Features of construction of multi-storey buildings and structures made of monolithic reinforced concrete in various climatic conditions

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Abstract. The construction of high-rise buildings with load-bearing structures made of monolithic reinforced concrete with the required quality is not an easy task. This applies mainly to the production of works in extreme temperature and humidity conditions. As the practice of construction using traditional technologies shows, the concrete of the erected floors does not reach the required strength. In winter, it is 85-90% of the project. In addition, on the upper floors where the concrete is in the hardening stage, its strength on average is even lower. Thus, high-rise buildings made of monolithic reinforced concrete at the construction stage do not meet the requirements of stability and reliability to the perception of seismic loads. This situation is not taken into account at the design stage. In the normative design and design approaches, the condition for setting the grade strength of concrete is laid down. In fact, the real picture differs significantly from the estimated one. And it is necessary to study transient design situations. This means that when designing, you should consider options for different combinations of applied loads and the actual strength of the concrete structure of the floors. Modern construction technologies provide favorable conditions for concrete hardening. All of them are associated with a significant increase in production costs (electricity, materials, labor), construction time, and therefore the cost of building construction. The way out of this situation is a systematic linking of design issues and organizational and technological capabilities of construction production. Options for such solutions are discussed in the article.

In Russia and abroad, monolithic reinforced concrete is the most popular material for forming load-bearing structures of buildings and structures.

The material is extremely reliable in the operation of buildings, provided of course that the necessary quality of work is observed [1, 2, 3].

But this applies to the finished building and structure when the concrete has reached its design strength. The situation is quite different at the construction stage.

The dynamics of the strength gain of hardening concrete under different climatic conditions and with different mix compositions has been comprehensively studied [4, 5, 6].

The so-called “normal hardening conditions” are achieved only in laboratory conditions, but this is not possible in practice on a construction site. When concreting building structures, it is recommended to remove the formwork when the concrete reaches “critical” strength. This indicator is different for different designs. For load-bearing structures (for example, floor slabs or beams), this minimum is 70% of the branded one. For vertical load-bearing structures, but not loaded or lightly loaded (for
example, walls and columns), this is 50%. This creates a situation when the erected load-bearing structures of the next tier (usually a floor) do not have sufficient strength to dynamic loads (including seismic ones) at the time of completion) [1, 7].

Achieving “critical strength” in almost any temperature and humidity conditions is theoretically possible. Many technical and technological solutions have been developed to ensure the conditions for achieving “critical strength”. In winter, various methods of winter concreting are used: the thermos method with preliminary heating of the concrete mixture and with keeping in insulated formwork, electric heating, electrical heating, steam heating, the device of greenhouses and many other methods [8, 9, 10, 12, 13]. But when using any of these methods, after reaching the decking strength, further strength gain occurs in conditions of negative outdoor temperature. And as practice shows, concrete never reaches its brand strength. Even if the strength of the concrete is 70%, the final strength of the concrete will be 85-90%. If the molten strength is even lower, then the final strength will be 50÷70% of the brand.

This creates a situation where the concrete of the constructed floors made of monolithic reinforced concrete in winter has a reduced strength compared to the design (vintage). In summer, the difference in the strength characteristics of concrete on the upper and lower floors is smaller, but this fact also occurs.

There is no doubt that there is a need to systematically link design issues and organizational and technological processes for the construction of buildings and structures. It is explained by the many and diverse manifestations and consequences of factors that determine the reliability of structures at the stages of construction, operation and maintenance. Their consideration at the stages of making design decisions is carried out with various conditional technological prerequisites that do not have sufficient design justification.

In particular, the construction of multi-storey buildings made of monolithic reinforced concrete in harsh climatic conditions and geotechnical activity of the bases is associated with the performance of concrete work at subzero temperatures. From the point of view of normative design approaches, this means that it is necessary to consider transitional design situations caused by:

a) changes in existing loads (insufficiently mature concrete becomes an element of impact, not resistance);

b) strength heterogeneity of structures in height according to objective technological conditions of construction;

c) the lack of sufficient justification for the concept of “critical strength of concrete” structures.

Without considering the last factor in detail here, we note that in the designer's understanding, it should provide the possibility of achieving concrete (in the future!) design parameters of internal resistance. For technologists, it is important to achieve it with the condition that it is possible to conduct subsequent operations and transfer loads to the considered level with the critical strength of concrete.

Justification of the necessary project coordination of issues related to the consideration of emerging transitional settlement situations is considered in this work.

Existing technologies of industrial construction provide for the use of advanced formwork systems and means of mechanization of the processes of laying and compacting concrete mixes [3, 10, 11]. This state-of-the-art equipment allows for high construction rates. For example, for high-rise buildings with small dimensions in the plan (“point” objects), the duration of construction of structures on one floor is about a week.

It is extremely important to find out what is the mass of load-bearing structures of a typical floor of a multi-storey building, for example, the size in plan is 24×18 m. with a step of load-bearing longitudinal and transverse walls of 6 m. The weight of monolithic reinforced concrete floor structures can be very approximately 400 tons.

