Structural fire design Eurocode 5-1.2 Timber structures

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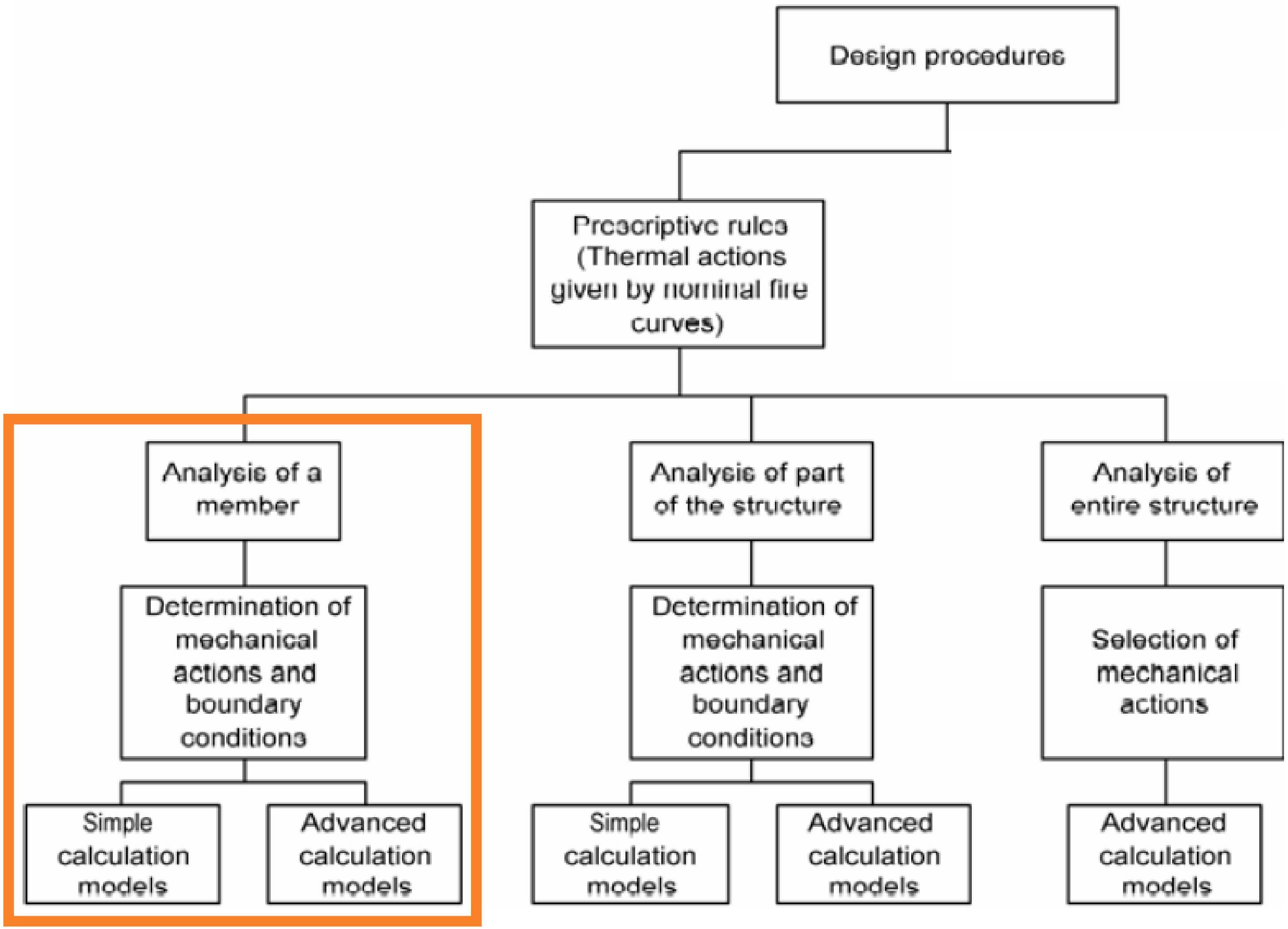
Scope of EN 1995-1-2

