FORM 36
Version 4.4

Draft for Public Comment

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Title: **ASSESSMENT OF CONCRETE COMPRESSIVE STRENGTH IN STRUCTURES OR IN STRUCTURAL ELEMENTS**

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Commenting on drafts

Introduction

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Draft no: prEN 13791	Project no.: 1999/07970	DPC no.: 99/109836
Short title:	Commentator:	Date:

Clause/ subclause	Paragraph/ Figure/ Table	Type of comment (General/ technical/editorial)	Comment (with rationale)	Proposed change
Examples: 3.1	1st definition	Editorial	Definition is ambiguous and needs clarifying.	Amend to read '... so that the mains connector to which no connection ...'
6.4	2nd paragraph	Technical	The use of the UV photometer as an alternative cannot be supported as serious problems have been encountered in its use in the UK, giving rise to misleadingly high results.	Delete reference to UV photometer.

EUROPEAN STANDARD

NORME EUROPÉENNE

EUROPÄISCHE NORM

DRAFT

prEN 13791

December 1999

ICS

English version

Assessment of concrete compressive strength in structures or in structural elements

Bewertung der Druckfestigkeit von Beton in Bauwerken oder in Bauwerksteilen

This draft European Standard is submitted to CEN members for enquiry. It has been drawn up by the Technical Committee CEN/TC 104.

If this draft becomes a European Standard, CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

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EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

Central Secretariat: rue de Stassart, 36 B-1050 Brussels

Ref. No. prEN 13791:1999 E

99/109836

Foreword

This draft European Standard was prepared by CEN/TC104/SC1, "Revision of ENV 206".

This draft European Standard supplements prEN 206-1 Concrete - Performance, production and conformity, prEN 13670-1 Execution of concrete structures, Part 1: Common rules and rules for buildings and ENV 1991-1 Basis of design, for cases where there is a need to assess the compressive strength in the structure.

0 Introduction

This Draft European Standard is intended to serve as a link between material, execution and design standards for concrete. The standard will make adequate performance requirements possible in future.

In prEN 206-1 and in prEN 13670-1, reference is made to tests on cores taken out from structures and elements and to non-destructive tests.

The following examples illustrate when it may be necessary to estimate the in-situ concrete compressive strength and where this standard may be used as one possible action:

- In case of non-conformity of compressive strength obtained by standard specimens.
- When serious doubt arises about the concrete compressive strength in the structure.
- When an existing structure is to be modified or re-designed.
- When deterioration of the concrete due to fire or other causes has to be assessed.
- When a relationship between the test method for assessment of the concrete compressive strength and the in-situ compressive strength is to be established.
- When an estimate of the in-situ concrete compressive strength is needed at various stages during construction, e.g. at prestressing, stripping.

This Draft European Standard is not intended to be used for the regular assessment of the conformity of the concrete compressive strength unless specified in the relevant product standard.

By knowing the in-situ concrete compressive strength as well as the strength of standard test specimens, it is possible to evaluate the uncertainty that is covered by the partial safety factor γ_m, and the design value can in consequence be modified. This could be used in development of an economical design system and at safety considerations. Further, there may also be a need to introduce the concept of the critical in-situ compressive strength.

1 Scope

This standard

- Gives a method for the assessment of compressive strength of concrete in concrete structures or elements.
- Outlines procedures for testing of concrete compressive strength in structures or elements.
- Provides criteria for evaluation of test results.
- Provides equivalent requirements for compressive strength in structures and elements.

Provides guidance and requirements for establishment of the relationship between the test results from indirect test methods (other than core tests) and the in-situ strength of the structure or element (as assessed by cores) and describes assessment of concrete strength in structures or structural elements by indirect methods.

2 Normative References

prEN 206-1
Concrete – Part 1: Specification, Performance, production and conformity

ENV 1991-1
Basis of design and actions on structures - Part 1: Basis of design

ENV 1992-1-2
Eurocode 2 - Design of concrete structures - Part 1-2: General rules; structural fire design

prEN 12504-1
Testing concrete in structures – Part 1: Cored specimens - Taking, examining and testing in compression

prEN 12504-2
Testing concrete in structures – Part 2: Non-destructive testing - Determination of rebound number

prEN 12504-3
Testing concrete in structures – Part 3: Determination of pull-out force

prEN 12504-4
Testing concrete in structures – Part 4: Determination of ultrasonic pulse velocity

prEN 12390-1
Testing hardened concrete – Part 1: Shape, dimensions and other requirments of specimens

prEN 12390-3
Testing hardened concrete – Part 3: Compressive strength of test specimens

prEN 13670-1
Execution of concrete structures – Part 1: Common rules and rules for buildings

3 Definitions and symbols

3.1 Definitions

3.1.1 Standard compressive strength

The standard compressive strength is the measured compressive strength of a standard test specimen which is sampled, made, cured and tested in accordance with the standard test methods prEN 12390-1 and prEN 12390-3.

3.1.2 Potential strength

The potential strength is the estimated strength value from a number of standard specimens.

3.1.3 Core compressive strength

The core compressive strength is the measured compressive strength of a core determined in accordance with prEN 12504-1.

3.1.4 In-situ compressive strength

The in-situ compressive strength is the compressive strength of concrete in a structure or in a structural element expressed as the strength of the standard specimen. The in-situ compressive strength is estimated from tests on a number of cores drilled from the structure or the structural element or it is estimated from a number of indirect tests on the structure or the structural element.

3.1.5 Characteristic in-situ compressive strength

The characteristic in-situ compressive strength is defined as that value of strength below which 5% of the population of all possible strength determinations of the volume of concrete under consideration, are expected to fall.

3.1.6 Test result

A test result is

the result obtained from a core test.

- the result obtained by an indirect method, consisting of one or several readings taken from a test area.
- the estimate of in-situ strength from a test area.

