
COMPARATIVE EVALUATION REGARDING THE EFFICIENCY OF THE METHODOLOGIES USED FOR DETERMINING THE COMPRESSIVE STRENGTH OF CONCRETE: STANDARD (DESTRUCTIVE) METHOD VS. NON-DESTRUCTIVE METHOD

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ABSTRACT

Determining the concrete compressive strength is an important issue for both existing and new constructions. Existing constructions, subject to retrofit and / or extension, require the determination of concrete compressive strength in specific elements, for the realistic and correct evaluation of the structure in terms of overall strength and stability. New constructions, on the other hand, may face situations when there are doubts about the quality of the delivered concrete, the casting operations or other technological or design flaws. The correct determination of the actual concrete compressive strength may be essential in evaluating the structural health and identifying the optimum design and technological solutions for the evaluated building. Non-destructive methods for determining the concrete strength are, by definition, minimally invasive methods, namely they do not affect the integrity of the structure. This paper provides a comparison between the combined non-destructive method and the destructive, classical method for compressive strength determination.

Keywords: non-destructive methods; destructive method; quality control; structural health

REZUMAT

Determinarea rezistenței la compresiune a betonului reprezintă un deziderat important atât pentru construcțiile existente, cât și pentru construcțiile noi. Construcțiile existente, supuse unor consolidări și / sau extinderi, necesită determinarea rezistenței la compresiune a anumitor elemente, pentru a putea efectua o evaluare realistă și corectă a structurii din punct de vedere al rezistenței și stabilității. Construcțiile noi, pe de altă parte, se pot confrunta cu situațiile când există dubii cu privire la calitatea betonului livrat, cu modul de punere în operă sau cu alte abateri tehnologice sau de proiectare. Determinarea corectă a rezistenței efective la compresiune a betonului poate fi esențială în evaluarea sănătății structurale și în identificarea și alegerea soluțiilor optime, de proiectare și tehnologice, pentru clădirea evaluată. Metodele nedistructive de determinare a rezistenței betonului sunt, prin definiție, metode minim invazive, în sensul că nu afectează integritatea structurii. Articolul oferă o comparație între metoda nedistructivă combinată și metoda standard, clasică, de determinare a rezistenței la compresiune.

Cuvinte cheie: metode nedistructive; metoda distructivă; controlul calității; sănătate structurală

1. INTRODUCTION

Worldwide concrete structures tend to be the most used types of structures. Concrete is a composite material with good compression behaviour and, because of this, the concrete compression strength is one of the most important properties that should be determined. Ideally, these tests should be conducted in a non-invasive manner, so that

the integrity of the concrete element is not affected. The concrete testing methods cover a wide range of procedures, according to the invasiveness point of view: starting with the completely non-destructive methods, which do not affect at all the investigated elements, continuing with the semi-destructive methods, where the surface of the elements is slightly damaged and ending with the destructive

methods, in which the investigated concrete element needs repairs after the testing procedure.

By using the non-destructive tests, various properties of the concrete can be determined, such as the compressive strength, the surface hardness, the hidden defects of the concrete, the position, diameter and concrete cover of the reinforcement.

For determining the above-mentioned characteristics of concrete and reinforced concrete elements, there are different techniques that can be used, independently or separately, as follows.

1. The first and probably one of the most relevant techniques is the **visual evaluation** (inspection), which can provide valuable information regarding the overall state of the building: cracking state, spalling, deflections, signs of exposed reinforcement and corrosion, possible segregation zones within the elements etc.

Cracks are the result of stresses exceeding the bearing capacity of a concrete element; they can be classified in two categories: structural cracks, produced due to low-quality design or execution, subgrade settlement, etc. and non-structural cracks, generally small opening cracks, inherent in cementitious materials, and generated by drying shrinkage or thermal cracking, etc.

Mapping the cracks and determining their size, nature and cause of appearance represents the first step in understanding and evaluating correctly the general health of a structure. Figure 1 emphasises some examples of structural and non-structural cracks.

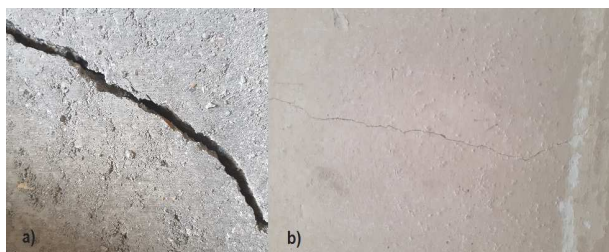


Fig. 1. Example of cracks: a) structural; b) non structural

Segregation is another indicator which should be considered as relevant during a

visual inspection of a building. Most commonly segregation is generated by poor concrete mix design or flawed casting technology (improper vibrating of concrete etc.).

