

BS 6089:2010



BSI Standards Publication

Assessment of in-situ compressive strength in structures and precast concrete components – Complementary guidance to that given in BS EN 13791

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ISBN 978 0 580 67274 3

ICS 91.080.40, 91.100.30

The following BSI references relate to the work on this standard:

Committee reference B/517

Draft for comment 09/30201029 DC

Publication history

First published November 1981

Second (present) edition, April 2010

Amendments issued since publication

Date	Text affected
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Summary of pages

This document comprises a front cover, an inside front cover, pages i to ii, pages 1 to 34, an inside back cover and a back cover.

Foreword

Publishing information

This British Standard is published by BSI and came into effect on 30 April 2010. It was prepared by Technical Committee B/517, *Concrete*. A list of organizations represented on this committee can be obtained on request to its secretary.

Supersession

This British Standard supersedes BS 6089:1981, which is withdrawn.

Information about this document

This is a full revision of the standard and introduces the following principal changes:

- this Standard has been completely re-structured as complementary guidance to BS EN 13791;
- techniques used in the assessment of the strength of structures, but not included in BS EN 13791, are described;
- flowcharts are included to help users find the appropriate information for their needs.

Use of this document

As a guide, this British Standard takes the form of guidance and recommendations. It should not be quoted as if it were a specification or a code of practice and claims of compliance cannot be made to it.

Contractual and legal considerations

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a British Standard cannot confer immunity from legal obligations.

Introduction

BS EN 13791 contains some methods for assessing the strength of structures, but there are other techniques that are useful for this purpose. As these techniques are not defined in the European standard, it is permitted to describe these techniques in a complementary British Standard. BS EN 13791 also permits the method for calculating the in-situ characteristic strength of existing structures about which there is no prior knowledge from core data to be defined in the place of use. Due to the uncertainties associated with investigating unknown structures, the committee wished to define a slightly more conservative system based on established statistical principles. This system is defined in this British Standard.

The publication of BS EN 13791 superseded part of BS 6089:1981. The information that was not superseded is still regarded as being useful and worthy of inclusion in a complementary British Standard to BS EN 13791. In addition, Concrete Society Technical Report (CSTR) 11 [1] is no longer regarded as best practice and is superseded in part by BS EN 13791. In places it also conflicts with BS EN 13791. Consequently, aspects of the CSTR 11 approach have been adopted within the overall system described in this British Standard and the Concrete Society's contribution to this British Standard is acknowledged.

BS EN 12504-1 describes the method for taking and reporting core tests, which is a building block for BS EN 13791 and this British Standard. BS EN 12504-1 describes how the core strength is measured and reported. To use such data in structural assessment, it is necessary to correct core test data for the length:diameter ratio and transverse reinforcement. The values for such corrections are given in the UK National Annex (NA) to BS EN 12504-1, and there is a recommendation in the UK NA to report both the measured strength and the corrected strength. In addition, it is useful and sometimes essential to know the voidage of the cores for the interpretation of the information. The UK NA to BS EN 12504-1 recommends the excess voidage be measured and reported. It ought to be noted that the corrected core strength does not include a correction for voidage as such a correction is inappropriate when determining characteristic in-situ strength.

The assessment of compressive strength in old structures is an area where fixed rules do not apply. The guidance supplied in this British Standard needs to be considered in the light of the specific situation and engineering judgement applied to the specific case.

In general, when dealing with disputes over concrete quality, an assessment with respect to structural adequacy gives the same outcome as an assessment of whether the concrete conforms to its specification. However, there will be a few situations where the concrete will be shown to conform to its specification, yet from a structural viewpoint be inadequate. BS 6089 provides no guidance on what should be done in such a situation. The relevant CEN Technical Committees have been made aware of this issue.

1 Scope

This British Standard complements BS EN 13791, which gives methods for determining the characteristic in-situ compressive strength in concrete structures and precast concrete components based on:

- a) core testing;
- b) rebound hammer, ultrasonic pulse velocity and pull-out force measurements after a relationship with core strength has been determined for the particular concrete under investigation.

This British Standard provides additional guidance on:

- planning an investigation (see Clause 5);
- selection of test methods (see 5.4);
- selection of the test locations (see 5.5 and 5.6);
- assessment of individual core results within a group (see 6.1);
- assessment where the strength of concrete based on test specimens is in doubt (see Clause 7).

In addition, this British Standard provides guidance on the following cases not covered by BS EN 13791:

- assessment of an unknown structure using a margin based on the t-statistic (see 6.2);
- use of indirect methods without correlation to core strength (see 6.3);
- relative testing, i.e. comparison of a volume of concrete under investigation with concrete in similar elements that has been accepted (see 6.4);
- action when the producer has declared nonconformity (see Clause 8).

