Influence of the Accuracy of Strength Control on the Quality of the Structures Being Erected

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Abstract. The influence of the accuracy of tests in the process of quality control is analyzed on the example of assessing the class of concrete in standard samples and non-destructive methods. Quality control is seen as part of the reliability triad, ensuring a level of reliability during construction. The relationship was established between the accuracy of test methods and quality control based on the result of construction. The factors influencing the efficiency increase of the quality control system are determined. The prospects for the development of the accuracy of standard destructive and non-destructive testing methods are assessed. A system for evaluating and monitoring the effectiveness of testing by non-destructive methods and a connection with the reliability of the structures being erected has been developed; A rational organization of concrete strength control using direct and indirect methods is proposed. The calculation of the organizational and technical potential for the use of non-destructive testing methods has been made; assessment of the influence of changes in the structural characteristics of concrete during its long-term operation on the results of non-destructive testing of strength.

1. Introduction
The quality control system for construction products is actively developing, new methods and means of control are emerging, but the fundamental approaches are changing much more slowly. At the same time, the existing quality control methods do not establish a direct connection between quality parameters and the level of reliability and durability, since they do not allow guaranteeing the failure of the structures being erected. Therefore, developing materials, calculation and design methods, construction and operation technologies do not allow avoiding emergency situations. Moreover, all types of structures made of various materials have the possibility of sudden destruction.

2. Research methodology (technique)
Analysis of accidents for several years allows to establish the most probable causes of the destruction of concrete structures. [1-2]:

- Violation of the requirements of regulatory documents and deviation from projects when performing construction and installation works 35%;
- Low quality of precast concrete structures used in construction 4%.

About 40% of all accidents in concrete and reinforced concrete structures are related to the quality of measurements, testing and control. As a result, using modern principles of quality control and ensuring the reliability of building structures, a high probability of failure-free operation is not achieved. There is no relationship between quality parameters and reliability assurance at the stage of
design and calculation of structures, in the process of construction and assessment of reserves of bearing capacity during operation. The transition to probabilistic design and calculation methods without taking into account the complex effect of the quality control system on the final result of construction products does not provide fundamentally possible guaranteed reliability indicators according to the level of reliability of structures [3-4]. The improvement of control methods and, above all, the mechanical properties of building materials and structures (concrete in particular) is the most important direction in the modern development of building science.

The accuracy of testing and evaluating parameters in the quality control system of the construction quality control system makes fundamental adjustments to the process of specifying products with a guaranteed probability of non-destruction. One of the important factors is the accuracy of the control of the physical and mechanical properties of materials and the correct interpretation of the results obtained. Reliable quality control of materials is part of the reliability triad. The level of reliability of building structures, reliability is laid down during the design, assessed and ensured during the construction process, maintained during operation. It is necessary to scientifically grounded approach to improving the accuracy of quality control of the measurement process and assessment of construction quality indicators [5-6].

To ensure the accuracy of control when determining the class of concrete in compression: the class of concrete in compression guaranteed strength with a probability of 95% according to the test results of standard samples, it is necessary to assess the requirements of direct measurements involved in the process.

Quality control systems often approach the assessment of strength in standard samples, treat the results as direct methods, and the measurement accuracy is regulated as for indirect ones (including directly measuring geometrical dimensions and breaking force). Taking into account the fact that the standards provide for the measurement accuracy of direct measurement methods when determining the strength [7-8]:

- for measuring geometrical dimensions, an error of geometrical $\delta_{a,b}=1\%$;
- for destructive force $\delta_P=0.5\%$ [9-10].

The limiting value of the coefficient of variation for concrete when determining the strength class is 13.5%. It does not take into account that the error component of the indirect measurement method can be significant. Methodological and instrumental error distorts the test results and, under unfavorable circumstances, leads to a decrease in the level of reliability of the erected building structures, as well as to cause the destruction of reinforced concrete and concrete structures. The influence of the measurement error in determining the strength of structural materials and its influence on the reliability of tests and the level of reliability of the structures being erected is an urgent task.