3.1.7 Test area

A limited area which is selected for measuring the properties, i.e. from which one core is drilled out or on which one rebound test result, pulse velocity test result or pull-out force test result is determined.

3.1.8 Test region

One or several structural elements produced under similar conditions constitute a test region. A test region contains several test areas.

A test region is a part of a structure in which

- the strength has to be assessed.
- the properties of concrete may be assumed to be distributed in the same way, which is to say that the concrete is assumed to belong to the same population.

3.2 Symbols

f_{ck} = characteristic compressive strength of standard specimens

$f_{ck,is}$ = characteristic in-situ compressive strength

f_{is} = in-situ compressive strength

$f_{m(n),is}$ = in-situ mean compressive strength of n test results

R = rebound number

v = pulse velocity

F = pull-out force

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4 Principles

Testing of cores provides a direct and the best estimate of the in-situ compressive strength.

Methods other than tests on cores do not directly provide the in-situ compressive strength and thus the reference method shall be the core test. Before an indirect test method is used for the assessment of in-situ strength, a relationship has to be established.

The in-situ compressive strength is classified into standardised strength classes by utilising an empirical relationship between the compressive strength of standard test specimens and the in-situ compressive strength. For each strength class a characteristic in-situ strength value is given.

By calculating the characteristic in-situ compressive strength from the test results, and using the classified requirements for in-situ compressive strength, an estimate of the corresponding strength class for design is obtained.

5 Classification of characteristic in-situ strength in relation to strength class

In Table 1 the in-situ compressive strength is classified in respect of the strength classes according to prEN 206-1.

The requirements for in-situ compressive strength are by analogy with requirements for strength classes in prEN 206-1, expressed in terms of the characteristic strength defined as that strength below which 5% of the population of all possible strength determinations, of the considered volume of the concrete in the structure, are expected to fall.

The classification in Table 1 is appropriate to the definition of characteristic strength when assessed either using in-situ or standard tests.

Table 1. In-situ compressive strength requirements for the strength classes according to prEN 206-1.

Strength class	Characteristic strength N/mm²		Ratio of in-situ to characteristic strength	In-situ characteristic strength N/mm²	
	$f_{ck,cyl}$	$f_{ck,cube}$		$f_{ck,is,cyl}$	$f_{ck,is,cube}$
C8/10	8	10	0,85	7	9
C12/15	12	15	0,85	10	13
C16/20	16	20	0,85	14	17
C20/25	20	25	0,85	17	21
C25/30	25	30	0,85	21	26
C30/37	30	37	0,85	26	31
C35/45	35	45	0,85	30	38
C40/50	40	50	0,85	34	43
C45/55	45	55	0,85	38	47
C50/60	50	60	0,85	43	51
C55/67	55	67	0,85	47	57
C60/75	60	75	0,85	51	64
C70/85	70	85	0,85	60	72
C80/95	80	95	0,85	68	81
C90/105	90	105	0,85	77	89
C100/115	100	115	0,85	85	98

NOTE 1: The in-situ compressive strength may be less than that measured on standard test specimens taken from the same batch of concrete. This is due to the different compacting and curing conditions. In design these differences are taken into account within the partial safety factor γ_c (or γ_m). If the in-situ strength for design purposes is used the partial safety factor can be reduced without reducing the safety level. The actual reduction will vary dependent on local γ values. Ratio 0,85 corresponds to γ_c = 1,5 in ENV 1992-1-2.

NOTE 2: The relationship in Table 1 has been obtained by testing of cores taken from the top pour of structures and elements that have been produced in accordance with standards of good practice. Different values to the ratio 0.85 may be applicable for other compaction and curing standards.

6 Assessment of characteristic in-situ compressive strength by testing of cores

6.1 Type of specimens

The in-situ strength may be measured by

1. Testing cores with length and diameter equal to 100 mm or up to 150 mm, which provide a strength value directly comparable with the strength of a standard cube 150 mm.
2. Testing cores of other sizes or with length to diameter ratios other than 1. In this case the in-situ strength is obtained by using appropriate conversion factors and number of specimens.

Cores with diameter less than 50 mm shall not be used.

6.2 Testing procedure

In-situ strength can be estimated by core testing provided that due account is taken of influencing factors such as shape and size of test specimens, treatment of end surfaces, moisture condition of specimens, testing procedure and age.

Apparatus, taking of cores, examination, preparation of cores, compression testing and expression of test results shall be according to prEN 12504-1.

If the cores are to be tested in air dry condition, the samples shall be allowed to dry for at least 3 days in laboratory atmosphere.

6.3 Number of test specimens

Usually, an assessment should be based on specimens from at least 9 cores from one test region.

An assessment of a particular structural element may be based on specimens from 3 cores from the element.

The number of specimens, mentioned above relates to cores with diameter 100 mm or more. The number of cores shall be increased when the diameter is less than 100 mm.

NOTE: When the core diameter is 50 mm, it may be appropriate to use three times the number cores used for 100 mm cores. For core diameters between 100 and 50 mm the number of cores may be obtained by a rectilinear interpolation.

6.4 Criteria

Conformity of in-situ compressive strength is assessed on core strength either by criteria A or B.

Criteria A are applied when 3 to 14 cores taken from one or several structural elements (beam, slab, column etc.) are available.

Criteria B are applied when at least 15 cores, taken from several structural elements from the same test region are available.

