METHODOLOGY FOR THE ASSESSMENT OF CONCRETE STRENGTH CHARACTERISTICS BASED ON THE ANALYSIS OF THE CRITICAL POINTS GENERATED BY CONCEALED WORKS

METODOLOGIE DE EVALUARE A CARACTERISTICILOR DE REZISTENȚĂ ALE BETONULUI BAZATĂ PE ANALIZA PUNCTELOR CRITICE GENERATE DE SPECIFICUL LUCRĂRILOR CARE DEVIN ASCUNSE

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This paper presents a methodology for assessing the concrete characteristics starting from the analysis of the critical points generated by concealed works. It presents a new approach to the existing one and is exemplified by an application for assessing the strength of concrete in new constructions. The application of the method is based on the most recent proposals for revision of specific European regulations.

Prezentul articol propune o metodologie de evaluare a caracteristicilor betonului plecând de la analiza punctelor critice generate de specificul lucrărilor care devin ascunse. Se prezintă o nouă abordare față de cea existentă şi se exemplifică printr-o aplicație pentru evaluarea rezistenței betonului din construcțiile nou executate. Aplicarea metodei se bazează pe cele mai recente propuneri de revizuire ale unor reglementări specifice europene.

Keywords: concrete, strength, assessment, methodology, concealed works

1. Introduction

The assessment of the concrete characteristics of the structural elements is a complex process that is a component of the control of the construction works. The approach envisages the differentiation of the quality control [1] depending on the importance of the constructions, the three levels of verification associated with the reliability classes defined in SR EN 1990, Annex B [2] and the type of construction works.

The provisions of the current design regulations, SR EN 1992-1-1 [3], only deal with RC2 reliability classes that meet IL2 for design verification and DSL2 for verification. However, there is no differentiation regarding the verification / evaluation of the characteristics of the concrete used in elements that become later difficult to inspect.

The article presents a methodology proposal that takes this into consideration, as well as the application of in-situ concrete assessment methods according to prEN 13791 [4].

2. Assessment of concrete characteristics according to current regulations

The assessment of the concrete characteristics, taking into account the specificity of this material, can be carried out during the concrete production stage, before casting and in structural elements already executed.

EN 206 [5] shows the minimum sampling frequency for conformity assessment (Table 1).

For continuous production, the evaluation of the compressive strength is performed according to a certain evaluation period and test frequency (the number of results of a concrete plant in a given period). Average strength must meet the following relationship:

$$f_{cm} \geq (f_{ck} + 1.48\sigma)\ N/mm^2 \quad (1)$$

Another verification step is that corresponding to a defined volume of concrete [5]. In this case, the concrete volumes are defined according to criteria related to the areas of a structure in which it is poured or the type and amount of the mixture. The number of samples will be at least three for the volume thus defined.

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Table 1

Minimum sampling frequency for conformity assessment
Frecventa minimă de eşantionare pentru evaluarea conformităţii

Production/*Producţia*	Minimum sampling frequency / *Frecvenţa minimă de eşantionare*		
	The first 50 m^3 of concrete from production/*Primii 50 m^3 de producţie*	From the first 50 m^3 of concrete from production, the highest frequency given by[a]*:/ De la primii 50 m^3 de producţie, frecvenţa cea mai mare dată de*[a]*:*	
		Concrete with production control certification/ *Beton cu certificarea controlului producţiei*	Concrete without certification of production control/ *Beton fără certificarea controlului producţiei*
Initial (until at least 35 results have been obtained) / *Iniţială (până ce au fost obţinute minimum 35 rezultate)*	3 samples/*3 probe*	one sample at every 200 m^3 or a sample in 3 days of production [d]/*o probă la fiecare 200 m^3 sau o probă la 3 zile de producţie*[d]	one sample at every 150 m^3 or one sample per day from production [d]/ o probă la fiecare 150 m^3 sau o probă pe zi de producţie [d]
Continuous[b] (once at least 35 results have been obtained) / *Continuă*[b] *(odată ce au fost obţinute minimum 35 rezultate)*		one sample at every 400 m^3 or a sample in 5 days of production [c, d]/*o probă la fiecare 400 m^3 sau o probă la 5 zile de producţie* [c, d] or a sample within one calendar month/ *sau o probă la o lună calendaristică*	

