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COMPUTATIONAL DESIGN OF NONLINEAR STRESS-STRAIN OF ISOTROPIC MATERIALS

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***Abstract**. The article deals with the problems of numerical modeling of nonlinear physical processes of the stress-strain state of structural elements. An elastoplastic medium of a homogeneous solid material is investigated. The results of computational experiments on the study of the process of physically nonlinear deformation of isotropic elements of three-dimensional structures with a system of one- and double-periodic spherical cavities under uniaxial compression are presented. The influence and mutual influence of stress concentrators in the form of spherical cavities, vertically located two cavities and a horizontally located system of two cavities on the deformation of the structure are investigated. Numerical algorithms have been developed for solving the problems of physically nonlinear deformation of structures made of structural materials, which make it possible to effectively use the capabilities of computer technology. The optimal parameters of computational experiments on the construction and calculation of structures made of fibrous composite materials using a specialized software package have been determined.*
***Keywords**: modeling, elastoplastic, stress, strain,reliability,plasticity,structural elements,cavity.*

***Аннотация.** Мақолада конструкция элементларининг кучланишли-деформацияланиш ҳолатларидаги ночизиқли физикавий жараёнларини сонли моделлаштириш масалалари кўриб чиқилган. Бир жинсли қаттиқ материалнинг эгилувчан-пластик муҳити тадқиқ этилган. Бир ўқли сиқилишда бир ва икки даврий сферик бўшлиқлар тизимига эга уч ўлчамли конструкцияларнинг изотроп элементларини физик ночизиқли деформацияланиш жараёнини тадқиқи бўйича ҳисоблаш элементларининг натижалари келтирилган. Сферик бўлиқлар, вертикал жойлашган иккита бўшлиқ ва горизонтал жойлашган икки бўлиқлар шаклидаги кучланиш концентраторларини конструкциялар деформациясига таъсири ва ўзаротаъсири тадқиқ этилган. Коструқцион материаллардан тайёрланган конструкцияларнинг жисмоний ночизиқли деформацияланиш масалаларини ечишнинг ҳисоблаш техникасини имкониятларидан самарали фойдаланиш имконини берадиган сонли алгоритмлари ишлаб чиқилган. Толали композицион материаллардан конструкциялар қуриш ва ҳисоблаш бўйича ҳисоблаш тажрибаларининг оптимал параметрлари махсус дастурий мажмуалардан фойдаланиб аниқланган.*
***Таянч сўзлар:** моделлаштириш, эгилувчан-пластиклик, кучланиш, деформация, ишончлилик, пластиклик, конструкция элементлари, бўшлиқ.*

***Аннотация.** Рассматриваются вопросы численного моделирования нелинейных физических процессов напряженно-деформированного состояния элементов конструкций. Исследована упругопластическая среда однородного твердого материала. Приведены результаты вычислительных экспериментов по исследованию процесса физически нелинейного деформирования изотропных элементов трехмерных конструкций с системой одно- и двупериодических сферических полостей при одноосном сжатии. Исследовано влияние и взаимовлияние концентраторов напряжений в виде сферических полостей, вертикально расположенных двух полостей и горизонтально расположенной системы из двух полостей на деформацию конструкции. Разработаны численные* *алгоритмы решения задач физически нелинейного деформирования конструкций из конструкционных материалов, позволяющие эффективно использовать возможности вычислительной техники. Определены оптимальные параметры вычислительных экспериментов по построению и расчету конструкций из волокнистых композиционных материалов с использованием специализированного программного комплекса.*

Ключевые слова: *моделирование, упругопластичность, напряжение, деформация, надежность, пластичность, элементы конструкции, полость.*

Introduction

Numerical modeling and study of strain processes of spatial structural elements with cavities or recesses are one of the urgent problems of calculating the strength and reliability of the construction of structures, mechanisms and machines. This is connected with conservation of used materials that have various physical and mechanical characteristics, on maintaining the strength of structures under the influence of external force factors. Problem of calculation of structural elements is reduced to solving three-dimensional problems of the theory of elasticity and plasticity, described by a system of partial differential equations with the corresponding boundary conditions. It is known that the analytical solution of this kind of problems is possible only in individual special cases, moreover in highly idealized simplified formulations. Therefore, an emphasis is placed on the search and development of various approximate, numerical, numerical-analytical methods. Various simplifications of the initial assumptions and mathematical models are applied, the solutions of which would satisfy the given constraints and requirements for the solution accuracy. Therefore various hypotheses are accepted, which are justified by experimental and practical results [1].

