



ASSY[®] SCREWS – MANUAL FOR ETA-11/0190

Design of connections and reinforcements
in timber construction

**READY
FOR WORK**



FOREWORD

Dear customers,

Wood is playing an increasingly important role in the construction industry, in particular due to its lower carbon footprint compared to mineral building materials. However, designing timber structures can be especially complex for engineers with little or no prior experience using timber as a building material. In particular, screw-based fastening and reinforcement systems pose difficulties to designers due to the wide range of connection and reinforcement options, the verification methods and the regulatory execution requirements. The aim of this manual is therefore to provide practitioners with a clear and concise guide to fastening systems using ASSY® screws in timber members.

The mechanical properties of ASSY® screws are defined in European Technical Assessment ETA-11/0190. In conjunction with design standards DIN EN 1995-1-1:2010, DIN EN 1995-1-1/A2:2014 and DIN EN 1995-1-1/NA:2013 (collectively referred to as EC 5), the manual serves as a consolidated document that enables users to design connections using ASSY® screws with nominal diameters ranging from 6 mm to 14 mm.

Since the introduction of EC 5 in 2010, there have been significant technical advancements in the field of timber construction. These developments will be regulated in forthcoming standard FprEN1995-1-1, referred to as Draft EC 5 here. At the time of publication of this manual, these advancements represent state-of-the-art developments of the currently valid EC 5 regulations. Therefore, the updates have been incorporated in the relevant sections of this manual. We have deliberately refrained from providing new design approaches for which existing models already exist in EC 5, as Draft EC 5 has not yet been introduced into building regulations.

All approvals and standards referenced in this document reflect the versions valid at the time of publication of this manual.

The first part of this manual addresses the general aspects of the ASSY® screw technology, such as the various screw types and their applications, execution specifications and fundamental design principles (Sections 1 and 2). The second part provides further details on the load-bearing capacity and geometric design of differently shaped screw connections (Sections 3 and 4), using calculation examples to illustrate the theory. The third part of the manual focuses on specific topics, such as the reinforcement of timber members using screws (Sections 6 to 11).

Best wishes from Künzelsau,



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1 SCREWS AND MATERIALS



1.1 Approval and monitoring

ASSY® wood screws have been approved for marketing within the European Economic Area in accordance with the Construction Products Regulation based on European Technical Assessment ETA-11/0190, the corresponding declaration of performance and CE marking. The performance characteristics defined in ETA-11/0190, such as tensile load-bearing capacity and withdrawal parameters, are continuously monitored and ensured through mandatory in-house production control and voluntary external production control by a notified body. This ensures safe and efficient products in the highest quality.

1.2 Screw types and their applications

Selecting the right screw can be challenging, as the various screw types have been developed to best meet the requirements of specific applications. To make it easier to choose the right type of screw from the wide range available, screws can first be divided into two groups: partially threaded screws and fully threaded screws.

1.2.1 Partially threaded screws

Partially threaded screws have a timber thread that extends from the screw tip over only a portion of the total length, as shown in Figure 1. The remaining length of the screw consists of the unthreaded screw shank and the screw head.

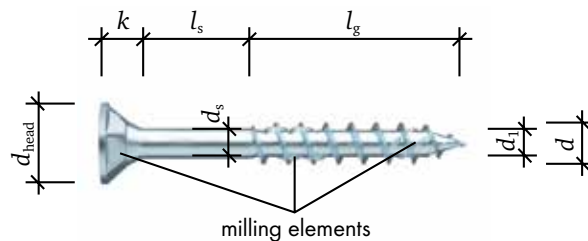


Figure 1: Partially threaded screw with component designations.

Partially threaded screws are generally used when two timber members need to be pulled together and connected without a gap. The screw is first inserted through member A into member B, with the thread portion being fully anchored in member B once the screwing process is complete. During tightening, the screw head begins to pull member A and member B together as soon as it comes into contact with the surface of member A, as shown in Figure 2.

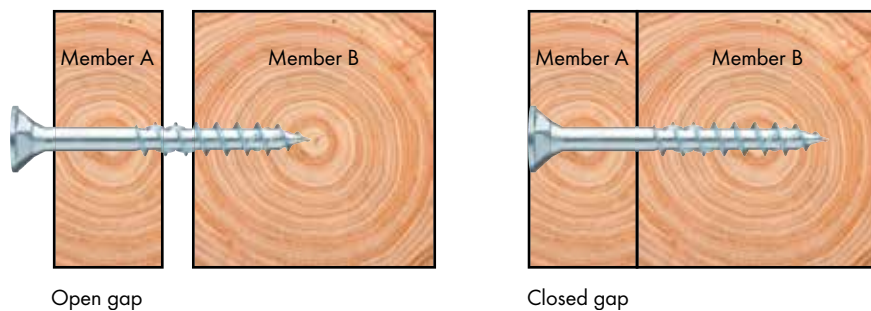


Figure 2: Partially threaded screw with members during installation (left) and after installation (right).

Milling elements on the screw tip, at the transition to the screw shank and, in the case of countersunk heads, below the screw head, reduce the tightening torque and ensure clean countersinking of the screw head. A distinctive feature of ASSY® screws is the integrated milling shank; see milling elements in the thread at the transition to the shank in Figure 1. The thread flanks on the screw head extend beyond the milling shank to minimise the risk of injury from the sharp milling shank, which on conventional screws is located between the thread and the shank. The coarse thread of partially threaded screws has a large thread pitch to speed up tightening compared to screws with single-start thread, thereby enabling more efficient installation.

Double-thread screws are a special type of partially threaded screw; see Figure 3. The ASSY® Isotop, ASSY® P and ASSY® PII double-thread screws feature the same basic design as partially threaded screws, but with a second thread below the screw head.

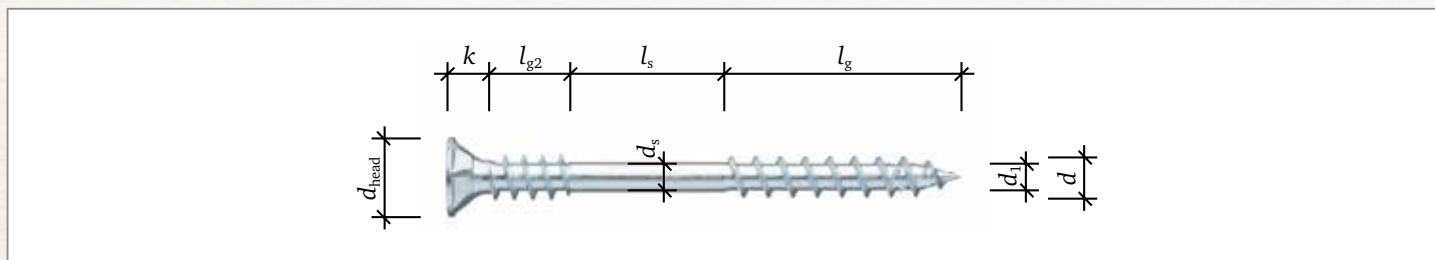


Figure 3: Double-threaded screw with components.

The differing thread pitches (ASSY® PII) and outer diameters (ASSY® P) of the two threads makes it possible to pull two components together by approx. 1 mm, whereas this is not limited with conventional partially threaded screws. The decisive advantage of the double-thread screws is the significantly higher head pull-through resistance than that of comparable partially threaded screws with countersunk head. Consequently, if the decisive failure case is the screw head being pulled through component A, double-threaded screws can achieve a significantly higher load-bearing capacity than comparable countersunk head screws.

1.2.2 Fully threaded screws

On fully threaded screws (Figure 4), the thread covers the entire length of the shank. This maximises the anchorage length of the screw in the timber and thus the withdrawal capacity against being pulled out in the direction of the screw axis.

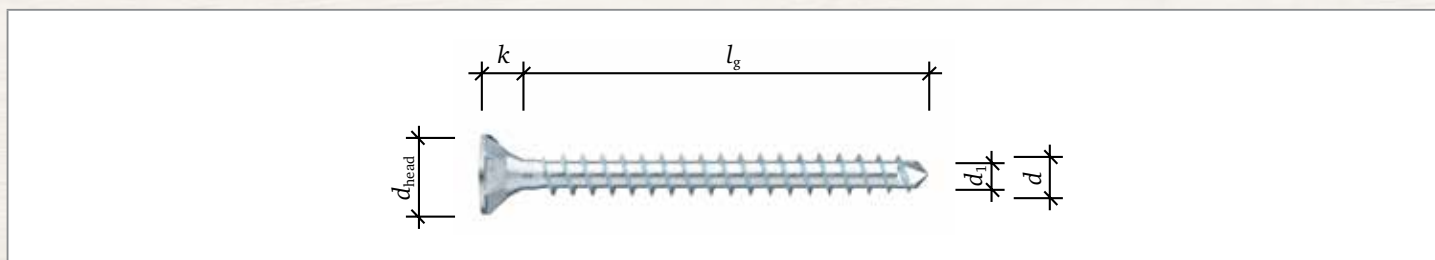


Figure 4: Fully threaded screw with components.

The more threads anchored in the timber, the greater the force required to pull the screw out of or into the timber. Therefore, in applications where high forces acting primarily in the direction of the screw axis need to be transmitted in component connections or reinforcements, fully threaded screws are preferable to partially threaded screws due to their longer thread length. The wide variety of screw lengths available makes it easy to achieve deep embedment depths. The special single-start thread on fully threaded screws reduces the screw-in torque even with very long thread engagement lengths, which enables greater control, for example when precisely tightening screws to mount metal fixtures on timber.

1.3 Head shapes

The screw feature with the greatest number of variants is the screw head. A wide range of screw head geometries are available to suit different applications. The head shapes can be classified into those suitable for connecting metal parts to timber and those optimised for maximum countersinking of the screw head in the timber or for a high head pull-through parameter. Table 1 provides an overview of the most common screw head shapes used in timber construction and the head diameters d_{head} for the nominal diameters available in the ASSY® range. The nominal diameter is the outer thread diameter d .

Table 1: Screw head shapes with nominal diameter d and corresponding screw head diameters d_{head} *

	CSMP	CS	CSMR A2	CSMR-WW	CH	ETX	Pan-JH	Pan	COMBI	WH	WH II	WH A2
												
d in mm	d_{head} in mm	d_{head} in mm	d_{head} in mm	d_{head} in mm	d_{head} in mm	d_{head} in mm	d_{head} in mm	d_{head} in mm	d_{head} in mm	d_{head} in mm	d_{head} in mm	d_{head} in mm
5.0	9.5	9.6 ^a	-	9.5	-	-	8.0	10.0 ^b	-	12.0	-	-
5.5	-	-	10.0	-	6.8 ^c	-	-	-	-	-	-	-
6.0	12.0	12.0 ^d	-	10.4	8.2	-	-	12.0 ^b	9.0	14.0	-	14.0
6.5	-	-	12.0	-	-	-	-	-	-	-	-	-
8.0	15.0 ^b	-	-	-	10.0 ^e	-	-	14.5 ^c	12.0	22.1	18.4	18.9
10.0	18.5	20.0	-	-	13.4 ^e	-	-	-	15.0 ^f	25.2	-	-
12.0	22.5	-	-	-	-	-	-	-	17.0 ^f	29.4	-	-
14.0	-	-	-	-	-	18.0	-	-	-	-	-	-

^a Diameter also available in A2, 1.4529 or 1.4539

^b Diameter also available in A2

^c Diameter only available in A2

^d Diameter only available in A2, 1.4529 or 1.4539

^e For the ASSY® Isotop, with a tip thread of 8 mm and underhead thread of 10 mm, the head diameter is $d_{\text{head}} = 11$ mm.

^f For the ASSY® 4 COMBI T, screws with nominal diameters of 10 mm and 12 mm have a width across flats of 17 mm, so the head diameter can be given as $d_{\text{head}} = 17$ mm.

Regulation: ETA-11/0190

Explanation

CSMP	Countersunk head with milling pockets
CS	Countersunk head
CSMR A2	Countersunk head with milling ribs on A2 screws
CSMR-WW	Countersunk head with milling ribs, high collar and large RW drive
CH	Socket head
ETX	External TX head
Pan-JH	Joist hanger screw head
Pan	Pan head
COMBI	Combination screw head with shank reinforcement
WH	Washer head
WH II	Washer head II
WH A2	Washer head on A2 screws (d_{head} reduced for $d = 8$ mm)

Screws with a **CSMP** head have milling pockets to create a clean countersink when screwed into timber, but also fit precisely into countersunk holes in steel fixtures. The **CS** head is primarily suitable for creating timber-to-steel connections where the screw heads need to be flush with the steel member and are countersunk accordingly. The CS head is also suitable for countersinking in timber. The **CSMR** and **CSMR-WW** head shapes have milling ribs and are optimised for clean countersinking in timber, but are less suitable for timber-to-steel connections. The WW variant provides an especially deep and secure fit of the bit in the screw head drive, which prevents the bit from slipping and spinning in the screw drive. The heavily reduced geometry of the **CH** head not only allows for very inconspicuous timber-to-timber connections, but also generates only minimal additional splitting forces when the screw head is countersunk into the timber. The external drive of the **ETX** head enables maximum power transmission while screwing and is therefore used on fully threaded screws with the largest diameter of 14 mm.

Screw heads are primarily suitable for creating timber-to-steel connections, as their underhead geometry ensures the most precise fit possible in the steel fixtures. Care must be taken to ensure that the screws are tightened correctly using a screwdriver with the specified torque limits. With its underhead reinforcement, the **Pan-JH** head is a development of the **Pan** head and forms a secure connection between steel and timber (e.g. in shear angles or tension ties). The **COMBI** head is suitable for highly stressed timber-to-steel connections. Similar to the Pan-JH head, the diameter of the underhead reinforcements fits precisely into the bore of the steel fixture, while the underside of the hexagon head presses the steel fixture against the timber member. In addition to the RW internal drive, the hexagon head ensures reliable transmission of the tightening torque.

Finally, the **WH** and **WH II** washer head variants enable timber members to be securely pulled together and offer increased resistance to pull-through forces on the screw head. The WH II head can be screwed flush with the timber surface for a visually appealing finish.

Many of the screw heads depicted can also be used in combination with various washers. In addition to classic washers, such as countersunk or DIN washers that increase member pull-together forces or head pull-through resistance, various angled washers are available to enable precise 45° sheet timber-to-steel connections, for example. Relevant washers are regulated in various sources, such as the annex of ASSY® ETA-11/0190.

1.4 Screw tips

ASSY® screws are available with two types of tips: the classic needle tip and the drill tip optimised for maximum cutting capacity; see Figure 5.



Figure 5: Most common tip geometries.

With the ASSY® needle tip (Table 2, columns 2 and 3), the screw thread extends to the conical screw tip, allowing for precise positioning and immediate pull-in of the screw in the timber. The milling elements in the thread at the needle tip (see Figure 5) reduce the screwing torque during screwing by effectively enlarging the screw channel for the following threaded section. The ASSY®plus drill tips with the "plus" suffix (Table 2, columns 4 and 5) feature special cutting edges that are designed to match the screw speed determined by the thread pitch while screwing in and essentially perform three functions. Firstly, the improved drilling performance reduces the screw-in torque compared to the classic needle tip, thereby minimising the stress on both the screw and the user during installation. Furthermore, the ASSY®plus drill tip significantly reduces splitting forces while screwing in. Particularly when there are small edge distances between the screws in the timber cross-section, cracking and splitting of the timber are effectively reduced, and smaller edge and minimum distances can be used in accordance with ETA-11/0190 compared to the classic needle tip. Finally, the ASSY®plus centring and Forstner bit tips (Table 2, column 4) are particularly suitable for coated and brittle engineered woods as they prevent surface chipping. Table 2 shows the tip/thread combinations that are most important for structural engineering. There are also further possible combinations in accordance with ETA-11/0190.

Table 2: Tip geometries and thread core diameters d_1 in mm.

	ASSY®	ASSY® A2	ASSY®plus	ASSY®plus
				
d in mm	d_1 in mm	d_1 in mm	d_1 in mm	d_1 ^{a)} in mm
5.0	3.2	3.2	3.2	3.2
6.0	3.9	3.9	3.9	3.8
8.0	5.3	5.0	5.3	5.0
10.0	6.3	-	-	6.2
12.0	7.2	-	-	7.1
14.0	-	-	-	8.5
^{a)} ASSY®plus VG 4 screws always have a drill tip without centring				
Regulation: ETA-11/0190				

1.5 Corrosion

The requirements for the corrosion protection of screws are provided in EN 1995-1-1 and for Germany in DIN SPEC 1052-100. The requirements for corrosion protection are comprised of service classes 1-3 in accordance with EN 1995-1-1 and corrosion categories C1-C5 of DIN EN ISO 12944-2 (see Table 3). The services classes describe the environmental climatic conditions and the corrosion categories describe the corrosiveness of the environment.

Table 3: Environmental corrosion categories.

Corrosion category	Examples of typical environments (for information only)	
	Outdoors	Indoors
C1 – very low	-	Heated building with neutral atmosphere, e.g. offices, sales rooms, schools, hotels
C2 – low	Atmospheres with low degree of pollution: mostly rural areas	Unheated buildings where condensation can occur, e.g. storage facilities, sports halls
C3 – medium	Urban and industrial atmospheres with moderate levels of sulphur dioxide pollution: coastal atmosphere with low salt exposure	Production facilities with high humidity and some air contamination, e.g. food processing plants, laundries, breweries, dairies
C4 – high	Industrial and coastal atmospheres with moderate salt exposure	Chemical plants, swimming pools, coastal shipyards and marinas
C5 – very high	Industrial areas with high humidity and aggressive atmospheres and coastal atmospheres with high salt exposure	Buildings and areas with near-constant condensation and heavy pollution
CX – extreme	Offshore areas with high salt exposure and industrial areas with extreme humidity and aggressive atmospheres, as well as subtropical and tropical atmospheres	Industrial areas with extreme humidity and aggressive atmospheres

Regulation: DIN EN ISO 12944-2

In Germany, the requirements for corrosion protection described in Table 4 are determined by the relationship between the service class and the corrosion category.

Table 4: Requirements for corrosion protection.

Corrosion category	C1 – very low or C2 – low			C3 – medium		C4 – high	C5 – very high
Service class	SC 1	SC 2	SC 3	SC 1	SC 2	SC 1, 2, 3	SC 3
Screws with $d > 4$ mm	None	None	Fe/Zn 25c ^{a)}	None ^{b), c)}	None ^{b), c)}	Average zinc layer thickness 55 µm	Suitable stainless steel ^{d), e)}

^{a)} If sheet steel is hot-dip galvanised, Fe/n 12C must be replaced by Z275, and Fe/Zn 25C by Z350 in accordance with EN 10346.

If dowel-type fasteners undergo hot dipping, Fe/Zn 12C must be replaced by a zinc layer of at least 39 µm and Fe/Zn 25C by a zinc layer of at least 49 µm in accordance with EN ISO 1461.

^{b)} For sheet timber-to-steel connections with external metal sheets, screws must have an average zinc layer thickness of at least 7 µm.

^{c)} For single-sided anchors made of sheet steel, an average zinc layer thickness of at least 55 µm must be applied.

^{d)} e.g. stainless steels for the corresponding corrosion resistance classes in accordance with DIBt national technical approval Z-30.3-6

^{e)} For fasteners completely enclosed in timber or engineered wood in the area relevant to load-bearing capacity (e.g. dowels, fully threaded screws), an average zinc layer thickness of at least 55 µm is sufficient.

Regulation: DIN SPEC 1052-100

For screws with a diameter of $d > 4$ mm, no corrosion protection is required for service classes 1 and 2 with very low (C1) or low (C2) exposure to corrosion. In service class 3, screws with a diameter of $d > 4$ mm must have a greater zinc layer thickness or be made of stainless steel when used in corrosion categories C1 and C2. For corrosion categories C3-C5, the special corrosion protection regulations listed in the table apply.

As a corrosion protection measure, ASSY® screws made of carbon steel are electro-galvanised as standard, even though this is not required by DIN SPEC 1052-100 in some cases. In electro-galvanising, a sacrificial layer of zinc with a thickness of at least 8 µm is formed on the screw surface for screws with a diameter of $d > 4$ mm, protecting the underlying carbon steel. Only after the protective zinc layer has degraded as white rust does the carbon steel begin to corrode in the form of red rust. In addition to electro-galvanising, ASSY® screws are blue passivated to further enhance the corrosion protection while avoiding the use of harmful chromium (VI). Special attention must be paid to corrosion when using timber types containing tannins, such as oak, chestnut, Douglas fir or tropical timbers. The same applies to modified timbers, for example those treated with preservatives, fire protection coatings and impregnations, and to thermally modified timber. Timber with a low pH value can lead to increased corrosion, usually in combination with increased timber moisture levels above 15 %. If the corrosion protection provided by electro-galvanised screws is insufficient for the application, for example in timbers containing tannin and with increased moisture content as described above or generally in service class 3, stainless steel ASSY® screws are used. Depending on the required corrosion resistance class (CRC), certain ASSY® screws are available in A2 stainless steel for CRCII, A4 for CRCIII or HCR (1.4539 for CRC IV and 1.4529 for CRC V).

When fastening metal fixtures to timber using screws, care must be taken to avoid contact corrosion. Contact corrosion occurs when two different precious metals come into direct contact, such as an aluminium sheet fastened with carbon screws, and a corrosive medium is present at the contact point, such as condensation from high humidity. Contact corrosion can be prevented by placing a non-conductive layer between the two precious metals.

1.6 Design of a screwed connection

Proper design and execution are key to creating safe and efficient screwed connections. The saying "a screw is not just a screw" applies here, because for safety and redundancy reasons, load-bearing connections must always consist of two or more screws. Exceptions to this rule include the fastening of form-work, support and counter battens, intermediate connections of builders band, rafters and purlins to trusses and wall plates as well as crossbeams to timber frames, provided that the trusses, wall plates and timber frames are also screwed together with at least two screws. Another exception is in connections where the screw thread is embedded at least $20 d$ into the timber and the screw is designed to be subjected exclusively to axial loads. However, the load-bearing capacity of the screw must be reduced to 50 % for these connections. The load-bearing capacity does not need to be reduced if the screw is used to reinforce timber members perpendicular to the grain direction.

ASSY® wood screws have been tested and approved for static and quasi-static loads. ASSY® wood screws are not permitted for use under fatigue loads.

1.7 Mechanical properties of the screws required for the design

Table 5: Characteristic value of the yield strength $f_{y,k}$ in N/mm².

	$f_{y,k}$	
ASSY®plus VG and ASSY® VG made of carbon steel	900	N/mm ²
Regulation: ETA-11/0190		

Table 6: Characteristic yield moment $M_{y,k}$ in kNm.

Screw type and material	Outer thread diameter d in mm					
	5	6	8	10	12	14
ASSY® made of carbon steel	5.9	10	23	36	58	-
ASSY® made of stainless steel	2.8	5.5	11	20	-	-
ASSY®plus VG made of carbon steel	-	9	23	40	62	86
Regulation: ETA-11/0190						

Table 7: Characteristic tensile resistance $f_{tens,k}$ in kN.

Screw type and material	Outer thread diameter d in mm					
	5	6	8	10	12	14
ASSY® made of carbon steel	7.9	12.5	21.5	26	41	-
ASSY®plus VG made of carbon steel	-	11.5	22	33	47	62
ASSY® made of stainless steel	5.2	8.2	14	19	-	-
Regulation: ETA-11/0190						

Table 8: Characteristic withdrawal parameter $f_{ax,k}$ in N/mm².

Engineered wood	ρ_k in kg/m ³	$\rho_{ref,k}$ in kg/m ³	Outer thread diameter d in mm					
			5	6	8	10	12	14
ST/FST, GL, CLT, SWP, LVL made of softwood	≤ 590	350	13		12	11.5	11	10
Beech LVL in accordance with ETA-14/0354	≤ 730	730	35					-
OSB/3, OSB/4	≥ 550	= ρ_k	7.0		-	-	-	-
Chipboard	≥ 640	= ρ_k	7.0		-	-	-	-
Regulation: ETA-11/0190								

Table 9: Characteristic head pull-through parameter $f_{\text{head,k}}$ in N/mm².

$f_{\text{head,k}}$ in N/mm ²	d_{head} in mm	Application, head shape	$\rho_{\text{ref,k}}$ in kg/m ³
For member thicknesses $t < 12$ mm			
8	≤ 32	For all specified engineered woods, $F_{\text{pull,k}} \leq 400$ N	350
For member thicknesses $12 \text{ mm} \leq t \leq 20$ mm			
8	≤ 32	For all specified engineered woods	350
For member thicknesses $t > 20$ mm			
$\min\{19.4 - 0.28 \cdot d_{\text{head}}; 14\}$	-	90° countersunk head, for all specified engineered woods	350
$\min\{28.4 - 0.64 \cdot d_{\text{head}}; 15\}$	≤ 30	180° washer head, for all specified engineered woods	350
13	≤ 19	Other head shapes, for all specified engineered woods	350
10	> 19	Other head shapes, for all specified engineered woods	350
15	-	Jamo und Jamo plus	350
23	-	Underhead thread	350
18	-	P II screws $d = 8$ mm with underhead thread	350
$40 - 0.5 \cdot d_{\text{head}}$	≤ 25	In beech LVL with $590 \text{ kg/m}^3 \leq \rho_k \leq 750 \text{ kg/m}^3$ and $t \geq 40$ mm	350
16	25	$d = 8$ mm with angled washers in LVL with $\rho_k \leq 590 \text{ kg/m}^3$	500
32	25	$d = 8$ mm with angled washers in beech LVL with $\rho_k \geq 680 \text{ kg/m}^3$ and $t \geq 40$ mm	730
Regulation: ETA-11/0190			

Table 10: Characteristic value of the breaking torque $f_{\text{tor,k}}$ in Nm.

Screw type and material	Outer thread diameter d in mm					
	5	6	8	10	12	14
ASSY® made of carbon steel	6.0	10.0	23.0	45.0	65.0	-
ASSY®plus VG made of carbon steel	-	10.5	25.0	47.0	76.0	115
ASSY® Isotop made of carbon steel	-	-	20.0 ^{a)} 12.0 ^{b)}	-	-	-
ASSY® made of stainless steel	4.0 ^{b)}	7.3 ^{b)}	17.0 ^{b)} 17.5 ^{d)}	30.0 ^{b)}	-	-
^{a)} Characteristic value of the breaking torque on the screw head ^{b)} Characteristic value of the breaking torque on the thread with screw tip ^{c)} Characteristic value of the breaking torque on ASSY® P screw screw heads ^{d)} Characteristic value of the breaking torque for solar roof screws						

1.8 Materials with fastening approval

Materials that can be fastened and dimensioned for load-bearing connections or reinforcements are listed in Table 58 and Section 3.2.

Draft EC 5 introduces two product groups: solid wood-based (SWB) and veneer based (VB) timber products. The first group includes structural lumber (SL), glued solid timber (GST), glued laminated timber (GL) and cross-laminated timber (CLT). The second group includes laminated veneer lumber (LVL), glued laminated veneer lumber (GLVL) and plywood (PW). These terms and abbreviations are used in this manual. For other commonly used terms from the Draft EC 5 nomenclature, see Table 57.

Steel parts and panel materials should only be positioned on the head side – i.e. panels can be mounted onto timber members using screws, but screws must not be anchored through timber members into panels on the screw tip side. If a value for the withdrawal parameter $f_{\text{ax,k}}$ is specified in Table 8 or in the corresponding approval (e.g. for solid wood panels, chipboard or OSB panels), a connection in which screws are anchored through a timber member into such a panel on the tip side is permitted.

If a connection with a panel is arranged between two timber members and screwed so that the screws engage in all three members, such a connection with an interlayer is approved as load-bearing. (see Section 4.9).

2 DESIGN



2.1 Pre-drilling/pilot drilling

Pre-drilling timber members when using screws reduces

- the screw-in torque,
- splitting
- and movement of the screw in the timber,

particularly when using slim screws. This means that pre-drilling or using ASSY®plus screws with a drill tip in softwood reduces the required minimum spacing. In general, ASSY® screws with an outer diameter of $d < 8$ mm, particularly ASSY®plus screws with a drill tip, can be inserted in softwood without pre-drilling. Screws with an outer diameter of $d \geq 8$ mm can be screwed into spruce, fir and pine without pre-drilling. For hardwood with an increased tendency to splitting and a higher screw-in torque, such as beech, oak and ash, pre-drilling is always required. The relevant pre-drilling diameters for the different outer diameters are specified in Table 11.

Table 11: Pre-drilling diameters for softwood, hardwood and glued laminated veneer lumber made of beech.

Outer thread diameter d in mm	Nominal drill bit diameter with a tolerance of ± 0.1 mm		
	Timber members made of softwood	Timber members made of beech, oak or ash	Timber members made of beech GLVL, ETA-14/0354
5	3.0	3.5	4.0
6	4.0	4.0	4.5
8	5.0	6.0	6.5
10	6.0	7.0	8.0
12	7.0	8.0	9.0
14	8.0	9.0	11.0

Regulation: ETA-11/0190

An exception to the regulations for hardwood is beech LVL in accordance with EN 14374 or ETA-14/0354, into which ASSY® and Jamo screws, both made of carbon steel, can be screwed up to certain maximum lengths without pre-drilling. These maximum lengths correspond to the values in Table 12.

Table 12: Permissible thread lengths without pre-drilling in beech laminated veneer lumber (LVL).

Outer thread diameter d in mm	Maximum length of thread engagement of the screw's threaded section without pre-drilling in mm	
	ASSY®plus and Jamo plus	ASSY® and Jamo screws without drill tip
5	-	50
6	30	60
7	-	70
7.5	-	75
8	48	80
10	80	100
12	96	-

Regulation: ETA-11/0190

If screws with thread lengths longer than those specified in Table 12 are to be screwed into beech LVL in accordance with EN 14374 or ETA-14/0354, the timber must be pre-drilled for the entire screw length with the diameter as specified in Table 11, column 4.

Stainless steel screws can be screwed into softwood members without pre-drilling. Hardwood members must be pre-drilled when using stainless steel screws.

When arranging crossing screws, care must be taken to ensure that the screws do not collide with each other during installation. Collisions can strip the threads, meaning that the required pull-out resistance of the screw can no longer be guaranteed. For this reason, it is recommended to plan sufficient spacing between crossing screws or to use pilot holes during installation.

In cases where pre-drilling is not required, the use of pilot holes may be recommended. Pilot holes are not pre-drilled for the entire length of the screw, but typically 10 to 50 % of the screw length. Particularly for ASSY®plus screws with drill tip, this results in faster engagement in the timber, lower screw-in torque and ensures correct positioning of the screw in the timber member. The latter is especially important for slim screws and with small minimum or edge distances. For ASSY®plus fully threaded screws with an outer diameter of 14 mm and a screw length of $l \geq 800$ mm, a pilot hole with a diameter of 8 mm and a length of $\geq 10\%$ of the screw length is required in softwood. Appropriate drilling jigs and drill stands can be used to ensure the correct positing and angle of the hole, and deep hole drilling systems are recommended for very long screws. When installing on-roof insulation systems, the screw must be screwed from the counter batten through the insulation and into the rafter in a single process.

