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SIMULATION OF AIRFLOW AT VERNADSKY STATION FOR MULTI-SITE DAMAGE IDENTIFICATION

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Abstract. Relevance of the study is that the consequences of premature destruction of the fuel tank or the wall of the building of the Ukrainian Antarctic Akademik Vernadsky station (Vernadsky station) may result in significant financial costs and human lives as a result of multi-site damage. Therefore, the main **objective** of the study is to identify the most probable places of snow accumulation and maximum wind pressure zones for identification and prevention of multi-site damage of buildings and engineering structures. Geometric modeling and simulation are chosen as research **methods**, which allow (accordingly) creating and investigating a three-dimensional computer model of an object. SolidWorks CAD-system was chosen for geometric modeling. The simulation was carried out in the ANSYS finite-element analysis software. **Results:** geometric modeling and simulation of Vernadsky station was conducted; in CAD-system SolidWorks based on the plan-scheme and photos of the station, its geometric model is built, which includes the model of the surrounding area; according to its geometric models the layout of the station is printed on a 3D-printer; in the CAE-system ANSYS a simulation of the influence of air flow at a speed of 45m/s on the station was conducted; vector velocity fields are constructed and based on them the most probable places of accumulation of snow are determined; vector pressure fields are constructed and the most loaded elements of the infrastructure are determined on their basis. **Conclusions:** analysis of simulation results showed that the most probable places of accumulation of snow are located near the walls of all buildings of the station and in places of significant change in the terrain of the surrounding area. The most loaded with wind pressure is the main housing and the storage tank for diesel fuel. In this regard, it was decided to additionally create geometric models of the fuel tank to study the effect of multi-site damage in the form of cracks on its integrity. It is also determined that the main impact on the elements of the infrastructure of the station is the wind from the mainland, but not from the ocean.

Key words: simulation, CAE, CAD, multi-site damage, Vernadsky station, ANSYS.

ІМІТАЦІЙНЕ МОДЕЛЮВАННЯ ОБТІКАННЯ СТАНЦІЇ «АКАДЕМІК ВЕРНАДСЬКИЙ» ПОВІТРЯНИМИ ПОТОКАМИ ДЛЯ ІДЕНТИФІКАЦІЇ БАГАТООСЕРЕДКОВОГО ПОШКОДЖЕННЯ

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Реферат. Актуальність роботи полягає в тому, що наслідками передчасного руйнування паливного бака або стіни будівлі Української антарктичної станції «Академік Вернадський» внаслідок багатоосередкового пошкодження можуть бути значні фінансові витрати і людські життя. Тому **метою** роботи є виявлення найбільш ймовірних місць скупчення снігу та зон максимального тиску вітру для ідентифікації та запобігання багатоосередкового пошкодження будівель та інженерних конструкцій. В якості **методів** дослідження обрані геометричне і імітаційне моделювання, які дозволяють відповідно створювати і досліджувати тривимірну комп'ютерну модель об'єкта. Для геометричного моделювання була обрана CAD-система SolidWorks. Імітаційне моделювання проходило в програмному комплексі скінчено-елементного аналізу ANSYS. **Результати:** проведено геометричне і імітаційне моделювання Української антарктичної станції «Академік Вернадський»; в CAD-системі SolidWorks на основі план-схеми і фотографій станції побудована її геометрична модель, яка включає і модель навколишньої місцевості; на 3D-принтері роздруковано макет станції по її геометричним моделям; в

CAE-системі ANSYS проведено імітаційне моделювання впливу повітряного потоку зі швидкістю 45м/с на станцію; побудовано векторні поля швидкості, на основі яких визначено найбільш ймовірні місця скупчення снігу; побудовано векторні поля тиску, на основі яких визначено найбільш навантажені елементи інфраструктури. **Висновки:** аналіз результатів моделювання показав, що найбільш ймовірні місця скупчення снігу знаходяться біля стін всіх будівель станції і в місцях значної зміни рельєфу навколишньої місцевості, а найбільш навантаженими від тиску вітру є головний корпус і резервуар для зберігання дизельного палива. У зв'язку з цим було прийнято рішення додатково створити геометричні моделі резервуара для дослідження впливу на його цілісність багатоосередкового пошкодження у вигляді тріщин. Також визначено, що найбільший вплив на елементи інфраструктури станції має вітер з материка, а не з океану.

