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APPLICATION OF NON-DESTRUCTIVE TESTING METHODS AND EVALUATION OF CONDITION OF REINFORCED CONCRETE FRAMING

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Abstract

The condition evaluation for reinforced concrete framing requires comprehensive analysis of the factors influencing their performance such as strength, protective layer thickness, rebar diameter, thermal conductivity, humidity, adhesion of coatings, etc. Non-destructive methods are especially relevant when the characteristics of concrete and rebars are unknown and the scope of testing is considerable. Non-destructive testing allows to effectively monitor the conditions of technical devices, structures and buildings and enables to evaluate the timeliness and quality of repair and maintenance of a facility. Non-destructive testing provides the most reliable characteristics of the parameters defining the technical condition of the facilities under test. Non-destructive testing of the structural strength is applied in those areas, which have been exposed to loads due to natural and man-made contingencies.

Keywords: non-destructive testing methods, reinforced concrete framing, buildings and structures, strength, natural and man-made contingencies.

I. Introduction

The reinforced concrete non-destructive testing is a method to obtain the compression strength and other properties of the concrete from existing structures. This test provides immediate results and informs on the actual strength and properties of the concrete framing. The standard method for evaluating the quality of concrete in buildings or structures is in parallel testing the specimens for strength, compression, bending, and tension.

II. Methods

The concrete strength non-destructive test methods are divided in two groups, as shown in Table 1.

Table 1: *Non-destructive test methods*

Direct (local failure methods)	Indirect
Edge chipping	Impact pulse
Shear test	Rebound resilience
Metal disk pullout test	Plastic yield
	Ultrasonic testing

I. Direct concrete test methods (local failure methods)

The local failure tests are tentatively non-destructive. Their basic advantage is veracity. They provide results as much as accurate that they may be used for plotting calibration curves for indirect methods, as shown in Table 2.

Table 2: *Direct concrete test methods*

Method	Description	Advantage	Disadvantages
Shear test method	Evaluation of the effort required to destroy the concrete while pulling out an anchor	- High precision - Commonly applied calibration curves	- Labor-intensive - Unable to be used to evaluate the strength of densely reinforced and thin-walled structures
Edge chipping	Measuring the effort required to chip off concrete on an edge of the structure. The method is used to test the strength of linear structures: piles, square-section columns, support beams	- Simple to use - No preliminary preparation	- Not applicable if the concrete layer is thinner than 2 cm or severely damaged
Disk pullout	Recording the effort to destroy the concrete while pulling out a metal disk. The method was widely used in Soviet time, currently it is hardly ever applied due to the temperature limits	- Suitable to test the strength of densely reinforced structures - Not as labor-intensive as shear test	- Requires preparation: the disks need to be glued onto the concrete surface 3-24 hours before testing

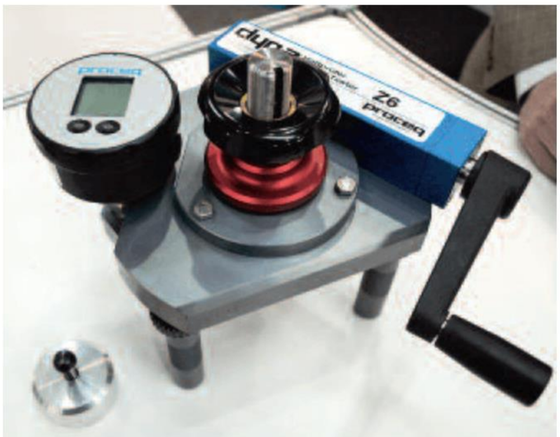
Examples of direct non-destructive test methods

Picture 1: *Shear test method*

Picture 2: *Shear test method*

Picture 3: *Shear test method*

Picture 4: *Edge chipping method*



Picture 5: *Disk pullout method*

II. Indirect concrete test methods

In contrast to local failure methods, the concrete impact pulse methods are more productive. However, the concrete strength is tested in the surface layer 25-30 cm thick, so their applicability is limited. In the said cases, it is necessary to scour the surface of the concrete areas to be tested or to remove the damaged surficial layer, as shown in Table 3.