Criteria A

Conformity is assessed for

- mean ($f_{m(n),is}$) of n non-overlapping test results, criterion 1.
- each (f_{is}) test result, criterion 2.

$$f_{m(n),is} \geq f_{ck,is} + k_1 \qquad (1)$$

$$f_{is} \geq f_{ck,is} - 4 \qquad (2)$$

$f_{m(n),is}$ = in-situ mean strength of n test results

f_{is} = in-situ strength test result

$f_{ck,is}$ = characteristic in-situ compressive strength according to Table 1

k_1 = coefficient dependent on the number of test results n

k_1 = 4, when n = 10-14

k_1 = 5, when n = 7-9

k_1 = 6, when n = 3-6

Criteria B

Conformity is assessed for

- mean ($f_{m(n),is}$) of groups of n non-overlapping test results, criterion 1.
- each (f_{is}) test result, criterion 2.

$$f_{m(n),is} \geq f_{ck,is} + 1.48 \cdot s \qquad (3)$$

$$f_{is} \geq f_{ck,is} - 4 \qquad (4)$$

s = standard deviation of test results, but not less than 2 MPa

7 Assessment of characteristic in-situ compressive strength by indirect Methods

7.1 General

This clause applies to methods other than core tests, which are used for strength estimation in-situ. The indirect tests provide alternatives to core tests for estimating the in-situ compressive strength of concrete in a structure, or can supplement the data obtained from a limited number of cores. The indirect methods are limited-destructive or non-destructive in nature and they may be used singly or in combination.

By a test with an indirect method a quantity other than strength is measured and it is thus necessary to use a relationship between the result of indirect tests and the compressive strength of cores.
Procedures for estimation of in-situ compressive strength are provided for three alternative ways.

Alternative 1 - Direct correlation with cores

A procedure applicable on a general basis for estimation of in-situ compressive strength, when a specific relationship between the in-situ strength and the test result by the method is established for the concrete under consideration, is described in section 7.3.

Alternative 2 - Calibration with cores for a limited strength range using a basic relationship

Procedures for estimation of in-situ strength within a limited range of strengths, based on basic relationships together with corrections established by means of core tests are described for rebound hammer tests, ultrasonic pulse velocity tests and pull-out tests in sections 7.4, 7.5 and 7.6.

The calibration procedure includes:

- selecting test areas for calibration.
  - determining in-situ compressive strengths, by means of core tests f_{is}
  - determining test results, R, v or F for rebound hammer tests, ultrasonic pulse velocity tests and pull-out tests respectively.
  - calculating a correction δf for each test area and a safe correction factor Δf for use in estimation of in-situ compressive strength.
  - calculating the range of test results for which the correction factor Δf is valid.

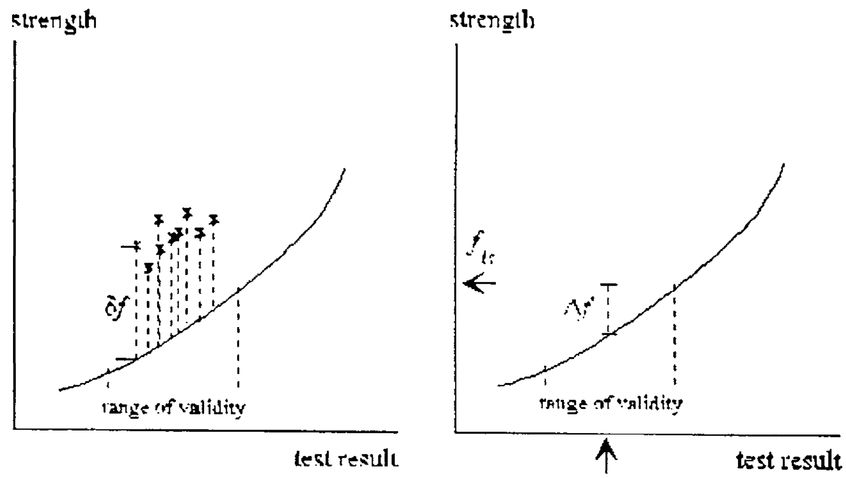

Figure 1. Calibration of the basic relationship with core tests.

x represents in-situ compressive strength versus the test result by the indirect method for one test area.

Figure 2. Use of a basic relationship for estimation of in-situ compressive strength.

Alternative 3 - Use of a standardised safe relationship for rebound hammer tests

A procedure for assessment of strength class based on rebound hammer tests without correction by means of core tests is described in section 7.7.

For the investigation of uniformity of in-situ strength reference should be made to Annex A.

Test results assessed by indirect test methods can be influenced by various factors other than concrete strength. Reference is made to Annex C for a description of such influencing factors.

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7.2 Assessment of characteristic strength

7.2.1 General

Criteria for assessment of results obtained by indirect test methods, which are consistent with the existing criteria for core strengths, are not available on a general basis for all indirect methods. Therefore no criteria for equivalent in-situ compressive strength based on indirect tests, analogous to the criteria for testing of cores have been established.

7.2.2 Number of tests

An assessment of characteristic in-situ compressive strength is based on at least 15 strength estimates f_{is} by one or more indirect methods, taken from several structural elements from the same test region. The strength estimates may be supplemented by estimates from core tests.

7.2.3 Criteria

Conformity of in-situ compressive strength is assessed on in-situ strength estimated by an indirect method, using criteria B.

The estimate of in-situ compressive strength, f_{is}, is obtained according to clauses 7.3.5, 7.4.5, 7.5.5 or 7.6.5.

Criteria B

Conformity is assessed for

- mean ($f_{m(n),is}$) of groups of n non-overlapping test results, criterion 1.
- each (f_{is}) test result, criterion 2.

$$f_{m(n),is} \geq f_{ck,is} + 1.48 \cdot s \quad (5)$$

$$f_{is} \geq f_{ck,is} - 4 \quad (6)$$

$f_{m(n),is}$ = in-situ mean strength estimated from n test results

s = standard deviation of test results, but not less than 2 MPa

7.3 Indirect tests correlated with in-situ strength

7.3.1 Application

This clause is applicable to indirect test methods for estimation of in-situ compressive strength when a specific relationship for the in-situ concrete is established by means of tests on cores.