Segregation leads to an element with lower compressive strength and durability issues as well, defective bond to the reinforcement etc., which might not satisfy the requirements for which it was designed. A relevant example of segregation is shown in Figure 2.



Fig. 2. Segregation of concrete in a corner column of a confined masonry structure

Another visual effect that can provide information is the porosity of concrete. To increase the desired workability, often water is added on site in the concrete mix. This affects the water/cement ratio and generates a higher volume of pores: the spaces between the aggregates are filled with water, which later evaporates and creates the pores.

Figure 3 presents an example of porous concrete surface.



Fig. 3. Example of porous concrete surface

2. **The rebound hammer testing** is based on the principle that a mass propelled by a spring develops an impact load on the concrete surface and the corresponding rebound (distance) offers clear information regarding the concrete quality, this represents the rough result of the procedure. The advantages of this method consist in its simple principle, ease of use and low cost and energy. Because this method tests the concrete strength only on a depth of 2-3 centimetres, it cannot be used alone and it must be combined with another non-destructive method or even with a destructive one.

3. **Ultrasonic testing** presumes measuring the time needed for the ultrasonic pulse to cross a concrete section from transmitter to receiver and then calculating the corresponding propagation speed.

Depending on the way the transducers are placed, the following test techniques are distinguished: direct transmission, when the receiver and transmitter are placed on opposite sides, diagonal transmission when the two transducers are placed on adjacent sides, and indirect transmission when the transducers are placed on the same side.

The normative document NP 137-2014 recommends using the direct transmission technique in order to obtain the best result.

The representation of these techniques is shown in Figure 4.

Although this method is recommended to be used in tracking the concrete hardening process during in its initial phases or even for determining the degree of compaction for concrete, it is not capable of providing reliable information regarding elements with high density of reinforcement, unknown concrete mixes or segregated elements.

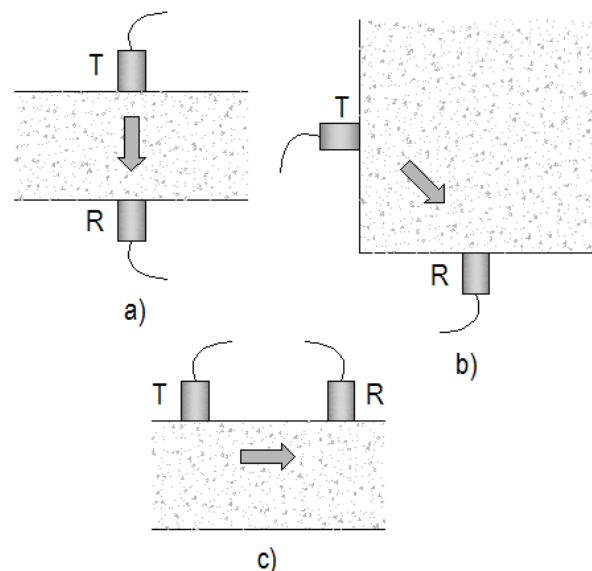


Fig. 4. Techniques of placing the transducers: a) direct; b) adjacent; c) indirect transmission

4. **Radiographic testing** consisting in a beam of X-rays or gamma rays passing through the material and being developed on the other side, on a radiation sensitive film.

5. **Infrared thermography** can determine internal voids or delamination by measuring the time delay before the temperature changes.

6. Using the **eddy current pulse induction** principle a rebar locator can determine the position, diameter and distance from the surface of reinforcements.

7. **The radioisotope testing** implies counting the gamma rays that passes through the concrete and reaches a detector in order to establish the dimensions or density of the concrete.

8. **The drilling resistance method** consists in estimating the concrete strength by counting the time required to drill to a certain depth while the force and the rotation speed are constant. Serkan et al. (2019) showed that estimating the compressive strength via

drilling resistance method proves reliably, especially when it is combined with the rebound hammer testing.

All these techniques measure certain properties that can indirectly provide an estimation regarding the generic compressive strength of the concrete.

Researchers all over the world are investigating new possibilities of combining different techniques in order to improve the reliability of the testing.

