EUROPEAN STANDARD

NORME EUROPÉENNE

EUROPÄISCHE NORM

EN 13791

January 2007

ICS 91.080.40

English Version

Assessment of in-situ compressive strength in structures and precast concrete components

Evaluation de la résistance à la compression du béton en place dans les structures et les éléments préfabriqués

Bewertung der Druckfestigkeit von Beton in Bauwerken oder in Bauwerksteilen

This European Standard was approved by CEN on 10 November 2006.

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. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the CEN Management Centre or to any CEN member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the CEN Management Centre has the same status as the official versions.

CEN members are the national standards bodies of Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and United Kingdom.

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

Management Centre: rue de Stassart, 36 B-1050 Brussels

Ref. No. EN 13791:2007: E

Contents

Page

Foreword

This document (EN 13791:2007) has been prepared by Technical Committee CEN/TC 104 "Concrete and related products", the secretariat of which is held by DIN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by July 2007, and conflicting national standards shall be withdrawn at the latest by July 2007.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and United Kingdom.

Introduction

This European Standard provides techniques for estimating in-situ compressive strength in concrete structures and precast concrete components. Testing in-situ strength takes into account the effects of both the materials and execution (compaction, curing, etc.).

These tests do not replace concrete testing according to EN 206-1.

EN 206-1 refers to the guidance of this standard for assessing the strength in structures and precast concrete components.

The following examples illustrate where this estimate of in-situ strength of concrete may be required:

— when an existing structure is to be modified or redesigned;

— to assess structural adequacy when doubt arises about the compressive strength in the structure due to defective workmanship, deterioration of concrete due to fire or other causes;

— when an assessment of the in-situ concrete strength is needed during construction;

— to assess structural adequacy in the case of non-conformity of the compressive strength obtained from standard test specimens;

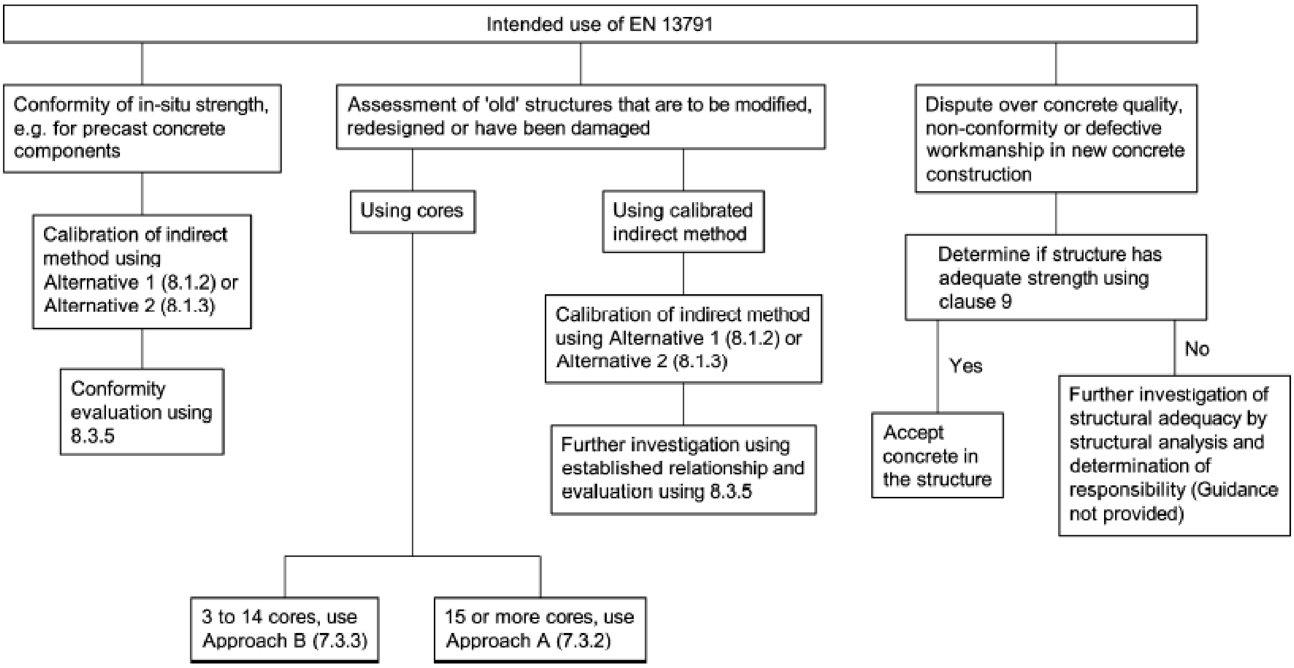
— assessment of conformity of the in-situ concrete compressive strength when specified in a specification or product standard.

Where identified in this standard, national provisions are permitted or required.

An outline of the procedures for these different uses of this standard is given in Flowchart 1.

For specific production conditions and constituent materials, development of economic design where permitted by national provisions may be possible through the assessing the partial safety factor, γ_c from knowledge of the in-situ compressive strength and the strength of standard test specimens.

When assessing compressive strengths in cases other than checking the quality of the concrete or the workmanship during execution or before accepting the structure for use, the appropriate reduction in the partial safety factor should be determined on a case-by-case basis according to national provisions.


