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Use of formwork systems in high-rise construction

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Abstract. Erection of high quality buildings and structures within a reasonable time frame is the crucial factor for the competitiveness of any construction organization. The main material used in high-rise construction is insitu reinforced concrete. The technology of its use is directly related to the use of formwork systems. Formwork systems and formwork technologies basically determine the speed of construction and labor intensity of concreting operations. Therefore, it is also possible to achieve the goal of reducing the construction time and labor intensity of works performed by improving the technology of formwork systems use. Currently there are unresolved issues in the area of implementation of monolithic technology projects, and problems related to the selection of a formwork technology, high labor intensity of works, poor quality of materials and structures, etc. are the main ones. The article presents organizational and technological measures, by means of which introduction it is possible to shorten the duration of construction. A comparison of operations performed during formwork installation according to the conventional technology and taking into account the implemented organizational and technological measures is presented. The results of a comparative analysis of economic efficiency assessments are also presented on the example of a specific construction project before and after the implementation of the above mentioned measures. The study showed that introduction of the proposed organizational and technological model taking into account optimization of reinforcing and concreting works significantly improves the efficiency of a high-rise construction project. And further improvement of technologies for the use of insitu reinforced concrete is a promising direction in the construction of high-rise buildings.

1 Introduction

Today erection of high quality buildings and structures within a reasonable time frame is the crucial factor for the competitiveness of any construction organization. It is possible to solve this problem, first of all, by means of introduction of modern technologies and optimization of existing organizational and technological solutions.

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For example, hundreds of well-known skyscrapers were built on the basis of a reinforced concrete skeleton, including world record holders - the Burj Dubai tower (818 m high) and the Petronas Towers in Malaysia (432 m high). The potential of mix-in-situ concrete is not used to the fullest extent in Russia. Obviously, extention of the scope of its application in high-rise construction is facilitated by the development of new technologies, including creation and implementation of modern formwork systems. It is formwork systems and formwork technologies that basically determine the speed of construction and labor intensity of concreting operations [1, 2].

To date there are unresolved issues in the area of monolithic technology projects and the main ones are as follows:

- Difficulties in choosing the most optimal formwork system for a specific development project.
- Insufficient informativity with respect to the rules and terms of concrete curing and further form stripping.
- High labour intensity of major types of construction and installation works.
- Low quality of finished structures.
- Low level of control over construction processes related to an improper regulatory framework.
- Low quality of building materials of home manufacture.

An integrated approach to the organization and technology of in-situ concreting is needed to solve the above mentioned problems.

- Improvement of applicable regulatory inactments.
- Improvement of solutions for the performance of construction and installation works.

Development of approaches to solve organizational and technological issues affecting the economic efficiency and overall profitability of project implementation.

2 Materials and Methods

A formwork system is a temporary or permanent construction form, which includes formwork and elements that ensure its rigidity and stability - supporting structures, scaffolds, and fasteners. There is a wide variety of formwork systems (Fig. 1).

Hydraulically operated travelling self-climing forms are used in the construction of external walls of buildings, which height exceeds 30 storeys. They represent a formwork module consisting of outer and inner formwork panels, working scaffolds and form anchors. It should be noted that sometimes it is impossible to use creanes at an altitude exceeding 100 m because of winds and fogs. They can be used 4-5 days per week, and this time is enough to build at least 1 storey. Self-climbing forms solve problems of shuttering and mechanical formwork removal, formwork mechanical movement by height, ensuring of safe working conditions and maximum protection from wind. Formworks differ in nature; they are designed and manufactured for a specific project. Special projects involving formwork movement by height, a hydraulic distribution arm and individual cranes placed on the carcass under construction are developed for extremely complex high-rise buildings [3, 4].

