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ЧИСЕЛЬНЕ МОДЕЛЮВАННЯ ВІТРОВОГО ТИСКУ НА ПОВЕРХНІ ВЕРТИКАЛЬНОГО ЦИЛІНДРИЧНОГО РЕЗЕРВУАРА

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Анотація. При проектуванні будівель і споруд однією з основних діючих навантажень є вітрове. Особливо великий вплив воно має для вертикальних циліндричних резервуарів (ВЦР) при розрахунку його елементів на стійкість. У даній статті розглядається порівняльний аналіз аеродинамічних характеристик для моделі ВЦР, і прогнозування на основі отриманих результатів аеродинамічних характеристик для групи ВЦР способом чисельного моделювання у програмному комплексі SolidWorks Flow Simulations, також запропоновано методичний підхід забезпечує коректне відображення фізичних процесів обтікання вітровим потоком стінки резервуара. Для групи з 4-х резервуарів на основі чисельного моделювання отримано уточнені значення аеродинамічних коефіцієнтів вітрового тиску для кожного з групи резервуарів, що забезпечують надалі уточнену оцінку напружено-деформованого стану конструкції стінки в порівнянні з нормованим зараз підходом за державними будівельними нормами (ДБН) та Єврокод.

Ключові слова: вертикальний циліндричний резервуар, чисельне моделювання, вітровий тиск, аеродинамічний коефіцієнт.

ЧИСЛЕННОЕ МОДЕЛИРОВАНИЕ ВЕТРОВОГО ДАВЛЕНИЯ НА ПОВЕРХНОСТИ ВЕРТИКАЛЬНОГО ЦИЛИНДРИЧЕСКОГО РЕЗЕРВУАРА

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Аннотация. При проектировании зданий и сооружений одной из основных действующих нагрузок является ветровая. Особенно большое влияние она имеет для вертикальных цилиндрических резервуаров (ВЦР) при расчете его элементов на устойчивость. В данной статье рассматривается сопоставительный анализ аэродинамических характеристик для модели ВЦР, и прогнозирование на основе полученных результатов аэродинамических характеристик для группы ВЦР способом численного моделирования в программном комплексе SolidWorks Flow Simulations, также предложен методический подход обеспечивающий корректное отображение физических процессов обтекания ветровым потоком стенки резервуара. Для группы из 4-х резервуаров на основе численного моделирования получены уточненные значения аэродинамических коэффициентов ветрового давления для каждого из группы резервуаров обеспечивающие в дальнейшем уточненную оценку напряженно-деформированного состояния конструкции стенки по сравнению с нормируемым в настоящий момент подходом по ДБН и Еврокод.

Ключевые слова: вертикальный цилиндрический резервуар, численное моделирование, ветровое давление, аэродинамический коэффициент.

NUMERICAL SIMULATION OF WIND PRESSURE ON A VERTICAL CYLINDRICAL TANK SURFACE

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Abstract. When designing buildings and structures one of the main existing loads is the wind. A particularly large impact it has for vertical cylindrical tanks (VCT) in the calculation of its members on sustainability. This article examines the comparative analysis of aerodynamic characteristics of the model VCT, and forecasting on the basis of the received results of aerodynamic characteristics for group VCT method of numerical modeling in complex software Solid Works Flow Simulations, also suggests a methodological approach which ensures the correct display of physical processes of the flow of the wind flow vessel wall. For the group of 4 tanks on the basis of numerical simulation, the specified values of aerodynamic coefficients of wind pressure for each group of tanks providing further refined assessment of stress-mode of construction of the wall in comparison with regulated in the present approach, DBN and Euro codes have been carried out.

Keywords: vertical cylindrical tank, numerical simulation, wind pressure, aerodynamic coefficient.

Introduction

Vertical cylindrical tanks are used for storing black and light oil products, chemicals, oil, water and all possible liquids. When designing the similar buildings and structures, one of the main existing loads affecting a tack is a wind load which is taken into account in the stability design of structure components.

To design a wind load of a structure there are some methods of determining the aerodynamic characteristics, with the analytical and experimental findings being used. The exact analytical solutions in the structural aerodynamics cover a sufficiently limited range of problems as it's rather difficult to get a clear-cut mathematical model for the aerodynamic processes and therefore in most cases the research for new and complex structures is carried on in the wind tunnel which is a reliable device to study the airflow around buildings, structures and their complexes. In recent years specialist tend to address themselves to the numerical simulation of the aerodynamic processes. What is more, the up-to-date multiprocessor computer systems are powerful enough to solve the similar problems. So, in the last years more and more attention is paid to the numerical simulation of these processes with the help of the computational hydrodynamics.