Ключові слова: імітаційне моделювання, CAE, CAD, багатоосередкове пошкодження, станція «Академік Вернадський», ANSYS.

ИМИТАЦИОННОЕ МОДЕЛИРОВАНИЕ ОБТЕКАНИЯ СТАНЦИИ «АКАДЕМИК ВЕРНАДСКИЙ» ВОЗДУШНЫМИ ПОТОКАМИ ДЛЯ ИДЕНТИФИКАЦИИ МНОГООЧАГОВОГО ПОВРЕЖДЕНИЯ

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Реферат. Актуальность работы заключается в том, что последствиями преждевременного разрушения топливного бака или стены здания Украинской антарктической станции «Академик Вернадский» вследствие многоочагового повреждения могут быть значительные финансовые затраты и человеческие жизни. Поэтому **целью** работы является определение наиболее вероятных мест скопления снега и зон максимального давления ветра для идентификации и предотвращения многоочагового повреждения зданий и инженерных сооружений. В качестве **методов** исследования выбраны геометрическое и имитационное моделирование, которые позволяют, соответственно, создавать и исследовать трехмерную компьютерную модель объекта. Для геометрического моделирования была выбрана CAD-система SolidWorks. Имитационное моделирование проходило в программном комплексе конечно-элементного анализа ANSYS. **Результаты:** проведено геометрическое и имитационное моделирование украинской антарктической станции «Академик Вернадский»; в CAD-системе SolidWorks на основе план-схемы и фотографий станции построена ее геометрическая модель, которая включает и модель окружающей местности; на 3D-принтере распечатан макет станции по ее геометрическим моделям; в CAE-системе ANSYS проведено имитационное моделирование воздействия воздушного потока со скоростью 45м/с на станцию; построены векторные поля скорости, на основе которых определены наиболее вероятные места скопления снега; построены векторные поля давления, на основе которых определены наиболее нагруженные элементы инфраструктуры. **Выводы:** анализ результатов моделирования показал, что наиболее вероятные места скопления снега находятся у стен всех зданий станции и в местах значительного изменения рельефа окружающей местности, а наиболее нагруженными от давления ветра являются главный корпус и резервуар для хранения дизельного топлива. В связи с этим было принято решение дополнительно создать геометрические модели резервуара для исследования влияния на его целостность многоочагового повреждения в виде трещин. Также определено, что наибольшее влияние на элементы инфраструктуры станции оказывает ветер с материка, а не с океана.

Ключевые слова: имитационное моделирование, CAE, CAD, многоочаговое повреждение, станция «Академик Вернадский», ANSYS.

1. Introduction

Current trends in construction (i.e. increase in buildings and number of storeys of buildings, construction of new lines of communication, development of underground space, the saturation by engineering structures, etc.) invariably lead to the emergence of negative technogenic influence (Antarctic Bases and Buildings, 2017). This is particularly important in conditions of Antarctica, where the ecological situation is controlled by many international agreements.

Ukrainian Antarctic Akademik Vernadsky station (Vernadsky station) is a system with its own infrastructure, which ensures its functioning throughout the year (ANSYS, 2017). Considering the enormous technical and logistics complexity of construction in the Antarctica, it is difficult to ensure reliable operation of the station and protect buildings from snow drifts and wind. Polar winds carry snow across the continent, and a snowy "tail" quickly grows on any vertical object, indicating the direction of the wind. Accumulated snow can lead to premature destruction of buildings.

The initial stage of destruction of structural elements of any design or structure is damage. Its causes may be, for example, external natural (wind and temperature) and man-made influences, internal factors, defects of the initial design, deficiencies and violation of rules of operation. External signs of damage are cracks. Cracks can be caused by many factors and have different effects, depending on the combination of external and internal pressures. Disclosure of the cracks in solid bodies can occur in different ways. The consequences of premature destruction of the fuel tank or wall of the building can be significant financial cost and human lives (Antarctic Bases and Buildings, 2017). We must prevent damage of buildings and engineering structures of Vernadsky station caused by wind and snow to avoid these consequences.

