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Experimental and theoretical results of the internal hydro static pressure of multilateral pipes

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ABSTRACT

The experimental research of glass-epoxy circular laminated plate with defects stress has been made. Three variants of the multi-layer anisotropic shell computational model according to the discreet-structural lamina theory are considered in this paper. This model consists of several stiff anisotropic layers. It is considered, that transversal shear and thickness reduction stresses are equal on the contact boundary. At the same time, the elastic sliding between adjacent layers contact boundaries are permitted. Theoretic results are compared with experimental one's and found satisfy matched.

KEYWORDS

Glass-epoxy;
Defects stress;
Fiberglass;
Anisotropic;
Composite pipe.

INTRODUCTION

Experimental studies of the stressed state of the samples of fiberglass in the form of circular plates with defects. Based on Discrete - thin structural theory of plates and shells embodiment discusses three computational model of the multilayer anisotropic membrane that is composed of several rigid anisotropic layers. It is believed that the transverse shear stresses and compression at the interface are the same. When this is allowed by the elastic sliding contact surfaces of adjacent layers. The theoretical results are compared with experimental data, there is satisfactory agreement between them.

Range of products from composite materials sufficiently varied: pipes of different diameters, the shell covering buildings and structures, pressure vessels and tanks. This is not an exhaustive list. Constructions and articles can be designed with a high degree of accuracy. However, the time of their production is largely dependent on the level of technology and physico-mechanical properties of the composite components.

The reinforcing material in the most economical cost is fiberglass. The strength of the monofilament is between 3.4 GPa to 4.5 GPa. Standard deviation is about 10%. The main reason for this is the wide spread of the presence of defects in the fibers and the effects of atmospheric moisture.

The results of tensile testing of fiber bundles or strands about 20% less than the average value for the monofilament. This is because after rupture of the individual fibers in the bundle a substantial overload occurs remaining fibers. One drawback which limits the use of rovings of glass fiber, is a small modulus of elasticity. The maximum value of the elastic modulus unidirectional composites is in the range 41.0 – 55.2 GPa. The value of the modulus of elasticity of steel is 210 GPa respectively.

The binder used is usually epoxy resins ED-20 brand. Are used, and other types of epoxy resins: brominated flame - with increased resistance to fire; elastic epoxy resin with a high coefficient of toughness and ductility. In the composition of the epoxy resin is further used various kinds of curing agents and plasticizers. The most widely used hardener - metilnadikangidrid and triethanolamine. As the plasticizer, dibutyl phthalate may be used. The tensile strength of the epoxy casting resin is in the range 55 – 130 MPa, a tensile modulus - 2.8 – 4.2 GPa, flexural strength – 120 MPa.

The mechanical properties of most of the composites, as well as for a number of other layered materials, determined by the structure of monolayers. Monolayer consists of fibers oriented at an angle of $\pm\alpha$ or unidirectional. From the standpoint of macromechanics monolayer properties determined by experimentation, and analysis of the structure is carried out by the transition from one layer to another. Micromachined approach, on the contrary, is the study of composite material parts, i.e. distribution of stresses and strains between the reinforcing fibers and the matrix.

To reduce stress in the matrix and to maximize fiber properties realization layers must be oriented in at least three ways: 0°, +45°, -45°. In most designs, the orientation of layers used in all four directions. This minimizes stresses in the matrix and allow optimum operation of the composite. However, it should be noted, the main difficulty in the design of the optimal structure of fiberglass - a relatively low resistance to interlayer shear (σ_{xz} = 25-50 MPa, G_{xz} = 2000 -2500 MPa) and transverse separation (σ_z = 20-55MPa).

The loss of the bearing capacity of fiberglass shells under the action of compressive load due to weak cross-resistance separation and the interlayer shear occurs long before the stress limits. Therefore, it seems urgent to conduct additional studies of this problem.

The basic assumption, which is traditionally used and constantly refined theory of multilayer plates and shells, is the assumption of continuity of the displacement and stress when passing through the mating surface adjacent to each other layers, ie it is believed that during the transition from one layer to another at the interfaces the conditions perfect contact. As will be shown below, this traditional formulation does not allow to get acceptable accuracy the results of solving a number of problems of practical importance. In the first place, it is possible to isolate a class of problems in which it is necessary to take into account the work of adhesive bonding to the surface of contact of adjacent layers. Furthermore, reinforced plastic laminates for consideration technological characteristics and physico-mechanical properties of the load under the action of the conjugate at the interface of thin layers are formed of heterogeneous interfacial layers, different kinds of defects, such as delamination or disbonds portions. In this case, the assumption of continuity of displacements and stresses in the transition through the boundary of contact may be significantly impaired.

Thus, there is a need to develop models of layered structures with adhesive layers of the heterogeneity, with portions disbonds, bundles, etc. slip zones. D. To simulate the contact areas weakened interfacial layers of conjugate, usually two approaches. The first - a phenomenological when at the interface mating surfaces postulated the presence of jumps of displacements and stresses. Second - physical, associated with the specific physical and mechanical properties of weakened interfacial adhesion layers.

The thermo-mechanical models proposed in this work are defined as fully-coupled because the temperature field is considered a primary variable of the problem as the displacement[1], [2], in this way the effects of the thermal field can be evaluated in the static and dynamic analysis of multilayered plates and shells[3], and such models can also be applied to the thermal stress analysis of aerospace structures[4] without the necessity of a priori defining the temperature profile (by assuming it linear in the thickness direction or by solving the Fourier heat conduction equation). In the open literature, a small amount of work has been devoted to the coupled thermomechanical analysis of structures (both thermoelastic and thermoplastic analysis), and only few of them give nu umerical results. Some interesting works about this topic are Yang et al.[5]. Method for solving nonlinear problems of contact between the two shells of different shapes and equidistant layers is proposed in[6 - 9]. A detailed analysis of the latest results and trends in the development of discrete-structural theory of laminated plates and shells can be found in[10].

