5.7.4 Flat slabs

(1) The following rules apply to flat slabs where the moment redistribution [AC1⟩ according to Section 5 of EN 1992-1-1, ⟨AC1] does not exceed 15%. Otherwise axis distances should be taken as for one-way slab (Column 3 in Table 5.8) and the minimum thickness from Table 5.9.

(2) For fire ratings of REI 90 and above, at least 20% of the total top reinforcement in each direction over intermediate supports, required by EN 1992-1-1, should be continuous over the full span. This reinforcement should be placed in the column strip.

(3) Minimum slab-thicknesses should not be reduced (e.g. by taking floor finishes into account).

(4) The axis distance *a* denotes the axis distance of the reinforcement in the lower layer.

Table 5.9: Minimum dimensions and axis distances for reinforced and prestressed concrete solid flat slabs

Standard fire resistance	Minimum dimensions (mm)	
	slab-thickness h_s	axis-distance *a*
1	2	3
REI 30	150	10*
REI 60	180	15*
REI 90	200	25
REI 120	200	35
REI 180	200	45
REI 240	200	50
* Normally the cover required by EN 1992-1-1 will control.		

5.7.5 Ribbed slabs

(1) For the assessment of the fire resistance of one-way reinforced and prestressed ribbed slabs, 5.6.2, 5.6.3 for the ribs and 5.7.3, Table 5.8, Columns 2 and 5, for the flanges are complied with.

(2) For two-way reinforced and prestressed ribbed slabs, adequate fire resistance may be assumed if the values in Tables 5.10 and 5.11, together with the following rules, apply.

(3) The values in Tables 5.10 and 5.11 are valid for ribbed slabs subjected to predominantly uniformly distributed loading.

(4) For ribbed slabs with reinforcement placed in several layers, 5.2 (15) applies.

(5) In continuous ribbed slabs, the top reinforcement should be placed in the upper half of the flange.

(6) Table 5.10 is valid for simply supported, two-way spanning ribbed slabs. It is also valid for two-way spanning ribbed slabs with at least one restrained edge and standard fire resistances lower than REI 180 where the detailing of the upper reinforcement does not meet the requirements in 5.6.3(3).

(7) Table 5.11 is valid for two-way spanning ribbed slabs with at least one restrained edge. For the detailing of the upper reinforcement, 5.6.3(3) applies for all standard fire resistances.

Table 5.10: Minimum dimensions and axis distance for two-way spanning, simply supported ribbed slabs in reinforced or prestressed concrete.

Standard Fire Resistance	Minimum dimensions (mm)			
	Possible combinations of width of ribs b_{min} and axis distance a			Slab thickness h_s and axis distance a in flange
1	2	3	4	5
REI 30	b_{min} = 80 a = 15*			h_s = 80 a = 10*
REI 60	b_{min} = 100 a = 35	120 25	≥200 15*	h_s = 80 a = 10*
REI 90	b_{min} = 120 a = 45	160 40	≥250 30	h_s = 100 a = 15*
REI 120	b_{min} = 160 a = 60	190 55	≥300 40	h_s = 120 a = 20
REI 180	b_{min} = 220 a = 75	260 70	≥410 60	h_s = 150 a = 30
REI 240	b_{min} = 280 a = 90	350 75	≥500 70	h_s = 175 a = 40
$a_{sd} = a + 10$				
AC1⟩ For prestressed ribbed slabs, the axis-distance a should be increased in accordance with 5.2(5). ⟨AC1 a_{sd} denotes the distance measured between the axis of the reinforcement and lateral surface of the rib exposed to fire.				
* Normally the cover required by EN 1992-1-1 will control.				

Table 5.11: Minimum dimensions and axis distances for two-way spanning ribbed slabs in reinforced or prestressed concrete with at least one restrained edge.