Intended use of EN 13791
Conformity of in-situ strength, e.g. for precast concrete components
Calibration of indirect method using Alternative 1 (8.1.2) or Alternative 2 (8.1.3)
Conformity evaluation using 8.3.5
Assessment of 'old' structures that are to be modified, redesigned or have been damaged
Using cores
Using calibrated indirect method
Calibration of indirect method using Alternative 1 (8.1.2) or Alternative 2 (8.1.3)
Further investigation using established relationship and evaluation using 8.3.5
3 to 14 cores, use Approach B (7.3.3)
15 or more cores, use Approach A (7.3.2)
Dispute over concrete quality, non-conformity or defective workmanship in new concrete construction
Determine if structure has adequate strength using clause 9
Yes
No
Accept concrete in the structure
Further investigation of structural adequacy by structural analysis and determination of responsibility (Guidance not provided)

Flowchart 1

1 Scope

This European Standard:

— gives methods and procedures for the assessment of the in-situ compressive strength of concrete in structures and precast concrete components;

— provides principles and guidance for establishing the relationships between test results from indirect test methods and the in-situ core strength;

— provides guidance for the assessment of the in-situ concrete compressive strength in structures or precast concrete components by indirect or combined methods.

This European Standard does not include the following cases:

— where indirect methods are used without correlation to core strength;

— assessment based on cores less than 50 mm in diameter;

— assessment based on less than 3 cores;

— use of microcores.

NOTE In these cases provisions valid in place of use apply.

This European Standard is not for the assessment of conformity of concrete compressive strength in accordance with EN 206-1 or EN 13369 except as indicated in EN 206-1:2000, 5.5.1.2 or 8.4.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 206-1:2000, *Concrete – Part 1: Specification, performance, production and conformity*

EN 12350-1,*Testing fresh concrete – Part 1: Sampling*

EN 12390-1, *Testing hardened concrete - Part 1: Shape, dimensions and other requirements for specimens and moulds*

EN 12390-2, *Testing hardened concrete – Part 2: Making and curing specimens for strength tests*

EN 12390-3, *Testing hardened concrete – Part 3: Compressive strength of test specimens*

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

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

EN 12504-3, *Testing concrete in structures – Part 3: Determination of pull-out force*

EN 12504-4, *Testing concrete in structures – Part 4: Determination of ultrasonic pulse velocity*

3 Terms and definitions

For the purposes of this European Standard, the terms and definitions given in EN 206-1:2000 and the following apply.

3.1
standard compressive strength
compressive strength determined on standard test specimens (cubes or cylinders) which are sampled, made, cured and tested in accordance with EN 12350-1, EN 12390-2 and EN 12390-3

3.2
core compressive strength
compressive strength of a core determined in accordance with EN 12504-1

3.3
in-situ compressive strength
strength in a structural element or precast concrete components expressed in terms of the equivalent strength of a standard cube or cylinder specimen

3.4
characteristic in-situ compressive strength
value of in-situ compressive strength below which 5 % of the population of all possible strength determinations of the volume of concrete under consideration are expected to fall

NOTE This population is unlikely to be the same population used to determine the conformity of the fresh concrete in EN 206-1.

3.5
test location
limited area selected for measurements used to estimate one test result, which is to be used in the estimation of in-situ compressive strength

3.6
test region
one or several structural elements, or precast concrete components assumed or known to be from the same population. A test region contains several test locations

4 Symbols and abbreviations

Δf shift of the basic curve

δf difference between the core strength and the strength value according to the basic relationship

$\delta f_{m(n)}$ mean of n, values of δf

F pull-out force test result

f_{is} in-situ compressive strength test result

$f_{is, lowest}$ lowest in-situ compressive strength test result

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

f_{ck} characteristic compressive strength of standard specimens

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

$f_{ck, is, cube}$ characteristic in-situ compressive strength expressed in equivalent strength of a 150 mm cube, see 7.1

$f_{ck, is, cyl}$ characteristic in-situ compressive strength expressed in equivalent strength of a 150 mm × 300 mm cylinder, see 7.1

$f_{is, 1}$ estimated in-situ compressive strength test result by indirect test methods when a specific relationship is established by core tests, (Alternative 1)

$f_{is, F}$ estimated in-situ compressive strength test result by pull-out tests calibrated by core tests, (Alternative 2)

$f_{is, R}$ estimated in-situ compressive strength test result by rebound hammer tests calibrated by core tests, (Alternative 2)

$f_{is, v}$ estimated in-situ compressive strength test result by ultrasonic pulse velocity tests calibrated by core tests, (Alternative 2)

f_F initial value of in-situ strength obtained from the basic curve for a pull-out force, Figure 4, test result F used in the determination of the shift

f_R initial value of in-situ strength obtained from the basic curve for a rebound hammer, Figure 2, test result R used in the determination of the shift

f_v initial value of in-situ strength obtained from the basic curve for a pulse-velocity, Figure 3 test result v used in the determination of the shift

γ_c partial safety factor for concrete

k margin associated with small numbers of test results

k_1 coefficient that depends on the number of paired tests

k_2 coefficient that depends upon provisions valid in the place of use or, if none are given, a coefficient with a value of 1,48

n number of test results

R rebound hammer test result

s standard deviation

v ultrasonic pulse velocity test result

5 Principles

Assessment of in-situ compressive strength directly from core tests constitutes the reference method, see 7. The assessment of in-situ compressive strength may also be done indirectly by other tests, see 8.2 and 8.3, or by a combination of various test methods, see 8.4. Where indirect tests are used, the uncertainty associated with the relationship between the test and core test is taken into account.

The test data may be used to estimate the in-situ characteristic strength and the corresponding strength class according to EN 206-1.

