JANUARY 2014
SFRC CONSORTIUM

# DESIGN GUIDELINE FOR STRUCTURAL APPLICATIONS OF STEEL FIBRE REINFORCED CONCRETE

Published by:

SFRC Consortium
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# Foreword

This guideline for the design of steel fibre reinforced concrete structures is to be applied in conjunction with DS EN 1992-1-1 incl. Danish National Annex. While this guideline covers the design aspects, execution aspects for casting of steel fibre reinforced concrete, in particular steel fibre reinforced self-compacting concrete, are given in the "Guideline for execution of SFRC".

This guideline is based on the German guideline "DAfStb-Richtlinie Stahlfaser-beton" from March 2010, but contains a number of modifications as discussed in the background document to this guideline.

Steel fibres transfer tensile forces across cracks similar to rebar reinforcement. This property can be utilized both in Serviceability Limit State SLS and Ultimate Limit State ULS. However, it needs to be considered that the residual tensile strength due to the effect of the steel fibres typically decreases with increasing deformation (crack opening). Figure F.1 illustrates the tensile behaviour of steel fibre reinforced concrete in comparison with plain concrete and conventionally reinforced concrete.

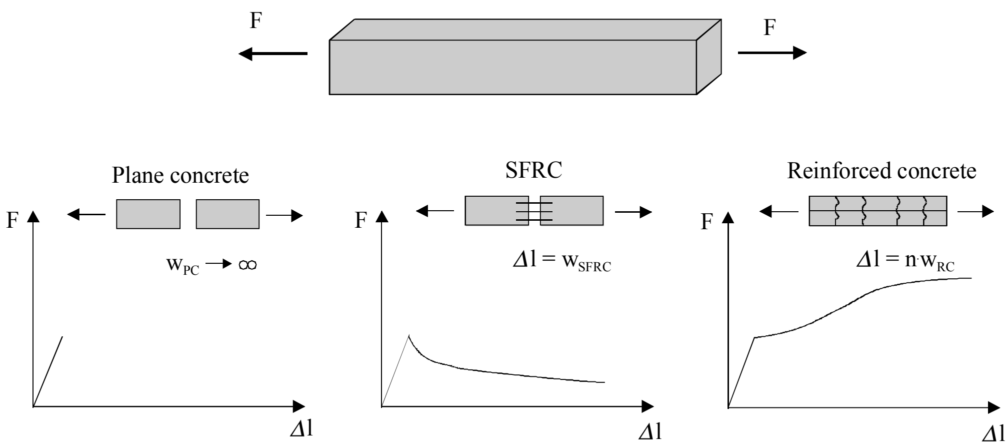



*Figure F.1: Tensile load-displacement behaviour of plain, steel fibre reinforced and conventionally reinforced concrete*

This guideline classifies steel fibre reinforced concrete based on performance classes. It distinguishes between

- Performance class L1 for small crack openings
- Performance class L2 for larger crack openings

The designer is responsible for specifying the required performance classes, and in case of self-compacting steel fibre reinforced concrete the fibre orientation factors. The supplier of the steel fibre reinforced concrete[1] is responsible for fulfilling the required performance class and delivering a concrete with a uniform fibre distribution. The contractor is responsible for achieving a uniform fibre distribution and the required fibre orientation in the structure.

[1] The supplier of the steel fibre reinforced concrete is the party mixing the fibres into the concrete.

# Part 1 - Supplements and modifications to DS EN 1992-1-1

# 1 General

## 1.1 Scope

### 1.1.2 Scope of Part 1-1 of Eurocode 2

Paragraph (1)P is replaced

(1)P This guideline applies in conjunction with DS EN 1992-1-1 to the design of civil engineering structures with steel fibre reinforced concrete and concrete with combined (steel fibre and steel rebar) reinforcement. The guideline applies up to and including strength class C50/60. The guideline applies only when using steel fibres with mechanical anchorage.

NOTE: Mechanically anchored fibres are usually undulated, hooked end or flat end fibres.

For members loaded in bending or in tension designed according to this guideline, it must be verified that the ultimate load of the system is larger than the crack initiation load. This verification is only possible, if at least one of the following conditions is fulfilled:

- Redistribution of sectional forces within statically indeterminate structures
- Application of combined (steel fibre and steel rebar) reinforcement
- Axial compression forces due to external actions

Statically determinate structures that obtain their bending capacity only by steel fibres in a single cross section are not allowed. For these cases the cross section equilibrium must be ensured by additional steel rebar reinforcement.

Paragraph (4)P is supplemented

Furthermore, this guideline does not apply to:

- Lightweight aggregate concrete
- High strength concrete of compressive strength class C55/67 or higher
- Steel fibre reinforced sprayed concrete
- Steel fibre reinforced concrete without steel rebar reinforcement in the exposure classes XS2, XD2, XS3 and XD3, if the steel fibres are considered in the structural verifications

Note to last bullet: Steel fibres can be considered in the structural verifications in all exposure classes in case of combined steel fibre and steel rebar reinforcement.

If this guideline is applied to prestressed or post-tensioned steel fibre reinforced structures, additional investigations shall be carried out to verify the design assumptions.

New paragraph (G.5) is added

(G.5) In principle, the application of this guideline for design of non-load bearing members is possible. The application of the guideline for that purpose should be agreed upon for the individual case.

# 1.2 Normative references

## 1.2.2 Other reference standards

The following reference standards are added

DS EN 14889-1: Fibres for concrete - Part 1: Steel fibres - Definitions, specifications and conformity

DS EN 14651: Test method for metallic fibre concrete - Measuring the flexural tensile strength (limit of proportionality (LOP), residual)

# 1.5 Definitions

## 1.5.2 Additional terms and definitions used in this Standard

The following terms are added

1.5.2.5 **Steel fibre reinforced concrete.** Steel fibre reinforced concrete is a concrete according to DS EN 206-1, to which steel fibres are added to achieve certain properties. This guideline takes account of the effect of the fibres.

1.5.2.6 **Residual tensile strength.** Notional residual tensile strength of the steel fibre reinforced concrete in the tension zone. It relates the true tensile forces in the steel fibres to the area of the tension zone and to the direction perpendicular to the crack plane.

1.5.2.7 **Residual flexural tensile strength.** It represents the post-crack flexural tensile strength of the cross section for bending.

1.5.2.8 **Performance class.** Classification of steel fibre reinforced concrete based on the characteristic values of post-crack flexural tensile strength for crack mouth opening displacements $CMOD$ = 0.5 and 3.5 mm in DS EN 14651 beam tests according to Part 3 of this guideline.

## 1.6 Symbols

The following symbols are added

*Latin upper case letters*

| | |
|---|---|
| $A_{ct}^{f}$ | Tension zone area of cracked cross sections or plastic hinges associated with the respective equilibrium state |
| $A_{s,min}^{f}$ | Minimum rebar reinforcement area of steel fibre reinforced concrete |
| $CMOD$ | Crack mouth opening displacement |
| $CMOD_{L1}$ | Crack mouth opening displacement in the tests according to Part 3 for evaluation of the residual tensile strength in performance class 1 |
| $CMOD_{L2}$ | Crack mouth opening displacement in the tests according to Part 3 for evaluation of the residual tensile strength in performance class 2 |
| $F_{fd}$ | Flexural tensile force resulting from the residual tensile strength of the steel fibre reinforced concrete |
| $L$ | Performance class |
| $L1$ | Performance class 1 |
| $L2$ | Performance class 2 |
| $V_{Rd,c}^{f}$ | Design value of the shear resistance of steel fibre reinforced concrete without shear reinforcement |
| $V_{Rd,cf}$ | Design value of the shear resistance due to the contribution of the steel fibres |
| $V_{Rd,s}^{f}$ | Design value of the shear resistance of steel fibre reinforced concrete with shear reinforcement including the contribution of the steel fibres |

*Latin lower case letters*

| | |
|---|---|
| $f_{ct0}^{f}$ | Basic value of the axial residual tensile strength of steel fibre reinforced concrete |
| $f_{ct0,L1}^{f}$ | Basic value of the axial residual tensile strength of steel fibre reinforced concrete in performance class 1 when applying the complete stress-strain curve according to Figure G.1 or Figure G.2 |
| $f_{ct0,L2}^{f}$ | Basic value of the axial residual tensile strength of steel fibre reinforced concrete in performance class 2 when applying the com- |

plete stress-strain curve according to Figure G.1 or Figure G.2

$f_{ct0,u}^{f}$ Basic value of the axial residual tensile strength of steel fibre reinforced concrete when applying the rectangular stress block

$f_{ct0,s}^{f}$ Basic value of the axial residual tensile strength of steel fibre reinforced concrete in SLS

$f_{cflk}^{f}$ Characteristic value of the flexural residual tensile strength of steel fibre reinforced concrete

$f_{ctd,L1}^{f}$ Design value of the axial residual tensile strength of steel fibre reinforced concrete in performance class 1 when applying the complete stress-strain curve according to Figure G.1 or Figure G.2

$f_{ctd,L2}^{f}$ Design value of the axial residual tensile strength of steel fibre reinforced concrete in performance class 2 when applying the complete stress-strain curve according to Figure G.1 or Figure G.2

$f_{ctd,u}^{f}$ Design value of the axial residual tensile strength of steel fibre reinforced concrete when applying the rectangular stress block

$f_{ctd,s}^{f}$ Design value of the axial residual tensile strength of steel fibre reinforced concrete in SLS

$f_{ctR,j}^{f}$ Calculation value of the axial residual tensile strength of steel fibre reinforced concrete

$f_{ctR,L1}^{f}$ Calculation value of the axial residual tensile strength of steel fibre reinforced concrete in performance class 1 when applying the complete stress-strain curve according to Figure G.1 or Figure G.2

$f_{ctR,L2}^{f}$ Calculation value of the axial residual tensile strength of steel fibre reinforced concrete in performance class 2 when applying the complete stress-strain curve according to Figure G.1 or Figure G.2

$f_{ctR,u}^{f}$ Calculation value of the axial residual tensile strength of steel fibre reinforced concrete when applying the rectangular stress block

$f_{ctR,s}^{f}$ Calculation value of the axial residual tensile strength of steel fibre reinforced concrete in SLS

$s_{w}^{f}$ Length, over which a crack in the steel fibre reinforced concrete is considered as smeared in order to calculate the tensile strain of steel fibre reinforced concrete

$v_{Rd,cf}^{f}$ Design value of the shear resistance along the control perimeter due to the contribution of the steel fibres

$v_{Rd,ct,a}^{f}$ Design value of the shear resistance along the control perimeter of a plate without punching shear rebar reinforcement, taking into

| | |
|---|---|
| | account the contribution of the steel fibres |
| $z_f$ | Internal lever arm of the flexural tension force resulting from the residual tensile strength of the steel fibre reinforced concrete |

*Greek lower case letters*

| | |
|---|---|
| $\alpha$ | Ratio of the calculation value of the residual tensile strength of steel fibre reinforced concrete to the mean value of the concrete tensile strength; reduction factor to take account of long-term effects on the residual tensile strength |
| $\alpha_f$ | Ratio of the calculation value of the residual tensile strength to the mean value of the concrete tensile strength |
| $\alpha_c^f$ | Reduction factor tailored to the design concept to take account of long-term effects on the residual tensile strength of steel fibre reinforced concrete |
| $\beta$ | Factor for determining the basic values of the axial residual tensile strength |
| $\beta_{L1}$ | Factor for the determination of the basic value of the axial residual tensile strength of steel fibre reinforced concrete in performance class 1 when applying the complete stress-strain curve according to Figure G.1 or Figure G.2 |
| $\beta_{L2}$ | Factor for the determination of the basic value of the axial residual tensile strength of steel fibre reinforced concrete in performance class 2 when applying the complete stress-strain curve according to Figure G.1 or Figure G.2 |
| $\beta_u$ | Factor for the determination of the basic value of the axial residual tensile strength of steel fibre reinforced concrete when applying the rectangular stress block |
| $\beta_s$ | Factor for the determination of the basic value of the axial residual tensile strength of steel fibre reinforced concrete in SLS |
| $\gamma_{ct}^f$ | Partial factor for the residual tensile strength of steel fibre reinforced concrete |
| $\varepsilon_c^f$ | Calculation value of compressive strain of steel fibre reinforced concrete |
| $\varepsilon_{ct}^f$ | Calculation value of tensile strain of steel fibre reinforced concrete |
| $\varepsilon_{ct,u}^f$ | Calculation value of ultimate tensile strain of steel fibre reinforced concrete |
| $\varepsilon_{sm}^f$ | Mean strain of the rebar reinforcement taking into account the con- |

tribution of the steel fibres

| | |
|---|---|
| $\kappa$ | Factor to take account of the size of the member (size effect); factor to take account of the fibre orientation |
| $\kappa_G^f$ | Factor to take into account the influence of the member size on the coefficient of variation |
| $\kappa_F^f$ | Factor to take into account the fibre orientation when determining the calculation values of the axial residual tensile strength from the basic values of the axial residual tensile strength |
| $\sigma_{ct}^f$ | Tensile stress of steel fibre reinforced concrete |
| $\phi_s^f$ | Modified rebar diameter of rebar reinforcement for the crack width verification with consideration of the steel fibre contribution |

# 2 Basis of design

## 2.2 Principles of limit state design

New paragraph (G.2) is added

(G.2) The ultimate limit state is reached, if in the critical sections of the structure

- the critical strain of the steel fibre reinforced concrete or
- the critical strain of the steel rebar reinforcement or
- the critical strain of the concrete is reached

or if the critical state of indifferent equilibrium of the structural system is reached. A stabilisation of the system by considering the tensile strength of the concrete or the tensile strength of steel fibre reinforced concrete is not allowed, whereas the residual tensile strength can be considered.