Research in this direction, for instance, has been carried out by many authors, in particular, when solving problems related to the calculation of elastic and elastoplastic bodies with a cavity or a recess under the action of various loads [2]. With this in mind, there is a wide area of application and a practical need for solving problems associated with calculating the stress state of spatial structural elements. More and more requirements for increasing accuracy and minimizing costs, while an increasing of the reliability of the calculated structural elements. It requires modeling and solving these problems in an elastoplastic formulation. Taking into account plastic strains, makes it possible to more accurately determine the actual stress-strain state of the body and thus allows you to reasonably choose the parameters of structures [3].

The strain theory of plasticity is most often used to solve practical problems. One of the effective methods for solving physically nonlinear problems of mechanics of a deformable solid, based on the theory of small elastoplastic strains, is the method of elastic solutions proposed by AA Ilyushin [4].

Moreover a large number of studies are devoted to the applicability of the theory of small elastoplastic strains, the method of elastic solutions, the existence and uniqueness of the solution of boundary value problems of equilibrium of elastoplastic bodies under active strain and convergence of various iterative processes [5].

Studies of the nature of the numerical convergence of the method of elastic solutions and its modifications for static problems of thin plates, shells and spatial structures are given in [6]. Likewise, in papers [7] generalizations and modifications of the method of elastic solutions are given. The research shown in [8] consider the numerical implementation of the method of elastic solutions and methods of using numerical methods to solve problems of elasticity and plasticity.

The study of the elastoplastic state of oblique and rectangular massifs under the influence of uniformly distributed surface loads is the subject of works [9, 10]. The problem is solved by the variation-difference method. The development of plastic zones is investigated depending on the type of applied surface load. In [11], solutions of specific problems of the theory of plasticity in prismatic domains of rectangular cross-section are presented and the numerical convergence of the method of elastic solutions in problems of constrained torsion is investigated.

Analysis of the above works shows that, studies of the elastic and elastoplastic state of structural elements are mainly devoted to the classical configuration. However, real structural elements are three-dimensional bodies with geometric features that are often used in the design of various structures. Therefore, the requirements for reliability and efficiency make it necessary to take into account the presence of cavities and recesses, which, in terms of strength, are the cause of the appearance of zones of increased stress [12-14].

In paper the results of computational experiments of physically nonlinear strain process study of isotropic elements of three-dimensional constructions with a system of one - and doubly periodic spherical cavities under uniaxial compression are presented. The influence of a cavities system on the stress state of constructions is studied.

Research Methods

A certain body of volume V is considered in the Cartesian coordinate systems (X,Y,Z), which is bounded by the surface $S(S_u, S_p)$ and is determined by elastic and elastoplastic characteristics. Suppose the displacement S_u is given $(U)_{S_u} = (u_0, v_0, w_0)'$, and on S_p - surface load. Volumetric forces can also be specified $(O_H) = (X,Y,Z)'$.

A mathematical model that describes static problems for elastic and elastoplastic bodies with respect to components:

stress tensor - $(\sigma) = (\sigma_x, \sigma_y, \sigma_z, \tau_{xy}, \tau_{yz}, \tau_{zx})'$,

strains - $(\varepsilon) = (\varepsilon_x, \varepsilon_y, \varepsilon_z, \gamma_{xy}, \gamma_{yz}, \gamma_{zx})'$,

displacement - $(U) = (u, v, w)'$,

is represented by the following relations:

equilibrium equations $[A_g]'(\sigma) + (O_H) = 0;$ (1)

physical laws $(\sigma) = [D](\varepsilon)$; (2)

geometric relationships $(\varepsilon) = [A_g](U);$ (3)

border conditions $[A_k]'(\sigma) = (P_H).$ (4)

