Analysis of Technological Errors that Caused the Monolithic Structures Collapse

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Abstract. This research paper presents systemized actual data on accidents and nonconformities in monolithic construction projects. The most common causes of damage to monolithic reinforced concrete structures are technological violations when assembling the reinforcing cage and ensuring the design strength during curing of concrete, including during heat treatment in the winter. It is proposed to develop and put into practice a number of specific preventive measures that would reduce the frequency of errors and “standard” accidents and the severity of their consequences, based on the experience gained in studying accidents and inconsistencies in monolithic construction works and their causes. It reviews findings of statistical study into accidents and nonconformities and causes thereof, as well as findings of analysis and classification with regards to the causes for building and structure collapses as part of monolithic construction projects. It also reveals and substantiates the need to develop integrated quality assessment and forecasting techniques for monolithic construction projects.

1. Introduction

The integrated safety of buildings and structures in construction projects is of key importance in the modern world. According to Rostekhnadzor (Federal Service for Ecological, Technological and Atomic Supervision) over the past five years, the number of accidents in the construction industry and the severity of their consequences are increasing, which is accompanied by more frequent structural collapse of unfinished projects related to deaths and lowering the quality of construction and construction safety works.

In this situation, collecting and analyzing reliable data on inconsistencies and accidents in construction is not easy due to the fact that most organizations prefer to hide information about destructive phenomena at construction sites.

There is a number of research works analyzing the causes for construction accidents in the Russian Federation [1-4]. According to A.G. Bublievskiy, accidents in construction of buildings and structures have occurred in the past, occur now and will occur with a high probability in the foreseeable future. It is important to realize whether they are “occasional or systematic?” [3].

2. Materials and methods

The objectives of this research are: collection of data on accidents and nonconformities in monolithic construction projects in the Russian Federation; analysis and classification; identification of their
causes; formulation of a scientific foundation for the development of integrated quality assessment and forecasting techniques for monolithic construction projects.

In order to attain these objectives, the following tasks have been accomplished by the authors [4]:

- Collection of data on accidents and nonconformities in monolithic construction projects in the Russian Federation;
- Statistical processing and system-based analysis of actual data on accidents and nonconformities in monolithic construction projects and causes thereof exemplified by a representative number of construction organizations;
- Preliminary identification of causes for defects in buildings and structures at each stage of monolithic operations.

Analysis has been based on the data on accidents and nonconformities on construction sites in the Russian Federation reported by Rostekhnadzor, NOSTROY (National Constructors’ Association), the Municipal Expertize Center, and the Construction Quality Center, as well as on materials published by Professor K.I. Yeremin, V.I. Zharnitsky, V.V. Kulyabko, N.P. Chetverik, A.G. Bublievskiy and others from 2016 to 2019. Three main criteria have been selected for accident analysis [5-6]:

- Fires;
- Collapse of construction structures;
- Breach of safety regulations.

Registered accidents broken down by the above-mentioned criteria are shown in Table 1.

**Table 1.** Registered accidents in the Russian Federation according to data of NOSTROY, Rostekhnadzor, the Municipal Expertize Center, the Construction Quality Center and others from 2016 to 2019 [6].

| Criterion                              | 2016 | 2017 | 2018 | 2019 |
|----------------------------------------|------|------|------|------|
| Structure collapse                     | 37   | 91   | 131  | 53   |
| Fire                                   | 17   | 30   | 30   | 18   |
| Breach of safety regulations           | 47   | 121  | 52   | 14   |
| Total                                  | 187  | 398  | 297  | 96   |

Analysis of the registered accidents and their main causes has been used to plot a dynamic pattern graph for these causes (Figure 1). The Structure Collapse curve on the graph shows that structure collapses in construction projects have become more frequent in the last two years. Moreover, this curve is on the rise and exceeds other criteria in percentage terms [7].