In this work, based on the discrete - thin structural theory of plates and shells embodiment discusses three computational model of the multilayer anisotropic membrane that is composed of several rigid anisotropic layers. According to the first contact pattern layers made rigid by means of an adhesive layer non-zero thickness. It is assumed that at a certain local portion of the adhesive layer of the shell is missing, so in this area is considered unilateral contact between the rigid layers.

For the second model is characterized by performing static contact condition on the mating surface of the individual layers. It is believed that the transverse shear stresses and compression at the interface are the same. When this is allowed by the elastic sliding contact surfaces of adjacent layers.

The third model is well known and often used in the calculation of the layered structures is performed if the assumption of perfect rigid contact of adjacent layers when the components of the displacement vector are continuous in thickness.

On the basis of a geometrically nonlinear discrete-structural theory of multilayer plates and shells is investigated stress-strain state of anisotropic elements with structural defects of the material. In the derivation of the equilibrium equations and geometric ratio takes into account the effect of transverse shear deformation and compression. The theoretical results are compared with experimental data.

BASIC AND GEOMETRIC EQUATIONS

In accordance with the theory of discrete structural mathematical model considered here, the multilayer shell consists of n thin anisotropic layers. The volume of *n* rigid layers is $V = \sum_{i=1}^{n} V_i$. Each cladding layer undeformed assigned to an orthogonal curvilinear coordinate system, α^i (*i*=1,2), $z^{(k)}$. Coordinate directed along the common normal $\vec{m}^{(k)}$ to the middle surface $S^{(k)}$ and equidistant surface $S_z^{(k)}$ *k-th layer. Index "z" with the introduction of other characters means that the corresponding values are to the point* $(\alpha^1, \alpha^2, z^{(k)})$ equidistant surface $S_z^{(k)}$.

Total displacement vector $\vec{u}_z^{(k)}$ k-th point of the hard layer according to the refined Timoshenko shell theory can be represented as

$$\vec{u}_z^{(k)} = \vec{u}^{(k)} + z^{(k)}\vec{\gamma}^{(k)} + \varphi^{(k)}\left(z\right)\vec{\psi}^{(k)}, \qquad (1)$$

Where $\vec{u}^{(k)}$ – displacement vector points of the middle surface $S^{(k)}$; $\vec{\gamma}^{(k)}$ – vector function of the angles of rotation and compression of the fibers in the direction normal to the undeformed middle surface $S^{(k)}$ during deformation; $\varphi^{(k)}(z)$ – nonlinear continuous distribution function tangential displacements through the thickness of the k-th layer, analysis and approximation given in[11]; $\vec{\psi}^{(k)}(\alpha_1^{(k)}, \alpha_2^{(k)})$ – vector shift function. Covariant components of vectors $\vec{u}^{(k)}, \vec{\gamma}^{(k)}, \vec{\psi}^{(k)}$ recorded using the following expressions:

$$\vec{u}^{(k)} = \vec{r}^{(k)i}u_i^{(k)} + \vec{m}^{(k)}w^{(k)},$$
$$\vec{\gamma}^{(k)} = \vec{r}^{(k)i}\gamma_i^{(k)} + \vec{m}^{(k)}\gamma^{(k)},$$
$$\vec{\psi}^{(k)} = \vec{r}^{(k)i}\psi_i^{(k)}. \qquad (2)$$

Deformation tensor components at $(\alpha^1, \alpha^2, z^{(k)})$ defined as half-sootetstvuyuschih metric tensor components before and after deformation:

$$2\varepsilon_{ij}^{(k)z} = g_{ij}^{(k)*} - g_{ij}^{(k)},$$
$$2\varepsilon_{i3}^{(k)z} = g_{i3}^{(k)*} - g_{i3}^{(k)},$$
$$2\varepsilon_{33}^{(k)z} = g_{33}^{(k)*} - 1. \qquad (3)$$

The conclusion of the equilibrium equations and boundary conditions for the solution of contact problems of laminated shells are usually made on the basis of Reissner variational principle. Considering that in the direction normal to the middle surface of the individual layers of the shell axial line of general and local coordinate systems are combined and also aligned with the local coordinate surfaces of the middle surface Layers, the variational equation for the Reissner principle multilayer shell written

$$\delta R=\sum_{k=1}^{n}\delta R^{(k)}=\sum_{k=1}^{n}\delta A_R^{(k)}-\sum_{k=1}^{n}\iiint_{V^{(k)}}\delta\left(\sigma_{(k)}^{\alpha\beta}\varepsilon_{\alpha\beta}^{(k)}-F^{(k)}\right)$$

$$dV=0\quad(\alpha,\beta=1,2,3)\qquad\textbf{(4)}$$

Numbering starts from the layers of negative values of z from 1 to n. wherein $F^{(k)}$ - specific additional work strain k-th layer, $\sigma_{(k)}^{\alpha\beta},\ \varepsilon_{\alpha\beta}^{(k)}$ – components of the stress tensor and the strain tensor.

