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Original Article

Organization of Construction Quality Control based on a Priori Risks of Works

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Abstract *- Quality control of construction works is one of the most important areas of research in the organization of construction. The paradigm of lean construction requires approaches for obtaining high-quality construction with minimal resource costs. In such a statement of the task, it is necessary to perform quality control of work, focusing on the level of risk of the construction process for the quality of construction. This study aims to develop a methodology for performing risk-based quality control of construction, which will allow determining the sequence and scope of quality control of construction processes in conditions of uncertainty. The objectives of the study include the calculation and assessment of a priori risks of construction processes for the quality of construction. A formula for assessing a priori risks of construction processes depending on their estimated cost and complexity of implementation is proposed. It includes replacing the probability of defects appearing with the expected value and assessing the latter by the complexity of the building process. Estimated cost of the building process is employed for assessing damage from potential defects. This article takes the first step to developing a risk-based quality control methodology when there is no statistical data about the construction project and the probability of defects is unknown. The approbation was performed during the construction of a residential complex in Moscow. Because of the risk-oriented construction control method applied, it became possible to decrease the number of workers in the quality control department by 25% with keeping the high-quality level of construction.*

Keywords *- Risk-based approach, Risk assessment, Quality control system, Risk-based quality control, Organization of construction.*

1. Introduction

In today's construction, one of the most important aspects of the organization of work is the implementation of quality control of work processes and operations. Regulatory documents assign quality control functions to the main participants in the construction, namely, the general contractor, contractors, and construction manager. Construction control ensures the receipt of high-quality final construction products, as well as compliance with the estimated cost of construction. But given the great complexity of the large-scale construction systems and the high pace of work, it is almost impossible to ensure that all construction processes and operations are monitored without failures leading to defects [1]. Quality control has a multi-stage structure of participants to minimize construction defects [2], shown in Figure 1.

Within these construction companies, the quality of production is ensured by continuous multi-stage control of raw materials and operations [3]. Figure 2 shows an example of the organization of quality control of monolithic work by the executors of the general contractor [4].

Fig. 1 Participants in construction quality control

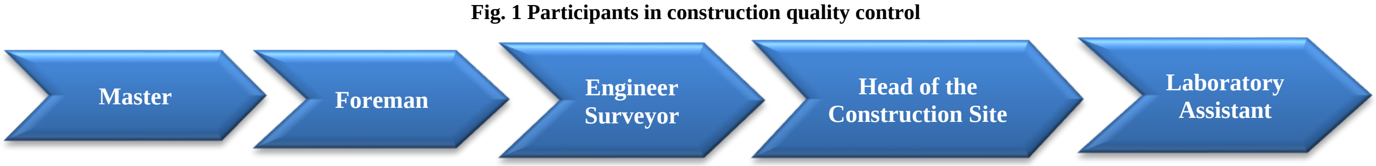

Fig. 2 Executors of the quality control of monolithic works in the general contractor

These examples show the multi-stage system of the organization of construction control, which reduces the number of failures in the construction process. But the number of parallel construction processes and operations in large-scale construction conditions of tight deadlines is many times higher than the number of executors in the quality control system of construction companies [5]. At the moment, this problem is being resolved by increasing the number of construction control system workers. This approach involves a significant increase in the number of employees of companies performing quality control in accordance with the number of parallel construction processes [6]. This increases the costs [7] and time of work due to a rise in the number of inspections. To solve this problem, the author carried out the research presented in this paper. Nowadays, multiple studies have been conducted regarding worker construction productivity [8], but not enough research on the productivity of engineer staff involved in construction. This paper presents the research that will allow increasing of work efficiency of quality control engineers.

