Consideration of Temperature Stresses in the Calculation of Crack Formation in Concrete Massifs of Buildings

S A Sazonova¹, S D Nikolenko², N V Akamsina³

¹Ph.D. in Technical Sciences, Associate Professor, Department of Technosphere and Fire Safety, Voronezh State Technical University, Voronezh, Russia
²Ph.D. in Technical Sciences, Associate Professor, Department of Technosphere and Fire Safety, Voronezh State Technical University, Voronezh, Russia
³Ph.D. in Technical Sciences, Associate Professor, Department of Control Systems and Information Technologies in Construction, Voronezh State Technical University, Voronezh, Russia

E-mail: ss-vrn@mail.ru, nikolenkoppb1@yandex.ru, akamsina@vgasu.vrn.ru

Abstract. Computer simulation of the thermal stress state of a concrete foundation slab of a building is considered. To simulate the thermal stress state, the specialized Midas Fea software package is used. The actual tensile stresses in concrete are compared with the maximum allowable values taking into account the equivalent age. It was established that the likelihood of cracking due to sudden changes in temperature is high, which entails the likelihood of destructive processes in concrete. Using the software package, calculations were made and graphs of the temperature changes in time at the control points were plotted, as well as the isofields of temperature distribution and crack formation coefficients over the volume of the considered array were graphically depicted and investigated. Based on the calculations and modeling of temperature processes in concrete, it is proposed to use surface thermal insulation or to reduce the initial temperature of the concrete mixture in order to reduce the heat transfer rate of the concrete surface.

1. Introduction
The calculation of the thermal stress state is reduced to a comparison of the actual tensile stresses in concrete and the maximum allowable taking into account the equivalent age. The comparison parameter is the crack ratio, equal to the ratio of the actual stress calculated to the maximum allowable. That is, in those places where the coefficient of crack formation is greater than one, the probability of a crack is high.

To simulate the thermal stress state, the specialized Midas Fea software package was used.

When writing the article, research materials were used [1-27].

2. Source data preparation
The calculation of the thermal stress state is performed for the foundation slab of the building. The base plate has variable dimensions in plan and height 2.5 m. In accordance with the requirements of SP 63.13330.2018 p. 11.1.5, in the manufacture of a block-like monolithic structure, measures must be taken to reduce the effect of the field of temperature and humidity stress associated with heat
generation, which observed after concreting, that is, during the hardening process of concrete. The nominal composition of concrete is accepted according to the report. The design capacity of the concrete plant is 60 m$^3$/h. The calculation of shrinkage and creep of concrete in the calculation is carried out in accordance with the requirements of CEP-FIP model code 90 [2, 3].

The following environmental parameters were adopted for the calculation: average air temperature plus 22 °C, humidity 64%, minimum average wind speed 3 m/s, average minimum soil surface temperature plus 14.2 °C.

The diagram of concrete temperature change (Figure 1) was adopted according to JSCE 2012. With Portland cement consumption of 350 kg/m$^3$ and an initial concrete mixture temperature of 25 °C, the maximum temperature rise under adiabatic conditions is 45.1 °C. In the calculation, the properties of materials according to table 1 were adopted.

![Diagram of concrete temperature rise due to heat generation.](image)

**Table 1. Properties of materials accepted in the calculation.**

| Material                  | Modulus of elasticity, MPA | Poisson's ratio | Density, kg/m$^3$ | Coefficient of thermal expansion | Heat conductivity coefficient, W/m·°C | Specific heat, kJ/kg·°C |
|---------------------------|-----------------------------|----------------|-------------------|-----------------------------------|---------------------------------------|-------------------------|
| Monolithic concrete B30   | 32500                       | 0.2            | 2500              | 1·10^{-5}                         | 2.67                                  | 1.0                     |
| Steel fiber concrete      | 41000                       | 0.2            | 2300              | 1·10^{-5}                         | 1.2                                   | 0.84                    |
| Waterproofing             |                             |                |                   |                                   |                                       |                         |
| Footing B20               | 27500                       | 0.2            | 2200              | 1·10^{-5}                         | 1.54                                  | 0.84                    |
| Hardened soil             | 1000                        | 0.3            | 2000              | 1·10^{-5}                         | 1.21                                  | 0.84                    |

To ensure the technological process of concreting, we break the foundation plate of the building into grips. The maximum size is a grapple with dimensions of 29.00 × 33.50 m and a height of 2.5 m. The estimated time of concreting of this grab at the estimated productivity of mortar-concrete unit (RBU) of 60 m$^3$/h is about 40 hours (the volume of concrete mix is 2429 m$^3$). We model word-by-word laying of a concrete massif within 40 hours. The estimated temperature of the concrete mixture at the time of installation is taken equal to plus 25 °C.

