CALCULATION EXAMPLES FOR X-FIX-C AND X-FIX-L CONNECTORS

1 GENERAL INDICATIONS

The design of the X-Fix-C and X-Fix-L connectors of the company Schilcher Trading & Engineering GmbH, X- Fix Holz - Holz Verbindungssysteme, Lamnitz 8, A-9833 Rangersdorf is shown for some typical applications in timber buildings.

The timber-to-timber-connections X-Fix-C and X-Fix-L are developed as birch or beech veneer plywood connectors for joining the cross laminated timber elements in wall-wall connections or ceiling joints. The X-Fix-C connector is designed as a locally placed, tapered (angle between the edges $\alpha = 12.5°$) dovetail or x-shaped dowel with the dimensions L/b/h = 130/95/90 mm. The X-Fix-L connector consists of conically cut coupling bars with dimensions of b/h = 80/50 mm and enables a linear connection up to a length of 3.0 m.

The load-carrying capacities and the slip moduli of the X-Fix-C and X-Fix-L connectors were determined from tension-, shear- and bending tests carried out at the Lignum Test Center, Institute of Timber Engineering and Wood Technology at the Technical University of Graz. The test results can be found in the test reports [1] and [2]. The shear test configuration included tests with a load-to-grain angle of 10° and 0°. The test specimens were assembled with 5-layered cross laminated timber (CLT) elements comprised of 20 mm thick single layers with a total thickness of 100 mm. Used material was "common" CLT with a characteristic density $\rho_k = 380$ kg/m³ and a mean density of $\rho_{mean} = 450$ kg/m³. For the connection system X-Fix-L additional tension and shear tests were performed with a 5-layered CLT elements with a total thickness of 120 mm (lay-up: 30/20/20/30 mm) and coupling bars made of beech veneer plywood.

The calculations are based on the standards ÖNORM EN 1990, ÖNORM EN 1995-1-1 und ÖNORM B 1995-1-1. Details of the calculations are given in the mentioned standards.

2 DEFINITION OF CHARACTERISTIC VALUES OF THE LOAD-CARRYING CAPACITY AND THE SLIP MODULUS

The characteristic values of the load-carrying capacity and the slip modulus of the X-Fix-C and X-Fix-L connectors were defined based on the results of the tension- and shear tests according to [1] and [2] and the regulations given in the standards ÖNORM EN 1990 [3], ÖNORM EN 1995-1-1 [4] and ÖNORM B 1995-1-1 [5]. Details to the design of the connections can be found in the stated standards.

The suggested load-carrying capacities and slip moduli are valid for:

- X-Fix-C and X-Fix-L connectors made of beech or birch veneer plywood
- 5-layered, "common" CLT with a minimum element thickness of $t_{CLT} = 100$ mm (20/20/20/20/20 mm)
- the investigated orientation of the X-Fix connector perpendicular to the top layer of the CLT element

The given load-carrying capacities and slip moduli can be also applied to CLT elements with a thickness of 120 mm (lay-up: 30-20-20-20-30 mm) and a thickness of 140 mm (lay-up: 40-20-20-20-40).

The load-carrying capacities and the slip moduli in Table 1 are related to one X-Fix-C connector. The load-carrying capacities and the slip moduli in Table 2 are related to the unit metre for coupling bar of the X-Fix-L-connector.

Table 1: load-carrying capacities and slip moduli of one X-Fix-C connector and for t_{CLT} = 100/120/140 mm

X-Fix-C – declaration per connector t_{CLT} = 100/120/140 mm; material of connector: beech or birch veneer plywood			
	test configuration/loads	load-carrying capacity R_k [kN]	slip modulus K_{ser} [kN/mm]
X-Fix-C	tension	22.0	18.0
	shear	22.0	20.0
	4-point-bending test	2.8	-

Table 2: load-carrying capacities and slip moduli of one X-Fix-L connector and for t_{CLT} = 100/120/140 mm

X-Fix-L – declaration per unit meter for coupling bar t_{CLT} = 100/120/140 mm; material of connector: beech or birch veneer plywood			
	test configuration/loads	load-carrying capacity R_k [kN/m]	slip modulus K_{ser} [(kN/mm)/m]
X-Fix-L	tension T-joint	15.0	14.5
	tension edge-joint 45°	14.0	8.3
	tension edge-joint 0°	8.5	7.8
	shear edge-joint 45°	8.0	6.5
	shear edge-joint 0°	5.5	4.9

3 CALCULATION EXAMPLES OF X-FIX-C

3.1 Basic cases

X-Fix-C connectors can be stressed in tension and shear or combined. The design of both basic cases is shown in the following subsections.

3.1.1 Design of X-Fix-C stressed in one principal direction - tension

The maximum design force and the related displacement should be calculated for the basic case “stress in tension” shown in Figure 1.

