NATIONAL BUILDING CODE OF FINLAND

Strength and stability of structures

Composite steel and concrete structures

Ympäristöministeriö
Miljöministeriet
Ministry of the Environment

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Foreword

The Ministry of the Environment publishes the recommendations for strength and stability related to the design of composite steel and concrete structures in the National Building Code of Finland. The instruction contains a compilation of all the National Annexes concerning the design of composite steel and concrete structures.

The beginning of each National Annex presents those clauses in the standard where national choice is permitted, and where such a choice has been made.

Helsinki, 20 December 2016

Head of the Buildings and Construction unit
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Contents

1. Scope

These instructions provide additional information when applying the Ministry of Environment Decree on load-bearing structures in the design and execution of composite steel and concrete structures. A solution pursuant to these instructions is considered to meet the requirements set for load-bearing structures.

These instructions are applied when composite steel and concrete structures are designed pursuant to standards SFS-EN 1994 and their Finnish national annexes, and executed pursuant to standards SFS-EN 13670, SFS 5975 and SFS-EN 1090-2.

For precast concrete elements manufactured pursuant to harmonised European product standards, the supplementary rules concerning design and manufacture presented in the product standards are followed.

2. Design of structures

2.1 Execution documents

Standards SFS-EN 13670, SFS 5975 and SFS-EN 1090-2 provide instructions on the preparation of the execution documents and the execution specification for composite steel and concrete structures.

Usually, the execution documents include, at a minimum, the following:

- construction drawings
- requirements pursuant to standards SFS-EN 13670, SFS 5975 and SFS-EN 1090-2, such as the execution classes and tolerance classes
- if necessary, steelwork not covered by SFS-EN 1090-2 (such as the fire protection work for the steel structure).
- other documents to be adhered to or references to other documents.

2.2 Contents of the structural designs

Usually, the structural designs for composite steel and concrete structures present, at a minimum, the following to the extent applicable to the design task:

a) consequences class
b) exposure classes and the planned service life of the structure
c) the R/E/I/M fire resistance class for the structural components
d) the adopted characteristic loads and load class

e) complete information on the dimensions and location of the structures
f) execution class
g) tolerances/tolerance class
h) as regards concrete and reinforcement, the matters presented in the concrete structures part of the National Building Code of Finland
i) as regards steel parts, the matters presented in the steel structures part of the National Building Code of Finland
j) the necessary casting holes and water, steam and air removal holes
k) support for reinforcements used inside the steel parts
l) supports used during construction and their removal, taking into account the prerequisites for the creation of a composite steel and concrete structure.

The following are also presented for factory-made construction components (included in manufacturing or installation drawings):
m) the information required for the assessment of the suitability and design
n) the CE labelling method adopted for the prefabricated elements and fabricated steel products (M1, M2, M3a or M3b)
o) the weight and centroid location for the structural component
p) the minimum support surfaces
q) lifting eyes and their placement
r) handling, support and lifting instructions if necessary.

The tolerances to be used are determined for each project. In composite steel and concrete structures, it is possible to use tolerance class 2 pursuant to standard SFS-EN 13670 for the concrete structures and partial factors reduced according to the manner presented in standard SFS-EN 1992. In this case, it should be ensured that all the prerequisites related to their use are met.

Normally, the tolerances presented in standard SFS-EN 1090-2 are applied to deviations in terms of frame location and the cross-sections of composite construction beams and columns. As regards the concrete parts of composite constructions, the tolerances presented in standard SFS-EN 13670 and its national application standard SFS 5975.

The thickness of the concrete cover on the reinforcements is determined from the outer surface of the concrete cross-section. The thickness of the steel part is not considered.

The supporting of the steel parts, such as the reinforcement used inside composite columns, is done by means of fastening welds or by using sufficiently robust spacers or a similar approach that results in the reinforcement concrete cover values being implemented in the completed structures. This applies to both factory and worksite manufacture.

2.3 Execution classes

The execution class is selected on the basis of standard SFS-EN 1990 and the consequences classes (CC1, CC2 and CC3) and risk factors related to the implementation. In composite steel and concrete structures, the execution classes for steel parts are determined according to the steel structures section of the National Building Code of Finland, whereas the execution classes for concrete parts are determined according to the concrete parts section.

There is no one single execution class for composite constructions; instead, the execution class of a composite steel and concrete structure is determined separately for both concrete and steel. The requirements for the steel structure execution classes are presented in standard SFS-EN 1090-2. The requirements for the concrete structure execution classes are presented in standards SFS-EN 13670 and SFS 5975.

2.4 Durability and design working life

In order to achieve the planned service life of composite steel and concrete structures, the section of the National Building Code of Finland on concrete parts is applied to the concrete parts and concrete reinforcement, and the section on steel parts is applied to the steel parts.

The exposure classes for concrete parts are selected according to standard SFS-EN 206, and the environmental exposure classes are selected according to standard SFS-EN ISO 12944-2.

3. Execution

3.1 Execution planning

The work plans for the execution of composite steel and concrete structures are drawn up on the basis of the execution documents in adherence with standards SFS-EN 13670, SFS 5975 and SFS-EN 1090-2.

