Review and analysis of winter concreting methods, used on construction sites in Russia

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Abstract. The features of the application of winter concreting methods on construction sites in Russia are considered: thermos methods (thermos, hot thermos), progressive methods (electrode heating, induction heating, infrared heating, the heating of the heating wires, heated in the mold thermoactive or thermoactive a flexible covering, heating in enclosures), concreting with antifreeze additives. The analysis of the application of winter concreting methods on construction sites in Eastern Siberia is carried out.

In modern construction, the construction of monolithic structures and buildings is carried out year-round. Production of concrete works in winter conditions is always associated with additional material, labor and energy costs. The cost of construction of monolithic structures increases by 1.3-2.0 times compared to summer conditions [3, 4].

When concrete freezes at an early age, irreversible processes occur in its forming structure, causing a significant decrease in the final strength and frost resistance. The final strength is not reduced if the concrete has gained a certain strength, which is called critical, before freezing [5].

Strength of concrete of monolithic and precast-monolithic structures at the moment of freezing (critical strength) [7]:

- for structures operated inside buildings, foundations for equipment that are not subjected to dynamic influences, underground structures, for concrete strength class:
  - up to B10-50% of the design;
  - up to B25-40% of the design;
  - B30 and above-30% of the design;
- for structures subjected to variable freezing and thawing in a water – saturated state at the end of aging-80%:
  - for long-span structures:
    - when flying up to 6 m-70%;
    - during the span of over 6 m – 80%;
  - in prestressed structures-80%;
- for concrete with antifreeze additives for classes:
  - up to B15-30% of the design;
  - up to B25-25% of the design;
  - B30 and above-20% of the design.
With normal (summer) methods of concreting to obtain the critical toughness at negative temperatures of external air is impossible.

According to SR 70.1330.2012 “Bearing and enclosing structures” [7] during the production of concrete works at the expected average daily outdoor temperature below +5°C (degrees Celsius) and the minimum daily temperature below 0°C (degrees Celsius), special methods of winter concreting should be used to ensure favorable heat and humidity conditions of concrete hardening.

In the arsenal of Russian builders there are the following methods of winter concreting [8, 9, 10]:

1 group. Thermos methods (heat is introduced before laying the concrete mixture in the formwork):

- thermos;
- hot thermos.

2 group. Progressive methods (heat is introduced after laying the concrete mixture in the formwork):

- electrode heating;
- induction heating;
- infrared heating;
- the heating of the heating wires;
- heated in the mold thermoactive or thermoactive a flexible covering (TAFC);
- heating in enclosures.

3 group. Concreting with antifreeze additives.

Thermos method was founded in 1910 by Russian professor Kireenko I. A., is the most simple and economical method of winter concreting.

The essence of the method is as follows. Concrete mix with an initial temperature of 10-20°C (degrees Celsius) is transported to the object and placed in insulated formwork, open surfaces are also insulated. During cooling to 0°C (degrees Celsius) concrete gains a certain strength, which should be no less critical.

The method is based on the use of heat introduced in the manufacture, as well as exothermic heat release of cement.

The thermos method is used for concreting massive structures (e.g. foundations) with a surface modulus up to $M_p = F: V < 8 \text{ m}^{-1}$, at low negative temperatures (up to -10-15°C) and the required strength is not higher than critical.

where $V$ is the volume of concrete of the constructed structure, m$^3$;

$F$ – surface area of the structure, m$^2$.

In the thermos method, it is advisable to use additives of hardening accelerators.

The method of hot thermos or preliminary heating of concrete mixture was proposed in 1962 by the Russian professor A. S. Arbenyev.

The essence of the method is that delivered to the construction site concrete mixture is heated by electric current to a predetermined temperature, placed in insulated formwork and maintained in compliance with the rules of the thermos method.

Electric heating of the concrete mixture is carried out in buckets equipped with plate electrodes.

The duration of forced heating of the concrete mixture is 5-20 minutes, the maximum temperature is 60°C.

Preservation of mobility of the warmed-up concrete mix is reached by introduction of the plasticizing or slowing down setting additives.

Electrode heating was proposed in 1931 by swedish engineers A. Brand and H. Bolin.

Electrode heating-based on the use of heat released in the concrete during the passage of an electric current through it. This is achieved by including freshly laid concrete as an active resistance in the alternating current circuit of industrial frequency using steel electrodes of various types and layouts.
The type of electrodes (rod, plate, strip, floating, string) for heating a particular structure is selected depending on its size and configuration, reinforcement parameters, the location of embedded parts.

