UDC 539.375

ANALYSIS OF THE STRESS-STRAIN STATE OF THE ROTARY DEVICE FASTENING PART BY THE SEMI-ANALYTICAL FINITE ELEMENT METHOD

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DOI: 10.32347/2410-2547.2024.112.67-74

The possibilities of the numerical apparatus developed on the basis of the semi-analytical finite element method are shown on the example of solving a specific problem. In the areas of maximum values, the parameters of the stress-strain state of the re-device fastening part were compared. It is worth noting the relatively complex configuration of the cross-section of the object, which led to a thorough study of the principles of constructing a grid area. The surface of interaction between the axis and the hull was modeled by a fairly thin layer of elements in relation to their thickness, which absorb only normal stresses. Analysis of the stress-strain state of the rotary device fastening part should be carried out from the standpoint of a spatial problem. Moreover, according to the results of the elastic calculation, the transition section between the body and the base plate turned out to be more loaded compared to the zone of contact interaction between the body and the axle. The data of the calculation performed in the elastic-plastic formulation made it possible to clarify the idea of the operating conditions of individual sections of the object and to draw a conclusion about the uniformity of the hull.

The carried out studies confidently demonstrated the wide possibilities of the developed approach in solving new, practically important problems of elastic deformation of prismatic bodies of complex shape in the spatial formulation of new ones. To substantiate the reliability of the results of the calculation of the elements under consideration, a sequential increase in the number of FE in the cross-section and the number of retained terms of the decomposition along the length of the body, as well as an increase in the accuracy of solving systems of equations, are given. In addition, an assessment of the satisfaction of natural boundary conditions on the surface of the body and the conditions of equilibrium in the integral sense is given according to the characteristic sections within the region, which showed their fairly good performance. New data on the regularities of behavior of critical structures in the process of loading, due to the consideration of their physical and geometric parameters, have been obtained.

Keywords: finite element method (FEM), semi-analytical finite element method (NMSE), stress-strain state (SSS), elastic deformation, rotary device fastening part, cylindrical body, sampling, elastoplastic formulation.

Entry. Among the main problems that arise in solving new problems is the justification of the choice of the design model of the object under consideration and the reliability of the results obtained. Often, the calculation of spatial prismatic structures is carried out within the framework of a flat formulation, which is due to the high labor intensity of solving a three-dimensional problem [1-4]. However, such a simplification of the design model is based on the hypothesis of the constancy of the parameters of the stress-strain state over the body length, can lead to an incorrect assessment of the working conditions of the structure. This is especially dangerous for critical high-load elements and parts, therefore, it is necessary to comprehensively take into account all factors that affect the spatial nature of the stress-strain state of the structures under study. Substantiation of the reliability of solving new problems by the finite element method is carried out, first of all, by sequential thickening of the grid domain. It should continue until there is a slight change in the results with a significant increase in the number of elements. It should be noted that the possibilities of the traditional variant of the finite element method in this respect are rather limited, and when it is applied, this requirement is generally not met [6-10].

Investigation of the stress-strain state of the fastening part of the rotary device. The fastening part is one of the most important elements of the rotary device, ensuring the reliability of its operation (Fig. 1). It is a hollow cylinder connected by a transition section to a rectangular plate, which is secured from displacements on the lower surface. A tubular axle is inserted into the cylindrical body, loaded at the ends with a uniformly distributed load $q^{1'}$, which reaches intensity in the modes of emergency overloads [5].

Part length $l = 8,4R_1$, height $H = 8,9R_1$, inner radius of the cylinder $R_2 = 2,2R_1$, external, radius $R_3 = 3,2R_1$ of curvature of the transition section $R_4 = R_1$, width of the base plate $B = 5R_1$, height $h = R_1$, inner radius of the axis $R_1 = 0,05\,\text{m}$. Modulus of elasticity of the material $E = 2 \cdot 10^5$ MPa of the structure, Poisson $\nu = 0,3$' s ratio, yield strength at pure shear $\tau_s = 160$ MPa. Only normal compressive stresses are transmitted over the contact surface between the axle and the housing.

