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STRENGTH AND STABILITY OF TWO-LAYER COMBINED CONCRETE/GLASS-FIBRE REINFORCED CONCRETE SLABS CONSIDERING TRANSVERSE SHEAR AND ADHESIVE JOINT PLIABILITY

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Abstract
The strength and stability of two-layer combined concrete and glass-fibre-reinforced plastic slabs are investigated in this paper, taking into account transverse shear and ductility of the adhesive joint. The influence of interlayer shear on the stability of two-layer combined concrete and fibreglass slabs has been investigated.

Keywords. Two-layer slab, reinforcing composite layer, shear modulus, shear function, tangential stress, displacements, shear modulus of layers and glue joints.

Introduction

In construction, aircraft construction, mechanical engineering, shipbuilding, chemical industry and other engineering fields combined reinforced plates (plates) and shells are common elements of structures. The modern level of design of these structures requires the creation of a sufficiently general algorithm of calculation, allowing to study a wide range of topical problems from unified positions. Experimental and theoretical studies of the stress-strain state (SS) and stability of such structures represent one of the important and complex sections of modern mechanics and are becoming increasingly important in practice[3,4].

Methods:

We consider that the considered two-layer composite slab consists of bearing (first) and reinforcing layers. We assume that:

1. the thicknesses of the bearing, reinforcing and bonding (joining) layers, are constant.
2. the thickness of the load-bearing, (strong) layer is much greater than that of the second reinforcing layer ($h > \delta_n$).
3. Applied to slabs, in this case, the accepted hypotheses according to the refined theory of S. A. Ambartsumian [1] are valid:

(a) The combined two-layer plate obeys the generalised Hooke's law and at each point has only one plane of elastic symmetry parallel to the median plane of the plate (see Fig.1.), and also each point has the property that any two directions symmetrical relative to this plane are equivalent with respect to elastic properties;

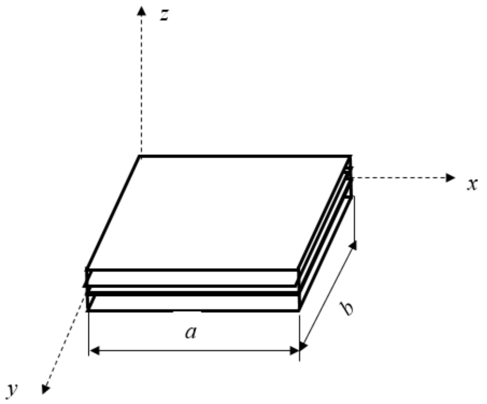

Fig.1. Combined two-layer plate (slab)

b) as in the classical theory, the displacement U_j, normal to the median plane of the plate, does not depend on the coordinate Z or **γ**;e_γ=0, w=w(x,y).

$$e_j=0;\ W=W(x,y) \qquad (1)$$

c) the tangential stresses τ_{xz} and τ_{yz}, or the corresponding strains ℓ_{xz} and ℓ_{yz} along the thickness of the slab, vary according to a given law, which allows the strains due to transverse shear to be taken into account.

4. The magnitude of shear along the thickness of the joint is constant [5].

Accepting the hypothesis of S.A.Ambartsumian [1], we consider that the relative elongation of the deformation along the Z direction is zero.

Shear strains of the first layer.

$$\ell_{xz}^{(1)} = 0{,}5\left(\frac{h^2}{4}-\gamma^2\right)\Phi_1 + \left(0{,}5-\frac{\gamma}{h}\right)\frac{\tau_1}{G_{13}^{(1)}}$$

$$\ell_{yz}^{(1)} = 0{,}5\left(\frac{h^2}{4}-\gamma^2\right)\Phi_2 + \left(0{,}5-\frac{\gamma}{h}\right)\frac{\tau_2}{G_{23}^{(1)}} \qquad (2)$$

Similarly, the shear strains of the second reinforcing layer along the thickness of the plate vary according to the following defined law

$$\ell_{\mathrm{xz}}^{(2)} = \left(0{,}5+\frac{\gamma_1}{\delta_n}\right)\frac{\tau_1}{G_{13}^{(2)}}$$

$$\ell_{yz}^{(2)} = \left(0{,}5+\frac{\gamma_1}{\delta_n}\right)\frac{\tau_2}{G_{23}^{(2)}} \qquad (3)$$

where h, δ_n are the thicknesses of the first (thick) and second (reinforcing) layers;

$\Phi_i = \Phi_i(x,y)$ - are arbitrary desired shift functions;

$\tau_i = \tau_i(x,y)$ - are the required tangential stresses;

$G_{i,K}^{(1)}, G_{i,K}^{(2)}$ - shear moduli of the first and second layers (i=1, 2; K=3).

