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USE OF 3D MODEL IN THE STUDY OF TOWER CRANE STABILITY

The article presents the results of a study of the stability of a tower crane during operation, taking into account the influence of loads on the supports. The results of comparing the distribution of loads on the crane supports determined as a result of mathematical and computer modeling during the turning and lifting of the boom are presented. An analysis of tower crane designs, installation methods and operating conditions, as well as methods for calculating their stability, shows that recently there has been a need to install cranes that can handle loading and unloading operations in confined spaces. This raises the question of how important the stability of cranes under different operating conditions and different wind loads is. In this case, the correct choice of the support circuit comes to the fore, for which it is very important to determine the loads on the support elements.

RESEARCH, TOWER CRANE, STABILITY, LOAD DISTRIBUTION, MATHEMATICAL MODEL, COMPUTER MODEL, ADEQUACY

О. І. Іваненко, З. Р. Мусаєв. Використання 3D-моделі у дослідженні стійкості баштового крану. У статті представлено результати дослідження стійкості баштового крану під час експлуатації з урахуванням впливу навантажень на опори. Наведено результати порівняння розподілу навантажень на опори крану, визначених у результаті математичного та комп'ютерного моделювання під час повороту та підйому стріли. Аналіз конструкцій баштових кранів, методів їх монтажу та умов експлуатації, а також методів розрахунку їх стійкості показує, що останнім часом зросла потреба у встановленні кранів, здатних виконувати вантажно-розвантажувальні роботи в обмежених просторах. Це питання про важливість забезпечення стійкості кранів в умовах різної експлуатації та дії вітрових навантажень. У такому випадку на перший план виходить правильний вибір опорного контуру, для чого надзвичайно важливим є визначення навантажень на опорні елементи.

ДОСЛІДЖЕННЯ, БАШТОВИЙ КРАН, СТІЙКІСТЬ, РОЗПОДІЛ НАВАНТАЖЕНЬ, МАТЕМАТИЧНА МОДЕЛЬ, КОМП'ЮТЕРНА МОДЕЛЬ, АДЕКВАТНІСТЬ

Introduction

An analysis of tower crane designs, installation methods and operating conditions, as well as methods for calculating their stability, shows that recently there has been a need to install cranes that can handle loading and unloading operations in confined spaces. This raises the question of how important the stability of cranes under different operating conditions and different wind loads is. In this case, the correct choice of the support circuit comes to the fore, for which it is very important to determine the loads on the support elements.

However, sometimes cranes have accidents that lead to serious consequences for people, equipment, structures, and significant material damage, so it is necessary to comply with existing safety rules when designing and operating them [1].

Sometimes an accident can be caused by the limited space of the construction site itself. In addition, the presence of several tower cranes in central urban areas with overlapping operating cycles can lead to a collision, which significantly increases the number of accidents.

The working environment of the crane also affects the safety of its operation, for example: - dynamic loads caused by work operations and wind. The resulting vibrations affect the base of the tower crane; - the presence of trenches near the crane that change the characteristics of the soil [2-3].

The development and further improvement of domestic tower cranes today is impossible without a thorough study of the loads acting on the crane, justification of tower crane support structures under various operating conditions, without studying the actual modes of crane use in construction, without developing advanced methods for calculating stability, calculating loads on the supports arising at the base of the crane at arbitrary boom positions, outreach and load on the hook. Fulfillment of these conditions for the development of tower cranes is of great practical importance, as ensuring safety during their operation always remains an urgent problem.

Research in the field of strength, stability and the impact on the stability of external loading is devoted to the works of A.A. Vinson, V.O. Podobed, M.F. Barshtein, L.O. Nevzorov, V.G. Krupko, O.V. Sinelshchikov, V.O. Obidenov, etc.

The analysis of scientific papers in recent years has shown that researchers' efforts are focused on improving models of external unsteady loading; searching for the most loaded elements of the metal structure; tower cranes of a certain design, making engineering and design decisions to reduce the stresses that arise, as well as developing adaptive control systems for tower cranes to reduce the impact of external loads.