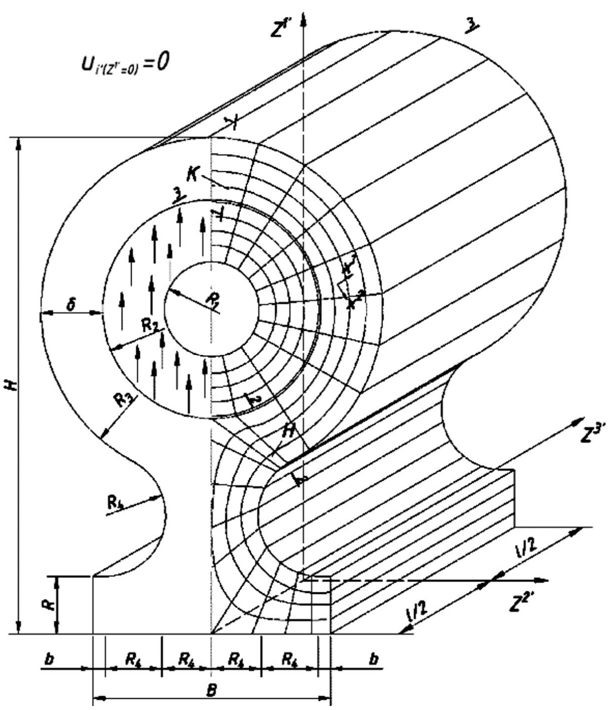

Fig. 1. Design diagram of the rotary device mounting part

Traditionally, the calculation of the structure in question was carried out within the framework of a flat formulation based on the assumption of a relatively uniform distribution along the axis $Z^{3'}$ of the forces transmitted to the hull. However, the validity of this hypothesis can only be tested on the basis of comparing the results of two-dimensional and spatial calculations.

Sampling of the rotary device mounting part using prismatic finite elements is shown in Fig. 1. It is worth noting the relatively complex configuration of the cross-section of the object, which led to a thorough study of the principles of constructing a grid area.

The surface of interaction between the axis and the body was modeled by a rather thin layer of elements in relation to their thickness, which perceive only normal stresses. Based on the condition that these stresses can only be compressive, in the tensile stress region, which is determined in an iterative way, elements with zero stiffness were used, shown in Fig. 1 hatching. Data from the convergence study $\tilde{\sigma}^{22}$ and *T* at the points *K* and *H* depending on the total number of nodes of the grid area *m*, the number of contained members of the decomposition *M* and the accuracy of the solution of the system of equations determined ε by, are given in Tables 1, 2, respectively. Their analysis allows us to conclude that for the calculation of the structure under consideration, we can take *m*=260, *M*=5 and $\varepsilon = 10^{-3}$. At these values of the projection parameters of the resultants on the axis, calculated from the contact area and in the body cross-sections by planes perpendicular to the axis $Z^{1'}$ and pass through the axis of rotation and the center of the transition section, differ from the resultant external loads by 2-3%.

The results of the elastic calculation of the fastener part, performed at $q^{1'} = 60$ MPa, are presented in Fig. 2, 3 in the form of stress diagrams $\tilde{\sigma}^{22}$ and T, plotted in sections 1-1 and 2-2, respectively. Solid lines indicate the solution data of the spatial problem, dotted lines – flat ones. Comparison of these diagrams showed that only in section 2-2 the results of two-dimensional and three-dimensional solutions are compared, and in the vicinity of the point *K*. The calculation under conditions of plane deformation gives an almost 5-fold lower value *T*. This is due to the significantly uneven distribution of normal stresses along the length of the body $\tilde{\sigma}^{11}$, the diagrams of which in section 3-3 are shown in Fig. 4. There are also diagrams of stresses $\tilde{\sigma}^{22}$ and *T*, the nature of which is determined by the noted peculiarity of the distribution $\tilde{\sigma}^{11}$ along the axis $Z^{3'}$. Based on these data, it can be concluded that the analysis of the stress-strain state of the fastening part of the rotary device should be carried out from the standpoint of the spatial problem. Moreover, according to the results of the elastic calculation, the transition section between the body and the supporting one turned out to be more loaded compared to the zone of contact interaction between the body and the axle Stove.

