Winter concrete: problems and solutions

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Abstract. Monolithic construction in winter faces problems of concrete strength set at negative ambient temperature. In order to ensure the necessary temperature conditions for hardening concrete use different methods of heating structures. One of the most effective ways is to warm up using a heating wire. The tasks of stood concrete in winter conditions are multifactorial, and computer modeling can significantly improve the efficiency of work. The ELCUT software complex is a tool in solving such problems, based on the method of the final elements. On the example of a monolithic foundation slab, the process of hardening of concrete at the temperature of the coldest five-day and medium-winter in Bratsk was simulated. The calculation of the concrete strength set and the analysis of temperature fields, taking into account the requirements for crack resistance, has been made. Computer simulations allowed to pick up the parameters of laying the heating wire in the concrete.

Ensuring year-round construction in the northern regions is associated with a number of problems, the main of which in winter concrete are low ambient temperatures, which lead to the freezing of water and subsequent expansion, as well as to the slowdown of hardening processes[1,2,3].

At negative temperatures in freshly laid concrete water that did not react with cement goes into a solid state, which entails the termination of chemical reactions with cement minerals, hydration stops, and concrete ceases to gain strength. At the same time, the concrete develops internal stresses due to the pressure of ice, caused by its increase in volume (approximately 9%)[4,5]. In this case, with early freezing of concrete, low-strength crystalline hydrate bonds are destroyed under ice pressure. Subsequently, during thawing, water again participates in the reactions, the strength of the concrete is renewed, but the broken bonds in the concrete are not completely restored. Therefore, freezing of concrete to a critical strength sufficient for the perception of thermal deformations is unacceptable[6]. To ensure the set of such strength at low temperatures, various methods of winter concreting are used.

Among the methods of electrothermoprocessing concrete, the warming wire occupies a special position. If in other heating methods heat from the source of heat output is brought to the concreted structure from the outside and provides heating from the surface with the gradual spread of heat into the inner layers of concrete, the heating of the heating wire occurs conductively from inside the structure. Since the source of the heat output - the wire - is directly in the structure, all the heat emitted by the heater is transferred to the concrete, ensuring maximum efficiency of heating[7].

To warm the concrete in the structures are used specially produced for this purpose heating wires with residential steel wire in polymer insulation. The heating wire is very convenient for heating concrete in any constructions, regardless of the nature of their reinforcement and configuration. The heating wire can be used to heat monolithic structures of different types with any degree of reinforcement, surface module from 2 and above and at outdoor air temperature up to -50 degrees
Celsius. Electrothermoprocessing with the help of a heating wire ensures the receipt of concrete with predetermined physical and mechanical properties not significantly different from the properties of concrete, hardening in normal conditions [8].

The tasks of stood concrete in winter conditions are multifactorial, and computer modeling can significantly improve the efficiency of work. The ELCUT software complex is a tool in solving such problems, based on the method of the final elements. The ELCUT program is equipped with a WinConcret add-on to calculate temperature fields, analysis of the nature of their distribution, and subsequent construction of concrete strength graphs, as well as the ability to determine temperature deformations during the process of heat treatment of concrete[9].

According to the results of computer modeling, it has been established that the distribution of temperature by a section of monolithic structures, sustained in winter conditions, occurs unevenly, often in peripheral zones recorded premature freezing [10]. At the same time, the greatest danger is the temperature deformations due to the significant exothermic heat output of cement, so the temperature difference to ensure the requirements for crack resistance should not exceed 20 degrees Celsius [3,11,12].

As a calculation model, a monolithic foundation slab, made using the method of an adjustable thermos with additional heating by an insulated heating wire, is considered. This method is considered as the main one, as the traditional thermos at temperatures in the Siberian region does not allow to obtain the required strength and provide crack resistance, leading to freezing of angular and end surfaces[13].

A foundation slab with sizes of 16 x 12 x 1 m (figure 1) has been selected for the simulation. As a formwork is accepted plywood thickness (δ) - 0.04 m, and for insulation used mineral mats from 100 to 250 mm thick. specific electrical resistance (p) - 0.157 Om mm2/m., the step, the length of the wire and the power varied depending on the conditions of stood.

![Figure 1. Cross-section of the simulated foundation with temperature control points.](image)

During the study, the simulation of the solidification processes of the monolithic foundation slab was carried out for the temperature of the coldest five-day (-43 degrees Celsius) in Bratsk[14].

As a result of the calculation, the temperature field was obtained before the start of warming, taking into account the thermal properties of the materials (Figure 2).
Figure 2. Simulation of the temperature field of the structure before the start of warming.

For the temperature of the coldest five-day (-43 degrees Celsius) the method of warming "adjustable thermos" has been adopted, in which the heating wire of the PNSV with a capacity of 40 watt/m (Figure 3) is laid on the ends and horizontal surfaces of the structure. The simulation found that the requirements for crack resistance are provided under the following conditions of installation of the heating wire: the layout step is 0.15 m; The length of the piece is 29.8 m. The required temperature difference to 20 degrees Celsius in the foundation slab is used to insulate the 150mm thick minero-filled slabs (Figure 4).

Figure 3. The heating wire layout scheme for the conditions of the coldest five-day in Bratsk.

Figure 4. The temperature field of the structure after 24 hours of warming (the temperature difference on the section was 14 degrees Celsius).
Figure 5 shows a graph of the concrete strength set at checkpoints.

Figure 5 shows that in acceptable for building conditions 8-9 days, concrete will gain the required strength (70% of the vintage) with the provision of requirements for crack resistance, and critical strength of 25% will be achieved in 3 days.

Simulations for the average temperature in Bratsk (~19.5 degrees Celsius) showed that it is enough to lay the heating wire on the ends of the foundation plate and insulate the formwork with mineral slabs 50 mm thick to ensure the requirements for crack resistance and a set of critical strength for 3 days.

To contain temperature deformations in winter concrete proposed to use dispersed reinforcement with high-modular fibers. Previous studies have shown that the crack resistance of steel-fibrobeton increases with the reduction of the diameter of fibers and the increase in their content in concrete, while significantly changing the nature of the destruction of the material [15]. Steel fiber performs many functions depending on the percentage of reinforcement. One of the initial functions is the reduction of micro- and macro-cracks. By blocking the cracks at the initial stage of their appearance, steel fibers prevent their spread. The rod, or wire mesh, is designed to protect concrete from the formation of the very first shrinkage cracks, rather than prevent their spread.

Adding steel fibre to the mixture as a dispersal reinforcement will allow to redistribute temperature voltages [16]. Steel fiber has a large thermal conductivity due to which to increase thermal conductivity and the concrete mixture itself at the stage of concrete. Due to the even distribution of fibres, the heating and cooling will also be more even. In addition, the time required to increase the temperature of steel and 10... 15% of the cooling time of such structures, because the rate of cooling of steel is higher. The specific electrical resistance of steel-fibrobeton is lower, which allows to warm the structures at low voltages. This reduces energy costs from 30 to 50%.

Computer modeling using the program "ELCUT" on the example of the foundation plate allowed to quickly choose the mode of heat treatment for winter temperatures in Bratsk by changing the thickness of the insulation layer of the formwork and the power of the heating wire [17]. The results allow to predict the risk of temperature stresses due to the critical temperature difference in control points to ensure the requirements for crack resistance, and dispersal reinforcement by increasing the crack resistance of concrete will improve the efficiency of winter concrete.

![Figure 5. The dependence of concrete strength in the control points of the structure on the time of stood (as a percentage of vintage strength).](image)
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