Standard Fire Resistance	Minimum dimensions (mm)			
	Possible combinations of width of ribs b_{min} and axis distance a			Slab thickness h_s and axis distance a in flange
1	2	3	4	5
REI 30	b_{min} = 80 a = 10*			h_s = 80 a = 10*
REI 60	b_{min} = 100 a = 25	120 15*	≥200 10*	h_s = 80 a = 10*
REI 90	b_{min} = 120 a = 35	160 25	≥250 15*	h_s = 100 a = 15*
REI 120	b_{min} = 160 a = 45	190 40	≥300 30	h_s = 120 a = 20
REI 180	b_{min} = 310 a = 60	600 50		h_s = 150 a = 30
REI 240	b_{min} = 450 a = 70	700 60		h_s =175 a = 40
$a_{sd} = a + 10$				

AC1) For prestressed ribbed slabs, the axis-distance a should be increased in accordance with 5.2(5). (AC1

a_{sd} denotes the distance measured between the axis of the reinforcement and lateral surface of the rib exposed to fire.

* Normally the cover required by EN 1992-1-1 will control

SECTION 6 HIGH STRENGTH CONCRETE (HSC)

6.1 General

(1)P This section gives additional rules for high strength concrete (HSC).

(2)P Structural elements shall be designed at elevated temperature with the properties of that type of concrete and the risk of spalling shall be taken into account.

(3) Strength properties are given in three classes and recommendations against spalling are given for two ranges of HSC.

Note: Where the actual characteristic strength of concrete is likely to be of a higher class than that specified in design, the relative reduction in strength for the higher class should be used for fire design.

(4) Properties and recommendations are given for fire exposure corresponding to standard temperature-time curve only.

(5) A reduction in strength, $f_{c,\theta}/ f_{ck}$, at elevated temperature should be made.

Note: The values $f_{c,\theta}/ f_{ck}$ for use in a Country may be found in its National Annex. Three classes are given in Table 6.1N. However the values given for each rely on a limited amount of test results. The selection and limit of use of these classes to certain strength classes or type of concrete for use in a Country may be found in its National Annex. The recommended class for concrete C 55/67 and C 60/75 is Class 1, for concrete C 70/85 and C80/95 is Class 2 and for concrete C90/105 is Class 3. See also note to 6.4.2.1 (3) and 6.4.2.2 (2).

Table 6.1N: Reduction of strength at elevated temperature

Concrete temperature θ °C	$f_{c,\theta}/ f_{ck}$		
	Class 1	Class 2	Class 3
20	1,00	1,0	1,0
50	1,00	1,0	1,0
100	0,90	0,75	0,75
200			0,70
250	0,90		
300	0,85		0,65
400	0,75	0,75	0,45
500			0,30
600			0,25
700			
800	0,15	0,15	0,15
900	0,08		0,08
1000	0,04		0,04
1100	0,01		0,01
1200	0,00	0,00	0,00

6.2 Spalling

(1) For concrete grades C 55/67 to C 80/95 the rules given in 4.5 apply, provided that the maximum content of silica fume is less than 6% by weight of cement. For higher contents of silica fume the rules given in (2) apply.

(2) AC1 For concrete grades 80/95 < C ⩽ 90/105 at least one of the following methods should be provided: AC1

Method A: A reinforcement mesh with a nominal cover of 15 mm. This mesh should have wires with a diameter ≥ 2 mm with a pitch ≤ 50 x 50 mm. The nominal cover to the main reinforcement should be ≥ 40 mm.

Method B: A type of concrete for which it has been demonstrated (by local experience or by testing) that no spalling of concrete occurs under fire exposure.

Method C: Protective layers for which it is demonstrated that no spalling of concrete occurs under fire exposure.

Method D: Include in the concrete mix more than 2 kg/m^3 of monofilament propylene fibres.

Note: The selection of Methods to be used in a Country may be found in its National Annex.

6.3 Thermal properties

(1) Values given in clause 3.3 may be applied also for high strength concrete.

Note 1: The value of thermal conductivity for high strength concrete for use in a Country may be given in its National Annex within the range defined by lower and upper limit in clause 3.3.3.

Note 2: Thermal conductivity of high strength concrete may be higher than that for normal strength concrete.

6.4 Structural design

6.4.1 Calculation of load bearing capacity

(1)P The load-carrying capacity in the fire situation shall be determined considering the following:

- thermal exposure and the consequent temperature field in the member
- reduction of material strength due to elevated temperatures
- effects of restraint forces due to thermal expansion
- second order effects

(2) This may be achieved by undertaking either a global structural analysis or a simplified member calculation. The global structural analysis should be based on verified information. The simplified calculation methods for columns, walls, beams and slabs are described below.