Table 1

ε	*M*	*m*	σ^{22}, MPa	%	*T*, MPa	%
0,001	5	168	140,8	4,41	121,9	3,40
		260	145,5	1,22	124,2	1,13
		396	147,3	-	126,2	-
0,001	3	260	142,4	3,19	122,0	2,63
	5		145,5	1,09	124,2	0,88
	7		147,1	-	125,3	-
0,01	5	260	142	2,80	119,9	4,08
0,001			145,5	0,41	124,2	0,56
0,0001			146,1	-	124,9	-

Table 2

ε	*M*	*m*	σ^{22}, MPa	%	*T*, MPa	%
0,001	5	168	251,3	4,70	155,6	3,95
		260	260,1	1,36	160,3	1,04
		396	263,7	-	162,0	-
0,001	3	260	252,4	4,03	157,1	2,96
	5		260,1	1,10	160,3	0,98
	7		263,0	-	161,9	-
0,01	5	260	249,8	4,58	153,2	5,14
0,001			260,1	0,65	160,3	0,74
0,0001			261,8	-	161,5	-

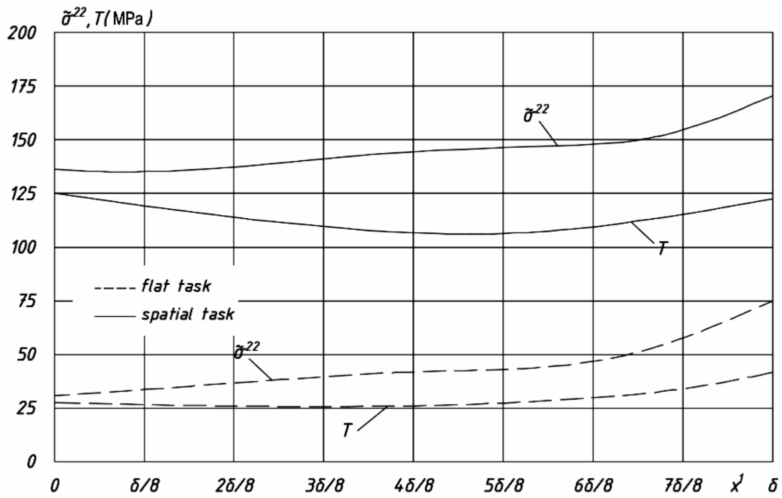

Fig. 2. Stress diagram $\tilde{\sigma}^{22}$ and *T* cross-section 1-1

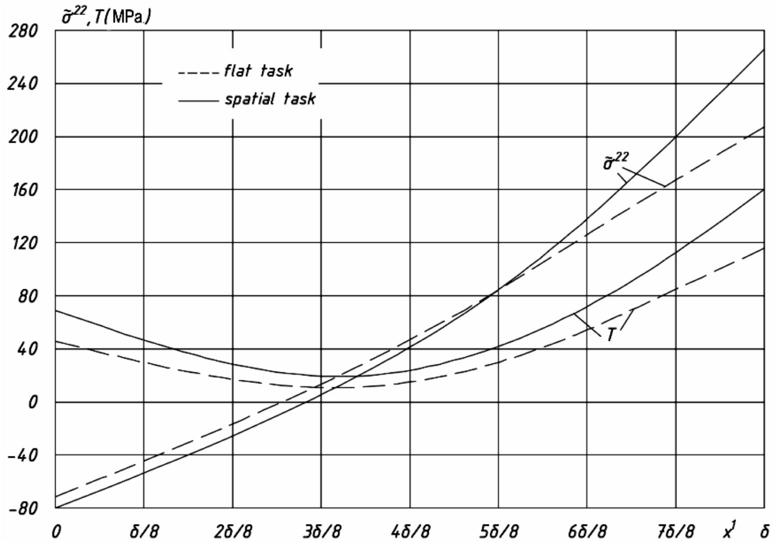

Fig. 2. Stress diagram $\tilde{\sigma}^{22}$ and T cross-section 2-2

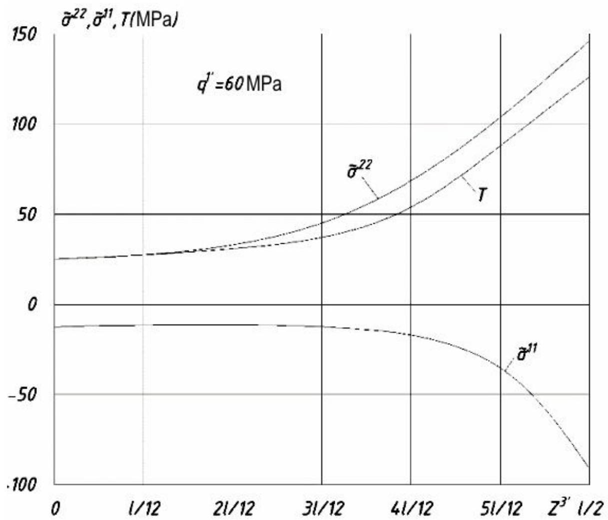

Fig. 3. Stress diagram $\tilde{\sigma}^{22}$ and T cross-section 3-3

The results of the calculation performed taking into account the plastic properties of the material when the object is loaded with the actions of maximum intensity are shown in Fig. 4 in