

# Application of non-destructive methods of control within the inspection of concrete structures

*Olga Zabelina\**

Moscow State University of Civil Engineering, 129377, Moscow, Russia

**Abstract.** This paper discusses the main non-destructive quality control methods that are used in the inspection of both under construction and already existing concrete structures. Purpose of the work: to conduct a comparative analysis of non-destructive testing methods, to consider a practical example of their application in the survey of a building being reconstructed, to identify the essential points of the organization of non-destructive quality control, which must be taken into account when developing a site work execution program. Materials and methods: the application of methods of non-destructive testing, separation with spalling and the ultrasonic method of surface sounding, is considered in detail. Results: the results of the inspection of structures by the methods separation with spalling and the ultrasonic method of surface sounding are presented, the test conditions, basic requirements for correct data interpretation, and the necessary calculations are given. Recommendations are given for planning the quality control of concrete structures at the stage of organizational and technological preparation of construction. Conclusions: non-destructive quality control finds its application both in the construction of new facilities and in the inspection of existing buildings. The choice of the survey method is made at the stage of development of a site work execution program, while it is necessary to take into account the features and scope of application of a particular method, probable measurement error, it is also possible to use several methods in combination.

## 1 Introduction

One of the main tasks in construction is to ensure the trouble-free operation of monolithic structures and buildings throughout the entire design period, which largely depends on the quality of concrete work [1, 2]. You also need reliable information about the current state of existing structures, especially after a significant operational period or in case of an accident at the facility. For this, at all stages of construction, production and technological control is carried out, including using non-destructive methods [3, 4, 5]. Non-destructive testing methods have a wide range of application. They are used in the construction of monolithic

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\*Corresponding author: [ZabelinaOB@mgsu.ru](mailto:ZabelinaOB@mgsu.ru)

reinforced concrete structures at construction sites, to prevent and detect rejects of prefabricated elements on production lines at precast factories, when inspecting and examining already existing and under construction objects. Their main task is to determine the strength characteristics of concrete. Such methods can be applied both in the early stages of concrete hardening when assessing stripping strength and during curing, and when monitoring the strength parameters of concrete of the most critical monolithic structures, until they reach the design values. No less important is the role of non-destructive testing in the survey of buildings and structures in operation, especially those operated under dynamic loads, the impact of unfavorable factors, as well as when performing work related to the reconstruction of the object [6].

## **2. Materials and Methods**

The article discusses in detail the practical application of non-destructive testing methods, separation with spalling and the ultrasonic method of surface sounding, and their comparative analysis.

## **3. Results**

The results of the examination of structures by the methods of shearing-off and ultrasonic method of surface sounding are presented, the test conditions, the main requirements for the correct interpretation of the data, the necessary calculations are presented. Recommendations are given for planning quality control of concrete structures at the stage of organizational and technological preparation of construction.

## **4. Discussion**

According to BC 48.13330.2019 "Organization of construction. Updated edition of SNIIP 12-01-2004 "Before the start of the work, organizational and technological documentation is developed, which, among others, should include decisions on construction control, stages, methods and terms of its implementation. Concrete strength control is carried out according to the test results [11]. For this purpose, control samples of material are made or taken from the structure for research [12, 13] or non-destructive control methods are used [14, 15]. Thus, samples of monolithic structures are to be made in situ concreting and store them in the same conditions in which the initial concrete mixture hardens. According to SP 63.13330.2012, in relation to monolithic structures, concrete strength control is carried out mainly by testing samples, that is, by destructive methods. But clause 4.3 of GOST 18105-2010 tells us that testing the strength of concrete of monolithic structures by samples is allowed only in exceptional cases when it is impossible to organize a continuous test using non-destructive methods [16, 17].

The control stages are determined by the age of the concrete. The strength at the design age is a subject to control, as well as the strength at the intermediate age (when removing the load-bearing formwork, when the structures are loaded until they reach the design strength, etc.). When removing the bearing formwork, control is carried out before it is removed. When removing the bearing formwork, control is carried out before it is removed. If the structure is not dismantled, access to concrete is usually difficult, and in this case, control is carried out by testing samples. If there is free access to the upper non-dismantled concrete surface, non-destructive quality control can be applied. At the intermediate age of concrete, the situation is different. The formwork has already been removed and access to the structure is free; therefore, non-destructive testing methods can be used. However,

access to some structures is difficult in principle, for example, a wall in the ground, bored piles, etc., in which case only control samples are used for testing. At the design age (usually 28 days, or another period specified in the project), the structure has already been formed, it is possible that adjacent, demising structures have been built up, which may impede access for non-destructive testing. Then control by samples will also be carried out.

