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NON-DESTRUCTIVE METHODS OF CONCRETE QUALITY CONTROL AS FACTOR IN RELIABILITY OF CONCRETE AND REINFORCED CONCRETE STRUCTURES IN TRANSPORT FACILITIES

Aim: The development of theory and practice of construction science leads to a need to enhance the basics of design, construction and operation of concrete and reinforced concrete structures. Despite significant progress, there is risk of collapse of different structures at various stages of their lifecycle. Current state of construction industry leads to a need to increase the quality and reliability of buildings and structures under construction.

Methods: The authors have used methods of probabilistic forecasting in this work

Results: The development of methods of construction materials control, particularly concrete and reinforced concrete, leads to a gradual implementation of non-destructive control methods. To assess the change of confidence and reliability coefficients of designed structures, the authors have substantiated the transition to probabilistic rationing of strength properties of concrete and reinforced concrete structures using classes. Also, the authors suggest implementation of non-destructive control methods. However, non-destructive control methods have a number of drawbacks, the key among these being the decrease of confidence coefficient while preparing a calibration curve, which drastically affects the results of quality control. It is possible to solve the problem by creating a set of control tests including both destructive and non-destructive quality control methods. This will provide systems for collecting testing information of high accuracy.

***Keywords*:** confidence interval, quality control methods, concrete, reinforced concrete, safety factor, reliability.

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НЕРАЗРУШАЮЩИЕ МЕТОДЫ КОНТРОЛЯ КАЧЕСТВА КАК ФАКТОР НАДЕЖНОСТИ БЕТОННЫХ И ЖЕЛЕЗОБЕТОННЫХ КОНСТРУКЦИЙ В ТРАНСПОРТНЫХ СООРУЖЕНИЯХ

Цель: Развитие теории и практики строительной науки позволяет совершенствовать основы проектирования, строительства и эксплуатации бетонных и железобетонных конструкций. Однако есть опасность разрушения конструкций на разных этапах жизненного цикла. Необходимо повышать качество и надежность возводимых зданий и сооружений.

Методы: В данной работе использованы методы вероятностного прогнозирования.

Результаты: Развитие методов контроля качества строительных материалов, в частности бетона и железобетона, постепенно переходит к неразрушающим методам контроля. Для оценки изменения доверительной вероятности и надежности проектируемых конструкций обоснован переход на вероятностное нормирование прочностных свойств бетонных и железобетонных конструкций с использованием классов и предложен переход на неразрушающие методы контроля. Однако неразрушающие методы контроля имеют ряд недостатков, основной из которых – снижение доверительной вероятности при построении градуировочной кривой, что кардинально влияет на результаты контроля качества. Решить эту проблему можно за счет создания комплекса контрольных испытаний, включающих как разрушающие, так и неразрущающие методы контроля качества. Это позволит организовать сбор испытательной информации повышенной точности.

Ключевые слова: доверительный интервал, методы контроля качества, бетон, железобетон, коэффициент запаса, надежность.

Introduction

The development of theory and practice of construction science leads to necessity to improve basics of design, construction and operation of concrete and reinforced concrete structures. Despite significant progress, there is risk of collapse of structures at various stages of their lifecycle. The literature sources based analysis of the quantity of collapses shows that concrete and reinforced

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concrete structures collapse during their operation. In the fig. 1, the common reasons for destruction of concrete structures are shown [1].

At first stage, the reasons for destructions are mistakes in construction, deviation from normative documents and poor quality of reinforced concrete assembly elements, which is connected with lack of quality control, as at the right quality control organisation all mistakes must be duly eliminated. The principled scheme of the quality control triad of the structures erected is given in the fig. 2 [2].