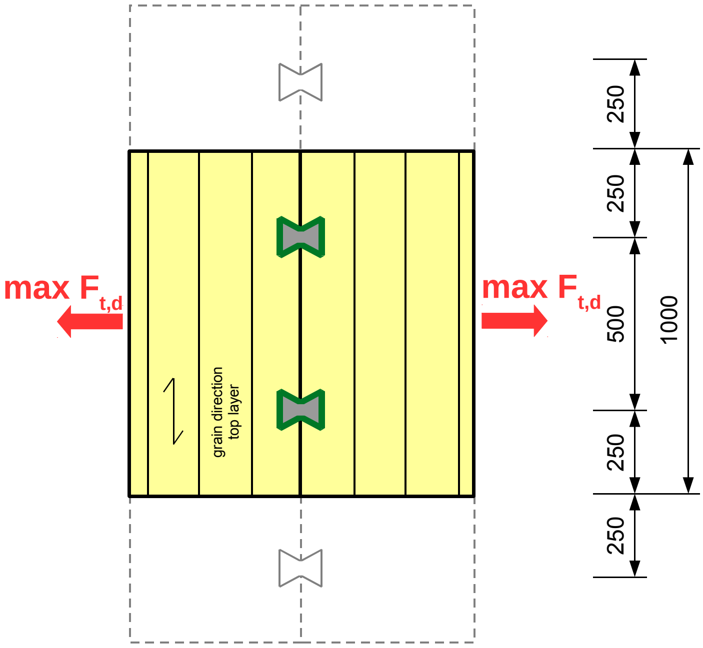

Figure 1: geometry of a X-Fix-C-connection stressed in tension (dimensions in mm)

The characteristic value of the load-carrying capacity in tension $R_{t,k}$ is defined with 22.0 kN. On the basis of the modification factor for duration of load and moisture content k_{mod} = 0.9 for service class 1, the load-duration class “short-term” according to ÖNORM EN 1995-1-1 as well as the distance of the connectors of e = 500 mm, the design tensile force per unit meter $R_{t,d}$ is calculated by

$$R_{t,d} = \frac{k_{mod} \cdot R_{t,k}}{\gamma_M} \cdot \frac{1}{e} = \frac{0.9 \cdot 22.0}{1.3} \cdot \frac{1}{0.50} = 30.5\ \text{kN/m}$$

The related displacement u of the connection in the serviceability limit state is calculated by

$$u = \frac{R_{t,k}}{K_{ser}} = \frac{22.0 \cdot \frac{1}{0.50}}{18.0} = 2.4\ \text{mm/m}$$

3.1.2 Design of X-Fix-C stressed in one principal direction - shear

The maximum design force and the related displacement should be calculated for the basic case “stress in shear” shown in Figure 2.

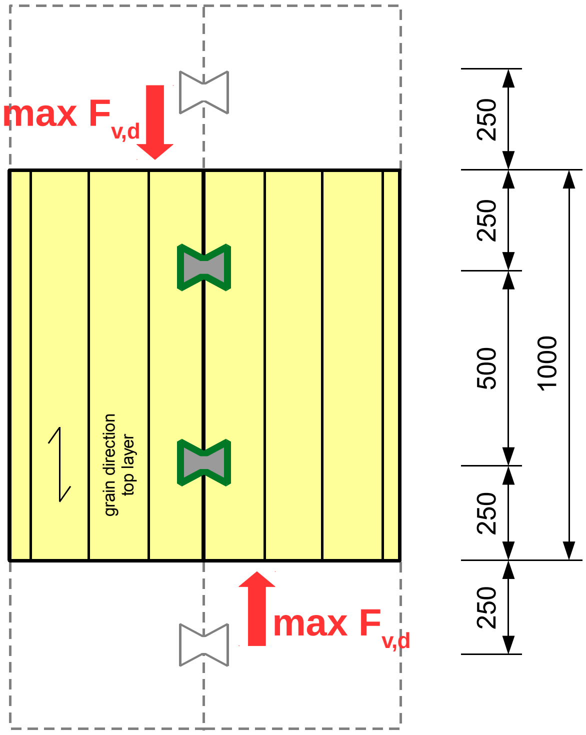

Figure 2: geometry of a shear stressed X-Fix-C-connection (dimensions in mm)

The characteristic value of the load-carrying capacity in shear $R_{v,k}$ is defined with 22.0 kN. On the basis of the modification factor for duration of load and moisture content $k_{mod} = 0.9$ for service class 1, the load-duration class “short-term” according to ÖNORM EN 1995-1-1 as well as the distance of the connectors of e = 500 mm, the design shear force per unit meter $R_{v,d}$ is calculated by

$$R_{v,d} = \frac{k_{mod} \cdot R_{v,k}}{\gamma_M} \cdot \frac{1}{e} = \frac{0.9 \cdot 22.0}{1.3} \cdot \frac{1}{0.50} = 30.5\ \mathrm{kN/m}$$

The related displacement u of the connection u in the serviceability limit state is calculated by

$$u = \frac{R_{v,k}}{K_{ser}} = \frac{22.0 \cdot \frac{1}{0.50}}{20.0} = 2.20\ \mathrm{mm/m}$$

3.2 Application examples

3.2.1 Load-carrying capacity and deformation of a CLT ceiling joined with X-Fix-C connectors

3.2.1.1 Basic conditions

The 5-layered CLT elements of the ceiling with a total thickness of t_{CLT} = 140 mm (lay-up: 40-20-20-20-40 mm) are joined by X-Fix-C connectors with distances of e = 1,000 mm, see Figure 3. Considering the height of a structure (storey height) of h = 3.25 m and a wind pressure of w_k = ± 1.00 kN/m², the static calculation of the wind action leads to a design value of the wind pressure:

$$w_d = \gamma_Q \cdot w_k \cdot h = 1.50 \cdot 1.00 \cdot 3.25 = 4.9\ \text{kN/m}$$