The main parameter controlled in concrete structures is the compressive strength (concrete class). Occasionally, the concrete protective layer or the nature of the reinforcement of structures (the correctness of the spatial position of the reinforcement) is monitored. The actual class of concrete depends on a whole range of parameters, namely: on the average strength of concrete, standard deviation, coefficient of variation, number of unit values of concrete strength, choice of strength control scheme [16]. These parameters are determined for each batch of concrete. Indeed, even if concrete of the same composition, of the same class, from the same supplier is supplied, the average strength can differ significantly, since it is additionally influenced by many factors, namely: transportation time, laying time, quality of concrete mix placement, hardening conditions. At the same time, the concrete strength of the control cubes and the strength of concrete in structures can also differ significantly. When inspecting newly built buildings and structures for a batch of concrete, according to GOST 18105, it is recommended to accept structures concreted within 1-7 days. One construction is taken for one batch of concrete. Monitoring the strength of structures under construction makes it possible to assess the stripping and tempering strength, to compare the actual characteristics of the material with the passport ones. All decisions on quality control, the choice of control methods and the timing of control are drawn up before the start of construction in a site work execution program [18]. The strength control of ready-made concrete structures is carried out according to a predetermined schedule. It can also be carried out as needed, for example, when reconstruction is planned or in case of emergencies at the facility.

Non-destructive methods of concrete control are most effective in cases where the characteristics of concrete and reinforcement are not known in advance, and the scope of control is significant. Non-destructive methods have a wide range of applications; they can be used both in laboratory conditions and directly at the construction sites. Their clear advantages are in maintaining the integrity of the tested structure and its performance characteristics. For a more reliable assessment of the state of concrete structures, a comprehensive analysis is required for all factors affecting the quality of concrete, such as strength, protective layer thickness, reinforcement diameter, thermal conductivity, moisture content, coating adhesion, etc. These characteristics can be determined using non-destructive methods. Non-destructive testing of concrete strength includes various research methods: mechanical (impact, separation, spalling, indentation), acoustic (ultrasonic), magnetic, electromagnetic, electrical, X-ray, radioisotope, using dye penetrant method, radio defectoscopy, infrared defectoscopy, etc.

All methods of non-destructive testing of concrete strength are divided into two main groups:

1. Direct (or methods of local destruction). When using these methods, it is allowed to apply universal grading dependencies, while it is necessary to determine only two parameters: the size of the aggregate and the type of concrete (heavy, light).

Direct methods include:

- rib cleaving method – is to measure the force required to chip the concrete at the corner of the structure. The method is used to study the strength of linear structures: piles, square columns, girders, support beams, lintels. The advantages of this method are high accuracy, ease of use, no preliminary preparation is required. Disadvantages - not applicable if the concrete layer is less than 2 cm or significantly damaged;

- separation with spalling method – consists in assessing the effort required for local destruction of concrete in the process of pulling out the anchor device from it. Advantages - also high accuracy, it is the only non-destructive method of strength control, for which calibration dependences are prescribed in the standards. Disadvantages - laboriousness, which is due to the need to prepare bore holes for the installation of an anchor, the method is not applicable for assessing densely reinforced and thin-walled structures;

- steel disc tearing method – consists in recording the tension required for local destruction of concrete when a metal disk is torn away from it. The method was widely used in Soviet times, now it is almost never used due to temperature regime restrictions. Advantages - the method has a very high accuracy, is suitable for checking the strength of densely reinforced structures, not as time consuming as separation with spalling. Disadvantages - the need for preparation: the discs must be glued to the concrete surface 3-24 hours before testing.

The main advantage of all direct methods is reliability, they give such accurate results that they are used to compile calibration curves for indirect methods. The main disadvantages of methods of local destruction are the high labor intensity, the need to calculate the depth of location the reinforcement, its axis. During tests, the surface of structures is partially damaged, which can affect their performance and appearance.

Indirect. These include shock impulse, elastic rebound, plastic deformation, ultrasound survey.

