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ASSESSMENT OF THE THERMO-STRESSED STATE OF A REINFORCED CONCRETE FOUNDATION SLAB

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Abstract. A common phenomenon in the construction practice of massive concrete structures is the formation of cracks during the process of gaining strength. The main reason for the formation of these cracks is the uneven distribution of temperatures in the mass of the structure, which occurs mainly due to the heat release of concrete during the exothermic reaction between water and cement.

Temperature impact is primarily associated with daily and seasonal changes in ambient temperature during the operation of a building or structure. External temperature factors can also act in combination with a certain (increased) thermal regime and other external factors that occur during the operation of a construction object.

The most favorable operating conditions for construction objects are formed under stationary temperature effects on them, under conditions of stable operation, when they are in relatively constant temperature conditions for a long time.

The example of a foundation slab shows the difference in the stress-strain state with different methods of applying temperature loads to the structure.

Technological solutions are proposed for constructive measures to level the impact of temperature loads on individual building structures (to minimize the difference between the temperature of the surrounding environment and connecting elements), for example, by final monolithic expansion joints after the construction of the entire frame and stabilizing the temperature of all structures and the environment.

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Heat generation processes in concrete structures, their kinetics and stages, and their dependence on the mineralogical composition of the cement are examined. The temperature regime of reinforced concrete foundation slabs and the main causes of cracks in massive reinforced concrete structures are also analyzed.

The need to use effective methods for assessing the thermal stress state of reinforced concrete foundation slabs at an early stage of concrete hardening prompts scientists to develop methods for analyzing the stress-strain state of reinforced concrete foundation slabs when exposed to temperature loads during the strength gain process.

Keywords: temperature deformations; stress-strain state; reinforced concrete foundation slab; technical operation; construction production technology.

INTRODUCTION

The kinetics of heat release of concrete is divided into several stages (fig.1):

1) Initial hydrolysis. Lasts the first 30 minutes from the start of mixing the mixture, characterized by a rapid increase in the temperature of the mixture by several degrees. The rapid reaction occurs as a result of the dissolution of ions in water and the reaction between tricalcium aluminate and gypsum.

2) Induction period (rest period). Lasts up to 4 hours after mixing. During the rest period, cement hydration stops, the concrete becomes fluid, and is most convenient to place. The temperature of the mixture practically does not change (if there is no heat loss), since heat release is extremely low. As the dissolution of ions continues over time, the concentration of tri- and dicalcium silicate ions in the concrete system increases.

3) Accelerated hydration period. At the end of the rest period, significant hydration begins again due to the interaction of tri- and dicalcium silicates. This period is characterized by a sharp increase in the rate of heat release and strength gain, which lasts up to 12 hours after mixing.

4) Slowdown period. As time increases, the rate of heat release gradually slows down. This period is characterized by a slow decline in the rate of heat release and strength gain, which lasts up to 4 days after mixing.

5) Period of slow strength gain (diffusion control phase). Finally, cement hydration reaches a steady state, slow heat release and strength gain occurs.

In Ukrainian practice, a classical model is used to describe heat release curves, on the basis of which new computer algorithms for calculating thermal stresses are built. [1]:

$$Q = Q_{\max} \cdot \left[1 - (1 + A_t \cdot \tau)^{\frac{1}{m-1}}\right], \qquad (1)$$

where:

$Q_{\max}$ – complete heat release of concrete;

A_t – coefficient characterizing the rate of heat release at the temperature *t;*

m – order of hydration reaction;

τ – time elapsed since solidification.

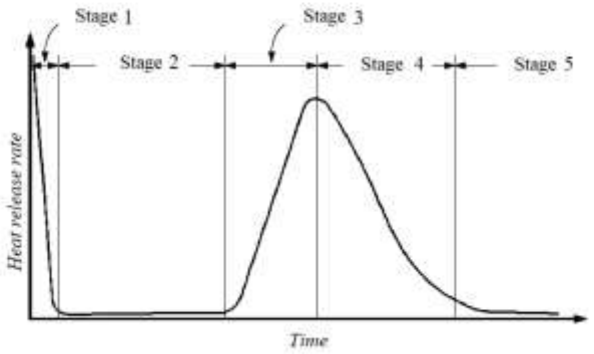

Fig. 1 Dependence of heat release rate of concrete on time

Рис.1 Залежність швидкості тепловиділення бетону від часу

Zaporozhets' equation should be used when describing the heat release of concrete older than 3 days, since there is a large error at the early stages of hydration. The type of curve obtained by the I.D. Zaporozhets' equation is shown in Fig. 2.

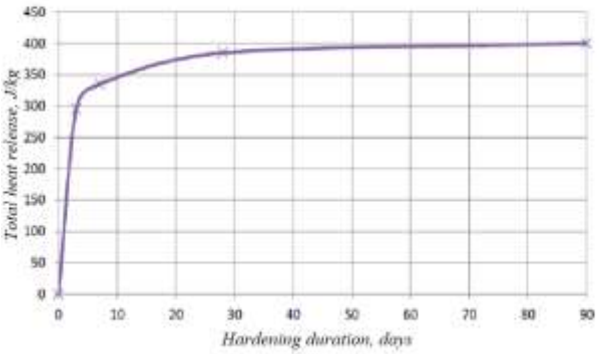

Fig. 2 Heat release curve according to the equation of I.D. Zaporozhets

Рис.2 Крива тепловиділення за рівнянням І.Д. Запорожця

Thus, the main factors influencing the heat release of concrete can be identified:

1) The specific content of cement per unit volume of concrete mix. An increase in the cement content causes an increase in the heat release of the concrete mix, since it is the basis for the heat release of concrete.
2) The type of cement. The heat release depends on the chemical and mineralogical composition (for example,

slag Portland cement has 15% less heat release).

3) Initial temperature of the concrete mix. The hydration process depends on the temperature of the concrete mix, thus, by regulating its initial temperature, it is possible to control the intensity of further heat release.
4) Fineness of grinding. The rate of the hydration process is proportional to the fineness of the cement grinding, since its specific surface area increases.
5) Water-cement ratio. Depending on the temperature of the mixture, the water-cement ratio affects the rate of heat release differently. Thus, at low temperatures (20-40 degrees Celsius), a high w/c ratio increases the rate of heat release, at high temperatures (60-90 degrees Celsius) there is an inverse relationship.
6) The presence of accelerators or retarders in the composition of hardening. The presence of additives accordingly affects the rate of heat release. The further in time the set of design strength by concrete is delayed, the better the temperature regime of the structure will be.