Usually, the work plans for the execution of composite steel and concrete structures present, at a minimum, the following to the extent applicable to the design task:

- the required execution drawings
- work phase plans pursuant to standards SFS-EN 13670, SFS 5975 and SFS-EN 1090-2 as required by the execution documents
- quality documents pursuant to standards SFS-EN 1090-2 and SFS-EN 13670 and the latter's supplementary standard SFS 5975.

As regards concrete structures, a separate concreting plan is drawn up for the execution of structures in execution classes 2 and 3.

An installation plan is drawn up concerning the installation of fabricated structural members and elements.

3.2 Construction products

The characteristics of the building products, materials and supplies used in composite steel and concrete structures are demonstrated by means of the CE label if they are covered by the scope of the harmonised product standard or if the manufacturer has acquired the European Technical Approval/Assessment for its product. Otherwise, they are demonstrated according to the Act on the Type Approval of Certain Construction Products (954/2012).

The characteristics of the materials and supplies presented in clauses 3.2 of the concrete structures and steel structures sections of the National Building Code of Finland are central in terms of the reliability of composite steel and concrete structures. In addition to these, key products in terms of reliability include the following:

- composite slabs
- composite beams
- joint components that are used for the composite effect.

4. Execution supervision and the suitability of structures

4.1 Execution supervision

The inspections related to the supervision of the execution of concrete structures are drawn up within the scope required by the execution documents, while applying standards SFS-EN 13670, SFS 5975 and SFS-EN 1090-2.

During the execution of the structures, the responsible work supervisor or a separately appointed specialist work supervisor will supervise that the plans and instructions concerning the manufacture of composite steel and concrete structures and the installation of the steel/concrete elements are followed and that the appropriate documents are prepared for the work.

If it is observed during the execution that a structure or detail does not meet the requirements laid down in the plans and execution documents, the occurrence locations and causes of the deviations are analysed. In this case, it is determined whether the deviation can be approved without a repair. If necessary, calculations are used to demonstrate that the reliability level required by standards SFS-EN 1994 and their National Annexes is achieved. If it cannot be demonstrated that the deviation is acceptable without a repair, the repair will be carried out to the necessary extent. The deviation and corrective action will be recorded in the quality control documents.

The quality control material is documented and compiled into a single entity.

4.2 Conformity of structures

When applying these instructions, the suitability appraisal for structures is based on the composite steel and concrete structures being designed appropriately pursuant to standards SFS-EN 1994 and their national annexes, and on the composite steel and concrete structures being executed and inspected pursuant to the execution documents.

5. References

If the version of a reference has not been specified, the latest edition of the reference (with amendments) is applied.

SFS-EN 206	Concrete. Specification, performance, production and conformity
SFS-EN 1090-2	Execution of steel structures and aluminium structures – Part 2: Technical requirements for steel structures
SFS-EN 1990	Eurocode. Basis of structural design
SFS-EN 1994-1-1	Eurocode 4: Design of composite steel and concrete structures. Part 1-1: General rules and rules for buildings
SFS-EN 1994-1-2	Eurocode 4: Design of composite steel and concrete structures. Part 1-2: General rules. Structural fire design
SFS-EN ISO 12944-2	Paints and varnishes. Corrosion protection of steel structures by protective paint systems. Part 2: Classification of environments
SFS-EN 13670	Execution of concrete structures
SFS 5975	Execution of concrete structures. Use of standard SFS-EN 13670 in Finland

6. National annexes to Eurocodes SFS-EN 1994

National Annex to standard SFS-EN 1994-1-1 Part 1-1: General rules and rules for buildings

As regards standard SFS-EN 1994-1-1, the recommended values set forth in standard SFS-EN 1994-1-1 and all the annexes to standard SFS-EN 1994-1-1 are followed unless otherwise stated in this National Annex.

The Non-Contradictory Complementary Information (NCCI) is presented in italics.

National choice is permitted in the following clauses of standard SFS-EN 1994-1-1:
– 2.4.1.1(1)
– 2.4.1.2(5)P
– 2.4.1.2(6)P
– 2.4.1.2(7)P
– 3.1(4)
– 3.5(2)
● 6.4.3(1)h
– 6.6.3.1(1)
● 6.6.3.1(3)
– 6.6.4.1(3)
– 6.8.2(1)
– 6.8.2(2)
● 9.1.1(2)P
– 9.6(2)
– 9.7.3(4), Note 1
– 9.7.3(8), Note 1
● 9.7.3(9)
– B.2.5(1)
– B.3.6(5).

A national choice has been made in the clauses marked ●.

Indirect demonstration of lateral torsional buckling resistance in building beams

6.4.3(1)(h)
The Table 6.1 concerning IPE and HE profiles may also be used for similar welded profiles. Profiles where $I_{f,z,w}/I_{f,z,hr} \geq 0.9$ and $0.95 \leq h_w/h_{hr} \leq 1.05$ are considered similar to rolled profiles. $I_{f,z,w}$ is the transverse second moment of area of the flange in a welded

profile and $I_{f,z,hr}$ is the transverse second moment of area of the flange in a rolled an IPE or HE profile. Respectively, h_w is the height of the welded profile and h_{hr} is the height of the rolled IPE or HE profile. $I_{f,z} = b^3 t_f/12$, when using the notation from Figure 1.1 of SFS-EN 1993-1-1.