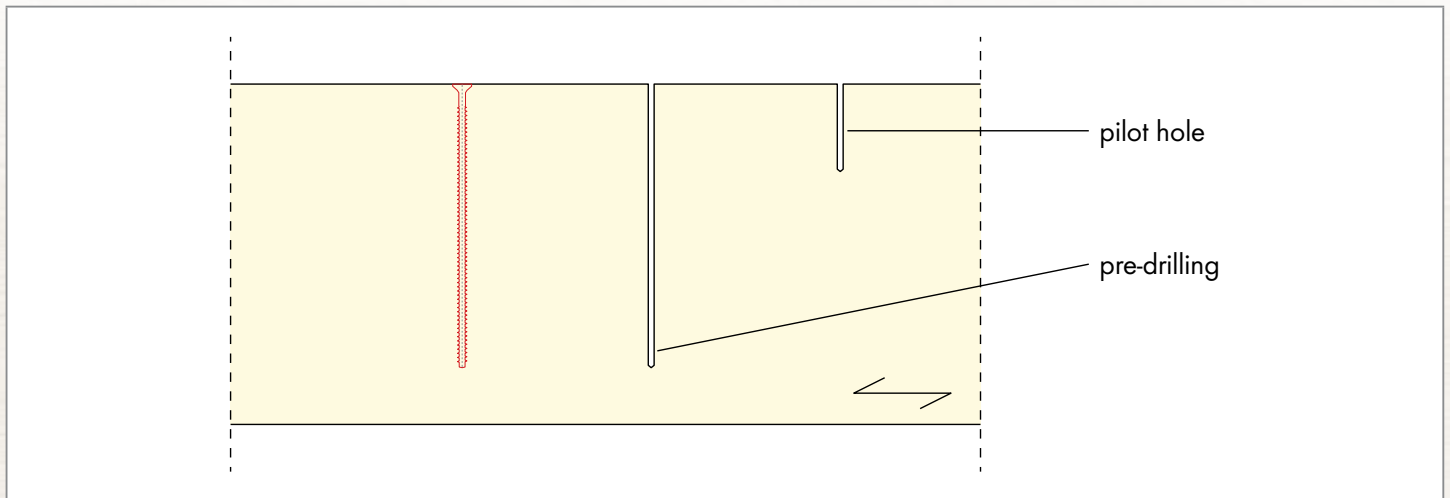


Figure 6: Member pre-drilled and with pilot hole.

2.2 Screwing in

When screwing in, it must be ensured that the wood moisture content of the member corresponds to the equilibrium wood moisture content at the place of installation.

$$\omega_{\text{mean, Montage}} \triangleq \omega_{\text{mean, Einbauort}} \quad (2.1)$$

Changes to the moisture content of the timber member can lead to high internal stresses in the screws and surrounding timber, as well as to cracks in timber members, both of which can result in reduced load-bearing capacity. The extent of these effects depends on the length of the screw/screw thread, the angle of the screw in relation to the grain and the number of adjacent screws, with all three factors having a progressively more negative impact as they increase. For pre-assembled screwed connections, adequate weatherproofing of the members must thus be ensured before transportation and installation.

To ensure that the correct screw position, such as the screw-in angle, can be reproduced in the timber, suitable screw-in aids or positioning templates should be used (see Figure 7). Before screwing in, the components to be connected must be secured, for example with screw clamps, to prevent gaps from forming and the members from separating during the screw-in process.

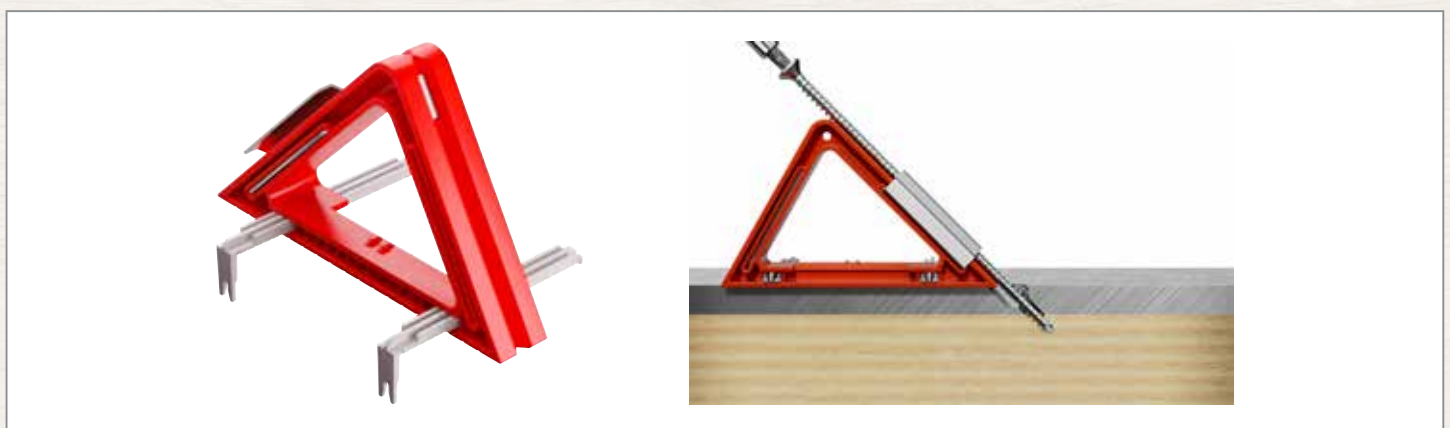


Figure 7: Screw-in aid.

It must be ensured that the screws are not screwed into shrinkage cracks or similar weak points.

Screws must not be reused, i.e. they must not be screwed into one member, removed and screwed into another member.

Long screws should be screwed in continuously without interruption until they reach their final position. This is because the heat generated by screwing in the screw can cause the timber components to melt, and if the screwing process is interrupted, these components cool down and the screw can stick to the timber. Furthermore, when continuing the screwing process after an interruption, there is an increased initial torque due to static friction between the screw thread and the screw shank in the timber.

If the screw head touches the timber surface and is countersunk flush, this is referred to as a "soft joint". Screws with pan, top, washer, joist hanger, combination, hexagon or external TX head are not countersunk and protrude above the timber surface. Unlike soft joints, in hard joints the screw head comes into contact with a steel fixture. Screws in timber-to-steel connections should be inserted in a single operation until just before the screw head makes contact with the surface. Just before the screw is seated, it is recommended to reduce the screw-in speed so that the screw is not subjected to excessive stress caused by the abrupt seating of the head on the metal fixture and the associated sudden increase in torque. The remaining thread length must be tightened until the head makes contact with the steel fixture in a controlled manner to a defined torque. This prevents the screw from being subjected to excessive stress and ensures uniform load distribution on the individual screws. The following procedure is recommended:

- Screw in the screw until just before the head is seated
- Immediately measure the prevailing torque M_W at a constant continuing rotational speed for approximately one complete revolution
- Calculate the maximum permissible tightening torque $M_{A,max}$ using the following equation:

$$M_{A,max} = M_W \cdot 1,2 < 0,9 \cdot f_{tor,k}$$
- Tighten the screw head with the designed tightening torque until the head is seated.

The above procedure is intended to ensure that screws are tightened with only the necessary amount of torque, up to a maximum of 90 % of the breaking torque $f_{tor,k}$ (values for $f_{tor,k}$ see Table 10). In general, torque wrenches or other torque-controlled screwdrivers are suitable for tightening screws to a defined torque.

Any screwdrivers that tighten with an undefined torque are not suitable. In particular, impact drivers should never be used to tighten screws in timber-to-steel connections. After the steel member is installed, it is essential to check that the connection has been carried out properly. This includes visually inspecting all accessible members for damage and, in particular, checking that the screw heads are properly seated in the steel member.

An optimal mechanical interlock between the screw head and the steel fixture must be ensured, e.g. by creating suitable countersinks in the fixture when using countersunk head screws. The bore in the fixture, particularly in the contact surface with the screw head, must be precisely created to ensure that the screw head sits flush against the fixture. Screw heads with milling ribs (CSMR) are not suitable for fastening steel fixtures.

To prevent damage to the screw thread and misalignment of the screw head in the fixture, the screw thread must not come in contact with the bore in the fixture.

These regulations also apply to the fastening of washers. Washers must be flush with the timber surface or with the surface of the steel fixture.

3 AXIALLY LOADED SCREWS



3.1 Failure mechanisms of axially loaded screws

The following failure mechanisms can occur in axially loaded screws:

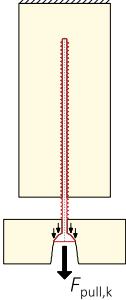
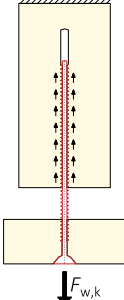
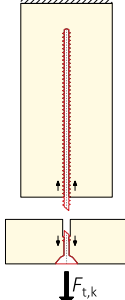
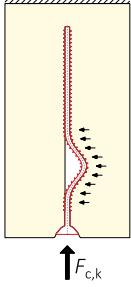
Resistivity	Characteristic head pull-through resistance	Characteristic pull-out resistance	Characteristic tensile resistance	Characteristic buckling resistance
Formula symbols	$F_{\text{pull,k}}$	$F_{\text{w,k}}$	$F_{\text{t,k}}$	$F_{\text{c,k}}$
Schematic representation				
Description	Pull-in or pull-through of the screw head	Pull-out of the screw thread	Shear-off of the screw	Buckling of the screw under axial compressive load
Section	3.2	3.3	3.4	3.5

Figure 8: Failure mechanisms of axially loaded screws.

3.2 Characteristic head pull-through resistance

The characteristic head pull-through resistance can be designed as follows:

$$F_{\text{pull,k}} = f_{\text{head,k}} \cdot d_{\text{head}}^2 \cdot \left(\frac{\rho_k}{\rho_{\text{ref,k}}} \right)^{0,8} \quad (3.1)$$

Where:

$f_{\text{head,k}}$	Characteristic head pull-through parameter in N/mm ² in accordance with Table 13
d_{head}	Head diameter or outer diameter of the washer in mm
ρ_k	Characteristic bulk density of the head-side member in kg/m ³
$\rho_{\text{ref,k}}$	Reference bulk density in kg/m ³

For all ASSY® self-drilling wood screws used in combination with the materials in the following list, the characteristic values of the head pull-through diameter $f_{\text{head,k}}$ in accordance with Table 13 apply.

- Solid timber (ST/FST) made of softwood, beech, oak or ash in accordance with EN 14081-1
- Glued solid timber (GST) made of softwood in accordance with EN 14080 or the national regulations applicable at the installation site
- Glued laminated timber (GL) made of softwood in accordance with EN 14080
- Glued laminated timber made of beech, oak or ash in accordance with the European technical assessment or the national regulations applicable at the installation site
- Cross-laminated timber (CLT) made of softwood in accordance with the European technical assessment or the national regulations applicable at the installation site
- Solid wood panels (SWP) in accordance with EN 13353 and EN 13986
- Laminated veneer lumber (LVL) made of softwood in accordance with EN 14374
- Glued laminated veneer lumber (GLVL) made of beech in accordance with ETA-14/0354
- Plywood (PW) in accordance with EN 636 and EN 13986
- Oriented strand board (OSB) in accordance with EN 300 and EN 13986 where $\rho_k \geq 550 \text{ kg/m}^3$
- Chipboard in accordance with EN 312 and EN 13986
- Fibreboard in accordance with EN 622-2, EN 622-3 and EN 13986
- Cement-bonded chipboard in accordance with EN 634-2 and EN 13986
- Gypsum plasterboard for load-bearing applications in accordance with the European technical assessment where $\rho_k \geq 650 \text{ kg/m}^3$
- Fermacell gypsum fibreboard in accordance with ETA-03/0050

Table 13: Characteristic head pull-through parameter $f_{\text{head,k}}$ in N/mm².

$f_{\text{head,k}}$ in N/mm ²	d_{head} in mm	Application, head shape	$\rho_{\text{ref,k}}$ in kg/m ³
For member thicknesses $t < 12$ mm			
8	≤ 32	For all specified engineered woods, $F_{\text{pull,k}} \leq 400$ N	350
For member thicknesses $12 \text{ mm} \leq t \leq 20$ mm			
8	≤ 32	For all specified engineered woods	350
For member thicknesses $t > 20$ mm			
$\min\{19.4 - 0.28 \cdot d_{\text{head}}'; 14\}$	-	90° countersunk head, for all specified engineered woods	350
$\min\{28.4 - 0.64 \cdot d_{\text{head}}'; 15\}$	≤ 30	180° washer head, for all specified engineered woods	350
13	≤ 19	Other head shapes, for all specified engineered woods	350
10	> 19	Other head shapes, for all specified engineered woods	350
15	-	Jamo und Jamo plus	350
23	-	Underhead thread	350
18	-	P II screws $d = 8$ mm with underhead thread	350
$40 - 0.5 \cdot d_{\text{head}}$	≤ 25	In beech LVL with $590 \text{ kg/m}^3 \leq \rho_k \leq 750 \text{ kg/m}^3$, $t \geq 40$ mm	350
16	25	$d = 8$ mm with angled washers in LVL with $\rho_k \leq 590 \text{ kg/m}^3$	500
32	25	$d = 8$ mm with angled washers in beech LVL or GLVL in accordance with ETA-14/0354 where $\rho_k \geq 680 \text{ kg/m}^3$ and $t \geq 40$ mm	730
Regulation: ETA-11/0190			

The following bulk densities can be applied for certain materials:

- Beech, oak or ash timber $\rho_k \leq 590 \text{ kg/m}^3$
- Laminated veneer lumber (LVL) made of softwood $\rho_k \leq 590 \text{ kg/m}^3$
- Laminated veneer lumber (LVL) made of beech or GLVL (ETA-14/0354) $\rho_k \leq 730 \text{ kg/m}^3$
- All listed engineered wood $\rho_k \leq 380 \text{ kg/m}^3$

For the head diameter: $d_{\text{head}} \geq 1.8 \cdot d_s$ where d_s is the diameter of the unthreaded shank or the thread core. If $d_{\text{head}} < 1.8 \cdot d_s$, the characteristic value of the head pull-through resistance is $F_{\text{pull,k}} = 0$ kN.

For engineered wood, the minimum member thickness of $1.2 \cdot d$ (where d is the outer thread diameter) and the specifications in Table 14 must be observed.

Table 14: Minimum thickness t of engineered wood.

Engineered wood	Minimum thickness t in mm	Material standard
Plywood	6	DIN EN 636
Fibreboard	6	DIN EN 622-2 DIN EN 622-3
OSB	8	DIN EN 300
Chipboard	8	DIN EN 312
Cement-bonded chipboard	8	DIN EN 634-2
Solid wood panels	12	DIN EN 13353
Regulation: ETA-11/0190		

In $F_{\text{pull,k}}$ or $f_{\text{head,k}}$ for washers with $d_{\text{head}} > 32$ mm, the procedure according to EC 5, Section 8.5.2 must be applied.

For all fully threaded ASSY® screws and ASSY® screws with underhead thread, the pull-out resistance of the threaded section in the timber member on the screw-head side can be used instead of the head pull-through resistance (see Figure 9). This also applies to partially threaded ASSY® screws, provided that a sufficient portion of the thread embeds in the timber member on the screw-head side, where $l_w \geq 4 \cdot d$. Figure 9 shows various scenarios. On the left of the figure is an ASSY®plus VG with CSMP head, and in the centre and on the right is an ASSY® screw with partial thread and WH head (centre) and with a combination head and washer (right). In each case, the maximum value derived from the characteristic head pull-through and withdrawal resistances of the threaded length can be used.

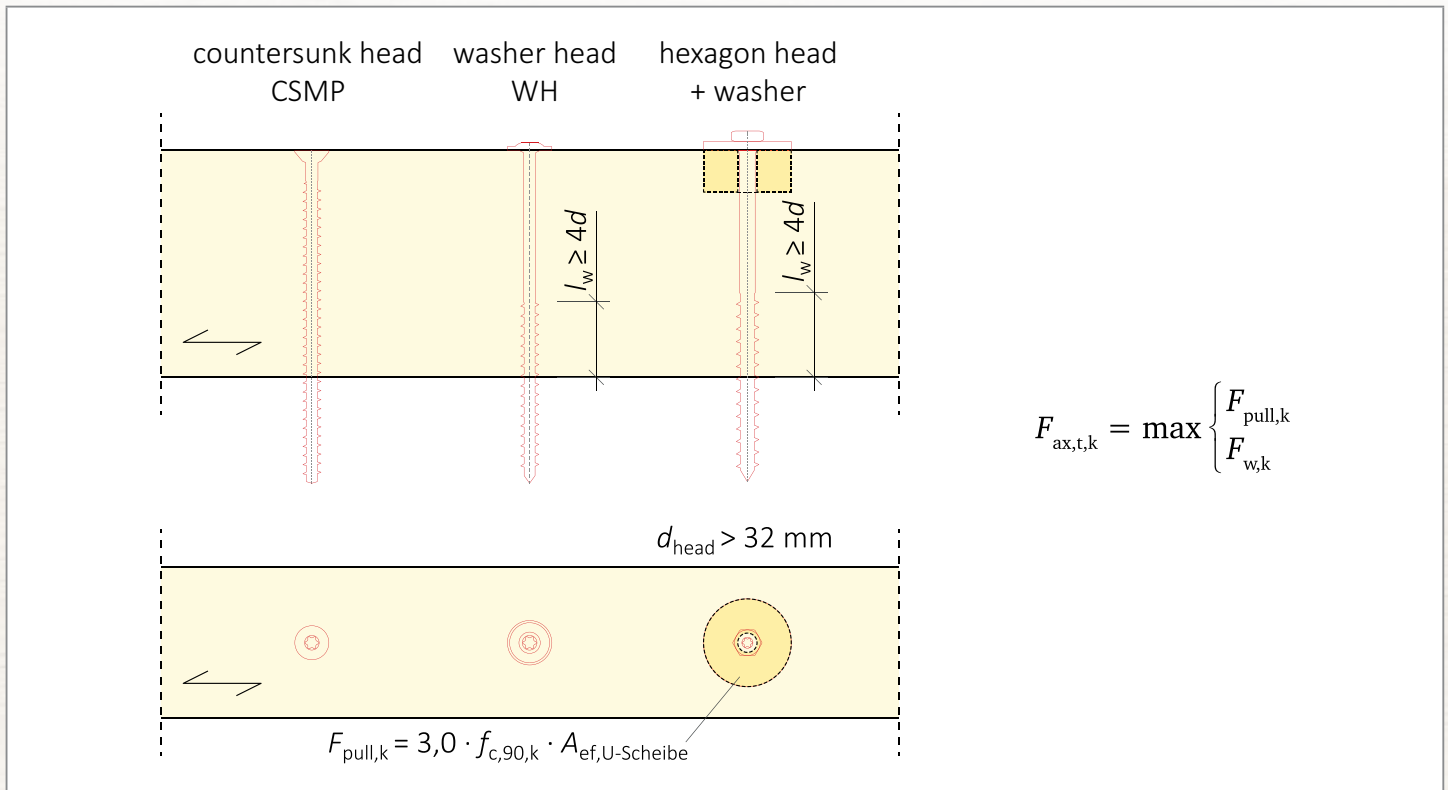


Figure 9: Head pull-through or withdrawal resistance of the threaded length in the screw-head side of the member.

In timber-to-steel connections, the head pull-through resistance of the screws is not considered.

3.3 Characteristic pull-out resistance

The characteristic pull-out resistance of a screw applies to both axial loads (tensile and compression) and is generally designed using Eq. (3.2). Angles ε and β are defined in Figure 10.

$$F_{w,k} = \frac{k_{ax} \cdot f_{ax,k} \cdot d \cdot l_w}{k_{\beta}} \cdot \left(\frac{\rho_k}{\rho_{ref,k}} \right)^{0,8} \quad (3.2)$$

Where:

k_{ax} Factor to account for the angle ε between the screw axis and the grain direction

$$k_{ax} = 1,0 \quad \text{für } 30^\circ \leq \varepsilon \leq 90^\circ \quad (3.3)$$

$$k_{ax} = a + \frac{b \cdot \varepsilon}{30^\circ} \quad \text{für } 0^\circ \leq \varepsilon < 30^\circ \quad (3.4)$$

Where

$$a = \begin{cases} 0,3 & \text{für ST/FST, GL, CLT, SWP} \\ 0,5 & \text{für LVL, GLVL (inkl. LVL, GLVL aus Buche (ETA-14/0354))} \end{cases}$$

$$b = \begin{cases} 0,7 & \text{für ST/FST, GL, CLT, SWP} \\ 0,5 & \text{für LVL, GLVL (inkl. LVL, GLVL aus Buche (ETA-14/0354))} \end{cases}$$

Note:

The factor k_{ax} can also be designed as follows for $\varepsilon \geq 15^\circ$ and $l_w \geq 20 d$:

$$k_{ax} = \frac{1}{1,2 \cdot \cos^2 \varepsilon + \sin^2 \varepsilon} \quad (3.5)$$

This consideration leads to a minor increase in the load-bearing capacity for LVL in the range of $15^\circ \leq \varepsilon \leq 21^\circ$ and $15^\circ \leq \varepsilon \leq 24^\circ$ for all other materials compared to Eq. (3.4).

k_β	Factor to account for the angle β between the screw axis and the wide face
$k_\beta = 1$	for ST, GL, GST, CLT and SWP
$k_\beta = 1,5 \cdot \cos^2 \beta + \sin^2 \beta$	for LVL
$f_{ax,k}$	Characteristic withdrawal parameter in N/mm ² in accordance with Table 15
d	Outer thread diameter in mm
l_w	Anchorage length of the threaded section of a screw (including the screw tip) in mm
ρ_k	Characteristic bulk density of the timber member in kg/m ³
$\rho_{ref,k}$	Reference bulk density in kg/m ³
β	Angle between the screw axis and wide face
ε	Angle between the screw axis and grain direction If $0^\circ \leq \varepsilon \leq 90^\circ$, the full thread length in the member can be used.

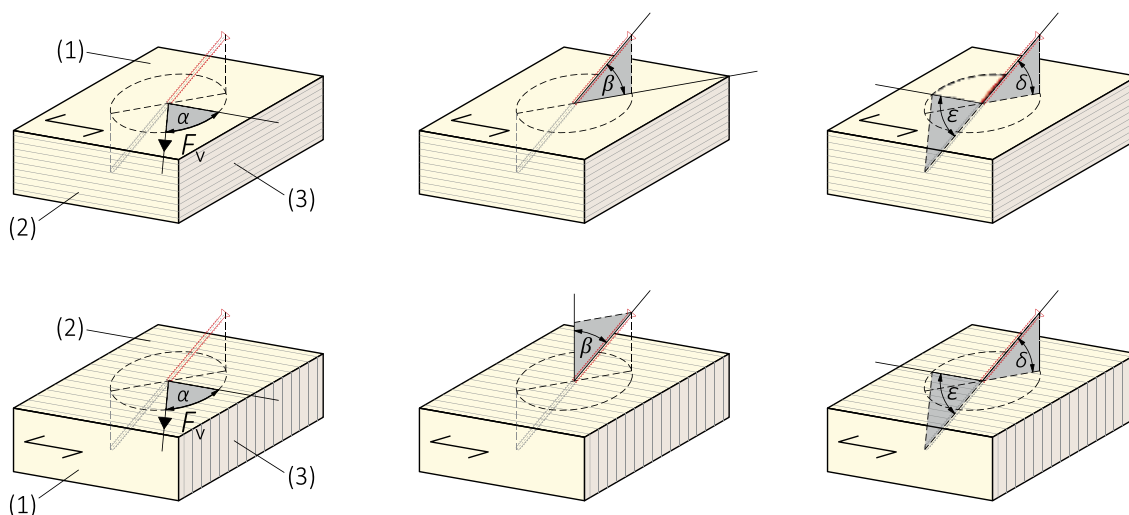


Figure 10: Definition of angles between the screw and member. (1) Wide face, (2) narrow face, (3) end grain surface, angle between (α) force and grain direction, (β) screw axis and wide face, (δ) screw axis and shear plane, (ε) screw axis and grain direction.

Table 15: Characteristic withdrawal parameter $f_{ax,k}$ in N/mm².

Engineered wood	ρ_k in kg/m ³	$\rho_{ref,k}$ in kg/m ³	Outer thread diameter d in mm					
			5	6	8	10	12	14
ST/FST, GL, CLT, SWP, LVL made of softwood	≤ 590	350	13		12	11.5	11	10
GLVL made of beech (ETA-14/0354)	≥ 730	730	35.0					-
OSB/3, OSB/4	≥ 550	$= \rho_k$	7.0		-	-	-	-
Chipboard	≥ 640	$= \rho_k$	7.0		-	-	-	-

Regulation: ETA-11/0190

The characteristic values of the withdrawal parameters also apply to cross-laminated timber layers made of softwood.

If screws in a cross-laminated timber connection are embedded in more than one layer, the characteristic withdrawal capacity can be designed as the sum of the individual load-bearing capacities of the panel layers, regardless of whether the screw is driven into the side face or the narrow face. The anchorage length l_w , the angle between the screw axis and grain ε and the characteristic bulk density ρ_k parameters for the respective panel layer must be taken into account.

The following regulations apply to screws driven into narrow faces.

Size equation (independent of the angle ε and the position of the panel layers)

The characteristic pull-out resistance of screws arranged in the narrow face of cross-laminated timber can be designed using Eq. (3.6) ($F_{w,k}$ in N, d and l_w in mm), regardless of their position or the angle between the screw axis and grain direction.

$$F_{w,k} = 20 \cdot d^{0,8} \cdot l_w^{0,9} \quad (3.6)$$

Defined position in the inner panel layers

If screws in the narrow face of cross-laminated timber are embedded in a single inner panel layer, the characteristic pull-out resistance can be determined using Eq. (3.2). In cross-laminated timber with five layers, for example, the inner layers would be layers 2 and 4. The distances between the screws and the edges of the panel layer are the same as for solid wood in Table 30, but the distance from the glue joint can be reduced to $2 \cdot d$; see Figure 11. In this case, screws should only be screwed in at $\varepsilon = 90^\circ$ (Figure 11, left: screwing into layer 3 permitted; right: screwing into layers 2 and 4 permitted).

The respective regulations from the cross-laminated timber approvals must be observed.

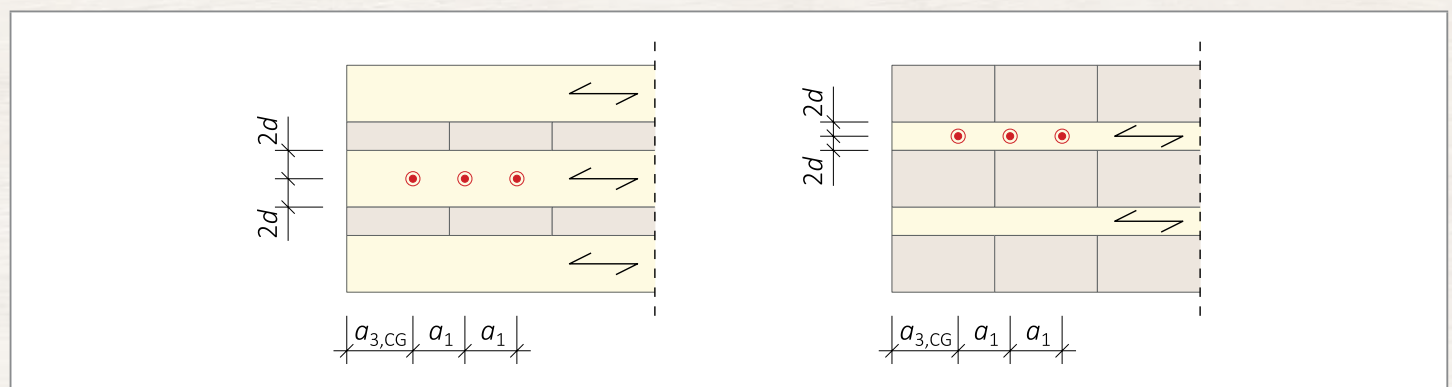


Figure 11: Defined screw positions for inner panel layers on the narrow face.

3.4 Characteristic tensile resistance of a screw

The characteristic tensile resistance of a screw is the maximum axial tensile force at which the steel cross-section of the screw fails (shears off). Values can be taken from Table 16. The following applies:

$$F_{t,k} = f_{tens,k} \quad (3.7)$$

Table 16: Characteristic tensile resistance $f_{tens,k}$ in kN.

Screw type and material	Outer thread diameter d in mm					
	5	6	8	10	12	14
ASSY® made of carbon steel	7.9	12.5	21.5	26	41	-
ASSY®plus VG made of carbon steel	-	12.5	22	33	45	62
ASSY® made of stainless steel	5.8	8.2	14	19	-	-

Regulation: ETA-11/0190

3.5 Characteristic buckling resistance

Screws subjected to axial compressive loading may fail due to buckling (see Figure 12). The following prerequisites apply when calculating the characteristic buckling resistance:

- ASSY®plus VG screws and fully threaded or double-thread ASSY® screws
- Screws in wood materials made of softwood or hardwood, solid timber (ST/FST), laminated veneer lumber (LVL), glued solid timber (GST), glued laminated timber (GL) and cross-laminated timber (CLT)
- Angle ε between the screw axis and the grain direction of $0^\circ \leq \varepsilon \leq 90^\circ$

The characteristic buckling resistance of a screw is generally designed using Eq. (3.8). For elastically bedded screws, an additional calculation is performed in accordance with Draft EC 5 using Eq. (3.12), (3.13), (3.14) and (3.15). For screws that can buckle freely within a specific area, an additional calculation is performed using Eq. (3.16) and (3.17).

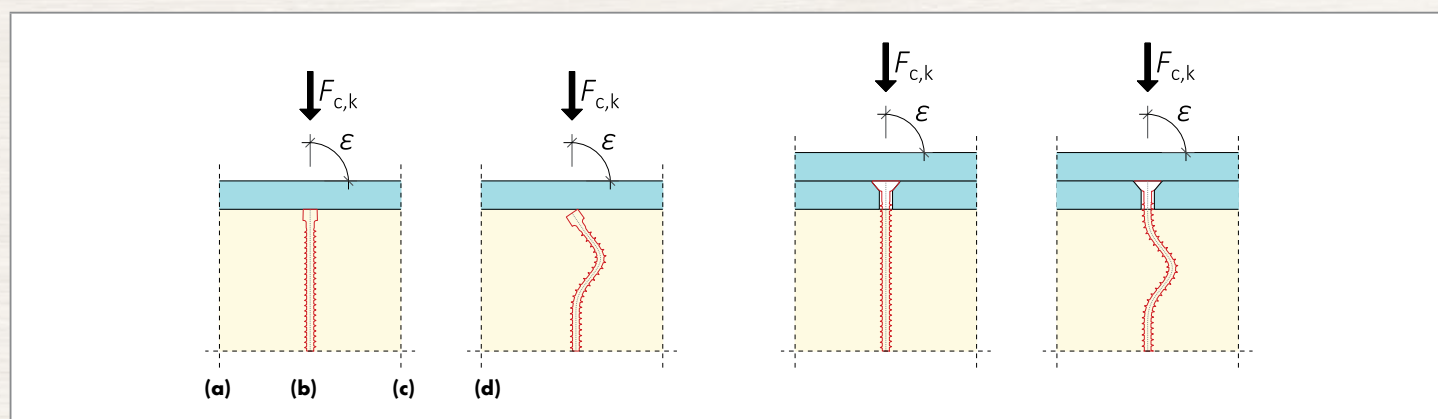


Figure 12: An embedded, axially compressive screw before reaching the buckling resistance (a, c), after reaching the buckling resistance (b, d), with unrestrained head (a, b) and with restrained head (c, d).

