Possibilities for Intensifying Construction Work’s Dynamic on Objects of the Annual Production Program by Winter Concreting Technology

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Abstract. The authors make decomposition of construction and installation works during the implementation of large investment and construction projects on the territory of mega-cities from monolithic reinforced concrete. Particular attention is focused on the seasonality of these works, on the features of organizational and technological solutions related to the effect of low temperatures on the binder hydration processes in the concrete mix, as well as on possible ways to minimize the increment of labor intensity and cost of work during these periods. As a result of the study, the authors of the article describe the principal algorithm for taking into account the features of winter concreting technology at the stage of current planning of annual production programs of construction organizations.

1. Introduction

The construction industry in the Russian Federation is developing from year to year and with it the requirements for building materials are increasing, among which concrete and reinforced concrete occupy a leading place. During the construction of large-scale objects there is a need for year-round work, including the implementation of concrete work at negative temperatures. As for the work during the winter time, it is not determined by the calendar readings, but by the temperature conditions, the phase transitions of water to the solid state, which depends on air temperature and atmospheric pressure. In many regions of the Russian Federation, fluctuations in temperature and pressure are frequent phenomena that predetermine difficulties in construction technology.

The relevance of the work is determined not only by the geographical location of the Russian Federation and the climatic conditions of work in most regions of the country, but also by the socio-economic aspects of the construction market [1-6].

Before considering the problems of technology, one should pay attention to the physico-chemical processes associated with the strength of concrete.
The strength of concrete is the result of the hydration of cement clinker minerals, which is represented by the following equations (1 – 4):

\[
3\text{CaO} \cdot \text{SiO}_2 + (n+1)\text{H}_2\text{O} \rightarrow 2\text{CaO} \cdot \text{SiO}_2 \cdot n\text{H}_2\text{O} + \text{Ca} (\text{OH})_2
\]

(1)

\[
2\text{CaO} \cdot \text{SiO}_2 + n\text{H}_2\text{O} \rightarrow 2\text{CaO} \cdot \text{SiO}_2 \cdot n\text{H}_2\text{O}
\]

(2)

\[
3\text{CaO} \cdot \text{Al}_2\text{O}_3 + 6\text{H}_2\text{O} \rightarrow 3\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot 6\text{H}_2\text{O}
\]

(3)

\[
4\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot \text{Fe}_2\text{O}_3 + (m+6)\text{H}_2\text{O} \rightarrow 3\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot 6\text{H}_2\text{O} + \text{CaO} \cdot \text{Fe}_2\text{O}_3 \cdot m\text{H}_2\text{O}
\]

(4)

However, at a negative temperature, the water that has passed into the solid phase (ice), ceases to participate in the hydration reaction and the strength of the material does not increase or does not flow at all, or is very weak.

For normal curing conditions, the temperature of the concrete mix at the time of casting should not be below 5 °C. In the process of hydration of cement clinker, heat is released due to the exothermic reaction, which increases the temperature of the mixture by 2-3°C.

With an average daily ambient temperature below 5°C and a minimum daily temperature below 0 °C [2], taking into account the necessary temperature of the concrete mix to set critical strength, you should use special winter concreting methods for keeping and heating the laid concrete in structures and structures erected on open air.

The choice of the method for producing concrete work in wintertime depends on a number of factors, namely, on the module of the surface of the structure and the volume of the concrete, the space-planning solution of the building, the nature of the reinforcement and the outdoor temperature. In each case, the choice of the method must be justified by technological and technical-economic calculations [2].

The most common methods of producing concrete work in winter time: a method thermos concreting using antifreeze additives preliminary electrowarming concrete mix, warm-methods, namely the electrode heating, warming thermosetting formwork steel insulated heating wire [2].

Before maintaining the concrete mix in one of the methods of winter concreting, it is necessary to deliver the mixture from the manufacturer to the construction site. The main task during the transportation of concrete mixtures is to preserve the rheological properties that ensure its workability.

In winter, the concrete mixture at the plant, as a rule, is heated. In accordance with Russian Code 70.13330.2012 [5] is allowed to issue a concrete mix with Portland cement temperature +35 °C. At ambient temperatures below 0 °C, for example -10 °C, the temperature difference is 45 °C.