6 Characteristic in-situ compressive strength in relation to compressive strength class

Table 1 gives requirements for the minimum characteristic in-situ compressive strength with respect to the compressive strength classes according to EN 206-1.

Table 1 — Minimum characteristic in-situ compressive strength for the EN 206-1 compressive strength classes

Compressive strength class according to EN 206-1	Ratio of in-situ characteristic strength to characteristic strength of standard specimens	Minimum characteristic in-situ strength N/mm^2	
		$f_{ck, is, cyl}$	$f_{ck, is, cube}$
C8/10	0,85	7	9
C12/15	0,85	10	13
C16/20	0,85	14	17
C20/25	0,85	17	21
C25/30	0,85	21	26
C30/37	0,85	26	31
C35/45	0,85	30	38
C40/50	0,85	34	43
C45/55	0,85	38	47
C50/60	0,85	43	51
C55/67	0,85	47	57
C60/75	0,85	51	64
C70/85	0,85	60	72
C80/95	0,85	68	81
C90/105	0,85	77	89
C100/115	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.

NOTE 2 The ratio 0,85 is part of γ_c in EN 1992-1-1: 2004.

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

7.1 Specimens

Cores shall be taken, examined and prepared in accordance with EN 12504-1 and tested in accordance with EN 12390-3. Except for where it is not feasible, cores shall be exposed to a laboratory atmosphere for at least 3 days prior to testing.

NOTE 1 For factors influencing the core strength, see Annex A.

NOTE 2 If for practical reasons 3 days of exposure is not feasible, record the period of exposure, if any. The influence of this deviation from standard procedure should be evaluated.

Where the in-situ strength is determined from cores:

— testing a core with equal length and a nominal diameter of 100 mm gives a strength value equivalent to the strength value of a 150 mm cube manufactured and cured under the same conditions;

— testing a core with a nominal diameter at least 100 mm and not larger than 150 mm and with a length to diameter ratio equal to 2,0 gives a strength value equivalent to the strength value of a 150 mm by 300 mm cylinder manufactured and cured under the same conditions;

— the transposition of the test results from cores with diameters from 50 mm up to 150 mm and other length to diameter ratios shall be based on conversion factors of established suitability.

NOTE 3 Conversion factors of established suitability for other specimen sizes and length to diameter ratios may be given in provisions valid in the place of use.

Normally the core result should not be modified to take account of the direction of drilling unless required by provisions valid in pace of use or required by the project specification.

7.2 Number of test specimens

The number of cores to be taken from one test region shall be determined by the volume of concrete involved and the purpose for the testing of cores. Each test location comprises one core.

For assessment of in-situ compressive strength for statistical and safety reasons, as many cores as are practicable should be used.

An assessment of in-situ compressive strength for a particular test region shall be based on at least 3 cores.

Consideration shall be given to any structural implications resulting from taking cores, see EN 12504-1.

NOTE The number of specimens identified above relates to cores with a nominal diameter of at least 100 mm. The number of cores should be increased when the nominal diameter is less than 100 mm, see A.3.1.

7.3 Assessment

7.3.1 General

In-situ characteristic compressive strength is assessed using either approach A in 7.3.2 or approach B in 7.3.3.

Approach A applies where at least 15 cores are available. Approach B applies where 3 to 14 cores are available. The applicability of the two approaches to the assessment of the strength of concrete in existing structures, about which there is no prior knowledge, may be defined in the place of use.

7.3.2 Approach A

The estimated in-situ characteristic strength of the test region is the lower value of:

$$f_{ck,is} = f_{m(n),is} - k_2 \times s \quad (1)$$

or

$$f_{ck,is} = f_{is,lowest} + 4 \quad (2)$$

where

s is the standard deviation of the test results or 2,0 N/mm^2, whichever is the higher value;

k_2 is given in national provisions or, if no value is given, taken as 1,48.

The strength class is obtained from Table 1 using the estimated in-situ characteristic strength.

NOTE 1 The estimate of characteristic strength using the lowest core result should reflect the confidence that the lowest core result represents the lowest strength in the structure or component under consideration.

NOTE 2 Where the distribution of the core strength appears to come from two populations, the region may be split into two test regions.

7.3.3 Approach B

The estimated in-situ characteristic strength of the test region is the lower value of:

$$f_{ck,is} = f_{m(n),is} - k \quad (3)$$

or

$$f_{ck,is} = f_{is,lowest} + 4 \quad (4)$$

The margin k depends on the number n of test results and the appropriate value is selected from Table 2.

Table 2 – Margin *k* associated with small numbers of test results

n	k
10 to14	5
7 to 9	6
3 to 6	7

NOTE Because of the uncertainty associated with small numbers of test results and the need to provide the same level of reliability, this approach gives estimates of characteristic strengths that are generally lower than those obtained with more test results. Where these estimates of in-situ characteristic strength are judged to be too conservative, it is recommended that more cores are taken or a combined technique approach, see 8.4, is used to obtain more test results. For this reason, this approach should not be used in cases of dispute over the quality of concrete based on standard test data, see clause 9 for details of a suitable approach.

8 Assessment of characteristic in-situ compressive strength by indirect methods

8.1 General

8.1.1 Methods

This clause applies to methods other than core tests, which are used for strength assessment in-situ. The indirect tests provide alternatives to core tests for assessing the in-situ compressive strength of concrete in a structure or they may supplement data obtained from a limited number of cores. The indirect methods are semi-destructive or non-destructive in nature. Indirect methods may be used after calibration with core tests in the following ways:

- singly;
- in a combination of indirect methods;
- in a combination of indirect methods and direct method (cores).

