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COMPRESSION STRENGTHS CORRESPONDENCE OF CONCRETES ACCORDING TO THEIR CLASSES AND MARKS

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Abstract. The article presents the problems related to the application of the provisions of the new European standards EN for concrete production, after the withdrawal of the obsolete national standards GOST regarding the correspondence of the classes to the concrete marks. In the context of the application of harmonized standards, there has been a need to establish the correspondence of classes to concrete marks, in order to help design and construction companies to correctly establish the strength mark of concrete to the corresponding class of concrete. The concrete class establishes the normative resistance of concrete for the calculation of constructions, for the service limit state, the prismatic resistance to compression adopted as normative resistance. The ratio between concrete classes and marks, in terms of compressive strength, is determined by the normative coefficient of variation V = 13.5%. The degree of homogeneity of the quality of the concrete is determined according to the values of the standard deviation σ and the average compressive strength of the concrete. As a result of the research, intermediate classes of concrete have been identified, which are not indicated in the normative documents, related to the production of concrete.

Keywords: *basic parameters, coefficient of variation*, *compliance criteria*, *concrete class*, *concrete mark*, *compression strength*, *correspondence, medium values*, *standard deviation*.

Rezumat. Articolul analizează problemele legate de aplicarea prevederilor noilor standarde europene EN pentru producția de beton, după retragerea standardelor naționale învechite (GOST) privind corespondența claselor cu mărcile de beton. În contextul aplicării standardelor armonizate a apărut necesitatea stabilirii corespondenței claselor cu mărcile din beton, pentru a ajuta firmele de proiectare și construcții să stabilească corect marca de rezistență a betonului la clasa corespunzătoare de beton. Clasa de beton stabilește rezistența normativă a betonului pentru calculul construcțiilor, pentru starea limită de serviciu, rezistența prismatică la compresiune adoptată ca rezistență normativă. Raportul dintre clasele și mărcile de beton, în ceea ce privește rezistența la compresiune, este determinat de coeficientul normativ de variație V = 13,5%. Gradul de omogenitate al calității betonului se determină în funcție de valorile abaterii standard σ și rezistența medie la compresiune a betonului. În urma cercetărilor au fost identificate clase intermediare de beton, care nu sunt indicate în documentele normative, legate de producția de beton.

Cuvinte cheie: *parametri de bază, coeficient de variație, criterii de conformitate, clasa betonului, marca betonului, rezistență la compresiune, corespondență, valori medii, abatere standard.*

Introduction

This article deals with issues related to the application of new European standards for concrete production, following the cancellation of obsolete national standards, regarding the correspondence of concrete classes to marks. The fields of design and construction are strictly regulated by provisions regarding concrete and reinforced concrete constructions, through normative documents and standards, in which the class and mark of concrete are very important.

The ratio between the class and the mark of concrete determines the engineering calculations for the production and construction of concrete elements, in which, as basic parameters are taken the data of laboratory tests on strength, using a concrete cube or cylinder of certain dimensions. The notion of "concrete class" is necessary for establishing the normative strength of concrete when calculating constructions at the service limit state, ie the prismatic compressive strength, adopted as normative strength.

The class according to SM EN 206 [1] and the mark according to GOST 26633-91 [2] characterize the strength of the concrete, but when designing the composition of the concrete mixture, the frost-thaw resistance (F), the impermeability of concrete to water (W) and other indicators must also be taken into account considering the individual characteristics of construction projects.

The strength of concrete depends on the ratio between water and cement (W/C), where the proportions W/C = 0.3 ÷ 0.5 are considered an ideal composition. If the ratio is lower - the concrete loses its plasticity, if the proportion of water increases - the resistance decreases, but the plasticity of the mixture becomes higher.

The compressive strength class according to SM EN 206 [1] is denoted by "C" being expressed in N/mm^2, and the compression strength mark according to GOST 26633-91 [2] is denoted by "M", expressed in kgf/cm^2. The difference between these concepts is that if the mark is an average indicator, then the class assumes guaranteed compliance with the specified level of strength of the concrete.