Risk-based construction quality control is the control of construction processes in sequence and amount based on their risk level. Such an approach will allow reducing the number of quality control engineers without losses in overall construction quality, which meets the principles of lean construction [9]. The purpose of risk-based control is to reduce the overall risk of construction of substandard structures [10] and not to exclude all possible defects and failures [11]. Currently, the effectiveness of the risk-based approach [12] in various areas of construction is justified [13]: management [14], safety [15, 16], contractual relations [17], and financing [18]. Risk assessment has been investigated in the construction of transport infrastructure [19], road construction [20], rail construction [21], underground construction [22], and low-rise construction [23]. Methods of monitoring the quality of work are being developed in construction control [24], various digital technologies are being introduced [25], models have been developed to assess and manage the risks of rework because of defects [26], defect classifications for various building constructions are designed [27], studies on the impact and risk management of the project duration have been conducted [28, 29]. The listed above extant literature demonstrate the relevance of a risk-oriented approach in construction. However, none of them addresses the organization of construction quality control based on the immanent risks of various building processes. There wasn't developed any reliable construction processes classification by their level of risk for construction quality. Currently, there is no proposed methodology for performing risk-based quality control of construction which allows for determining the priority and amount of control. That creates a problem in organizing a quality control system by the contractor and construction manager in large-scale construction. The purpose of this article is to develop a methodology for assessing the risks of construction processes in the field of quality control during the construction of large-scale projects. The objectives of the study are the mathematical formalization of the calculation of the risks of the construction process, the determination of a priori risks in conditions of uncertainty of the probability of defects, the presentation of examples of calculation of risks of construction processes, determination of prospects for further research.

2. Materials and Methods

The calculation of risk of the construction of substandard structures is determined by the formula according to ISO 13824:2009 [30]. Risk R is calculated as the product of chance multiplied by damage.

Let's imagine construction as a system of complex construction processes in the example of the construction of a residential complex, as shown in Figure 3.

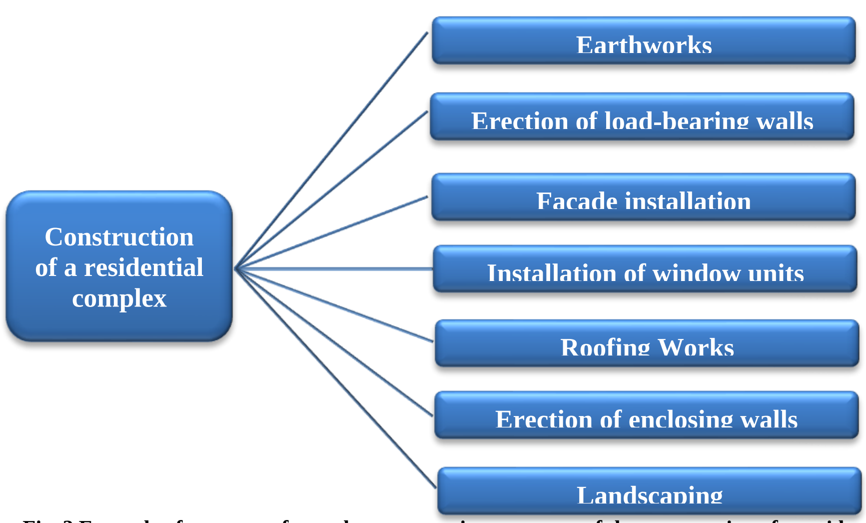

Fig. 3 Example of a system of complex construction processes of the construction of a residential complex

During the construction of a residential complex, these complex processes are carried out in parallel on one construction site. To minimize failures and defects, it is possible to increase the number of engineers performing verification of production quality, process control and acceptance quality control of work. But this will increase the cost of construction. Therefore, a more rational solution, according to the principles of lean construction, is to assess the risk level of each construction process and determine the sequence and scope of control in accordance with these risks. To determine the priority and amount of quality control for each process, it is necessary to assess the risk of each process according to the risk *R* calculation.

The complex process consists of simple construction processes, as shown in Figure 4.