When testing with an indirect method a property other than strength is measured. It is thus necessary to use a relationship between the results of indirect tests and the compressive strength of cores.

Two alternative methods for assessment of in-situ compressive strength are provided, see 8.1.2 and 8.1.3.

When an indirect technique is combined with only one or two core test results, interpretation shall be based on provisions valid in place of use.

8.1.2 Alternative 1 – Direct correlation with cores

Sub-clause 8.2 describes procedures applicable on a general basis for assessment of in-situ compressive strength, when a specific relationship between the in-situ compressive strength and the test result by the indirect method is established for the concrete under consideration.

Alternative 1 requires at least 18 core test results to establish the relationship between the in-situ compressive strength and the test result by the indirect method

8.1.3 Alternative 2 – Calibration with cores for a limited strength range using an established relationship

Sub-clause 8.3 describes procedures for assessment of in-situ strength within a limited range of strengths, based on an established relationship, i.e. a basic curve, together with a shift of the basic curve, established by means of core tests. Procedures are described for rebound hammer tests, ultrasonic pulse velocity tests and pull-out tests.

NOTE Test results assessed by indirect test methods can be influenced by various factors other than concrete strength, see Annex B.

8.2 Indirect tests correlated with in-situ compressive strength, (Alternative 1)

8.2.1 Application

Sub-clause 8.2 is applicable to indirect test methods for assessment of in-situ compressive strength when a specific relationship for the in-situ concrete is established by means of core tests.

8.2.2 Testing procedure

The apparatus, the test procedure and the expression of test results shall be in accordance with EN 12504-1 for the core tests and EN 12504-2, EN 12504-3 and EN 12504-4 when rebound number, pull-out force or ultrasonic pulse velocity is measured.

8.2.3 Establishing the relationship between test result and in-situ compressive strength

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

The relationship shall be based on at least 18 pairs of results, 18 core test results and 18 indirect test results, covering the range of interest.

NOTE 1 A pair of test results is a core test result and an indirect test result from the same test location.

NOTE 2 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.

Establishing the relationship comprises the following steps:

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

NOTE 3 The data used for obtaining the best-fit curve or line should be evenly spaced within the limits that are covered by the data.

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

— The relationship is determined as the lower ten percentile of strength.

NOTE 4 The relationship that is used for strength estimation gives a safety level where 90 % of the strength values are expected to be higher than the estimated value.

8.2.4 Assessment of in-situ compressive strength

The in-situ compressive strength test result, $f_{is,\,I}$, is estimated from the established relationship.

The relationship shall only be used for the estimation of in-situ strength for the specific concrete and conditions for which it was established. The relationship shall only be used within the range covered by test data.

For the assessment of in-situ characteristic compressive strength the following conditions apply:

- assessment for each test region shall be based on at least 15 test locations;
- standard deviation shall be the value calculated from the test results or 3,0 N/mm², whichever is the higher value.

The in-situ characteristic compressive strength of the test region is the lower value of

$$f_{ck,is} = f_{m(n),is} - 1{,}48 \times s \qquad (5)$$

or

$$f_{ck,is} = f_{is,lowest} + 4 \qquad (6)$$

where

s is the standard deviation of test results.

8.3 Use of a relationship determined from a limited number of cores and a basic curve, (Alternative 2)

8.3.1 General

Rebound hammer tests, ultrasonic pulse velocity tests and pull-out tests may be used for the assessment of in-situ compressive strength using a basic curve and shifting it to the appropriate level determined by core tests.

This technique can be used to assess a population comprising normal concretes made with the same set of materials and manufacturing process.

A test region is selected from such a population and at least 9 pairs of test results, (core test results and indirect test results from the same test location), are used to obtain the value Δf (shift) by which the basic curve needs to be shifted to establish the relationship between indirect measurements and in-situ compressive strength.

For the assessment of in-situ compressive strength indirect tests are then undertaken on the specific concrete and the established relationship is used to estimate in-situ compressive strength and the characteristic in-situ compressive strength is calculated.

8.3.2 Testing

The apparatus, the test procedure and the expression of test results shall be in accordance with EN 12504-1, EN 12504-2, EN 12504-3 and EN 12404-4 as appropriate.

8.3.3 Procedure

The following procedure shall be used for determining the relationship between the indirect method and in-situ compressive strength.

a) Select a test region containing at least 9 test locations.

b) At each test location obtain a test result for rebound hammer in accordance with EN 12504-2, pull-out force in accordance with EN 12504-3 or ultrasonic pulse velocity in accordance with EN 12504-4, as appropriate.

c) At each test location, take and test a core in accordance with EN 12504-1.

d) Following the principles illustrated in Figure 1, plot the in-situ core strength (y-axis) against the indirect test results on copies of Figures 2 to 4, as appropriate.

