



BSI Standards Publication

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

National foreword

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English Version

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 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) Gijssbers	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 Wöhl	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
$f_{c,is}$	<i>in situ</i> compressive strength
$f_{ck,is}$	characteristic <i>in situ</i> 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 <i>in situ</i> compressive strength at a specific test location
$f_{c,is,reg}$	indirect test value converted to its equivalent <i>in situ</i> 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 $f_{c,is}$
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 <i>in situ</i> 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 <i>in situ</i> 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 $0,85f_{ck, spec}$ 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 series¹⁾ 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 Committee²⁾. 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 Rüsç 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 (Rüsç 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 $(20 \pm 2) ^\circ\text{C}$ 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

most *in situ* concrete has a moisture content less than saturated and this increases strength, difference in moisture content is a positive factor. By changing the curing to wet curing, the negative portions are retained and the positive portion is removed. This was not regarded as a technically sound approach. As explained in 5.1(3), core testing takes account of more than what is allocated to the 0,85 factor and consequently there is some additional margin.

(5) By having a difference between the EN 13791:2019, Clause 8 and Clause 9 curing conditions for cores, problems are created if the same set of cores are used both for an assessment under EN 13791:2019, Clause 9 and an estimation of *in situ* compressive strength under EN 13791:2019, Clause 8. This might be the case if the concrete was shown to be non-conforming and it was necessary to check whether the structure is still sufficiently safe at a lower concrete strength. For this structural check an unknown moisture correction would have to be introduced depending upon the degree of saturation in the *in situ* concrete. Given these difficulties, the required curing of cores is the same for the EN 13791:2019, Clause 8 and Clause 9 procedures.

5.4 Effect of maturity on concrete strength

(1) The rate of strength gain both pre and post-28 days is dependent upon the cement type, addition type, admixtures and the temperature of the concrete.

(2) Provided there is sufficient water for hydration, concrete will continue to develop strength with time.

(3) Design is usually based on the characteristic strength of laboratory samples of concrete moist-cured for 28 days at 20 °C. When comparing the strength of test specimens with the *in situ* strength this should be done at equal maturity, not equal age. Maturity is a function of both time and concrete temperature and there are various maturity functions that are widely used [9].

(4) The partial factor for materials does not include differences in maturity; however, the design may include an ageing factor to take account of strength development over time. A proven increase in strength with time may be decisive in deciding whether a structure has an acceptable strength.

(5) When estimating *in situ* compressive strength under EN 13791:2019, Clause 8, maturity is usually not a critical issue as the structure is likely to be several years old. When interpreting an assessment under the EN 13791:2019, Clause 9 procedures, the maturity of the concrete is something that should be considered.

(6) EN 13791:2019, Clause 6 requires for the Clause 9 procedures that core testing is not be undertaken on cores with a maturity less than that used as the basis for conformity testing, e.g. 28 days at 20 °C.

5.5 Effects of curing

(1) The strength of a core will be influenced by the curing history of the structure and the age of the concrete when the core is taken.

(2) The effects of curing are complex and include:

- if the temperature of the concrete is low for the first few hours, the ultimate strength is increased compared with standard curing;
- if the temperature of the concrete is high for the first few hours, the ultimate strength is decreased compared with standard curing;
- as the peak temperature of the concrete increases due to the release of the heat of hydration or due to accelerated curing, the early strength is increased but the long term strength is reduced [9];
- maturity equations are valid for normal conditions and they may not reflect the effects listed above.

(3) All the above assumes that there is sufficient water in the concrete as to not impede hydration. This assumption may not be valid for slabs that are not adequately cured or for concrete with a very low water

content. There is no simple factor for taking the effects of curing into account. But it is clear that if the concrete is placed on a hot day, placed in a large section or cured by accelerated methods, the effect of curing on *in situ* strength may be significant. The effects of early temperature history on the eventual concrete strength will depend on cement type, section size, formwork type and placing temperature. For these reasons it is not easy to estimate the combined effects but it is known that hydrating concrete reaching temperature in excess of 70 °C will have lower ultimate strength than concrete cured at lower temperatures and may undergo deleterious reactions such as delayed ettringite formation.

(4) The partial safety factor used in the design process takes account of some effects of curing history.

5.6 Effects of vibration

(1) Internal water and air movements caused by the process of vibrating the concrete will cause variations in the strength. The reduction in strength at the top of a vertical element is a well-recognized phenomenon.

(2) Self-compacting concrete is claimed to eliminate these variations, but such a claim is only valid if the concrete is not prone to static segregation.

(3) The partial safety factor used in the design process takes account of the effects of vibration.

5.7 Effects of excess entrapped air

(1) Increased voidage decreases the strength. Approximately 1 % voidage decreases the strength by 5 % to 8 %.