Since the concrete mass is symmetrical, we only simulate one quarter of it. At the base of the foundation slab, we model: steel-fiber-reinforced concrete waterproofing with a thickness of 35 mm; sub concrete (non-reinforced concrete of class B20) 115 mm thick; reinforced soil 3000 mm thick.
At a wind speed of 3 m/s, the heat transfer coefficient according to formula (6) will be equal to $\alpha_{ex} = 26 \text{ W/m}^2 \cdot ^\circ \text{C}$. To analyze the calculation results, we take as control points that are located in the plan in the middle of the concrete block and at a distance of 500 mm from its edge at heights from the bottom of the slab 0.15 m, 1.25 m, and 2.45 m.

3. Charting

At control points, we obtained diagrams of changes in temperature, actual stresses, and crack formation coefficients in relation to the time required for gaining strength. The results are presented in figures 2 - 4.

In carrying out the research, materials from articles on the construction and examination of the current state of buildings and structures [4, 5, 6] from concrete and fiber-reinforced structures [7, 8, 9, 10] were used.

**Figure 2.** Temperature change in time at the control points a) in the middle of the block b) at a distance of 500 mm from the edge.

**Figure 3.** Change in time at control points a) in the middle of the block b) at a distance of 500 mm from the edge.

**Figure 4.** Time variation of the cracking coefficient at the control points: a) in the middle of the block b) at a distance of 500 mm from the edge.
4. Isopole of temperature distribution and cracking coefficients

The isopoles of temperature distribution and crack formation coefficients in the volume of the studied array are shown in figures 5 and 6.

**Figure 5.** The nature of the temperature distribution after concreting: a) after 40 hours.

**Continuation of figure 5.** The nature of the temperature distribution after concreting: b) after 64 hours.

**Continuation of figure 5.** The nature of the temperature distribution after concreting: c) after 112 hours.

**Continuation of figure 5.** The nature of the temperature distribution after concreting: d) after 208 hours.

**Figure 6.** The coefficients of cracking after concreting: a) after 40 hours.

**Continuation of figure 6.** The coefficients of cracking after concreting: b) after 64 hours.
Continuation of figure 6. The coefficients of cracking after concreting: after 112 hours.

Continuation of figure 6. The coefficients of cracking after concreting: d) after 208 hours.

As an improvement in the operational properties of concrete (reducing crack formation), dispersed concrete reinforcement can be recommended. The positive effect of dispersed reinforcement is indicated in [8-19]. With dispersed reinforcement, it is important to ensure uniform distribution of fibers in concrete [20-27].

5. Conclusion
Based on the calculation, it was found that the likelihood of cracking due to temperature changes is high, namely:
- in accordance with figures 4 (b) and 4 (a), the coefficient of crack formation after concreting exceeds 1.4, therefore, the possibility of cracking is great;
- environmental conditions, concrete properties and the size of the grip contribute to the heating of the concrete mass to a temperature of plus 47 ° C;
- the temperature gradient on the surface and in the core in the early stages of curing is about 17-20 ° C, which increases the likelihood of destructive processes in concrete;
- based on the calculation, it is advisable to reduce the temperature gradient by reducing the heat transfer rate of the concrete surface. This can be achieved through the use of surface thermal insulation or by reducing the initial temperature of the concrete mixture to 10-15 ° C.

