BS EN 12390-13:2021

BSI Standards Publication

Testing hardened concrete

Part 13: Determination of secant modulus of elasticity in compression

bsi.

National foreword

This British Standard is the UK implementation of EN 12390-13:2021. It supersedes BS EN 12390-13:2013, which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee B/517/1, Concrete production and testing.

A list of organizations represented on this committee can be obtained on request to its committee manager.

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Testing hardened concrete - Part 13: Determination of secant modulus of elasticity in compression

Essais pour béton durci - Partie 13 : Détermination du module sécant d'élasticité en compression

Prüfung von Festbeton - Teil 13: Bestimmung des Elastizitätsmoduls unter Druckbelastung (Sekantenmodul)

This European Standard was approved by CEN on 7 June 2021.

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European foreword

This document (EN 12390-13:2021) has been prepared by Technical Committee CEN/TC 104 "Concrete and related products", the secretariat of which is held by SN.

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of an identical text or by endorsement, at the latest by January 2022, and conflicting national standards shall be withdrawn at the latest by January 2022.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN shall not be held responsible for identifying any or all such patent rights.

This document supersedes EN 12390-13:2013.

The following amendments have been made in comparison to the former edition:

— upper limit of lower stress increased to prevent sample unloading when testing low strength concrete;

— change to the loading profile in Method B.

This document is based on an extensive investigation and comparison of existing National Standards: ASTM, BS, DIN, ISO, NORD TEST and UNI followed by the analysis of a test programme involving five laboratories carried out by UNI.

This document is one of a series on testing concrete.

EN 12390 , *Testing hardened concrete*, consists of the following parts:

— *Part 1: Shape, dimensions and other requirements for specimens and moulds*

— *Part 2: Making and curing specimens for strength tests*

— *Part 3: Compressive strength of test specimens*

— *Part 4: Compressive strength – Specification for testing machines*

— *Part 5: Flexural strength of test specimens*

— *Part 6: Tensile splitting strength of test specimens*

— *Part 7: Density of hardened concrete*

— *Part 8: Depth of penetration of water under pressure*

— *Part 10: Determination of the carbonation resistance of concrete at atmospheric levels of carbon dioxide*

— *Part 11: Determination of the chloride resistance of concrete, unidirectional diffusion*

— *Part 12: Determination of the potential carbonation resistance of concrete: Accelerated carbonation method*

— *Part 13: Determination of secant modulus of elasticity in compression*

— *Part 14: Semi-adiabatic method for the determination of heat released by concrete during its hardening process*

— *Part 15: Adiabatic method for the determination of heat released by concrete during its hardening process*

— *Part 16: Determination of shrinkage of concrete*

— *Part 17: Determination of creep of concrete in compression*

— *Part 18: Determination of chloride migration coefficient (in preparation)*

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1 Scope

This document specifies the method for the determination of the secant modulus of elasticity in compression of hardened concrete on test specimens which can be cast or taken from a structure.

The test method allows the determination of two secant moduli of elasticity: the initial modulus, $E_{C,0}$ measured at first loading and the stabilized modulus, $E_{C,S}$ measured after three loading cycles.

Two different test methods are given. The first (Method A) is for determination of both initial and stabilized moduli, the second (Method B) is for determination of stabilized modulus only.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 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 12390-4, *Testing hardened concrete - Part 4: Compressive strength - Specification for testing machines*

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

EN 12620, *Agregates for concrete*

EN ISO 9513, *Metallic materials - Calibration of extensometer systems used in uniaxial testing (ISO 9513)*

3 Terms, definitions, symbols and abbrivations

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at https://www.electropedia.org/

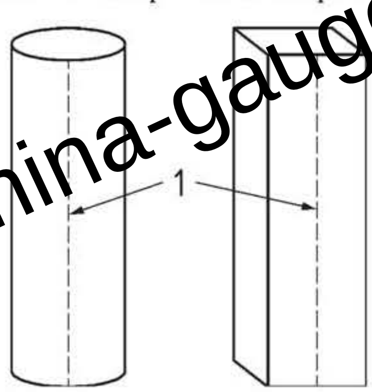
— ISO Online browsing platform: available at https://www.iso.org/obp

3.1.1
initial secant modulus of elasticity
$E_{C,0}$
secant slope of the stress strain curve at first loading

3.1.2
stabilized secant modulus of elasticity
$E_{C,S}$
secant slope of the stress strain curve after three loading cycles