Analysis of the recent research and publications

The wind effect and aerodynamic behavior of vertical cylindrical tanks for storing oil and oil products was thoroughly studied by P. A. MacDonald and R. J. Holroyd [1–3, 9–12], by G. A. Savitsky [4] and in Kucherenko Research Institute [5].

Using a vertical cylindrical tank (VCT) as an example, the verification analysis of the aerodynamic characteristics given in [13] was carried out for the VCT experimental model and presented in this paper together with the results of the numerical simulation in the software package Solid Works Flow Simulations [18]. Besides, there was performed a comparative analysis of the obtained results and the current normative documents [15].

The purpose of this paper is a comparative analysis of the aerodynamic characteristics for the VCT model obtained with the use of different techniques and forecasting developed from the obtained results of the aerodynamic characteristics of the VCT group.

Statement of the problem for the numerical experiment

- to obtain the aerodynamic coefficients for a free-standing vertical cylindrical tank represented as a smooth circular cylinder with the set-up geometric and thermodynamic metrics;
- to compare the obtained results in the form of the coefficients of wind pressure on a VCT wall and the experimental data in [13] and norms in [14, 15];
- a permissible convergence being in the range of 10–15 %, to perform the calculations for a group of 4 vertical cylindrical tanks.

When designing buildings and structures, the aerodynamic formulas given in the normative documents DBN (State Building Norms) and Eurocods [14, 15] are used to determine wind loads. When designing according to the normative requirements [14, 15], the wind load is determined with the use of the diagram of dependence of the aerodynamic coefficients on the position of the angle between the element of the cylindrical surface and the wind flow direction. The quantity of these values therewith depends on Reynolds' number. For the home norms, the coefficients are determined at $Re > 4 \cdot 10^5$, and for the European norms the coefficients are determined from three values of Reynolds' number, namely, $Re = 2 \cdot 10^6$, $Re = 10^7$, $Re = 5 \cdot 10^5$.

To analyze the convergence of the results of determining the wind load on a wall of the full-scale tank design and a model made relative to the tank size $V = 2.5$ thousand m^3 at the 1/400th scale, consider an example of determining the aerodynamic coefficients of the wind load from Eurocode 1 [15]

Initial data of simulation
U = 25 m/sec;
$Re = 4{,}9 \cdot 10^5$;
h / d = 2;
d = 300 mm.

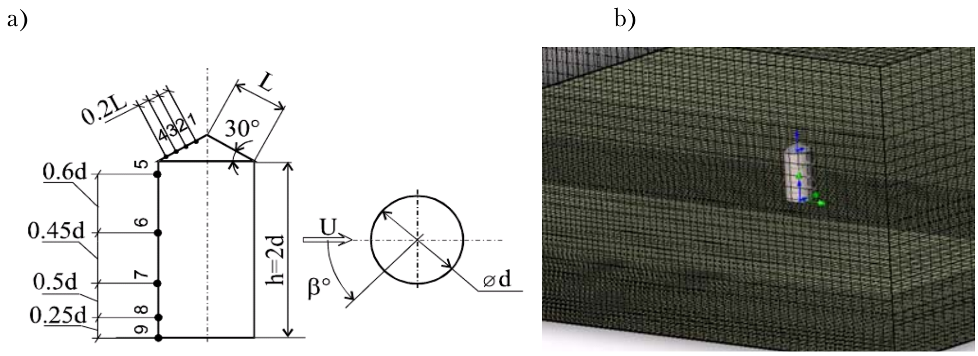

Figure 1. Model of a cylindrical vertical tank tested in a wind tunnel [13]: a) the model design; b) a fragment of the design model SolidWorks Flow Simulation.

