Experts for Specialised Construction and Concrete Systems

## TESTING SPRAYED CONCRETE

# EFNARC THREE POINT BENDING TEST

# ON SQUARE PANEL WITH NOTCH

**Flexural tensile strength of fibre concrete on sprayed test specimen.**

## June 2011

**Acknowledgements**

EFNARC wishes to gratefully acknowledge the work undertaken by the members of its

Fibres Technical Committee in the preparation of this document.

All comments on this test method should be submitted to the EFNARC secretary: secretary@efnarc.org.

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## FOREWORD

The European standard for sprayed concrete, EN 14487-1, mentions the different ways of specifying the ductility of fibre reinforced sprayed concrete in terms of residual strength and energy absorption capacity. It also mentions that both ways are not exactly comparable and are measured using different test specimen geometries.

1) **The energy absorption** value, measured on panel specimens, can be prescribed when, as in case of rockbolting, emphasis is placed on energy which has to be absorbed during the deformation of the rock.; especially useful for primary sprayed concrete linings (EN 14488-5:Testing sprayed concrete, part 5: Determination of energy absorption capacity of fibre reinforced slab specimens ).

2) **The residual strength** value, measured on beam specimens, can be prescribed when the concrete characteristics are used in a structural design model (EN 14488-3:Testing sprayed concrete, part 3: Flexural strengths of fibre reinforced beam specimens)

**The test method described here for the measurement of residual strength is a three point bending test on square panel specimens with notch instead of the EN 14488-3 four point bending test on beam specimens.**

This test method has the following advantages:

- The geometry is the same as in the panel test for the measurement of Energy Absorption;
- The geometry and dimensions of the specimens, as well as the spray method adopted ensure the distribution of the fibres in the matrix are as close as possible to that encountered in the real structure;
- The dimensions of the test specimen are acceptable for handling within a laboratory (no excessive weights or dimensions);
- The test is compatible, as far as the experimental means permit, with use in a large number of normal equipped laboratories (no unnecessary sophistication).
- The panel can be sprayed on the job site;
- No requirement to saw prisms from the panel which can influence the result;
- The experimental scatter of results should be lower than the current standardised beam test;
- The notch provides a slower cracking process, thereby reducing the risk of a sudden fall;
- By analogy to EN 14651, test method for metallic fibre concrete, this test method defines residual flexural strength ($f_{R,1}$, $f_{R,2}$, $f_{R,3}$, $f_{R,4}$) according to the updated international standard (RILEM - *fib* Model Code 2010). The obtained mechanical property will serve as input for the dimensioning method.

## 1 SCOPE

This proposal specifies a method of measuring the flexural tensile strength of fibre reinforced concrete on sprayed test specimen. The method provides for the determination of the limit of proportionality (*LOP*) and of a set of residual flexural tensile strength values.

The method can be used for metallic fibres, synthetic or other fibres, or a combination of fibre types.

## 2 TERMS AND DEFINITIONS

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

**2.1**
**crack mouth opening displacement**
linear displacement measured by a transducer installed as specified in 7.1 and illustrated in Figure 3, on a plate subjected to a central line load *F.*

**2.2**
**deflection**
linear displacement measured by a transducer installed as specified in 7.2 and illustrated in Figure 4, on a plate subjected to a central line load *F.*

**2.3**
**limit of proportionality**
stress at the tip of the notch which is assumed to act in an uncracked mid-span section, with linear stress distribution, of a plate subjected to the central line load $F_L$, defined in 8.2.

**2.4**
**residual flexural tensile strength**
fictitious stress at the tip of the notch which is assumed to act in an uncracked mid-span section, with linear stress distribution, of a plate subjected to the central line load $F_j$ corresponding to $CMOD_j$ where $CMOD_j > CMOD_{F_L}$ or to $\delta_j$ where $\delta_j > \delta_{F_L}$ ($j$ = 1, 2, 3, 4), defined in 8.3.

