Methodology for a comprehensive analysis of the construction projects’ accidents causes at various stages of their life cycle

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Abstract. Today, accidents at capital construction facilities are encountered at various stages of the buildings’ life cycle, which is associated with errors in the design and construction as well as the rules violation for the buildings’ operation. Now there is no unified system of accounting and technical analysis of the causes in the current situation, therefore, it is necessary to pay attention to monitoring and methods of construction sites accidents causes’ complex diagnosis. The scientific research is devoted to the methodological foundations’ development for a comprehensive analysis of the accidents on the construction sites and the development of organizational and technological measures to reduce the probability of their occurrence. The main objective of the scientific article is to consider the causes of the accident at various stages of the building’s life cycle. The article discusses the building life cycle stages and the causes of accidents from the pre-design stage to the capital construction object’s demolition. The buildings and structures’ collapse statistics and their causes are analyzed. An algorithm for analyzing the accidents causes throughout their operation life is proposed. The importance of the capital construction facilities accidents’ monitoring and analysis stage, the improving methods for their diagnosis and warning to prevent the emergency situations recurrence is proved. A set of organizational and technological measures for the capital construction objects accidents’ prevention throughout their operation life is proposed.

1 Introduction
Accidents occur at various stages in the buildings’ life cycle. To reduce the probability of their occurrence, the analysis of emergency situations and the analysis of the causes of their occurrence are necessary. The main operational performance of the building is reliability. Reliability considers the quality of the whole object as a whole. The reliability indicator depends on the quality of design documentation and construction production. Loss of performance results in failure, and as a result of an accident in buildings and structures. The probability of their occurrence depends on physical deterioration, the type of damage and the causes of accidents. The causes of accidents are mainly associated with design errors, with the quality of manufactured products, improper operation, external causes independent of the facility and global changes (Figure 1).
2 Materials and Methods

According to information from experts on technical diagnostics of buildings of the City Center of Expertise Group of Companies (CCEG), in 53% of cases the collapse occurs due to a set of violations...
committed at various stages of design, construction and operation. During the year, during the collapse of buildings in Russia, 30 people died and 58 people were injured. Non-compliance with the technology for construction, installation and repair work (including safety regulations) accounts for 32% of the collapses causes (in 2016 - 39%). Defects, low quality of building materials - 9% (in 2016 - 17%). As a result of the conditions’ violations (including terms) of the buildings’ operation, about 53% of collapses occur (in 2016, 44%). Errors in building design are the reasons of 6% of accidents (Figure 2).

**Figure 3.** Statistics of the collapse of buildings and structures

### 3 Results
After analyzing all the processes occurring at different phases of the life cycle, an algorithm for the comprehensive analysis of the accidents causes was compiled (Figure 4).

The paper proposes a classification of organizational and technological measures to reduce the probability of accidents at different stages of the building object’s life cycle (Figure 4).
Building Type Definition

Responsibility Assessment

| Level         | Low level | Normal level | Advanced level |
|---------------|-----------|--------------|----------------|

Analysis of performance parameters at different life cycle stages

| Stage          | Predesign | Design       | Construction | Exploitation                       | Capital Construction Demolition |
|----------------|-----------|--------------|--------------|------------------------------------|---------------------------------|
| • analysis of operating experience | • verification of methods for calculating building elements of space-planning decisions achieved in the project. | • study of documents on input, operational and acceptance quality control of manufacturing and installation of structures | • analysis of the act of acceptance of design and actual values of the PEC of the building | • comparison of actual values with normative | • analysis of the compliance of the operating facility with the requirements of regulatory and technical documentation |
| • theoretical and laboratory studies to substantiate the accepted PEC in the project | | | • study of accepted diagnostic methods to determine the actual PEC values of the building being commissioned | | • during current and major repairs, the available documentation is analyzed |

Investigation of the causes and records of accidents and failures

| Term       | Predesign | Design       | Construction | Exploitation                       | Capital Construction Demolition |
|------------|-----------|--------------|--------------|------------------------------------|---------------------------------|
| 10 days to create a technical commission | | | | | |
| Term       | five months | three months | two months   | | |

Conclusion Approval

Publication of the opinion (deadline and place not determined)

Accident Monitoring and Analysis System

Improvement and prevention of accidents at the capital construction facilities

**Figure 4.** Algorithm for a comprehensive analysis of the construction projects accidents’ causes at all phases of the life cycle
Measures to reduce the probability of emergencies at the construction sites

| Building Lifecycle Stages |
|---------------------------|
| Predesign                |
| Design                    |
| Building                  |
| Operation                 |
| Demolition ACS            |

- **Predesign**
  - Geotechnical analysis of the built-up area – identification of easements, analysis of the presence of dangerous geological processes
  - Variant analysis of the measures to reduce geotechnical risks of the construction area

- **Design**
  - Verification of methods for calculating building elements of space-planning decisions achieved in the project