The methodological part

With the implementation of the standard on the specification, performance, production and conformity of concrete SM EN 206 [1], the need arose to expose the correspondence of concrete classes with concrete marks, established by the standard on heavy concrete and fine-grained concrete GOST 26633-91 [2]. The correspondence between concrete classes and marks according to GOST 26633-91 [2] has the value of compressive strength (tensile) evaluated by the normative coefficient of variation V = 13.5% which is not found in SM EN 206 [1]. This value of the coefficient is used in the case of initial tests and when there is no statistical data on the actual uniformity of the concrete, according to GOST 27006-86 [3]. The strength mark of the concrete is an average value of the compressive strength expressed in kgf/cm^2 by the normative coefficient of variation V.

According to the provisions of the standard SM EN 206 [1], the conformity of the compressive strength of concrete is evaluated on samples tested at 28 days, and each individual test result on the cube f_{ci} must satisfy the relationship:

$$f_{ci} \geqslant (f_{ck} - 4)\ N/mm^2 \quad (1)$$

In the case when, the production of a concrete family starts, for the first time, the average strength of the groups of three consecutive results, performed on the samples, which overlap or not, must satisfy the relationship (Compliance Criterion 1, according to SM EN 206 [1]):

$$f_{cm} \geqslant (f_{ck} + 4)\ N/mm^2 \quad (2)$$

When we have a continuous production of concrete, the conformity assessment will be made on the results of the tests over an evaluation period of at least 15 results and not more than 35 consecutive results obtained over a period not exceeding 6 months, in case when the number of results of the tests is less than 35 per quarter, and over a period not exceeding 3 months in cases when the number of test results is more than 35 per quarter. The degree of homogeneity of the concrete quality is determined according to the values expressed in N/mm^2 of the standard deviation σ and the average compressive strength f_{cm} of the concrete (Conformity criterion 1 according to SM EN 206 [1]):

$$fcm \geqslant (fck + 1{,}48\sigma)\ N/mm^2 \quad (3)$$

The standard deviation σ is determined for a minimum of 15 results recorded in a period of maximum 6 months, according to the relation:

$$\sigma = \sqrt{\frac{1}{N}\sum_{i-1}^{N}(f_{ci-1}f_{cm})^2} \quad (4)$$

where:

σ - standard deviation;

N – number of results;

f_{ci} – individual result of compressive strength;

f_{cm} – average compressive strength.

It is also important to note that testing larger specimens provides more information about concrete. The standard SM EN 206 [1] specifies two types of samples, cubes with a side of 150 mm and cylinders of 150 mm diameter and 300 mm height, while the standard GOST 26633-91 [2] specifies cubes with a side of 100 mm, according to GOST 22685-89 [4]. When testing samples with a side of 100 mm, the volume of the concrete under test decreases and the variation of the resistance on the samples increases, which can be solved by increasing the number of samples or their dimensions.

The experimental part

For the preparation of concrete mixtures with different cement dosages, crushed aggregates of sand and gravel sort (fraction) 0-4, 4-8 and 8-16 mm and plasticizer/superplasticizer additive were used. The experimental tests, performed on concrete, were performed in accordance with the national standard SM EN 206 [1] and the canceled standard GOST 26633-91 [2].

In the preparation of concrete, for both cases, the effective W/C ratio was used, which took into account the water absorption of the aggregates (determined in accordance with SM EN 1097-6 [5]), the cement dosages being 260 kg/m^3, 280 kg/m^3, 300 kg/m^3, 320 kg/m^3, 340 kg/m^3, 380 kg/m^3, 420 kg/m^3, 440 kg/m^3 to which appropriate amounts of plasticizer/superplasticizer were added.

The concrete mixtures were designed so that the compaction class was S3 (100-150 mm), the test being performed according to SM EN 12350-2 [6]. After stripping, the concrete samples according to SM EN 206 [1] were immersed in water and the samples according to GOST 26633-91 [2] maintained in laboratory conditions, at a humidity of 95 %, at a temperature of plus 20 °C up to the trial period of 28 days. The determination of the compressive strength of the concrete samples (Figure 1) was performed on cubes with a side of 150 mm, according to SM EN 206 [1] and with a side of 100 mm, according to GOST 26633-91 [2], and SM EN 12390-1 [7], these being manufactured and stored in accordance with SM EN 12390-2 [8].