If we assume that the dual faces of the k-th layer of the conditions of perfect contact:

$$u_\beta^{(k,k-1)}=u_\beta^{(k-1,k)},\ X_{(k,k-1)}^{\beta}=X_{(k-1,k)}^{\beta},\qquad\textbf{(5)}$$

Qr in vector form:

$$\vec{u}_{z}^{(k)}\left(\alpha_i^{(k)},\ -h^{(k)}/2\right)=\vec{u}_{z}^{(k-1)}(\alpha_i^{(k-1)},h^{(k-1)}/2),$$

$$\vec{X}_{(k)}\left(\alpha_i^{(k)},\ -h^{(k)}/2\right)=\vec{X}_{(k-1)}\left(\alpha_i^{(k-1)},\ h^{(k-1)}/2\right)\quad(i=1,2),\qquad\textbf{(6)}$$

Variation of the elementary work of external forces δA_R can be represented as

$$A_R=\sum_{k=1}^{n}\delta A_R^{(k)}=\sum_{k=1}^{n}\iint_{S_{(k)}}$$

$$\left(\vec{X}_{(k)}\delta\vec{u}^{(k)}+M_{(k)}^{i}\vec{r}_i^{(k)}\delta\vec{\gamma}^{(k)}+B_{(k)}^{i}\vec{r}_i^{(k)}\delta\vec{\psi}^{(k)}+M_{(k)}^{3}\delta\varepsilon_{33}^{(k)z}\right)dS+$$

$$+\sum_{k=1}^{n}\int_{l_1^{(k)}}\left(\vec{\Phi}_{(k)}^{S}\delta\vec{u}^{(k)}+\vec{G}_{(k)}^{S}\delta\vec{\gamma}^{(k)}+\vec{L}_{(k)}^{S}\delta\vec{\psi}^{(k)}\right)dl+$$

$$+\sum_{k=1}^{n}\int_{l_2^{(k)}}\left(\vec{\Phi}_{(k)}\delta\vec{u}^{(k)}+G_{(k)}\delta\vec{\gamma}^{(k)}+\vec{L}_{(k)}\delta\vec{\psi}^{(k)}+\left(\vec{u}^{(k)}-\vec{u}_S^{(k)}\right)\delta\vec{\Phi}_{(k)}+\right.$$

$$\left.+\left(\vec{\gamma}^{(k)}-\vec{\gamma}_S^{(k)}\right)\delta\vec{G}_{(k)}+\left(\vec{\psi}^{(k)}-\vec{\psi}_S^{(k)}\right)\delta\vec{L}_{(k)}\right)dl\ .\qquad\textbf{(7)}$$

Here $S_{(k)}$- middle surface of the k-th layer; $l_1^{(k)},\ l_2^{(k)}$ - part of the circuit $l^{(k)}$. Vectors external forces $\vec{X}_{(k)}$, moments $\vec{M}_{(k)}$ and additional points $\vec{B}_{(k)}$, are included in the equation (7), are defined by:

$$\vec{X}_{(k)}=\vec{X}_{(k)}^{+}-\vec{X}_{(k)}^{-}+\int_{-h^{(k)}/2}^{h^{(k)}/2}\vec{P}^{(k)}dz\ ,$$

$$\vec{M}_{(k)}=\frac{h^{(k)}}{2}\left(\vec{X}_{(k)}^{+}-\vec{X}_{(k)}^{-}\right)+\int_{-h^{(k)}/2}^{h^{(k)}/2}\vec{P}^{(k)}z^{(k)}dz\ ,$$

$$\vec{B}_{(k)}=\varphi^{(k)}\left(\frac{h^{(k)}}{2}\right)\left(\vec{X}_{(k)}^{+}-\vec{X}_{(k)}^{-}\right)+\int_{-h^{(k)}/2}^{h^{(k)}/2}\vec{P}^{(k)}\varphi^{(k)}(z)dz\ ,\qquad\textbf{(8)}$$

Where the vectors $\vec{X}_{(k)}^{+},\ \vec{X}_{(k)}^{-}$ include the contravariant components of the tensor of contact stresses $\sigma_{(k)}^{i3+},\ \sigma_{(k)}^{i3-}\quad(i=1,2,3)$:

$$\vec{X}_{(k)}^{+}=\sigma_{(k)}^{i3+}\vec{\rho}_i^{(k)*}+\sigma_{(k)}^{33+}\vec{m}^{(k)*}\ ,$$

$$\vec{X}_{(k)}^{-}=\sigma_{(k)}^{i3-}\vec{\rho}_i^{(k)*}+\sigma_{(k)}^{33-}\vec{m}^{(k)*}\quad(i=1,2)\ .\qquad\textbf{(9)}$$

Subscripts “+” and “-” indicate the top and bottom faces of the k-th layer. A similar entry are vectors of the external load $\vec{q}_{(n)}^{+},\ \vec{q}_{(1)}^{-}$:

$$\vec{q}_{(n)}^{+}=q_{(n)}^{i3+}\vec{\rho}_i^{(n)*}+q_{(n)}^{33+}\vec{m}^{(n)*},$$

$$\vec{q}_{(1)}^{-}=q_{(1)}^{i3-}\vec{\rho}_i^{(1)*}+q_{(1)}^{33-}\vec{m}^{(1)*}\qquad(i=1,2).\qquad\textbf{(10)}$$

Vector $\vec{P}^{(k)}$ takes into account the effect of its own weight. contravariant components $M_{(k)}^{i},\ M_{(k)}^{3}$ vector moment $\vec{M}_{(k)}$ with respect to the basis vectors $\vec{r}_i^{(k)*}$ and $\vec{m}^{(k)*}$ are according to the equation

$$\vec{M}_{(k)}=M_{(k)}^{i}\vec{r}_i^{(k)*}+\vec{m}^{(k)*}M_{(k)}^{3}\ .\qquad\textbf{(11)}$$

In addition, elementary work (7) th layer of the shell is characterized mainly by the vector $\vec{\Phi}_{(k)}^{S}$, the main point $\vec{G}_{(k)}^{S}$, additional main point $\vec{L}_{(k)}^{S}$, that arise from the action of the given external forces on the contour $l_1^{(k)}$, as well as the main vector $\vec{\Phi}_{(k)}$, the main point $\vec{G}_{(k)}$, additional main point $\vec{L}_{(k)}$, associated with the voltage at circuit $l_2^{(k)}$ due to a predetermined displacement of the contour points $\vec{u}_S^{(k)}$.