[a] The sampling should be allocated to the production as a whole and normally not more than one sample per 25 m^3/ *Eşantionarea trebuie repartizată pe ansamblul producţiei şi normal nu trebuie să comporte mai mult de o probă la 25 m^3*

[b] When the calculated standard deviation for the last 15 test results is superior to the s_n limit, according to Table 19 [5], the sampling frequency shall be (brought to) the required frequency for the initial production until the following 35 test results are obtained/ *Când abaterea standard calculată, pentru ultimele 15 rezultate ale încercărilor este superioară limitei sn, în conformitate cu Tabelul 19 [5], frecvenţa de eşantionare trebuie să fie (adusă la) frecvenţa cerută pentru producţia iniţială până la obţinerea următoarelor 35 rezultate de încercări.*

[c] If there are more than 5 production days in seven consecutive calendar days, once per calendar week / *Dacă sunt mai mult de 5 zile de producţie din 7 calendaristice consecutive, o dată pe sătămâna calendaristică/*

[d] The definition of a 'production day' must be indicated in the provisions in force at the place of production of the concrete/ *Definirea unei „zile de producţie" trebuie să fie indicată în dispoziţiile în vigoare la locul de producere a betonului.*

Table 2

Minimum sampling frequency for conformity assessment of cast concrete in a structure
Frecvenţa minimă de etansionare pentru evaluarea conformităţii betonului turnat într-o structură

No./ Nr.	The object verification *Obiectul verificării*	Features or conditions provided *Caracteristicile sau condiţiile prevăzute*	Verification methods *Metode de verificare*	Frequency Verification *Frecvenţa verificării*	Measures in case of non-compliance *Măsuri în cazul neconformităţii*
	Sampling and producing specimens for testing hardened concrete / *Prelevarea probelor şi confectionarea epruvetelor pentru încercări pe beton întărit* a) to check the compressive strength at 28 days (3 cubes or cylinders made from a sample) / *a) pentru verificarea rezistenţei la compresiune la 28 zile (3 cuburi sau cilindri confecţionaţi dintr-o probă)*	SR EN 12390-1		at least one sample for each type of concrete, batch, exchange (day) and, depending on the strength class:/ *cel puţin o probă pentru fiecare tip de beton, lot, schimb (zi) şi, în funcţie de clasa de rezistenţă*: -100 m^3 (≤C16/20) -50 m^3 (>C16/20)	in-situ testing/ *încercări in-situ*

Another important control step is the verification of concrete at casting sites, respecting the complishment conditions regulated in NE012-2 [1]. In this case both the conformity criteria (Table 2) and the concrete volumes from which the samples are extracted are regulated.

Frequency is mainly determined according to the concrete class.

The actual mechanical properties of the concrete put into operation depend, obviously, on the concrete putting into operation (casting, compaction, treatment), the values being obtained, usually, after 28 days.

3. Proposal for methodology for assessment of concrete characteristics

An eloquent example of the need for a new approach is that of concrete in foundations. In this case, if the results of sample tests taken at the concrete plant and / or the casting place indicate the non-realization of the concrete class, the following situations may appear in case of the application of the current norms:

i. The period in which the results are obtained for the characterization of the concrete class is longer, considering the proposed increase of the term in which the concrete class is determined, in case of slow development of the concrete strength [6].

ii. Difficulties in identifying the elements in which the concrete was inadequately poured (for example, in case of isolated foundations under the column) when applying the sampling frequencies of concrete samples currently used.

iii. Technical difficulties and high costs of investigations / in-situ trials.

iv. Costly strengthening when nonconformities are found.

From the description presented in the previous section, two evaluation blocks are distinguished: the evaluation of the concrete characteristics at the concrete plant (I) and on the casting concrete and respectively on the casting concrete and / or the structural element (II).

It is noted, however, that in the case of hidden works, the verification framework shown in Figure 2 [4] can not be applied in the event of non-compliance with the criteria for conformity on the destructively tested samples.