This British Standard does not provide guidance on:

- the use of cores with a diameter of less than 50 mm or the use of microcores;
- whether a structure has adequate durability;
- the use of in-situ testing as an alternative to conformity testing based on test specimens.

NOTE For completeness, Figure 1 and Figure 2 identify such a procedure but this British Standard does not attempt to provide any of the necessary detail.

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.

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

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

BS EN 12390 (all parts), *Testing hardened concrete*

BS EN 12504-1, *Testing concrete in structures – Part 1: Cored specimens – Taking, examining and testing in compression* (including National Annex)

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

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

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

BS EN 13791:2007, *Assessment of in-situ compressive strength in structures and precast concrete components*

PD 6687, *Background paper to the UK National Annexes to BS EN 1992-1*

AINSWORTH, P. R. and HOPKINS, C. J. *Action in the case of nonconformity of concrete structures, C519*. CIRIA, 2000. ISBN 978 0 86017 519 3¹⁾

3 Terms and definitions, symbols and subscripts

3.1 Terms and definitions

For the purposes of this standard, the terms and definitions given in BS EN 13791, BS EN 12504-1 and the following apply.

3.1.1 corrected core strength

core compressive strength modified to a given length:diameter ratio, usually 1:1 or 2:1 and adjusted to take account of transverse reinforcement, if any

NOTE See UK National Annex to BS EN 12504-1.

3.1.2 estimated potential strength

estimate of the 28-day cube/cylinder strength of the concrete supplied to the works under investigation based on a measured in-situ core strength

NOTE See 3.1.5.

3.1.3 excess voidage

voidage in excess of that achieved in standard test specimens or in the case of air-entrained concrete, voidage in excess of the upper limit on air content

NOTE See BS EN 206-1:2000, 5.4.3.

3.1.4 maturity

function of age and temperature such that for a given concrete, any batch with the same maturity will have the same compressive strength

NOTE General current practice is to express maturity as equivalent age in days at 20 °C.

¹⁾ Available from Construction Industry Research and Information Association (CIRIA) at www.ciria.org.uk.

3.1.5 potential strength

notional compressive strength of concrete in the volume represented by the core if it had been wholly moulded as standard specimens and tested at 28 days in accordance with the relevant parts of BS EN 12390

3.2 Symbols and subscripts

For the purposes of this standard, the symbols and subscripts in Table 1, Table 2 and Table 3 apply.

Table 1 Symbols

Symbol	Explanation
K_v	correction factor for excess voidage
n	number of results
R_t	ratio used when testing for statistical outliers
s	sample standard deviation
s_r	sample standard deviation of reference element
s_s	sample standard deviation of element under investigation
$t_{0.05}$	t-value used in the determination of characteristic strength
ν	degrees of freedom
$\overline{X_r}$	mean ultrasonic pulse velocity (UPV)/rebound number of the reference element
$\overline{X_s}$	mean UPV/rebound number of the element under investigation
γ_m/η	partial safety factor for difference in strength between test specimens and the structure
σ_{is}	estimated population standard deviation of in-situ strength measurements

Table 2 Subscripts used in the relationships between different expressions of strength when the compressive strength of the structure is to be assessed using equivalent cubes

Subscript	Explanation
f_{is}	Core compressive strength. Compressive strength of a core, tested in accordance with BS EN 12504-1.
$f_{is, \text{cube}}$	Core compressive strength expressed as the strength of an equivalent cube. Compressive strength of a core, tested in accordance with BS EN 12504-1 when the length:diameter ratio is 1:1. <i>NOTE</i> Whenever practical, the Engineer ought to specify that cores to be tested have a length:diameter ratio of 1:1. In this case f_{is} is equal to $f_{is, \text{cube}}$.
$f_{is, \text{cube, corrected}}$	Corrected core strength expressed as the strength of an equivalent cube. Core compressive strength after correction for any transverse reinforcement and the length:diameter ratio using the factors given in the UK National Annex to BS EN 12504-1, $f_{is, \text{cube, corrected}} = K_{is, \text{cube}} K_s f_{is}$. <i>NOTE</i> If the core has a length:diameter ratio of 1:1 and no transverse reinforcement, $f_{is} = f_{is, \text{cube}} = f_{is, \text{cube, corrected}}$. These are the individual core data that are used for the assessment of structural adequacy.
$f_{is, \text{cube, location}}$	Average in-situ core strength at a single location. Mean strength of two or more corrected core strengths taken at a single location.
$f_{is, \text{lowest}}$	Lowest core strength expressed as the strength of an equivalent cube. Lowest value of $f_{is, \text{cube, corrected}}$ for a set of "n" results.
$f_{m(n), is}$	Mean core strength expressed as the strength of an equivalent cube. Mean of "n" values of $f_{is, \text{cube, corrected}}$.
$f_{ck, is, \text{cube}}$	Characteristic in-situ strength expressed as the strength of an equivalent cube. Characteristic in-situ cube strength determined from the set of "n" values of $f_{is, \text{cube, corrected}}$ or $f_{is, \text{cube, location}}$ and determined in accordance with the requirements of BS EN 13791 and this British Standard. <i>NOTE</i> Prior to taking the cores, it ought to be agreed if the individual corrected core results or the average core strength at each location are to be used to determine the in-situ characteristic strength.
f_{ck}	Characteristic strength. Estimated characteristic cube strength used in structural assessment, determined from $f_{ck, is, \text{cube}}/0.85$.
$f_{ck, \text{spec}}$	Specified characteristic strength. The minimum characteristic strength associated with the specified compressive strength class; see BS EN 206-1:2000, Table 7 and Table 8.
$f_{is, \text{cube, corrected, compacted}}$	Corrected core strength if fully compacted. Corrected core strength adjusted for excess voidage in accordance with A.3, expressed as the strength of an equivalent cube. <i>NOTE</i> This is only used in the determination of potential strength.
$f_{\text{pot, cube}}$	Potential strength. Potential strength expressed in terms of cube strength; see 3.1.5.

