MATHEMATICAL MODELING OF CALCULATION OF SPATIAL STRUCTURES UNDER VARIABLE LOADS

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ANNOTATION:

The technology for calculating the stress-strain state of elastoplastic bodies with a cavity or a cavity, using the developed software, is based on the ideas of algorithmization, computational experiment and modular programming.

Keywords. Elastic, plastic, deformation, tension, hardening-softening, cyclic.

Introduction:

In the use of many modern structures, the diffusion of materials into the plastic field occurs in their most loaded areas, which also leads to a number of additional effects under the influence of variable loads, such as the Baushinger effect, i.e. secondary plastic deformations; -shows softening and anisotropy, leads to deformation aging, accumulation of damage and the spread of cracking [1-5].

RESULTS AND DISCUSSION:

In the n-th half cycle of loading the stress tensor and deformation components $\sigma_{ij}^{(n)}$ and we define with $\varepsilon_{ij}^{(n)}$.

According to the equations of the theory of small elastoplastic deformations, the following relationship between stresses and strains under alternating loads occurs [2].

$$\bar{S}_{ij}^{(n)} = \frac{2\bar{\sigma}_u^{(n)}}{3\bar{\varepsilon}_u^{(n)}} \bar{Э}_{ij}^{(n)} \qquad (1)$$

$$\bar{\sigma}^{(n)} = K\bar{\theta}^{(n)}, \qquad (2)$$

$$\bar{\sigma}_u^{(n)} = \Phi\left(\bar{\varepsilon}_u^{(n)}\right) \qquad (3)$$

In the linear approximation of the deformation diagrams we obtain the following (3)

$$\omega^{(n)} = \begin{cases} 0, & \text{при } \bar{\varepsilon}_u^{(n)} \le \varepsilon_{sn} \\ \lambda_n\left(1 - \dfrac{\varepsilon_{sn}}{\bar{\varepsilon}_u^{(n)}}\right), & \text{при } \bar{\varepsilon}_u^{(n)} > \varepsilon_{sn} \end{cases} \qquad (4)$$

In the case of the generalized Mazing principle **l_n=l**, **e_{sn}=$a_n s_s$**, The scale coefficient is determined experimentally, and for hardening and softening materials can be expressed in the form of the following expression:

$$an=Q(n-1)k \qquad (5)$$

and also for cyclic anisotropic materials

$$\alpha_n = Q^*(n-1)^\kappa + \left\{\frac{Q-Q^*}{2} + (-1)^n \frac{Q-Q^*}{2}\right\}(n-1)^\kappa, \qquad (6)$$

where **Q, Q*, k** –is material changes.

When using Gusenkov-Schneiderovich deformation diagrams [4] **e_{sn}=2e_s**, **l_n=1–g_n**, here **g_n** is determined as follows:

for cyclic hardening materials

$$g_n = \left\{1 + \frac{A^*}{2G}\frac{1}{(n-1)^\alpha} + \frac{1}{2G(n-1)^\alpha}\left[\frac{A-A^*}{2} - (-1)^n \frac{A-A^*}{2}\right]\right\}^{-1}, \qquad (7)$$

for cyclic softening materials

$$g_n = \left\{1 + \frac{A^*}{2G}\exp[\beta(n-1)] + \frac{1}{2G}\exp[\beta(n-2)]\left[\frac{A-A^*}{2} - (-1)^n \frac{A-A^*}{2}\right]\right\}^{-1} \qquad (8)$$

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If the accumulated damage is taken into account, $\mathbf{l_n=l}$

$$\varepsilon_{sn} = \alpha_1^{n-2}(1+\alpha_1)\varepsilon_s + \frac{B^{1/\alpha}}{3G}\left[1-\frac{(1+\alpha_1)\alpha_1^{n-2}}{2}\right]\left[1-(1-\eta)^{1+\alpha}\right]^{1/\alpha}(n-1)^{-1/\alpha}, \tag{9}$$

The damage function is determined by the h-kinetic equation:

$$\frac{d\eta}{dn} = A\left(\bar{\sigma}_u^{(n)}\right)^{\alpha}(1-\gamma\eta)^{-\beta} \tag{10}$$

if **h(0)=0**, **h(N)=1**, where **N** is the number of half-cycles before the boundary condition (injury) occurs.