Prerequisites for a restrained head (c, d): 1. Head surface is flush with the panel surface; 2. Minimum panel thickness: Outer thread diameter d

$$F_{c,k} = \phi_c \cdot N_{pl,k} \quad (3.8)$$

Where:

$$N_{pl,k} = \pi \cdot \frac{d_1^2}{4} \cdot f_{y,k} \quad (3.9)$$

$$\phi_c = \frac{1}{\phi + \sqrt{\phi^2 - \bar{\lambda}_k^2}} \quad (3.10)$$

$$\phi = 0,5 \cdot \left[1 + 0,49 \cdot (\bar{\lambda}_k - 0,2) + \bar{\lambda}_k^2 \right] \quad (3.11)$$

Elastic buckling

$$\bar{\lambda}_k = \sqrt{\frac{N_{pl,k}}{N_{ki,k}}} \quad (3.12)$$

$$N_{ki,k} = \begin{cases} \sqrt{c_h \cdot E_s \cdot I_s} & \text{Kopf nicht eingespannt} \\ 2 \cdot \sqrt{c_h \cdot E_s \cdot I_s} & \text{Kopf eingespannt} \end{cases} \quad (3.13)$$

$$c_h = (0,19 + 0,012 \cdot d) \cdot \rho_k \cdot \left(\frac{90^\circ + \varepsilon}{180^\circ} \right) \quad (3.14)$$

$$I_s = \frac{\pi \cdot d_1^4}{64} \quad (3.15)$$

Free buckling

$$\bar{\lambda}_k = \frac{l_{ef} \cdot 4}{d_1 \cdot \pi \cdot \sqrt{\frac{E_s}{f_{y,k}}}} \quad (3.16)$$

$$l_{ef} = l_{ne} + 20 \text{ mm} \quad (3.17)$$

Where:

$N_{pl,k}$	Characteristic value of the normal force load capacity of the net cross-section in N
ϕ_c	Reduction factor for screw buckling (-)
d_1	Thread core diameter in mm in accordance with Table 17
$f_{y,k} = 900$	Characteristic value of the yield strength of hardened carbon steel in N/mm ²
ϕ	Factor (-)
$\bar{\lambda}_k$	Relative slenderness ratio (-)
$N_{ki,k}$	Characteristic ideal elastic buckling load of a screw in N
c_h	Elastic bedding of a screw in N/mm ²
$E_s = 210.000$	Elasticity modulus of the steel in N/mm ²
I_s	Second moment of area for the circular cross-section in mm ⁴
l_{ef}	Calculated screw length (see Section 3.5.2) in mm
l_{ne}	Unbedded screw length (see Table 26) in mm

Table 17: Thread core diameter d_1 in mm for all fully threaded ASSY® screws.

	Outer thread diameter d in mm					
	5	6	8	10	12	14
d_1 for ASSY®plus VG	-	3.8	5.0	6.2	7.1	8.5
d_1 for fully threaded ASSY®	3.2	3.9	-	-	-	-

Regulation: ETA-11/0190

3.5.1 Elastic buckling

For fully threaded carbon steel ASSY® screws, the characteristic buckling resistance $F_{c,k}$ can be determined using Eq. (3.8) and Table 18 to Table 25 for different characteristic bulk densities ρ_k and **angles** ε . The higher values are only permitted if the screw head is structurally restrained (see Figure 12 c and d).

Table 18: Characteristic buckling resistance $F_{c,k}$ in kN, where $\rho_k = 350 \text{ kg/m}^3$ (e.g. C24).

	Head unrestrained						Head restrained			
ε	$d = 6 \text{ mm}$		$d = 8 \text{ mm}$		$d = 10 \text{ mm}$		$d = 12 \text{ mm}$		$d = 14 \text{ mm}$	
0°	5.43	7.29	9.62	12.8	15.1	19.9	20.2	26.4	29.5	38.2
30°	5.85	7.60	10.3	13.3	16.2	20.7	21.6	27.4	31.5	39.6
45°	6.02	7.72	10.6	13.5	16.7	21.0	22.2	27.8	32.3	40.1
60°	6.17	7.83	10.9	13.7	17.0	21.3	22.7	28.1	33.0	40.6
90°	6.42	8.00	11.3	14.0	17.7	21.7	23.5	28.7	34.2	41.4
Regulation: Draft EC 5										
with $f_{yk} = 900 \text{ N/mm}^2$										

Regulation: Draft EC 5

with $f_{y,k} = 900 \text{ N/mm}^2$

Table 19: Characteristic buckling resistance $F_{c,k}$ in kN, where $\rho_k = 365 \text{ kg/m}^3$ (e.g. GL 24c).

	Head unrestrained						Head restrained			
ε	$d = 6 \text{ mm}$		$d = 8 \text{ mm}$		$d = 10 \text{ mm}$		$d = 12 \text{ mm}$		$d = 14 \text{ mm}$	
0°	5.49	7.34	9.73	12.9	15.3	20.0	20.4	26.5	29.8	38.4
30°	5.91	7.65	10.5	13.4	16.4	20.8	21.8	27.5	31.8	39.8
45°	6.08	7.77	10.7	13.6	16.8	21.1	22.4	27.9	32.6	40.3
60°	6.23	7.87	11.0	13.8	17.2	21.4	22.9	28.2	33.3	40.8
90°	6.48	8.04	11.4	14.0	17.8	21.8	23.7	28.8	34.4	41.5
Regulation: Draft EC 5										
with $f_{yk} = 900 \text{ N/mm}^2$										

Regulation: Draft EC 5

with $f_{y,k} = 900 \text{ N/mm}^2$

Table 20: Characteristic buckling resistance $F_{c,k}$ in kN, where $\rho_k = 390 \text{ kg/m}^3$ (e.g. GL 28c, GL 24c).

	Head unrestrained					Head restrained				
ε	$d = 6 \text{ mm}$		$d = 8 \text{ mm}$		$d = 10 \text{ mm}$		$d = 12 \text{ mm}$		$d = 14 \text{ mm}$	
0°	5.59	7.41	9.90	13.0	15.5	20.2	20.7	26.8	30.2	38.7
30°	6.01	7.71	10.6	13.5	16.6	21.0	22.2	27.7	32.2	40.1
45°	6.17	7.83	10.9	13.7	17.1	21.3	22.7	28.1	33.0	40.6
60°	6.32	7.93	11.1	13.9	17.4	21.5	23.2	28.4	33.7	41.1
90°	6.57	8.10	11.6	14.1	18.1	21.9	24.0	29.0	34.9	41.8
Regulation: Draft EC 5										
with $f_{yk} = 900 \text{ N/mm}^2$										

Regulation: Draft EC 5

with $f_{y,k} = 900 \text{ N/mm}^2$

Table 21: Characteristic buckling resistance $F_{c,k}$ in kN, where $\rho_k = 385 \text{ kg/m}^3$ (e.g. GL 24h).

	Head unrestrained						Head restrained			
ε	$d = 6 \text{ mm}$		$d = 8 \text{ mm}$		$d = 10 \text{ mm}$		$d = 12 \text{ mm}$		$d = 14 \text{ mm}$	
0°	5.57	7.40	9.87	13.0	15.5	20.2	20.7	26.7	30.1	38.7
30°	5.99	7.70	10.6	13.5	16.6	20.9	22.1	27.7	32.1	40.0
45°	6.16	7.82	10.9	13.7	17.0	21.2	22.7	28.1	32.9	40.6
60°	6.30	7.92	11.1	13.8	17.4	21.5	23.1	28.4	33.6	41.0
90°	6.55	8.08	11.5	14.1	18.0	21.9	24.0	28.9	34.8	41.8
Regulation: Draft EC 5										
with $f_{yk} = 900 \text{ N/mm}^2$										

Regulation: Draft EC 5

with $f_{y,k} = 900 \text{ N/mm}^2$

Table 22: Characteristic buckling resistance $F_{c,k}$ in kN, where $\rho_k = 425 \text{ kg/m}^3$ (e.g. GL 28h, GL 30h).

	Head unrestrained						Head restrained			
ε	$d = 6 \text{ mm}$		$d = 8 \text{ mm}$		$d = 10 \text{ mm}$		$d = 12 \text{ mm}$		$d = 14 \text{ mm}$	
0°	5.72	7.50	10.1	13.2	15.9	20.4	21.2	27.1	30.8	39.1
30°	6.13	7.80	10.8	13.6	16.9	21.2	22.6	28.0	32.8	40.5
45°	6.29	7.91	11.1	13.8	17.4	21.5	23.1	28.4	33.6	41.0
60°	6.44	8.01	11.3	14.0	17.7	21.7	23.6	28.7	34.3	41.4
90°	6.68	8.17	11.8	14.3	18.4	22.1	24.4	29.2	35.4	42.2
Regulation: Draft EC 5										
with $f_{yk} = 900 \text{ N/mm}^2$										

Table 23: Characteristic buckling resistance $F_{c,k}$ in kN, where $\rho_k = 480 \text{ kg/m}^3$ e.g. LVL made of softwood, flatwise or edgewise; see Figure 13.

	Head unrestrained						Head restrained			
ε	$d = 6 \text{ mm}$		$d = 8 \text{ mm}$		$d = 10 \text{ mm}$		$d = 12 \text{ mm}$		$d = 14 \text{ mm}$	
0°	5.89	7.63	10.4	13.4	16.3	20.8	21.8	27.5	31.7	39.7
30°	6.30	7.92	11.1	13.8	17.4	21.5	23.1	28.4	33.6	41.0
45°	6.46	8.02	11.4	14.0	17.8	21.8	23.7	28.7	34.4	41.5
60°	6.60	8.12	11.6	14.2	18.2	22.0	24.1	29.1	35.0	41.9
90°	6.84	8.27	12.0	14.4	18.8	22.4	24.9	29.5	36.1	42.6
Regulation: Draft EC 5										
with $f_{yk} = 900 \text{ N/mm}^2$										

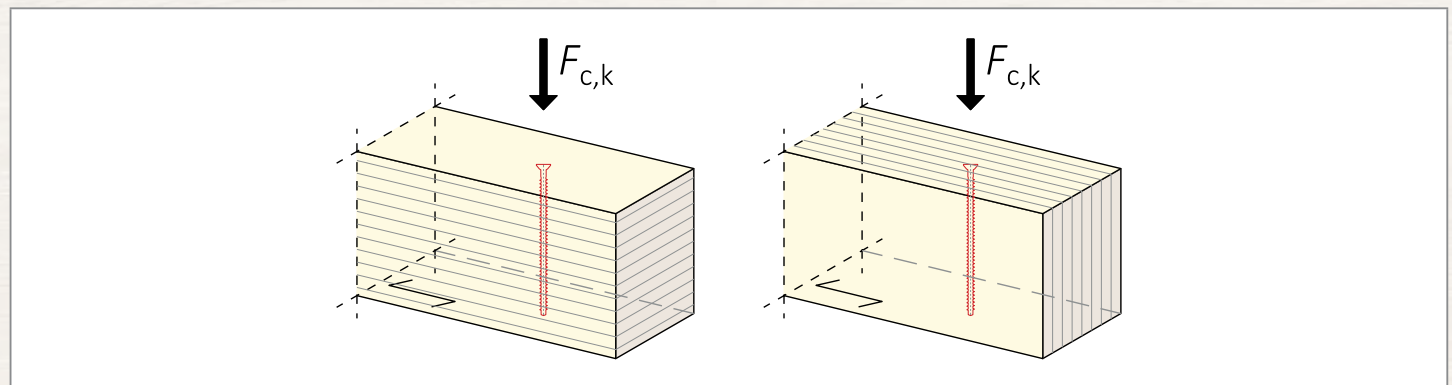


Figure 13: LVL-P_{flatwise} (laminates lying flat; left); LVL-P_{edgewise} (laminates upright on edge; right)

Table 24: Characteristic buckling resistance $F_{c,k}$ in kN, where $\rho_k = 600 \text{ kg/m}^3$ e.g. GL made of birch (ETA-19/0031).

	Head unrestrained						Head restrained			
ε	$d = 6 \text{ mm}$		$d = 8 \text{ mm}$		$d = 10 \text{ mm}$		$d = 12 \text{ mm}$		$d = 14 \text{ mm}$	
0°	6.21	7.85	11.0	13.7	17.1	21.3	22.8	28.2	33.2	40.7
30°	6.60	8.12	11.6	14.2	18.2	22.0	24.1	29.1	35.0	41.9
45°	6.75	8.22	11.9	14.4	18.5	22.2	24.6	29.4	35.7	42.4
60°	6.89	8.31	12.1	14.5	18.9	22.5	25.1	29.7	36.3	42.8
90°	7.11	8.45	12.5	14.7	19.4	22.8	25.8	30.1	37.4	43.4
Regulation: Draft EC 5										
with $f_{yk} = 900 \text{ N/mm}^2$										

Table 25: Characteristic buckling resistance $F_{c,k}$ in kN, where $\rho_k = 730 \text{ kg/m}^3$ e.g. GLVL made of beech (ETA-14/0354).

	Head unrestrained					Head restrained				
ε	$d = 6 \text{ mm}$		$d = 8 \text{ mm}$		$d = 10 \text{ mm}$	$d = 12 \text{ mm}$		$d = 14 \text{ mm}$		
0°	6.48	8.04	11.4	14.0	17.8	21.8	23.7	28.8	34.4	41.5
30°	6.85	8.28	12.1	14.5	18.8	22.4	25.0	29.6	36.2	42.7
45°	7.00	8.38	12.3	14.6	19.2	22.6	25.4	29.9	36.8	43.1
60°	7.13	8.46	12.5	14.8	19.5	22.9	25.8	30.2	37.4	43.5
90°	7.34	8.59	12.9	15.0	20.0	23.2	26.5	30.6	38.4	44.1
Regulation: Draft EC 5										
with $f_{yk} = 900 \text{ N/mm}^2$										

3.5.2 Free buckling

For fully threaded or double-thread carbon steel ASSY® screws, the characteristic buckling resistance $F_{c,k}$ can be determined using Eq. (3.8) and Table 26. The values in Table 26 are based on the assumption of the second Euler case, where the buckling length corresponds to the length of the screw section between the members plus 10 mm on each side (embedment depth) (see Figure 14 and Eq. [3.17]).

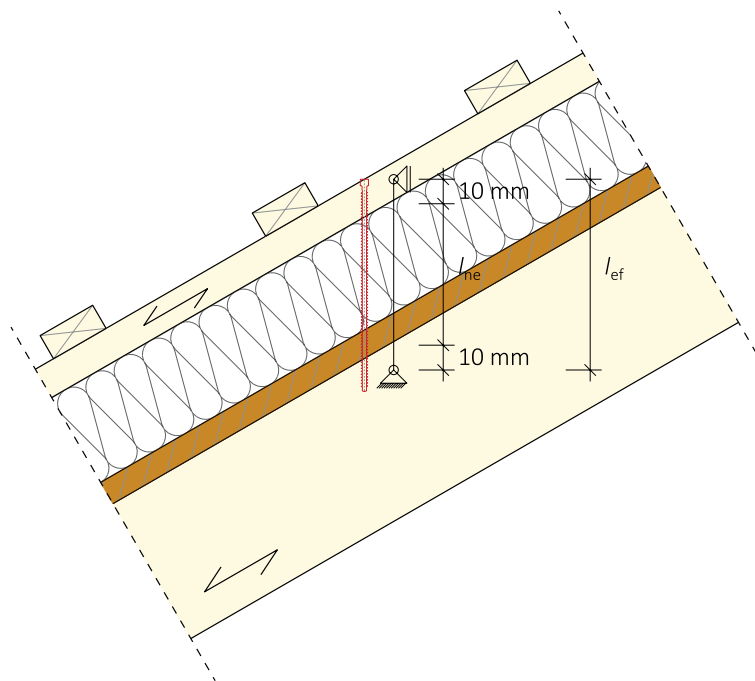


Figure 14: Example of a static system for an unbedded, free buckling screw

Table 26: Characteristic buckling resistance $F_{c,k}$ in kN for a screw with an unbedded shank section.

Unbedded screw length l_{ne} in mm	ASSY®plus VG					ASSY® Isotop	
	Outer thread diameter d in mm						
	6	8	10	12	14		8/10 ^{a)}
≤ 100	1.11	3.21	8.07	12.9	21.0	10.1	
120	0.84	2.45	6.27	10.2	16.9	8.30	
140	0.66	1.93	4.99	8.19	13.7	6.84	
160	0.53	1.56	4.05	6.70	11.3	5.70	
180	0.43	1.28	3.35	5.57	9.48	4.79	
200	-	1.07	2.82	4.69	8.03	4.08	
220	-	0.91	2.41	4.01	6.89	3.51	
240	-	0.78	2.08	3.48	5.96	3.04	
260	-	0.68	1.81	3.03	5.21	2.67	
280	-	0.59	1.59	2.66	4.61	2.35	
300	-	0.53	1.40	2.36	4.09	2.10	
320	-	0.47	1.25	2.10	3.65	1.88	
340	-	0.42	1.12	1.89	3.28	1.69	
360	-	0.37	1.01	1.70	2.96	1.53	
380	-	0.34	0.92	1.55	2.69	1.45	
400	-	0.31	0.83	1.42	2.45	1.26	
420	-	0.28	0.77	1.30	2.25	1.16	
440	-	0.26	0.70	1.18	2.06	1.06	
460	-	0.24	0.65	1.10	1.90	0.99	
480	-	0.22	0.59	1.01	1.76	0.91	

^{a)} The ASSY® Isotop has an 8 mm thread at the tip and 10 mm thread under the head (with a core diameter of 7.05 mm).

Regulation: ETA-11/0190

3.6 Load-bearing capacity of axially loaded screws

The characteristic load-bearing capacity $F_{ax,t,k}$ and the design value of the load-bearing capacity $F_{ax,t,d}$ for an axially tensile screw is the smallest value of the resistances resulting from the possible failure mechanisms.

Therefore, the characteristic load-bearing capacity $F_{ax,t,k}$ for an axially tensile screw is designed using Eq. (3.18) and the design value of the load-bearing capacity $F_{ax,t,d}$ using Eq. (3.19):

$$F_{ax,t,k} = \min \begin{cases} F_{w,k} \\ F_{pull,k} \\ F_{t,k} \end{cases} \quad (3.18)$$

$$F_{ax,t,d} = \min \begin{cases} \frac{k_{mod}}{\gamma_M} \cdot \begin{cases} F_{w,k} \\ F_{pull,k} \end{cases} \\ \frac{F_{t,k}}{\gamma_M} \end{cases} = \min \begin{cases} F_{w,d} \\ F_{pull,d} \\ F_{t,d} \end{cases} \quad (3.19)$$

Where:

$\gamma_M = 1.3$ in accordance with EC 5 NA Germany

For an axially compressive screw, the characteristic load-bearing capacity $F_{ax,c,k}$ is obtained using Eq. (3.20) and the design value of the load-bearing capacity $F_{ax,c,d}$ using Eq. (3.21):

$$F_{ax,c,k} = \min \begin{cases} F_{w,k} \\ F_{c,k} \end{cases} \quad (3.20)$$

$$F_{ax,c,d} = \min \begin{cases} \frac{k_{mod}}{\gamma_M} \cdot F_{w,k} \\ \frac{F_{c,k}}{\gamma_{M1}} \end{cases} = \min \begin{cases} F_{w,d} \\ F_{c,d} \end{cases} \quad (3.21)$$

Where:

$\gamma_M = 1.3$ in accordance with EC 5 NA Germany and $\gamma_{M1} = 1.1$ in accordance with EC 3-1-1 NA Germany

The design value of the load-bearing capacity of an axially tensile ($F_{ax,t,d}$) or axially compressive screw ($F_{ax,c,d}$) in a connection is the minimum value of the resistance in each member to which the screw will be connected. The design value of the load-bearing capacity of the screw is the minimum value of all failure mechanisms that may occur for the connection in question. The number and type of possible failure mechanisms depend on the following boundary conditions:

- Type of connection, e.g. timber-to-steel, timber-to-timber or engineered timber-to-timber
- Screw type, e.g. partially threaded or fully threaded
- Direction of the load, i.e. pulling out or pressing in the screw

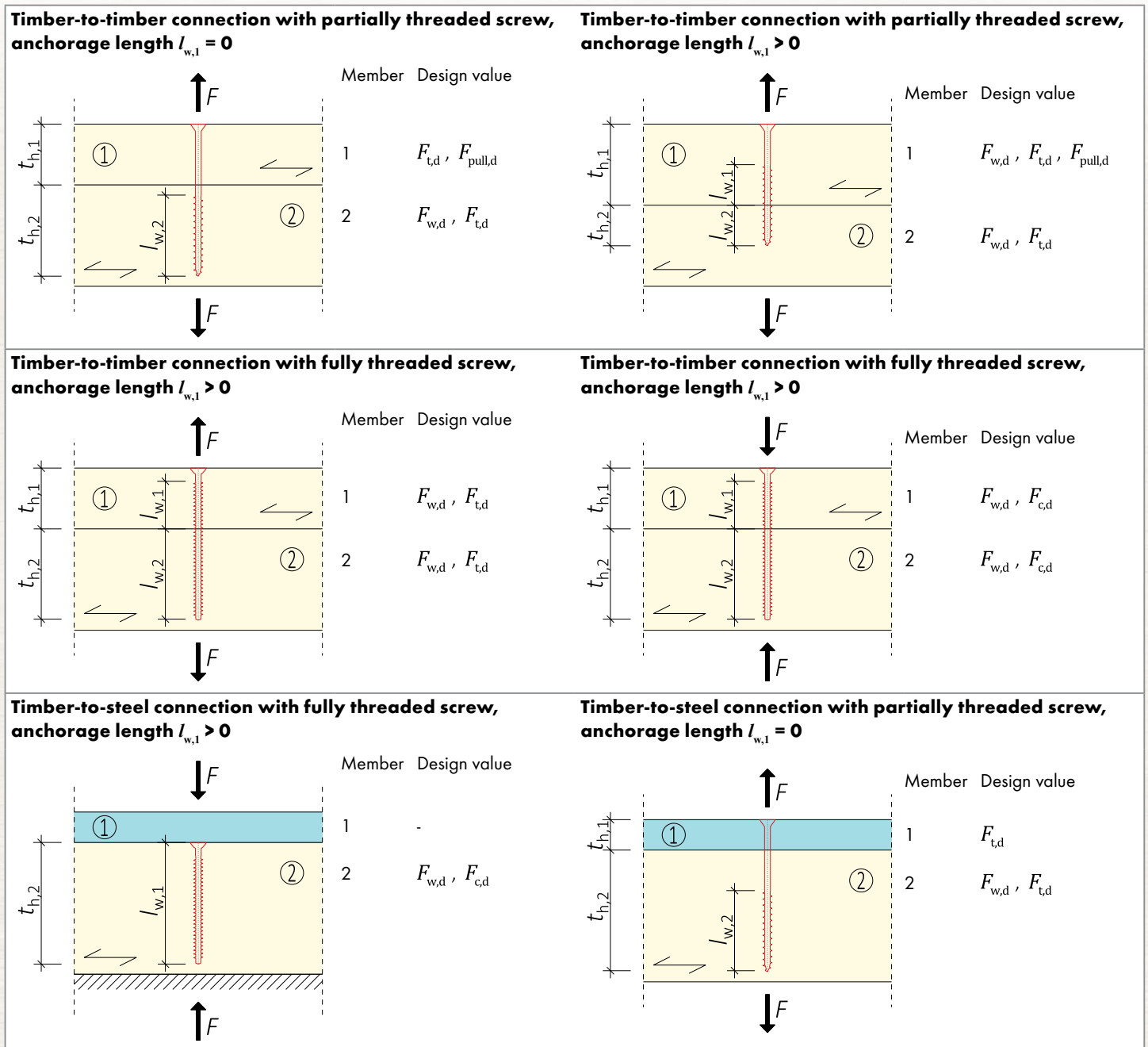


Figure 15: Overview of possible boundary parameters and the corresponding required design values.

3.7 Design values for the load-bearing capacity of connections with screws designed to be exclusively axially stressed

3.7.1 Design value of the load-bearing capacity of connections with axially tensile screws

The design value of the load-bearing capacity of a connection with screws subjected to tensile stress $F_{v,Rd}$ is generally designed as follows:

$$F_{ax,t,Rd} = n_{ef} \cdot F_{ax,t,d} \quad (3.22)$$

Where:

n_{ef} Effective number of fasteners in accordance with Section 3.7.3

$F_{ax,t,d}$ Design value of the load-bearing capacity of a tensile screw as determined by Eq. (3.19)

3.7.2 Design value of the load-bearing capacity of connections with axially compressive screws

The design value of the load-bearing capacity of a connection with screws subjected to compression $F_{ax,c,Rd}$ is generally designed as follows:

$$F_{ax,c,Rd} = n_{ef} \cdot F_{ax,c,d} \quad (3.23)$$

Where:

n_{ef} Effective number of fasteners in accordance with Section 3.7.3

$F_{ax,c,d}$ Design value of the load-bearing capacity of a compressive screw as determined by Eq. (3.21)

3.7.3 Effective number of fasteners

For axially loaded screws, the following equations are used to calculate the effective number of screws:

Transverse tension reinforcement, transverse compression reinforcement, shear reinforcement and load transfers		
	$n_{ef} = n$	(3.24)
Continuous connections and continuous load transfers (e.g. beam reinforcement, on-roof insulation)		
	$n_{ef} = n$	(3.25)
Timber-to-timber and engineered timber-to-timber connections		
Per fastener group where $n \leq 10$	$n_{ef} = n^{a), b)}$	(3.26)
Per fastener group where $n > 10$	$n_{ef} = 0,9 \cdot n$	(3.27)
Screws crossed in pairs subjected to tension/compression, where n_x is the number of screw crosses or pairs (where $n_x > 10$)	$n_{ef} = n_x^{0,9}$	(3.28)
Sheet timber-to-steel connections		
Per fastener group where $30^\circ \leq \delta \leq 60^\circ$ in shear connections with inclined, axially loaded screws	$n_{ef} = 0,9 \cdot n$	(3.29)
For all other sheet timber-to-steel connections	$n_{ef} = n^{0,9}$	(3.30)

a) For screws crossed in pairs subjected to tension/compression (where $n_x \leq 10$): $n_{ef} = n_x$

b) When applying Equation (3.26), an additional verification for block shear must be performed. If Equation (3.27) is applied for fastener groups with $n \leq 10$, the additional block shear verification is not required.

3.8 Minimum member dimensions and minimum spacings for axially loaded screws

3.8.1 General information

Regardless of whether screws are subjected to axial or lateral load, the permissible member dimensions and axis and edge distances depend on the force/grain angle α , the timber or engineered wood, the screw tip geometry and whether the members are pre-drilled before screwing.

Tables 30 to 36 match the specifications in ETA-11/0190.

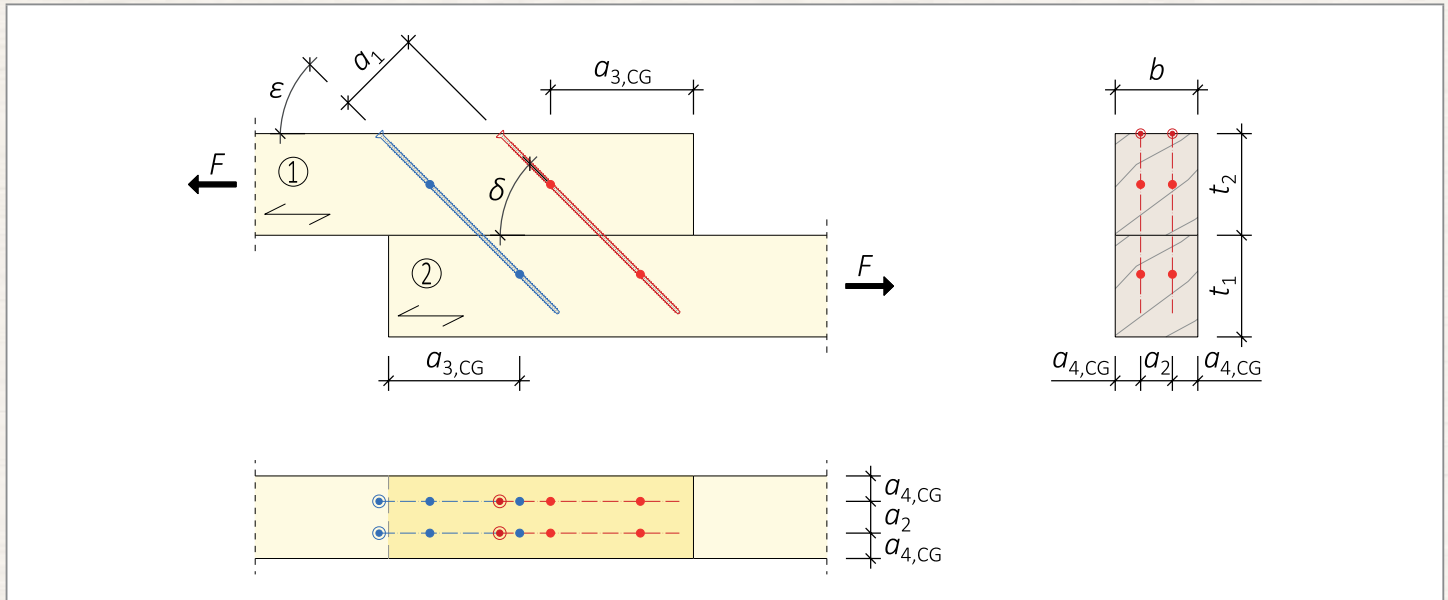


Figure 16: Minimum spacings and angle specifications for screws inclined in the direction of the grain, $\delta = \varepsilon$.

