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INVESTIGATION OF THE INFLUENCE OF FLANGE THICKNESS ON THE NATURE OF DEVELOPMENT OF PLASTIC ZONES INTHE CASING DETAIL

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In this work, using the method described in [1, 9, 13, 16], a numerical analysis of the stress-strain state of a spatial object was performed, namely the study of the influence of flange thickness on the nature of the development of zones of plasticity in the casing detail. It should be noted that the use of a thickened flange allowed to localize the zone of plasticity and its length in this case does not exceed half the length of the bell. In this case, the additional cost of material for the manufacture of thickened flange is fully justified. This reduces the level of plastic deformations and stresses in the hazardous area and prolongs the life of the casing detail.

Keywords:finite element method (FEM), semi-analytical finite element method (SAFEM), stress-strain state,elastic and elastic-plastic deformation, curvilinear prismatic bodies, flange, plasticity zones, the casing detail.

Introduction. For prismatic bodies with variable physico-mechanical and geometrical parameters, the matrix of the system of solving equations is completely filled and it is not possible to reduce the dimension of the problem. The conditionality of the matrix of the system of solving equations of SAFEM depends on the rational choice of the system of coordinate functions. High efficiency of the method can be achieved only by ensuring the predominance of diagonal elements.

Trigonometric [4-6] and beam functions [8, 13] are usually used in most works on the application of SAFEM to the calculation of prismatic objects as basic ones. Recently, there have been publications proposing to use spline approximation [7, 14, 20] or polynomial decomposition [2, 3, 17].Beam functions, Horvey polynomials [10], as well as some types of trigonometric decompositions, for example, proposed by Filonenko-Borodych [9], are focused on the calculation of only thin-walled objects. They, being orthogonal, do not have the property of completeness in the energy space of the operator of the theory of elasticity and can not be used in constructing the solution relations of a universal finite element focused on the calculation of massive and thin-walled bodies. The use of approximation of displacements by segments of the Fourier series [12, 16] provides a straightforward prismatic body complete separation of variables, but such a system of coordinate functions allows to model the boundary conditions of only a particular species. Since it is supposed to consider curvilinear inhomogeneous bodies with arbitrary boundary conditions, the system of basic functions [12] is adopted, the first two members of which are Langrange polynomials of zero and first order, the others - Michlin polynomials [2, 3, 17]. This approach allows to satisfy arbitrary boundary conditions in the traditional way for the FEM, which is to exclude the corresponding equations.

Investigation of the influence of flange thickness on the stress-strain state of a casing detail. The casing detailconsists of alternating fragments, the general view of one of which is presented in Fig. 1.

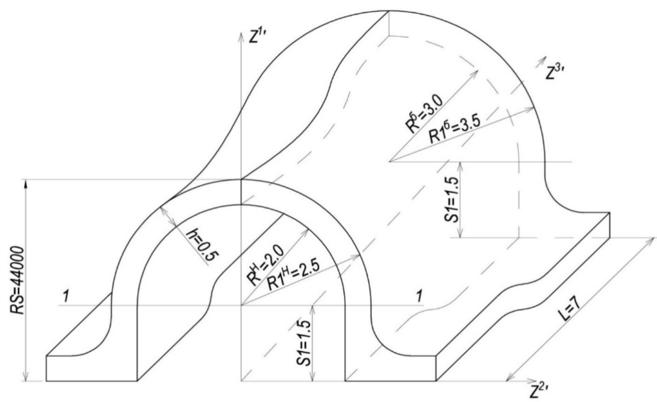


Fig. 1. The casing detail

The object under study is a semi-cylinder of variable radius connected to a flange rigidly fixed to the frame. The radius of the inner surface of the cylindrical section *R* in the isthmus is 20 mm, in the area of maximum expansion *R* = 30 mm. The thickness of the shell h remains constant and is equal to 5 mm. Between the isthmus and the bell is a transition area, the shape of which is described by the arcs of two circles with a radius of 16 mm (Fig. 2). Fragment length *L* = 70 mm. The stress-strain state of the body with a flange whose thickness is equal to the wall thickness of the cylindrical section *h* is investigated. The radius of the filler transition

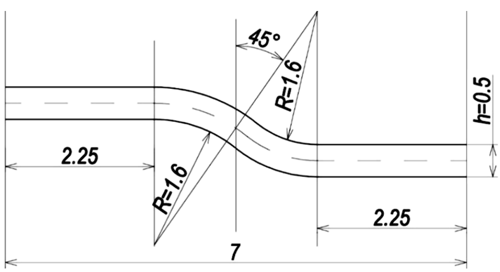


Fig. 2. The transition area between the isthmus and the bell of the casingdetail

$R2$ is 75 mm. In Fig. 2 shows the cross section of the flange and indicates all the required dimensions.