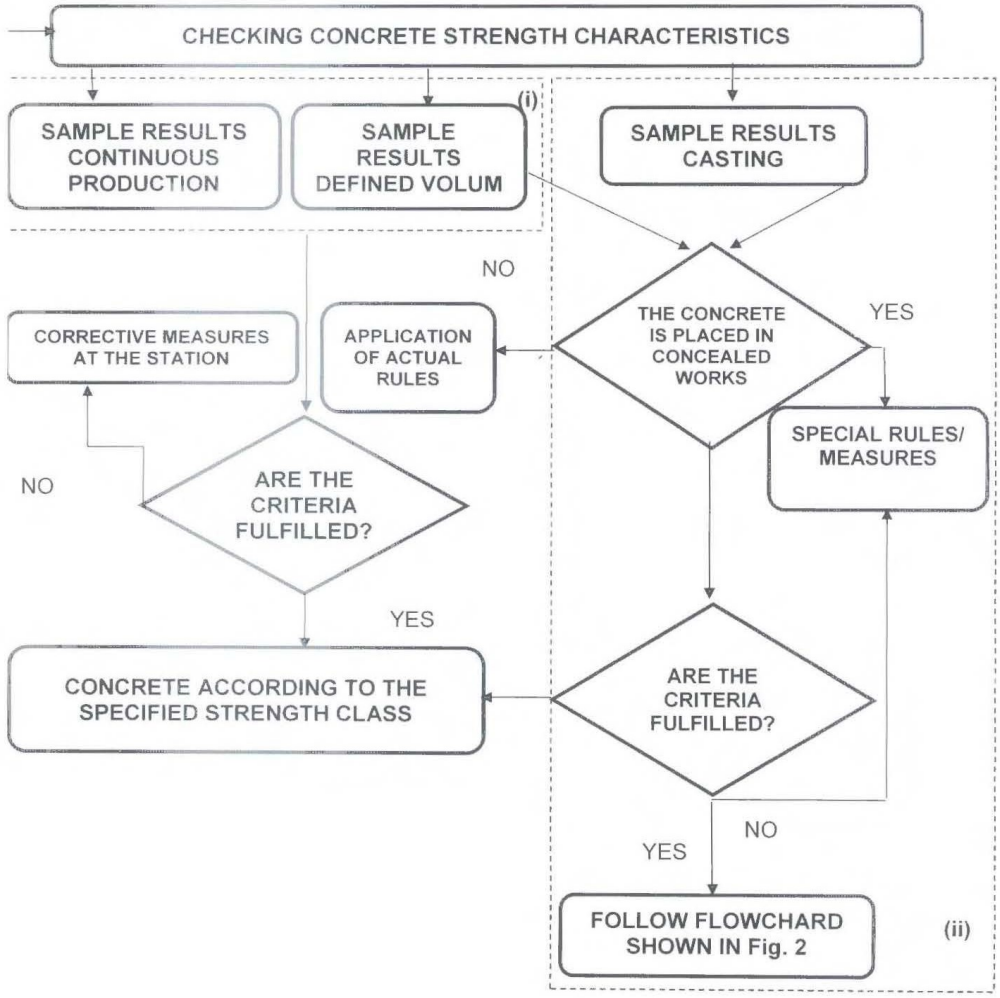

Fig. 1 - Flowchart for the application of the methodology for assessing the strength characteristics of concrete
Schema logică pentru aplicarea metodologiei de evaluare a caracteristicilor de rezistență a betonului.

