2%), які визначаються похибками виготовлення стандартних зразків, за якими здійснюється налаштування цих приладів.

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SIMULATION OF THE IMPACT OF WIND LOAD ON THE VERTICAL STEEL TANK

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Current requirements for the safe operation of tanks with environmentally hazardous substances (TEHS) rise new challenges for researchers and engineers, among them is development of effective methods and techniques for continuous monitoring of technical condition of TEHS. This is particularly important when the TEHS is operating in harsh environmental conditions, due to which there is a risk of an emergency situations.

Other authors usually do not consider the selection of geometric model and analysis of the causes of cracks, so the purposes of this article are: 1) development of the geometric models of the TEHS and study of the influence of structural elements on the simulation results; 2) simulation and *determination of the influence of the wind load (as one of the strongest external influence in the Antarctic region) on the TEHS.*

That is why in this paper six geometric assembly units of tanks were built and the influence of the elements of their design on simulation results was studied. A comparison of simulation and analytical calculation of wind loads on the tank was conducted. The analysis of the interaction of fluid-structure was conducted. Locations of the greatest stresses and strains of the tank, due to wind load, were defined.

Analysis of the results of the study of geometrical models allowed to justify the selection of the optimal model in terms of simplicity and accuracy for use in information-diagnostic complex. Further study of the seismic influence and the relationship between the internal and external tank will allow to define technical condition of the internal tank based on the monitoring of the external tank.

Keywords: *simulation, wind load, vertical steel tank, stress-strain state.*

Introduction

Tasks of the implementation of new technologies to ensure safe operation of various objects with environmentally hazardous substances (EHS) with the increasing requirements are very important for compliance with national and international standards.

The list of tasks that need to be solved includes the development of effective means of monitoring of the technical condition of objects with EHS, as well as rapid transfer of measurement results to the operator for further processing by modern methods.

Among the objects with EHS specific role is assigned for the steel tanks, due to the fact that, on the one hand, they are most common and on the other – often collapse during the operation due to various internal and external influences.

The presence of defects that arose during manufacture or damage caused by transportation, installation, operation; changes of the mechanical characteristics of used materials and other factors [1] make it necessary to monitor and diagnosis of such objects using modern information technology.

To prevent environmental catastrophes on objects that are dangerous to humans and the environment, namely the tanks with EHS, information-diagnostic complex (IDC) [2] is developed to monitor the functional state of the tanks. The bases of the above mentioned IDC are: measuring system; control system; system for signal processing and decision making; system for simulation, determination and prediction of parameters of the mode of deformation.

Other authors [3,4] considered the cases of catastrophic tank failure due to the presence of cracks in the wall.

The disadvantages of these works are: 1) the lack of selection of geometric model of object; 2) the lack of analysis of the causes of cracks.

The purposes of this work are:

a) development of the geometric models of the testing object and study of the influence of structural elements on the simulation results;

b) simulation and determination of the influence of the wind load on the testing object.

Model Requirements

The modelling process always involves making assumptions of more or less importance. The essential task here is to assess the required accuracy and precision of the results of the initial data, coordination of them among themselves and with precision of the used model.

At the same time to assess the adequacy of the model, especially in the initial design stage, when the type of object is not yet known, is very difficult. On the other hand, the study of the finished object having his drawings and the results of instrumental examination is possible to construct a sufficiently adequate model with low loss of accuracy of simulation results.

The model must be considered these requirements:

- adequacy (compliance of model and original object, and, first of all, taking into account the most important qualities, characteristics and bonds);
- accuracy (degree of coincidence of results, obtained in the simulation, with predetermined, desired);
- universality (applicability of the model to the analysis of a number of similar objects in one or more modes of operation, it allows to expand search of decisions);
- suitable efficiency (accuracy of the results and the common solution of the problem must be linked to the cost of modelling).

Modelling errors caused by both objective, related to the simplification of the real objects and processes, and subjective reasons.

The following methods can be used for evaluation of the obtained result:

- verification of compliance of results for the physical sense;
- verification of compliance of special case of the model when the solution is obvious;
- verification of compliance of trends of magnitudes and signs of results (monotonicity, cyclic recurrence, smoothness, etc.);
- validation of the dimension of the result (if the work is carried out with analytic dependencies).