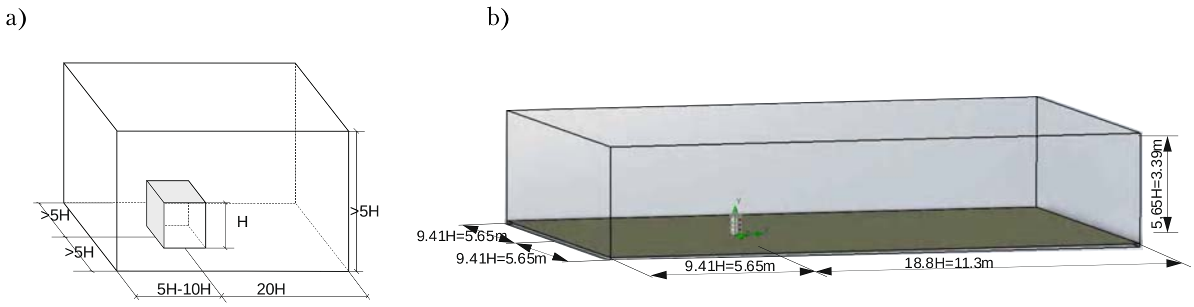

Figure 2. The rated operating conditions in the computer simulation of the wind influence: a) guidelines of how to plot the rated operating conditions; b) the rated operating conditions for the model under study.

and from the results of the numerical simulation with the use of the software package Solid Works Flow Simulations [18]. At the initial data of the characteristics of the velocity wind flow, the value of Reynolds' number is determined from the formulae:

$$Re = \frac{b \cdot U(z_e)}{\nu},$$

where b is the diameter, b = 0.3 m;

ν is the kinematic viscosity of air, $\nu = 1.5 \cdot 10^{-5}$ m²/sec;

$U(z_e)$ is the peak value of wind velocity, $U(z_e) = 25$ m/sec.

$Re = 4.9 \cdot 10^5$, that corresponds to the values of the coefficients determined from Eurocod 1 at $Re = 5 \cdot 10^5$ [15].

In Fig. 1a, there are given the characteristics of the object investigated both in the wind tunnel and in the numerical experiment. To carry out the numerical experiment, there was used the software package Solid Works Flow Simulations which is a complementary module of the engineering analysis PC SolidWorks [18]. It comprises the simulation of fluid and gas flow, the computational grid operation, the application of different physical models of fluids and gases, the complex thermal design, hydro/gas-dynamic and thermal models of technical means, stationary and non-stationary analyses, design of rotating objects and results export in SolidWorks Simulation. The pre-processor SolidWorks Flow Simulation makes it possible to realize a fully-automatic or freehand