It is often necessary to remove snow from the surrounding area due to snow storms. To avoid drifts, all buildings of the Vernadsky station are installed on low reinforced concrete piles, but this does not always help. Long-term snowfall and strong winds can lead to accumulation of snow under and on the sides of buildings (ANSYS, 2017). Snow drifts, which arise in this case, can block the exits from buildings and the station staff will be trapped.

The architecture of modern Antarctic stations is rapidly developing. The buildings have aerodynamic design (for example, Fig. 1, (Halley VI Research Station by Hugh Broughton Architects, 2017), (Hutton D.,2008)) and are installed on high steel piles (Fig. 2, (Komenchuk I. et. al., 2017)-(Lukyanchenko O. et al., 2017)), so the wind can freely blow snow beneath them. Such designs of Antarctic stations help reduce the load from wind and snow on buildings. Thus, the risk of multi-site damage of buildings from the effects of these natural influences is much smaller.

a) b)

Fig. 1. Stations with aerodynamic design: a) Jang Bogo; b) Princess Elizabeth.

The stationary laboratories of the Halley series (Fig. 2, a, (Komenchuk I., 2017)) of British Antarctic stations were regularly swept up by snowstorms, or because of the active thawing of ice they slid into the ocean (ANSYS, 2017). Therefore, the Halley VI is a chain of mobile units on hydraulic supports. This makes it possible to raise and lower the scientific laboratory, depending on the amount of snow that has fallen out. The station modules can be isolated from each other in order to prevent the spread of possible fires. Also, modules can be detached from each other and transported to a new location, where in the future it is possible to assemble the station back.

a) b)

c)

Fig. 2. Stations on high steel piles: a) Halley VI; b) Taishan; c) Neumayer.

The same principle, but in an improved version, was applied in the project of the German Antarctic station Neumayer-3 (Fig. 2, c, (Lukyanchenko O. et al., 2017)), which opened in 2009. Sixteen hydraulic columns allow the whole structure of the station to be lifted. Approximately once a year the building is lifted by one meter. After that, the lower end of each hydraulic pile is also lifted and re-placed in compacted snow.

Since in the near future there is no plan to update the architecture of the Vernadsky station, the main objective of the study is to identify the most probable places of snow accumulation and maximum wind pressure zones for identification and prevention of multi-site damage of buildings and engineering structures. Such research can be carried out using numerical methods and simulation.

2. Methods and materials

In recent decades, the transition from industrial society to an information stage is going. This increases the impact of information and computer technologies on the development of industry, politics, medicine and life in general. There is a great emphasis on "heavy" software complexes of finite-element analysis in the field of scientific and technical software. These programs allow engineering analysis calculation of stress-strain state (including non-linear) and can take into account different by nature multi-source loads.

Relevance of numerical methods for the design of new objects and researching of existing ones is growing every year (Neumayer Station III, Antarctica, 2017). It is not always possible to get the exact result of the calculation using analytical methods for complex spatial structures. That is why it is necessary to introduce a number of assumptions to simplify the mathematical model. The result will be approximate and matching physical sense will largely depend on the accepted simplifications. Numerical methods (including finite element method, (Panoramic view of Jang Bogo Antarctic Research Station 3, 2017)) allow by passing restrictions of analytical methods. Finite element method allows solving not only tasks of mechanics and frequency analysis of structures, but also hydro-gas-dynamics.