EN 1995-1-2

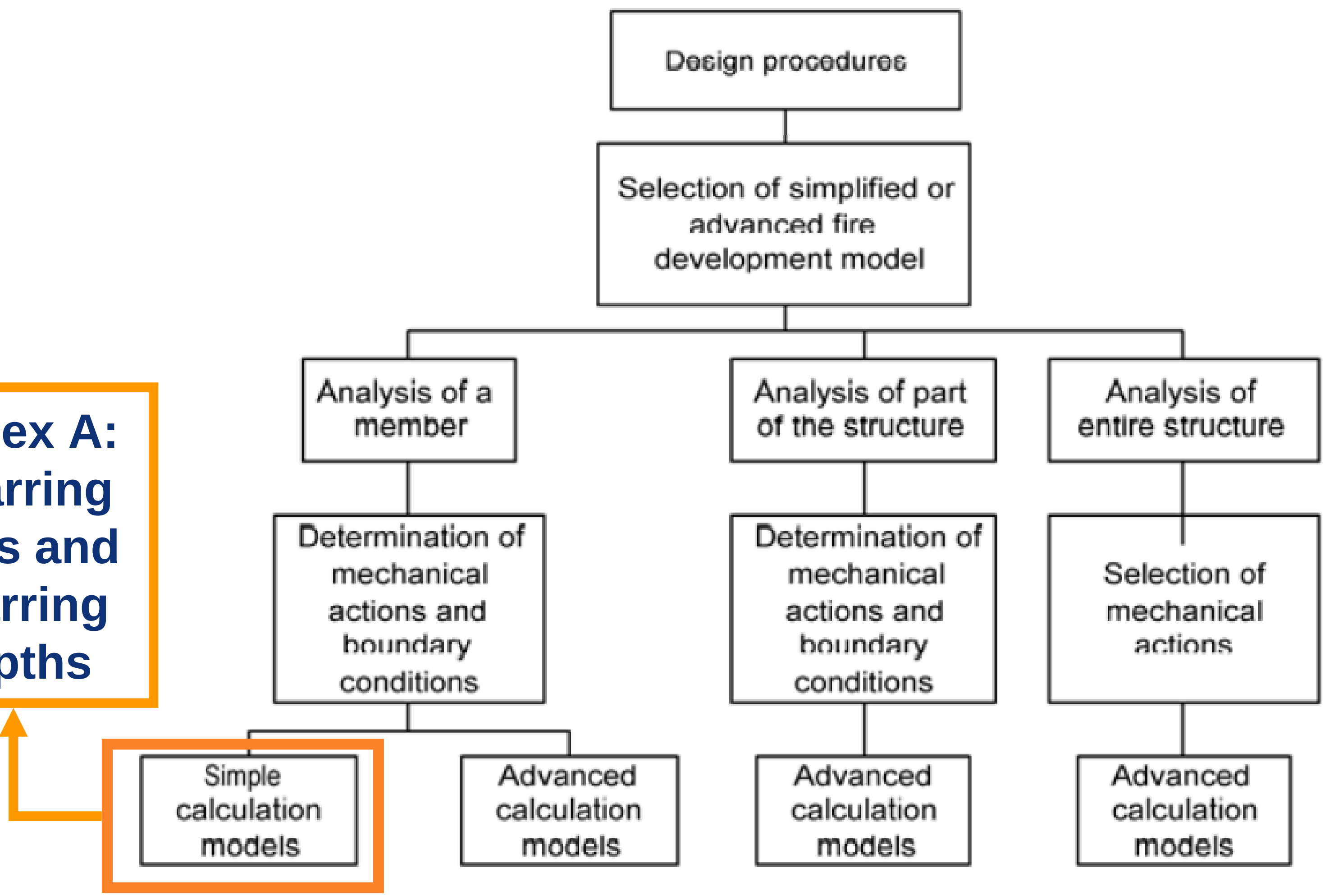
- shows the design of timber structures for the accidental situation of fire exposure
- to be used in conjunction with EN 1995-1-1 and EN 1991-1-2.
- only identifies differences from, or supplements normal temperature design.
- deals only with passive methods of fire protection
- applies to building structures with load-bearing function and/or separating function

Design procedure (1)



Design procedure (2)

Annex A: Charring rates and charring depths



Basis of design (1)

Basic requirements

- mechanical resistance
- fire compartmentation
- deformation criteria

Requirements (R, E, I) concerning

- nominal fire exposure
- parametric fire exposure

→ same as EN 1991-1-2

Actions

→ see EN 1991-1-2

- emissivity coefficient of wood surfaces: e = 0,8

Design values of material properties and resistances

$$f_{d,fi} = k_{mod,fi} \frac{f_{20}}{\gamma_{M,fi}}$$

$$f_{20} = k_{fi} \, f_k$$

$$S_{d,fi} = k_{mod,fi} \frac{S_{20}}{\gamma_{M,fi}}$$

$$S_{20} = k_{fi} \, S_{05}$$

	k_{fi}
Solid timber	1,25
Glued-laminated timber	1,15
Wood-based panels	1,15
LVL	1,1
Connections with fasteners in shear with side members of wood and wood-based panels	1,15
Connections with fasteners in shear with side members of steel	1,05
Connections with axially loaded fasteners	1,05

$f_{d,fi}$ is the design strength in fire;

$S_{d,fi}$ is the design stiffness property (modulus of elasticity $E_{d,fi}$ or shear modulus $G_{d,fi}$) in fire;

f_{20} is the 20 % fractile of a strength property at normal temperature;

S_{20} is the 20 % fractile of a stiffness property (modulus of elasticity or shear modulus) at normal temperature;

$k_{mod,fi}$ is the modification factor for fire;

$\gamma_{M,fi}$ is the partial safety factor for timber in fire.

Design values of material properties and resistances

$$R_{d,t,fi} = \eta \frac{R_{20}}{\gamma_{M,fi}}$$

$R_{d,t,fi}$	is the design value of a mechanical resistance in the fire situation at time t;
R_{20}	is the 20 % fractile value of a mechanical resistance at normal temperature without the effect of load duration and moisture (k_{mod} = 1);
η	is a conversion factor;
$\gamma_{M,fi}$	is the partial safety factor for timber in fire.

Verification methods

$$E_{d,fi} \leq R_{d,t,fi}$$

$E_{d,fi}$ is the design effect of actions for the fire situation, determined in accordance with EN 1991-1-2:2002, including effects of thermal expansions and deformations;

$R_{d,t,fi}$ is the corresponding design resistance in the fire situation.

$$E_{d,fi} = \eta_{fi} \, E_d \qquad \eta_{fi} = \frac{G_k + \psi_{fi} \, Q_{k,1}}{\gamma_G \, G_k + \gamma_{Q,1} \, Q_{k,1}}$$

$Q_{k,1}$ is the characteristic value of the leading variable action;

G_k is the characteristic value of the permanent action;

γ_G is the partial factor for permanent actions;

$\gamma_{Q,1}$ is the partial factor for variable action 1;

ψ_{fi} is the combination factor for frequent values of variable actions in the fire situation, given either by $\psi_{1,1}$ or $\psi_{2,1}$, see EN 1991-1-2:2002;

ξ is a reduction factor for unfavourable permanent actions G.