NOTE The terms f_{is} , $f_{is, \text{lowest}}$, $f_{m(n), is}$ and f_{ck} are also used when the adequacy of a structure is to be determined using equivalent cylinders, but the derivation and numerical values are different; see Table 3.

Table 3 Subscripts used in the relationships between different expressions of strength when the compressive strength of the structure is to be assessed using equivalent cylinders

Subscript	Explanation
f_{is}	Core compressive strength. Compressive strength of a core, tested in accordance with BS EN 12504-1.
$f_{is, cyl}$	Core compressive strength expressed as the strength of an equivalent cylinder. Compressive strength of a core, tested in accordance with BS EN 12504-1 when the length:diameter ratio is 2:1. <i>NOTE</i> Whenever practical, the Engineer ought to specify that cores to be tested have a length:diameter ratio of 2:1. In this case f_{is} is equal to $f_{is, cyl}$.
$f_{is, cyl, corrected}$	Corrected core strength expressed as the strength of an equivalent cylinder. Core compressive strength after correction for any transverse reinforcement and the length:diameter ratio using the factors given in the UK National Annex to BS EN 12504-1, $f_{is, cyl, corrected} = K_{is, cyl} K_s f_{is}$. <i>NOTE</i> If the core has a length:diameter ratio of 2:1 and no transverse reinforcement, $f_{is} = f_{is, cyl} = f_{is, cyl, corrected}$. These are the individual core data that are used for the assessment of structural adequacy.
$f_{is, cyl, location}$	Average in-situ cylinder strength at a single location. The average strength of two or more corrected core strengths taken at a single location.
$f_{is, lowest}$	Lowest core strength expressed as the strength of an equivalent cylinder. Lowest value of $f_{is, cyl, corrected}$ for a set of "n" results.
$f_{m(n), is}$	Mean core strength expressed as the strength of an equivalent cylinder. Mean of "n" values of $f_{is, cyl, corrected}$.
$f_{ck, is, cyl}$	Characteristic in-situ strength expressed as the strength of an equivalent cylinder. Characteristic in-situ cylinder strength determined from the set of "n" values of $f_{is, cyl, corrected}$ or $f_{is, cyl, location}$ and determined in accordance with BS EN 13791 and this British Standard. <i>NOTE</i> Prior to taking the cores, it ought to be agreed if the individual corrected core results or the average core strength at each location are to be used to determine the in-situ characteristic strength.
f_{ck}	Characteristic strength. Estimated characteristic cylinder strength used in structural assessment, determined from $f_{ck, is, cyl}/0.85$.
$f_{ck, spec}$	Specified characteristic strength. The minimum characteristic strength associated with the specified compressive strength class; see BS EN 206-1:2000, Table 7 and Table 8.
$f_{is, cyl, corrected, compacted}$	Corrected core strength if fully compacted. Corrected core strength adjusted for excess voidage in accordance with A.3 expressed as the strength of an equivalent cylinder. <i>NOTE</i> This is only used in the determination of potential strength.
$f_{pot, cyl}$	Potential strength. Potential strength expressed in terms of cylinder strength; see 3.1.5.

NOTE The terms f_{is} , $f_{is, lowest}$, $f_{m(n), is}$ and f_{ck} are also used when the adequacy of a structure is to be determined using equivalent cubes, but the derivation and numerical values are different; see Table 2.

Throughout BS EN 13791, where the term f_{is} is used, this should be taken as meaning $f_{is, \text{cube, corrected}}$ or $f_{is, \text{cyl, corrected}}$ depending upon whether the strength is to be assessed using equivalent cubes or equivalent cylinders. By agreement prior to testing, it can also mean $f_{is, \text{cube or cyl, location}}$.