3.1.3
gauge length
base length
length used as reference base for strain measurement

3.1.4
measuring line
straight line laying on the lateral surface of the specimen and parallel to the vertical axis (see Figure 1)



Key
1 measuring line

Figure 1 — Measuring line on cylinder and prismatic specimens

3.2 Symbols and abbreviations

For the purposes of this document, the following symbols apply.

d Specimen diameter or width

D Upper sieve size (for definition of aggregates size, see EN 12620)

D_{max} Declared value of D of the coarsest fraction of aggregates actually used in the concrete

f_c Compressive strength of concrete determined by testing companion specimens – cylinders, prisms, cubes or cores – or estimated from non-destructive tests

$E_{C,0}$ Initial secant modulus of elasticity

$E_{C,S}$ Stabilized secant modulus of elasticity

ε Measured strain

ε_a Strain along each measuring line at upper stress

$\varepsilon_{a,\,n}$ Average strain at upper stress on loading cycle n

ε_b Strain along each measuring line at lower stress

$\varepsilon_{b,\,n}$ Average strain at lower stress on loading cycle n

$\Delta\varepsilon_s$ Strain difference during third loading cycle

$\Delta\varepsilon_0$ Strain difference during first loading cycle

L Specimen length

L_0 Initial gauge length of instrument

ΔL Change in measured length

σ_a Nominal upper stress = f_c / 3

σ_b Nominal lower stress – arbitrary value between 10 % and 20 % of f_c

σ_p Nominal preload stress – arbitrary value between 0,5 MPa and σ_b

σ_a^m Measured stress corresponding to nominal upper stress, σ_a

σ_b^m Measured stress corresponding to nominal lower stress, σ_b

$\Delta\sigma$ Difference between measured stresses σ_a^m and σ_b^m

4 Principle

A test specimen is loaded under axial compression, the stresses and strains are recorded and the slope of the secant to the stress-strain curve is determined at first loading (Method A only) and after three loading cycles (Methods A and B).

The secant slope is known as the secant modulus of elasticity in compression.

The test specimens may be either cast or taken from an existing structure.

5 Apparatus

5.1 Test machine

Compression testing machine conforming to EN 12390-4 with following additional requirements:

a) suitable for execution of programmable loading cycles;

b) able to increase and decrease the load at a constant rate within a given tolerance (see 7.3.1 and 7.3.2);

c) able to maintain a constant load at selectable nominal values with a maximum variation within ± 5 %;

d) calibrated as Class 1 to EN 12390-4 over the working range from the lower stress to the upper stress as defined in 7.3.1 and 7.3.2.

NOTE The test lends itself to the use of automatic control test machines. However, if manual control test machines can be shown to comply with b), c) and d) above, they can be used.

5.2 Instrumentation

Instrumentation measuring the strain of the specimen under axial compression along a measuring line shall be Class 2 as determined in accordance with EN ISO 9513 in the range from 0 µm/m to 1 000 µm/m.

The instrumentation can measure strain directly (e.g. resistive strain gauges) or take the form of measuring length change from which the strain, ε, is calculated with Formula (1).

$$\varepsilon = \frac{\Delta L}{L_0} \qquad (1)$$

5.3 Gauge length

The gauge length of the strain measuring instrument L_0 shall be between two-thirds of the specimen diameter (or section width) and one-half of the specimen length and not less than $3D_{max}$.

NOTE For specimens where L/d is between 3,5 and 4,0 the gauge length can be increased to up to 2/3 of the specimen length.

6 Test specimens

6.1 Shape and dimensions of specimens

The test specimens shall be moulded (cylinder or prism) or drilled cores complying with the requirements of EN 12390-1 or EN 12504-1. The dimension d (diameter or width) shall be at least 3,5 times D_{max}. The ratio between the specimen length L and the dimension d shall be in the range $2 \leq L/d \leq 4$.

The recommended test specimen shall be cylinders of diameter 150 mm and height 300 mm (reference specimen). Alternatively, other test specimens generally complying with the requirements of EN 12390-1 may be used, provided that the specimen complies with the dimensions and aggregate size to diameter or width stated above. In the case of specimens drilled or cut from a structure, this requirement sometimes cannot be fulfilled; in such cases, this shall be stated in the test report.

NOTE The size of the test specimen can have an influence on the result.

