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SWEDISH STANDARDS INSTITUTE

Fiberbetong – Dimensionering av fiberbetongkonstruktioner

Fibre Concrete – Design of Fibre Concrete Structures

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Content

Introduction

This Standard has been prepared in order to provide National guidelines on how to design fibre concrete structures in accordance with SS-EN 1992-1-1. SS 812310 is not a Eurocode but it is complement to SS-EN 1992-1-1. Both documents should be read in conjunction with each other for a full comprehension of the subject.

This Standard follows the same Section configuration as SS-EN 1992-1-1 and provides additional paragraphs and amended text where necessary to aid fibre concrete design, plus relevant figures, tables and equations.

Repetition of text from SS-EN 1992-1-1 has been avoided as far as possible and is only included when absolutely necessary for the comprehension of this Standard. Figures, tables and equations are numbered according to the separate Sections, i.e. the first figure in Section 3 is notated as 3.1, the second figure 3.2 and so on.

This Standard deals mainly with fundamental requirements concerning general issues, basis of design, materials, structural analysis, ultimate limit state, and serviceability limit state (Sections 1, 2, 3, 5, 6, and 7). Durability is treated equally for fibre concrete and conventionally reinforced concrete and is covered in SS-EN 1991-2, Section 4. This Standard addresses Section 8.2 S*pacing of bars* and both Sections 9.2 *Beams* and 9.3 *Solid slabs* with regards to minimum flexural reinforcement. There is no need for changes to SS-EN 1992-1 Section 10 *Additional rules for precast concrete elements and structures* or Section 12 *Plain and lightly reinforced concrete structures*. This standard for fibre concrete covers creep and shrinkage, members not requiring design shear reinforcement and punching (Section 11).

This Standard covers fibre concrete structures. The term “fibre concrete” instead of “steel fibre concrete” or “steel fibre reinforced concrete” has been selected deliberately since the intention is to develop a standard that is material-independent regarding the fibre material. However, the scientific basis for the Standard is predicated on numerous test results and literature references primarily devoted to steel fibre concrete and secondly, but to a much lesser degree, polymer fibre concrete. Despite the fact that the fibre concrete material properties and equations given are defined or derived from proposed fibre material-independent tests it is emphasized that the polymer fibres currently available in the market may either lead to very low values of strength, moment capacity and/or stiffness of the fibre concrete or mixes needing such high fibre amounts that they will be difficult to cast outside the laboratory.

1 General

1.1 Scope

This Standard applies to the design of buildings and other civil engineering works in concrete with steel fibres and or polymer fibres according to SS-EN 14889-1 and SS-EN 14889-2. The Standard does not cover glass, carbon, basalt or any other type of fibres.

This Standard is intended to be used in conjunction with SS-EN 1992-1-1 Eurocode 2: Design of structures – Part 1-1: General rules and rules for buildings.

NOTE SS 812310 is not a Eurocode.

The following subjects are dealt with in this Standard:

Section 1:	General
Section 2:	Basis of design
Section 3:	Materials
Section 5:	Structural analysis
Section 6:	Ultimate limit states (ULS)
Section 7:	Serviceability limit states (SLS)
Section 8:	Detailing of reinforcement and prestressing tendons - General
Section 11:	Lightweight aggregate concrete structures

Annex O:	Calculation of strains and stresses in bending
Annex P:	Production and conformity control of fibre concrete
Annex Q:	Execution control of fibre concrete
Annex R:	Expected Coefficient of Variation for beam tests according to SS-EN 14651
Annex S:	Fibre concrete, statically indeterminate structures, and magnification factors

1.2 Normative references

The following normative documents contain provisions which, through references in this text, constitute provisions of this Standard. For dated references, subsequent amendments to or revisions of any of these publications do not apply. However, parties to agreements based on this Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references the latest edition of the normative document referred to applies.

SS-EN 206:2013, *Concrete — Specification, performance, production and conformity*

SS-EN 14488-7, *Testing sprayed concrete — Part 7: Fibre content of fibre reinforced concrete*

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

SS-EN 14721, *Test method for metallic fibre concrete — Measuring the fibre content in fresh and hardened concrete*

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

SS-EN 14889-2, *Fibres for concrete — Part 2: Polymer fibres — Definitions, specifications and conformity*

SS-EN 1992-1-1:2005, *Eurocode 2: Design of concrete structures — Part 1-1: General rules and rules for buildings*

1.5 Definitions

1.5.2 Additional terms and definitions used in this Standard

1.5.2.5 Fibre concrete

Structural or non-structural concrete members in which the concrete matrix provides compressive strength and protection of the fibres, whereas the fibres provide tensile strength and ductility after cracking. For structural members the fibre has to fulfil the requirements in SS-EN 14889-1 (steel fibres) and SS-EN 14889-2 (polymer fibres).

1.5.2.6 Steel fibre

Straight or deformed pieces of cold-drawn steel wire, straight or deformed cut sheet fibres, melt extracted fibres, shaved cold drawn wire fibres and fibres milled from steel blocks which are suitable to be homogeneously mixed into concrete or mortar.

