TECHNICAL DESIGN CALCULATION REPORT

Sections of the structural elements

CLT floors

Floor geometric characteristic

h_b: CLT panel thickness

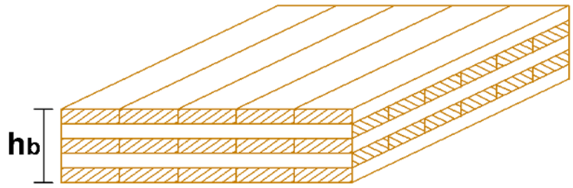


Figure: CLT floor geometric characteristics

The following table sets out the details concerning the CLT floors.

Section name	Manufacturer	CLT panel name	Material	Number of layers	Thickness h_b[mm]	Layers	External layers orientation
CLT 120 mm - 5 layers	TimberTech	TimberTech CLT 120 5s	C 24	5	120	20 - 30 - 20 - 30 - 20	Parallel to the calculation direction

Sections of the elements in the fire situation

According to clause 4.2.2 of EN 1995-1-2 an effective cross-section should be calculated by reducing the initial cross-section by the effective charring depth d_{ef}

$$d_{ef} = d_{char} + k_0 \cdot d_0$$

where:

d_{char} is the charring depth which, depending on the case, may be conventional ($d_{char,n}$) or one-dimensional ($d_{char,0}$)

$k_0 \cdot d_0$ is the thickness of the residual section, close to the char line, for which the material is assumed to have zero strength and stiffness, while the strength and stiffness properties of the remaining cross-section are assumed to be unchanged.

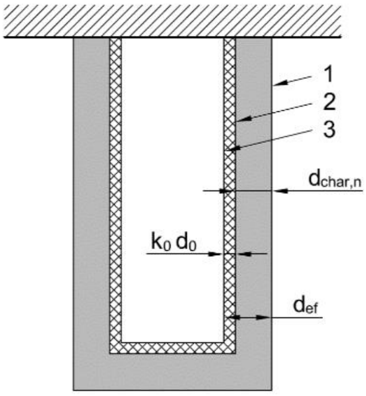


Figure: Definition of residual cross-section and effective cross-section.1 - Initial surface of member; 2 - Border of residual cross-section; 3 - Border of effective cross-section

Charring depth

Unprotected surfaces – CLT

For CLT elements made with **fire resistant adhesives** the charring rate is taken as constant in the transition from one layer to another. The charring depth is calculated as:

$$d_{char,0} = \beta_{0,CLT} \cdot t$$

where:

β_0 is the CLT one-dimensional charring rate

t is the time of fire exposure.

For CLT elements made with **adhesives not resistant to fire** the charring rate is considered to vary in the passage from one layer to the underlying one. In fact, it is considered that the heat-insulating char layer may fall off and, as the protective function of this layer is lost, an increase in the carbonization rate occurs. Only when the new carbonized layer reaches a thickness of 25 mm it can offer an effective protection and the charring rate decreases.

For the **first layer** the charring depth is calculated as:

$$d_{char,0} = \beta_{0,CLT} \cdot t$$

where:

$\beta_{0,CLT}$ is the CLT one-dimensional charring rate

t is the time of fire exposure.

For the **second and subsequent layers**, until the charring depth of the individual layer exceeds 25 mm, the charring rate is:

$$\beta_{0,XLAM,k3} = k_3 \cdot \beta_{0,CLT}$$

where k_3 = 2.

For the **second and subsequent layers**, after the charring depth of the individual layer exceeds 25 mm, the charring rate is $\beta_{0,CLT}$.

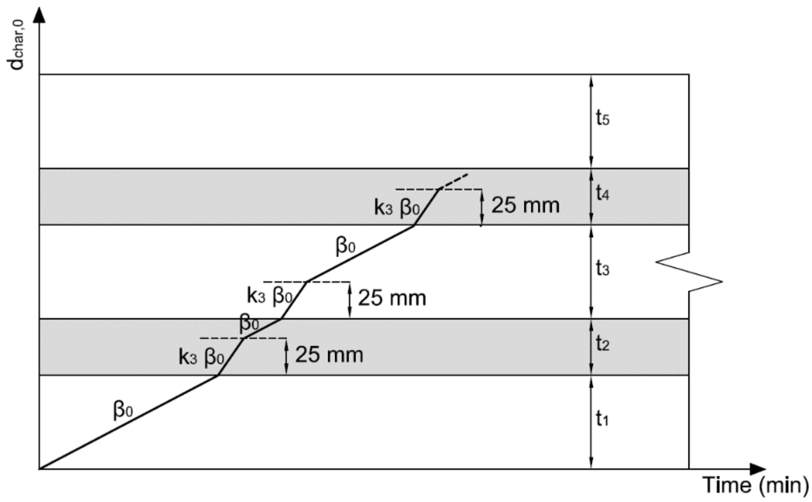


Figure: Diagram illustrating the variation of the charring rate in the passage from one layer to the underlying one of a CLT element with adhesives not resistant to fire.