The choice of an adequate and, at the same time, universal geometric model for use in IDC, as well as providing the required accuracy of modelling are considered one of the most important tasks of the simulation.

Geometric models of the object

The testing object is the vertical steel tank for storage of EHS in critical conditions, which was installed and put into operation at the Ukrainian Antarctic station Academic Vernadsky in early 2007 (Fig. 1). The tank capacity is 200m^3. It was designed double-walled, with two bottoms and roofs to improve operational and emergency safety. However, because of the risk of emergencies, there is a possibility of leakage of fuel from the tank or piping that, depending on the size, can lead to deterioration in ecological condition near the station or an environmental disaster. Therefore, ensuring the safe operation of the fuel tank on the Ukrainian Antarctic station Academic Vernadsky is an important task.

Design of the tank is quite complicated. It contains, besides the main structural elements, a lot of additional elements. Additional elements are essential for the operation of object, but they greatly complicate the preparation of a geometric model and are not critical to determine the resource of object. Therefore, we used an approach from simple models of object with their gradual complication.

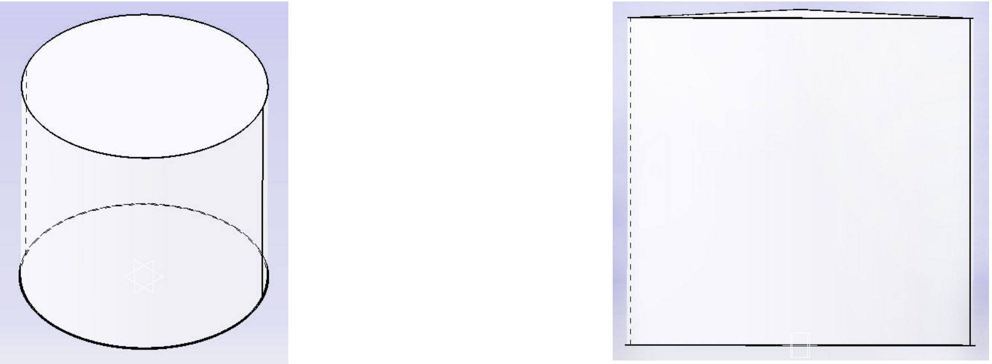
Figure 1. The fuel tank during operation

Building of simplified models (held in the CAD-system CATIA V5) due to the necessity of obtaining basic input data for identifying, analyzing and comparing the influence of individual structural elements on the simulation results.

Model with a flat roof is chose as the basic model. The following simplifications are made for building simple model with a flat (Fig. 2,a) roof:

- connection between the outer and inner tank is missing (loads on the external tank do not affect the internal). Thus, will be investigated the behaviour only of the external (protective) tank;
- roof, wall and bottom are solid (singleton);
- roof and wall are in direct contact (mounting elements are absent);
- roof, wall and bottom are combined (tank is singleton).

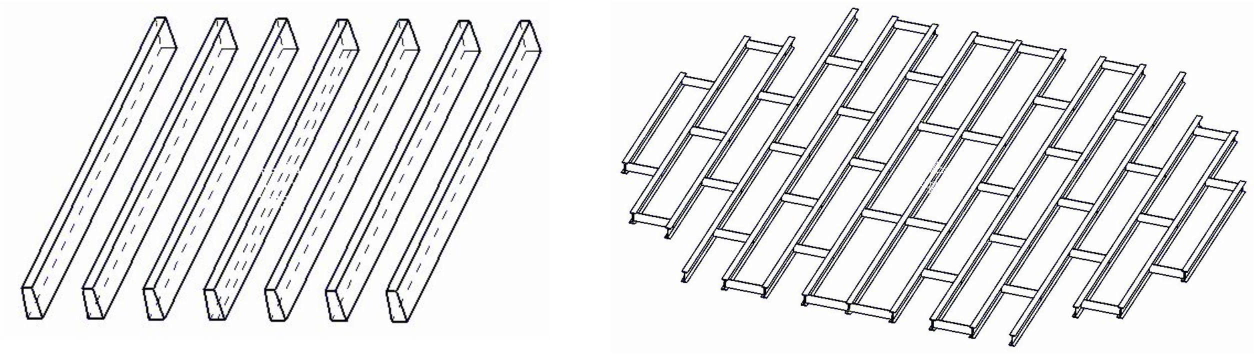
After careful review of drawings and photos of the real tank highlighted a number of design key elements that can significantly affect the results of the study of wind flow. Among them are the foundation with a welded steel frame to it, the air vent valves and cone (Fig. 2, b) roof.