Design resistance

6.6.3.1(3)

Where studs are arranged in a way such that splitting forces occur in the direction of the slab thickness, the design resistance of the studs is determined on the basis of shear tests in accordance with section B.2 of Annex B to SFS-EN 1994-1-1.

Deflections

7.3.1

Deflections are calculated according to clause 7.3.1 of SFS-EN 1994-1-1 and they need to be below the limits stated in Table 1. The table presents the recommended maximum values for final deflections and displacements caused by characteristic loads in statically loaded composite constructions, unless other limits are more suitable due to the type or intended purpose of the structure or the nature of the activity.

Table 1. Maximum values for the deflections and displacement of composite constructions at the serviceability limit state

$w_{max} = w_i + w_{lt} + w_{st} - w_c$ *Deflection is calculated from the characteristic load combination according to expression (6.14) in SFS-EN 1990* with expressions (1.1) and (1.2)		
Recommended deflection limits for	w_{max}	$w_{lt} + w_{st}$
Beams and slabs in roofs	*L/200*	*L/250*
Beams and slabs in floors, normal	*L/250*	*L/300*
Beams and slabs in floors that support columns	*L/400*	*L/500*
Deflections of structures supporting easily cracking walls after wall installation	*L/400*	*L/500*
Horizontal displacement of a structure *- Buildings of up to 2 storeys* *- Other buildings*	*H/150* *H/400*	

where:

L	*is the span width of the structure*
H	*is the height of the building in the section considered*
w_c	*is the pre-camber of steel member*
w_i	*is the long-term deflection caused by the own weight of the structure*
w_{lt}	*is the long-term deflection caused by the quasi-permanent share of variable actions*

w_{st} *is the immediate and reversible deflection caused by the short-term share of actions*

Bending w_{lt} is calculated from the actions

$$Q_{lt} = Q_{k,lt,1} + \sum_{i>1} \psi_{0,i} Q_{k,lt,i} \quad (1.1)$$

where:

$Q_{k,lt,1}$ *is the long-term part of the dominant variable action*

$Q_{k,lt,i}$ *is the long-term part of the simultaneous other variable actions.*

Bending w_{lt} is calculated from the short-term variable actions

$$Q_{st} = \sum_{i \geq 1} \psi_{1,i} Q_{k,st,i} \quad (1.2)$$

where:

$Q_{k,st,1}$ *is the short-term part of the dominant variable action*

$Q_{k,st,i}$ *is the short-term part of the simultaneous other variable actions.*

For composite constructions, a pre-camber is required that eliminates at least the bending w_i.

Scope

9.1.1(2)P

The upper limit for the ratio defining the narrowly spaced webs, b_r/b_s is 0.6. Figure 9.2 of standard SFS-EN 1991-1-1 contains additional clarifying instructions.

When the vertical sides of the rib are shaped, the maximum rib width b_r is used.

Longitudinal joint shear for slabs without end anchorage

9.7.3(9)

In expression (9.8) of the standard, the resultant N_c can be increased by μR_{Ed} provided that $\tau_{u,Rd}$ is specified by taking into account the appropriate longitudinal shear resistance caused by the supporting reaction. The factor μ is 0.5, provided the product specification for the composite sheeting reliably indicates that the additional resistance caused by the supporting reactions has been taken into account, and μ is 0 in other cases.

National Annex to standard SFS-EN 1994-1-2 Part 1-2: General rules. Structural fire design

As regards standard SFS-EN 1994-1-2, the recommended values set forth in standard SFS-EN 1994-1-2 and all the annexes to standard SFS-EN 1994-1-2 are followed unless otherwise stated in this National Annex.

The Non-Contradictory Complementary Information (NCCI) is presented in italics.

National choice is permitted in the following clauses of standard SFS-EN 1994-1-2:

- • 1.1(16)
- • 2.1.3(2)
- – 2.3(1)P, Note 1
- – 2.3(2)P, Note 1
- • 2.4.2(3), Note 2
- • 3.3.2(9), Note 1
- • 4.1(1)P
- • 4.3.5.1(10), Note 1.

A national choice has been made in the clauses marked ●.

Scope

1.1(16)
When designing in accordance with standard SFS-EN 1994-1-2, the highest strength class of concrete is C50/60.

Parametric fire exposure

2.1.3(2)
No values are given for the average temperature rise $\Delta\theta_1$ and for the maximum temperature rise $\Delta\theta_2$ during the cooling phase of fire.

The requirement for the separation function is only based on a standard fire and on temperature limits set by it.

The fire safety requirement is also deemed to be satisfied if the building is designed and executed based on design fire scenarios which cover the situations likely to occur in the said building. The satisfaction of the requirement is attested case-by-case taking into consideration the properties and use of the building.

Member analysis

2.4.2(3), Note 1

When using the partial factors from standard SFS-EN 1990 and the Ministry of Environment Decree 3/16 concerning its application, Figure 2.1 in standard SFS-EN 1992-1-2 will change as presented in Figure 1.