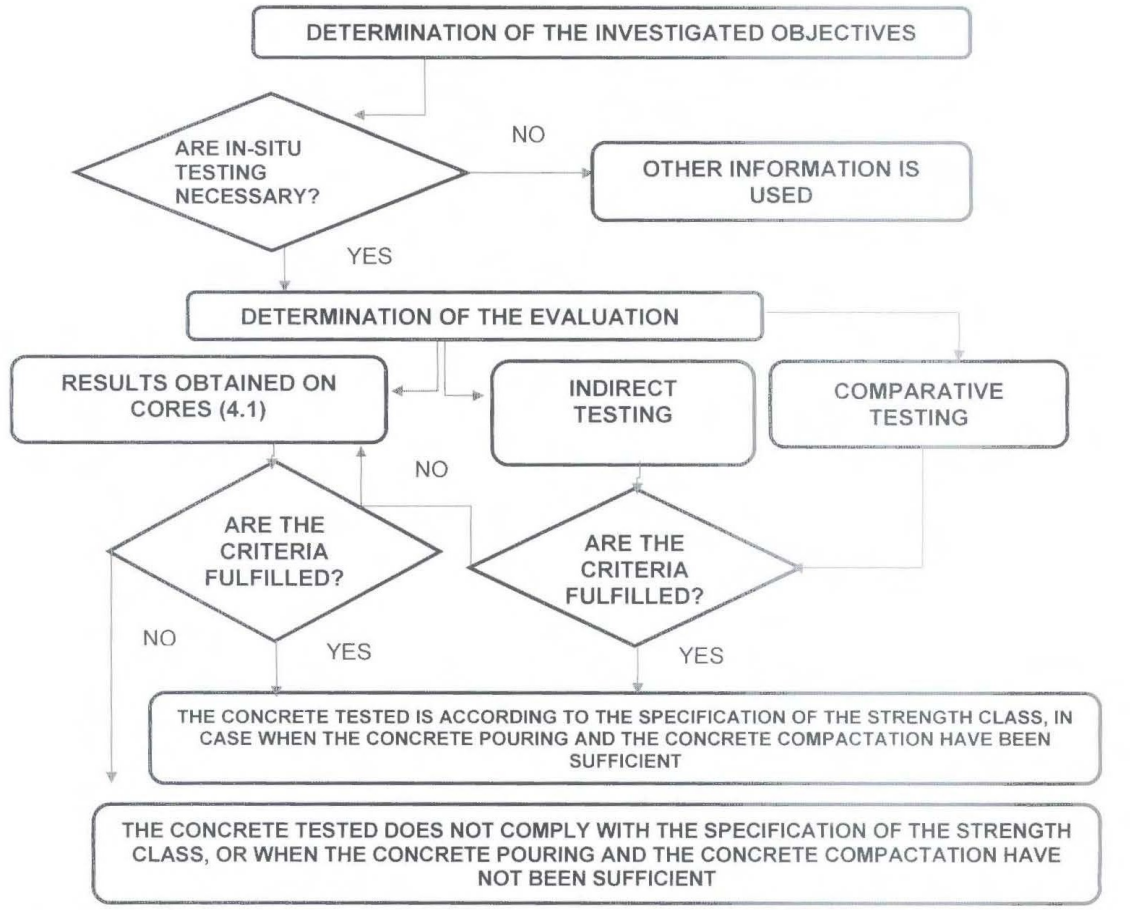

Fig. 2 - Flowchart to determine if the concrete supplied is in accordance with the specification and has been cast and compacted properly
Schema logică pentru a se determina dacă betonul furnizat este conform specificației și dacă a fost pus în operă și compactat corespunzător.

According to the flowchart shown in Figure 1, special measures are required in this case. These measures are taken in view of identifying the critical points given by the specifics of the construction works, for example:

- Concealed works.
- Use of cements that produce a slow development of concrete strength.
- Use of special cements in case of high chemical aggressiveness.
- The possibility of in-situ trials.
- Implications of subsequent interventions.
- Types of structural elements.
- Incorporating construction into consequences classes, etc.

One example is the concrete used in the foundations. In the case of massive elements, the concrete is made with cements that have a slow hardening speed.

According to prEN 1992-1-1 [6], the characteristic resistance will be determined at times ranging from t_{ref} = 28 days and t_{ref} = 91 days. In these cases special measures are possible related to:

- Increase the sampling frequency and number of samples from the one provided in the current norms in order to determine the strength of the concrete for smaller volumes and the evolution of the concrete properties over time. The results will be compared to the results obtained at the concrete plant.
- Classification in reliability classes, respectively verification levels superior to the one in which the construction falls.
- Studying the possibility of differentiating reliability by load coefficients or partial strength coefficients.

In the case of construction elements that have not been sampled at the time of casting the concrete or the results have been inadequate and where in-situ investigation methods can be applied, it is recommended that, in the case of special structures, correlation curves must be determined, for a certain type of concrete. These curves should show the relation between the compressive strength obtained by destructive methods and the results of indirect tests (ultrasonic velocities and / or rebound number). These curves can be used for later checks to assess the strength of the concrete in the structure.

Figure 2 [4] presents a specific compliance verification methodology with the strength class specification.