7.3.2 Considerations on precision

The tests with some indirect methods are sensitive to the local conditions where the test is performed. In such cases more than one reading shall be taken. The test result is then taken as the mean or median value of the readings by the method. The number of readings required and the basis for discarding suspect readings is specified in the test method prEN12504-2 when the rebound number is measured. For other methods the repeatability must be considered in order to determine the precision of the test result.

7.3.3 Testing procedure

The apparatus, the test procedure and the expression of test results shall be in accordance with prEN 12504-2, prEN 12505-3 and prEN 12504-4 when rebound number, pull-out force or ultrasonic pulse velocity is measured.

The correct functioning of the test apparatus shall be checked with calibration devices.

7.3.4 Relationship between test result and in-situ compressive trength

7.3.4.1 Testing programme

To establish a specific relationship between the in-situ strength and the test result by the indirect method, a comprehensive testing programme has to be carried out.

A set of observations is made for structural elements of a particular concrete.

At least 6 structural elements shall be sampled for each relationship. These elements should provide the largest possible range of core strengths. On each structural element 3 test areas shall be selected. From each test area 1 core shall be taken and an appropriate number of readings by the indirect test method shall be taken for a test result. The numbers of readings by the indirect test method are chosen so that the in-situ strengths by core testing and the indirect test results are measured with the same degree of certainty.

NOTE 1: These numbers are a minimum but in many cases it is advantageous to have a considerably higher number of observations in the data set to establish a relationship.

The number of structural elements and test areas may be changed depending on the actual conditions, provided that at least 18 cores are taken. If a tested element is too small to provide three test areas the number of elements should be increased.

NOTE 2: If the structural element tested is large enough to consist of several batches of concrete it may be difficult to define three test areas corresponding to a certain level of concrete strength. It may then be advantageous to conduct a series of indirect tests to locate areas of different strength levels (uniformity testing). At least 18 cores taken from the chosen areas will give a range of strengths.

7.3.4.2 Establishing a relationship

A relationship between the result by the indirect test method and the measured in-situ strength from core specimens is established.

The procedure for establishing a relationship is described by the following steps:

1. The best fit line or curve is determined by regression analysis on the data pairs that are obtained in the testing programme. The test result is viewed as a variable and the estimated compressive strength as a function of that variable.

NOTE: The data used for obtaining the best-fit curve or line should be evenly spaced within the limits that are covered by data.

2. The standard error of estimate shall be computed and the confidence limits for the best-fit line or curve hall be determined as well as the tolerance limits for individual observations.

3. The relationship, which is used for strength estimation, is determined as the lower ten percentile of strength.

The relationship which is used for strength estimation is given a safe level where 90% of the strength values at that particular confidence level are expected to fall above the relationship line or curve i.e. give strength estimates on the safe side.

7.3.4 Estimation of in-situ compressive strength

An estimate of the in-situ compressive strength is derived from the established relationship. A test result by the indirect method is used to estimate the in-situ compressive strength f_{is}.

The relationship shall only be used for direct estimation of in-situ strength for the type of concrete and conditions for which it was established.

The relationship shall only be used within the range covered by test data.

For evaluation of conformity clause 7.2 applies.

7.4 Rebound hammer tests calibrated by core tests

7.4.1 Application

This clause is applicable to rebound hammer testing for in-situ strength estimation when calibration is undertaken with cored samples. In-situ strength is estimated using a basic relationship and a correction valid for the particular concrete.

7.4.2 Testing procedure

The equipment and test procedure shall be in accordance with prEN 12504-2 both for calibration measurements and for measurements used for strength estimation. A test result should be based on a number of rebound readings chosen so that the indirect test result is measured with the same degree of certainty as the result from testing one core.

Due account shall be taken of influencing factors such as treatment of test surface, hammer orientation and age at test.

A calibration procedure with paired observations of rebound test results and core strengths is used to determine a correction factor to the basic relationship which is used for strength estimation.

7.4.3 Basic relationship used together with corrections for estimation of in-situ compressive strength

A basic relationship between rebound hammer test results R and rebound strength f_R is given in Figure 3. The basic relationship is valid for Schmidt Rebound hammer type N and normal weight concrete. The basic relationship represents the lower boundary curve of expected test results. This relationship is used for estimation of in-situ strength f_{is} only when combined with a correction determined by testing of cores taken from the specific concrete, unless a more precise relationship is available.

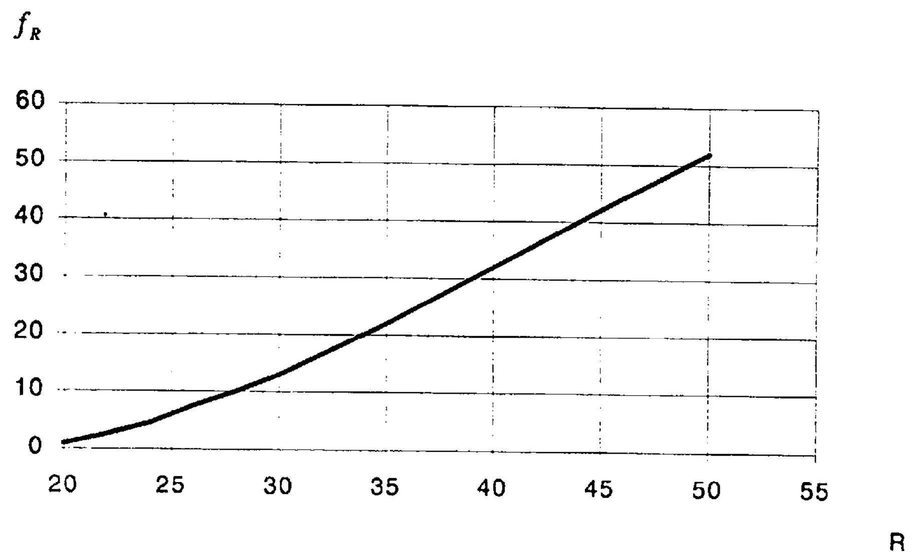

Figure 3. **Basic relationship between rebound test result R and rebound strength f_R according to alternative 2.**

7.4.4 Calibration Tests

One test region of a structural component is selected for calibration. The region shall be large enough to provide at least 9 test areas for taking rebound readings and taking out cores.