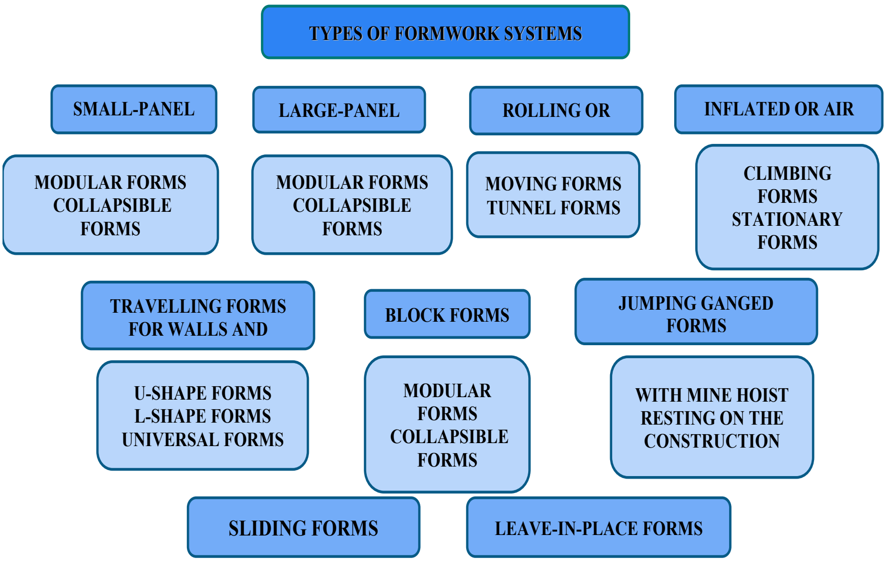

Fig. 1. Types of formwork systems.

The number of in-situ concreting operations performed, as well as their sequence, in which these types of formwork systems are used, is changed in the process of development of organizational and technological solutions for the improvement of formwork.

3 Results

When studying shuttering work processes, a number of operations, which optimization will reduce the duration of construction and, consequently, increase project efficiency were identified.

Improvement of methods of formwork installation:

- rational choice of formwork, including enlargement of shuttering panels into reusable cards with no need to demount them and application of shaft formwork, which shorten the duration of shuttering works
- application of coatings eliminating adhesion and the need to lubricate formwork
- reduction of the distance of formwork movement by a crane

A reasonable approach to choosing a formwork system is an important factor for reducing the period of construction of buildings and structures. When choosing formwork it is necessary to take into account characteristics and parameters of a future building, dimensions of structures under concreting, as well as climatic conditions. Use of the latest formwork systems for the implementation of monolithic technology projects contributes to improving the use of technology and construction quality [5].

A formwork system is chosen at the design stage, when the number of panels and the sequence of works on erection (dismantling) are selected. Main ideas and solutions for works optimization are considered at this stage.

A development project is divided into assembly areas, tiers, bays and a working project is drawn up for formwork system selection. Currently, there are many specialized software systems that allow carrying out a detailed calculation of the amount of formwork, its layout for horizontal and vertical structures. Introduction of optimization solutions allows to reduce the area of the shuttering system used and achieve the maximum possible reduction in the number of panels.

Depending on the configuration of the structures being erected, the number of formwork panels is selected. By means of additional swivel and hinge elements formwork panels can be put longitudinally, transversally, perpendicularly. Formwork auxiliary elements are as follows [6]:

- Leveling beams.
- Scaffolds brackets.
- Struts.
- Clamps.

A competent calculation of formwork elements affects the reliability of the system, which ensures the following:

- Strength and rigidity for various types of loads.
- A possibility to use automatic means during installation.
- Humidity conditions that are required for concrete hardening and curing.
- Fast installation and dismantling.
- Convenience for repair and replacement of individual elements.
- Minimization of labor and material costs.

The maximum number of formwork elements is determined taking into account the technology of works execution and the sequence of construction processes in the course of a development project erection. Formwork panels for the construction of vertical and horizontal structures are selected based on the number of bays, 2 largest or 3 respectively. It should be borne in mind that one system is used for reinforcement works, the second one - for concrete works and the third one - for installation [7].

In the course of the study it was found out that three sets on the floor for horizontal structures are not always enough in case of reduction of the time of works execution up to two days per floor. It is required to take into account one additional formwork set per bay. The formwork is removed from the structures when concrete cures and support racks are installed. Intermediate support racks are required only if concrete strength is 45-85% [3].

To calculate the number of oversupporting racks, it is required to take into account several factors, such as:

1) Climatic parameters, i.e. air temperature in the area of the development project construction.
2) Number of floors.
3) Speed of works execution.
4) Concrete hardening time.

In order to calculate the number of oversupporting racks, it is necessary to calculate coefficient K. As a rule, oversupporting racks are calculated per floor, per bay or per one set of forms for floors. In practice, K coefficient per floor is calculated by the following formula for multi-storey development projects:

$$K^e = \frac{\sum_{i=1}^{i=n}(m_i * n_i)}{k} \quad (1),$$

K coefficient per bay or per workform system set will be calculated as follows:

$$Kz=Ke*Kbay \quad (2),$$

where

mi - the percentage of oversupporting racks for a given level of intermediate strength of a floor used for concreting divided by 100%.

ni - the time of relevancy of this percentage of racks determined by the schedule of concrete strength development in days.

k - the average speed of floor erection, days/floor.

Kbay - the number of bays on the floor.

Kfw - the number of bays, for which a formwork set is designed.

The following list of works presented in Table 1 is recommended to optimize the execution of shuttering works of vertical structures.

