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Further guidance on the application of EN 13791:2019 and background to the provisions

Weiterführende Anleitung zur Anwendung der EN 13791:2019 und Hintergrund zu den Regelungen

Guide pour l’application de la norme EN 13791:2019 et contexte des spécifications

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Further guidance on the application of EN 13791:2019 and background to the provisions

Guide pour l'application de la norme EN 13791:2019 et contexte des spécifications

Weiterführende Anleitung zur Anwendung der EN 13791:2019 und Hintergrund zu den Regelungen

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EUROPEAN COMMITTEE FOR STANDARDIZATION
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European foreword

This document (CEN/TR 17086:2020) has been prepared by Technical Committee CEN/TC 104 “Concrete and related products”, the secretariat of which is held by Standards Norway.

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This document should be read in conjunction with EN 13791:2019.

Introduction

(1) To achieve a balanced standard, CEN/TC 104/SC 1/TG 11 comprises experts with different backgrounds and affiliations. The membership of TG 11 is given in Table 1.

Table 1 — Membership of the European Technical Standard Committee, CEN/TC 104/SC 1/TG 11, responsible for the revision of EN 13791

Member	Affiliation
Professor Tom Harrison	Convenor
Dr Chris Clear	Secretary
Vesa Anttila	Rudus, Finland
Prof. Wolfgang Breit (papers only)	Technische Universität Kaiserslautern, Germany
Dr Neil Crook	The Concrete Society, UK
Ir. F.B.J. (Jan) Gijsbers	CEN/TC250/SC2
Bruno Godart	IFSTTAR, France
Dr. Arlindo Gonçalves	Laboratório Nacional de Engenharia Civil, Portugal
Christian Herbst	JAUSLIN + STEBLER INGENIEURE AG, Switzerland
Rosario Martínez Lebrusant	Jefe del Área de Certificación y Hormigones, Spain
Dorthe Mathiesen (papers only)	Danish Technological Institute, Denmark
David Revuelta	Instituto Eduardo Torroja, Spain
Dr.-Ing. Björn Siebert followed by Dr Enrico Schwabach	Deutscher Beton- und Bautechnik-Verein E.V.
Prof. Johan Silfwerbrand	Swedish Cement and Concrete Research Institute, Sweden
Ceyda Sülün followed by Francesco Biasioli	ERMCO
José Barros Viegas (papers only)	BIBM
Dr.-Ing. Ulrich Wöhnl	German expert and member of former TG11
Christos A Zeris (papers only)	National Technical University of Athens, Greece

(2) In addition, guidance on rebound hammer and pulse velocity testing was provided by David Corbett of Proceq, Switzerland and statistical help with combining core and indirect test results was provided by André Monteiro of the Laboratório Nacional de Engenharia Civil, Portugal.

(3) Contact and exchange of information was also maintained with RILEM Technical Committee TC ISC 249, which works on onsite non-destructive assessment of concrete strength.

(4) Where a reference is cited to a paragraph without being preceded by a reference to a standard, e.g. EN 13791:2019, Clause 6, the reference is to a paragraph in this document. For example ‘13.3 (2)’ means paragraph (2) in 13.3 of this document.

1 Scope

This document explains the reasoning behind the requirements and procedures given in EN 13791 [1] and why some concepts and procedures given in EN 13791:2007 [2] were not adopted in the 2019 revision. The annex comprises worked examples of the procedures given in EN 13791:2019.

2 Symbols and abbreviated terms

For the purposes of this document, the following symbols and abbreviated terms apply.