Given the fact that the strength of this reinforced concrete is lower than the design value, as well as the insufficient strength of the concrete of the underlying floors, the question arises – whether the earthquake resistance of the building is provided during its construction.
For the perception of static loads, the strength of concrete may be sufficient, but with dynamic loads the question is open. The following diagrams reflect the situation during the construction period, taking into account the time of year and the dynamics of the growth of concrete strength (figure 1, figure 2).

These schematic diagrams are conditional.
First, the pace of work may be different.
Secondly, it is accepted that during the winter period, the necessary conditions are provided for concrete to achieve critical strength during the first week of hardening.
Third, the production of works may fall on the spring, autumn and transition periods of the year.

Figure 1. Schematic diagram of the strength distribution of hardening concrete of a high-rise building constructed in the summer.

Figure 2. Schematic diagram of the strength distribution of hardening concrete of a high-rise building erected in the winter season.
Fourth, in winter conditions, it is not provided for the use of any measures to insulate the underlying floors (which is almost always the case in construction practice).

In this regard, the given indicators of the strength of hardening concrete and mass may vary significantly. But the fact that there are significant masses of reinforced concrete structures up to 1.5-2.0 thd. tons with an average strength of up to 50% of the design (brand) is available. And these masses are based on structures with 100% strength (in summer) or a maximum of 90% strength (in winter).

To analyze the presented hypothesis, we consider two (Pic. 1 and 2) conditional options for the construction of a multi-storey building made of monolithic concrete, the technological difference of which is in the conditions of hardening. The structural consequences determined by the technology are integrally evaluated by the modified (floor-by-floor) strength spectrum. Their individual indicators are taken from generalized time models of strength gain for technological periods of time of floor construction. It is assumed that during the initial period of concrete hardening (at least 7 days), even in winter, the conditions of hardening are sufficient to achieve “critical strength”.

Calculation of buildings and structures for seismic effects is carried out with the condition that the concrete has gained its brand (design) strength. At the stage of building construction, the design characteristics of materials and structures are different, but calculations for seismic effects are not made. At the same time, it is obvious that during an earthquake, concrete masses with insufficient strength can lose stability, and structures can get serious deformations and damage. At the design stage, this fact should be taken into account, that is, the transition design situation should be taken into account.

Pictures 1 and 2 show, in the temporal aspect, histograms of the mass of structures perceived by the concrete (reinforced concrete) of the underlying floors. Their comparison shows that the probability of a design load with a strength of less than 50% of the brand is extremely high. Moreover, the use of specialized technological techniques (insulation, additives, heating, etc.) can remove the frequency of these situations, but do not exclude them at all.

This fact allows us to believe that the analysis of such situations should be considered at the design stage, especially for structures for seismically active areas. As an initial approach, it is possible to consider the background intensity of seismic activity and establish the “critical strength” value based on the corresponding calculations. Moreover, the value of the latter, obviously, it is advisable to differentiate not only by design (separately for columns, wall coverings, etc.), but also by floor.

Obviously, with this approach, it is possible to consider additional (market-economic) technological measures to ensure the continuity of concrete work.

What is the way out of this situation? It is necessary to make a thorough factor analysis at the design stage of the work production process (development of construction organization projects, work production projects and process maps). Namely, take into account the time of year, the timing of work (the rate of concreting), the availability of machinery and technological equipment, the qualification of quality control services.

The most radical solution is to create a thermal contour of the building. But technologically and organizationally, this is practically impossible. And energy costs increase significantly. In addition, if you combine work on concreting structures and creating a thermal circuit, dangerous production factors appear due to the intersection of dangerous zones, that is, the appearance of a zone of adjacent work.

A half-hearted solution (aimed at a partial solution to the problem) can be the following solution. After a set of concrete tiers (floors) of critical strength and unpacking – this is the creation of a thermal circuit, that is, closing and insulation of openings, and heating of internal premises. And even when the outer walls come into contact with cold air, due to conductive heat exchange (provided that the inner surfaces of the walls have a positive temperature), the strength of concrete will increase more intensively.

Since it is an indisputable fact that the concrete strength is insufficient after deburring, the following solutions can be offered for consideration:
- when designing buildings and structures, provide for a class (brand) of concrete higher than required by calculation, which of course will lead to an increase in the cost of construction;
- increasing the holding period of hardening concrete in insulated formwork (or using other methods of winter concreting) to reach 85-90% of the brand strength, which will lead to an increase in the time of work and the cost of production resources;
- strengthening of the structures (possibly temporary) of the floors after unpacking, which will also lead to an increase in the cost of construction;
- modernization of concrete mix compositions by using additives that reduce the hardening time (hardening accelerators), antifreeze and complex.

It is possible to use a combination of the above design and organizational and technological solutions. In any case, the decisions made must be justified by appropriate calculations and reflected in the settlement documentation, construction management project, project of manufacture of works, technological map.

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