## 2.4 Verification by the partial factor method

### 2.4.2 Design values

#### 2.4.2.4 Partial factors for materials

An additional column is added in Table 2.1N

*Table 2.1N: Partial factors for materials for ultimate limit states*

| Design situations | $\gamma_{ct}^{f}$ for steel fibre reinforced concrete with and without steel rebar reinforcement |
|---|---|
| Persistent & Transient | 1.25 |
| Accidental | 1.25 |

## 2.5 Design assisted by testing

Paragraph (1) is supplemented

Design assisted by testing needs to fulfil the same principles, safety concepts and structural integrity as described in DS EN 1992-1-1 and this guideline.

For steel fibre reinforced concrete, special investigations are required if the contribution of fibres should be taken into account in the design of dynamically loaded structures.

Additional investigations are required to verify the design assumptions, if this guideline is applied to prestressed or post-tensioned steel fibre reinforced structures.

# 3 Materials

New Section 3.5 is added

## 3.5 Steel fibres

(1)P DS EN 1992-2 and DS EN 14889-1 apply. The conformity of the steel fibres is required to be documented by a CE certificate of conformity (system 1).

New Section 3.6 is added

## 3.6 Steel fibre reinforced concrete

### 3.6.1 General

(1)P Steel fibres are oriented in different directions and their ability to transfer tensile forces depends on their orientation relative to the crack plane. The information about the relative amount of fibres in the different directions is referred to as the fibre orientation. If the relative amount of fibres in different directions varies, then the ability of fibres to transfer tensile forces also varies depending on the direction. This will result in a variation of the residual tensile strength in different directions.

(2)P The effect of the fibre orientation on the residual tensile strength of steel fibre reinforced concrete is accounted for as follows (Annex L):

The performance classes define the residual tensile strength for the reference fibre orientation as observed in 3-point beam bending tests with steel fibre reinforced slump concrete according to Part 3.

For steel fibre reinforced self-compacting concrete, the test beams are cast with a reference casting method as defined in Part 3, Section 7.2, which results in a reproducible fibre orientation. The strength values from the tests are converted to strength values and performance classes for the reference fibre orientation.

The fibre orientations in the actual structural applications are considered by a fibre orientation factor $\kappa_F^f$.

(2)P The performance classes of steel fibre reinforced concrete are identified with the prefix L. The performance classes shall be specified in accordance with the crack openings associated with the limit state and failure mode. Table G.1 contains recommended performance class definitions. The first value specifies the performance class L1 for a crack mouth opening displacement $CMOD_{L1}$ = 0.5 mm and the second value the performance class L2 for $CMOD_{L2}$ = 3.5 mm.

*Table G.1:* $CMOD$ *values and performance classes for steel fibre reinforced concrete*

| Performance class | Verification in | $CMOD$ values determined according to Part 3 of this guideline |
|---|---|---|
| L1 | SLS | $CMOD_{L1}$ = 0.5 mm |
| L2 | ULS | $CMOD_{L2}$ = 3.5 mm |

## 3.6.2 Properties

Steel fibre reinforced concrete has a residual tensile strength (cf. Figure G.1 and Figure G.2). This notional residual tensile strength is related to the cross section of the concrete. It must not be used for determining the steel stresses in the fibres.

## 3.6.3 Strength

(1)P The performance class values correspond to the characteristic values of the residual flexural tensile strength for the reference fibre orientation and the respective crack mouth openings. These characteristic values are to be verified according to Part 3 of this guideline.

Performance classes should be specified according to the following examples:

**C30/37 L1.2/0.9 - XC1** for a steel fibre reinforced slump concrete

**SCC30/37 L1.2/0.9 - XC1** for a steel fibre reinforced self-compacting concrete

where:

| | |
|---|---|
| C30/37<br>SCC30/37 | Compressive strength of the concrete according to DS EN 206-1 |
| L1.2/0.9 | Steel fibre reinforced concrete of performance class L1-1.2 for $CMOD_{L1}$ and performance class L2-0.9 for $CMOD_{L2}$ cf. Part 3 of this guideline |
| XC1 | Exposure class of the concrete |

NOTE: The performance class L1 is typically larger than or equal to performance class L2.

For self-compacting concrete, fibre orientation factors $\kappa_F^f$ and the associated directions shall be specified for each structural member / casting section, cf. Part 5 of this guideline.

(2)P The basic values of the axial residual tensile strength in Table G.2 are obtained from the characteristic values of the flexural residual tensile strength as

$$f_{ct0,L1}^f = f_{cflk,L1}^f \cdot \beta_{L1} \tag{G.3.31}$$

$$f_{ct0,L2}^f = f_{cflk,L2}^f \cdot \beta_{L2} \tag{G.3.32}$$

$$f_{ct0,u}^f = f_{cflk,L2}^f \cdot \beta_u \tag{G.3.33}$$

$$f_{ct0,s}^f = f_{cflk,L1}^f \cdot \beta_s \tag{G.3.34}$$

where:

| | |
|---|---|
| $f_{ct0,L1}^f$ | Basic value of the axial residual tensile strength according to Table G.2 column 2 |
| $f_{ct0,L2}^f$ | Basic value of the axial residual tensile strength according to Table G.2 column 4 |
| $f_{ct0,u}^f$ | Basic value of the axial residual tensile strength according to Table G.2 column 5 |
| $f_{ct0,s}^f$ | Basic value of the axial residual tensile strength according to Table G.2 column 6 |
| $\beta_{L1}$ | Value according to paragraph (3) |
| $\beta_{L2}$ | Value according to paragraph (3) |
| $\beta_u = 0.37$ | For the rectangular stress block |
| $\beta_s = 0.40$ | For SLS |

(3) If the ratio of the performance class values L2/L1 is larger than 0.7, $\beta_{L1} = 0.40$ and $\beta_{L2} = 0.25$ may be used. Otherwise, the rectangular stress block must be used for the ULS verification. Reference is made to Annex K for more detailed determination of $\beta_{L2}$.

(4)P If the ratio of the performance class values L2/L1 is larger than 1.0, the rectangular stress block must not be used.

(5)P The calculation values of the axial residual tensile strength are determined based on the basic values of the axial residual tensile strength as:

$$f_{ctR,L1}^{f} = \kappa_F^f \cdot \kappa_G^f \cdot f_{ct0,L1}^{f} \tag{G.3.35}$$

$$f_{ctR,L2}^{f} = \kappa_F^f \cdot \kappa_G^f \cdot f_{ct0,L2}^{f} \tag{G.3.36}$$

$$f_{ctR,u}^{f} = \kappa_F^f \cdot \kappa_G^f \cdot f_{ct0,u}^{f} \tag{G.3.37}$$

$$f_{ctR,s}^{f} = \kappa_F^f \cdot \kappa_G^f \cdot f_{ct0,s}^{f} \tag{G.3.38}$$

where:

| | |
|---|---|
| $\kappa_G^f$ | Factor to take into account the influence of the member size on the coefficient of variation $= 1.0 + A_{ct}^f \cdot 0.5 \leq 1.70$ |
| $\kappa_F^f$ | Fibre orientation factor. For slump concrete, $\kappa_F^f = 0.5$ shall be used in general, however, for plane structures cast in horizontal position (width > 5 height) $\kappa_F^f = 1.0$ may be used for flexural and tensile loading. For self-compacting concrete, reference is made to Annex L for determination and verification of fibre orientation factors. Recommended values for fibre orientation factors in specific applications and design aspects are contained in Section 9 of this guideline. |
| $A_{ct}^f$ | Cross sectional area of the cracked areas or plastic hinges in $m^2$ associated with the respective equilibrium state |

NOTE: For members subject to pure bending without axial force $A_{ct}^f$ may be assumed as 0.9 $A_c$.

*Table G.2: Performance classes L1 and L2 for steel fibre reinforced concrete with corresponding basic values of the axial residual tensile strength in MPa*

| L1 | $f^f_{ct0,L1}$ | L2 | $f^f_{ct0,L2}$ | $f^f_{ct0,u}$ | $f^f_{ct0,s}$ 2) |
|---|---|---|---|---|---|
| 0 | < 0.16 | 0 | – | – | – |
| 0.4 1) | 0.16 | 0.4 1) | 0.10 | 0.15 | 0.15 |
| 0.6 | 0.24 | 0.6 | 0.15 | 0.22 | 0.22 |
| 0.9 | 0.36 | 0.9 | 0.23 | 0.33 | 0.33 |
| 1.2 | 0.48 | 1.2 | 0.30 | 0.44 | 0.44 |
| 1.5 | 0.60 | 1.5 | 0.38 | 0.56 | 0.56 |
| 1.8 | 0.72 | 1.8 | 0.45 | 0.67 | 0.67 |
| 2.1 | 0.84 | 2.1 | 0.53 | 0.78 | 0.78 |
| 2.4 | 0.96 | 2.4 | 0.60 | 0.89 | 0.89 |
| 2.7 | 1.08 | 2.7 | 0.68 | 1.00 | 1.00 |
| 3.0 | 1.20 | 3.0 | 0.75 | 1.11 | 1.11 |

1) Only for plane members (b > 5h)
2) Applies if L2/L1 ≤ 1.0. If L2/L1 > 1.0, see paragraph (4)P

NOTE: In case $f_{ctk} < f^f_{ct0,L1}$ or $f_{ctk} < f^f_{ct0,L2}$, only $f^f_{ct0,L1} = f^f_{ct0,L2} = f^f_{ct0,u} = f^f_{ct0,s} = f_{ctk}$ are allowed to be used in the design.

### 3.6.4 Stress-strain relation for non-linear structural analysis and for deformation analysis

(1) The stresses and strains model notionally the behaviour of steel fibre reinforced concrete. Depending on the ratio L2/L1 (cf. Annex K), either the trilinear stress-strain relation or the rectangular stress block shall be used. Symbols in Figure G.1 and Figure G.2 are as follows:

| | |
|---|---|
| $\sigma^f_{ct}$ | Tensile stress of steel fibre reinforced concrete |
| $f^f_{ctd,L1}$ | Design value of the axial residual tensile strength of steel fibre reinforced concrete in performance class 1 when applying the entire stress-strain curve given in Figure G.1 and Figure G.2 |
| $f^f_{ctd,L2}$ | Design value of the axial residual tensile strength of steel fibre reinforced concrete in performance class 2 when applying the entire stress-strain curve given in Figure G.1 and Figure G.2 |
| $f^f_{ctd,u}$ | Design value of the axial residual tensile strength when applying |

the rectangular stress block

$f^f_{ctd,s}$ Design value of the axial residual tensile strength in SLS

$\varepsilon^f_{ct}$ Strain of steel fibre reinforced concrete

$\gamma^f_{ct}$ Partial factor according to Table 2.1N

$\alpha^f_c$ = 0.85; reduction factor tailored to the design concept to take account of long-term effects on the residual tensile strength of steel fibre reinforced concrete

(2)P For non-linear analysis, the linear progression of the stress-strain curve up to $f_{ctm}$ should be considered. This also holds for detailed deformation analysis. For the determination of cross sectional forces and for approximate deformation analysis the linear progression up to $f_{ctm}$ may be disregarded.

