

# *In situ* strength assessment

## BS EN 13791 Assessment of in-situ compressive strength in structures and precast concrete components

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# BS EN 13791: 2019 *Assessment of in-situ compressive strength in structures and precast concrete components*

National foreword

European foreword

Introduction

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- 3 Terms, definitions, symbols and abbreviations
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Annex A Guidance on undertaking an investigation

National Annex NA Guidance on complementary provisions

**Major revision with significant technical changes since 2007!**



## **BS EN 13791: 2019**

### **National foreword**

This British Standard is the UK implementation of EN 13791:2019. It supersedes BS EN 13791:2007 and BS 6089:2010, which are withdrawn.

The background to EN 13791:2019, as well as further guidance and worked examples, is given in CEN/TR 17086 (publication anticipated in 2020).

All the relevant content of BS 6089:2010 is now covered by BS EN 13791:2019, including its national annex; PD CEN/TR 17086 (publication anticipated in 2020); and BS EN 12504-1:2019, including its national annex.

This British Standard should be used in conjunction with BS EN 12504-1:2019 and its national annex.

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 31 January 2020.

### **European foreword**

This document supersedes EN 13791:2007.

## BS EN 13791: Introduction/1 Scope/2 References/3 Definitions

Covers core testing and indirect testing by rebound hammer and UPV



## Introduction/1 Scope/2 References/3 Definitions

Introduces the two applications of *in situ* strength assessment

- a) to estimate *in situ* characteristic compressive strength  $f_{ck, is}$  of a test region and/or *in situ* strength at specific locations (Clause 8)
- b) assessment of compressive strength class of concrete supplied to a structure under construction where there is doubt about the compressive strength based on results of standard tests or doubt about the quality of execution (Clause 9)

There are Clause 8 and Clause 9 specific requirements included in earlier clauses that cover general requirements

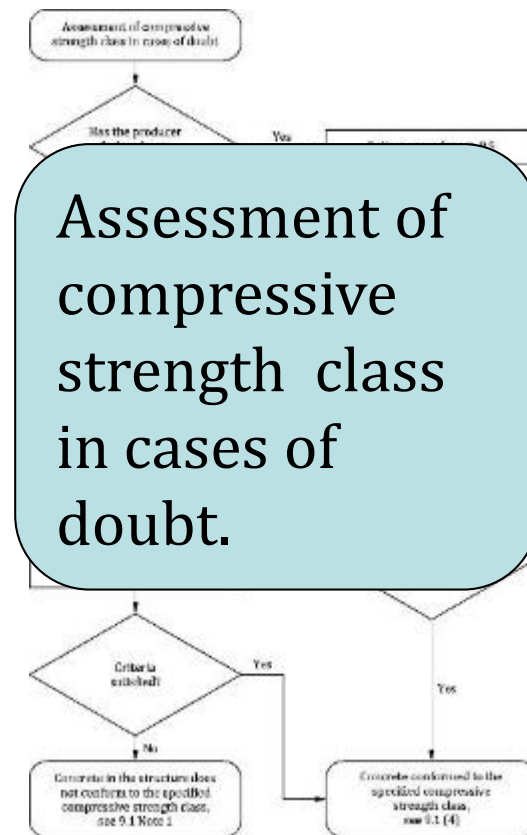
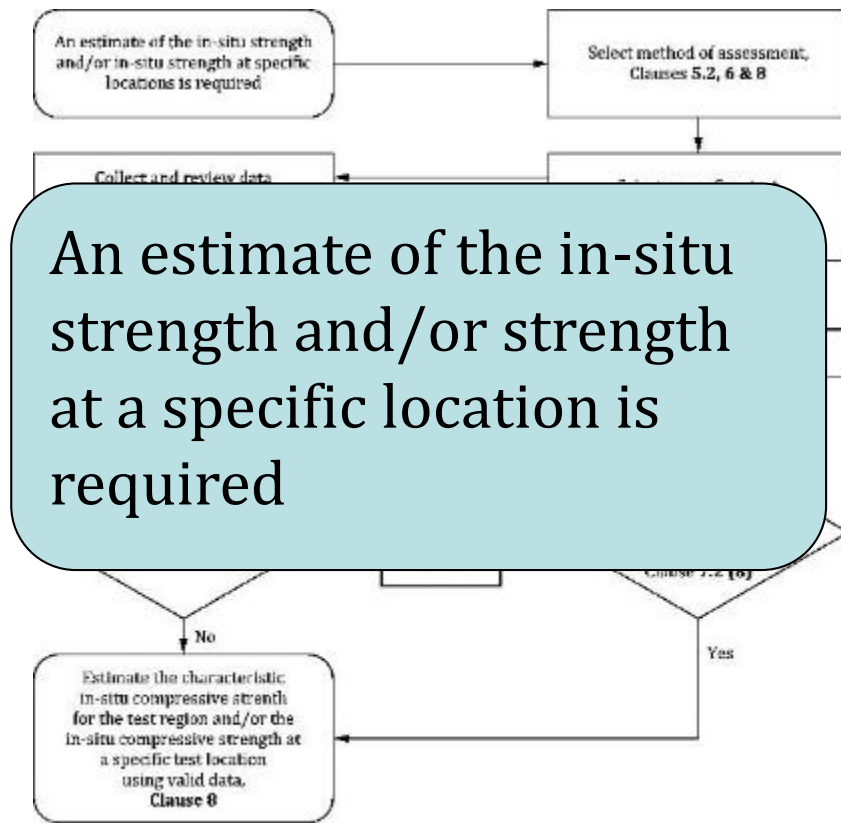
This presentation will consider the generalities, followed by description of Clause 9 and then Clause 8