(2) The entrapped air in the structure is likely to be higher than that in test specimens and as a consequence the *in situ* strengths are likely to be lower. With certain precast concrete components that are formed with intense vibration, the entrapped air may be lower than in test specimens.

(3) The partial safety factor for concrete does not assume any upper limit of unsatisfactory compaction, segregation or separation. A high entrapped air may be an indication of delays in discharge or a failure to compact the concrete adequately.

6 Testing variables that influence core strength

6.1 Introduction

(1) In addition to the factors that influence the *in situ* strength (see Clause 5) there are testing factors that influence the core strength and these factors are introduced in this section.

(2) It is assumed that testing of cores will be strictly in accordance with EN 12390-3 [10], but the test machine characteristics that affect normal compressive strength testing will also affect core testing and probably more so with 50 mm diameter cores.

(3) Some of the influencing factors have to be taken into account when evaluating the test results. Some other factors may need to be considered, whilst others are normally ignored.

6.2 Direction relative to the casting

(1) The measured strength of a core drilled vertically in the direction of casting might, depending on the stability of the fresh concrete, be greater than the strength of a core drilled horizontally from the same concrete. The magnitude of the difference is typically from 0 % to 8 %. The direction of drilling is not taken into account in EN 13791:2019.

6.3 Imperfections

(1) Flaws can occur in cores from various causes. These include cracking and microcracking, water gain beneath flaky particles or horizontal reinforcement and voids due to local segregation. The validity of

strength assessment from such cores and their ability to represent the general *in situ* strength should be separately assessed.

(2) Such imperfections might be the reason why a core is a statistical outlier.

6.4 Diameter of core

(1) The core diameter influences the measured strength and the strength variability. The strength of a horizontally drilled core with 100 mm diameter and height ($l/d = 1$) corresponds to the strength of cube specimens with side length 150 mm.

(2) Where core diameter is less than 100 mm at $l/d = 1$, then strength variability is greater than that of 100 mm diameter cores.

(3) The variability of the measured strength increases with decreasing diameter to upper aggregate size ratio.

NOTE See Clause 11 for further information.

(4) While on average smaller diameter cores are weaker than larger diameter cores, there is a wide scatter in the published literature. For the range of core diameters covered by EN 13791:2019, no allowance is made for the impact of core diameter on strength.

(5) Cores with a diameter smaller than 50 mm (microcores) require procedures that are not covered by EN 13791:2019.

6.5 Length/diameter ratio

(1) The ratio length/diameter influences the measured strength. The strength decreases for ratios $l/d > 1$ and increases for ratios $l/d < 1$. This is mainly due to restraint from the test machine platens.

(2) It is not recommended to use length to diameter ratios greater than 1 for core diameters in the range 50 mm to 70 mm as this leads to even greater variability than with 1:1 cores.

6.6 Flatness of end surfaces

(1) Deviation from flatness decreases the measured strength. The tolerance for flatness should be the same as for standard specimens, i.e. as specified in EN 12390-1 [11].

6.7 Capping of end surfaces

(1) Capping of low strength will decrease the strength. Thin capping of high strength mortar or high strength sulfur will not significantly influence the strength. Grinding the end surfaces is recommended particularly for high strength concrete. The recommendations in EN 12504-1 [12] should be followed.

6.8 Effect of drilling

(1) Drilling operations may produce damage in immature or inherently weak concrete and normally it is not possible to see effects on the cut surface.

(2) A core may be inherently weaker than a cylinder because the surface of a core includes cut pieces of aggregate that may only be retained in the surface by adhesion of the matrix. Such particles are likely to contribute little to the strength of the core. The impact is greater on small diameter cores. See Clause 11 for further information.

6.9 Reinforcement

(1) Cores used to measure strength of concrete should not contain reinforcement. Where this cannot be avoided it must be expected that a reduction in measured strength will occur for a core containing steel (other than along its axis). Any cores containing reinforcing bars in or close to the longitudinal axis are not suitable for testing strength.

- (2) By permitting the use of cores down to a diameter of 50 mm and a length to diameter ratio of 1:1, reinforcement can usually be avoided or the core length cut to avoid inclusion of the reinforcement.
- (3) EN 13791 does not provide adjustments to take account of transverse reinforcement.