The rebound test result R is determined for each test area and the rebound strength f_R is estimated from Figure 3, based on the rebound test result R for the specific test area.

From each test area a core is taken out and tested for in-situ compressive strength f_{is} according to prEN 12504-1.

Correction factor, Δf

For each test area a correction δf is calculated

$$\delta f = f_{is} - f_R$$

where f_R (rebound strength) is the strength reading from Figure 3 based on the rebound test result R for the specific test area and f_{is} is the in-situ compressive strength in [MPa], from the corresponding core.

The mean value $\delta f_{m(n)}$ of the n corrections δf and the standard deviation s of the corrections shall be calculated.

The correction factor Δf , which is used for estimation of in-situ compressive strength, is calculated.

$$\Delta f = \delta f_{m(n)} - k \cdot s$$

The value of the coefficient k is dependent on the number of test results in accordance with Table 2.

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Table 2. Coefficient k

Number of test results n	Coefficient k
9	1.67
10	1.62
11	1.58
12	1.55
13	1.52
14	1.50
≥15	1.48

Validity

The correction is valid for estimation of in-situ strength of the particular concrete and conditions for which it was established. The correction is valid for rebound test results that are within the range of ± 2 units outside the range of rebound results at the calibration.

7.4.5 Estimation of in-situ compressive strength

The in-situ compressive strength is estimated from the rebound strength using the correction determined from a calibration with results from cores.

The rebound strength is derived from the given relationship based on a rebound test result.

The in-situ strength f_{is} for a test area is estimated as

$$f_{is} = f_R + \Delta f$$

f_{is} = estimated in-situ strength [MPa]

f_R = strength value obtained from Figure 3

Δf = correction factor according to section 7.4.4

For evaluation of conformity clause 7.2 applies.

7.5 Ultrasonic pulse velocity tests calibrated by core tests

7.5.1 Application

This clause is applicable to ultrasonic pulse velocity tests for in-situ strength estimation when a specific relationship for the in-situ concrete is not determined. Calibration with cored samples is required. In-situ strength is estimated using a basic relationship and a correction valid for the particular concrete.

7.5.2 Testing Procedure

The apparatus, the test procedure and the expression of test results shall be in accordance with prEN 12504-2 when ultrasonic pulse velocity v is measured, both for calibration measurements and for measurements used for strength estimation. A test result should be based on a number of measurements of ultrasonic pulse velocity chosen so that the indirect test result is measured with the same degree of certainty as the result from testing one core.

A calibration procedure with paired observations of pulse velocity results and core strengths is used to determine a correction factor that is used for estimation of in-situ strength.

7.5.3 Basic relationship used together with corrections for estiation of in-situ compressive strength

A basic relationship between ultrasonic pulse velocity test results v and ultrasonic pulse velocity strength f_v is given in Figure 4. The basic relationship is valid for normal weight concrete made with cement of type CEM I. The shape of the basic relationship is in accordance with extensive test data. The basic relationship represents the lower boundary curve of expected test results. This relationship is used for estimation of in-situ strength f_{is} when combined with a correction determined by testing of cores taken from the specific concrete, unless a more precise relationship is available.

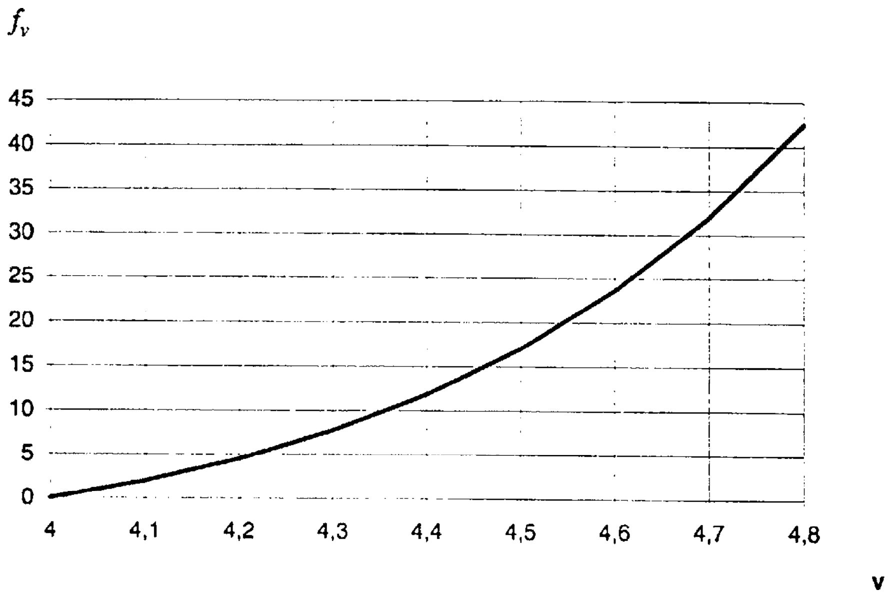

Figure 4. Basic relationship between ultrasonic pulse velocity test result v [km/s] and pulse velocity strength f_v according to alternative 2.

7.5.4 Calibration

One test region of a structural component is selected for calibration. The region shall be large enough to provide at least 9 test areas for making pulse velocity measurements and taking out cores.

The pulse velocity test result v is determined for each test area and the ultrasonic pulse velocity strength f_v is estimated from Figure 4, based on the pulse velocity test result v for the specific test area.

From each test area a core is taken out and tested for in-situ compressive strength f_{is} according to prEN 12504-1.

