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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*

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 It supersedes **BS EN 13791:2007** and **BS 6089:2010**, which are withdrawn.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 relevant content of **BS 6089:2010** is covered by **BS EN 13791:2019**, including its national annex; and **BS EN 12504-1:2019** including its national annex.

Major revision with significant technical changes since 2007!

Background to EN 13791:2019, as well as further guidance and worked examples, is given in CEN/TR 17086 *Further guidance on the application of EN 13791 :2019 and background to the provisions* (publication in 2020).

In situ strength assessment

Covers core testing and indirect testing by rebound hammer and UPV

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

Content

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 start with the preliminaries, followed by running through the most significant requirements of **Clause 9** and then **Clause 8.**

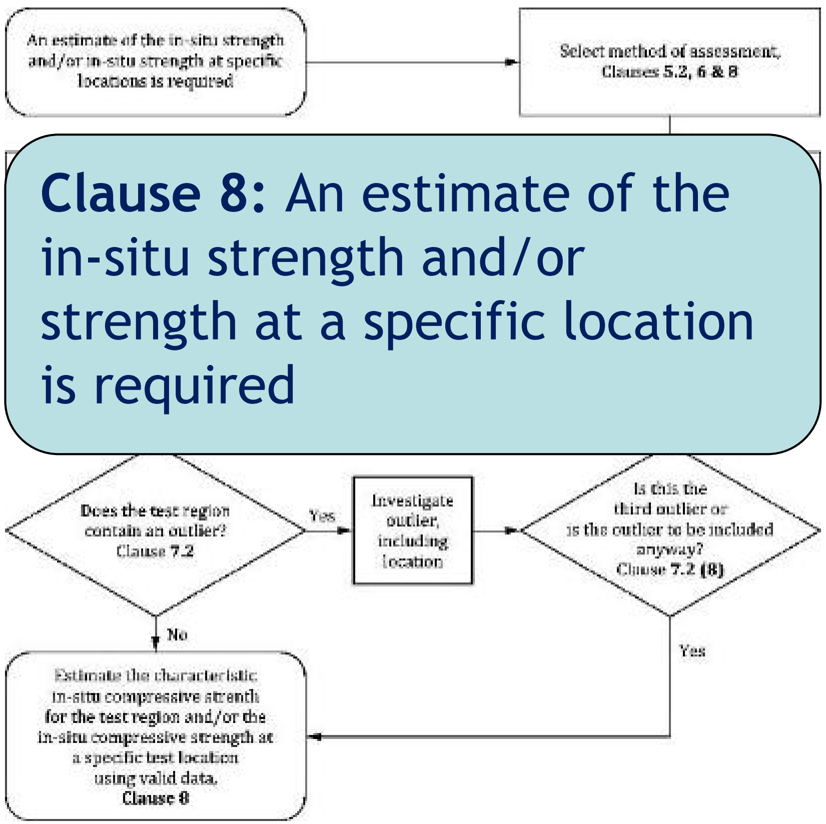
3 Nomenclature

Aligns with EN 1992-1-1, Eurocode2

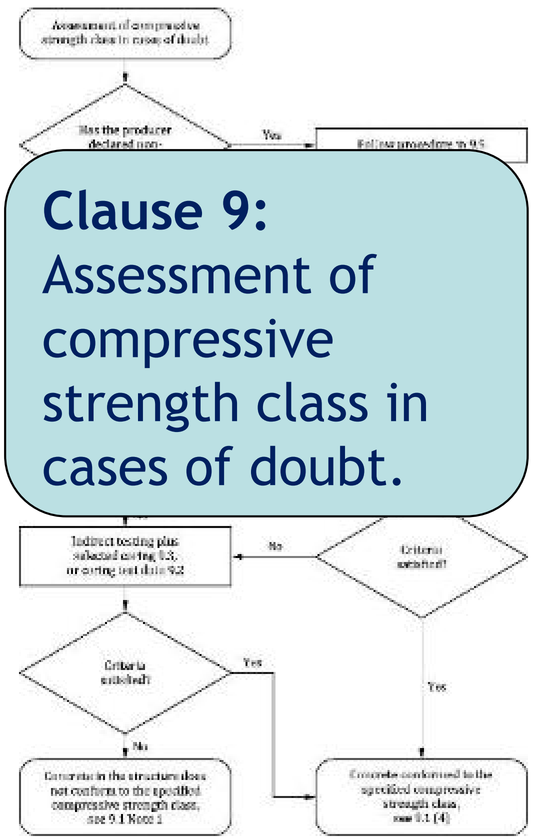
Abbreviations used for compressive strength	
Abbreviation	Description and explanation
$f_{c,is}$	Compressive strength of a core taken at a test location within a structural element or precast concrete component expressed in terms of the strength of a 2:1 core of diameter ≥ 75 mm. NOTE 1 If more than one core is taken at a test location, the test result is the mean of the individual test measurements. NOTE 2 This value is based on the *in situ* moisture condition and it is not adjusted to a standard moisture condition.
$f_{ck,is}$	Characteristic *in situ* compressive strength (expressed as the strength of a 2:1 core of diameter ≥ 75 mm), i.e. the in situ 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. NOTE 1 These values are not normalized to a standard moisture condition. NOTE 2 The *in situ* 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.
$f_{ck,spec}$	Minimum characteristic strength of 2:1 cylindrical test specimens associated with the specified compressive strength class. NOTE For example $f_{ck,spec}$ is 30 MPa for compressive strength class C30/37. See EN 206 for all strength classes.

