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# Calculate the impact of climatic conditions on the structure of bending reinforced concrete FREE

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# Calculate The Impact of Climatic Conditions on The Structure of Bending Reinforced Concrete

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**Abstract.** The calculation of the thermally stressed state of reinforced concrete elements, taking into account the climatic conditions of a dry, hot climate, is one of the important tasks in the field of their design. The impact of climatic factors (intense solar radiation, daily and seasonal temperature changes, humidity) causes destructive processes and worsens the durability of reinforced concrete structures. This article proposes an improved engineering method for designing reinforced concrete beams, taking into account the influence of climatic conditions in a dry, hot climate. The proposed method takes into account the nature of changes in climatic factors and allows you to more accurately determine the thermally stressed state of the reinforced concrete element. This method is designed to more accurately determine the behavior of reinforced concrete elements under the influence of temperature fluctuations in climatic conditions of a dry, hot climate. This is especially important when designing and operating reinforced concrete structures that are not protected from solar radiation. The development of reliable criteria for assessing the thermally stressed state also plays an important role in predicting the durability of reinforced concrete structures and preventing unforeseen deformations, cracks and other destructive processes, ensuring their reliability and safety.
**Keywords:** calculation method, climatic factors, dry hot climate, deformation, movement, reinforced concrete element, thermally stressed state.



## INTRODUCTION

Reinforced concrete structures erected and operated in dry, hot climates are subjected to intense thermal influences, significant temperature fluctuations at low humidity and active solar radiation. The impact of a complex of climatic factors on the properties of concrete and reinforced concrete structures of buildings and structures causes the appearance of nonlinear and often alternating temperature stresses, forced deformations and microcracks in the concrete structure. Daily and seasonal temperature fluctuations, as well as the season of manufacture of reinforced concrete elements affect the strength and deformation characteristics of concrete reinforced concrete elements of buildings and structures [1-4].

According to V.M.Khudaverdyan [5], the strength of concrete made in summer in hot climates can decrease by up to 50% compared to the strength of concrete under standard conditions. V.A.Schmit's research [6], analyzing the influence of the amplitude of daily and seasonal temperature fluctuations and air humidity in a hot climate, which affects the strength of concrete, indicates that winter with high humidity and moderate temperature creates more favorable conditions for concrete solidification compared with the summer period. This statement is also confirmed by the results of research by other authors [7-11].

O.G.Tarasov's research [12, 13] has shown that each level of temperature and humidity corresponds to a certain optimal value of concrete strength. The strength and deformation characteristics of concrete are influenced by the composition of concrete, the size of concrete elements, the direction of exposure to solar radiation on the surface of the element, as well as the manufacturing season and loading time of reinforced concrete structures [14].

Cyclic heating and cooling of the structure under the influence of solar radiation leads over time to changes in the physical and mechanical properties of materials and other destructive phenomena. In this regard, one of the

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leading areas of research is theoretical and applied studies of the influence of climatic factors on the operation of concrete and reinforced concrete structures, including the development of reliable and objective methods for assessing the stress-strain state of structures of buildings and structures [15-20].

The analysis of the results of earlier studies and literature data showed the insufficiency of comprehensive studies covering the influence of climatic factors on the operation of reinforced concrete structures, namely the influence of cyclic daily and seasonal temperature fluctuations, as well as the lack of methods for calculating reinforced concrete structures taking into account the influence of climatic temperature.

The conducted studies clearly demonstrate that in real conditions the temperature field of concrete and reinforced concrete structures continuously changes in cross-section over time, being non-stationary and nonlinear [21-23]. The calculation of structures in such a sequential state can be carried out using a numerical method, the implementation of which requires theoretical approaches.