In this paper, the stability of two-layer composite boards is investigated taking into account interlayer shears. The derivation of equations and the formulation of boundary conditions taking into account interlayer shear and the pliability of the glue joint are given in [2]. The elongation components are expressed through the displacements of the body points, since the stability problems are not linear with respect to the displacements, the quadratic summands are taken into account, the following nonlinear relations are obtained for the elongation components [1].

$$\varepsilon_x = \frac{\partial U}{\partial x} + \frac{1}{2}\left[\left(\frac{\partial U}{\partial x}\right)^2 + \left(\frac{\partial \nu}{\partial x}\right)^2 + \left(\frac{\partial \omega}{\partial x}\right)^2\right];$$

$$\varepsilon_y = \frac{\partial v}{\partial y} + \frac{1}{2}\left[\left(\frac{\partial U}{\partial y}\right)^2 + \left(\frac{\partial \nu}{\partial y}\right)^2 + \left(\frac{\partial \omega}{\partial y}\right)^2\right];$$

$$\gamma''_{xy} = \varepsilon_{xy}\frac{\partial U}{\partial y} + \frac{\partial v}{\partial x} + \left(\frac{\partial U}{\partial x}\frac{\partial U}{\partial y} + \frac{\partial \nu}{\partial x}\frac{\partial \nu}{\partial y} + \frac{\partial \omega}{\partial x}\frac{\partial \omega}{\partial y}\right);$$

$$\gamma''_{xy} = \varepsilon_{xz}\frac{\partial U}{\partial z} + \frac{\partial w}{\partial x} + \left(\frac{\partial U}{\partial x}\frac{\partial U}{\partial z} + \frac{\partial \nu}{\partial x}\frac{\partial \nu}{\partial z} + \frac{\partial \omega}{\partial x}\frac{\partial \omega}{\partial z}\right);$$

$$\gamma''_{yz} = \varepsilon_{yz}\frac{\partial v}{\partial z} + \frac{\partial w}{\partial y} + \left(\frac{\partial U}{\partial y}\frac{\partial U}{\partial z} + \frac{\partial \nu}{\partial y}\frac{\partial \nu}{\partial z} + \frac{\partial \omega}{\partial y}\frac{\partial \omega}{\partial z}\right); \qquad (4)$$

Let us apply these relations to the study of the stability of two-layer elastic plates loaded by a system of dead forces to determine the value of the load parameter (Pkr). We calculate the change in the total potential energy of the system with accuracy to the squares of displacements describing the transition of the system to a new, deviated state.

Taking into account [1,4] and [5], to the written expression of the functional we add the terms that are related to the nonlinear relations of the elongation components (4). The functional has the following form

$$U(z) = P\iiint\limits_{V}\left[\overset{-0}{\sigma}_x\varepsilon''_x + \overset{-0}{\sigma}_y\varepsilon''_y + \overset{-0}{\tau}_{xy}\gamma''_{xy} + \overset{-0}{\tau}_{xz}\gamma''_{xz} + \overset{-0}{\tau}_{yz}\gamma''_{yz}\right]dv; \qquad (5)$$

Where $\sigma^{\circ}_{x,y}$ $\tau^{\circ}_{i,k}$ - is the initial stress; P is the critical parameter (load).

Having the full functional (5) and using Euler's variational equation, we obtain the partial differential equations of stability for two-layer plates taking into account transverse shears and glue joint pliability [2]

To analyse the influence of transverse shear and ductility of the glue joint on the stability, we consider as an example a two-layer hinged jointed composite slab along the contour

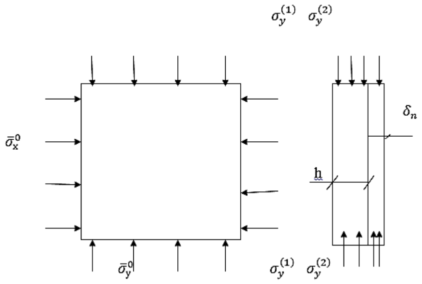

Figure 2. Compressive loads

Assume that: a) the initial tangential stresses τ_{x_i}, τ_{y_i} are absent;