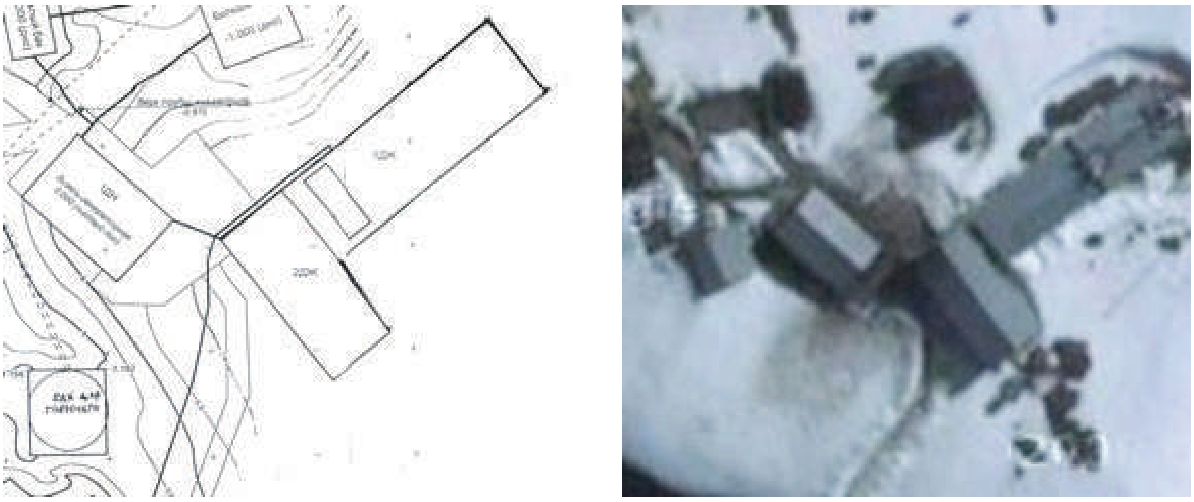
To use any of a wide variety of software for finite-element analysis it is necessary to create three-dimensional geometric model of the object of study. Creating of geometric models is possible by using the integrated pre-processor of CAE-systems or specialized external programs. As a rule, using of the integrated preprocessor is not always convenient due to its limited functionality. Therefore, in this work, an external CAD-program (SolidWorks, Pustovoit et al., 2017) will be used for geometric modeling.

SolidWorks is designed to automate the work of an industrial company at the stages of design and technological preparation of products of any degree of complexity and purpose. Specialized SolidWorks modules solve tasks at the stages of production and operation. The process of building a 3D model is based on the creation of bulk geometric elements and the execution of various operations with them. The model consists of standard elements (blocks) and can be edited by adding (deleting) these elements, or by changing the specific parameters of blocks. The 3D model carries the most complete description of the physical properties of the object (volume, mass, moments of inertia).

In the field of computer modeling for the study and forecasting of the impact of various man-made and natural factors, many powerful computing systems have been developed in our time. Therefore, for simulation is used ANSYS (SolidWorks, 2017) – "heavy" software package of engineering analysis. ANSYS is a versatile, finite-element software suite designed to solve problems in various engineering areas. The set of ANSYS modules allows you to solve any complex tasks that a modern researcher might face.

3. Results and discussion

The Vernadsky station is located on the rocky terrain. The terrain was recreated using the station's plan-scheme (Fig. 3) and its few photographs in the software environment of the SolidWorks CAD-system using splines.



a) b)

Fig. 3. Vernadsky station: a) plan-scheme; b) satellite photo.

Besides the main station buildings (main building, diesel generator, warehouse, carpentry workshop) the model of wooden bridges that connect all the buildings together was also created. Among the additional structures, three models of fuel tanks were created (one cylindrical vertical and two rectangular horizontal). All buildings and additional objects are placed on the assembly model (Fig. 4) according to plan-scheme of the station. Simplifications used for creating of geometric models will bring no significant errors in the results of the simulation.