- shock pulse method - the most common method of testing concrete strength of all non-destructive methods. It consists in registering the energy arising at the moment the striker hits the concrete surface. Instruments for determining the strength of concrete by the shock impulse method are usually compact and easy to use, which ensures their ubiquity. They measure the compressive strength of concrete and the strength class of concrete;

- elastic rebound method – ranks second in applicability among methods of impact on concrete. It consists in measuring the magnitude of the rebound of the striker upon impact with the concrete surface, as a result of which the concrete surface hardness is determined. Sclerometers are used to test concrete by this method. These devices are spring hammers with spherical dies, which are arranged as a system of springs, allowing a free rebound of the striker after impact on concrete or on a steel plate pressed against concrete;

- plastic deformation method - based on measuring the dimensions of the imprint left on the concrete surface after a steel ball collides with it. This method is the simplest and cheapest of all, however, it is considered obsolete and is not recommended for use. The strength of concrete is determined from the ratio of the dimensions of the prints.

- ultrasound method - is the most advanced and safe, consists in recording the speed of passage of ultrasonic waves. Test technology is divided into: through sounding, when the sensors are placed on different sides of the test sample, and surface sounding, when the sensors are located on one side of the research object. The method of through ultrasonic sounding allows you to control the strength not only in the near-surface layers of concrete, but also the strength of the body of the concrete structure. Ultrasonic devices can be used not only to control the strength of concrete, but also to identify hidden, internal structural defects, to control the quality and depth of concreting, to search for reinforcement in concrete. The ultrasonic method makes it possible to test products of any shape repeatedly, in flow, to continuously monitor the increase or decrease in strength. The relationship between the speed of propagation of ultrasound and the compressive strength of concrete is determined in advance for a given concrete composition of concrete. This is due to the fact that the use of 2 calibration dependences for concretes of other compositions can lead to errors in determining the strength, and in some cases the composition of the concrete is completely unknown in advance. The dependence of the strength of concrete on the speed of propagation of ultrasound is influenced by the amount and grain size of the aggregate,

change in cement consumption by more than 30%, method of preparing concrete mixture, degree of compaction of concrete, stress state of concrete. The main disadvantage of this method is the error in the transition from acoustic to strength characteristics. In addition, according to GOST 17624-87, ultrasonic devices cannot be used to control the quality of high-strength concretes [15].

When determining the strength of concrete using non-destructive testing methods, it is impossible to give priority to any one method, all of them have their own advantages, disadvantages and limitations in application [19, 20]. The most significant factor that determines the method and means of measurement and control is the maximum permissible measurement error. Convenience of work, simplicity of results processing are also important. Non-destructive methods are based on indirect characteristics such as a print on concrete; the energy spent on the blow; stress leading to local destruction of concrete. The indirect parameters of non-destructive testing methods are, to varying degrees, influenced by changes in the physical and mechanical properties of the tested concrete. This means that assessments of strength by non-destructive methods will depend not only on the actual strength of concrete (determined by press tests of samples), but also on its other characteristics: elastic modulus, dynamic viscosity, structural heterogeneity, etc. When choosing one or another method of quality control of concrete structures, their comparative efficiency and ease of implementation should be taken into account, as well as the ability to meet the requirements of the daily work schedule.

Let us consider the practice of applying non-destructive testing methods using the example of the survey of a reconstructed three-story building with a mezzanine floor. The building is rectangular in plan with dimensions of 20.42 x 14.46 m (main volume) + 3.23 x 9.25 m (attached staircase). The height of the building from the pavement to the top of the parapet is  $H = 11.82$  m. Floor heights (from the existing floor to the bottom of the floor slabs) - 2.58 m (1-2 floors), 2.88 m (mezzanine of the 2nd floor), 2.73 m (3rd floor). The year of construction has not been established, presumably it's the beginning of the 20th century. Structural scheme of the building - mixed frame: bearing external brick walls and internal monolithic columns; floors and covering - monolithic girderless slabs. Spatial rigidity is provided by the joint work of external and internal walls, columns, as well as hard disks of floor slabs and coverings. The columns of the building are monolithic reinforced concrete with a section of 400 x 400 mm with an irregular pitch of 3.3-4.7 m. Monolithic columns in axes 2 / B, 4 / B are installed on their own foundations of concrete cushions. Monolithic columns in axes 3 / B, 5 / B are installed on the brick walls of the first floor. Columns are reinforced with 8Ø20AIII. Due to the irregular step of the columns established by actual measurements, it was revealed that the monolithic floor slabs between the axes A-B have a span that varies in length. The bearing capacity of monolithic columns is provided for the perception of the actually acting loads. Shrinkage cracks with an opening width of 0.1 mm were revealed along the concrete protective layer of the columns.