Table 3

Criteria for assessing the compressive strength class of fresh concrete delivered under the assessment, supervision and certification of production control / *Criterii de evaluare a clasei de rezistență la compresiune a betonului livrat recent sub evaluarea, supravegherea și certificarea controlului producției*

Number of volumes of 30 m^3 / *Număr de volume de 30 m^3*	The minimum number of cores having a diameter between 80 mm and 160 mm for each volume[a]/ *Numărul minim de carote având diametrul între 80 mm - 160 mm pentru fiecare volum[a]*	The average of the results obtained on samples for total volume *Media rezultatelor obținute pe carote pentru volumul total*	The average of the results obtained on samples for each volume [b,c] *Media rezultatelor obținute pe carote pentru fiecare volum [b,c]*
1[d]	3	—	≥0,85 ($f_{ck,\,spec}$ – M)
2 – 4	2	≥0,85 ($f_{ck,\,spec}$ + 1)	≥0,85 ($f_{ck,\,spec}$ – M)
5 – 6	2	≥0,85 ($f_{ck,\,spec}$ + 2)	≥0,85 ($f_{ck,\,spec}$ – M)

[a] When samples are taken with diameters between 50 mm and 80 mm, their number is considered to be in accordance with [4]. *Când sunt prelevate carote cu diametre cuprinse între 50 mm și 80 mm, numărul acestora se consideră în conformitate cu [4].*

[b] *M* = 4 N/mm² classes greater than or equal to C20/25. For C16/20, C12/15 and C8/10, the margin of error *M* is reduced to 4 to 3, 2 and 1 respectively. / *M = 4 N/mm² clase mai mari sau egale cu C20/25. Pentru C16/20, C12/15 și C8/10, marja M se reduce la 4 la 3, 2 și respectiv 1*

[c] The spread of the results should not exceed 15% of the average value. If the investigation justifies rejection of certain results, the final result will be considered as a valid average and result. / *Cu condiția ca răspândirea rezultatelor să nu fie mai mare de 15 % față de valoarea medie. Dacă investigarea justifică respingerea unor rezultate, rezultatul final se va considera ca fiind medie a rezultatelor valabile rămase.*

[d] Supplied in one day / *Furnizat într-o singură zi*

Table 4

Identification Criteria for Compressive Strength / *Criterii de identificare pentru rezistența la compresiune*

Number "n" of the test results for compressive strength from defined volume of concrete / *Numărul " n " al rezultatelor de rezistență la compresiune pentru volumul de beton definit*	Criterion 1	Criterion 2
	Mean of " n " results / *Media a " n " rezultate* f_{cm} N/mm²	All individual test results/ *Toate rezultatele individuale* f_{ci} N/mm²
1	Not applicable/ *Neaplicabil*	≥ f_{ck} - 4
2-4	≥f_{ck} + 1	≥ f_{ck} - 4
5-6	≥ f_{ck} + 2	≥ f_{ck} - 4

The article presents two specific approaches and how to apply them.

4. Applying methods for evaluation of the compressive strength class of the freshly delivered concrete

According to prEN 13791 [4], there are two main methods, one using the results obtained on the concrete samples and the other using indirect tests and concrete samples.

4.1. Using the results obtained on the concrete samples

Table 3 presents the criteria for assessing a class of compressive strength of the freshly delivered concrete.

Example::

- Evaluation of the C 20/25 concrete class of a structural wall with the volume: 10m x 3m x 0.4m = 12 m^3
- According to Table 3 it represents a single volume
- Three cores (aspect ratio of 2:1) of 100 mm diameter were extracted from areas where the application of the rebound numbers indicated the lowest results. By testing the samples in compression, the following results were obtained: 25 N/mm², 20 N/mm² and 21 N/mm².
- The average result is 22 N/mm².
- The average of the results obtained on a sample for each volume must be ≥ 0.85x($f_{ck,\,spec}$ – M) (Table 3).
- Considering the shape of the concrete samples, the characteristic strength is associated with the value given for cylindrical specimens, so for the class C20/25, the characteristic strength is 20 N/mm².
- Thus 22≥0.85x(20 – 4) = 13.6 N/mm² .
- In conclusion, the concrete is the same as the prescribed class.

The relationships in Table 3 relate to the compression resistance identification criteria in Annex B of the EN 206 standard [5]. The identification criteria for compressive strength for a defined volume of concrete are shown in Table 4 [5].

The subunit coefficient of 0.85 is applied considering that the strength reductions that may occur when casting concrete are no longer to be taken into account.

