Analysis of Quality Control Methods and Equipment for Monolithic Reinforced-Concrete Structures

D Topchiy¹, A Bolotova², A Grebennikov³, M Danilochkin⁴

¹Assistant Professor, Ph.D. Technical Science, Federal State Budget Educational Institution of Higher Education – State University of Civil Engineering (National Research University), Institute of Construction and Architecture, Department of Technologies and Organizations of Construction Production, 129337, Moscow, Yaroslavskoye shosse, 26, Russian Federation
²Ph.D. Technical Science, Federal State Budget Educational Institution of Higher Education – State University of Civil Engineering (National Research University), Institute of Construction and Architecture, Department of Technologies and Organizations of Construction Production, 129337, Moscow, Yaroslavskoye shosse, 26, Russian Federation
³Student, Federal State Budget Educational Institution of Higher Education – State University of Civil Engineering (National Research University), Institute of Construction and Architecture, Department of Technologies and Organizations of Construction Production, 129337, Moscow, Yaroslavskoye shosse, 26, Russian Federation
⁴Student, Federal State Budget Educational Institution of Higher Education – State University of Civil Engineering (National Research University), Institute of Construction and Architecture, Department of Technologies and Organizations of Construction Production, 129337, Moscow, Yaroslavskoye shosse, 26, Russian Federation

E-mail: dvtopchiy0405@gmail.com

Abstract. This article deals with the study of methods and equipment for nondestructive testing of concrete strength and describes the characteristics of ultrasonic devices used for control and determination of concrete mix integrity. Quality control for monolithic reinforced-concrete structures covers a range of issues associated with testing the material strength of structures and determining, if necessary, armoring parameters of reinforced-concrete structures, testing concrete cubes, as well as analyzing design and as-built documentation, drawing up control section diagrams, etc. The article contains a description of quality control equipment and methods for concrete and reinforced-concrete structures and an analysis of the main quality control methods and means. Generalization and systematization of available data lead to a conclusion on the need for development of technical solutions that would prevent potential defects at the initial stage of construction and installations works.
1. Introduction

Construction control includes nondestructive testing methods for detection of discontinuity or impairment of uniformity of material structure, deviations in the chemical composition, as well as for other purposes that do not require destruction of material samples or the product in its entirety. Detection of the most hazardous defects requires inspection of the structure using the following nondestructive testing methods.

Nondestructive testing methods (NMC), or flaw detection, is a generic name for materials (products) that are used to detect violations of the continuity or uniformity of the macrostructure, deviations in the chemical composition, and other purposes that do not require the destruction of samples of the material and/or the product as a whole.

Basic requirements for non-destructive testing methods, or flaw detection:
- ability to control all stages of production, operation and repair of products;
- ability to control product quality for most of the specified parameters;
- consistency of the time spent on monitoring with the operating time of other process equipment;
- high reliability of flaw detection equipment and the possibility of using it in various conditions;
- simplicity of control methods, technical availability of control tools in the conditions of production, repair and operation.

2. Materials and methods

Depending on the principle of operation, all NMCs are divided into acoustic (ultrasonic); capillary; magnetic (or magnetic powder); optical (visually optical); radiation; radio waves; thermal; leak detection control; electric; electromagnetic, or eddy current (eddy current methods).

Acoustic methods are based on recording vibrations that are excited or occur in a controlled object. They are used to detect surface and internal defects (discontinuity, heterogeneity of the structure, intergranular corrosion, bonding, soldering, welding, etc.) in parts and products made of various materials.

They allow you to control the geometric parameters with a one-way tolerance to the product, as well as the physical and mechanical properties of metals and metal products without destroying them. Currently, shadow, resonant, echo-pulse, emission, and free oscillation methods have been developed and successfully applied. These methods are also called ultrasound.

Capillary methods are based on capillary penetration of indicator liquid droplets in the cavities of surface defects. When checking these methods, a penetrating liquid is applied to the cleaned surface of the part, which fills the cavities of surface defects. Then the liquid is removed, and the remaining part in the cavities of defects is detected using a developer, which forms an indicator pattern. Capillary methods are used in field, shop and laboratory conditions, in a wide range of positive and negative temperatures. They allow you to detect thermal and grinding cracks, hairlines, sunsets, etc. Capillary methods can be used to detect defects in parts made of metals and nonmetals of simple and complex shapes.

Magnetic control methods are based on the registration of magnetic scattering fields that occur over defects, or on the determination of the magnetic properties of the controlled products.

These methods allow us to detect defects such as material discontinuities (cracks, hairlines, sunsets), as well as to determine the mechanical characteristics of ferromagnetic steels and cast irons by changing their magnetic characteristics.