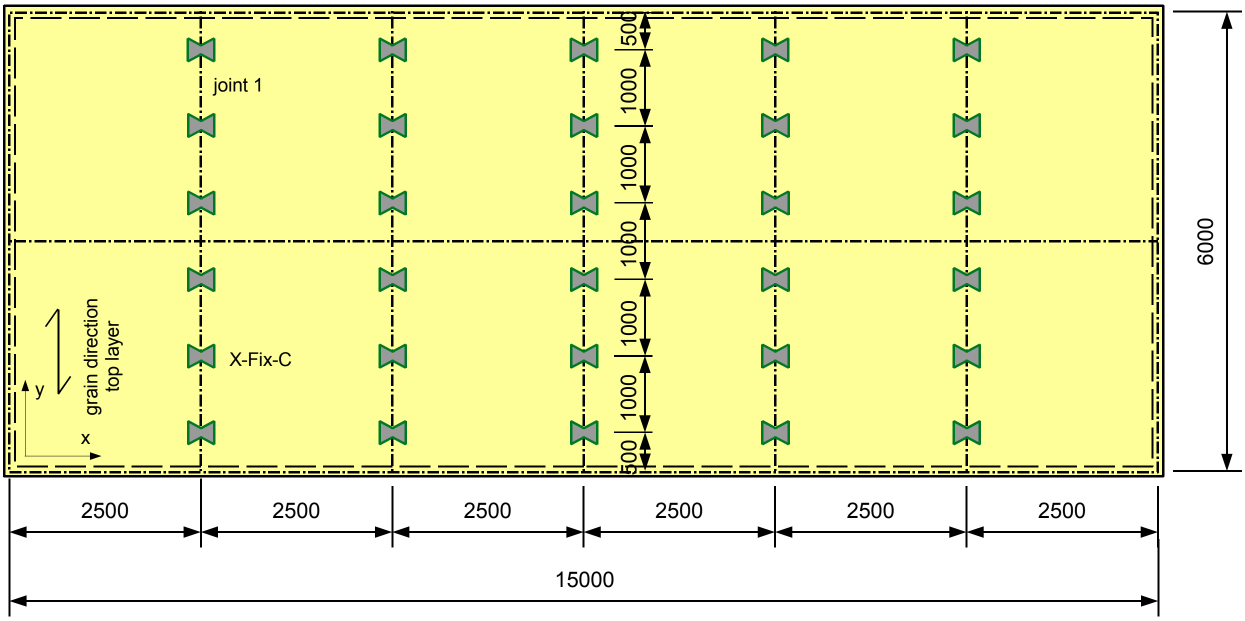

Figure 3: geometry of a CLT ceiling joined by X-Fix-C connectors (dimensions in mm)

3.2.1.2 Verification of the load-carrying capacity in the midspan – loads in-plane

The maximum bending moment in the midspan M_d is calculated by

$$M_d = \frac{w_d \cdot l^2}{8} = \frac{4.9 \cdot 15.0^2}{8} = 137.8\ \text{kNm}$$

The verification of the load-carrying capacity of the X-Fix-connectors is based on the frictionless boundary/support of the ceiling element and the location of the rotation point (the neutral axis respectively) at a distance of z = 500 mm from the edge. The polar moment of inertia I_p which is needed for the determination of a tensile force in the connector is calculated by

$$I_p = \sum_i y_i^2 = 1.0^2 + 2.0^2 + 3.0^2 + 4.0^2 + 5.0^2 = 55.0\ \text{m}^2$$

The design value of the maximum tensile force $F_{t,d}$ for the most stressed connector is calculated by

$$\max F_{t,d} = \frac{M_d}{I_p} \cdot y_{max} = \frac{137.9}{55.0} \cdot 5.0 = 12.5\,\text{kN}$$

The design value of the tensile load-carrying capacity $R_{t,d}$ of a X-Fix-C connector is given by

$$R_{t,d} = \frac{k_{mod} \cdot R_{t,k}}{\gamma_M} = \frac{0.9 \cdot 22.0}{1.3} = 15.2\,\text{kN}$$

The verification leads to

$$\frac{F_{t,d}}{R_{t,d}} = \frac{12.5}{15.2} = 0.82 < 1.0 \qquad \text{Design fulfilled!}$$

3.2.1.3 Verification of the load-carrying capacity in the first butt joint – loads in-plane

The decisive shear force $V_{d,1}$ in the first butt joint is calculated by

$$V_{d,1} = w_d \cdot \left(\frac{l}{2} - b_1\right) = 4.9 \cdot \left(\frac{15.0}{2} - 2.5\right) = 24.5\,\text{kN}$$

The related bending moment $M_{d,1}$ at the first butt joint is calculated by

$$M_{d,1} = \frac{w_d \cdot b_1}{2} \cdot (l - b_1) = \frac{4.9 \cdot 2.50}{2} \cdot (15.0 - 2.5) = 76.6\,\text{kNm}$$

The design shear force $F_{v,d}$ of one X-Fix connector is determined with

$$F_{v,d} = \frac{V_{d,1}}{n} = \frac{24.5}{6} = 4.1\,\text{kN}$$

The design tensile force $F_{t,d}$ of the maximum stressed connector due to the bending moment is calculated by

$$\max F_{t,d} = \frac{M_{d,1}}{I_p} \cdot y_{max} = \frac{76.6}{55.0} \cdot 5.0 = 7.0\,\text{kN}$$

The design value of the tensile load-carrying capacity $R_{t,d}$ of a X-Fix-C connector is given by

$$R_{t,d} = \frac{k_{mod} \cdot R_{t,k}}{\gamma_M} = \frac{0.9 \cdot 22.0}{1.3} = 15.2\,\text{kN}$$

and the design value of the shear load-carrying capacity $R_{t,d}$ of a X-Fix-C connector is calculated by

$$R_{v,d} = \frac{k_{mod} \cdot R_{v,k}}{\gamma_M} = \frac{0.9 \cdot 22.0}{1.3} = 15.2\,\text{kN}\,.$$