Foreign scientists have studied the stability and distribution of support reactions of tower cranes [4-5].

Most authors point to the imperfection of tower crane design methods, which does not allow taking into account the flexibility of the crane's metal structure and the presence of additional loads [6-9].

The aim of this work is to develop a computer model of a tower crane during its operation and compare the results with a mathematical model.

The main part

To build a computer model of the tower crane and its subsequent analysis, theSolidWorks computer-aided designsystemwith the Simulation applicationwas chosen. This program is designed for use on a personal computer in the Microsoft Windows environment. SolidWorks uses the principle of three-dimensional solid and surface parametric design, which allows the designer to create three-dimensional parts and assemble assemblies in the form of three-dimensional models.

Three-dimensional product modeling offers many advantages over traditional two-dimensional design. With SolidWorks, you can see the future product from all sides in volume and give it a realistic representation in accordance with the selected material for a preliminary design assessment.

The associative relationships between parts, assemblies, and their SolidWorks drawings ensure that the model and drawing are consistent, as any changes made to a part are automatically transferred to the associated assembly and drawing.

Processing and comparison of the results with the mathematical model. The study is carried out for different angles of rotation and tilt of the crane boom. Consider the load of the support points at the boom lift angle $\alpha = 00$ crane parking angles $\gamma = 0$, $\theta = 000$. After completing the calculation, you can estimate the load on the bearing surface in the Feature Manager study window by calling the context menu of the Results section and selecting Reaction force. By indicating the upper edges of the rails on which the crane stands in the open window and selecting the "Free body force" item, you can view their supporting reactions, and therefore the forces acting on the crane (Fig. 1).

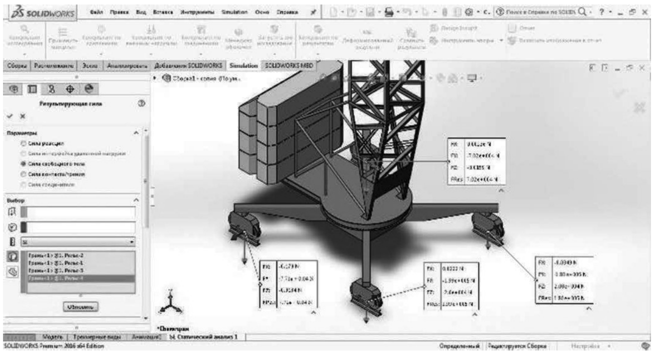

Fig. 1. Forces acting on the supports at the angle of rotation $\beta = 00$

Changing the angle of the boom, we continue to calculate the loads in increments of 450. We compare the results with the result of the mathematical study and draw a graph (Fig. 2).

Changing the angle of the boom, we continue to calculate the loads in increments of 450. For convenience, we summarize the results in Table 1, compare them with the results of the mathematical study, and draw a graph.

Table 1

Comparison of loads determined in the mathematical and computer models when changing the boom angle

			Boom angle β, deg							
			0	45	90	135	180	225	270	315
Load on the support, kN	Support 1	mate. mod.	69,5	33,7	69,5	144,0	223,4	258,2	233,4	144,0
		comp. mod.	70,2	38,2	72,3	142,6	234,6	260,8	236,8	141,1
		discrepancy	1,01	7,00	4,03	0,97	5,01	1,01	6,00	2,01
	Pillar 2	mate. mod.	191,6	114,2	35,7	2,0	35,7	114,2	191,6	223,4
		comp. mod.	180,1	115,3	38,2	1,7	36,1	113,1	201,2	212,2
		discrepancy	6,00	0,96	7,00	15,00	1,12	0,96	5,01	5,01
Load on the support, kN	Pillar 3	mate. mod.	191,6	223,4	191,6	114,2	35,7	2,0	35,7	114,2
		comp. mod.	199,3	216,7	182,0	124,5	32,8	2,1	36,8	119,9
		discrepancy	4,02	3,00	5,01	9,02	8,12	5,00	3,08	4,99
	Pillar 4	mate. mod.	69,5	144,0	223,4	258,2	233,4	144,0	69,5	33,7
		comp. mod.	77,1	131,0	234,6	250,5	230,1	152,6	72,3	34,6
		discrepancy	10,94	9,03	5,01	2,98	3,00	5,97	4,03	3,08