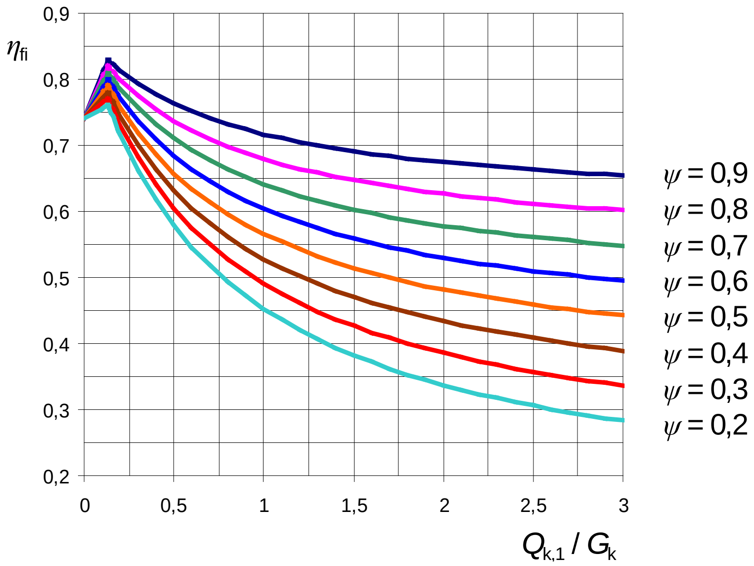

Figure 1. *The variation of the reduction factor η_{fi} as a function of the load ratio of the nominal values of dominant variable action and permanent action $Q_{k,1} / G_k$ according to the load combination rules presented in the Ministry of Environment Decree 3/16 concerning the application of standard SFS-EN 1990.*

2.4.2(3), Note 2

Approximate values are not used.

Normal weight concrete

3.3.2(9), Note 1

An upper limit value in accordance with expression (3.6a) in Standard SFS-EN 1994-1-2 is used for the thermal conductivity λ_c of normal weight concrete.

Introduction

4.1(1)P

Advanced calculation methods may be used in Finland. Their validity is verified in accordance with clause 4.4.4.

Structural behaviour

4.3.5.1(10), Note 1
The values *0.5* and *0.7* times the system length *L* are used for the buckling lengths L_{ei} and L_{et}.

Annex H
A simple calculation model for concrete filled hollow sections exposed to fire all around the column according to the standard temperature-time curve

Annex H is not used.

Instead of Annex H, the document NCCI 1 that follows this National Annex may be used.

NCCI 1 for standard SFS-EN 1994-1-2: Structural fire design of concrete filled steel hollow section columns

Area of application for the method

The simple design method set out in this document may be used for the fire design of concrete filled steel hollow section columns; its principles are pursuant to clause 4.3.5.1 of SFS-EN 1994-1-2. The method concerns columns exposed to standard fire exposure on each side in the same way. The simple method described below is only used when designing columns in laterally braced frames. The column's modified slenderness $\bar{\lambda}$ *(SFS-EN 1994-1-1, clause 6.7.3.3(2)) may be at most 2. The wall thickness of the column's steel tube must meet the slenderness criterion demonstrated in Table 6.3 of SFS-EN 1994-1-1.*

Method description

The method is based on the use of design temperatures for the column's material parts, steel profile, its concrete filling and related reinforcement, which are used to determine the compression strength $N_{fi.pl.Rd}$ *for the column cross-section and the effective bending stiffness* $(EI)_{fi.eff}$ *for the column.*

The steel profile design temperatures $\theta_{a.30}$, $\theta_{a.60}$, $\theta_{a.90}$ *and* $\theta_{a.120}$ *are presented as average temperatures in Tables 1 and 2 corresponding to standard fire R30, R60, R90 and R120.*

The concrete fill design temperatures are presented as equivalent temperatures $\theta_{c.equ.30}$, $\theta_{c.equ.60}$, $\theta_{c.equ.90}$ *and* $\theta_{c.equ.120}$ *in expressions (1.1) and (1.2), corresponding to standard fire R30, R60, R90 and R120.*

The temperatures for the reinforcement contained in the concrete fill, θ_s, *are presented in Tables 3a–5b corresponding to standard fire R30, R60, R90 and R120. In the case of square columns, the temperatures* θ_{sc} *for the corner bars of the cross-section (Tables 4a and 4b) and* θ_{sm} *for the side centre bars (Tables 5a and 5b) are presented separately. In round columns, each rod is assumed to be at the same temperature (Tables 3a and 3b).*

The effective bending stiffness $(EI)_{fi.eff}$ *used for a column exposed to fire is the bending stiffness defined with the reduction coefficients* $\varphi_{a.\theta}$, $\varphi_{s.\theta}$ *and* $\varphi_{c.\theta}$. *The reduction factors and design temperatures related to this method are method-specific values that are used together in order to achieve acceptable correlation with the results from the col-*

umn fire exposure tests. The values for the reduction factors are given in Tables 8a and 8b.

The compression resistance $N_{fi.Rd}$ for an axially loaded column during a fire is always calculated by using the buckling curve c in clause 6.3.1 of SFS-EN 1993-1-1. The effective length of the column exposed to fire may differ from the effective length of a similar column at normal temperature. The rules concerning this are given in Table 9.

The compression resistance $N_{fi.Rd.\delta}$ for an eccentrically loaded column is calculated as a function of eccentricity e_{fi} from expressions (1.9) and (2.0), by first defining the bending resistance $M_{fi.pl.Rd}$ and axial compression resistance $N_{fi.Rd}$ for the column.