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.



Clause 8: An estimate of the in-situ strength and/or strength at a specific location is required



Clause 9: Assessment of compressive strength class in cases of doubt.

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
- ≤10 m^3, or ≤30 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^3, 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 ≤180 m^3

6 Core testing

Diameter, length : diameter ratio

Cores of diameter ≥ 75 mm

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

Reinforcement

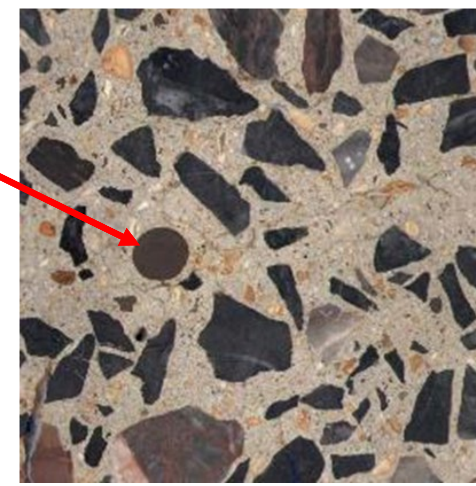
Reference to EN 12504-1 National Annex NA.

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,

are considered not to significantly affect the core strength result.

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



6 Core testing

Reference to BS 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

6 Core testing

Concrete maturity

For structural assessment to **Clause 8** procedures it will generally be the case that the concrete is significantly older than 28 days and so the maturity will be greater than that equivalent to 28 days at 20°C.

For **Clause 9**, the assessment of compressive strength class from recently supplied concrete, core testing shall not be undertaken on cores with a maturity less than that used for conformity testing.

There are a number of maturity functions that can be used but for a rough guide if the average concrete temperature is only 10°C then it would take 42 days to be as mature as concrete cured at 20°C.

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 indirect 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.

7 Initial evaluation of data

Assessment of individual results within a region – statistical outliers

$$\frac{f_{\text{c,is,highest}} - f_{\text{c,m(n)is}}}{s} > G_{\text{p}} \qquad \frac{f_{\text{c,is,lowest}} - f_{\text{c,m(n)is}}}{s} > G_{\text{p}}$$

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

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.

Excess voidage

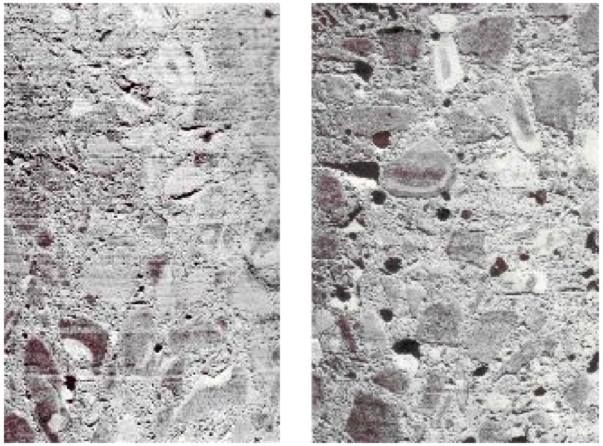
Estimating excess voidage, BS EN 12504-1 National Annex NA. An indication of the adequacy of placing and compaction.

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

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

For structural assessment, **Clause 8**, the presence of voidage may be just an indicator of poor workmanship

For assessment of strength class, **Clause 9**, as supplied then excess voidage of in-situ concrete may be a significant factor.