6.4.2 Simplified calculation methods

(1)P The simplified calculation methods given in Annex B apply for high strength concrete.

6.4.2.1 Columns and walls

(1) Verification of the load-carrying capacity of columns and walls in the fire situation may be conducted for a reduced cross-section, using the methods applicable for normal design, e.g. Annex B.1.

(2) The reduced cross-section should be derived on the basis of the simplified method of Annex B, however incorporating an enhanced deduction of the AC1 ineffective concrete AC1 due to the influence of second order effects.

(3) In calculation of the AC1 reduced cross-section AC1 the reduced concrete thickness is calculated from the depth of the 500 °C isotherm, a_{500}, increased by a factor k. Hence in calculation of the reduced cross-section for columns and walls Expression (6.4) should be used.

$$a_z = k\, a_{z,\,500} \tag{6.4}$$

Note : k allows for the conversion from the 500°C to the 460°C isotherm depth for Class 1 in Table 6.1N, and to the 400°C isotherm depth for Class 2 in Table 6.1N. The value of k for use in a Country may be found in its National Annex. The recommended value is 1,1 for Class 1 and 1,3 for Class 2. For Class 3 more accurate methods are recommended.

(4) The moment capacity for cross-sections subjected to combined bending and axial loading may be calculated using the zone method, Annex B.2, taking account $E_{c,fi}(\theta) = k_c^2(\theta)\cdot E_c$ if relevant.

(5) Time-temperature regimes which do not comply with the criteria of the simplified method require a separate comprehensive analysis which accounts for the relative strength of the concrete as a function of the temperature.

6.4.2.2 Beams and slabs

(1) The moment capacity of beams and slabs in the fire situation may be calculated based on the [AC1) reduced cross-section, (AC1] as defined in Annex B.1, using the methods applicable for normal design.

(2) An additional reduction of the calculated moment capacity is should be made:

$$M_{d,fi} = M_{500} \cdot k_m \tag{6.5}$$

where

$M_{d,fi}$ is the design moment capacity in the fire situation

M_{500} is the calculated moment capacity based on the [AC1) reduced cross-section, (AC1] defined by the 500°C isotherm

k_m is a reduction factor

Note: The value of k_m, which depends on the reduction strength given in Table 6.1N, for use in a Country may be found in its National Annex. The recommended value is given in Table 6.2N. For Class 3 more accurate methods are recommended

Table 6.2N: Moment capacity reduction factors for beams and slabs.

Item	**k_m**	
	Class 1	**Class 2**
Beams	0,98	0,95
Slabs exposed to fire in the compression zone	0,98	0,95
Slabs exposed to fire in the tension side, $h_1 \geq 120$ mm	0,98	0,95
Slabs exposed to fire in the tension side, $h_1 = 50$ mm	0,95	0,85
where h_1 is the concrete slab thickness (see Figure 5.7)		

(3) For slab thickness in the range of 50 to 120 mm, with fire exposure on the tension side, the reduction factor may be obtained from linear interpolation.

(4) Time heat regimes which do not comply with the criteria of the simplified method should be supported by a separate comprehensive analysis which accounts for the relative strength of the concrete as function of the temperature.

6.4.3 Tabulated data

(1) The Tabulated method given in Section 5 may also be used for HSC if the minimum cross section dimension are increased by:

- $(k-1)a$ for walls and slabs exposed on one side only
- $2(k-1)a$ for all other structural members and the axis distance is factored by k.

Where

k is the factor given in 6.4.2.1(3)

a is axis distance required in Section 5.

Note: For columns the degree of utilisation in the fire situation μ_{fi} *or* load level of a column at normal temperature conditions n should be defined before calculating the increase of the cross-section dimensions by $2(k-1)a$

Annex A (informative)

Temperature profiles

(1) This annex provides calculated temperature profiles for slabs (Figure A.2), beams (Figures A.3 - A.10) and columns (Figures A.11 - A.20). Figure A.2, for slabs, also applies to walls exposed on one side.