7 Scope in EN 13791:2019, Clause 1

- (1) EN 13791 provides rules for using combined techniques and rules for the initial assessment of a data set.
- (2) EN 13791 does not cover comparative testing as consensus on the level of risk in rejecting conforming concrete could not be reached. Comparative testing is where a reference element is compared with the one under investigation using an indirect testing survey (see 14.6).
- (3) The European Precast Concrete Industry and the European Ready Mixed Concrete Organization confirmed that routine conformity control of concrete or precast concrete products based on *in situ* testing is not within the scope of EN 13791. With routine conformity control sufficient data are available to reliably determine the coefficient of variation. Consequently the use of different k_n values to those given in EN 13791 is appropriate.
- (4) In most European countries the standard core diameter is either 75 mm or 100 mm. While the use of 50 mm diameter cores is common in some European countries, the use of cores less than 50 mm diameter is not normal for the applications covered by EN 13791 and so no provisions or guidance is provided on core diameters less than 50 mm.
- (5) EN 13791 does not provide specific requirements for lightweight concretes and in particular the relationship between *in situ* compressive strength and 1:1 cores (see 5.2) and the example of a screening test in EN 13791:2019, Annex B is not applicable to lightweight concretes. Nevertheless most of the techniques described in EN 13791 are applicable to lightweight concretes.

8 Terms and definitions, symbols and abbreviations in EN 13791:2019, Clause 3

- (1) Abbreviations have been aligned with those used in EN 1992-1-1 [4].
- (2) Consideration was given to basing the definition of characteristic *in situ* compressive strength and *in situ* compressive strength on the equivalent strength of a 300 mm long by 150 mm diameter cylinder, or the strength of a 2:1 core of diameter ≥ 75 mm. As cast cylinders tend to have a higher strength than cores of the same diameter, due to cut particles of aggregate contributing little to strength, there is an argument for the core strength to be increased by 6 % to account for this difference if the expression of *in situ* strength is based on cylinder strength. The difference depends upon the specimen diameter and the difference is greater for small diameter specimens.
- (3) Views differ on whether this difference is included in the 0,85 factor and the safe assumption is to regard it as being included. To reduce problems over whether a factor should be applied, the definitions of characteristic *in situ* compressive strength and *in situ* compressive strength was agreed as being the strength of a 2:1 core of diameter ≥ 75 mm.
- (4) This does not completely resolve the issues as in EN 13791:2019, 9.4 the use of a screening test is permitted. This requires a procedure for calibrating a correlation from test specimens. An example of such a procedure is given in 14.4 using laboratory test specimens. In theory these values should be reduced slightly to align with core strengths, but as the test specimen size is relatively large and consequently the difference is small, no adjustment is made.
- (5) As the use of 1:1 cores is common, for normal-weight and heavyweight concretes a default *CLF* of 0,82 should be applied to convert this core test result to the *in situ* compressive strength, i.e. the compressive strength of a 2:1 core, except where a different *CLF* has been proven by testing. The 0,82 is the average ratio of the cube to cylinder strength given in EN 206 [5]. See 5.2 and 6.4 (1) for further information.

9 Investigation objective and test parameters in EN 13791:2019, Clause 4

(1) This is a new section and the approach used is to provide requirements in the normative text of EN 13791:2019 and guidance in its Annex A.

(2) If the objectives of the investigation are clearly defined, there is less risk of the investigation not achieving what was intended and lower risks of dispute over the interpretation of the results.

10 Test regions and test locations in EN 13791:2019, Clause 5

(1) The concepts of test regions and test locations have been retained.

(2) In EN 13791:2019, the Clause 9 procedures apply to a test region comprising a 'defined' volume of concrete often meaning the volume of concrete where identity testing is indicating that the concrete did not conform to its specified compressive strength class. See 14.2 for the explanation as to why a volume limit is placed on the test region for assessment under Clause 9 of EN 13791:2019.

(3) In EN 13791:2007 [2] the concept of a small test region was used without defining what is 'small'. This created problems. It was agreed that 'small' would be defined as a volume cast in a single day and that volume has been agreed as being 30 m³, which is four 7,5 m³ loads or three 10 m³ loads of concrete. The word 'approximately' was added as it did not seem sensible to split, for example, a volume of 31 m³ into two volumes for assessment purposes. While this additional word solves one problem, it creates another: namely what does the word 'approximately' mean. It would be wrong to assume that 'approximately' stretches to another full load of concrete and therefore the boundary must be somewhere between 30 m³ and a part of a full load of concrete.

(4) To minimize confusion, the term 'test result' has been defined in EN 13791:2019, 3.1.5 as:

'arithmetic mean of the measurements or in the case of a rebound number the median of the measurements taken at a test location'.

If a single ≥ 75 mm diameter core is taken, the test result for the test location is a single measurement. The approach in EN 13791 is similar to that used in EN 206 with respect to a compressive strength test result, which is the average of the individual cylinder/cube measurements.

(5) In most cases the test result is sufficient to have confidence that the test result reflects the measured property at the test location; the exception being when there are less than the recommended minimum number of 50 mm diameter cores given in Table 4 of EN 13791:2019.