We consider that the equality is true $\frac{\sigma_x^{(1)}}{E^{(1)}} = \frac{\sigma_x^{(2)}}{E^{(2)}}$;

Then, under the assumption

$$\sigma_{\mathrm{x}}^{(1)} = \sigma_{\mathrm{y}}^{(1)} = \sigma_0 \sigma_{\mathrm{x}}^{(2)} = \sigma_0 \frac{\mathrm{E}_1^{(2)}}{\mathrm{E}_1^{(1)}}, \quad \sigma_{\mathrm{y}}^{(2)} = \sigma_0 \frac{\mathrm{E}_2^{(2)}}{\mathrm{E}_2^{(1)}} \qquad (6)$$

We find the solution in the form

$$W = \sum_m \sum_n A_{mn} \sin\frac{m\pi x}{a} \sin\frac{n\pi y}{b}, \Phi_2 = \sum_m \sum_n F_{mn} \sin\frac{m\pi x}{a} \cos\frac{n\pi y}{b},$$

$$U_0 = \sum_m \sum_n B_{mn} \cos\frac{m\pi x}{a} \sin\frac{n\pi y}{b}, \tau_1 = \sum_m \sum_n D_{mn} \cos\frac{m\pi x}{a} \sin\frac{n\pi y}{b},$$

$$V_0 = \sum_m \sum_n C_{mn} \sin\frac{m\pi x}{a} \cos\frac{n\pi y}{b}, \tau_2 = \sum_m \sum_n T_{mn} \sin\frac{m\pi x}{a} \cos\frac{n\pi y}{b},$$

$$\Phi_1 = \sum_m \sum_n E_{mn} \cos\frac{m\pi x}{a} \sin\frac{n\pi y}{b}, q = \sum_m \sum_n q_{mn} \sin\frac{m\pi x}{a} \cos\frac{n\pi y}{b} \qquad (7)$$

Substituting (7) into the system of differential equations [2,3] for two-layer plates, we obtain a system of algebraic equations with respect to $A_{mn}, B_{mn}, C_{mn}, D_{mn}, E_{mn}, F_{mn}, T_{mn}$.

As an example of solving the problem of stability of a two-layer combined orthotropic slab with consideration of transverse shear and ductility of the glue joint, a hinge-supported slab is chosen along the contour. The slab is made on the basis of concrete and fibreglass (a=2.0m, b=3.0m, $\mathrm{E}_1^{(1)}$ =1,08 10^4МПа, $\mathrm{E}_2^{(1)}$ =,081 10^4МПа, $\mu_{12}^{(1)} = \mu_{21}^{(1)} = 0{,}12$, $E_1^{(2)} = 3{,}05 \cdot 10^4$МПа, $E_2^{(2)} = 1{,}88 \cdot 10^4$МПа, $\mu_{12}^{(2)} = \mu_{21}^{(2)} = 0{,}18$, $\delta_n = 1{,}0$ см, $G_{13}^{(1)} = G_{23}^{(1)} = 3 \cdot 10^4$ МПа, $G_{12}^{(2)} = 0{,}49 \cdot 10^4$МПа, $G_{13}^{(2)} = 0{,}31 \cdot 10^4$МПа, $G_{23}^{(2)} = 0{,}35 \cdot 10^4$МПа,h=15см).

Summary

Results of a concrete slab with external fibreglass reinforcement loaded along the contour with initial stresses $\overset{\circ}{\sigma}_x$ and $\overset{\circ}{\sigma}_y$. The shear modulus of the joint and the thickness of the joint were varied. The calculation showed that increasing the shear modulus $G_{\text{шiк}}$ shik of the weld by a factor of 10 from 3.2 MPa to 32 MPa leads to a change in critical stresses by 36%. For larger values, the effect of the shear modulus of the weld $G_{\text{шiк}}$ is much smaller.

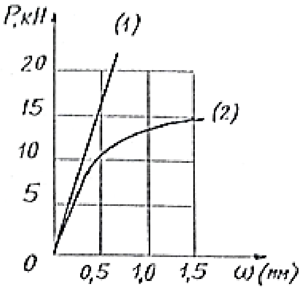

Fig. 3. Deflections in the centre of the slab (1) - theoretical calculation, (2)-experimental data.

Increasing the joint thickness by a factor of 10 from 10^{-3} to 10^{-2}cm results in a 5.8% reduction in critical stresses. The effect of joint shear decreases as the thickness of the bearing and reinforcing layers increases.

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