The most common combination of non-destructive techniques for estimating the concrete strength is the rebound hammer and the ultrasonic testing; this combination proved along time to be reliable and generates high accuracy of the offered results, especially in the cases with technological errors. Nonetheless, its precision is considered to be around $\pm (15 \div 20) \%$, according to the normative document NP 137-2014.

2. GENERAL OVERVIEW

2.1. Materials used

At the Timișoara Branch of NIRD URBAN-INCERC, ten concrete cubes were preserved in order to determine the concrete compressive strength after years of exposure.

Half of them were casted in one day and are part of the same sample, and the other half, one week later, in June 1989, and are part of a different sample.

The nominal dimensions of the cubes are roughly 140x140x140 mm, in accordance with the norms and standards valid during that period.



Fig. 5. General overview of the two sample groups

Both samples (Figure 5) show traces of degradation due to time wear: broken edges, porous surfaces and small surface cracks

(Figures 6 and 7). This degradation of specimen surface is considered quite normal taking into account the fact that they were preserved in outdoor conditions and, consequently, faced the local climate conditions for the past 30 years.

Using ultrasonic testing, the narrow range of values indicates the fact that the deteriorations are superficial, only on the surface of the specimens. It is assumed that concrete with internal voids or delamination would have presented a larger area of scattered values. To eliminate the error that might occur during destructive testing, the broken edges were repaired with epoxy resin.



Fig. 6. Example of porous and surface cracks



Fig. 7. Example of broken edges

2.2. Testing methods

In order to determine the concrete compressive strength in a non-invasive manner, a combination between the rebound hammer and ultrasonic pulse velocity was chosen for the present evaluation.

The combined non-destructive method was carried out following the normative document NP137-2014, Chapter 8.4, while the destructive method was conducted with respect to SR EN 12390-3/2009, Chapter 6.

The rebound hammer testing was conducted with a device capable of measuring the surface hardness, in this case Proceq DigiSchmidt 2000, shown in Figure 8.

The ultrasonic testing was conducted with a device capable of measuring the velocity of ultrasonic pulses, model Proceq Tico, with transducers with 54 kHz frequency, shown in Figure 9.

The destructive method was conducted with a hydraulic press model Controls Automax 5, which has a 3000 kN compressive capacity and a loading rate of 0.6 MPa/s, presented in Figure 10.



Fig. 10. Controls Automax 5

For the rebound hammer test the concrete cubes were fixed in a press machine with a preload of 10 N/mm^2 , in order to eliminate the vibrations that could be caused by the rebound and to simulate the massiveness of an actual concrete element.



Fig. 8. Proceq DigiSchmidt 2000

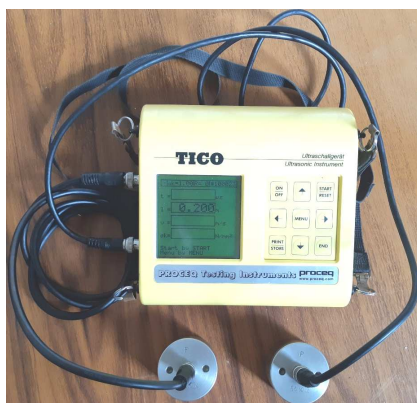


Fig. 9. Proceq Tico



Fig. 11. Concrete cube ready for the rebound hammer test

For the ultrasonic test the transducers were placed on the opposite faces of the cubes and the measurements were performed in three points located as shown in Figure 12. As the

normative recommends, the casting side and the corresponding opposite face are avoided.



Fig. 12. Pattern used for the transducers

3. RESULTS

The purpose of this paper is to offer a preliminary but pertinent analysis regarding the efficiency of non-destructive, much friendlier testing methodologies for concrete, when compared to the much reliable, destructive testing. The evaluation is performed by comparing the two sets of results: I. the non-destructive method results; II. the destructive, compressive testing results (Table 1).