The second term of equation (4) should be represented in the form:

$$\delta\Pi_R=\sum_{k=1}^{n}\left(\delta\Pi_{1R}^{(k)}+\delta\Pi_{2R}^{(k)}\right)=\sum_{k=1}^{n}\iiint_{V^{(k)}}\sigma_{(k)}^{\alpha\beta}\delta\eta_{\alpha\beta}^{(k)}dV\ ,$$

$$-\sum_{k=1}^{n}\iiint_{V^{(k)}}\left(\partial F^{(k)}/\partial\sigma_{(k)}^{\alpha\beta}-\eta_{\alpha\beta}^{(k)}\right)\delta\sigma_{(k)}^{\alpha\beta}dV\qquad\textbf{(12)}$$

Where

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$$\delta\Pi_{1R}^{(k)} = \iiint\limits_{V^{(k)}} \sigma_{(k)}^{\alpha\beta}\delta\eta_{\alpha\beta}^{(k)}dV = \iiint\limits_{V^{(k)}} \left(\sigma_{(k)}^{ij}\delta\varepsilon_{ij}^{(k)\neq} + 2\sigma_{(k)}^{i3}\delta\varepsilon_{i3}^{(k)\neq} + \sigma_{(k)}^{33}\delta\varepsilon_{33}^{(k)\neq}\right)dV,$$

$$\delta\Pi_{2R}^{(k)} = -\iiint\limits_{V^{(k)}} \delta W_{(k)}^{f}dV = -\iiint\limits_{V^{(k)}} \left\{\left(\partial F^{(k)} / \partial\sigma_{(k)}^{ij} - \varepsilon_{ij}^{(k)\neq}\right)\delta\sigma_{(k)}^{ij} + \left(\partial F^{(k)} / \partial\sigma_{(k)}^{i3} - 2\varepsilon_{i3}^{(k)\neq}\right)\times\right.$$

$$\left.\times\delta\sigma_{(k)}^{i3} + \left(\partial F^{(k)} / \partial\sigma_{(k)}^{33} - \varepsilon_{33}^{(k)\neq}\right)\delta\sigma_{(k)}^{33}\right\}dV \quad (i,j = 1,2).$$

Then, substituting the geometric relation (3) (4), (7), (12) and varying the mutually independent displacements and stresses can be obtained for each individual cladding layer system of equilibrium equations, physical relationships, static and kinematic boundary conditions. Application of the generalized Hooke's law, the nonlinear theory of the average bending membranes[12] simplifies the derivation of the equilibrium equations and boundary conditions. The transition to the physical components used in this study tensors, the conclusion of the equilibrium equations and boundary conditions can be found in[13].

For a rotating shell which comprises n layers of coaxial surfaces of revolution, resolving system of partial differential equations of the form:

$$\frac{\partial\vec{Y}^{(k)}}{A_{(k)}\partial\alpha_1^{(k)}} = D_o^{(k)}\vec{Y}^{(k)} + D_1^{(k)}\frac{\partial\vec{Y}^{(k)}}{B_{(k)}\partial\alpha_2^{(k)}} + D_2^{(k)}\frac{\partial^2\vec{Y}^{(k)}}{B_{(k)}^2\partial\alpha_2^{(k)2}} + \vec{f}^{(k)}, \qquad k = 1,2\ldots n, \tag{13}$$

Where $\vec{Y}^{(k)} = \left\{T_{11}^{(k)}, T_{12}^{(k)}, Q_1^{(k)}, M_{11}^{(k)}, M_{12}^{(k)}, L_{11}^{(k)}, L_{12}^{(k)}, u_1^{(k)}, u_2^{(k)}, w^{(k)}, \gamma_1^{(k)}, \gamma_2^{(k)}, \psi_1^{(k)}, \psi_2^{(k)}\right\}^T$, $\vec{f}^{(k)} = \left\{f_1^{(k)}, f_2^{(k)}, \ldots, f_{14}^{(k)}\right\}$,

$D_0^{(k)}, D_1^{(k)}, D_2^{(k)}$ - Square matrices *14th* Therefore order. The main unknown function takes a value that define the boundary conditions on the lateral contour of the *k-th* layer denoted shell. Due to the lack of space to show resolution system equations, physical and geometrical ratio in expanded form is not possible. Kinematic and static contact condition (5) facial surface stey k-th layer and associated surfaces, *k + 1* and *k - 1-th* layer, co-according to the notation introduced earlier take the form:

$$2u_i^{(k)} = u_i^{(k+1)} + u_i^{(k-1)} - \frac{h^{(k+1)}}{2}\gamma_i^{(k+1)} + \frac{h^{(k-1)}}{2}\gamma_i^{(k-1)} - \varphi^{(k+1)}\left(\frac{h^{(k+1)}}{2}\right)\psi_i^{(k+1)} + \varphi^{(k-1)}\left(\frac{h^{(k-1)}}{2}\right)\psi_i^{(k-1)}, \quad (i = 1,2).$$

$$2w^{(k)} = w^{(k+1)} + w^{(k-1)} - \frac{h^{(k+1)}}{2}\gamma_i^{(k+1)} + \frac{h^{(k-1)}}{2}\gamma_i^{(k-1)}; \tag{14}$$

$$\sigma_{i3}^{(k)+} = \sigma_{i3}^{(k+1)-}; \quad \sigma_{i3}^{(k)-} = \sigma_{i3}^{(k-1)+} \qquad (i = 1,2).$$

$$\sigma_{33}^{(k)+} = \sigma_{33}^{(k+1)-}; \quad \sigma_{33}^{(k)-} = \sigma_{33}^{(k-1)+} \tag{15}$$

Given the kinematic relations (14) in the construction of resolving ing system (13) for the entire package element layers and performing stacal conditions on personal contact mating surfaces (15) on based on the penalty function method[11], we can make a decision algorithm contact problem of discrete-structural theory of multilayer shells.