Correction factor, Δf

For each test area a correction δf is calculated

$$\delta f = f_{is} - f_v$$

where f_v (pulse velocity strength) is the strength reading from Figure 4 based on the pulse velocity test result v for the specific test area and f_{is} is the in-situ compressive strength in [MPa], from the corresponding core.

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The mean value $\delta f_{m(n)}$ of the n corrections δf and the standard deviation s of the corrections shall be calculated.

The correction factor Δf, which is used for estimation of in-situ compressive strength, is calculated.

$$\Delta f = \delta f_{m(n)} - k \cdot s$$

The value of the coefficient k is dependent on the number of test results in accordance with Table 2.

NOTE: The numerical value of the correction factor is influenced by the experimental data in relation to the basic relationship.

Validity

The correction is valid for estimation of in-situ strength of the particular concrete and conditions for which it was established. The correction is valid for ultrasonic pulse velocity test results that are within the range of ± 0.05 km/s outside the range of pulse velocity test results at the calibration.

7.5.5 Estimation of in-situ compressive strength

The in-situ compressive strength is estimated from the ultrasonic pulse velocity strength using the correction determined from a calibration with results from cores.

The pulse velocity strength is derived from the given relationship based on a pulse velocity test result.

The in-situ strength f_{is} for a test area is estimated as

$$f_{is} = f_v + \Delta f$$

f_{is} = estimated in-situ strength [MPa]
f_v = strength value obtained from Figure 4
Δf = correction factor according to section 7.5.4

For evaluation of conformity clause 7.2 applies.

7.6 Pull-out tests calibrated by core tests

7.6.1 Application

This clause is applicable to pull-out tests for in-situ strength estimation when a specific relationship for the in-situ concrete is not determined. Calibration with cored samples is required. In-situ strength is estimated using a basic relationship and a correction valid for the particular concrete.

7.6.2 Testing Procedure

The apparatus, the test procedure and the expression of test results shall be in accordance with prEN 12504-3 when pull-out force F is measured.

A test result should be based on a number of measurements of pull-out force chosen so that the indirect test result is measured with the same degree of certainty as the result from testing one core.

7.6.3 Basic relationship used together with corrections for estimation of in-situ compressive strength

A basic relationship between pull-out force F and pull-out strength f_F is given in Figure 5. The basic relationship is valid for Lok-tests and Capo-tests on normal weight concrete made with cement of type CEM I. The basic relationship represents the lower boundary curve of expected test results. This relationship is used for estimation of in-situ strength f_{is} when combined with a correction determined by testing of cores taken from the specific concrete, unless a more precise relationship is available.

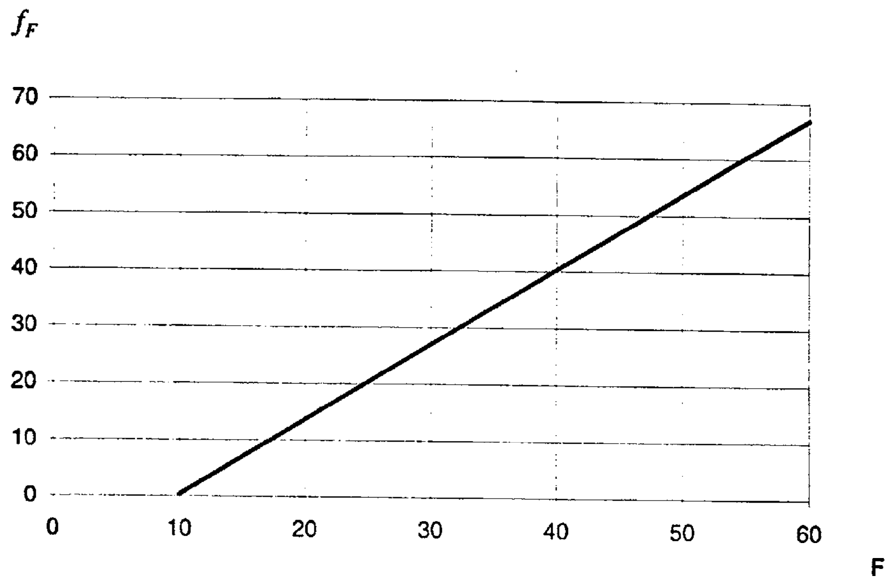

Figure 5. **Basic relationship between pull-out force F [kN] and pull-out strength f_F according to alternative 2.**

7.6.4 Calibration Tests

One test region of a structural component is selected for calibration. The region shall be large enough to provide 9 test areas for measuring pull-out force and taking out cores.

The pull-out force is determined for each test area.

From each test area a core is taken out and tested for in-situ compressive strength f_{is} according to prEN 12504-1.

Correction factor, Δf

For each test area a correction δf is calculated

$$\delta f = f_{is} - f_F$$

where f_F (pull-out strength) is the strength estimated from the basic relationship in 7.6.3 based on the pull-out force F for the specific test area and f_{is} is the in-situ compressive strength in [MPa] from the corresponding core.

The mean value $\delta f_{m(n)}$ of the n corrections δf and the standard deviation s of the corrections shall be calculated.

The correction factor Δf, which is used for estimation of in-situ compressive strength, is calculated.

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$$\Delta f = \delta f_{m(n)} - k \cdot s$$

The value of the coefficient k is dependent on the number of test results in accordance with Table 2.

NOTE: The numerical value of the correction factor is influenced by the experimental data in relation to the basic relationship.

Validity

The correction is valid for estimation of in-situ strength of the particular concrete and conditions for which it was established. The correction is valid for pull-out test results that are within the range of ± 2.5 kN outside the range of pull-out test results at the calibration.

7.6.5 Estimation of in-situ compressive strength

The in-situ compressive strength is estimated using the correction determined from a calibration with results from cores.

The pull-out strength is derived from the given relationship based on a pull-out test result.