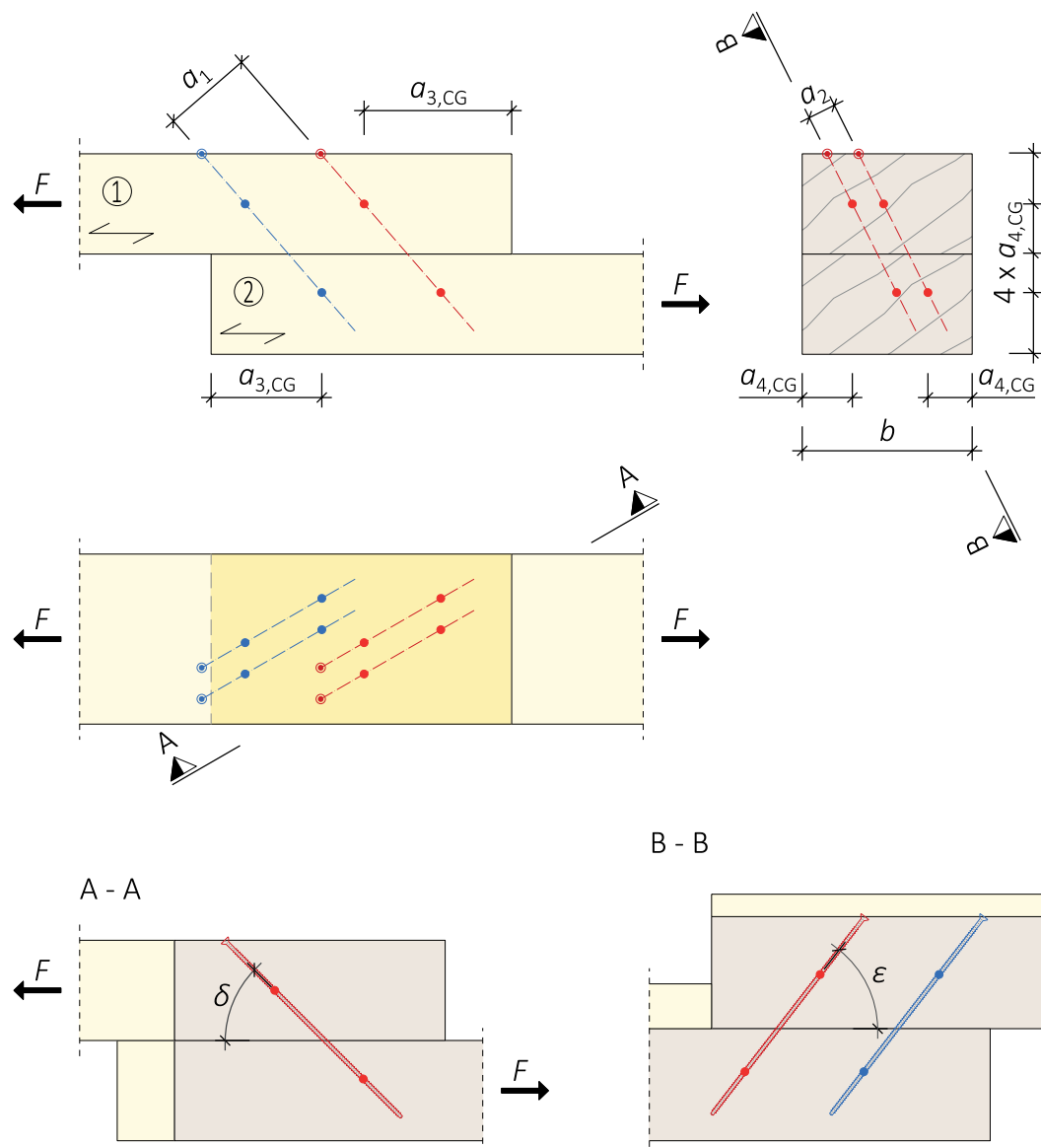


Figure 17: Minimum spacings and angle specifications for screws inclined in two directions, $\delta \neq \varepsilon$.

a_1	Minimum distance between two fasteners parallel to the grain direction
a_2	Minimum distance between two fasteners perpendicular to the grain direction
$a_{3,CG}$	Minimum distance between the edge and the screw centre of gravity in the member parallel to the grain direction
$a_{4,CG}$	Minimum distance between the edge and the screw centre of gravity perpendicular to the grain direction
a_x	Minimum distance between two screws in a screw cross
b	Member width
t_1	Thickness of member 1
t_2	Thickness of member 2
F	Acting force
α	Angle between the force direction and grain direction
β	Angle between the screw axis and wide face
δ	Angle between screw axis and shear plane
ε	Angle between the screw axis and grain direction
1	Member 1 (in a connection)
2	Member 2 (in a connection)

3.8.1.1 Minimum member thicknesses

The required minimum member dimensions when using ASSY® screws that are not pre-drilled are based on the regulations of EC 5:

- Members made of timber types at high risk of splitting (e.g. silver fir, Douglas fir etc.) should be pre-drilled if their thickness t is less than:

$$t = \max \left\{ \begin{array}{l} 14d \\ (13d - 30) \frac{\rho_k}{200} \end{array} \right. \quad (3.31)$$

- Timber products made of pine or timber products made of other timber types with edge distances $a_{4,CG} \geq 10d$ where $\rho_k \leq 420 \text{ kg/m}^3$ or $a_{4,CG} \geq 14d$ where $420 \text{ kg/m}^3 < \rho_k \leq 500 \text{ kg/m}^3$ should be pre-drilled if their thickness t is less than:

$$t = \max \left\{ \begin{array}{l} 7d \\ (13d - 30) \frac{\rho_k}{400} \end{array} \right. \quad (3.32)$$

See also Table 30 and 31 for timber types at high/low risk of splitting.

The regulation stipulated by Eq. (3.32) can also be applied when fastening formwork and load-bearing or counter battens, as well as intermediate connections of builders band and crossbeams to timber frames of all timber types, provided these members are connected with at least two screws.

Table 27: Minimum member thicknesses when using ASSY®plus screws that are **not** pre-drilled.

Outer thread diameter d in mm	≤ 6	8	10	12	14
Minimum member thickness $t_{\min}$ in mm	24	30	40	80	100
Regulation: ETA-11/0190					

The minimum member thicknesses shown in Table 27 also apply to **non**-pre-drilled ASSY® screws if the spacing between the screws in the direction of the grain and the end grain is at least $25 \cdot d$.

This rule does not apply to engineered wood boards or laminated veneer lumber with cross layers (LVL-C).

When using screws that are intended to be exclusively axially stressed and applying the reduced minimum spacings ($a_1 = 5 \cdot d$; $a_2 = 2.5 \cdot d$; $a_{3,CG} = 5 \cdot d$; $a_{4,CG} = 3 \cdot d$; $a_1 \cdot a_2 = 25 \cdot d^2$), the values for the minimum member thickness and width given in Table 28 and 29 apply.

Table 28: Minimum member thickness and width for **members made of solid wood-based products** (SWB) when using ASSY®plus screws.

Outer thread diameter d in mm	6	8	10	12	14
Minimum member thickness $t_{\min}$ in mm	60	80	100	120	140
Minimum member width $b_{\min}$ in mm	60	64	80	96	112
Regulation: ETA-11/0190					

Table 29: Minimum member thickness and width for **members made of laminated veneer lumber (LVL) made of softwood** when using ASSY®plus screws.

Outer thread diameter d in mm	6	8	10	12	14
Minimum member thickness $t_{\min}$ in mm	36	48	60	72	84
Minimum member width $b_{\min}$ in mm	60	64	80	96	112
Regulation: ETA-11/0190					

3.8.1.2 Minimum axial and edge distances

The required minimum spacings for axially loaded screws always refer to the thread centre of gravity of the screw in the member in question (see Figure 16).

The spacings given in EC 5 apply (spacings in columns 2 and 3 of Tables 30 to 33).

When using ASSY®plus screws or screws in solid wood-based products (SWB) or veneer-based products (VB), the spacings between the axially loaded screws can be reduced (see Tables 30 to 33, column 1). However, the following conditions must be met:

- $a_1 \geq 5 \cdot d$
- $a_2 \geq 2.5 \cdot d$ and
- $a_1 \cdot a_2 \geq 25 \cdot d^2$

For crossed screws in solid wood-based products (SWB) or veneer-based products (VB), a minimum screw spacing of $a_x = 1.5 \cdot d$ must be maintained at the crossing point. Appropriate measures must be taken to ensure that the screws do not collide when screwing in.

3.8.2 Minimum spacings and minimum member dimensions for axially loaded screws in members made of solid timber (ST/FST)

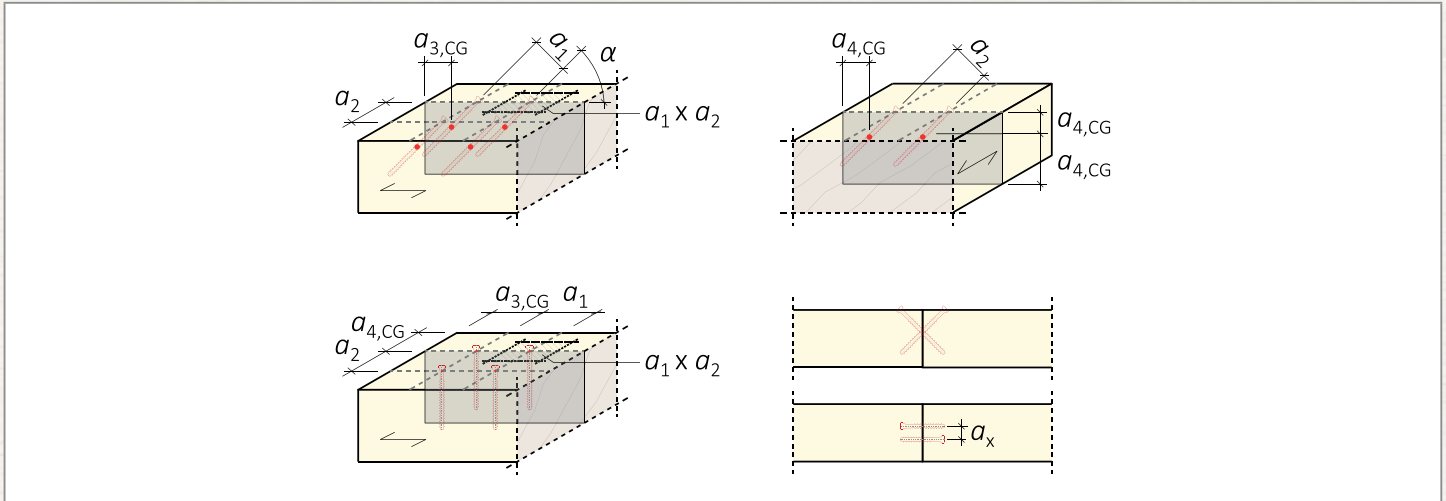


Figure 18: Spacings and angles in solid timber (ST/FST).

Table 30: Minimum spacings and minimum member dimensions for axially loaded screws in **solid timber (ST/FST)**, **glued solid timber (GST)** or **glued laminated timber (GL)** where $\rho_k \leq 420 \text{ kg/m}^3$.

	ASSY®plus: not pre-drilled					ASSY®plus: not pre-drilled ASSY®: pre-drilled					ASSY®: not pre-drilled				
a_1	$5 d$					$(4 + \cos \alpha) d$					$k_a (5 + 7 \cos \alpha) d^{a)}$				
a_2	$2.5 d$					$(3 + \sin \alpha) d$					$5 d$				
$a_{3,CG}$	$5 d$					$7 d$					$k_a 10 d^{a)}$				
$a_{4,CG}$	$3 d$					$3 d$					$5 d$ $10 d^{b)}$				
$a_1 \times a_2$	$25 d^2$					No specifications					No specifications				
a_x	$1.5 d$					$1.5 d$					$1.5 d$				
Minimum member dimensions for different outer thread diameters d															
d	6	8	10	12	14	6	8	10	12	14	6	8	10	12	14
$t_{\min}$	60	80	100	120	140	24	30	40	80	100					
$b_{\min}$	60	64	80	96	112										
Timber types at low risk of splitting. In accordance with NDP in 8.3.1.2(7) for pine (pinus sylvestris) ^{c)}															
$t_{\min} (\rho_k = 350 \text{ kg/m}^3)$											42	65	88	110	133
$t_{\min} (\rho_k = 420 \text{ kg/m}^3)$											50	78	105	132	160
Timber types at high risk of splitting. In accordance with NDP in 8.3.1.2(7) for all timber types ^{c)} except pine															
$t_{\min} (\rho_k = 350 \text{ kg/m}^3)$											84	130	175	221	266
$t_{\min} (\rho_k = 420 \text{ kg/m}^3)$											101	155	210	265	320
Table values in mm. The specifications also apply to connections between solid timber (ST/FST), glued solid timber (GST) or glued laminated timber (GL) and engineered wood in accordance with Table 14 or sheet steel															
^{a)} In general, $k_a = 1.0$; for Douglas fir $k_a = 1.5$															
^{b)} Minimum value for members made of timber types at high risk of splitting, whereby the minimum timber thicknesses for timber less prone to splitting (pine) can be applied.															
^{c)} For other characteristic bulk densities, see Section 3.8.1															
Regulation: ETA-11/0190, EC 5 (spacings in Columns 2 and 3; $t_{\min}$ based on ρ_k)															

Table 31: Minimum spacings and minimum member dimensions for axially loaded screws in **solid timber** (ST/FST), **glued solid timber** (GST) or **glued laminated timber** (GL) where $\rho_k > 420 \text{ kg/m}^3$.

	ASSY®plus: not pre-drilled $\rho_k > 500 \text{ kg/m}^3$: always pre-drilled	ASSY®plus: not pre-drilled ASSY®: pre-drilled $\rho_k > 500 \text{ kg/m}^3$: always pre-drilled	ASSY®: not pre-drilled $420 \text{ kg/m}^3 < \rho_k \leq 500 \text{ kg/m}^3$												
a_1	$5 d$	$(4 + \cos \alpha) d$	$k_a (7 + 8 \cos \alpha) d^{a)}$												
a_2	$2.5 d$	$(3 + \sin \alpha) d$	$7 d$												
$a_{3,CG}$	$5 d$	$7 d$	$k_a 15 d^{a)}$												
$a_{4,CG}$	$3 d$	$3 d$	$7 d$ $14 d^{b)}$												
$a_1 \times a_2$	$25 d^2$	No specifications	No specifications												
a_x	$1.5 d$	$1.5 d$	$1.5 d$												
Minimum member dimensions for different outer thread diameters d															
d	6	8	10	12	14	6	8	10	12	14	6	8	10	12	14
$t_{\min}$	60	80	100	120	140	24	30	40	80	100					
$b_{\min}$	60	64	80	96	112										
Timber types at low risk of splitting. In accordance with NDP in 8.3.1.2(7) for pine (pinus sylvestris) ^{c)}															
$t_{\min} (\rho_k = 425 \text{ kg/m}^3)$											51	79	106	134	162
$t_{\min} (\rho_k = 500 \text{ kg/m}^3)$											60	93	125	158	190
Timber types at high risk of splitting. In accordance with NDP in 8.3.1.2(7) for all timber types ^{c)} except pine															
$t_{\min} (\rho_k = 425 \text{ kg/m}^3)$											102	157	212	268	323
$t_{\min} (\rho_k = 500 \text{ kg/m}^3)$											120	185	250	315	380
Table values in mm. The specifications also apply to connections between solid timber (ST/FST), glued solid timber (GST) or glued laminated timber (GL) and engineered wood in accordance with Table 14 or sheet steel ^{a)} In general, $k_a = 1.0$; for Douglas fir $k_a = 1.5$ ^{b)} Minimum value for members made of timber types at high risk of splitting, whereby the minimum timber thicknesses for timber less prone to splitting (pine) can be applied. ^{c)} For other characteristic bulk densities, see Section 3.8.1															
Regulation: ETA-11/0190, EC 5 (spacings in Columns 2 and 3, $t_{\min}$ based on ρ_k)															

3.8.3 Minimum spacings and minimum member dimensions for axially loaded screws in members made of laminated veneer lumber (LVL) from softwood

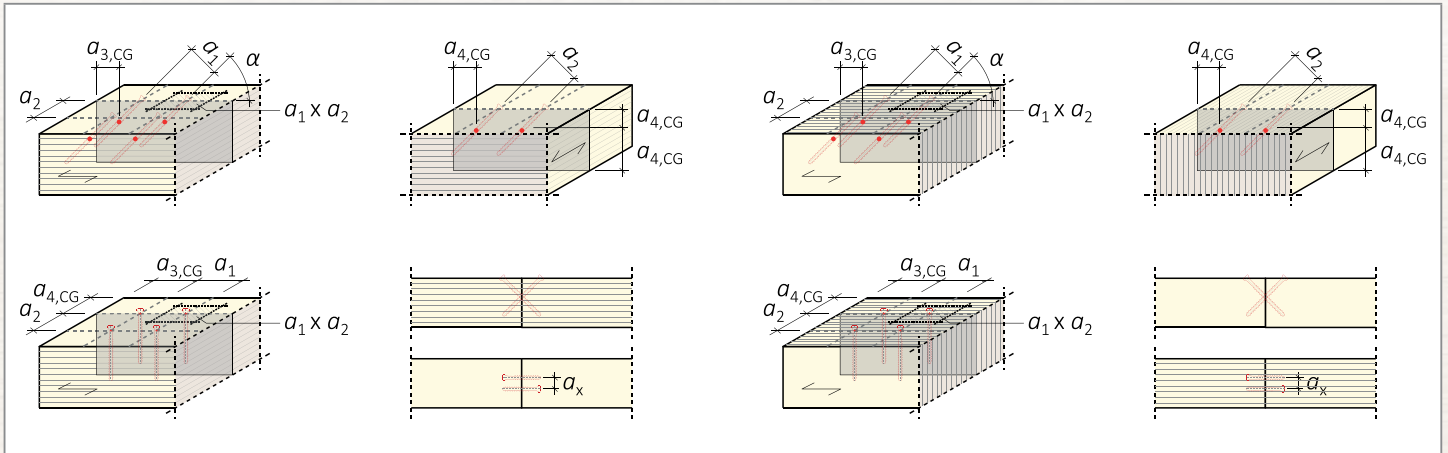


Figure 19: Spacings and angles in laminated veneer lumber (LVL) made of softwood for installation in the wide face (left, $\beta = 90^\circ$) and in the narrow face (right, $\beta = 0^\circ$).

Table 32: Minimum spacings and minimum member dimensions for axially loaded screws in **laminated veneer lumber (LVL) made of softwood** in accordance with DIN EN 13986, DIN EN 14279 and DIN EN 14374.

	ASSY®plus: not pre-drilled					ASSY®plus: not pre-drilled ASSY®: pre-drilled					ASSY®: not pre-drilled				
a_1	5 d					(4 + cos α) d					(5 + 7 cos α) d				
a_2	2.5 d					(3 + sin α) d					5 d				
$a_{3,CG}$	5 d					7 d					10 d ^{a)}				
$a_{4,CG}$	3 d					3 d					5 d ^{a)}				
$a_1 \times a_2$	25 d ²					No specifications					No specifications				
a_x	1.5 d					1.5 d					1.5 d				
Minimum member dimensions for different outer thread diameters d															
d	6	8	10	12	14	6	8	10	12	14	6	8	10	12	14
t _{min}	36	48	60	72	84	24	30	40	80	100	72 ^{b)}	96 ^{b)}	120 ^{b)}	144 ^{b)}	168 ^{b)}
b _{min}	60	64	80	96	112										
Table values in mm. The specifications also apply to connections between laminated veneer lumber and engineered wood in accordance with Table 14 or sheet steel. Members with a characteristic bulk density of $\rho_v > 500 \text{ kg/m}^3$ must be pre-drilled before the screws are inserted. ^{a)} For LVL-C in accordance with general type approval Z-9.1-890, $a_{3,CG}$ can be assumed as 5d and $a_{4,CG}$ as 3d. ^{b)} $t_{\min} = 12 \cdot d$. For LVL-S in accordance with Z-9.1-847, the following applies: For non-pre-drilled ASSY® screws when arranged in the wide face $t_{\min} = \max \{ (12d - 36\text{mm}); 5d \}$															
Regulation: ETA-11/0190, EC 5 (spacings in columns 2 and 3)															

3.8.4 Minimum spacings and minimum member dimensions for axially loaded screws in glued laminated veneer lumber (GLVL) made of beech in accordance with ETA-14/0354

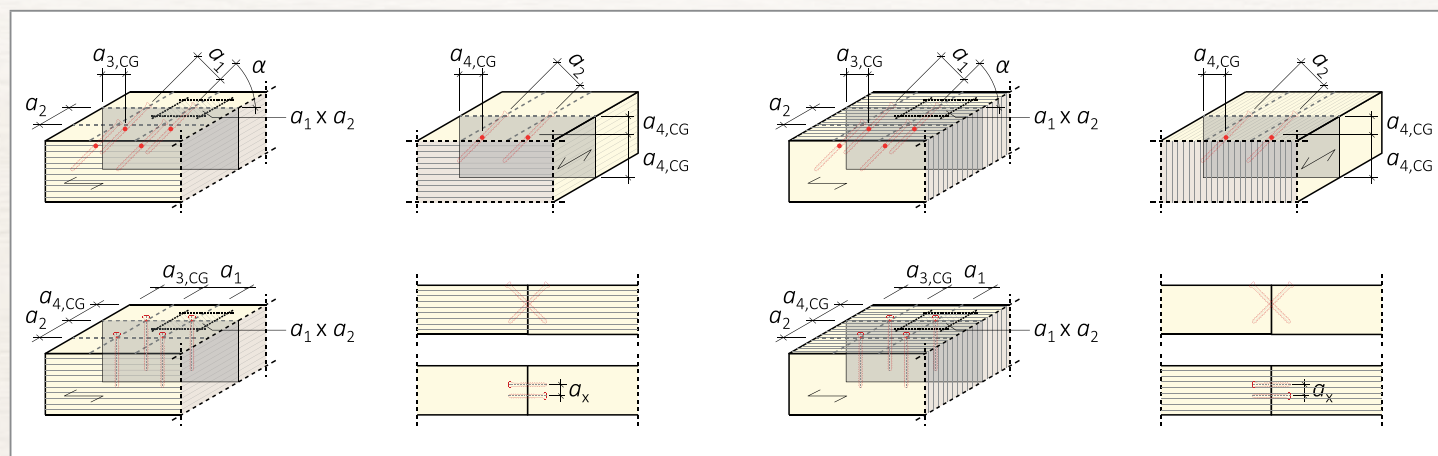


Figure 20: Spacings and angles in laminated veneer lumber (LVL) made of beech for installation in the wide face (left, $\beta = 90^\circ$) and in the narrow face (right, $\beta = 0^\circ$).

Table 33: Minimum spacings and minimum member dimensions for axially loaded screws in glued laminated veneer lumber (GLVL) made of **beech** (ETA-14/0354).

	ASSY®plus: pre-drilled	ASSY®plus: pre-drilled ASSY®: pre-drilled	ASSY®plus: not pre-drilled ASSY®: not pre-drilled										
a_1	5 d	$(4 + \cos \alpha) d$	$(7 + 8 \cos \alpha) d$										
a_2	2.5 d	$(3 + \sin \alpha) d$	7 d										
$a_{3,CG}$	5 d	7 d	15 d										
$a_{4,CG}$	3 d	3 d	7 d										
$a_1 \times a_2$	25 d^2	No specifications	No specifications										
a_x	1.5 d	1.5 d	1.5 d										
Minimum member dimensions for different outer thread diameters d													
d	6	8	10	12	14	6	8	10	12	6	8	10	12
$t_{\min}$	60	80	100	120	140	42 ^{a)}	56 ^{a)}	70 ^{a)}	84 ^{a)}	42 ^{a)}	56 ^{a)}	70 ^{a)}	84 ^{a)}
$b_{\min}$	60	64	80	96	112								
Table values in mm. The specifications also apply to connections between GLVL made of beech and engineered wood in accordance with Table 14 or sheet steel. ^{a)} Minimum thicknesses $t \geq 7 d$ apply where $5 \leq d \leq 12$, type S; there is no minimum thickness for type Q.													
Regulation: ETA-11/0190, EC 5 (spacings in columns 2 and 3)													

The thread engagement length without pre-drilling in GLVL made of beech (ETA-14/0354) is limited. Table 34 specifies the maximum permissible embedment depths of the threaded section of the screw $l_{w,max}$ that can be screwed in without pre-drilling.

Table 34: Maximum permissible embedment depth of the threaded section $l_{w,max}$ without pre-drilling.

	ASSY®plus				ASSY®					
Outer thread diameter d in mm	6	8	10	12	5	6	7	7.5	8	10
Embedment depth $l_{w,max}$ in mm	30	48	80	96	50	60	70	75	80	100

Regulation: ETA-11/0190

3.8.5 Minimum spacings and minimum member dimensions for axially loaded screws in cross-laminated timber (CLT)

Unless otherwise stated in the approvals by the cross-laminated timber (CLT) manufacturer, the minimum values for axial and edge spacings for screws in cross-laminated timber (CLT) provided in Table 35 apply. The grain direction on the face layer is used as the grain direction in calculations. The minimum spacings in the narrow faces are not dependent on the angle between the screw axis and grain direction.

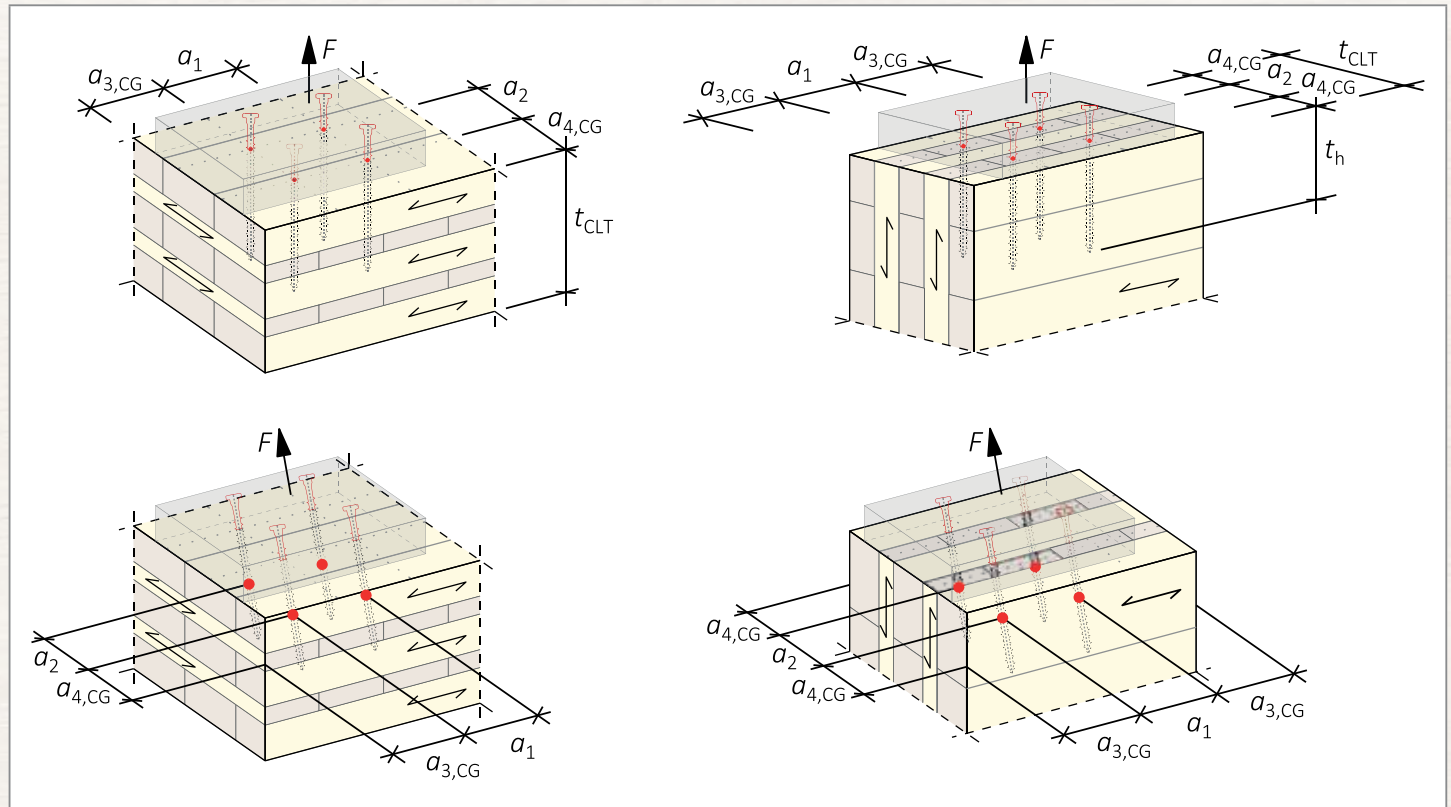


Figure 21: Spacings and formula symbols in the side face (left) and narrow face (right) of cross-laminated timber (CLT).

Table 35: Minimum spacings for screw connections in the side faces or narrow faces of **cross-laminated timber (CLT) made of softwood**.

	ASSY®plus: not pre-drilled ASSY®: not pre-drilled									
	Side face					Narrow face				
a_1	$4\ d$					$10\ d$				
a_2	$2.5\ d$					$4\ d$				
$a_{3,CG}$	$6\ d$					$7\ d$				
$a_{4,CG}$	$2.5\ d$					$3\ d$				
$a_1 \times a_2$	No specification					No specification				
a_x	$1.5\ d$					$1.5\ d$				
Minimum member thicknesses t_{CLT} and embedment depths t_h for different outer thread diameters d										
d	6	8	10	12	14	6	8	10	12	14
t_{CLT}	60	80	100	120	140	60	80	100	120	140
t_h	No specifications					60	80	100	120	140
Table values in mm. The specifications also apply to connections between cross-laminated timber (CLT) and sheet steel. Screws in the narrow face that only engage in the outermost layer (face layer) are not permitted. If double edge layers (two edge layers orientated in the same direction) are used, the inner edge layer is considered to be a separate layer. Supplementary regulation "Defined position in the inner panel layers" in Section 3.3.										
Regulation: ETA-11/0190										

3.8.6 Minimum spacings and minimum member dimensions for screws arranged parallel to the grain in the end grain of solid wood-based products (SWB) and laminated veneer lumber (LVL)

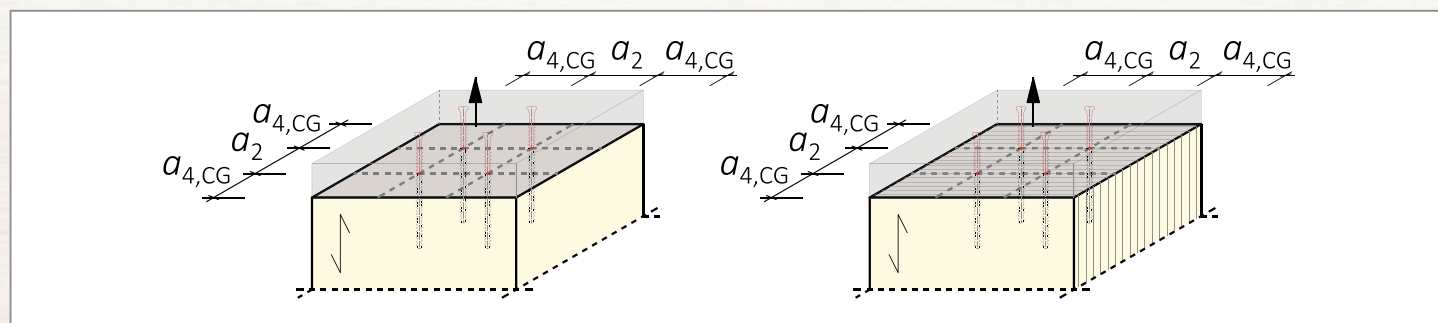


Figure 22: Definition of the edge and axial spacings of screws arranged parallel to the grain in the end grain ($\varepsilon = 0^\circ$) for solid wood-based products (left) and laminated veneer lumber (right).