Based on the consideration of combined tensile and shear stresses in a quadratic interaction, the verification of the most stressed X-Fix C connector leads to

$$\left(\frac{F_{v,d}}{R_{v,d}}\right)^2 + \left(\frac{F_{t,d}}{R_{t,d}}\right)^2 = \left(\frac{4.1}{15.2}\right)^2 + \left(\frac{7.0}{15.2}\right)^2 = 0.07 + 0.21 = 0.28 < 1.0 \qquad \text{Design fulfilled!}$$

3.2.1.4 Verification of the deflection in the midspan – loads in-plane

The verification of the deflection in the midspan is based on a simple spring model with consideration of a pliable and flexible shear CLT plate element. The friction parts of the cross walls will be neglected. The deflection of the CLT ceiling due to the connectors consists of the translational and the rotational spring.

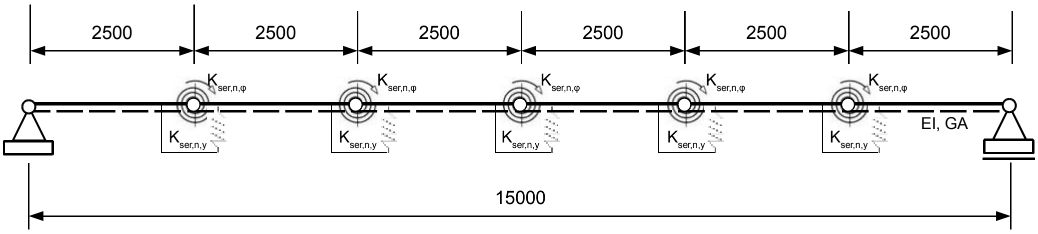

Figure 4: spring model for calculation of deflections in midspan (dimensions in mm)

The application of the wind action on the joined CLT ceiling elements leads to an interaction between the translation of the connector (consideration of the slip modulus in shear $K_{ser,v}$) and the rotation resulting with gaps of the X-Fix-C-Connector (consideration of the slip modulus in tension $K_{ser,t}$).

Considering the slip modulus $K_{ser,s}$ for shear, the slip modulus of the translational part $K_{ser,n,y}$ of the X-Fix-C connectors in the butt joint is calculated with

$$K_{ser,n,y} = K_{ser,v} \cdot n = 20{,}000 \cdot 5 = 100{,}000\ \text{N/mm} = 1.0 \cdot 10^5\ \text{kN/m}$$

Considering the slip modulus $K_{ser,t}$ for tension, the slip modulus of the rotational spring $K_{ser,n,\varphi}$ of the X-Fix-C connectors in the butt joint is calculated with

$$K_{ser,n,\varphi} = K_{ser,t} \cdot I_p = 18{,}000 \cdot 55.0 = 990{,}000\ \text{kNm/rad}$$

In the serviceability limit state the deflection w_m of the CLT ceiling in the midspan is calculated by

$$
\begin{aligned}
w_m &= \int_l \frac{M \cdot \bar{M}}{E_{0,CLT,mean} \cdot I} \cdot dx + \int_l \frac{V \cdot \bar{V}}{G_{CLT,mean} \cdot A_v} \cdot dx + \sum_i \frac{V_i \cdot \bar{V}_i}{K_{ser,n,y}} + \sum_i \frac{M_i \cdot \bar{M}_i}{K_{ser,n,\varphi}} = \\
&= 2 \cdot \frac{15.0}{2} \cdot \frac{5}{12} \cdot \frac{91.4 \cdot 3.75}{1.16 \cdot 10^7 \cdot 0.720} + 2 \cdot \frac{15.0}{2} \cdot \frac{1}{2} \cdot \frac{24.4 \cdot 0.50}{4.50 \cdot 10^5 \cdot 0.70} + \\
&+ \frac{2 \cdot 16.3 \cdot 0{,}50 + 2 \cdot 8.1 \cdot 0.50 + 0}{100.000} + \frac{2 \cdot 50.8 \cdot 1.25 + 2 \cdot 81.3 \cdot 2.50 + 91.4 \cdot 3.75}{990.000} = \\
&= 2.56 \times 10^{-4} + 2.90 \times 10^{-4} + 2.44 \times 10^{-4} + 8.86 \times 10^{-4} = 1.68 \times 10^{-3} \text{ m} = 1.68 \text{ mm} \\
&(= 15.3\% + 17.3\% + 14.6\% + 52.8\% = 100\%)
\end{aligned}
$$

where:

M, V	maximum bending moment and shear force due to real load ($w_d = \gamma_Q \cdot w_k \cdot h = 1.0 \cdot 1.00 \cdot 3.25 = 3.25$ kN/m)
$\bar{M}, \bar{V}$	maximum bending moment and shear force due to virtual load
$E_{0,CLT,mean}$	mean value of the modulus of elasticity of the CLT element [kN/m²]
$G_{CLT,mean}$	mean value of the effective shear modulus of the CLT element [kN/m²]
I	moment of inertia [m^4] (only the cross layers taken into account) $I = \frac{\sum t_Q \cdot h^3}{12} = \frac{0.04 \cdot 6.00^3}{12} = 0.72 \text{ m}^4$
A_v	shear area [m²] $A_s = \frac{A}{\kappa} = \frac{0.14 \cdot 6.00}{1.20} = 0.70 \text{ m}^2$