Based on the theory of small elastoplastic strains [4], the physical laws for an elastoplastic body can be represented as:

$$(\sigma) = [D](\varepsilon) - [\overline{D}]\omega(\varepsilon) \tag{5}$$

where $(\ )'$- transposition;

$$[A_g] = \begin{bmatrix} \partial/\partial x & 0 & 0 \\ 0 & \partial/\partial y & 0 \\ 0 & 0 & \partial/\partial z \\ \partial/\partial y & \partial/\partial x & 0 \\ 0 & \partial/\partial z & \partial/\partial y \\ \partial/\partial z & 0 & \partial/\partial x \end{bmatrix}; \qquad [A_k] = \begin{bmatrix} \cos(n,x) & 0 & 0 \\ 0 & \cos(n,y) & 0 \\ 0 & 0 & \cos(n,z) \\ \cos(n,y) & \cos(n,x) & 0 \\ 0 & \cos(n,z) & \cos(n,y) \\ \cos(n,z) & 0 & \cos(n,x) \end{bmatrix};$$

$$[D] = [\overline{D}] + [\overline{D}]; \tag{6}$$

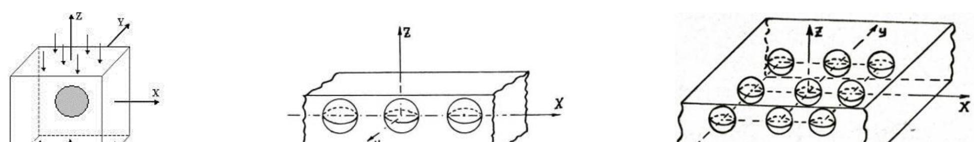
$$[\overline{D}] = \begin{bmatrix} 1 & 1 & 1 & 0 & 0 & 0 \\ 1 & 1 & 1 & 0 & 0 & 0 \\ 1 & 1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \frac{E}{3(1-2\mu)}; \qquad [\overline{\overline{D}}] = \begin{bmatrix} 4/3 & -2/3 & -2/3 & 0 & 0 & 0 \\ -2/3 & 4/3 & 1 & 0 & 0 & 0 \\ -2/3 & -2/3 & 4/3 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \frac{E}{3(1+\mu)};$$

$$\omega(\varepsilon)=\begin{cases}0, & if \quad \varepsilon_i \le \varepsilon_s \\ \bar{\lambda}\cdot\left(1-\frac{\varepsilon_s}{\varepsilon_i}\right), & if \quad \varepsilon_i > \varepsilon_s\end{cases}$$ - the plasticity function of A.A.Ilyushin,

where $\bar{\lambda}=\left(1-\frac{E_k}{E}\right)$ - is the hardening parameter;

$\varepsilon_i=\frac{\sqrt{2}}{3}\sqrt{(\varepsilon_x-\varepsilon_y)^2+(\varepsilon_y-\varepsilon_z)^2+(\varepsilon_z-\varepsilon_x)^2+3/2({\gamma_{xy}}^2+{\gamma_{yz}}^2+{\gamma_{zx}}^2)}$ - intensity of strains; ε_s - yield point; μ - Poisson's ratio; E - Young's modulus.

Problem 1. Isotropic bodies in idle cube form with isolated cavity with r-radius in the center, in the form of an endless rod of square section with one-periodical cavities system and infinite plate of unique thickness with doubly periodical cavities system under uniformly-distributed uniaxial compression along the OZ -axis (fig. 1) are considered. Inner surfaces of cavities are free from load.



a *b* *c*

Figs. 1(a)-(c). ***Location of cavities in constructions.***

This problem is solved using following geometrical and mechanical characteristics: $P_{zz}=-140MPa$; $\varepsilon_s=0.85\cdot10^{-3}$; $E=2\cdot10^5 MPa$; $\mu=0.3$; $\bar{\lambda}=0.3$; r = {0.1, 0.2}. Hereinafter all linear dimensions are given relative to the unit size plate.

Received Results and Discussion

Comparing values of elastic displacement while $r=0.1$ (Table 1), we can say that in an infinite rod compression case - maximum values of strain intensity is 12% less than in the case with the isolated cavity, and 25% less than in the case with plate (at the cross points of horizontal section of the cavity with the diametrical OX-axis). For elastic-plastic problems solution the corresponding values amounts are decreasing to about 25%.

Table 1.