If between *k-th* and *k + 1-th* cladding layers Assuming no kinematic connections at the surface interface of these layers may occur effort unknown vectors $\vec{q}_{(k)}$, $\vec{q}_{(k+1)}$ contact interaction. 3 According to Newton's second law is a dependence $\vec{q}_{(k)} = -\vec{q}_{(k+1)}$. To account for the impact of the efforts of the contact interaction of the layers in the variational equation Reissner principle (4) it is necessary to introduce a term that takes into account the work force of contact interaction in the motion vector of each layer portion of the mating surface:

$$A_q = \sum_{m=k}^{k+1} \iint_{S_z^{(k,k-1)}} \vec{q}_{(m)} \vec{u}_z^{(m)} dS. \quad (16)$$

Efforts contact interaction $\vec{q}_{(k)} = q^i_{(k)} \vec{r}_i^{(k)} + q^3_{(k)} \vec{m}^{(k)}$ arise when the condition:

$$(\vec{u}_z^{(k)} - \vec{u}_z^{(k+1)}) < 0 \quad (17)$$

Coupling in areas hard layers. In the case, where the inequality (17) is not performed while moving the field of points $S_z^{(k,k+1)}$ during deformation, the contact pressure $\vec{q}_{(k)}$ in equation (13) takes the value $\vec{q}_{(k)} = 0$. Solving the system of equations (13), it is easy to find the value of a given accuracy of the contact pressure on the basis of the iterative method proposed in[6].

RESULTS AND DISCUSSION

To test cases investigated plate round shape in terms of diameter *0.17 m* regular structure of fiberglass. Five plates of type 1 was prepared from *16 layers* of fiberglass roll PCT - -X 250 (107) TU 6-48-87-92 by laying pre-impregnated with epoxy resin ED-20 and heated in an oven at *100 ° C* for at least three hours. Four plates of type 2 made of *16 layers* of structural fiberglass T-13 (100) GOST 19170 - 73 and also impregnated with epoxy resin ED - 20. Five plates third type were made of 4 layers of fiberglass TG 430 - C (100) (producer - Latvia). The binder used polyester orthophthalic resin with low styrene emission Cristic 2 - 446 PA (producer - UK). Two plates 4 - type different from plates third type of primary defect in the form of an area disbonds circular diameter of *0.15 m* in the middle of the plate, which is located between the second and third layers of the plate. Lots disbonds created during pre-production of samples with a thin plastic film.

Physical and mechanical properties of fiberglass plates were determined as follows. Initially, according to GOST 25,601 - 80 determined the elastic modulus and Poisson's ratio of the tensile specimens made of fiberglass. Mechanical testing suggest that the material is treated platelets can be classified as a transversely isotropic ($E_{11} = E_{22} = 1.5 \times 10^4$ *MPa*, $\upsilon_{12} = \upsilon_{21} = 0.12$). The rest of the physical and mechanical properties of fiberglass determined by the integral over the entire packet layers of the plate on the basis of dependency[8], when the elastic moduli of the 1st kind, Poisson's ratios of the fibers and the matrix are equal to: $E_B=7.0 \times 10^4$ $E_M a$, $E_M= 3.5 \times 10^3$ $E_M à$, $V_B=0.22$, $V_M=0.35$.

For the pilot study was designed and manufactured test setup shown schematically in Figure 1. The deflection of the plate was measured using dial gauges with an accuracy of 0.01 mm. To measure the strain gages were used KF4P1-3-200. Sticker gages carried out according to the instructions on the label AZHV2.782.001 THAT. To measure the output signals of the strain gauges and reporting digi-

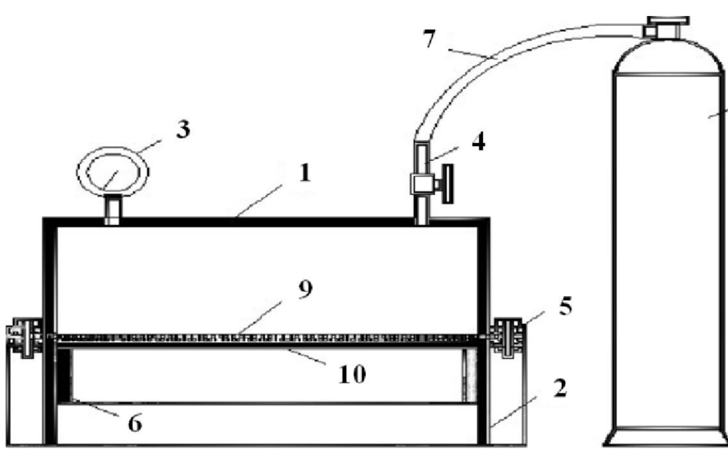

Figure 1 : Test setup for experimental studies of bending of plates of composite materials under the action of uniformly distributed load: 1 - Cover 2 - Stand 3 - gauge, 4 - transition crane, 5- flanges 6 - reference table, 7- connecting hose, 8 - cylinder,9 - elastic strip, plate 10 investigated Three - dimensional diagram and general view of the setup shown in Figure 2 and 3

