Features of peripheral heating of monolithic reinforced concrete structures

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Abstract. The winter period in Russia lasts quite a long time, several months. During this time, at construction sites the works, such as laying a concrete mix into formwork structures, continues. During heat treatment of concrete, an uneven distribution of temperature across structural section is observed. The formed quality of concrete structures is related to heat treatment parameters. A favourable thermostressed state in concrete is achieved using methods, which assure that, when hardening, the temperature in the central part of concrete is higher than at the periphery. These are thermos and pre-heating methods. The modern method of using a heating wire ensures even temperature distribution across structural section, but the steel core remains in the concrete block. The peripheral heating method using a heating formwork makes heat treatment with soft impact on concrete possible. A repeated use of a heating formwork allows cost reduction in comparison with the method of heating wire. The mathematical program developed at the Department of Building Construction and Structural Theory makes it possible to determine the parameters of heat treatment. The economic effect of the proposed method is shown.

1. Introduction

Currently, the parameters of winter curing methods for monolithic reinforced concrete structures on construction sites are well studied. One of the modern effective methods is the method of using a heating wire for heating monolithic structures. This method is based on transmission of alternating current through a steel core in polyvinyl chloride insulation. The wire is fixed to the reinforcing parts inside the structure. In the electricity resistant wire, heat is released and transmitted to the concrete by thermal conductivity.

The advantages of the heating wire method are a fairly even temperature distribution across structural section and the possibility of smooth regulation of the current in the areas of heating [1-3]. The disadvantages include a sufficiently large labour input for layout and fixing the wire to the reinforcement inside the structure and the consumption of steel per wire, which remains in the body of concrete.

Technologies of winter concreting are described in the works of A.S. Arbeniev, A.I. Gnyr, S.G. Golovnev, B.M. Krasnovsky, B.A. Krylov, S.A. Mironov and other Russian scientists [4-13].

The quality of monolithic reinforced concrete structures is subject to the requirements contained in statutory documents [14]. One of the indicators is the thermostressed state of the concrete block. The level of temperature stresses, which was acquired by concrete while curing, affects durability of the structure. If the temperature of the outer layers of concrete when curing in the formwork is higher than

in the centre, the thermal expansion will be greater. Then, after cooling down the structure, the central part will be in a compressed state, and the peripheral part will be in a state of stretching. This is an unfavourable condition for the outer layers as there is a high probability of cracks, moisture penetration, damage to the reinforcement and concrete structure in the stretched outer zone. The state when the concrete in the centre of the structure has a temperature higher than on its periphery is considered to be a favourable thermostressed state. In this case, after cooling the structure down the periphery will be in a compressed state. Such distribution character is observed at pre-heating of a concrete mix [15-17].

Maintaining the quality of monolithic reinforced concrete structures at construction sites remains an important task. The solution to such a problem is possible by setting reasonable parameters for heat treatment of structures.

2. Method of calculation of heat treatment parameters

The research was devoted to development of a technology for heating of concrete in a warming formwork, which allowed to reach the required quality of concrete. A mathematical model was developed to calculate temperature and strength fields in concrete structures, as well as temperature stresses. The program took into account various factors of work, such as outside air temperature, the module of the structure surface and the formwork heat transfer coefficient. The main parameters in the calculations were concrete temperature, curing time, strength of concrete, temperature stress and deformation of concrete. Similar programs of calculation had been developed earlier.

The following expression was used to calculate temperature stresses at point X of the cross section of a concrete structure

$$\sigma_{X,\tau} = \alpha E \left(t_{cp,\tau} - t_{X,t} \right) / \left(1 - \nu \right)$$

where $\sigma_{X,\tau}$ – temperature stress in concrete at point X at time t, MPa, α – coefficient of linear thermal expansion of concrete, $1/^{\circ}C$, E – modulus of elasticity of concrete at time t, MPa, $T_{cp,\tau}$ – average temperature of concrete across structural section at time t, $^{\circ}C$; $t_{X,\tau}$ – temperature of concrete at the point with X-coordinate at time t, $^{\circ}C$; ν – Poisson's ratio.

During the calculations, the influence of the following factors was considered: the modulus of the structure surface – 3, 5, 6, 7, 12.5 m[1]; the heat transfer coefficient of the formwork – from 1 to 5 W/(m[2], $^{\circ}C$); outdoor temperature – from minus 5 to minus 25 $^{\circ}C$; specific power of the heaters of the heating formwork – from 50 to 300 W/m^{2}.