## 3 SYMBOLS AND ABBREVIATED TERMS

### 3.1 Symbols

| | |
|---|---|
| $CMOD_{F_L}$ | *CMOD* at *LOP* |
| $CMOD_j$ | value of *CMOD*, $j$ = 1, 2, 3 or 4 |
| $F$ | load |
| $F_j$ | load value, $j$ = 1, 2, 3 or 4 |
| $F_L$ | load at *LOP* |

| | |
|---|---|
| $L$ | length of test specimen |
| $M$ | bending moment |
| $M_j$ | bending moment value, $j$ = 1, 2, 3 or 4 |
| $M_L$ | bending moment corresponding to the load at *LOP* |
| $b$ | width of test specimen |
| $f_{R,j}$ | residual flexural tensile strength, $j$ = 1, 2, 3 or 4 |
| $f_{ct,L}^{f}$ | *LOP* |
| $h_{sp}$ | distance between the tip of the notch and the top of the test specimen in the mid-span section |
| $l$ | length of span |
| $x$ | width of notch |
| $y$ | distance between bottom of test specimen and axis of displacement transducer |
| $\delta$ | deflection |
| $\delta_{F_L}$ | deflection at LOP |
| $\delta_j$ | deflection value, $j$ = 1, 2, 3 or 4 |

**3.2 Abbreviations**

| | |
|---|---|
| *CMOD* | crack mouth opening displacement |
| *LOP* | limit of proportionality |

**4 PRINCIPLE**

The tensile behaviour of metallic fibre concrete is evaluated in terms of residual flexural tensile strength values determined from the load-crack mouth opening displacement curve or load-deflection curve obtained by applying three point bending test on a square plate.

**5 APPARATUS**

**5.1** Saw with rotating carborundum or diamond blade with adjustable and fixable cutting depth and 90° direction of saw-cut to the specimens l engths for notching the test specimens.

**5.2** Calliper, capable of reading the dimensions of test specimens to an accuracy of 0,1 mm.

**5.3** Rule, capable of reading the dimensions of test specimens to an accuracy of 1 mm.

**5.4** Testing machine meeting the machine class 1 requirements in EN 12390-4, capable of operating in a controlled manner i.e. producing a constant rate of displacement (*CMOD* or deflection), and with sufficient stiffness to avoid unstable zones in the load-*CMOD* curve or load-deflection curve.

**5.5** Device for transmitting the load of the testing machine to the test specimen, made up of two supporting rollers and one loading roller (see Figure 1).

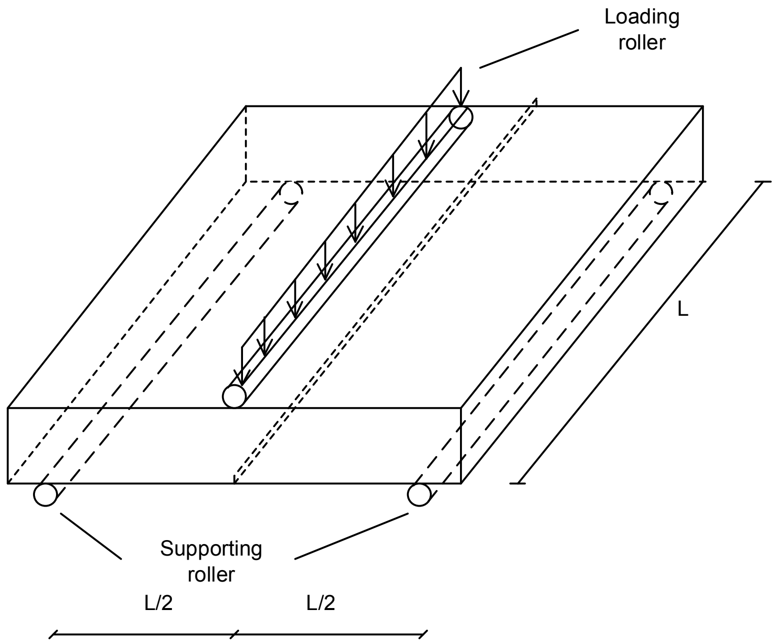


**Figure 1 – Arrangement of loading of test specimen**

All rollers shall be manufactured from steel and shall have a circular cross-section with a diameter of 30 mm ± 1 mm. They shall be at least 10 mm longer than the width of the test specimen. They shall have a clean and smooth surface.