(6) EN 13791 does not include requirements on the range of individual measurements for a test result such as the within 15 % of the mean value for moulded specimens to EN 206:2013+A1:2016 [5], but this is something to consider for a future revision of EN 13791.

(7) It was recognized that in certain situations, what is of interest is only the average *in situ* compressive strength and the characteristic *in situ* compressive strength of the element(s) under investigation and not the strengths at individual test locations. In such cases a procedure for using more test locations with single small diameter core values is specified. With this procedure the values of the average and characteristic *in situ* compressive strengths are reliable estimates; however, a single small diameter core is not reliable as the estimate of the *in situ* strength at a test location.

11 Core testing and the determination of the *in situ* compressive strength in EN 13791:2019, Clause 6

(1) Current practice in Europe is to use cores with a length: diameter ratio of either 2:1 or 1:1.

(2) As the *in situ* compressive strength is defined in terms of the test result for a 2:1 core, the test result for a 1:1 core is converted to *in situ* strength by multiplying it by a *CLF* where EN 13791:2019 specifies a default value of 0,82 for normal-weight or heavyweight concrete except where a different value has been

proven by testing. How a different *CLF* is 'proven' is not specified. See 5.2 for further information on this factor.

(3) By providing a practical tolerance on the length, the need for any other length: diameter ratio will be exceptional. Consequently no conversion for these other length: diameter ratios is provided in EN 13791.

(4) Smaller diameter cores are more variable than larger diameter cores and to achieve the same confidence in the test result at a test location where 50 mm diameter cores are used, the minimum number of individual core strengths to achieve a test result has been increased.

(5) EN 13791:2007, A.3.1 [2], recommends for 1:1 cores three times as many 50 mm diameter cores but it does not define the associated upper aggregate size. This Standard requires conformity to EN 12504-1 [12] for core testing. EN 12504-1:2019 does not specify any upper aggregate size in relationship to the core diameter, but states that when the upper aggregate size to core diameter is greater than 1:3, aggregate size has a significant influence on the core strength. For a 50 mm diameter core this ratio aligns with a 17 mm upper aggregate size. EN 13791:2019 contains the same information about the influence of aggregate size on core strength.

(6) It is practice in some CEN Member Countries to use 50 mm diameter cores for concrete containing 20mm upper aggregate size, but consensus could not be reached on making this a permission in EN 13791. As EN 13791 does not contain a requirement on the ratio between the upper aggregate size and core diameter, provisions valid in the place of use may contain such a requirement.

(7) The minimum number of 50 mm diameter 1:1 cores for larger aggregate size is based on the information given in EN 13791:2007, Annex A and the Swiss requirements [13,14].

(8) EN 13791 does not provide requirements for 2:1 50 mm diameter cores due in part to lack of reliable data; however, it is far more practical to take 1:1 50 mm diameter cores. For example, a single 50 mm diameter core through a 200 mm thick slab can provide three 1:1 cores but only one 2:1 core. As a consequence there does not appear to be a need to provide requirements for 2:1 50 mm diameter cores.

(9) The moisture condition at testing has also changed. In EN 13791:2007 [2] there is a requirement to expose the cores to at least three days of laboratory air. The drier the core, the higher is the core strength. EN 13791 aims to test the core at its *in situ* moisture content as the objective of the EN 13791:2019, Clause 8 procedures is to estimate the *in situ* compressive strength at its existing moisture content. Coring may increase the moisture condition at the core surface, but this is offset to an unknown extent by the requirement to expose the cores to laboratory air for 16 hours to 24 hours prior to sulfur capping and/or testing.

(10) Grinding may also increase the moisture content of the core above that in the structure and so EN 12504-1 [12] permits a period of exposure after grinding of 16 to 24 h. If testing is delayed beyond this period, the core should be returned to its sealed container.

(11) There is evidence that with 20 mm upper aggregate size, 100 mm diameter 2:1 cores are approximately 7 % stronger than 2:1 50 mm diameter cores (see EN 12504-1 [12]), but there is insufficient evidence to quantify the difference for 1:1 cores and so it is not taken into account.

(12) There is a recommendation that cores should not contain reinforcement, but in practice this is not always possible. The risk of a core containing reinforcement is reduced if the core diameter is 50 mm. Reinforcement in a core will impact on the core strength. The presence of reinforcement in a core may be the reason a core is an outlier. EN 13791 provides no adjustments for core strength when the core contains reinforcement and therefore CEN Members are free to introduce requirements in their National Provisions.

12 Initial evaluation of the data set in EN 13791:2019, Clause 7

(1) This is a completely new clause. It requires for mature structures a check to confirm that the test region contains a single compressive strength class and the identification of outliers.