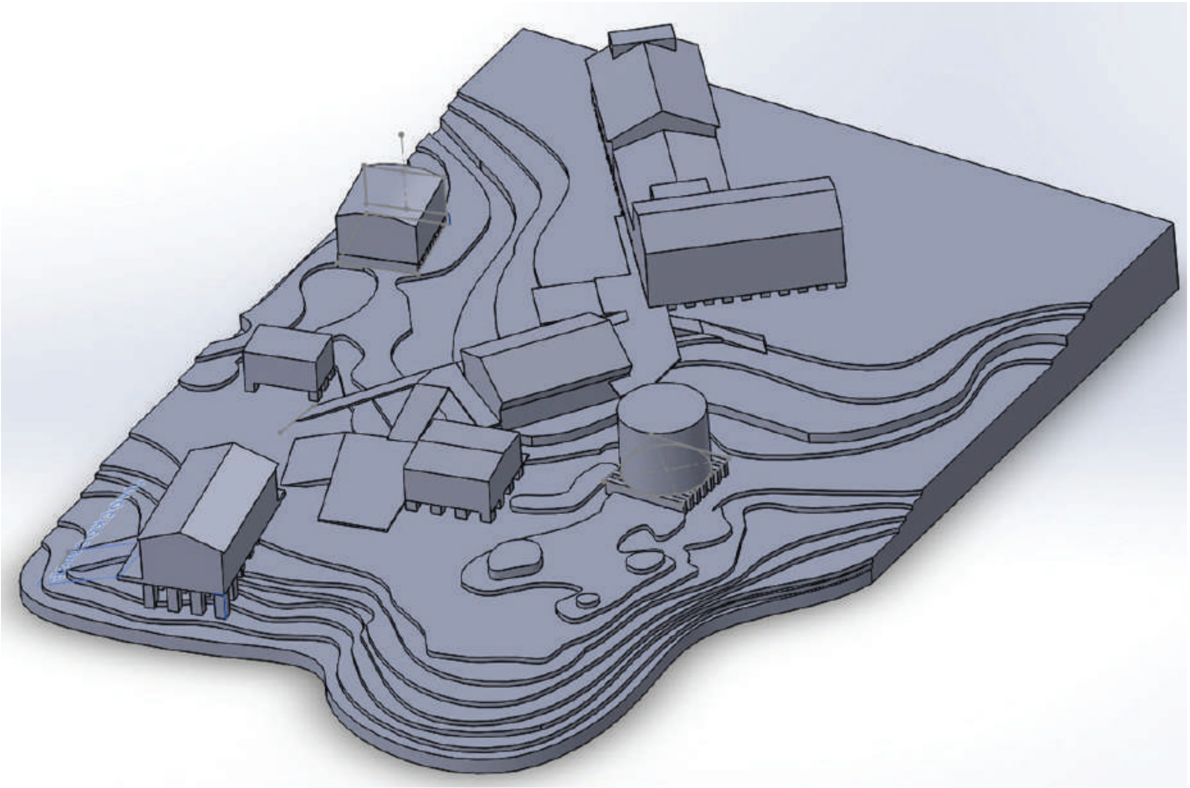
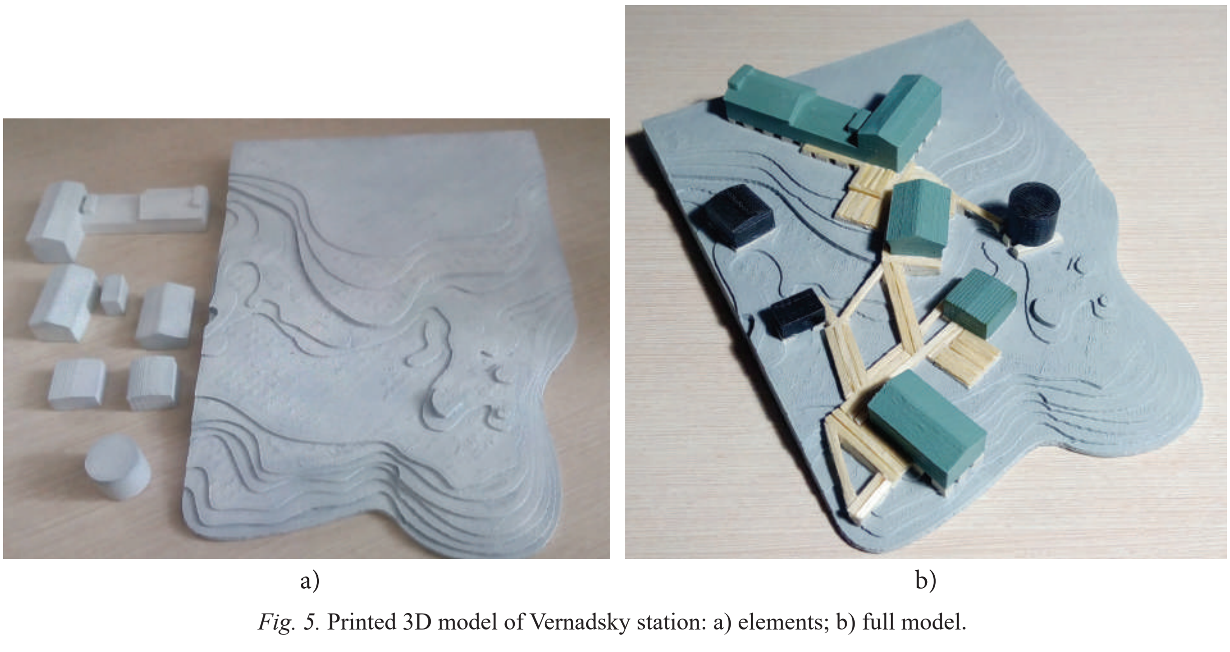


Fig. 4. Geometric model of Vernadsky station.