### 3 Nomenclature

Abbreviations used for compressive strength	
Abbreviation	Description and explanation
$f_{c, is}$	<p>Compressive strength of a core taken at a test location within a structural element or precast concrete component expressed in terms of the strength of a 2:1 core of diameter <math>\geq 75</math> mm.</p> <p>NOTE 1 If more than one core is taken at a test location, the test result is the mean of the individual test measurements.</p> <p>NOTE 2 This value is based on the <i>in situ</i> moisture condition and it is not adjusted to a standard moisture condition.</p>
$f_{ck, is}$	<p>Characteristic <i>in situ</i> compressive strength (expressed as the strength of a 2:1 core of diameter <math>\geq 75</math> mm), i.e. the <i>in situ</i> compressive strength below which 5 % of test results are expected to fall if all the volume of concrete under consideration had been cored and tested.</p> <p>NOTE 1 These values are not normalized to a standard moisture condition.</p> <p>NOTE 2 The <i>in situ</i> volume of concrete under consideration is unlikely to be the same volume used to determine the conformity of the fresh concrete in accordance with EN 206. It is generally a smaller volume.</p>
$f_{ck, spec}$	<p>Minimum characteristic strength of 2:1 cylindrical test specimens associated with the specified compressive strength class.</p> <p>NOTE For example <math>f_{ck, spec}</math> is 30 MPa for compressive strength class C30/37. See EN 206 for all strength classes.</p>

## 4 Investigation objective and test parameters

Includes a requirement to define the objective before testing is initiated. Flowchart guidance for Clause 8 or Clause 9 procedures.



## 5 Test regions, test location and number of tests

### Test region

The test region shall be defined:

- a single concrete
- a series of similar elements, or a large element
- may include concrete from different production units using the same materials

### Clause 8

#### Small test region

- shall not include significantly different concrete
- $\leq 10 \text{ m}^3$ , or  $\leq 30 \text{ m}^3$  where there are no supply issues and where indirect testing is used to identify locations of lower compressive strength





## 5 Test regions, test location and number of tests

### Clause 9

- a volume is not more than about 30 m<sup>3</sup>, supplied in a single day and no indication that any load is different to the others
- The region may comprise up to six volumes, so  $\leq 180$  m<sup>3</sup>



## 6 Core testing and determination of the *in situ* compressive strength

Assessment of in-situ strength is based on a minimum number of core results and so more than the minimum number of cores are required in case a core does not produce a valid result e.g. due to presence of reinforcement or voids

Only covers length : diameter ratios of:

- 2:1, permitted range 1.95:1 to 2.05:1, or
- 1:1, permitted range 0.90:1 to 1.10:1

Cores of diameter  $\geq 75$  mm

Cores less than 50 mm diameter shall not be used.

Requirements for using 50 mm diameter cores are included in EN 13791, where three times as many cores are required but this is not covered in this presentation.