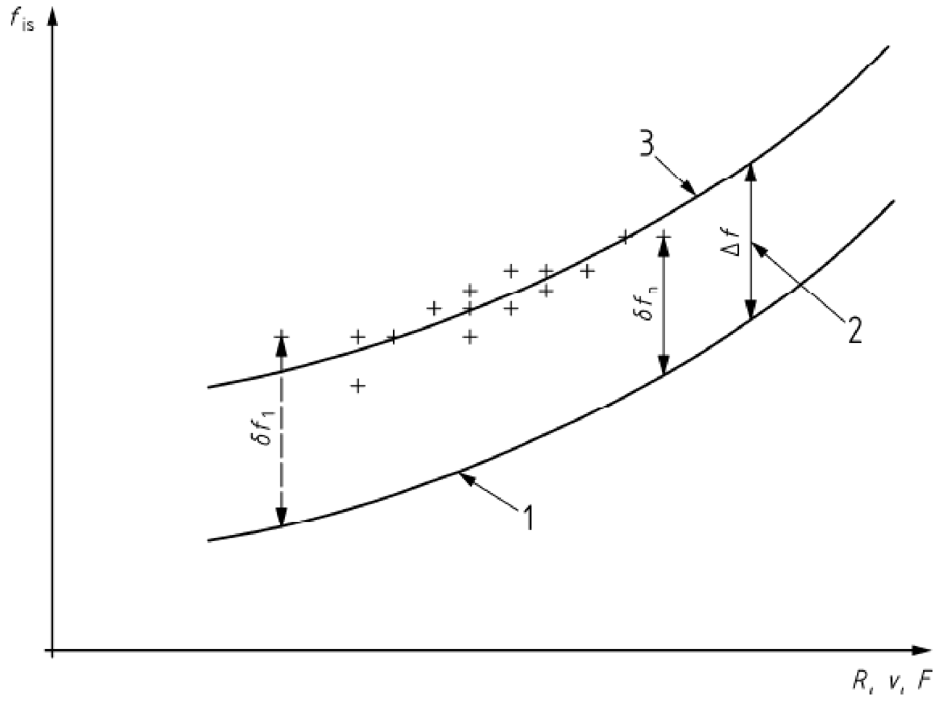
e) For each test location determine the difference in in-situ strength between the measured value on the core and the value given by the basic curve, $\delta f = f_{is} - f_{R,\ v\ or\ F}$.

f) Calculate the mean $\delta f_{m(n)}$, for the '*n*' results and the sample standard deviation, *s*.

g) Calculate the amount by which the basic curve should be shifted, Δf, from: $\Delta f = \delta f_{m(n)} - k_1 \times s$ where k_1 is obtained from Table 3.

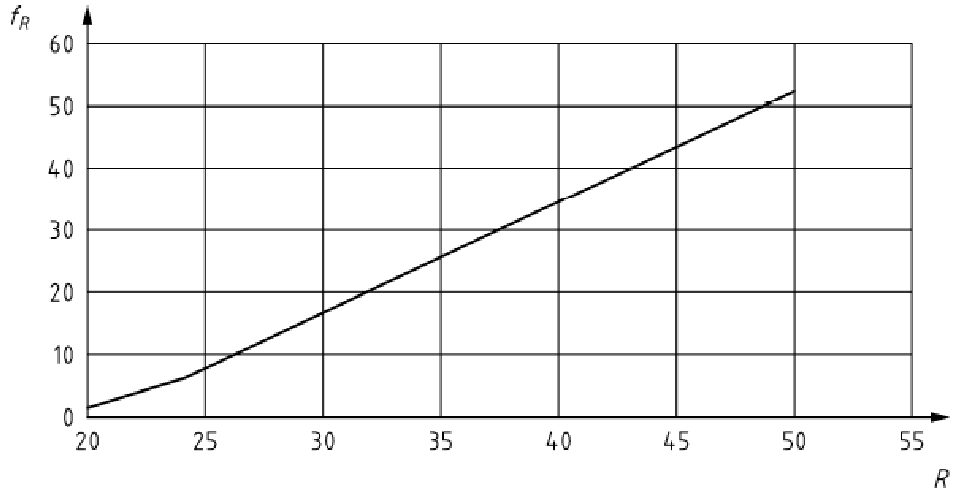
NOTE The basic curve has been set at an artificially low position so that the shift is always positive.

h) Shift the basic curve by Δf to obtain the relationship between the indirect test method and in-situ compressive strength for the specific concrete under investigation.



1	Basic curve
$\delta f_{1...n}$	Difference between the individual core strength and the strength value according to the basic relationship
2	Δf Shift of the basic curve
3	Relationship between the indirect test method and in-situ compressive strength for the specific concrete under investigation
R	Rebound number in accordance with EN 12504-2
F	Pull-out force in accordance with EN 12504-3
v	Ultrasonic pulse velocity in accordance with EN 12504-4

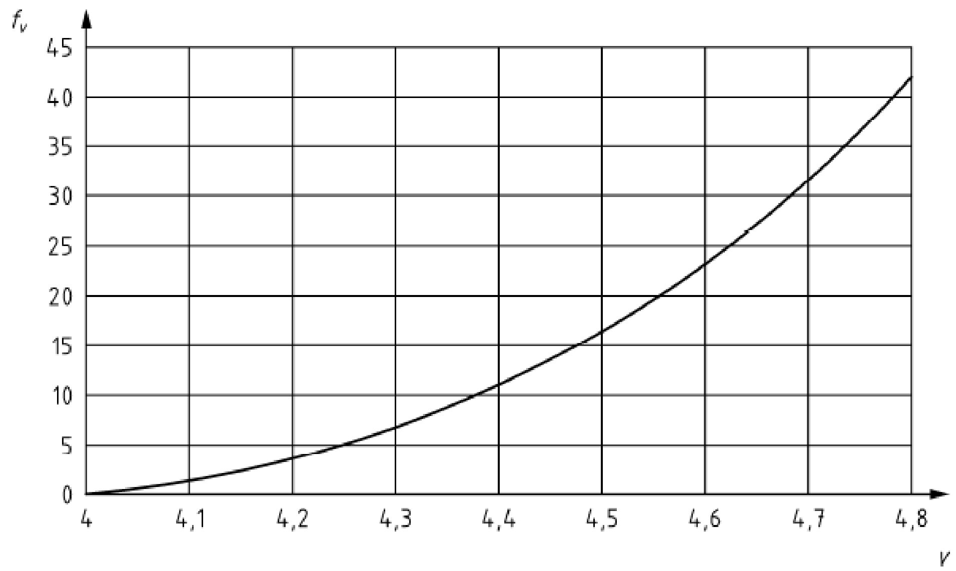
Figure 1 — Principle for obtaining the relationship between in-situ compressive strength and indirect test data