The maximum deflection for bracings is restricted to *l*/500 according to ÖNORM EN 1995-1-1. Thus, the limited value in the presented example is

$$\max w = \frac{l}{500} = \frac{15{,}000}{500} = 30.0 \text{ mm}$$

The verification of the deflection of the CLT ceiling for in-plane loads leads to

$$\frac{w_m}{\max w} = \frac{1.68}{30.0} = 0.056 < 1.0 \qquad \text{Design fulfilled!}$$

3.2.2 Load-carrying capacity and deformation of a CLT wall (diaphragm) joined with X-Fix-C connectors

Figure 5 shows a CLT wall which should transfer the resulting horizontal actions to the underlying floor. The wall assembly comprises several panels which are joined with X-Fix-C connectors. Because of the large storey height (h = 3.25 m) an upper panel is needed which consists of a single CLT element with a height of 0.655 m and is joined and braced at a distance of 6.0 m by cross walls on each side. It is assumed that the joined CLT wall diaphragm can transfer all occurring loads without buckling. The friction in the joint of the upper element with the lower CLT wall elements will be neglected. The X-Fix-C connector in the wall part between the windows is not considered in the calculation of the wall diaphragm.

The loads in-plane comprise the vertical loads, which consists of permanent loads amounting to g_k = 2,50 kN/m and snow loads with s_k = 5,0 kN/m, and the shear loading due to wind action in horizontal direction $w_k = \pm 1.00$ kN/m².

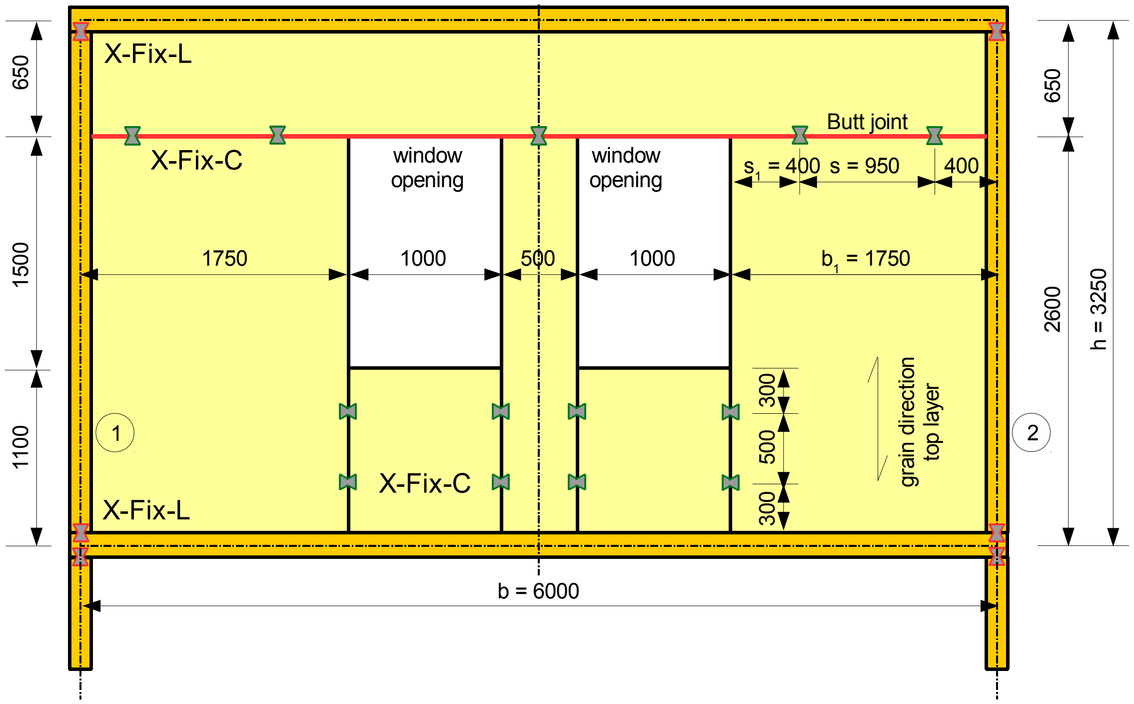

Figure 5: geometry of a CLT wall joined with X-Fix-C connectors (dimensions in mm)

3.2.2.1 Horizontal load transfer in the butt joint – loads in-plane

Because of the wind action on the outer CLT wall 2 (effective length l = 6.0 m) the floor and ceiling CLT panels get the horizontal shear loads which are transferred to the inner CLT wall and into the butt joint of the upper and lower CLT element respectively. The horizontal load transfer takes place only in areas on the left and on the right of the window openings - the area between the window openings is not considered in the calculation. The horizontal load H_d in the butt joint is calculated with

$$H_d = \gamma_Q \cdot w_k \cdot h \cdot l \cdot 0.5 = 1.5 \cdot 1.00 \cdot 3.25 \cdot 6.0 \cdot 0.5 = 14.6\,\mathrm{kN}$$

Due to design requirement two sets of X-Fix-C connectors, each comprising two connectors, are positioned in the areas with a length of b_1 = 1.75 m. The distances between two connectors and to the sides amounts to s = 950 mm and s_1 = 400 mm, respectively.