Values of stresses-strains intensity

Type of problem	Component	Isolated cavity	One-periodical cavities system	Doubly periodic system of cavities
elastic	σ_i / E	$1.29*10^{-3}$	$1.13*10^{-3}$	$0.963*10^{-3}$
	ε_i	$1.29*10^{-3}$	$1.13*10^{-3}$	$0.963*10^{-3}$
plastic	σ_i / E	$1.03*10^{-3}$	$0.868*10^{-3}$	$0.874*10^{-3}$
	ε_i	$1.13*10^{-3}$	$0.845*10^{-3}$	$0.838*10^{-3}$

Fig.2 illustrates boundaries of plastic zones around cavities at $r=0.2$. For a cube with isolated cavity zone has a shape of “mustache” spearhead of which indicates the direction of its propagation (fig.2.a). In the case of rod - boundary of plastic strain zone follows the contours of cavity and is concentrated in the immediate cavity vicinity (fig.2.b). In this case, the influence each other of neighboring cavities located along the OX- axis is clearly expressed. A narrow strip of plastic strain zone encircling the vicinity of the cavity horizontal diametric section is the result of solving the problem of compression plate with the system of doubly periodic cavities (fig.2.c).

Figs. 2(a)-(c). ***The zone of plasticity in XOZ- cross section.***

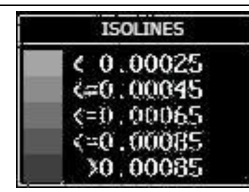
Here the strain field's imposition is clearly seen along as the OX-axis as well as along OY- axis. In the zones between cavities a vast elastic area of all-round compression is formed, which prevents the spread of plastic strain. Thus, it can be said that the doubly periodic arrangement of cavities in the constructions is optimal.

Further, construction in the plate form with dimension of height 1.0, which is uniaxial stretched along the OZ-axis by uniformly distributed load of $R_{zz}=850MPa$ is considered (plate width – 0.5 and thickness – 0.1). Mechanical parameters of an isotropic material are defined as follows: $E=2\cdot10^5 MPa$, $\varepsilon_s=0.85\cdot10^{-3}$, $\mu=0.3$, $\bar{\lambda}=0.5$.

Computer experiment on the study of various stress concentrators effect is held. Suppose that holes have a circular shape of radius $r=0.05$, and the length of straight crack in the center – 0.1 (fig. 3). Analysis of results of the elastic problems (Table 2) confirm the emergence of unload effect in establishing additional holes. Successful arrangement of concentrators reduces stress concentration and unloads the danger zones of construction. Establishing two vertically spaced holes instead of one reduces the maximum of stress intensity by 10%.

Table 2.

Elastic values of stress intensities

Concentrator	$\sigma_i / E\cdot10^3$	$K=\sigma_i/\sigma_{nom}$	
Isolated cavity	1.26	2.967	
Two vertical cavities	1.13	2.690	
Two vertical cavities with crack in center	1.09	2.565	

The presence of the central horizontal rectilinear crack between the holes helps to further vicinities' unloading of stress concentrators, and decreasing of stress intensity reaches to about 14%. Table 3 shows the maximum values of elastic-plastic stress state of components, and intensity of stress-strains in the presence of concentrators.

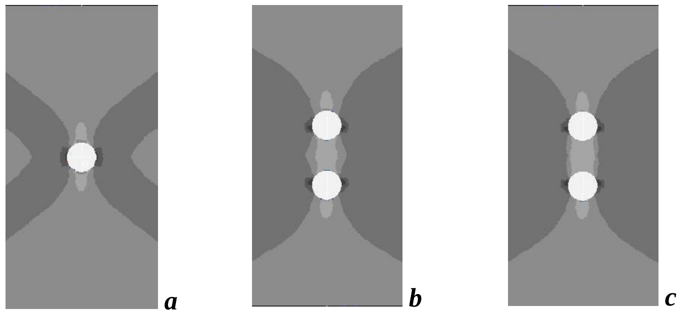
Table 3.

The maximum values of the stress-strain components

Concentrator	$\sigma_{xx} / E\cdot10^4$	$\sigma_{zz} / E\cdot10^3$	$\tau_{xz} / E\cdot10^4$	$\sigma_i / E\cdot10^3$	$\varepsilon_i\cdot10^3$
isolated cavity	9.451	1.634	-0.121	1.010	1.086
two vertical cavities	7.099	1.565	-1.643	1.048	1.153
two vertical cavities with crack in center	5.759	1.511	-1.839	1.064	1.203