Table 36: Minimum spacings for axially loaded screws in the end grain surfaces with an angle of $\varepsilon = 0^\circ$ between the screw axis and grain direction, members made of **solid timber** (ST/FST), **glued solid timber** (GST), **glued laminated timber** (GL) or **laminated veneer lumber** (LVL).

	ASSY® plus: not pre-drilled ^{a)} ASSY®: pre-drilled		ASSY®: not pre-drilled		
			$\rho_k \leq 420 \text{ kg/m}^3$	$420 \text{ kg/m}^3 < \rho_k \leq 500 \text{ kg/m}^3$	
a_2	3 d		5 d	7 d	
$a_{4,CG}$	3 d		5 d	7 d	
Minimum embedment depths t_h for different outer thread diameters d					
d	6	8	10	12	14
t_h	120	160	200	240	280
Table values in mm. The specifications also apply to connections between solid timber (ST/FST), glued solid timber (GST) or glued laminated timber (GL) and engineered wood in accordance with Table 14 or sheet steel					
^{a)} Members with a characteristic bulk density $\rho_k > 500 \text{ kg/m}^3$ generally require pre-drilling.					
Regulation: ETA-11/0190, see EC 5 (Table 8.2)					

3.9 Screw-induced failure mechanisms in the affected members – block shear

Block shear failure perpendicular to the grain direction can occur, whereby a block surrounded by a group of screws is pulled out of the timber matrix. Blaß and Flaig (2019) have shown that such a failure can be prevented by reducing the effective number of screws to $n_{ef} < n$ (see Section 3.7.3) and therefore does not need to be taken into account. However, if the effective number of screws is assumed as $n_{ef} = n$, this failure must be taken into account.

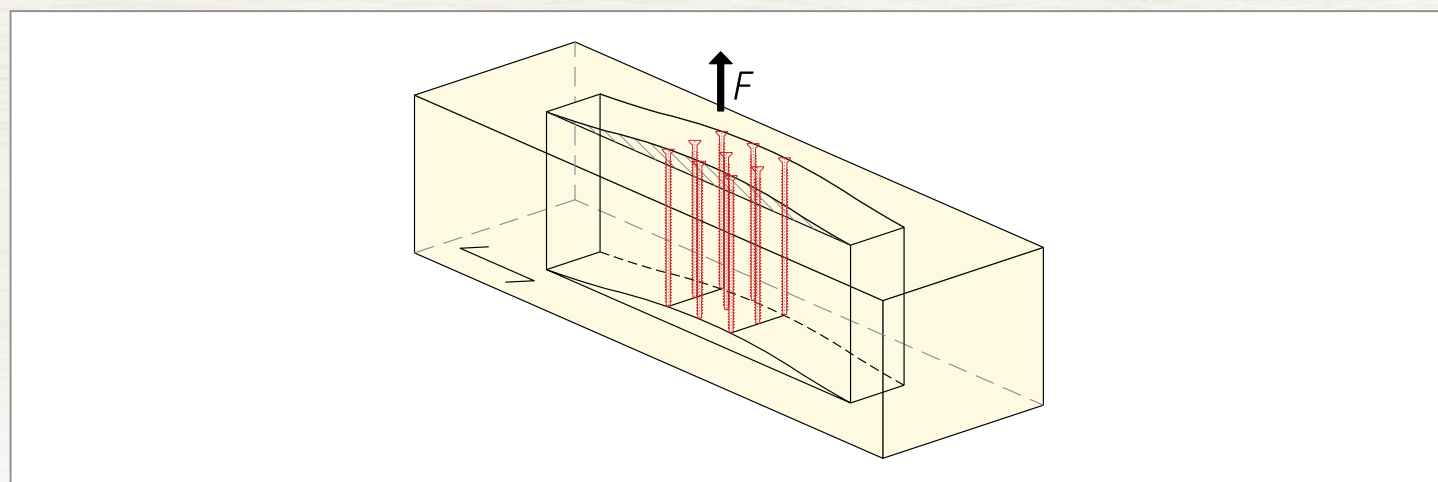


Figure 23: Block shear failure in axially loaded screwed connections.

However, if screws inserted at an angle are subjected to stress in the end grain direction within the area of influence of the end grain, a block surrounded by these screws can be pulled out, as shown in Figure 24. In this case, the inclined screws do not form a plastic hinge, so the thread engagement length t_1 projected perpendicular to the shear plane is equal to the effective embedment depth t_{ef} . To prevent this failure mechanism, the characteristic block shear capacity $F_{bs,ax,Rk}$ of the member must be verified:

$$F_{bs,ax,Rk} = \max \begin{cases} 0,7 \cdot A_{net,v} \cdot f_{v,k} \\ 1,5 \cdot A_{net,t} \cdot f_{t,0,k} \end{cases} \quad (3.33)$$

Where:

$f_{v,k}$ Characteristic value of the shear strength of the timber
 $f_{t,0,k}$ Characteristic value of the tensile strength of the timber parallel to the grain direction

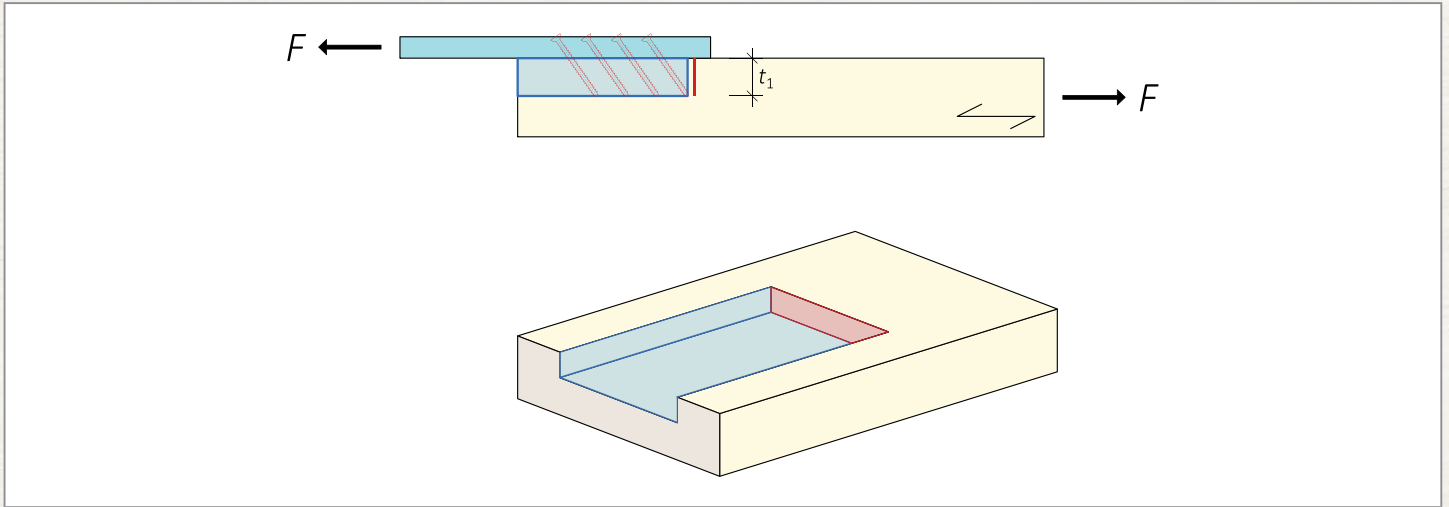


Figure 24: Block shear failure in tensile shear connections (Case 2).

As with block shear failure in accordance with EC 5 for laterally loaded fasteners (see Section 4.8), the characteristic block shear capacity must be determined for two different cases. The case with the lower block shear capacity is decisive. For Case 1 (failure over the entire cross-sectional height), the net shear plane $A_{net,v}$ is determined using Eq. (4.26) and the net tensile area $A_{net,t}$ using Eq. (4.27). For Case 2 (failure over part of the cross-sectional height), the net shear plane $A_{net,v}$ is determined using Eq. (3.34) and the net tensile area $A_{net,t}$ using Eq. (3.35). The corresponding dimensions can be determined using Figure 25.

$$A_{net,v} = (2 \cdot t_1 + b_1) \cdot \left(l_v + \sum_i \left(\frac{a_{1,i}}{\sin \delta} \right) \right) + b_1 \cdot 0,5 \cdot l_w \cdot \cos \delta \quad (3.34)$$

$$A_{net,t} = t_1 \cdot b_1 \quad (3.35)$$

Where:

$b_1 = \sum_{i=1}^n a_{2,i} - \sum_{i=1}^{n-1} d$	Net width of the connection
$t_1 = l_w \cdot \sin \delta$	Embedment depth projected perpendicular to the shear plane
$l_v = a_{3,CG,ist}$	Spacing between the edge and the centre of gravity of the first row of screws in the timber parallel to the grain direction
$\sum_i a_{1,i}$	Sum of the i spacings between screws parallel to the grain direction
l_w	Anchorage length of the threaded section of a screw
δ	Angle between the screw axis and shear plane
$\sum_{i=1}^n a_{2,i}$	Sum of the n spacings between screws perpendicular to the grain direction
$\sum_{i=1}^{n-1} d$	Sum of the $(n-1)$ outer thread diameters of the screws

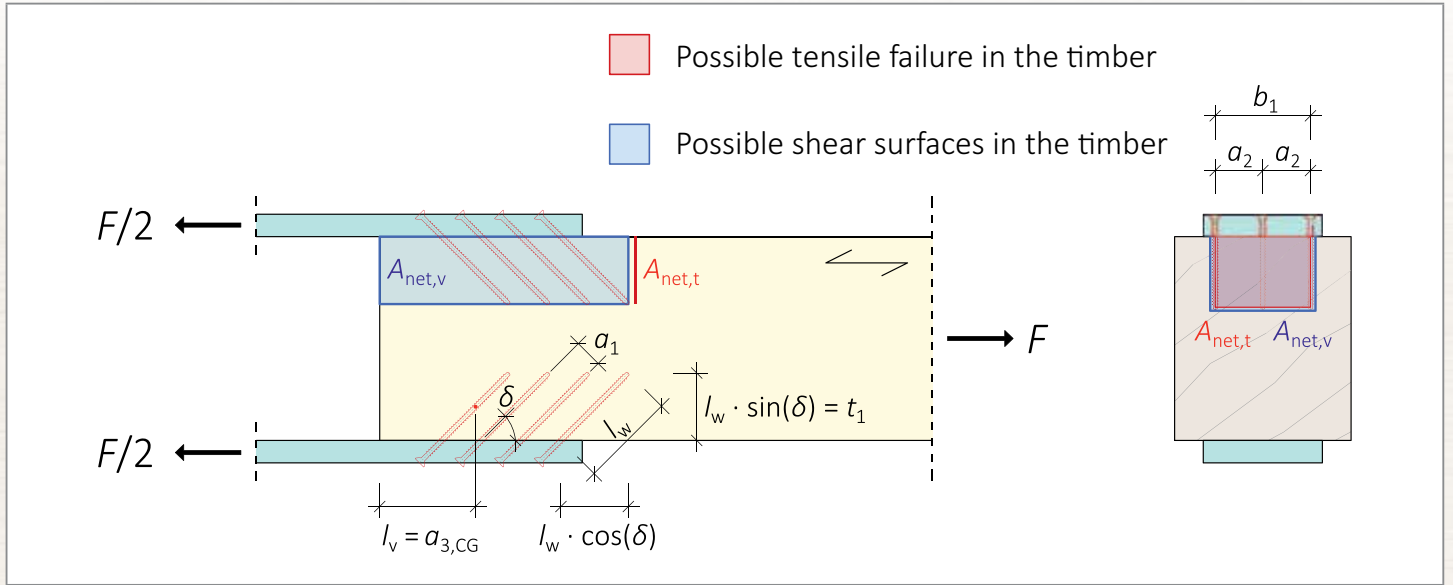


Figure 25: Contributing areas for the verification of block shear in shear connections with inclined, axially loaded screws.

3.10 Design of axially loaded screws exposed to fire

The design of connections with axially loaded screws exposed to fire is determined independently of the fire behaviour of the members. The residual load-bearing capacity of the screws in the event of fire depends solely on their distance from the edge of the member. Joints must be either closed or treated as edges.

Screws subjected to pull-out forces must generally be protected against direct fire exposure (by countersinking or covering with timber, engineered wood or other suitable materials) or they must be designed and installed with sufficient spacing from the adjacent member edges. The design value of the axial load-bearing capacity in the event of fire $F_{ax,t,d,fi}$ can be determined using Eq. (3.36). This approach applies to screw diameters and screw head shapes in engineered wood as specified in Table 50 of this document.

$$F_{ax,t,d,fi} = \eta \cdot \frac{F_{ax,t,R20}}{\gamma_{M,fi}} \quad (3.36)$$

Where:

- η Reduction factor, see Eq. (3.38)
- $F_{ax,t,R20}$ 20 % fractile value of the load-bearing capacity of a screw

$$F_{ax,t,R20} = k_{fi} \cdot F_{ax,t,k} \quad (3.37)$$

Where:

- k_{fi} Conversion factor from 5 % fractile values to 20 % fractile values for axially loaded fasteners 1.05
- $F_{ax,t,k}$ Characteristic load-bearing capacity of a tensile screw in accordance with Section 3.6
- $\gamma_{M,fi}$ Partial safety factor for timber in the event of fire, generally 1.0

The reduction factor η for modifying the axial load-bearing capacity is determined using Eq. (3.38).

$$\eta = \begin{cases} 0 & \text{für } a_{1,fi} \leq 0,6 \cdot t_{d,fi} \\ \frac{0,44 \cdot a_{1,fi} - 0,264 \cdot t_{d,fi}}{0,2 \cdot t_{d,fi} + 5} & \text{für } 0,6 \cdot t_{d,fi} \leq a_{1,fi} \leq 0,8 \cdot t_{d,fi} + 5 \\ \frac{0,56 \cdot a_{1,fi} - 0,36 \cdot t_{d,fi} + 7,32}{0,2 \cdot t_{d,fi} + 23} & \text{für } 0,8 \cdot t_{d,fi} + 5 \leq a_{1,fi} \leq t_{d,fi} + 28 \\ 1,0 & \text{für } a_{1,fi} \geq t_{d,fi} + 28 \end{cases} \quad (3.38)$$

Where:

$a_{1,fi}$ Side covering in mm, see Figure 26

$t_{d,fi}$ Required fire resistance period in minutes

The conditions of Eq. (3.39) and (3.40) must also be met.

$$a_{2,fi} \geq a_{1,fi} + 40 \quad (3.39)$$

$$a_{3,fi} \geq a_{1,fi} + 20 \quad (3.40)$$

If $a_{2,fi} = a_{1,fi}$ and $a_{3,fi} \geq a_{1,fi} + 20$ mm (for screws arranged centrally in the member), the conversion factor η as determined by Eq. (3.38) must be designed using a required fire resistance period $t_{d,fi}$ increased by 25 %.

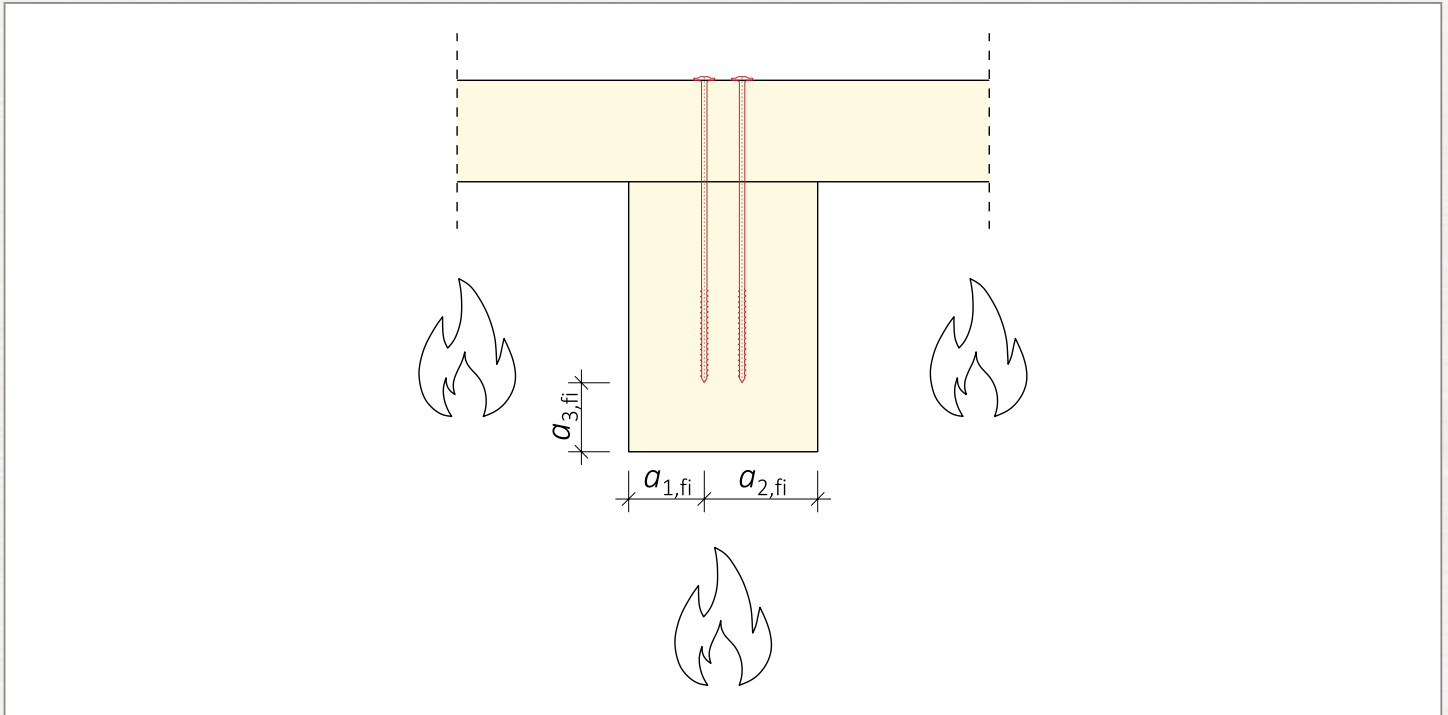


Figure 26: Spacing conventions for axially loaded screws indirectly exposed to fire.

3.11 Slip modulus of axially loaded screws

3.11.1 Slip modulus in timber-to-timber, engineered timber-to-timber and timber-to-steel connections

In accordance with ETA 11/0190, the slip modulus $K_{SLS,w}$ of the threaded section of screws designed for axial loading can be designed for the respective connected member in the serviceability limit state using Eq. (3.41) (with d and l_w in mm and ρ_{mean} in kg/m³), regardless of whether softwood or hardwood is used and independent of the angle δ between the screw axis and the shear plane.

$$K_{SLS,w} = 1250 \cdot d^{0,2} \cdot l_w^{0,4} \cdot \rho_{mean}^{0,2} \quad \text{for screws in timber members in N/mm} \quad (3.41)$$

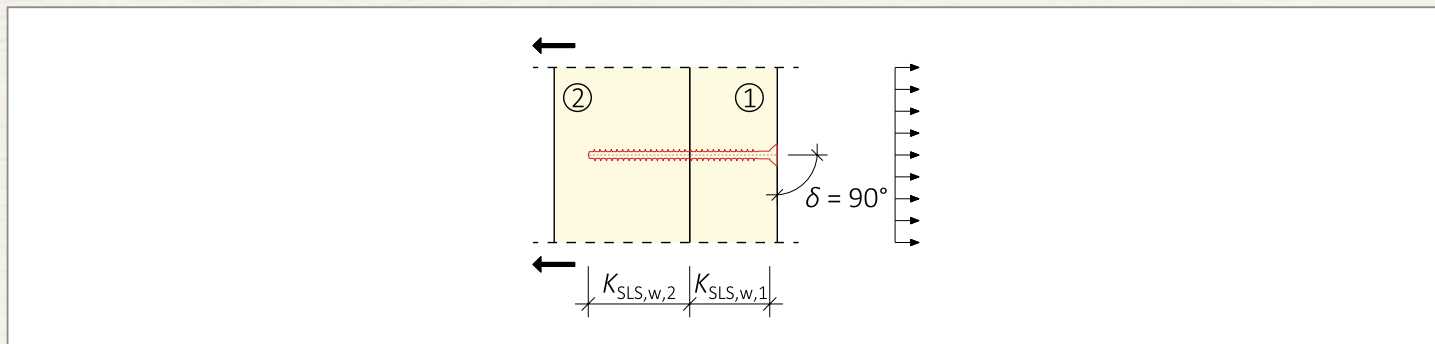


Figure 27: Slip modulus in timber-to-timber connections.

3.12 Calculation examples

3.12.1 Shear connections with inclined, axially loaded screws

3.12.1.1 General information

This example is based on the connection shown in Figure 28, which is subjected to a force of $F_{Ed} = 120$ kN ($k_{mod} = 0.8$). Verifications must be carried out for screw pull-out and block shear. The minimum permissible fastener spacings and edge distances have been selected.

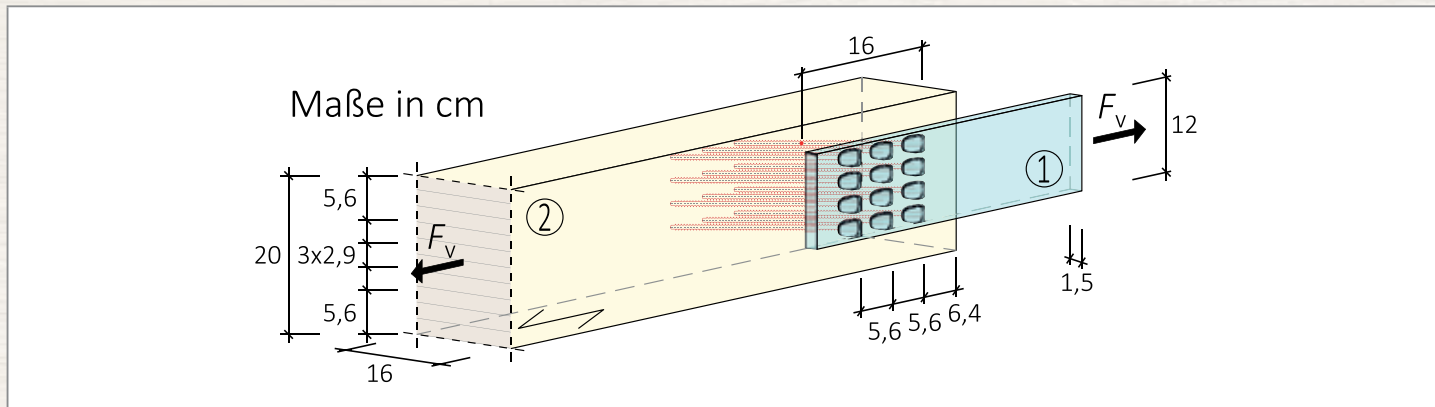


Figure 28: Calculation example – tensile shear connection.

The following specifications apply:

Geometry and material

Member 1			
Material, steel grade			S235
Thickness/height	t_s/h_1	=	1.5 cm/12.0 cm
Yield strength	$f_{y,k}$	=	235 N/mm ²
Member 2			
Material, strength class			GL 28h
Thickness/height	t_2/h_2	=	16.0 cm/20 cm
Force/grain angle	α	=	0°
Raw density	ρ_k	=	425 kg/m ³
Modification factor	k_{mod}	=	0.80
Tensile strength	$f_{t,0,k}$	=	22.3 N/mm ²
Shear strength	$f_{v,k}$	=	3.5 N/mm ²
Action			
Service class	Service class		1
Load duration class			Medium
Design value of the shear force	$F_{v,Ed}$	=	120 kN
Fasteners			
	ASSY®plus VG 4 CSMP 8.0 x 260 + angled washer		
Diameter	d	=	8.0 mm
Head diameter	d_{head}	=	15.0 mm
Length	l	=	260 mm
Withdrawal parameter	$f_{ax,k}$	=	12.0 N/mm ²
Tensile resistance	$f_{tens,k}$	=	22.0 kN
Partial safety factor	γ_M	=	1.3
Screw/shear plane angle	δ	=	45°
Screw/grain angle	ε	=	45°
Selected spacing between the edge and the centre of gravity of the first row of screws in the member parallel to the grain direction	$a_{3,CG,ist}$	=	$20d = 160$ mm

3.12.1.2 Calculation of the axial load-bearing capacity of a screw

In this calculation example, the angle between the grain direction and the shear plane is zero, meaning that the angle between the screw axis and grain ε and between the screw axis and the shear plane δ are equal: $\varepsilon = \delta$. If $\varepsilon \neq \delta$, i.e. the angle between the grain direction and the shear plane is not zero, this must be taken into account when calculating the anchorage length of the threaded section of the screw l_w . Therefore:

$$l_w = l - \left(\frac{t_s}{\sin \varepsilon} + l_{aw} \right) = 260 - \left(\frac{15}{\sin 45^\circ} + 12,7 \right) = 226 \text{ mm}$$

Where:

l_{aw} Effective length in the angled washer in accordance with ETA-11/0190

The characteristic load-bearing capacity of the thread in member 2 $F_{w,k,2}$ can be designed as follows:

$$F_{w,k,2} = \frac{k_{ax} \cdot f_{ax,k} \cdot d \cdot l_w}{k_\beta} \cdot \left(\frac{\rho_k}{\rho_{ref,k}} \right)^{0,8} = \frac{1,0 \cdot 12,0 \cdot 8 \cdot 226}{1,0} \cdot \left(\frac{425}{350} \right)^{0,8} = 25,4 \text{ kN}$$

Where:

$$k_{ax} = 1,0 \text{ für } 45^\circ \leq \varepsilon \leq 90^\circ$$

$$k_\beta = 1,0 \text{ für GL}$$

The design value of the load-bearing capacity for a fastener $F_{ax,t,d}$ is obtained using Eq. (3.19) as follows:

$$F_{ax,t,d} = \min\left(\frac{k_{mod} \cdot F_{w,k,2}}{\gamma_M}; \frac{F_{t,k}}{\gamma_M}\right) = \min\left(\frac{0,8 \cdot 25,4}{1,3}; \frac{22,0}{1,3}\right) = 15,6 \text{ kN}$$

The calculation of the design value for the shear load-bearing capacity of the connection $F_{v,Rd}$ requires the following values:

$n_0 = 3$	Number of fastener rows parallel to the load
$n_{90} = 4$	Number of fastener rows perpendicular to the load
$n_{ef} = 0,9 \cdot (n_0 \cdot n_{90}) = 0,9 \cdot 3 \cdot 4 = 10,8$	Effective number of screws in the connection as determined by Eq. (3.29)
$\mu = 0,25$	Friction coefficient between steel and timber

The axial load-bearing capacity of a screw must be converted into a resistance acting in the direction of the joint, whereby the design value for the shear load-bearing capacity of the connection $F_{v,Rd}$ is designed as follows:

$$F_{v,Rd} = n_{ef} \cdot F_{ax,t,d} \cdot (\cos \varepsilon + \mu \cdot \sin \varepsilon) = 10,8 \cdot 15,6 \cdot (\cos 45^\circ + 0,25 \cdot \sin 45^\circ) = 148,9 \text{ kN}$$

The utilisation factor η_v of the connection is given by:

$$\eta_v = \frac{120 \text{ kN}}{149 \text{ kN}} = 0,81 \leq 1 \quad \checkmark$$

3.12.1.3 Block shear verification

Since the tensile shear connection is located in the end grain area and is subjected to stress in the direction of the end grain, brittle failure of the connection (see Section 3.9) must be taken into account.

First, the net width of the connection b_1 and the net embedment depth t_1 are designed as input variables:

$$b_1 = \sum_{i=1}^n a_{2,i} - \sum_{i=1}^{n-1} d = 3 \cdot 29 - (4 - 1) \cdot 8 = 63 \text{ mm}$$

$$t_1 = l_w \cdot \sin \delta = 226 \cdot \sin 45^\circ = 159 \text{ mm}$$

The net tensile area $A_{net,t}$ and the net shear plane $A_{net,v}$ (where $l_v = a_{3,CG,ist} = 160 \text{ mm}$) are designed for **Case 2** as follows:

$$\begin{aligned} A_{net,t,2} &= t_1 \cdot b_1 = 159 \cdot 63 = 10.017 \text{ mm}^2 \\ A_{net,v,2} &= (2 \cdot t_1 + b_1) \cdot \left(l_v + \sum_i \left(\frac{a_{1,i}}{\sin \delta} \right) \right) + b_1 \cdot 0,5 \cdot l_w \cdot \cos \delta \\ &= (2 \cdot 159 + 63) \cdot \left(160 + 2 \cdot \frac{41}{\sin 45^\circ} \right) + 63 \cdot 0,5 \cdot 226 \cdot \cos 45^\circ \\ &= 110.179 \text{ mm}^2 \end{aligned}$$

The net tensile area $A_{\text{net,t}}$ and the net shear plane $A_{\text{net,v}}$ (where $l_v = a_{3,\text{CG,ist}} = 160 \text{ mm}$) are designed for **Case 1** as follows:

$$A_{\text{net,t,1}} = t \cdot b_1 = 160 \cdot 63 = 10.080 \text{ mm}^2$$

$$A_{\text{net,v,1}} = 2 \cdot t \cdot \left(l_v + \sum_i \left(\frac{a_{1,i}}{\sin \delta} \right) \right)$$

$$= 2 \cdot 160 \cdot \left(160 + 2 \cdot \frac{41}{\sin 45^\circ} \right) = 88.309 \text{ mm}^2$$

The design value of the tensile strength $f_{t,0,d}$ and the shear strength $f_{v,d}$ are designed as follows:

$$f_{t,0,d} = \frac{k_{\text{mod}}}{\gamma_M} \cdot f_{t,0,k} = \frac{0,8}{1,3} \cdot 22,3 = 13,7 \text{ N/mm}^2$$

$$f_{v,d} = \frac{k_{\text{mod}}}{\gamma_M} \cdot f_{v,k} = \frac{0,8}{1,3} \cdot 3,5 = 2,15 \text{ N/mm}^2$$

The design value of the block shear capacity $F_{\text{bs,ax,Rd}}$ is given by:

$$F_{\text{bs,ax,Rd}} = \min \left\{ \begin{array}{l} F_{\text{bs,ax,Rd,1}} \\ F_{\text{bs,ax,Rd,2}} \end{array} \right. = \min \left\{ \begin{array}{l} 207 \\ 206 \end{array} \right. = 206 \text{ kN}$$

$$F_{\text{bs,ax,Rd,1}} = \max \left\{ \begin{array}{l} 0,7 \cdot A_{\text{net,v,1}} \cdot f_{v,d} \\ 1,5 \cdot A_{\text{net,t,1}} \cdot f_{t,0,d} \end{array} \right. = \max \left\{ \begin{array}{l} 0,7 \cdot 88.309 \cdot 2,15 = 133 \text{ kN} \\ 1,5 \cdot 10.080 \cdot 13,7 = 207 \text{ kN} \end{array} \right.$$

$$F_{\text{bs,ax,Rd,2}} = \max \left\{ \begin{array}{l} 0,7 \cdot A_{\text{net,v,2}} \cdot f_{v,d} \\ 1,5 \cdot A_{\text{net,t,2}} \cdot f_{t,0,d} \end{array} \right. = \max \left\{ \begin{array}{l} 0,7 \cdot 110.179 \cdot 2,15 = 166 \text{ kN} \\ 1,5 \cdot 10.017 \cdot 13,7 = 206 \text{ kN} \end{array} \right.$$

Case 2 (failure over part of the cross-sectional height) is decisive for the block shear capacity. The design value of the load-bearing capacity $F_{\text{bs,ax,Rd}} = 206 \text{ kN}$ of the block surrounded by screws in this example is greater than the design value of the shear load-bearing capacity $F_{\text{v,Rd}}$ of the screwed connection. As such, the shear load-bearing capacity $F_{\text{v,Rd}}$ is decisive for this connection (in this example).