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[A)]	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.

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.

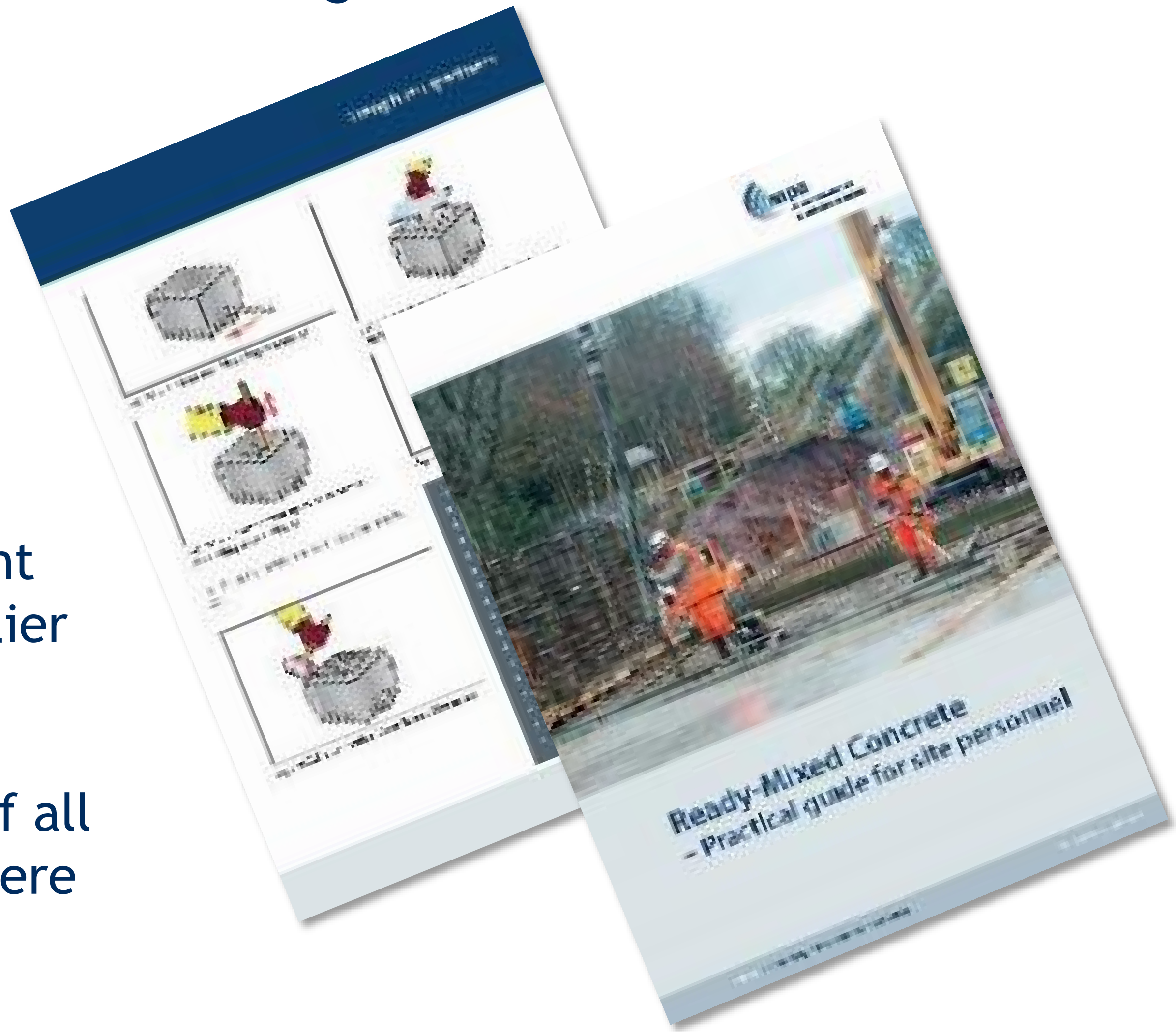
Doubt often includes, but is not limited to, the following:

- 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, too few internal vibrators

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 or cores, **9 - 20 indirect tests** with **3 cores** for up to 180 m^3 (2 cores for a single ≤ 30 m^3 volume)

- Cores only, **3 to 12 cores** for 30 to 180 m^3

Comparative testing

- BS EN 13791:2019 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 and non-generic indirect test relationships with laboratory specimens or core test data. These methods are not generally used in the UK.

