Reasons for the collapse of ceilings during the construction of monolithic buildings

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Abstract. Construction works, as a rule, differ in complexity and hazards of works. Nowadays, cases of collapses of a formwork of the cast concrete section of a building under construction in the course of concreting became frequent. Accidents entail death of people and significant material losses. Purpose of the research: the purpose of the research is to study accidents occurred during installation of in-situ concrete floors of buildings and to reveal the typical causes of a formwork system collapse. The initial materials were the data on the causes of accidents at construction sites obtained on the basis of the analysis of statistical materials on injuries, as well as data on the identified violations of the requirements for safe work practices in capital construction and reconstruction of buildings and structures. A total of 148 accidents at construction sites from 1997 to 2019 were considered. The paper systematizes some main errors and violations of technologies committed in the course of in-situ concrete works. Typical causes common for all formwork collapses during concrete works for in-situ floor slabs installation are revealed. Among the objective causes of accidents and high injury rate in this type of construction works the following should be highlighted: the lack of method statements and construction plans; lack of supervision of the correct and safe execution of works; shortcomings in the organization of training and testing of labor protection knowledge; violation of technological regulations and safety rules.

1. Introduction

According to the Federal Labor and Employment Agency, 2344 people died from injuries in workplace accidents in organizations of all types of business activity in 2014, 2089 - in 2015 and 2072 - in 2016 [1, 2]. In 2017, 1722 people died due to workplace accidents in Russia. Most people died due to accidents in the construction sector - 24% of the total number of deaths at workplace in all types of enterprises, as reported by the judge of the Supreme Court of the Russian Federation [3].

Construction works, as a rule, differ in complexity and hazards of works. In this industry, a significant number of severe accidents occur annually due to the fall of the injured from a height, structure collapse, fall of objects and materials [4, 5].

Professional risks of injury of construction workers are connected with the specifics of the work, including the occurrence of emergency situations during the construction of buildings and structures accompanied with the collapse of structural elements of buildings, applied technological equipment [6].

At the present stage of construction, cast reinforced concrete is used in the construction of public facilities and residential buildings, especially multi-storey and high-rise ones. The technology of cast-in-situ construction is the most mobile technology; it makes it possible to erect buildings of different
heights and shapes in the shortest possible time in cramped urban conditions, and in many cases with more favorable economic indicators [7].

Almost all the elements of buildings are constructed applying the technology of cast-in-situ construction: foundations, supporting columns and walls, floor and roof slabs. The share of facilities built using this technology in the total number of buildings under construction in Russia increases annually. This technology consists of several main stages: installation of a reinforcement cage, installation (assembly) of a formwork, concreting, removal of the formwork. For the installation of horizontal elements of in-situ concrete construction in the required specified position the system of a slab formwork is intended. The most common today is the system of slab formwork with telescopic extension legs.

However, as the practice of construction shows, in the course of the work due to the lack of Method Statement confirmed with necessary engineering calculations, violations of the technology of concrete mixture preparation, the technology of work during the construction of formwork and reinforcement, pouring, removing the formwork, can be the causes of emergency situations and collapses of structures in the process of work.

Besides, the market has a lot of "novice developers" who tend to make various kinds of "non-standard decisions" that go against safety standards, which leads to a large number of accidents.

Purposes of the research of the study were to study accidents that occurred during the installation of monolithic slabs of a reinforced concrete building and to identify typical causes of the collapse of the formwork system.

2. Materials and methods

The source materials were data on the causes of accidents at construction sites, obtained on the basis of analysis of statistical materials on injuries, as well as data on violations of the requirements for safe work practices during capital construction and reconstruction of buildings and structures.

The causes of failures of formwork systems when installing concrete slabs on site were established on the basis of statistical data from the National Association of builders (NOSTROY), the National Association of expert organizations in the field of construction (NOEX), the company "welding", other organizations, as well as from other open sources [8, 9], including the Internet. A total of 148 accidents at construction sites were reviewed from 1997 to 2019.