The main reason for the formation of temperature cracks is the uneven distribution of temperatures in the structure massif. Since foundation slabs are usually protected from the effects of high temperatures, their thermal cracking in the early stages occurs mainly due to the heat release of concrete during the exothermic reaction between water and cement. The temperature difference causes the colder part of the massif to compress more than the warmer part, which leads to the appearance of tensile stresses [1].

There are 3 types of uneven temperature distribution:

1) Between the center of the element and the upper face. It occurs due to heat transfer to the environment through the upper face of the element. It increases at negative air temperatures.
2) Between the center of the element and the lower face. There is contact of the lower face of the element with the soil. The soil has a low temperature and high heat capacity; it takes up a large portion of heat in the first stages of hardening and gives off the accumulated energy at subsequent stages. Thus, it can overcool the lower face in the initial stages, when the center of the element is the hottest part, and overheat it in the final stages, when heat transfer is insignificant, and the center of the element has a low temperature.
3) Between the center and the side faces. It occurs due to contact of the side surface of the massif with the environment. Similarly to the first option, it increases at negative temperatures.

Thermal cracking caused by excessive temperature changes in cast-in-place concrete manifests itself as random cracking on the surface of the element. Thermally induced staggered or patchy cracking usually occurs within a few days of formwork removal [1].

The key to reducing thermal cracking is to identify the causes that may cause it and take steps to minimize it.

Common methods for reducing temperature changes in massive reinforced concrete structures [1, 2, 3] are:

1) Concrete mix adjustment - reducing the heat of hydration by optimizing the binders by using fly ash or slag, as well as using chemical additives that slow down the setting of concrete. According to research results [1], when using 65% slag cement in the mixture, the peak temperature of the structure decreased by 10.5 degrees Celsius, and when using 80% slag cement - by 23 degrees Celsius.
2) Control of the temperature of the concrete mass:
   a) Setting the temperature requirements for concrete at the time of delivery to the construction site;
   b) Thermal insulation by warming the edges of the massif;
   c) Use of cooling pipes.
3) Preliminary preparation - the temperature difference between the center of the element and its bottom edge can be reduced by preheating the base or

warming the lower layers of the structure before installing the main layers of the concrete mass.

ANALYSIS OF LATEST RESEARCH AND PUBLICATIONS

An assessment of existing methods for calculating thermal stresses during concreting of massive reinforced concrete foundation slabs has been carried out [4].

In general, many research works are devoted to modeling the above-mentioned issues. It should be noted that the full modeling of these effects requires interdisciplinary knowledge covering hygrothermal, chemical and mechanical issues. In this context, many works are devoted to the mathematical formulation of heat transfer and mechanical effects in early-age concrete [5-9]. The finite element method (FEM) is often used to solve such complex mathematical equations [10-13].

Concreting of massive monolithic reinforced concrete structures is associated with the risk of early cracking caused by temperature and shrinkage deformations, especially in high-strength concretes.

Therefore, an important task is to regulate the temperature regime during concrete curing [1]: “In massive monolithic structures, measures should be taken to reduce the effects of temperature and humidity-induced stress fields by maintaining the specified temperature regime.”

It is noted that "the cooling rate of concrete in massive structures should not exceed the value determined by calculation and ensures the absence of cracks in the surface layers of concrete" [1, 2].

As technological measures for regulating the temperature regime of hardening, it is recommended to “heat the peripheral part during the heating period of the concrete mass due to the exothermicity of the cement (approximately from 1.5 to 3.0 days) to level the structure by more than 5 °C/h after reaching the maximum temperature”.

According to [1], to regulate the temperature regime of concrete aging during the construction of massive structures, it is advisable to combine prescriptions, in particular, the use of low-thermal cements in combination with limiting the cement content in the concrete mix and introducing hardening retarding additives and technological factors, for example, regulating heat loss temperatures [2, 3].

Modern technology allows, by controlling the recipe factors, to provide the necessary technological parameters in a wide range depending on the temperature conditions, the features of the structure being erected and the capabilities of the manufacturer of the works. Numerous data, some of which are presented in Table. 1, obtained both as a result of the examination of real structures and as a result of modeling the temperature regime and the stressed-deformed state in the early period of the construction of massive monolithic reinforced concrete structures, indicate the relevance of the problem.

Since temperature gradients are one of the main causes of stress formation, an important task is to improve the algorithm for calculating temperature stresses, which includes calculating temperature fields in the early period of construction of the structure, taking into account the kinetics of heat release of concrete, heat transfer conditions, and ambient temperature.

In particular, it was established that the tensile stress value of concrete exceeded its tensile strength limit after approximately 3.5 days of aging. During studies using unique equipment, it was recorded that for concrete with a design strength of 80 MPa, the tensile stress value (≈ 3 MPa) exceeded the tensile strength limit after approximately 54 hours of aging.

In [6], for tensile stresses on the upper surface of the slab after 72 h, which corresponded to the maximum temperature in the center of the slab, the value of tensile stresses of 2.43 MPa was obtained, which is comparable to the axial tensile strength of concrete of class C20/25 at the design age.

Taking into account the large number of mix-design and technological factors affecting the formation of temperature fields during the construction of massive reinforced concrete structures, this study employs a developed methodology for calculating temperature fields to perform a numerical simulation. The simulation is carried out using a temperature block of a foundation slab measuring 20 × 20 × 2 m (h), with a surface modulus of 1.2 m^{-1}.

The influence of the following technological factors is considered. These include the layer overlapping time ranging from 2 to 24 h and the ambient temperature ranging from 5 °C to 35 °C. The temperature of the concrete mixture is assumed to be 10 °C at an ambient temperature of 5 °C and 25 °C at 35 °C. The heat transfer coefficient varies from 1 to 23 W/m²·K. The concrete compressive strength class ranges from C20/25 to C35/45, and the hardening kinetics vary from rapid to slow.