When calculating temperature stresses, the method of crushing the normal section of a reinforced concrete element into elementary parts, proposed by A.F. Milovanov [24], is taken into account and implemented in the normative documents CMC 2.03.04-84 "Concrete and reinforced concrete structures designed to work under conditions of exposure to elevated and high-temperature environments", and then in CMC 2.03.04-98 "Concrete and reinforced concrete structures reinforced concrete structures designed to work in conditions of exposure to elevated and high-temperature environments. " [5], this method is used to solve problems related to the effects of elevated temperatures on reinforced concrete structures. This method assumes a stationary effect of temperature and a one-way orientation of the structure relative to the temperature flow. This approach is quite acceptable for regulatory calculations, although it often contains significant simplifications [25]. The improved method proposed by us is based on dividing the section of the element into horizontal and vertical sections under the influence of heat flow by the volume of the element. This makes it possible to evaluate the stress-strain state of the normal section of a reinforced concrete element as a set of individual reduced sections subjected to heating with different temperature values for each cell [26]. This approach makes it possible to consider elements of almost any size and shape of the cross section when exposed to different heating directions. This method provides for the determination of the distribution of temperature fields in the sections of structural elements based on the theory of thermal conductivity and calculation of temperature fields. This allows you to accurately determine the temperature deformation, stress and displacement for each cell of the element during heating.



## THE ESSENCE OF THE CALCULATION METHOD

When calculating structures taking into account temperature influences, it is recommended to take into account both permanent and temporary loads in the most unfavorable combination. For a more accurate assessment of the stress-strain state of a reinforced concrete structure, the scheme of distribution of temperature fields along the section of the reinforced concrete element, as well as the strength characteristics of concrete, is taken into account.

The temperature distribution can be determined by solving the thermal conductivity equation under given initial and boundary conditions [8]. To do this, numerical methods are used to calculate temperature fields taking into account the complex geometric and physical characteristics of the structure. This method allows us to take into account the dynamics of temperature changes at various points of the structure and obtain more reliable results, which is important for ensuring the safety and durability of the considered reinforced concrete elements.

$$T = t \cdot (x, y, z, T = 0) \tag{1}$$

Equation (1) defines the initial condition for the calculation and assumes that the temperature is set in the volume of the structure at the initial time. Taking into account temperature influences, the dependence between deformations and stresses is established according to Hooke's law, according to the presented equation (2):

$$\varepsilon_{(x,y,z\ \ )} = \frac{1}{E} \cdot \left[\sigma_{(x,y,z)} - v \cdot \sigma_{(y,x,x)} + \sigma_{(z,z,y)}\right] + \alpha t \tag{2}$$

To calculate temperature stresses, it is necessary to know the temperature distribution over the section of the structure. The temperature difference in the section of the structure is used to determine changes in deformations. In turn, temperature stresses can be calculated from the resulting deformations (see Fig. 1). Temperature stresses in reinforced concrete structures are considered as a factor of elastic stress-strain state.

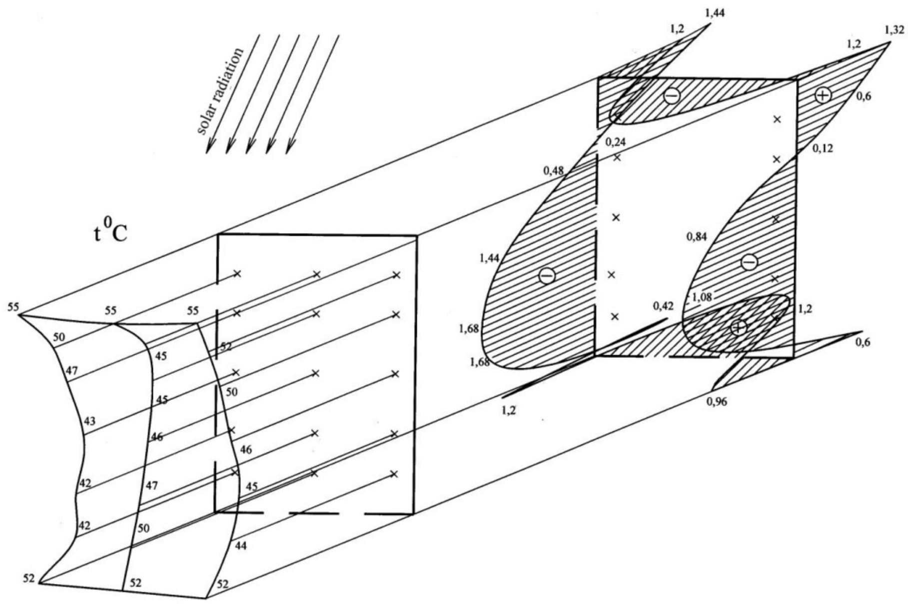


**FIGURE 1.** The change in the temperature of concrete t, $^0C$ and the temperature stress t along the section of the structure (at t = 400 $^0C$ and a time of 1600 hours).