The results obtained were subject to statistical processing, analysis and systematization for the same type of causes of the accident. Systematization in this context is carried out for the first time.

3. Results and Discussion

3.1. Features of accidents with formwork systems of buildings and structures under construction

Some accidents at construction sites that occurred in different years and different regions of Russia are considered below.

A typical example of such situations can be the accident that occurred on August 10, 2006 in OOO "Rospromservice". During the concrete works in the addition to the structure of the shopping center "New Era" in Nizhny Novgorod, the in-situ concrete ceiling of the building under construction in the Sormov highway collapsed. The total area of the collapse was 540 sqm. During the investigation of the accident, it was found out that no Method statements (MS) for construction and installation works (for the installation of the formwork, installation of reinforcement cages, pouring concrete) had been developed. There was no substantiation of the choice of service poles (calculation of actual loads acting on the poles) and their arrangement pattern for the floor formwork. At the moment of the accident, the poles failed (broke) because they were installed improperly - either with a vertical deviation after installation above the permissible (safe) values, or with a pitch above the permissible due to the lack of the pole arrangement pattern and MS for installation work. As a result of the collapse, six construction workers suffered injuries of varying severity, two construction workers died.
The Technical Commission investigating the circumstances of the collapse on the 7th of November 2007 of the between floor slabs in a reconstructed building of hypermarket "Big dipper" in Novosibirsk, concluded that they had collapsed because of the buckling of the formwork shores. According to the conclusion of the Technical Commission, the cause of the collapse of the formwork while installing the floor, was the loss of stability of the shores. As a result of this there was an additional load in the place of leakage of the concrete onto the support part of the shore that led to the fall of the formwork on the slabs of the basement. The area of the collapse was more than 400 sq. m. According to the Commission, the main violations caused the accident committed by the contractor were failure to comply with the requirements of technological documentation and the lack of necessary control by the responsible officials of the execution of construction works.

Less than a year later (21.08.2008) in Novosibirsk, there was a group accident resulting in death of four workers during in-situ reinforced concrete works. When pouring concrete on the second floor of the shopping center under construction, about 400 sq. m of the floor collapsed. As it was found out by the construction expertise, the building collapsed due to the non-compliance with the technology for the formwork installation.

In Kozhevnicheskaya street in Moscow, on 03.09.2009 in the multilevel 600 sqm garage under construction one of the underground floors collapsed. Under the rubble, one worker was killed and three others were injured.

In the suburbs of Vladivostok, on 01.09.2011, during concreting works at a water pump station, a floor collapsed. As a result of the accident, one person was killed and four were injured.

In the Nevsky district of St. Petersburg, on 07.05.2012 in Krzhizhanovsky street, a formwork collapsed when concreting a floor slab of the parking lot. The consequences of the accident are shown in figure 1.

![Figure 1. Collapsed formwork during the construction of a Parking lot in St. Petersburg: fragment of the consequences.](image)

A similar situation occurred in St. Petersburg on 01.03.2018 in Krasnoselsky district in Admiral Tributs street - the formwork of the parking lot under construction collapsed. It happened while concrete was being poured into the formwork. A worker died under the collapsed structure.

In Novoshakhtinsk, the Rostov region, in December 2011, during the execution of works on concreting the floor slab of the 3rd floor collapse occurred. It was found out that during the execution of concrete works the slab of the third floor was subjected to a dynamic impact by the broken container with concrete.
A multi-storey building under construction collapsed in Moscow on April 17, 2012. During the production of filling floors with liquid concrete, the floor collapsed on an area of 2.5 thousand square meters. Six floors at once formed a "layer cake". There were workers on the floors. Among the workers there are dead and injured. The accident happened in an industrial zone on the territory of the former ZIL automobile plant. The building was to house a new office center for commercial companies.

