4. Загальні дії. Вітрові навантаження (EN 1991-1-4:2005, IDT). – Уведено вперше ; чинні 01.07.2013. К. : Мінрегіон України, 2013. 165 с. (Національний стандарт України).
24. Tominaga Y., Mochida A., Shirasawa T. [et al.] Cross comparisons of CFD results of wind environment at pedestrian level around a high-rise building and within a building complex // Journal of Asian Architecture and Building Engineering. 2004. Vol. 3. Pp. 63–70.
25. ДБН В.1.2-2:2006. Державні будівельні норми. Система забезпечення надійності та безпеки будівельних об'єктів. Навантаження і впливи. Норми проектування [Text]. – Замість СНиП 2.01.07-85 ; надано чинності 2007-01-01. К. : Мінбуд України, 2006. 61 с.
26. СП 20.13330.2011. Нагрузки и воздействия. Актуализированная редакция СНиП 2.01.07-85* [Text]. – Введ. 20-05-2011. М. : Госстандарт, 2011. 80 с. (Свод правил).
27. Franke J., Hirsch C., Jensen A.G. [et al.] Recommendations on the Use of CFD in Wind Engineering // Proceedings of the International Conference on Urban Wind Engineering and Building Aerodynamics: COST C14 – Impact of Wind and Storm on City life and Built Environment. Rhode-Saint-Genèse . 2004. Pp. 1.1–1.11.
28. Типовой проект 704-1-70. Стальной вертикальный цилиндрический резервуар для нефти и нефтепродуктов емкостью 20000 куб. м [Text]. Альбом I. Рабочие чертежи КМ резервуара. – М. :

Moscow: Ministry of Regional Development of Russia, 2011. 80 p. (rus)

27. Franke, J., Hirsch, C., Jensen, A.G., Krüs, H.W., Schatzmann, M., Westbury, P.S., Miles, S.D., Wisse, J.A., Wright, N.G. Recommendations on the Use of CFD in Wind Engineering. Proceedings of the International Conference on Urban Wind Engineering and Building Aerodynamics: COST C14 – Impact of Wind and Storm on City life and Built Environment, Rhode-Saint-Genèse / J.P.A.J. van Beek (Ed.). Rhode-Saint-Genèse : Von Karman Institute for Fluid Dynamics, 2004. Pp. 1.1–1.11.
28. Tipovoy proyekt 704-1-70. Stalnoy vertikalnyy tsilindricheskiy rezervuar dlya nefti i nefteproduktov yemkostyu 20000 kub. m. Albom I. Rabochiye chertezhi KM rezervuara [Type design 704-1-70. Steel vertical cylindrical tank of 20000 volume for crude oil and refined products. Album I. Drawing design of tank]. Moscow: Research and Development Establishment Projectsteelconstructions of State Committee for Construction of the USSR, 1972. 46 p. (rus)
29. Tcepliaev, M. Modelirovaniye real'noy epyury vetrovogo davleniya na tsilindricheskiy rezervuar v srede SCAD [Simulation of real epure of wind pressure on a cylindrical tank in SCAD environment]. Metal Constructions. 2016. Vol. 22. No. 4. Pp. 183–192. (rus)

ЦНИИпроектстальконструкция Госстроя СССР, 1972. – 46 с.

29. Цепляев М.Н. Моделирование реальной эпюры ветрового давления на цилиндрический резервуар в среде SCAD // Металлические конструкции. 2016. Т. 22. № 4. С. 83–192.

Volodymyr Mushchanov,*
+380(50)368-08-04;
volodymyr.mushchanov@mail.ru

Hanna Zubenko,
+380(50)815-93-47; zubienko_anna@mail.ru

Maxim Tsepliaev,
+380(71)319-82-29; m.s.sepliaev@donnasa.ru

Владимир Филиппович Мущанов,*
+380(50)368-08-04;
эл. почта: volodymyr.mushchanov@mail.ru

Анна Васильевна Зубенко,
+380(50)815-93-47;
эл. почта: zubienko_anna@mail.ru

Максим Николаевич Цепляев,
+380(71)319-82-29;
эл. почта: m.s.sepliaev@donnasa.ru