If relevant, the adjustment of test specimen shall comply with EN 12390-3.

Companion specimens should be available for the determination of compressive strength as described in 7.2 and shall be made from the same batch of concrete in the case of cast specimens, or shall be drilled from the same zone in the case of drilled specimens.

6.2 Curing, storage and conditioning

Moulded specimens shall be cured or stored in accordance with EN 12390-2, cored specimen in accordance with EN 12504-1. Before testing, they shall be maintained at (20 ± 2) °C for sufficient time for strain measuring instruments to be securely fixed but not longer than 24 h out of water. During the time out of water, precautions shall be taken to ensure the specimen remains moist.

If alternative storage conditions are specified in provisions valid in the place of use, these need to be considered for storing and conditioning.

7 Method

7.1 Specimen instrumentation and positioning

The strain measuring instruments shall be positioned in such a way that the measuring base is at equivalent distance from the end faces of the specimen.

At least two strain measuring instruments shall be symmetrically arranged with respect to the central axis of the specimen.

The specimen shall be centred on the lower platen.

It is recommended that in order to have adequate information on centering of cylinder specimens, at least three measurement lines are required.

7.2 Determination of compressive strength

The compressive strength of concrete f_c shall be determined in accordance with EN 12390-3 on companion specimen(s) preferably having the same size and shape of those specimens used for secant modulus of elasticity determination.

If alternative curing conditions are specified in provisions valid in the place of use, companion specimen(s) for the determination of compressive strength shall be stored under the same conditions as specified in 6.2.

If the companion specimens are not of the same size and shape as the specimen used for the determination of secant modulus of elasticity, the difference in compressive strength obtained from specimens of different shape and sizes shall be taken into account.

The compressive strength (measured or estimated), f_c is used to define the stress levels of the test cycle for the determination of secant modulus of elasticity.

If companion test specimens for the determination of compressive strength are not available, the compressive strength may be estimated from non-destructive tests or by national provisions valid in the place of use of the concrete. Details of the test method and results from the non-destructive method adopted shall be indicated in the test report.

7.3 Determination of secant modulus of elasticity

7.3.1 Method A – Determination of initial and stabilized secant modulus of elasticity

7.3.1.1 Preloading cycles

Three preloading cycles are carried out in order to check the wiring stability (first check) and specimen positioning (second check).

Place the test specimen, with the measuring instruments attached axially, centrally in the testing machine.

For the first loading cycle, apply stress to the specimen at a rate of (0,6 ± 0,2) MPa/s up to the lower stress σ_b. Hold the lower stress within ± 5 % of the nominal value for a period as short as possible but not exceeding 20 s. Record the lower stress. Reduce the stress at a rate of (0,6 ± 0,2) MPa/s down to the preload stress σ_p. Hold the preload stress for a period as short as possible but not exceeding 20 s. At the end of this period, zero the strain measuring instruments.

Repeat the loading cycles above for a further two times, i.e. cycles two and three. At the end of each of the second and third cycles at the lower stress level, record the strain ε_b along each measuring line.

After the three cycles, maintain the preload stress within ± 5 % of the nominal value and perform the following consecutive checks within 60 s.

First check

On each measuring line, the variation of ε_b from the second cycle to the third cycle shall not be greater than 10 %.

If the strain difference is greater than 10 %, stop the test; adjust the measuring instruments and restart. If it is not possible to reduce the difference below 10 % after re-starting, the test shall be stopped.

Second check

The strains ε_b at the third cycle on all the measuring lines shall not differ from their average by more than 20 %.

If the limit is not achieved, re-centre the specimen and restart the test. If it is not possible to reduce the difference below 20 %, the test shall be stopped and the specimen rejected.

7.3.1.2 Loading cycles

Increase the stress at a rate of (0,6 ± 0,2) MPa/s from the preload stress to the lower stress. Hold the lower stress within ± 5 % of the nominal value for a period as short as possible but not exceeding 20 s. At the end of this period, record the strain along each measuring line and calculate the average strain $\varepsilon_{b,0}$ at this stress level.

Three loading cycles are carried out.

For each cycle, increase the stress applied to the specimen at a rate of (0,6 ± 0,2) MPa/s until the upper stress, σ_a, is reached. Hold the upper stress within ± 5 % of the nominal value for a period as short as possible but not exceeding 20 s. For cycles one and two, reduce the stress at a rate of (0,6 ± 0,2) MPa/s to the lower stress. Hold the lower stress within ± 5 % of the nominal value for a period as short as possible but not exceeding 20 s.