Due to the violation of construction technology on 13.12.2012 in Taganrog, the Rostov region, a three-storey building under construction collapsed. 18 workers were trapped, five of them died. The building was built using the technology of leave-in-place expanded polystyrene formwork. The collapse occurred when builders began to erect the fourth floor, although permission was granted for the construction of a three-story apartment building with shops and an underground parking lot. According to the Town planning code, buildings with a height of up to three floors are not capital construction facilities, and their construction does not require project documentation which must be submitted for examination to the state regulatory authorities. Developers take advantage of this and go to the trick - get permits for the construction of buildings with a greater number of floors.

Collapse of a metal structure of the formwork and erected in-situ concrete floor in the addition to the shopping center "Suvorovsky" occurred on 11.06.2013 in Penza. The accident is related to the overload of the formwork during the work on pouring concrete floor of the second floor.

It was not the first case when during construction of shopping centers in Penza the situation got out of control. So, on 25.08.2007 in the center of Penza, ceilings and part of the wall of the building "Children's world" collapsed. One worker died and 13 were injured.

In the Irtysh lane in Vladivostok, on 07.03.2013 due to the violation of the technology of construction processes a cast-in-place concrete building under construction collapsed. This was caused by the removal of the supporting elements of the formwork before the concrete hardened. A few hours after the first collapse the remaining part of the structure collapsed, the lower floors failed to carry the additional load. The construction of this building was carried out without permits. A judicial decision in 2012 prohibited construction and installation works at the site. Despite everything, the work continued until the first signs of the collapse.

The next day, on 08.03.2013, there was a partial collapse of the shopping and entertainment complex under construction in Moscow in the area of Borisov ponds. The collapse of the formwork and the structure occurred during pouring of concrete on the third floor slab of the shop under construction. The total area of the collapse of the third floor was 200 sq. m. During the accident one of the bearing supports on the corner of the building collapsed. Of the six workers who were at the time of the accident at the construction site, no one was injured.

In Sochi, on 27.03.2013, during the reconstruction of the "Shopping Gallery" a floor collapsed. The accident occurred at the time of pouring in-situ concrete ceiling of the first floor. The cause of the collapse was the fact that the formwork shores failed. The consequences of the accident are shown in figure 2.

The collapse of the ceiling of the third floor and the roof fall of the building under construction occurred on 27.08.2013 in the Kirov district of Novosibirsk. Two people were trapped, both were rescued and taken to hospital. The cause of the collapse was a violation of the technology of pouring concrete floors.

In Vladivostok, in Yeniseiskaya street, on 12.08.2014 during construction and installation works at the construction site of the administrative and hotel complex "Yeniseiskaya Plaza" there was a collapse of the supporting elements of the formwork with the reinforcement of the section of the floor slab and concrete mixture.

During concreting, the load on the formwork poles exceeded the permissible load, resulting in the failure of the formwork shores, which caused the collapse of building structures. Three builders were injured. There was no Method Statement (MS) and technological maps, consequently, construction and installation works were carried out without developed and approved organizational and technological documentation. The installed formwork poles in the place of the collapse had inadmissible length of more than 7 m without spatial horizontal laterals and vertical bracing, formwork shores rested on
cantilever wooden joists without considering their twisting in the case of off-center installation (relative to the axis of the joist) of the formwork poles; the poles were installed without the use of special tripods.

![Figure 2](image-url)

**Figure 2.** Consequences of the collapse during the construction of a monolithic ceiling of the building of the "Trade Gallery" in Sochi.

The following day, on 13.08.2014, in the same place in Vladivostok in Kalinin street, under similar circumstances during construction works, a partial collapse of the structures of the shopping center under construction occurred. Four people were injured in the accident.

In St. Petersburg, on the Okhta river embankment, on 31.01.2015, a 300-square-meter floor collapse occurred in a shopping center under construction.

In New Devyatkin, the Vsevolozhsk district of the Leningrad region, on 04.04.2015 a floor slab under construction of a three-storey parking lot collapsed. The collapse occurred during the concreting of the formwork of reinforced concrete structures.