Table 1. Data on temperature conditions during the construction of massive reinforced concrete structures
Табл. 1. Дані щодо температурного режиму при зведенні масивних залізобетонних конструкцій

№	Structure	Module, m^{-1}	Concrete	Temperature, °C			Time T_c/T_s max	T_{aver}
				Concrete mix	structure			
					center	surface		
Measurement results in structures								
1	4,5x4,5x2(h)	1,9	B25	-	47	-	29	12...30
2	16x9x2,5(h)	1,4	B30	16	69,5	38,7	54/62	4...15
3	16x9x2,5(h)	1,4	B30	29	71,1	54,3	26/34	21...34
4	12,2x11,1x3,5	1,4	B30	13...17	66,0	47,0	48/20	7...17
5	10,2x2,3x1,5	2,4	B45	24	56,0	49,0	37/37	14...27
6	33,7x5,2x2(h)	1,4	B45	8	58,6	40,2	39/37	11...18
7	28,7x4x2(h)	1,6	B45	15	56,4	40,0	32/36	8...13
8	32x16x1(h)	2,2	B30	18	44,6	36,8	24/40	11...20
According to numerical simulation data								
9	D=52, h=2	< 1,1	B35	-	≈64,5	≈29	≈75/52	≈19...27
10	h=1	-	B70	-	≈62	-	≈24/-	-
11	h=2	-	B30	-	≈63,8	≈28,2	≈72/48	-
12	h=1,4 h=1,5	-	B35 B40	-	≈73 ≈48	-	≈60/- ≈60/-	-
Note. B25 (C20/25), B30 (C 25/30), B 35 (C28/35), B40 (C32/40), B45 (C35/45), B70 (C55/67).								

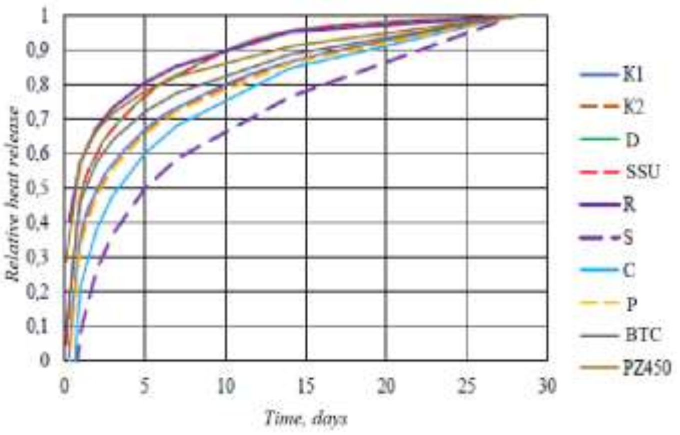

Fig. 3 Relative heat release of concretes
K1, K2 – Kardumyan G.S., D – Dobretsova; R, S – dependencies adopted for modeling (R) – fast and (S) slow-hardening concrete; BTC – according to data Kravchenko I.V., PZ450 – according to data Lur H.P, Efes Ya

Рис. 3 Відносне тепловиділення бетонів
К1, К2 – Кардумян Г.С., Д - Добрецова; R, S – залежності, що прийняті для моделювання (R) – швидко та (S) повільнотвердіючого бетону; БТЦ – згідно данних Кравченко І.В., PZ450 – згід но даних Люр Х.П, Ефес Я

Modeling of the temperature regime of the thermal-shrinkage block was performed together with the soil massif, while the soil temperature at a sufficient distance was assumed to be given and constant. Since, except for the edges of the foundation slab, the temperature distribution across the cross section is one-dimensional, the differential equation for heat conductivity looks as follows:

$$\lambda\left(\frac{\partial^2 \mathrm{T}}{\partial x^2}+\frac{\partial^2 \mathrm{T}}{\partial y^2}+\frac{\partial^2 \mathrm{T}}{\partial z^2}\right)+Q=\rho\cdot c\cdot\frac{\partial \mathrm{T}}{\partial t} \qquad (2)$$

taking into account the boundary conditions for convective heat exchange with the environment on the upper and side surfaces of the foundation in the form of:

$$\lambda\frac{\partial \mathrm{T}}{\partial n}+h\left(\mathrm{T}-\mathrm{T}_\infty\right)=0 \qquad (3)$$

to define a function *T(z, t)* can be taken to view:

$$\lambda(z,t)\frac{\partial^2 T}{\partial z^2}+Q=\rho\cdot c\cdot\frac{\partial T}{\partial t}, \qquad (4)$$

formulas (2) - (4) are designated:
λ – thermal conductivity coefficient;
T – temperature;
Q – density of internal heat sources;
ρ – material density;
c – specific heat capacity;
t – time;
n – normal to the surface;
h – heat transfer coefficient;
T_∞ – ambient temperature.

When implementing a numerical experiment to calculate the kinetics of heat release of concrete in a temperature-shrinkage block, the dependence (5) was used:

$$Q_\tau=Q_{28}\cdot\exp\left(k\cdot\left(1-\left(\frac{28}{\tau}\right)^x\right)\right), \qquad (5)$$

in which the values of the parameters *k* and *x* are obtained as a result of processing the data on the kinetics of heat release of various concretes presented in Fig. 3.

Fig. 4 presents data on the temperature change in the center of the structures listed in Table 1 and the results of modeling using the method for fast- and slow-hardening concretes of classes C20/25 and C35/45. In addition to the massiveness of the structure, factors such as the concrete class (i.e., the cement content and, therefore, the total amount of heat released during the hydration process) and the kinetics of concrete hardening (i.e., the intensity of heat release) have a significant impact on the temperature change.

The number of factors and their significant influence on the formation of temperature fields determines the relevance of modeling in studying the influence of recipe and technological factors on temperature fields and stresses during the construction of structures.

Since the cause of early cracking of massive monolithic structures is stresses arising from temperature gradients, the current task is to estimate their magnitude depending on the formulation and technological factors.

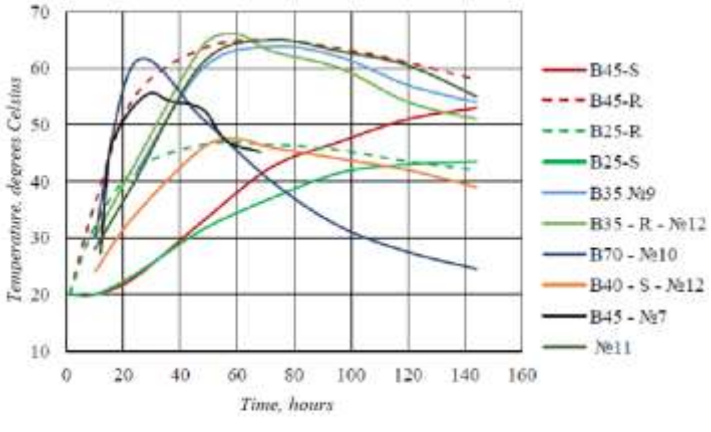

Fig. 4 Temperature change in the center of the structure according to Table 1

Рис. 4 Зміна температури в центрі конструкції за даними табл. 1

During concreting, due to the exothermic reaction of cement paste hardening, the self-heating effect increases [1, 2]. In massive structures, unlike thin-walled ones, only the surface layers cool, while in the center of the concreting block there is significant heating and expansion. As a result, tensile stresses arise in the surface layers of the structure, which lead to the formation of thermal cracks [4].