Table 5

Minimum number of test positions in the case of indirect methods for each volume
Numărul minim de poziții de încercare în cazul aplicării metodelor indirecte pentru fiecare volum

Number of volumes / *Numărul de volume*	Minimum number of test positions for each volume *Numărul minim de poziții de încercare pentru fiecare volum*
1 [a]	9
2 – 4	6
5 – 6	5
[a] Supplied in one day / *Livrat într-o zi*	

Table 6

Location of required samples and evaluation criteria[a] / *Localizarea carotelor selectate și criterii de evaluare*[a]

Approximately 30 m^3 of concrete volume *Aproximativ 30 m^3 de volum de beton*	Minimum locations for sampling/ *Minimum de locații pentru prelevare*	Average values of sample resistance[b,c]/ *Valorile medii ale rezistențelor*[b,c]	Minimum values of sample resistance[b,c,d]/ *Valorile minime ale rezistențelor*[b,c,d]
1	A sample from three of the lowest values obtained by applying indirect methods/ *O probă din cele mai reduse rezultate obținute prin aplicarea metodelor indirecte*	—	≥ 0,85 ($f_{ck,\,spec} - M$)
2 – 4	A sample from the area with the lowest value obtained by applying indirect methods and a sample from each 2 test zones having values close to the average of the values obtained by applying the indirect tests *O carotă din zona cu cea mai scăzută valoare obținută prin aplicarea metodelor indirecte și o carotă la fiecare 2 zone de încercare având valori apropiate de media valorilor obținute prin aplicarea testelor indirecte*	≥ 0,85 ($f_{ck,\,spec} + 1$)	≥ 0,85 ($f_{ck,\,spec} - M$)
5 – 6		≥ 0,85 ($f_{ck,\,spec} + 2$)	≥ 0,85 ($f_{ck,\,spec} - M$)

[a] There are no criteria for concrete that is not subject to a production compliance check./ *Nu se prezintă criterii pentru betonul care nu se supune unui control de conformitate al producției.*
[b] If samples are taken having the diameter between 50 mm and 80 mm, the equivalent number shall be determined in accordance with [4]./ *În cazul în care se prelevează carote a căror diametru este cuprins între 50 mm și 80 mm numărul echivalent se determină în conformitate cu [4].*
[c] The strenght of the samples can be expressed as $f_{c,1:1\ core}$ or $f_{c,2:1\ core}$ depending on the selected value of $f_{ck,\,spec}$ /*Rezistența carotelor poate fi exprimată ca $f_{c,1:1\ core}$ sau $f_{c,2:1\ core}$ în funcție de valoarea selectată a $f_{ck,\,spec}$.*
[d] M = 4 N/mm^2 for strength classes greater than or equal to C20/25. For C16/20, C12/15 and C8/10 margin M is reduced from 4 to 3, 2 and 1 respectively / *M = 4 N/mm^2 pentru clase de rezistență mai mari sau egale cu C20/25. Pentru C16/20, C12/15 și C8/10 marja M se reduce de la 4 la 3, 2 și respectiv 1.*

4.2. Indirect tests and samples

Tables 5 and 6 show the conditions for performing indirect tests on samples.

Here is an example of how to apply:

- ♣ It is considered a structural wall with the volume: 12m x 3m x 0.3m = 10.8 m^3
- ♣ The prescribed concrete class is C25/30.
- ♣ According to Table 3 it represents a single volume but the verification is done also for the average value.
- ♣ The results recorded by applying the rebound number method are shown in Figure 3.
- ♣ Figure 3 shows that for the zones 2, 4 and 6, the rebound number values are less than 38, so samples were taken from these positions and compared with in-situ minimal strength.
- ♣ For the assessment of the in-situ average strength, the samples were taken from zones 1, 5 and 8 (closest to the average of all the results, 39.7).
- ♣ Since in-situ strength will be expressed as the strength obtained on cubes, samples were drawn having an 1:1 aspect ratio. Strength values are shown in Figure 4.
- ♣ The evaluation criteria are:
  - Average of cube strength ≥ 0.85x(30 + 1) = 26.4 N/mm^2 .
  - The lowest cube strength ≥ 0.85x(30 - 4) = 22.1 N/mm^2 .
- ♣ Strength of samples taken from test positions 2, 4 and 6 meets the criterion, being greater than 22.1 N/mm^2.
- ♣ The average strength of the samples extracted from zones 1, 5 and 8 is 30 N/mm^2 and meets the average strength criterion.
- ♣ The concrete class in the zone corresponds to the specified concrete class.

