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Heat dissipation of cement and calculation of crack resistance of concrete massifs

Тепловыделение цемента и расчеты трещиностойкости бетонных массивов

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Abstract. In this paper, the problems of thermal cracking resistance of massive concrete and reinforced concrete structures during the building period are considered. The calculation results of a research on the effect of hardening temperature on the process of heat dissipation process of concrete are given. The analysis of the thermal stressed state of a massive foundation plate with a fixed thickness of thermal insulation was carried out, the values of the minimum thicknesses of the surface thermal insulation ensuring cracking resistance of structure were obtained. Calculations are performed at various plate heights taking into account the effect of hardening temperature on heat dissipation and without this account. The conducted research demonstrates that not taking into account the effect of hardening temperature on the process of heat dissipation in problems of ensuring cracking resistance of concrete and reinforced concrete massifs leads to a noticeable increase in the required thickness of the necessary thermal insulation.

Аннотация. В настоящей работе рассматриваются вопросы термической трещиностойкости массивных бетонных и железобетонных конструкций в период строительства. Представлены результаты расчетного исследования по оценке влияния температуры твердения на процесс тепловыделения бетона. Проведен анализ термонапряженного состояния массивной фундаментной плиты при фиксированной толщине теплоизоляции, получены значения минимальных толщин поверхностной теплоизоляции, обеспечивающих трещиностойкость конструкции. Расчеты выполнены при различных высотах плиты с учетом влияния температуры твердения на тепловыделение и без данного учета. Проведенное исследование показывает, что не учет влияния температуры твердения на процесс тепловыделения в задачах обеспечения трещиностойкости бетонных и железобетонных массивов приводит к заметному увеличению требуемой толщины необходимой теплоизоляции.

1. Introduction

Calculations of thermal cracking resistance of the massive concrete and reinforced concrete structures during the building period are based on thermal stressed state definition and thermal field irregularity inside of these structures [1–5]. In the design and construction of massive concrete and reinforced concrete structures, much attention is paid to the regulation of the temperature regime of the concrete mix during the construction period [6–9]. This is due to the fact that the reaction of cement hydration during the hardening of concrete leads to the release of a noticeable amount of heat which gives rise to the temperature of concrete [10–14]. The resulting irregular thermal fields in the structure

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generate tensile thermal stresses, first on the surface of the structure and then in its central zones, and are the main cause of the formation of thermal cracks [15–17].

Using a complex of special structural and technological measures for the erection (covering the surface of the structure with thermal insulation, peripheral concrete electric cable, forced cooling of the concrete mix, pipe cooling of the plate), it is possible to ensure the absence of thermal cracks in the building period in the construction [18–20]

Calculations of the thermal stressed state of concrete plates in the building period and the assessment of cracking resistance are classified as complex problems in the mechanics of a solid deformed body. Some researchers close to solution of these problems in a simplified variant. The influence of the hardening temperature on the heat dissipation of concrete [21–24] and its deformation characteristics is not taken into account in part of the techniques used in practical calculations at the present time.

The purpose of this work is to estimate the influence of the hardening temperature on the process of heat dissipation of massive concrete and reinforced concrete structures in the calculations of the thermal stressed state and cracking resistance in the building period and the calculation justification for the need for such accounting

2. Methods

Calculation of the thermal stressed state of a concrete foundation slab during the hardening period is carried out with the help of the TERM software developed by the staff on the Structural Mechanics and Building Structures department of the Institute of Civil Engineering at the Peter the Great St.Petersburg Polytechnic University [25]. The program takes into account the influence of temperature on the thermophysical and deformative characteristics of concrete. In order to estimate the cracking resistance of the concrete foundation slab, we would use the deformation criterion suggested by P.I. Vasiliev [13]. According to this criterion, concrete elongation deformations, determined in view of the concrete creep factor and variable deformation modulus, should not exceed the ultimate concrete elongation.

Considering horizontal mats sizes significantly exceed their height, we can study a one-dimensional structural model for the mat central part with the reasonable degree of accuracy. In this model, stress and temperature are functions of the vertical coordinate space.