Using the three-dimensional geometric models created in SolidWorks CAD-system, model of Vernadsky station in 1/612 scale (ANSYS, 2017) was printed using 3D-printer (Fig. 5, a). Because of the limitations that impose the diameter of the printer nozzle some elements (wooden bridges) were not printed but were created from matches and added to the model (Fig. 5, b).



a) b)

Fig. 5. Printed 3D model of Vernadsky station: a) elements; b) full model.

To carry out the simulation of airflow of the station, it is necessary to create an airspace model. The geometric model of the airspace (Fig. 6) is a parallelepiped from which the model of the station (created earlier) was cut out.

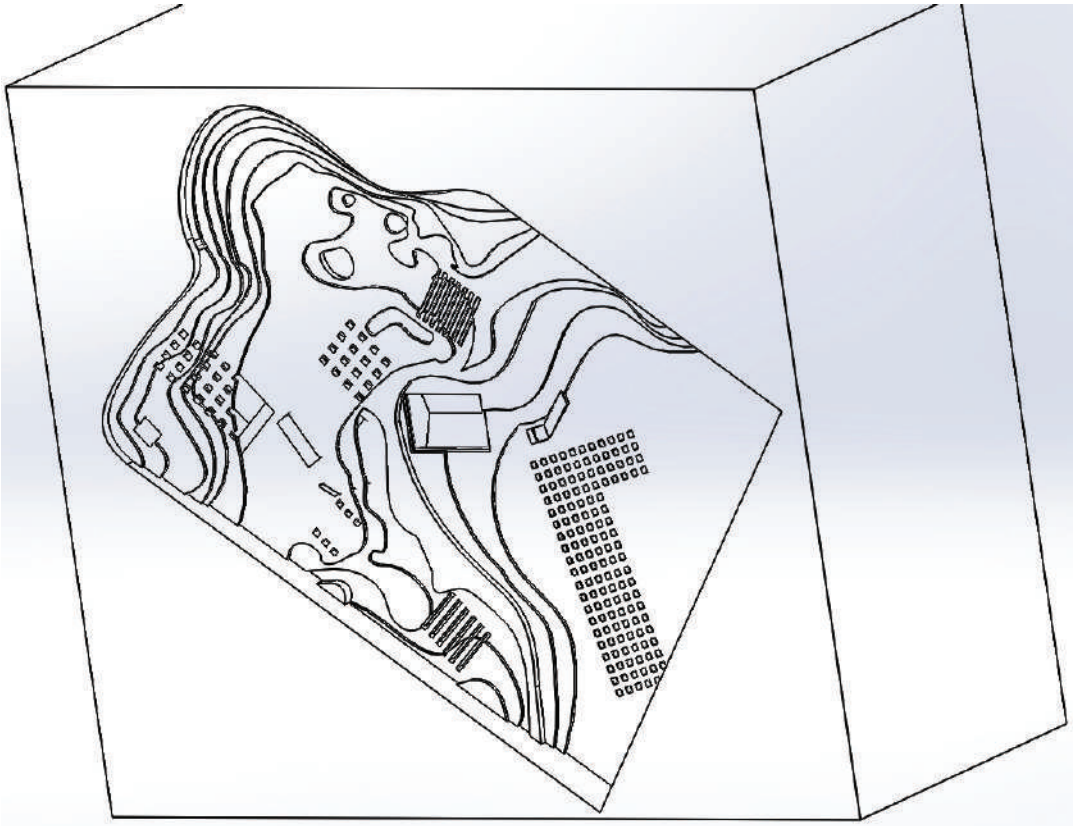


Fig. 6. Geometric model of station airspace.

The average wind speed is 35m/s, and the maximum – 45m/s near Vernadsky station according to (Neumayer Station III, Antarctica, 2017). Thus, the infrastructure elements of the station (buildings and tanks) are in adverse operating conditions, since the prolonged exposure to wind load with significant airstream speed can cause excessive stress and residual strain, the occurrence and development of cracks (through the interaction with low ambient temperature) and other damage.