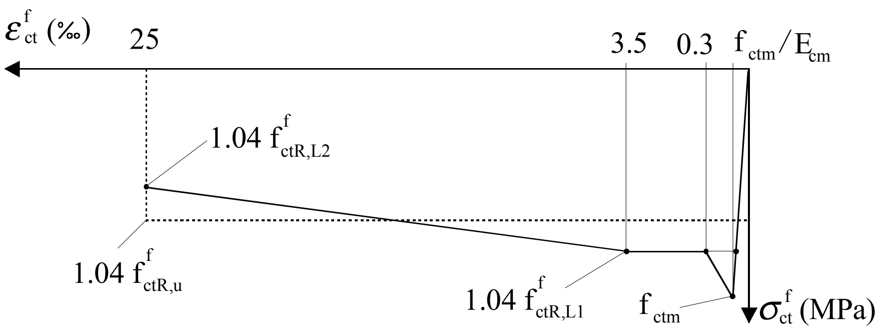



*Figure G.1: Stress-strain relation of steel fibre reinforced concrete in the tension zone for the determination of sectional forces by non-linear structural analysis and for deformation analysis*

## 3.6.5 Stress-strain relation for cross section verification

Depending on the ratio L2/L1 (cf. Annex K), either the complete stress-strain relation (solid lines) or the rectangular stress block (dashed lines) in Figure G.2 shall be used in the tension zone for the cross section design in ULS.

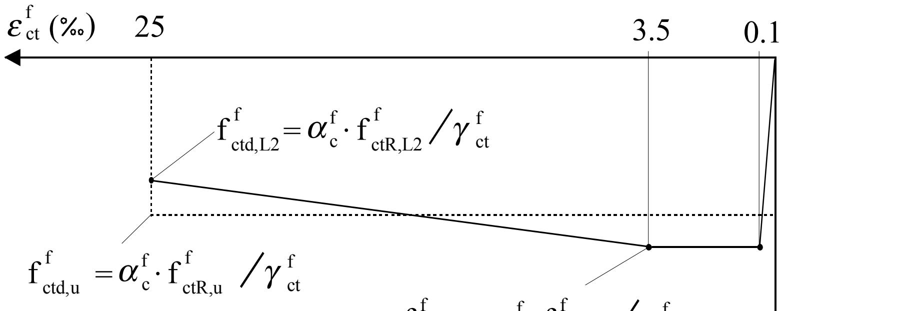



*Figure G.2: Stress-strain relation of steel fibre reinforced concrete in the tension zone for cross sectional design in ULS except for non-linear structural analysis*

# 4 Durability and cover to reinforcement

## 4.4 Methods of verification

### 4.4.1 Concrete cover

#### 4.4.1.2 Minimum cover, $c_{min}$

Paragraph (1)P is supplemented

For the verification of fire resistance of structural members with combined reinforcement, DS EN 1992-1-2 incl. Danish National Annex applies.

Paragraph (5) is supplemented

The minimum cover $c_{min,dur}$ only applies to rebar reinforcement and not to steel fibres. Fibres close to the surface may corrode, which may cause rust stains. However, the durability is not affected by corrosion of fibres.

# 5 Structural analysis

## 5.6 Plastic analysis

### 5.6.1 General

New paragraph (G.5)P is added

(G.5)P Methods based on plastic analysis are generally applicable for steel fibre reinforced concrete structures, if the major part of the tensile and bending resistance is provided by rebar reinforcement. Otherwise, the application of plastic analysis is limited to ground supported slabs, anchored underwater concrete slabs, pile supported floor slabs, shell structures and monolithically cast, prefabricated containing structures.

## 5.7 Non-linear analysis

Paragraph (1) is supplemented

Non-linear methods of analysis are generally applicable for steel fibre reinforced concrete structures, if the major part of the tensile and bending resistance is provided by rebar reinforcement. Otherwise, the application of non-linear analysis is limited to ground supported slabs, anchored underwater concrete slabs, pile supported floor slabs, shell structures and monolithically cast, prefabricated containing structures.

Paragraph (G.6) to (G.11) are added

(G.6) A suitable non-linear method of analysis including cross section verification is described in paragraph (G.6) to (G.11).

For steel fibre reinforced concrete structures, the design resistance is defined as

$$R_d = R\left(f_{cR};\, 1.04 \cdot f^{f}_{ctR,Li};\; f_{yR};\; f_{tR}\right)/\gamma_R \qquad \text{(G.5.12.1)}$$

where:

$1.04 \cdot f^{f}_{ctR,Li}$ the mean value of the residual tensile strength of steel fibre reinforced concrete in performance class 1 and 2 according to Section 3.6.3

$f_{cR}, f_{yR}, f_{tR}$ the respective mean value of the strength of concrete and rebar reinforcement steel:

$$f_{cR} = 0.85 \cdot \alpha_{cc} \cdot f_{ck} \quad \text{(G.5.12.2)}$$

$$f_{yR} = 1.1 \cdot f_{yk} \quad \text{(G.5.12.3)}$$

$$f_{tR} = 1.05 \cdot f_{yR} \text{ for Class A} \quad \text{(G.5.12.4)}$$

$$f_{tR} = 1.08 \cdot f_{yR} \text{ for Class B} \quad \text{(G.5.12.5)}$$

$\gamma_R$ the partial factor for the resistance of the structural system

(G.7)P For deformation analysis and determination of internal forces of steel fibre reinforced concrete, the stress-strain relation in Figure G.2 shall be used for the tension zone. For the compression zone, Section 3.1.5 applies without modification. For rebar reinforcement steel, Section 3.2 applies.

(G.8) For steel fibre reinforced concrete, $\gamma_R$= 1.4 shall be applied. For combined reinforcement, generally $\gamma_R$= 1.35 may be applied, or

$$1.3 \leq 1.3 + \frac{0.1 \cdot F_{fd}}{F_{fd} + F_{sd}} \leq 1.4 \quad \text{(G.5.12.2)}$$

$F_{fd}$ and $F_{sd}$ are explained in Figure G.3.

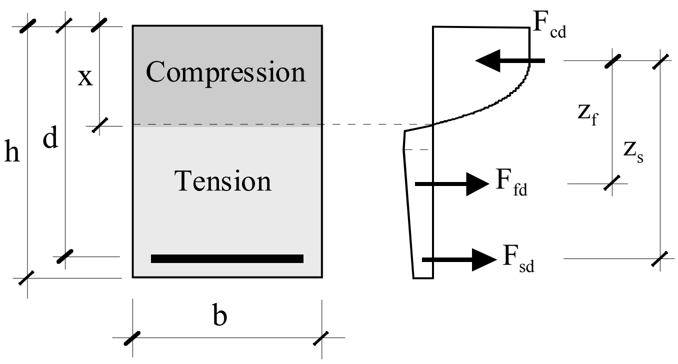



*Figure G.3: Contribution of steel fibres $F_{fd}$ and contribution of rebar reinforcement $F_{sd}$ to the bearing capacity*

(G.9)P The design resistance must not be smaller than the design value of the effect of actions.

(G.10)P The ultimate limit state is reached, if the ultimate strain of the concrete, the ultimate strain of the rebar reinforcement steel or the ultimate strain of steel fibre reinforced concrete $\varepsilon^{f}_{ct}$= 25 ‰ according to Section 3.6.4 is reached in any cross section of the structural system. The ultimate limit state is further reached, if a state of indifferent equilibrium is reached in (part of) the structural system. The ultimate strain of the rebar reinforcement steel shall be taken as $\varepsilon_{ud} = 0.025$ or $\varepsilon_{ud} = \varepsilon_p^{(0)} + 0.025 \le 0.9\varepsilon_{uk}$.

(G.11) For steel fibre reinforced concrete, tension stiffening should be considered according to the standard rules for reinforced concrete. When calculating the stress in the rebar reinforcement, the effect of the steel fibres should be considered.

## 5.8 Analysis of second order effects with axial load

### 5.8.2 General

New paragraph (7) is added

(G.7) For steel fibre reinforced members subject to buckling, the effect of the fibres must not be considered in the design.

## 5.9 Lateral instability of slender beams

New paragraph (5) is added

(G.5) For the verification of lateral instability of slender steel fibre reinforced beams, the effect of the fibres must not be considered.

## 5.10 Prestressed members and structures

If the provisions in this section are applied to steel fibre reinforced concrete structures, additional investigations shall be carried out to verify the design assumptions.

# 6 Ultimate limit states (ULS)

## 6.1 Bending with or without axial force

Paragraph (2)P is supplemented

When determining the ultimate resistance of steel fibre reinforced concrete cross sections, the following additional assumptions are made:

- The compressive and tensile stresses in the steel fibre reinforced concrete are determined by means of the stress-strain curve in Figure G.4.
- For a cross section without rebar reinforcement, the effective depth $d$ is taken equal to the overall depth of the cross section $h$. For a steel fibre reinforced concrete cross section with rebar reinforcement the rules in DS EN 1992-1-1 apply.
- The strain in the tension zone is limited to $\varepsilon_{s,u} = \varepsilon_{ct,u}^{f} = 25$ ‰.

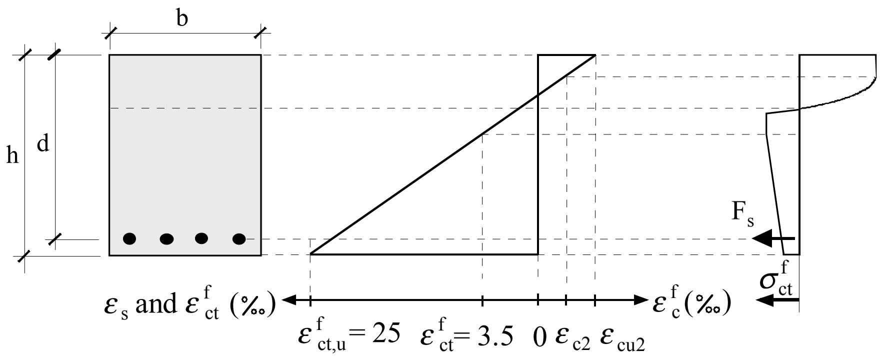



*Figure G.4: Determination of stresses and strains for steel fibre reinforced concrete*

New paragraph (G.9)P is added

(G.9)P For bending with or without normal force of steel fibre reinforced concrete cross sections, the fibre orientation factor $\kappa_F^f$ shall represent the strength normal to the cross section.

New paragraph (G.10)P is added

(G.10)P The contribution of the steel fibres must not be considered in construction joints.

## 6.2 Shear

### 6.2.1 General verification procedure

Paragraph (1)P is supplemented

$V_{Rd,c}^f$ is the design value of the shear resistance of steel fibre reinforced concrete without shear rebar reinforcement

$V_{Rd,s}^f$ is the design value of the shear resistance of steel fibre reinforced concrete with shear rebar reinforcement including the contribution of the steel fibres

Paragraph (4) is supplemented

For steel fibre reinforced concrete, the minimum shear reinforcement according to DS EN 1992-1-1 9.2.2 (5) may be reduced to zero also for beam-like structures (b ≤ 5 h) by taking into account the contribution of the fibres according to Equation (G.9.5.a).

### 6.2.2 Members not requiring design shear reinforcement

Paragraph (1) is supplemented

The design value of the shear resistance $V_{Rd,c}^f$ of steel fibre reinforced concrete members should generally be determined according to:

$$V_{Rd,c}^f = V_{Rd,c} + V_{Rd,cf} \qquad \text{(G.6.2.c)}$$

where:

$V_{Rd,c}$ according to DS EN 1992-1-1, Equation (6.2)

$$V_{Rd,cf} = \frac{\alpha_c^f \cdot f_{ctR,u}^f \cdot b_w \cdot h}{\gamma_{ct}^f} \tag{G.6.2.d}$$

For the determination of $f_{ctR,u}^f$, $A_{ct}^f$ shall be taken as $A_{ct}^f = b_w \cdot d \leq b_w \cdot 1.50$. $f_{ctR,u}^f$ shall be based on a fibre orientation factor $\kappa_F^f$ which represents the strength in the direction normal to the 45 degrees shear crack.

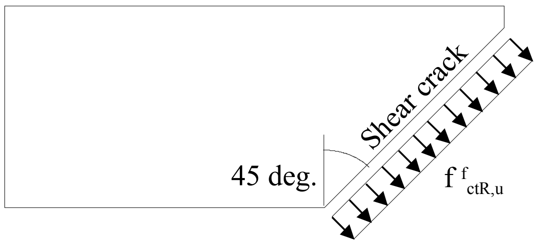



*Figure G.5: Shear resistance due to the contribution of the steel fibres*

For cross sections subject to a tensile normal force, the effect of the fibres must not be considered for shear: $V_{Rd,cf} = 0$.