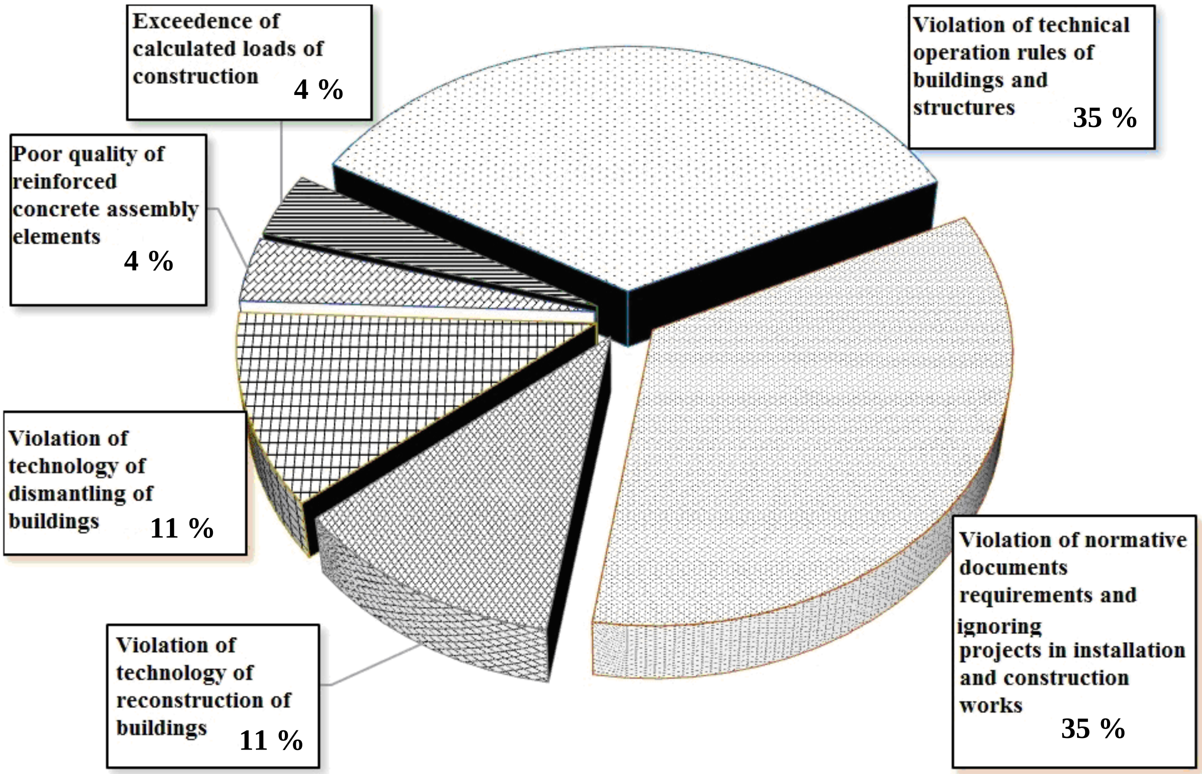

Fig. 1. Reasons for destruction of common types of structures

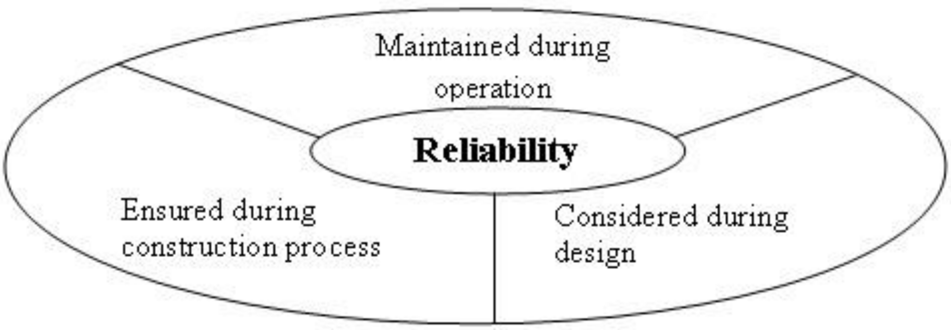

Fig. 2. The principled scheme of the quality control triad of the structures under erection

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Setting the task

To realise this task, one would have to consider joint deformation and crack formation processes in construction materials, which lead to destruction (fig. 3), as well as the real structure of materials, physical and chemical indices and their variability [3].