the form of stresses $\tilde{\sigma}^{11}$, $\tilde{\sigma}^{22}$ and T, plotted in section 3-3. There is a noticeable redistribution of stresses near the ends of the hull compared to the elastic calculation $\tilde{\sigma}^{22}$, due to the development of plastic deformations in this area. Fig. Diagrams 5 and 6 are presented ε_i^p, built in sections 2-2 and 3-3 at different values of external load.

Despite the fact that K plastic deformations appear later in the point region than in the point area, H their development in section 3-3 is faster and the $q^{1'} = 140$ MPa magnitude ε_i^p at both points is equalized. Thus, the data of the calculation performed in the elastic-plastic formulation made it possible to clarify the idea of the operating conditions of individual sections of the object and to draw a conclusion about the equistrength of the body.

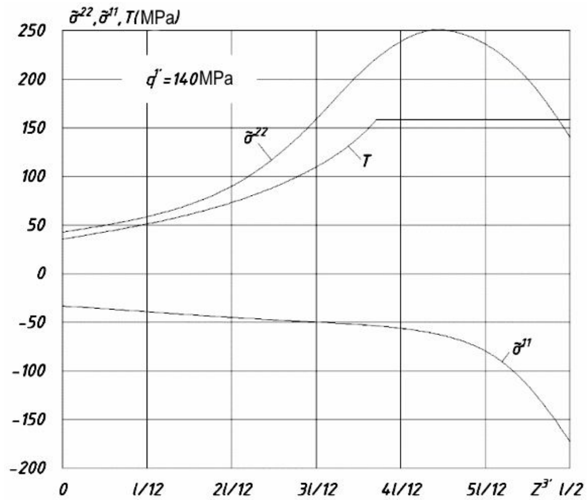

Fig. 4. Diagram of stresses $\tilde{\sigma}^{11}$ in $\tilde{\sigma}^{22}$ T section 3-3, taking into account the plastic properties of the material when the object is loaded with actions of maximum intensity

