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Assessment of Organizational and Technological Reliability Monolithic Works

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Abstract

Every year in the construction process new technologies are introduced, the use of new building materials increases, a large number of contractors are involved, with a significant increase in the scale of construction and the need to ensure the reliability of construction. There arises a necessity to forecast and correct activities of construction organizations, to give adequate assessments of the adopted organizational and technological solutions (OTS), which, as a rule, leads to a decrease in the prescriptive term of construction. Monolithic structure construction process design is closely connected with the necessity of clear and correct choice of the necessary organizational-technological solutions. Depending on the made decisions it is possible to estimate the reliability of monolithic works. This in its turn gives the possibility to forecast the terms of production, the cost of monolithic works on the stage of design of dwelling buildings and industrial objects directly. The article offers a methodology for calculating the evaluation of organizational and technical reliability of the process of monolithic structures. For the successful performance of monolithic works it is necessary to ensure the reliable functioning of all participants of the process from designers to construction teams. The article presents the calculation of organizational and technological reliability index (OTR) of monolithic works. To calculate the index the author proposed a model and introduced the concept of reliability of the considered process of monolithic works as a probability of achieving the final goal. At the same time, the process of monolithic works performance both for residential and civil objects is taken as a complex stochastic system, which includes a set of co-dependent relations. The application of the assumed approach for the calculation of organizational and technological reliability of monolithic works with small changes, refinements can be applied to the calculation of other works in the construction of buildings and structures throughout the life cycle of construction. At the same time, this methodology makes it possible to obtain a numerical value of reliability assessment, which is very relevant when choosing organizational and technological solutions.

1. Introduction

Design and construction of large objects today is held in "extreme conditions" increase in the cost of materials, reduction of consumer activity, in which there are many different negative factors, which together lead to a significant reduction in the reliability of construction and therefore lead to violations of the three fundamental indicators of construction such as construction time, construction costs, quality of construction work.

Construction seems to be a complex production system, the main distinguishing feature of the construction system is its organizational nature. The concept of "system" includes many different elements, interacting with each other to form an integral, unified system (Gusakov, 1974). Consistent and precise functioning of these elements makes this system the most effective in construction. At the same time, even small failures of individual elements of the system lead to the destabilization of the entire complex system (Sinenko, 1992, Kabanov & Mikhailova 2012). Reliability is taken as a set of technological, organizational, managerial decisions that ensure the achievement of the required result in the occurrence of random failures, which are inherent in a complex system of construction (Gusakov, 1974). Failures in construction production occur under the influence of negative factors throughout the life cycle of construction (Kostyuchenko, 2013).

Under the concept of the life cycle of the construction object means the time period during which the construction object exists as an object of management, that is, the period from the birth of the idea for construction to the final stage - the liquidation of the object

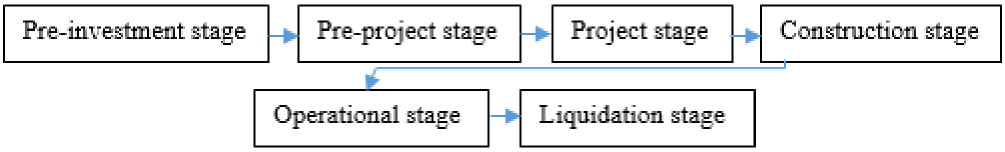

Fig. 1 *Stages of the life cycle of a construction object.*
Source: Compiled by the author

It is at these stages of the life cycle of the construction project "failures" occur, which lead to a violation of the integrity of the system, which in turn will lead to disruption of construction time and increase the estimated cost of construction.