Key

R Rebound number in accordance with EN 12504-2

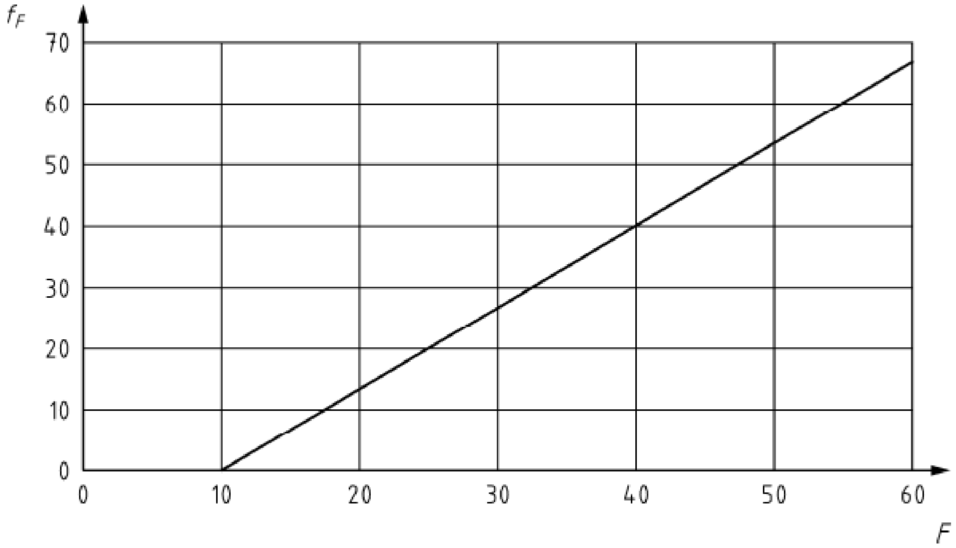
Figure 2 – Basic curve for rebound hammer test.



Key

v Ultrasonic pulse velocity in km/sec in accordance with EN 12504-4

Figure 3 — Basic curve for ultrasonic pulse velocity test



Key

F Pull-out force in N in accordance with EN 12504-3

Figure 4 — Basic curve for pull out force test

The basic curves in Figures 2, 3 and 4 or their enlarged copies may be used for graphic calculations without infringing copyright.

For the purpose of numerical calculations mathematical functions of the curves are as follows:

Figure 2 - Rebound hammer:

$$f_R = 1{,}25 \times R - 23 \qquad 20 \leq R \leq 24$$

$$f_R = 1{,}73 \times R - 34{,}5 \qquad 24 \leq R \leq 50$$

Figure 3 – Ultrasonic pulse velocity

$$f_v = 62{,}5 \times v^2 - 497{,}5 \times v + 990 \qquad 4 \leq v \leq 4{,}8$$

Figure 4 – Pull-out force

$$f_F = 1{,}33 \times (F - 10) \qquad 10 \leq \mathrm{F} \leq 60$$

Other well-established relationships and basic curves may be used.

Table 3 — Coefficient k_1 dependent on the number of paired tests

Number of paired test results n	Coefficient k_1
9	1,67
10	1,62
11	1,58
12	1,55
13	1,52
14	1,50
≥15	1,48

8.3.4 Validity of relationships

The relationship established by the procedure given in 8.3.3 may be used within the following ranges:

- ± 2 rebound numbers outside the range used to obtain the shift;
- ± 0,05 km/s outside the range of pulse velocity test results used to obtain the shift;
- ± 2,5 kN outside the range of pull-out force used to obtain the shift.

8.3.5 Estimation of in-situ compressive strength

The in-situ compressive strength test result, f_{is}, is estimated from the relationship established using the procedure given in 8.3.3. The relationship shall only be used for estimating in-situ compressive strength for the specific concrete and conditions for which it was established. The relationship shall only be used within the range for which it is valid, see 8.3.4.

For the assessment of in-situ characteristic compressive strength, the conditions and procedure given in 8.2.4 apply.

Assessment based on testing cores with equal length and diameter and applying the basic curves given in Figures 2, 3 and 4, gives in-situ compressive strength equivalent to cube strength. After calculation of the characteristic strength, the equivalent compressive strength class according to EN 206-1 may be assessed using Table 1. When the assessment is based on testing 2:1 cores with a diameter at least 50 mm, Table 1 is also used to obtain the corresponding strength class.

When needed, the actual core result may be converted to an equivalent in-situ cube or in-situ cylinder strength using a relationship valid in the place of use.

8.4 Combination of in-situ strength test results by various test methods

NOTE This standard does not provide guidance on the use of combined methods. See national provisions and specialist literature for combining different methods.