The greater the temperature difference between the block and the environment, the greater the temperature difference between the core of the massif and its edges. Cracks are dangerous because they contribute to the loss of strength and rigidity of the structure, acceleration of reinforcement corrosion and violation of tightness, which is unacceptable in hydraulic structures and in critical parts of structures, such as foundations [2].

Without the appointment of special measures to regulate the temperature regime of hardening of the concrete mixture, cracking cannot be avoided [1]. The temperature effects of the construction period are determined taking into account exotherm and other conditions of hardening of concrete, including design and technological measures to regulate the temperature regime of the structure, outdoor air temperature, etc.

The modeling of changes in ambient temperature over a certain period (day, year, month) and the assessment of the impact of this fluctuation are the works of both domestic and foreign authors. In the calculations of the thermal stress state and thermal crack resistance of massive concrete structures during the construction period, air temperature, along with the initial data on the geometric shape and characteristics of concrete, is the main factor [1]:

- the greater the temperature difference between the concreting block and the surrounding environment, the greater the temperature difference between the core of the block and its faces, which leads to the development of stresses in the structure;
- the influence of air temperature on the process of heat release of concrete: laboratory and field studies have shown that the higher the hardening temperature, the more intensively the heat release process occurs;
- the effect of air temperature on the growth of the concrete modulus of deformation: as the temperature increases, the rate of increase in the modulus of deformation increases, i.e. the aging process is more intense;
- the effect of air temperature on the creep of concrete: an increase in temperature affects the rate of creep deformation and its limit values.

Previously, in studies of the distribution of temperature fields and thermal stress, some constant, average monthly air temperature was given. However, there is a daily course. Accounting for the influence of variable air temperature is a complex dynamic process, containing both explicit, described by mathematical formulas, and random components.

Since most of the currently used methods and software packages do not take this into account, the current task is to improve the method for calculating the thermal crack resistance of massive concrete structures of buildings and structures in order to increase their reliability.

PURPOSE AND OBJECTIVES OF THE RESEARCH

The goal and task are to conduct a finite element analysis of the stress-strain state of the building foundation slab taking into account the climatic effect. The calculation of the foundation slab for temperature effects was implemented in the "LIRA FEM" software package.

The calculation of the foundation slab for climatic impact was performed on the temperature difference from the average temperature of the foundation slab at the age of 28 days, which is 45.1 °C, to the average annual temperature in Kyiv – 7.0 °C.

The calculation was performed to verify the specified reinforcement of the foundation slab and to analyze its stress–strain state under climatic influences. This was necessary because the spatial planning and design solutions did not provide for the installation of a temperature joint in a monolithic reinforced concrete building exceeding 50 m in length, which, according to regulatory requirements, necessitates appropriate calculations, including those for temperature effects.

RESEARCH METHODOLOGY

The materials of the foundation slab are concrete C20/25 and reinforcement of class A500C reinforcement with a diameter of 12 mm. The reinforcement pitch is 200 mm in both directions.

The formation of cracks is assumed when the main tensile relative deformations exceed the ultimate tensile strength of concrete. Since the cooling of the foundation slab is a rapid process (relative to the total residential cycle of the structure), the ultimate tensile strength of concrete is taken in accordance with [17] as under short-term loading equal to $\varepsilon_{bt,1}=1\cdot 10^{-4}$.

The standard values of changes in average temperatures across the cross-section of the element in the warm Δt_w and cold Δt_c periods of the year are determined by formulas (6), (7):

$$\Delta t_w - t_{0c} = 29{,}1 - (-11{,}9) = 41°C \qquad (6)$$

$$\Delta t_c = t_c - t_{0w} = 20 - 13 = 7°C\,. \qquad (7)$$

where t_w - normative value of average temperatures across the cross-section of the element in the warm zone, which is determined in accordance with regulatory documents;

t_c - normative value of average temperatures across the cross-section of the element in the cold period of the year, determined in accordance with regulatory documents;

t_{0w} - initial temperature in the warm period of the year, which is taken in accordance with DSTU-N B V.1.1-27:2010 "Construction Climatology" [25];

t_{0c} - initial temperature in the cold period of the year, which is taken in accordance with [25].

The initial temperature corresponding to the closure of the structure or its part into a complete system in the warm t_{0w} and cold t_{0c} periods of the year is determined by formulas (8), (9):

$$t_{0w} = 0{,}8t_{VII} + 0{,}2t_I = 0{,}8(21{,}3) + \\ + 0{,}2(-20{,}2) = 13°C; \qquad (8)$$

$$t_{0c} = 0{,}2t_{VII} + 0{,}8t_I = 0{,}2(21{,}3) + \\ + 0{,}8(-20{,}2) = -11{,}9°C; \qquad (9)$$

The increment θ_4 and θ_5 °C are determined by formulas (10), (11):

$$\theta_4 = 0{,}05\rho S_{\max} k = 0{,}05\cdot 0{,}7\cdot 895\cdot 0{,}4 = \\ = 12{,}53°C; \qquad (10)$$

$$\theta_5 = 0{,}05\rho S_{\max}(1-k) = 0{,}05\cdot 0{,}7\cdot 895\cdot \\ \cdot(1-0{,}4) = 18{,}80°C; \qquad (11)$$

where ρ - solar radiation absorption coefficient by the material of the outer surface of the structure;

$S_{\max}$ - maximum value of total (direct, diffuse and reflected) solar radiation, W·h/m², accepted for horizontal surfaces according to tables DSTU-N B V.1.1-27:2010 "Building Climatology";

k - coefficient taken from reference tables.