Linear and volumetric temperature voltage  calculated by formulas (3), (4) respectively:

$$\sigma_{max} = E_b \cdot (t_2 - t_1) \;, \tag{3}$$

or $$\sigma_{max} = \frac{E_b \cdot \alpha \cdot (t_2 - t_1)}{1 - C \cdot \mu} \;, \tag{4}$$

where $E_b$ is the modulus of elasticity of concrete, is the coefficient of thermal expansion of concrete, $t_1$ and $t_2$ are temperatures at various points of the structure, is the Poisson's ratio, is the heat capacity of concrete. These factors, if they are not taken into account in the calculation, can negatively affect not only the strength, but also the rigidity of structures, especially their crack resistance. This may lead to an earlier achievement of the limit states for group II with the combined effect of stress and adverse environmental factors.

To do this, it is proposed to divide the section of the reinforced concrete element first into horizontal strips-sections, and then into vertical ones, so that the section is divided into several rectangular (square) elements with coordinates i, j (Fig.2,3). This makes it possible to take into account the change in temperature stresses more accurately, taking into account the direct impact of solar radiation during the operation of the structure in natural climatic conditions.

According to this method, it is proposed to divide the calculation into two stages: the first stage is short-term daily heating of the structure in summer and winter, the second stage is long–term heating in summer and cooling in winter in accordance with the calculated outdoor temperature.

To determine the temperature stresses, it is necessary to know the temperature distribution over the section of the structure. Due to the temperature difference along the section of the structure, it is possible to determine the values of deformations, and temperature stresses based on them. Temperature stresses in reinforced concrete structures are considered as a factor of elastic stress-strain state. The cross-sectional area of the cell is determined by the following formulas:

$$A_{red,i} = \frac{A_i \;\cdot \beta_{bi} \cdot \overline{v_i}}{\varphi_{bii}} \tag{5}$$

For fittings $$A_{s,red} = \frac{A_s \;\cdot E_s \cdot \beta_s}{E_b \cdot \varphi_{bi1}} \tag{6}$$

$$A'_{s,red} = \frac{A'_s \;\cdot E_s \cdot \beta_s}{E_b \cdot \varphi_{bi1}} \tag{7}$$