Table 1. Comparative analysis of operations during shuttering works of vertical structures.

According to the current Russian standards	Optimized option
• Marking of places for formwork installation along laying out axes. • Installation of panels. • Panels bolting. • Formwork alignment. • Formwork fastening by struts, ledgers, braces and ties.	• Formwork sorting. • Assembling into cards according to the working project. • Installation of scaffolds on the formwork. • Installation of scaffolds for external walls. • Marking of installation points on the concrete. • Slinging and installation of one side of the formwork, removal of slings. • Installation of plastic cones and tubes, installation of elements forming openings. • Slinging and installation of the second side of the formwork. • Installation of leveling beams. • Formwork fastening with ledgers and nuts, fixation of struts, closing of ends, closure of gaps between the formwork and concreted structures. • Alignment of the formwork prior to concreting, final alignment of the formwork after concrete placement.

To optimize works on walls formwork removal, let's compare the option of operations that is applied today according to the current standards with an optimized option for the performance of this type of works.

Table 2. Comparative analysis of operations during wall wormwork removal.

According to the current regulations	Optimized option
• Removal of struts. • Loosening of bolted connections of panels and removal of formwork anchors. • Removal of the formwork from the surface of concrete. • Removal of panels and fixtures and their transfer to the place of storage. • Formwork cleaning. • Formwork lubrication.	• Removal of struts and nuts from the formwork. • Release of struts. • Removal of ends fixtures. • Warehousing of fasteners. • Panels removal from the concrete surface. • Panels transfer to the intermediate site, panels cleaning from concrete and their lubrication. • Removal of end cutoffs and elements forming openings. • Removal of plastic cones.

For the installation and dismantling of forms for floors, a comparison of the operations, which are used today in accordance with the current regulations, with an optimized option for this type of works was carried out.

Table 3. Comparative analysis of operations during installation and dismantling of forms for floors.

According to the current regulations	Optimized option
• Installation of sub-curve pieces and fastening. • Installation of curve pieces. • Installation of panels.	• Formwork sorting. • Supply of formwork elements to the bay. • Installation of racks with tripods. • Installation of universal forks.

According to the current regulations	Optimized option
• Formwork alignment. • Installation of frame boards and fastening.	• Installation of longitudinal beams. • Installation of intermediate racks without tripods. • Installation of transverse beams. • Initial formwork alignment. • Plywood installation. • Closure of seams between plywood sheets. • Installation of elements forming openings (casings). • Final formwork alignment.

The proposed organizational and technological measures for the execution of shuttering works should ensure a reduction in the duration of construction and labor intensity.

4 Conclusion

The technical and economic assessment of the proposed organizational and technological model for the implementation of investment and construction monolithic technology projects is based on a comparison of options. The comparison was carried out on the example of implementation of a 30-storey multifunctional residential complex with an underground parking. Construction is carried out using monolithic technology [8, 9].

- In the first option the project is implemented taking into account the accepted organizational and technological solutions, where the average speed of storey erection is 3 days.
- In the second option the project is implemented in the ordinary and usual course (traditional technology), where the average speed of storey erection is 6 days.

The average time for the execution of works of a single cycle is 30 calendar days, taking into account delivery of the required resources/materials. It is necessary to understand that there may be unplanned downtimes at the construction site for various reasons, so it should be taken into account when planning work days. As practice shows, most often a downtime does not exceed 10-15 days. As a result it takes 90 working days to build the carcass.

As per calculation, about 95 m of concrete is poured per day: walls 0.22 m thick - 38 m3, horizontal structures 0.18 m thick - 57 m3.

According to the calculation, about 420 m2 of formwork is required for concreting of 1 bay of vertical structures. Carrying out simple calculations that take into account the volume of the concrete mix per day, it was found that 11m of vertical formwork is required for 1m3 of concrete mix. At least 840m2 of formwork is required for two bays to ensure uninterrupted works execution.

Table 3. Comparison of technical and economic indicators of projects before and after the implementation of organizational and technological measures.

Economic efficiency indicators	Option 1 (taking into account the organizational and technological decisions)	Option 2 (using the conventional technology)
NPV	384,436,335.53 rubles	370,956,858.09 rubles
IRR	64.55%	46.20%
PI	1.27	1.1
T	8 city blocks	9 city blocks

It was stipulated earlier that the technology of execution of formwork installation works to a greater extent depends on the chosen formwork. Formwork temporary indicators of "PERI ELPOS" and "TIPOS DOKA" systems are used for the implementation of the development project.

It should be noted that organizational and technological solutions were implemented not only for formwork operations, but also for the execution of reinforcing and concrete works.

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