- **Building**
  - 1. Ensuring the functioning of control systems at all the facilities under construction
  - 2. Increasing the effectiveness of technical supervision of the customer and the field supervision of design organizations with the certification of workers employed in the field of construction quality control
  - 3. Certification of quality control systems of the existing construction industry enterprises and the building materials industry

- **Operation**
  - Organization of continuous monitoring of the load-bearing structures’ state in the buildings under construction and in operation
  - Definition of the list of objects for mass stay of people most dangerous from the point of view of the load-bearing building structures’ state
  - Development of the rules and standards for the construction sites’ operation
  - Appointment by the managers of technical maintenance services involved in monitoring the condition of load-bearing and enclosing building structures, specialists with a building education and experience in construction
  - Investigate the causes of each accident

**Figure 5.** Organizational and technological measures to reduce the probability of accidents at different
Let us consider the reasons for the building structures and constructions’ collapse, depending on the quality of the building materials used.

As noted above, one of the reasons for the building structures and buildings’ collapse is also the quality of the applied building materials. What does the quality of the materials used mean? In accordance with various sources of regulatory documentation of the Russian legislation, as well as reference and regulatory literature of foreign production, building materials can be considered high-quality if they comply with the standards and do not violate the requirements for the purpose.

Let us consider an example of a concrete mixture delivered to a construction site, if workability and fastening time correspond to the quality certificate, then we can assume that the material used is of proper quality. But what do builders face? After some time, cracks and fading begin to appear on the concrete structures’ surface. And the structures were poured from the same concrete mixture. Of course, there are many factors. But let us look at an example when the operational control, the exposure time of the concrete mix in the formwork, temperature and maintenance are all appropriate. What is the reason then? And these cracks are not a contra phenomenon, that is, not because of the concrete mixture shrinkage.

Examining the crumbling concrete structure, the expert discovers easy exfoliation of the coarse aggregate. Any technologist will say that this can happen due to the presence of dusty-clay particles on the crushed stone surface. That is, dusty gravel was used in the concrete mix production. This operation is not controlled in any way; it is also not possible to detect this in the finished concrete mixture. As a result, there are cracks in concrete, and further collapse of the structure is possible.

Or another option of the substandard building materials used in the manufacture of building structures, is the formwork.

Due to the fact that the formwork is used to ensure the design shape, geometric dimensions and surface quality of the structures being erected within the established tolerances, when choosing the type of formwork used in the construction of concrete and reinforced concrete structures, it should be ensured: formwork’s manufacture and installation accuracy; quality of concrete surface and monolithic structure after formwork; formwork turnover. The formwork must be certified according to GOST R 52085 by the manufacturer.

For the erection of the object during monolithic construction, the formwork was used - large-panel collapsible, wooden (material - plywood) partially used once. But on the surface of the finished concrete structures, again, the cracks may appear. The expert comes to the conclusion about the possible unsatisfactory technical condition of the formwork and, accordingly, not suitable for re-use, due to the surface quality. In this regard, the turnover rate of the formwork has changed.

The human factor can also be taken as a very important aspect. High-quality and proper installation of the formwork system directly depends on its turnover. In case of errors made during the assembly, storage and operation of the formwork, non-observance of the formwork turnover norms, it is possible to significantly limit its service life.

The last factor that should paid attention to, when choosing the formwork, which affects its turnover, is the operating conditions of the formwork system during the process of pouring concrete or other building mixtures. The conditions include air humidity, average temperature, landscape soil conditions and other operational factors.

The main problem in the preparation of accounting and tax estimates when taking into account the costs of operating the formwork is that the legislation of the Russian Federation does not have precise and specific guidelines for the formwork norms. Therefore, the general rules should be used for this purpose. Property which value exceeds 20 thousand rubles and exceeds the operating time of twelve months is considered depreciable. Therefore, when drawing up estimates, the formwork is included in depreciable objects.

To determine the term, it is recommended to accept the manufacturer’s recommendations. In the case when the manufacturer does not indicate the specific time periods for the use of the formwork, it is necessary to change the cycles into months. This is an inaccurate and complex operation that the
designer or the work manufacturer will have to perform at his discretion when drawing up the turnover of the formwork in the estimates and at the construction site.

What problems do experts face? Not always normative and technical literature as well as the well-known methods for assessing the structures’ quality are reliable.

Summary
The analysis showed that accidents at capital construction facilities occur at various stages of the building life cycle. The statistics of the buildings and structures’ collapse and their causes are analyzed. It is revealed that they are associated with errors in the design and construction and violations of the buildings’ operation rules. At present, there is no unified system of accounting and technical analysis of the reasons for the current situation, in connection with which there is a need to pay special attention to monitoring and methods of complex diagnostics of the construction sites accidents’ causes.

The studies made it possible to develop the methodological foundations for a comprehensive analysis of accidents of construction sites, propose an algorithm of actions and develop a classification of organizational and technological measures to reduce the probability of their occurrence from the pre-project stage to the demolition of the capital construction.

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