Material properties

Mechanical properties

- simplified methods for cross section and timber frame members in wall and floor assemblies completely filled with insulation
- advanced calculation methods.

Thermal properties

Charring (depth)

- for all surfaces of wood and wood-based panels directly exposed to fire,
- for surfaces initially protected from exposure and charring occurs during the relevant time of fire exposure.

Material properties: Charring (1)

Surfaces unprotected throughout the time of fire exposure

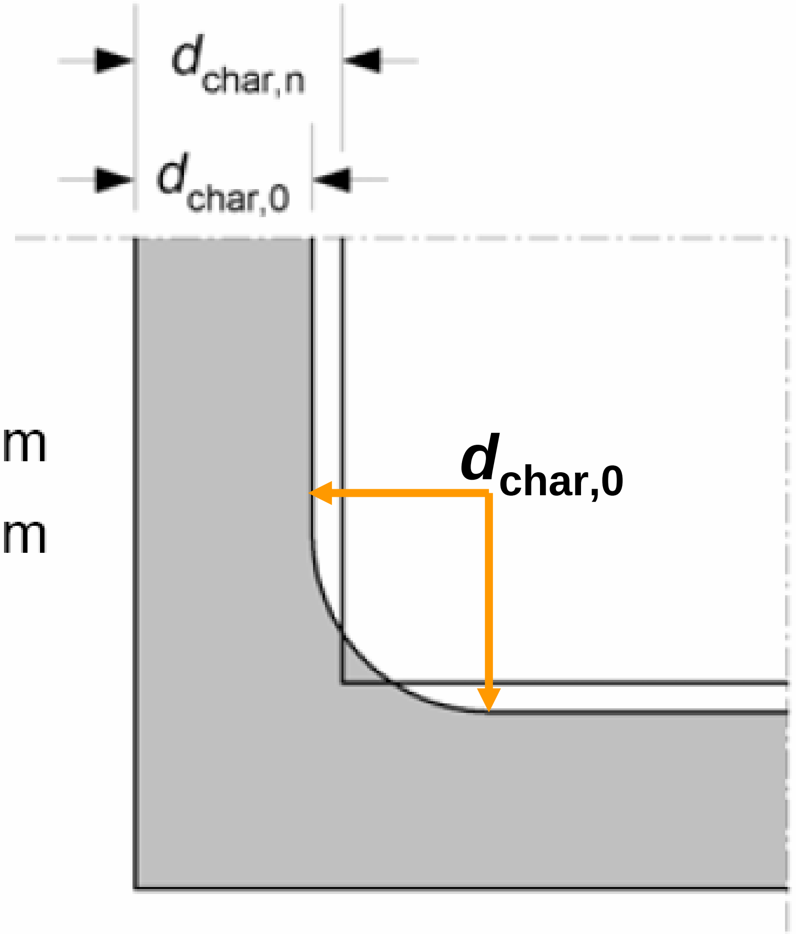
- one-dimensional charring

$$d_{\mathrm{char,0}} = \beta_0 \, t$$

$$b_{\min} = \begin{cases} 2\, d_{\mathrm{char,0}} + 80 & \text{for } d_{\mathrm{char,0}} \geq 13 \text{ mm} \\ 8{,}15\, d_{\mathrm{char,0}} & \text{for } d_{\mathrm{char,0}} < 13 \text{ mm} \end{cases}$$

- notional charring

$$d_{\mathrm{char,n}} = \beta_n \, t$$



Material properties: Charring (2)

	β_0 mm/min	β_n mm/min
a) Softwood and beech		
Glued laminated timber with a characteristic density of ≥ 290 kg/m^3	0,65	0,7
Solid timber with a characteristic density of ≥ 290 kg/m^3	0,65	0,8
b) Hardwood		
Solid or glued laminated hardwood with a characteristic density of 290 kg/m^3	0,65	0,7
Solid or glued laminated hardwood with a characteristic density of ≥ 450 kg/m^3	0,50	0,55
c) LVL		
with a characteristic density of ≥ 480 kg/m^3	0,65	0,7
d) Panels		
Wood panelling	0,9[a]	–
Plywood	1,0[a]	–
Wood-based panels other than plywood	0,9[a]	–
[a] The values apply to a characteristic density of 450 kg/m^3 and a panel thickness of 20 mm; see 3.4.2(9) for other thicknesses and densities.		