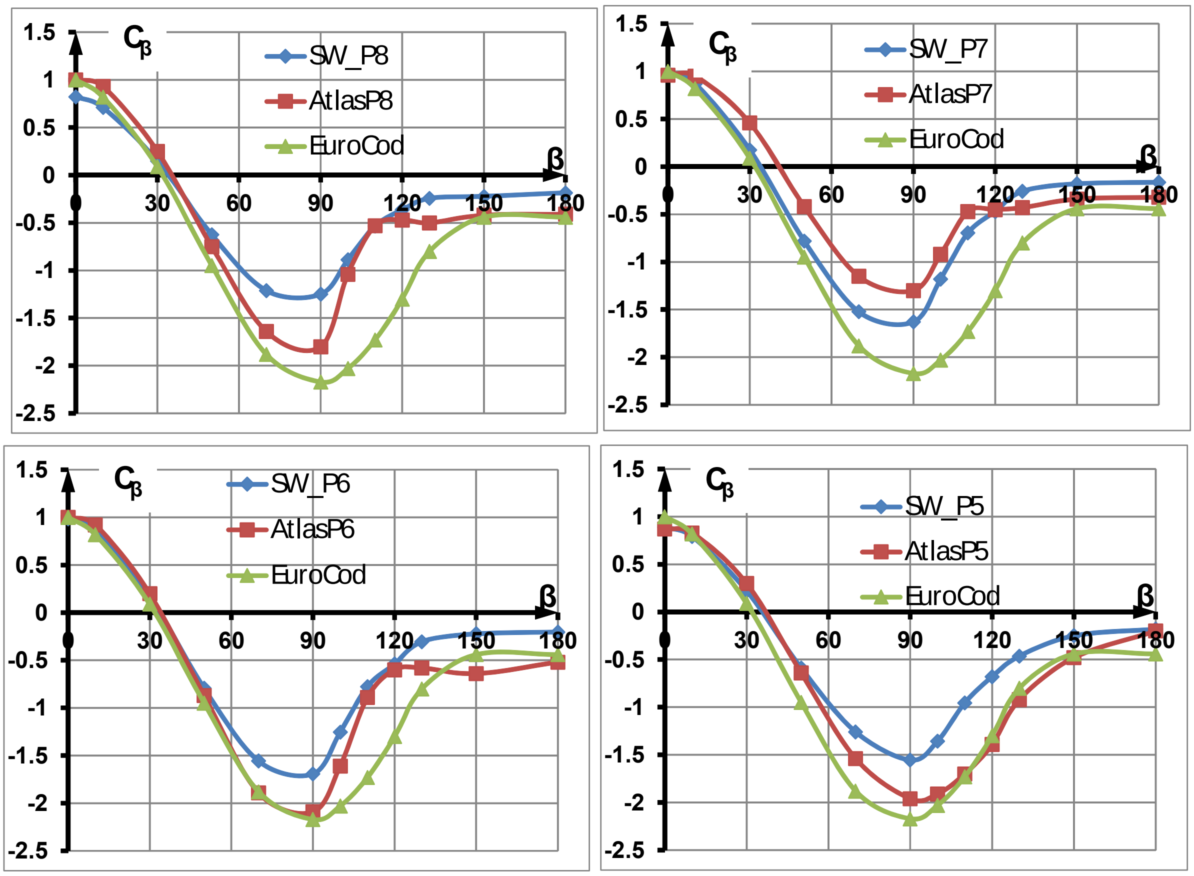

Figure 3. Diagram of the aerodynamic coefficients for a single tank:
– SW_P5 corresponds to the characteristics obtained from the numerical simulation in SolidWorks Flow Simulation for point 5 (Fig. 1), (SW_P6–SW_P8 for points 6–8, respectively);
– AtlasP5 corresponds to the characteristics obtained from the experiment in the wind tunnel [13] for point 5 (Fig. 1), (SW_P6–SW_P8 points 6–8, respectively);
– the Eurocod data from the normative document Eurocod 1 [15].

method of the block construction of a computational grid.

A three-dimensional parametric geometric model of the object under study is made in the CAD-program SolidWorks. In the program SolidWorks Flow Simulation they determine the medium properties, boundary conditions, accuracy of solution, geometry of a design zone and the numerical solution of the problem is implemented. The program automatically analyzes the body geometry and forms a computational grid in a zone of computation – domain – specified in the flow in the form of parallelepiped, with the body under study being inside (Fig. 1b). The computational grid is created by dividing the domain into cubic cells with the sides orthogonal to the axes of the Cartesian coordinate system.

The domain size of the VCT design model was created in accordance with the guidelines in [17]. In Fig. 2 there are shown the rated operating conditions of the model.

As a result of the numerical simulation the aerodynamic coefficients for the model under study were obtained. In Fig. 3, there are shown the

