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A comprehensive approach to concrete strength testing: combining destructive, non-destructive and wireless sensor methods

Abstract. To assess the condition of the structures of buildings and structures it is necessary to perform a comprehensive analysis of the factors affecting their performance characteristics - concrete strength, thermal conductivity and humidity of concrete, frost resistance, and water resistance. However, with a variety of controllable parameters the control of concrete strength takes a special place because the main factor of structure condition estimation is the correspondence of actual concrete strength to the design requirements. The paper presented the basic methods of concrete strength control which are used while examining the constructions of buildings and structures. The results of the experiments comparing the data obtained by destructive, non-destructive, and alternative methods were investigated. A wireless sensor of concrete strength, produced in Kazakhstan, was used when carrying out the tests with the use of smart technology. And the graphical quantitative-qualitative method "web" used by the authors allowed to determine and identify the features of each method.
Keywords: concrete, strength, samples, test, monitoring.

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1. Introduction

Concrete strength is one of the most frequently monitored parameters during the construction and inspection of reinforced concrete structures. The strength characteristics of concrete determine the reliability and durability of structures. There are many control methods used in practice. To obtain qualitative results from concrete strength testing, it is necessary to thoroughly study the features and order of application of various techniques.

Thus, the authors [1] note the control of concrete strength by combined methods. In-situ tests of concrete of monolithic columns having close terms of strength gain are carried out by non-destructive methods, including the method of tearing off with shear (OMSH-1), ultrasonic pulse method (IPS-MG4), and a combined method. Field tests have shown that in some cases acceptable for practice the accuracy of concrete strength control of the design classes of strength C20/25-C30/45 can be obtained based on standardized test methods without using the procedure of correction of their graduation dependencies.

In the research work [2] the core strength test according to the European standards is presented and the European methods of concrete compressive strength estimation in building constructions are considered. The purpose of this study was to obtain important information about the quality of concrete, the type of aggregate, its granularity, and the structure of concrete and to identify any defects within the structure. One of the most promising nondestructive testing measurements that can be applied to verify the quality of concrete in existing structures appears to be the shear tear-off method, particularly CAPO-TEST. Studies have proven that shear-bar method measurements provide an accurate assessment of the strength directly in the structure.

The authors considered [3] the problems of reliability of concrete strength estimation by non-destructive methods. In the course of the work, the classification of methods of concrete strength estimation has been considered. The advantages and disadvantages of direct and indirect methods of strength estimation have been analyzed. Graduation dependences linking actual compressive strength of concrete and indirect strength characteristics by non-destructive methods which use impact energy and speed of ultrasound as indirect characteristics have been built and corrected. The authors concluded that more reliable results are the data obtained by an ultrasonic non-destructive method using the device Pulsar-1.1. In the research work [4], the analysis and evaluation of methods for determining the strength of concrete for additive technology. The purpose of the study is to substantiate and develop a method for determining the strength of concrete as applied to 3D-printing technology. The authors have proposed and investigated the methods of forming and preparing samples to determine the strength of the cured concrete mixture as applied to additive technology in three ways.

Based on the experimental studies [5], an algorithm for nondestructive control of concrete strength by the parameters of the electrical response to elastic shock excitation has been developed. The research was carried out by means of a laboratory complex, allowing to make pulse mechanical excitation of materials and registration of an electric signal. Impulse mechanical excitation of samples was carried out with the help of an electromechanical shock device, with the normalized force of impact. The studies have shown that the proposed generalized amplitude-independent parameter for nondestructive strength control using the phenomenon of mechanical-electrical transformations gives significantly higher accuracy of strength prediction in comparison with the standard mechanical method. The error of strength determined using the proposed algorithm is 9% for heavy concrete.