Table 1. Results from the destructive method applied on concrete cubes

Sample name	No.	Compressive strength [N/mm ²]	Mean compressive strength [N/mm ²]
Sample 1	1.1	42.1	51.1
	1.2	51.6	
	1.3	57.4	
	1.4	52.2	
	1.5	52.3	
Sample 2	2.1	45.8	40.3
	2.2	29.5	
	2.3	43.4	
	2.4	45.0	
	2.5	37.9	

Taking into account the concrete usual mix proportions, regularly used in the

INCERC laboratory at the time when the two concrete samples were casted, some correction coefficients were chosen, as follows; the primary information for coefficient estimation is completed by important information, like concrete class, derived from the destructive testing of the specimens (Table 2):

Table 2. Correction coefficients

Coefficients	Notation	Value
Concrete age: more than one year	C_v	0.90
Type of cement: CEM II A	C_c	1.00
River aggregate	C_a	1.00
Maximum size of the aggregate	C_ϕ	
Sample 1: 8 mm		1.09
Sample 2: 31.5 mm		1.00
Cement dosage	C_d	
Sample 1: 376 kg/m ³		1.10
Sample 2: 320 kg/m ³		1.03

The total coefficient of influence was calculated 1.11 for sample 1 and 0.95 for sample 2.

The results for the combined non-destructive method are presented in Table 3.

Table 3. Results from the combine non-destructive method applied on concrete cubes

Sample name	No.	Mean ultrasonic velocity [m/s]	Mean rebound hammer [div]	Mean compressive strength [N/mm ²]
Sample 1	1.1	4295	44	46.1
	1.2	4245	46	
	1.3	4165	44	
	1.4	4356	47	
	1.5	4380	51	
Sample 2	2.1	3830	44	34.3
	2.2	4375	43	
	2.3	4190	45	
	2.4	4100	46	
	2.5	4110	46	

4. CONCLUSIONS

Starting from the generally accepted assumption that the destructive test can be considered the standard, reliable testing method, the combined non-destructive method offers an 85-90% confidence for this particular case, as shown in Figure 13.

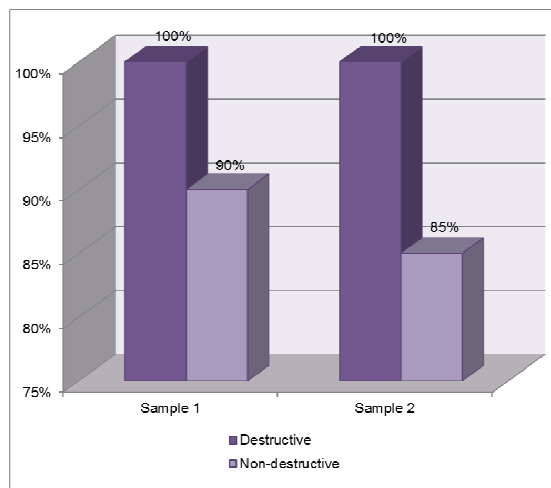


Fig. 13. Percent representation between destructive and non-destructive method

The comparison was performed considering the average concrete compressive strength, derived from the two methods. The combined non-destructive method, performed in accordance to the provisions of the normative document NP 137-2014, uses the minimum compressive strength as a key value for establishing the concrete class. This value is obtained by using the calculation algorithm presented in the above-cited document.

A graphic representation of the mean concrete compressive strength values obtained on the two samples by using both methods is shown in Figure 14.

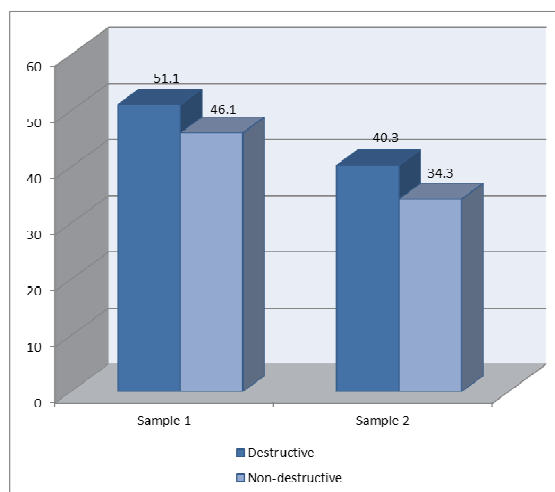


Fig. 14. Representation of the mean concrete compressive strength

The accuracy of the non-destructive method depends on the assumption on the values of the correction coefficients. The

normative document NP 137-2014 stipulates that the precision must be at least 80-85%, if all the necessary elements of the concrete mix are correctly known. Another factor that needs to be taken in consideration, in order to achieve this accuracy, is to follow strictly the surface preparation and testing procedures.

If concrete cores are available, it is expected that the precision be at least as high as 85-90%. On the other hand, in case the concrete mix is unknown and no concrete cores are at disposal, it is expected that the errors reach $\pm (25 \div 35) \%$.

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