On the inner surface of the casing detailis loaded with an evenly distributed load, intensity 29 MPa. The modulus of elasticity of the material E = 2 · 105 MPa, Poisson's ratio υ= 0,3, yield strength at pure shearts τ= 160 MPa. Boundary conditions at the ends of the fragment:

$$U^{3'}/Z^{3'} = 0,5L \quad (1)$$

model the plane of symmetry. Along the length of the flange, there is no displacement in all three directions.

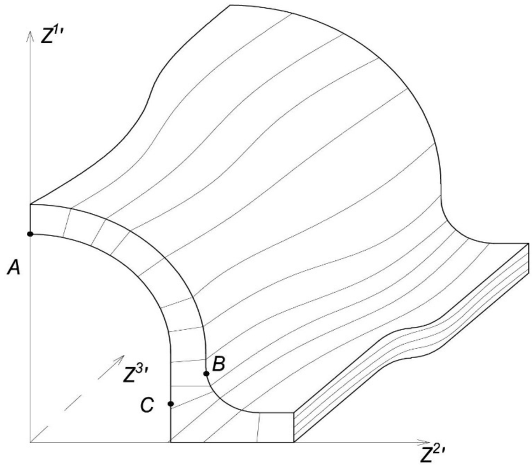
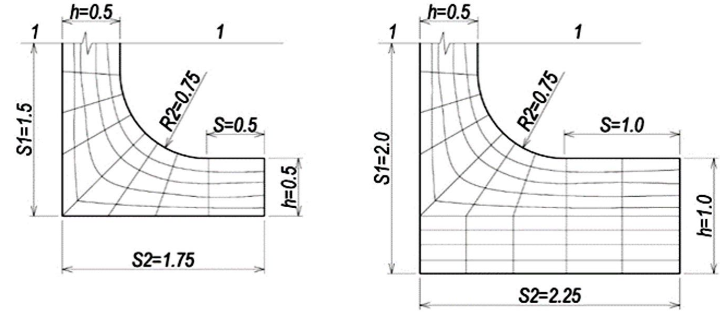


Fig. 3. Estimated scheme of the object

The calculation scheme of the object is shown in Fig. 3, but in Fig. 4(a) shows an approximating grid in the cross section of the flange.To more accurately describe the geometry of the body, an uneven grid of finite elements is used, both in thickness and length of the object. Along $Z^{3'}$ a series decomposition by basic functions is applied.



(a) (b)

Fig. 4. Approximate grid in the cross section of the flange

In order to substantiate the reliability of the obtained results, convergence was established depending on the number of finite elements in the cross-sectional plane and the number of retained members of the series.As a result of the research, a finite element grid with a total number of nodes 102 was adopted, and 9 members of the decomposition were stored along $Z^{3'}$. Further change of these parameters leads to deviations of the results of the solution within 1.5%.

At the first stage, the calculation of the casing detail was carried out by elastic staging. Analysis of the results of the solution allows us to conclude that the highest stress level is reached at points A and C on the inner surface and at the point on the outer (see Fig. 3). For these points, the intensity curves of tangential stresses along the length of the product are constructed (Fig. 5).

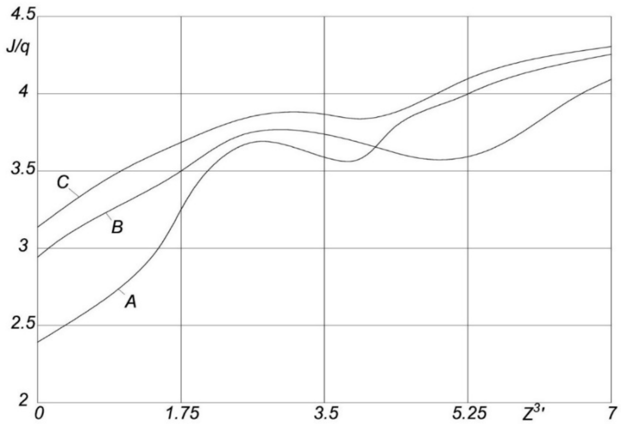


Fig. 5. The intensity curves of the tangential stresses along the length of the product

As we can see, the maximum level of intensity at all points under consideration is achieved in the cross section lying in the plane of symmetry on the side of the bell. Since at this yield strength plastic deformations will develop at $I/q = 4$, we can predict the presence of three zones of plasticity.