[SS-EN 14889-1 Section 3.1]

1.5.2.7 Polymer fibre

Straight or deformed pieces of extruded, oriented and cut material which are suitable to be homogeneously mixed into concrete or mortar.

[SS-EN 14889-2 Section 3.2]

1.5.2.8 Designed concrete

Concrete for which the required properties and additional characteristics if any are specified to the producer who is responsible for providing a concrete conforming to the required properties and additional characteristics.

[SS-EN 206 Section 3.1.1.4]

1.5.2.9 Prescribed concrete

Concrete for which the composition of the concrete and the constituent materials to be used are specified to the producer who is responsible for providing a concrete with the specified composition.

[SS-EN 206 Section 3.1.1.10]

1.6 Symbols

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

NOTE All other relevant symbols for comprehension of this standard can be found in SS-EN 1992-1-1.

Latin upper case letters

C_i	Residual strength factor
R_{ax}	Factor defining the degree of external axial restraint provided by elements attached to the element considered or by friction with the soil

Latin lower case letters

$f_{ct,L}^{f}$	Limit of proportionality as obtained from beam testing in accordance with SS-EN 14651
$f_{R,1}$	Characteristic residual flexural tensile strength of a fibre concrete of class R_1
$f_{R,3}$	Characteristic residual flexural tensile strength of a fibre concrete of class R_3
$f_{R,4}$	Characteristic residual flexural tensile strength of a fibre concrete of class R_4
$f_{R,1,i}$	Individual test results for residual flexural tensile strength of a fibre concrete of class R_1
$f_{R,3,i}$	Individual test results for residual flexural tensile strength of a fibre concrete of class R_3

$f_{R,1m}$	Mean residual flexural tensile strength of a fibre concrete of class R_1
$f_{R,3m}$	Mean residual flexural tensile strength of a fibre concrete of class R_3
$f_{ctk,0.05}$	Characteristic value of the tensile strength for the concrete matrix in accordance to the current codes
$f_{ft,R1}$	Characteristic residual tensile strength of a fibre concrete of class R_1
$f_{ft,R3}$	Characteristic residual tensile strength of a fibre concrete of class R_3
$f_{ftd,R1}$	Design residual tensile strength of a fibre concrete of class R_1
$f_{ftd,R3}$	Design residual tensile strength of a fibre concrete of class R_3
k_n	Statistical factor
k_f	Factor to consider the ratio between the residual tensile strength and the tensile strength
l_{cs}	Characteristic length
w_u	Ultimate crack opening

Greek lower case letters

γ_f	Partial factor for fibre concrete
η_f	Fibre orientation factor
η_{det}	Factor considering the degree of statically determination
ε_{ct}	Tensile cracking strain
ε_{ftu}	Ultimate tensile strain in fibre concrete
$\phi_{s,f}$	Modified reinforcement bar size for fibre reinforced concrete

2 Basis of design

2.3 Basic variables

2.3.2 Material and product properties

2.3.2.1 General

(3) Provisions for fibre reinforced concrete are given in Section 3.

(4) Structural components designed with this Standard shall have structural system stability (system equilibrium) in ultimate limit state after a fully developed crack system. This requires that one of the following conditions is fulfilled:

— stress redistribution is possible in a statically indeterminate system

— conventional steel bar reinforcement or pre-tensioned steel reinforcement in combination with fibre concrete is used

— external normal forces maintain equilibrium.

2.3.2.2 Shrinkage and creep

(4) For fibre concrete the effects of shrinkage and creep shall be considered at ultimate limit states according to;

(i) the theory of elasticity, where stresses caused by restrained shrinkage and creep, if any, have to be superposed to the stresses due to mechanical loading,

or

(ii) the theory of plasticity, where the strength has to be considered at an increased strain value considering the increased ductility demand that is caused by cracking due to shrinkage and creep. For concrete reinforced with only fibre, the design should be based on $f_{R,3}$ instead of $f_{R,1}$ or on $f_{R,4}$ instead of $f_{R,3}$.

In the (frequent) case where the fibre concrete member is subjected to flexure, the potential difference between compressive creep and flexural creep should be considered.

In cases where polymer fibres are used, creep properties should be evaluated through long-term tests. If the fibre concrete structure is to be subjected to elevated temperature, the long-term tests should be conducted under elevated temperature simulating the conditions that are likely to occur in reality.

NOTE Creep effects may, for example, be assessed as tensile creep where beam specimens used for testing flexural tensile strength are subjected to long term loading using the same load and support arrangements as in the flexural tensile strength test but with load levels equalling 50 % of the short term cracking load.

2.3.3 Deformations of concrete

(4) The effects of temperature and shrinkage shall either be considered as additional load effects or as increased ductility demands on the moment capacity. For fibre concrete structures, the effects of temperature and shrinkage are of great importance in cases where restraint is present. The reason is that fibre concrete elements usually have less ductility than corresponding conventionally reinforced concrete members.