At the end of the upper stress phase of the first and third cycles and when the load is stable, record the corresponding strains along each measuring line and calculate the average strains, $\varepsilon_{a,1}$ and $\varepsilon_{a,3}$, at these stress levels.

At the end of the lower stress phase of the second cycle and when the load is stable, record the strain along each measuring line and calculate the average strain $\varepsilon_{b,2}$ at this stress level.

The measured value of the lower stress σ_b^m shall be recorded.

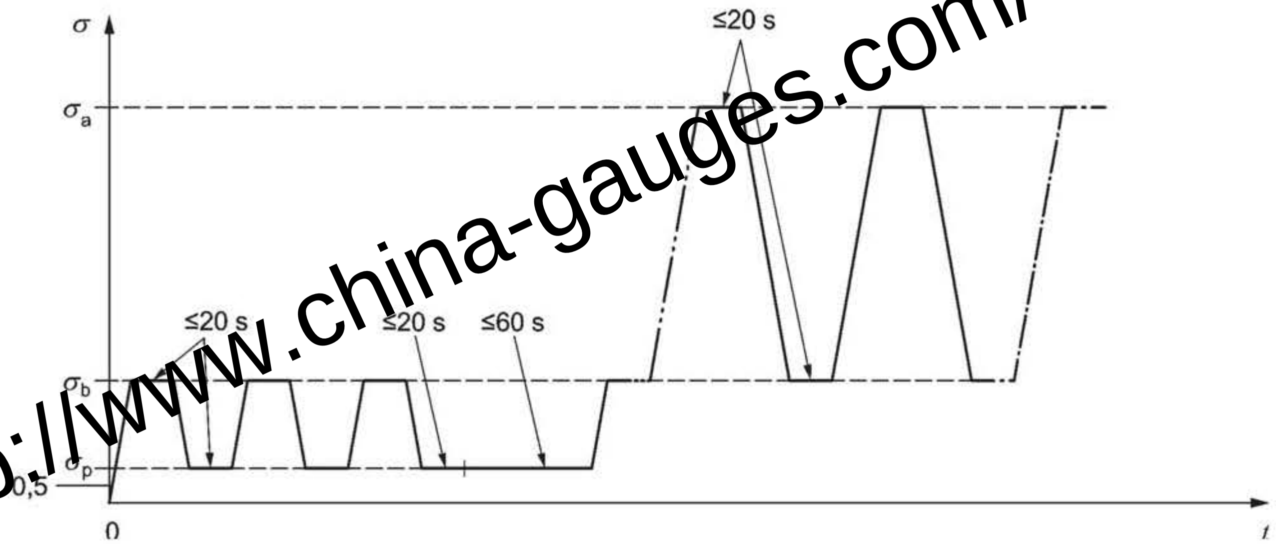
The measured value of the upper stress σ_a^m shall be recorded.

When all measurements are completed at the upper stress level of the third loading cycle, the compressive strength of the specimen shall be determined in accordance with the loading procedure given in EN 12390-3. Record the compressive strength to the nearest 0,1 MPa.

In order to prevent permanent damage to the measuring gauges, it may be desirable to remove them from the specimen before the load is increased to failure. This should be performed safely.

If the measured compressive strength differs from f_c by more than 20 %, it shall be noted in the test report.

The test cycle for the determination of elastic modulus is given in Figure 2.



Key

————	loading cycle
—·-·—	loading cycle for the determination of initial secant modulus of elasticity – Method A
—·—	loading cycle for the determination of stabilized secant modulus of elasticity – Method A
σ	applied stress in MPa
σ_a	upper stress – f_c / 3
σ_b	lower stress – $0,10 \times f_c \leq \sigma_b \leq 0,20 \times f_c$
σ_p	preload stress – $0,5$ MPa $\leq \sigma_p \leq \sigma_b$
t	time in s

Figure 2 — Cycle for the determination of initial and stabilized secant modulus of elasticity (Method A)

7.3.2 Method B – determination of stabilized secant modulus of elasticity

Three loading cycles are carried out. The specimen positioning (first check) and wiring stability check (second check) are carried out at the end of the second and third cycles. The stabilized secant modulus of elasticity is determined on the third cycle.