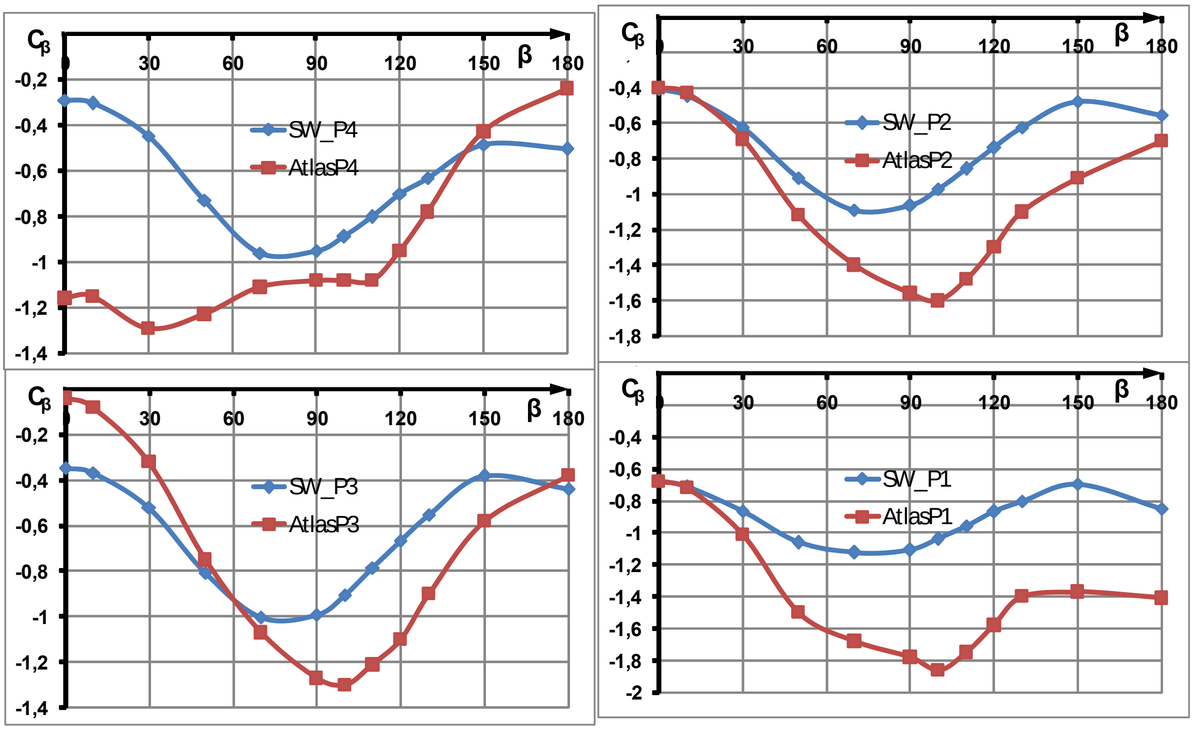

Figure 4. Analysis of the aerodynamic coefficients for a conical roof by the corresponding points of measurements from the experimental and numerical data.

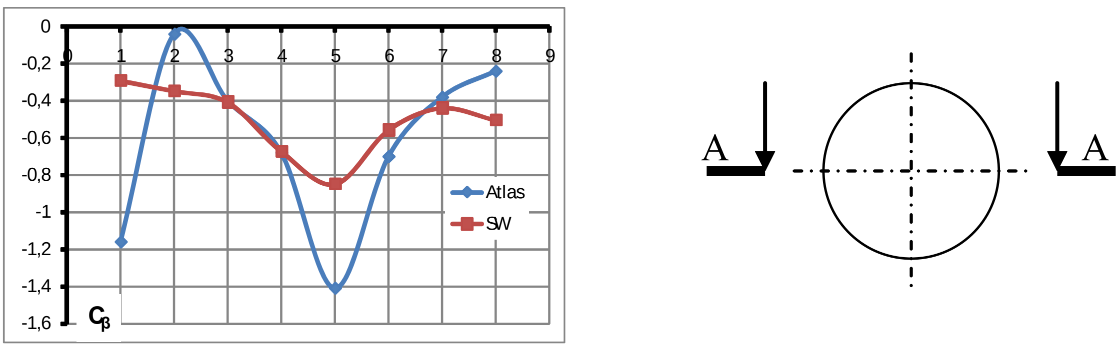

Figure 5. Analysis of the aerodynamic coefficients for a conical roof by the A-A sectional elevation.

graphs of distribution of the wind pressure coefficient C_β for the wall of the VCT model obtained from the experimental data in the wind tunnel [13] as a result of the numerical simulation in SolidWorks Flow Simulation and from the normative data given in the normative document Eurocod 1 [15].

The values of the aerodynamic coefficients obtained from the numerical simulation and from the experiment [13] being compared, a good compatibility (in the range of 15 %) was obtained. For points 8 and 5 the maximum discrepancy of 20.0 and 26.3 %, respectively, was obtained, which is to say that these points are in the zone in which the air flow is non-stationary, the flow turbulence scales up and in this context the convergence deteriorates.

For a conical roof of the model under study only a qualitative form of compatibility of the results obtained in the experimental [13] and numerical investigations is observed (Fig. 4, 5).

In accordance with the above stated problems and using the input data of simulation for a single tank, the calculations were performed for a VCT group. The basic simulation schemes of the wind influence on a group of tanks are shown in Fig. 6.

In Fig. 7 a change of the wind direction by the surface of the VCT group is shown more clearly.

In Fig. 8 a comparison by the points of measurements 7 and 6 for a single spacing and for a group of the VCT models is shown, numbers I to IV being the numbers of spacing in the group.