Since the highest intensity of tangential stresses takes place on the inner contour of the object (points *A* and *C*) to determine the dangerous area, we construct the distribution of the intensity of tangential stresses in a circle (Fig. 6). The diagram has two pronounced maxima and according to the elastic calculation we can assume the presence of two zones of plasticity that pose a danger - one in the central part of the cylindrical section, the other - near the rigid foundation.

To clarify the information obtained, the calculation of casing detail in the elastic-plastic setting was given.

The results of solving the problem in the elastic-plastic formulation are presented in the form of isolines of plastic deformations in Fig. 7, 8. As expected, in the process of deformation there are three zones of plasticity, two of which are located on the inner surface - in the central part of the cylindrical section (near point *A*) and in the area of rigid foundation (near point *C*), and one on the outer contour in the area of the joint of the filler and the rectilinear section (point *B*). Although zones A have a sufficient length along $Z^{3'}$ and capture the length of most of the bell, their intensity is small and in the maximum range does not exceed 0.15%. The zone of plasticity in the area of fixing the flange on the frame, the length of which exceeds the length of the bell, is dangerous. Zone C is close to the clamped corner of the flange and the maximum intensity in this area is 0.5%.

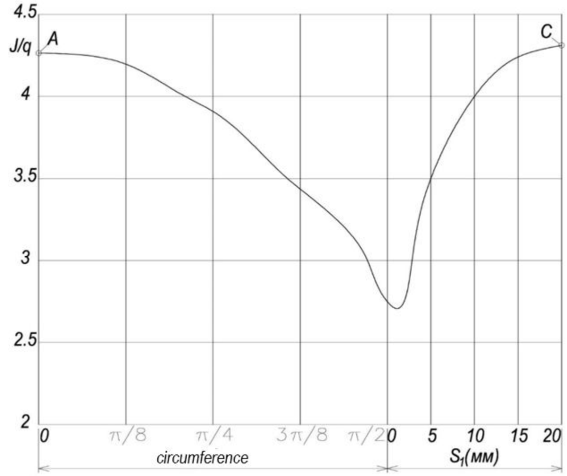


Fig. 6. Distribution of the intensity of tangential stresses in a circle

Thus, the assessment of the load-bearing capacity of the structure, carried out on the basis of elastic calculation, allowed only to determine the areas of occurrence of plastic zones. Detection of the dangerous zone of plastic deformations is possible only with the help of elastic-plastic solution.

One of the ways to reduce plastic deformations in the area of fastening is to increase the geometric dimensions of the flange. Consider the stress-strain state of a casingwith a flange $2h$ thick.The dimensions of the cross section of the thickened flange and the option of dividing it into finite elements are shown in Fig. 4(b). In this case, there are also three zones of plasticity. The length along $Z^{3'}$ and the maximum intensity of plastic deformations in regions A and B for the body with a thickened flange (Fig. 8) differ slightly from those previously obtained with a flange of thickness h.In what follows, we distinguish between flange № 1 and flange № 2 with thickness h and 2h, respectively. In the area near the rigid foundation, the intensity of plastic deformation for thecasing detailwith a flange № 2 is more than 3 times lower than in the presence of a thin flange and is 0.15%.

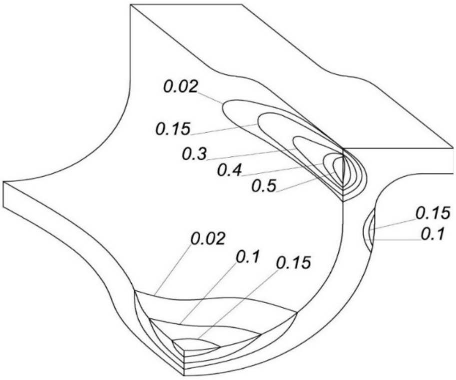


Fig. 7. Isolines of plasticdeformations

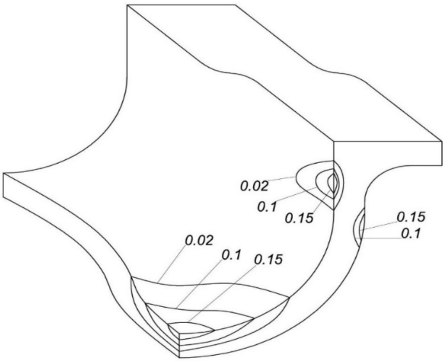


Fig. 8. Isolines of plasticdeformations

It is also of interest to compare the nature of the stress change along the inner and outer contours of the section, which lies in the plane of symmetry on the side of the bell, which achieves the maximum level of plastic deformation.