**Figure 1.** Dynamic pattern of accident causes registered in the Russian Federation from 2016 to 2019 [6].
Monolithic construction was chosen to analyze the causes of the collapse of buildings and structures. Monolithic construction occupies a leading position, as evidenced by data provided by the information and analytical center of the marketing service of the company "Peresvet-invest". As of June 2019, apartments in buildings built using monolithic technologies in Moscow and the Moscow region accounted for 80.2%. the Share of apartments in new buildings made of bricks was 17.0%, and in panel houses-2.8%. In Saint Petersburg and the Leningrad agglomeration, the leader is the brick-monolith technology-54% of the market. In second place—a monolith (29%), in third—a panel (13%), followed by a brick (3%). Large developers often build brick-monolithic houses. Today it is the most effective, high-quality and reliable construction technology. It allows you to create any layout of the apartment. A monolithic frame is built faster than a brick building, but at the same time, brick walls provide the house with frost resistance and noise insulation. The technology of monolithic construction has been most actively used in the last 20 years.

Consider the data of the requirements issued by the engineers during the construction control. Frequently encountered violations, their causes and methods for preventing errors during construction are presented in Table 2. The collected violations according to the data of construction supervisory organizations, including the scientific research and testing center “Scientific Research Institute of PTES” are distributed by technological stages and are presented in Table 3.

Table 2. Errors and violations detected during construction.