а) б)

Figure 2. The geometric model of the tank: a) with a flat roof; b) with a conical roof

The foundation consists of seven bars of trapezoidal shape, and frame which consists of fifteen I-beams, which are located across the base and interconnected by the steel plates. Fig. 3 shows the model elements of the foundation and steel frame to which is welded bottom of the external tank.



а) б)

Figure 3. Geometric model of the: a) foundation; b) steel frame

Simplified geometric models of the air vent valves are shown in Fig. 4.

Complexity of models held by adding new elements to the basic model with a flat roof.

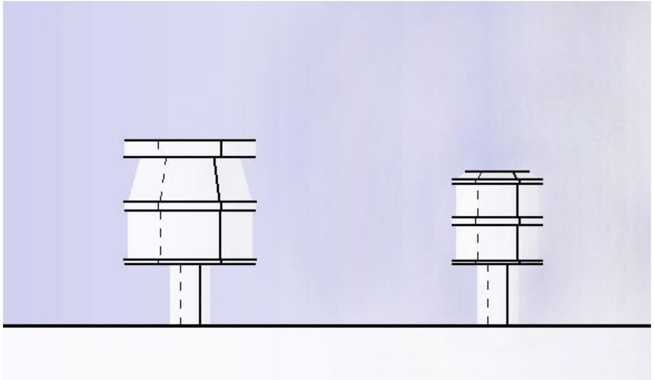


Figure 4. Geometric models of air vent valves

Six main geometrical models for the study are created:

- model number 1 – flat roof;
- model number 2 – conical roof;
- model number 3 – flat roof, foundation at 90 degrees to the velocity vector;
- model number 4 – flat roof, the foundation at 45 degrees to the velocity vector;
- model number 5 – a flat roof, air valves at 90 degrees to the velocity vector;
- model number 6 – a flat roof, air valves at an angle of 0 degrees to the velocity vector.

Analytical calculation of the value of the wind load

The climatic conditions of the tank construction site are listed in Table 1.

Table 1 – Climatic conditions of the construction site

The construction site	Antarctica
Standard value of the weight of snow cover	50 [kgf/m^2]
Standard value of wind pressure	123,5 [kgf/m^2]

Maximum winter temperature of air	-30 [°C]
Maximum summer temperature of air	+20 [°C]

The wind is one of the significant influences on the tank in the Antarctic. Wind is dynamic load, since its rate changes all the time. The reaction of constructions will be different: rigid structures perceive it as static, the reaction of flexible structures depends on the frequency of free (natural) oscillations [5].

The main causes of accidents can be errors in the project value of the calculated value of wind load, a misconception about the nature of its distribution on the object, inadequate accounting of the aerodynamic characteristics, vibration of the object.

However, the simulation of the wind load are not enough correct with the above mentioned models. Necessary element is an air environment, which is built in the form of a rectangular parallelepiped and combined with other models into assemblies. Six assembly units of different configurations are built.

We must calculate two values of the wind load [6]:

- Limiting calculated value of the load – load value corresponding to an emergency situation that may occur more than once during the lifetime of structure and is used to test the limit states of the first group. Going beyond their limits is equivalent to the total loss of efficiency of construction.
- Operational calculated value of load – load value, which characterizes the conditions of construction normal use. Typically, the operational calculated value is used to test the limit states of the second group associated with the difficulty of normal operation (occurrence of unacceptable displacements of construction, unacceptable vibration, excessive opening of cracks in reinforced concrete structures, etc.).