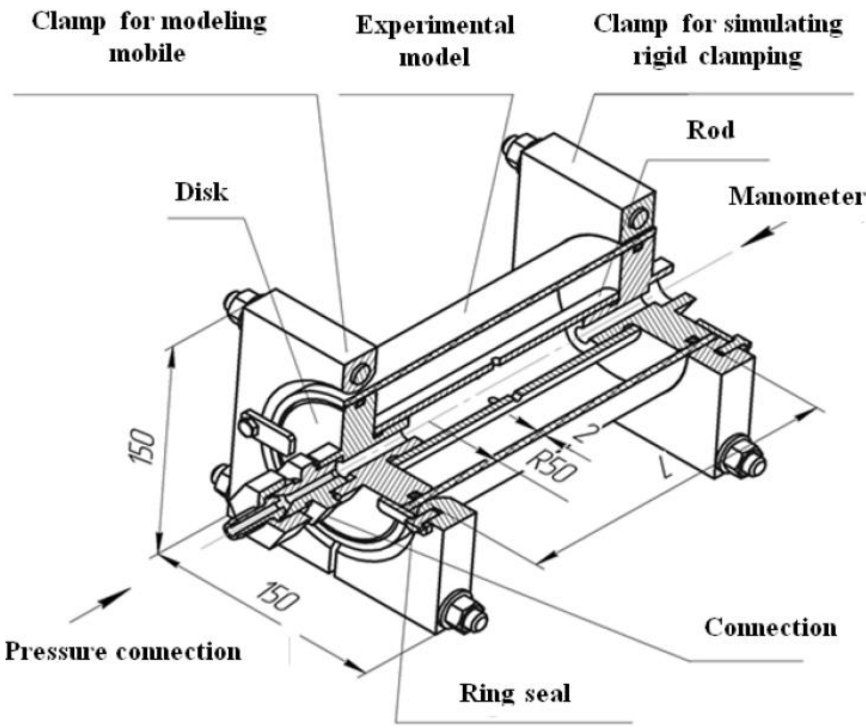

Figure 2 : Scheme of the experimental setup to test cylinders

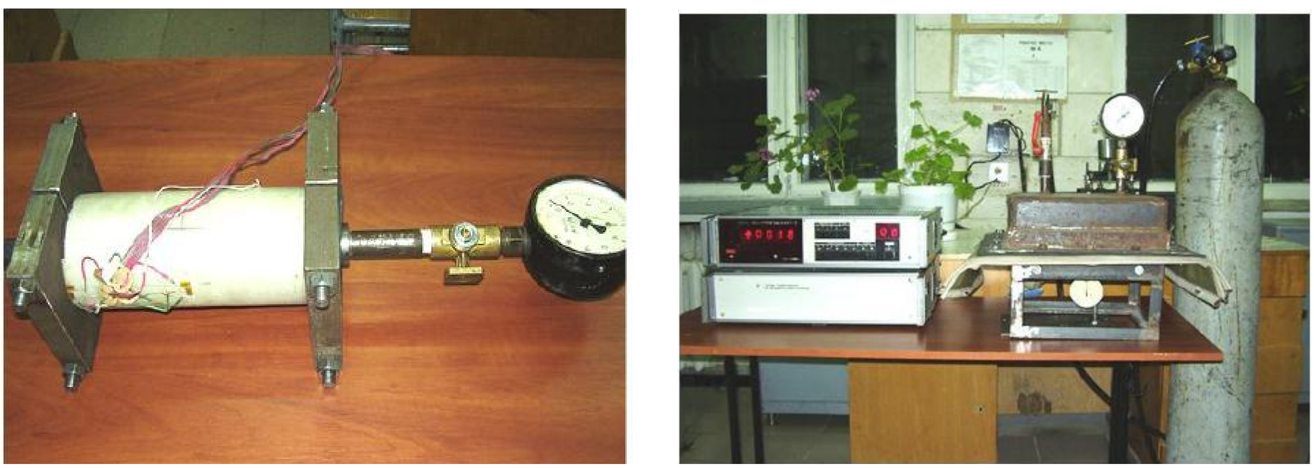

Figure 3 : General view of experimental setup for testing cylinders

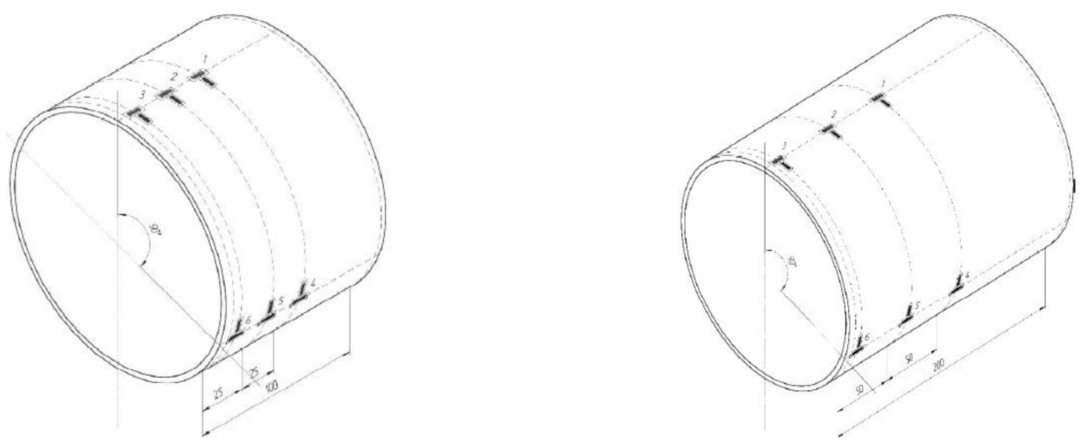

Figure 4 : Points stickers strain of cylindrical samples

tally measuring system used SIIT-3.