CLF	core length factor
CoV	coefficient of variation
f_c or $f_{c,cube}$	compressive strength of standard test specimens, 2:1 cylinder or cube
$f_{c,1:1core}$ or $f_{c,2:1\ core}$	core compressive strength associated with a length: diameter ratio of either 1:1 or 2:1
f_{cd}	design compressive strength in the structure
f_{ck}	minimum characteristic compressive strength of test specimens based on 2:1 cylinders
$f_{ck,\ cube}$	minimum characteristic compressive strength of test specimens based on cubes
$f_{c,is}$	*in situ* compressive strength
$f_{ck,is}$	characteristic *in situ* compressive strength (expressed as the strength of a 2:1 core of diameter ≥ 75 mm)
$f_{ck,is,28}$	assumed characteristic compressive strength in the structure
$f_{ck,is,>28}$	assumed characteristic compressive strength in the structure after 28 days
$f_{ck,spec}$	specified minimum characteristic strength
$f_{ck,spec,cube}$	specified minimum characteristic cube strength (Some CEN members specify cube strength)
$f_{c,is,highest}$	highest value of $f_{c,is}$ for a set of '*n*' results.
$f_{c,is,lowest}$	lowest value of $f_{c,is}$ for a set of '*n*' results
$f_{c,is,est}$	estimated *in situ* compressive strength at a specific test location
$f_{c,is,reg}$	indirect test value converted to its equivalent *in situ* compressive strength using a regression equation
$f_{c,m}$	mean (average) concrete compressive strength of 2:1 test cylinders
$f_{c,m(n)is}$	mean (average) value of a set of '*n*' values of $f_{c,is}$
$\mathrm{k_n}$	factor applied to the sample standard deviation
k_t	reduction factor for α_{cc}
m	number of valid indirect test results in test region under investigation
n	number of core test results
p	number of parameters of the correlation curve
R^2	coefficient of determination

s	estimate of the overall standard deviation of *in situ* compressive strength
s_c	residual standard deviation, which is a measure of the spread of the core strength test data around the fitted regression curve
s_e	standard deviation of all the estimated strength values, which is a measure of the spread of the estimated core strengths around its mean value
s_r	sample standard deviation of reference element(s)
s_s	sample standard deviation of element(s) under investigation
UPV	ultrasonic pulse velocity
$\bar{X}_r$	mean UPV/rebound number of the reference element
$\bar{X}_s$	mean UPV/rebound number of the element under investigation
x_0	indirect test value at test location '0' (where the *in situ* strength is required for structural assessment purposes)
$x_{i,cor}$	indirect test value at test location *i* that is used for the correlation
$\bar{x}$	mean (average) of the *m* indirect test values used for the correlation
α_{cc}	coefficient taking account of long term effects on the concrete compressive strength
γ_c	partial safety factor for concrete for persistent and transient design situations

3 General principles adopted for the revision

(1) The scope of the revision retains covering both the estimation of compressive strength for the structural assessment of an existing structure (EN 13791:2019, Clause 8) and assessment of compressive strength class of supplied concrete in case of doubt (EN 13791:2019, Clause 9). Presenting EN 13791 as two parts was considered as it would emphasize the differences between the estimation of compressive strength for a structural assessment and assessment of compressive strength class of supplied concrete in case of doubt. It was decided to keep EN 13791:2019 as a single standard to avoid duplication of requirements.

(2) EN 13791 was not drafted to cover exceptional situations. EN 13791 aims to cover the most common situations.

(3) As the objective was to produce a technically sound European standard and not a collation of national provisions, the requests to refer to provisions valid in the place of use were resisted. Nevertheless, techniques not specified and topics not addressed by EN 13791:2019 may be detailed in national provisions or left to the investigator involved.

(4) Requirements have been placed in the EN 13791:2019 normative text and guidance in its Annex A and this document.

(5) Statistical principles are applied and this has consequences when there are small sets of data. For all other things being equal, a small set of data will lead to a lower estimate of the characteristic *in situ* compressive strength when applying the EN 13791:2019, Clause 8 procedures. On the other hand, in the EN 13791:2019, Clause 9 procedures, the smaller data set, the lower is the risk of rejecting concrete.

(6) Uncertainty of measurement is not taken into account but there are recommendations as to the minimum number of test results to help ensure the estimates are reliable. This means that with respect to uncertainty of measurement, the producer and user risks are the same.

(7) EN 13791 [1] is drafted to be compatible with EN 1990 [3], EN 1992-1-1 [4] and EN 206 [5]. The recommended value of 0,85 for the factor η in A.2.3(1) of EN 1992-1-1:2004 [4] has been applied and if

national provisions use a different factor, the national annex to EN 13791 would need to provide the appropriate value. Where EN 13791 is used with design standards other than EN 1992-1-1 then some factors may need to be reviewed or adjusted, but this is outside the scope of the revision.