Interfloor floor slabs: monolithic slabs 130 ÷ 187 mm thick. Reinforcement of the slabs - steel ropes Ø12, type K-7 with a pitch of 40-100 mm in a plastic pipe Ø20 mm (in spans) and rods Ø10, 12AIII with a pitch of 66-230 mm. Numerous cracks with an opening width of 0.1-0.2 mm were revealed along the protective concrete layer of the lower surface of the slabs due to their deflections. Covering: monolithic slab 172 mm thick. Reinforcement of the slab - steel ropes Ø12 of the K-7 type with a pitch of 40-100 mm in a plastic pipe of Ø20 mm (in spans) and rods Ø10, 12AIII with a pitch of 66-230 mm. Numerous cracks with an opening width of up to 1 mm were revealed in the concrete of the lower surface of the slab due to their deflections.

To determine the physical and mechanical characteristics of structural materials for checking the bearing capacity (checking the strength of concrete and reinforcement of floor

and covering elements), an examination was carried out using instruments with the following non-destructive testing methods:

- ultrasonic method for determining the strength of concrete - 30 areas have been surveyed;
- separation with spalling method - 5 areas;
- magnetic method for determining the thickness of the concrete cover and the location of the reinforcement - 30 areas.

The strength of concrete of the inspected monolithic reinforced concrete structures of columns, floors and coverings was determined by the ultrasonic method of surface sounding in accordance with GOST 17624-2012 "Concrete. Ultrasonic method for determining strength "using the device" PULSAR-1.1" using a universal calibration dependence, tied to specific conditions by parallel testing of the same sections of structures by the ultrasonic method and mechanical non-destructive method of separation with spalling in accordance with GOST 22690-2015 "Concrete. Determination of strength by mechanical methods of non-destructive testing" and MI 2016-03 "Technique for performing measurements during field tests by the anchor pull-out method" using the ONIKS-OS device [14, 21]. The compressive strength class of concrete is determined in accordance with clause 7.5 of GOST 18105-2010 "Concrete. Rules for the control and assessment of strength". The test sites were located on the concrete surface of the structures accessible for testing: for columns - on the side faces, for floor slabs / covering - on the bottom edge. Each site was cleaned of contamination before testing [22, 23]. Then the position of the reinforcement was determined by a non-destructive magnetic method using the "Profoscope+" device. At each test site using the "PULSAR-1.1" device, at least 3 measurements of the ultrasound propagation velocity in two mutually perpendicular directions were made, the average value was recorded in the direction  $V_{i,j}$  (Fig. 1).



**Fig. 1.** Testing of the column by the ultrasonic method of surface sounding using | the "PULSAR-1.1" device

Further, to clarify the universal calibration dependence in individual selected sections (3 sections on columns and 3 sections on structures of floors / roofs), tests were carried out by the separation with spalling method using the “ONIKS-OS” device (Fig. 2).



**Fig. 2.** Performing slab test from a bottom out by the separation with spalling method using the “ONIKS-OS” device

Pullout force  $P_{0,j}$  was recorded during tests and the amount of slip of the anchor was measured  $\Delta h_i$  (fig.3).

When processing test results [24, 25], performed by the method of separation with spalling, strength of concrete on the site  $R_i$  was calculated according to the formula:

$$R_i = m_1 * m_2 * P_{0,i} * \gamma_i \quad (1)$$

where  $m_1 = 1$  – coefficient taking into account the maximum size of coarse aggregate in the tear-out zone (coefficient  $m_1$  accepted for aggregate with particle size less than 50 mm),  $m_2 = 0.9$  – proportionality factor for the transition from pull-out force in kN to strength in MPa (for anchor  $\varnothing 24$  mm, with embedment depth  $h_{emb} = 48$ mm),  $\gamma_i = h_{emb} / (h_{emb} - \Delta h_i)$  – correction factor depending on the depth of the anchor embedment ( $h_{emb} = 48$ mm) and the amount of slippage ( $\Delta h_i$ ) (see table 1).