The in-situ strength f_{is} for a test area is estimated as

$$f_{is} = f_F + \Delta f$$

f_{is} = the estimated in-situ strength [MPa]
f_F = strength value obtained from figure 5
Δf = correction factor according to 7.6.4

For evaluation of conformity clause 7.2 applies.

7.7 Rebound hammer tests without calibration with cores

7.7.1 Application

This clause is applicable to rebound hammer tests when calibrations with cores are not made. The strength class can for certain purposes be estimated directly from the rebound hammer test result R.

The evaluation of the rebound hammer test results permits only a statement about the in-situ compressive strength at the time of testing. A conversion to any other age is in general not possible.

7.7.2 Testing procedure

The equipment and test procedure shall be in accordance with prEN 12504-2.

Due account must be taken of influencing factors such as treatment of test surface, hammer orientation and age.

7.7.3 Number of tests

For the classification of the concrete in a test region, at least 9 test areas shall be examined with rebound hammer tests.

7.7.4 Classification of rebound value in relation to strength grade

The concrete is assessed both for the mean value R_m of the test results from the 9 test areas (i.e. one test region) and for each individual test result R of a test area. The assessment is valid for test results with Schmidt Rebound hammer type N and normal weight concrete.

Conformity with the strength classes according to prEN 206-1 is confirmed when the test results satisfy both the criteria given in table 3.

Table 3.Conformity criteria for rebound hammer test results.

Criterion 1	Criterion 2	Strength Class
Minimum value for the mean of rebound hammer test results, R_m	Minimum value for individual rebound hammer test results, R	
30	26	C8/10
33	30	C12/15
36	33	C16/20
38	35	C20/25
41	38	C25/30
44	41	C30/37
48	45	C35/45
50	47	C40/50
53	50	C45/55

NOTE: This application has severe limitations since it produces a very safe estimate of the actual in-situ compressive strength.

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ANNEX A (informative)

Assessment of uniformity of in-situ strength

A.1 Field of application

This annex applies to all methods that can be used for assessment of uniformity of in-situ strength. This annex applies to limited-destructive or non-destructive methods, which reflect variations in concrete strength when, used without calibrations with cored samples as described in section 8.

A.2 Testing procedure

The test apparatus shall be checked for correct functioning.

The test procedure shall be in accordance with a standard applicable to the test method or according to information provided by the manufacturer.

A.3 Estimation of uniformity of strength

The relationship between the reading by the test method and concrete strength may be taken from published information by a research establishment or the manufacturer of the equipment.

A strength estimate obtained from a relationship curve that is not made for the particular concrete, is not an estimate of the actual in-situ strength. The results may be used for estimation of the variation of the in-situ strength within a particular concrete.

ANNEX B (informative)

B Factors influencing core strength

B.1 General

Factors influencing core strength may be assigned to the categories according to whether the influence is related to a characteristic of the concrete or is caused by a testing variable.

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.

B.2 Concrete characteristics

B.2.1 Moisture content

The moisture content of the core will influence the measured strength. The strength of a saturated core is 10-15 % lower than that of a comparable dry core.

B.2.2 Curing conditions

The curing conditions will influence the measured strength. The strength increases with maturity.

B.2.3 Porosity

Increased porosity decreases the strength. Approximately 1% porosity decreases the strength by 5%-8%.

B.2.4 Direction relative to the casting

The measured strength of a core, drilled vertically, in the direction of casting may, 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 between 0 to 8 %.

From walls and columns cores are drilled horizontally, from slabs vertically and from beams horizontally or vertically. Standard cubes are normally tested at right angles to the direction of casting, i.e. in the same direction as horizontally drilled cores.

B.2.5 Imperfections

Flaws can occur in cores from various causes. These include water gain beneath horizontal reinforcement or 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.

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B.3 Testing variables

B.3.1 Diameter of core

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

As the diameter decreases for the same length of core, the ratio of cut surface area increases. Due to this the variability in strength increases and the strength level can be expected to change as the diameter reduces.

The variability of the measured strength increases when the ratio, diameter to maximum aggregate size decreases.

B.3.2 Length/diameter ratio

The ratio length/diameter influences the measured strength.

B.3.3 Flatness of end surfaces

Deviation from flatness decreases the measured strength. The tolerance for flatness should be the same as for standard specimens.

B.3.4 Capping of end surfaces

Caps of low strength will decrease the strength. Thin caps of high strength mortar will not significantly influence the strength. Grinding of end surfaces is preferred.

B.3.5 Effect of drilling

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

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.

B.3.6 Reinforcement

Cores used to measure strength of concrete should not contain steel. 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 shall not be used in tests for strength.

ANNEX C (informative)

Factors influencing results by indirect test methods

C.1 Rebound hammer tests

The relationship between strength and rebound number can be affected by both characteristics of the concrete and test conditions. These factors are outlined in Annex B of prEN 12504-2 and should be considered when evaluating test results.

Further information on establishing correlation between strength and rebound number is also given in Annex A of prEN 12504-2

C.2 Ultrasonic pulse velocity measurements

The relationship between strength and ultrasonic pulse velocity measurements can be affected by both characteristics of the concrete and test conditions. These factors are outlined in Annex B of prEN 12504-4 and should be considered when evaluating test results.

Further information on establishing correlation between strength and ultrasonic pulse velocity is also given in Annex C of prEN 12505-4.

C.3 Pull-out tests

The relationship between strength and measured pull-out force can be affected by both characteristics of the concrete and test conditions.

