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THE IDENTIFICATION OF MATERIAL PARAMETERS IN NONLINEAR DEFORMATION MODELS OF METALLIC-PLASTIC CYLINDRICAL SHELLS UNDER PULSED LOADING

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Abstract. A method of identification of material parameters in defining relations of elastic deformation of composite materials is developed based on the minimization of disagreement between experimental data and the results of numerical analysis of the dynamic behavior of double-layered metallic-plastic cylindrical shells under explosive loading.

1. Introduction

Any progress in designing modern engineering structures is only possible with the use novel composite materials. However, their use is hampered by certain difficulties connected with the lack of comprehensive and reliable data on deformational and strength characteristics of such materials, required for equipping mathematical models used in strength analyses.

One of the methods of determining parameters of models of physical correlations of composite materials is directly using experimental information obtained from loading structural elements made of the materials in question. Such identification methods were used in a number of works for determining effective elastic characteristics of composite materials, based on the results of computational-experimental analysis both for statically [1] and dynamically [2] loading structural elements made of homogeneous composite materials. The present work is an extension of these studies, aimed at determining elastic deformation characteristics of composite materials based on experimentally and theoretically investigating the dynamic behavior of inhomogeneous metallic-plastic structural elements under pulsed loading.

2. Formulation of the identification problem

Let there exist a numerical solution of an axisymmetric problem of non-stationary deformation of a metallic-plastic cylindrical shell in the form of circumferential and longitudinal deformations on the outer surface of the shell as a function of time. And let there exist the corresponding deformation tensograms obtained in experimental tests. As the computed and experimental deformation oscillograms are assumed to be mono-harmonic oscillations it is possible to determine maximal and minimal values of computed e_{ii}^{m} and experimental e_{ii}^{*m} strains, as well as the corresponding times t_i^m и t_i^{*m} ($m=\overline{1,M}$) they are reached at. In what follows, a parameterized version of the formulation of the parameter identification problem for a model of elastic behavior of a composite material of a double-layered metallic-plastic shell is presented. The task is to find a complex (vector) of stiffness characteristics of defining relations of the composite elastic material of the outer layer of a shell $\overline{E}=\left(E_{11},\, E_{22},\, E_{33},\, G_{13},\, \nu_{13},\, \nu_{23}\right)^{T}$, for which the numerical solution of the problem of dynamic behavior of cylindrical shells agrees best with the experimental data. Here, E_{ii}, G_{13} are elasticity moduli, ν_{13}, ν_{23} are Poisson coefficients. As a result, a problem of minimization of objective multi-variable function is obtained in the form of a sum of mean-square disagreements between the theoretical and experimental values of the strain

$$C\left(\overline{E}\right)=\sum_{k=1}^{K}\left\lfloor \sum_{m=1}^{M}\left\lfloor \sum_{i=1}^{2}\left(\left(\left(e_{ii}^{m}-e_{ii}^{*m}\right)/e_{ii}^{*}\right)^{2}+\left(\left(t_{i}^{m}-t_{i}^{*m}\right)/t^{*}\right)^{2}\right)\right\rfloor\right\rfloor_{k}, \tag{1}$$

where K is number of points for which experimental information about strains is known, e_{ii}^{*} are maximal values of circumferential and longitudinal strains in the first half-period of vibrations, t^{*} is time of the process.

Thus, the problem in question is reduced to a classical problem of nonlinear programming: to find the values of the vector components of controlled parameters $\overline{E}=\left(e_{1},e_{2},...,e_{r}\right)^{T}$, to which the minimal value of objective function $C\left(E^{*}\right)=\min C\left(\overline{E}\right)$ corresponds in the region of admissible values $D=\left\{\overline{E}:\, f\left(\overline{E}\right)\leq 1, \overline{E}\in \Pi\right\}$ belonging to search region $\Pi=\left\{\overline{E}: e_{j}^{-}\leq e_{j}\leq e_{j}^{+},\, j=\overline{1,r}\right\}$. The limits of the search region e_{j}^{-}, e_{j}^{+} are determined by conditions of stability of the material and experimental data [3].