When mixing a concrete mix in an auto concrete mixer, as in a concrete mixer of a gravitational action, large areas of the free surface of the mixture are revealed. Due to the large temperature difference from the constantly exposed free surfaces of the concrete mix, water evaporates, which leads to a dramatic change in the water-cement ratio and loss of mobility of the concrete mix. This, in turn, causes difficulties in laying and compacting the concrete mix and deterioration in the quality of concrete.

At the end of the installation of the formwork and the installation of reinforcement, the cavities to be concreted must be covered with a tarpaulin and awning fabric, excluding the ingress of precipitation in the form of snow and rain. To remove the ice on the fixtures and formwork, which appears due to lack of shelter, blown hot air should be used.

When feeding and laying concrete mix, it is necessary to minimize heat loss and maintain mobility. The decisive factors influencing the choice of the method of supplying the concrete mix are: space-planning and design solutions of the object being constructed and its structural element; volume and intensity of concreting. The main factors that must be performed when laying concrete mix are:
- the concrete mixture must be laid in the formwork and compacted before the cement begins to set, that is, until its mobility is lost;
- after laying and compacting the concrete mix and from the moment the cement begins to set, it is forbidden to subject the concrete to vibration and other mechanical effects. This is necessary for the formation of a solid structure of stone and concrete.

2. Materials and methods
In most countries of central Europe, the typical scheme of distribution of construction objects according to the annual production program of work has a similar structure (see Fig. 1). At the same time, a significant part of the time period laying in the zone of the so-called autumn-winter period, which is characterized by a negative range of ambient temperatures, as well as the most dangerous fact for building materials - the transition of the temperature gradient through zero mark (alternating temperature effects on materials and structures). In this study, we considered exclusively the construction facilities of the programs erected from monolithic reinforced concrete (see Table 1), for which the greatest influence of the climatic factor on organizational and technological decisions during their erection is evident. In this case, a natural question arises about the need to take into account such influence both in the production key (in winter, the labor intensity of monolithic work increases due to new organizational and technological solutions) and in economic terms. So, you need to consider a few directions for taking into account the influence of climatics on organizational and technological (first of all, it is labor intensity and duration) and economic components of a construction project (see Table 2).

**Figure 1.** Principal model groups of objects of the production program of a construction organization: 1, 2, 3, 4 - serial numbers of typical blocks (groups); I, II - the category of the object on the criticality of the implementation of the terms in accordance with construction contracts.

**Table 1.** Identification card of objects involved in the study.

| №  | Parameter name                  | Parameter value                                      |
|----|---------------------------------|------------------------------------------------------|
| 1. | The functional purpose of the object | Non-industrial buildings - residential, administrative |
| 2. | Constructive material           | Monolithic reinforced concrete                        |
| 3. | Floors                          | 15 - 28                                              |
| 4. | Construction region             | Central Europe and Russian Federation                |
Table 2. Analysis of objects especially exposed to natural climatic factors in the autumn-winter period at negative ambient temperatures.

| №  | The name of the direction of the winter increment | Winter increment accounting objects | Level of responsibility | The way to account for the winter increment (Compensation measure) |
|----|-------------------------------------------------|------------------------------------|------------------------|-------------------------------------------------|
| 1. | Organizational and technological parameter (complexity) | • Statement of quantities<br>• Material and Technical Records<br>• Labor costing | Organizational and technological design (Projects of work; Technological maps) | Accounting is possible with a careful calculation of the complexity with the use of appropriate technical regulation manuals |
| 2. | Organizational and technological parameter (duration of work) | • Schedules and schedules<br>• Network models | Organizational and technological design (Projects of work; Technological maps); Planning and production (production program) | Accounting is possible with a careful calculation of the complexity with the use of appropriate technical regulation manuals |
| 3. | Organizational and technological parameter (density of distribution of labor resources) | • Schedules of labor movement (diagrams) | Planning and production (production program) | Not standardized. There is no deterministic method. |
| 4. | Estimated project cost | • Local estimates<br>• Object estimates<br>• Summary estimate calculation | Economic planning | Economic planning |

As we see from the analytical analysis (see Table 2) of the current situation, the actual and obvious increase in the labor intensity of performing work in winter time (taking into account the characteristics of winter concreting technologies) is compensated exclusively at the stage of estimated calculations by entering an additional multiplying factor — the coefficient of winter appreciation. This compensation measure, in essence, gives an increment to the labor intensity and duration of the work due to the introduction of additional processes into the production cycle and the order of additional materials and equipment. However, from the point of view of planning, the next question remains unclear - how to correctly and comprehensively take these circumstances into account in the production program.