4 Relationship between standard specimen 28-day strength and in-situ strength

NOTE 1 The ratio of characteristic in-situ compressive strength to characteristic compressive strength of standard specimens is based on comparing cores and standard specimens with exactly the same maturity and it is not valid when the maturity is different.

In BS EN 13791:2007, Clause 6, the compressive strength class is determined from characteristic in-situ strength divided by 0.85 with some rounding to give whole numbers.

The characteristic strength (f_{ck}) can be used directly for checking structural adequacy without converting it into a compressive strength class.

The characteristic strength $f_{ck} = f_{ck, is, \text{cube}}/0.85$ or $f_{ck, is, \text{cyl}}/0.85$ depending on whether the characteristic strength is to be expressed in terms of cube strength or 2:1 cylinder strength. If structural adequacy is being checked using British Standards of national origin, e.g. BS 8110, the characteristic strength should be in terms of cube strength. However, if it is being checked using BS EN 1992-1-1 or other European design codes, the characteristic strength should be in terms of cylinder strength. While it is possible to estimate the characteristic strength expressed in terms of cubes or 2:1 cylinders from any set of core length:diameter ratios, the conversion factors introduce additional uncertainty into the estimated characteristic strength, which can be avoided by specifying that the cores be tested at the appropriate length:diameter ratio (1:1 for cubes and 2:1 for 2:1 cylinders). Where correction factors are needed, these are given in the UK National Annex to BS EN 12504-1.

The calculated compressive strength class is a function of the maturity of the cores at testing. In normal situations, concrete gains strength with increasing maturity provided that there is water for continued hydration and so any estimate based on cores taken at an earlier age will give conservative (safe) estimates of the compressive strength class. When testing structures with a maturity greater than 28 days at 20 °C, it is not necessary to take maturity into account except when estimating potential strength.

The procedure in BS EN 13791:2007, 7.1, for curing cores should be followed. However, if it is necessary to test saturated cores, the strength may be enhanced to take this difference in testing into account; see 5.4 for a recommended value.

NOTE 2 According to BS EN 13791:2007, 7.1, the cores are normally tested after three days of storage in laboratory air and this gives a higher strength than if they had been tested in a saturated condition (see BS EN 13791:2007, A.2.1). The factor of 0.85 in BS EN 13791 is compatible with previous UK practice, which used a factor of 0.77 for Portland cement (CEMI) concrete and water cured cubes.

BS EN 13791:2007, 7.1, Note 3, recommends that the core compressive strength is not modified for the direction of drilling. The National Annex to BS EN 12504-1 also recommends not modifying the core compressive strength for the direction of drilling.

NOTE 3 Past practice in the UK has been to take account of the direction of drilling. As this British Standard recommends that the tested core does not contain concrete from the top of a section, enhancing the core compressive strength of vertically cut cores for the direction of drilling is not justified.

The 0.85 ratio is used for calculating the minimum acceptable in-situ strength in cases of doubt over concrete quality. BS EN 206-1 permits the strength of an individual batch, which, for example, can comprise the concrete in several columns, to be $(f_{ck} - 4)$ N/mm². Therefore, the minimum acceptable in-situ compressive strength for a conforming batch of concrete is: $0.85 (f_{ck} - 4)$ N/mm².

In BS EN 13791:2007, Clause 9, this equation is used to check if a local area came from concrete conforming to BS EN 206-1. If this requirement is satisfied, further checks on structural adequacy are not needed.

In practice, the in-situ strength is also a function of the location in the section. Generally, the concrete is weaker on the upper sections, particularly with columns, and stronger at the base of a section. This is why the selection of the test locations is so important.

5 Planning an investigation

5.1 Information required from the tests

Knowledge of the in-situ compressive strength of concrete in a structural member might be required for one or more of the following reasons:

- a) assessment of an existing structure prior to refurbishment or new use;
- b) deterioration of concrete due to:
 - overloading;
 - fatigue;
 - chemical action;
 - fire;
 - explosion;
 - weathering;
- c) to ascertain whether the in-situ strength of concrete is acceptable for:
 - the designed loading system;
 - the actual loading system;
 - a projected loading system for a new use;
- d) doubt concerning the strength of concrete in the structure due to:
 - nonconformity of concrete;
 - differences between identity testing and conformity;
 - workmanship involved in placing, compacting or curing of concrete.

NOTE Where the strength in the structure is unknown, e.g. in assessing an old structure, the assessment of characteristic in-situ compressive strength ought to be conservative and the fewer the number of data, the more conservative the estimated characteristic strength ought to be to compensate for the uncertainty associated with few data.