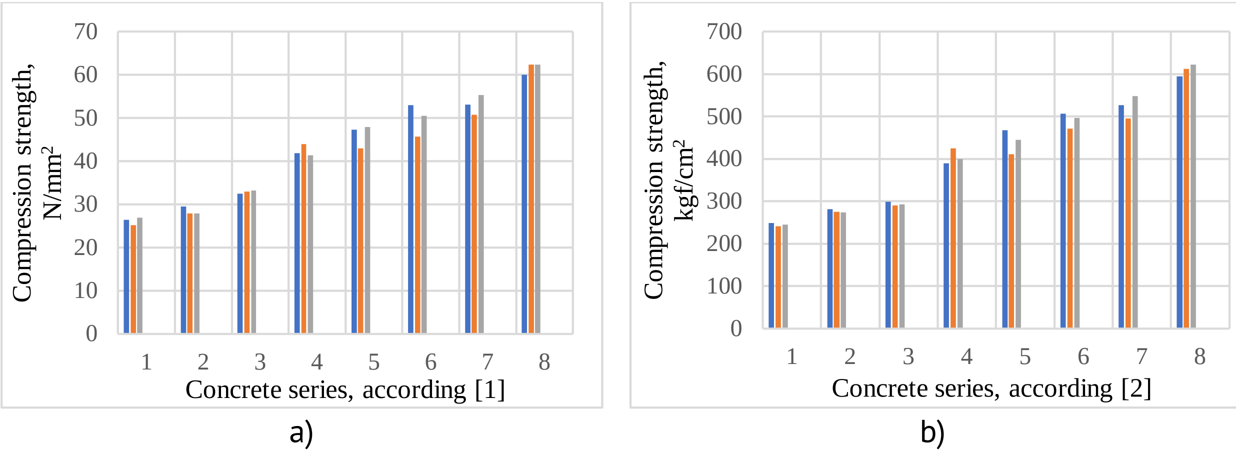


Figure 1. Average values of compressive strengths of concrete batches with different cement dosages: a) tests performed on eight series of cubes, with a side of 150 mm, according to SM EN 206 [1]; b) tests performed on eight series of cubes, with side 100 mm, according to GOST 26633-91 [2].

The average values of the tests on the cubes are presented in Table 1. Concrete classes were established based on the application of different compliance criteria for compressive strength, depending on the number of test results (f_{cm}), for a concrete in the family, applying the criterion ($f_{cm} \geq f_{ck} + 4$). In this case, the relation f_{ck} + 8 N/mm^2 was applied, the concrete classes obtained being presented in Table 2.

Table 1

Average values of compressive strengths obtained on concrete samples

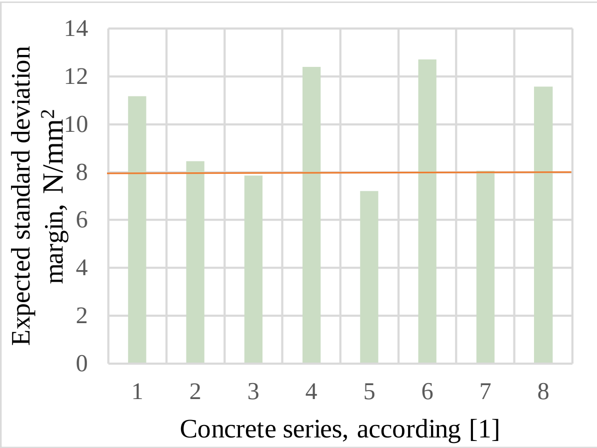
Series	Cement dosage, kg/m^3	Average compressive strength, N/mm^2 [1]	Series	Cement dosage, kg/m^3	Average compressive strength $\overline{R}$, kgf/cm^2 [2]
1	260	26,17	1	260	244,73
2	280	28,46	2	280	276,93
3	300	32,86	3	300	293,62
4	320	42,39	4	320	404,70
5	340	44,21	5	340	441,05
6	380	49,71	6	380	491,47
7	420	53,05	7	420	523,30
8	440	61,58	8	440	609,65