Design temperatures

The design temperature for the pipe profile of a column cross-section is calculated as a function of the cross-section's outer diameter D or side dimension b by applying Tables 1 and 2.

Table 1. Average temperature θ_a °C for round pipe profiles as a function of outer diameter D

Standard fire	*R30*	*R60*	*R90*	*R120*
$\theta_a(D)$	$620 + 95\times\left(\frac{510-D}{370}\right)^{0,8}$	$820+ 4,18\sqrt{510-D}$	$955+ 20\times\left(\frac{510-D}{290}\right)^{1,5}$	*1015*
Limiting conditions	*$135 \le D \le 510$*	*$165 \le D \le 510$*	*$200 \le D \le 510$*	*$270 \le D \le 510$*

Table 2. Average temperature θ_a °C for square pipe profiles as a function of outside dimension b

Standard fire	*R30*	*R60*	*R90*	*R120*
$\theta_a(b)$	$650+ 45\times\sqrt{\frac{400-b}{280}}$	$860+ 30\times\sqrt{\frac{400-b}{350}}$	$970+ 5\times\left(\frac{400-b}{200}\right)^{1,5}$	*1025*
Limiting conditions	*$120 \le b \le 400$*	*$150 \le b \le 400$*	*$200 \le b \le 400$*	*$250 \le b \le 400$*
When b > 400, the temperatures corresponding to dimension b = 400 are used				

For round columns, the equivalent temperature of the concrete cross-section is calculated as a function of the pipe's outer diameter D with the expressions:

$$\begin{cases} \theta_{c.equ.30}(D)=11000/D^{0,64} \text{ kun } 135 \leq D510 \\ \theta_{c.equ.60}(D)=16300/D^{0,66} \text{ kun } 165 \leq D \leq 510 \\ \theta_{c.equ.90}(D)=13100/D^{0,58} \text{ kun } 200 \leq D \leq 510 \\ \theta_{c.equ.120}(D)=1180-2,96D+0,0028D^{2} \text{ kun } 220 \leq D \leq 510 \end{cases} \qquad (1.1)$$

For square columns, the equivalent temperature of the concrete cross-section is calculated as a function of the pipe's outside dimension b with the expressions:

$$\begin{cases} \theta_{c.equ.30}(b)=779-2,6754b+0,0032b^{2} \text{ kun } 120 \leq b \leq 400 \\ \theta_{c.equ.60}(b)=21572/b^{0,69} \text{ kun } 150 \leq b \leq 400 \\ \theta_{c.equ.90}(b)=1366-4,513b+0,0054b^{2} \text{ kun } 200 \leq b \leq 400 \\ \theta_{c.equ.120}(b)=1496-4,643b+0,0053b^{2} \text{ kun } 250 \leq b \leq 400 \end{cases} \qquad (1.2)$$

In the case of round cross-sections, the temperatures of the reinforcement bars in the concrete cross-section are determined according to Tables 3a and 3b. The temperatures of the corner bars of square columns are determined according to Tables 4a and 4b, and the temperatures of the bars in the centres of the sides are determined according to Tables 5a and 5b.

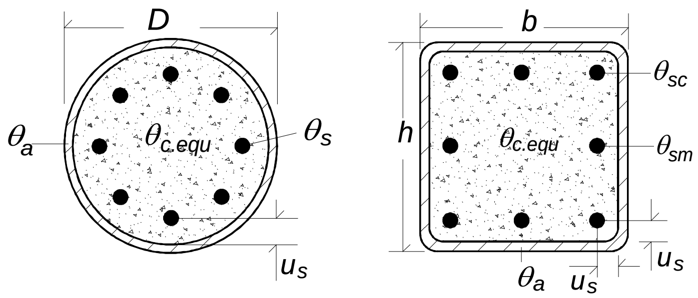

Figure 1. *Design temperatures θ_a, $\theta_{c.equ}$ and θ_s (round columns), θ_{sc} and θ_{sm} (square columns)*

Table 3a. Reinforcement temperatures θ_s °C in round composite columns in the case of standard fires R30 and R60

	R30 standard fire					*R60 standard fire*				
	Steel profile diameter, D [mm]					*Steel profile diameter, D [mm]*				
u_s [mm]	*140*	*200*	*250*	*350*	*500*	*140*	*200*	*250*	*350*	*500*
20	*370*	*335*	*320*	*310*	*310*	*645*	*570*	*540*	*520*	*520*
30	*307*	*260*	*245*	*232*	*232*	*592*	*487*	*455*	*427*	*427*
40	*245*	*185*	*170*	*155*	*155*	*540*	*405*	*370*	*335*	*335*
50	*217*	*142*	*132*	*120*	*120*	*515*	*357*	*312*	*277*	*270*
60	*190*	*100*	*95*	*85*	*85*	*490*	*310*	*255*	*220*	*205*
80	*-*	*80*	*65*	*55*	*55*	*-*	*265*	*185*	*140*	*130*
110	*-*	*-*	*35*	*35*	*35*	*-*	*-*	*120*	*85*	*75*

Table 3b. Reinforcement temperatures θ_s °C in round composite columns in the case of standard fires R90 and R120