The load carrying capacity $R_{v,d}$ of one X-Fix-C connector is

$$R_{v,d} = \frac{k_{mod} \cdot R_{v,k}}{\gamma_M} = \frac{0.9 \cdot 22.0}{1.3} = 15.2\ \text{kN}\ .$$

3.2.2.2 Verification of the uplift forces

The calculation of the moment is based on the simplified procedure assuming that the center of rotation lies on the axis of the X-Fix-C connectors. The influence of the bending stiffness of the upper panel will be neglected (conservative approach). The design value of the bending moment M_d can be calculated with consideration of the upper panel height of $h_2 = 650$ mm by

$$M_d = H_d \cdot h_2 = 14.6 \cdot 0.65 = 9.5\ \text{kNm}$$

The design value of the maximum tensile force $F_{t,d}$ for one connector is

$$F_{t,d} = \frac{M_d}{s} = \frac{9.5}{0.95} = 10.0\ \text{kN}$$

The design value of the resulted compression load $F_{c,d}$ due to the permanent load is calculated with consideration of a sufficient bending stiffness of the upper panel:

$$F_{c,d} = \gamma_G \cdot g_k \cdot (\frac{s}{2} + s_1) = 1.0 \cdot 2.5 \cdot (\frac{0.95}{2} + 0.40) = 2.2\ \text{kN}$$

The X-Fix-C connector has to transfer following resulting load F_d:

$$F_d = F_{t,d} - F_{c,d} = 10.0 - 2.2 = 7.8\ \text{kN}$$

Based on the consideration of combined tensile and shear loads in a quadratic interaction, the verification of the most stressed X-Fix C connector leads to:

$$\left(\frac{F_{v,d}}{R_{v,d}}\right)^2 + \left(\frac{F_d}{R_{t,d}}\right)^2 = \left(\frac{\left(\frac{14.6}{4}\right)}{15.2}\right)^2 + \left(\frac{7.8}{15.2}\right)^2 = 0.06 + 0.26 = 0.32 < 1.0 \qquad \text{Design fulfilled!}$$

Note 1:

The bending stiffness in the area of the horizontal butt joint has to be ensured for a sufficient load-carrying capacity of the joined CLT wall against buckling. For example, this can be done by facade elements which are assembled and connected with the CLT wall elements with a load carrying connection.

Note 2:

The verification of the load carrying capacity of the CLT wall for loads in-plane has to be done separately. The calculation requires the determination of the design member forces for the most unfavourable load combination.

Note 3:

For the load introduction in-plane in lengthwise direction additional connections have to be provided (e.g. angle brackets).

4 CALCULATION EXAMPLES OF X-FIX-L COUPLING BARS

4.1 Basic cases

4.1.1 Design of X-Fix-L coupling bars in tension T-joints

The characteristic value of the load-carrying capacity in tension $R_{t,k}$ for a T-joint is defined with 15.0 kN (see Table 2 and Figure 6). The amount of the shear force V_d in the loaded CLT wall will be neglected.

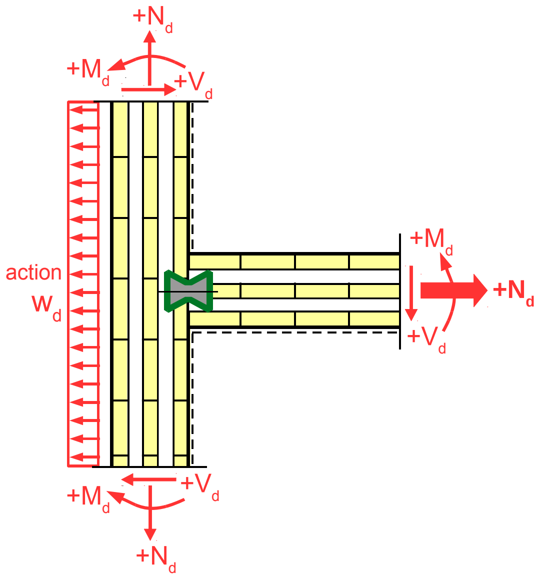

Figure 6: X-Fix-L coupling bar in a tension T-joint

On the basis of the modification factor for duration of load and moisture content k_{mod} = 0.9 for service class 1 and the load-duration class "short-term" according to ÖNORM EN 1995-1-1, the design tensile force per unit meter $R_{t,d}$ is calculated by:

$$R_{t,d} = \frac{k_{mod} \cdot R_{t,k}}{\gamma_M} = \frac{0.9 \cdot 15.0}{1.3} = 10.4\ \text{kN / m}$$

The related displacement of the connection in the serviceability limit state is calculated by:

$$u = \frac{R_{t,k}}{K_{ser}} = \frac{15.0}{14.5} = 1.03\ \text{mm}$$

4.1.2 Design of X-Fix-L coupling bars in tension edge-joints

4.1.2.1 Edge joint – butt joint 0°

The characteristic value of the load-carrying capacity in tension $R_{t,k}$ for an edge-butt joint is defined with 8.5 kN (see Table 2 and Figure 7). The amount of the shear force V_d in the loaded CLT wall will be neglected.

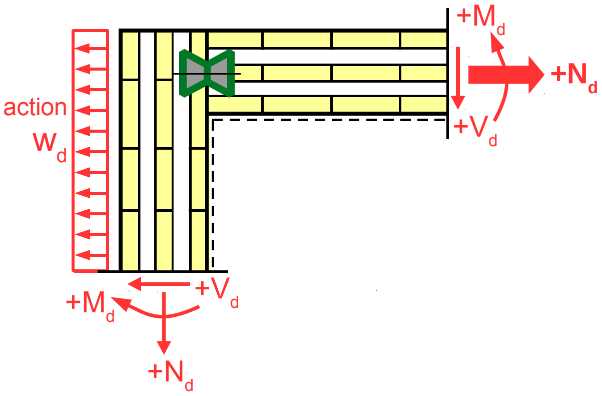

Figure 7: X-Fix-L coupling bar in a tension edge-joint (butt joint 0°)