Values of k_0 and d_0

The value of the depth of layer with assumed zero strength and stiffness is taken 7 mm.

For unprotected surfaces, k_0 should be determined from table below

Time	k_0
t < 20 minutes	t/20
t ≥ 20 minutes	1,0

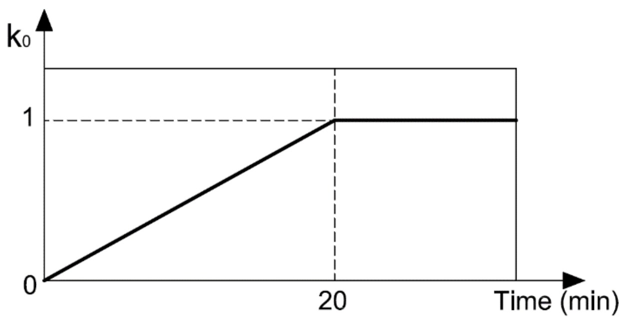


Figure: Variation of k_0 for unprotected members.

Calculation of the effective cross-sections

CLT Floors

The following tables show the calculation of the effective cross-section of the elements of the CLT floors in the fire situation.

Floor name	Fire data name	Glue line integrity maintained	Fire resistance class R [min]	β_0	$d_{char,0}$ [mm]
Floor 3	R60 - 1 side exposed - Glue line integrity maintained	Yes	60	0.65	39

Floor name	Section name	$d_{char,0}$ [mm]	d_{eff} [mm]	b_{eff} [mm]	h_{eff} [mm]	Fire stratigraphy
Floor 3	TimberTech CLT 120 5s	39	46	1000	74	20 - 30 - 20 - 4

Fire resistance checks

Design values of material properties and resistances

According to 2.3 of EN 1995-1-2, for verification of mechanical resistance, the design values of strength properties of the material shall be determined from

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

where:

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

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

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

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

The 20% fractile of a strength or a stiffness property is calculated as:

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

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

where k_{fi} is given in table below (table 2.1 of EN 1995-1-2).

Material	k_{fi}
Solid timber	1.25
Glued-laminated timber	1.15
Wood-based panels	1.15
LVL	1.10

Load combinations for structural fire design

For obtaining the relevant effect of action during fire exposure, the actions are combined with the combination for accidental design situations

$$G_1 + G_2 + P + \psi_{21} \cdot Q_{k1} + \psi_{22} \cdot Q_{k2} + \cdots$$

CLT floors checks in the fire situation

Bending strength

The checks are conducted according to § 6.1.6 of EN 1995-1-1 using the effective cross section according to 4.2.2 of EN 1995-1-2. The following expression shall be satisfied:

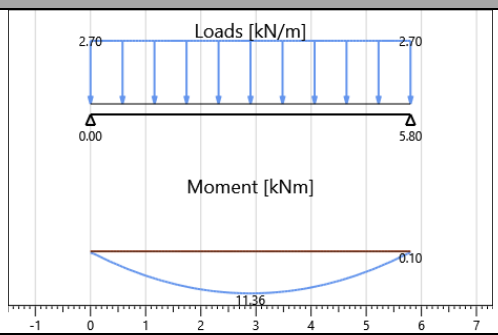
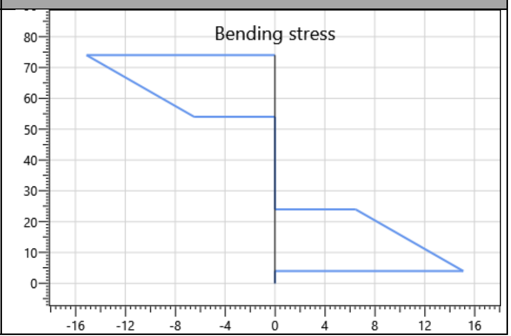
$$\frac{\sigma_{m,d,fi}}{f_{m,d,fi}} \leq 1$$

being

$\sigma_{m,d,fi}$ the design bending stress in the fire situation

$f_{m,d,fi}$ the design bending strength in the fire situation

The following table illustrates the structural schemes and the envelopes of the diagram of the bending moment for the part of each floor with the most sever checks.