These values are defined by the following formulas:

$$W_m = \gamma_{fm} \cdot W_0 \cdot C,$$

$$W_e = \gamma_{fe} \cdot W_0 \cdot C,$$

where γ_{fm} – reliability coefficient for the limiting value of wind load; γ_{fe} – reliability coefficient for the operational value of the wind load; W_0 – characteristic value of wind pressure, Pa; C – coefficient determined by the formula:

$$C = C_{aer} \cdot C_h \cdot C_{alt} \cdot C_{rel} \cdot C_{dir} \cdot C_d,$$

where C_{aer} – aerodynamic coefficient; C_h – coefficient of the height of construction; C_{alt} – coefficient of geographic height; C_{rel} – coefficient of relief; C_{dir} – coefficient of direction; C_d – coefficient of dynamic.

After determining the required coefficients and completing mathematical operations we obtain:

$$\begin{cases} W_m = \gamma_{fm} \cdot W_0 \cdot C = 1{,}59 \cdot 1210{,}3 \cdot 1 = 1924{,}377 (Pa) \\ W_e = \gamma_{fe} \cdot W_0 \cdot C = 0{,}42 \cdot 1210{,}3 \cdot 1 = 508{,}326 (Pa) \end{cases}.$$

Simulation of the wind load on the tank

The software FlowVision and ANSYS are used for simulation.

Fig. 5 shows the pressure fields the horizontal plane, which cuts through the tank at a height of 3m above the ground.

The simulation results are shown in Table 2. From the analysis of the results we can see that significant changes in the nature of the distribution of the studied parameters (pressure and velocity of air flow) within the computational domain are caused by adding to the original model №1 foundation with a steel frame.

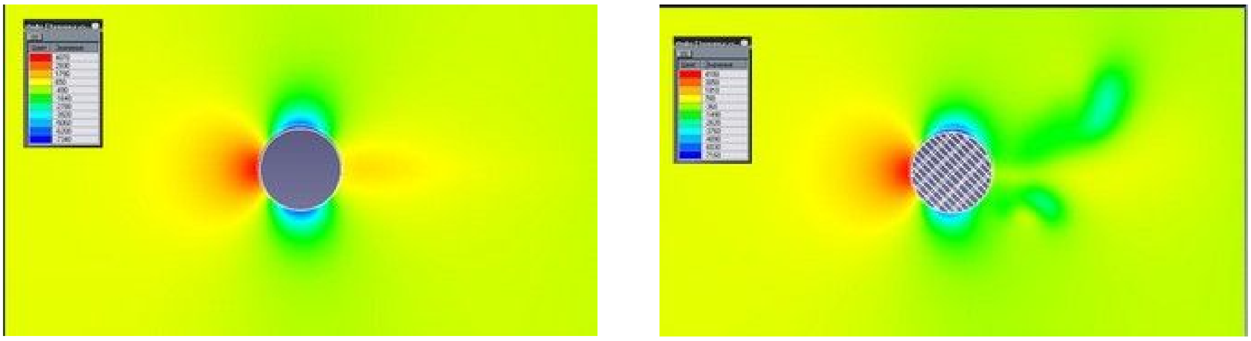
Table 2 – Quantitative simulation results

Model number	1	2	3	4	5	6
Maximal pressure, [Pa]	3960.565	3954.756	4230.677	4068.719	3971.371	3990.171
Minimal pressure, [Pa]	-7229.892	-7218.151	-7456.376	-7051.877	-7209.402	-7352.591
Velocity, [m/s]	120.432	120.287	112.308	116.447	120.395	121.219

Analysis of Table 2 shows the following:

- if we consider the maximum pressure of the air flow as the main characteristic of wind load, the most distinguished is model №3;
- if we consider the minimum pressure, it is necessary to take into account the model №4 and model №6.

Thus, three models selected for further analysis. Distribution of the pressure for the model №6 is not very different from the model №1. Therefore, the model №6 exclude from further analysis. To estimate the remaining two models wind direction and strength at the Ukrainian Antarctic station Academic Vernadsky are analyzed. The strongest winds are in the northern and southern directions, which approximately correspond to the conditions of the study of model №4, which is chosen for further analysis.



a) b)

Figure 5. Pressure field of model: a) №1; b) №4

However, before proceeding to study of the model has been verified the accuracy of the results (obtained using FlowVision). For this purpose simulated project velocity of the wind flow (43m/s) using the basic model.