The distribution of ring stresses on the inner and outer contours of the part is shown in Fig. 9, 10 respectively.

On Fig. 9 diagram $\sigma^{2'2'}$ are denoted by the number 1, and the number 2 - graphs of tangential stresses, which reach a significant value in the area of rigid clamping. At the junction of cylindrical and rectilinear sections on the inner surface there is a marked decrease in the value of $\sigma^{2'2'}$, and on the outer - an increase. It should be noted that the flange thickness has little effect on the distribution of both normal and tangential stresses on cylindrical surfaces.

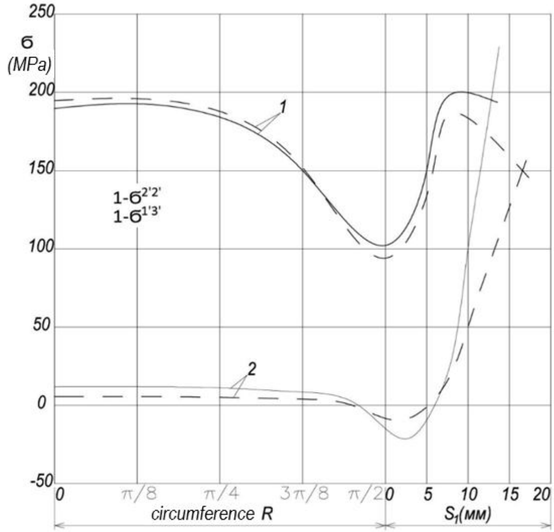


Fig. 9. Distribution of annular stresses along the inner contour of the detail

Thickening of the flange causes a decrease in $\sigma^{2'2'}$ and $\sigma^{3'1'}$ in the region of their maximum values on the inner circuit and some increase in compressive ring stresses in the area of braking. In general, the use of the flange № 2 did not lead to any significant change in the picture of the stress-strain state in areas not adjacent to the rigid foundation.

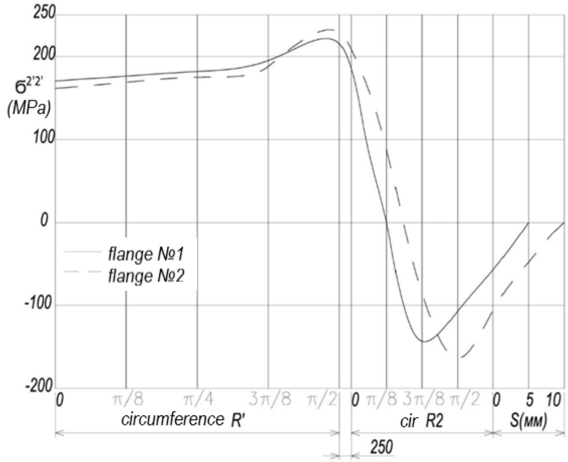


Fig. 10. Distribution of annular stresses along the outer contour of the detail

Conclusion. Thus, the thickening of the flange has reduced the intensity of plastic deformations in the hazardous area and with this design solution, the maximum level of plastic deformations for all three zones of plasticity is the same. It should also be noted that the use of a thickened flange allowed to localize the zone of plasticity and its length in this case does not exceed half the length of the bell.

In this case, the additional cost of material for the manufacture of thickened flange is fully justified. This reduces the level of plastic deformations and stresses in the hazardous area and ensures the extension of the service life of the casing detail.

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

ДОСЛІДЖЕННЯ ВПЛИВУ ТОВЩИНИ ФЛАНЦЯ НА ХАРАКТЕР РОЗВИТКУ ЗОН ПЛАСТИЧНОСТІ В КОРПУСНІЙ ДЕТАЛІ

В роботах [11, 15, 18] реалізовано розв'язувальні співвідношення та алгоритм методу блочних ітерацій розв'язання лінійних і нелінійних рівнянь напіваналітичним методом скінчених елементів для криволінійних неоднорідних призматичних тіл. У роботі [1] виконано чисельне дослідження збіжності розв'язання, розглянуто широке коло тестових задач для тіл з плавно і стрибкоподібно мінливим фізичними та геометричними характеристиками в пружній та пружно-пластичній постановці. В [21] для підтвердження достовірності одержуваних

результатів на основі напіваналітичного методу скінчених елементів, показано ефективність застосування даного підходу для розрахунку криволінійних неоднорідних призматичних об'єктів. Розв'язання контрольних задач теорії пружності, термопружності та термопластичності, а також задач формозміни дає можливість зробити висновок про достовірність результатів дослідження виділеного класу об'єктів на базі розробленої методики та реалізує її пакет прикладних програм.