Two rollers, including the upper one, shall be capable of rotating freely around their axis.

The distance between the centres of the supporting rollers (i.e. the span length) shall be equal to 500 mm. All rollers shall be adjusted to their correct position with all distances having an accuracy of ± 2,0 mm.

**5.6** Load measuring device, capable of measuring loads to an accuracy of 0,1 kN.

**5.7** Linear displacement transducer(s), capable of measuring displacements to an accuracy of 0,01 mm.

**5.8** Device (frame or jig) for mounting displacement transducer(s), capable of being installed in a manner that ensures accurate determination of net mid-span deflections excluding any effects due to seating or twisting of the test specimen on its supports (only if deflection is measured instead of *CMOD*).

**5.9** Data recording system coupled directly to electronic outputs of load and *CMOD* or deflection, with a recording rate not less than 5 Hz.

## 6 TEST SPECIMENS

### 6.1 Shape and size of test specimens

The test specimens shall be plates conforming to EN 14488-1 with a nominal width of 600 mm and an L of 600 mm. The nominal thickness is 100 mm.

### 6.2 Manufacture and curing of test specimens

The test specimens shall be sprayed in compliance with EN 14488-1 unless specified otherwise.

### 6.3 Notching of test specimens

Wet sawing shall be used to notch the test specimens. The specimens shall be sawn through the width of specimen at mid-span (see Figure 2). The notch needs to be applied at the surface which was in contact with the bottom of the mould during spraying.

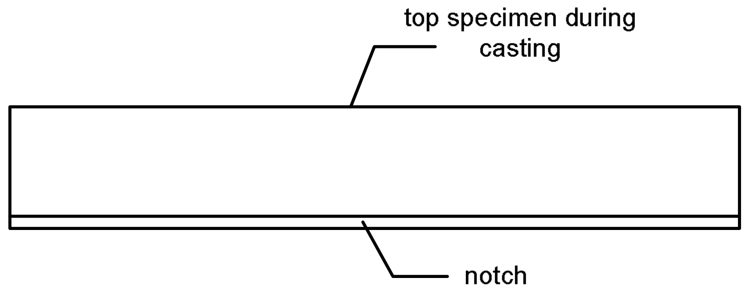


**Figure 2 – Position of the notch sawn into the test specimen**

The width of the notch × shall be 5 mm or less, the distance $h_{sp}$ shall be 90 mm ± 1 mm (see Figure 3).

The test specimens shall be cured according to EN 12390-2, unless specified otherwise, for a minimum of 3 days after sawing until no more than 3 h before testing (leaving sufficient time for preparation including any location devices for the transducer(s)). Testing shall normally be performed at 28 days.

## 7 TESTING PROCEDURE

### 7.1 Preparation and positioning of test specimens

The average width of the specimen and distance between the tip of the notch and the top of the specimen in the mid-span section shall be determined from two measurements to the nearest 0,1 mm of width and distance in the notched part of the test specimen, using callipers.

When the crack (or notch) mouth opening displacement is measured, a displacement transducer shall be mounted along the longitudinal axis at the mid-width of the test specimen, such that the distance y between the bottom of the specimen and the line of measurement is 5 mm or less (see Figure 3).