Conclusions

Relying on the obtained data of the comparative analysis of the experimental, analytical and normative data, there was developed a design model for calculating a single VCt and a VCT group in the *Solid Works Flow Simulation* medium for the numerical simulation of the aerodynamic

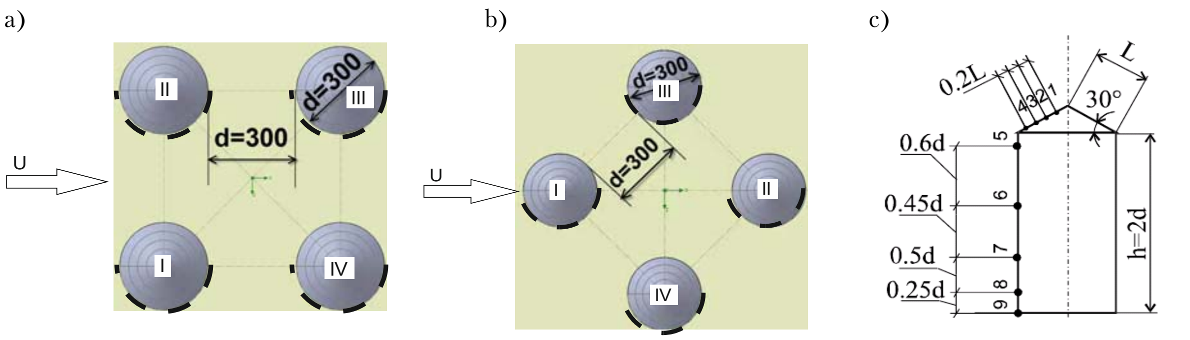

Figure 6. The layout of a VCT group: a) wind direction onto a face; b) wind direction onto an edge; c) the model sectional view.

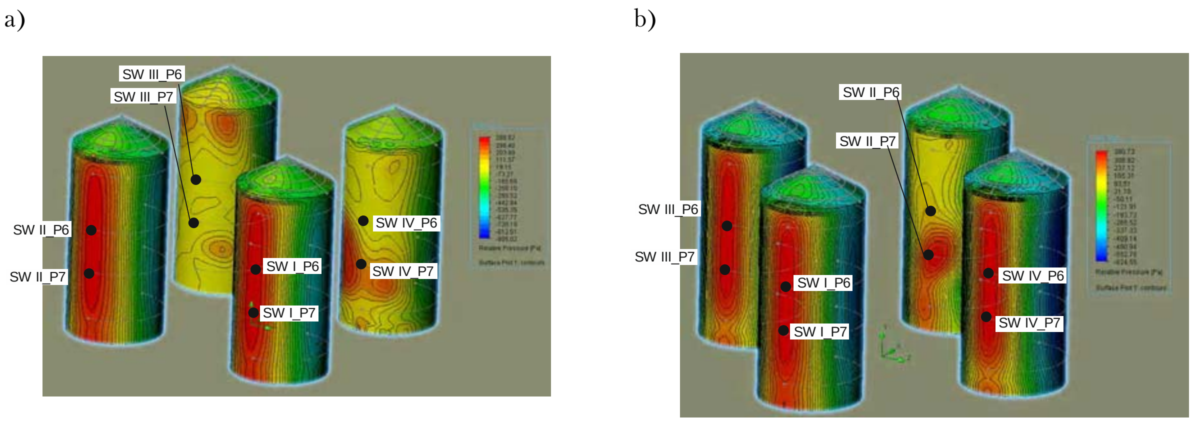

Figure 7. The iso-fields of the wind pressure distribution by the VCT surface in the group according to the diagrams a) and b).