NOTE: For beams, a minimum reinforcement is always required, unless the fibre contribution according to 9.2.2 is sufficient.

## 6.2.3 Members requiring design shear reinforcement

Paragraph (3) is supplemented

The design value of the shear resistance $V_{Rd,s}^f$ of steel fibre reinforced concrete members with vertical shear reinforcement shall be determined according to:

$$V_{Rd,s}^f = V_{Rd,s} + V_{Rd,cf} \leq V_{Rd,max} \tag{G.6.8.1}$$

where:

$V_{Rd,s}$ according to DS EN 1992-1-1, Equation (6.8), and $V_{Rd,cf}$ according to Equation (G.6.8.1). The maximum shear resistance $V_{Rd,max}$ shall be determined according to DS EN 1992-1-1, Equation (6.9).

Paragraph (4) is supplemented

The design value of the shear resistance $V_{Rd,s}^f$ of steel fibre reinforced concrete members with inclined shear reinforcement shall be determined according to Equation (G.6.8.1)

where:

$V_{Rd,s}$ according to DS EN 1992-1-1, Equation (6.13), and $V_{Rd,cf}$ according to Equation (G.6.2d). The maximum shear resistance $V_{Rd,max}$ shall be determined according to DS EN 1992-1-1, Equation (6.14).

### 6.2.4 Shear between web and flanges of T-sections

Paragraph (4) is replaced

(4) The shear resistance may be verified according to Equation (G.6.2.c) and Equation (G.6.2.d), with $b_w = h_f$ and $z = \Delta x$. $\sigma_{cp}$ may be taken as the average longitudinal normal stress in the flange over the length $\Delta x$. As a simplification, $\cot\theta = 1.0$ and $\cot\theta = 1.2$ may be assumed for tension and compression flanges, respectively.

### 6.2.5 Shear at the interface between concrete cast at different times

Paragraph (1) is supplemented

The contribution of the steel fibres must not be considered in construction joints.

## 6.3 Torsion

### 6.3.1 General

Paragraph (G.6)P is added

(G.6)P The contribution of the steel fibres must not be considered in the verification of torsion resistance.

## 6.4 Punching

### 6.4.3 Punching shear calculation

Paragraph (1)P is supplemented

$v^f_{Rd,c}$ is the design value of the punching shear resistance of a steel fibre reinforced slab without punching shear rebar reinforcement along the control section considered, taking into account the contribution of the steel fibres.

Paragraph (2) is supplemented

The shear forces for the punching verification shall be determined based on the theory of elasticity.

Paragraph (2) point b) is replaced

Punching shear reinforcement is not necessary if:

$$v_{Ed} \leq v^f_{Rd,c} \quad \text{(G.6.37.1)}$$

### 6.4.4 Punching shear resistance of slabs and column bases without shear reinforcement

Paragraph (1) is supplemented

For steel fibre reinforced slabs and foundations without punching shear reinforcement, the design punching shear resistance [MPa] may be calculated as follows:

$$v^f_{Rd,c} = 2\frac{d}{a} v_{Rd,c} + v_{Rd,cf} \leq v_{Rd,max} \quad \text{(G.6.47.1)}$$

where:

$v_{Rd,c}$ according to DS EN 1992-1-1, Equation (6.47)

$$v_{Rd,cf} = 0.85 \frac{\alpha_c^f \cdot f_{ctR,u}^f}{\gamma_{ct}^f} \quad \text{(G.6.47.2)}$$

$$v_{Rd,max} = 1.4 \cdot v_{Rd,c} \quad \text{(G.6.53.1)}$$

$f_{ctR,u}^f$ shall be based on a fibre orientation factor $\kappa_F^f$ which represents the strength in the direction normal to the 45 degrees punching shear crack.

For cross sections subject to a tensile normal force, the effect of the fibres must not be considered for punching: $v_{Rd,cf} = 0$.

For slabs, $a = u_1 = 2d$.

NOTE: In ground supported slabs without rebar reinforcement for bending, no tension chord can be established due to the softening material behaviour of steel fibre reinforced concrete. Therefore, bending failure is always governing.

### 6.4.5 Punching shear resistance of slabs and column bases with shear reinforcement

Paragraph (1) is supplemented

The combined action of steel fibres and punching shear reinforcement must not be applied in the design without detailed verifications.

Paragraph (4) is supplemented

For steel fibre reinforced concrete, $v_{Rd,c}$ in Equation (6.54) may be replaced by $v_{Rd,c}^f$ according to Equation (G.6.47.1), if $v_{Rd,c}$ is determined with $C_{Rd,c} = 0.15/\gamma_c$.

## 6.5 Design with strut and tie models

### 6.5.1 General

New paragraph (G.2)P is added

(G.2)P If one of the following conditions is fulfilled, tie forces may be taken by steel fibres only:

- The tensile stresses before cracking are smaller than $f_{ctd,u}^f$ (with $f_{ctd,u}^f$ based on a fibre orientation factor $\kappa_F^f$ which represents the strength in the direction of the tie force).
- Crack widths in ULS are verified to be limited to $w_k = 0.5$ mm.

Otherwise, rebar reinforcement is required and only up to 30 % of the tie force are allowed to be taken by the steel fibres (based on $f_{ctd,u}^f$).

## 6.7 Partially loaded areas

Paragraph (4) is supplemented

The tie force in Figure G.6 may be taken by steel fibres only or by combined reinforcement according to Section 6.5. The verification shall be based on $f_{ctd,u}^{f}$ and $f_{ctR,s}^{f}$ (with $f_{ctd,u}^{f}$ and $f_{ctR,s}^{f}$ based on a fibre orientation factor $\kappa_{F}^{f}$ which represents the strength in the direction of the tie force).

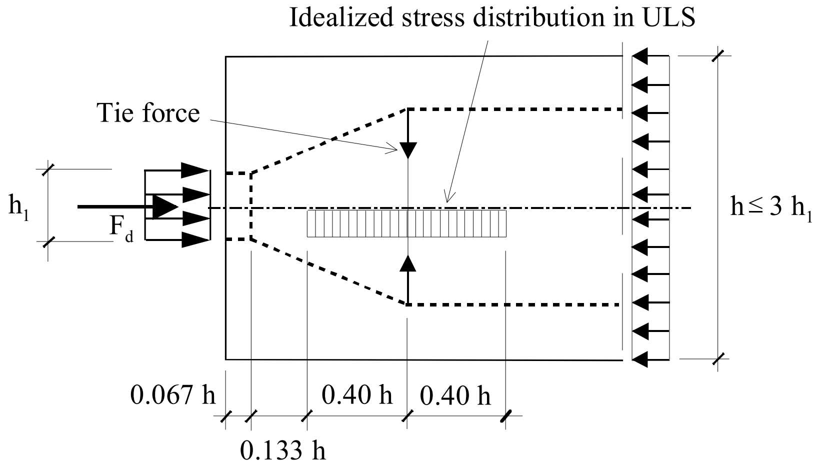



*Figure G.6: Strut and tie model for design of partially loaded areas*

## 6.8 Fatigue

### 6.8.1 Verification conditions

Paragraph (G.3)P is added

(G.3)P In general, steel fibres shall not be considered in fatigue verifications of dynamically loaded structures.

NOTE: The consideration of the effect of steel fibres in special cases must be documented by additional investigations.

# 7 Serviceability limit states (SLS)

## 7.3 Crack control

### 7.3.1 General considerations

Paragraph (5) is supplemented

If steel fibres are used for ULS design, DS EN 1992-1-1 Table 7.1N is supplemented by Table G.3. For combined reinforcement, the requirements of DS EN 1992-1-1 Table 7.1N apply.

*Table G.3: Recommended values of $w_{max}$ (mm) for steel fibre reinforced concrete*

| Exposure Class | Steel fibre reinforced concrete without additional steel rebar reinforcement |
|---|---|
| | Quasi-permanent load combination |
| X0, XC1[1] | 0.4 |
| XC2, XC3 | 0.3 |
| XC4, XD1, XS1 | 0.2 |
| Note 1: For X0, XC1 exposure classes, crack width has no influence on durability and this limit is set to guarantee acceptable appearance. In the absence of appearance conditions this limit may be relaxed. | |

Paragraph (9) is supplemented

The crack width limitation for steel fibre reinforced concrete members without additional steel rebar reinforcement may be verified according to DS EN 1992-1-1 Section 7.3.4 in conjunction with this guideline in the following cases:

- For statically indeterminate structures, an equilibrium state is verified based on redistribution of cross sectional forces, where all cracked cross sections fulfil the crack width requirement at the time t = ∞. For the calculation of deformations, the tension stiffness of the steel fibre reinforced concrete between the cracks (tension stiffening) shall be taken into consideration.
- For other structures with permanent compression zone.
- If $\alpha_f \geq k \cdot k_c$ with $\alpha_f$ from Equation (G.7.2.a).

The crack width determined according to Section 7.3.4 must be verified to be compatible with the deformation of the structure.

In all other situations, combined reinforcement must be used to limit the crack width.

## 7.3.2 Minimum reinforcement areas

Paragraph (2) is supplemented

For the design of minimum reinforcement to limit the crack width according to DS EN 1992-1-1, Section 7.3.2 and 7.3.3, as well as for the crack width calculation according to DS EN 1992-1-1, Section 7.3.4, steel fibre reinforced concrete can be taken into account.

For the required minimum reinforcement area of steel fibre reinforced concrete, DS EN 1992-1-1 Equation (7.1) is replaced by:

$$A_{s,min}^{f} = f_{ct,eff} \cdot k_c \cdot k \cdot (1 - \alpha_f) \cdot \frac{A_{ct}}{\sigma_s} \qquad \text{(G.7.1)}$$

where:

$\alpha_f = \frac{f_{ctR,L1}^{f}}{f_{ctm}}$ — $f_{ctR,L1}^{f}$ shall be based on a fibre orientation factor $\kappa_F^{f}$ which represents the strength normal to the cross section (G.7.2a)

$\sigma_s$ — Rebar stress in the crack without consideration of the contribution of the steel fibres

For situations outside the range of DS EN 1992-1-1 Table 7.2, the rebar stress may be determined by:

$$\sigma_s = \sqrt{\frac{1.5 \cdot k_c \cdot k \cdot h_{cr} \cdot f_{ct,eff}}{\phi_s \cdot (h - d)} \cdot w_k \cdot E_s} \geq \sqrt{\frac{6 \cdot f_{ct,eff}}{\phi_s} \cdot w_k \cdot E_s} \qquad \text{(G.7.3)}$$

NOTE: Alternatively, a detailed verification according to Section 7.3.4 may be done.

New paragraph (G.5) is added

(G.5) For thicker members, the minimum reinforcement for crack width limitation under restraint axial tension may be calculated for each face of the structural member considering an effective tension area $A_{c,eff}$:

$$A_{s,min}^{f} = f_{ct,eff} \cdot \frac{A_{c,eff}}{\sigma_s} \cdot (1 - \alpha_f) \qquad \text{(G.7.4)}$$

However, $A_{s,min}^{f}$ shall not be lower than:

$$A_{s,min}^{f} = f_{ct,eff} \cdot \frac{A_{ct}}{f_{yk}} \cdot \left(k - \alpha_f\right) \qquad \text{(G.7.5)}$$

where:

$A_{c,eff}$ — Effective tension area $A_{c,eff} = h_{c,ef} \cdot b$ according to Figure 7.1 and Figure G.7.1.

$\sigma_s$ — Rebar stress in the crack without consideration of the contribution of the steel fibres

The rebar stress $\sigma_s$ in Equation (G.7.4) may be calculated by:

$$\sigma_s = \sqrt{\frac{6 \cdot f_{ct,eff}}{\phi_s} \cdot w_k \cdot E_s} \qquad \text{(G.7.6)}$$

Equation (G.7.1) and (G.7.2a) and Section 7.3.4 define an upper limit for the required minimum reinforcement.