Table 2

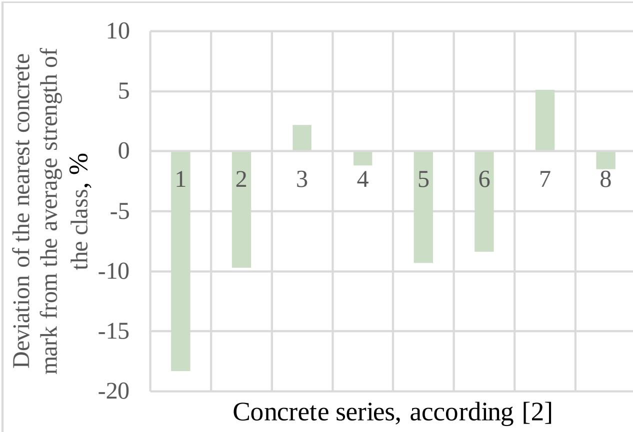
Determination of concrete classes according to SM EN 206 [1] and marks according to GOST 26633-91 [2]

Series	Criterion 1, N/mm^2	Concrete class, C, [1]	Series	Deviation of the nearest concrete mark from the average strength of the class, % $(M - \bar{R})/\bar{R} \times 100$	Concrete marks, *M*, [2]
1	26,17 – 15 = 11,17	C12/15	1	200 – 244,73/244,73 × 100 = −18,3	M200
2	28,46 – 20 = 8,46	C16/20	2	250 – 276,93/276,93 × 100 = −9,7	M250
3	32,86 – 25 = 7,86	C20/25	3	300 – 293,62/293,62 × 100 = +2,2	M300
4	42,39 – 30 = 12,39	C25/30	4	400 – 404,70/404,70 × 100 = −1,2	M400
5	44,21 – 37 = 7,21	C30/37	5	400 – 441,05/441,05 × 100 = −9,3	M400
6	49,71 – 37 = 12,71	C30/37	6	450 – 491,47/491,47 × 100 = −8,4	M450
7	53,05 – 45 = 8,05	C35/45	7	550 – 523,30/523,30× 100 = +5,1	M550
8	61,58 – 50 = 11,58	C40/50	8	600 - 609,65/609,65 × 100 = −1,5	M600

From Table 2 it is observed that the series 3 and 5 of concrete samples, executed according to SM EN 206 [1], with cement dosages of 300 kg and 340 kg respectively, did not satisfy the relation f_{ck} + 8 N/mm^2 (Figure 2 a) or were close to the default values. Therefore, these series can be classified in intermediate concrete classes, respectively C18/22 and C28/35.



a)



b)

Figure 2. Criteria for accepting the initial tests of f_{ck} + 8 N/mm^2 concrete: a) expected standard deviation margin; b) deviation of the nearest concrete mark from the average strength of the class.

The values of the deviations of the closest concrete marks from the average strength of the class (Figure 2 b), differ insignificantly from those indicated in GOST 26633-91 [2], exceeding the allowed deviation of 5 %, which can be explained by deviation from the average values at compression, due to model uncertainties, variations in geometric and material properties, as well as the required level of safety.

Based on the results obtained and the concrete marks established, in "Table V.1" of the normative document CP H.04.04 [9], appropriate concrete classes and intermediate marks can be introduced (Table 3).

Table 3

Marks and classes of compressive strength for concrete, according to GOST 26633 [2] and SM EN 206 [1]

Compression strength marks according to GOST 26633, kgf/cm^2	Compression strength classes according to SM EN 206	Minimum characteristic resistance on cylinders, $f_{ck,cil}$ N/mm^2	Minimum characteristic resistance on cubes, $f_{ck,cub}$ N/mm^2
M150	C8/10	8	10
M150	**C10/12**	**10**	**12**
M200	C12/15	12	15
M250	C16/20	16	20
M300	**C18/22**	**18**	**22**
M350	C20/25	20	25
M350	**C22/27**	**22**	**27**
M400	C25/30	25	30
M450	**C28/35**	**28**	**35**
M500	C30/37	30	37
M550	C32/40	32	40
M600	C35/45	35	45

According to the SM EN 1992-1-1 standard [10], the strength of the concrete is obtained by applying the formula:

$$f_{cd} = \frac{\alpha_{cc} f_{ck}}{Y_c} \quad (5)$$

where:

Y_c – partial safety factor, set as 1.5.

$$Y_c = Y_M \cdot Y_{conv} \quad (6)$$

where:

Y_M has a value of 1.3 and is a factor, which takes into account the deviation from the value f_{ck}, due to model uncertainties, variations in geometric and material properties, and the level of safety established.

