Ways to improve the quality of monolithic reinforced concrete structures

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Abstract. In the construction sector, according to official statistics, the quality of construction products in recent years has tended to deteriorate. The number of defects affecting the structural safety of constructed buildings and structures has increased, and there is a tendency to increase the specific gravity of violations at the facilities. The cause of most defects in monolithic structures is poor-quality formwork. The application of a systematic approach to improving the quality of formwork structures is an essential element of the quality control system of monolithic structures. This paper presents data on the main structural elements, as well as gives a classification of the main defects that occur when formwork is performed, the causes of their occurrence are identified, and ways to eliminate them are proposed.

1 Introduction

One of the main indicators of the level of development of industry in general, and construction production in particular, is the quality of any product [1]. The quality of construction products depends on many factors: the quality of engineering surveys and project documentation [2-5], the quality of materials and products [6-11], the observance of the quality control system during the construction of an object [12, 13], the correct maintenance, etc.

The study [14] indicates that to improve the quality of production of reinforced concrete structures in the factory, there is a need to improve the quality management system, as well as updating the working documentation. Studies [15] are devoted to the study of low quality of monolithic reinforced concrete slabs of effective forms, the determination of the main defects and damages arising from their construction. The composition of operations and controls is proposed. In [16], it is noted that one of the main causes of premature destruction of concrete and reinforced concrete structures is a violation of the integrity of waterproofing coatings. In [17], the authors indicate that the quality, reliability and durability of welded joints of metal structures largely depend on the production conditions and the accuracy of execution. For wooden structures, such a basic quality indicator as durability is ensured by the use of high-quality protective coatings [18].

The practice of monolithic construction involves the use of all of the above materials. The authors of [19] devote particular attention to works related to reinforcing and concreting. However, the important technological process of monolithic housing construction is the formwork, which includes the formwork system and the technology for the production of formwork [20-23].

In recent years, the number of defects that affect the structural safety of constructed buildings and structures has increased, a tendency to increase in the specific weight of violations per object has appeared [24]. This is partly due to the deterioration of the quality of projects [25]. The reason for about 14% of defects in monolithic structures is poor-quality formwork.

The popularity of the application of monolithic housing construction leads to the nomination of requirements for the quality of formwork, fasteners and equipment, as well as the production of this type of work.

The quality of formwork depends on many factors. In particular, from the compliance of the materials from which the formwork is made with regulatory documents, from the careful use of the
formwork and monitoring the condition of all the constituent elements of the formwork system, the correctness and level of development of technological documentation, compliance with technological discipline, as well as the qualifications of workers.

Formwork systems consist of a large number of structural elements that require studying the influence of their parameters on the reliability of the system as a whole, the manufacturability of this type of work, and also on the quality of the finished monolithic structure at the outlet.

The purpose of this work is to identify the most common defects of monolithic reinforced concrete structural elements that occur when formwork systems are installed, as well as the development of recommendations for their elimination.

In this paper, special attention is paid to studying the influence of the quality of monolithic reinforced concrete structures on the technical condition of the formwork systems used. Ways are proposed to improve the quality of monolithic reinforced concrete structures by introducing additional stages of operational control.

In his work [26] Kobeleva S. provides information that the deformation of formwork systems during the construction of monolithic reinforced concrete structures is a function that depends on a number of variables:

1) the composition and properties of the concrete mixture (aggregate size, cement activity, water-cement ratio, temperature, etc.);
2) technology for the production of concrete work (laying methods, compaction of concrete mix, intensity of concreting, etc.);
3) climatic and atmospheric effects on the formwork (ambient temperature, wind load);
4) physico-mechanical characteristics of the formwork materials (elastic modulus, linear expansion coefficient, bulk density, etc.) and design features of the formwork (section of elements, types of joints, etc.);
5) the initial defects of the formwork elements: manufacturer’s defects (deflections, cracks, corrosion of materials, etc.), the accuracy of the installation of formwork elements at the construction site [26].

The material requirements for the formwork shield are:
- compatibility with the poured mortar, that is, the material of the shield should not impede the hardening of concrete and not collapse under its influence. So for gypsum concrete and gypsum-cement-pozzolanic concrete, the use of metal formwork is unacceptable, due to the increased alkalinity of the medium, leading to acceleration of metal corrosion processes [27, 28];
- the shield of the construction formwork must provide sufficient tightness to hold the components of the building mixture, in particular fine particles and cement milk;
- the material must have sufficient bearing capacity to withstand the pressure of the building mixture;
- the shield material should have low adhesion to the concrete mortar, so that during the removal it does not wear out itself and does not lead to surface destruction of concrete;
- shield material should be inexpensive, easy to use and as durable as possible.

To date, in the production of formwork, various materials for the shield are used, but mainly shields of wood, metal (steel or aluminum), plastic and laminated plywood are found.

To connect the shuttering boards, wedge, eccentric, universal and other types of locks are used, which differ in principle of action.

The task of the castle is to connect the shields and align them in one plane, avoiding the formation of cracks.