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^3

2 cores for a single ≤ 30 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.

NB: $10m^3$ a day for three days is to be treated as three different volumes.

In the UK Concrete strength is normally assessed by cubes, and *in situ* strength is normally assessed 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^3.

Number of volumes in region, all ≤30 m^3	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	**2 cores:** One core at each of the two lowest indirect test values for the test region	—	$\geq 0.85(f_{ck,spec,cube} - 4^{A)})$
2	12	**3 cores:** 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.	$\geq 0.85(f_{ck,spec,cube} + 1)$	
3				
4				
5	20		$\geq 0.85(f_{ck,spec,cube} + 2)$	
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 ≤30 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 required
to assess up to 180 m^3.

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

Cores only

Minimum core requirements and assessment criteria for a region of concrete up to 180 m^3.				
Number of volumes in region, all <30 m^3	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	—	$\geq 0.85(f_{ck,spec,cube} - 4^{E)})$
2	2	4	$\geq 0.85(f_{ck,spec,cube} + 1)$	
3	2	6		
4	2	8		
5	2	10	$\geq 0.85(f_{ck,spec,cube} + 2)$	
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 C519, *Action in the case of nonconformity of concrete structures, 2000.*

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

To check structural integrity, e.g. after a fire, because of deterioration or because of an intended increase in loading

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 ≥ 75 mm with length : diameter ratios of 2:1 or 1:1.

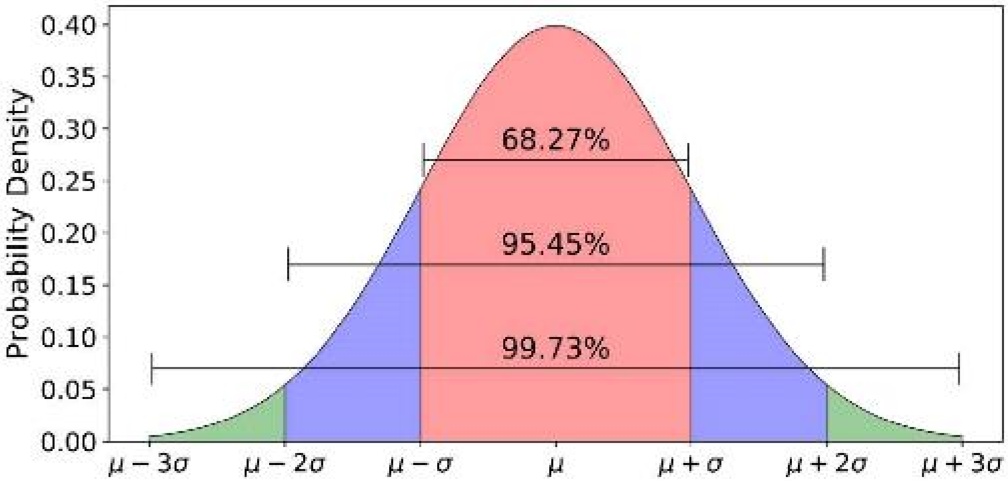
To ensure the minimum of **eight valid test results** it is recommended that at **least ten cores** are obtained from the structure because a test value may be rejected e.g. Presence of reinforcement or voids.

10

- but in many cases more will be required

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

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… miscellaneous

Small cores

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

Cores with indirect testing

There is a complicated methodology included in the Standard for the use of indirect test data and core test data, using a minimum of ten pairs of results.

Log-normal calculations

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.

For these items refer to the Standard as they are not covered in this presentation.

8 Estimation of compressive strength for structural assessment…

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 *in situ* 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

n	8	10	12	16	20	30	∞
k_n	2.00	1.92	1.87	1.81	1.76	1.73	1.64

M

M = 4 for strength ≥20 MPa
M = 3 for strength ≥16 <20 MPa
M = 2 for strength ≥12 <16 MPa
M = 1 for strength <10 MPa

8 Estimation of compressive strength for structural assessment… Small test region

Less than around 10 m^3

At least three cores, and at least one core from each element. 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^3

Indirect testing is used to determine variability and locations of lower strength. The **mean** value of the **three or more cores** may be assumed to be $f_{ck,is}$ for structural assessment purposes.

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. A wider spread of results indicate further investigation is required.

Below expectation

If the estimated characteristic *in situ* compressive strength does not meet expectation than there is some useful guidance in CIRIA C519, *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 approaches 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 downloads, and

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