Some possible factors are:

- Aggregate type
- Compaction on calibration
- Curing on calibration
- Moisture condition at test
- Depth of embedment
- Surface abnormalities

ANNEX D (informative)

Concepts concerning the relationship between in-situ strength and potential strength

The compressive strength of cores and in-situ strength will generally be less than that measured on standard test specimens, potential strength, taken from the same batch of concrete. This is due to a range of factors including the degree of compaction and curing in practical site conditions and dependent on the location in the member where in-situ strength is determined. Tests on in-situ concrete indicate the following:

a) In-situ strength can vary within a structural member both randomly and, often, in an ordered fashion.

b) The magnitude of variations of in-situ strength within structural members may vary from one member to another.

c) With height of a concrete pour, in-situ strength decreases toward the top of a pour, even for slabs, and can be up to 25% less at the top than in the body of the concrete. Concrete of lower strength is often concentrated in the top 300 mm or 20% of the depth whichever is the less.

Figure D.1 illustrates the numerical differences for the different strengths linked to one batch of concrete cast into a structural member such as a column. It is an example only based on particular site conditions using average constants and rounding to the nearest MPa. Cores are assumed to have a diameter and length equal to 100 mm, e.g. length/diameter ratio (λ) equal to 1.

Design of reinforced and prestressed concrete structure is based on the commonly accepted principle that concrete can be considered as a randomly variable material, the test results of which follow a normal distribution. Differences between in-situ strength of concrete and that of standard specimens are inevitable. In design, these differences among other factors are taken into account by the introduction of the partial safety factor for strength γ_c. For the analysis of sections the design strength is given by f_{ck} / γ_c where f_{ck} is the characteristic strength based on standard specimens. Where the in-situ characteristic strength can be better defined the partial safety factor is capable of being reduced.

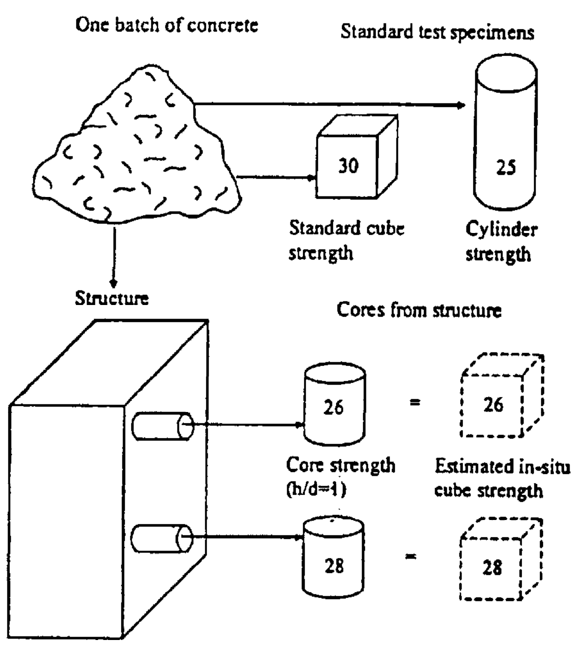

Figure D.1. Illustrative example of approximate relationship of compressive strengths.

ANNEX E (informative)

Guidelines for planning, sampling and evaluation of test results when assessing in-situ strength

E.1 Planning

The purpose for the examination of in-situ strength in a structure affects the planning of test regions. One or several test regions are identified, and within each test region a number of test areas are selected. The choice of the size of test areas depends on the test method used.

The number of test areas in each test region is chosen. The number of test results from a test region influence the reliability of the assessment.

When the strength class in a whole building, structure or structural components is to be assessed by determining the in-situ strength then it shall be divided into test regions in which the concrete may be assumed to belong to the same population and be representative of the general quality.

Consideration should be given in assessing the in-situ strength, that the strength of the concrete usually is lowest in the vicinity of the top surface of the structural member or element, and that the strength then increases, as the depth below the top surface becomes greater.

In the cases where the bearing capacity is to be assessed, the test regions should be concentrated to the significantly stressed parts of the structure.

When the type or extent of a damage is to be estimated, the test regions should be concentrated to the parts where harmful effects are known, or may be supposed to have occurred. In these cases it may be beneficial to compare with samples taken from undamaged parts.

E.2 Sampling

The individual test areas in each test region should be sampled at random in conformity with statistical principles.

The amount of cores taken or non-destructive measurements made will depend on the method used for estimation of in-situ strength. Some information on size of test area, number of tests etc. is given in prEN12504-1, prEN12504-2, prEN 12504-3 and prEN 12504-4.

Generally, sampling should be planned in such a way as to make sure that the random sample taken from a structural element or structure represents the distribution of the properties of the concrete in the whole element or structure.

E.3 Testing programme

The method of testing should be specified together with the test regions and the number of tests to be taken from each test region.

E.4 Evaluation

Estimation of in-situ strength involves consideration of the age at testing and the moisture conditions in the structure. The strength of the concrete may be assessed at any age, but the age should be reported and taken into account if necessary.

In the cases where for instance the load-bearing capacity of a structure is of interest, it is mainly the strength at the time of testing (actual in-situ strength) that is of interest. Therefore, a conversion to 28-day strength is not necessary in such cases, unless it is required for special reasons.

The moisture conditions in the structure should be taken into account. In cases where the actual in-situ strength is assessed in a structure or element in wet conditions, the cores shall be tested in saturated condition, similarly, the actual in-situ strength in a structure or element in dry conditions shall be assessed

on cores tested in dry condition. In cases where the strength class is assessed the cores should be tested in the same condition as the corresponding standard specimens, i.e. dry or saturated

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In evaluating the critical in-situ compressive strength use may be made of cores drilled in other directions than the direction of the main compressive force, provided it is shown, e.g. by initial testing or other established data, that these directions do not result in higher core compressive strength values than cores from the direction of the main compressive force. Alternatively corrections may be applied where a relationship has been established between core results in the different directions.

The critical in-situ compressive strength may be assumed to represent the true compressive strength of the concrete at the time of testing.

Conformity of the concrete strength in the structure (in-situ strength) does not necessarily imply conformity of durability or other prescriptive requirements for concrete provided to the construction. Similarly, non-conformity of the concrete strength in the structure (in-situ strength) does not necessarily imply non-conformity of the concrete supplied