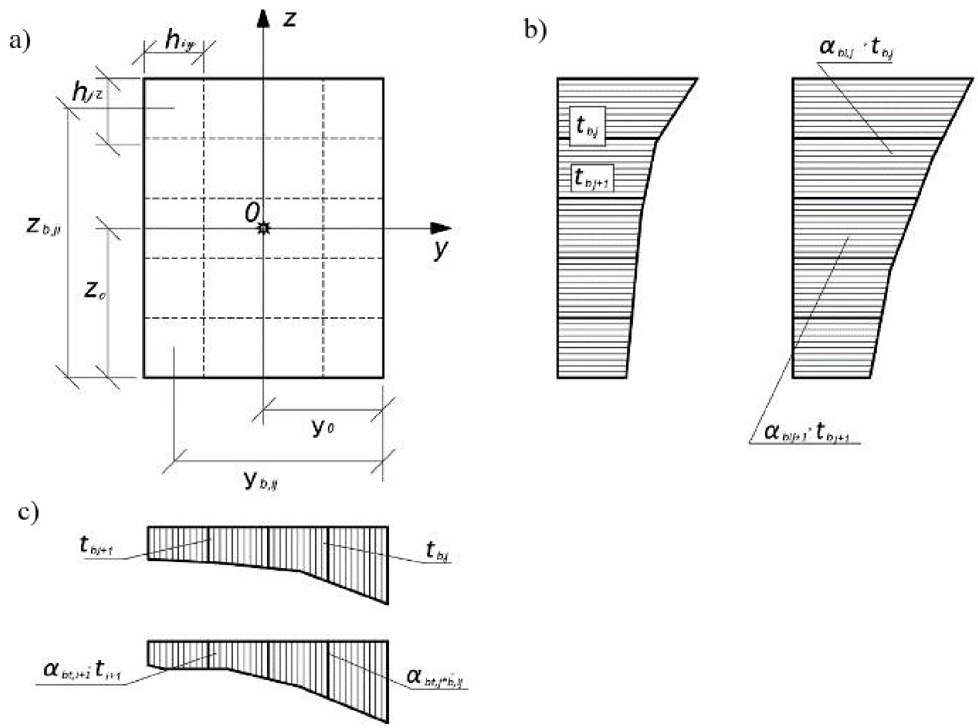


**FIGURE 2.** The scheme of temperature distribution over the sections of the element.
a) calculation Scheme, b) vertical effusions, c) horizontal effusions



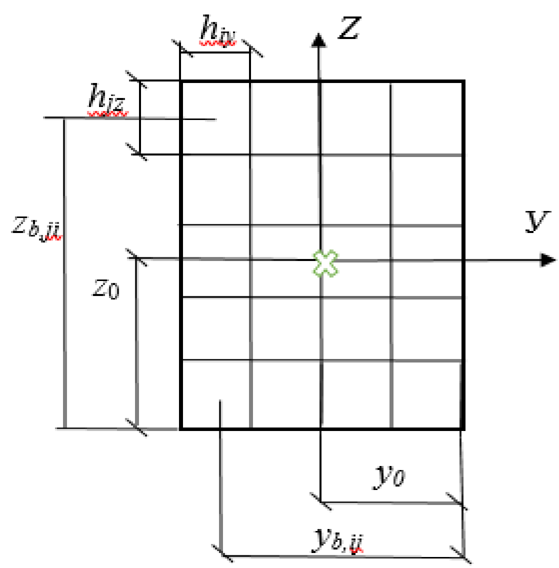


**FIGURE 3.** Calculation scheme. i, j are the coordinates of the element sections.

Temperature deformation for cell i, j according to Fig.3.

$$\varepsilon_t = \frac{\sum_{i,j=1.1}^{ny,nz} A_{red} \cdot \varepsilon_{t,ij} + A'_{s,red} \cdot \varepsilon_{s,red} + A'_{s,red} \cdot \varepsilon_s}{A_{red}} \tag{8}$$

Curvature along the Y and Z axes:

$$\left(\frac{1}{r}\right)_{t,y} = \frac{K_y + \sum_{i,j=1.1}^{ny,nz} A_{red,ij} \cdot z_{b,ij} \cdot \varepsilon_{t,ij} + \sum_{i,j=1.1}^{ny,nz} \left(\frac{1}{r}\right)_{f,i,j,y} \cdot J_{red,j,y}}{J_{red}} \quad (9)$$

$$\left(\frac{1}{r}\right)_{t,z} = \frac{K_z + \sum_{i,j=1.1}^{ny,nz} A_{red,ij} \cdot y_{b,ij} \cdot \varepsilon_{t,ij} + \sum_{i,j=1.1}^{ny,nz} \left(\frac{1}{r}\right)_{f,i,j,z} \cdot J_{red,j,z}}{J_{red}} \quad (10)$$

where $K_y$, $K_z$ - coefficients accepted according to CMC 2.03.04-98 [25].

Lengthening $\varepsilon_{t,ij}$ and curvature $\left(\frac{1}{r}\right)_{t,y}$, $\left(\frac{1}{r}\right)_{t,z}$ for the elementary part of the section (i, j):

$$\left(\frac{1}{r}\right)_{t,ij} = \frac{\alpha_{bt,i} \cdot t_{b,i} + \alpha_{bt,i+1} \cdot t_{b,i+1} + \alpha_{bt,j} \cdot t_{b,j} + \alpha_{bt,j+1} \cdot t_{b,j+1}}{n}$$

where n is the number of elementary sections along the Z axis (in this case n=4),