2.4 Verification by the partial factor method

2.4.2 Design values

2.4.2.4 Partial factors for materials

(1)

NOTE SLS and partial factors for fibre concrete have been added to Table 2.1N in SS-EN 1992-1-1.

Table 2.1N — Partial factors for materials

Design situations	γ_C for concrete	γ_S for reinforcing steel	γ_S for prestressing steel	γ_f for fibre concrete
Persistent & Transient	1,5	1,15	1,15	1,5
Accidental	1,2	1,0	1,0	1,2
SLS	1,0	1,0	1,0	1,0

3 Materials

3.5 Fibre concrete

3.5.1 Residual flexural tensile strength classes

(1) The residual flexural tensile strength of fibre concrete is denoted by residual flexural tensile strength classes, (R-classes) which relate to the characteristic residual flexural tensile strength, $f_{R,i}$, determined from beam testing in accordance to SS-EN 14651 at an age of 28 days.

(2) The residual flexural tensile strength classes (R-classes) are provided in Table 3.1. Class R_1 is required for SLS design while ULS design generally requires that both classes (R_1 and R_3) are specified. A simplified design approach in ULS may however be based on class R_3 alone, see Figure 3.2.

Table 3.1 — Residual flexural tensile strength classes (R-classes) for fibre concrete

Class R_1	$f_{R,1}$ (MPa)	Class R_3	$f_{R,3}$ (MPa)	Class R_4	$f_{R,4}$ (MPa)
$R_1$1	1,0	$R_3$1	1,0	$R_4$1	1,0
$R_1$2	2,0	$R_3$2	2,0	$R_4$2	2,0
$R_1$3	3,0	$R_3$3	3,0	$R_4$3	3,0
$R_1$4	4,0	$R_3$4	4,0	$R_4$4	4,0
$R_1$5	5,0	$R_3$5	5,0	$R_4$5	5,0
$R_1$6	6,0	$R_3$6	6,0	$R_4$6	6,0

Note 1 Residual flexural tensile strength is the characteristic value obtained from beam testing in accordance to SS-EN 14651 at a CMOD (crack mouth opening displacement) of 0,5; 2,5 and 3,5 mm respectively for $f_{R,1}$, $f_{R,3}$ and $f_{R,4}$, see Figure 3.1.

Note 2 Higher residual flexural tensile strength than given in the table may be utilised if the specified value is verified by test results according to SS-EN 14651.

Note 3 The following conditions must be satisfied: $C_1 = 100 \cdot f_{R,1}/f_{ctk,0.05} \geq 50$ % and $100 \cdot f_{R,3}/f_{R,1} \geq 50$ %. The intention is to ensure a certain minimum ductility of the fibre concrete.

Note 4 In most cases $f_{R,1}$ is higher than or equal to $f_{R,3}$ and $f_{R,1}$ is lower than $f_{ct,L}^{f}$, so called bending softening behaviour, see Figure 3.1.

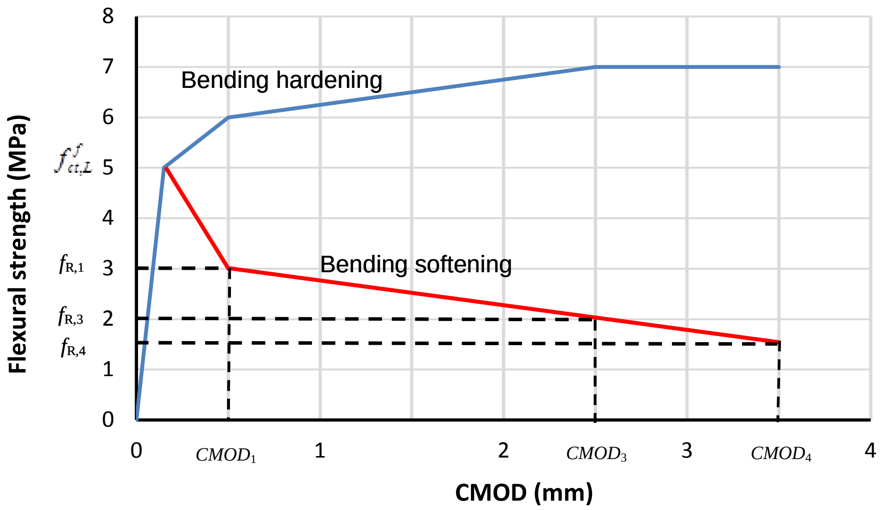

Figure 3.1 — Schematic behaviour from beam testing in accordance to SS-EN 14651.

(3) Following the classification described above a fibre concrete can be specified as the following example:

C30/37-$R_1$3/$R_3$2

This corresponds to a concrete of compressive strength of 30 MPa (cylinder) or 37 MPa (cube) and a residual flexural tensile strength of 3,0 MPa and 2,0 MPa in class R_1 and R_3 respectively (see Figure 3.1).

The structural engineer also has the possibility of specifying a value for class R_3 alone, if a simplified analysis in the ULS is sufficient. This results in the following specification, e.g. C30/37-$R_3$2. Likewise it is possible to specify class R_1 only if ULS design is not required, e.g. C30/37-$R_1$2.