Material properties: Charring (3)

Charring for panels with other densities than ρ = 450 kg/m³ and smaller thickness h_p = 20 mm

$$\beta_{0,\rho,t} = \beta_0 \, k_\rho \, k_h$$

$$k_\rho = \sqrt{\frac{450}{\rho_k}}$$

$$k_h = \sqrt{\frac{20}{h_p}}$$

Example:
OSB – panel: ρ_k = 700 kg/m³
h_p = 20 mm → $ß_{o,\rho,t}$ = 0,72 mm/min
h_p = 12 mm → $ß_{o,\rho,t}$ = 0,93 mm/min

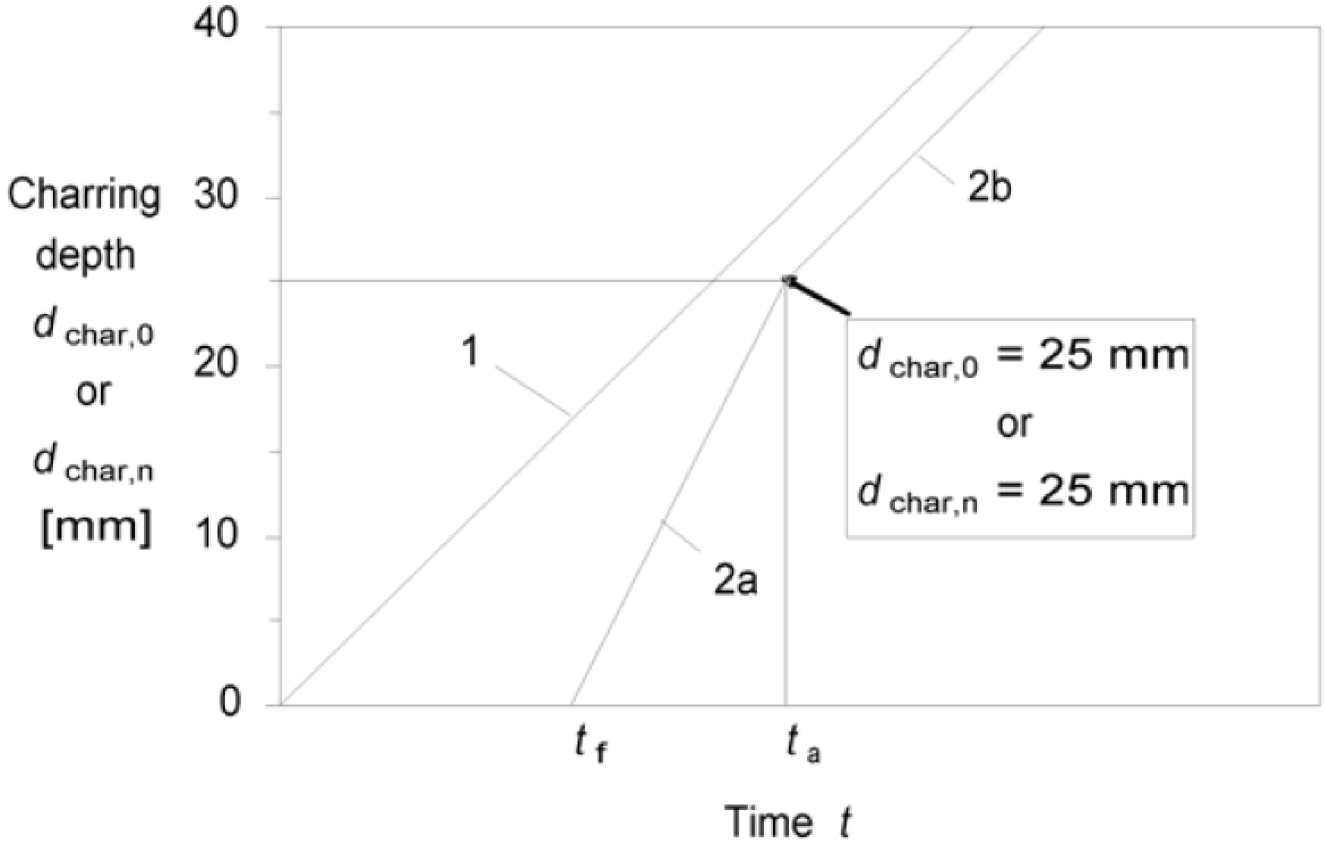
Material properties: Charring (4)

Surfaces of beams and columns initially protected from fire exposure

- the start of charring is delayed until time t_{ch};
- charring may commence prior to failure of the fire protection, but at a lower rate than the described charring rates until failure time t_f of the fire protection;
- after failure time t_f of the fire protection, the charring rate is increased above the shown values until the time t_a described below;
- at the time t_a when the charring depth equals either the charring depth of the same member without fire protection or 25 mm whichever is the lesser, the charring rate reverts to the described value.