3. Results and discussion
When considering a wide range of factors that have a significant impact on the duration and complexity of the implementation of facilities in the production program, experts with the required
level of consistency of opinions call the climatic factor \([5, 6]\). But its weight characteristic takes the smallest value, which could indicate the possibility of excluding this factor from the regression model of the annual production program. To interpret expert research in this case should be as follows. Natural and climatic phenomena certainly have an impact on the duration and complexity of construction and installation works, but given the availability of relevant technologies, they do not pose a big problem for the units. Thus for the characteristic objects and the corresponding climate zones scheduled service must provide a combination of factors, wherein the regression equation is taken into account as base current basis, and the additional factor - conditioner, at certain periods of the action having a significant impact on the construction process (see. Table 3).

**Table 3.** Regression analysis of production program factors.

| Regression analysis | Combination number | Basic components of the regression equation | Additional significant regression equations for objects built at negative ambient temperatures |
|---------------------|--------------------|---------------------------------------------|---------------------------------------------------------------------------------|
| Presentation form   |                    | (Labor intensity)                           |                                                                                 |
| The symbolic form   | I                  | \(Q = a_0 + a_1 \cdot F_3 - a_2 \cdot F_4\) | \(a_3 \cdot F_5\) (weather and climate conditions - winter concreting technology) |
| Numeric form        | I                  | \(Q = (-532) \cdot 10^5 + 514 \cdot F_3 \cdot 10^5 - 453 \cdot F_4 \cdot 10^2\) | \(184 \cdot F_5 \cdot 10^4\) (weather and climate conditions - winter concreting technology) |

Also, when forming the plot of the movement of labor for the objects, it is necessary to foresee differences in the links (see Table 4) and the teams of workers, due to the new specialty required.
Table 4. Qualification and the numerical composition of the level of workers per 1 m³ of monolithic concrete.

| №  | Qualification composition of the link | Numerical link | Link device monolithic structures | Letter designation in a mathematical model |
|----|--------------------------------------|----------------|-----------------------------------|--------------------------------------------|
| 1. | Installers                          |                |                                   | R1                                        |
|    | (Formwork)                          | 2              | 2                                 |                                            |
| 2. | Concrete Workers                    |                |                                   | R2                                        |
|    | (Concrete Work)                     | 2              | 2                                 |                                            |
| 3. | Machinist                           | 1              | 1                                 | R3                                        |
| 4. | Reinforcement workers               | 3              | 3                                 | R4                                        |
| 5. | Electricians                        | 0              | 3                                 | R5                                        |
|    | TOTAL                               | 8              | 11                                |                                            |

The coefficient of combination of workers - 15%

Further on, the leading flow is produced according to the proposed methods, observing the fundamental condition:

\[
\sum_{i=1}^{n} \sum_{j} R_{ij}^{fact} \leq \sum_{i}^{m} \sum_{j} R_{ij}^{plan}
\]

Where,

\( R_{ij}^{fact} \) – the required amount of resource according to the results of calculations of the movement of labor;

\( R_{ij}^{plan} \) – the planned capacity of the construction company;

n – the number of objects;

i – the sequence number of the object;

m – the number of required specialties of working professions;

j – the serial number of the specialty.
The above algorithm obviously considers a particular case of the possibility of changing the technology used to optimize the production program of a construction organization. At the same time, he vividly shows the potential for further application and research in terms of labor resource regulation along the lead stream, taking into account the planned number of workers in the construction organization at the end of the year.

**Figure 2.** Principal algorithm.
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