3.12.2 Crossed screws – main beam to secondary beam connection

3.12.2.1 General information

This example concerns the connection between the main beam and secondary beam as shown in Figure 29. The members are connected using three screw crosses made up of ASSY®plus VG 4 CH 8.0 x 260 mm screws. A load of $F_{\text{v,Ed}} = 25 \text{ kN}$ will be transferred.

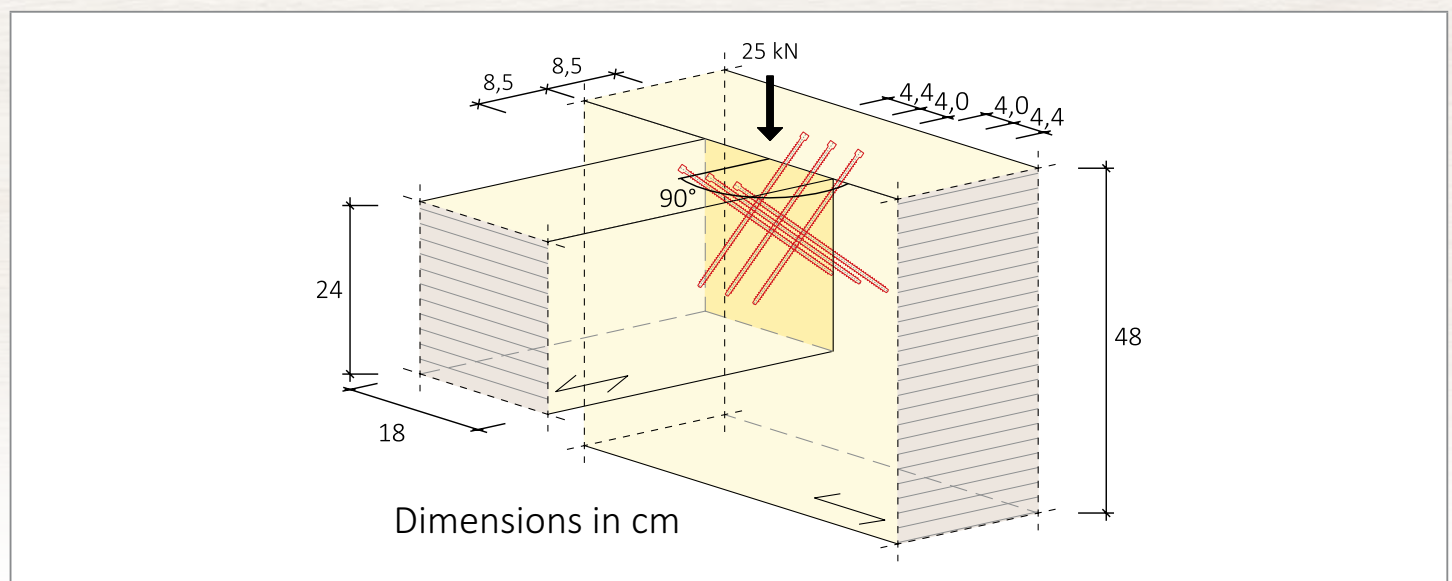


Figure 29: Calculation example – verification of an MB/SB connection with screw crosses.

The following parameters apply:

Main beam			
Width	b_{HT}	=	24.0 cm
Height	h_{HT}	=	48.0 cm
Material: Glued laminated timber			GL 28c
Raw density	$\rho_{k,HT}$	=	390 kg/m ³
Modification factor	$k_{mod,HT}$	=	0.8
Partial safety factor	γ_M	=	1.3
Secondary beam			
Width	b_{NT}	=	18.0 cm
Height	h_{NT}	=	24.0 cm
Material: Glued laminated timber			GL 24h
Raw density	$\rho_{k,NT}$	=	385 kg/m ³
Modification factor	$k_{mod,NT}$	=	0.8
Partial safety factor	γ_M	=	1.3
Fasteners ASSY®plus VG 4 CH 8.0 x 260			
Diameter	d	=	8 mm
Length	l	=	260 mm
Head height	k	=	7.5 mm
Tensile resistance	$f_{tens,k}$	=	22.0 kN
Withdrawal parameter	$f_{ax,k}$	=	12.0 N/mm ²
Partial safety factor	γ_{M1}/γ_M	=	1.1/1.3
Angle designations			
Force/grain angle	$\alpha_{HT/NT}$	=	90°
Screw/shear plane angle	$\delta_{HT/NT}$	=	45°
Screw/grain angle	ϵ_{NT}	=	45°
Screw/grain angle	ϵ_{HT}	=	90°
Action			
Load	$F_{v,Ed}$	=	25 kN
Service class	Service class		1
Load duration class			Medium

For screw crosses subjected to shear stress, one screw undergoes tensile stress and the other undergoes compressive stress. When calculating the pull-out resistance of the compressive screw, the screw head height must be subtracted from the effective anchorage length. The load-bearing capacities of the individual screws are designed below.

3.12.2.2 Load-bearing capacity of the tensile screw in MB-SB

Due to the different bulk densities of the connected members, two pull-out resistance values ($F_{w,k,HT}$ and $F_{w,k,NT}$) must be designed. For identification purposes, the load-bearing capacities of the tensile screw are given an additional index "t". The following anchorage lengths are derived from the installation dimension $m_{HT} = m_{NT} = 85$ mm:

$$l_{w,t,HT} = \frac{m_{HT}}{\cos \delta_{HT}} = \frac{85}{\cos 45^\circ} = 120 \text{ mm}$$

$$l_{w,t,NT} = l - l_{w,t,HT} = 260 - 120 = 140 \text{ mm}$$

$$F_{w,t,k,HT} = \frac{k_{ax,HT} \cdot f_{ax,k} \cdot d \cdot l_{w,t,HT}}{k_{\beta,HT}} \cdot \left(\frac{\rho_{k,HT}}{\rho_{ref,k}} \right)^{0,8} = \frac{1,0 \cdot 12,0 \cdot 8 \cdot 120}{1,0} \cdot \left(\frac{390}{350} \right)^{0,8} = 12,6 \text{ kN}$$

$$F_{w,t,k,NT} = \frac{k_{ax,NT} \cdot f_{ax,k} \cdot d \cdot l_{w,t,NT}}{k_{\beta,NT}} \cdot \left(\frac{\rho_{k,NT}}{\rho_{ref,k}} \right)^{0,8} = \frac{1,0 \cdot 12,0 \cdot 8 \cdot 140}{1,0} \cdot \left(\frac{385}{350} \right)^{0,8} = 14,5 \text{ kN}$$

Where:

$$k_{ax,HT} = k_{ax,NT} = 1,0 \text{ für } 45^\circ \leq \varepsilon \leq 90^\circ$$

$$k_{\beta,HT} = k_{\beta,NT} = 1,0 \text{ für GL}$$

The design value of the load-bearing capacity of the tensile screw $F_{ax,t,d}$ is:

$$\begin{aligned} F_{ax,t,d} &= \min \left\{ \frac{k_{mod,HT} \cdot F_{w,t,k,HT}}{\gamma_M}; \frac{k_{mod,NT} \cdot F_{w,t,k,NT}}{\gamma_M}; \frac{F_{t,k}}{\gamma_M} \right\} \\ &= \min \left\{ \frac{0,8 \cdot 12,6}{1,3}; \frac{0,8 \cdot 14,5}{1,3}; \frac{22,0}{1,3} \right\} = 7,75 \text{ kN} \end{aligned}$$

3.12.2.3 Load-bearing capacity of the compressive screw in MB-SB

Due to the different bulk densities of the connected members, two pull-out resistance values ($F_{w,k,HT}$ and $F_{w,k,NT}$) must be designed for press-in. For identification purposes, the load-bearing capacities of the compressive screw are given an additional index "c". The following anchorage lengths are derived from the installation dimension $m_{HT} = m_{NT} = 85 \text{ mm}$:

$$\begin{aligned} l_{c,NT} &= \frac{m_{NT}}{\cos \delta_{NT}} = \frac{85}{\cos 45^\circ} = 120 \text{ mm} \\ l_{w,c,NT} &= l_{c,NT} - k = 120 - 7,5 = 112,5 \text{ mm} \\ l_{w,c,HT} &= l - l_{c,NT} = 260 - 120 = 140 \text{ mm} \\ F_{w,c,k,NT} &= \frac{k_{ax,NT} \cdot f_{w,k} \cdot d \cdot l_{w,c,NT}}{k_{\beta,NT}} \cdot \left(\frac{\rho_{k,NT}}{\rho_{ref,k}} \right)^{0,8} = \frac{1,0 \cdot 12,0 \cdot 8 \cdot 113}{1,0} \cdot \left(\frac{385}{350} \right)^{0,8} = 11,7 \text{ kN} \\ F_{w,c,k,HT} &= \frac{k_{ax,HT} \cdot f_{w,k} \cdot d \cdot l_{w,c,HT}}{k_{\beta,HT}} \cdot \left(\frac{\rho_{k,HT}}{\rho_{ref,k}} \right)^{0,8} = \frac{1,0 \cdot 12,0 \cdot 8 \cdot 140}{1,0} \cdot \left(\frac{390}{350} \right)^{0,8} = 14,7 \text{ kN} \end{aligned}$$

Where:

$$k_{ax,HT} = k_{ax,NT} = 1,0 \text{ für } 45^\circ \leq \varepsilon \leq 90^\circ$$

$$k_{\beta,HT} = k_{\beta,NT} = 1,0 \text{ für GL}$$

The buckling resistance of the screw in both the main beam and secondary beam must be considered. Using the materials and the diameter of the screws, a buckling resistance of $F_{c,k,HT} = 11,6 \text{ kN}$ and $F_{c,k,NT} = 10,9 \text{ kN}$ can be obtained from Table 20 and Table 21 in Section 3.5.1 for $\varepsilon_{HT} = 90^\circ$ and $\varepsilon_{NT} = 45^\circ$.

The characteristic values of the screws for pull-in and buckling resistance, the modification factor k_{mod} and the partial safety factors γ_M and γ_{M1} are used to calculate the design value of the load-bearing capacity of a compressive screw:

$$\begin{aligned} F_{ax,c,d} &= \min \left\{ \frac{k_{mod,NT} \cdot F_{w,c,k,NT}}{\gamma_M}; \frac{k_{mod,HT} \cdot F_{w,c,k,HT}}{\gamma_M}; \frac{F_{c,k,NT}}{\gamma_{M1}}; \frac{F_{c,k,HT}}{\gamma_{M1}} \right\} \\ &= \min \left\{ \frac{0,8 \cdot 11,7}{1,3}; \frac{0,8 \cdot 14,7}{1,3}; \frac{10,9}{1,1}; \frac{11,6}{1,1} \right\} = 7,2 \text{ kN} \end{aligned}$$

3.12.2.4 Load-bearing capacity of a screw cross

The load-bearing capacity of a screw cross $F_{ax,x,d}$ is twice the minimum load-bearing capacity of the threaded sections. The compressive screw and the tensile screw must be taken into account. The following applies in this case:

$$\begin{aligned} F_{ax,x,d} &= 2 \cdot \min \{ F_{ax,t,d}; F_{ax,c,d} \} \\ &= 2 \cdot \min \{ 7,75; 7,2 \} = 14,4 \text{ kN} \end{aligned}$$

If the design values for push-in or pull-out resistance are exceeded in either of the two members, the condition is considered undefined. For this reason, it cannot be assumed that $F_{ax,x,d} = F_{ax,t,d} + F_{ax,c,d}$.

3.12.2.5 Load-bearing capacity of the connection

In accordance with Section 3.7.3, Eq. (3.28), the effective number of fasteners is designed based on the number of screw crosses. Therefore, the shear capacity of the connection is obtained as follows:

$$\begin{aligned} F_{v,Rd} &= n_x \cdot F_{ax,x,d} \cdot \sin \varepsilon \\ &= 3 \cdot 14,4 \cdot \sin 45^\circ = 30,5 \text{ kN} \end{aligned}$$

The utilisation factor η_v of the connection is:

$$\eta_v = \frac{F_{v,Ed}}{F_{v,Rd}} = \frac{25,0}{30,5} = 0,82 \leq 1,0 \quad \checkmark$$

4 LATERALLY LOADED SCREWS



4.1 General information

The outer thread diameter of the screw d should be used as the effective diameter of the screw in accordance with EC 5.

4.2 Failure mechanisms

Connections in which the screws are subjected to lateral (shear) stress may exhibit significant deformation, as shown in Figure 30. This elasto-plastic, ductile behaviour results from the interaction between the plastic deformation of the screw, the embedment (bearing stress) of the timber along the screw shank and the geometry of the connection. Maintaining minimum spacings ensures that the ductile behaviour occurs and brittle failure mechanisms (such as splitting) are generally avoided. The forces transmitted by the mechanisms described can be referred to as the load-bearing capacity $F_{D,k}$ based on Johansen's yield theory.

Due to the inclined position of the screw in the connection, suspension or rope forces develop along the screw shank in addition to the load-bearing capacity $F_{D,k}$. These forces act as tensile forces in the screw, pressing the members together at the joint and generating friction. The tensile forces in the direction of the screw axis created by the rope effect can be considered in the design in addition to the load-bearing capacity $F_{D,k}$ based on Johansen's yield theory. For screws, the effective friction contribution is limited to $F_{rp,k} \leq F_{D,k}$.

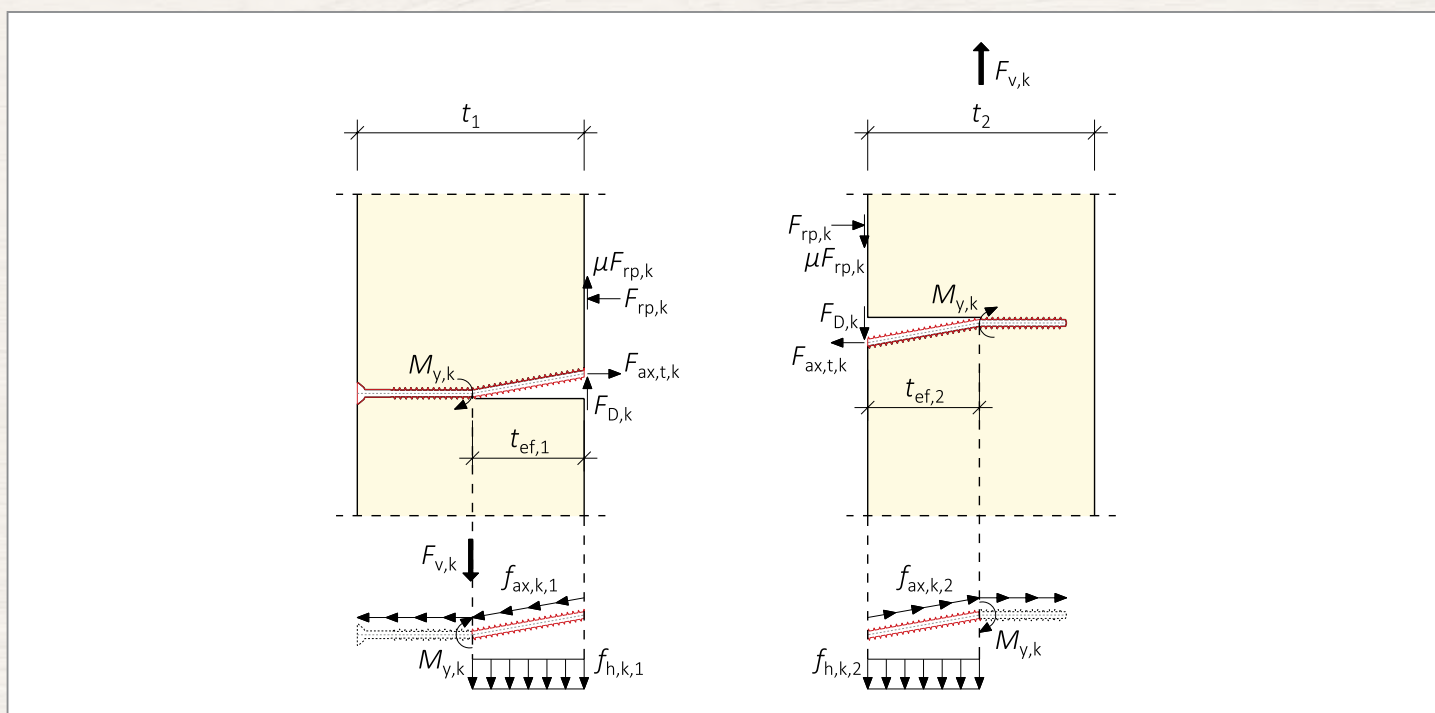


Figure 30: Force equilibrium for a timber-to-timber connection with a fully threaded screw and failure mechanism with two plastic hinges per shear plane.

4.3 Characteristic load-bearing capacity of a laterally loaded screw

The characteristic load-bearing capacity of a laterally loaded screw $F_{v,k}$ per shear plane and screw consists of the load-bearing capacity $F_{D,k}$ based on Johansen's yield theory and the rope effect contribution $F_{rp,k}$, see Eq. (4.1). This load-bearing capacity $F_{D,k}$ should, in each case, be taken as the minimum value that results from the following equation (the "Johansen equations") for the individual failure mechanisms.

$$F_{v,k} = F_{D,k} + F_{rp,k} \quad (4.1)$$

The conventions below apply for Eq. (4.2) to (4.6). For connections with three members (dowels subjected to double shear), the index 1 indicates the outer members and the index 2 indicates the inner member.

d	Outer thread diameter of the screw
$f_{h,k,1}$	Characteristic embedment strength of member 1, see pg. 59 f
$f_{h,k,2}$	Characteristic embedment strength of member 2, see pg. 59 f
t_1	Smaller value of the member thickness and embedment depth of member 1
t_2	Smaller value of the member thickness and embedment depth of member 2
$\beta = \frac{f_{h,k,2}}{f_{h,k,1}}$	Ratio of the embedment strength between two members
$F_{ax,t,k}$	Characteristic load-bearing capacity of a tensile screw, see Eq. (3.18)
$M_{y,k}$	Characteristic yield moment of a screw

Table 37: Characteristic yield moment $M_{y,k}$ in kNm.

Screw type and material	Outer thread diameter d in mm					
	5	6	8	10	12	14
ASSY® made of carbon steel	5.9	10	23	36	58	-
ASSY® made of stainless steel	2.8	5.5	11	20	-	-
ASSY®plus VG made of carbon steel	-	9	23	40	62	86

Regulation: ETA-11/0190

4.3.1 Contact ratio $F_{D,k}$ in timber-to-timber and engineered timber-to-timber connections

For a single-shear timber-to-timber or engineered timber-to-timber connection, Eq. (4.2) and Figure 31 are used (see EC 5 [8.6] [a] to [f]).

$$F_{D,k} = \min \left\{ \begin{array}{ll} f_{h,k,1} \cdot t_1 \cdot d & (a) \\ f_{h,k,2} \cdot t_2 \cdot d & (b) \\ \frac{f_{h,k,1} \cdot t_1 \cdot d}{1 + \beta} \cdot \left[\sqrt{\beta + 2\beta^2 \cdot \left[1 + \frac{t_2}{t_1} + \left(\frac{t_2}{t_1} \right)^2 \right] + \beta^3 \cdot \left(\frac{t_2}{t_1} \right)^2} - \beta \cdot \left(1 + \frac{t_2}{t_1} \right) \right] & (c) \\ 1,05 \cdot \frac{f_{h,k,1} \cdot t_1 \cdot d}{2 + \beta} \cdot \left[\sqrt{2\beta \cdot (1 + \beta) + \frac{4\beta \cdot (2 + \beta) \cdot M_{y,k}}{f_{h,k,1} \cdot d \cdot t_1^2}} - \beta \right] & (d) \\ 1,05 \cdot \frac{f_{h,k,1} \cdot t_2 \cdot d}{1 + 2\beta} \cdot \left[\sqrt{2\beta^2 \cdot (1 + \beta) + \frac{4\beta \cdot (1 + 2\beta) \cdot M_{y,k}}{f_{h,k,1} \cdot d \cdot t_2^2}} - \beta \right] & (e) \\ 1,15 \cdot \sqrt{\frac{2\beta}{1 + \beta}} \cdot \sqrt{2 \cdot M_{y,k} \cdot f_{h,k,1} \cdot d} & (f) \end{array} \right. \quad (4.2)$$

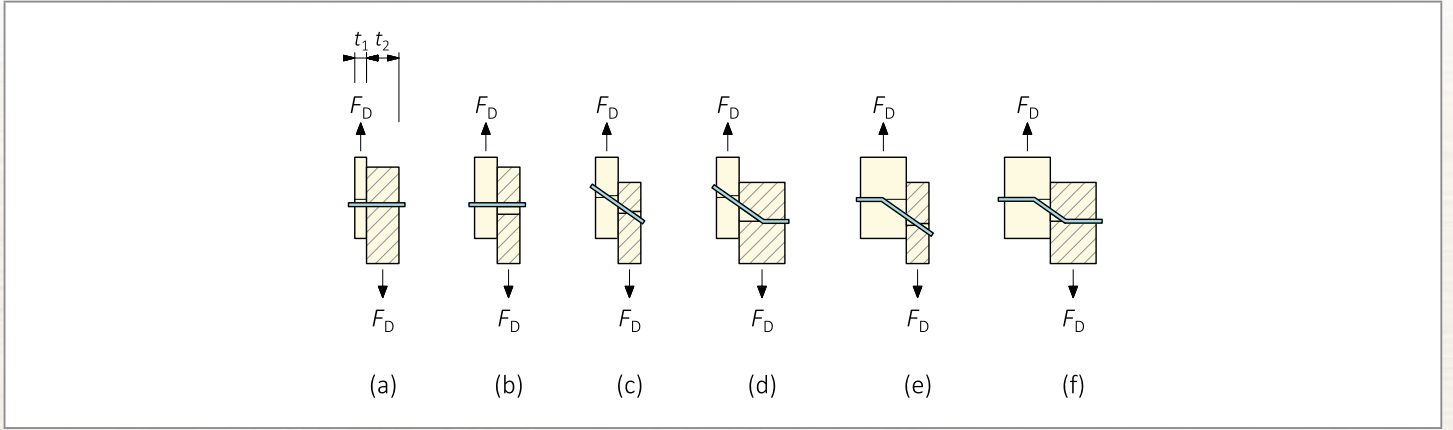


Figure 31: Possible failure mechanisms for a single-shear timber-to-timber or engineered timber-to-timber connection.

For a double-shear timber-to-timber or engineered timber-to-timber connection, Eq. (4.3) and Figure 32 are used (see EC 5 [8.7] [g] to [k]).

$$F_{D,k} = \min \begin{cases} f_{h,k,1} \cdot t_1 \cdot d & (g) \\ 0,5 \cdot f_{h,k,2} \cdot t_2 \cdot d & (h) \\ 1,05 \cdot \frac{f_{h,k,2} \cdot t_1 \cdot d}{2 + \beta} \cdot \left[\sqrt{2\beta \cdot (1 + \beta) + \frac{4\beta \cdot (2 + \beta) \cdot M_{y,k}}{f_{h,k,1} \cdot d \cdot t_1^2}} - \beta \right] & (i) \\ 1,15 \cdot \sqrt{\frac{2\beta}{1 + \beta}} \cdot \sqrt{2 \cdot M_{y,k} \cdot f_{h,k,1} \cdot d} & (k) \end{cases} \quad (4.3)$$

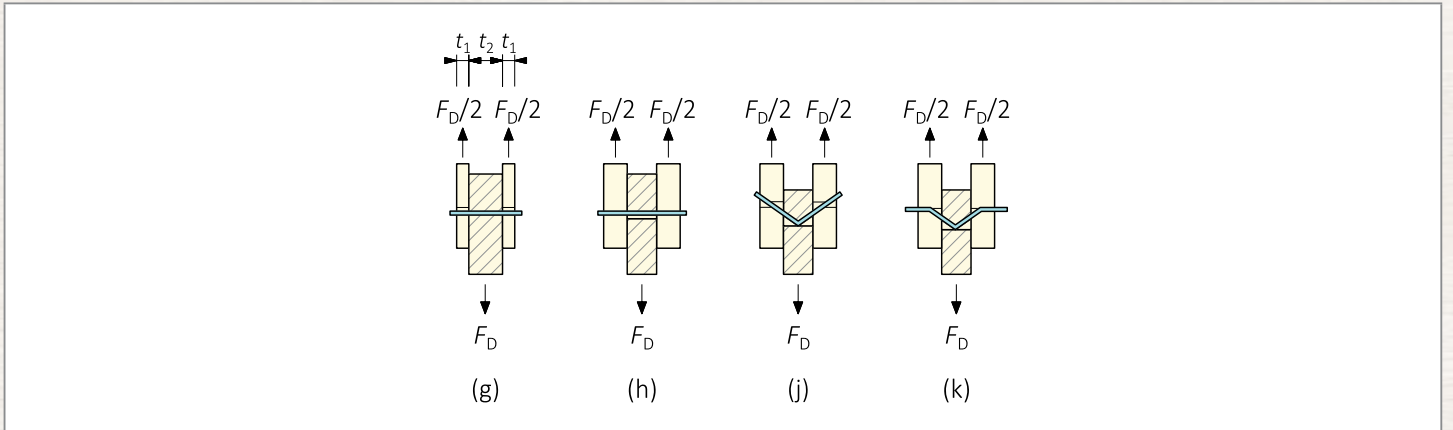


Figure 32: Possible failure mechanisms for a double-shear timber-to-timber or engineered timber-to-timber connection.

4.3.2 Contact ratio $F_{D,k}$ in timber-to-steel connections

When determining the characteristic load-bearing capacity of a screw subjected to shear stress in timber-to-steel connections, a distinction must be made between "thin" and "thick" sheet steel, with the thread outer diameter d being used as the reference dimension. According to EC 5, sheet steel is considered "thin" if the sheet thickness $t_s \leq 0,5 \cdot d$. If $t_s \geq d$, the sheet is considered "thick". If sheet thickness $0,5 \cdot d \leq t_s \leq d$, the value for the characteristic load-bearing capacity can be interpolated.

For sheet timber-to-steel connections with laterally loaded screws, the characteristic load-bearing capacity is obtained from the smallest value determined by the following equations:

For a single-shear timber-to-steel connection with thin sheet steel ($t_s \leq 0,5 \cdot d$), Eq. (4.4) and Figure 33 are used (see EC 5 [8.9], [a] to [b]).

$$F_{D,k} = \min \begin{cases} 0,4 \cdot f_{h,k} \cdot t_1 \cdot d & (a) \\ 1,15 \cdot \sqrt{2 \cdot M_{y,k} \cdot f_{h,k} \cdot d} & (b) \end{cases} \quad (4.4)$$

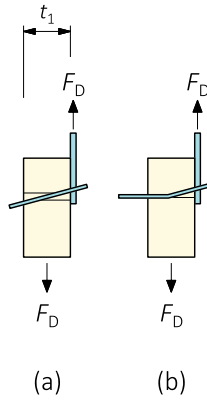


Figure 33: Possible failure mechanisms for a single-shear timber-to-steel connection with thin sheet steel.

Note:

For thin sheet steel, the load-bearing capacity of the sheet under tensile and bearing stress must be taken into account.

For a single-shear timber-to-steel connection with thick sheet steel ($t_s \geq d$), Eq. (4.5) and Figure 34 are used (see EC 5 [8.10], [c] to [e]).

$$F_{D,k} = \min \begin{cases} f_{h,k} \cdot t_1 \cdot d & (c) \\ f_{h,k} \cdot t_1 \cdot d \cdot \left[\sqrt{2 + \frac{4M_{y,k}}{f_{h,k} \cdot d \cdot t_1^2}} - 1 \right] & (d) \\ 2,3 \cdot \sqrt{M_{y,k} \cdot f_{h,k} \cdot d} & (e) \end{cases} \quad (4.5)$$

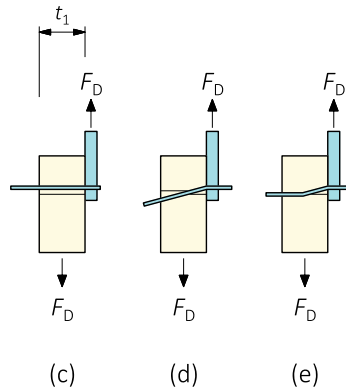


Figure 34: Possible failure mechanisms for a single-shear timber-to-steel connection with thick sheet steel.