The maximum pressure of 1400,76Pa received as a result. This suggests that result of modelling in FlowVision get close to the value of the characteristic value of the wind load. Calculate the absolute and relative errors of the wind load determination.

$$\Delta = \left| x - x_{\text{mod}} \right|, \tag{1}$$

where Δ – absolute error in units of measured value; x – actual value of measured value; x_{mod} – the value of measured value received by simulation.

$$\delta = \frac{\Delta}{x} \cdot 100\%, \tag{2}$$

where δ – relative error.

By substituting appropriate values in the formulas (1) and (2), we obtain:

$$\Delta_1 = \left| x - x_{\text{mod}} \right| = \left| 1210{,}3 - 1400{,}76 \right| = 190{,}46(Pa),$$

$$\delta_1 = \frac{\Delta_1}{x} \cdot 100\% = \frac{190{,}46}{1210{,}3} \cdot 100\% = 15{,}74\%.$$

As you can see, the relative error is quite large, so we need to identify factors that influence the value of measured value received by simulation. After the analysis of the coefficients, which are absent in the analytical calculation, and a number of simulations is determined that significantly on this error affects the gravity vector. If it is excluded from the FlowVision variant (set as zero), the maximum pressure at the same velocity of the wind flow will be 1231,85Pa. If we calculate errors, then with the received pressure value we get:

$$\Delta_2 = \left| x - x_{\text{mod}} \right| = \left| 1210{,}3 - 1231{,}85 \right| = 21{,}55(Pa),$$

$$\delta_2 = \frac{\Delta_2}{x} \cdot 100\% = \frac{21{,}55}{1210{,}3} \cdot 100\% = 1{,}78\%.$$

This confirms fact that the simulation result, without taking into account the gravity vector, is the characteristic value of the wind load and, as you can see, it is in a good agreement with analytical calculations. On the other hand, we can conclude that it is always necessary to consider the gravity vector, because it changes the result of calculation by almost 16%.

Having the determined optimal model, we can study it in terms of the varying wind flow velocity.

Among the quantitative characteristics we consider the maximum pressure within the computational domain, which, it has been shown previously, corresponds to the characteristic value of wind load. The simulation results are shown in Table. 3.

Fig. 6 shows a graph of pressure on the velocity of the wind flow dependence, which was built by the values of Table 3. In addition, also done interpolation and extrapolation to estimate the critical velocity of the wind flow.

Analysis of the graph shows that considering the static problem (the object is completely rigid) at velocities of the wind flow up to 22m/s the pressure on the tank will not exceed the designed operational value of wind load. Irreversible destructive processes (up to destruction) are possible at velocities of the wind flow greater than 50m/s.

Table 3 – Maximum pressure at different velocity of of the wind flow

Velocity of the wind flow, [m/s]	75	50	43	25
Maximum pressure, [Pa]	4068,72	1885,34	1400,76	601,62