2. Methods and materials

This study examines the features of the methods of determining the strength of concrete: the destructive method (press), the non-destructive method (ultrasound device), and the alternative method (sensors maturity). Tests to determine the strength of concrete by the destructive method of the press and the ultrasonic device are conducted in accordance with GOST 28570-90 [6]. This standard regulates the methods of determining the strength of concrete in precast and monolithic concrete and reinforced concrete structures and products, taking samples from structures, and making control samples from these samples. GOST 10180-2012 [7] methods of determining the strength of reference samples are distributed to concretes of all kinds, used in all areas of construction, and established methods for determining the breaking strength of short-term static tests of specially referred concrete samples. Determining the strength of concrete in accordance with this standard consists of measuring the minimum force, destroying the specially made control samples of concrete under their static loading at a constant rate of increase of load, and the subsequent calculation of stress under these conditions.

The test algorithm for the destructive method is presented in Figure 1.

The ability of concrete to effectively resist external influences due to internal stress is directly related to the cement grade and the constituent components of the mortar. When checking the concrete for compliance with the specified grade, the examined sample should be free of deformations, fractures, delamination, and cracks [8].

A great influence on the strength of the concrete being tested, have an external environment in which the pouring and hardening of concrete. The strength is also significantly increased using vibration, which removes air bubbles from the monolith, making it denser [8].

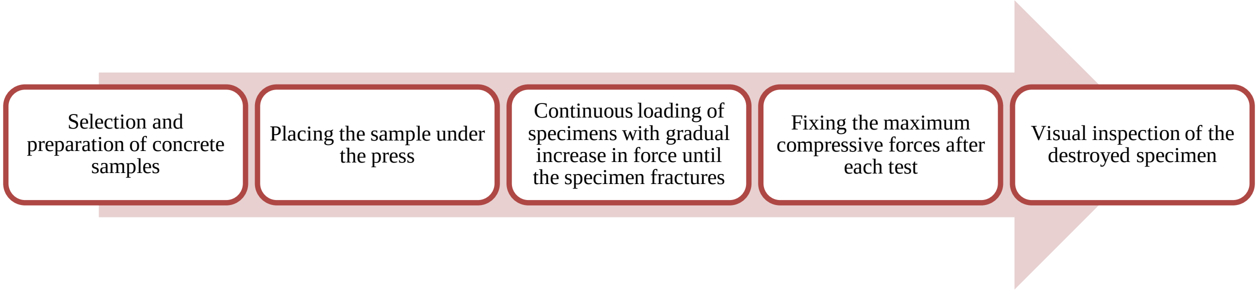

Figure 1. Algorithm of concrete testing with a compression press

In this study, concrete grade M350, cl.C20/25, selected during the pouring of the structure in a special ready-made form (Figure 2) to make a cube sample of size 100x100x100 mm was used. Accordingly, on the 7th and 28th day the test was carried out.

Before testing specimens, a visual inspection for defects was carried out. The specimen was centered on the axis of the press so that the layers of concrete in the cube when hammered were parallel to the lower and upper bed. The compressive strength was then tested by destructive testing under the press starting loading at a constant rate of acceleration until it failed.

a) before the start of the test **b) during the test**

Figure 2. Destructive method

The following test was conducted by a non-destructive method using the IPS device.

The test for the ultrasonic method of determining the strength of concrete is carried out in accordance with GOST 17624-2012[9], which regulates the ultrasonic measurements in concrete by the methods of through or surface sounding.

The test algorithm for determining the strength of concrete by non-destructive method with the ultrasonic device "IPS" is shown in Figure 3.