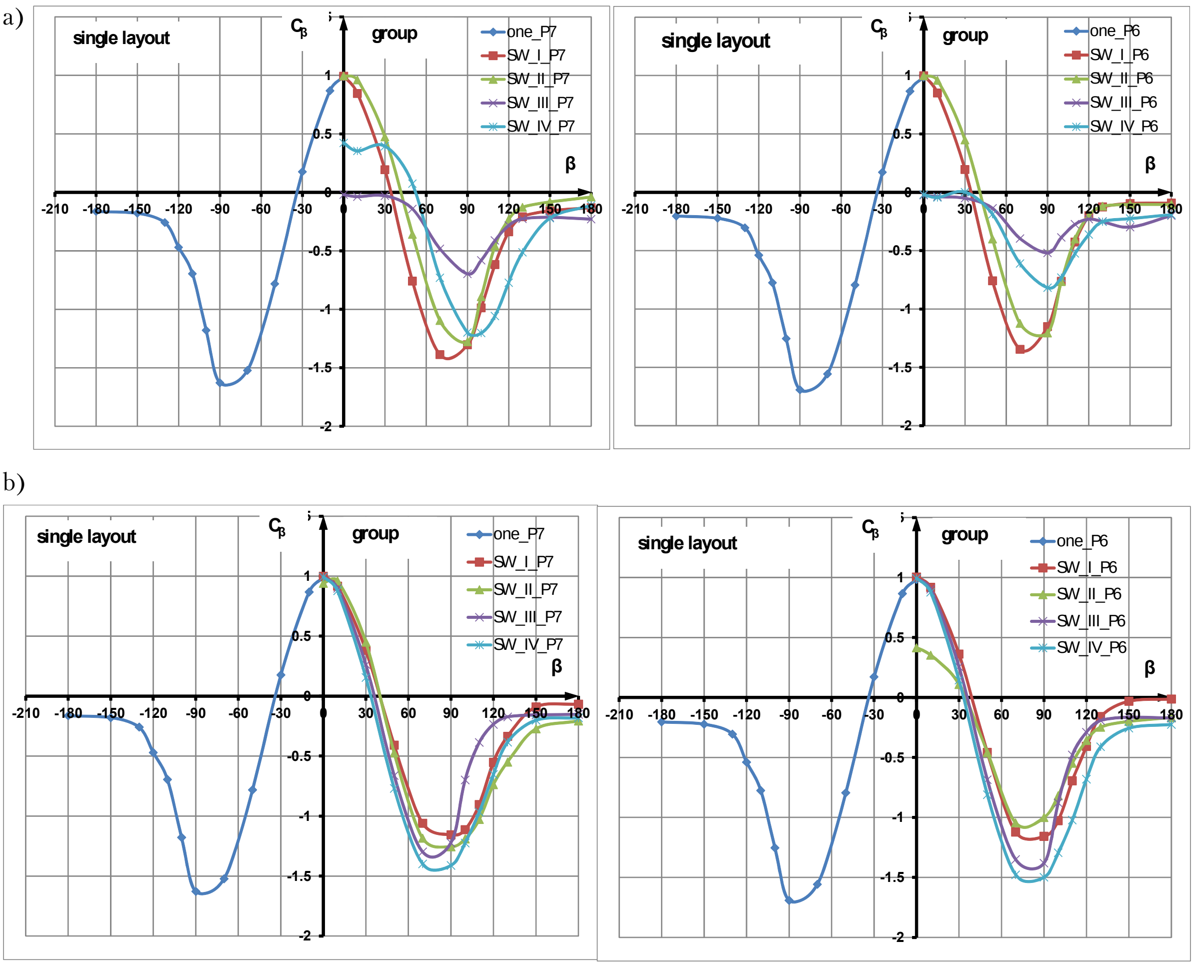

Figure 8. The diagram of the aerodynamic coefficients for a VCT group corresponding to the layout in a) and b) (see Fig. 6).

processes. The basic feature of this procedure is the determination of the computer simulation zone which is 18.8H × 28.2H × 3.39H (Fig. 2b).

1) There is proposed a technical approach providing a correct representation of the physical processes of the wind flow past a tank wall (the comparison of the experimental and numerical investigation results provides convergence in the range of 15 %).
2) For a group of 4 tanks the numerical simulation resulted in the improved values of the aerodynamic coefficients of wind pressure for each tank of the group which, in their turn, will provide an improved estimation of the mode of deformation of a wall structure as compared with the approach which is currently rated by the DBN (State Building Norms) and Euro Cods.
3) The main design situation for calculating a VCT group is pressure on a face (Fig. 6a), with the values of the active pressure being by 35 % less in reference to the normative data.

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Мущанов Володимир Пилипович – д.т.н., професор кафедри теоретичної і прикладної механіки Донбаської національної академії будівництва і архітектури. Академік Української академії наук, академік Академії будівництва і архітектури, член-кореспондент Академії архітектури України, дійсний член Міжнародного інституту інженерів будівельників і член Міжнародної асоціації «Просторові конструкції». Наукові інтереси: теорія надійності, розрахунок, проектування та технічна діагностика просторових металевих конструкцій.

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