In Rostov-on-Don, on 29.10.2015 during the construction of shopping Mall "Megamag" there was the collapse of the floor formwork during the concrete work. Three workers were taken to hospital with injuries of varying severity.

At the construction site of Sovgavanskaya CHP in Khabarovsk Krai, Sovetskaya Gavan, on 27.05.2016, the formwork collapsed. Six builders were trapped. There were no fatalities.

In Vladivostok, on 21.10.2017, the floor of the shop building under construction collapsed during pouring concrete on the 3rd floor. The regional Construction Supervision and Control body of Primorsky Krai conducted an inspection of the collapse of the floors of the building. The construction permit was issued on October 11, 2016 by Vladivostok authorities. According to the documents, the developer announced the construction of a two-storey building. As the inspection showed, the developer, contrary to the permits, began to build the third floor. During the formwork installation the in-situ concrete floor structures collapsed. The cause of the collapse was the deviation from the design.

In Kursk, on December 11, 2017, during the construction works, the roof collapsed in a factory reinforced concrete building; the area of the collapse on the premises of OOO "Kursk solod" was 400 sq. m. Workers arranged the formwork and began to fill it with concrete. At this point, the structure failed and collapsed. Four builders were injured.

In the village of Boguchany, the Krasnoyarsk region, on 18.03.2016 at the construction site of "Central district hospital" a concrete slab of the third floor of the building collapsed. Two concrete carpenters were killed.
In the Oktyabrsksky district of Ivanovo on 27.12.2017, during the construction of an apartment building of the RC "Panorama", a formwork collapse occurred during the pouring of concrete, as a result of which two builders were injured.

In the Orthodox Church of the Blessed Matrona of Moscow under construction in Biscayskaya street near the "German village" in Krasnodar, on 27.04.2018, ceilings collapsed. During the in-situ concrete pouring, the formwork failed. Rescuers pulled the injured trapped builders.

In Yakutsk, on 5.05.2018, there was a collapse of the formwork in the building of school No. 25 under construction. The area of the collapse was about 140 sq. m. The collapse of the formwork occurred in the process of concrete pouring. The installed supports failed to carry the weight of the concrete mixture. The accident happened because of the violation of the concrete work technology.

Two weeks later, on May 19, 2018, again in Yakutsk, there was a collapse of the floor slab in the "National school for 550 students"; the total area of the collapse was about 53 sq. m. During concreting, the formwork failed and collapsed, because the installed demountable jack-legs failed to carry the load.

In Kursk, on 19.01.2019 in the course of the construction works in a new school building, the formwork shores failed to carry the concrete weight. The slab collapsed avalanche-like around the perimeter. The area of the collapse was 400 square meters. The consequences of the accident are shown in figure 3.

In Yaroslavl, on 31.08.2019 in the surgery of the oncological hospital under construction there was a collapse of an intermediate ceiling. When pouring concrete, the formwork failed to carry its weight, and the structure collapsed and, in some places, it caved in and so did the reinforcement. The area of the collapse and the sagging was 350 sq. m. Among the causes there were problems with the poles that supported the formwork of the concrete structure. The poles failed due to a manufacturing defect.

There are a lot of examples of similar accidents. Of course, these kinds of accidents don't usually happen every day, but they do happen.

Figure 3. The Collapse of the floor slab during the construction of a school building in Kursk.

3.2. Systematization of identified causes of accidents
Analysis of accidents at construction sites shows their regular recurrence. As a result of this, the designers, construction participants and supervisory authorities study the causes leading to the collapses of in-situ concrete slabs of buildings and structures in order to prevent them in the future. Nowadays it is an urgent problem.
As a rule, the same mistakes are repeated in design and organizational decisions, and violations of performing work technology that could lead to similar events.