Electrode heating of designs is carried out by means of heating oil transformers with voltage on a secondary winding of 55, 65, 75, 85, 95 V.

**Heating concrete heating wire.**

To warm up the concrete, a cheap single-core insulated wire with a steel core with a diameter of 1.2-2.0 mm is used.

The wire is attached to the reinforcement cage before laying the concrete, after heat treatment remains in the body of the structure.

Heating of the heating wire is used for pouring high-density reinforcement structures, joints of precast concrete.

The step of fastening of a wire in a structure is accepted by calculation and makes 50-150 mm. The wire is wound turns on a reinforcing skeleton or stacked along reinforcing bars.

Heat treatment of concrete is carried out at a voltage of up to 95 V from the heating transformers.

**Infrared heating of concrete** is developed by the Russian professor Danilov N. N., is based on use of energy of infrared radiation submitted on open surfaces of concrete or a surface of not warmed steel timbering.

In the production of concrete works in winter conditions infrared heating is recommended:

- for warming frozen soil and concrete foundations, reinforcement and formwork, removal of snow and ice;
- for pre-warming zone of the joints of precast concrete structures;
- for creation of thermal protection of the surfaces inaccessible for warming;
- for heat treatment of joints of precast concrete and monolithic structures (with the possibility of creating closed volumes, excluding convective heat exchange of heated surfaces with the environment).

Infrared installation consists of a spherical or trapezoidal body-reflector, in the inner cavity of which are placed radiators (TEHs, ceramic radiators, infrared lamps) with mounting elements and current supply.

To avoid intensive evaporation of moisture, the open surfaces of freshly laid concrete are closed with a plastic film and sprinkled with a layer of sand.

**Induction heating** developed in 1946 by Russian professor Netushil A.V., based on the use of heat generated in the reinforcement or steel formwork, located in the electromagnetic field of the coil-inductor, which flows through an alternating electric current. To do this, an insulated inductor wire is laid in successive turns on the outer surface of the formwork.

An alternating electric current of 55-95 V, passing through the inductor, creates an alternating electromagnetic field, which causes eddy currents in the metal located in this field, which leads to its heating. The heat from the reinforcement and metal formwork is transferred to the concrete due to thermal conductivity.

Induction heating is most effective when concreting structures of linear type (columns, beams, crossbars, etc.) densely saturated with reinforcement with, as well as when using metal formwork.

**Heating of concrete in thermoactive formwork.**

The essence of the method is to transfer heat to concrete from electric heaters installed in insulated inventory formwork. Heat in the concrete is distributed due to thermal conductivity.

The advantages of the method are the exclusion of any additional operations for the preparation and conduct of heat treatment: all includes a standard cycle of formwork. Also the costs of consumables are included (electrodes, heating wire).

Large-Board thermoactive formwork consists of a steel formwork shield frame structure, heaters (TEHs, heating cable), screen (aluminum foil), insulation (foam, mineral wool), protective casing.
Small-Board formwork can have the following design solution: plywood formwork frame structure, fixed on the deck removable heating element of conductive sheet or filler plastic (e.g., polypropylene with graphite filler) and plastic sheet with a heater fused to the rear of the nichrome wire. Russian manufacturers (PC “Concrete Heating”, PC “Thermal systems”) offer small-panel formwork with film heaters and thermal insulation installed between layers of moisture-resistant plywood.

For heating of horizontal surfaces of constructions – overlappings, concrete preparations – thermoactive flexible coverings (TFC) are used, which consist of:

- flexible heaters (as a rule, the heating wire nichrome residential);
- protective moisture-insulating shell (polymer film);
- elastic insulation.

**Heating of concrete in enclosures.**

Enclosures are temporary structures within which a positive temperature is maintained and either the entire cycle of concrete work is performed, or only concrete aging. The essence of the method is to create conditions close to summer in the local area around the concreted structure.

The temperature in the enclosures at the bottom of the concreted structure should be at least 5°C. The average height temperature is usually taken in the range of 15-25°C.

By design, dimensions and methods of laying concrete mixture in them, the following types of enclosures are used:

- *small enclosures* (installed after laying the concrete mix): caps frame structure, canvas tents, shelters made of polymer film;
- *volumetric* (frame structure or air-supporting shells), inside which the means of mechanized laying of the mixture are placed and the entry of vehicles is provided;
- *mobile* (frame structure with tarpaulin coating), moved along the rails along the concreted extended structures (usually zero cycle): inside the entire cycle of concrete works.