For a double-shear timber-to-steel connection with internal sheet steel in either thickness, Eq. (4.6) and Figure 35 are used (see EC 5 [8.11], [f] to [h]).

$$F_{D,k} = \min \begin{cases} f_{h,k,1} \cdot t_1 \cdot d & (f) \\ f_{h,k,1} \cdot t_1 \cdot d \cdot \left[\sqrt{2 + \frac{4M_{y,k}}{f_{h,k,1} \cdot d \cdot t_1^2}} - 1 \right] & (g) \\ 2,3 \cdot \sqrt{M_{y,k} \cdot f_{h,k,1} \cdot d} & (h) \end{cases} \quad (4.6)$$

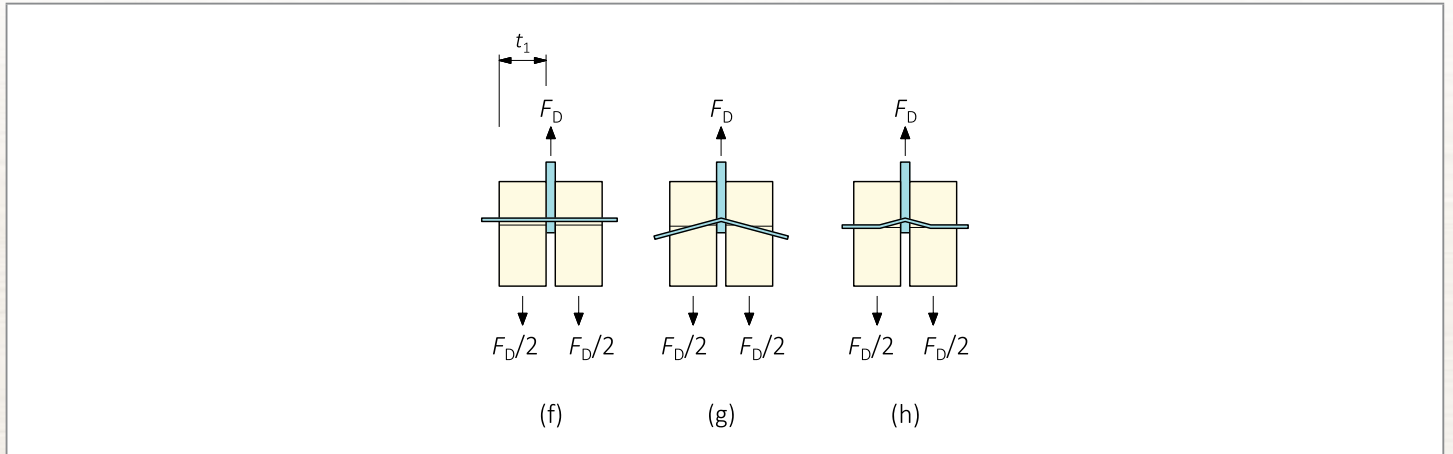


Figure 35: Possible failure mechanisms for a double-shear timber-to-steel connection with internal sheet steel.

4.3.3 Rope effect contribution $F_{rp,k}$

Only if the members to be connected are in contact can the rope effect considered for the following failure cases by using Eq. (4.7):

- For timber-to-timber connections in failure cases (c), (d), (e), (f), (i) and (k)
- For timber-to-steel connections in failure cases (b), (d), (e), (g), (h)

For screws designed to be simultaneously subjected to pull-out and shear forces, the planned tensile force in the shear plane must be subtracted from the load-bearing capacity $F_{ax,t,k}$ in Eq. (4.7).

$$F_{rp,k} = \min \begin{cases} 1,0 \cdot F_{D,k} \\ 0,25 \cdot F_{ax,t,k} \end{cases} \quad (4.7)$$

Where:

$F_{D,k}$ Characteristic value of the load-bearing capacity based on Johansen's yield theory as given by Eq. (4.2) to (4.6)

$F_{ax,t,k}$ Characteristic load-bearing capacity of a tensile screw as given by Eq. (3.18)

4.4 Embedment strength

The characteristic embedment strength $f_{h,k}$ for screws in members made of solid timber (ST/FST), glued solid timber (GST), glued laminated timber (GL), laminated veneer lumber (LVL) made of softwood or cross-laminated timber (CLT) made of softwood is given by:

$$f_{h,k} = \frac{0,082 \cdot \rho_k \cdot d^{-0,3}}{k_e \cdot k_\beta} \quad \text{N/mm}^2 \quad (4.8)$$

For all ASSY® screws in **non-pre-drilled** members

$$f_{h,k} = \frac{0,082 \cdot \rho_k \cdot (1 - 0,01 \cdot d)}{k_e \cdot k_\beta} \quad \text{N/mm}^2 \quad (4.9)$$

For all ASSY® screws in **pre-drilled** members

Where:

$$k_{\varepsilon} = 2,5 \cdot \cos^2 \varepsilon + \sin^2 \varepsilon$$

$$k_{\beta} = \begin{cases} 1 & \text{ST/FST, GST, GL, CLT} \\ 1,5 \cdot \cos^2 \beta + \sin^2 \beta & \text{LVL aus Nadelholz} \end{cases}$$

ρ_k Characteristic bulk density in kg/m³, $\rho_k \leq 500 \text{ kg/m}^3$

d Outer thread diameter of a screw in mm

β Angle between the screw axis and wide face, $0^\circ \leq \beta \leq 90^\circ$

ε Angle between the screw axis and grain direction, $0^\circ \leq \varepsilon \leq 90^\circ$

See also Figure 36 for angles.

Eq. (4.9) is also used for members made of beech, oak or ash timber, whereby the maximum calculable characteristic bulk density is limited to $\rho_k \leq 590 \text{ kg/m}^3$.

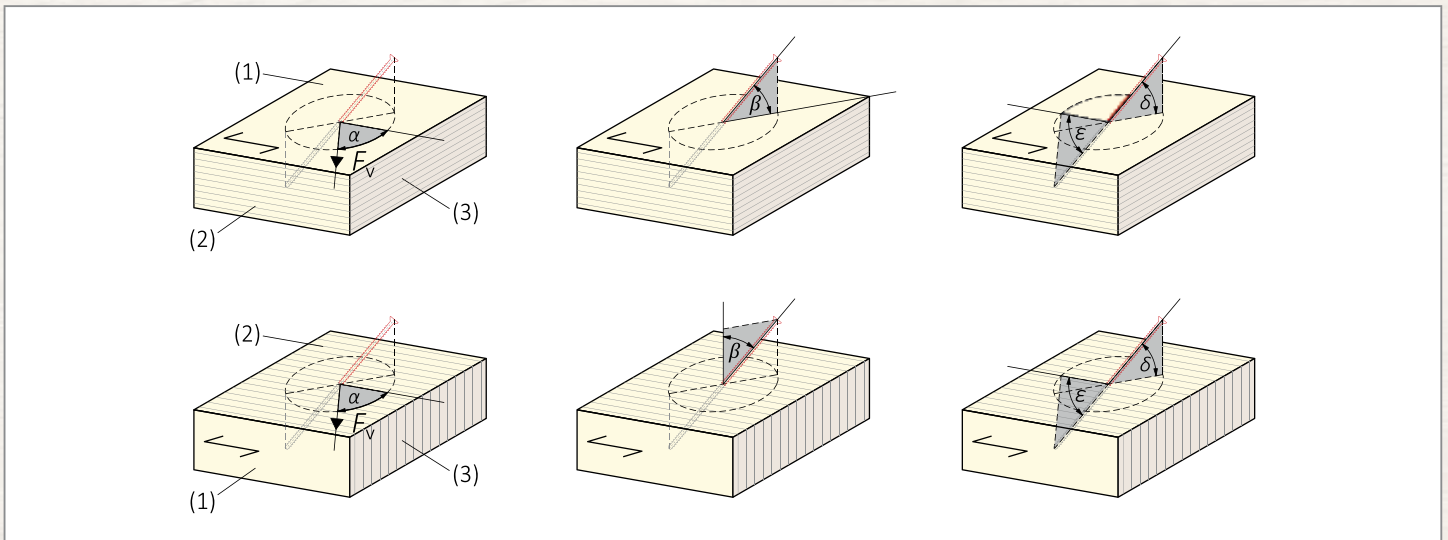


Figure 36: Definition of angles between the screw and member. (1) Wide face, (2) narrow face, (3) end grain surface.

Angle between (α) force and grain direction, (β) screw axis and wide face, (δ) screw axis and shear plane, (ε) screw axis and grain direction.

The characteristic embedment strength $f_{h,k}$ for screws in members made of beech LVL in accordance with EN 14374 or beech GLVL (ETA-14/0354) can be designed using Eq. (4.10).

$$f_{h,k} = \frac{0,082 \cdot \rho_k \cdot d^{-0,15}}{k_{\alpha} \cdot k_{\varepsilon} \cdot k_{\beta}} \text{ N/mm}^2 \quad (4.10)$$

For all ASSY® screws in **pre-drilled or non-pre-drilled** members

Where:

ρ_k Characteristic bulk density in kg/m³, for GLVL made of beech (ETA-14/0354): $\rho_k = 730 \text{ kg/m}^3$

d Outer thread diameter of the screw in mm

α Angle between the force direction and grain direction, $0^\circ \leq \alpha \leq 90^\circ$

$$k_{\alpha} = (0,5 + 0,024 \cdot d) \cdot \sin^2 \alpha + \cos^2 \alpha$$

$$k_{\varepsilon} = 2,5 \cdot \cos^2 \varepsilon + \sin^2 \varepsilon$$

$$k_{\beta} = 1,2 \cdot \cos^2 \beta + \sin^2 \beta$$

β Angle between the screw axis and wide face

ε Angle between the screw axis and grain direction

The characteristic embedment strength $f_{h,k}$ for screws arranged in the **narrow face** of **cross-laminated timber** (CLT), regardless of the angle ε between the screw axis and the grain direction, is:

$$f_{h,k} = 20 \cdot d^{-0.5} \text{ N/mm}^2 \quad (4.11)$$

For all ASSY® screws in **pre-drilled or non-pre-drilled** members

Alternatively, the characteristic values of the embedment strength based on Eq. (4.8) and (4.9) can also be assumed for screws within a layer of cross-laminated timber, provided that the layer is considered as a single member and the minimum spacings between the layers, perpendicular to the edge and in the grain direction are observed. For inner layers, the required minimum edge distance perpendicular to the grain direction can be reduced to $3 \cdot d$. Equation (4.11) only applies to layers made of softwood.

The specifications of the relevant European technical assessments or national approvals for cross-laminated timber (CLT) must always be taken into account.

The embedment strength of screws inserted into the side faces of cross-laminated timber can be assumed to be the same as for solid timber (ST/FST). The characteristic bulk density of the face layer must be used. If relevant, the angle between the force direction and grain direction on the outer layer must be taken into account. The force must act perpendicular to the screw axis and parallel to the side face of the cross-laminated timber.

The characteristic embedment strength $f_{h,k}$ for screws in **plywood** (PW) according to DIN EN 636:2015-05 is:

$$f_{h,k} = 0,11 \cdot \rho_k \cdot d^{-0.3} \text{ N/mm}^2 \quad (4.12)$$

For all ASSY® screws in **non-pre-drilled** members

$$f_{h,k} = 0,11 \cdot (1 - 0,01 \cdot d) \cdot \rho_k \text{ N/mm}^2 \quad (4.13)$$

For all ASSY® screws in **pre-drilled** members

The characteristic embedment strength $f_{h,k}$ for screws in **OSB** according to DIN EN 300:2006-09 is:

$$f_{h,k} = 65 \cdot d^{-0.7} \cdot t^{0.1} \text{ N/mm}^2 \quad (4.14)$$

For all ASSY® screws in **non-pre-drilled** members

$$f_{h,k} = 50 \cdot d^{-0.6} \cdot t^{0.2} \text{ N/mm}^2 \quad (4.15)$$

For all ASSY® screws in **pre-drilled** members

Where:

d	Outer thread diameter of a screw in mm
t	Thickness of the OSB panel in mm
ρ_k	Characteristic bulk density of the engineered wood in kg/m ³

Eq. (4.11) to (4.15) are used for outer thread diameters of $6 \text{ mm} \leq d \leq 14 \text{ mm}$.

Note:

The specified embedment strengths apply irrespective of the screw tip geometry. The equations for pre-drilled members can only be used if a hole with the diameters specified in Section 2.1 has been drilled before the screw is inserted.

4.5 Design value of the load-bearing capacity of a screw subjected to shear stress

The design value of the shear resistance $F_{v,d}$ is obtained using Eq. (4.16).

$$F_{v,d} = \frac{k_{\text{mod}}}{\gamma_M} \cdot F_{v,k} \quad (4.16)$$

Where:

$F_{v,k}$	Characteristic load-bearing capacity of a screw subjected to shear stress as determined by Eq. (4.1)
γ_M	Partial safety factor for shear connections where γ_M 1.3 in accordance with EC5
k_{mod}	Modification factor; if the modification factors of the connected members differ ($k_{\text{mod},1}$ and $k_{\text{mod},2}$) and the embedment strength has been reached in both members, the following value can be assumed for k_{mod} : $k_{\text{mod}} = \sqrt{k_{\text{mod},1} \cdot k_{\text{mod},2}}$ For failure mechanisms (a), (b), (g) and (h) in timber-to-timber or engineered timber-to-timber connections, the modification factor k_{mod} of the member in which the embedment strength is reached should be used.

4.6 Design value of the load-bearing capacity of a connection subjected to shear stress

4.6.1 Design value of the load-bearing capacity

The design value of the load-bearing capacity for a connection with screws subjected to shear stress $F_{v,Rd}$ is generally obtained by:

$$F_{v,Rd} = n_{\text{ef}} \cdot F_{v,d} \quad (4.17)$$

Where:

n_{ef}	Effective number of fasteners in accordance with Section 4.6.2
$F_{v,d}$	Design value of the load-bearing capacity of a screw subjected to shear stress as determined by Eq. (4.16)

4.6.2 Effective number of fasteners

In a row with n_0 screws arranged parallel to the grain direction of the timber, the load-bearing capacity in the grain direction must be designed using an effective number of fasteners n_{ef} .

Per fastener row and with force 0° to the grain direction:

$$n_{\text{ef},0} = n_0^{k_{\text{ef}}} \quad (4.18)$$

Per fastener row and with force 90° to the grain direction:

$$n_{\text{ef},90} = n_{90} \quad (4.19)$$

n_{ef}	Applies to timber and timber products with one grain direction over the entire cross-section (ST/FST, GST, GL, LVL-P).
n_0	Number of fasteners in a row parallel to the grain direction
$n_{\text{ef},0}$	Effective number of fasteners in a row parallel to the grain direction
n_{90}	Number of fasteners perpendicular to the grain direction
$n_{\text{ef},90}$	Effective number of fasteners perpendicular to the grain direction
k_{ef}	Exponent for reducing the number of fasteners screwed in to the effective number of fasteners

Table 38: Values for the exponent of the number of screws per row (for force/grain angles of $\alpha = 0^\circ$).

Screw spacing a_1	k_{ef}	
	Not pre-drilled	Pre-drilled
$\geq 14 d$	1.00	1.00
$13 d$	0.96	0.96
$12 d$	0.93	0.93
$11 d$	0.89	0.89
$10 d$	0.85	0.85
$9 d$	0.80	0.80
$8 d$	0.75	0.75
$7 d$	0.70	0.70
$6 d$	-	0.63
$5 d$	-	0.57
$4 d$	-	0.50

Regulation: EC 5

For screws in the wide faces of LVL-P, Eq. (4.18) is used; for screws in the wide faces of LVL-C, Eq. (4.19) is used.

For intermediate values $0 < \alpha < 90^\circ$, $n_{ef,\alpha,i}$ must be designed for each row of screws using $n_{ef,0,i}$ as per Eq. (4.18). Since the number of fasteners only needs to be reduced if the force component acting in the grain direction $\alpha = 0^\circ$, $n_{ef,\alpha}$ for the entire connection is determined using Eq. (4.20).

$$n_{ef,\alpha} = \sum_i n_{ef,\alpha,i} = \sum_i \min \left\{ \frac{n_{0,i}^{k_{ef}}}{\cos \alpha}; n_{0,i} \right\} \quad (4.20)$$

If moments are to be transmitted in addition to normal and shear forces in a connection, the effective proportion acting on each screw must be considered separately for each fastener. For this purpose, the effective number of fasteners per row of screws determined by Eq. (4.18) is related to the actual number of screws $n_{0,i}$ in the row, see Eq. (4.21). The applicable load-bearing capacity component per fastener j of a connection is determined using Eq. (4.22).

$$k_{sf,i} = \frac{n_{ef,0,i}}{n_{0,i}} \quad (4.21)$$

$$n_{ef,\alpha,j} = \min \left\{ \frac{k_{sf,i}}{\cos \alpha}; 1 \right\} \cdot n_i \quad (4.22)$$

If a connection is formed with asymmetrically arranged screws, i.e. the number of screws parallel and/or perpendicular to the grain varies in each row, the effective number of screws parallel and/or perpendicular to the grain in each row can be determined using Eq. (4.20) and then added together.

If the screws in a row are offset by at least $1 \cdot d$ perpendicular to the grain direction, the spacing between the screws in the grain direction a_1 can be doubled when calculating the effective number of screws n_{ef} .

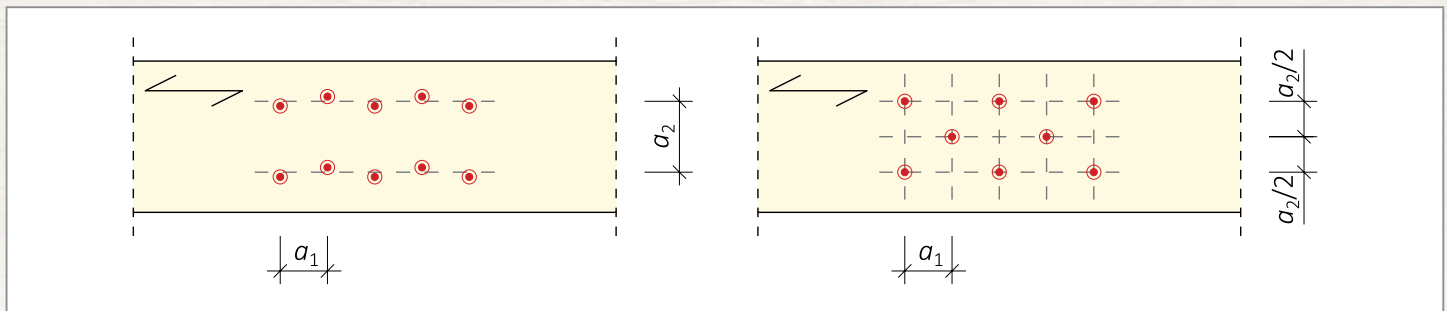


Figure 37: Offset arrangement. Left: minimum offset, right: recommended offset.

Example for determining the effective number of screws n_{ef} with asymmetrically arranged screws and a force/grain angle α other than 0° or 90° .

Pre-determined:		
Material	Solid timber (ST)	
Spacing in grain direction	a_1	$10d$
Screws in grain direction	$n_{0,1}$	5
	$n_{0,2}$	5
	$n_{0,3}$	3
Force/grain angle	α	30°
Specification:	Pre-drilled ASSY®plus screw or ASSY® screw	

For each row of screws in the direction of the grain, $n_{ef,\alpha,i}$ is designed using Table 38 and Eq. (4.20). Using the material, $a_1 = 10 \cdot d$ and the specification, the exponent $k_{ef} = 0.85$ is determined for $\alpha = 0^\circ$:

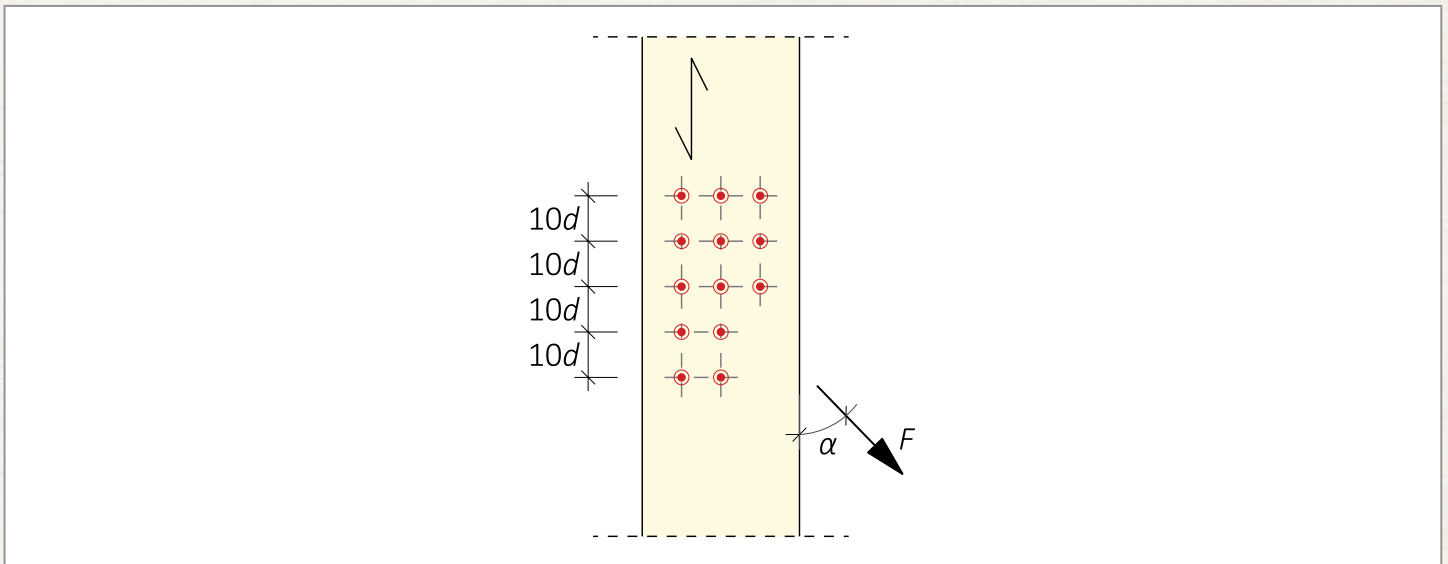


Figure 38: Calculation example for $n_{ef,30^\circ}$ connection with $2 \times 5 + 1 \times 3 = 13$ screws.

$$\begin{aligned}
 n_{0,1} &= n_{0,2} = 5^{0,85} = 3,92 \\
 n_{0,3} &= 3^{0,85} = 2,54 \\
 n_{ef,\alpha,1} &= n_{ef,\alpha,2} = \min \left\{ \frac{3,92}{\cos 30^\circ}; 5 \right\} = 4,53 \\
 n_{ef,\alpha,3} &= \min \left\{ \frac{2,54}{\cos 30^\circ}; 3 \right\} = 2,93 \\
 n_{ef,\alpha} &= \sum_i n_{ef,\alpha,i} = 2 \cdot 4,53 + 1 \cdot 2,93 = \underline{\underline{12,0}}
 \end{aligned}$$

Of the 13 screws inserted, 12 can be taken into account in the calculation.

Note:

If screws are arranged asymmetrically in a connection, eccentricities occur which lead to non-uniform loading of the screw group. These eccentricities must be taken into account.

4.7 Minimum member dimensions and minimum spacings of laterally loaded screws

4.7.1 General information

Regardless of whether screws are subjected to axial or lateral load, the permissible member dimensions and axis and edge distances depend on the force/grain angle α , the timber or engineered wood, the screw tip geometry and whether the members are pre-drilled before screwing.

Tables 41 to 47 match the specifications in ETA-11/0190.

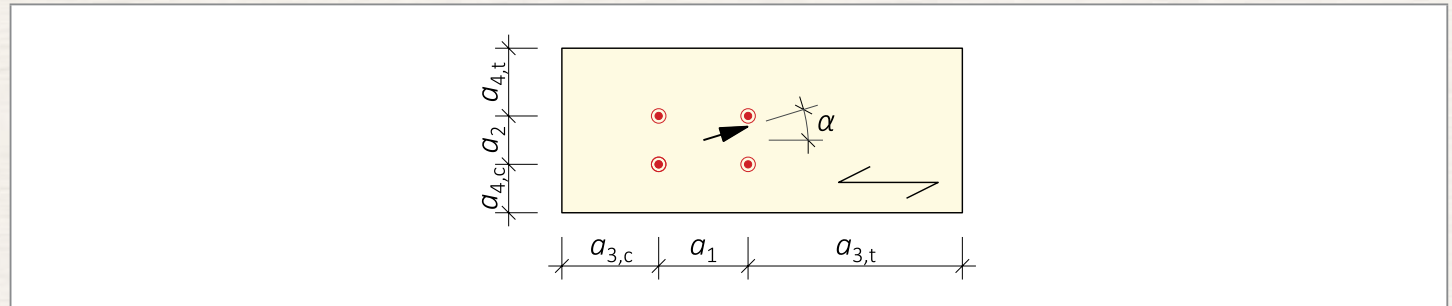


Figure 39: Minimum spacings for laterally loaded screws.

a_1	Minimum distance between two fasteners parallel to the grain direction
a_2	Minimum distance between two fasteners perpendicular to the grain direction
$a_{3,c}$	Minimum distance between the unloaded edge and fastener parallel to the grain direction
$a_{3,t}$	Minimum distance between the loaded edge and fastener parallel to the grain direction
$a_{4,c}$	Minimum distance between the unloaded edge and fastener perpendicular to the grain direction
$a_{4,t}$	Minimum distance between the loaded edge and fastener perpendicular to the grain direction
α	Angle between the force direction and grain direction

4.7.1.1 Minimum member thicknesses

The required minimum member dimensions when using ASSY® screws that are not pre-drilled are based on the regulations of EC 5:

- Members made of timber types at high risk of splitting (e.g. silver fir, Douglas fir etc.) should be pre-drilled if their thickness is less than:

$$t = \max \left\{ \begin{array}{l} 14d \\ (13d - 30) \frac{\rho_k}{200} \end{array} \right. \quad (4.23)$$

- Members made of pine or with $a_4 \geq 10 \cdot d$ where $\rho_k \leq 420 \text{ kg/m}^3$ or if $a_4 \geq 14 \cdot d$ where $420 \text{ kg/m}^3 < \rho_k \leq 500 \text{ kg/m}^3$ should be pre-drilled if their thickness is less than:

$$t = \max \left\{ \begin{array}{l} 7d \\ (13d - 30) \frac{\rho_k}{400} \end{array} \right. \quad (4.24)$$

See also Table 41 and 42 for timber types at high/low risk of splitting.

The regulation stipulated by Eq. (4.24) can also be applied when fastening formwork and load-bearing or counter battens, as well as intermediate connections of builders band and crossbeams to timber frames of all timber types, provided these members are connected with at least two screws.

Table 39: Minimum member thicknesses when using ASSY®plus screws that are **not** pre-drilled.

Outer thread diameter d in mm	≤ 6	8	10	12	14
Minimum member thickness $t_{\min}$ in mm	24	30	40	80	100
Regulation: ETA-11/0190					

The minimum member thicknesses given in Table 39 also apply to **non**-pre-drilled ASSY® screws if:

- The spacing between the screws, both in the direction of the grain and to the end grain, is at least $25 \cdot d$
- The member in the connection area is reinforced with fully threaded screws in accordance with the specifications of Section 8

These rules do not apply to engineered wood boards or laminated veneer lumber with cross layers (LVL-C).

In a connection consisting of several timber members, the screw tips can overlap, provided that the following condition is met: $(t - t_{h,i}) > 4 \cdot d$, see also Figure 40.

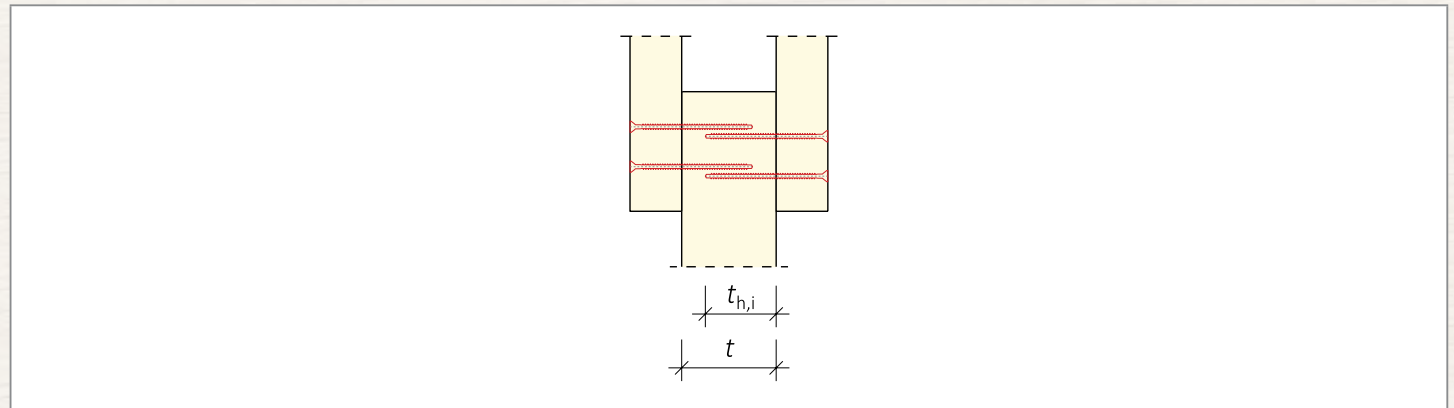


Figure 40: Overlapping of screws in a member.

In addition, when applying the rules listed, restrictions regarding the minimum and maximum thicknesses apply for the use of certain engineered wood. All relevant information can be found in Table 40.

Table 40: Minimum and maximum member thicknesses of engineered wood.

Board material	$t_{\min}$ in mm	$t_{\max}$ in mm
OSB/3 and OSB/4	12	30
Chipboard	13	
Gypsum plasterboard	12.5	-
Fermacell gypsum fibre	10	-
Regulation: ETA-11/0190		

4.7.1.2 Minimum axial and edge distances

The minimum spacings required for laterally loaded screws as specified in Tables 41 to 44 and 46 to 47 always refer to the centre point of the screw in the shear plane in question (see Figure 39).

The spacings given in EC 5 apply (spacings in columns 1 and 2 of Tables 41 to 44).

The minimum axial and edge spacings must be considered separately for each member in the shear plane. The angle α between the force and grain direction must be considered separately for each member based on the face layer.

If the spacing between the screws, both in the grain direction and to the end grain is at least $25 \cdot d$, the spacing to the unloaded edge perpendicular to the grain can be reduced to $a_{3,e} = 3 \cdot d$ even for member thicknesses $t < 5 \cdot d$.

4.7.2 Minimum spacings and minimum member thicknesses for laterally loaded screws in solid timber (ST/FST)

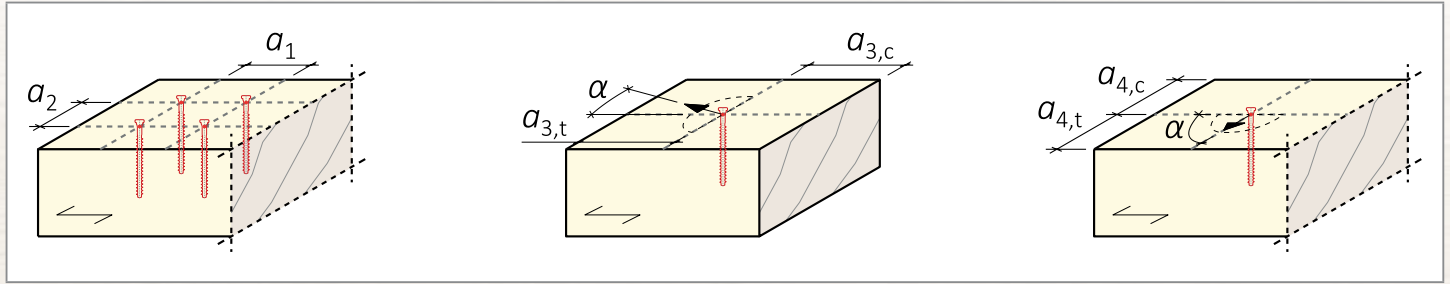


Figure 41: Spacings and angles in solid timber products.