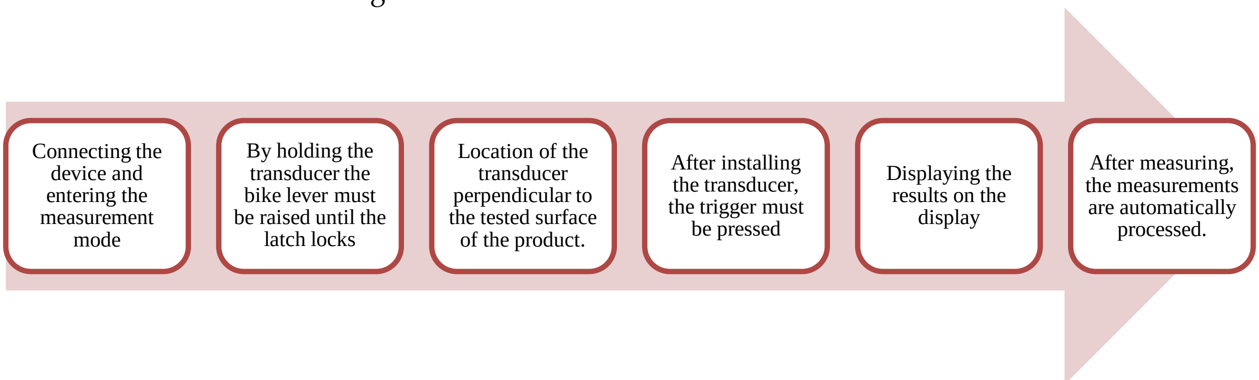

Figure 3. Concrete strength test algorithm with non-destructive method

The test was carried out on 3 cube specimens at 28 days. During the test, the instrument was positioned so that the force was applied perpendicular to the tested surface.

In determining the strength of concrete, the number and location of the controlled areas were taken at least 3 and no more than 15. The distance between the test points (place of impact) was taken at least 15 mm.

When determining the concrete on specimens, the test was carried out on the sides of the specimens, with the specimens clamped in the press with a force of 30 kN. The operation of the device was carried out by bouncing from the surface of the concrete sample, then the results were displayed on the screen of the device. As a unit value of concrete strength was taken as the average strength of concrete, defined as the arithmetic mean value of the strength of concrete in the controlled areas.

Figure 4. Measuring device IPS-MG

And one of the modern methods of determining the strength of concrete is sensors of maturity and strength of concrete. Application and installation of wireless sensors in concretes are applied in the world according to ASTM C1074-98 [10]. This standard provides a procedure for evaluating the strength of concrete using the maturity method. It also requires setting the strength-to-maturity ratio of the concrete mixture in the laboratory and recording the temperature condition of the concrete for which strength is to be evaluated. The algorithm of application and installation of wireless sensors for concrete strength control is shown in Figure 5. In the study, a waterless sensor for monitoring the strength of concrete BDM-1 was used (Figure 6).

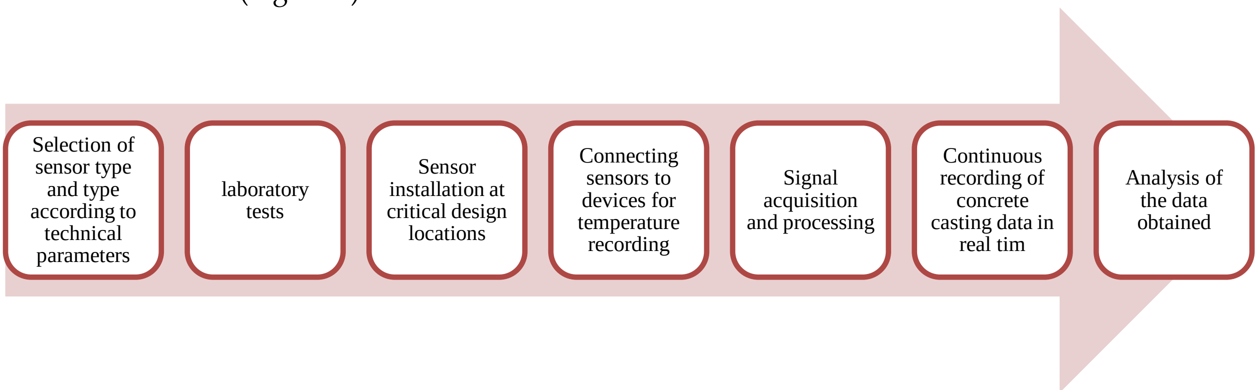

Figure 5. Algorithm of application and installation of concrete strength control sensors

A fully integrated sensor measures the temperature of the concrete in situ and then calculates it into concrete strength data. It then reads the temperature data in real-time and then calculates the strength according to ASTM standard requirements [11].