9 Assessment where conformity of concrete based on standard tests is in doubt:

For a test region comprising many batches of concrete with 15 or more core data, if

$$f_{m(n),is} \geq 0,85(f_{ck} + 1,48 \times s) \tag{7}$$

and

$$f_{is,\ lowest} \geq 0,85(f_{ck} - 4) \tag{8}$$

the region may be deemed to contain concrete with adequate strength and the concrete in the region conformed to EN 206-1.

NOTE 1 Failure of an individual core may indicate a local rather than a global problem.

Alternatively, by agreement between the parties, where there are 15 or more indirect test data and at least two cores taken from the locations that indicate the lower strengths, if

$$f_{is,lowest} \geq 0,85(f_{ck} - 4) \tag{9}$$

the region may be deemed to contain concrete with adequate strength.

In a small region that contains one or a few batches of concrete, the specifier may use experience to select two locations for coring and if

$$f_{is,lowest} \geq 0,85(f_{ck} - 4) \tag{10}$$

the region may be deemed to contain concrete with adequate strength.

If the test region is deemed to contain concrete with adequate strength, the concrete shall be deemed to have come from a conforming population.

NOTE 2 Where the strength is less than $0,85(f_{ck} – 4)$ the design assumptions are not valid and the structure should be assessed for structural adequacy. A low in-situ strength may be caused by a number of factors including the failure of the concrete to meet the specification, poor compaction or the uncontrolled addition of water on site. The producer and user may need to identify which factors are significant, but this involves taking account of voidage and reinforcement in the cores and the maturity of the core at testing. Guidance on this is not provided in this standard.

10 Assessment report

The assessment report shall include:

a) Purpose of the assessment.

b) Identification and description of the structure or precast concrete components.

c) Information available about the concrete (mix composition, strength class, age etc.)

d) Method used for assessment; core tests or indirect methods according to Alternative 1 or 2

e) Establishment the relationship when Alternative 1 is used.

f) Test program including:
test methods;
cores (dimensions, treatment, exposure etc);
sampling plan;
number of tests;
deviations from the standard method (eg exposure time), if any.

g) Test data and results.

h) Calculations.

g) Assessment of in-situ characteristic compressive strength and, if necessary, equivalent compressive strength class according to EN 206-1.

Annex A
(informative)
Factors influencing core strength

A.1 General

Factors influencing core strength may be split into those where the factor is related to a characteristic of the concrete and those where it is a testing variable.

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.

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.

A.2 Concrete characteristics

A.2.1 Moisture content

The moisture content of the core will influence the measured strength. The strength of a saturated core is 10 % to 15 % lower than that of a comparable air-dried core, which normally has a moisture content between 8 % and 12 %.

A.2.2 Voidage

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

A.2.3 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 difference in magnitude is typically between 0 % to 8 %.

A.2.4 Imperfections

Flaws can occur in cores from various causes. These include water gain beneath flaxy 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 assessed separately.

A.3 Testing variables

A.3.1 Diameter of core

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

In cores with diameters less than 100 mm and l/d = 1, strength variability is generally greater. For this reason, with 50 mm cores it may be appropriate to use three times as many cores as are used when tests are performed on 100 mm diameter cores, with a rectilinear interpolation for diameters between 100 mm and 50 mm.

The variability of the measured strength increases with decreasing diameter to maximum aggregate size ratio.

Cores with a diameter smaller than 50 mm (microcores) require procedures that are not covered by this standard.

A.3.2 Length/diameter ratio

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.

A.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, i.e. as specified in EN 12390-1.

A.3.4 Capping of end surfaces

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

A.3.5 Effect of drilling

Drilling operations may produce damage in immature or inherently weak concrete and 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.

A.3.6 Reinforcement

Cores used to measure the strength of concrete should not contain reinforcing bar. When 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.

Annex B
(informative)
Factors influencing results by indirect test methods

B.1 Rebound hammer tests

The relationship between strength and rebound number is affected by both characteristics of the concrete and test conditions.

B.2 Ultrasonic pulse velocity measurements

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

Further information for establishing a correlation between strength and ultra sonic pulse velocity is also given in EN 12504-4.

B.3 Pull-out tests

The relationship between strength and measured pull-out force is affected by characteristics of the concrete as well as of the test conditions.

Some possible factors are:

— Aggregate type;

— Compaction;

— Curing;

— Moisture condition at test;

— Depth of embedment;

— Surface abnormalities;

— Presence of reinforcement.

In particular the presence of reinforcing steel in close proximity to the test location may affect the results.

Further information on establishing correlation between strength and pull-out force is given in EN 12504-3.

Annex C
(informative)
Concepts concerning the relationship between in-situ strength and strength from standard test specimens

The compressive strength of cores and the in-situ strength will generally be less than that measured on standard test specimens 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:

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

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

3. 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.

Design of a reinforced and pre-stressed 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 concrete strength γ_c.

Annex D
(informative)
Guidelines for planning, sampling and evaluation of test results when assessing in-situ strength

D.1 Planning

The purpose of the assessment of in-situ compressive strength in a structure or precast concrete components affects the planning of test regions. One or several test regions are identified, and within each test region a number of test locations are selected. The choice of the size of test locations depends on the test method used. The number of test results from a test region influences the reliability of the assessment.

When the compressive strength class in a whole building structure is to be assessed for in-situ strength, the structure should be divided into test regions in which the concrete may be assumed to belong to the same population having one mode and being representative of the general quality. The core data should be reviewed to check that the assumption of a single modal distribution is reasonable.