With standard destructive test methods, the error is determined as for indirect measurement methods based on the known permissible errors of direct measurements. Based on the influence of the accuracy of the assessment of geometric dimensions and destructive force. The error of the indirect method for determining the strength is determined by the relationship [11-12]:

$$\delta_R = \sqrt{\frac{\partial R}{\partial a} \delta a^2 + \frac{\partial R}{\partial b} \delta b^2 + \frac{\partial R}{\partial P} \delta P^2}$$

(1)

where $\frac{\partial R}{\partial a}$, $\frac{\partial R}{\partial b}$, $\frac{\partial R}{\partial P}$ the coefficients of significance of direct measurements for the corresponding variable.

a, b, P - geometric dimensions and breaking force measured during the test. $
\Delta a, \Delta b, \Delta P, ...$ much less than the values of the quantities a, b, P.

Let us consider the influence of the indirect measurement error using the example of determining the class of concrete B 30 in standard samples and evaluate the influence of the indirect method error. When testing the class of concrete in standard samples with dimensions 150x150x150 cm, the strength should be at the level of 38.3 MPa, and the breaking force should be at the level of 868 kN.

The error will be: $\delta_R = 0.071$;
3. Practical relevance

The error of the indirect method can reach about 7%, i.e., with an allowable coefficient of variation of 13.5%, half of the allowable range of strength indicators during testing can be attributed to the error of the most accurate method. An additional error, undetectable by the control method, reduces the reliability of the control. While maintaining the error of direct measurements within acceptable limits, it can significantly distort the test results. This means that, taking into account the measurement accuracy, sufficient indicators of the stability of the mechanical properties of concrete should be within $\nu' = 13.5 - 7 = 6.5\%$ (fig. 1).

![Graphical representation of the probability of error in determining the strength due to measurement inaccuracy.](image)

**Figure 1.** Graphical representation of the probability of error in determining the strength due to measurement inaccuracy.

The results show that taking into account the permissible error of direct methods when determining the class of concrete significantly distorts the results (errors of the indirect method). This will significantly affect the probabilistic calculation of the reliability level in terms of the probability of failure-free operation and the safety index [13-14]. The decrease in the safety index of concrete structures, taking into account the measurement accuracy indicator, will be 10%, and the probability of material failure in the structure will double from $P_f = 73 \times 10^{-4}$ do $185.9 \times 10^{-4}$.

The transition to non-destructive methods of monitoring mechanical properties on the one hand increases the coverage of controlled volumes, but the probability of not detecting a local defective zone decreases due to the lower measurement accuracy. When switching to non-destructive methods, an additional standard deviation of the method appears when constructing a calibration curve. When constructing the calibration curve, the standard deviation is allowed equal to $S_{nm} = 12\%$, except for the separation method [15-16]. For the method of separation with shearing, an increase in RMS $S = 4\%$ for an anchor with a length of 48 mm and $S_{nm} = 7\%$ for an anchor with a length of 20 mm is allowed [17-18]. The authors considered how the additional error of the non-destructive method affects the resulting reliability of the control, and hence the reliability of the erected structures with this level of control.

An increase in the standard deviation leads to a decrease in the reliability of the information obtained, which in turn increases the scatter of the obtained results of testing mechanical properties. This leads to a decrease in the reliability of the structures being built, since the guaranteed safety factor decreases.

Estimating the likelihood of uptime
where $\beta$ – safety characteristic (reliability index)

$$\beta = \frac{K_{\text{sum}} - 1}{\sqrt{(v_R^2 K_{\text{sum}} + v_Q^2)}}. \quad (3)$$

$\nu_Q = \frac{S_Q}{Q}, \nu_R = \frac{s_R}{R}$; coefficient of variation of the load effect and bearing capacity;

Then the safety factor can be represented by the formula:

$$K_{st} = \frac{(2 + \beta^2 v_R^2)}{2} + \sqrt{(2 + \beta^2 v_R^2)^2 - 4(1 - \beta^2 v_Q^2)} \quad (4)$$

In order to ensure the appropriate confidence interval, it is necessary to change the Student's coefficient, and therefore to reduce the reliability of the tests. To maintain the average strength of concrete corresponding to the class of concrete (B30), it is necessary to reduce the Student's coefficient, which in turn will lead to a decrease in the confidence level. To maintain strength indicators with a confidence interval corresponding to the class of concrete, the reliability of tests is $P = 0.92$, which contradicts the requirements of regulatory documents [19-20].

The studies carried out show that the transition only to non-destructive methods should change the approach to determining the permissible values of mechanical characteristics, taking into account their guaranteed strength. The existing approach to control only by non-destructive methods implies a decrease in the reliability obtained as a result of tests from the reliability indicator $P = 0.92$ to $0.95$, which in turn reduces the safety factors, and hence the reliability indicators of the structures being erected.