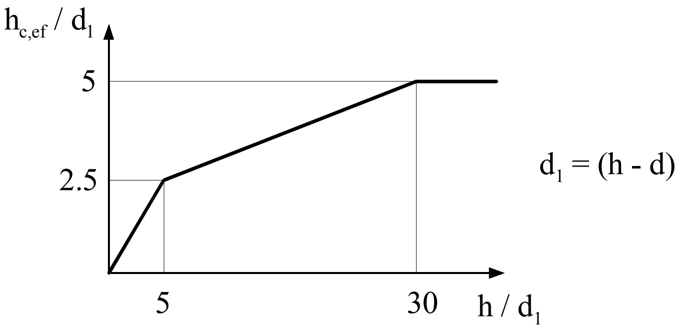



*Figure G.7.1: Height of the effective tension area as a function of the member thickness*

### 7.3.3 Control of cracking without direct calculation

Paragraph (1) is deleted

Paragraph (2) Note is supplemented

For steel fibre reinforced concrete, the maximum bar diameter should be modified as follows:

Minimum reinforcement for bending according to Section 7.3.2:

$$\phi_s^f = \phi_s^* \cdot \frac{k_c \cdot k \cdot h_{cr}}{4(h-d)} \cdot \frac{f_{ct,eff}}{2.9} \cdot \frac{1}{(1-\alpha_f)^2} \geq \phi_s^* \cdot \frac{f_{ct,eff}}{2.9} \cdot \frac{1}{(1-\alpha_f)^2} \quad \text{(G.7.7.a)}$$

Minimum reinforcement for uniform axial tension according to Section 7.3.2:

$$\phi_s^f = \phi_s^* \cdot \frac{k_c \cdot k \cdot h_{cr}}{8(h-d)} \cdot \frac{f_{ct,eff}}{2.9} \cdot \frac{1}{(1-\alpha_f)^2} \geq \phi_s^* \cdot \frac{f_{ct,eff}}{2.9} \cdot \frac{1}{(1-\alpha_f)^2} \quad \text{(G.7.7.b)}$$

Loading:

$$\phi_s^f = \phi_s^* \cdot \frac{\sigma_s \cdot A_s}{4(h-d) \cdot b \cdot 2.9} \cdot \frac{1}{(1-\alpha_f)^2} \geq \phi_s^* \cdot \frac{f_{ct,eff}}{2.9} \cdot \frac{1}{(1-\alpha_f)^2} \quad \text{(G.7.7.c)}$$

where:

$\phi_s^f$ is the adjusted maximum bar diameter for steel fibre reinforced concrete

$\phi_s^*$ is the maximum bar size given in the Table 7.2N

$\sigma_s$ is the rebar stress in the crack without consideration of the contribution of the steel fibres

$A_s$ is the reinforcement area within the tension zone

$h$ is the overall depth of the section

$d$ is the effective depth to the centroid of the outer layer of reinforcement

$b$ is the width of the tension zone

For situations outside the range of DS EN 1992-1-1 Table 7.2, $\phi_s^f$ may be determined by:

$$\phi_s^f = \frac{1.5 \cdot \frac{A_s}{b}}{\sigma_s \cdot (h-d)} \cdot w_k \cdot E_s \cdot \frac{1}{\left(1-\alpha_f\right)^2} \geq \frac{6 \cdot f_{ct,eff}}{{\sigma_s}^2} \cdot w_k \cdot E_s \cdot \frac{1}{(1-\alpha_f)^2} \tag{G.7.7.c}$$

NOTE: Alternatively, a detailed verification according to Section 7.3.4 may be done.

### 7.3.4 Calculation of crack widths

New paragraph (G.6) is added

(G.6) For steel fibre reinforced concrete with combined reinforcement, Equation (7.8) is replaced by:

$$w_k = s_{r,max} \cdot (\varepsilon_{sm}^f - \varepsilon_{cm}) \tag{G.7.8.a}$$

Equation (7.9) is replaced by:

$$\varepsilon_{sm}^f - \varepsilon_{cm} = \frac{\left(1-\alpha_f\right) \cdot \left(\sigma_s - 0.4 \cdot f_{ct,eff} \cdot \frac{1}{\rho_{p,eff}}\right)}{E_s} \geq 0.6 \cdot \left(1-\alpha_f\right) \frac{\sigma_s}{E_s} \tag{G.7.9.a}$$

where:

$$s_{r,max} = \left(1-\alpha_f\right) \cdot \frac{\phi_s}{3.6 \cdot \rho_{p,eff}} \leq \left(1-\alpha_f\right) \cdot \frac{\sigma_s \cdot \phi_s}{3.6 \cdot f_{ct,eff}} \tag{G.7.11.a}$$

NOTE: In case of welded mesh reinforcement, $s_{r,max}$ can further be limited to two times the mesh spacing.

$\alpha_f$ according to Equation (G.7.2.a)

$\rho_{p,eff}$ According to DS EN 1992-1-1 Equation (7.10)

$\varepsilon_{sm}^{f}$ is the mean strain in the reinforcement under the relevant combination of loads, considering the tension stiffness of the steel fibre reinforced concrete between the cracks (tension stiffening)

$\varepsilon_{cm}$ is the mean strain in the concrete between cracks

$f_{ct,eff}$ is the mean value of the tensile strength of the concrete effective at the considered time

$\sigma_s$ is the rebar stress in the crack without consideration of the contribution of the steel fibres

For cracking caused by restraint, $\varepsilon_{sm}^{f} - \varepsilon_{cm}$ may be based on a rebar stress $\sigma_s$ calculated for a cracked section under the combination of restraint actions which cause formation of the first crack.

In the crack width calculation, $\sigma_s$ is a fictitious value which may exceed the yield stress $f_{yk}$. It should then be verified that, with consideration of the effect of the fibres $f_{ctR,s}^{f}$ the yield stress is not exceeded.

New paragraph (G.7)P is added

(G.7)P Under the conditions in Section 7.3.1 (9), the crack width $w_k$ of steel fibre reinforced concrete without additional rebar reinforcement shall be calculated for bending by:

$$w_k = s_w^f \cdot \varepsilon_{ct}^f \quad \text{(G.7.8.b)}$$

where:

$s_w^f = 140$ mm

$\varepsilon_{ct}^{f}$ is the tensile strain of the steel fibre reinforced concrete

NOTE: The assumption for $s_w^f$ only applies for bending.

New paragraph (G.8)P is added

(G.8)P If the conditions in Section 7.3.1 (9) are not fulfilled or if the verification according to Equation (G.7.8.b) is not possible, combined reinforcement is required.

## 7.4 Deflection control

### 7.4.1 General considerations

Paragraph (6) Note is supplemented

For cracked steel fibre reinforced members, the deflection may increase due to bond creep of the fibres.

# 8 Detailing of reinforcement and prestressing tendons – General

## 8.2 Spacing of bars

Paragraph (2) is supplemented

Rebar spacing and fibre length shall be such that blockage of fibres is avoided. In case of steel fibre reinforced slump concrete, the rebar clear spacing shall not be smaller than 0.5 times the fibre length. In case of steel fibre reinforced self-compacting concrete, the rebar clear spacing is recommended to be minimum 2 times the fibre length. If the pump hose is moved during casting, the latter may be relaxed to 1.5 times the fibre length.

## 8.10 Prestressing tendons

If the provisions in this section are applied to steel fibre reinforced concrete structures, additional investigations shall be carried out to verify the design assumptions.

# 9 Detailing of members and particular rules

## 9.1 General

New paragraph (G.4) is added

(G.4) For steel fibre reinforced concrete members, sudden failure at the crack initiation load can be avoided, if it can be verified that the bearing capacity of the entire system after all plastic hinges are formed is greater than the action that leads to the formation of the first plastic hinge (ductility requirement).

New paragraph (G.5) is added

(G.5) The ductility requirement may also be fulfilled by minimum reinforcement according to 9.2.1.1.

## 9.2 Beams

### 9.2.1 Longitudinal reinforcement

#### 9.2.1.1 Minimum and maximum reinforcement areas

Paragraph (1) Note 2 is supplemented

For steel fibre reinforced concrete, $f_{ctR,u}^{f}$ may be considered on the resistance side. The minimum reinforcement to ensure a ductile behaviour is given by:

$$A_{s,min} = \rho \cdot A_{ct} \quad \text{(G.9.1.a)}$$

where:

$$\rho = \frac{k_c \cdot f_{ctm} - f^f_{ctR,u}}{f_{yk}}$$

$f^f_{ctR,u}$ shall be based on a fibre orientation factor $\kappa^f_F$ which represents the strength normal to the cross section.

Rebar reinforcement is not necessary, if

$$f^f_{ctR,u} \geq k_c \cdot f_{ctm} \qquad \text{(G.9.1.b)}$$

Paragraph (2) is replaced

Sections containing less reinforcement than $A_{s,min}$ should be considered as unreinforced (see Section 12), unless for steel fibre reinforced concrete it can be verified that the ductility requirement in paragraph (G.4) is fulfilled.

#### 9.2.1.3 Curtailment of longitudinal tension reinforcement

Paragraph (1) is supplemented

The resisting tensile force is the sum of the tensile force in the reinforcement and the tensile force due to the effect of the steel fibres.

### 9.2.2 Shear reinforcement

Paragraph (4) is supplemented

For steel fibre reinforced concrete, the required shear reinforcement may be determined with consideration of the effect of the steel fibres.

Paragraph (5) is supplemented

For steel fibre reinforced concrete, the minimum shear reinforcement may be reduced:

$$\rho^f_{w,min} = \rho_{w,min} - f^f_{ctR,u}/f_{yk} \cdot 0.394 \frac{\sqrt{f_{ck}}}{f_{ctm}} \geq 0 \qquad \text{(G.9.5.a)}$$

$f^f_{ctR,u}$ shall be based on a fibre orientation factor $\kappa^f_F$ which represents the strength in the direction normal to the 45 degrees shear crack.

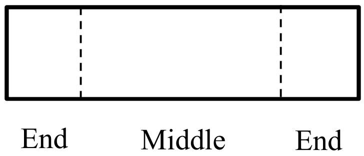
New Section 9.2.6 is added

### 9.2.6 Steel fibre reinforcement

(1) For steel fibre reinforced self-compacting concrete, a detailed determination of fibre orientation factors may be carried out according to Annex L.

(2) For steel fibre reinforced self-compacting concrete, the recommended fibre orientation factors $\kappa^f_F$ in Table G.4 may be used. Reference is made to the "Guideline for execution of SFRC". For shear, no general recommendation for the fibre orientation factor $\kappa^f_F$ can be given for steel fibre reinforced self-compacting concrete at the moment. It needs to be assessed for the individual case.

*Table G.4: Recommended fibre orientation factors $\kappa_F^f$ for beams*




| Middle | | | End | | |
|---|---|---|---|---|---|
| Longitudinal | Vertical | Transverse | Longitudinal | Vertical | Transverse |
| 1.25 | 0.40 | 0.40 | 0.75 | 0.40 | 0.40 |

## 9.3 Solid slabs

### 9.3.2 Shear reinforcement

Paragraph (G.6) is added

(G.6) For steel fibre reinforced slabs, $V_{Rd,c}$ may be replaced by $V_{Rd,c}^f$.

New Section 9.3.3 is added

### 9.3.3 Steel fibre reinforcement

(1) For steel fibre reinforced self-compacting concrete, a detailed determination of fibre orientation factors may be carried out according to Annex L.

(2) For steel fibre reinforced self-compacting concrete, the recommended fibre orientation factors $\kappa_F^f$ in Table G.5 may be used. Reference is made to the "Guideline for execution of SFRC". For shear, no general recommendation for the fibre orientation factor $\kappa_F^f$ can be given for steel fibre reinforced self-compacting concrete at the moment. It needs to be assessed for the individual case.

*Table G.5: Recommended fibre orientation factors $\kappa_F^f$ for solid slabs*

| Longitudinal | Vertical | Transverse |
|---|---|---|
| 1.00 | 0.30 | 1.00 |

# 9.5 Columns

## 9.5.3 Transverse reinforcement

Paragraph (1) Note is added

NOTE: The effect of steel fibres may not be considered with respect to transverse reinforcement of columns.

New Section 9.5.4 is added

## 9.5.4 Steel fibre reinforcement

(1) For steel fibre reinforced self-compacting concrete, a detailed determination of fibre orientation factors may be carried out according to Annex L.

(2) For steel fibre reinforced self-compacting concrete, no recommendations for fibre orientation factor $\kappa_F^f$ can be given at the moment.

# 9.6 Walls

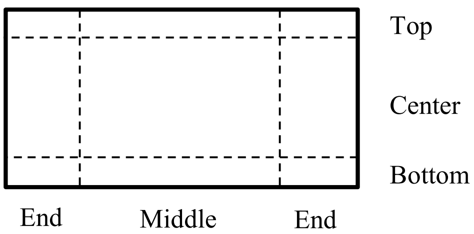
New Section 9.6.5 is added

## 9.6.3 Steel fibre reinforcement

(1) For steel fibre reinforced self-compacting concrete, a detailed determination of fibre orientation factors may be carried out according to Annex L.