Figure 6. Wireless Concrete Strength Monitoring Sensor [12]

3. Results and discussion

The results of the tests carried out by destructive, non-destructive, and alternative methods are shown in Table 1.

After testing all specimens, the values are derived, and the design strength of the concrete is calculated that the concrete is fully compliant with the grade M350 (C20/25). The test results of the concrete specimens are recorded in the test report (Table 1).

Table 1. Test report

No.of experience	Class of concrete	Concrete age	Strength parameters,kg/cm²		
			Destructive method (press)	Non-destructive method (IPS)	An alternative method (wireless BDM sensor)
1	B25	28 days	334.4	335	333.4
2	B25	28 days	331.4	331	331.4
3	B25	28 days	330.4	331	330.8

Analysis of the results of experimental studies shows that the values of strength indicators determined by different methods differ from each other by no more than 2%. That confirms the reliability of the obtained results.

Also, the graphical quantitative-qualitative method "web" allowed a multi-criteria comparison of these methods. Two circles were plotted for orientation, a large circle, and a small circle for method evaluation. Radiuses equal to the number of criteria (Table 1) marked with Roman numerals from 1 to 8 were drawn on the circles. For each radius, there is a different jackal and a notation to measure the values of the methods' parameters in percent according to Table 2.

Then each method of strength control was marked with letters, for the destructive method - A, non-destructive method - B, and alternative method - C. In the diagram the control method is marked with lines, the destructive method of strength control is marked with yellow color, the non-destructive method of strength control with red color, alternative method with purple color (Figure 7). The previously mentioned labels of each method (A, B, C) are connected by lines. After entering all the values, an analysis is done on the diagram. According to the area of the connected lines, the quality and convenient method of concrete strength control are determined.

Table 2. Criteria for evaluating concrete test method

Criteria	Method of monitoring concrete strength		
	A	Б	C

		Destructive method	Non-destructive method	An alternative method (sensor)
I	Regulated by standards	100%	100%	70%
II	Accuracy of performance during testing	100%	75%	80%
III	Speed	75%	85%	90%
IV	Availability	100%	100%	50%
V	Automation of device and data processing	55%	85%	100%
VI	Obtaining absolute values that are important for the operation of the product	90%	75%	80%
VII	Direct testing of material samples	95%	60%	90%
VIII	Saving time	75%	85%	90%

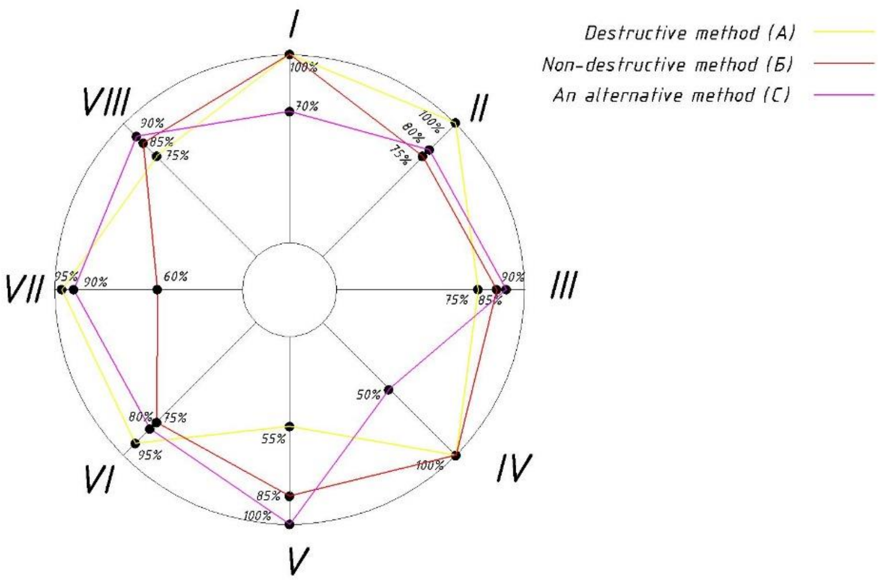

Figure 7. Diagram of assessment by the quantitative-qualitative method "Web"