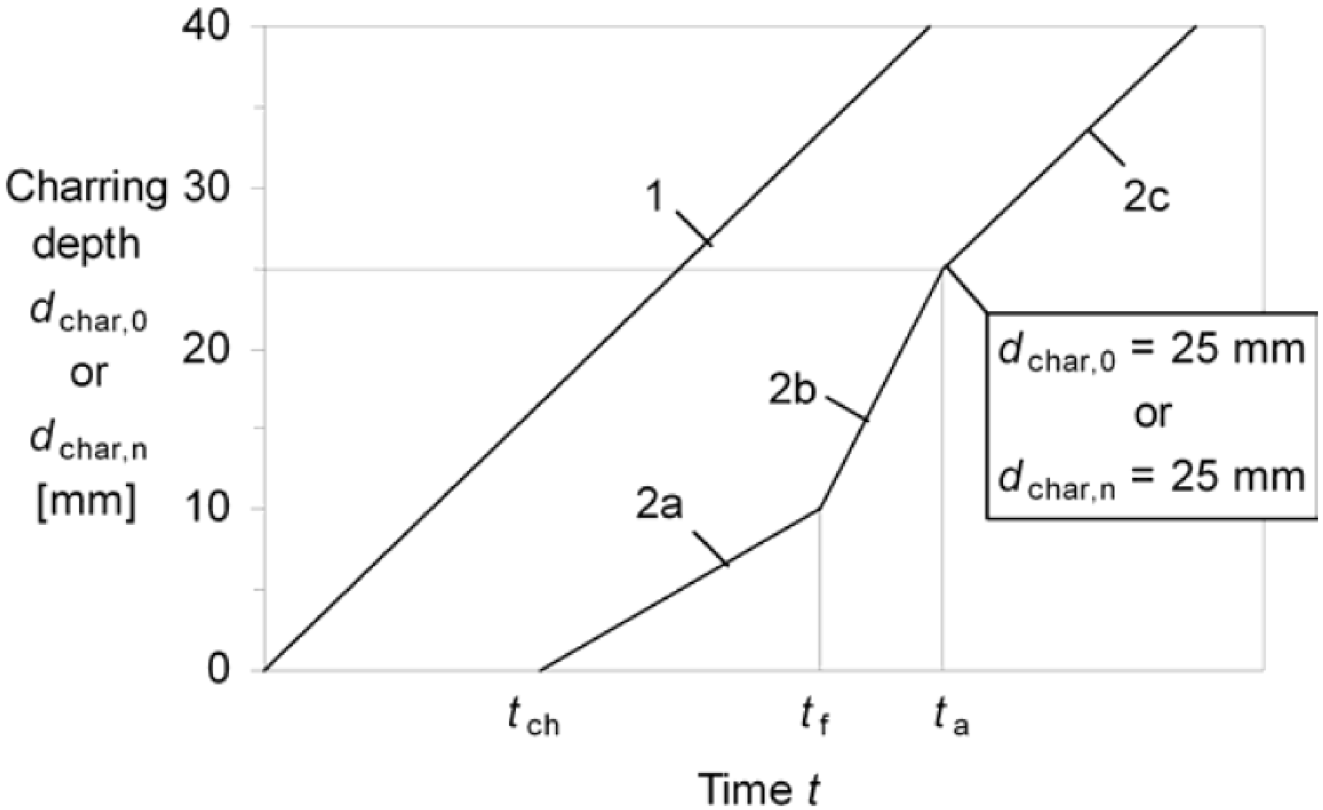
Material properties: Charring (5)

Surfaces of beams and columns initially protected from fire exposure



Material properties: Charring (6)

Surfaces of beams and columns initially protected from fire exposure



Simplified rules for determining cross-sectional properties - Reduced cross-section method