Table 3: *Indirect concrete test methods*

Method	Description	Advantage	Disadvantages
Impact pulse	Recording the energy generated as a striking block hits. A. Schmidt hammer is used for the studies.	- Compact equipment - Simple and easy - Concrete class can be determined at the same time	Relatively poor accuracy
Rebound resilience	Measuring the striking block path when hitting the concrete. A Schmidt sclerometer and similar devices are used for the studies.	- Simple and fast testing	- Strict requirements to the test area preparations - Equipment requires to be frequently calibrated
Plastic yield	Measuring the imprint left on the concrete upon hitting by a metal ball. Obsolete but still frequently used method. A Kashkarov hammer	- Easy-to-find equipment - Simple and easy	- Low precision of results

Method	Description	Advantage	Disadvantages
	and static pressure devices are used for the evaluation. Kashkarov hammer concrete strength evaluation		
Ultrasonic method	Measuring the oscillation rate of the ultrasound penetrating the concrete	- Possibility to conduct massive inspections for an indefinite number of times - Low cost of the testing - Possibility to evaluate the strength of structural deep layers	- Higher requirements to surface quality - Highly skilled worker is required

Examples of indirect non-destructive test methods

Picture 6: *Impact pulse method*

Picture 7: *Rebound resilience method*

Picture 8: *Ultrasonic method*

Impact pulse method

The impact pulse method is widely used among the non-destructive methods owing to the simple measurements. It allows to determine the concrete class, to measure at different angles to the surface, to consider the plasticity and resilience of concrete.
Essence of the method: A spring actuated spherically tipped striking block hits the surface. The blow energy is consumed for the deformation of the concrete. The plastic strains result in a dimple, while the elastic strain

produces a reactive force. An electromechanical transducer converts the mechanical impact energy into an electric pulse. The results are issued in compression strength units.
The advantages of the method include its promptness, low labor input, no sophisticated calculations, and low dependence on the concrete composition. Its disadvantage is that the strength can only be determined in a layer max 50 mm deep.

Rebound resilience method

The rebound resilience method is leveraged from the metal hardness determination practice. The tests are conducted with sclerometers – spring-loaded hammers with spherical dies. The springs allow the free rebound after the impact. A scale with a pointing needle shows the path of the rebounding tip. The concrete strength is determined by the calibration curves that account for the hammer's position as the rebound magnitude depends on its direction. The average value is calculated by the data of 5 to 10 measurements made on a certain area. The distance between the impact spots is 30 mm or more.
The rebound resilience measuring range is between 5 and 50 MPa. The method's advantages include simplicity and quickness of measurement and the possibility to evaluate the strength of densely reinforced structures. Its key disadvantages are the same as with the other impact methods: surficial strength check (to a depth of 20-30 mm), need for frequent calibrations (every 500 blows) and the plotting of calibration curves.

Plastic yield method

The plastic yield method is known as one of the cheapest. Its essence is the determination of hardness of a surface by measuring the mark left by a steel ball/pin built in a hammer. For the testing, the hammer is oriented perpendicular to the concrete surface and used to make several hits. An angle scale is, then, used to measure the imprints on the striking block and the concrete. In order to facilitate diameter measurements, carbon or white paper sheets are used. The characteristic outputs are recorded and the average value is calculated. The concrete strength is determined by the ratio of sizes of the imprints.
The working principle of the plastic yield testing instruments is based on the die impression by a hit or with static pressure. Static pressure devices have limited use, though; impact instruments are most common: hand-held and spring-loaded hammers, pendulum devices with ball/disk die. The minimum hardness of the die steel is HRC60, the ball's diameter is at least 10 mm, and the disk's thickness is 1 mm or more. The impact energy should be equal to or greater than 125 N.
This method is simple and fast and may be used for densely reinforced structures, but only suitable for evaluating the strength of concrete up to M500.

Ultrasonic testing

The ultrasonic method is the record of the velocity of penetrating ultrasonic waves. The tests technically distinguish point-to-point scanning, when probes are set on different sides of the tested specimen, and surficial scanning, when the probes are set at one side. The point-to-point scanning, contrary to all other strength NDT methods, allows to test the strength in sub-surficial and deep layers of structures.
Ultrasonic instruments for non-destructive concrete testing may be used not only for the concrete strength determination but also for the flaw detection, quality control of concrete casting, determination of depth and search for reinforcement bars in concrete. They allow to conduct multiple massive tests of products of any shape and to continuously monitor the increase or decrease in strength.
The concrete strength vs. ultrasound velocity ratio is subject to the filler amount and composition, cement flow rate, concrete mix preparation and concrete compaction degree. A drawback of the method is the relatively high error at the acoustic-to-strength performance transition.
Apart from the methods listed here, there are some less popular strength test methods. Electric potential method, infrared, vibration and acoustic methods are at their experimental stage of use.