	R90 standard fire					*R120 standard fire*				
	Steel profile diameter, D [mm]					*Steel profile diameter, D [mm]*				
u_s [mm]	*140*	*200*	*250*	*350*	*500*	*140*	*200*	*250*	*350*	*500*
20	*815*	*715*	*680*	*650*	*635*	*920*	*820*	*780*	*745*	*715*
30	*772*	*645*	*597*	*560*	*537*	*890*	*760*	*705*	*655*	*622*
40	*730*	*575*	*515*	*470*	*440*	*860*	*700*	*630*	*565*	*530*
50	*710*	*537*	*457*	*407*	*372*	*845*	*660*	*580*	*497*	*462*
60	*690*	*500*	*400*	*345*	*305*	*830*	*620*	*530*	*430*	*395*
80	*-*	*100*	*330*	*250*	*210*	*-*	*575*	*460*	*335*	*295*
110	*-*	*-*	*250*	*150*	*115*	*-*	*-*	*385*	*235*	*190*

Table 4a. Reinforcement temperatures θ_{sc} °C in the corner bars of square composite columns in the case of standard fires R30 and R60

	R30 standard fire					*R60 standard fire*				
	Steel profile side dimension, b [mm]					*Steel profile side dimension, b [mm]*				
u_s [mm]	*140*	*180*	*220*	*300*	*500*	*140*	*180*	*220*	*300*	*500*
20	*395*	*390*	*385*	*385*	*385*	*660*	*640*	*630*	*625*	*625*
30	*302*	*290*	*287*	*287*	*287*	*575*	*537*	*522*	*517*	*517*
40	*210*	*190*	*190*	*190*	*190*	*490*	*435*	*415*	*410*	*410*
50	*167*	*142*	*142*	*142*	*142*	*465*	*372*	*345*	*332*	*332*
60	*125*	*95*	*95*	*95*	*95*	*440*	*310*	*275*	*255*	*255*
80	*-*	*75*	*65*	*55*	*55*	*-*	*270*	*180*	*150*	*150*
110	*-*	*-*	*30*	*30*	*30*	*-*	*-*	*100*	*75*	*75*

Table 4b. Reinforcement temperatures θ_{sc} °C in the corner bars of square composite columns in the case of standard fires R90 and R120

	R90 standard fire					*R120 standard fire*				
	Steel profile side dimension, b [mm]					*Steel profile side dimension, b [mm]*				
u_s [mm]	*140*	*180*	*220*	*300*	*500*	*140*	*180*	*220*	*300*	*500*
20	*820*	*780*	*765*	*765*	*765*	*915*	*875*	*855*	*855*	*855*
30	*755*	*690*	*667*	*662*	*662*	*872*	*802*	*767*	*760*	*760*
40	*690*	*600*	*570*	*560*	*560*	*830*	*730*	*680*	*665*	*665*
50	*672*	*547*	*497*	*472*	*472*	*810*	*685*	*610*	*577*	*577*
60	*655*	*495*	*425*	*385*	*385*	*790*	*640*	*540*	*490*	*490*
80	*-*	*445*	*335*	*270*	*270*	*-*	*575*	*475*	*365*	*365*
110	*-*	*-*	*230*	*155*	*145*	*-*	*-*	*415*	*250*	*215*

Table 5a. Reinforcement temperatures θ_{sm} °C in the centre bars of square composite columns in the case of standard fires R30 and R60

	R30 standard fire					*R60 standard fire*				
	Steel profile side dimension, b [mm]					*Steel profile side dimension, b [mm]*				
u_s [mm]	*140*	*180*	*220*	*300*	*500*	*140*	*180*	*220*	*300*	*500*
20	*285*	*250*	*240*	*235*	*235*	*560*	*480*	*445*	*415*	*410*
30	*230*	*192*	*180*	*175*	*175*	*517*	*412*	*355*	*337*	*332*
40	*175*	*135*	*120*	*115*	*115*	*475*	*345*	*265*	*260*	*255*
50	*155*	*115*	*97*	*92*	*90*	*410*	*320*	*240*	*210*	*207*
60	*135*	*95*	*75*	*70*	*65*	*450*	*295*	*215*	*160*	*160*
80	*-*	*65*	*50*	*40*	*40*	*-*	*215*	*165*	*105*	*100*
110	*-*	*-*	*30*	*30*	*30*	*-*	*-*	*130*	*80*	*60*

Table 5b. Reinforcement temperatures θ_{sm} °C in the centre bars of square composite columns in the case of standard fires R90 and R120

	R90 standard fire					*R120 standard fire*				
	Steel profile side dimension, b [mm]					*Steel profile side dimension, b [mm]*				
u_s [mm]	*140*	*180*	*220*	*300*	*500*	*140*	*180*	*220*	*300*	*500*
20	*740*	*650*	*495*	*535*	*535*	*870*	*770*	*715*	*625*	*615*
30	*710*	*592*	*475*	*455*	*450*	*842*	*722*	*650*	*550*	*532*
40	*680*	*535*	*455*	*375*	*365*	*815*	*675*	*585*	*475*	*450*
50	*667*	*507*	*412*	*322*	*305*	*802*	*647*	*545*	*420*	*390*
60	*655*	*480*	*370*	*270*	*245*	*790*	*620*	*505*	*365*	*330*
80	*-*	*450*	*330*	*195*	*170*	*-*	*600*	*465*	*300*	*250*
110	*-*	*-*	*245*	*135*	*100*	*-*	*-*	*395*	*240*	*160*