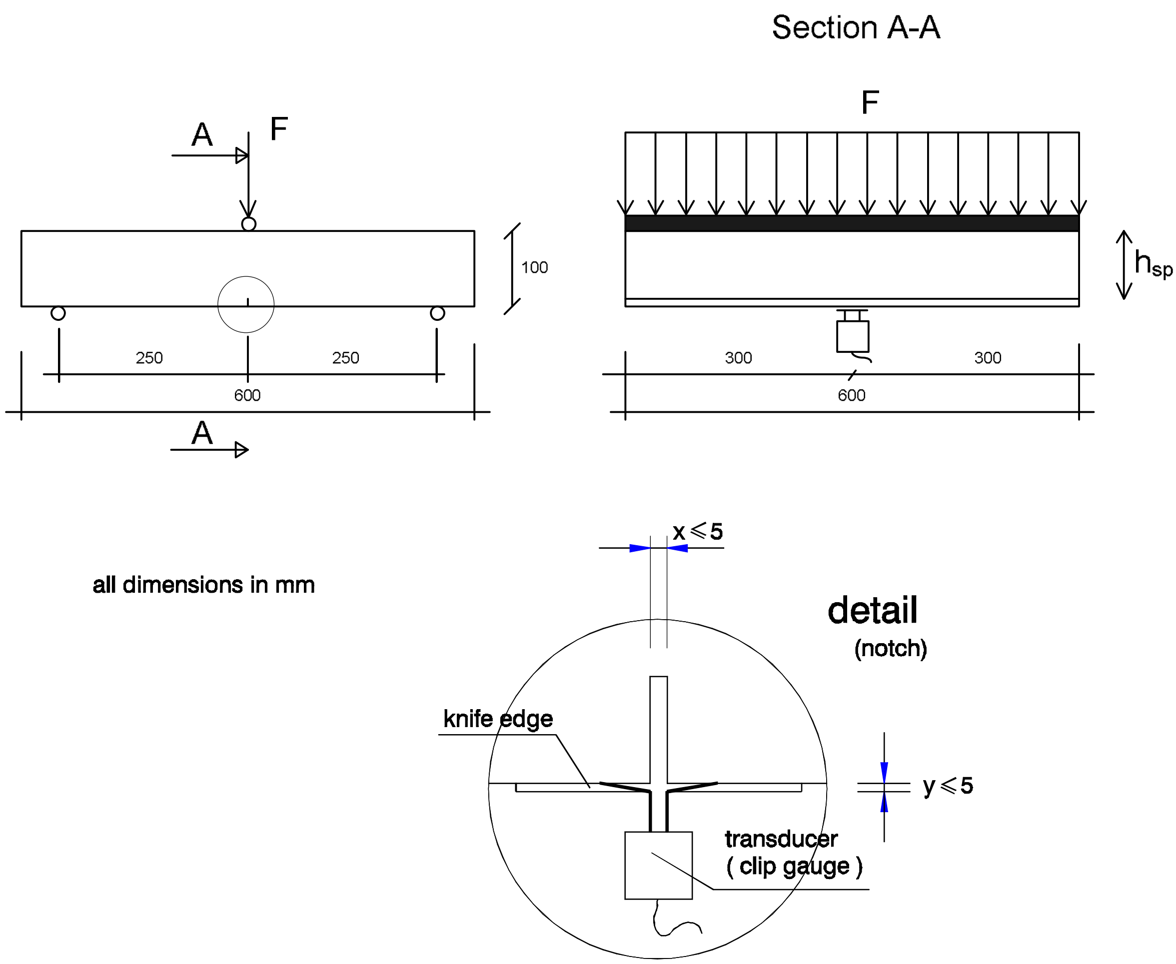


**Figure 3 – Typical arrangement for measuring CMOD**

When the deflection is measured instead of the *CMOD*, a typical arrangement is as follows. A displacement transducer shall be mounted on a rigid frame that is fixed to the test specimen at mid-height over the supports (see Figure 4). One end of the frame should be fixed to the specimen with a sliding fixture and the other end with a rotating fixture. Since the transducer should measure the deflection, a thin plate fixed at one end can be placed at mid-width across the notch mouth at the point of measurement (see Figure 4).

All bearing surfaces shall be wiped clean and any loose grit or other extraneous material from the surfaces of the test specimen that will be in contact with the rollers shall be removed.

The test specimen shall be placed in the testing machine, correctly centred and with the longitudinal axis of the specimen at right angles to the longitudinal axis of the upper and lower rollers.