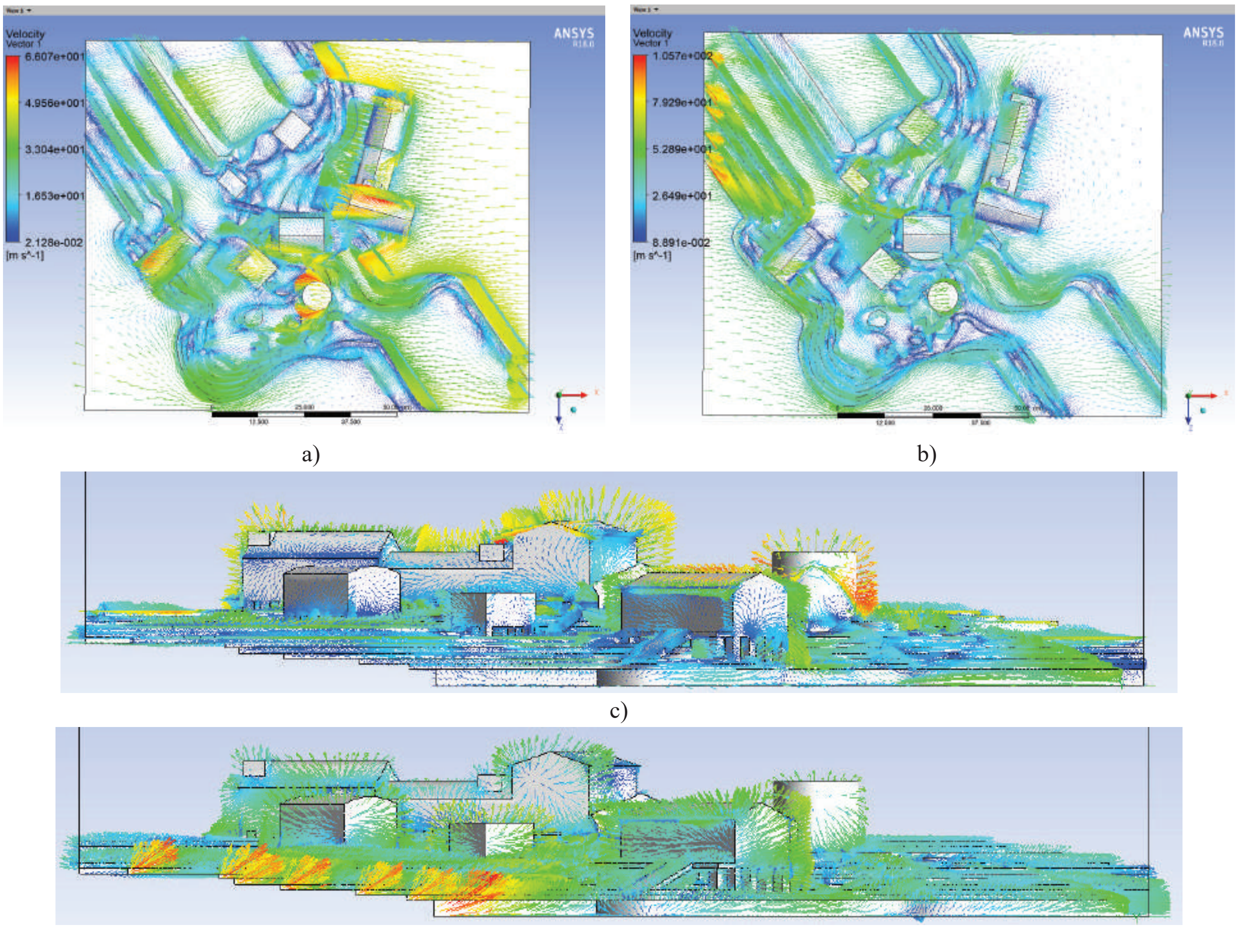
In order to determine the vector fields of the airflow velocity and its pressure, simulation of the wind load on the station was carried out using its created geometric model at airflow rates below the average (25 m/s) and above the average (maximum 45 m/s). The analysis of the obtained results (Fig. 7) allowed determining the most probable places of snow accumulation. The blue vectors indicate a low velocity of airflow. The most probable accumulation of snow is in these areas. They are located near the walls of all buildings of the station and in places of significant change in the terrain of the surrounding area.