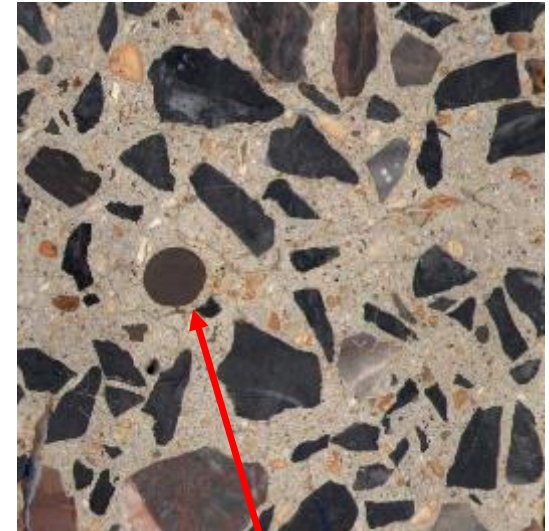
## 6 Core testing and determination of the *in situ* compressive strength

Cores are stored in a sealed container to retain *in situ* moisture condition.

For Clause 9 procedures: core testing shall not be undertaken on cores with a maturity less than that used for conformity testing, e.g. 28 days at 20°C

### Reference to EN 12504-1 National Annex NA.

Less than 2% by volume of reinforcement in 1:1 cores, or less than 2% by volume reinforcement in the outermost 30 mm of 2:1 cores, is considered not to significantly affect the core strength result.



1% = 10 mm bar  
through centre of  
100 mm 1:1 core

## 6 Core testing and determination of the *in situ* compressive strength

Reference to EN 12504-1.

End preparation by grinding is recommended. Capping by calcium aluminate cement mortar or sulfur mixture should not be used where anticipated strength is greater than 50 MPa for 2:1 specimens or 60 MPa for 1:1 specimens



## 7 Initial evaluation of data

Check the region contains a single strength class. If this cannot be confirmed by documentation than it is often preferable to carry out an direct test survey using a rebound hammer or UPV measurements.

If appropriate the recommendation is to split the data and apply  $t$ -test with pooled variances.

Check for outliers, working from most extreme result. If more than two outliers check that the region may comprise more than one concrete.

Grubb test is used as standard test but it is noted that other techniques may permit more than two outliers.

## Assessment of individual results within a region - statistical outliers

$$\frac{f_{c, is, highest} - f_{c, m(n) is}}{s} > G_p$$

$$\frac{f_{c, is, lowest} - f_{c, m(n) is}}{s} > G_p$$

- $f_{c, is, highest}$  Highest value of n consecutive test values, one or more results at location
- $f_{c, is, lowest}$  Lowest value of n consecutive test values, one or more results at location
- $f_{c, m, (n) is}$  Mean value of n consecutive test values
- $s$  Estimate of the overall standard deviation of  $f_{ck, is}$

### Critical values ( $G_p$ ) for testing outliers

Number of test values	$G_p$	Number of test values	$G_p$	Number of test values	$G_p$
4	1.496	10	2.482	16	2.852
5	1.764	11	2.564	17	2.894
6	1.973	12	2.636	18	2.932
7	2.139	13	2.699	19	2.968
8	2.274	14	2.755	20	3.001
9	2.387	15	2.806	25	3.135

The values of  $G_p$  are based on a significance level of 1%. Other significance levels may be adopted for establishing  $G_p$  values.

## 9 Assessment of compressive strength class of concrete in case of doubt

Doubt about the *in situ* quality may arise from doubts about the quality of the concrete supplied to the site, problems during the execution of the works or after some exceptional event on site.

“Doubt” often includes, but is not limited to, the following:

- insufficient compressive strength of samples taken for identity testing e.g. poorly made or cured cubes;
- workability is excess of that specified, e.g. addition of water at behest of site personnel
- problems during execution of the works, e.g. movement of forms, insufficient resource for compaction.

The assessment criteria are based on concrete that is under production control certification.

## 9 Assessment of compressive strength class of concrete in case of doubt

The first action is to check the reason for doubt. Contact the concrete supplier who may have relevant production results and autographic batching records. It is important to work with the supplier to collate all relevant information to try and identify the location of all the concrete where there is concern.





## 9 Assessment of compressive strength class of concrete in case of doubt

Where doubt remains there are three practical methods to assess the compressive strength class from *in situ* concrete:

- comparative indirect test testing, **20 indirect test results** for both volumes
- Indirect testing combined with a minimum of cores, **9 - 20 indirect tests** with **3 cores** for up to 180 m<sup>3</sup> (2 cores for a single  $\leq 30$  m<sup>3</sup> volume)
- Cores only, **3 to 12 cores** for 30 to 180 m<sup>3</sup>

## 9 Assessment of compressive strength class of concrete in case of doubt

### Comparative testing covered by

- BS EN 13791 National Annex NA
- PD CEN/TR 17086:2020 *Further guidance on the application of EN 13791 :2019 and background to the provisions*

The recommendation is to take not less than **20 indirect test measurements**, rebound hammer or UPV, in the region under investigation and compare with a **20 indirect test measurements** for a reference region for which the compressive strength class is confirmed.