(2) For steel fibre reinforced self-compacting concrete, the recommended fibre orientation factors $\kappa_F^f$ in Table G.6 may be used. Reference is made to the "Guideline for execution of SFRC". For shear, no general recommendation for the fibre orientation factor $\kappa_F^f$ can be given for steel fibre reinforced self-compacting concrete at the moment. It needs to be assessed for the individual case.

*Table G.6: Recommended fibre orientation factors $\kappa_F^f$ for walls*




| | Middle | | | End | | |
|---|---|---|---|---|---|---|
| | Longitudinal | Vertical | Transverse | Longitudinal | Vertical | Transverse |
| Bottom | 1.25 | 0.42 | 0.42 | 0.92 | 0.42 | 0.42 |
| Center | 1.00 | 0.50 | 0.42 | 0.83 | 0.56 | 0.50 |
| Top | 0.83 | 0.50 | 0.27 | 0.67 | 0.67 | 0.50 |

## 9.8 Foundations

New Section 9.8.6 is added

### 9.8.6 Steel fibre reinforcement

(1) For fibre orientation factors in strip foundations made with steel fibre reinforced self-compacting concrete, reference is made to Section 9.2.6.

(2) For fibre orientation factors in foundation slabs made with steel fibre reinforced self-compacting concrete, reference is made to Section 9.3.3.

# 11 Lightweight aggregate concrete structures

This Section does not apply in conjunction with this guideline.

# Annex E (Informative)

## Indicative strength classes for durability

New paragraph (G.3) is added

(G.3) For steel fibre reinforced concrete, the strength class should be minimum C20/25.

NOTE: Steel fibre reinforced concrete is concrete with embedded metal.

New Annex K is added

# Annex K (Normative) – Detailed determination of the factor $\beta_{L2}$

According to Part 1, Section 3.6.3, the factor $\beta_{L2}$ may be determined according to Figure K.1.

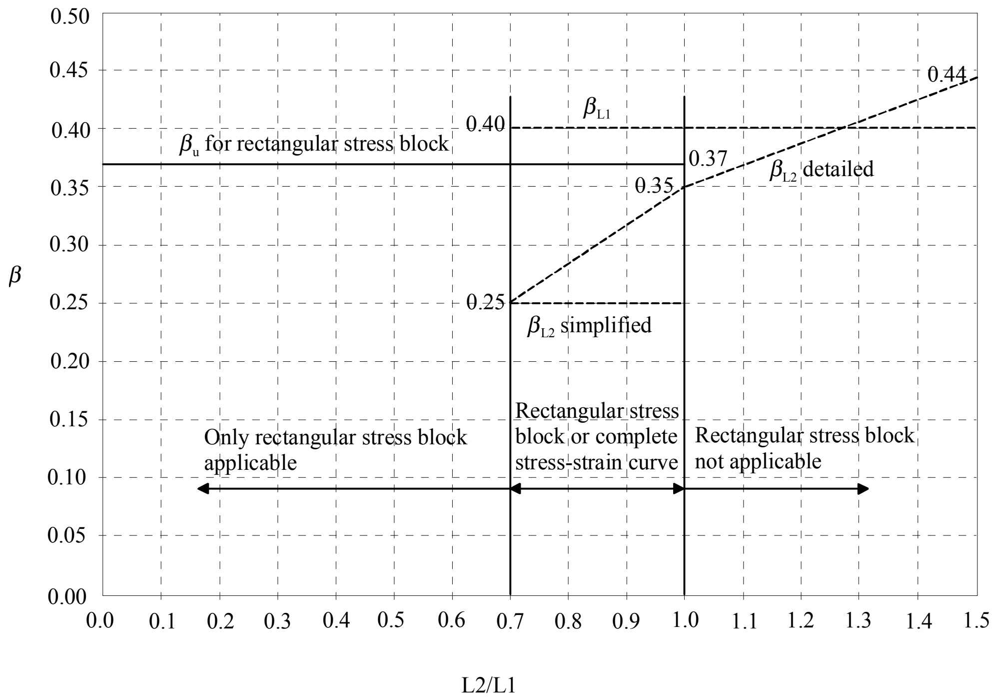



*Figure K.1: Factors $\beta_{L1}$, $\beta_{L2}$ and $\beta_u$ for determination of axial residual tensile strength as a function of the ratio L2/L1*

If the performance class ratio L2/L1 is larger than or equal to 0.7 and smaller than or equal to 1.0, $\beta_{L2}$ shall be determined according to Equation (K.1). If the performance class ratio L2/L1 is larger than 1.0 and smaller than or equal to 1.5, $\beta_{L2}$ shall be determined according to Equation (K.2). In both cases $\beta_{L1}$ = 0.4. If the performance class ratio L2/L1 is larger than 1.5, $\beta_{L2}$ = 0.44 shall be used.

$$\beta_{L2} = \frac{1}{3} \cdot \frac{L2}{L1} + 0.02 \quad \text{for} \quad 0.7 \leq \frac{L2}{L1} \leq 1.0 \tag{K.1}$$

$$\beta_{L2} = 0.18 \cdot \frac{L2}{L1} + 0.17 \quad \text{for} \quad 1.0 < \frac{L2}{L1} \leq 1.5 \tag{K.2}$$

If the performance class ratio L2/L1 is larger than 1.0, the rectangular stress block must not be used.

New Annex L is added

# Annex L (Normative) – Determination and verification of fibre orientation factors

## L.1 General

The fibre orientations in structural members depend mainly on the following aspects:

- Geometry of the structural member
- Type of reinforcement (steel fibres only or combined reinforcement) and reinforcement density
- Concrete type and characteristics
- Casting method

## L.2 Definition of fibre orientation factors $\kappa_F^f$

The residual tensile strength of steel fibre reinforced concrete is directly proportional to the number of fibres in the crack plane. The relation between the number of fibres in a given cross section, the geometrical characteristics and volume concentration of the fibres and the fibre orientation is given by:

$$N_f = \frac{V_f}{\pi r_f^2}\alpha_0 \qquad \text{(L.1)}$$

where:

| | |
|---|---|
| $N_f$ | Number of fibres per unit cross-sectional area in a given cross section ("fibre count") |
| $V_f$ | Fibre volume concentration (ratio between fibre volume and total volume) |
| $r_f$ | Fibre radius |
| $\alpha_0$ | Factor representing the fibre orientation, with the following values for "standard" fibre orientations: |

$\alpha_0 = 0.5$ in the case of 3D random fiber orientation (for any sectional plane)

$\alpha_0 = 0.64$ in the case of 2D random fiber orientation (for any sectional plane perpendicular to the fiber plane)

$\alpha_0 = 0$ in the case of 2D random fiber orientation (for a sectional plane parallel to the fiber plane)

$\alpha_0 = 1$ in the case of 1D aligned fibers (for a sectional plane perpendicular to the fiber direction)

$\alpha_0 = 0$ in the case of 1D aligned fibers (for any sectional plane parallel to the fiber direction)

Using the fibre orientation in a beam test with steel fibre reinforced slump concrete according to Part 3 (for which $\alpha_{0,ref} = 0.6$) as reference, the residual tensile strength $f_{ct0}^{f}$ for a given fibre orientation represented by $\alpha_0$ in a given direction can be expressed with the fibre orientation factor $\kappa_F^f$:

$$f_{ct0}^{f} = \frac{\alpha_0}{\alpha_{0,ref}} f_{ct0,ref}^{f} = \kappa_F^f f_{ct0,ref}^{f} \qquad \text{(L.2)}$$

i.e.

$$\kappa_F^f = \frac{\alpha_0}{0.6} \qquad \text{(L.3)}$$

## L.3 Determination of fibre orientation factors for design purposes

Fibre orientation factors $\kappa_F^f$ can be determined by:

- Casting simulations
- Trial castings with sampling and fibre counting
- Experience (when a sufficient amount of examples and data is available)

For numerical simulations of casting processes, reference is made to the literature.

Fibre counts on samples can be determined by:

- Visual inspection of cutting planes or crack surfaces
- CT scanning
- Casting simulations

For design purposes, fibre orientation factors shall be cautious estimates rather than estimates of average fibre orientation factors.

## L.4 Verification of fibre orientation factors in structural members

Actual fibre orientation factors $\kappa_F^f$ in structural members can be verified by:

- Fibre counting on core samples taken from the structural member

# Part 2 - Supplements and modifications to DS EN 206-1

## 1 Scope

4th paragraph is replaced

Part 2 of this guideline applies to concrete compacted to retain no appreciable amount of entrapped air other than entrained air. It applies to normal-weight steel fibre reinforced concrete for structures according to Part 1 of this guideline. Steel fibres have to be added at the mixing plant.

## 2 Normative references

The following normative references are added

EN 14651, *Test method for metallic fibre concrete - Measuring the flexural tensile strength (limit of proportionality (LOP), residual)*

## 3 Definitions, symbols and abbreviations

### 3.2 Symbols and abbreviations

The following symbols are added

| | |
|---|---|
| $m_{f,i}$ | Steel fibre content in one fresh concrete sample |
| $\bar{m}_f$ | Average steel fibre content in the tested truck mixer |
| $m_{f,min}$ | Minimum value of the steel fibre content as defined in connection with initial testing of the performance class |
| $M_{fc,i}$ | Mass of one fresh concrete sample |
| $M_{f,i}$ | Mass of steel fibres in one fresh concrete sample |
| $\rho_{fc,i}$ | Density of one fresh concrete sample |
| $V_{fc,i}$ | Volume of one fresh concrete sample |
| $V_{diff}$ | Voltage difference for determination of the steel fibre content |
| $V_i$ | Induced voltage in direction x, y, z |
| $V_{empty}$ | No-load voltage of the empty sensor |

# 4 Classification

## 4.3 Hardened concrete

New Section 4.3.3 is added

### 4.3.3 Performance classes for steel fibre reinforced concrete

For steel fibre reinforced concrete, performance classes are defined in Part 1, Section 3.6.3, Table G.2 of this guideline.

# 5 Requirements for concrete and methods of verification

## 5.4 Requirements for fresh concrete

New Section 5.4.5 is added

### 5.4.5 Steel fibre content

The steel fibre content shall be documented for each load in the production records of the mixing plant. The steel fibre content is defined as a minimum value $m_{f,min}$.

# 6 Specification of concrete

## 6.2 Specification for designed concrete

### 6.2.2 Basic requirements

Section 6.2.2 is supplemented

In addition, for steel fibre reinforced concrete:

i) performance class.

# 8 Conformity control and conformity criteria

## 8.2 Conformity control for designed concrete

### 8.2.3 Conformity control for properties other than strength

An additional line is added in Table 17

*Table 17: Conformity criteria for properties other than strength*

| Property | Test method or method of determination | Minimum number of samples or determinations | Acceptance number | Maximum allowed deviation of single test results from the limits of the specified class or from the tolerance on the target value | |
|---|---|---|---|---|---|
| | | | | Lower limit | Upper limit |
| Steel fibre content | See 5.4.5 | 1 determination per production day | See Table 19a | 0.95 $m_{f,min}$ | No limit [a] |
| [a] If no limits are defined. | | | | | |

# 9 Production control

## 9.2 Production control systems

3rd paragraph is replaced

The production control system shall contain adequately documented procedures and instructions. These procedures and instructions shall, where relevant, be established in respect of the control requirements as given in Section 9.9, tables 22, 23 and 24. The intended frequencies of tests and inspections by the producer shall be documented. The results of tests and inspections shall be recorded.

## 9.5 Concrete composition and initial testing

1st paragraph is replaced

In the case of using a new concrete composition, initial testing shall be performed to provide a concrete that achieves the specified properties or intended performance with an adequate margin (see Part 3).

2nd paragraph is replaced

New concrete compositions obtained by interpolation between known concrete compositions or extrapolations of compressive strength not exceeding 5 MPa are deemed to satisfy the requirements for initial testing of compressive strength. For the performance class, initial testing is always required.

NOTE: For determination of the performance class, interpolations according to Annex M, Section M.6 are allowed.

3rd paragraph is replaced

Concrete compositions shall be reviewed periodically to provide assurance that all concrete designs are still in accordance with the actual requirements, taking account of the change in properties of the constituent materials and the results of conformity testing on the concrete compositions. This comprises e.g. the beam bending tests according to DS EN 14651, which shall be repeated annually.