To maintain the required temperature in enclosures, it is recommended to use electric heaters of various designs, heat guns on liquid or gas fuel.

**Concretes with antifreeze additives.**

Application in winter conditions of concretes with antifreeze additives allows to do without heating of the laid concrete and warming of the basis. Additives are introduced into the concrete mixture during its preparation in the form of aqueous solutions.

In concretes with antifreeze additives at negative temperatures, the liquid phase is preserved, which provides the possibility of hydration processes (interaction of cement with water) and, as a consequence, hardening and strength gain by concrete in the cold.

The scope of application of a particular antifreeze additive is limited by the freezing point of its solutions.

Antifreeze additives by the mechanism of action can be divided into two groups:

*Group 1* includes additives that reduce the freezing point of the liquid phase of concrete and practically do not affect the rate of structure formation. This group includes SC, SN and U (sodium chloride NaCl, sodium nitrite NaNO₂, urea (NH₂)₂CO). Concrete with these additives slowly gains strength at an early age.

*Group 2* includes additives that greatly accelerate the setting and hardening, and their solutions have a sufficiently low eutectic temperature. These additives include P, CH, CN, NCN (potash K₂CO₃, calcium chloride CaCl₂, calcium nitrate CA(NO₃)₂, nitrite calcium nitrate CA(NO₃)₂+ CA(NO₂)₂).

In connection with the above, it is recommended to use complex additives that allow to obtain concrete mixtures optimized for freezing point, hardening rate and degree of aggressiveness to the reinforcement.

Concrete with antifreeze additives is allowed to be used if the temperature of the concrete with the maximum permissible dosages of additives does not fall below during the holding until the critical strength is acquired:
-15 °C – for SN;
-20 °C – for CH+SC, CN+U, NCN, NCN+U;
-25 °C – for P, CH+SN, SNCH, SNCH+U.

For the design temperature, the average value of the outdoor temperature is taken according to the forecast for the first 20 days from the moment of laying concrete.

The amount of antifreeze additive is determined by the calculated temperature of hardening to a set of critical strength: the lower the outside temperature, the higher the consumption of the additive.

In accordance with GOST 24211-2008 “Additives for concrete and mortars” [2] antifreeze additives are divided into two groups:

- for “cold concrete” - provide hardening of concretes and mortars at negative temperatures;
- for “warm concrete” - provide protection of concrete mix from freezing for the period from its production to laying and supply of external heat.

As a rule, these are the same additives with different dosages in concrete.

Practice of winter concreting in the Siberian region.
The analysis of application of winter methods of concreting in Eastern Siberia is given in table 1.

### Table 1. Features of application in eastern Siberia

| № s.c. | Method for winter concreting | Features of application in eastern Siberia |
|--------|------------------------------|------------------------------------------|
| 1      | Thermos's                    | It is used in the construction of massive structures (ribbon and columnar foundations, grillages, foundation slabs) in the spring and autumn periods |
| 2      | Hot thermos                  | It is not used due to the significant required electrical power and loss of mobility of the concrete mixture during heating and laying |
| 3      | Electrode heating            | Prevailed in the application of up to 2000 years. In modern construction it is not often used due to the consumption of steel for electrodes and aluminum wire for switching electrodes |
| 4      | Induction heating            | Not applicable |
| 5      | Infrared heating             | It is used for heat treatment of precast concrete joints, warming of soil base and formwork cavity |
| 6      | Heating by heating wires     | Currently the most common progressive method |
| 7      | Heated in the mold thermoactive thermoactive flexible coatings (TAFC) | Not applicable due to limited (constructive solutions) offers from domestic manufacturers and the high cost of imported thermoactive formwork and TAFC |
| 8      | Heating in enclosures        | Enclosures are applied in the form of caps of a skeleton design, tent coverings |
| 9      | Antifreeze additives         | Antifreeze additives are used mainly for "warm concrete" - provide protection of the concrete mixture from freezing for the period from its manufacture to installation and supply of external heat. |