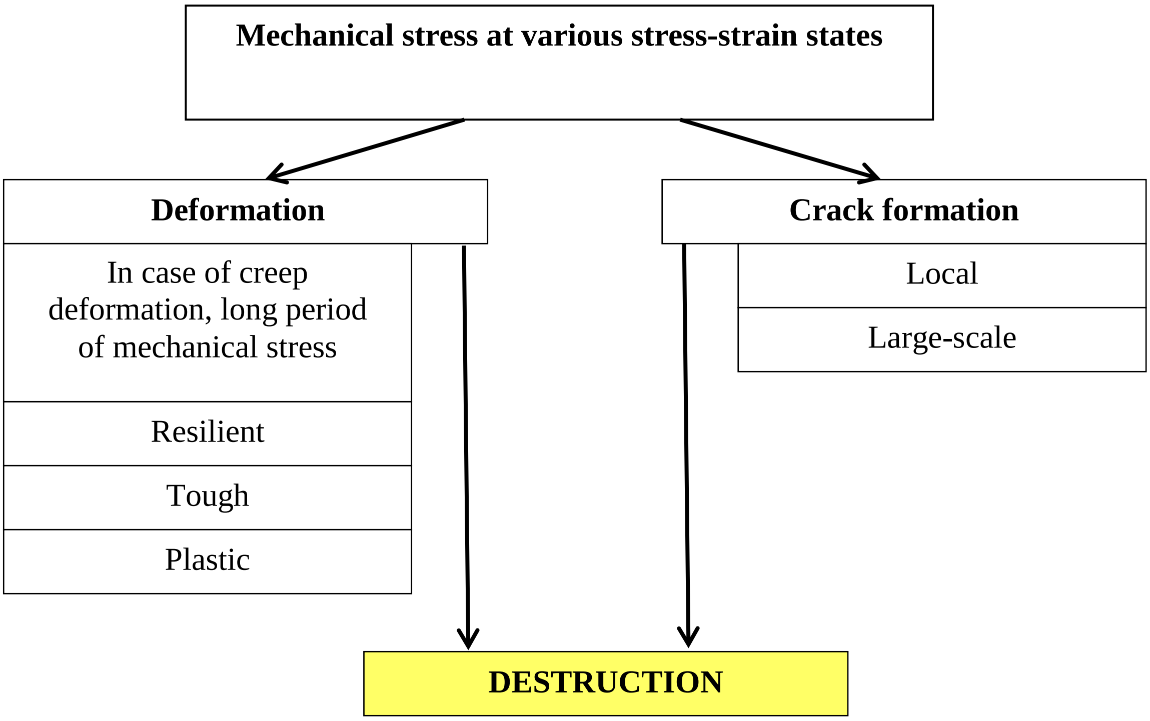

Fig. 3. Scheme of connection between character of deformation and crack formation in composite materials

Assumptions

The destruction of materials takes place due to external impacts, connected with excessive energy: mechanical loads, cyclic freezing and defrosting, chemical reactions and physical processes, etc. After exerting critical amount of energy, the destruction of internal connections of the structural elements of the material. Reliability comprises indices of failure-free operation, durability, repairability, retentivity. One of the defining factors in increase of durability is the principle of mechanical units' control.

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Materials and methods of research

The increase of reliability of structures may be achieved by two ways:

- the first – study of the structure and the properties of materials for enhancing stability of properties with the use of the probabilistic methods and their application in design works and in materials' acceptance test methods;
- the second – increase of quality of inspection and repair systems on the basis of character and speed of crack development in the material under the actual level of load [4].

This results in necessity of improvement of quality control methods, as an important part of ensuring reliability of the buildings and structures erected, primarily in terms of mechanical properties' assessment [5–7]. The development of constructional methods of test and control leads to relevance of substitution of conventional selective destructive control methods of structural behaviour and deformation properties of concrete with all-round non-destructive control. The transition to non-destructive methods allows a substantial effect in terms of quality and labour intensity of control:

- it allows using all-round control, thus detecting defective structures and elements, which cannot be detected by means of selective destructive control methods (e.g. technology violations, improper transportation, gravitational segregation);
- it reduces the time spent for tests and control costs, yet all-round non-destructive control should have influence on reliability of the obtained information.