The following requirements apply to locks:
- the ability to clamp formwork boards as fast as possible;
- obtaining tight joints of the shield formwork, providing a smooth concrete surface;
- the ability to perceive both tensile and compressive forces;
- lack of gradual “slipping” under dynamic loads (for example, blows with an assembly hammer).
- the presence of design features of the castle, due to which the ingress of mortar, paint, plaster does not affect its performance [26].

2 Methods
At the first stage of the work studied regulatory sources in the field of quality of monolithic reinforced concrete structures.

At the second stage, the main defects and damages of monolithic reinforced concrete structures at construction sites of the city of Kazan, Russia were identified.

At the third stage, defects and damage to the shuttering systems during the installation of monolithic wall structures were studied.

To determine the geometric deviations, a visual-measuring control kit (Figure 1), a CX-105 total station, and a laser range finder Leica DISTO D5 were used.

To control the quality of monolithic structures, we used a measuring magnifier with a 10-fold increase of LI-3-10x, an ultrasonic flaw detector UK-14PM, a concrete strength meter Original Schmidt N-34 (Figure 2), a concrete protective layer meter POISK-2.5.

![Figure 1. The process of determining the overall dimensions of structural elements.](image1)

![Figure 2. The process of determining the strength of concrete.](image2)
3 Results
3.1 Deformation and wear of the shield of shields
Inadmissible deflection of the formwork board, local crumple of the formwork profile, as well as geometric and size deviations (for example, the difference in the measurements of the board diagonals), all this occurs due to impacts of the formwork during movement, effect of vibration on the formwork during packing of the concrete mixture, as well as during installation and dismantling formwork cards. Most often, the formwork gets deformed when concreting the structure due to non-compliance with the speed of concreting. As a result of the shield deformation, its destruction occurs, and repair of the faulty formwork leads to a rise in the cost and increase in the complexity of formwork, as well as a decrease in the turnover rate (table 1).

Table 1. The number of turnover cycles of large-panel formwork, depending on the shield material.

| Type of formwork (shield) | The number of turnover cycles for forming / supporting structural elements (in revolutions or meters of displacement) |
|--------------------------|-----------------------------------------------------------------------------------------------------------------|
| Large-panel:             | Class 1 (not less) Class 2 (not less) Class (before)                                                               |
| Wall plywood             | 80                                                                | 60                                                                | 60                                |
| Wood, plastic            | 30                                                                | 20                                                                | 20                                |
| Steel, aluminum          | 300/400                                                          | 200/50                                                           | 200/250                          |

It was established that the wear on the shield of the boards occurs due to insufficient quality material or poor lubrication on the molding surface (Figure 3).

Figure 3. Violation of the integrity of the surface coating of the formwork board.

The surface of the formwork in contact with concrete must be coated with grease before laying concrete.

The problem of improving the lubricating compositions for formwork is raised in [29]. It states that formwork lubricant is one of the essential components of formwork systems. Their main purpose is to facilitate the separation of concrete from the formwork material and to ensure high quality of the outer surface of the molded structures. Thanks to the use of lubricants, the service life of the shield of shields is increased. Improving the quality of the surface layers of concrete occurs as a result of a decrease in the adhesion forces in the contact zone and, consequently, leads to a better surface of the concrete structure.

It has been determined that openings with various types of bushings are provided for screeding the formwork panels. The destruction of the bushings occurs due to the fact that during the concreting
process, concrete flows in them and concrete plugs are formed, which must be removed. Most often, plugs are removed using a puncher or a special cone, which, under dynamic influence (hammer blows or special tools) removes the plug. As a result, the bushing collapses and concrete flows out through it. On finished structures, gravel and shells begin to appear (Figure 4). A destroyed shrink bushings in many cases leads to the displacement of plastic retainers during concrete pouring, as a result of which the shrink anchor is jammed [30].

![Figure 4: Sinks and gravel surface of concrete.](image)

### 3.2 Destruction of the protective coating of the formwork frame

During the operation of shuttering boards after 20-25 cycles of concreting, as a rule, cracking and detachment of the coating begins, as a result of which corrosion develops in significant areas of the shuttering frame. Reducing the actual thickness of the profile due to corrosion leads to an increase in the deformation of the shields when laying concrete mixture (Figure 5).

![Figure 5: Deformation of the formwork frame.](image)

### 3.3 The destruction of the lock elements

It was established that at the construction site, lock elements are exposed to various influences. The main defects that arise in this case are the deformation of the lock (bending of the wedge) and the detachment of the movable bracket from the stationary (Figure 6).
Figure 6. The bend of the lock wedge.

Since the lock is an important element for fastening the shields together, it is important that the connection is reliable and the lock is working. Improving the design of connecting locks is an important and promising development of improving the quality of monolithic structures.

3.4 The influence of the parameters of the formwork profile used
In the manufacture of shield frames, special rolling profiles are used, which are crucial in the strength and functional characteristics of large-panel elements.