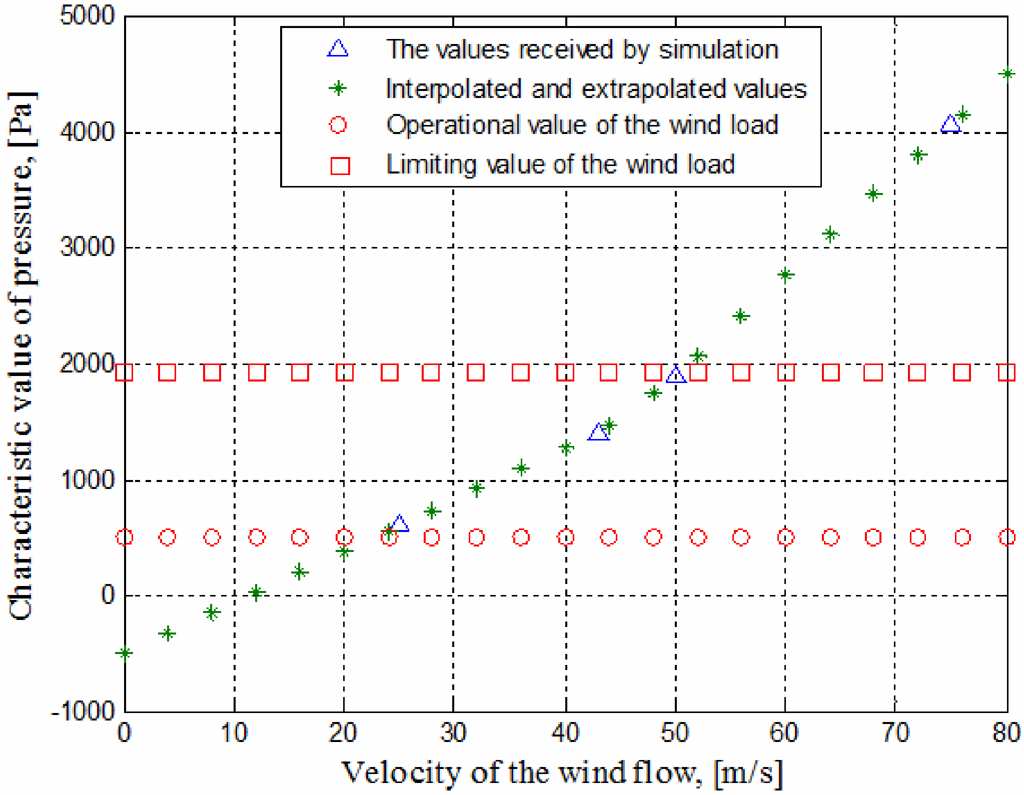
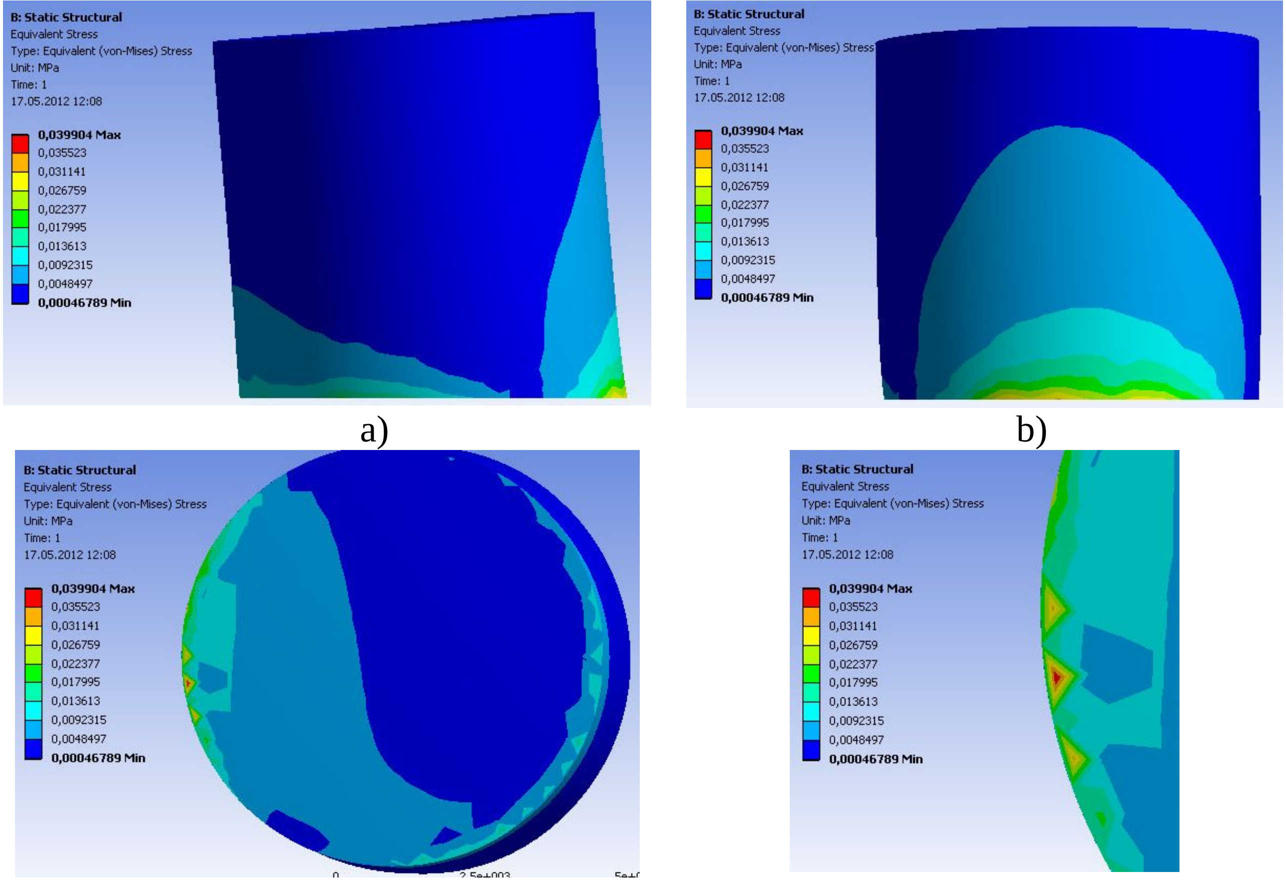