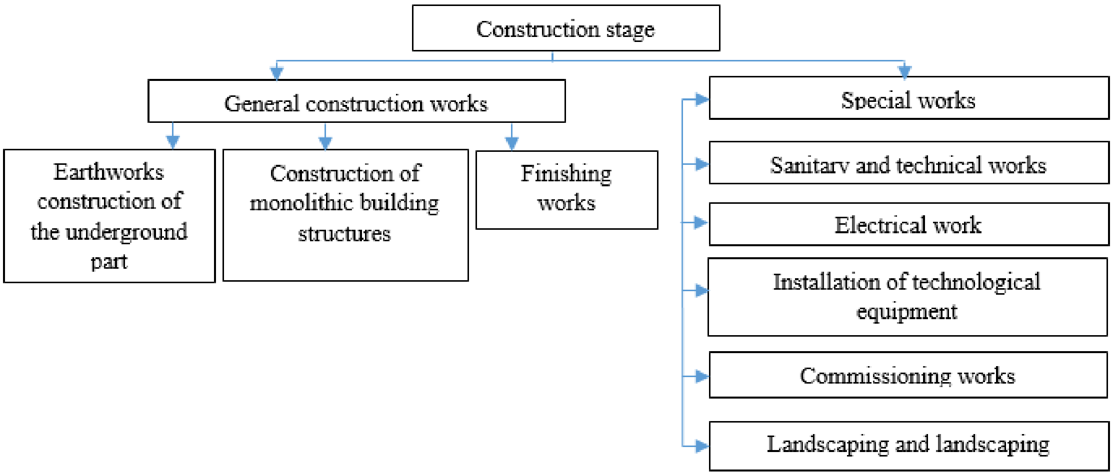

Fig. 2 *Structure of works included in the construction phase.*
Source: Compiled by the author

Today the global use of concrete exceeds 3.5 billion m3 per year. The world leader in concrete production today is China, the annual volume of concrete produced is about 730 billion m3.

Table 1 *Volume of concrete production, mln м3*

Country	**Year**					**Average volume (m^3) for 2015-2019**	**Percentage of volume increase (m^3) since 2015**
	2015	**2016**	**2017**	**2018**	**2019**		
Germany	46.0	49.5	52.0	52.7	53.5	50.74	15.50 %
France	34.8	36.1	38.7	39.7	40.3	37.92	15.02 %
Italy	25.3	27.4	27.3	27.3	28.4	27.14	11.96 %
Turkey	107.0	109.0	115.0	100.0	67.0	99.6	-36.52 %
Spain	16.3	16.3	19.7	22.2	24.8	19.86	45.25 %

United Kingdom	23.7	24.6	22.9	25.7	24.9	24.36	5.99 %
United States	260.0	265.0	270.0	274.0	280.0	269.8	7.46 %

Source: EUROSTAT: http://ec.europa.eu/eurostat

Application of monolithic concrete in house-building in Russia originated later than in foreign countries, but application of new and competitive technologies allowed to reduce the lag. Analyzing the data, we can note the increase in production of concrete from January to September 2022 to the same months, but in 2021 by about 12.99% up to 39.9 million m3, but with these figures Russia is far from the first places (Journal "Industrialist of Siberia").

To date, there are pressing issues related to improving organizational and technological reliability (OTR), based on the definition of accounting technological and organizational factors that have a different impact on construction production, finding methods through which it is possible to manage these factors are especially important (Ginzburg, 2013). The analysis of scientific and technical literature (Gusakov, 1974; Madu, 2005; Kuznetsov et al, 2007; Karbasian & Rostamkhani, 2020) revealed that to date there is no methodology that takes into account the probabilistic nature of construction production, which leads to a decrease in the reliability of organizational, technological and managerial decisions in the industry. It should be noted that the construction organizations are interested in high-quality work of the designer, who needs to make effective decisions, through which it is possible and if necessary, to increase the organizational and technological reliability.

Not every customer/developer is ready to erect the object "blindly" without taking into account the accepted organizational and technological solutions. Analyzing the scientific and technical literature, it can be noted that the methodology of assessing the value of the reliability indicator is presented as an assessment of the completion of work within the specified time, but based on practice it can be noted that in developing the principles and methods of reliability it is necessary to provide a probabilistic and statistical approach in solving the problem (Ginzburg, 2010, Wu, et al., 2006).

2. Materials and Methods

Developing a new project designer are often faced with a number of problems limited resources, tightly defined construction deadlines, limitation in financing. At the same time, the designer is tasked with ensuring the reliability of the project with the condition of performing all functions with minimal financial costs. The simplest method for distributing reliability is to distribute it evenly over all components of the process. Two basic approaches are used to improve reliability: the first is failure prevention and the second is system fault tolerance. Failure prevention can generally be reduced by using good and reliable system components. Fault tolerance can be increased by redundancy, which can lead to increased design complexity, cost, etc.

Before deciding whether it is necessary to increase the reliability values, it is necessary to make a comprehensive assessment of each element of the system under study. After obtaining the reliability assessment of each component of the system, they are analyzed and it is determined whether the system has achieved the required reliability. The methodology for calculating the reliability of monolithic works consists of several stages.