Calculating compression resistance and effective bending resistance in a cross-section

The compression resistance for a column cross-section during a fire, pursuant to clause 4.3.5.1(4) of SFS-EN 1994-1-2, is calculated from the expressions (1.3a) - (1.3d):

$$N_{fi.pl.Rd} = N_{fi.a.Rd} + N_{fi.s.Rd} + N_{fi.c.Rd} \tag{1.3a}$$

$$N_{fi.a.Rd} = k_{y.\theta}(\theta_a) f_y A_a / \gamma_{M.fi.a} \tag{1.3b}$$

$$N_{fi.s.Rd} = k_{s.\theta}(\theta_s) f_{sk} A_s / \gamma_{M.fi.s} \tag{1.3c}$$

$$N_{fi.c.Rd} = k_{c.\theta}(\theta_{c.equ}) f_{ck} A_c / \gamma_{M.fi.c} \tag{1.3d}$$

The effective bending stiffness for a column cross-section during a fire, pursuant to clause 4.3.5.1(5) of SFS-EN 1994-1-2, is calculated from the expressions (1.4a) - (1.4d):

$$(EI)_{fi.eff} = \varphi_{a.\theta}(EI)_{a.\theta} + \varphi_{s.\theta}(EI)_{s.\theta} + \varphi_{c.\theta}(EI)_{c.\theta} \tag{1.4a}$$

$$(EI)_{a.\theta} = k_{Ea.\theta}(\theta_a) E_a I_a \tag{1.4b}$$

$$(EI)_{s.\theta} = k_{Ea.\theta}(\theta_s) E_a I_s \tag{1.4c}$$

$$(EI)_{c.\theta} = E_{c.sec.\theta}(\theta_{c.equ}) I_c = \frac{f_{c.\theta}(\theta_{c.equ})}{\varepsilon_{c1.\theta}(\theta_{c.equ})} I_c = k_{Ec.\theta}(\theta_{c.equ}) \frac{f_{ck}}{\varepsilon_{c1}} I_c \tag{1.4d}$$

In the expressions, $(EI)_{a.\theta}$, $(EI)_{s.\theta}$ and $(EI)_{c.\theta}$ are the nominal bending stiffness values of the steel cross-section, reinforcement and concrete cross-section, and I_a, I_s and I_c are the second moments of area for the cross-section parts. The reduction factors for the mechanical properties of steel materials are pursuant to Table 6 and the reduction factors of the mechanical properties of concrete are pursuant to Table 7.

The values for the adjustment coefficients $\varphi_{a.\theta}$ are given in Table 8 and the values for adjustment coefficients $\varphi_{s.\theta}$ are given in Table 9. Coefficient $\varphi_{c.\theta} = 1.2$ in all cases.

Table 6. Reduction factors for the mechanical properties of steel materials pursuant to SFS-EN 1994-1-2 and SFS-EN 1992-1-2

Temperature	*Structural steel and hot rolled reinforcement rods*		*Cold formed reinforcement rods*	
θ_a, θ_s	$k_{Ea.\theta}$, $k_{Es.\theta}$	$k_{y.\theta}$, $k_{s.\theta}$	$k_{Es.\theta}$	$k_{s.\theta}$
20	*1*	*1*	*1*	*1*
100	*1*	*1*	*1*	*1*
200	*0.9*	*1*	*0.87*	*1*
300	*0.8*	*1*	*0.72*	*1*
400	*0.7*	*1*	*0.56*	*0.94*
500	*0.6*	*0.78*	*0.4*	*0.67*
600	*0.31*	*0.47*	*0.24*	*0.4*
700	*0.13*	*0.23*	*0.08*	*0.12*
800	*0.09*	*0.11*	*0.06*	*0.11*
900	*0.0675*	*0.06*	*0.05*	*0.08*
1000	*0.045*	*0.04*	*0.03*	*0.05*
1100	*0.0225*	*0.02*	*0.02*	*0.03*
1200	*0*	*0*	*0*	*0*
	$k_{Ea.\theta} = \frac{E_{a.\theta}}{E_a}$, $k_{Es.\theta} = \frac{E_{s.\theta}}{E_s}$; $k_{y.\theta} = \frac{f_{ay.\theta}}{f_y}$, $k_{s.\theta} = \frac{f_{sy.\theta}}{f_{sk}}$		$k_{Es.\theta} = \frac{E_{s.\theta}}{E_s}$, $k_{s.\theta} = \frac{f_{sy.\theta}}{f_{sk}}$	

Table 7. Reduction factors for the material properties of concrete pursuant to SFS-EN 1992-1-2