It is necessary to provide a list of such errors and violations:

- the developer has no design solutions for specific sections of slabs with a detailed study of formwork pickup fittings;
- solutions for placing formwork without the approval and confirmation by calculations of formwork suppliers;
- there is no rejection and removal of deformed or substandard molding elements from the construction site, as a result of which damaged structural elements of the molding are used for further operation;
- the presence of defects and violations during the operation of formwork locks;
- increase in the number of formwork turnover cycles;
- the wrong choice of the type of formwork systems initially, inattentive attitude to the material the formwork is made of (in particular, to steel grade and its quality, plywood, wood, components, locks);
- non-compliance (and often lack of technological maps) with the order of concreting sites and unauthorized performance of those works that are not provided for by the project of production of works;
- inadequate organization and control of various types of activities in order to ensure the necessary quality of work and the conformity of production processes with the prescribed safety requirements;
- unauthorized storage of reinforcement and construction equipment on the formwork system structures;
- a significant excess of working loads on the formwork, leading to twofold (or more) excess of the permissible vertical load on formwork poles;
- installation of the structure on an unprepared non-rigid, deformable base;
- absence of horizontal elements and diagonal connections when using the slab formwork (or low-quality elements) in the positions determined by the project of work;
- installation of slab formwork and scaffolding with deviations from the vertical and horizontal, if the final adjustment of formwork by builders was not carried out;
- the presence of sagging or deflexion of slab formwork;
- dynamic impacts on the formwork with a concrete boom when feeding concrete or a container with concrete;
- ignoring the operation instructions of formwork systems, although all professional patented products are delivered with detailed and thoroughly prescribed instructions for operation, installation and dismantling of the system.

When working with a formwork and performing concrete work the exclusion of the above and other errors can guarantee the absence of force majeure at the construction site.

It should also be noted that critical defects allowed during the installation of an in-situ concrete slab are potentially the causes that can cause a collapse of structures during the operation of buildings when an unfavorable combination of factors affect them.

3.3. Discussion of the causes

Following the global practices and trends of architecture and urban planning, there appeared buildings on the construction market, the construction of which requires the implementation of complex structural solutions. But modern and reliable formwork systems [10, 11], high-quality technology and organization of construction, as well as highly qualified construction personnel must correspond to the complexity of the design. In modern domestic construction, these requirements are not fully met. It turned out that there is a shortage of qualified personnel to carry out large volumes of work and implement new construction technologies [12 - 14]. But the market demands, and personnel can be found in other
countries. In 2017, 6.3 million people were employed in the construction industry in Russia, labor migrants were a significant proportion of them. Since 2019, the share of foreigners employed in construction is proposed to be limited to 80%. Previously, there were no restrictions on the engagement of foreign workers in construction.

However, the engaged labor migrants are mainly not specialists, but people who have little understanding of construction engineering. The use of labor of foreign migrants in construction creates a number of new problems for site managers. The main ones are: poor knowledge of the Russian language, low vocational and educational training, misunderstanding of instructions and orders, complication of production communication and coordination of interaction, and, as a result, low quality of work performed, violation of safety requirements. Inconsistency with the professional level of migrant workers often leads to faulty work. According to research [15], only 40% of labor migrants from Tajikistan employed in construction were familiar with the rules of safety technology, 55% were not provided with special clothing, 40% - with personal protective equipment. Thus, legal requirements for construction organizations to ensure safety are not fulfilled [16].

Execution of complex construction work by unprofessional firms without trained personnel leads to the considered consequences. Violations of construction rules and regulations during the construction of facilities of various purposes have become commonplace. Therefore, the presence of professional competencies corresponding to the envisaged work should be checked by the certification committee before admission to work [17]. Engineers and technicians should know the urgent issues of construction, including technology of in-situ concrete construction, types of formwork used in such construction and features of concrete work [10, 11].

Studying the problem of personnel in construction, the authors of the paper [18] have noted: "According to recruiting agencies, there is a large shortage of foremen, architects, design engineers, designers, and project management specialists in the construction industry today. Therefore, many companies simply "outbid" scarce specialists from competitors. Company executives complain that the majority of experienced builders working at construction sites in the Soviet era are of pre-retirement or retirement age. At the same time, the problem of young personnel remains very important. The preparedness of current graduates of construction faculties and universities is low, primarily due to the lack of motivation of students to study".