Calculated values of the change in average temperatures across the cross section of the element:

- in the warm period of the year:

Δt_w = 41 · 1,1 = 45,1 °C;

- in the cold period of the year:

Δt_c = 7,0 · 1,1 = 7,7 °C.

A monolithic foundation slab with a thickness of $h = 500$ mm and a length of $l = 76{,}1$ m is shortened by the value

$$\Delta_f = \alpha \Delta t_l = 1{,}0 \cdot 10^{-5} \cdot 45{,}1 \cdot 7610 = 3{,}43 \text{ cm},$$

where α - coefficient of linear expansion of concrete at temperatures ranging from -40 to +50 °C for heavy concrete.

To calculate temperature effects, LIRA FEM implements 2 methods of setting temperature loads for both plate SEs and rod SEs, which allow modeling any temperature effect:

- uniform heating/cooling;
- temperature bending.

When the temperatures of the upper and lower fibers of a symmetrical cross-section are equal in magnitude and sign, this is analogous to uniform expansion or contraction of the fibers along the axis of the rod. This results in tensile or compressive stresses in a statically indeterminate system, or corresponding deformations in a statically determinate system.

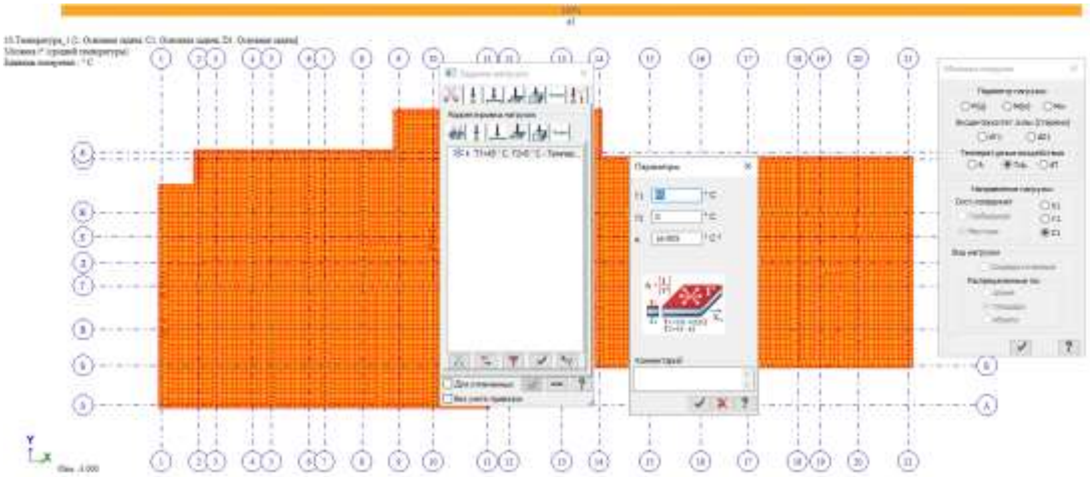

Fig. 5 Setting uniform heating of the foundation slab
Рис. 5 Завдання рівномірного нагріву фундаментної плити

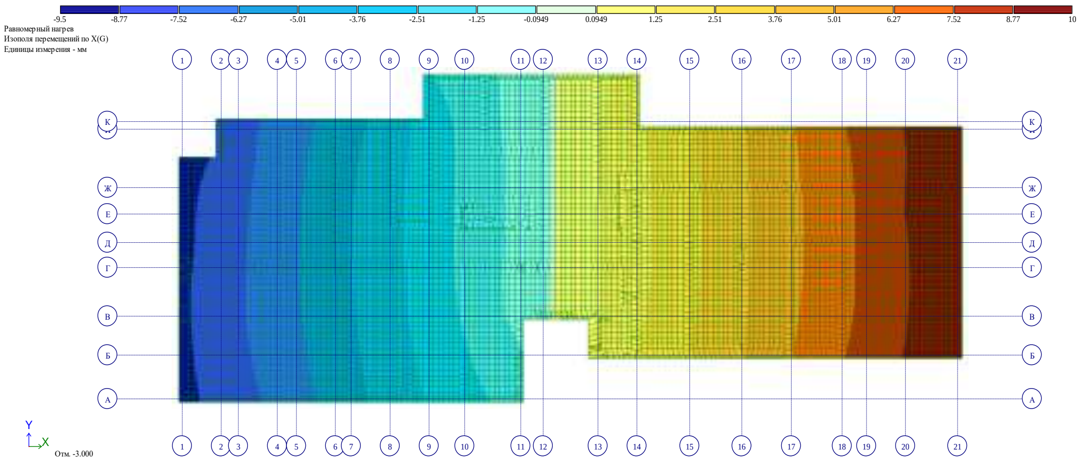

Fig. 6 Horizontal movements of the foundation plate along the X axis as a result of uniform heating
Рис. 6 Горизонтальні переміщення фундаментної плити по осі X в результаті рівномірного нагріву

If the rod is subject to temperature changes, the hotter fibers of its cross section will be compressed, and the less hot ones will be stretched - this is thermal bending.

It should be noted that the principle of setting temperature effects in LIRA FEM is somewhat different from the requirements of the standards and is universal in nature.

We determine the elongation of the foundation slab at the cracking stress N_{crc} immediately before cracking:

$$N_{crc} = f_{ctd} \cdot A_b = 10{,}50 \cdot 5000 = 52500\ kgf.$$

The deformability of the foundation slab in tension is determined when the modulus of deformation of concrete in tension E_{bt} is equal to [17]:

$$E_{bt} = 0{,}5E_b = 0{,}5 \cdot 3{,}0 \cdot 10^5 = 1{,}5 \cdot 10^5\ kgf/cm^2.$$