$$\varepsilon_{t,ij} = \frac{\alpha_{bt,i} \cdot t_{b,i} + \alpha_{bt,i+1} \cdot t_{b,i+1} + \alpha_{bt,j} \cdot t_{b,j} + \alpha_{bt,j+1} \cdot t_{b,j+1}}{n} \quad (11)$$

$$\left(\frac{1}{r}\right)_{t,ij,y} = \frac{\alpha_{bt,j} \cdot t_{b,j} - \alpha_{bt,j+1} \cdot t_{b,j+1}}{h_{i,z}} \quad (12)$$

$$\left(\frac{1}{r}\right)_{t,ij,z} = \frac{\alpha_{bt,j} \cdot t_{b,j} - \alpha_{bt,j+1} \cdot t_{b,j+1}}{h_{i,y}} \quad (13)$$

Armature extension: $\varepsilon_s = \alpha_{st} \cdot t_s \quad \varepsilon'_s = \alpha_{st} \cdot t'_s$ (14)

Values $A_{red}, A_{red,ij}, A_{s,red}, A'_{s,red}, y_{b,ij}, y_s, y'_s, z_{b,ij}, z_{s,ij}, J_{red}, J_{red,x}, J_{red,y}$

It is accepted according to CMC 2.03.04-98 [25] and according to the calculation schemes (Fig.2 and 3).

Consider the tensile stresses on the cell i,j when heated from the cross-section temperature:

$$\sigma_{bt,ij} = \left[\varepsilon_t - \varepsilon_{t,ij} + \left(\frac{1}{r}\right)_{t,ij,y} \cdot z_{b,ij} + \left(\frac{1}{r}\right)_{t,ij,z} \cdot y_{b,ij}\right] \cdot E_b \cdot \beta_{b,ij} \cdot \overline{v}_{b,ij} \quad (15)$$

Compressive stresses during short-term heating:

$$\sigma_{b,ij} = \frac{N_x}{A_{red}} + \left(\frac{M_y}{B_y} \cdot z_{b,ij} + \frac{M_z}{B_z} \cdot y_{b,ij}\right) E_b \cdot \varepsilon_{b,ij} \cdot \overline{v}_{b,ij} \quad (16)$$

Tensile stress during cooling due to shrinkage and creep in concrete:

$$\sigma_{csc,ij} = \left[\varepsilon_{csc} - \varepsilon_{csc,ij} - \varepsilon_{c,ij} + \left(\frac{1}{r}\right)_{crc,ij,y} \cdot z_{b,ij} + \left(\frac{1}{r}\right)_{crc,ij,z} \cdot y_{b,ij}\right] \cdot b_b \quad (17)$$

Here are My, Mz, Nx bending moments along the Y and Z axes and the longitudinal force

When the reinforced concrete element cools down, the strain dependences have the following form (for elements without cracks in the stretched zone):

- axial deformation of the element

$$\varepsilon_{csc,ij} = \frac{\sum_{i,j=1.2}^{ny,nc} A_{red,ij} \cdot \varepsilon_{red,ij}}{A_{red}} \quad (18)$$

curvature of a reinforced concrete element with uneven heating of the section along the Y, Z axes:

$$\left(\frac{1}{r}\right)_{csc,y} = \frac{\sum A_{red,y} \cdot \varepsilon_{csc,ij} \cdot z_{b,ij}}{J_{red}} + \frac{\sum \left(\frac{1}{r}\right)_{csc,ij,y} \cdot J_{red,ij,y}}{J_{red,y}} \quad (19)$$

$$\left(\frac{1}{r}\right)_{csc,z} = \frac{\sum A_{red,z} \cdot \varepsilon_{csc,ij} \cdot z_{b,ij}}{J_{red}} + \frac{\sum \left(\frac{1}{r}\right)_{csc,ij,z} \cdot J_{red,ij,z}}{J_{red,z}} \quad (20)$$