There are screening tests based on German experience of rebound hammer non-generic indirect test relationships with laboratory specimens or core test data but these methods are not generally used in the UK, apart from comparative testing.

## 9 Assessment of compressive strength class of concrete in case of doubt: comparative test

### Comparative test

$$t_{calc} = \frac{(\bar{X}_r - \bar{X}_s)}{\sqrt{\frac{(s_r^2 + s_s^2)}{20}}}$$

- $n$  number of results in each set
- $\bar{X}_r$  is the mean of the  $n$  indirect testing results from the reference concrete
- $\bar{X}_s$  is the mean of the  $n$  indirect testing results from the concrete under investigation
- $s_r$  is the sample standard deviation of the indirect testing results from the reference concrete
- $s_s$  is the sample standard deviation of the indirect testing results from the concrete under investigation

For twenty results from each region where  $t_{calc}$  is within the range -2.024 to +2.024 then there is a 95% probability of no significant difference between the two sets of results, that is the reference concrete and the concrete under investigation are very likely to be of the same strength class.

Where  $t_{calc}$  is outside the range, or where there is no region of concrete that can be used as a reference then it will be necessary to do further testing, say indirect testing with minimum coring.

## 9 Assessment of compressive strength class of concrete in case of doubt : Indirect testing and minimum cores

Minimum 9 - 20 indirect tests with 3 core results for up to 180 m<sup>3</sup>

2 cores for a single  $\leq 30$  m<sup>3</sup> volume placed in a single day, where there is no indication that any load is different to the others delivered to that volume.

NB: 10m<sup>3</sup> a day for three days is to be treated as three different volumes.

In the UK Concrete strength is normally assessed by cubes with *in situ* strength assessment using 1:1 cores. i.e. the strength of 1:1 cores is compared to the specified cube characteristic strength class,  $f_{ck, spec, cube}$

## 9 Assessment of compressive strength class of concrete in case of doubt : Indirect testing and minimum cores

Indirect test locations, cores and assessment criteria for a region of concrete up to 180 m <sup>3</sup> .				
Number of volumes in region, all ≤30 m <sup>3</sup>	Minimum total number indirect-test locations for region	Minimum number of 1:1 core results and locations for coring	Assessment criteria Note: Both criteria need to be satisfied	
			Mean of core test results at the locations closest to the to the median rebound number or the mean UPV for the test region.	Lowest core result
1	9	<b>2 cores:</b> One core at each of the two lowest indirect test values for the test region	—	≥0.85( $f_{ck,spec,cube} - 4^A$ )
2	12	<b>3 cores:</b> One core at the lowest indirect test value for the test region, and one core at each of the test locations closest to the median rebound number or the mean UPV for the test region.	≥0.85( $f_{ck,spec,cube} + 1$ )	
3				
4				
5	20		≥0.85( $f_{ck,spec,cube} + 2$ )	
6				

A) For specified strength C16/20 the constant is reduced to 3, for specified strength C12/15 the constant is reduced to 2, and for specified strength C8/10 the constant is reduced to 1.

Where the assessment criteria are met the concrete the concrete is accepted as conforming to its specification.

If criteria are not met it may be appropriate to extend core testing for a core testing only assessment.

## 9 Assessment of compressive strength class of concrete in case of doubt : Using cores only

Minimum of three core results for a single  $\leq 30 \text{ m}^3$  volume placed in a single day, where there is no indication that any load is different to the others delivered to that volume.

Up to 12 core results to assess up to  $180 \text{ m}^3$ .

## 9 Assessment of compressive strength class of concrete in case of doubt : Using cores only

Minimum core requirements and assessment criteria for a region of concrete up to 180 m <sup>3</sup> .				
Number of volumes in region, all <30 m <sup>3</sup>	Minimum number of 1:1 cores for each volume	Minimum number of 1:1 cores for region	Assessment criteria Note: Both criteria need to be satisfied	
			Mean of all core results from the region:	Lowest core result
1	3	3	—	≥0.85( $f_{ck,spec,cube} - 4 E)$ )
2	2	4	≥0.85( $f_{ck,spec,cube} + 1)$ )	
3	2	6		
4	2	8		
5	2	10	≥0.85( $f_{ck,spec,cube} + 2)$ )	
6	2	12		

A) For specified strength C16/20 the constant is reduced to 3, for specified strength C12/15 the constant is reduced to 2, and for specified strength C8/10 the constant is reduced to 1.