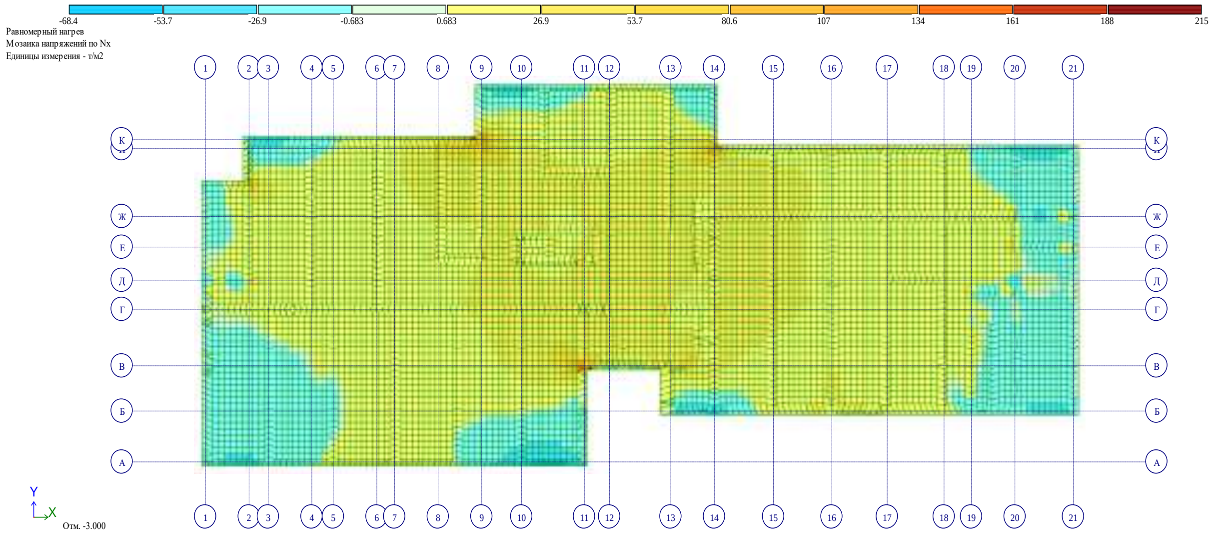

Fig. 7 Tensile forces in the foundation slab as a result of uniform heating
Рис. 7 Зусилля розтягу в фундаментній плиті в результаті рівномірного нагріву

Immediately before cracking occurs at a stress N_{crc} the elongation of the foundation slab Δf^* is equal to:

$$\Delta f^* = \frac{N_{crc} l}{\left(E_{bt} A_b\right)} = \frac{52500 \cdot 7610}{1{,}5 \cdot 10^5 \cdot 5000} = 0{,}53cm. \tag{12}$$

Оскільки:

$$\Delta f^* = 0{,}53см \lhd \Delta f = 3{,}43cm, \tag{13}$$

then at N=N_{crc} the process of opening transverse cracks will begin, which will continue until the elongation of the slab reaches a value of 3.43 cm. The distance between the cracks during stretching of the foundation slab is equal to:

$$l_{crc} = \frac{\eta \cdot A_b}{S} = \frac{0{,}7 \cdot 5000}{37{,}68} = 92{,}89cm, \tag{14}$$

where $\eta = 0{,}7$ – experimental coefficient for periodic profile reinforcement;
s– perimeter of reinforcement (when reinforcing the upper and lower zones of the slab with 5 rods with a diameter

$$d = 1{,}2см - s = 10\pi d = 10 \cdot 3{,}14 \cdot 1{,}2 = 37{,}68cm.$$

The short-term opening of transverse cracks is taken to be equal to a_{crc} = 0,158 mm. Then, on the length of the foundation slab 76.1 m, approximately 82 transverse cracks with a total opening width of 1.30 cm can occur, which is less than $\Delta f = 3{,}43cm.$ (the obtained reduction of the floor slab in the PC LIRA FEM software complex is 1.0 cm). Thus, the compressive shortening of the foundation slab at the calculated value of the change in average temperatures across the cross-section of the element will be completely extinguished within the transverse cracks that have formed.

Since, in addition to temperature effects, other loads act on the slab, the floor slab develops cracks from bending, but the flexibility of the foundation slab in the horizontal direction does not decrease.

As calculations show, with the joint action of bending and stretching on the foundation slab from temperature effects, there is a slight increase in the required area of the foundation slab reinforcement. The tensile force is transmitted to the elevator and staircase block in axes 8-9 and 13-14, while the main and additional reinforcement of the foundation slab adopted in the project is sufficient to perceive the specified temperature effects without additional constructive measures.

For the selection of reinforcement in plate elements (beams-walls, slabs, shells), the Karpenko method was implemented for the standards DBN V.2.6-98:2009 "Concrete and reinforced concrete structures. Basic provisions" (except Eurocode 2), and for Eurocode 2, the Wood method was implemented [16, 17, 19, 20].

For each element of the foundation slab, CFC (calculated force combinations) were calculated and reinforcement was selected, including temperature effects.

The area of the lower reinforcement in the X and Y directions of the foundation slab without taking into account the temperature effect and with taking into account the temperature effect is shown in Fig. 8-11.

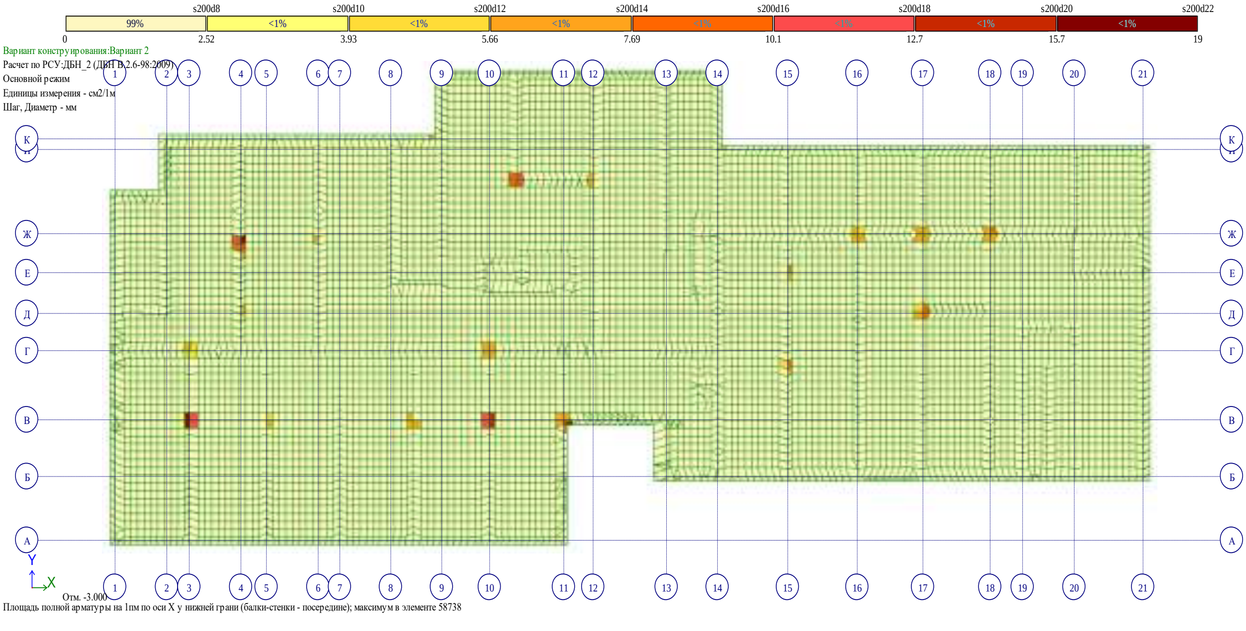

Fig. 8 Area of the lower reinforcement in the X direction of the foundation slab (excluding temperature effects)