Deformation during cooling (reduction) $\varepsilon_{csc,ij}$ and curvature $\left(\frac{1}{r}\right)_{csc,y}$, $\left(\frac{1}{r}\right)_{csc,z}$ the elementary section i, j is determined by the formula:

$$\varepsilon_{csc,i,y} = \frac{\alpha_{cs,i} + \varepsilon_{c,i} + \alpha_{cs,i+1} \cdot t_{b,i+1} + \alpha_{cs,j} \cdot t_{b,j} + \alpha_{cs,j+1} \cdot t_{b,j+1}}{n} + \frac{\alpha_{cs,j} \cdot t_{b,j} + \varepsilon_{c,i} + \varepsilon_{c,j+1} + \varepsilon_{c,j} + \varepsilon_{c,j+1}}{n} \quad (21)$$

$$\left(\frac{1}{r}\right)_{csc,ij,y} = \frac{(\alpha_{cs,j} \cdot t_{b,j} + \varepsilon_{c,j}) - (\alpha_{cs,j+1} \cdot t_{b,j+1} + \varepsilon_{c,j+1})}{h_{j,z}} \quad (22)$$

$$\left(\frac{1}{r}\right)_{csc,ij,z} = \frac{(\alpha_{cs,i} \cdot t_{b,i} + \varepsilon_{c,i}) - (\alpha_{cs,i+1} \cdot t_{b,i+1} + \varepsilon_{c,i+1})}{h_{j,y}} \quad (23)$$

The reduced cross-sectional area is determined by the formula

$$A_{red} = \sum_{i,j=1}^{ny} A_{red,i,j} + A_{s,red} + A'_{s,red} \quad (24)$$

The coordinates of the center of gravity: $Y_{0,}Z_0$ are determined by the formula:

$$Y_0 = \frac{S_{red,y}}{A_{red,y}} \qquad Z_0 = \frac{S_{red}}{A_{red,y}} \tag{25}$$

The static moment of the reduced section has the form

$$S_{red,z} = \sum A_{red,ij} \cdot Y_{b,ij} + A_s \cdot Y_{s,i} + A'_s \cdot y'_{s,i} \tag{26}$$

$$S_{red,y} = \sum A_{red,ij} \cdot Y_{b,ij} + A_s \cdot Y_{s,i} + A'_s \cdot y'_{s,i} \tag{24}$$

accordingly, the moment of inertia:

$$J_{red,y} = \sum J_{red,i,j,y} + \sum A_{red,ij} \cdot Z^2_{b,i,j} + A_{s,red} \cdot Z^2_{,s} + A'_{red,i,} \quad \cdot Z'_{s,red} \cdot (Z'_S)^2 \tag{28}$$

$$J_{red,z} = \sum J_{red,z} + \sum A_{red,ij} \cdot y^2_{b,i,j} + A_{s,red} \cdot y^2_{,s} + A'_{red,i,} \quad \cdot Z'_{s,red} \cdot (y'_S)^2 \tag{29}$$

$$y_{bi,j} = y_{ij} - y_o \quad Z_{bi,j} = z_{ij} - z_o$$

$$J_{red,ij,y} = \frac{A_{red,ij} \cdot h^2_{i,z}}{12}, \quad J_{red,ij,z} = \frac{A_{red,ij} \cdot h^2_{i,y}}{12}$$

## CONCLUSION

The practical use of this technique allows us to determine the actual temperature stresses, deformations, and displacements in reinforced concrete elements for each cell during heating and cooling of the structure. The calculation model, which includes the division of the section into elementary sections-cells, takes into account the uneven temperature distribution over the section of the element, as well as the nonlinearity of temperature changes and temperature deformations in the body of the structure. Studies have confirmed that the temperature field of concrete and reinforced concrete structures in real conditions continuously changes in cross-section over time, being non-stationary and nonlinear.

Due to the effects of solar radiation at large temperature differences, a complex stress state and significant deformations along the cross section of the element occur. For a reliable assessment of the stress-strain state of the structure, taking into account climatic temperature influences, as well as to determine its strength and crack resistance, information on the distribution of temperature fields in the section of the element is necessary. Based on the calculated data, diagrams of temperature changes, deformations and stresses of normal sections of a reinforced concrete element in the horizontal and vertical planes at characteristic points are constructed. These diagrams allow us to estimate the dynamics of temperature changes, deformations and stresses in three-dimensional coordinates along the section of the element.

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