(8) As the EN 1992-1-1 is based on 2:1 cylinder strengths, the *in situ* compressive strength in EN 13791 is expressed as the strength of a 2:1 core.

(9) For structural assessment, the output of EN 13791:2007 [2] was the estimated compressive strength class of the concrete prior to placing in the structure. At the request of the structural engineers, the approach was changed to estimating either the characteristic *in situ* compressive strength for the test region or the *in situ* compressive strength at a specific location.

(10) When estimating the *in situ* compressive strength for the structural assessment of an existing structure (EN 13791:2019, Clause 8 procedures), the strength is estimated purely from the data analysis with no presumption as to the concrete strength.

(11) When assessing the compressive strength class of supplied concrete in case of doubt (EN 13791:2019, Clause 9 procedures), it is assumed that the concrete conformed to its specification with respect to compressive strength and the truth of this assumption is tested. For statistical analysis, this assumption is known as the null hypothesis. This is the same philosophy as used in EN 206 [5] for conformity and identity testing and in EN 13791:2007 [2].

(12) The criteria in EN 13791:2019, 9.2 and 9.3 are based on the identity testing criteria for compressive strength given in EN 206:2013+A1:2016, Annex B, B.3.1.

(13) It is possible that an EN 13791:2019, Clause 8 calculation from core results may indicate that the estimated *in situ* strength is insufficient, whilst an EN 13791:2019, Clause 9 analysis may indicate that the concrete placed conformed to the specified strength class.

NOTE For example, EN 13791:2019, 9.2 would accept a small element with a mean of three cores giving an *in situ* compressive strength below the 0,85$f_{ck,\ spec}$ provided every core is not less than 0,85($f_{ck,\ spec}$ – 4) and in this situation a structural analysis is not needed. Nevertheless, if the same three core test results were used in the EN 13791:2019, 8.1(7) procedure, the lowest core test result would be taken as the characteristic *in situ* compressive strength and this value used in a structural analysis based on EN 1990.

(14) When interpreting the data, engineering judgement will be required. For example, EN 13791:2019 now includes procedures for identifying statistical outliers, but whether any outliers are included in the estimation of the characteristic *in situ* compressive strength is left to engineering judgement.

4 *In situ* compressive strength and other concrete properties assumed in the EN 1992-1-1 design process

4.1 General

(1) Before describing the background to the provisions in EN 13791:2019, this section sets out the assumptions related to the *in situ* concrete compressive strength and other concrete properties in the EN 1992 series[1)] structural design process. The EN 1992 series of standards is commonly known as Eurocode 2.

(2) For structural design, various concrete strength and deformation properties (mechanical properties) are defined in EN 1992-1-1, namely:

1) The standards in the EN 1992-series are:

EN 1992-1-1, *Eurocode 2: Design of concrete structures — Part 1-1: General rules and rules for buildings*

EN 1992-1-2, *Eurocode 2: Design of concrete structures — Part 1-2: General rules — Structural fire design*

— compressive strength;

— tensile strength;

— splitting tensile strength;

— flexural tensile strength;

— modulus of elasticity;

— Poisson's ratio;

— coefficient of thermal expansion;

— creep coefficient;

— drying shrinkage strain and autogenous shrinkage strain;

— stress-strain relationship.

(3) The properties listed in 4.1(2) are assumed to be related to the compressive strength of concrete except for Poisson's ratio and the coefficient of thermal expansion. The appropriate relationships are given in EN 1992-1-1 [4] for normal weight aggregate concrete and for lightweight aggregate concrete. Additional properties of concrete, which are relevant for structural fire design, are given in EN 1992-1-2.

(4) As in EN 13791:2019, distinction is made in this section between two situations, namely the situation in which the concrete compressive strength in the structure is based on test specimens (see 4.2) and the situation in which the concrete compressive strength in the structure is based on cores extracted from the structure (see 4.3). Normally the first situation applies to new structures whereas the second situation applies to existing structures for which a structural assessment is required.

