Check of stress values in reinforcement and joints of wall panels

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Abstract. The exterior walls of buildings are subjected to not only forces but also thermal shrinkage effects. These effects are particularly significant for buildings constructed using single-layer and three-layer panels. Temperature forces and deformations occur both within the plane of the outer walls and outside of it. As a result, it is necessary to conduct calculations to ensure that the design solutions for exterior walls made of single-layer and laminated panels are both strong and deformable. These calculations are necessary for frameless buildings with a regular structural scheme. By conducting these calculations, it is possible to verify that the design solutions for exterior walls can withstand the forces and deformations that they will experience during their lifetime.

Key words: three-layer reinforced concrete structures, monolithic binding layers, computer modeling, deformations, stress-strain state, enclosing structures, concrete strength

1 Introduction

The temperature and moisture forces and deformations arise in the exterior wall panels included in the statically indeterminate spatial system of a large-panel building, when the ambient temperature and humidity change and when the concrete shrinks due to the constraint of free deformation of external and internal structures by the bonds between them, as well as due to the embedding of the building aboveground structures in the foundation [1-5].

Previous studies have shown that the temperature and moisture effects on exterior wall panels are influenced by various factors, including the material properties, the design of the wall panels, the method of construction, and the environmental conditions. The effects of these factors on the strength and deformability of the wall panels need to be considered during the design phase to ensure that the building is safe and durable.

The design horizontal longitudinal forces acting in the plane of the exterior wall and the design horizontal transverse forces acting from the wall plane are considered in this work. The design stresses in the horizontal reinforcement of the panels and in the joint bonds, and the design deformations of the vertical joints are checked against the action of these forces.

The methods of strength and deformability testing are given as applied to the design solutions of exterior walls made of single-layered and laminated panels of large-panel frameless buildings.

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2 Methodology

The calculations consider load-bearing, self-supporting and non-supporting walls made of panels of single-row and double-row cuts of one and two planning steps, structurally connected with the floors and interior walls. The calculations can also be used to check the walls made of panels in three planning steps.

The design longitudinal temperature forces and deformations are determined depending on the design values of the temperature parameter Δt, the design transverse forces and deformations - depending on the design values of the temperature parameter $\Delta\theta$ [6,7,8].

As a rule, exterior walls made of single-layered and laminated panels are checked separately for the influence of design values of temperature parameters Δt and $\Delta\theta$.

At joint influence of temperature parameters Δt and $\Delta\theta$, the forces and deformations occurring in the structures are summarized on the basis of the principle of independent action of forces.

Design solutions of structures have been checked for temperature effects during two periods: during construction, when a building is considered to be unheated and concrete shrinkage is not taken into account, and during operation, when the combined effect of temperature and concrete shrinkage is taken into account [9-20].

The design forces and deformations in the external walls at the action of design temperature parameters Δt and $\Delta\theta$ are determined taking into account the design values of the parameters of yield strength of prefabricated elements and their connections.

Check of wall sections for strength and deformability, and determination of design values of stiffnesses of panel sections and joints of exterior walls in the longitudinal and transverse directions are performed in accordance with the guidelines of SP 63.13330.2018 Concrete and reinforced concrete structures.

Overall, this methodology provides a systematic approach for evaluating the effects of temperature and moisture on exterior wall panels and ensuring that design solutions are both strong and deformable. It also incorporates industry standards and guidelines to ensure the accuracy and reliability of the calculations.

3 Results

The design stresses in the tensile reinforcement of the wall panels and in the joints, connections are determined as the sum of stresses arising under the simultaneous action of the longitudinal force N_e and the bending moment M_e, M_c.

Designed value of stresses in the reinforcement of the panels and joints in the bonds should not exceed the calculated resistance of the reinforcement in accordance with the requirements of SP 63.13330.2018. For example, the calculated value of stresses in the longitudinal joint bonds between the panels must not exceed: in the welded wire bonds of steel class A-I-2100 kg/cm^2, in the looped links of reinforcing steel class A-I diameter 12 mm - 1600 kg/cm2.

Design stresses in the tensile reinforcement of single-layered and laminated panels with a rigid bond between the layers under the influence of temperature parameters Δt and $\Delta\theta$ are determined by the formula:

$$\sigma_{\text{ae}} = \frac{N_{\text{п}}}{F_a} \pm M_e \frac{E_{a(h_o - z_c)}}{B_e \psi_{\text{a}}} \quad (1)$$

stresses in the longitudinal bonds of vertical joints are determined by the formula:

$$\sigma_{\text{a,c}} = \frac{N_e}{F_{a,\text{c}}} \pm M_{\text{c}} \frac{E_{a(h_o - z_c)}}{B_e \psi_{\text{a}}} \quad (2)$$

In formulas 1 and 2, the stress values are maximal when the signs of the first and second terms are the same. In these formulas

N_e - is the design longitudinal temperature stress in the panels and external walls, determined under the influence of the design temperature value Δt;

M_e, M_c - are design bending moments in the panels and joints, determined depending on the scheme of fixing of the panels to the walls and floors according to the formulas presented in Table 1;

B_e - design bending stiffness of the lintel frame;

F_a, $F_{a,c}$ - design cross-section areas of the reinforcement of the panels and the connections of the butt joints, respectively.