For control of the fresh and hardened concrete properties, the following variations in the concrete composition are allowed:

| | |
|---|---|
| Cement: | ±15 kg/m$^3$ |
| Additions (excl. steel fibres): | ±15 kg/m$^3$ |
| Admixtures: | Between 0 and max. dosage according to 5.2.6 |

The dosages, the order of adding the constituents and the mixing duration shall be specified for the respective mixing plant in the batching instruction.

## 9.9 Production control procedures

*Table 22 – Control of constituent materials*

Table 22 is supplemented

| | Constituent material | Inspection / test | Purpose | Minimum frequency |
|---|---|---|---|---|
| 15 | Steel fibres | Inspection of delivery ticket | To ascertain if the consignment is as ordered and from the correct source | Each delivery |
| 16 | | Visual inspection | To ascertain if the consignment is as ordered and from the correct source<br><br>Visual check of fibre geometry; measurement of fibre geometry in case of doubt | Each delivery |
| 17 | | Weight check of dosing unit (not required in case of separate weighing of the steel fibres) | To ascertain if the weight of the steel fibres is as ordered | Spot check |

*Table 23 – Control of equipment*

Table 23 is supplemented

| | Equipment | Inspection / test | Purpose | Minimum frequency |
|---|---|---|---|---|
| 12 | Dosing system for steel fibres and dispersion equipment (e.g. blower blast equipment) for steel fibres | Visual inspection of functionality | To ascertain if the measurement system functions properly | Every 7 days of production |
| 13 | | Check of precision | To avoid inaccurate dosing | On installation<br><br>Periodically [a] after installation<br><br>In case of doubt |
| [a] The frequency depends on the kind of equipment, its sensitivity in use and the production conditions of the plant. | | | | |

*Table 24 – Control of production procedures and of concrete properties*

Table 24 is supplemented

| | Equipment | Inspection / test | Purpose | Minimum frequency |
|---|---|---|---|---|
| 17 | Even distribution of steel fibres when loading the truck mixer | Testing according to Annex L | To ascertain that the following requirements are fulfilled:<br><br>$m_{f,i} \geq 0.80 \cdot m_{f,min}$<br><br>$\overline{m}_f \geq 0.85 \cdot m_{f,min}$ | As frequently as compressive strength test, see row 16 |
| 18 | Residual flexural tensile strength | Testing according to Part 3 | Determination of performance class | Every year<br><br>In case of doubt |

# Annex A (normative) – Initial test

Annex A does not apply in conjunction with this guideline and is replaced by Annex M.

# Annex H (informative) – Additional provisions for high strength concrete

Annex H does not apply in conjunction with this guideline.

New Annex L is added

# Annex L (normative) – Determination of the steel fibre content

## L.1 Wash-out test

### L.1.1 General

This instruction describes the method for determining the steel fibre content by wash-out tests. Three samples are taken from a load. The samples with a specified volume are washed out. Subsequently, the steel fibres are separated, dried and weighed.

### L.1.2 Apparatus

The following equipment is required:

- Three 10 to 15 liter buckets
- Sieve or filter equipment, suitable for washing out cement and other fine materials from fresh concrete
- Drying apparatus
- Magnet for collection of the fibres
- Balance with an accuracy of ± 1 g

### L.1.3 Testing procedures

Three samples shall be taken with the buckets from the truck mixer and labelled as follows:

- Sample 1 from the first one third of the load, disregarding the very first part of the load
- Sample 2 from the middle one third of the load
- Sample 3 from the last one third of the load, disregarding the very last part of the load

First, the empty buckets shall be weighed. Then, the three buckets shall be filled from the truck. The concrete shall be compacted and levelled off. The mass of the fresh concrete $M_{fc,i}$ is determined by weighing each bucket again and subtracting its empty weight. Considering the fresh concrete density measured according to DS EN 12350-6, the volume of the fresh concrete sample is determined by:

$$V_{fc,i} = \frac{M_{fc,i}}{\rho_{fc,i}} \quad \text{in m}^3 \qquad \text{(L.1)}$$

where:

| | |
|---|---|
| $M_{fc,i}$ | Mass of one fresh concrete sample in kg |
| $\rho_{fc,i}$ | Fresh concrete density according to DS EN 12350-6 in kg/m$^3$ |

Each sample shall be placed in a sieve or filter equipment where the cement and other fine materials and aggregates can be washed out so that the fibres can be separated from the mass. Care shall be taken not to lose any fibres. All fibres shall be collected directly or by using the magnet. The collected fibres shall be cleaned, dried and then weighed to determine the mass of each fibre sample $M_{f,i}$ in kg.

The steel fibre content of each sample is determined by:

$$m_{f,i} = \frac{M_{f,i}}{V_{fc,i}} \quad \text{in kg/m}^3 \qquad \text{(L.2)}$$

The average steel fibre content $\overline{m}_f$ in the tested truck mixer is determined by:

$$\overline{m}_f = \frac{m_{f,1} + m_{f,2} + m_{f,3}}{3} \quad \text{in kg/m}^3 \qquad \text{(L.3)}$$

### L.1.4 Test report

The test report shall include:

a) Identification of the concrete load;

b) Place, date and time of testing, testing institute and person responsible for testing;

c) Fresh concrete density;

d) Steel fibre content of the samples $m_{f,1}$, $m_{f,2}$ and $m_{f,3}$;

e) Average steel fibre content $\overline{m}_f$;

f) Identification of the fibres, manufacturer, certificate number and description of product from the CE conformity marking;

g) Reference to this guideline;

h) Signature of the person technically responsible for the test

## L.2 Magnetic induction test

This instruction describes the method for determining the steel fibre content by magnetic induction tests. Three samples are taken from a load. The steel fibre content is determined by measuring the induction current.

### L.2.2 Apparatus

The following equipment is required:

- Three 10 to 15 liter buckets
- Cubical plastic container with internal edge lengths of 150 mm
- Trowel
- Compaction device (vibrating table or poker vibrator)
- Induction measurement device with cubical double-inductor sensor

### L.2.3 Testing procedures

Three samples shall be taken with the buckets from the truck mixer and labelled as follows:

- Sample 1 from the first one third of the load, disregarding the very first part of the load
- Sample 2 from the middle one third of the load
- Sample 3 from the last one third of the load, disregarding the very last part of the load

Each bucket shall be filled up to the 10 liter mark. Care shall be taken to ensure that the samples are homogeneous.

First, the induced no-load voltage with the empty sensor $V_{empty}$ shall be determined. Afterwards, the fresh concrete is poured into the cubical plastic container. The double-inductor sensor is put over the container and the induced voltage is measured. This measurement is carried out for all three directions of the sample and the three measurement results are averaged. The difference $V_{diff}$ between the average voltage of the three directions and the no-load voltage depends directly on the steel fibre content and the fibre type of the concrete sample:

$$V_{diff} = \frac{V_x + V_y + V_z}{3} - V_{empty} \qquad \text{(L.4)}$$

Based on a calibration curve, $V_{diff}$ is converted to a steel fibre content for the respective sample.

The average steel fibre content $\overline{m}_f$ in the tested truck mixer is determined by:

$$\overline{m}_f = \frac{m_{f,1} + m_{f,2} + m_{f,3}}{3} \qquad \text{(L.5)}$$

### L.2.4 Test report

The test report shall include:

a) Identification of the concrete load;

b) Place, date and time of testing, testing institute and person responsible for testing;

c) Fresh concrete density, if tested;

d) Steel fibre content of the samples $m_{f,1}$, $m_{f,2}$ and $m_{f,3}$;

e) Average steel fibre content $\overline{m}_f$;

f) Identification of the fibres, manufacturer, certificate number and description of product from the CE conformity marking;

g) Reference to this guideline;

h) Signature of the person technically responsible for the test

New Annex M is added

# Annex M (normative) – Initial test of steel fibre reinforced concrete

## M.1 General

This annex provides details of initial testing as indicated in Section 5.2.1, 5.2.5.1, 6.1 and 9.5.

The initial test shall establish a concrete that satisfies all specified requirements for fresh and hardened concrete.

## M.2 Party responsible for initial tests

Initial tests shall be the responsibility of the producer for designed concrete.

## M.3 Frequency of initial tests

Initial tests shall be performed before using a new concrete or concrete family.

Initial tests shall be repeated annually as confirmation.

Initial tests shall be repeated if there is a significant change either in the constituent materials or in the specified requirements on which the previous tests were based.

## M.4 Test conditions

In general, initial tests shall be carried out on fresh concrete with a temperature of 15 to 22 ºC.

NOTE: If concreting on the site will be done under widely divergent temperature conditions, or if heat treatment is applied, the producer should be informed about this, so that he can consider the concerning effects on the properties of the concrete and the need for any additional tests.

The time between mixing and consistence testing, and the results shall be recorded.

The initial tests shall verify that the applied and documented production procedures result in a uniform fibre distribution in the load.

## M.5 Scope of initial tests

The scope of the initial tests on fresh and hardened concrete is given in Table M.1.

The residual flexural tensile strength tests according to DS EN 14651 for determination and control of the performance class shall be carried out with a batching tolerance on the steel fibre content. The steel fibre content in the tests shall not be more than the specified minimum steel fibre content $m_{f,min}$.

*Table M.1: Scope of initial tests for steel fibre reinforced concrete*

| Property | Test | Purpose | Numer of samples |
|---|---|---|---|
| Consistence | According to DS EN 12350-2, -3, -4 or -5 | Determination of consistence class | One determination |
| Residual flex-ural tensile strength | According to DS EN 14651 | Determination and control of perfor-mance class | ≥ 6 beams |
| Compressive strength | According to DS EN 12390-3 | Determination of compressive strength class | 3 cubes |

## M.6 Determination of intermediate values of residual flexural tensile strength

Under the following conditions, linear interpolation is allowed for initial testing.

**Interpolation with respect to steel fibre content (same compressive strength class):**

For concretes which are tested according to Appendix N and which differ only in terms of steel fibre content by maximum 20 kg/m$^3$, the mean residual flexural tensile strength of concretes with intermediate values of steel fibre content may be determined by linear interpolation. The concretes may further differ in terms of plasticizer and superplasticizer dosages. For determination of characteristic values according to Part 3, Equation (G.4.3) and (G.4.4), interpolated standard deviations may be used.

Interpolation is not allowed when involving performance class L0 or a performance class larger than L2.4.

**Interpolation with respect to compressive strength (same steel fibre content):**

For concretes with the same constituent materials which are tested according to DS EN 14651 and which differ only in terms of compressive strength, the mean residual flexural tensile strength of concretes with intermediate values of compressive strength may be determined by linear interpolation based on the mean axial tensile strength of the concrete $f_{ctm}$ according to DS EN 1992-1-1. Concretes with the same constituent materials in this respect are concretes fulfilling the following conditions:

- Aggregates of the same geological origin
- Same cement type and cement strength class

- Same type of additions
- Same type of admixtures.

## M.7 Criteria for adoption of initial tests

The rules given in DS EN 206-1 apply. For the performance class, DS EN 14651 shall be considered.

# Part 3 - Supplements and modifications to DS EN 14651

## 1 Scope

First paragraph is replaced

Part 3 of this guideline specifies a method for determining the performance class of steel fibre reinforced concrete.

## 7 Test specimens

### 7.1 Shape and size of test specimens

Second paragraph is replaced

The specified shape and size of test specimens are suitable for concrete with maximum nominal upper aggregate size no larger than 16 mm for rounded aggregates and 22 mm for crushed aggregates. For larger aggregate sizes, special considerations are needed regarding the shape and size of the test specimens. The length of the steel fibres shall be minimum 1.5 times the maximum nominal upper aggregate size.

### 7.2 Manufacture and curing of test specimens

First paragraph is replaced

Not less than 6 test specimens shall be cast and cured in compliance with DS EN 12350-1 and DS EN 12390-2.

New paragraph is added

The following sequence for mixing of the concrete shall be observed to achieve a uniform fibre distribution:

a) Filling of aggregates into the mixer. Glued steel fibres may be added to the aggregates in one go. The minimum mixing duration is 30 s.

b) Adding of cement and additions, minimum mixing duration 30 s.

c) Adding of water and admixtures with another mixing duration of not less than 30 s.

d) Continuous adding of loose steel fibres via a channel to avoid fibre balling with another mixing duration of not less than 60 s. The subsequent mixing duration shall not be less than 90 s. It shall be checked that all fibres are separated (in case of glued fibres) and evenly dispersed in the concrete. Otherwise, the mixing shall be continued.