Visual optical control methods are based on the interaction of light radiation with the controlled object (CO). According to the nature of the interaction, there are methods of past, reflected, scattered
and induced radiation (the latter refers to the optical radiation of an object under external influence, for example, luminescence) [1].

Informative parameters of these methods are the amplitude, phase, degree of polarization, frequency or frequency spectrum, time of light passing through the object, the geometry of refraction or reflection of radiation. Optical methods are widely used because of the wide variety of ways to obtain primary information about the presence of external defects, regardless of the material of the controlled product.

Radiation monitoring methods are based on the registration and analysis of penetrating ionizing radiation. Using x-rays, gamma radiation, neutrino fluxes etc. Passing through the thickness of the product, penetrating radiation is differently attenuated in defective and defect-free sections and carry information about the internal structure of matter and the presence of defects inside the product. These methods are used to control welded and brazed joints, castings, rolled products, etc.

The effectiveness of an NMC is determined by a large number of factors, the main of which are the detection of defects, productivity, efficiency, safety, and cost [2].

Visual and capillary methods of inspection of products made of ferromagnetic materials allow detecting defects only on the surface of the product. Magnetic and current-vortex methods can detect both surface and subsurface defects. Radiation and acoustic methods can detect surface, subsurface and internal defects.

From the point of view of control automation, eddy current methods, magnetic methods with ferrosonde, induction and similar types of converters, radiation and some types of thermal methods are most favorable.

The main advantages of these methods are the absence of direct contact between the transducer and the product and the provision of information about defects in the form of instrument readings.

The ultrasonic methods from this point of view require contact of the transducer with the product, for example, through a layer of water. The difficulty of automating other control methods is the need for visual processing of information about defects [3].

The quality of the concrete and reinforced concrete products and structures largely depends on the efficient and effective control the strength and homogeneity of concrete, concrete cover and arrangement of reinforcement, the stresses in the reinforcement of prestressed concrete structures.

The strength of concrete can be determined by standard methods by manufacturing and testing samples. However, the accuracy of control of the strength and uniformity of concrete by standard models is inadequate because of several reasons: the amount of testing of standard samples do not exceed 0.01 % of the laid into the concrete structure, terms of vibroforming and modes of hardening of specimens and structures of different, standard methods cannot determine the homogeneity of the concrete in the product and the strength of its individual parts.

For non-destructive testing (NDT) of concrete strength, devices based on methods of local destruction (separation with chipping, chipping of an edge, separation of steel discs), impact on concrete (shock impulse, elastic rebound, plastic deformation) and ultrasonic sounding are used.

When inspecting monolithic structures and large masses of concrete, the use of shock-pulse and ultrasonic devices should be combined with tests of concrete by methods of separation with chipping, chipping of an edge or sampling (cores) [4-5].

When choosing non-destructive testing methods and devices for concrete testing, the user must take into account their features and recommended applications.

Devices based on methods of local destruction are used mainly in monolithic housing construction and in the survey of buildings and structures. The disadvantages of these methods are due to the increased labor intensity and necessity determination of the armature axis and depth of its occurrence, which limits their use in determining the strength of concrete of individual structures or their sections, as well as in clarifying the calibration dependencies of ultrasonic and shock-pulse devices in accordance with State Standart 22690.

Non-destructive testing of concrete strength is performed, as a rule, by high-performance devices after establishing a correlation of their indirect characteristics (basic dependence) with the actual
strength of the controlled concrete. For these purposes, impact devices based on the methods of shock pulse (elastic rebound, plastic deformation) and ultrasonic meters of the speed (time) of propagation of ultrasonic vibrations in concrete are used. When using ultrasonic devices to determine the strength of concrete, it should be borne in mind that the range of controlled strengths is limited to classes B7.5...B35 (10...40 MPa) according to State Standard 17624-87. At higher strengths, only flaw detection of concrete and localization of hidden defects (cracks, sinks, discontinuities) is possible [6].