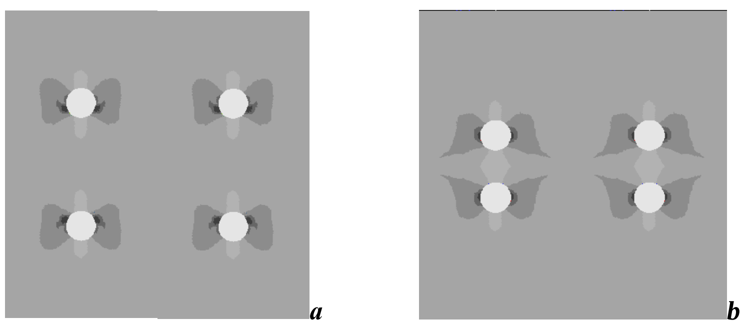
The presence of isolated cavity leads to appearance of plastic strain in areas located on lateral parts of the cavity (fig.3.a). The areas located in the vicinity of upper and lower parts of cavities are unloaded. The presence of two vertically spaced holes increases the size of the areas with high strain; the plastic zones are concentrated and shifted to the center of the plate (figs.3.b, c). This is due to a sharp increasing of tangential stress τ_{xy} of component (Table 3). Areas located at the sides of cavities and between them are unloaded.

In order to investigate the influence of cavities on the stressed state of the construction elements the uniaxial tension along the OZ -axis of infinite rectangular strip of width -1.0 with the system of pair vertically spaced circular cavities are considered. The thickness of the strip is 0.1. The radius of holes is $r = 0.05$, the distance between the cavities horizontally is $l = 0.5$.



Figs.3(a)-(c). ***the distribution of the strain intensity ε_i values.***

The problem is solved with $h = 0.4$ and $h = 0.2$, where h - the distance between the centers of cavities vertically. Presence of cavities horizontally leads to formation of areas with all-round stretching at the sides of cavities. Thus, when $h = 0.4$ (fig.4.a.) the local areas of high stress in side parts vicinities of cavities in shaped like "ears" are formed.



Figs. 4(a)-(b). ***Mutual effect of cavities system (fragments).***

Areas with plastic strain, with “petal-look” configuration, are located in vicinity of lower side parts of the cavities. Mutual effect of cavities vertically is nominal and horizontally - leads to decreasing of maximum stress values by 10%. Decreasing value of h in 2 times ($h = 0.2$) leads to localization of increased strain in vicinity of the side parts of cavities and is associated with the presence of cavities in the horizontal direction. Changing the configuration of the plastic areas is associated to the mutual influence of vertical cavities and decreasing distance between them (fig.4.b).

Problem 2.

In order to study the effect of grooves with different sectional shapes located on the outer surface of the body or on the face, the case is considered when the cavity is located in the middle of the lateral edges of a unit cube (fig. 5). The cube is under the action of uniformly distributed compressive loads along the OZ axis.

Taking into account this formulation of the problem, the 1/8 part of the body is considered (fig. 6, where the coordinate axes x ', y' are shifted in parallel) with the following boundary conditions:

on the XOY plane at $Z=\frac{1}{2}$: $\tau_{xz}=\tau_{yz}=0$; $\sigma_{zz}/E=q$;

at $Z=0$: $\tau_{xz}=\tau_{yz}=0$; $w=0$;

on the YOZ plane at $X=\frac{1}{2}$: $u=0$; $\tau_{yx}=\tau_{zx}=0$;

at $X=0$: $\sigma_{xx}=\tau_{yx}=\tau_{zx}=0$;

on the XOZ plane at $Y=\frac{1}{2}$: $\tau_{xy}=0$; $v=0$; $\tau_{zy}=0$.

at $Y=0$: $\tau_{xy}=\sigma_{yy}=\tau_{zy}=0$;

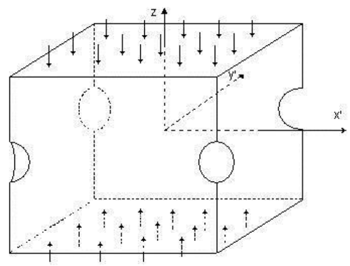


Fig. 5. ***The body is in the form of a cube with notches in the middle of the lateral ribs.***