→ $k_{mod,fi} = 1,0$

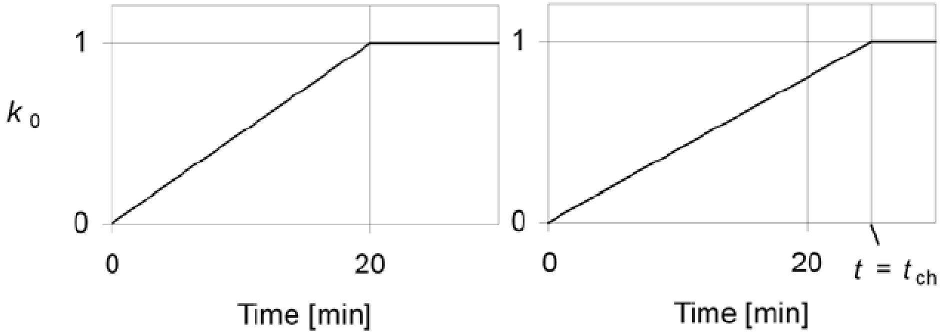
$$d_{ef} = d_{char,n} + k_0 \, d_0$$

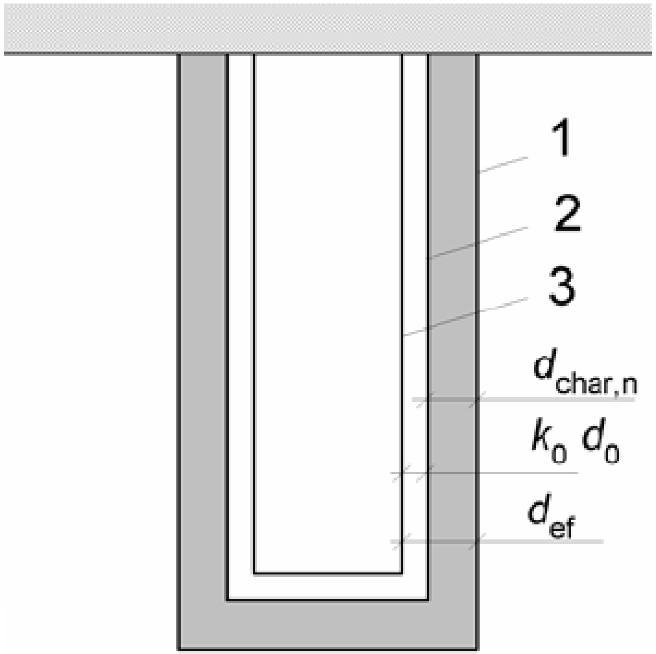
$$d_0 = 7 \text{ mm}$$

k_0: unprotected surface

	k_0
t < 20 minutes	t/20
$t \geq$ 20 minutes	1,0

k_0: intial protected surface

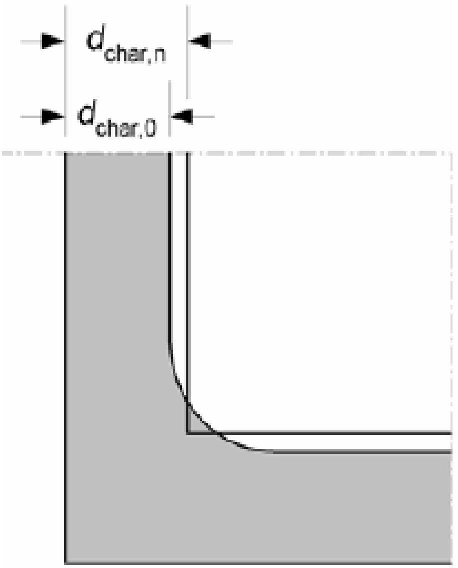




Key
1 Initial surface of member
2 Border of residual cross-section
3 Border of effective cross-section

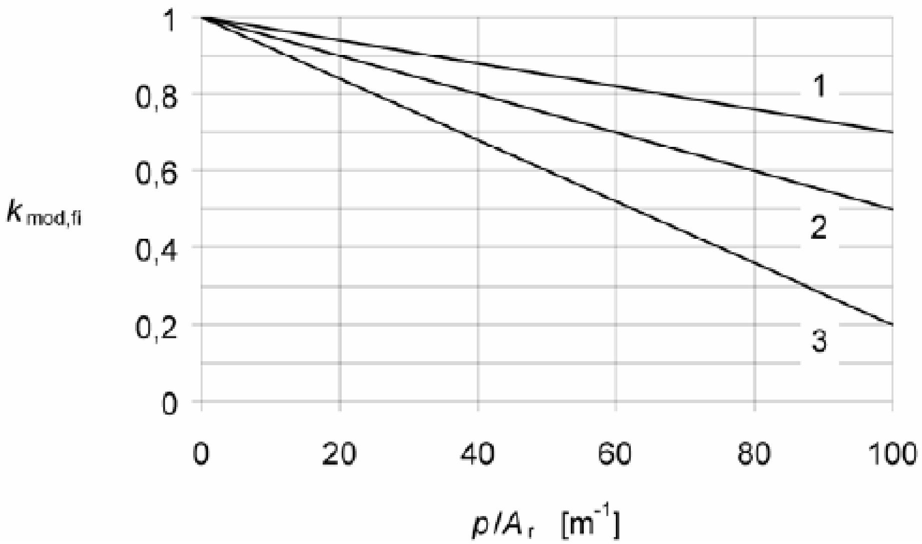
Simplified rules for determining cross-sectional properties - Reduced properties method

→ $k_{mod,fi} = f\ (\rho/A_r$ and strength, stiffness)



- apply only to rectangular cross-sections of softwood exposed to fire on three or four sides and
- round cross-sections exposed along their whole perimeter.

$k_{mod,fi}$ (t equal or greater 20 min):



1 Tensile strength, Modulus of elasticity
2 Bending strength
3 Compressive strength

Simplified rules for analysis of structural members and components

General

- Compression perpendicular to the grain may be disregarded.
- Shear may be disregarded in rectangular and circular cross-sections.

Beams, columns

- bracing fails should be considered

Mechanically jointed members

- reduction in slip moduli in the fire situation shall be taken into account

Bracings

Advanced calculation methods

- for determination of the mechanical resistance and the separating function shall provide a realistic analysis of structures exposed to fire,
- based on fundamental physical behaviour to lead to a reliable approximation of the expected behaviour of the relevant structural component under fire conditions.

Analysis of load-bearing function

- shall be designed for fire exposure on both sides at the same time.

Analysis of separating function

- take into account the contributions of different material components and their position in the assembly.

Connections (1)

- applies to connections between members under standard fire exposure, for fire resistances not exceeding 60 min.

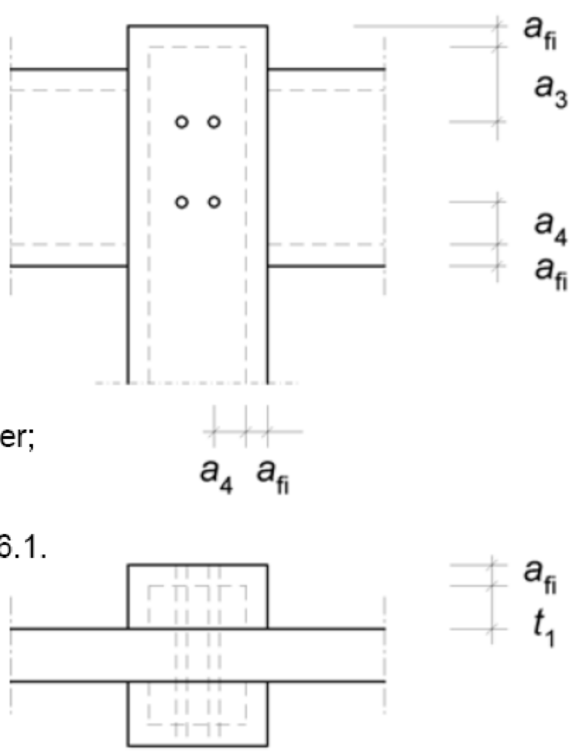
Connections with side members of wood
Simplified rules - unprotected connections

	Time of fire resistance $t_{d,fi}$ min	Provisions[a]
Nails	15	$d \geq 2{,}8$ mm
Screws	15	$d \geq 3{,}5$ mm
Bolts	15	$t_1 \geq 45$ mm
Dowels	20	$t_1 \geq 45$ mm
Connectors according to EN 912	15	$t_1 \geq 45$ mm

[a] d is the diameter of the fastener and t_1 is the thickness of the side member

Connections with side members of wood
Simplified rules - unprotected connections

- greater t_{dfi} is possible (not more than 30 min) by increasing the following dimensions by a_{fi}:
  - –the thickness of side members,
  - –the width of the side members,
  - –the end and edge distance to fasteners.