Consider B35 foundation slab (thickness varies from 1.0 to 3.0 m) with the cement consumption of 340 kg/m^3. The concrete bedding layer B12.5 with the grade foundation supports the foundation slab. Thermal and physical characteristics of the concrete B35 are defined by the concrete thermal conductivity λ = 2.67 W/(m·°C) and thermal capacity c = 1.0 kJ/(kg·°C). The air temperature is 20 °C, the concrete mix is 20 °C. The top surface of the slab is open – it does not have a special thermal insulation.

The heat dissipation process follows the I.D. Zaporozhets equation [26]. The equation parameters I.D. Zaporozhets gets from experimental evidence on concrete heat dissipation.

$$Q(\tau) = Q_{\max}\left[1 - \left(1 + A_T\tau\right)\right]^{-\frac{1}{m-1}} \tag{1}$$

where $Q_{\max}$ – is limit to which heat dissipation of concrete tends;

A_T – the heat release coefficient characterizing the rate of heat release at a constant temperature T;

m – the order of the water hydration reaction, which depends on the type of additives used for portland cement (from 1.1 to 2.3)

The effect of hardening temperature on the heat release of concrete is carried out using the temperature function:

$$f_T = 2^{\frac{T_1 - T_2}{\varepsilon}},$$

where ε – the characteristic temperature difference.

When the the temperature function $T_1 - T_2 = \varepsilon$ is $f_T = 2$, that is when the temperature is raised by ε degrees, the rate of heat dissipation will increase by 2 times.

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In this paper there is suggested the hypothesis of "reduced time" according to which at times of equal heat dissipation $Q_1 = Q_2$, where Q_1, Q_2 are the heat dissipations at temperatures respectively T_1, T_2. The ratio of the rates of heat dissipation as well as the corresponding terms τ_2 and τ_1 remains constant throughout the process and equal to the temperature function:

$$\frac{(\partial Q/\partial \tau)_1}{(\partial Q/\partial \tau)_2} = \frac{\tau_2}{\tau_1} = f_T = const$$

The parameters of the heat dissipation process were determined experimentally: heat-liberation value of cement $q = Q / C$ = 482.2 kJ/kg; A_{20} = 2.12·10 $^{-6}$ c^{-1}. The cement consumption C is 340 kg/m^3.

As shown in [22] it is possible to neglect the influence of the hardening temperature on the remaining thermophysical characteristics of concrete (thermal diffusivity, heat capacity, thermal conductivity) in calculations of the thermal stressed state of massive concrete and reinforced concrete structures during the building period.

3. Results and Discussion

3.1. Investigation of the effect of temperature hardening on the heat dissipation process

We will illustrate the results of calculations using a 2.0 m thick plate as an example. The graph of the temperature changes in the control points of the slab (top surface, bottom surface and center) is shown in Figure 1