Objective function (1) is computed by numerically solving the direct problem of dynamic deformation of a metallic-plastic cylindrical shell under explosive loading.

The metallic-plastic shell is supposed to be formed by cross-spirally winding a unidirectional composite material around a metallic case. The cinematic model of deformation of a multilayered package is based on a non-classical theory of shells. To this end, the components of the displacement vector are approximated by finite series across the thickness of the multilayered package [4, 5]. The formulation of geometric correlations is based on the relations of the simplest quadratic version of the nonlinear elasticity theory in curvilinear coordinates [5].

The correlation between stress and strain tensors in the composite layer is determined using Hook’s law for orthotropic bodies in combination with the effective moduli theory

$$\sigma_{ii}=\sum_{j=1}^{3}C_{ij}e_{jj}\quad (i=\overline{1,3}),\quad \sigma_{13}=G_{13}e_{13}, \tag{2}$$

where C_{ij}, G_{13} are effective stiffness characteristics expressed using components of vector $\overline{E}$.

The defining relations for the isotropic metallic layer are formulated using the differential theory of plasticity with linear hardening [5].

An energy-matched resolving system of equations of motion of the shell is constructed using the virtual displacement principle [5].

3. The method of solving the identification problem

The numerical solution of the formulated identification problem is subdivided into three stages: 1) solving the initial boundary-value problem of nonlinear deformation of metallic-plastic cylindrical shells under pulsed loading, 2) analyzing the sensitivity of the objective function for the sought parameters (design variables) 3) seeking a global minimum of the objective function.

The first stage of solving the identification problem is based on the explicit variational-difference scheme [5].

the identification problems are shown in Table 1 (S_i are total one-dimensional sensitivity indicators; $\Delta_i = \left((e_i - e_i^*)/e_i\right)\cdot 100\%$ are deviations of identified parameters e_i of the model from preset values e_i^*). It follows from Table 1 that the circumferential elasticity modulus is the most meaningful parameter of the elastic model. The sensitive parameters of the model are determined with a higher accuracy as compared with the less sensitive ones. Inaccuracy in assigning initial oscillograms has no considerable effect on the results of determining the sensitive parameters of the model of defining relations.

Table 1. One-dimensional indicators of sensitivity and deviations of the identified parameters of elastic deformation of the composite layer.

Model parameter	S_i, %		Δ_i, %	
	DO*	NO**	DO*	NO**
E_{11}	0,30	0,37	0,46	0,53
E_{22}	99,10	98,99	1,66	1,82
E_{33}	0,17	0,18	28,44	30,55
G_{13}	0,01	0,01	4,04	28,92
ν_{13}	0,09	0,01	0,19	0,47
ν_{23}	0,03	0,05	1,91	2,61

* DO – deterministic oscillogram.
** NO – “noisy” oscillogram.

Further on, the problem of identification based on the results of experimentally studying the dynamic behavior of metallic-plastic cylindrical shells under local pulsed loading was considered [8]. Maximal values of the circumferential strain in the central cross-section of the shell and the time to reach it, as well as the radial oscillation period, given in [8] were used as initial data. The shell geometry and loading conditions are the same as in the above considered example.

The results of numerical computation with the identified material parameters (denominator) and of experimental data (numerator) for maximal values of circumferential strain e_{22}^* in the central cross-section of the shell on its outer surface and for radial oscillation period T are as follows:

$$e_{22}^* = \frac{1{,}10}{1{,}14},\ T = \frac{187}{204}.$$

One can see that the maximal inaccuracy for the oscillation amplitude is 3,6 %, and for the oscillation period 9 %. It is to be noted that inaccuracy in the experimental measurements amounted to 10 % [8].

5. Conclusions

A computational-experimental method is presented that makes it possible, with a required accuracy, to determine material parameters of defining correlations of elastic deformation of composite materials and to adequately describe the dynamic behavior of metallic-plastic cylindrical shells.

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