### 7.2 Bending test

Before the bending test, the average span length of the test specimen shall be determined from two measurements to the nearest mm of the axis distance between the supporting rollers on both sides of the specimen, using a ruler.

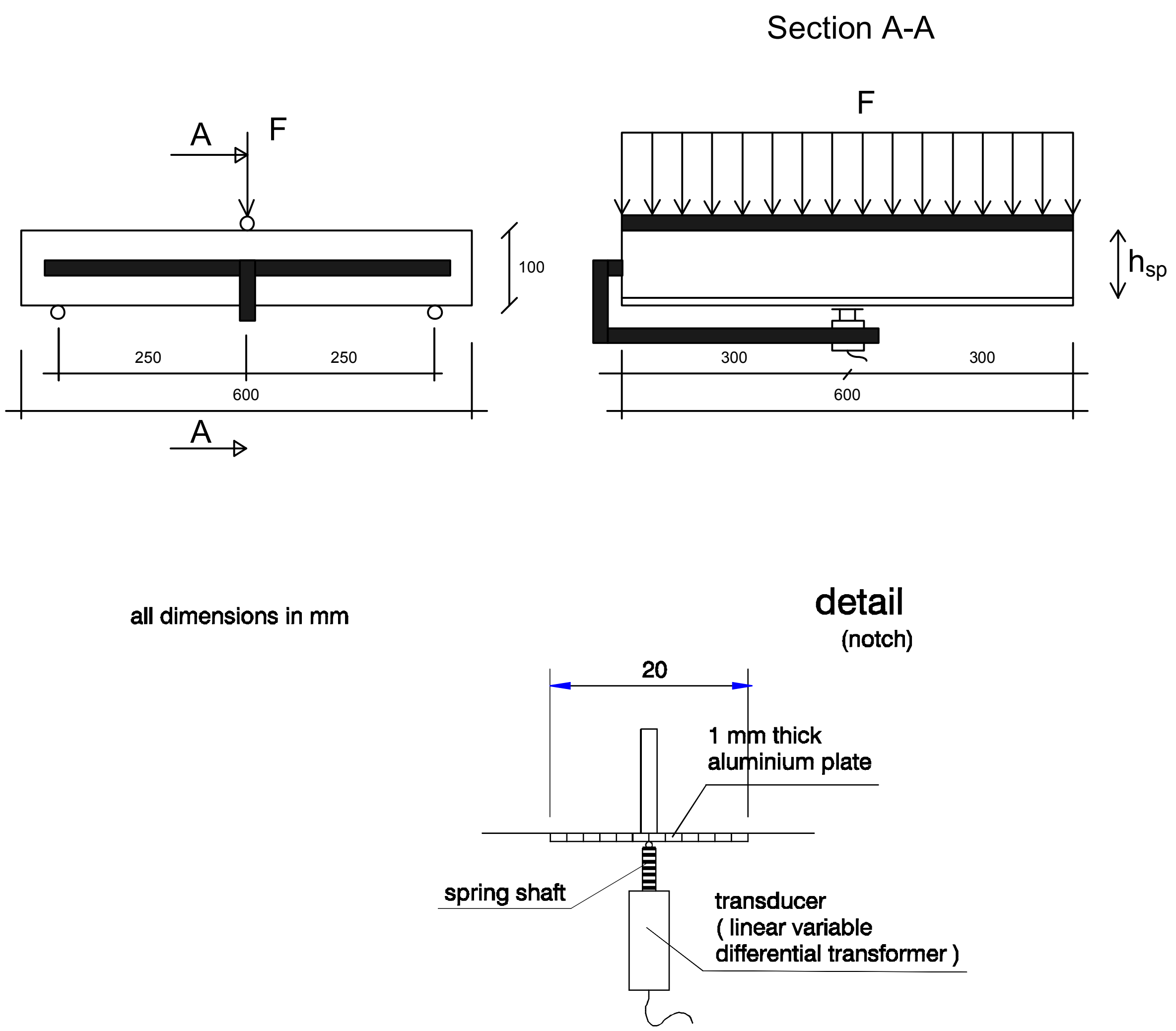


**Figure 4 – Typical arrangement for measuring deflection**

The load shall not be applied until all loading and supporting rollers are resting evenly against the test specimen.