Total bending moments M_i, support reactions R_i and rotation angles φ_i in walls with embedded joints on elastic supports under the joint action of the temperature parameter $\Delta\theta$ and the longitudinal force with eccentricity e_m

Table 1. Bending moments

Bending moments $M_i = M_i^{\theta} + M_i^N$	
First case	Second case
$M_{n-1,c} = -(M_\theta + M_N)\cdot\frac{(m_1+m_5)\xi\eta + m_5 + 1}{(m_1+m_5)\zeta\eta + m_5 + 1}$ $M_{n-1,п} = -(M_\theta + M_N)\cdot\frac{(m_1+m_5)\xi\eta + m_5 + 1}{(m_1+m_5)\zeta\eta + m_5 + 1} + M_N$ $M_{n,п} = -(M_\theta + M_N)\cdot\left[\frac{(m_1+m_5)(\zeta-\xi)\eta}{(m_1+m_5)\zeta\eta + m_5 + 1} + 1\right] + M_N$	$M_{n-1,п} = 0$ $M_{n-1,п} = M_N$ $M_{n,п} = -(M_\theta + M_N)\cdot\left(\frac{m_2 - m_5}{m_1 + m_5} + 1\right) + M_N$
Reference reactions $R_i = R_i^{\theta} + R_i^N$	
First case	Second case
$R_{n-1} = -R_n = -(M_\theta + M_N)\cdot\frac{m_3(\zeta-\xi)\eta}{l_п[(m_1+m_5)\zeta\eta + m_5 + 1]}$	$R_{n-1} = -R_n = -(M_\theta + M_N)\cdot\frac{m_3}{l_п(m_1+m_5)}$
Pivot angles on supports $\varphi_i = \varphi_i^{\theta} + \varphi_i^N$	
First case	Second case
$\varphi_{n-1} = (M_\theta + M_N)\frac{l_п}{2B_п}\cdot\frac{(m_5+1)(\zeta-\xi)\eta}{(m_1+m_5)\zeta\eta+m_5+1}$ $\varphi_n = -(M_\theta + M_N)\frac{l_e}{2B_e}\cdot\frac{(1-2S)(m_2-m_5)(\zeta-\xi)\eta}{(m_1+m_5)\zeta\eta+m_5+1}$	$\varphi_{n-1} = (M_\theta + M_N)\frac{l_e}{2B_e}\cdot\frac{m_5+1}{m_1+m_5}$ $\varphi_n = -(M_\theta + M_N)\frac{l_e}{2B_e}\cdot\frac{(1-2S)(m_2-m_5)}{m_1+m_5}$

$$M_\theta = \frac{\alpha_e\Delta\theta_e B_e}{h_п};\ M_N = -N_e e_N;\ \xi = \frac{\alpha_c}{\alpha_п};\ \zeta = \frac{B_e}{B_c};\ \eta = \frac{l_c}{l_e};\ S = \frac{l_s}{l_e};$$

$$m_1 = \frac{3-4S}{S(2-3S)};\ m_2 = \frac{1}{2-3S};\ m_3 = \frac{3(1-S)}{S^2(2-3S)};\ m_5 = \frac{6\varepsilon}{S^3(2-3S)};\ \varepsilon = \frac{(\lambda_0+\lambda_1)B_e}{l_e^3}$$

All formulas are given for elastic supports. For rigid supports опорах $\lambda_0 = \lambda_1 = 0, \varepsilon = 0\ and\ m_5 = 0$

The design stresses in the tensile reinforcement of the i-th reinforced concrete layer of the three-layer panel with flexible links are determined by the formula:

$$\sigma_{\mathrm{a}i} = \frac{N_i}{F_{ai}} \pm M_i \frac{E_a(h_{oi} - z_{ci})}{\psi_{\mathrm{a}} B_i} \quad (3)$$

где i - I - for the inner layer, 3 - for the outer layer;

N_i, M_i — design longitudinal force and design bending moment in the i-th layer;

B_i - design bending stiffness of the i-th layer;

F_{ai} - design cross-sectional area of the reinforcement;

h_{oi} - the design distance from the center of gravity of the stretched reinforcement to the compressed edge of the concrete of the design reinforced concrete cross-section for the i-th layer of the layered panel;

z_{ci} - design height of the compressed concrete zone of the design reinforced concrete section of the panel or joint under the action of the design bending moment for the i-th layer of the layered panel.

4 Conclusion

During operation, the exterior walls of large-panel buildings experience, in addition to the force loads, also temperature and humidity effects. Correctness in determining the loads and effects has an impact on the safe operation of not only individual structural elements, which include the exterior walls, but also on the whole structural system of the building in which they participate.

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