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GENERAL PROVISIONS OF ESTIMATING THE VELOCITY PRESSURE SIMULATION OF AN EXPLOSIVE WAVE

ЗАГАЛЬНІ ПОЛОЖЕННЯ ОЦІНКИ МОДЕЛЮВАННЯ ШВИДКІСНОГО НАТИСКУ ВИБУХОВОЇ ХВИЛІ

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Abstract. *The operation of tower cranes on construction sites depends on the action of dynamic loads. One component of these loads is the high-speed pressure of the air shock wave, which can lead to the shutdown of cranes, as well as possible accidents or overturning lead to downtime and significant economic costs. The article discusses the tasks and general provisions of the assessment of modeling the high-speed pressure of an explosive wave on tower cranes. The paper presents the main tasks of numerical modeling of wind loading of a stationary tower crane.*

Key words: *tower crane, high-speed pressure, air shock wave, simulation.*

Introduction.

Tower cranes are the most used among construction cranes that solve the issue of mechanization of loading and unloading work in construction. But their accidents account for 40% of the total number of accidents of boom lifting cranes [1, 2].

The fall of tower cranes occurs both in our country and abroad, even if all operating rules and safety requirements are observed. The development and subsequent improvement of domestic tower cranes, especially in wartime, is impossible without researching the loads that act on the crane during air shock waves.

Since the beginning of the large-scale invasion of the territory of Ukraine, many areas have been damaged during shelling. In particular, active hostilities took place on the territory of the Kyiv region within the settlements: Irpin, Bucha, Borodyanka, Makariv, Gostomel, Vorzel, etc. The result was the destruction and damage of a large number of buildings and structures and various equipment on construction sites and, accordingly, also tower cranes. The tower cranes suffered damage to their metal structures from shock-explosive damage, and stationary cranes fell on the rails, which is not typical for further operation in peacetime conditions.

There are studies on the stability of tower cranes under conditions of wind loads, strong gusts of wind, which can be close to an explosive wave in a certain area of damage.

The calculation of the impact of the high-speed pressure of the blast wave on the crane is necessary to determine the wind loads on the structure with the subsequent calculation of both its own and cargo stability, as well as in the design or development of safety devices.

The necessary information on the distribution of wind loads on the metal structure of tower cranes can be obtained using analytical dependencies, numerical computer or physical modeling in wind tunnels [3].

General provisions of estimating the velocity pressure simulation of an explosive wave.

The existing norms for calculating cranes for wind load, as noted above, are based on coefficients that take into account drag, change in dynamic pressure in height, dynamic pressure and windward area of the structure [4].

The drag coefficient is a dimensionless value depending on the shape and size of the streamlined body and is determined by examination. When calculating the wind load, both for the working and for the non-working state of the crane, the aerodynamic resistance is determined for each individual part of the crane according to the reduced coefficients for typical elements. Any complex bidirectional position of the structural elements leads to an erroneous determination of the drag coefficient. The presence of incorrect shapes of sections of elements also makes it difficult to find and determine this parameter.

Another factor given in these methods determines the relationship between the height above the ground and wind speed [4]. To simplify the calculations, this coefficient is given in a linear relationship. With different methods of setting the speed pressure of the wind in the height of the crane (constant stepped, stepped) and the shape of the windward area, in the calculations the speed pressure of the wind can be taken constant within the height of individual parts of the crane (boom, turntable, etc.). In this case, the pressure value should be taken at a height equal to half the height of the investigated structure. This condition is a simplification of the dependence of the distribution of wind pressure on the height of the crane, which is a static function. The dynamic pressure coefficient is half the derivative of the air density and the square of the wind velocity.

An important factor in determining the wind load is the windward area of the crane. When the wind load on the truss structure of the boom, tower or other elements of the tower crane is not possible to take into account the shaded areas that are also subject to wind action. With small turns of the boom or other assembly units of a folded shape relative to the wind head, an increase in the windward area occurs, due to the transition of shaded areas in the windward. There are also no torque characteristics for trusses and tower crane structures.

Aerodynamic moments acting on the boom structure relative to the vertical axis of rotation of the crane are determined by calculation by aerodynamic forces known for individual elements of the boom structure, without taking into account the moments acting directly on these elements. Calculation of aerodynamic coefficients of crane structures having complex combinations and mutual arrangement of elements, for example, stepped joints of boom metal structures, which have recently been widely used, with a different set of cross-sections of tubular braces, seems to be quite complicated.