**Fig. 3.** View of the area after the separation with spalling test.

According to the results of parallel tests of the same sections of structures by the ultrasonic method and the method of separation with spalling, the coincidence coefficient  $K_c$  was determined to clarify the universal calibration dependence (see Table 2). In this case, formula D.1 of Appendix D of GOST 17624-2012 was used:

$$K_c = \frac{\sum_{i=1}^n \frac{R_{s,i}}{R_{usc,i}}}{n} \quad (2)$$

When processing the results of tests performed by the ultrasonic method, the average values of the ultrasound propagation velocity in each section  $V_{m,i}$  were calculated (see Table 3).

Further, using a universal calibration dependence:

$$R_{s,i} = 0.016 \times V_{m,i} - 27.3 \quad (3)$$

taking into account the adjusting coefficient  $K_c = 0.904$  (for columns); 1.038 (for floor / covering structures), the strength of concrete at the site  $R_{s,i}$  was determined (the final determination of the average values of the concrete strength of a group of similar structures was made taking into account the rejection of concrete strength values in the area that differ from the average value by more than 15%).

The actual class of concrete in terms of compressive strength of the examined structures is calculated by the formula:

$$B_{ac,i} = 0,8 \times R_{m,i} \quad (4)$$

subject to the clause "but not more than the minimum particular value of concrete strength in a separate section of the structure".

**Table 1.** A list of the results of determining the strength of concrete of monolithic reinforced concrete columns by the method of separation with spalling using the "ONIKS-OS" device

No. of test site	Location of the test site	Working depth of anchoring device hemb, mm	Measured breakout force $P_{o,i}$ , kN	Slip value of anchor $\Delta h_i$ , mm	Correction factor $\gamma_i$	Aspect ratio $m_2$	Strength of concrete on site $R_i$ , MPa
1	2	3	4	5	6	7	8
10	Column of the 3rd floor in axes B / 2	48	33.49	1.5	1.07	0.9	32.1
30	Column of mezzanine of the 2nd floor in axes B / 4	48	24.24	1.5	1.07	0.9	23.2
40	Column of the mezzanine of the 2nd floor in axes B / 5	48	37.61	0.5	1.02	0.9	34.6

Notes:

1. Concrete design class of tested structures - no data available.
2. The age of concrete structures at the time of testing is more than 28 days. (more than 2 months).
3. The tests were carried out in accordance with GOST 22690-2015.
4. The value of the strength of concrete at the site  $R_i$  (cube compressive strength of concrete) was obtained according to the formula B.1 GOST 22690-2015 (taking into account clause 7.6.3. of GOST 22690-2015).



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|----|---|
| 5. | Aggregate size <50 mm, coefficient taking into account the maximum size of a coarse aggregate in the tear-out zone $m_1 = 1$ based on Appendix B GOST 22690-2015. |
| 6. | The proportionality coefficient is taken equal to $m_2 = 0.9$ based on the table B.1 of GOST 22690-2015.  |
| 7. | Location of test sites is on the diagrams in the technical report.  |

**Table 2.** Correction of the universal calibration dependence "ultrasonic testing speed - concrete strength" used to determine the concrete strength of the inspected monolithic reinforced concrete columns

No. of test site, i	Results of determination of concrete strength by ultrasonic method				Strength of concrete in the area, obtained by the method of separation with spalling $R_i$ , MPa	Coincidence, $K_c$
	The speed of passage of ultrasound in the area $V_{i,j}$ , m / s	Average value of ultrasound transmission in the area $V_{m,i}$ , m / s	Strength of concrete on site $R_{s,i}$ , MPa			
1	2	3	4	5	6	7
10	3768	3760	3764	32.9	32.1	0.904
30	3476	3544	3510	28.9	23.2	
40	4036	4022	4029	37.2	34.6	
Notes:						
The strength of concrete in the area obtained by the ultrasonic method (column 5 of the table) is calculated using the universal calibration dependence shown in Fig. D.1 Appendix GOST 17624-2012.						
Location of test sites on the diagrams in the technical report.						