The equations given above include equilibrium equations, boundary conditions, and Cauchy relations:

if $\bar{\sigma}_{ij}^{(n)}$, $\bar{\varepsilon}_{ij}^{(n)}$ if found for any n, then the voltages $\sigma_{ij}^{(n)}$ and deformations $\varepsilon_{ij}^{(n)}$, sought are determined by the following formula:

$$\sigma_{ij}^{(n)} = \sigma'_{ij} + \sum_{k=2}^{n}(-1)^{k-1}\bar{\sigma}_{ij}^{(k)}, \quad \varepsilon_{ij}^{(n)} = \varepsilon'_{ij} + \sum_{k=2}^{n}(-1)^{k-1}\bar{\varepsilon}_{ij}^{(k)} \tag{11}$$

If Mazin's generalized principle is used, according to VV Moskvitin's theorem on variable loads [2], $\bar{\sigma}_{ij}^{(n)}$, $\bar{\varepsilon}_{ij}^{(n)}$ values are the corresponding values for the first boot $\mathbf{s_{ij}}$, $\mathbf{e_{ij}}$ is determined by the limit of their leakage $\mathbf{s_s}$ is to $\mathbf{a_n s_s}$ and external power is achieved by switching to $\mathbf{F'_i}$, $\mathbf{R'_i}$ $(-1)^{n-1}\left(F_i^{(n-1)} - F_i^{(n)}\right)$, $(-1)^{n-1}\left(R_i^{(n-1)} - R_i^{(n)}\right)$.

Provides automation of the process of stress-strain state of the spatial structure on the basis of the finite element method and the Ilyushin-Moskvitin method of elastic solutions using advanced software [3,6].

In the process of creating this system, the main focus was on the following principles:

1) The principle of a systematic approach;
2) Taking into account the prospects for the development of technical means of computer technology;
3) The principle of the optimal combination of design and automation of the user experience;
4) The principle of flexibility, stability and reliability;
5) The principle of creating algorithmic systems.

By the nature of the functions performed, management programs perform two groups of two operations:

1) the formation of logical operations and variable plastic problem associated with the input and analysis of operational data, which formalized a meaningful description of the problem;
2) numerical solution of boundary or optimization problems, the implementation of computer algorithms and the organization of the calculation of spatial structures on the state of stress-strain.

The operation of the control modules begins with filling in the order form and entering the operational data in their subsequent editing, followed by their editing. The order form has 9 sections in addition to the official user details:

1) -Calculation accuracy and established limitations;
2) - Geometry of the projected object .;
3) - The scheme of division of the object into blocks;
4) - Placement of load-bearing elements of each block;
5) - Operating mode of each load-bearing element;
6) - The material of the supporting element;
7) -Mechanical properties of the material of each load-bearing element;
8) - External forces applied to the load-bearing element;
9) - Boundary conditions of the load-bearing element.

An example of the application of the software package is the analysis of the stress-strain state of a right-angled parallelepiped as a console and a hollow right-angled parallelepiped as an example [4].

The problem is solved by the method of finite elements, the division of the considered area into pieces is solved by means of is oparo metric finite elements in the form of octagonal hexagons. The sampling parameters and the characteristics of the system of linear algebraic equations are determined by the following values: number of finite elements-1000, number of nodes-1331, system order-3993, half-width of the tape-402, number of divisions along the axes -11,11,11.

Figure 1 shows three types of elastic-plastic spheres: elastic, incomplete, and complete plastic, when the number of cycles is k = 1,3,5,9, and the coordinate points are x = 2.5, u = 10, and z = 40.

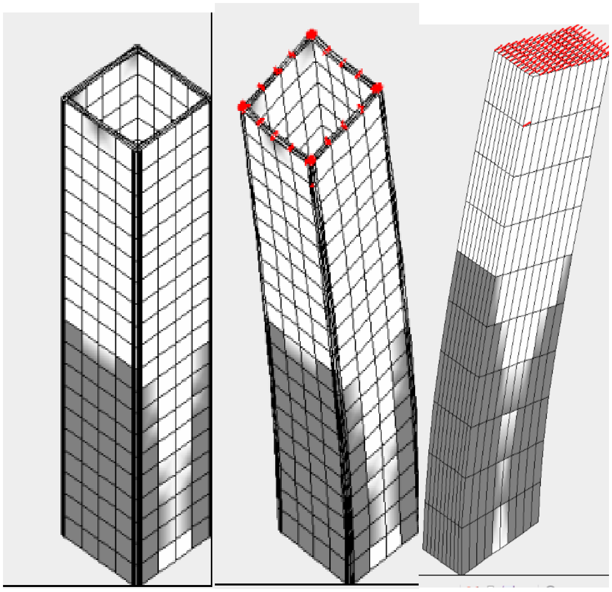

Figure 1 (- elastic, - incomplete, and - complete plastic)

For comparison, Table 1.2 shows the maximum values of the values calculated for the parallelepiped, respectively, according to the generalized Mazing principle and the generalized Gusenkov-Schneiderovich cyclic deformation diagram..