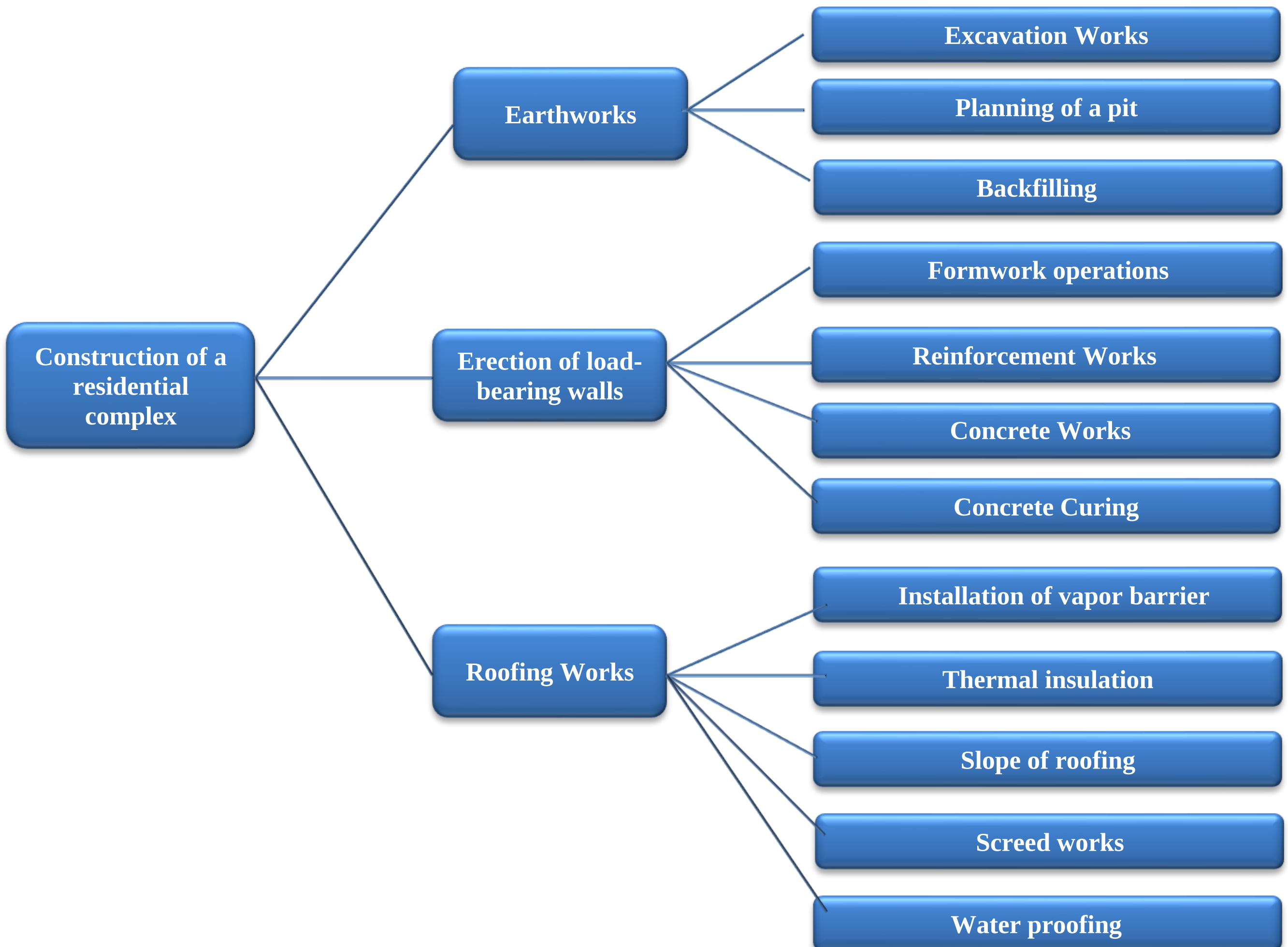

Fig. 4 Structure of complex construction processes

3. Results

According to risk *R* calculation, the risk of a complex *i*-th process can be represented as follows

$$R_i(A) = \sum_{n=1}^{N} P(B_n)U(B_n), \quad (1)$$

where *B* is the event "failure of a simple construction process, which caused the appearance of a defect"

N – the number of simple processes in a complex process. Failure is a violation of the rules of work, which causes the appearance of a defect.