III. Results

Table 4: *Accuracy of concrete non-destructive test methods*

№	Method	Application range, MPa	Measuring accuracy
1	Plastic yield	5…50	± 30... 40%
2	Rebound resilience	5... 50	± 50%
3	Impact pulse	10... 70	± 50%
4	Pullout	5... 60	no data
5	Shear test	5... 100	no data
6	Edge chipping	10... 70	no data
7	Ultrasonic	10... 40	± 30... 50%

The test area requirements are listed in the following table 5:

Table 5: *Test methods*

Method	Total measurements per area	Minimum distance between measuring sports in an area, mm	Minimum structure edge to measuring spot distance, mm	Minimum structure thickness, mm
Rebound resilience	9	30	50	100
Impact pulse	10	15	50	50
Plastic yield	5	30	50	70
Edge chipping	2	200	-0	170
Pullout	1	2x disk diameter	50	50
Shear test at anchor depth: 40 mm < 40 mm	1 2	5h	150	2h

The most challenging cases for testing the concrete framings are when they are exposed to aggressive factors: chemical (salts, acids, oils), thermal (high temperatures, freezing at an early age, varying freezes and thaws), atmospheric (carbonization of the surface layer). During the inspection it is necessary to visually, by tapping or wetting with phenolphthalein solution (cases of concrete carbonization) identify the surface layer with disturbed structure. The concrete of such framings for non-destructive testing is prepared by removing the surface layer at the control area and scouring the surface with a honing stick. In such a case, the strength of concrete should be primarily determined by local failure methods or by sampling. When impact-pulse and ultrasonic devices are used, surface roughness should not exceed Ra 25, as shown in Table 6.

Table 6: *Strength of concrete grades*

Concrete compression strength class (B)	Nearest concrete grade (M) by compression strength	Average strength of concrete of this class, kgf/cm^2	Deviations of the nearest concrete grade from the strength of concrete of this class, %
B3,5	M50	45.84	+9.1
B5	M75	65.48	+14.5
B7,5	M100	98.23	+1.8
B10	M150	130.97	+14.5
B12,5	M150	163.71	-8.4
B15	M200	196.45	+1.8
B20	M250	261.94	-4.6
B22,5	M300	294.68	+1.8
B25	M350	327.42	+6.9
B27,5	M350	360.16	-2.8

Concrete compression strength class (B)	Nearest concrete grade (M) by compression strength	Average strength of concrete of this class, kgf/cm^2	Deviations of the nearest concrete grade from the strength of concrete of this class, %
B30	M400	392.90	+1.8
B35	M450	458.39	-1.8
B40	M500	523.87	-4.6
B45	M600	589	
B50	M650	655	
B55	M700	720	
B60	M800	786	

Non-destructive humidity testing

A certain moisture (up to 30-50% for cellular concrete) dwells in construction materials in the course of manufacturing process (the process moisture). Normally, the moisture content of concrete framings during the first heating period reduces to 4-6% by weight.
In order to obtain the whole picture, it is advisable to proceed with several evaluations with different physical principles. Moisture meters or humidity testers are used to measure the moisture content of concrete. The operating principle of a moisture meter is based on the dependence between the dielectric permittivity of a material and its moisture content. It is important to note that the moisture content of a concrete differs from its content on the surface. The measuring methods on the surface are resultant for a depth down to 20 mm and do not always follow the reality.

IV. Conclusions

Based on the studies performed, we may conclude that the actual strength of concrete framings can be set by various non-destructive methods, as well as the main parameters affecting the quality of products and building structures by modern, high-precision instruments.
In order to check and evaluate the concrete strength, it is advisable to use non-destructive test methods as they are more accessible and inexpensive in comparison with laboratory testing of specimens. The main provision to obtain reliable values is the construction of calibration curves of the instruments. It is also necessary to address any factors leading to distorted measuring results.
Cost-effectiveness can be achieved both during the construction of buildings and structures and in the process of their operation. This is promoted by non-destructive methods of quality testing and evaluation of the materials used.

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