(2) The figures are based on the following values:

- Specific heat of concrete is as given in 3.3.2 with moisture content 1,5%. The temperature graphs are conservative for moisture contents greater than 1,5%

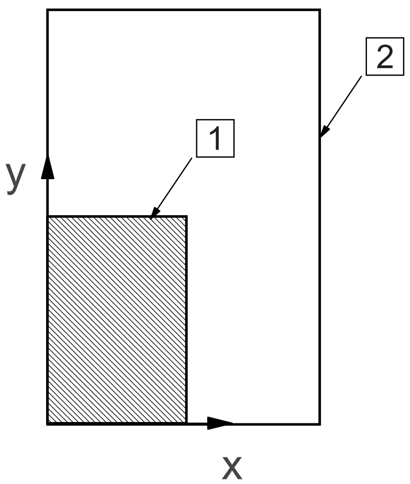
- The lower limit of thermal conductivity of concrete is as given in 3.3.3

  Note: the lower limit of thermal conductivity has been derived from comparisons with temperatures measured in fire tests of different types of concrete structures. the lower limit gives more realistic temperatures for concrete structures than the upper limit, which has been derived from tests for steel/concrete composite structures.

- The emissivity related to the concrete surface 0,7, is as given in 2.2

AC1 - Convection factor is 25 W/m^{2}K AC1

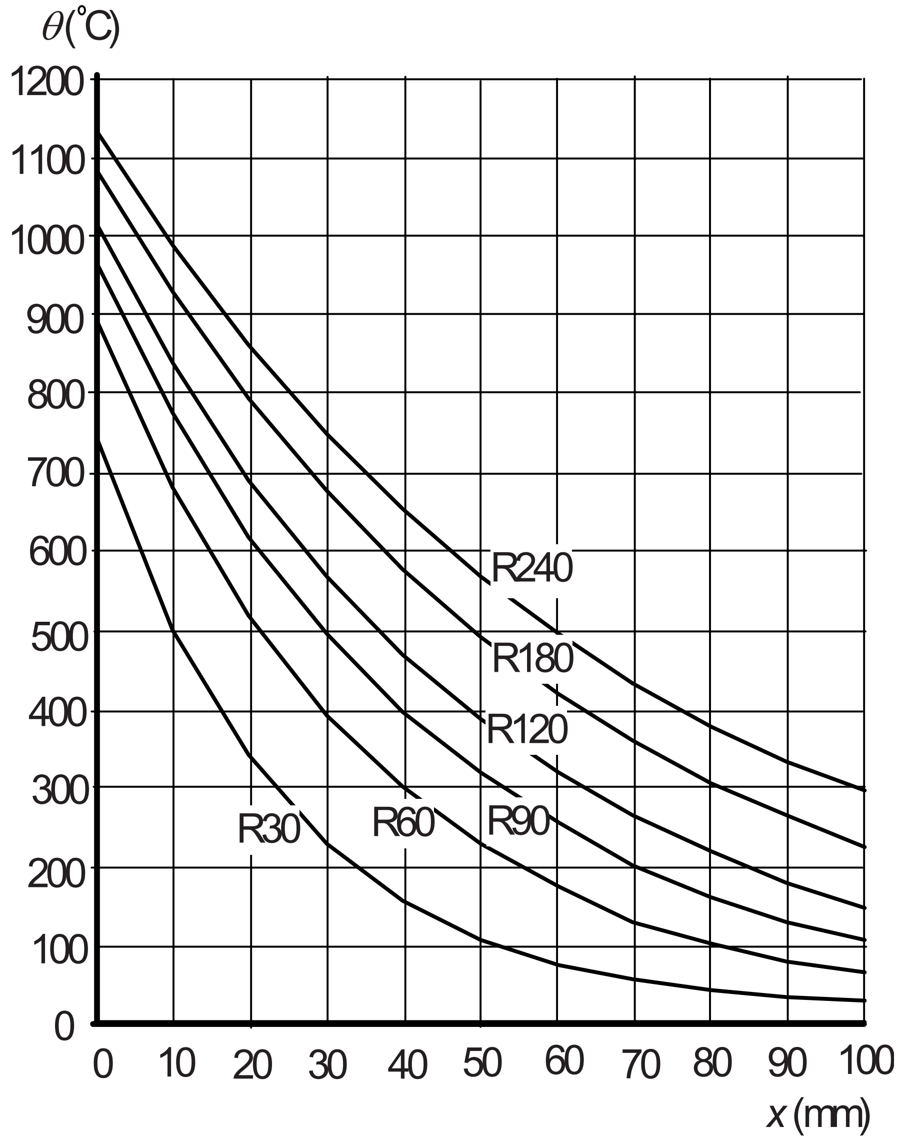
(3) Figure A.1 shows how the temperature profiles represent the temperature in the cross-section of beams and columns taking symmetry into account.