In case of a testing machine controlling the rate of increase of *CMOD*, the machine shall be operated so that *CMOD* increases at a constant rate of 0,05 mm/min. When *CMOD* = 0,2 mm, the machine shall be operated so that *CMOD* increases at a constant rate of 0,2 mm/min.

During the first two minutes of the test, the values of the load and corresponding *CMOD* shall be recorded at a rate not less than 5 Hz, afterwards this rate may be reduced to not less than 1 Hz.

The test shall be terminated at a *CMOD* value not less than 5 mm.

In case the minimum load value in the range $CMOD_{F_L}$ to *CMOD* = 0,5 mm is less than 30 % of the load value corresponding to $CMOD_{F_L}$, the testing procedure shall be checked for instability.

In case of a testing machine controlling the rate of increase of deflection, the above testing procedure shall be applied provided that the *CMOD* related parameters are transformed into deflection related parameters (see 8.1).

Tests during which the crack starts outside the notch shall be rejected.

## 8 EXPRESSION OF RESULTS

### 8.1 Equivalence between *CMOD* and deflection

The relation between crack opening, CMOD and deflection may be approximated by:

$$crack\ opening = \frac{4 \cdot \delta \cdot (0{,}9 \cdot h)}{span}$$

$$CMOD = \frac{4 \cdot \delta \cdot (0{,}9 \cdot h + notch\ depth)}{span}$$

where

$\delta$ is the deflection, in millimetres;

*CMOD* is the *CMOD* value, in millimetres, measured at the bottom of the notch

h is the unnotched height of the specimen in millimetres

To evaluate the residual strength at the same crack openings as in EN14651, the loads need to be recorded at the CMODs or deflections which are mentioned in the table below.

| | Residual crack strength | CMOD (in mm) | Deflection (in mm) | Crack opening (in mm) |
|---|---|---|---|---|
| EN14651 beam test | $f_{R,1}$ | 0.5 | 0.454 | 0.409 |
| | $f_{R,2}$ | 1.5 | 1.364 | 1.227 |
| | $f_{R,3}$ | 2.5 | 2.273 | 2.045 |
| | $f_{R,4}$ | 3.5 | 3.182 | 2.864 |
| 3 point bending test on square panels with notch of 10 mm | $f_{R,1}$ | 0.5 | 0.631 | 0.409 |
| | $f_{R,2}$ | 1.5 | 1.894 | 1.227 |
| | $f_{R,3}$ | 2.5 | 3.156 | 2.045 |
| | $f_{R,4}$ | 3.5 | 4.420 | 2.864 |

### 8.2 Limit of proportionality

The *LOP* is given by the expression:

$$f_{\mathrm{ct,L}}^{\mathrm{f}} = \frac{3F_{\mathrm{L}}\,l}{2bh_{\mathrm{sp}}^{2}}$$

where

$f_{\mathrm{ct,L}}^{\mathrm{f}}$ is the *LOP*, in Newton per square millimetre;

$F_{\mathrm{L}}$ is the load corresponding to the *LOP*, in Newton (see Figure 5);

$l$ is the span length, in millimetres;

$b$ is the width of the specimen, in millimetres;

$h_{\mathrm{sp}}$ is the distance between the tip of the notch and the top of the specimen, in millimetres.