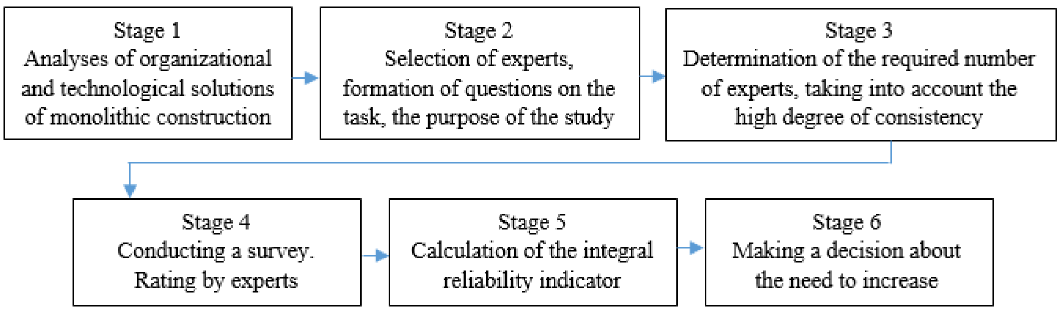

Fig. 3 *Scheme of the reliability calculation methodology*
Source: Compiled by the author

For example: there is a system with three components, which determine the reliability of the process, and each element of the system has its own reliability: R1=70%, R2=80%, R3=90%. The target reliability Rg=85% is accepted for this system.

Determine the current reliability of the system:

$$R_s = (R_1 \cdot R_2 \cdot R_2) \cdot 100 = (0,7 \cdot 0,8 \cdot 0,9) \cdot 100 = 50,4\% \quad (1)$$

As we can see the calculated reliability of the elements does not correspond to the target reliability of the whole system. Obviously, to achieve the target reliability it is necessary to increase the reliability of all elements of the system to achieve the goal. First, let's increase the reliability of one of the elements from R1=70% to R1=77%, and recalculate the current reliability of the system:

$$R_s = (R_1 \cdot R_2 \cdot R_2) \cdot 100 = (0,7 \cdot 0,8 \cdot 0,9) \cdot 100 = 55,44\% \quad (2)$$

However, if we consider increasing one element of the system to a hypothetical value of 1, which corresponds to 100% reliability (the element will never fail), the target reliability of the system will still not be achieved.

$$R_s = (R_1 \cdot R_2 \cdot R_2) \cdot 100 = (1,0 \cdot 0,8 \cdot 0,9) \cdot 100 = 72,0\% \quad (3)$$

The next step is to try to increase the reliability of the remaining two elements of the system, but there is a problem of choosing which element to choose, you can increase two elements of the system at once, but then it is possible that this will lead to increased costs and will be less effective. To solve this problem, it is necessary to qualitatively evaluate the elements of the system.

When modeling a computational mathematical model, one of the problems that arises is the qualitative determination of the weight characteristics of the identified organizational and technical solutions. The resulting input data are different values, because of the difficulty of calculating the mathematical model. The maximum value of weight values of all elements of the system under consideration should not exceed 1, 0.

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The purpose of the study is to find and evaluate the reliability indicator for the construction of monolithic structures. In order to solve the research purpose, it is necessary to solve the set task - to determine reasonable and objective organizational-technological solutions, influencing on the reliability of monolithic works and, if necessary, to optimize these solutions. The adopted hypothesis of the research is the ability to assess the reliability of the construction process on the basis of the developed integral index.

In determining the organizational and technological solutions of monolithic works we used the method of expert evaluations, which was attended directly by representatives of construction organizations, the main direction of which was monolithic works.

The necessary consistency of the group of experts was carried out on the basis of the use of Kendell's rank correlation coefficient:

$$W = \frac{S}{\frac{1}{12} m^2 (n^3 - n) - m \sum_{i-1}^{L} T_i} \quad (4)$$

Where Ti = 1 12 ∑ $(ti$ 3 $-ti)$ L i−1 , L – number of repeat types of elements in assessments of i-th expert, tl - number of elements in l -th bundle for expert (number of repeat elements). If there are no ranks, Ti equals zero. Ti – indicator of connected ranks assigned by j expert (Gusarov & Gusarova, 2021).

The required number of experts is determined by the formula:

$$N = 0,5(\frac{3}{\alpha} + 5) \quad (5)$$

$0 < \alpha \geq 1$- Parameter defines minimal level of expert errors.

In the article, the author proposes to consider only monolithic works, which are included in the construction phase, since they are the main ones in the construction of the object, and therefore the reliability of these works determines both the reliability itself and the directive term of the construction of the object. To calculate the reliability and to determine all the components of the monolithic works, the following scheme was used.