Physical modeling in a wind tunnel also presents a number of difficulties associated with scaling and executing the model of the crane design under study. Any minor deviations in the manufacture of a scale model of the crane lead to a significant error in calculations. Another significant drawback of wind pressure modeling in a conventional wind tunnel is the constancy of wind speed in height. To simulate the real loading conditions of the crane structure, it is necessary to use special wind tunnels with the possibility of creating a thick boundary layer with a working length of about 50-100 m, which entails an increase in the cost of research, since there are only a few such installations.

Alternative methods of calculations based on the technology of discrete vortex elements in an ideal liquid, methods of fast three-dimensional calculation are also known [5]. However, the inevitable simplifying assumptions about the properties of the air environment lead to the fact that the speed of the wind flow should be constant in height. In turn, the shift in the average wind speed in height creates great difficulties in the way of the correct application of such methods.

Recently, computer EPSS - systems of mathematical modeling based on the finite element method and the finite volume method - have been widely used to solve the problems of aerodynamics and continuum mechanics. The peculiarity of the finite element method lies in its power and reliability of studying the behavior of structures and individual elements in conditions of various actions. The finite element method relies on the variational problem of the minimum error of approximation of the desired solution by basis functions. For the most part, this method was widespread in the mechanics of solids.

The integral formulation of the laws of conservation of mass, momentum, energy, etc. is taken as the basis for solving the problems of the finite volume method. Balance relations are written for a small control volume. Their discrete analogue is obtained by summing over all faces of the selected volume of mass flows, momentum, and so on, calculated by quadrature formulas. Since the integral formulation of conservation laws does not impose restrictions on the form of the control volume, the finite volume method can be used to sample the equations of hydrogas dynamics both on structured and unstructured meshes with different cell shapes, which, in principle, completely solves the problem of complex geometry of the calculated region [6].

The development of computer 3D design tools (CAD - systems) and calculation modules (EPSS - systems) made it possible to create new high-tech products at the design stages.

The developed international digital standards for data exchange between different CAD systems in conjunction with universal calculation modules made it possible to expand the range of tasks to be solved and the ability to transfer information created in one CAD system to other similar systems. As a result, 3D models at the stages of production can be used for writing programs for CNC machines, and when calculating strength and so on.

In many cases, the logically interrelated use of CAD and EPSS means leads to a significant acceleration of the preparation of design models for the study of the calculated strength, dynamic or other properties and characteristics of the designed structure [7].

The composition of modern calculation systems includes universal modules, combined into logical groups by functional affiliation.

Modeling of continuum mechanics affects the field of CFD technologies, based on the numerical solution of systems of equations reflecting the general laws of continuum mechanics and designed to solve a wide range of problems of applied hydrogas dynamics and heat exchange. Software CFD - packages are widely used in the construction field when performing calculations of the flow of high-rise buildings, in the aircraft industry when determining the voltage and resistance factors, in medicine when designing heart valves, etc. [8]. In the production of crane structures, this technique is just beginning to be applied.

One of the main difficulties in modeling wind loads as part of a complete three-dimensional formulation of the problem of viscous turbulent flow around the metal structure of the tower crane boom is associated with increased power requirements for computing platforms. It should be noted that the use of unstructured meshes is quite complex in algorithmic terms, time-consuming to implement and resource-intensive when performing calculations, especially when solving three-dimensional problems. This is due both to the variety of possible shapes of the cells of the calculated grid, and to the need to use more complex methods to solve a system of mathematical equations that do not have a predefined structure.

Conventional personal computers provide adequate resources only when solving two-dimensional problems, which is unacceptable for modeling the wind load of crane structures. To perform complex three-dimensional calculations using the listed CFDs, expensive high-performance multiprocessor systems are required.

The object of the study is a model of a stationary quick-erecting tower crane LIEBHERR 63K v/n 6t. As an EPSS system, the SOLIDWORKS calculation complex was used, consisting of CFD, a software package for numerical analysis -

SOLIDWORKS Flow Simulation.

The SOLIDWORKS software package is widely known and popular among researchers dealing with dynamics and strength. The means of the SOLIDWORKS finite element method allow calculations of the static and dynamic stress-strain state of structures (including geometrically and physically nonlinear problems of the mechanics of a deformable solid), vibration shapes and frequencies, analysis of structural stability, nonlinear transients, etc.

The SOLIDWORKS preprocessor has the ability to both import and re-create rather complex geometric models for performing further analysis. To describe the problems of fluid and gas mechanics in the preprocessor SOLIDWORKS Flow Simulation, which is part of SOLIDWORKS, there is a specialized set of tools that includes various models of turbulence for modeling and laminar and turbulent processes, tools for describing boundary conditions with the possibility of setting a dynamic problem, etc. [9, 10]. Appearance in 2003 the first bit operating systems contributed to an increase in the power of calculation packages, which expanded the range of tasks to be solved and made it possible to use a larger number of finite elements (volumes). In this regard, the SOLIDWORKS computing module is designed to use a multiprocessor and a large amount of RAM.