В даній роботі використовуючи методику викладену в наведених вище роботах було виконано чисельний аналіз напружено-деформованого стану просторового об'єкту, а саме дослідження впливу товщини фланця на характер розвитку зон пластичності в корпусній деталі. Слід відзначити, що застосування потовщеного фланця дозволило локалізувати зону пластичності і її довжина в цьому випадку не перевищує половини довжини розтруба. У цьому випадку додаткова витрата матеріалу на виготовлення потовщеного фланця цілком виправдана. Це призводить до зниження рівня пластичних деформацій та напружень у небезпечній області та забезпечує продовження терміну служби корпусної деталі.

Ключові слова: метод скінчених елементів (МСЕ), напіваналітичний метод скінчених елементів (НМСЕ), напружено-деформований стан, пружне та пружно-пластичне деформування, криволінійні призматичні тіла, фланець, зони пластичності, корпусна деталь.

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

INVESTIGATION OF THE INFLUENCE OF FLANGE THICKNESS ON THE NATURE OF DEVELOPMENT OF PLASTIC ZONES IN THE CASING DETAIL

In papers [11, 15 18] the solution relations and the algorithm of the method of block iterations of solving linear and nonlinear equations by the semivanalytic finite element method for curvilinear inhomogeneous prismatic bodies are realized. In paper [1], a numerical study of the convergence of solutions was performed, and a wide range of test problems for bodies with smoothly and abruptly changing physical and geometric characteristics in elastic and resilient-plastic formulation was considered. In paper [21], to confirm the reliability of the results obtained on the basis of the semi-analytical finite element method, the effectiveness of this approach for the calculation of curvilinear inhomogeneous prismatic objects is shown. Solving control problems of the theory of elasticity, thermoelasticity and thermoplasticity, as well as problems of shape change makes it possible to draw conclusions about the reliability of the results of the study of a selected class of objects based on the developed methodology and implements its application package.

In this work, using the method described in the above works, a numerical analysis of the stress-strain state of a spatial object was performed, namely the study of the influence of flange thickness on the nature of the development of plasticity zones in the casing detail. It should be noted that the use of a thickened flange allowed to localize the zone of plasticity and its length in this case does not exceed half the length of the bell. In this case, the additional cost of material for the manufacture of thickened flange is fully justified. This reduces the level of plastic deformations and stresses in the hazardous area and prolongs the life of the casing detail.

Keywords: finite element method (FEM), semi-analytical finite element method (SAFEM), stress-strain state, elastic and elastic-plastic deformation, curvilinear prismatic bodies, flange, plasticity zones, the casing detail.

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Максим'юк Ю.В., Чуприна Ю.А., Козак О.В., Мартинюк І.Ю., Максим'юк О.В. **Дослідження впливу товщини фланця на характер розвитку зон пластичності в корпусній деталі.** // Опір матеріалів і теорія споруд: наук.-тех. збірн. – Київ: КНУБА, 2022. – Вип. 108. – С. 97-106.

В даній роботі, використовуючи методику викладену в попередніх роботах, було виконано чисельний аналіз напружено-деформованого стану просторового об'єкту, а саме дослідження впливу товщини фланця на характер розвитку зон пластичності в корпусній деталі.

Іл. 10. Бібліогр. 21 назв.

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Maksimyuk Yu.V., Chuprina Yu.A., Kozak O.V., Martyniuk I.Yu., Maksimyuk O.V. **Investigation of the influence of flange thickness on the nature of the development of zones of plasticity in casing detail** // Resistance of materials and theory of structures: scientific and technical collection. – Kyiv: KNUBA, 2022. – Issue. 108. – P. 97-106.
In this work, using the method described in previous works, a numerical analysis of the stress-strain state of a spatial object was performed, namely the study of the influence of flange thickness on the nature of the development of zones of plasticity in the casing detail.
Fig. 10. Ref. 21.

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Максимюк Ю.В., Чуприна Ю.А., Козак А.В., Мартынюк И.Ю., Максимюк А.В. **Исследование влияния толщины фланца на характер развития зон пластичности в корпусной детали**// Сопротивление материалов и теория сооружений: науч.-тех. сборн. – К.: КНУСА, 2022. – Вып. 108. – С. 97-106.
В данной работе, используя ранее изложенную методику, был выполнен численный анализ напряженно-деформированного состояния пространственного объекта, а именно исследование влияния толщины фланца на характер развития зон пластичности в корпусной детали.
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