θ_c	$k_{c.\theta}$	$k_{\varepsilon.\theta}$	$k_{\varepsilon u.\theta}$	$k_{Ec} = k_{c.\theta}/k_{\varepsilon.\theta}$
20	1	1	1	1
100	1	1.6	1.125	0.625
200	0.95	2.2	1.250	0.432
300	0.85	2.8	1.375	0.304
400	0.75	4	1.500	0.188
500	0.6	6	1.635	0.100
600	0.45	10	1.750	0.045
700	0.3	10	1.875	0.03
800	0.15	10	2.000	0.015
900	0.08	10	2.125	0.008
1000	0.04	10	2.250	0.004
1100	0.01	10	2.375	0.001
1200	0	-	-	0

$$k_{c.\theta}=\frac{f_{c.\theta}}{f_{ck}};\ k_{\varepsilon.\theta}=\frac{\varepsilon_{c1.\theta}}{\varepsilon_{c1}};\ E_{c.sec.\theta}=\frac{f_{c.\theta}}{\varepsilon_{c1.\theta}}=\frac{k_{c.\theta}}{k_{\varepsilon.\theta}}\frac{f_{ck}}{\varepsilon_{c1}}=k_{Ec.\theta}\frac{f_{ck}}{\varepsilon_{c1}}$$

$$\varepsilon_{c1} = 0.0025$$

Table 8a. Values of reductiont coefficient $\varphi_{a.\theta}$ according to pipe profile size

Standard fire	Round pipe profiles, outer diameter D							Square pipe profiles, outside dimension b	
	135	165	200	220	250	273	≥323	≤150	≥180
R30	0.45	0.5	0.60	0.70	0.70	0.70	0.70	0.45	0.60
R60	-	0.4	0.50	0.60	0.60	0.65	0.70	0.45	0.60
R90	-	-	0.40	0.40	0.40	0.40	0.50	-	0.45
R120	-	-	0.30	0.30	0.30	0.35	0.40	-	0.35

Table 8b. Values of reduction coefficient $\varphi_{a.\theta}$ according to rod placement

u_s [mm]	30	40	50	≥60
$\varphi_{s.\theta}$	0.8	0.9	1.0	1.0

Compression resistance of an axially loaded column

The compression resistance of a column $N_{fi.Rd}$ is calculated as a buckling resistance from the expression

$$N_{fi.Rd}=\chi(\bar{\lambda}_\theta)N_{fi.pl.Rd} \tag{1.5}$$

where $\chi(\bar{\lambda}_\theta)$ is the reduction factor depending on the column's relative slenderness ratio $\bar{\lambda}_\theta$; it is always calculated according to the European buckling curve c (SFS-EN 1993-1-1 clause 6.3.1).

relative slenderness ratio $\bar{\lambda}_\theta$ is

$$\bar{\lambda}_\theta = \sqrt{\frac{N_{fi.pl.R}}{N_{fi.cr}}} \tag{1.6}$$

where $N_{fi.pl.R}$ is the resistance of the cross-section pursuant to clauses (1.3a..d), when the partial factors $\gamma_{M.fi.a}$, $\gamma_{M.fi.s}$ and $\gamma_{M.fi.c}$ have a value of one. $N_{fi.cr}$ is calculated as a function of the column's effective length $L_{e.\theta}$ and effective bending stiffness $(EI)_{fi.eff}$ during a fire

$$N_{fi.cr} = \frac{\pi^2 (EI)_{fi.eff}}{L_{e.\theta}^{\;2}} \tag{1.7}$$

Table 9. When each floor of a laterally supported frame forms a separate fire compartment, the effective lengths $L_{e.\theta}$ depend on the position of the column, floor height L and the assumptions regarding the end supports

$L_{e.\theta} = \beta L$	β
Continuous columns, top floor exposed to fire	*0.7*
Continuous columns, middle floor exposed to fire	*0.5*
Continuous columns, bottom floor exposed to fire	*0.6*
Single floor columns, β depends on the column end fasteners and is the same as at the normal temperature	

Accounting for the interaction of the moment and the axial load

The bending of the column during a fire is accounted for as the eccentricity e_{fi} of the axial load $N_{fi.Ed}$, which is

$$e_{fi} = \frac{M_{fi.Ed}}{N_{fi.Ed}} \tag{1.8}$$

where $M_{fi.Ed}$ is the highest bending moment occurring along the length of the column that is exposed to fire and $N_{fi.Ed}$ is the axial load related to the load case that corresponds to moment $M_{fi.Ed}$. The compression resistance $N_{fi.Rd.\delta}$ of an eccentrically loaded column is calculated as a share of the resistance $N_{fi.Rd}$ of an axially loaded column:

$$N_{fi.Rd.\delta} = XN_{fi.Rd}\,,\;\; X = 0{,}5\left(B_{fi} - \sqrt{B_{fi}^{\;2} - 4/\chi(\bar{\lambda}_\theta)}\right) \tag{1.9}$$

$$B_{fi} = 1 + \frac{1}{\chi(\bar{\lambda}_\theta)} + e_{fi}\frac{N_{fi.pl.Rd} - N_{fi.c.Rd}}{M_{fi.pl.Rd}} \tag{2.0}$$

where $N_{fi.pl.Rd}$ is the compression resistance of a column cross-section according to expression (1.3a) and $N_{fi.c.Rd}$ is the compression resistance of a concrete cross-section according to expression (1.3d).

The bending resistance $M_{fi.pl.Rd}$ for a column exposed to fire is calculated in the same manner as clean bending resistance at normal temperature; however, the design *strengths used for material components are* $k_{y.\theta}(\theta_a)f_y/\gamma_{M.fi.a}$ *(steel profile),* $k_{s.\theta}(\theta_s)f_{sk}/\gamma_{M.fi.s}$ *(reinforcement) and* $k_{c.\theta}(\theta_{c.equ})f_{ck}/\gamma_{M.fi.c}$ *(concrete).*