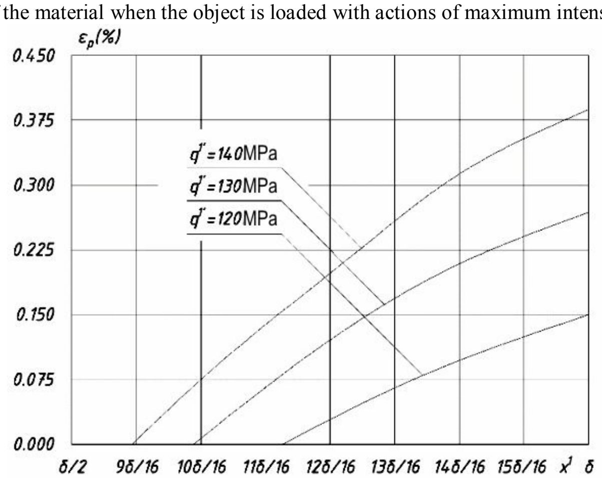

Fig. 5. Diagram of stresses ε_i^p in section 2-2

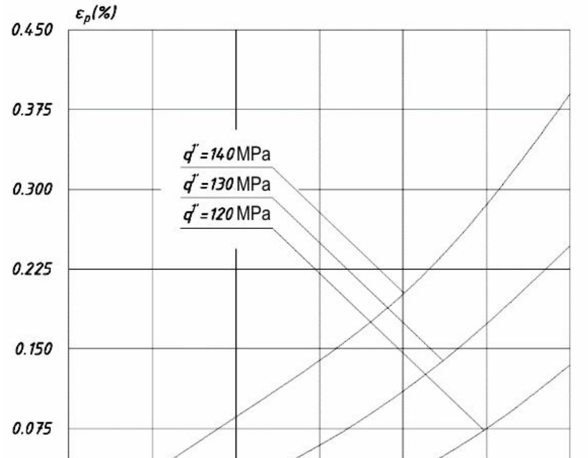

Fig. 6. Stress diagram ε_i^p in section 3-3

Conclusion. The carried out studies confidently demonstrated the wide possibilities of the developed approach in solving new, practically important problems of elastic deformation of prismatic bodies of complex shape in the spatial formulation. To substantiate the reliability of the results of the calculation of the elements under consideration, a sequential increase in the number of FE in the cross-section and the number of retained terms of the decomposition along the length of the body is given, as well as an increase in the accuracy of solving systems of equations. In addition, estimation of satisfaction of natural boundary conditions on the surface of the body and conditions of equilibrium in the integral sense by characteristic cross-sections within the region, which showed their fairly good performance. New data on the regularities of behavior of critical structures in the process of loading, due to the consideration of their physical and geometric parameters, have been obtained.

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Стаття надійшла 28.03.2024

Максим'юк Ю.В., Шкриль О.О., Мартинюк І.Ю., Козак А.А., Максим'юк О.В.

АНАЛІЗ НАПРУЖЕНО-ДЕФОРМОВАНОГО СТАНУ ДЕТАЛІ КРІПЛЕННЯ ПОВОРОТНОГО ПРИСТРОЮ НАПІВАНАЛІТИЧНИМ МЕТОДОМ СКІНЧЕННИХ ЕЛЕМЕНТІВ

Можливості розробленого на основі напіваналітичного методу скінченних елементів чисельного апарату показано на прикладі розв'язання конкретної задачі. В областях максимальних значень проведено зіставлення параметрів напружено-деформованого стану деталі кріплення повторного пристрої. Варто зазначити відносно складну конфігурацію поперечного перерізу об'єкта, що зумовило ретельне опрацювання принципів побудови сіткової області. Поверхня взаємодії осі та корпусу моделювалась досить тонким по відношенню до їхньої товщини шаром елементів, що сприймають виключно нормальні напруження. Аналіз напружено-деформованого стану деталі кріплення поворотного пристрою варто проводити з позиції просторової задачі. Причому за результатами пружного розрахунку більш навантаженими в порівнянні із зоною контактної взаємодії корпусу та осі виявилась перехідна ділянка між корпусом та опорною плитою. Дані розрахунку, виконаного в пружно-пластичній постановці, дозволили уточнити представлення про умови роботи окремих ділянок об'єкта і зробити висновок про рівноміцність корпусу.