(5) The standards in the EN 1992 series are intended to be used for the structural design of buildings and civil engineering works in concrete (EN 1992-1-1:2004, 1.1.1), i.e. for new structures. For the structural assessment of existing buildings and civil engineering works in concrete, additional rules are being developed by the European Concrete Design Committee[2]. These additional rules will become available as part of the second generation of Eurocodes, which are expected to be published around 2023. The information given in 4.3 is based on current draft proposals and consequently may be subject to change before publication.

4.2 Concrete compressive strength based on test specimens

(1) The concrete compressive strength in the structure is related to the compressive strength of test specimens, namely the characteristic (5 %) 2:1 cylinder strength (f_{ck}) or the characteristic (5 %) cube strength ($f_{ck,\ cube}$) (EN 1992-1-1:2004, 3.1.2(1)P).

(2) The 2:1 cylinder strength is assumed to be 0,82 times the cube strength. The factor 0,82 is the average value of the ratio between the 2:1 cylinder strength and the cube strength for the range of concrete strength classes, C12/15 to C90/105, covered by EN 1992-1-1:2004, Table 3.1 (see 5.2).

2) CEN/TC 250/SC 2

EN 1992-2, *Eurocode 2: Design of concrete structures — Part 2: Concrete bridges — design and detailing rules*

EN 1992-3, *Eurocode 2: Design of concrete structures — Part 3: Liquid retaining and containment structures*

(3) According to EN 1992-1-1, the variation of the concrete compressive strength in the structure is given as a lognormal distribution. The average concrete compressive strength f_{cm} for normal and high strength concrete at 28 days is assumed as (EN 1992-1-1:2004, Table 3.1) given in Formula (1).

$$f_{cm} = f_{ck} + 8 \text{ (values in MPa)} \quad (1)$$

(4) The characteristic (5 %) concrete compressive strength in the structure at 28 days ($f_{ck,is,28}$) is assumed to be 85 % of the corresponding characteristic (5 %) strength (f_{ck}) of 2:1 cylinder test specimen at 28 days, see Formula (2):

$$f_{ck,is,28} = 0{,}85 \times f_{ck} \quad (2)$$

NOTE The factor 0,85 is the recommended value of the conversion factor η in A.2.3(1) of EN 1992-1–1:2004.

(5) After 28 days a strength increase of 18 % (1/0,85) is assumed. Formula (3) takes this strength gain into account:

$$f_{ck,is,>28} = (1/0{,}85) \times 0{,}85 \times f_{ck} = f_{ck} \quad (3)$$

(6) The value of the design concrete compressive strength in the structure f_{cd} is defined in (3.1.2(4) and 3.1.6(1)P of EN 1992-1-1:2004) and reproduced as Formula (4):

$$f_{cd} = k_t\, \alpha_{cc}\, f_{ck}/\gamma_c \quad (4)$$

where

k_t is a reduction factor for α_{cc} with:

k_t = 1,0 when the strength is determined at 28 days;

k_t = 0,85 when the strength is determined after 28 days (3.1.2(4) of EN 1992-1–1:2004).

α_{cc} is the coefficient taking account of long term effects on the concrete compressive strength. This coefficient is also known as the Rüsch factor for reduced strength under sustained load. The recommended value of α_{cc} is 1,0 (3.1.6(1)P of EN 1992-1–1:2004);

γ_c is the partial safety factor for concrete, with a recommended value of 1,5 for persistent and transient design situations (2.4.2.4(1) of EN 1992-1–1:2004).

NOTE 1 It is assumed that the increase in the compressive strength after 28 days is offset by the reduction of the compressive strength due to long term effects (Rüsch factor). This implies in fact an assumed value of 0,85 for α_{cc}.

NOTE 2 The value of 0,85 (Formula (2)) is included in the partial safety factor for concrete.

NOTE 3 It is assumed that all variations related to execution (placing, compaction and curing of concrete) are covered by the partial safety factor for concrete provided execution is in accordance with the requirements of EN 13670 [6].