Let us consider the influence of transition to all-round non-destructive control in erection of concrete and reinforced concrete structures on veracity of the information and reliability of buildings and constructions.

Results

The authors have assessed the influence of the change of confidence of information and reliability on the example of the assessment of concrete grade, which forms a significant amount of safety factor of concrete and reinforced concrete structures. During the assessment, it was assumed that the number of tests was quite significant and was subject to the normal distribution law. The reason for that is quite a large variability of concrete mechanical properties and, primarily, concrete strength. The index of strength is regulated when determining the concrete grade:

$$B = \overline{R}(1 - vt).$$

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For standard and destructive methods, the scheme of test results distribution is given in the fig. 4 (reliability rate is P = 0,95 since the acceptable concrete variability coefficient is 13,5 %, with Student's coefficient making t = 1,64) [8, 9].

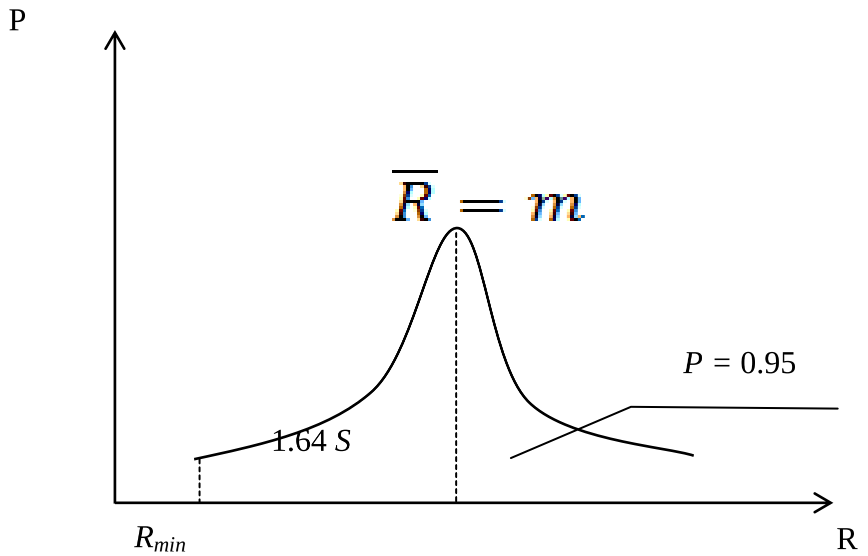

Fig. 4. The relation of basic indices in assessment of strength properties of concrete

Further, the example of application of B30 concrete is given $(\overline{R} = \dfrac{30}{1-1{,}64\cdot 0{,}135} = 36{,}8\ \text{МПа})$. For a sequence of significant number of B30 concrete samples, the minimum acceptable strength index, considering the acceptable variability coefficient 13.5 %, should make no less than:

$$R_{\min} = \overline{R} - 1{,}64S = \overline{R} - 1{,}64\overline{R}v = 36{,}8(1–1{,}64 \cdot 0{,}135) = 30\ \text{МПа}.$$

The variation will make 6.8 MPa whereby the deviation towards the minimum is dangerous for construction and decreases the reliability of structure. With the reduction of strength within acceptable limits, the safety factor of concrete structures also decreases. Practically, on the example of B30 concrete the calculated limit of strength in the first group of limit state will make 17 MPa [8–11].