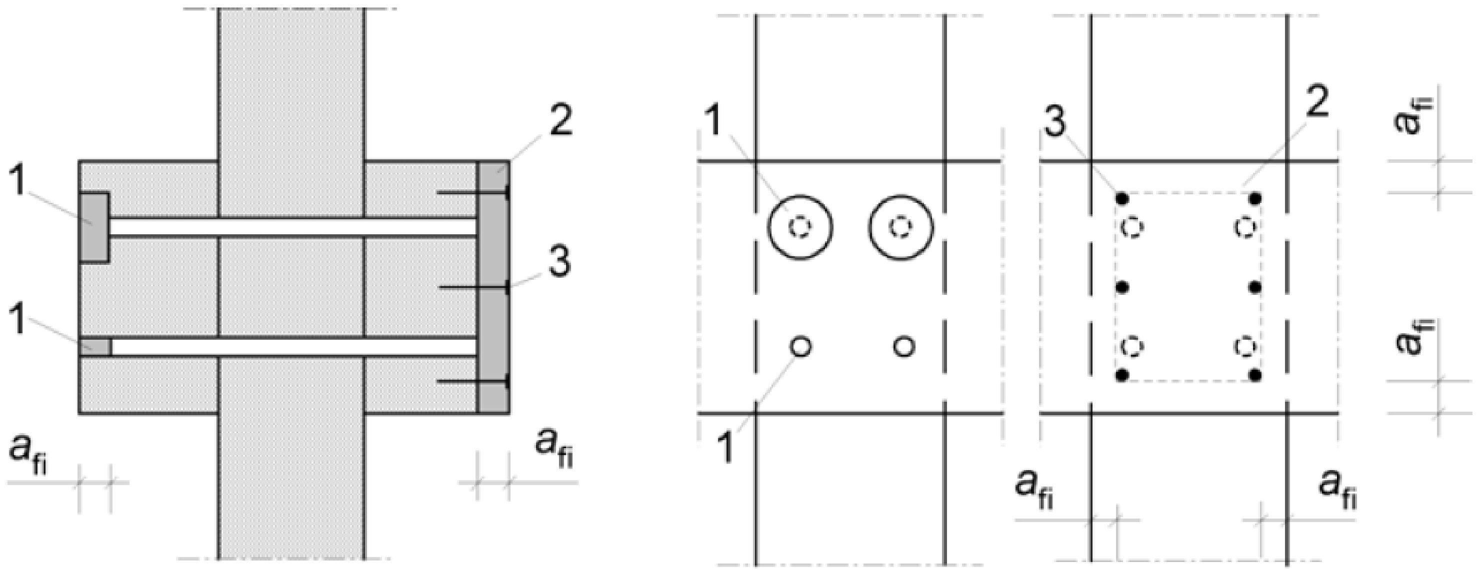


$$a_{fi} = \beta_n \, k_{flux} \, (t_{req} - t_{d,fi})$$

β_n	is the charring rate according to table 3.1;
k_{flux}	is a coefficient taking into account increased heat flux through the fastener;
t_{req}	is the required standard fire resistance period;
$t_{d,fi}$	is the fire resistance period of the unprotected connection given in table 6.1.