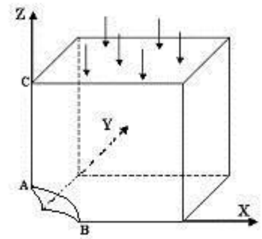


Fig. 6. ***One eighth of the body.***

The recess surfaces are free of stress. As physical and geometric characteristics, the following values are used:

$$E=2\cdot 10^5 MPa;\ \mu=0.3;\ \bar{\lambda}=0.5;\ P_{zz}=160\,MPa;\ \varepsilon_s=0.00085;$$

$$-0.5\le x'\le 0.5,\quad -0.5\le y'\le 0.5,\quad -0.5\le z\le 0.5\cdot$$

When solving the problem along the faces (NS) and along the coordinate axes (NP), the following partitions were used: NS = 8; NP = 5 and the order of the system of algebraic equations is N = 1098. Small finite elements were used in the vicinity of the cut.

Table 4.

Convergence of the iteration method for r_3 = 0.2.

Iteration number	$\varepsilon_i\cdot 10^2$	$(\sigma_i/E)\cdot 10^2$	$(\sigma_{zz}/E)\cdot 10^2$
0	0.11390	0.11390	-0.11764
1	0.11119	0.09814	-0.10045
2	0.11125	0.09884	-0.10976
4	0.11131	0.09907	-0.10967
5	0.11174	0.09925	-0.10903
6	0.11169	0.09923	-0.10953
7	0.11165	0.09922	-0.10956

Table 5.

Influence of the radius r_3 on the stress-strain state.

r_3	$\varepsilon_i\cdot 10^2$	$(\sigma_i/E)\cdot 10^2$	$(\sigma_{zz}/E)\cdot 10^2$
0.0125	0.26360	0.17445	-0.31342
0.0250	0.22433	0.15526	-0.26413
0.0500	0.18054	0.13400	-0.20385
0.1000	0.14090	0.11444	-0.14670
0.2000	0.11165	0.09922	-0.10956
0.3000	0.09995	0.09305	-0.09871
0.3500	0.09670	0.09151	-0.09689

Table 4 shows the values of displacements, the intensity of deformations and stresses at the point of the beginning of plasticity B. The convergence of the process in table.1 is achieved at n=5, where the results of strain and stress intensity coincide up to two to three significant digits. Moreover, this coincidence is achieved approximately at n = 3 or n=4, and a further increase in iteration in the method of elastic solutions of A.A. Ilyushin leads to the refinement of the fourth and fifth significant digits. Table 5 shows the values of displacement, strain rates and stresses depending on the radius of the cavity.

Analysis of the results shown in table 5 shows that with an increase in the curvature of the cavity, the displacements of the point of onset of plastic deformations decrease, and the corresponding intensities of deformations and stresses increase. This indicates that with a decrease in the radius of the spheroid r_3, at the point of the beginning of plastic deformations, the maximum values of the intensity of deformations and stresses are concentrated. In fig. 7 shows the zones of plastic deformations, depending on the decrease in the height of the spheroid (r_3), and clearly demonstrates the concentration of the maximum values of the intensities of deformations and stresses in the vicinity of the equatorial zone of the cavity.

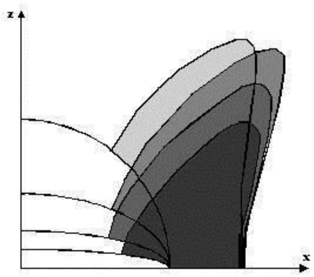


Fig.7. ***Change of the plastic zone depending on the decrease in the radius r_3.***

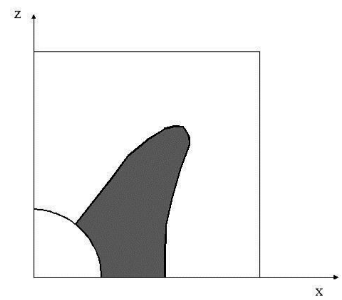


Fig.8. ***Location of the plastic zone in the vicinity of the cavity at r_3 = 0.15.***

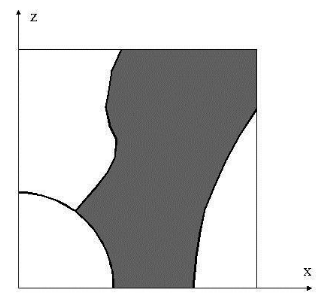


Fig. 9. ***Location of the plastic zone in the vicinity of the cavity at r_3 = 0.2.***

In order to study the influence of the dimensions of the spheroidal cavity on the stress state of the body, the distribution of the plastic zone is considered at the values of the radius of the cavity r = {0.15, 0.2}. The picture of the shape of the plastic zone at r = 0.1, i.e. in the case when the radius of the cavity is 1/5 of the body size, it is similar to the picture when the spherical cavity of the same dimension is located in the center of the body. In this case, the mutual influence of the grooves is not observed, and therefore a pattern similar to that when the cavity is in the middle of the body takes place. With an increase in the radius of the groove, for example, at r = 0.15, the zone of plastic deformation expands. That is, the zone is stretched along the diagonal, and in the area of the diametrical section there is a slight expansion of the plastic zone (fig. 8).