(7) When the strength is determined on the basis of the characteristic (5 %) strength of 2:1 test cylinders at 28 days f_{ck}, the design value of the concrete compressive strength in the structure is calculated using Formula (5):

$$f_{cd} = k_t\, \alpha_{cc}\, f_{ck}/\gamma_c = 1{,}0 \times 1{,}0 \times f_{ck}/\gamma_c = f_{ck}/\gamma_c \quad (5)$$

(8) When the strength is determined on the basis of the characteristic (5 %) strength of 2:1 test cylinders after 28 days $f_{ck,>28}$, the design value of the compressive strength in the structure is calculated using Formula (6):

$$f_{cd} = k_t \, \alpha_{cc} f_{ck,>28}/\gamma_c = 0{,}85 \times 1{,}0 \times f_{ck,>28}/\gamma_c = 0{,}85 \times f_{ck,>28}/\gamma_c \quad (6)$$

4.3 Concrete compressive strength based on the strength of cores from the structure

(1) Structural assessment of existing concrete structures may be based on the strength of cores, which are extracted from the structure.

(2) The design value of the concrete compressive strength in the structure is derived from the characteristic (5 %) value of the concrete compressive strength, i.e. the value which has an exceedance probability of 95 %.

(3) It is assumed that the characteristic (5 %) concrete compressive strength in the structure equals the characteristic (5 %) compressive strength ($f_{ck,is}$) of 2:1 cores extracted from the structure.

(4) When the strength is estimated on the basis of the 2:1 core strength ($f_{ck,is}$), the design value of the concrete compressive strength in the structure is calculated using Formula (7):

$$f_{cd} = k_t \, \alpha_{cc} f_{ck,is}/\gamma_c = 0{,}85 \times 1{,}0 \times f_{ck,is}/\gamma_c = 0{,}85 \times f_{ck,is}/\gamma_c \quad (7)$$

(5) Using Formula (7) the value of the partial safety factor γ_c for concrete may be reduced to a recommended value of 1,3 (A.2.3 in EN 1992-1-1:2004). This is to allow for the reduction in uncertainties as the compressive strength is derived from the structure directly.

5 Differences between test specimens and concrete in the structure

5.1 Introduction

(1) There are a number of reasons why the strength *in situ* is different to that assessed on test specimens. Depending upon the purpose of the investigation, these differences may need to be taken into account somewhere in the assessment.

(2) All execution that is in accordance with the requirements of EN 13670 [6] is intended to be covered by the partial safety factor for materials. For concrete this factor is 1,5 and it covers statistical variation in produced concrete, conversion to *in situ* strength and statistical variation of *in situ* strength within the limits set by execution in accordance with EN 13670. The portion of this factor allocated to the conversion to *in situ* strength is 1,2 (i.e. the inverse of 0,85). Indications are that this portion is in the range from 0,75 to 0,95. Tests from offshore concrete thick slip-formed walls with much re-vibration gave values above 1,0, while members with less re-vibration like domes are high but below 1,0. Little is actually known on the statistical distribution of *in situ* strength and what fractile is $< 0{,}85 f_{ck}$, but it is probably larger than 5 % in many cases; however, experience indicate that a partial factor for concrete of 1,5 is still adequate.

(3) When the *in situ* strength is measured by cores, the portions of the partial factor taken into account are:

— the conversion to *in situ* strength;

— most of the statistical variation in produced concrete;

— some of the statistical variation in *in situ* strength.

Nevertheless, the procedures in EN 13791:2019, Clause 9 only take the portion of the partial factor allocated to conversion to *in situ* strength into account. Given the uncertainties associated with the allocation of the portions, the structural designers were adamant that no further allowance should be made when applying the EN 13791:2019, Clause 9 procedures.

(4) Many of the following influences on *in situ* compressive strength are only relevant when assessing responsibility for non-conformity under EN 13791:2019, Clause 9 procedures, i.e. maturity, curing compaction.

(5) Clause 5 and Clause 6 contain what was originally in EN 13791:2007, Annex A plus additional information.