Figure 4 Strain, method of their stickers and strain measurements taken are the same as for the tested plates.

As a mathematical model for calculating the two-layer model was used plate. The plate is composed of two rigid layers transtropic thickness $h_{(1)}=h_{(2)}=1.0 \times 10^{-3}$ m and connected by a thin adhesive layer of thickness h [0] = 0.1×10^{-3} m (first model) and without adhesive layer (second model). The problem was solved by the method of orthogonal sweep SK Godunov in geometrically nonlinear formulation.

To check the options model calculation plate held in spatial axisymmetric formulation based on the finite element method (FEM complex ANSYS 8.0). 3400 model is represented by rectangular 8-node elements. Defect simulated local area disbonds considering hard contact layers (first model). Used two-dimensional 8-node element PLANE 183.

The material properties of the hard layer orthotropic fiberglass are respectively: Ex = $1.5 \cdot 10^4$ MPa; Ey = 4.188×10^3 MPa; Ez = 1.5×10^4 MPa; $\nu_{xy} = 0.242$; $\nu_{yz} = 0.12$; $\nu_{xz} = 0.12$; $G_{xy} = 1.715 \cdot 10^3$ MPa; Gyz = 1.715×10^3 MPa; $G_{xz} = 6.039 \times 10^3$ MPa. Clay was considered isotropic material: Ex = 3.5×10^3 MPa; $\nu_{xy} = 0.35$.

The results of such studies plates 4 with disbonds circular shape and a radius $R_d = 7.5 \times 10^{-2}$ m, the middle plate located between the layers 3 and 4 are shown in Figure 5.

The relative error of the theoretical value of the deflection in the center of the plate (the second model) when compared with the experimental data was less than *3%: $w_z = 0.2 \times 10^{-2}$ m* - for hard zascheml¸nnogo circuit; *$W_c = 0.45 \times 10^{-2}$ m* - for free op¸rtogo circuit.

Assessment of the reliability of the proposed first model discrete-structural theory held in this sample. Considered work two-layer cross-reinforced cylindrical shell under the action of distributed load $q = -q_0 \cdot \sin^8(\pi x / l)$.

The solution of this problem in three-dimensional formulation of anisotropic elasticity theory presented in the[15]. Layers of shells made of orthotropic material, making the fibers relative to the coordinate lines at an angle $+\varphi$ in the inner layer and $-\varphi$ in the external. Physical and mechanical properties of the material layers of data in[15]

$$b_{11} = E_0^{-1}/5{,}7; \;\; b_{22} = b_{33} = E_0^{-1}/1{,}4;$$

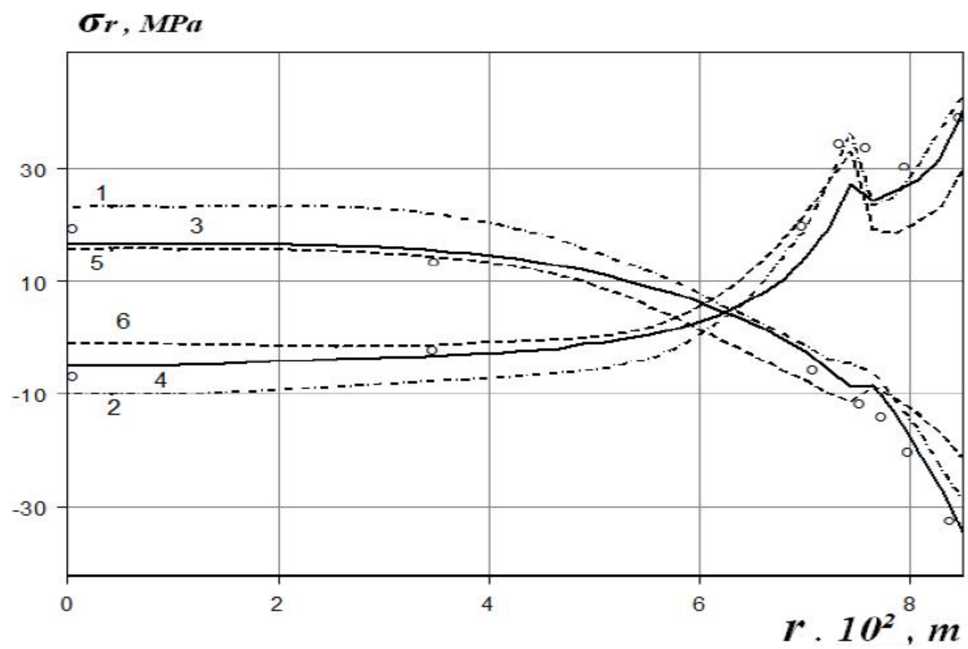

Figure 5 - The radial stresses on the faces of the plates 4 - type with rigid attachment circuit pressure and q = 0,025 MPa (1 and 2 - two-layer plate with the adhesive layer (the first pattern), 5, 6 - double plate with the adhesive layer (calculation results in three-dimensional formulation based program ANSYS); 3,4 - two-layer plate without the adhesive layer (second model); ° - the results of the experiment)