In normal conditions the calculated safety factor will make S_{factor}= 36,8 / 17 = 2,13. So, on average, the constructions are designed with ample strength which ensures the required level of safety and failure-free operation. Additional-

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ly, reliability is characterised by reliability index and probability of failure-free operation, making [12]:

$$\beta = \frac{\overline{R} - \overline{Q}}{\sqrt{S_R^2 + S_Q^2}},$$

where $\overline{R}, \overline{Q}$ – strength and load effect values;

S_R; S_Q – Squared deviation from the mean (SDM) of strength properties of materials and loads;

The probability of failure is determined by formula [9, 10]

$$P_f = \frac{1}{2} - \Phi(\beta) = \frac{1}{2} - \frac{1}{\sqrt{2\pi}} \int_0^\beta \exp(-\frac{x^2}{2}) dx.$$

The asymptotic formula of probability of failure-free operation is expressed [9]

$$P_f = \frac{1}{\sqrt{2\pi}} \frac{\beta^2 - 1}{\beta^3} \exp(\frac{-\beta^2}{2}),$$

where $\beta = \frac{S_{factor} - 1}{\sqrt{(\nu_R^2 S_{factor} + \nu_Q^2)}}$;

v_R, v_Q – variability coefficient of strength properties of materials and loads.

Discussion of the results

Transition to non-destructive control methods should positively change the situation by means of increasing control points and transitioning to all-round control. In accordance with normative documents, during preparation of calibration curve, the squared deviation from the mean (SDM) is accepted, which equals $S_{НМ}$ = 12 %, except for the separation methods [13]. For separation method with shearing, SDM S = 4 % for 48 mm long anchor and $S_{НМ}$ = 7 % for 20 mm long anchor are accepted [14]. The authors have studied how the additional tolerance of non-destructive methods affects the resulting accuracy of control, hence the reliability of the erected structures with this level of control.

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The increase of SDM leads to reduction of the accuracy of the obtained information, which in its turn leads to enhanced variation of the obtained results of mechanical properties' tests.

To ensure the required confidence interval, one would have to change Student's coefficient, hence to reduce the accuracy of tests. To secure the average strength of concrete, corresponding to the B30 grade of concrete, one would have to reduce Student's coefficient, causing the reduction of confidence probability:

$$tS = t'(S + S_{\text{нм}}),$$

where t и t' – Student's coefficient at the given confidence probability (at standard test $P=0.95$);

S, $S_{\text{нм}}$ – SDM of the standard test during the preparation of calibration curve by means of non-destructive methods.

Then, the results of calculations show that the corresponding coefficient considering SDM will make $t' = 1{,}46$. To secure the strength index with the confidence interval corresponding to the concrete grade, the accuracy of tests makes $P = 0{,}92$, which contradicts the normative documents' requirements [15].

Conclusion

The research carried out shows that transition solely to non-destructive methods should change the approach to determination of acceptable values of mechanical characteristics, considering their guaranteed strength. The existing approach lays decrease of accuracy obtained as a result of the tests from the confidence index $P = 0{,}92$ to $0{,}95$, which in its turn decreases the safety factor, hence the reliability indices of the erected structures. It follows then that it is obligatory to more substantially approach the choice of final inspection of the construction process. The solution to the problem is possible by virtue of establishing a set of control tests, including both destructive and non-destructive methods. This approach will allow creating systems of accumulating high-accuracy test information.

References

1. Accidents of buildings and constructions in the territory of the Russian Federation in 2003. Moscow; 2004. 67 p. (In Russ.)

2. Efremov IV, Rahimova N. Reliability of Technical Systems and Technogenic Risk. Orenburg; 2013. 163 p. (In Russ.)

Библиографический список

1. Аварии зданий и сооружений на территории Российской Федерации в 2003 году. – М.: Центр качества строительства, 2004. – 67с.

2. Ефремов И.В., Рахимова Н.Н. Надежность технических систем и техногенный риск. – Оренбург: ОГУ, 2013. – 163 с.

Received: 29.01.2018. Accepted: 18.03.2018

3. Belencov YuA, Il'inskaya GG, Lesovik VS. *Stroitel'nye materialy*. 2011;3: 90–92. (In Russ.)

3. Беленцов Ю.А., Ильинская Г.Г., Лесовик В.С. Повышение надежности конструкций управлением параметрами композиционного материала // Строит. материалы. – 2011. – № 3. – С. 90–92.