1 Area of temperature profile

2 Full cross section

Figure A.1: Area of cross-section for which the temperature profiles are presented



x is the distance from the exposed surface

Figure A.2: Temperature profiles for slabs (height *h* = 200) for R60 - R240

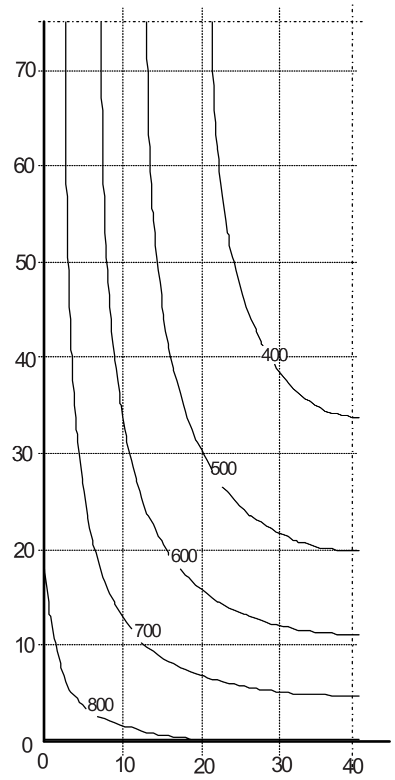
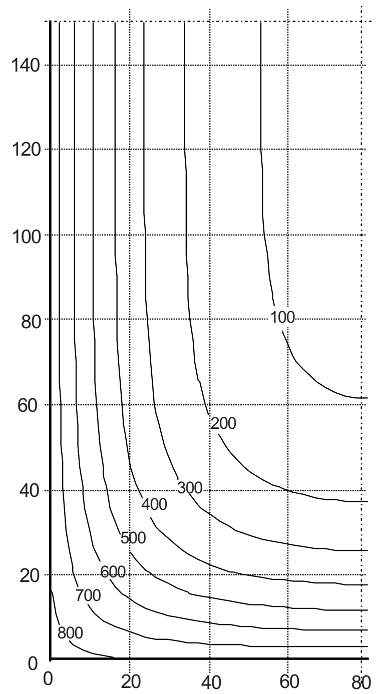
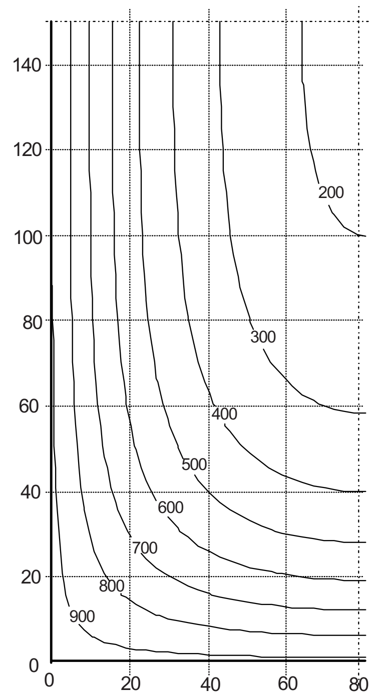


Figure A.3: Temperature profiles (°C) for a beam, *h* x *b* = 150 x 80 - R30



a) R30



b) R60

Figure A.4: Temperature profiles (°C) for a beam, *h* x *b* = 300 x 160