On the basis of the modification factor for duration of load and moisture content k_{mod} = 0.9 for service class 1 and the load-duration class “short-term” according to ÖNORM EN 1995-1-1, the design tensile force per unit meter $R_{t,d}$ is calculated by:

$$R_{t,d} = \frac{k_{mod} \cdot R_{t,k}}{\gamma_M} = \frac{0.9 \cdot 8.5}{1.3} = 5.9 \text{ kN/m}$$

The related displacement of the connection in the serviceability limit state is calculated by:

$$u = \frac{R_{t,k}}{K_{ser}} = \frac{8.5}{7.8} = 1.09 \text{ mm}$$

4.1.2.2 Edge joint – mitre joint 45°

The characteristic value of the load-carrying capacity in tension $R_{t,k}$ for a mitre joint is defined with 14.0 kN (see Table 2 and Figure 8). The amount of the shear force V_d in the loaded CLT wall will be neglected.

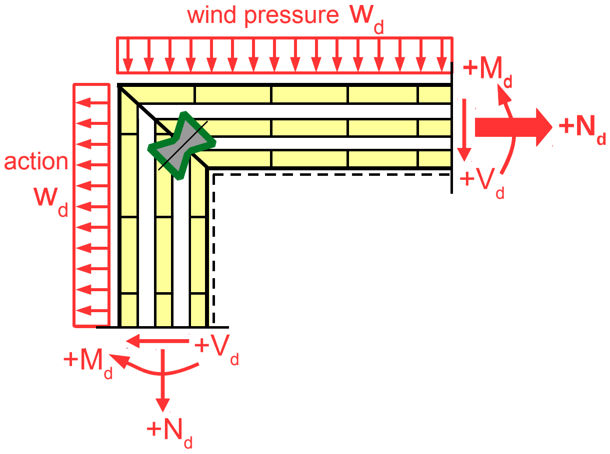

Figure 8: X-Fix-L coupling bar in a tension edge-joint (mitre joint 45°)

On the basis of the modification factor for duration of load and moisture content k_{mod} = 0.9 for service class 1 and the load-duration class "short-term" according to ÖNORM EN 1995-1-1, the design tensile force per unit meter $R_{t,d}$ is calculated by:

$$R_{t,d} = \frac{k_{mod} \cdot R_{t,k}}{\gamma_M} = \frac{0.9 \cdot 14.0}{1.3} = 9.7\ \mathrm{kN/m}$$

The related displacement of the connection in the serviceability limit state is calculated by:

$$u = \frac{R_{t,k}}{K_{ser}} = \frac{14.0}{8.3} = 1.69\ \mathrm{mm}$$

4.1.3 Design of X-Fix-L coupling bars in shear edge-joints

4.1.3.1 Edge joint – butt joint 0°

The characteristic value of the load-carrying capacity in shear $R_{v,k}$ for an edge-butt joint is defined with 5.5 kN (see Table 2 and Figure 9). The amount of the tension force N_d in the loaded CLT wall will be neglected.

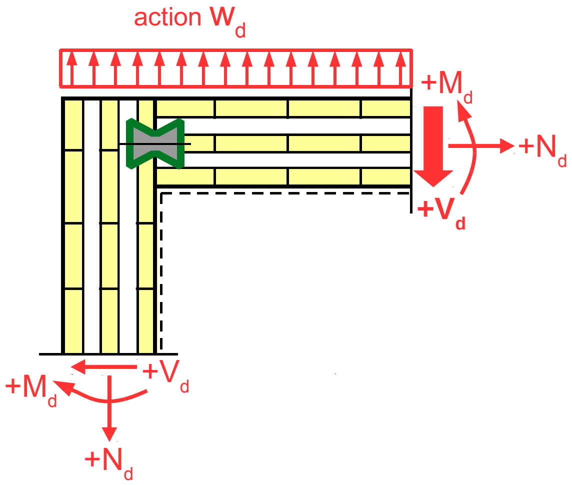

Figure 9: X-Fix-L coupling bar in a shear edge-joint (butt joint 0°)

On the basis of the modification factor for duration of load and moisture content k_{mod} = 0.9 for service class 1 and the load-duration class "short-term" according to ÖNORM EN 1995-1-1, the design shear force per unit meter $R_{v,d}$ is calculated by:

$$R_{v,d} = \frac{k_{mod} \cdot R_{v,k}}{\gamma_M} = \frac{0.9 \cdot 5.5}{1.3} = 3.8\ \mathrm{kN/m}$$

The related displacement of the connection in the serviceability limit state is calculated by:

$$u = \frac{R_{v,k}}{K_{ser}} = \frac{5.5}{4.9} = 1.12\ \mathrm{mm}$$

4.1.3.2 Edge joint – mitre joint 45°

The characteristic value of the load-carrying capacity in shear $R_{v,k}$ for an edge-mitre joint is defined with 8.0 kN (see Table 2 and Figure 10). The amount of the tension force N_d in the loaded CLT wall will be neglected.

