

**G.M. KULIKOV**

***Non-Linear Boundary Value Problems of Mechanics of Thin-Walled Multilayered Anisotropic Structures (1991)***

**Abstract**

In the present work, the theory and numerical methods for the analysis of nonlinear multilayered anisotropic shells have been developed, where a pneumatic tire is a special case. The developments are characterised by a range of considered problems and a general approach to their solution. In particular, the attention is paid to the simplicity of realization of computational procedures for multilayered composite shells that permits the direct use of these procedures in engineering.

It has been developed the geometrically nonlinear theory of multilayered anisotropic shells based on independent assumptions concerning the distributions of displacements and transverse shear stresses through the thickness of the shell. The governing equations of the theory are obtained by applying the three-field Reissner mixed variational principle and their order equals 10. The feature of this approach is that the equations of Hooke's law for the transverse shear stresses and strains are satisfied integrally over the thickness of the shell.

The proposed Timoshenko-Mindlin shell theory has been generalized to the geometrically nonlinear theory of multilayered anisotropic shells based on the independent assumptions concerning the *non-homogeneous* distributions of displacements and transverse shear stresses through the thickness of the shell. The governing equations of the theory are obtained by applying the three-field Reissner mixed variational principle and their order equals 12. The feature of this approach is that the equations of Hooke's law for the transverse shear stresses and strains are satisfied integrally not only over the thickness of the shell but also over the thickness of each layer.

A new method for describing geometry of shells of revolution with complicated forms has been proposed. The reference surfaces of such shells are formed by revolution of arbitrary curves given on a plane by a discrete number of points whose coordinates are defined with random errors of measurement. The solution of this problem is obtained with the help of the effective procedure based on smoothing the data by spline functions.

It has been developed a new geometrically nonlinear theory of multilayered anisotropic shells based on the piecewise linear approximation of displacements in the thickness direction. The order of governing differential equations in this theory is dependent on a number of layers and equals  $4N+6$ , where  $N$  is the total number of layers of the shell.

The proposed layer-wise shell theory has been extended to the geometrically nonlinear theory of multilayered anisotropic shells based on the piecewise nonlinear approximation of displacements in the thickness direction. The order of governing differential equations in this theory is also dependent on a number of layers and equals  $4N+8$ . This permits one to keep up with the complicated distribution of in-plane and transverse shear stresses through the thickness of the composite shell.

The analysis of the effect of anisotropy in angle-ply shells of revolution has been presented. It has been shown that neglecting the effect of anisotropy can lead to an incorrect description of the stress-strain fields in angle-ply shells. The tire modeling and computational models for tires are discussed in detail. The truck and passenger car tires of bias-ply and radial configurations are examined by using both Timoshenko-Mindlin theories of multilayered anisotropic shells. A more general analysis of radial tires based on the both layer-wise shell models is also studied that allows us to investigate some microstructural effects at layer interfaces.