Виконані дослідження упевнено продемонстрували широкі можливості розробленого підходу при розв'язанні в просторовій постановці нових, практично важливих задач пружного деформування призматичних тіл складної форми. Для обґрунтування достовірності результатів розрахунку розглядуваних елементів приведене послідовне збільшення

кількості СЕ в поперечному перерізі та кількості утримуваних членів розкладу по довжині тіла, а також підвищення точності розв'язання систем рівнянь. Крім того приведена оцінка задоволення природних граничних умов на поверхні тіла та умов рівноваги в інтегральному сенсі за характерними перерізами всередині області, яка показала їхнє досить хороше виконання. Отримані нові дані про закономірності поведінки відповідальних конструкцій в процесі навантаження, обумовлені врахуванням їхніх фізичних та геометричних параметрів.

Ключові слова: метод скінченних елементів (МСЕ), напіваналітичний метод скінченних елементів (НМСЕ), напружено-деформований стан (НДС), пружне деформування, деталь кріплення поворотного пристрою, циліндричний корпус, дискретизація, пружно-пластична постановка.

Maksimyuk Yu.V., Shkryl O.O., Martyniuk I.Yu., Kozak A.A., Maksimyuk O.V.

STRESS-STRAIN STATE ANALYSIS OF ROTARY DEVICE FASTENING PARTS BY SEMI-ANALYTICAL FINITE ELEMENT METHOD

The possibilities of the numerical apparatus developed on the basis of the semi-analytical finite element method are shown on the example of solving a specific problem. In the areas of maximum values, the parameters of the stress-strain state of the re-device fastening part were compared. It is worth noting the relatively complex configuration of the cross-section of the object, which led to a thorough study of the principles of constructing a grid area. The surface of interaction between the axis and the hull was modeled by a fairly thin layer of elements in relation to their thickness, which absorb only normal stresses. Analysis of the stress-strain state of the rotary device fastening part should be carried out from the standpoint of a spatial problem. Moreover, according to the results of the elastic calculation, the transition section between the body and the base plate turned out to be more loaded compared to the zone of contact interaction between the body and the axle. The data of the calculation performed in the elastic-plastic formulation made it possible to clarify the idea of the operating conditions of individual sections of the object and to draw a conclusion about the uniformity of the hull.

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УДК 539.375

Максим'юк Ю.В., Шкриль О.О., Мартинюк І.Ю., Козак А.А., Максим'юк О.В. **Аналіз напружено-деформованого стану деталі кріплення поворотного пристрою напіваналітичним методом скінченних елементів** // Опір матеріалів і теорія споруд: наук.-тех. збірн. – Київ: КНУБА, 2024. – Вип. 112. – С. 67-74.

Виконані дослідження упевнено продемонстрували широкі можливості розробленого підходу при розв'язанні в просторовій постановці нових, практично важливих задач пружного деформування призматичних тіл складної форми. Для обґрунтування достовірності результатів розрахунку розглядуваних елементів приведене послідовне збільшення кількості СЕ в поперечному перерізі та кількості утримуваних членів розкладу по довжині тіла, а також підвищення точності розв'язання систем рівнянь. Крім того приведена оцінка задоволення природних граничних умов на поверхні тіла та умов рівноваги в інтегральному сенсі за характерними перерізами всередині області, яка показала їхнє досить хороше виконання. Отримані нові дані про закономірності поведінки відповідальних конструкцій в процесі навантаження, обумовлені врахуванням їхніх фізичних та геометричних параметрів.

Табл. 2. Іл. 6. Бібліогр. 10 назв.

UDC 539.375

Maksimyuk Yu.V., Shkryl O.O., Martyniuk I.Yu., Kozak A.A., Maksimyuk O.V. **Analysis of the stress-strain state of the rotary device fastening part by the semi-analytical finite element method** // Strength of Materials and Theory of Structures: Science-Technology. Born. – Kyiv: KNUCA, 2024. – Vyp. 112. – P. 67-74.

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Tabl. 2. Fig . 6. Ref. 10.

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