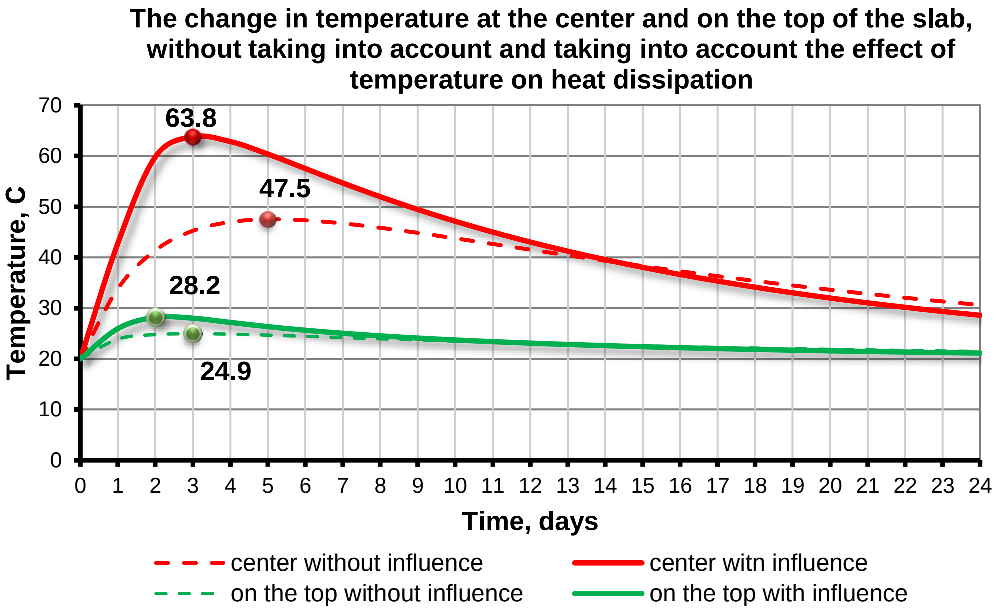

Figure 1. The graph of the temperature dependence in the center and on the top of the slab (solid line with the influence of temperature of hardening, dash line without of such influence)

Analysis of the results shows the following:

1. The nature of the change in temperature in the center and on the upper surface of the base slab in time is the same in both cases.
2. Without taking into account the influence of the hardening temperature on the process of heat generation (dash lines), the maximum temperature in the center of the slab is reached on the 5th day from the moment of laying the mixture and is 47.5 °C, and on the upper surface – on 3-rd day and is 24.9 °C.
3. Accounting for the effect of temperature (solid line) gives a peak at 63.8 °C in the center of the slab for 3rd day, and on the upper surface, the peak occurs on 2nd day and is 28.2 °C.

In such a way ignoring the influence of the hardening temperature on the heat dissipation process leads to an underestimation of the temperature in the center of the plate (by 26 %) and on the upper surface (by 12 %). The moment of formation of the peak of temperature rise in the structure shifts to an earlier period (from 5 days to 3 days).

Figure 2 shows the graphs of the stress changes at the reference points of the foundation slab (the upper surface and the center) ignoring and taking into account the effect of hardening temperature on the heat dissipation of concrete.

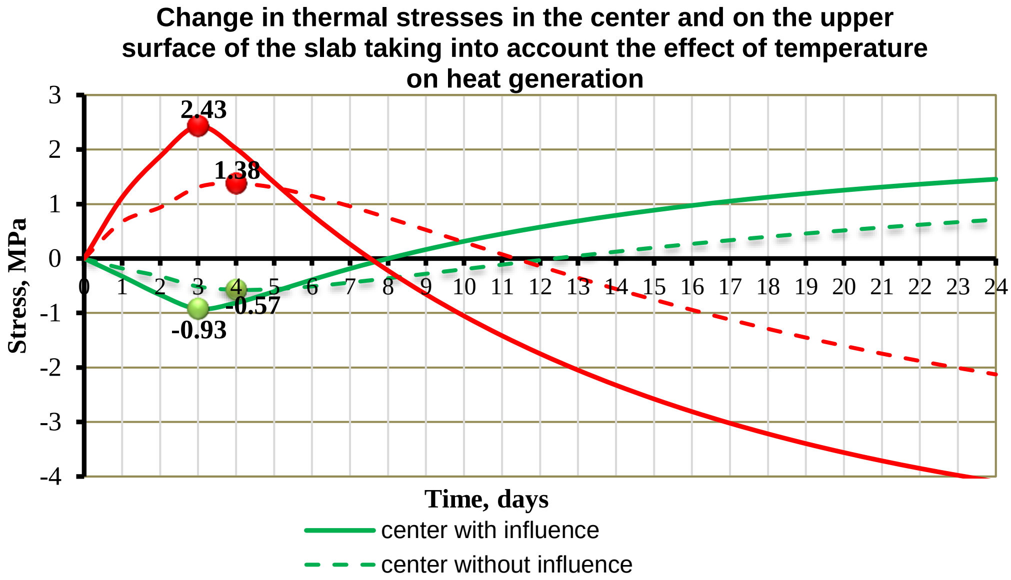

Figure 2. The graph of the dependence of thermal stresses in the center and on the top surface of the slab on time without taking into account and taking into account the effect of hardening temperature on heat dissipation