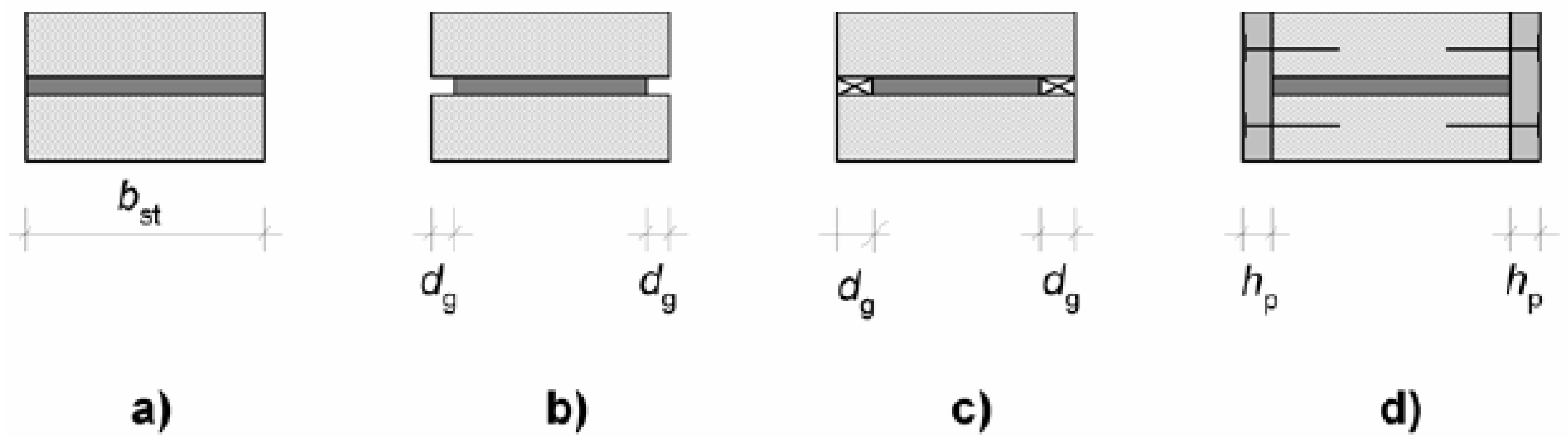
- $\boldsymbol{k_{flux} = 1{,}5}$

Connections with side members of wood
Simplified rules - protected connections



1 Glued-in plugs
2 Additional protection using panels
3 Fastener fixing panels providing additional protection

Connections with side members of wood
Additional rules for connections with internal steel plates



Connections with side members of wood
Reduced load method
Unprotected wood

$$F_{v,Rk,fi} = \eta \, F_{v,Rk}$$

$$\eta = e^{-k\, t_{d,fi}} \qquad t_{d,fi} = -\frac{1}{k} \ln \frac{\eta_{fi}\, \gamma_{M,fi}}{\gamma_M \, k_{fi}}$$

Connection with	k	Maximum period of validity for parameter *k* in an unprotected connection min
Nails and screws	0,08	20
Bolts wood-to-wood with $d \geq 12$ mm	0,065	30
Bolts steel-to-wood with $d \geq 12$ mm	0,085	30
Dowels wood-to-wood[a] with $d \geq 12$ mm	0,04	40
Dowels steel-to-wood[a] with $d \geq 12$ mm	0,085	30
Connectors in accordance with EN 912	0,065	30

[a] The values for dowels are dependent on the presence of one bolt for every four dowels

$F_{v,Rk}$ is the characteristic lateral load-carrying capacity of the connection with fasteners in shear at normal temperature, see EN 1995-1-1 section 8;

η is a conversion factor;

k is a parameter given in table 6.3;

$t_{d,fi}$ is the design fire resistance of the unprotected connection, in minutes.

Protected wood

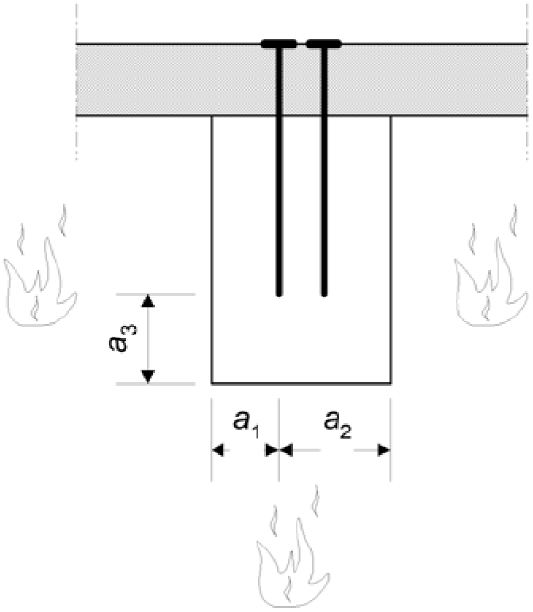
Connections (6)

Connections with external steel plates

- unprotected
- protected

Simplified rules for axially loaded screws

- design resistance of the screws
- conversion factor η



Detailing

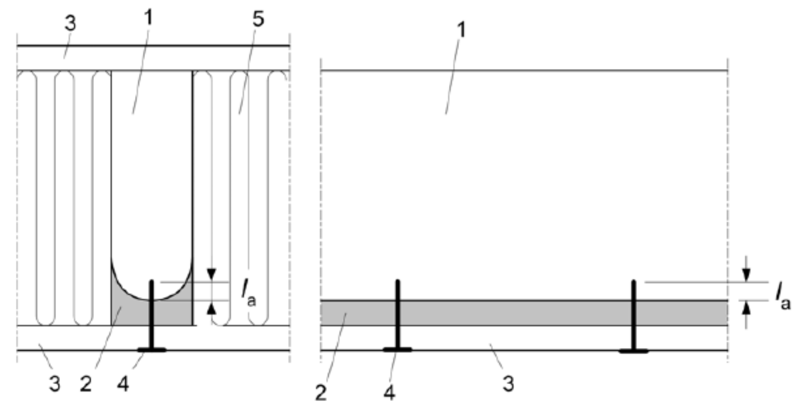
Walls and floors

- Dimensions and spacings

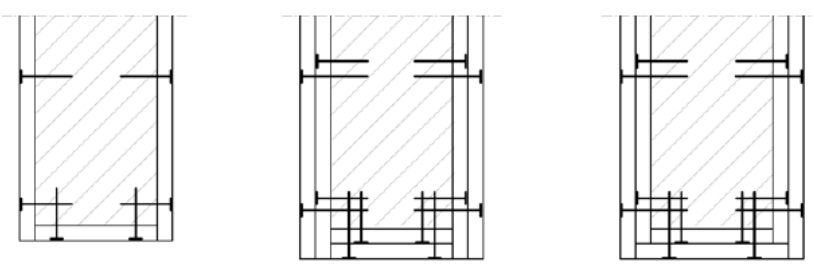
- Detailing of panel connections

- Insulation

- Other elements



1 Unburnt timber
2 Char layer
3 Panel
4 Fastener
5 Insulation



Thank you very much for your attention!

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