**Table 1.** Testing methods and means and devices used for measuring these parameters.

| No. | Concrete strength testing method | Device | Testing method | Notes |
|-----|----------------------------------|--------|----------------|-------|
| 1   | core drilling                    | IE 1806, URB-175, URB-300 | STATE STANDART 10180-2012 and STATE STANDART 28570-90 | assessment of concrete internal condition, local destruction of the construction is required |
| 2   | shear test (concrete strength)   | GPNV-5, GPNS-4, GPNS-5, PIB, POS-50, MG4 | STATE STANDART 22690-2015, STATE STANDART 18105-2010 | no partial calibration curve is required no information is obtained about concrete inner structure |
| 3   | structure rib shear test         | GPNV-5, GPNS-4, GPNS-5, PIB, POS-50, MG-2 | STATE STANDART 22690-2015 | |
| 4   | plastic deformations             | Poldi and Schmidt, OMSH-1, C181N, PM-2, Ts-22, Kashkarov hammer, MZ, LISI, etc. | STATE STANDART 22690-2015 | measuring of concrete surface hardness of the construction |
| 5   | rebound hammer                   | Poldi and Schmidt, OMSH-1, C181N, PM-2, Ts-22, Kashkarov hammer, MZ, LISI, etc. | STATE STANDART 22690-2015 | measuring of concrete surface hardness of the construction |
| 6   | ultrasonic                       | Beton-12, Beton-22, UK-144P, UK-10PM, UF-10P, UF-57SK, etc. | STATE STANDART 17624-2012 | testing of strength of surface layers and body of concrete, used in nondestructive testing, concreting quality control, crack depth determination, etc. |
| 7   | shock pulse                      | IPS, MG4.01, VSM, Onyx 2.3 | STATE STANDART 22690-2015 | only the strength of concrete surface layers is determined |
Strength control by shock and ultrasonic methods is carried out in the surface layers of concrete (except for through ultrasonic sounding), in this connection, the state of the surface layer can have a significant impact on the results of the control. In cases where aggressive factors (chemical, thermal or atmospheric) effects the concrete, it is necessary to identify the thickness of the surface layer with a broken structure. Testing methods and means and devices used for measuring these parameters are described in Table 1 [7-8].

There is a great diversity of available nondestructive testing methods for concrete structures [3]. However, in order to obtain the most complete and trustworthy testing results for the strength of massive critical structures, for example, foundation slabs and floors, the most rational and efficient method or a set of methods should be selected. Most of nondestructive testing methods make it possible to determine the strength of surface layers of concrete only, while internal defects in its structure may escape detection [9-10]. An important testing parameter of determining the quality of a reinforced-concrete structure is the degree of concrete mix consolidation at placing. Determination of concrete mix continuity gives an indication of the internal structure of concrete. Inasmuch as all of the above-mentioned devices and methods were designed for the use with hardened concrete, there are a number of restrictions concerning the application of these devices in investigation of the structure of liquid concrete mix. The main parameters worth taking note of first and foremost include the device base, ultrasonic testing performance in various working environments, availability of an oscillograph, type of converters, contact surface, type of scanning, etc. These parameters have been used for assessing the applicability of nondestructive testing methods and devices for determination of concrete consolidation degree in massive bridge structures (see Table 2) [11-12].

Table 2. Characteristics of ultrasonic devices used in concrete continuity testing.

| No | Name         | Exterior (photo) | Working environment (contact) | Gauge length, mm | Time measurement range, µs | Operation temperature |
|----|--------------|------------------|-------------------------------|-----------------|---------------------------|----------------------|
| 1  | Pulsar 1.1   | dry              | surface - 120                | 10…999.9        | from -10 to +40           |
| 2  | Pulsar 2.1/2.2 | dry             | surface - 120                | 10…20,000       | from -10 to +40           |
|   | Device          | Condition | Range            | Temperature Range  |
|---|-----------------|-----------|------------------|--------------------|
| 3 | Pulsar 2.2 DBS  | dry       | 10…20,000        | from -10 to +40    |
| 4 | UK1401M         | dry       | up to 500        | 15…100             | from -20 to +50    |
| 5 | UKS-MG4S        | dry       | surface – 120    | 15…2,000           | from -20 to +40    |
|   |                 |           | pass-through –   |                    |                    |
|   |                 |           | from 70 to 1,200  |                    |                    |
| 6 | Beton-32        | dry       | surface – 120    | 15…9,999.9         | from -10 to +50    |
|   |                 |           |                  |                    |                    |
| 7 | A1220 MONOLITH  | dry       | up to 600        | 150…1,600          | from -20 to +45    |
| 8 | MIRA 1040       | dry       | up to 2,500      |                    | from -10 to +50    |
3. Conclusion
The authors of this article have reviewed and studied various nondestructive testing means and identified the limits for applying each of them [13-14]. As a result, it has been concluded that a correspondence exists between the ultrasound transmission time in a working environment and voids, cavities and other more significant defects that have developed in concrete due to insufficient compacting; however, there is a lack of assessment criteria for continuity of unhardened concrete [15-16]. Regulatory sources don’t offer any express method to determine the continuity of newly laid concrete mix in a reinforcement cage structure. Accordingly, there is a need for development of recommendations that would be instrumental in improving the technological process at the concreting stage and for conducting a scientific experiment of their implementation using ultrasonic nondestructive testing methods for monolithic structure strength. This research also provides for improving the standard design model of construction control schemes for monolithic reinforced-concrete structures [17-18]. It is necessary to develop engineering solutions that would prevent defects and nonconformities at the initial stage of construction and installation works.

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