It is necessary to be more demanding in choosing a control scheme for the construction process, creating a multi-level quality control system. The solution to this is possible by creating a set of control tests, including both destructive and non-destructive methods. This approach will make it possible to create systems for collecting test information of increased accuracy. It is necessary to improve the accuracy of measuring geometric dimensions, which, as shown above, determine the accuracy of the indirect method for determining strength.

![Figure 2](image_url)

**Figure 2.** A schematic diagram of the triad of reliability of concrete and reinforced concrete structures being erected.
Ensuring the required level of reliability of building structures is achieved by implementing the triad of reliability. Reliability is laid down in the design, provided during the construction process and maintained during operation. A schematic diagram of the formation of the triad of reliability of the structures being erected is shown in fig. 2.

If during the construction process we cannot provide the required confidence interval of measurements, tests, then the whole scheme is violated. It is not possible to ensure the quality of construction and operation, which means that the level of reliability falls with an unpredictable result. Analysis of the causes of the destruction of buildings says that a significant part of building accidents are associated with construction errors, deviations from regulatory documents and low quality of precast concrete elements, which is associated with imperfect quality control, since with the correct organization of quality control, errors must be eliminated in a timely manner, fig. 3. [analysis].

**Figure 3.** The reasons for the destruction of the main types of structures.

### 4. Results and discussion

It is necessary to link the accuracy indicators of the measurement method with the assessment of geometric dimensions during testing and in the process of erecting geotechnical structures. Improving control methods and increasing measurement accuracy will reduce the likelihood of accidents in geotechnical construction. The implementation of practice should be based on the assumption that control methods should reduce instrumental and methodological quality control of materials by increasing the accuracy of control. In the process of assessing the quality of concrete, it is necessary to ensure that the accuracy of measuring the geometric dimensions of standard concrete samples with destructive methods decreases to acceptable values. In this case, the metrological requirements must be observed, which will make it possible to provide tests with methods and measuring instruments.

Metrological assessment allows you to establish the required changes in measurement accuracy. Due to the peculiarities of physical processes, the main share of the error in determining the strength in standard samples is determined by the accuracy of measuring geometric dimensions. The recommended error when increasing the accuracy of geometric measurements should be with an error in measuring geometric dimensions:

\[
- \delta_T^2 = 0.5\% \text{ then } \delta_R = 3.5\%; \\
- \delta_A^2 = 0.25\% \text{ then } \delta_R = 1.7\%
\]

Therefore, to solve the problem of increasing the level of reliability of concrete and reinforced concrete structures, it is necessary to ensure the accuracy of measuring geometric dimensions at the level 0.5%.
Improving the control accuracy is not the only way to achieve the required level of reliability; at the same time, development should go on at all stages of the “life cycle of structures”. In the process of design and production and in the process of operation, it is necessary to implement the following tools for the development of the reliability of construction processes:

– study of the structure and properties of materials to improve the stability of properties using probabilistic methods of calculation and design, implementation of application in design work and methods of acceptance testing of materials;

– improving the quality of the system of inspections and repairs based on the nature and rate of propagation of cracks in the material at the actual level of load.

Improvement of quality control methods, as an important part of ensuring the reliability of structures of buildings and structures being erected, primarily from the point of view of evaluating mechanical properties. The development of construction testing and control methods lead to the expediency of replacing the traditional methods of controlling the strength and deformative properties of concrete with a complex combining high accuracy of destructive with continuous non-destructive testing. The transition to a complex of destructive and non-destructive methods gives a significant effect in terms of quality and labor intensity of control:

1) allows the use of complete control, revealing defective structures and elements that cannot be determined by selective control by destructive methods (for example, due to technology violations, improper transportation of concrete mixture, gravitational stratification);

2) reduces test time and costs for testing, but at the same time continuous non-destructive testing should affect the reliability of the obtained measurement information.

3) provides a high level of control accuracy, while maintaining the confidence interval, which has a positive effect on construction results.

5. Conclusion
Prospects for the development of control methods are associated with the transition to probabilistic design methods and related methods of quality control and assessment of bearing capacity reserves. To improve the culture of production and the quality of work on the construction site and to reduce the impact of critical deviations and defects.

European regulations provide for the need to ensure the reliability of structures throughout the entire product life cycle, due to the interconnection of design, construction, quality control and operation processes. This cannot be solved without creating a system of increased control accuracy in construction, which ensures a high level of reliability of the structures being erected.

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