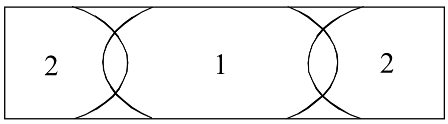
If the mixer has fixed mixing blades, they shall be lifted regularly to avoid accumulation of fibres at the blades. Visual inspection during the mixing shall always be carried out.

Second paragraph is replaced

The procedure for filling the mould with steel fibre reinforced slump concrete is indicated in Figure 2a; the size of increment 1 should be twice that of increment 2. The mould shall quickly be filled up to approximately 90 % of the height of the test specimen before compaction. The mould shall be topped up and levelled off while being compacted. Compaction shall be carried out by external vibration. Concretes with consistence class F6 may be compacted manually by poking. For consistence classes F3 and F4, a vibration duration of 30 s is typically sufficient for complete compaction. The vibrating table shall have a sufficient size.

In the case of steel fibre reinforced self-compacting concrete, the mould shall be filled with a funnel kept at one end of the mould as shown in Figure 2b and shall be levelled off without any compaction.

After compaction, the mould shall be covered by a plastic sheet and stored in a climate chamber for 2 days. For concretes with rapid hardening cement, 24 hours storage are sufficient.




Key:
1 and 2 order of filling

*Figure 2a: Procedure for filling the mould in case of slump concrete*

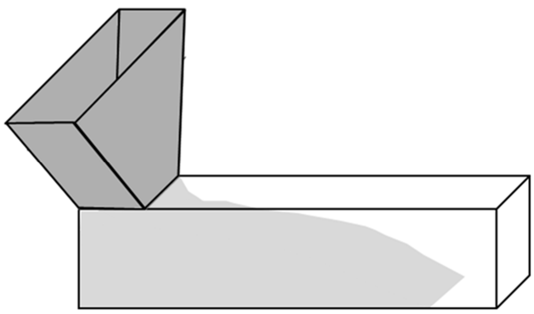


*Figure 2b: Procedure for filling the mould in case of self-compacting concrete*

## 7.3 Notching of test specimens

3rd paragraph is replaced

After notching, the test specimens shall be stored at approximately 100 % humidity (plastic sheet – to be sealed with tape, water curing or climate chamber with 95 % relative humidity) for a minimum of 3 days until no more than 3 hours before testing (leaving sufficient time for preparation including any location devices for the transducer(s)). Testing shall normally be performed at 28 days. For particular applications, it may be necessary to perform the testing after more than 28 days.

# 9 Expression of results

## 9.3 Residual flexural tensile strength

Section 9.3 is supplemented

The mean residual flexural tensile strengths of the test series with $n \geq 6$ test specimens are determined by:

$$f_{cflm,L1}^{f} = \frac{1}{n}\sum_{i=1}^{n} f_{R,1} \quad \text{in MPa} \tag{G.4.1}$$

$$f_{cflm,L2}^{f} = \frac{1}{n}\sum_{i=1}^{n} f_{R,4} \quad \text{in MPa} \tag{G.4.2}$$

For determination of the performance class, the characteristic values of the residual flexural tensile strength $f_{cflk,Li}^{f}$ of the test series with $n \geq 6$ test specimens are determined by:

$$f_{cflk,Li}^{f} = e^{\left(Lf_{cflm,Li}^{f} - k_s \cdot Ls_{Li}\right)} \leq 0.51 \cdot f_{cflm,Li}^{f} \quad \text{For slump concrete} \tag{G.4.3}$$

$$f_{cflk,Li}^{f} = k_{\alpha,\mathrm{SCC}} \cdot e^{\left(Lf_{cflm,Li}^{f} - k_s \cdot Ls_{Li}\right)} \leq k_{\alpha,\mathrm{SCC}} \cdot 0.51 \cdot f_{cflm,Li}^{f} \quad \text{For self-compacting concrete} \tag{G.4.4}$$

where:

$Lf_{cflm,Li}^{f}$ Mean value of the logarithmic individual test results:

$$Lf_{cflm,L1}^{f} = \frac{1}{n}\sum_{i=1}^{n} \ln\left(f_{R,1,i}\right)$$

$$Lf_{cflm,L2}^{f} = \frac{1}{n}\sum_{i=1}^{n} \ln\left(f_{R,4,i}\right)$$

$Ls_{Li}$ Standard deviation of the logarithmic individual test results:

$$Ls_{L1} = \sqrt{\frac{\sum_{i=1}^{n}\left(Lf_{cflm,L1}^{f} - \ln\left(f_{R,1,i}\right)\right)^2}{n-1}}$$

$$Ls_{L2} = \sqrt{\frac{\sum_{i=1}^{n}\left(Lf_{cflm,L2}^{f} - \ln\left(f_{R,4,i}\right)\right)^2}{n-1}}$$

$k_s$ Fractile factor for the unknown standard deviation of the 5 % fractile with 75 % confidence according to Table G.7.

$k_{\alpha,\mathrm{SCC}} = \frac{\alpha_{0,ref}}{\alpha_{0,SCC}}$ Ratio between the fibre orientation factor in slump concrete test beams ($\alpha_{0,ref} = 0.6$ cf. Part 1, Annex L), and the fibre orientation factor in SCC test beams $\alpha_{0,SCC}$. The recommended value is $\alpha_{0,SCC} = 0.84$.

*Table G.7: Fractile factor $k_s$*

| Number of test specimens $n$ | Fractile factor $k_s$ |
|---|---|
| 6 | 2.336 |
| 9 | 2.141 |
| 12 | 2.048 |
| 15 | 1.991 |
| 20 | 1.932 |
| 25 | 1.895 |
| 100 | 1.760 |
| ∞ | 1.645 |

NOTE: A modification of Equation (G.4.3) for lower coefficients of variation is not possible, as the values of $\kappa_G^f$ in Part 1, Section 3.6.3 have been calibrated for the factor 0.51.

The load-$CMOD$ diagram shall be monotonously decreasing. Otherwise, the lowest value $F'_4$ in the interval between $CMOD$ = 0.5 mm and $CMOD$ = 3.5 mm (cf. Figure G.8) shall be used for determination of $f_{R,4}$ according to Equation (4) in DS EN 14651.

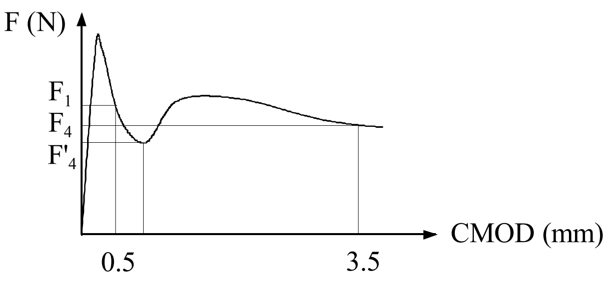



*Figure G.8: Evaluation of load- $CMOD$ diagram if it is not monotonously decreasing*

# 10 Test report

Text is replaced

The test report shall include:

a) Identification of the test specimen;

b) Identification of concrete type (slump / self-compacting) and concrete composition;

c) Identification of the fibres, manufacturer, certificate number and description of product from the CE conformity marking;

d) Type of concrete mixer;

e) Description and timing sequence of the mixing;

f) Date of manufacture;

g) Method and duration of compaction;

h) Date of notching;

i) Place and date of testing, testing institute and person responsible for testing;

j) Number of specimens tested;

k) Curing history / storage conditions and moisture condition of specimen at test;

l) Average width of specimen to the nearest 0.1 mm;

m) Average distance between the tip of the notch and the top of the specimen to the nearest 0.1 mm;

n) Width and height of specimen, in mm;

o) Span length of specimen to the nearest mm;

p) Rate of increase of $CMOD$ or deflection and any deviation thereof;

q) Load- $CMOD$ curve or load-deflection curve;

r) $LOP$ to the nearest 0.1 MPa;

s) Residual flexural tensile strength values corresponding to $CMOD_j$ or $\delta_j$ ( $j$ = 1, 2, 3, 4) to the nearest 0.1 MPa;

t) Evaluations according to Equations (G.4.1) to (G.4.4);

u) Reference to this guideline;

v) Any deviation from the standard testing method;

w) Optionally, observation of uniformity of fibre distribution at the fracture surface;

x) Signature of the person technically responsible for the test

# Part 4 - Supplements and modifications to DS EN 13670 / DS 2427

## 1 Scope

Paragraph (1) is replaced

(1) Part 4 of this guideline gives common requirements for execution of steel fibre reinforced concrete structures designed according to Part 1 and made with concrete produced according to Part 2 and 3 of this guideline. It applies to both in-situ works and construction using prefabricated concrete elements. The scope is limited to structures as specified in Section 1.1.2 of Part 1 of this guideline.

## 4 Execution management

### 4.3 Quality management

#### 4.3.1 Execution classes

New paragraph (8) is added

(G.8) Steel fibre reinforced concrete structures of performance class ≤ L1-1.2 are categorized as Execution class 1. Steel fibre reinforced concrete structures of performance class ≤ L1-1.2 are categorized as Execution class 2.

## 8 Concreting

### 8.1 Specification of concrete

New paragraph (G.5) is added

(G.5) The necessary effort for mixing, casting and compaction of steel fibre reinforced concrete generally increases with increasing steel fibre content and increasing aspect ratio (length / diameter ratio).

### 8.3 Delivery, reception and site transport of fresh concrete

Paragraph (4) is supplemented

For steel fibre reinforced concrete, requirements for inspection and testing are given in Table G.3a.

*Table G.3a: Inspection and testing requirements for steel fibre reinforced concrete*

| Subject | Method | Requirement | Frequency for execution class | | |
|---|---|---|---|---|---|
| | | | 1 | 2 | 3 |
| Steel fibre content | Visual inspection | Normal appearance | Spot check | Every load | – |
| | According to Part 2 Annex L | According to Table G.3b | – | In case of doubt | – |
| Residual flexural tensile strength | According to Part 3 | According to Table G.3c | – | In case of doubt | – |
| In case of doubt for execution class 2, it is sufficient to test either steel fibre content or residual flexural tensile strength. | | | | | |

In case of doubt for execution class 2, either the steel fibre content or the residual flexural tensile strength shall be tested. Acceptance criteria are given in Table G.3b and G.3c.

*Table G.3b: Acceptance criteria for steel fibre content of the concrete load*

| | Steel fibre content in kg/m$^3$ |
|---|---|
| Each individual result | $m_{f,i} \geq 0.80 \cdot m_{f,min}$ |
| Average of 3 results | $\overline{m}_f \geq 0.85 \cdot m_{f,min}$ |

*Table G.3c: Acceptance criteria for residual tensile strength of the concrete load*

| | Residual tensile strength |
|---|---|
| Each individual result | ≥ L1 and ≥ L2 |
| NOTE: The value of the test result shall not be multiplied by the factor 0.51 according to Equation (G.4.3) and (G.4.4) in Part 3. | |

The concrete load shall be accepted, if the criteria in Table G.3b and G.3c are satisfied. In case the criteria are not satisfied, they may be checked instead on samples from the structure, e.g. determination of steel fibre content on core samples.

## 8.4 Placing and compaction

New Section 8.4.7 is added

### 8.4.7 Steel fibre reinforced concrete

The concrete flow in the formwork may have a certain influence on fibre orientation for slump concrete, and has a significant influence on fibre orientation for self-compacting concrete. Further guidance for different applications and casting methods is given in Sections 9 and 10 of Part 1. Too intensive compaction shall be avoided, as it may result in fibre sedimentation.

# Part 5 - Supplements and modifications to BIPS C213 Tegningsstandarder Del 3 - Betonkonstruktioner og Pæle

The following supplements and modifications are made to BIPS C213 Tegningsstandarder Del 3 - Betonkonstruktioner og Pæle, December 2012.

Section 1.6.3 is supplemented

Reinforcement drawings are to be prepared also for steel fibre reinforced concrete and concrete with combined reinforcement. Casting sections and structural members to be cast with steel fibre reinforced concrete shall be marked. The casting sequence shall be defined. Depending on the spacing of rebar reinforcement, an upper limit for the fibre length may be defined.

Performance classes shall be specified according to Section 3.6.3 of this guideline. If self-compacting concrete is specified, minimum fibre orientation factors for each direction of each structural member shall be specified. A reference shall be made to this Design Guideline and to the "Guideline for execution of SFRC".