Analysis of the results shows the following:

1. The character of the change in thermal stresses in the center and on the upper surface of the slab is the same.
2. The maximum stresses at the peak of exothermic warming without taking into account the effect of hardening temperature on the heat dissipation (red dash line) are observed on 4-th day: tensile stresses on the slab surface are 1.38 MPa, compressive in the center are 0.57 MPa. In the first day cracks on the surface of the slab are observed – the criterion for cracking resistance is not satisfied by 35 %. The thickness of the surface layer of thermal insulation ensuring the absence of cracks is 0.5 cm, (coefficient of heat conductivity λ = 0.03 W / m·°C).
3. Taking into account the effect of hardening temperature on the process of heat dissipation, the maximum stresses are observed on 3-rd day: tensile at the slab surface – 2.43 MPa, compressive in the center of the slab – 0.93 MPa. The formation of cracks is observed in the first day (the criterion is not satisfied by 61 %). The thickness of the surface layer of thermal insulation, ensuring the absence of cracks is 6.1 cm, (coefficient of heat conductivity λ = 0.03 W / m·°C).

In such a way ignoring the influence of the hardening temperature on the heat dissipation process leads to an underestimation of tensile stresses on the upper surface of the slab by 43 %, and compressive in the center of the plate by 38 %. In addition, dangerous tensile stress at earlier times (shift for one day). The calculation results are close to the actual data [9].

With an increase in the thickness of the foundation slab, an increase in the hardening temperature in the center, on the upper and lower surfaces of the slab was observed, and the thermal stresses at these control points also increased. (Figures 3, 4).

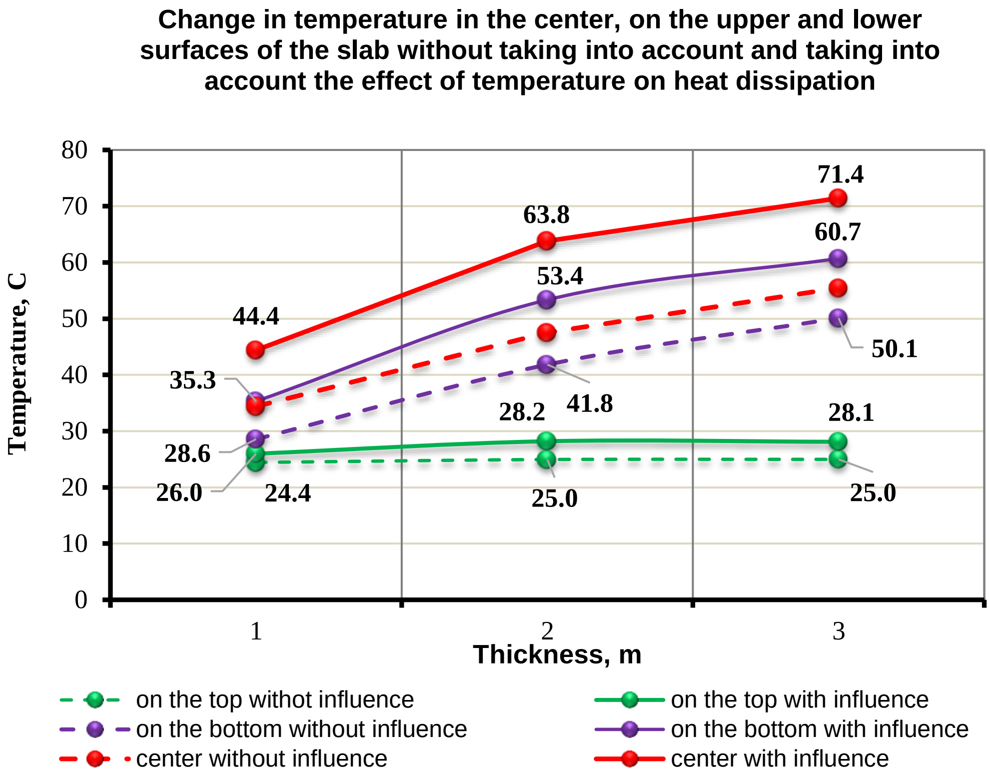

Figure 3. The graph changes the temperature in the center, on the top and bottom surfaces of the plate, depending on the thickness without taking into account and taking into account the influence of the hardening temperature on the heat dissipation