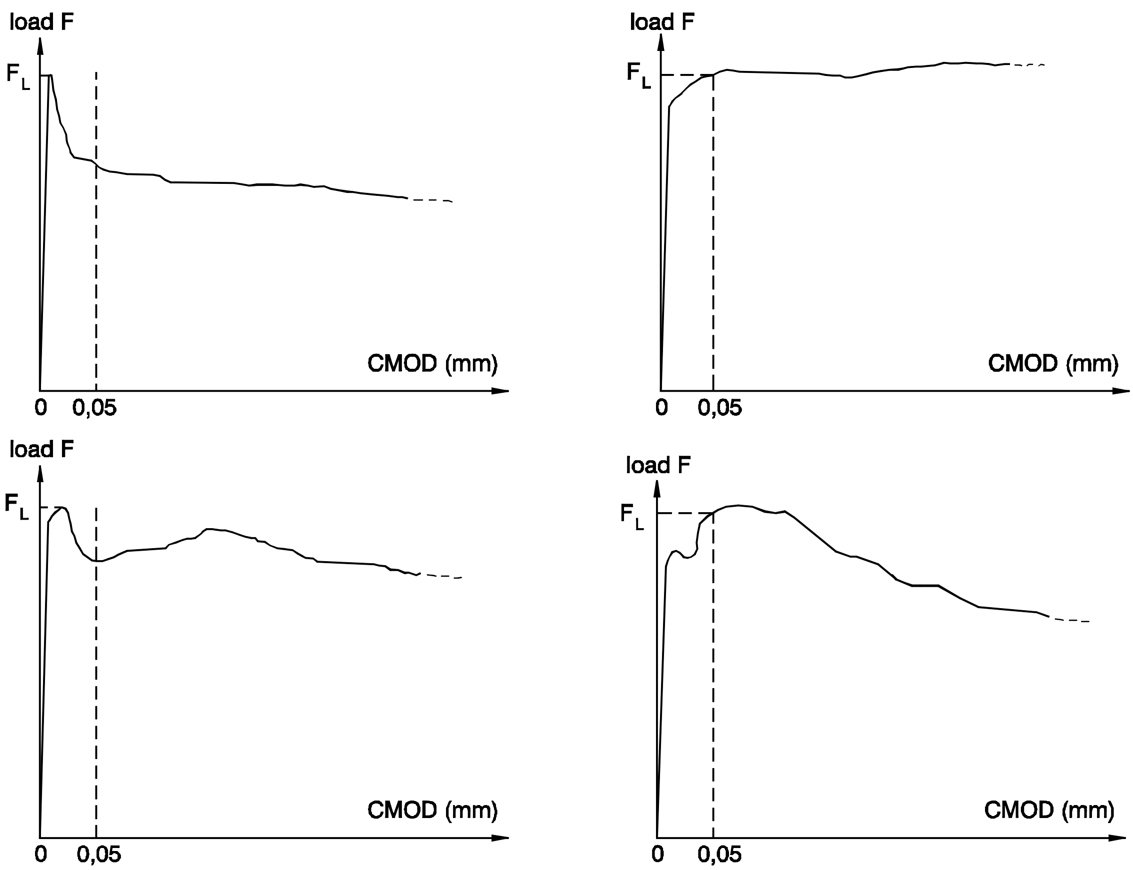


**Figure 5 – Load-*CMOD* diagrams and $F_{\mathrm{L}}$**

The load value $F_{\mathrm{L}}$ shall be determined by drawing a line at a distance of 0,05 mm and parallel to the load axis of the load-*CMOD* or load-deflection diagram and taking as $F_{\mathrm{L}}$ the highest load value in the interval of 0,05 mm (see Figure 5).

The *LOP* shall be expressed to the nearest 0,1 N/mm$^2$.

### 8.3 Residual flexural tensile strength

The residual flexural tensile strength $f_{R,j}$ is given by the expression:

$$f_{R,j} = \frac{3F_j l}{2bh_{sp}^2}$$

where

- $f_{R,j}$ is the residual flexural tensile strength corresponding with $CMOD = CMOD_j$ or $\delta = \delta_j$ ($j$ = 1, 2, 3, 4), in Newton per square millimetre;
- $F_j$ is the load corresponding with $CMOD = CMOD_j$ or $\delta = \delta_j$ ($j$ = 1, 2, 3, 4), in Newton (see Figure 6);
- $l$ is the span length, in millimetres;
- $b$ is the width of the specimen, in millimetres;
- $h_{sp}$ is the distance between the tip of the notch and the top of the specimen, in millimetres.