Further increase in radius, i.e. at r = 0.2, the zone of plastic deformation increases even more diagonally and reaches the middle part of the upper body surface (fig. 9). The elastic region encircles the central equatorial part of the body and has the shape of a cone, as well as the regions in the vicinity of the notches. The presence of an elastic region in the central part is explained by the presence of all-round compression in this part of the body. Compression occurs due to the mutual influence of grooves and prevents the appearance of plastic deformations (i.e., all-round compression occurs).

For a more visual representation of the appearance of a zone of plastic deformation, in figs. 10-11 for r = 0.2 at P_{zz} = 160 MPa, the location of the plastic zones in the sections Z = 0, 0.2 and 0.5 is shown. In the section Z = 0.2, an increase in the plasticity surface is observed, with the splicing of their surfaces, and the formation of an elastic zone at the center of the surface. It has the shape of a rhombus, the sides of which have a certain curvature. The tops of the rhombus are directed towards the lateral surface of the body. With an increase in the height of the section, the zone of elastic deformations narrows without changing its shape and disappears in the section Z = 0.35. Starting from this section, a picture is observed similar to the picture shown in fig. 12. The results obtained correctly reflect the physics of the ongoing process.

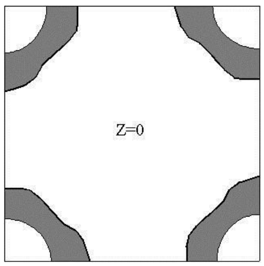


Fig. 10. ***Zones of plasticity in section Z = 0.***

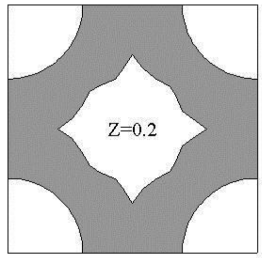


Fig.11. ***Plastic zone in section Z = 0.2.***

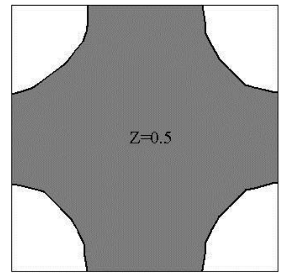


Fig. 12. ***Zone of plasticity in section Z = 0.5 (on the body surface).***

Thus, analysis of the results of computational experiments allows designing a rational structure of fiber composites, to determine placement of the structural holes and to reduce the concentration of stress in constructions.

Conclusion

- On the basis of finite element method and the theory of small elastic-plastic deformations for a transversely isotropic environment the numerical model, computational algorithms and software for three-dimensional problems of physically nonlinear deformation of structural materials are developed.
- The presence of doubly periodic system of spherical cavities in an infinite homogeneous thick plate provides the appearance of a narrow strip in the plastic deformation zone, encircling the neighborhood diametrical cross section of the cavities, and reduces the intensity of deformation by 11.8%, and the weight of the structure by 6.74%.
- In assessing the structural strength and reliability of constructions, application of finite element method, the simplified theory of small elastic-plastic deformations of transversely isotropic media and method of construction of the finite element mesh of a complex configuration leads to high performance of industrial processes.
- The degree of influence of grooves of various shapes on the ribs on the stress state of three-dimensional elastoplastic bodies was studied;
- The areas of the appearance and development of the zone of plastic deformations are established, depending on the elastoplastic, geometric and physical characteristics of the body under consideration, with geometric features.
- The numerical convergence of the method of elastic solutions is established, which depends on the values of the intensity of deformations and the specified yield point. With their sufficiently comparable values, the convergence of the process of the method of elastic solutions of A.A. Ilyushin is high, and when the intensity of deformations is several times higher than the yield point, the number of iterations increases accordingly.

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