The case of wind from the ocean (Fig. 7, b) is more dangerous in terms of the snow accumulation at Vernadsky station.

Fields of wind pressure (Fig. 8) help us to identify the most loaded elements of the infrastructure, which are the main building, the fuel tank and the carpentry workshop in case of airflow from the mainland. This result will allow the development of a set of multi-site damage preventive measures.

Unlike the case of snow accumulation, the case of wind pressure from the ocean (Fig. 8, b) is more secure for elements of the infrastructure of the station. In both cases of airflow rate (25 m/s and 45 m/s) the pressure distribution in the "wind from the mainland" case does not change, but the numerical values of pressure change.

The fuel tank is an important element of the station's infrastructure (Taishan station construction completed, 2017)-(Zshukovsky, Y., Kuzko, O. 2015). Its damage and destruction can lead to terrible consequences. In addition to wind, one of the most powerful and dangerous external natural loads in Antarctica is the low temperature. In combination with other loads (wind, for example), it can give rise to cracks in brittle materials of the fuel tank. Especially dangerous is the emergence of brittle cracks in welds which are continuous.

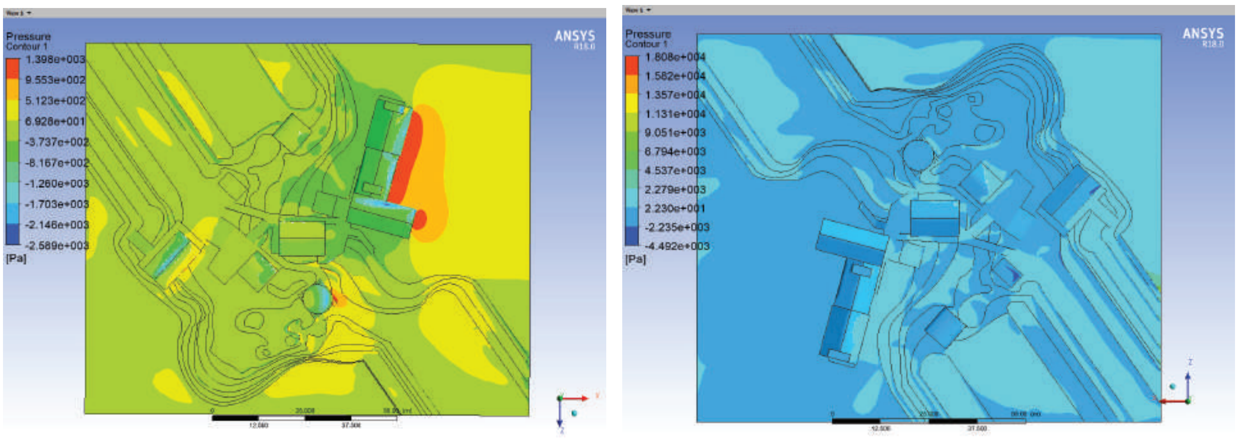


a) b)

c)

d)

Fig. 7. Vector fields of velocity: a) wind from mainland (Y-axis view); b) wind from ocean (Y-axis view); c) wind from mainland (-X-axis view); d) wind from ocean (-X-axis view).



a) b)

Fig. 8. Fields of wind pressure: a) wind from mainland; b) wind from ocean.

As the simulation results showed that the fuel tank is one of the most loaded elements of the infrastructure, it is necessary to study in more detail the possibility of cracks development in case of multi-site damage. It is also necessary to develop algorithms and software to facilitate the identification of fuel tank multi-site damage by the operator.

4. Conclusions

The geometric modeling and simulation was applied to study the airflow at Vernadsky station. Analysis of simulation results showed that the most probable places of accumulation of snow are located near the walls of all buildings of the station and in places of significant change in the terrain of the surrounding area. The most loaded with wind pressure is the main housing and the storage tank for diesel fuel. In this regard, it was decided to additionally create geometric models of the fuel tank to study the effect of multi-site damage in the form of cracks on its integrity. It is also determined that the main impact on the elements of the infrastructure of the station is the wind from the mainland, but not from the ocean.

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