Рис. 8 Площа нижньої арматури по напрямку X фундаментної плити (без урахування температурного впливу)

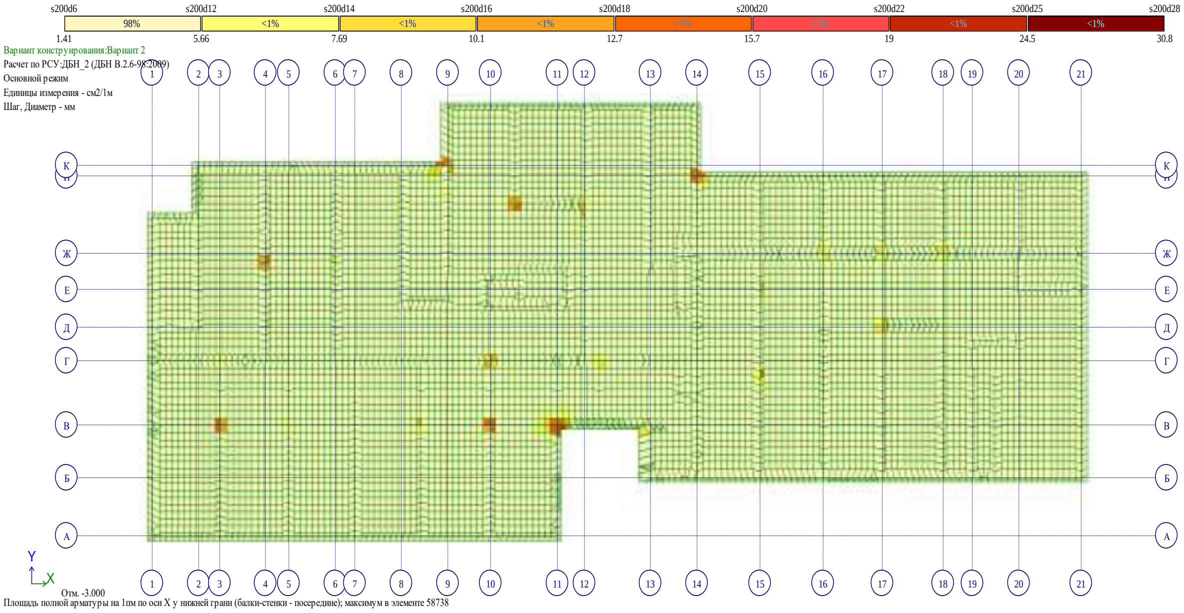

Fig. 9 Area of the lower reinforcement in the X direction of the foundation slab (taking into account temperature effects)

Рис. 9 Площа нижньої арматури по напрямку X фундаментної плити (з урахуванням температурного впливу)

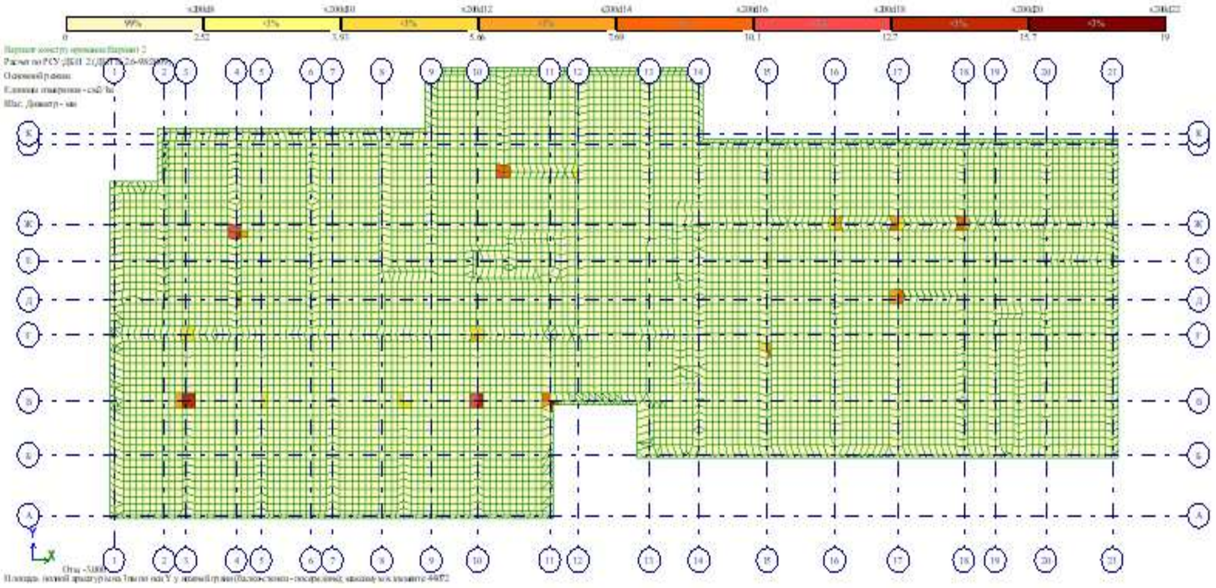

Fig. 10 Area of the lower reinforcement in the Y direction of the foundation slab (excluding temperature effects)

Рис. 10 Площа нижньої арматури по напрямку Y фундаментної плити (без урахування температурного впливу)