The SOLIDWORKS Flow Simulation postprocessor allows you to determine any possible combinations of loads, moments, pressures, and the like. Wind load modeling using the finite volume method and the finite element method allows us to assess the influence of wind, both on shaded areas and on complex structural elements, to determine the drag coefficients of elements and assembly units..

Conclusions.

The main tasks in assessing the simulation of the high-speed pressure of the blast wave of a stationary tower crane are:

1. Construction of a mathematical model of wind loading of a stationary tower crane.

2. Determination of critical speed head for operating and non-operating condition of the crane.

3. Creation of a dependence on the data of mathematical modeling of the speed head, the position of the boom and the torque created by the wind flow relative to the axis of rotation of the crane.

4. Determination of influence of boom position relative to wind flow direction on crane stability.

5. Comparison of drag coefficient versus Reynolds number for cylindrical rods.

References:

1. B. Ren, A. Leung, J. Chen, and X. Luo (2015). “A hybrid control mechanism for stabilizing a crane load under environmental wind on a construction site”. Computing in Civil Engineering, vol. 2015, pp. 499-506.

2. H. Liu and G. Tian, (2019). “Building engineering safety risk assessment and early warning mechanism construction based on distributed machine learning algorithm,” Safety Science,vol. 120, pp. 764-771.

3. Gorbatyuk Ie., Mishchuk D., Bulavka O., Voliyanuk V. (2023). Analysis of studies of stationary tower cranes under wind loads. Girnichi, budivelni, dorozhni ta meliorativni mashini [Mining, construction, road and reclamation machines]. Nr.102, 17-23. (in Ukrainian). https://doi.org/10.32347/gbdmm.2023.102.0201.

4. ДСТУ EN 14439:2016 Вантажопідіймальні крани. Крани баштові. Вимоги щодо безпечності (EN 14439:2006 + A2:2009, IDT). DSTU EN 14439:2016 Lifting cranes. Tower cranes. Safety requirements (EN 14439:2006 + A2:2009, IDT).

5. Довгий С.О., Буланчук Г.Г. Математичне моделювання аеродинаміки міських забудов // Вісник Сумського державного університету. 2003. № 12 (58). С. 72 – 76.

6. Плашихін С.В. «Параметричне моделювання технологічних процесів» Розділ 2. Моделювання фізичних процесів в CAD/CAE системі SolidWorks. Навчальний посібник. Київ. КПІ ім. Ігоря Сікорського 2022р.

7. Gorbatyuk Yevgenii, Bulavka Oleg. (2023). Review and analysis of damage and existing systems of protecting tower cranes under the influence of a blast wave. Avtomobilnyj transport [Automobile transport]. Nr.53, 13-22. (in Ukrainian).

https://doi.org/10.30977/AT.2219-8342.2023.53.0.02.

8. Фідровська Н. М., Слепужніков Є. Д., Перевозник І. А. (2020) Експериментальні дослідження динамічних навантажень при роботі ходових кранових коліс з еластичними вставками. Машинобудування. Nr.25. 28-37. Fidrovska N.M., Slepuzhnikov Ye.D., Perevoznyk I.A. (2020) Eksperymentalni doslidzhennia dynamichnykh navantazhen pry roboti khodovykh kranovykh kolis z elastychnymy vstavkamy. Mashynobuduvannia Nr.25. 28-37. (in Ukrainian).

9. Solidworks у завданнях 3D моделювання та інжинірингу технічних систем: навч. посібник / В.Я. Ворощук, Т.М. Вітенько. Тернопіль: ФОП Паляниця В.А., 2021. 164 с.

10. Solidworks у завданнях 3D моделювання та інжинірингу технічних систем: навч. посібник / В.Я. Ворощук, Т.М. Вітенько. Тернопіль: ФОП Паляниця В.А., 2021. 164 с.

Анотація. *Робота баштових кранів на будівельних майданчиках залежить від дії динамічних навантажень. Однією складовою цих навантажень є швидкісний натиск повітряної ударної хвилі, що може призвести до зупинки кранів, а також можливі аварії або перекидання ведуть до простію та значних економічних витрат. В статті розглядаються задачі та загальні положення оцінки моделювання швидкісного натиску вибухової хвилі на баштові крани. В роботі наведені основні завдання чисельного моделювання вітрового вантаження стаціонарного баштового крану.*

Ключові слова:*. баштовий кран, швидкісний натиск, повітряна ударна хвиля, моделювання.*

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