If the assessment criteria are met the concrete the concrete is accepted as conforming to its specification.

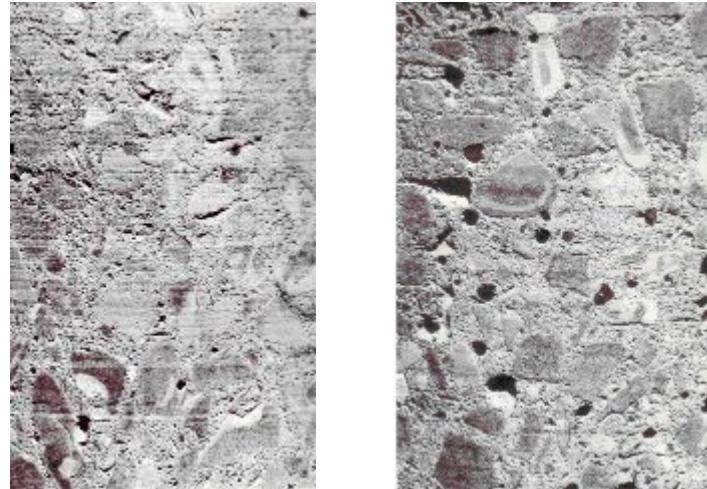
If criteria not satisfied then refer to CIRIA C517, *Action in the case of nonconformity of concrete structures, 2000*.

## Correction for excess voidage

Estimating excess voidage, BS EN 12504-1 National Annex NA. An indication of the adequacy of placing and compaction.

From BS EN 13791 National Annex NA an estimate of *in situ* strength assuming fully compacted concrete may be calculated from:

$$= k_v \times f_{c,is}$$



Correction factor for excess voidage, $k_v$	
Estimated excess voidage, %	Correction factor to fully compacted in situ strength $k_v$
0.0	1.00
0.5	1.03
1.0	1.06
1.5	1.09
2.0	1.12
2.5 <sup>A)</sup>	1.15

A) Where the excess voidage exceeds 2.5% it is unlikely that any estimate of the fully compacted *in situ* cube strength using an assumed voidage correction factor is reliable.



## 8 Estimation of compressive strength for structural assessment of an existing structure

Check the region contains a single strength class.

Requires a minimum of **eight valid test results** of *in situ* compressive strength from cores of diameter  $\geq 75$  mm with length : diameter ratios of 2:1 or 1:1.

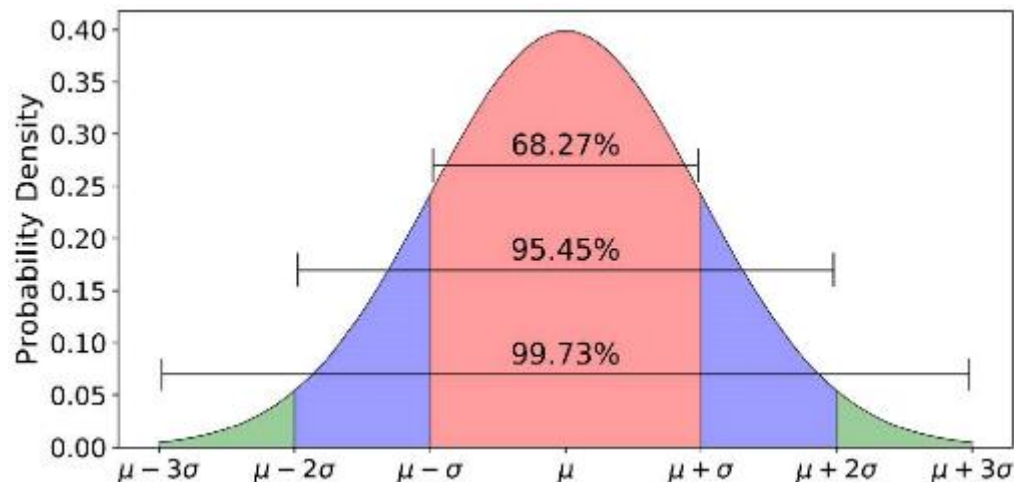
To ensure the minimum of **eight valid test results** it is recommended that at **least ten cores** are obtained from the structure because a test value may be rejected e.g. Presence of reinforcement or voids.