In October 2014, the IX national Congress "Modernization of Russian industry: development priorities" was held in Moscow. One of its main topics was the training of personnel necessary for the modernisation of the construction industry. As one of the speakers put it, a systematic personnel crisis has begun in the Russian construction industry. This applies not only to the training of workers and specialists with higher education, but also to the overall state of the professional level of builders, ranging from working professions to the highest level [19]. In November 2016, at the section "Housing and utilities: infrastructure and infrastructure development" of the XII National Congress "Modernization of industry in Russia. Development priorities", the speakers again drew attention to the decrease in professional competence of specialists working in the construction industry (primarily designers) and the fact that the system of qualification education of specialists in working professions is also not developed [20].

It should be noted that in papers [5, 21] we considered the issues of preserving the quality of labor resources in construction; in particular, it was proved that the lack of high-quality training creates a "platform" for the growth of injuries in the industry, since the personnel subsystem of this process is unsecured. These forecasts are fully confirmed. Nowadays professionals make up only 10 - 15% of the total number of construction workers [22].

Insufficient level of education does not allow a designer to issue high-quality projects at once. Truly safe projects are designed by him only years later when he gains experience analyzing his mistakes. Designers of specific facilities should put into practice computer-aided design technologies that are implemented in modern software products with high accuracy and model the behavior of formwork structures correctly (which is especially important when calculating structures with complex architectural forms, space-planning and structural solutions).
Today the training of professional personnel in working professions, the training of civil engineers, as well as advanced training and retraining of both are the primary tasks for national education. The training program for specialists in the field of technology and the organization of construction should be constantly updated, take into account modern requirements, have a practical orientation and be carried out in close interconnection with other general professional and special disciplines [12, 13].

Now we need to focus on the following tasks: improving international exchange of modern knowledge and technologies; development of innovative forms of higher education, science and construction based on the study of international experience; activation of multi-lateral mobility of students, postgraduates and teachers; integration with the global educational space.

We need to improve information support of construction. The essence of this problem is a thorough, highly professional investigation of the causes of accidents by independent engineering and consulting firms, publication of information about accidents in special publications accessible to the general engineering community, creation of special services, centers that conduct a statistical analysis of the causes of accidents and develop measures to prevent them. However, the reality is that: after an accident, commissions are created to find the "culprit" in a short time, and all information about their activities is not available even for professionals. This makes it impossible to collect all the information for conducting official statistics, analyzing the real causes of major accidents and making relevant decisions to prevent them. Gathering information about cases of accidents at construction sites, summarizing and systematizing this information, openness of data and a thorough analysis of the causes are very important scientific and practical work aimed at preventing similar situations from happening again in the future [23].

4. Conclusions
The various causes of collapse of formwork systems and injuries are closely related to each other and are so intertwined and mutually determined in most cases that it is impossible to imagine each of them in a separate form. Therefore, a single detailed classification of the causes of collapses and injuries cannot be made at all stages of in-situ concrete work, since the specificity of various processes requires taking into account well-defined initial events and technology features of the type of work under consideration.

The developer and the person executing construction works should fully control the safety of building structures, the quality and correct use of the formwork used and the work performed [24].

Accident prevention is a set of measures including professional selection of personnel, improving the quality of professional construction education, mastering advanced construction technologies and management methods of construction organizations [25], as well as organizing and implementing customer construction control (technical supervision) of the construction of facilities.

Specialists in the field of technology and organization of construction production should have a deeper education in order to thoroughly and qualitatively consider the issues of construction production from the point of view of innovative achievements, have an idea of the main provisions and directions for improving the technology, organization and planning of construction production, and advanced domestic and foreign methods of production of construction works. Only on the basis of a constant exchange of experience can they activate reserves for improving the efficiency and safety of construction production. Especially interesting in terms of gaining experience should be considered training and practical work on construction sites of landmark projects, both in Russia and abroad.

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