Under conditions of uncertainty, let's assume that the probability of failures for simple processes is the same,

$$P(B_n) = p_B \quad (2)$$

then

$$R(A) = p_B \sum_{n=1}^{N} U(B_n) \quad (3)$$

The consequences caused by failures in construction processes are expressed in the financial costs of correcting the defects that have arisen [31, 32]. To calculate the a priori risk, the author considers the influence of critical defects in which normal operation of structures is impossible. In case of such defects, the construction structure is subject to rework. The rework costs can be estimated based on the estimated cost of the work, which is defined in the project documentation. Therefore, the consequences can be estimated when calculating the a priori risk using the following formula

$$U(B_i) = v(C_i + C_{Di}) + C_T, \quad (4)$$

where C_i- estimated cost of a simple i-th construction process,

C_{Di}- estimated cost of dismantling structures because of identified defects,

C_T- the cost of compensatory measures to eliminate the backlog of the construction project because of rework,

v - the share of the total volume of structures that are subject to rework due to defects.

The share of defective building structures depended on the number of defects and the stage of the construction process when they were fixed. To assess a priori risk, this factor can be excluded from the calculation. The estimated cost of D in mantling structuresC_{Di} depends on the stage of detection of defects and the volume of work performed at this stage. The cost of compensatory measures to eliminate the backlog of the construction project$C_T$depends on the available time reserve for the construction process. If the delay does not exceed the time reserve, then $C_T = 0$. Therefore, at the stage of assessing a priori risks in conditions of uncertainty, these factors can be excluded from the calculation (4).

The probability of defects $p_B$is a complex parameter that depends on many factors: the qualification of workers, the quality of project documentation, the quality of tools and inventory, the quality of materials, the technology of work, etc. These factors change at various construction sites and may also change during the construction of one object [33]. Therefore, calculating the probability of a defect is a difficult and time-consuming task, especially in conditions of uncertainty when there are no statistics on the appearance of defects. In this regard, to assess a priori risks in conditions of a lack of information about the project, it is proposed to use the average possible number of defects that lead to damage instead of the probability of defects (2). The average potential number of defects$N_B$depends on the complexity of the complex process, that is, on the number of simple processes$N$. The failure of a simple construction process is a random variable that can be estimated using mathematical expectations as follows

$$N_B = E(B) = Np_B, \quad (5)$$

The sum of the estimated cost of simple processes is equal to the estimated cost of a complex process, and under conditions of uncertainty, the author excludes the probabilityp_B from the calculation. Then the author obtains a formula for calculating the a priori risk of defective process under conditions of uncertainty

$$R_i(A) = NC_i \quad (6)$$

A more accurate risk value is a posteriori risk, including the probability of defects; it is possible to calculate during the construction of an object when statistical information about the implementation of certain risks appears.

According to (7), it is possible to calculate a priori risks of construction processes at any time of construction and organize the implementation of quality control in priority order, starting with the processes with the greatest risks. Figure 5 shows an example of the assessment of a priori risks of construction processes and prioritizing quality control of these works in the example of the construction of a residential complex in the city of Moscow.

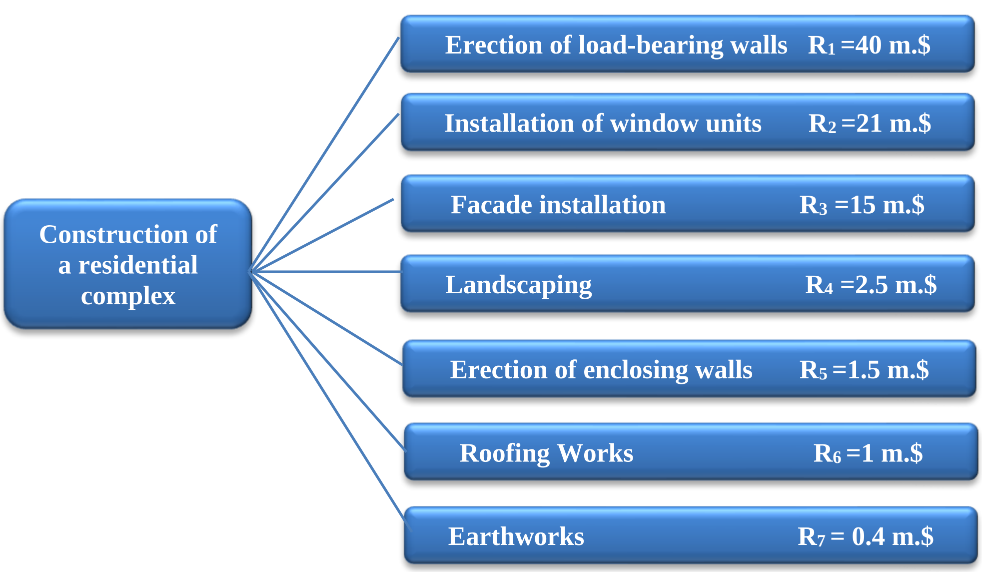

Fig. 5 Assessment of a priori risks of the construction processes on the example of the construction of a residential complex in the city of Moscow