## 8 Estimation of compressive strength for structural assessment of an existing structure

A spread of results of more than 15% from the mean is an indication that more information about the test region should be sought.

The sample standard deviation  $s$  is used for the assessment calculation with the limitation that it shall not be less than a value equivalent to a coefficient of variation of 8% e.g. where the mean strength of core specimens is 37.5 MPa the minimum value of  $s$  is 3.0 MPa.



## 8 Estimation of compressive strength for structural assessment of an existing structure

Reminder:

- 2:1, permitted range 1.95:1 to 2.05:1, or
- 1:1, permitted range 0.90:1 to 1.10:1. Where 1:1 cores are taken the value should be corrected to a 2:1 values using a Core Length Factor (CLF) of 0.82

## 8 Estimation of compressive strength for structural assessment of an existing structure

Cores less than 50 mm diameter shall not be used. Requirements for using 50 mm diameter cores are included in EN 13791, where three times as many cores are required but this is not covered in this presentation.

There is a methodology included in the Standard for the use of indirect test data and core test data, using a minimum of ten pairs of results. This is a complicated process and is not covered further in this presentation.

In the Standard there is an option to use a log-normal form of the calculation to assess *in situ* compressive strength from the mean and standard deviation of the cores results, but precise details are not set out in the Standard nor covered in this presentation.

## 8 Estimation of compressive strength for structural assessment of an existing structure

Characteristic *in situ* compressive strength  $f_{ck, is}$  is estimated from the lower of:

$$f_{ck, is} = f_{c, m(n)is} - k_n s \qquad f_{ck, is} = f_{c, is, lowest} + M$$

$f_{ck, is}$	Characteristic <i>in situ</i> compressive strength																
$f_{c, is, lowest}$	Lowest value of the eight or more test results																
$f_{c, m, (n) is}$	Mean value of eight or more valid test results																
$s$	Sample standard deviation of the test region in the structure, but not less than a value giving a coefficient of variation of 8%																
$k_n$	<table border="1" data-bbox="382 925 1576 1048"> <thead> <tr> <th>n</th> <th>8</th> <th>10</th> <th>12</th> <th>16</th> <th>20</th> <th>30</th> <th>∞</th> </tr> </thead> <tbody> <tr> <td><math>k_n</math></td> <td>2.00</td> <td>1.92</td> <td>1.87</td> <td>1.81</td> <td>1.76</td> <td>1.73</td> <td>1.64</td> </tr> </tbody> </table>	n	8	10	12	16	20	30	∞	$k_n$	2.00	1.92	1.87	1.81	1.76	1.73	1.64
n	8	10	12	16	20	30	∞										
$k_n$	2.00	1.92	1.87	1.81	1.76	1.73	1.64										
$M$	<p><math>M = 4</math> for strength <math>\geq 20</math> MPa  <math>M = 3</math> for strength <math>\geq 16 &lt; 20</math> MPa  <math>M = 2</math> for strength <math>\geq 12 &lt; 16</math> MPa  <math>M = 1</math> for strength <math>&lt; 10</math> MPa</p>																

## 8 Estimation of compressive strength for structural assessment of an existing structure, small test region

**Less than around 10 m<sup>3</sup>**

**At least three cores**, and at least one core from each element. Providing each core represents concrete that is to remain in the structure and the spread of results is less than 15% of the mean value result, then the **lowest** value of the three or more cores may be assumed to be  $f_{ck,is}$  for structural assessment purposes.

**Less than around 30 m<sup>3</sup>**

Indirect testing is used to determine variability and locations of lower strength. Providing each core represents concrete that is to remain in the structure and the spread of results is less than 15% of the mean value result, then the **mean** value of the **three or more cores** may be assumed to be  $f_{ck,is}$  for structural assessment purposes.

## 8 Estimation of compressive strength for structural assessment of an existing structure

If the estimated characteristic *in situ* compressive strength does not meet expectation than there is some useful guidance in CIRIA C517, *Action in the case of nonconformity of concrete structures, 2000*.

Last word: Do not confuse the Clause 8 *Estimation of compressive strength for structural assessment of an existing structure* procedures with Clause 9 *Assessment of compressive strength class of concrete in case of doubt* procedures, they have different approached that may lead to significantly different outcomes.

**BS EN 13791 Assessment of in-situ compressive strength in  
structures and precast concrete components**

***Thank you for attending***

Additional guidance available at  
[www.brmca.org.uk](http://www.brmca.org.uk) downloads, and

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