4. Plyuvinazh G. Mechanics of elastic-plastic fracture. Moscow: Mir; 1993. 448p. (In Russ.)

4. Плювинаж Г. Механика упругопластического разрушения. – М.: Мир, 1993. – 448 с.

5. Shtengel' VG. *V mire nerazrushayushchego kontrolya*. 2009;3:56–62. (In Russ.)

5. Штенгель В.Г. О корректном применении НК в обследованиях железобетонных конструкций длительно эксплуатирующихся сооружений // В мире неразрушающего контроля. – 2009. – № 3. – С. 56–62.

6. Ulybin AV. *Inzhenerno-stroitel'nyj zhurnal*. 2011;4(22):10–15. (In Russ.)

6. Улыбин А.В. О выборе методов контроля прочности бетона построенных сооружений // Инженерно-строительный журнал. – 2011. – № 4 (22). – С. 10–15.

7. Ulybin AV, Fedotov SD, Tarasova DS. *Mir stroitel'stva i nedvizhimosti*. 2012;45:2–5. (In Russ.)

7. Улыбин А.В., Федотов С.Д., Тарасова Д.С. Определение прочности бетона при обследовании зданий и сооружений // Мир строительства и недвижимости. – 2012. – № 45. – С. 2–5.

8. SP 63.13330.2012. Concrete and Reinforced Concrete Construction Design Standards. Moscow; 2015. 147 p. (In Russ.)

8. СП 63.13330.2012. Бетонные и железобетонные конструкции: нормы проектирования (введ. 01.01.2013). – М.: Изд-во стандартов, 2015. – 147 с.

9. Rzhanicyn AR. The Theory of Calculation of Building Structures on the Reliability. Moscow: Sroyizdat; 1978. 239 p. (In Russ.)

9. Ржаницын А.Р. Теория расчета строительных конструкций на надежность. – М.: Стройиздат, 1978. – 239 с.

10. Rajzer VD. The Theory of Reliability of Construction. Moscow: ACB; 2010. 384 p. (In Russ.)

10. Райзер В.Д. Теория надежности сооружений. – М.: АСВ, 2010. – 384 с.

11. Rajzer VD. Optimization of structural reliability and safety. (Conf.) “Actualnie problemmi issledovaniy po teorii soorugeniy”. Vol. 1. Moscow; 2009. P. 22–31. (In Russ.)

11. Райзер В.Д. Оптимизация надежности конструкций и безопасности человека // Актуальные проблемы исследований по теории сооружений: сб. науч. ст. конф., Москва. Т. 1. – М.: ЦНИИСК им. Кучеренко, 2009. – С. 22–31.

12. Kazanskaya LF, Grigor'ev DS, Makarov YuV. *Estestvennye i tekhnicheskie nauki*.

12. Казанская Л.Ф., Григорьев Д.С., Макаров Ю.В. Микромеханические свойства

Received: 29.01.2018. Accepted: 18.03.2018

2014;2(70):292–295. (In Russ.)

контактной зоны в бетонах на основе техногенного сырья // Естественные и технические науки. – 2014. – № 2 (70). – С. 292–295.

13. GOST 22690-88. Concretes. Determination of Strength by Mechanical Methods of Nondestructive Testing. Moscow; 2016. 20 p. (In Russ.)

13. ГОСТ 22690-2015. Бетоны. Определение прочности механическими методами неразрушающего контроля (введ. 04.01.2016). – М.: Стандартинформ, 2016. – 20 с.

14. GOST 18105-2010. Concretes. Rules for Strength Monitoring. Moscow; 2013. 16 p. (In Russ.)

14. ГОСТ 18105-2010. Бетоны. Правила контроля и оценки прочности (введ. 09.01.2012). – М.: Стандартинформ, 2013. – 16 с.

15. GOST 27751-2014. Reliability of Building Structures and Foundations. Fundamentals. Moscow; 2015. 16 p. (In Russ.)

15. ГОСТ 27751-2014. Надежность строительных конструкций и оснований. Основные положения (введ. 07.01.2015). – М.: Стандартинформ, 2015. – 16 с.

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