Figure 6. Dependence of pressure on the velocity of the wind flow

The cause of failure of the object may be construction defect or the strain of structural elements due to the increase of efforts due to various factors: overload, forced temperature deformation, corrosion, the redistribution of forces due to deformation of the base, as well as between the individual elements. Therefore, an analysis of the stress-strain state of the tank is conducted.

Conduct a combined analysis of fluid-structure is to use the results of one type of simulation (wind load) as input for another (structural analysis).

Analysis of the equivalent stresses, calculated by von Mises criterion, and strain of the tank showed that: zones of greatest stress (Fig. 7) due the wind load appear on the wall and bottom of the tank from the direction of external forces action and the opposite side of the tank, and the largest displacements occur on the roof.



a) b)

c) d)

Figure 7. Stress caused by wind load, view: a) along the axis Z; b) along the axis X; c) along the axis Y (bottom); d) enlarged image c)

Conclusions

Analysis of the results of the study of geometrical models allowed to justify the selection of the optimal model in terms of simplicity and accuracy for use in information-diagnostic complex. Model № 4 is universal due to possibilities of CAD-system CATIA V5.

For the tank, selected as a control object, stress and strain caused by the wind are analyzed and determined the most probable places for installation of measuring transducers (places of the greatest stress). Defined:

- the pressure on the tank, caused by the wind flow velocities up to 22m/s, will not lead to irreversible consequences;
- at the wind flow velocities of 22m/s to 50m/s occur problems associated with the difficulties of normal operation;
- irreversible destructive processes (up to destruction) are possible at velocities of the wind flow greater than 50m/s.

Further study of the relationship between the internal and external tank and of the seismic influence on the stress-strain state will allow to define technical condition of the internal tank based on the monitoring of the external tank.

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ПРИСТРІЙ ДЛЯ КОМПЕНСАЦІЇ ВПЛИВУ ТЕМПЕРАТУРИ ПРИРОДНОГО ГАЗУ НА ТОЧНІСТЬ ЙОГО ОБЛІКУ ПОБУТОВИМИ ЛІЧИЛЬНИКАМИ ГАЗУ

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В Україні використовується значна частина побутових лічильників газу, в яких відсутні пристрої корекції температури газу. Розроблений пристрій компенсації впливу температури газу на точність його обліку побутовими лічильниками газу, який забезпечує вищу точність приведення об'єму газу до стандартних умов ніж розрахункові методи та встановлення якого не вимагає втручання в роботу лічильника газу. Введення в систему обліку газу механічного компенсатора дозволить без заміни існуючого лічильника газу компенсувати вплив температури газу на обліковані об'єми газу, тобто привести величину облікованого об'єму газу до стандартних умов. Предметом подальших наукових досліджень буде проведення експериментальних досліджень розробленого пристрою компенсації температури газу та формування вимог до номенклатури типорозмірів цих пристроїв в залежності від геометричних параметрів газопроводів, на які встановлюватимуться компенсатори.