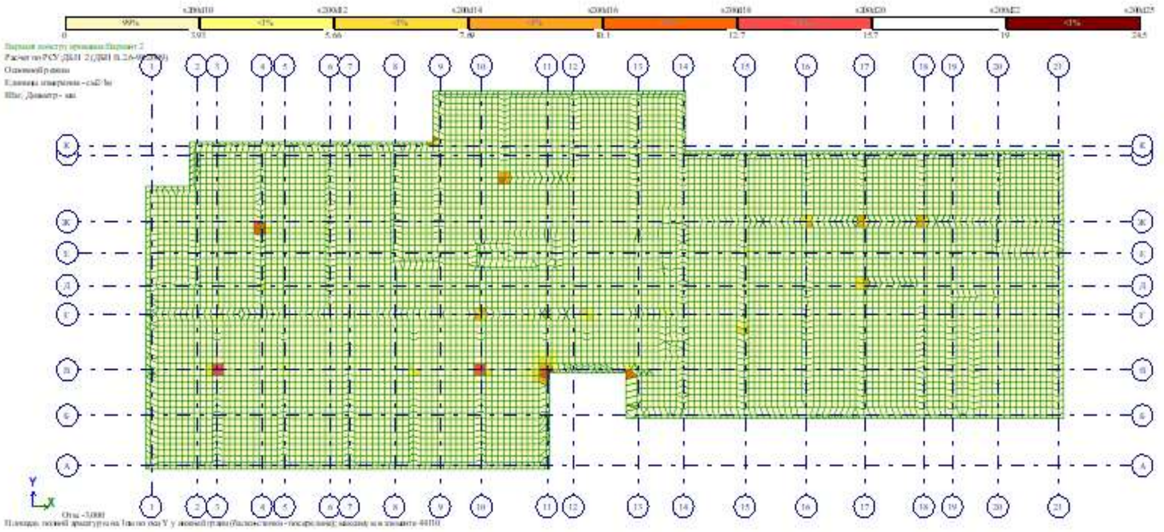

Fig. 11 Area of the lower reinforcement in the Y direction of the foundation slab (taking into account temperature effects)

Рис. 11 Площа нижньої арматури по напрямку Y фундаментної плити (з урахуванням температурного впливу)

Based on the results of the calculation of the foundation slab for climatic effects, the following conclusions can be drawn:

1) with the combined action of bending and stretching on the foundation slab from temperature effects, there is a slight increase in the required area of the foundation slab reinforcement. The tensile force is transmitted to the elevator and staircase block in axes 8-9 and 13-14, while the main and additional reinforcement of the foundation slab adopted in the project is sufficient to perceive the specified temperature effects without additional constructive measures;
2) it is necessary to exclude complete fastening of the foundation slab with the base to prevent the formation and opening of temperature deformation cracks;
3) to reduce the forces from temperature deformations, it is recommended to arrange temporary temperature joints in the floor slabs (on 1-3 floors);
4) structures located above the foundation slab (especially columns) must be designed for forces from temperature deformations, taking into account the plate displacements obtained as a result of calculations.

CONCLUSIONS AND PROSPECTS FOR FURTHER RESEARCH

A review of scientific and technical literature has shown that the consideration of temperature effects in the calculation of building structures has not been sufficiently studied; the methods of analyzing the thermal stress state adopted in practice are diverse; there are no regulatory documents regulating the accounting of temperature effects of structures.

Temperature and climatic effects can, under certain conditions, significantly change the stress-strain state of buildings and structures. Sometimes their influence can be decisive for determining the dimensions of the cross-sections of load-bearing elements and their reinforcement.

It is necessary to carefully approach the determination of the initial design characteristics of temperature effects (initial temperature) and understand the process of combining individual parts of a building or structure into one block (closing temperature).

It is possible to level the effect of temperature loading on the building frame by constructive measures (minimize the difference between the temperature of the surrounding environment and connecting elements), for example, by final monolithic expansion joints after the erection of the entire frame and stabilization of the temperature of all structures and the environment [1, 2].

Such problems can be solved by numerous studies in software modules of modern CAD, in particular the PC "LIRA FEM" [11, 12, 18].

The need to use effective methods for the construction of massive reinforced concrete structures encourages scientists to build rational models of their actual deformation - with the presence of different types and levels of cracks [12, 13, 14, 23, 24], which certainly affect the further change in the stiffness of structures [14, 21, 22].

ETHICAL DECLARATIONS

The authors have no relevant financial or non-financial interests to report.

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ОЦІНКА ТЕРМОНАПРУЖЕНОГО СТАНУ ЗАЛІЗОБЕТОННОЇ ФУНДАМЕНТНОЇ ПЛИТИ

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Валентина БАКУЛІНА

Анотація. Частим явищем у будівельній практиці масивних бетонних конструкцій є утворення тріщин у процесі набору міцності. Головною причиною утворення цих тріщин є нерівномірний розподіл температур у масиві конструкції, що виникає головним чином через тепловиділення бетону в процесі екзотермічної реакції між водою та цементом.

Температурний вплив у першу чергу пов'язаний із добовими та сезонними змінами температури навколишнього середовища в процесі експлуатації будівлі чи споруди. Зовнішні температурні фактори можуть діяти і в поєднанні з певним (підвищеним) тепловим режимом та іншими зовнішніми факторами, що мають місце при експлуатації будівельного об’єкту.

Найбільш сприятливі умови функціонування для будівельних об'єктів складаються при стаціонарному температурному впливі на них, в умовах сталого режиму експлуатації, коли вони тривалий час перебувають у відносно незмінних температурних умовах.

На прикладі фундаментної плити показана різниця у напружено-деформованому стані при різному способі завдання температурного навантаження на конструкцію.

Запропоновані технологічні рішення щодо конструктивних заходів нівелювання впливу температурного навантаження на окремі конструкції будівлі (мінімізувати різницю між температурою оточуючого середовища та з’єднувальних елементів), наприклад, за рахунок кінцевого замонолічування деформаційних швів після зведення всього каркасу та стабілізації температури всіх конструкцій та середовища.

Розглянуті процеси тепловиділення у бетонних конструкціях, кінетику та стадійність даного процесу, залежність від мінералогічного складу цементу. Також проаналізовано температурний режим залізобетонних фундаментних плит та основні причини утворення тріщин в масивних залізобетонних конструкціях.

Необхідність використання ефективних методів оцінки термонапруженого стану залізобетонних фундаментних плит на ранній стадії твердіння бетону спонукає науковців до розробки методів аналізу напружено-деформованого стану залізобетонної фундаментної плити при дії на неї температурних навантажень у процесі набору міцності.

Ключові слова: температурні деформації; напружено-деформований стан; фундаментна залізобетонна плита, технічна експлуатація; технологія будівельного виробництва.

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