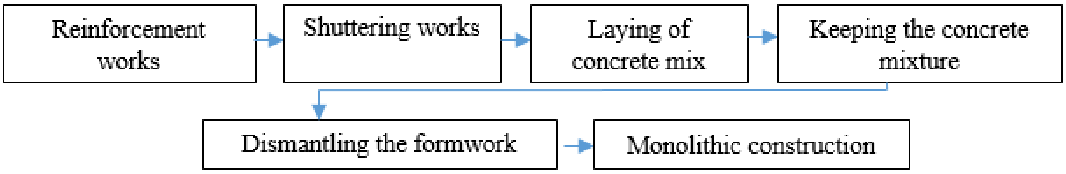


Fig. 4 *The scheme of the device of monolithic structures.*
Source: Compiled by the author

Since the system has a stochastic nature, achieving 100% reliability is hypothetically possible, but, unfortunately, unlikely, since the system is affected by many different parameters that lead to failures. To calculate the reliability of monolithic the author proposes to go to the reliability evaluation scale.

Table 2 *Accepted scale reliability value*

Indicator	The value of the indicator
High level of reliability	0,55-1,0
Satisfactory level of reliability	0,34-0,54
Unsatisfactory level of reliability	0-0,33

Source: Compiled by the author

To interpret the results obtained from this table, let us give an example: the monolithic works consist of six successive works, the target reliability of these works will be added up as the reliability of all stages of the monolithic construction.

$$R_g = R_{rw} + R_{sw} + R_{lc} + R_{kc} + R_{dw} \quad (6)$$

Where Rrw - reliability of reinforcement work, Rsw - reliability of shuttering works, Rlc - reliability of laying concrete mix, Rkc - reliability of concrete mix retention, Rdw - dismantling the formwork.

The obtained result must be compared with the set scale and on the basis of the analysis a decision must be made. Unsatisfactory result indicates a large number of failures in this work, satisfactory result - the number of failures is limited, but the system functions and performs its functions, high level of reliability - the number of failures does not affect the system in any way.

In this case if one of the stages of the monolithic structure erection has an unsatisfactory result it does not mean that the whole subsystem is unreliable, at the expense of other stages it is possible to level out the target reliability.

3. Results

One of the main indicators in the construction phase is the reliability of each construction process, the duration of which affects the directive period of construction. That is why the customer is directly interested in the predictive evaluation of the reliability of each stage of the life cycle of the building, while it is necessary to comply with other important aspects of construction cost, quality.

To determine the reliability of each stage, the author proposes to introduce a target indicator of construction reliability. This indicator is calculated on the basis of specific identified organizational and technological solutions. The developed index allows to estimate to what extent the customer can influence the term of construction, to reduce the cost at the expense of the use of new technologies. On the basis of the function the reliability indicator is calculated:

$$R_g = \sum_{j}^{i} R_{i-j} \cdot \chi_{i-j} \quad (7)$$

Where Ri-j – the maximum possible value of the reliability of the adopted organizational and technological solutions, χi-j - the weight value of the identified organizational and technological solution.

Each construction company will have its own value of reliability index, because it depends on many different indicators, which are inherent only to one company. After an expert survey of the heads of construction companies, a table with the identified organizational and technological solutions was compiled, weighting characteristics according to the experts' assessments, the maximum possible value of the reliability of the adopted organizational and technological solutions were determined.

Table 3 *Expert Survey table*

Identified organizational and technological solutions	**Maximum possible value of the reliability of the adopted organizational and technological solutions**	**Weight value of the identified organizational and technological solution**
Reinforcement works (The use of various methods of connecting fittings)		
Connection of vertical reinforcement with couplings, the use of a manual automatic gun for tying reinforcement horizontal structures (P_1)	53%	0.54
Connection of vertical and horizontal structures with binding wire (P_2)	31%	0.35
Welded joint (P_3)	16%	0.11
Reinforcement works (Application of various types of reinforcement products)		
Factory reinforcement products are used (P_1)	53%	0.61
Reinforcement products manufactured on the construction site in reinforcement shops are use (P_2)	35%	0.32
Reinforcing products made of individual rods are used at the place of the construction device (P_3)	12%	0.07
Shuttering works		
A complete set of formwork for the construction of the floor (P_1)	51%	0.64
Half of the complete set of formwork for the construction of the floor (P_2)	39%	0.35
Absence of more than half of the formwork for the construction of the floor (P_3)	15%	0.11
Laying of concrete mix		
Concrete mix supply "bucket crane" + "concrete pump" (P_1)	57%	0.67
Concrete mix feeding by concrete pump (P_2)	33%	0.32
Feeding of concrete mix by means of a bucket (P_3)	10%	0.25