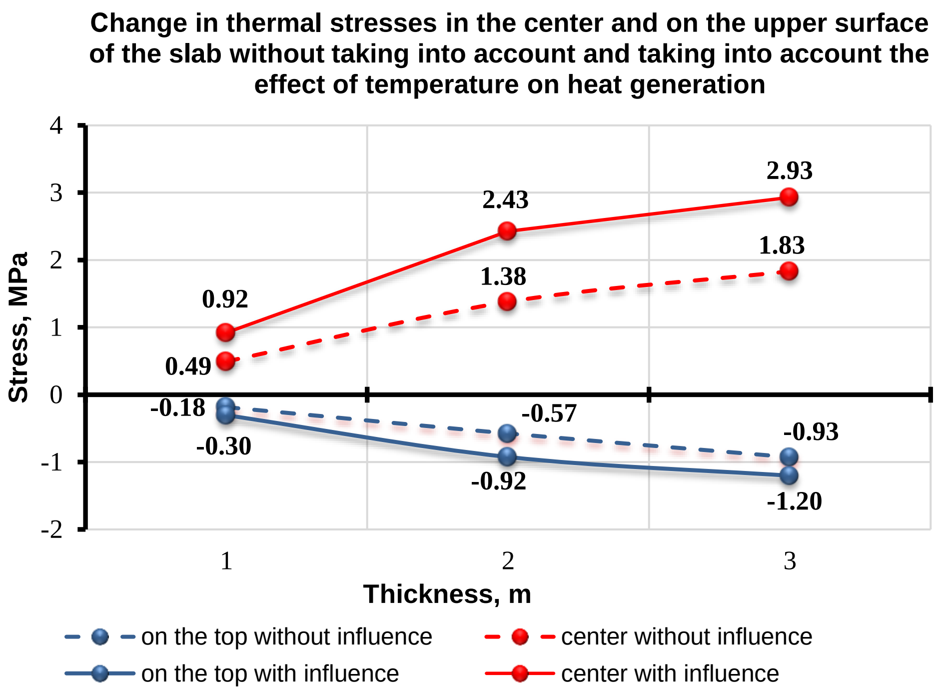

Figure 4. The graph of the dependence of the change in thermal stresses in the center and on the upper surface of the slab depending on the thickness of the slab without taking into account and the influence of the hardening temperature on the heat dissipation

In studies carried out by some authors earlier [21, 22] a calculation evaluation of the effect of hardening temperature on the thermal stressed state of massive concrete hydraulic structures was carried out. As is known, concrete mixtures used for such structures have a relatively low consumption of cement and a relatively low heat dissipation. In this paper concrete was considered with a significant cement consumption, cement also had a relatively high specific heat dissipation (concretes with similar characteristics were used for the construction of base slabs of nuclear power plants and other unique buildings and structures).

4. Conclusions

The results of the conducted experiments allow us to make following conclusions:

1. Not taking into account the effect of hardening temperature on the process of heat generation of massive concrete and reinforced concrete structures in the calculation of the thermal stressed state leads to a significant underestimation of the temperature at control points (up to 26 %) and tensile stresses (up to 43 %) on the slab surface.
2. The safe thicknesses of the surface thermal insulation, determined without taking into account the influence of temperatures, have significant deviations (upwards) from similar values obtained with such influence. Deviations were up to 92 %.
3. When the thickness of the slab is increased from 1.0 to 3.0 m, taking into account the influence of temperature leads to an increase in the maximum temperature in the body of the slab from 22 % to 52 %, and the maximum deformation of elongation on the plate surface is from 21 % to 60 %.

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