HSV 1.2 wire, which is in demand in construction, is specially designed for winter pouring of concrete with gradual heating of surfaces. The product is a wire in PVC insulation with a thin (1.2 mm in diameter) core of steel alloy. The electrical resistance of the steel wires of 0.15 Ohm/m, working current 15A. The cost of wire 1000-1500 RUB/1,000 m. Switching (cold ends, highway) heating wire is an insulated aluminum wire, the heating is carried out from the step-down transformer.
Russian manufacturers of chemical additives in concrete: companies “Fort”, “Formula concrete”, “Sonstrumax”, production company “Gidrostroykomplekt”, manufacturer of construction chemicals TM “Sika”, PC "POLYPLAST”, PC “RAMEKO”, PC “Skytrade”, PC “Chemical holding” and others produce complex antifreeze additives, the composition of which is not disclosed:

- Krioplast P25;
- Krioplast PC;
- Krioplast Premium;
- Krioplast Extra;
- Штайнберг FROST15;
- Штайнберг FROST25;
- Term’s;
- Frost 30;
- PUFAS.

Sodium nitrite and sodium formate $\text{HCO}_2\text{Na}$ are supplied from China to Russia.

Here are the main characteristics of one of the complex antifreeze additives “Krioplast P25”:

Manufacturer PC "POLYPLAST".

The additive is a mixture of antifreeze and plasticizing component. Available in dry and liquid commodity forms.

In case of application by the customer of the additive “Krioplast P25” in dry commercial form it is recommended to observe the following dosages (table 2):

| Average design temperature of concrete hardening, °C | Dosage range of dry product, %, by weight of cement |
|-----------------------------------------------------|-----------------------------------------------------|
| on “warm” concrete:                                  |                                                     |
| -5                                                  | 0,7                                                 |
| -10                                                 | 1,0 – 1,5                                           |
| -15                                                 | 2,0 – 2,5                                           |
| -20                                                 | 2,5 – 3,0                                           |
| -25                                                 | 3,5 – 4,5                                           |
| on the “cold” concrete:                             |                                                     |
| -5                                                  | 1,0                                                 |
| -10                                                 | 1,5 – 2,0                                           |
| -15                                                 | 2,5 – 3,5                                           |
| -20                                                 | 3,5 – 4,0                                           |
| -25                                                 | 5,0 – 6,0                                           |

The cost of the solution concentration of 35-40% additives “Krioplast P25” is 40-50 rubles / kg, dry additives- 80-90 rubles / kg. Manufacturers of ready-mixed concrete prefer to purchase an additive in the form of solutions, which simplifies the technology of feeding additives in the preparation of concrete mix.

In the near future, the specifics of the application of winter concreting methods at construction sites in eastern Siberia, apparently, will remain. Although, it is possible and the appearance of thermoactive formwork and thermoactive heating coatings (TAFC).

References
[1] Afanasyev A A, Matveyev Ye P, Minakov Yu A 1997 Technological efficiency of accelerated concrete hardening methods in monolithic housing construction *Industrial and civil construction* 8 p 36-37
[2] GOST 24211-2008. Additives for concrete and mortars, p 16
[3] Golovnev S G 2010 Modern construction technologies p 262
[4] Golovnev S G, Krasny Yu M, Krasny D Yu 2012 Production of concrete works in winter Conditions Quality assurance and efficiency p 336
[5] Krasnovskiy B M 2004 Engineering and physical bases of winter testing methods concretings p 470
[6] Mozgalev K M Intensification of technological processes for winter concreting of monolithic buildings South Ural state University p 130- 133
[7] SR 70.13330.2012. Bearing and enclosing structures pp 71-79
[8] R-NP SRO SSK-02-2015. Recommendations for the production of concrete works in the winter Period P 84
[9] Guide to the production of concrete works in winter conditions, areas of the Far East, Siberia and the Far North 1982 p 313
[10] Guide to heating concrete in monolithic structures. Research Institute of concrete and reinforced Concrete 2005 p 276
[11] Telichenko V I, Terentyev O M, Lapidus 2006 Construction technology buildings and structures p 446
[12] Tyuryukhanov K Yu and Pugin K G 2019 Impact of the surface of particles of moulding sand on the structural formation of asphalt concrete Proceedings of Universities. Investment. Construction. Real estate 9(3) pp 566–577
[13] Dobruskina M A, Petrov A V and Bat-Erdene Z 2019 Improving the technology of retaining walls in the Irkutsk region using gabion baskets Proceedings of Universities. Investment. Construction. Real estate 9 (2) pp 312–323
[14] Moskvitin V A., Emelyanova N A. and Mashovich A Y 2019 Experimental studies of air permeability indicators of composite "Poroplast CF" Investment. Construction, Real estate 9 (2) pp 342–353