Source: Compiled by the author

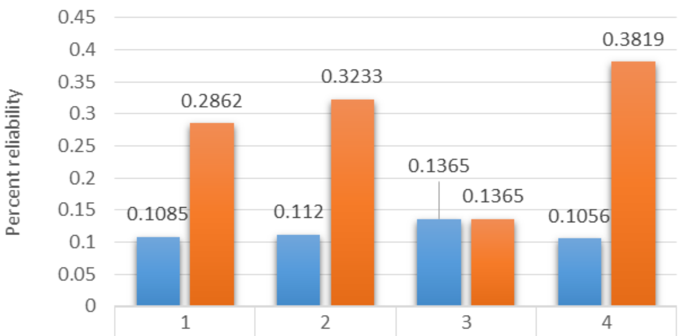
Depending on the adopted organizational and technological solutions for each identified stage, let's calculate all the parameters with the values of P2:

$$R_{g1} = ((0,31 \cdot 0,35) \cdot (0,35 \cdot 0,32) \cdot (0,39 \cdot 0,35) \cdot (0,33 \cdot 0,32)) \cdot 100 = 0,017 \quad (8)$$

The result indicates that under these organizational and technological solutions reliability corresponds to the unsatisfactory result, as stated earlier at the expense of the overall reliability of the other elements of the system will be possible to raise the overall level of reliability, but it is still proposed to increase the identified organizational and technological solutions in order to raise the reliability level at least to a satisfactory result.

$$R_{g2} = ((0,53 \cdot 0,54) \cdot (0,53 \cdot 0,61) \cdot (0,39 \cdot 0,35) \cdot (0,57 \cdot 0,67)) \cdot 100 = 0,4823 \quad (9)$$

The new result shows that due to the selected new organizational and technological solutions the reliability was increased and lies at a satisfactory level of reliability.



	1	2	3	4
Option 1	0.1085	0.112	0.1365	0.1056
Option 2	0.2862	0.3233	0.1365	0.3819

Fig. 5 *Histogram of reliability changes depending on changes in organizational and technological solutions. Source: Compiled by the author*

4. Discussion

The production cycle of monolithic structures is influenced by a large number of external and internal factors such as: technological, financial, organizational, and climatic. Influence of such factors as a rule leads to the fact that terms, cost of works are beyond the planned results. From the above stated it is possible to point out the following: the control system of the process should work accurately and realize various measures by which failures and deviations will be minimized and the required result will be reached. The solution to the problem of reliability of the construction process is seen in the development and implementation of solutions as an organizational and technological order, as well as management solutions (Farzaliyev & Guluzadeh, 2022).

Analyzing Russian and foreign scientific and technical literature, aimed at ensuring the reliability of organizational and technological solutions, it was found that at the moment there are no clear guidelines for these solutions. Basically, the choice of such solutions is based on statistics, which was obtained on similar objects, at that, specialists in this field give rather different recommendations in what limits the reliability should lie.

Having considered scientific and practical recommendations made by the leading specialists, it is possible to say that the recommended reliability of the concrete project should lie within 90-95%, which is a rather high limit, at that achieving such values will probably entail increasing construction costs, which in some projects is simply impossible, since a clear estimated construction cost is set. If such high reliability targets are not achieved, methodological development and application of additional measures to achieve the goal is recommended.

5. Conclusion

Nowadays there is a tendency to find, evaluate and, if necessary, improve the reliability of construction. Construction is a complex system, which has a probabilistic nature because it is influenced by many factors, the impact of which is quite difficult to predict. Provision of reliability of construction is seen in the need to integrate theoretical and practical approaches to solve the problem. It is worth noting that the modeling process should include the development of interconnected organizational and technological solutions and operational management model.

Using statistical data received as a result of the conducted expert poll, there have been revealed reasonable organizational and technological solutions of the process of monolithic works. The essence of the developed model consists in determining the limits in which the reliability of monolithic works should be situated, taking into account no variability of the terms of works and costs. The model is used for analyzing complex influence of organizational and technological solutions on the reliability of the process.

The developed estimation of reliability gives an opportunity both for a building organization and for a customer (investor) to choose the decisions which will allow to increase reliability of production process.

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