| №  | Violation                                                                 | Reason                                                                                     | Normative document                                                                 |
|----|---------------------------------------------------------------------------|-------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|
| 1  | Exposure of fittings subject to active corrosion                           | Non-compliance with the thickness of the protective layer. This type of defect according   | SP 70.13330.2012 Bearing and enclosing structures of clause 5.16.16. Reinforcement of structures shall be carried out in accordance with the design documentation taking into account the permissible deviations according to table 5.10. Section 5.16.12. Installation of reinforcing structures should be carried out mainly from large-sized blocks or standardized prefabricated meshes with the provision of fixing the protective layer according to table 5.10. |
| 2  | Reinforcing frame is not cleaned before installation                       | Debris was not removed from the rebar frame                                                | SP 70.13330.2012 Supporting and enclosing structures. Updated edition of SNiP 3.03.01-87 p.17.17.7 Formwork and reinforcement of massive structures before concreting must be cleaned with compressed (including hot) air from snow and ice. Cleaning and heating valves with steam or hot water is not allowed. |
| №  | Violation                                                                 | Reason                                                                                                                                                                                                 | Normative document                                                                                     |
|----|---------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------|
| 3  | The fittings are too close to the surface                                  | If you lay the rebar too close to the surface - the rebar may rust from lack of material on top, if you lay it too deep - steel will not protect the concrete from cracks in the upper layer of concrete. | SP 70.13330.2012 Supporting and enclosing structures. Updated edition of SNiP 3.03.01-87 p.5.16.16       |
| 4  | Mounting tacks from the base metal are not cleaned                        | No machining of welded joints from slag, welding spatter and metal flows. Mounting tacks on the bottom of the ribbed plate are not cleaned.                                                               | SP 70.13330.2012 Supporting and enclosing structures. Updated edition of SNiP 3.03.01-87 p.6.8.3         |
| 5  | Pores and voids in monolithic structures                                  | Violations of the technology for the preparation of concrete mixtures, violations of formwork, inefficient vibration in concrete                                                                    | SP 63.13330.2018 Concrete and reinforced concrete structures. The main provisions. SNiP 52-01-2003 prescribes the laying and compaction of concrete in such a way that “in order to guarantee sufficient uniformity and density of concrete in the structures that meet the requirements stipulated for the building structure in question” |
| 6  | Deviation of structures from horizontal and vertical planes (mismatch of geometric parameters of products and structures to design standards) | Initially incorrect, uncorrected position of the formwork, premature removal of it, weak foundation or non-compliance with solidification conditions monolith. |                                                                                                        |
| №  | Violation                                      | Reason                                                                                                                                 | Normative document                                                                 |
|----|-----------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------|
| 7  | Cracks and chips of concrete                  | Due to the heterogeneity of concrete, its strength is lost and delamination occurs. Due to the anisotropy of the material properties (their unevenness), different sections of the wall are torn away from each other - for example, during thermal expansion, which will not be the same. | Homogeneity should be ensured already at the level of conversion of the dry mixture into solution. |
| 8  | Shrink cracks                                 | Concrete hardening is not an easy process, and the greater the thickness of the hardening mass, the more difficult it is. The setting reaction is accompanied by heat. |                                                                                   |
| 9  | Heights and smudges                           | Non-compliance of the parameters of the concrete used (frost resistance, density, water resistance, etc.) with the project and its application conditions. The instability of the material to high |                                                                                   |
| №  | Violation                                                                 | Reason                                                                 | Normative document                                                                 |
|----|---------------------------------------------------------------------------|------------------------------------------------------------------------|------------------------------------------------------------------------------------|
| 10 | Through a vertical crack                                                  | humidity leads to the penetration of moisture to concrete structures, causing corrosion and affecting the strength of the concrete |                                                                                  |
|    |                                                                           | Requires the adoption of urgent measures for repair and restoration of the bearing capacity |                                                                                  |
| 11 | There is no tight coupling between the concreted sections                 | Seams between ceiling tiles are formed due to incorrect filling. Moreover, different sections of the overlap may have different brands of concrete. A cold seam between them appears when work is interrupted for a long time. When pouring concrete, a layer of cement milk is formed on it, which deprives the surface of adhesion. This layer was necessary before pouring a new batch of concrete, then the grip would be strong. There is no mechanical treatment of welded joints from slag, welding splashes and metal surges. | Shuttering works are performed in small sections of various configurations, since it is impossible to fill the entire site at once. But the slab must still be solid. |
|    |                                                                           | SP 70.13330.2012 Supporting and enclosing structures. Updated edition of SNiP 3.03.01-87                                             |                                                                                  |
| 12 | The welded joint has not been machined                                    |                                                                                   |                                                                                  |
| №  | Violation                                                                 | Reason                                                                 | Normative document                                                                                           |
|----|---------------------------------------------------------------------------|------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------|
| 13 | There is no executive geodetic survey of the mounted structure, the assembled reinforcing cages have a curved shape | Work on the reinforcement device is carried out without geodetic control, there is no Data on the construction control of the person carrying out the construction. | SP 70.13330.2012 Supporting and enclosing structures. Updated edition of SNiP 3.03.01-87                      |
| 14 | Not tied rods of the upper grid of reinforcing cages                        | Reinforcement defects - deviations from the design scheme of reinforcement, understating the values of the protective layer. | SP 63.13330.2018 Concrete and reinforced concrete structures. The main provisions. SNiP 52-01-2003            |
| 15 | Offset of the center axes of structures that exceed the standard values    | There have been many cases when the performers of works, in order to hide defects, cut off the outputs from the columns of the underlying tiers, installing the formwork of the overlying columns according to the design dimensions. |
### Table 3. Errors and violations at each stage of the monolithic construction technology according to construction supervisory organizations, including Scientific Research and Testing Center “NII PTES”.

| №  | Reinforcement caging | Formwork setting | Concreting | Heat treatment (at winter) | Concrete curing | Removal of formwork |
|----|----------------------|------------------|------------|---------------------------|----------------|---------------------|
| 1  | exposure of reinforcement susceptible to active corrosion | inconformity of geometrical parameters of products and structures with design specifications | improper concrete mix packing in forms | shrinkage cracks | weak compression is not removed from a joint in non-continuous concreting | timber elements are present in concrete |
| 2  | integrity damage of a bearing wall with working reinforcement cut off | formwork is not sufficiently rigid and solid and deforms in the process of concreting | segregating compression | concrete freezing | improper care of fresh concrete in a structure | dismantling of forms before concrete reaches design density |
| 3  | dirt is not removed from the reinforcement cage before installation | installation of supports of improper grade | lack of firm contact between concreted sections | improper temperature development in concrete | concrete drying out, concrete is not covered with polyethylene film |
| 4  | protection layer is insufficiently thick or absent | concrete mix fails to conform to workability requirements | poor monitoring of the temperature regime of solidification |
| 5  | poor quality of welding of structure units and reinforcement joints | poor tightness of framework | concrete mix sticking to reinforcement and framework | failure to maintain the required drop height when packing concrete mix in forms |
| 6  | inconfornity of structural reinforcement with design specifications | | | |
| 7  | use of heavily corroded reinforcement |