The difference between the results of mathematical and computer modeling is calculated according to the following relationship:

$$\varepsilon = \frac{|P_k - P_м|}{P_м} \times 100\% ,$$

where P_k is the load on the support calculated by a computer model;

R_m is the load on the support calculated by the mathematical model;

Now consider the change in the load of each anchor point as the boom outreach changes from the maximum to the minimum value. Repeat the calculation for each boom position from 00 to 500 in ten-degree increments. Boom angle β = 00; crane parking angles γ = 00, θ = 00. The obtained values are also entered in Table 2, evaluating the data discrepancy and building a graph (Fig. 3).

Table 2

Comparison of loads determined in the mathematical and computer models when changing the angle of the boom

			Boom lift angle α, deg					
			0	10	20	30	40	50
Load on the support, kN	Supports 1, 4	mathematical model	69,5	86,8	111,8	139,7	169,7	194,6
		computer model	66,7	85,1	107,0	145,0	196,0	189,0
		discrepancy	2,82	0,41	3,01	1,09	5,01	4,05
	Pillars 2, 3	mathematical model	191,6	170,7	142,7	109,8	77,8	46,9
		computer model	197,0	170,	147,	111,0	81,7	45,0
		discrepancy	4,03	1,96	4,29	3,79	3,71	2,88

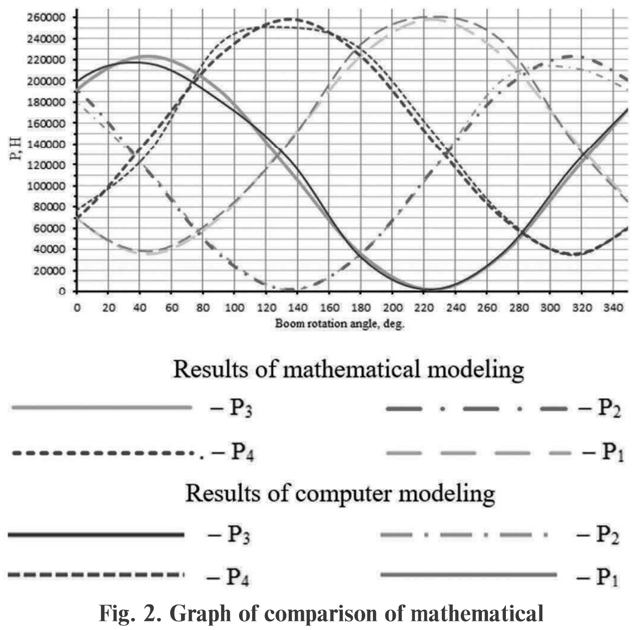

Fig. 2. Graph of comparison of mathematical and computer models

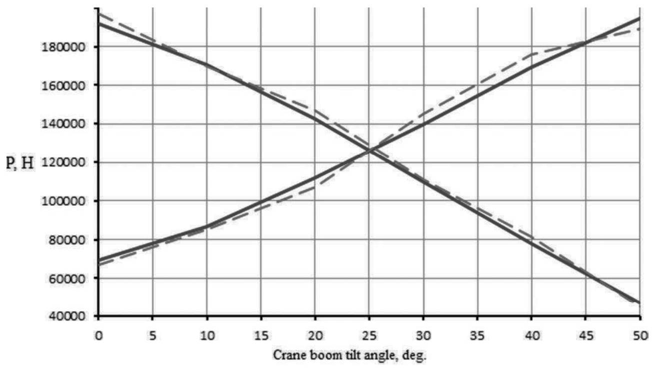

Fig. 3. Graph of comparison of mathematical and computer models

Analyzing the graphs shown in Fig. 3, it can be seen that the discrepancy between the results of the study of the mathematical and computer models varies within ten percent, averaging 4.83%. Taking into account possible inaccuracies in the construction of the computer model, this gives a fairly good result and allows us to consider the mathematical model adequate.