In [30], the task was formulated to select the optimal combination of the thickness of the profile used and the steel grade used. Scientists decided to conduct a computer simulation of the formwork shield under load using SolidWorks CAD tools. When calculating the tested model of the shield, the maximum permissible uniform pressure of 90 kN / m² is taken. The results of computer modeling showed that the most optimal combination of the used thickness of the shuttering profile and steel grade is 3.5 mm and St10 respectively. Elements made of this material have better performance characteristics, are less prone to deformation, work better on local crumpled elements.

3.5 Improving the reliability of the protective coating of the formwork frame elements
An important significance in the influence of the quality of formwork systems on the technological parameters is played by the type of coating used to protect the elements of the frame of the formwork panels from corrosion and the degree of adhesion of the coating to concrete.

Damage to the protective coating of the formwork frame occurs according to the following scheme: 1 - the occurrence of chips or scratches during various technological operations; 2 - a local increase in the cleavage area along radial surfaces, places of conjugation of elements; 3 - the widespread occurrence of chipping, the occurrence of corrosion.

One of the reasons for peeling paintwork is poor preparation of the surface of the frame before applying. Thus, it is necessary to introduce constant input quality control of the paintwork during the supply of shuttering boards to the construction organization. We can also recommend construction organizations to choose a manufacturer of formwork systems using shot-blasting preparation of the metal surface during coating, which provides higher adhesion of the coating to the metal. The quality control of the coating by the lattice notch method in accordance with GOST R 54563-2011, which allows determining the degree of adhesion of the coating to metal, can be performed at the construction site. The introduction of this input control will allow the use of formwork panels with a
higher quality of paintwork and will reduce labor costs for additional work on cleaning the frame of panels from concrete and ready-made monolithic structures from rust and traces of paint. The service life of formwork panels will approach the period guaranteed by the manufacturer.

3.6 The influence of the parameters of the bushing on the quality of monolithic structures

In the formwork panels, holes and grooves with various types of bushings for screed are provided. The bushings are hollow cylindrical tubes through which fastenings for screed formwork are pushed.

After analyzing the damage to the bushings in the formwork structures, we can conclude that the most common occurs type "spall". Their formation begins with the appearance of a fracture focus, while the fracture is not accompanied by a noticeable plastic deformation and is observed as almost brittle. Further development of the cracks in micro and macroscale is mixed [31]. Thus, in the conditions of construction production under sharp dynamic influences (hammer blows, tightening the nut) along the plane of the weld, the sleeve is destroyed. Bushings with various design features were tested under production conditions with various kinds of dynamic effects on the attachment unit. On the first samples obtained, axial displacement of the sealing collar of the sleeve occurred, which is an unacceptable defect, since the fixing strength of the sleeve is violated and planes are formed along which reinforcement of adhesion of concrete plugs to the base metal of bushing.

During the exploitation of prototypes at construction sites, data were obtained on the appearance of microcracks on the bushings and the displacement of the sealing collars of the bushings, these flaws can be eliminated by switching to another material (from St3 to St10).

4 Discussion

The defectiveness of monolithic structures is a consequence of poor-quality or faulty formwork. This encourages a deeper study of this issue. Therefore, damage and defects of the formwork systems themselves during operation were also considered. The following are the most common damage to component formwork systems:

- Deformation of shields;
- Destruction of bushings;
- Deterioration of the covering of the shield of shields
- Destruction of the protective coating of the shield frames;
- The destruction of the castle joints.

Arising defects in the elements of the shuttering structures lead to the following defects in monolithic reinforced concrete structures:

- Deviation from the vertical of monolithic building structures, exceeding the maximum permissible values;
- Deviation from the design dimensions of structural elements;
- Inflows and shells on the surface of the structure;
- Engraving the surface of concrete.

The study of these damages leads to the idea that improving the design of formwork systems is an important and promising key to the development of improving the quality of monolithic structures. Which in turn suggests that it is possible to establish a certain dependence of the influence of individual parameters of formwork systems on the quality of concrete surfaces.

The quality of concrete monolithic structures is influenced by many parameters of formwork systems.

One of the main elements is the profile of the formwork board. Having studied the research on this issue, it was found that the most optimal combination of the used thickness of the shuttering profile and steel grade is 3.5 mm and St10. Elements made of this material have better performance characteristics, are less prone to deformation, work better on local crushing.

It is important to use new structural grades for formwork systems in order to reduce metal consumption and increase the bearing capacity of formwork.
It is promising to increase the manufacturability of formwork systems by introducing a strapping profile with a modified wall thickness over the cross section, depending on the perceived loads.

Of no small importance is the introduction of incoming quality control of adhesion of the protective coating performed at the construction site. This can significantly improve the quality of the coating and increase the number of turnover cycles of the formwork.

The parameters of the bushings and the methods of their fastening also affect the quality of the resulting concrete structure. Using the design of the pressed-in oval-conical sleeve according to the results of the studies studied, it is possible to eliminate the defect in the destruction of the bushings and to increase the speed of cleaning the elements from "concrete plugs".

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