### 3. Results

On the basis of analyzed data from national sources, damage to monolithic reinforced concrete structures is proposed to be divided into three groups according to its impact on the load bearing capacity (Table 4) [10].

Analysis of the main nonconformities and violations in the manufacturing technology for monolithic structures leads to a conclusion that the most common causes for damage to monolithic reinforced structures are technological violations in assembling a reinforcement cage and in ensuring design strength in concrete curing, including heat treatment at winter.

Below we consider an example of how the change in the position of the longitudinal working reinforcement affects the strength of beams and plates. If the longitudinal tensile reinforcement is moved closer to the neutral axis, i.e. increase the protective layer of concrete, then the shoulder of the
inner pair of forces will decrease, and with it the strength of normal sections will decrease. If the protective layer is reduced, then the strength will increase. However, a decrease in the protective layer has other, extremely negative consequences. It leads to the formation of shrinkage cracks on the concrete surface (often hardly noticeable), through which the vapor-air mixture or aggressive gases penetrate the surface of the reinforcement and cause corrosion of the metal. Corrosion products (rust) occupy a larger volume than steel, burst concrete from the inside and, in the end, lead to the collapse of the protective layer of concrete. As a result of exposure of the reinforcement, its adhesion to concrete is lost and an additional decrease in the bearing capacity of the structure occurs. In addition, the reduction and, especially, the destruction of the protective layer lead to a decrease in the fire resistance of structures. Therefore, the reinforcement must be installed strictly according to the design, not exceeding the deviations allowed by the norms.

During winter concreting, along with the use of mixtures with antifreeze additives are widely used and electric heating of laid concrete. Regardless of the winter mode when concreting, keep in mind that the concrete before freezing must have time to gain the so-called critical strength, otherwise, the design strength after thawing it won't. The critical strength value is expressed in percent of the design strength. For concrete without antifreeze additives of class up to B10 inclusive it is 50%, up to B25-40 %, from B30 and above-30%, and for concrete with antifreeze additives by the time it is cooled to the temperature for which the additives are calculated – at least 20%. Most often, weak strength occurs in cases when monolithic concrete comes into contact with cold massive bodies: when concreting joints of precast structures and in the nodes of precast-monolithic structures.

The challenge of system-based quality management in monolithic construction operations requires the development of comprehensive quality assessment techniques, a task of utmost importance both for the property developer and the contractor, because such techniques will enable efficient monitoring of monolithic construction operations with the purpose of managing their quality. It is proposed, proceeding from the accumulated experience of research into accidents and nonconformities in monolithic construction operations and causes thereof, that a number of specific preventive measures be developed and introduced in practice that would reduce repeatability of errors and “standard” accidents and the gravity of their consequences.

| Group | Damage | Example |
|-------|--------|---------|
| 1     | structural strength and durability are not reduced | surface cavities, voids; cracks, including shrinkage cracks, with an opening of up to 0.2 mm, as well as cracks that grow in width by no more than 0.1 mm affected by temporary loads and temperature; concrete chipping with no exposure of reinforcement, etc. |
| 2     | structural durability is reduced | corrosion-prone cracks with an opening of up to 0.2 mm and cracks with an opening of more than 0.1 mm in the working reinforcement zone of pre-stressed superstructures, including those along permanent load sections; cracks with an opening of more than 0.3 mm under temporary loads; cavities, voids and chips with exposed reinforcement; surface and deep corrosion of concrete, etc. |
| 3     | load bearing capacity of structures is reduced | cracks not allowed by strength or durability calculations; inclined cracks in beam walls; horizontal cracks in beam-to-superstructure connections; large cavities and voids in the concrete compression zone, etc. |