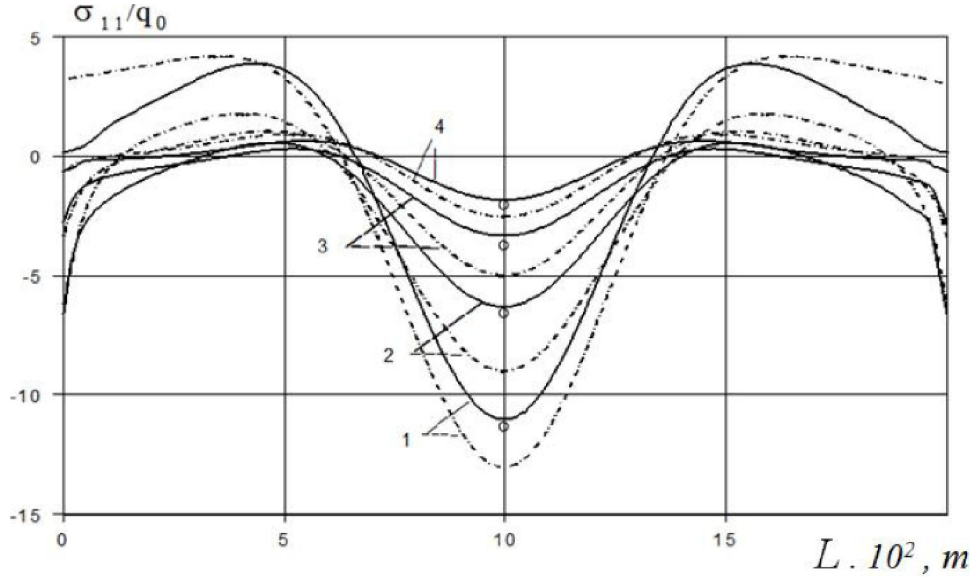

Figure 6 : Distribution of normal stresses along the length of the cylinder σ_{11} (1 – $\varphi = 0$; 2 – $\varphi = \pi/4$; 3 – $\varphi = \pi/3$; 4 – $\varphi = \pi/2$; ° – results of[15])

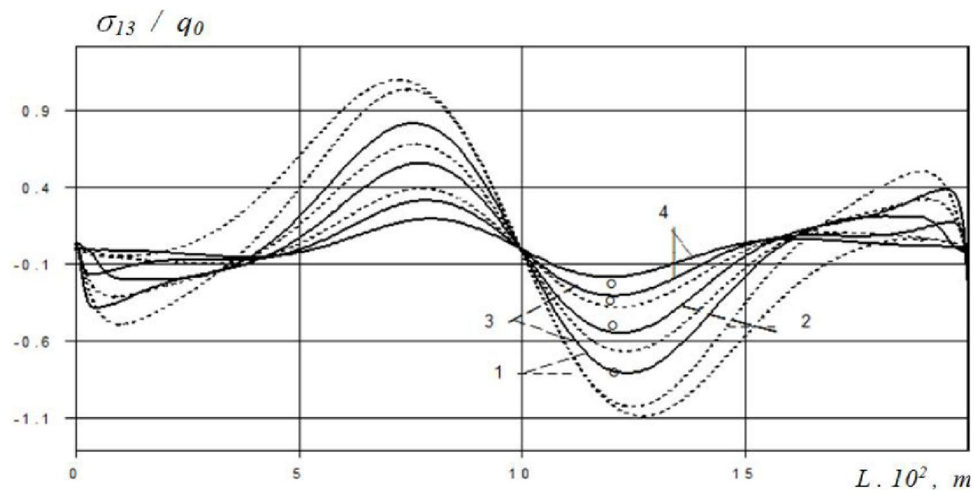

Figure 7 : Transverse shear stress distribution along the length of the cylinder σ_{13} *(1 – $\varphi = 0$; 2 – $\varphi = \pi/4$; 3 – $\varphi = \pi/3$; 4 – $\varphi = \pi/2$; °– results of[15])*

$$b_{44} = E_0^{-1}/0{,}5;$$

$$b_{55} = b_{66} = E_0^{-1}/0{,}575; \quad b_{12} = b_{13} = -0{,}068E_0^{-1}/1{,}4; \quad b_{23} = -0{,}4E_0^{-1}/1{,}4.$$

Geometric shell inner radius is r_0, external – $r_n = 1.1\, r_0$, thickness equal to each other the length of the shell $L = 0.2\ m$. Boundary conditions at the ends of the shell ($x = 0.0$ *and* $x = 0.2\ m$), adopted in[15].

Figure 6, 7 shows a graph of stress σ_{11}, σ_{13} on the outer surface of the middle and according to length of anisotropic cylinder.

Here solid line corresponds to a dual layer cylinder (first model), dotted bar - single layer cylinder (third model), numbers with graphics from different angles making fibers. It should be noted that taking into account the discrete arrangement of layers with different angles of laying fiber significantly refines the results of calculations. For example, the discrepancy results from the first and third models σ11 stress at the corner of laying fiber $\varphi = \pm\pi/4$ *was 21 %.*

Comparison of values of deflection w at the outer surface of the shell, which was received on the basis of the proposed settlement beyond the first model, with similar data from[15] showed their satisfactory correspondence. The relative error was less than one percent.

Thus, in this subsection on the basis of geometrically nonlinear discrete-structural theory of layered structural elements and investigated the stress-strain state of anisotropic cylindrical shells. The combination of hard anisotropic layers in the interlayer boundaries are modeled three computational models, which included conditions of perfect and loose contact.

CONCLUSIONS

Kinematic and static conditions contact faces conjugate hard layers of anisotropic structural elements make significant changes in the distribution pattern of the strain and stress of transverse shear and compression. When the kinematic constraints on any portion of the conjugate faces are absent, ie there are areas disbonds, bundles, etc., the suggested model of layered construction elements adequately reflects their work and to determine the contact area, contact pressure, the changing nature of the state of stress at the interface.

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