According to the generalized Mazing-Moskvitin principle (B-96) Table

К	α_k	$\overline{v}^{(k)}$	$\overline{w}^{(k)}$	$\overline{\sigma}_x^{(k)}$	$\overline{\sigma}_y^{(k)}$	$\overline{\sigma}_z^{(k)}$	$\overline{\sigma}_u^{(k)}$
1	1	-0,61749	0,10211	4518,0	4524,8	6618,9	2322,7
2	2,080	1,11973	-0,18588	-8345,8	-8355,1	-12631,3	4734,0
3	2,140	1,03414	-0,17241	-7807,1	-7813,1	-12154,1	4798,5
4	2,190	1,03414	-0,17241	-7807,1	-7813,1	-12154,1	4798,5
5	2,220	0,94482	-0,15849	-7191,6	-7194,0	-11631,0	4894,9
6	2,240	0,91737	-0,15422	-7007,7	-7008,9	-11467,8	4916,0
7	2,260	0,89819	-0,15124	-6871,6	-6871,8	-11356,7	4941,8
8	2,279	0,88073	-0,14853	-6744,9	-6744,2	-11254,0	4966,5
9	2,290	0,87094	-0,14702	-6672,4	-6671,0	-11195,5	4980,8

К	$v^{(k)}$	$w^{(k)}$	$\sigma_x^{(k)}$	$\sigma_y^{(k)}$	$\sigma_z^{(k)}$
1	-0,50224	0,08377	3827,9	3830,3	6012,4
2	0,53190	-0,08864	-3979,2	-3982,7	-6141,7
3	-0,50224	0,08377	3827,9	3830,3	6012,4
4	0,44258	-0,07472	-3363,7	-3363,6	-5618,5
5	-0,47479	0,07950	3644,0	3645,3	5849,3
6	0,42340	-0,07174	-3227,6	-3226,5	-5507,4
7	-0,45733	0,07679	3517,3	3517,7	5746,6
8	0,41362	-0,07023	-3155,1	-3153,4	-5448,9

According to the generalized Gusenkova - Shneyderovich principle (B-96) Table 2

К	λ_k	$\overline{v}^{(k)}$	$\overline{w}^{(k)}$	$\overline{\sigma}_x^{(k)}$	$\overline{\sigma}_y^{(k)}$	$\overline{\sigma}_z^{(k)}$	$\overline{\sigma}_u^{(k)}$
1	0,950	-0,61749	0,10211	4518,0	4524,8	6618,9	2322,7
2	0,920	1,03933	-0,17390	-7815,7	-7820,2	-12207,4	4845,1
3	0,897	0,94285	-0,15901	-7170,3	-7170,2	-11675,2	4962,2
4	0,881	0,90013	-0,15247	-6860,0	-6857,6	-11442,8	5043,0
5	0,868	0,86544	-0,14714	-6615,2	-6611,0	-11250,2	5096,6
6	0,858	0,84610	-0,14418	-6469,4	-6464,1	-11147,9	5141,7
7	0,848	0,82853	-0,14149	-6335,4	-6329,0	-11055,6	5184,8
8	0,840	0,81076	-0,13875	-6210,1	-6202,7	-10955,1	5209,6
9	0,833	0,80062	-0,13720	-6130,5	-6122,5	-10903,4	5238,4

К	$v^{(k)}$	$w^{(k)}$	$\sigma_x^{(k)}$	$\sigma_y^{(k)}$	$\sigma_z^{(k)}$
1	0.61749	-0.10211	-4518.0	-4524.8	-6618.9
2	-0.42184	0.07179	3297.7	3295.4	5588.6
3	0.52101	-0.08723	-3872.6	-3874.8	-6086.6
4	-0.37912	0.06525	2987.4	2982.8	5356.2
5	0.48632	-0.08189	-3627.8	-3628.2	-5894.1
6	-0.35978	0.06229	2841.6	2835.9	5253.9
7	0.46875	-0.07920	-3493.8	-3493.2	-5801.7
8	-0.34201	0.05955	2716.4	2709.6	5153.4
9	0.45861	-0.07765	-3414.2	-3412.9	-5750.0

The calculation was performed with the following data: $\alpha = 0{,}4$, $\grave{A}^* = 1{,}15$, G_T=0,05, Q=2,02, ǽ=0,03. The construction material is D-16T cyclic reinforced aluminum alloy.

The conditions for the emergence of secondary, tertiary and other plastic fields are as follows $\overline{\sigma_u^{(k)}} \geq \alpha_n \sigma_s$, where α_n is is the scale coefficient.

CONCLUSION:

Comparing the calculated values, we confirm experimentally [2] that the difference between the results obtained from the two diagrams of cyclic deformation is small (about 5-10%) and reflect the main properties and characteristics of low cyclic load resistance of structural elements, taking into account hardening-softening and cyclic anisotropy [5-6].

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