Place the test specimen, with the measuring instruments attached axially, centrally in the testing machine. Apply the preload stress σ_p. Hold the preload stress for a period as short as possible but not exceeding 20 s. At the end of this period, zero the strain measuring instruments.

First cycle

Increase the stress applied to the specimen at a rate of (0,6 ± 0,2) MPa/s from the preload stress to the upper stress σ_a. Hold the upper stress within ± 5 % of the nominal value for a period as short as possible but not exceeding 20 s. At the end of this period, record the strain along each measuring line and calculate the average strain, $\varepsilon_{a,1}$.

Reduce the stress at a rate of (0,6 ± 0,2) MPa/s down to the lower stress. Hold the lower stress for a period as short as possible but not exceeding 20 s. At the end of this period, record the strain along each measuring line and calculate the average strain, $\varepsilon_{b,1}$.

Second cycle

Increase the stress at a rate of (0,6 ± 0,2) MPa/s from the lower stress to the upper stress. Hold the upper stress within ± 5 % of the nominal value for a period as short as possible but not exceeding 20 s. At the end of this period, record the strain along each measuring line and calculate the average strain, $\varepsilon_{a,2}$.

Reduce the stress at a rate of (0,6 ± 0,2) MPa/s down to the lower stress. Hold the lower stress for a period as short as possible but not exceeding 20 s. At the end of this period, record the strain along each measuring line and calculate the average strain, $\varepsilon_{b,2}$.

First check

On the second cycle, the strain ε_a on each measuring line shall not differ from the average $\varepsilon_{a,1}$ by more than 20 %.

If the limit is not achieved, re-centre the specimen and restart the test. If it is not possible to reduce the difference below 20 %, the test shall be stopped and the specimen rejected.

Third cycle

Increase the stress at a rate of (0,6 ± 0,2) MPa/s from the lower stress to the upper stress. Hold the upper stress within ± 5 % of the nominal value for a period as short as possible but not exceeding 20 s. At the end of this period, record the strain along each measuring line and calculate the average strain, $\varepsilon_{a,3}$.

Second check

On each measuring line the variation of ε_a from the second to the third cycle shall not be greater than 10 %.

If the strain difference is greater than 10 %, stop the test; adjust the measuring instruments and restart. If it is not possible to reduce the difference below 10 % after re-starting, the difference shall be included in the test report.

The measured value of the lower stress σ_b^m shall be recorded.

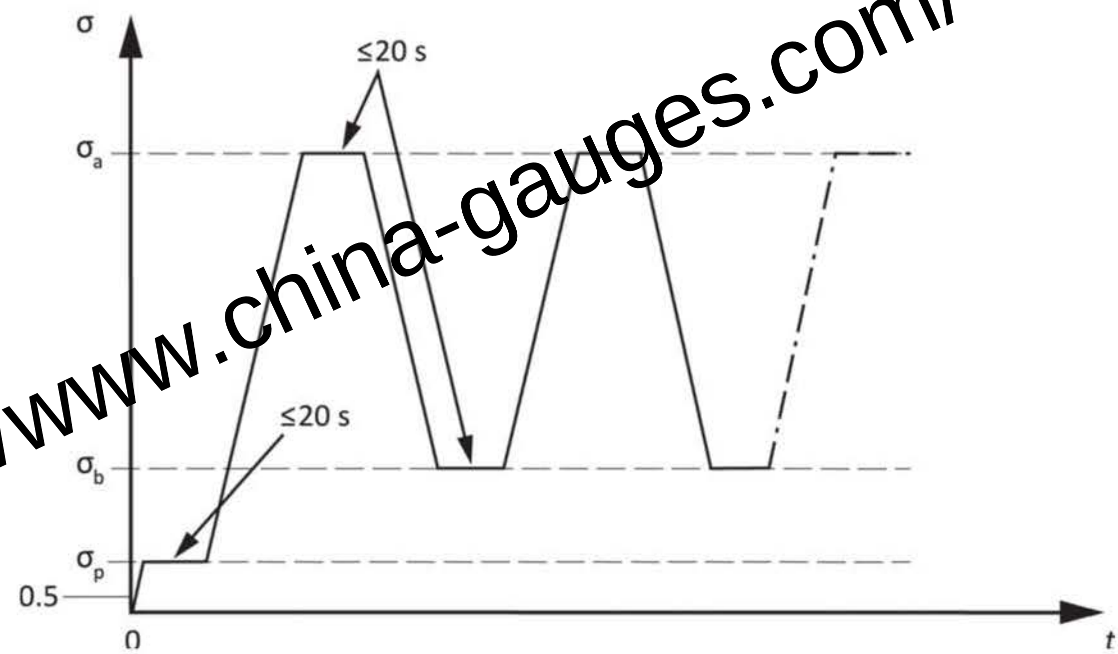
The measured value of the upper stress σ_a^m shall be recorded.