Floor name	Combination	Diagram $M_{3\text{-}3}$	Bending stresses
Floor 3	Quasi permanent		

The checks are summarized below. The values resulting from the calculations, relating to each verification, are reported in the form of a percentage.

Floor name	Section	J_{eff} [mm^4]	$M_{3\text{-}3}$ [kNm]	$k_{mod,fi}$	$\gamma_{M,fi}$	k_{fi}	$f_{m,d,fi}$ [MPa]	$\sigma_{m,d,fi}$ [MPa]	Check
Floor 3	TimberTech CLT 120 5s	26333333	11.36	1	1	1.15	27.60	15.10	55%

Shear strength

Shear strength of the layers parallel to the calculation direction

The checks are conducted according to § 6.1.7 of EN 1995-1-1 using the effective cross section according to 4.2.2 of EN 1995-1-2. The following expression shall be satisfied:

$$\frac{\tau_{v,d,fi}}{f_{v,d,fi}} \leq 1$$

being:

$\tau_{v,d,fi}$ the design shear stress in the fire situation

$f_{v,d,fi}$ the design shear strength in fire

The maximum design shear stress in the longitudinal layers can be evaluated using the following expression:

$$\tau_{v,d,fi} = \frac{V_{d,fi} \cdot S_{max,eff}}{J_{eff} \cdot b}$$

where:

V_d, fi is the total shear force at the location in question in the fire situation

$S_{max,eff}$ is the static moment of area of the effective CLT cross section

J_{eff} is the moment of inertia of the effective CLT element cross section

b is the width of the CLT element cross section ($k_{cr} = 1$)

Rolling shear strength of the transversal layers

The checks are conducted according to § 6.1.7 of EN 1995-1-1 using the effective cross section according to 4.2.2 of EN 1995-1-2. The following expression shall be satisfied:

$$\frac{\tau_{R,d,fi}}{f_{v,R,d,fi}} \leq 1$$

being:

$\tau_{R,d,fi}$ the design rolling shear stress in the fire situation

$f_{v,R,d,fi}$ the design shear strength in fire

The maximum design shear stress in the transversal layers can be evaluated using the following expression:

$$\tau_{R,d,fi} = \frac{V_{d,fi} \cdot S_{R,max,eff}}{J_{eff} \cdot b}$$

where:

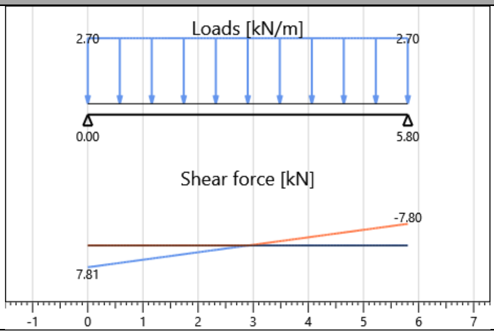
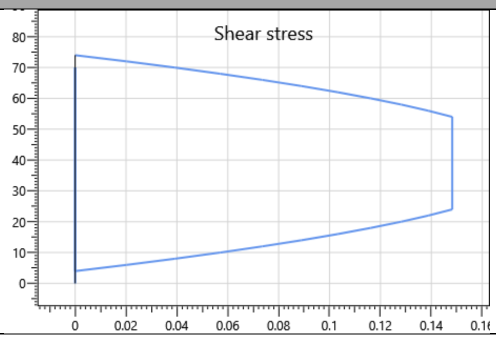
$V_{d,fi}$ is the total shear force at the location in the fire situation

$S_{R,max,fi}$ is the statical moment of area

J_{eff} is the moment of inertia of the effective CLT element cross section

b is the width of the CLT element cross section ($k_{cr} = 1$)

The following table illustrates the structural schemes and the envelopes of the diagram of the shear force for the part of each floor with the most sever checks.

Floor name	Combination	Diagram V_2	Shear stresses
Floor 3	Quasi permanent		

The checks are summarized below. The values resulting from the calculations, relating to each verification, are reported in the form of a percentage.

Floor name	Cross section	J_{eff} [mm^4]	V_2 [kN]	$k_{mod,fi}$	$\gamma_{M,fi}$	k_{fi}	$f_{v,d,fi}$ [MPa]	$\tau_{v,d,fi}$ [MPa]	Check	$f_{R,d,fi}$ [MPa]	$\tau_{R,d,fi}$ [MPa]	Check
Floor 3	TimberTech CLT 120 5s	26333333	7.81	1	1	1.15	4.60	0.15	3%	1.15	0.15	13%