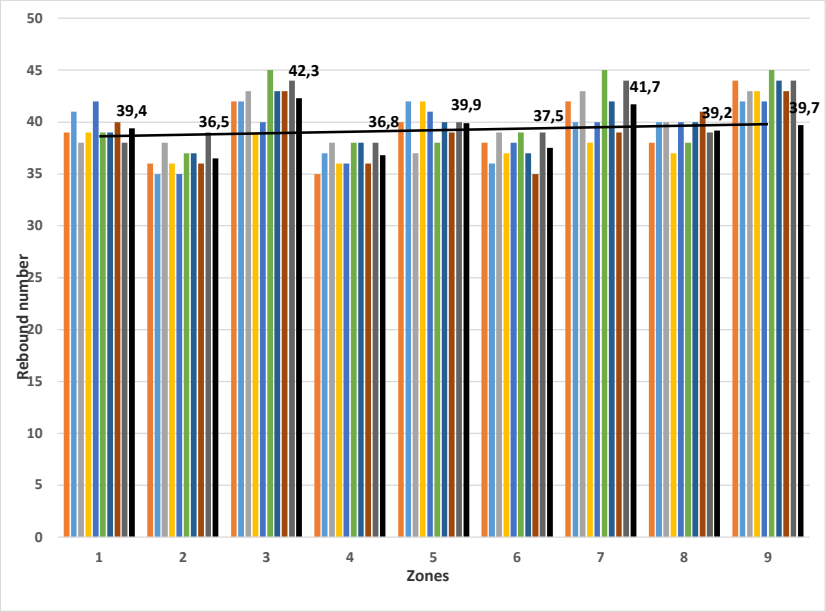

Fig. 3 - Results recorded using the rebound number method / *Rezultate înregistrate prin aplicarea metodei indicilor de recul.*

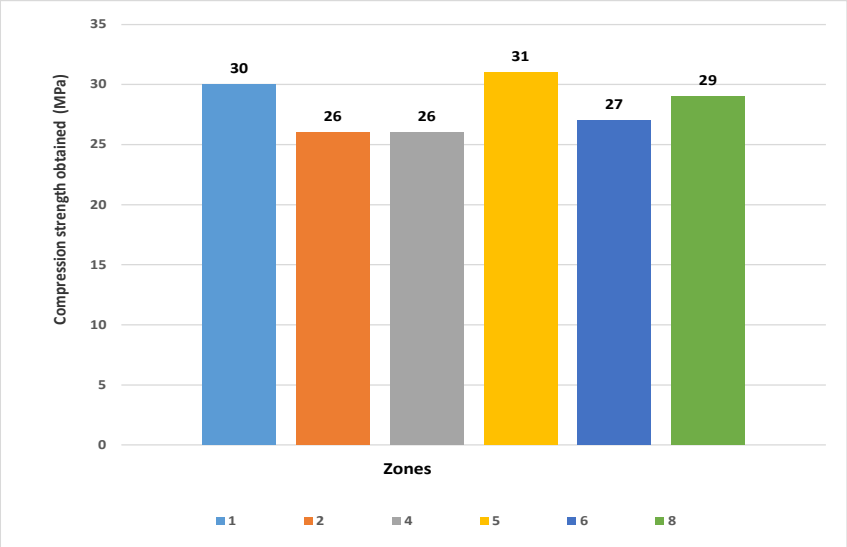

Fig. 4 - Compression strength values obtained by core testing / *Valorile rezistențelor la compresiune obținute prin încercarea carotelor.*

5. Conclusions

1. The article presents a new approach to the assessment of concrete characteristics, based on the analysis of the specifics of concrete works, including the concealed works. The approach starts from the analysis of the current Romanian regulations, as well as the proposed revisions for the European regulations specific to the reinforced concrete works.

2. The analysis of the steps to verify the concrete strength characteristics has led to a proposal to improve the current system, especially in the case of concealed works and to which, in general, no further control can be made. The article proposed specific measures to be taken in these cases.

3. The article also integrates into the proposed methodology, examples of application of in-situ verification of strength characteristics based on proposals to revise the European Concrete Assessment Standard in existing structures.

4. The evaluation of the concrete strength characteristics is an essential part of the control of the reinforced concrete works and the developments in the field, reflected at the level of the proposals for revision of the European regulations. Such changes must be found as soon as possible in the structure of the specific Romanian normative documents.

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