During the calculations, the changes of technological parameters were analysed: the temperature and strength of the concrete, the stresses arising across structural section, the level of stress.

The initial temperature of concrete in the formwork was taken equal to 10–15 $^{\circ}C$, the rate of temperature rise in the range from 5 to 20 $^{\circ}C/h$. During the calculations, the tensile stresses in structural section were controlled so that they do not exceed the tensile strength of concrete, $\sigma_{p,x} < R_{t,x}$.

3. Results of calculations

The peculiarity of concrete hardening is that concrete acquires the properties of an elastic body at a strength of 22–30% of R_{28} [18]. At that, temperatures are distributed across structural section so that strains are assumed to be zero. From this moment, stretching and compressing stresses appear in the concrete.

In the course of calculations, it was assumed that stresses in concrete occur immediately after the start of heating, 0.5–1 h after laying and compaction of a concrete mix. This assumption goes into the reserve of concrete strength and thermostressed state [19,20].

Below are the results of calculations of peripheral heating parameters for structures with surface modulus 5 and 12.5 m[1]. The power of formwork heaters in these examples was 100 and 200 W/m^{2}.

Tables 1 and 2 show the results of some calculations. After 8 hours of heating structures with surface modulus 5 m[1] (table. 1) with the power of heaters of 200 W/m^{2}, the concrete periphery

temperature was 70 ^{o}C and the temperature difference between the periphery and the centre was 29 ^{o}C. Tensile stresses on the surface of the concrete was 0.92 MPa. The voltage level in this case was close to 0.6 of the limit value. Such speed of temperature rise is admissible for peripheral heating.

After 8 hours of heating structures with the surface module of 12.5 m[1] (table. 2), the temperature of concrete on the surface was 72 ^{o}C. The temperature difference at this point was equal to 17 ^{o}C, the voltage in the outer zone of concrete was 0.54 MPa. The voltage level was close to 0.3.

Table 1. Changes of temperature and stresses in concrete during heating the structure with surface module 5 m[1].

Time of heating, h	Power of heaters, W/m^2	Periphery temperature of concrete, ^{0}C	Temperature of concrete in the centre, ^{0}C	Tensile stresses on the surface, MPa
1	100	13	10	0.09
5	100	28	12	0.50
8	100	34	18	0.50
1	200	22	10	0.38
5	200	56	26	0.96
8	200	70	41	0.94

Table 2. Changes of temperature and stresses in concrete during heating the structure with surface module 12.5 m[1].

Time of heating, h	Power of heaters, W/m^2	Periphery temperature of concrete, ^{0}C	Temperature of concrete in the centre, ^{0}C	Tensile stresses on the surface, MPa
1	100	15	10	0.16
5	100	31	20	0.35
8	100	36	25	0.35
1	200	20	12	0.26
5	200	59	42	0.54
8	200	72	55	0.54

Previously, it had been known that temperature stresses in concrete could be considered dangerous if the temperature difference across structural section exceeds 1 ^{o}C/cm [20]. In the above calculations, the maximum temperature gradient was 0.75 ^{o}C/cm when heating the structure with a surface modulus of 5 m[1] and the power of the formwork heaters 200 W/m^2. Data are given for the heat transfer coefficient of formwork α = 3 W/(m^2·^{o}C), ambient temperature T = -15°C.

The greatest value of the temperature difference across structural section in the calculations was 30 ^{o}C. This value was observed when heating the structure with a surface modulus of 5 m[1] and 200 W/m^2 heaters. As we can see from the results, it is necessary to approach the purpose of formwork heaters power reasonably. The temperature gradient across structural section is determined by the value of formwork heaters power. To a lesser degree, the temperature gradient depends on the massiveness of the structure, and the heat transfer coefficient of the formwork.

Technical and economic calculations of heating parameters were carried out. Fastening a mesh heater on formwork leads to the cost increases compared to the method of using a heating wire. Later, the heating formwork is used repeatedly. It evens out its use against the cost, as costs for a single use of a heating wire, which remains in the concrete after heating, rise.

4. Conclusion
Technical and economic comparison of calculation results has shown good efficiency of the method of heating concrete in a heating formwork. The duration of laying and heating monolithic structures is

reduced by 10–15% compared to the method of heating wire. The cost of heating in a heating formwork was 5–7% lower compared to the method of heating wire.

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