Consideration should be given in assessing the in-situ compressive 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 load bearing capacity of an existing structure is to be assessed, the tests should be concentrated on concrete which is representative of the most stressed parts of the structure. However, the sampling should not adversely affect the load-bearing capacity.

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

D.2 Sampling

The individual test locations in each test region should be sampled at random if the objective is to obtain representative data.

The number of cores taken or indirect measurements made will depend on the method used for the assessment of in-situ strength.

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

D.3 Testing programme

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

D.4 Assessment

Assessment of in-situ compressive strength may include consideration of the age at testing and the moisture conditions in the concrete. The strength 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 is of interest, it is mainly the compressive strength at the time of testing (actual in-situ strength) that is of interest.

The moisture conditions of the structure should be taken into account. In cases where a structure or precast concrete component is in wet conditions, the cores should be tested in the saturated condition, similarly, where the structure or precast concrete component is in dry conditions, the cores should be tested in dry condition. Unless otherwise specified, cores will be tested in a dry condition, see 7.1.

Bibliography

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

[2] ENV 13670-1, *Execution of concrete structures – Part 1: Common rules and rules for buildings*

[3] EN 13369 *Common rules for precast concrete products*

National Annex NA (informative) Additional guidance for UK users

NA.1 General

Complementary guidance is being prepared in the form of a National Annex to BS EN 12504-1 and as a complementary standard. On publication of BS EN 13791:2006, this guidance will not be available in the public domain. As an interim step, the following guidance is provided.

NA.2 Planning a structural investigation

General guidance on planning an investigation is given in BS 6089:1981, Clause **4**.

NA.3 Test methods

General guidance on test methods is given in BS 6089:1981, Clause **5** and in BS 1881-201.

NA.4 Limitations on core location

If the limitations on core location recommended in CSTR 11:1987, **3.2.2.3** are followed, the core should not be adjusted for the direction of drilling.

CSTR 11:1987, **3.2.2.4** gives guidance on the number of cores needed to give a reliable estimate of strength.

To convert the actual core result into an equivalent in-situ cube or 2:1 cylinder strength, the actual core strength is multiplied by the K_{is} factor given below.

Correction factors (K_{is}) for the core dimensions are given by:

$$K_{is,\ cube} = \frac{2.5}{1.5 + 1/\lambda}$$

$$K_{is,\ cyl} = \frac{2.0}{1.5 + 1/\lambda}$$

λ = length/diameter ratio of the core.

See CSTR 11:1987, Appendix 4 to Part 3 for corrections to apply when there is transverse reinforcement in the core.

As permitted in BS EN 13791, Approach A (**7.3.2**) and Approach B (**7.3.3**) should be replaced by a method that uses the t-distribution to determine the characteristic strength.

NA.5 Determining adequate strength

Clause **9** sets out a procedure to determine in the case of dispute whether the concrete in the structure has adequate strength. Where the structure is shown to have insufficient strength, it will be helpful to estimate the voidage in the concrete using the procedure given in CSTR 11:1987, Appendix 2 to Part 3. This is an indication of how well the concrete was compacted and therefore an indication of the influence of workmanship on in-situ strength.

References

BS 1881-201, *Testing concrete – Part 201: Guide to the use of non-destructive methods of test for hardened concrete*

BS 6089:1981, *Guide to assessment of concrete strength in existing structures*

CSTR 11:1987, *Concrete core testing for strength* Concrete Society Technical Report No. 11

BSI — British Standards Institution

BSI is the independent national body responsible for preparing British Standards. It presents the UK view on standards in Europe and at the international level. It is incorporated by Royal Charter.

Revisions

British Standards are updated by amendment or revision. Users of British Standards should make sure that they possess the latest amendments or editions.

It is the constant aim of BSI to improve the quality of our products and services. We would be grateful if anyone finding an inaccuracy or ambiguity while using this British Standard would inform the Secretary of the technical committee responsible, the identity of which can be found on the inside front cover. Tel: +44 (0)20 8996 9000. Fax: +44 (0)20 8996 7400.

BSI offers members an individual updating service called PLUS which ensures that subscribers automatically receive the latest editions of standards.

Buying standards

Orders for all BSI, international and foreign standards publications should be addressed to Customer Services. Tel: +44 (0)20 8996 9001. Fax: +44 (0)20 8996 7001. Email: orders@bsi-global.com. Standards are also available from the BSI website at http://www.bsi-global.com.

In response to orders for international standards, it is BSI policy to supply the BSI implementation of those that have been published as British Standards, unless otherwise requested.

Information on standards

BSI provides a wide range of information on national, European and international standards through its Library and its Technical Help to Exporters Service. Various BSI electronic information services are also available which give details on all its products and services. Contact the Information Centre. Tel: +44 (0)20 8996 7111. Fax: +44 (0)20 8996 7048. Email: info@bsi-global.com.

Subscribing members of BSI are kept up to date with standards developments and receive substantial discounts on the purchase price of standards. For details of these and other benefits contact Membership Administration. Tel: +44 (0)20 8996 7002. Fax: +44 (0)20 8996 7001. Email: membership@bsi-global.com.

Information regarding online access to British Standards via British Standards Online can be found at http://www.bsi-global.com/bsonline.

Further information about BSI is available on the BSI website at http://www.bsi-global.com.

Copyright

Details and advice can be obtained from the Copyright & Licensing Manager. Tel: +44 (0)20 8996 7070. Fax: +44 (0)20 8996 7553. Email: copyright@bsi-global.com.

BSI
389 Chiswick High Road
London
W4 4AL