Y_{conv} has a value of 1.15 and is a factor, which takes into account the possible decrease in the strength of concrete in its application.

Figure 3 presents the conformity criteria for the compressive strength of concrete in different stages, starting from the determination of the concrete composition for initial tests (stage I), to the accepted resistance, in case of in situ tests (stage VII), taking - into consideration the acceptance criteria for fresh concrete on the construction site.

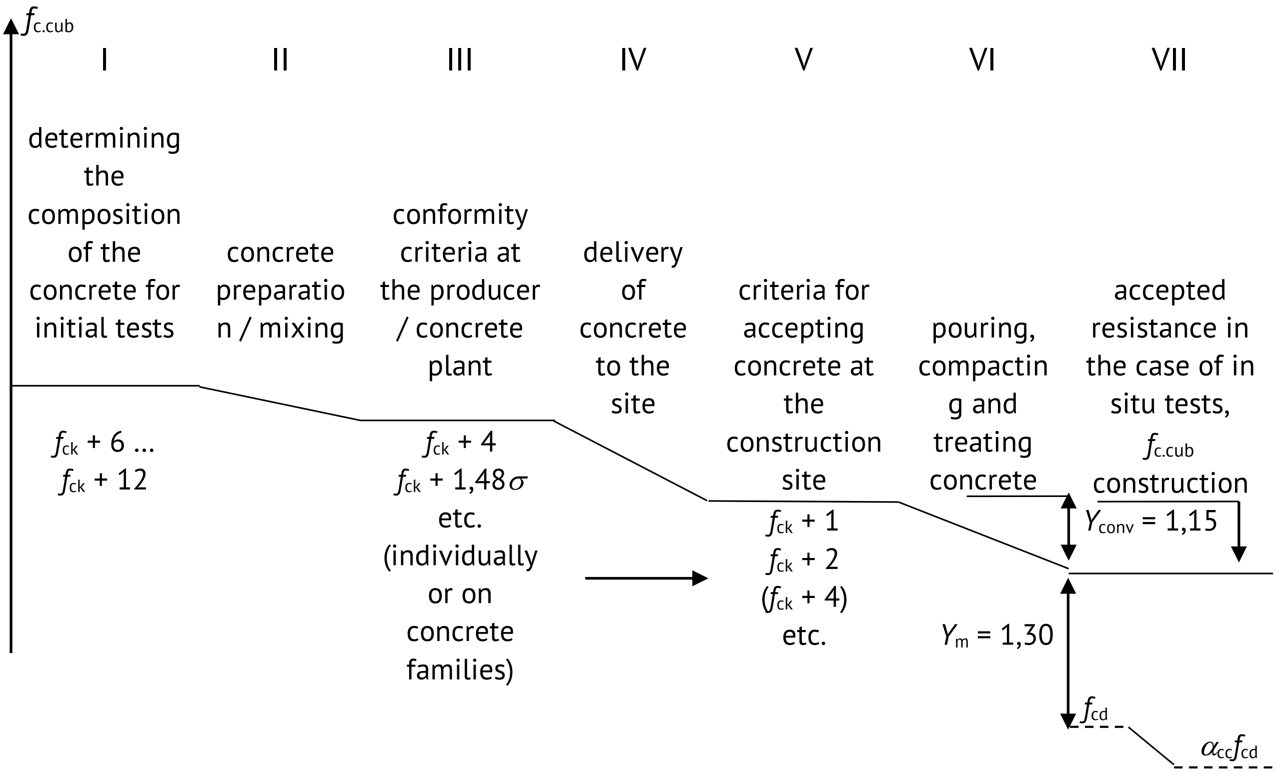


Figure 3. Conformity criteria for the compressive strength of concrete in different stages.

Conclusions

Assessing the compressive strength of concrete is an important activity, as it provides data on the most important characteristic of concrete, - the strength class.

In the context of the application of harmonized standards, within [10], there was a need to establish the correspondence of classes with concrete marks, in order to help design and construction companies to correctly establish the strength mark of concrete with the corresponding class of concrete.

Not all concrete marks, according to GOST 26633-91 [2] have corresponding classes, according to SM EN 206 [1], hence the need for their establishment, by introducing intermediate classes of concrete.

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