Conclusions

Using the developed algorithm for calculating the loads on crane supports, a computational experiment was conducted to determine the magnitude and nature of changes in the loads on crane supports under different operating conditions: with different loads and variable outreaches, wind loads.

It was found that the load of the crane support elements is oscillatory in nature with an amplitude of about 200 kN.

When the crane boom is rotated by 1350, support 4 can withstand the largest load of 250 kN, and support 2 is almost unloaded — 5 kN. At a turn of β = 2250, a similar situation occurs with supports 1 and 3, respectively.

When changing the outreach, supports 1 and 4 can withstand the same loads ranging from 68 to 190 kN, and supports 2 and 3 can withstand loads ranging from 190 to 50 kN.

At maximum outreach, the critical positions of the crane are those with boom angles of β=450 and β=3150, in which case the crane rests on almost three supports.

References:

[1] Pravyla pobudovy i bezpechnoi ekspluatatsii vantazhopidiomnykh kraniv. NPDOPO.00-1.01-07. K. : Osnova, P68 2007. 312 s.

[2] Slavomir Hric, Jozef Tkac Darina Matiskova, Milan Micko , Dusan Mandulak. Preliminary analysis of tower crane as a type of truss structure. MATEC Web of Conferences 299, 03003 (2019)ttps://doi.org/10.1051/matecconf/201929903003 MTeM 2019. https://www.matec- conferences.org/rticles/matecconf/pdf/2019/48/matecconf_mtem2019_03003.pdf

[3] Ivanenko O. I., Shcherbak O. V., Liubimov Yu. Yu. Kompiuterne modeliuvannia stiikosti na modeli bashtovoho kranu na osnovi vyznachennia opornykh reaktsii. Naukovi visti Dalivskoho universytetu. №18 2020 rik. Elektronne naukove fakhove vydannia. m. Sievierodonetsk, ISSN 2222-3428.http://nvdu.snu.edu.ua/wp-content/uploads/2020/02/2020-18-6.pdf

[4] Krupko I., Ivanenko O., Yermakova S. Substantive provisions of improvement of methods of calculation of loads on carrying and propelling devices of lifting and transport machines / Norwegian Journal of development of the International Science. – VOL.1 – №57/2021. – p. 54-59. ISSN 3453-9875. DOI: 10.24412/3453-9875-2021-57-1-54-59.

[5] Ivanenko O.I. , Krupko I.V. , Yermakova S.O. Teoretychni doslidzhennia stiikosti bashtovoho kranu z urakhuvanniam rozpodilu navantazhen na opory. Pidiomno-transportna tekhnika. Odesa 2020 3(64). S 81-95

[6] Ivanenko O.I., Krupko I.V., Yermakova S.O. Doslidzhennia stiikosti bashtovykh kraniv z urakhuvanniam rozpodilu navantazhen na oporni elementy / Visnyk Donbaskoi derzhavnoi mashynobudivnoi akademii. Vypusk № 3 (47) 2019. – Kramatorsk. – S. 46-50.

[7] Kyselov V. V. "Doslidzhennia stiikosti bashtovykh kraniv za dopomohoiu 3D modeliuvannia". – Naukovyi zhurnal inzhenerii ta arkhitektury, 2021. – T. 15, №3, s. 25–32.

[8] Myronenko O. O., Petrov I. I. "Vykorystannia tsyfrovykh modelei pry otsintsi bezpeky bashtovykh kraniv". – Visnyk budivelnykh nauk, 2019. – № 4, s. 45–53.

[9] Kumar, R., & Singh, D. "Stability Analysis of Tower Cranes Using Finite Element Method (FEM) and 3D Modeling." – International Journal of Structural Engineering and Mechanics, 2020, Vol. 13(5), pp. 231–240.

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