4. Conclusions

The study revealed that in recent years the number of accidents and collapses in monolithic construction has increased. Monolithic construction today occupies a leading position in commissioning facilities in the Moscow and Leningrad regions, as evidenced by data provided by the information and analytical center. Systematic data on accidents and inconsistencies at construction sites in the Russian Federation make it possible to identify the causes of defects in buildings and structures at each stage of monolithic work. To determine the most significant violations, the
requirements issued by the customer’s building control service were analyzed. Examples of builders' mistakes and violations of the requirements of normative and technical documentation are distributed by technological stages and are conveniently presented in tabular form.

However, currently there is an urgent need to optimize the quality control system for construction in order to eliminate errors and violations caused by lack of information support, lack of human factor. The use of automated building control systems is designed to eliminate a number of problems that affect the activities of the technical customer at the construction site. Further studies suggest the creation of a system that can significantly reduce the time spent in the process of building control. The transition to automated building control systems can reduce the time it takes to complete various tasks, increase the efficiency of both the Customer and contractors, and minimize the appearance of errors and inaccuracies. In this connection, the creation of an automated building control system is designed to accelerate and simplify the activities of the technical customer.

References
[1] Lapidus A, Abramov I 2018 Formation of production structural units within a construction company using the systemic integrated method when implementing high-rise development projects, E3S Web of Conferences, 33
[2] Topchy D, Skakalov V, Yurguaitis A 2018 International Journal of Civil Engineering & Technology (IJCIET) Volume 9, Issue 1pp. 85-993.
[3] Bolotova A S, Treskina G E. Herald of Tomsk State Architectural and Civil Engineering University. 2016. No. 2 (55). P. 176-183.
[4] Abramov I, Poznakhirko T, Sergeev A 2016 The analysis of the functionality of modern systems, methods and scheduling tools, MATECWebConf No. 86.
[5] Topchy D, Kochurina E 2018 Estimation of the degree of influence of environmental factors on construction in a dense urban environment, System technologiesNo. 1 [26], - p. 107-111.
[6] Rubtsov I V, Treskina G E, Bolotova A S 2015 Classification of monolithic reinforced-concrete structure defects and their impact on quality, Scientific review. No.18. – P. 58–63.
[7] Topchy D Skakalov V 2017 Structural and functional modeling of multi-level and multi-criteria links of organizational and technological, managerial structures and information support when implementing construction control over the course of re-development of industrial facilities, Prospects of science. No. 10 (97) - P. 44-50.
[8] Topchy D V, Kochurina E O, MATEC Web Conf. Volume 193, 05032. – 2018.
[9] Topchy D, Tokarskiy A 2018 MATEC Web Conf. Volume 196, 04029. – 2018
[10] Bolotova A S, Ginzburg A V 2016 Journal of Economy and entrepreneurship No. 10, - p. 647–651.
[11] Topchy D and Bolotova A 2019 J. Phys.: Conf. Ser. 1425 012005
[12] Bolotova A S 2016 Methods of increasing the organizational and technological reliability of monolithic construction operations, Science Review. 18 186–190.
[13] Topchy D, Bolotova A, Vorobiev A, 2019 International Journal of Civil Engineering and Technology 2 2160
[14] Ginzburg A, Bolotova B, Vedyakov I, Advances in Intelligent Systems and Computing 692 1160
[15] Bolotova A S 2014 Process safety and quality control of monolithic construction, Construction - formation of living environment pp. 501–504
[16] Cutler M E J, Boyd D S, 2012 “Estimating tropical forest biomass with a combination of SAR image texture and Landsat TM data: An assessment of predictions between regions,” ISPRS J. Photogramm. Remote Sens., vol. 70, pp. 66–77.
[17] Bolotova A S, Sviridov V N 2016 Main challenges of organizing and exercising control of quality indicators in monolithic construction operations, Science Review. 24 25–29.