**Table 3.** List of the results of determining the strength of concrete of monolithic reinforced concrete columns by the ultrasonic method of surface sounding using the "PULSAR -1.1" device

No. of test site, i	Location of the test site	The speed of passage of ultrasound in the area $V_{i,j}$ , m / s		The average value of the speed of passage of ultrasound in the area $V_{m,i}$ , m / s	Strength of concrete on site $R_{s,i}$ , MPa	Average strength of concrete of a group of similar structures, $R_{m,i}$ , MPa	Conditional class of concrete of a group of similar structures $B_i = 0,8 R_{m,i}$ , MPa
		3	4				
1	2	3	4	5	6	7	8
1	Column of the 3rd floor in axes B / 2	3752	3767	3760	29.7	27.2	21.7
2	Column of the 3rd floor in axes B / 3	3518	3566	3542	26.5		
3	Column of the 3rd floor in axes B / 5	3754	3661	3708	28.9		
4	Column of the 3rd floor in axes B / 4	3304	3354	3329	23.5		
9	Column of	3367	3478	3423	24.8	25.4	20.3

	the mezzanine of the 2nd floor in axes B / 2						
10	Column of mezzanine of the 2nd floor in axes B / 4	3535	3494	3515	26.1		
11	Column of the mezzanine of the 2nd floor in axes B / 5	4047	4015	4031	33.6		
25	Column of mezzanine of the 2nd floor in axes B / 3	3434	3468	3451	25.2		
26	Column of the 2nd floor in axes B / 2	3752	3757	3755	29.6	29.8	23.9
27	Column of the 2nd floor in axes B / 3	3782	3787	3785	30.		
Notes:							
<ol style="list-style-type: none"> <li>1. Concrete design class of tested structures - no data available.</li> <li>2. The age of concrete structures at the time of testing is more than 28 days. (more than 2 months).</li> <li>3. The tests were carried out in accordance with GOST 17624-2012.</li> <li>4. When processing the results, a universal calibration dependence was used, shown in Fig. D.1 of Appendix G of GOST 17624-2012, taking into account the clarifying coefficient <math>K_c</math> given in Table. 2.</li> <li>5. Italic font indicate test areas with abnormally low / high values of ultrasound velocity and rejected when determining the average concrete strength of a group of similar structures (the value of concrete strength on a site differs from the average concrete strength of a group of similar structures by more than 15%).</li> <li>6. The locations of the test sites are shown in the diagrams in the technical report.</li> </ol>							

## 5. Conclusions

Inspection of the technical condition of building structures is an important and integral part of the construction process. With the growth of construction volumes, there is a need for the use of high-performance methods of quality control of building structures. It is equally important to conduct surveys during the reconstruction of existing buildings and structures, since during the operation of the facility due to various reasons, physical deterioration of building structures, reduction and loss of their bearing capacity, deformation of both individual elements and the structure as a whole occurs. Therefore, non-destructive methods for controlling the quality of concrete, especially ultrasonic and shock effects, should be continuously developed, improved and introduced into production. Improving the reliability in assessing the strength of concrete is possible through a combination of standardized non-destructive testing methods. Experience in the practical use of a

combination of non-destructive testing methods allows us to recommend it for widespread use in construction industry.

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## References

1. Yu.S. Kunin, V.I. Kotov, L.Kh. Safina, *Decreased building performance due to design errors. Part 1*, Scientific Review **7** 36-40 (2017).
2. Yu.S. Kunin, V.I. Kotov, L.Kh. Safina, *Decreased building performance due to design errors. Part 2*, Scientific Review **7** 45-49 (2017).
3. A.A. Lapidus, R.M. Leus, A.V. Mushkin, *Modern methods of measuring and quality control of reinforced concrete structures at a construction site*, Technology and organization of construction production **3** 17-22 (2013).
4. V.P. Popov, D.V. Popov, *Features of the use of non-destructive methods when organizing quality control of concrete in a construction site conditions*, In the collection: Traditions and innovations in construction and architecture. Construction. Digest of articles. ed. by M.I. Balzannikova, K.S. Galitskova, V.P. Popova; Samara State University of Architecture and Civil Engineering, Samara, 341-344 (2015).
5. V.P. Popov, D.V. Popov, A.Yu. Davidenko, *Features of the application of operational methods of concrete quality control in a construction site conditions*, In the collection: Traditions and innovations in construction and architecture. Construction. Digest of articles. Samara State Technical University. Samara 321-324 (2017).
6. S.A. Butenko, R.V. Demidov, *Application of methods of non-destructive testing of concrete strength in the examination of under construction and existing buildings*, In the collection: Traditions and innovations in construction and architecture. Construction technologies. Digest of articles. Samara State Technical University. Samara 142-145 (2017).
7. *Resolution of the Government of the Russian Federation of February 16, 2008 N 87 (as amended on April 28, 2020) "On the composition of sections of project documentation and requirements for their content"*.
8. O.B. Zabelina, Kharichkova E.V. Consideration of factors affecting the quality of construction products in the organizational and technological preparation of construction // Engineering Bulletin of Don. 2020. No. 5.
9. Zabelina O.B., E.V. Kharichkova, *Influence of qualitative characteristics of production control of construction products on the safety of capital construction facilities* In the collection: DESIGN AND CONSTRUCTION. collection of scientific papers of the 3rd International Scientific and Practical Conference of Young Scientists, Postgraduates, Masters and Bachelors. Southwest State University, Moscow State Machine-Building University 164-167 (2019).
10. A.V. Kamenchukov, I.D. Alekseeva, *Modern methods of concrete quality control*, Far East: problems of development of the architectural and construction complex **1** 37-39 (2017).
11. G.N. Atanesyan, A.M. Slavin, *The choice of the optimal method for non-destructive quality control of concrete in the conditions of winter concreting* In the collection: Scientific trends: questions of exact and technical sciences. collection of scientific