5.2 Reference test specimen

(1) EN 13791:2019 is based on *in situ* strength being expressed as the strength of 2:1 cores. Cube strengths are approximately 20 % higher than the strength of 2:1 cylinders due to the lateral restraint from the test machine platens. This difference is taken into account in EN 206 by having different minimum characteristic strength requirements for 150 mm cubes and 150 mm diameter by 300 mm cylinders. The default core length factor (*CLF)* of 0,82 given in EN 13791:2019, Clause 6 for normal-weight and heavyweight concretes is the average ratio between these different measures of compressive strength. The use of a different *CLF* is permitted where justified by testing. The *CLF* is used to convert 1:1 cores to the equivalent strength of 2:1 cores.

(2) The ratio between 2:1 cylinder and cube strength in the EN 206 compressive strength classes is given in Table 2. Some of the differences are due to rounding errors, but the higher factor for the higher strength classes is a reflection of the evidence that as the compressive strength class increases, the factor increases.

(3) No *CLF* is given in EN 13791 for lightweight concretes. If the same approach as used for normal-weight concrete were to be applied, the factor would be 0,91 based on Table 13 of EN 206:2013+A1:2016 [5], but EN 206 permits other relationships if they are established and documented.

(4) ASTM [7] use for normal weight concrete a ratio of 0,87 to convert 1:1 cores to 2:1 cores and some literature [8] indicates that the 0,82 factor is conservative particularly for high strength concrete. The evidence is mixed and further research is being encouraged to provide definitive guidance. The default relationship should be reviewed at the next revision of EN 13791.

(5) While the difference between a *CLF* of 0,82 and, for example, 0,87 is small (see Example A2), it may be the difference between acceptability and rejection. For this reason EN 13791:2019 permits other CLFs to be used if proven by testing.

Table 2 — Ratio between 2:1 cylinder strength and cube strength for the EN 206 compressive strength classes for normal-weight and heavyweight concrete

EN 206 compressive strength class	2:1 cylinder strength MPa	Cube strength MPa	Ratio
C8/10	8	10	0,80
C12/15	12	15	0,80
C16/20	16	20	0,80
C20/25	20	25	0,80
C25/30	25	30	0,83
C30/37	30	37	0,81
C35/45	35	45	0,78
C40/50	40	50	0,80
C45/55	45	55	0,82
C50/60	50	60	0,83
C55/67	55	67	0,82
C60/75	60	75	0,80
C70/85	70	85	0,82
C80/95	80	95	0,84
C90/105	90	105	0,86
C100/115	100	115	0,87
Average ratio			0,82

(6) A number of the key reasons for differences between test specimens and 2:1 cores taken from the structure are given in the following sub-sections and in Clause 6.

5.3 Effects of the moisture condition on *in situ* specimens

(1) The moisture condition of the core will influence the measured strength. A dry specimen will have a higher core strength than a wet core all other things being equal.

NOTE According to EN 13791:2007, A.2.1 [2], if cores are tested wet, the strength is reduced by 8 % to 12 % compared to testing in a dry condition. An implication of this fact is that if a core is tested wet the measured strength could be enhanced by at least 8 % when calculating the dry *in situ* strength. 'Wet' is defined as soaked underwater at (20 ± 2) °C for at least 48 h before testing.

(2) EN 13791 requires the core to be tested at a moisture condition similar to the *in situ* moisture condition. This is an appropriate moisture condition when determining the *in situ* characteristic strength in accordance with EN 13791:2019, Clause 8.

(3) In elements that function in a dry or semi-dry condition, the compressive strength in the structure is thus enhanced over that of standard test specimens; but in other circumstances, for elements that function in a wet condition, e.g. foundations, the *in situ* strength is not enhanced in the same way.

(4) As test specimens are cured in the wet condition, the option of testing cores for the EN 13791:2019, Clause 9 procedures was reviewed. The EN 1992-1-1 [4] design process has a factor of 0,85 to account for differences between 2:1 cylinders and the concrete in the structure, i.e. the concrete in the structure may be up to a factor 0,85 less than that of test specimens. The 0,85 includes various elements but each element is not allocated a specific portion of the factor. Most of the difference between test specimens and the structure are negative, i.e. the *in situ* strength is lower than that of test specimens; however, as