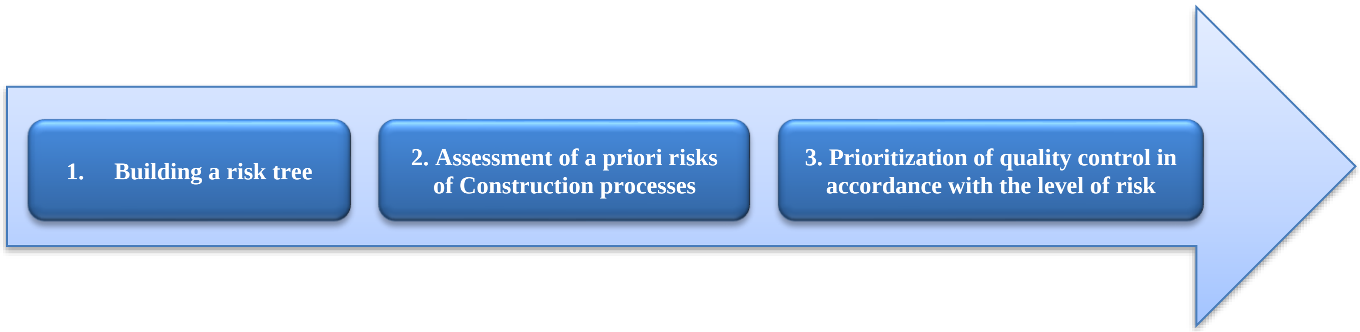

Fig. 6 Methodology for determining the priority and scope of quality control of construction processes

The methodology for determining the priority and scope of quality control of construction can be presented in the form of a block diagram shown in Figure 6.

The approval of the research was carried out during the construction of a residential complex in Moscow. The method of risk-oriented quality control was introduced to the construction developer's quality control department. That department included 9 quality control engineers, and each of them was assigned to a complex construction process. Introducing the risk-oriented quality control allowed to organize of the department's work using only 7 engineers, while 2 relieved engineers were employed for a new complex process – finishing works. After 6 months of construction work, federal construction control revealed no increase in violation of requirements of work quality, which serves as evidence of the developed method's effectiveness.

4. Discussion

The novelty of the performed research is the creation of a method for the evaluation of complex construction processes risks. The implementation of this method allows for the optimization of the organization of quality control while building a residential complex, namely, to distribute of working hours of quality control engineers according to levels of risk in construction processes. The developed method also allowed the designing of a quality control program that determines the amount and priority of control for every building process, resulting in a high level of construction quality with less number of quality control department members engaged. It became possible to achieve such a result after calculating a priori risks in construction processes that allowed the classification of them by the level of risk. The results of this study are important for the general contractor and construction manager. Compared to the existing approaches, risk-oriented quality control will increase the productivity of quality control departments due by decreasing their maintenance costs without any loss of quality in construction results.

5. Conclusion

This article substantiates the relevance of the introduction of risk-based quality control instead of a multi-stage model of construction control, which involves an increase in the number of operations and control participants to minimize defects. The study shows the advantages of risk-based quality control: improving the quality of construction with minimal resource costs by determining the sequence and scope of control in accordance with the risk level of construction processes. This article presents a mathematical formalization of the calculation of the risk of a complex construction process. A priori risks of construction processes are calculated in conditions of lack of information about the construction project when it is not possible to assess the probability of defects. A principal methodology for performing risk-based quality control under uncertainty in the form of a block diagram is presented. In future studies, it is planned to mathematically formalize the calculation of a posteriori risk, which will consider the probability of defects and damage from the time spent on rework, as well as the financial costs of dismantling. Solving these tasks will allow us to form a risk management tool for quality control of work in large-scale construction.

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