- papers based on the materials of the VI international scientific conference 33-34 (2017).
12. V.P. Popov, T.V. Dormidontova, *Practical organization of instrumental monitoring of load-bearing structures*, Scientific Review **4** 130-133 (2014).
  13. V.M. Vlasov, A.A. Donovan, V.V. Chebotarev, *Assessment of the quality of concrete at the Bureyskaya HPP using non-destructive control methods B.E. Vedeneeva* **277** 63-79 (2015).
  14. N.V. Kovalevskaya, *Assessment of the technical condition of the building structures on the Sotsialisticheskogo Truda street in the city of Salsk, Rostov region* In the collection: INNOVATIONS IN SCIENCE AND PRACTICE. Collection of articles based on the materials of the V international scientific and practical conference. Responsible editor: Khalikov A.R., 116-121 (2018).
  15. A. Mochko, M. Mochko, V.I. Andreev, *Checking the quality of concrete in existing structures. Technologies of European standards Vestnik of MGSU* **14** (8) 967-975 (2019).
  16. D.Yu. Snezhkov, S.N. Leonovich, A.V. Latysh, *Monitoring of reinforced concrete structures under construction based on non-destructive testing of strength parameters of concrete* Bulletin of the Brest State Technical University **1** 102-106 (2014).
  17. S.N. Konoplev, *Again about the dominant method of controlling the strength of concrete in monolithic structures* Concrete Technologies **1-2** 53-55 (2015).
  18. O.B. Zabelina, D.V. Leonov, *Improving the processes of winter concreting of monolithic building structures* Prospects for science **11 (122)** 10-14 (2019).
  19. A.N. Larionov, V.I. Lapin, *Substantiation of organizational and technological solutions for the use of antifreeze additives using heating methods and "thermos"*, Materials of the V-th International scientific-practical conference "Innovative approaches to the development of economy and management in the XXI century." Moscow, RANEP, Sputnik + Publishing House, 53-62 (2019).
  20. J.H. Bungey, S.G. Millard, M.G. Grantham, *Testing of concrete in structures. 4th Edition* (Taylor and Francis, 2006).
  21. V.M. Malhotra, N.J. Carino, *Handbook on nondestructive testing of concrete. Second Edition* (CRC Press, Boca Raton, 2004).
  22. B. Mohammadi, M.R. Nokken, *Influence of moisture content and water absorption in concrete*, Proceedings of 3rd Specialty Conference on Material Engineering & Applied Mechanics, Montreal, Canada, 2013.
  23. H. Thun, U. Ohlsson, L. Elfgren, *Determination of concrete compressive strength with pullout tests*, Structural Concrete **10 (4)** 173-180 (2009). DOI: 10.1680/stco.2009.10.4.173
  24. O.B. Zabelina, D.V. Leonov, *The choice of an effective method for winter concreting of monolithic building structures*, Prospects for science **6 (129)** 67-70 (2019).
  25. A.T. Moczko, N. Carino, C. Petersen, *CAPOTEST to estimate concrete strength in bridges*, ACI Materials Journal **113** (6) 27-836 (2016). DOI: 10.14359/51689242.