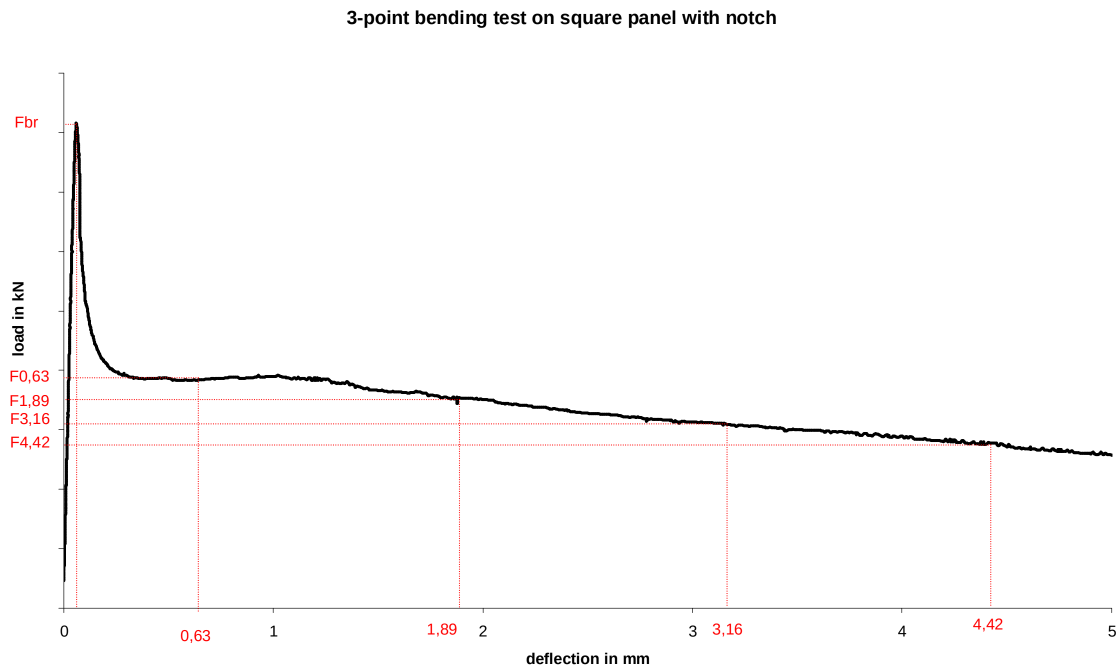


**Figure 6 – Load-*CMOD* diagram and $F_j$ ($j$ = 1, 2, 3, 4)**

The residual flexural tensile strength shall be expressed to the nearest 0,1 N/mm$^2$.

## 9 TEST REPORT

The test report shall include:

a) identification of the test specimen;

b) identification of the concrete composition;

c) date of manufacture;

d) date of notching;

e) date of testing;

f) number of specimens tested;

g) curing history and moisture condition of specimen at test;

h) the average width of specimen to the nearest 0,1 mm;

i) the average distance between the tip of the notch and the top of the specimen to the nearest 0,1 mm;

j) the dimensions x and *y*, in mm (see Figure 3);

k) the span length to the nearest mm;

l) the rate of increase of *CMOD* or deflection and any deviation thereof;

m) the load-*CMOD* curve or load-deflection curve;

n) the *LOP* to the nearest 0,1 N/mm$^2$;

o) the residual flexural tensile strength values corresponding to $CMOD_j$ or $\delta_j$ ($j$ = 1, 2, 3, 4) to the nearest 0,1 N/mm$^2$;

p) reference to this standard;

q) any deviation from the standard testing method;

r) optionally, observation of uniformity of fibre distribution at the fracture surface;

s) a declaration from the person technically responsible for the test that the testing was carried out in accordance with this standard, except for the indicated deviation(s).

## 10 PRECISION

There is currently no precision data for this test.