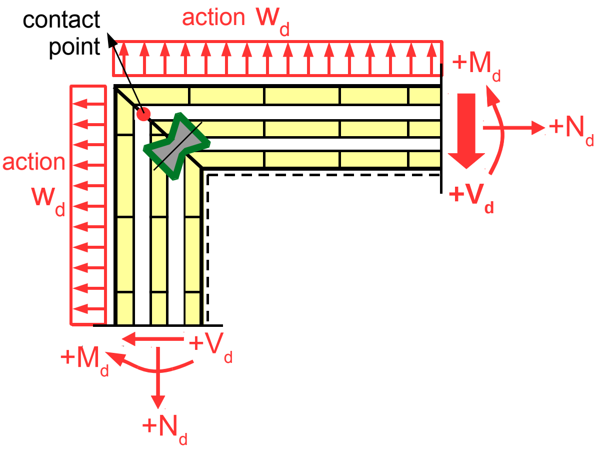

Figure 10: X-Fix-L coupling bar in a shear edge-joint (mitre joint 45°)

On the basis of the modification factor for duration of load and moisture content k_{mod} = 0.9 for service class 1 and the load-duration class “short-term” according to ÖNORM EN 1995-1-1, the design shear force per unit meter $R_{v,d}$ is calculated by:

$$R_{v,d} = \frac{k_{mod} \cdot R_{v,k}}{\gamma_M} = \frac{0.9 \cdot 8.0}{1.3} = 5.5\,\text{kN}/\text{m}$$

The related displacement of the connection in the serviceability limit state is calculated by:

$$u = \frac{R_{v,k}}{K_{ser}} = \frac{8.0}{6.5} = 1.23\,\text{mm}$$

4.2 Application examples

4.2.1 Wind load transfer from wall elements to ceiling for loads out of plane

The CLT wall element is connected with the upper and lower CLT ceiling panels by X-Fix-L coupling bars which have to transfer the wind loads acting out of plane, see Figure 5. The design value w_d of the occurred wind pressure $w_k = \pm$ 1.00 kN/m² is calculated with:

$$w_d = \gamma_Q \cdot w_k \cdot h = 1.50 \cdot 1.00 \cdot \frac{1}{2} \cdot 3.25 = 2.4\,\text{kN}/\text{m}$$

On the basis of the modification factor for duration of load and moisture content k_{mod} = 0.9 for service class 1 and the load-duration class “short-term” according to ÖNORM EN 1995-1-1, the design shear force per unit meter $R_{v,d}$ is calculated by (the friction in the joint between ceiling and wall is neglected):

$$R_{v,d} = \frac{k_{mod} \cdot R_{v,k}}{\gamma_M} = \frac{0.9 \cdot 5.5}{1.3} = 3.8\,\text{kN}/\text{m}$$

The verification leads to:

$$\frac{w_d}{R_{v,d}} = \frac{2.4}{3.8} = 0.63 < 1.0 \text{ Design fulfilled!}$$

4.2.2 Wind load transfer of wall elements with edge joint connection

Two CLT wall elements connected with the X-Fix-L coupling bars in an edge butt joint have to bear the local wind forces acting. The X-Fix-L connector is thereby loaded in tension and shear. The considered effective width of the CLT wall elements is b = 1.75 m. The design value of the occurred wind pressure $w_k = \pm 1.00$ kN/m² is calculated with:

$$w_d = \gamma_Q \cdot w_k \cdot b = 1.5 \cdot 1.0 \cdot 1.75 = 2.6\, kN/m$$

On the basis of the modification factor for duration of load and moisture content $k_{mod} = 0.9$ for service class 1 and the load-duration class “short-term” according to ÖNORM EN 1995-1-1, the design shear force per unit meter $R_{v,d}$ and the design tension force per unit meter $R_{t,d}$ is calculated by:

$$R_{v,d} = \frac{k_{mod} \cdot R_{v,k}}{\gamma_M} = \frac{0.9 \cdot 5.50}{1.3} = 3.8\, kN/m\,,$$

$$R_{t,d} = \frac{k_{mod} \cdot R_{t,k}}{\gamma_M} = \frac{0.9 \cdot 8.5}{1.3} = 5.9\, kN/m\,.$$

Based on the consideration of combined tensile and shear loads in a quadratic interaction, the verification of the X-Fix-L connector leads to:

$$\left(\frac{w_d}{R_{v,d}}\right)^2 + \left(\frac{w_d}{R_{t,d}}\right)^2 = \left(\frac{2.6}{3.8}\right)^2 + \left(\frac{2.6}{5.9}\right)^2 = 0.47 + 0.19 = 0.63 < 1.0$$

4.3 Summary

This paper shows some calculation examples for the connection systems X-Fix-C and X-Fix-L connectors of the company Schilcher Trading & Engineering GmbH , X- Fix Holz - Holz Verbindungssysteme, Lamnitz 8, A-9833 Rangersdorf.

Both connection systems are applicable for smaller timber buildings made of CLT and transfer the common loads – especially wind actions – in tension and shear. The used characteristic values of the load-carrying capacities and slip moduli are based on the test reports in [1], [2] and are valid for the defined boundary conditions in the mentioned reports.

The presented calculation examples can be applied generally. The static verification has to be done for each building individually.

For the load introduction in-plane in the lengthwise direction (e.g. loads in the floor joint) additional connections (e.g. angle brackets) and separate verifications have to be provided.

5 DOCUMENTS

[1] Silly, G.: Forschungsbericht zur FFG-Machbarkeitsstudie für Klein- und Mittelbetriebe "GREENETHIC X-FIX BSP-Verbindungssystem". holz.bau forschungs gmbh, Graz, June 2014, 91 pages (in german)

[2] Silly, G.: "Greenethic X-Fix-C und X-Fix-L Verbindungssysteme für BSP". Forschungsbericht, holz.bau forschungs gmbh, Graz, April 2016, 48 pages (in german)

[3] ÖNORM 1995-1-1: Eurocode 5: Design of timber structures — Part 1-1: General — Common rules. 2015-06-15

holz.bau forschungs gmbh Graz
M. Augustin
25th of April 2016

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