According to the criteria, the destructive method has the highest percentage of 86.25%, the non-destructive method has 83.125%, and the alternative method has 81.25%. This analysis shows that the results for the selected criteria do not differ from each other by more than 3.3%.

4. Conclusion

When inspecting a building, one of the indicators of its condition is the actual residual strength of its building materials. The strength and deformation characteristics of reinforced concrete will change under load and over time. The quality of concrete and reinforced concrete products and structures largely depends on the efficiency and effectiveness of concrete strength and homogeneity control.

The study identified the best practices of the world, based on which were analyzed techniques and objectives of methods of temperature-strength control of concrete, the requirements of which led to the effectiveness of the results. According to the results of the quantitative-qualitative method analysis, all 3 methods of concrete strength control have their positive and negative qualities.

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Кешенді тәсілмен бетонның беріктігін сынау: бұзу, бұзбау және сымсыз сенсорлық бақылау әдістерінің үйлесуі

Андатпа. Ғимараттар мен құрылыстардың құрылымдарының жай-күйін бағалау үшін олардың өнімділігіне әсер ететін факторлардың - бетонның беріктігін, жылу өткізгіштігін және бетонның ылғалдылығын, аязға төзімділігін және суға төзімділігін кешенді талдау қажет.

Дегенмен, әртүрлі бақыланатын параметрлермен бетонның беріктігін бақылау ерекше орын алады, өйткені конструкциялардың жағдайын бағалаудың негізгі факторы бетонның нақты беріктігінің жобалық талаптарға сәйкестігі болып табылады. Мақалада ғимараттар мен құрылыстардың конструкцияларын тексеруде қолданылатын бетонның беріктігін бақылаудың негізгі әдістері келтірілген. Деструктивті, бүлдірмейтін және альтернативті әдістермен алынған мәліметтерді салыстыру бойынша эксперимент нәтижелері зерттеледі. Интеллектуалды технологияларды қолдану арқылы тестілеу кезінде Қазақстанда шығарылған сымсыз бетон беріктігі датчигі пайдаланылды. Ал авторлар қолданатын графикалық сандық-сапалық әдіс «веб» әр әдістің ерекшеліктерін анықтауға және анықтауға мүмкіндік берді.

Түйін сөздер: бетон, беріктік, үлгілер, сынау, бақылау.

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Комплексный подход к испытанию бетона на прочность: сочетание разрушающего, неразрушающего и беспроводного сенсорного методов

Аннотация. Для оценки состояния конструкций зданий и сооружений необходимо проводить комплексный анализ факторов, влияющих на их эксплуатационные характеристики: прочность бетона, теплопроводность и влажность бетона, морозостойкость и водонепроницаемость. Однако при многообразии контролируемых параметров контроль прочности бетона занимает особое место, так как основным фактором оценки состояния конструкций является соответствие фактической прочности бетона проектным требованиям. В статье представлены основные методы контроля прочности бетона, которые используются при обследовании конструкций зданий и сооружений. Исследованы результаты экспериментов по сопоставлению данных, полученных разрушающими, неразрушающими и альтернативными методами. При проведении испытаний с применением интеллектуальных технологий использовался беспроводной датчик прочности бетона казахстанского производства. А использованный авторами графический количественно-качественный метод «паутина» позволил определить и выявить особенности каждого метода.

Ключевые слова: бетон, прочность, образцы, испытание, мониторинг.

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