After all measurements are completed at the upper stress level, the compressive strength of the specimen shall be determined in accordance with the loading procedure given in EN 12390-3. Record the compressive strength to the nearest 0,1 MPa.

In order to prevent permanent damage to the measuring gauges, it may be desirable to remove them from the specimen before the load is increased to failure. This should be performed safely.

If the measured compressive strength differs from f_c by more than 20 %, it shall be noted in the test report.

The test cycle for the determination of elastic modulus is given in Figure 3.



Key

————	loading cycle
——·——	loading cycle for the determination of stabilized secant modulus of elasticity – Method B
σ	applied stress in MPa
σ_a	upper stress – f_c / 3
σ_b	lower stress – 0,10 × $f_c \le \sigma_b \le$ 0,20 × f_c
σ_p	preload stress – 0,5 MPa $\le \sigma_p \le \sigma_b$
t	time in s

Figure 3 — Cycle for the determination of stabilized secant modulus of elasticity (Method B)

8 Calculation of secant modulus of elasticity

8.1 Initial secant modulus of elasticity (Method A)

The initial secant modulus of elasticity $E_{C,0}$ is defined in Formula (2).

$$E_{C,0} = \frac{\Delta\sigma}{\Delta\varepsilon_0} = \frac{\sigma_a^m - \sigma_b^m}{\varepsilon_{a,1} - \varepsilon_{b,0}} \tag{2}$$

8.2 Stabilized secant modulus of elasticity (Method A and B)

The stabilized secant modulus of elasticity $E_{C,S}$ is defined in Formula (3).

$$E_{C,S} = \frac{\Delta\sigma}{\Delta\varepsilon_S} = \frac{\sigma_a^m - \sigma_b^m}{\varepsilon_{a,3} - \varepsilon_{b,2}} \tag{3}$$

NOTE 1 The degree of variation of the secant modulus of elasticity from $E_{C,0}$ to $E_{C,S}$ (Method A) can be an indication of the material susceptibility to stress-induced micro-cracking or micro-cracking caused by drilling in the case of cores taken from a structure.

NOTE 2 The calculation can be based on the linear regression between a and b or the best fit curve of the measured stress and strain on the last loading cycle.

9 Test report

The report shall include:

a) a reference to this document, including its year of publication;

b) description and identification of the test specimen;

c) age of specimen at time of test (if available);

d) shape, designated dimension and actual dimension of specimen;

e) curing and storage conditions;

f) condition of the specimen when received and any surface treatment;

g) temperature, humidity (if available) and duration of the pre-conditioning period of the specimen before testing;

h) type of adjustment of specimen ends;

i) date of test;

j) type and number of measuring instruments including base or gauge length;

k) compressive strengths of companion specimens to the nearest 0,1 MPa (N/mm^2) or estimated from non-destructive testing;

l) compressive strength of the specimen used for secant modulus of elasticity test to the nearest 0,1 MPa (N/mm^2) if measured;

m) method used to determine secant modulus of elasticity (A or B);

n) strain difference from second check if exceeding the specified value;

o) initial secant modulus of elasticity $E_{C,0}$ obtained from Formula (2) (Method A only) to the nearest 0,1 GPa (100 N/mm^2);

p) stabilized secant modulus of elasticity $E_{C,S}$ obtained from Formula (3) to the nearest 0,1 GPa (100 N/mm^2);

q) any deviations from the standard method of testing;

r) a declaration by the person responsible for the test that it has been carried out in accordance with this document except as detailed in item q).

The report may include:

s) mass of the specimen, in kg;

t) apparent density of specimen, to the nearest 10 kg/m^3;

u) if cores are used for the test, include sampling and testing information as indicated in EN 12504-1.

10 Precision

There is currently no precision data for this test.

Bibliography

[1] EN 12350-1, *Testing fresh concrete - Part 1: Sampling and common apparatus*

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