6. References
[1] SP 63.13330.2018 Concrete and reinforced concrete structures The main provisions
[2] CEB-FIP Model Code-1990 1991 Design Code Comite Euro-International du Beton 437 p
[3] Benin A V, Semenov A S, Semenov S G and Melnikov B E 2013 Mathematical modeling of the process of fracture adhesion of reinforcing bar with concrete Part 1 Models taking into account discontinuities of the connection Magazine of Civil Engineering 5 pp 86–99
[4] Mikhnevich I V and Nikolenko S D 2017 Research on the influence of thermal effects on the strength characteristics of concrete Scientific journal of construction and architecture 3 (47) pp 43-51
[5] Sazonova S A 1993 Free vibrations of rectangular mesh plates with an elastic contour Izvestiya Akademi Nauk Solid Mechanics 6 pp 153-155
[6] Sazonova S A 2010 Models for assessing the disturbed state of a heat supply system Engineering Physics 3 pp 45–46
[7] Beaudoin James J 1990 Handbook of Fiber Reinforced Concrete Principles, properties Development and Applications (United State of America, New Jersey: Noyes Publications) pp 57-63
[8] Hughes T J R and Belytschko T 1983 A precis of development in computational methods for transient analysis Journal of Applied Mechanics vol 50 pp 1033 – 1041
[9] Nizina T A and Balukov A S 2016 Experimental-statistical models of properties of modified fiber-reinforced fine-grained concretes Magazine of Civil Engineering 2 pp 13–25
[10] Taheri Fard A R, Soheili H, Ramzani Movafagh S and Farnood Ahmadi P 2016 Combined Effect of Glass Fiber and Polypropylene Fiber On Mechanical Properties of Self-Compacting Concrete Magazine of Civil Engineering 2 pp 26–31
[11] Nikolenko S D and Stavrov G N 1986 An experimental study of the work of fiber-reinforced concrete structures under alternating low-cycle loading News of higher educational institutions Construction and architecture 1 pp 18-22
[12] Nikolenko S D, Sushko E A, Sazonova S A, Odnolko A A and Manokhin V Ya 2017 Behavior of concrete with a dispersed reinforcement under dynamic loads Civil Engineering Journal 7 (75) pp 3-14
[13] Karrar Ali Al-lami 2015 Experimental Investigation of Fiber Reinforced Concrete Beams A thesis submitted in partial fulfillment of the requirements for degree of Master of Science (Portland State University Press)
[14] Kuznetsova L A, Nikolenko S D, Sazonova S A, Osipov A A and Zalozhnykh N V 2018 Study of the effect on the strength of structural bending elements reinforced with metal fibers Modeling systems and processes vol 11 4 pp 51-57
[15] Vairagade Vikrant S 2012 Kene Kavita S Introduction to Steel Fiber Reinforced Concrete on Engineering Performance of Concrete International Journal of Scientific & Technology Research vol 1 issue 4 may pp 139–141
[16] Xu Z, Hao H and Li H 2012 Experimental study of dynamic compressive properties of fibre reinforced concrete material with different fibres Materials & Design vol 33 pp 42–55
[17] Morozov V I and Pukharenko Yu V 2014 The effectiveness of the use of fiber-reinforced concrete in structures under dynamic impacts Bulletin of MSCU 3 pp 189-196
[18] Tiberti G, Minelli F and Plizzari G 2015 Cracking behavior in reinforced concrete members with steel fibers: a comprehensive experimental study Cem Concr Res 68 pp 24–34
[19] Nikolenko S D, Tkachenko A N and D V Fedulov 2007 Features of technological schemes for the preparation of fiber concrete In the collection: Actual problems of modern construction materials of the International scientific and technical conference (Penza) pp 320-323
[20] Nikolenko S D, Sazonova S A and Asminin V F 2019 Mathematical modeling of dispersed concrete reinforcement Modeling of systems and processes vol 12 1 pp 74-79
[21] Asminin V F, Druzhinina E V, Sazonova S A and Osmolovsky D S 2019 Development and application of a portable lightweight sound suppression panel to reduce noise at permanent and temporary workplaces in the manufacturing and repair workshops Akustika vol 34 pp 18-21
[22] Abrishambaf A, Cunha V M C F and Barros J A O 2015 The influence of fibre orientation on the post-cracking tensile behaviour of steel fibre reinforced self-compacting concrete Frattura ed Integrità Strutturale 31 pp 38-53
[23] Žirgulis G, Švee O, Sarmiento E V and et al 2015 Importance of quantification of steel fibre orientation for residual flexural tensile strength in FRC Mater Struct 49 pp 3861–3877
[24] Jasniūnienė E, Cičiūnas V, Grigaliūna P and et al 2018 Influence of the rheological properties on the steel fibre distribution and orientation in self-compacting concrete Materials and Structures 51 p 103
[25] Vereshchagin A Yu, Nikolenko S D and Sazonova S A 2019 The program of geotechnical monitoring of objects included in the zone of influence of construction Modeling of systems and processes vol 12 4 pp 4-9
[26] Ignatyuk A S, Nikolenko S D and Sazonova S A 2019 The process of thermal imaging inspection of building envelopes Modeling of systems and processes vol 12 4 pp 66-72
[27] Galaeva S S, Nikolenko S D, Sazonova S A 2019 Research on the process of assessing the state of wooden structures Modeling systems and processes vol 12 4 pp 10-16