Table 41: Minimum spacings and minimum member thicknesses for laterally loaded screws in **solid timber** (ST/FST), **glued solid timber** (GST) or **glued laminated timber** (GL) where $\rho_k \leq 420 \text{ kg/m}^3$.

	ASSY® plus: not pre-drilled ASSY®: pre-drilled					ASSY®: not pre-drilled				
a_1	$k_a \cdot (4 + \cos \alpha) d^{a)}$					$k_a \cdot (5 + 7 \cos \alpha) d^{b)}$				
a_2	$k_a \cdot (3 + \sin \alpha) d^{a)}$					$k_a \cdot 5 d^{a)}$				
$a_{3,t}$	$(7 + 5 \cos \alpha) d$					$k_a \cdot (10 + 5 \cos \alpha) d^{c)}$				
$a_{3,c}$	$7 d$					$k_a \cdot 10 d^{c)}$				
$a_{4,t}$	$(3 + 4 \sin \alpha) d$					$(5 + 5 \sin \alpha) d^{d)}$				
$a_{4,c}$	$3 d$					$5 d^{d)}$				
Minimum member thicknesses $t_{\min}$ for different outer thread diameters d										
d	6	8	10	12	14	6	8	10	12	14
$t_{\min}$	24	30	40	80	100					
Timber types at low risk of splitting. In accordance with NDP in 8.3.1.2(7) for pine (pinus sylvestris) ^{e) f)}										
$t_{\min} (\rho_k = 350 \text{ kg/m}^3)$						42	65	88	110	133
$t_{\min} (\rho_k = 420 \text{ kg/m}^3)$						50	78	105	132	160
Timber types at high risk of splitting. In accordance with NDP in 8.3.1.2(7) for all timber types except pine ^{e) f)}										
$t_{\min} (\rho_k = 350 \text{ kg/m}^3)$						84	130	175	221	266
$t_{\min} (\rho_k = 420 \text{ kg/m}^3)$						101	155	210	265	320
Table values in mm.										
^{a)} $k_a = 1.0$ for timber-to-timber connections, $k_a = 0.85$ for engineered timber-to-timber connections (see Table 14), $k_a = 0.7$ for sheet timber-to-steel connections										
^{b)} $k_a = 1.0$ for timber-to-timber connections (Douglas fir: $k_a = 1.5$), $k_a = 0.85$ for engineered timber-to-timber connections (see Table 14; Douglas fir: $k_a = 1.275$), $k_a = 0.7$ for sheet timber-to-steel connections (Douglas fir: $k_a = 1.05$)										
^{c)} In general, $k_a = 1.0$; for Douglas fir $k_a = 1.5$										
^{d)} If an increased spacing of $10 \cdot d$ is applied for the spacings $a_{4,t}$ and $a_{4,c}$, the minimum timber thicknesses $t_{\min}$ for pine can also be used for timber types at high risk of splitting.										
^{e)} For other characteristic bulk densities, see Section 4.7.1.										
^{f)} The minimum timber thicknesses for pine can also be applied when fastening: 1. Formwork, load-bearing battens and counter battens ($n \geq 2$ per connection) 2. Builders band ($n \geq 2$ per connection) 3. Crossbeams on timber frames ($n \geq 2$ per connection)										
Regulation: ETA-11/0190, EC 5 (spacings, $t_{\min}$ based on ρ_k)										

Table 42: Minimum spacings and minimum member thicknesses for laterally loaded screws in **solid timber** (ST/FST), **glued solid timber** (GST) or **glued laminated timber** (GL) where $\rho_k > 420 \text{ kg/m}^3$.

	ASSY®plus: not pre-drilled ASSY®: pre-drilled $\rho_k > 500 \text{ kg/m}^3$: always pre-drilled					ASSY®: not pre-drilled 420 kg/m³ < $\rho_k \leq 500 \text{ kg/m}^3$				
a_1	$k_a \cdot (4 + \cos \alpha) d^{a)}$					$k_a \cdot (7 + 8 \cos \alpha) d^{b)}$				
a_2	$k_a \cdot (3 + \sin \alpha) d^{a)}$					$k_a \cdot 7 d^{a)}$				
$a_{3,t}$	$(7 + 5 \cos \alpha) d$					$k_a \cdot (15 + 5 \cos \alpha) d^{c)}$				
$a_{3,c}$	$7 d$					$k_a \cdot 15 d^{c)}$				
$a_{4,t}$	$(3 + 4 \sin \alpha) d$					$(7 + 5 \sin \alpha) d^{d)}$				
$a_{4,c}$	$3 d$					$7 d^{d)}$				
Minimum member thicknesses for different outer thread diameters d										
d	6	8	10	12	14	6	8	10	12	14
$t_{\min}$	24	30	40	80	100					
Timber types at low risk of splitting. In accordance with NDP in 8.3.1.2(7) for pine (pinus sylvestris) ^{e) f)}										
$t_{\min} (\rho_k = 425 \text{ kg/m}^3)$						51	79	106	134	162
$t_{\min} (\rho_k = 500 \text{ kg/m}^3)$						60	93	125	158	190
Timber types at high risk of splitting. In accordance with NDP in 8.3.1.2(7) for all timber types except pine ^{e) f)}										
$t_{\min} (\rho_k = 425 \text{ kg/m}^3)$						102	157	212	268	323
$t_{\min} (\rho_k = 500 \text{ kg/m}^3)$						120	185	250	315	380
Table values in mm. ^{a)} $k_a = 1.0$ for timber-to-timber connections, $k_a = 0.85$ for engineered timber-to-timber connections (see Table 14), $k_a = 0.7$ for sheet timber-to-steel connections ^{b)} $k_a = 1.0$ for timber-to-timber connections (Douglas fir: $k_a = 1.5$), $k_a = 0.85$ for engineered timber-to-timber connections (see Table 14; Douglas fir: $k_a = 1.275$), $k_a = 0.7$ for sheet timber-to-steel connections (Douglas fir: $k_a = 1.05$) ^{c)} In general, $k_a = 1.0$; for Douglas fir $k_a = 1.5$ ^{d)} If an increased spacing of $10 \cdot d$ is applied for the spacings $a_{4,t}$ and $a_{4,c}$, the minimum timber thicknesses $t_{\min}$ for pine can also be used for timber types at high risk of splitting. ^{e)} For other characteristic bulk densities, see Section 4.7.1. ^{f)} The minimum timber thicknesses for pine can also be applied when fastening: 1. Formwork, load-bearing battens and counter battens ($n \geq 2$ per connection) 2. Builders band ($n \geq 2$ per connection) 3. Crossbeams on timber frames ($n \geq 2$ per connection)										
Regulation: ETA-11/0190, EC 5 (spacings, $t_{\min}$ based on ρ_k)										

4.7.3 Minimum spacings and minimum member thicknesses for laterally loaded screws in laminated veneer lumber (LVL) made of softwood

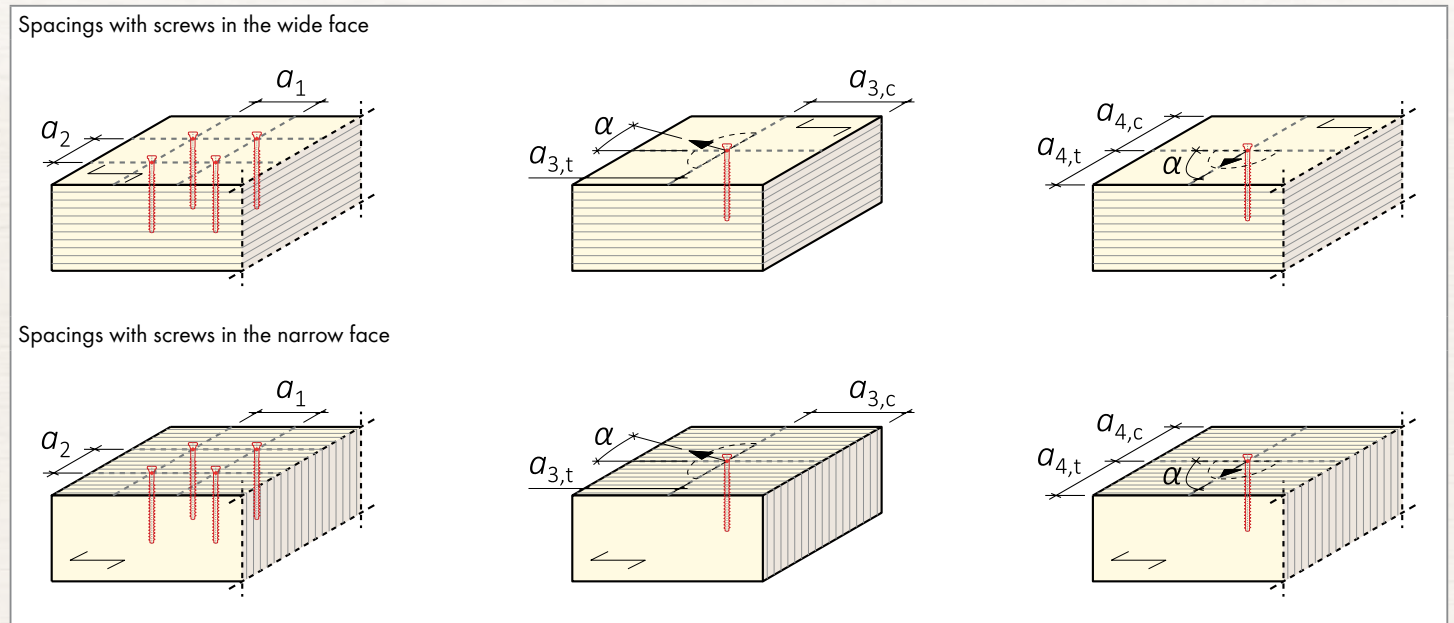


Figure 42: Spacings and angles in laminated veneer lumber (LVL) made of softwood.

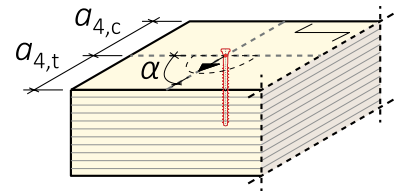
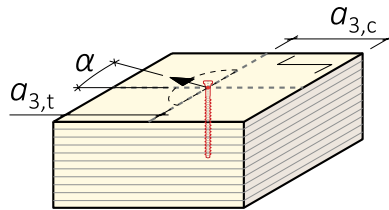
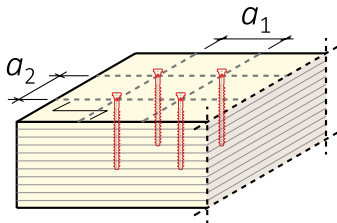
Table 43: Minimum spacings and minimum member thicknesses for laterally loaded screws in members made of **laminated veneer lumber (LVL)** made of **softwood** in accordance with DIN EN 13986, DIN EN 14279 and DIN EN 14374.

	ASSY®plus: not pre-drilled ASSY®: pre-drilled					ASSY®: not pre-drilled				
a_1	$k_a \cdot (4 + \cos \alpha) d^{a)}$					$k_a \cdot (7 + 8 \cos \alpha) d^{a)}$				
a_2	$k_a \cdot (3 + \sin \alpha) d^{a)}$					$k_a \cdot 7 d^{a)}$				
$a_{3,t}$	$(7 + 5 \cos \alpha) d$					$(15 + 5 \cos \alpha) d$				
$a_{3,c}$	$7 d$					$15 d$				
$a_{4,t}$	$(3 + 4 \sin \alpha) d$					$(7 + 5 \sin \alpha) d$				
$a_{4,c}$	$3 d$					$7 d$				
Minimum member thicknesses t_{min} for different outer thread diameters d										
d	6 ^{b)}	8	10	12	14	6 ^{b)}	8	10	12	14
t_{min}	24	30	40	80	100	24	30	40	80	100
Table values in mm. ^{a)} $k_a = 1.0$ for timber-to-timber connections, $k_a = 0.85$ for engineered timber-to-timber connections (see Table 14), $k_a = 0.7$ for sheet timber-to-steel connections ^{b)} Minimum outer thread diameters for screws in the narrow faces of laminated veneer lumber with cross layers (LVL-C) Members with a characteristic bulk density of $\rho_k > 500 \text{ kg/m}^3$ must be pre-drilled before the screws are inserted.										
Regulation: ETA-11/0190, EC 5 (spacings)										

For special cases, refer to the type approval of the respective LVL manufacturer.

4.7.4 Minimum spacings and minimum member thicknesses for laterally loaded screws in glued laminated veneer lumber (GLVL) made of beech in accordance with ETA-14/0354

Spacings with screws in the wide face



Spacings with screws in the narrow face

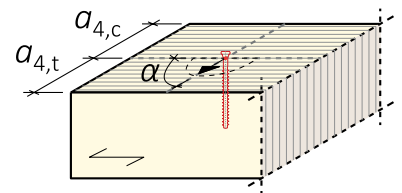
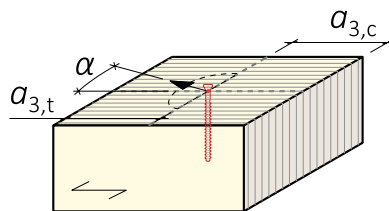
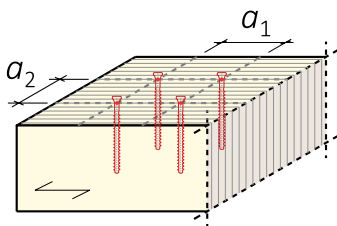


Figure 43: Spacings and angles in laminated veneer lumber made of beech.

Table 44: Minimum spacings and minimum member thicknesses for laterally loaded screws in glued laminated veneer lumber (GLVL) made of **beech** (ETA-14/0354).

	ASSY®plus: pre-drilled ASSY®: pre-drilled					ASSY®plus: not pre-drilled ASSY®: not pre-drilled			
a_1	$k_a \cdot (4 + \cos \alpha) d^{a)}$					$k_a \cdot (7 + 8 \cos \alpha) d^{a)}$			
a_2	$k_a \cdot (3 + \sin \alpha) d^{a)}$					$k_a \cdot 7 d^{a)}$			
$a_{3,t}$	$(7 + 5 \cos \alpha) d$					$(15 + 5 \cos \alpha) d$			
$a_{3,c}$	$7 d$					$15 d$			
$a_{4,t}$	$(3 + 4 \sin \alpha) d$					$(7 + 5 \sin \alpha) d$			
$a_{4,c}$	$3 d$					$7 d$			
Minimum member thicknesses for different outer thread diameters d									
d	6	8	10	12	14	6	8	10	12
$t_{\min}$	24	30	40	80	100	42 ^{b)}	56 ^{b)}	70 ^{b)}	84 ^{b)}
Table values in mm. ^{a)} $k_a = 1.0$ for timber-to-timber connections, $k_a = 0.85$ for engineered timber-to-timber connections (see Table 14), $k_a = 0.7$ for sheet timber-to-steel connections ^{b)} Minimum thicknesses $t \geq 7 d$ apply where $5 \leq d \leq 12$, type S; there is no minimum thickness for type Q.									
Regulation: ETA-11/0190, EC 5									

Table 45 contains the maximum permissible embedment depths $t_{h,max}$ for carbon steel screws that can be screwed in without pre-drilling. Larger embedment depths must be pre-drilled for the entire screw length.

Table 45: Maximum permissible embedment depth $t_{h,max}$ without pre-drilling.

	All ASSY®plus				ASSY®					
Outer thread diameter d in mm	6	8	10	12	5	6	7	7.5	8	10
Embedment depth $t_{h,max}$ in mm	30	48	80	96	50	60	70	75	80	100
Regulation: ETA-11/0190										

4.7.5 Minimum spacings and minimum member thicknesses for laterally loaded screws in cross-laminated timber (CLT)

Unless otherwise stated in the approvals by the cross-laminated timber (CLT) manufacturer, the minimum values for axial and edge spacings for screws in cross-laminated timber (CLT) provided in Table 46 apply.

The grain direction of the face layer should be used as the basis for arranging screws in the side face. For screws arranged in the narrow face, the grain direction of the respective layer applies, if relevant.

Screw connections in the narrow face that are subjected to loads perpendicular to the face layer plane may, under certain circumstances, be subjected to transverse tensile stresses, which can be absorbed by appropriate screws acting as transverse tensile reinforcement.

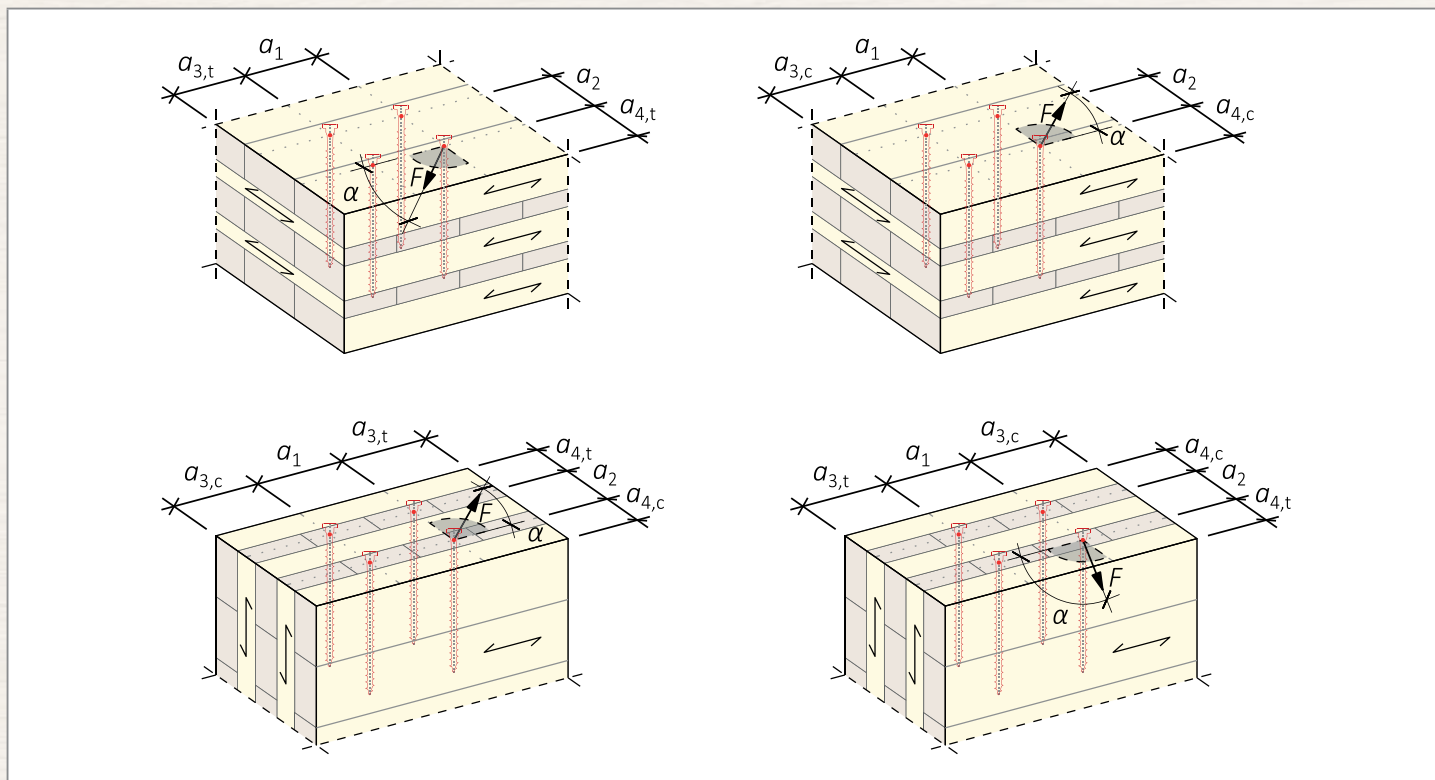


Figure 44: Spacings in cross-laminated timber.

Table 46: Minimum spacings for screw connections in the side faces or narrow faces of **cross-laminated timber (CLT)** made of **softwood**.

	ASSY®plus: not pre-drilled ASSY®: not pre-drilled									
	Side face					Narrow face				
a_1	$4\ d$					$10\ d$				
a_2	$2.5\ d$					$4\ d$				
$a_{3,i}$	$6\ d$					$12\ d$				
$a_{3,c}$	$6\ d$					$7\ d$				
$a_{4,i}$	$6\ d$					$6\ d$				
$a_{4,c}$	$2.5\ d$					$3\ d$				
Minimum member thicknesses and minimum embedment depths for different outer thread diameters d										
d	6	8	10	12	14	6	8	10	12	14
d	6	8	10	12	14	6	8	10	12	14
t_{CLT}	60	80	100	120	140	60	80	100	120	140
t_h	No specifications					60	80	100	120	140

Table values in mm.

The specifications also apply to connections between cross-laminated timber and sheet steel.

A narrow-face screw connection in the face layer is only permissible if the face layer is considered a single member ("board") and the corresponding fastener spacings are adhered to. See also Eq. (4.11). If two outer board layers are orientated in the same direction, the inner board layer is considered a separate layer.

Regulation: ETA-11/0190

4.7.6 End-grain screw connection

For screw connections in the end grain ($\varepsilon = 0^\circ$), the spacings given in Table 47 should be used.

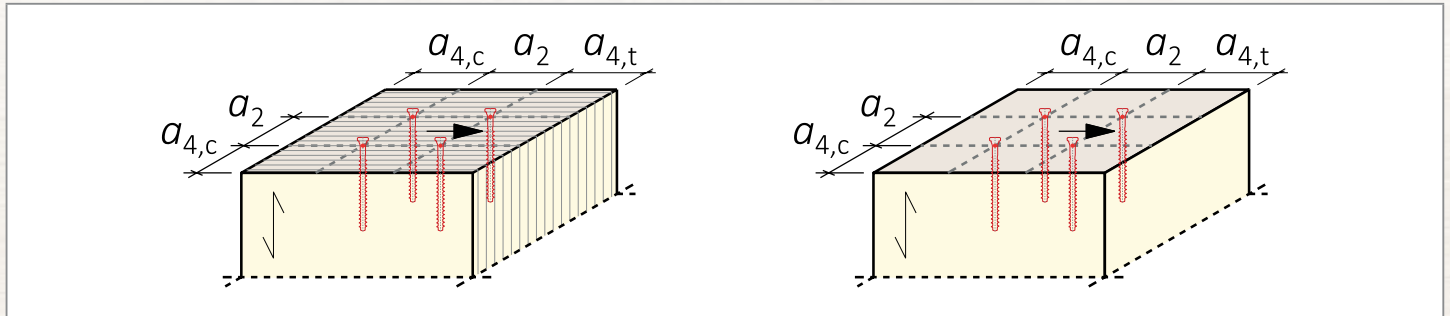


Figure 45: Definition of the edge and axial spacings of screws arranged parallel to the grain in the end grain ($\varepsilon = 0^\circ$) for solid wood-based products.

Table 47: Minimum spacings for laterally loaded screws in the end grain surfaces with an angle of $\varepsilon = 0^\circ$ between the screw axis and grain direction, members made of solid timber (ST/FST), **glued solid timber** (GST) or **glued laminated timber** (GL) made of **softwood**.

	ASSY®plus: not pre-drilled ASSY®: pre-drilled		ASSY®: not pre-drilled		
	$\rho_k \leq 500 \text{ kg/m}^3$		$\rho_k \leq 420 \text{ kg/m}^3$	$420 \text{ kg/m}^3 < \rho_k \leq 500 \text{ kg/m}^3$	
a_2	4 d		5 d	7 d	
$a_{4,t}$	7 d		10 d	12 d	
$a_{4,c}$	3 d		5 d	7 d	
Minimum embedment depths t_h for different outer thread diameters d					
d	6	8	10	12	14
d	6	8	10	12	14
t_h	60	80	100	120	140
Table values in mm.					
Regulation: ETA-11/0190, see EC 5 (Table 8.2)					

4.7.7 Examples for spacings, effective number of screws and member thickness

Example 1: 2 x 3 ASSY® 4 CSMP 6.0 x 240/70 mm screws

Pre-determined:

- Arrangement not offset
- Installation without pre-drilling

$$\rho_{k,1} = 350 \text{ kg/m}^3 \text{ (see table 58)}$$

$$\rho_{k,2} = 365 \text{ kg/m}^3$$

$$\alpha = 0^\circ \text{ (} \cos 0^\circ = 1; \sin 0^\circ = 0 \text{)}$$

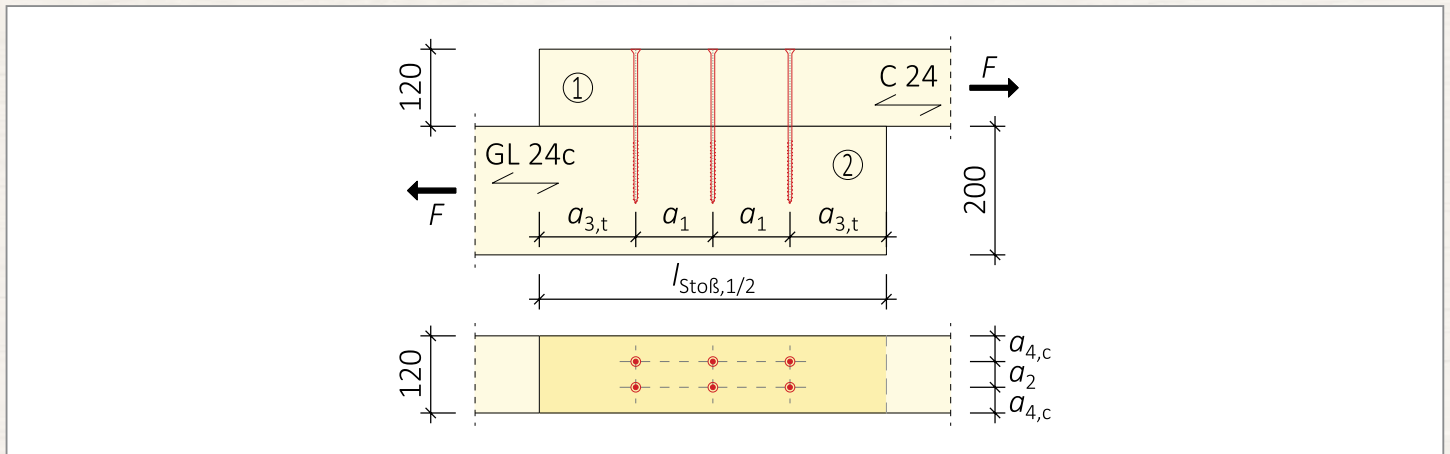


Figure 46: Butt strap joint, spacings not pre-drilled, no drill tip.

Sought: $n_{ef,ges}$; $l_{Stoß,1/2}$

based on Table 41, column 3:

$$a_1 = (5 + 7)d = 12d$$

$$a_2 = 5d$$

$$a_{3,t,1/2} = (10 + 5)d = 15d$$

$$a_{4,c} = 5d$$

based on Eq. (4.18), (4.19) and Table 38:

$$n_{ef,0} = n_0^{k_{ef}} = 3^{0,93} = 2,78$$

$$n_{ef,90} = n_{90} = 2$$

$$n_{ef,ges} = n_{ef,90} \cdot n_{ef,0} = 2,78 \cdot 2 = 5,56$$

$$\begin{aligned} l_{Stoß,1/2} &= (n_0 - 1) \cdot a_1 + 2 \cdot a_{3,t,1/2} \\ &= 2 \cdot 72 \text{ mm} + 2 \cdot 90 \text{ mm} \\ &= 324 \text{ mm} \end{aligned}$$

Example 2: 2 x 3 ASSY®plus 4 CSMP 8.0 x 240/100.5 mm screws
Pre-determined:

- Arrangement not offset
- Installation without pre-drilling

$$\rho_{k,1} = 350 \text{ kg/m}^3 \text{ (see table 58)}$$

$$\rho_{k,2} = 365 \text{ kg/m}^3$$

$$\alpha = 0^\circ \text{ (} \cos 0^\circ = 1; \sin 0^\circ = 0 \text{)}$$

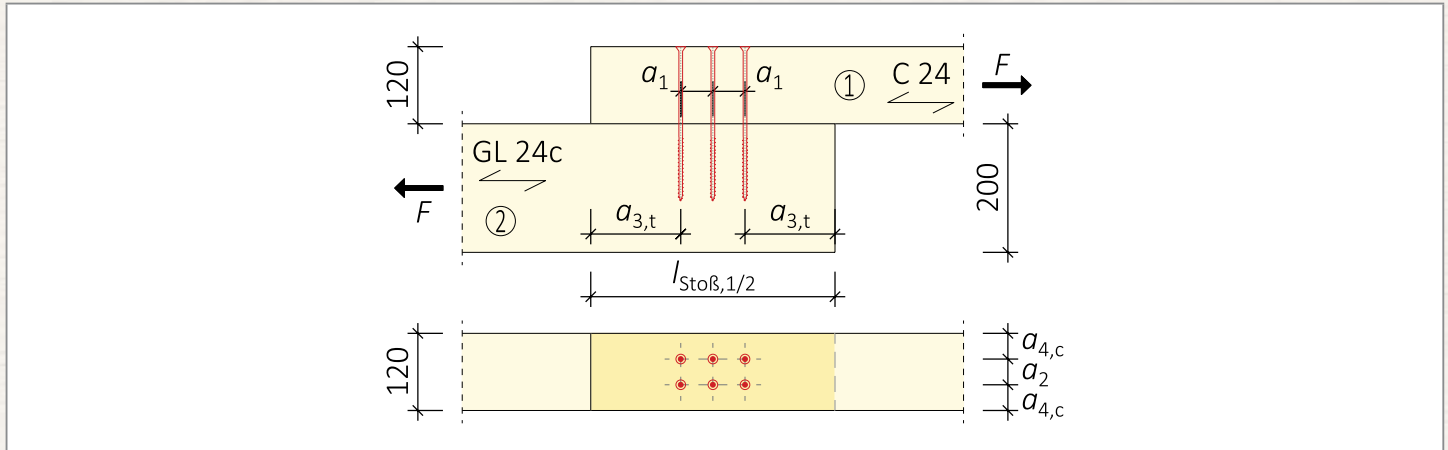


Figure 47: Butt strap joint, spacings not pre-drilled, with drill tip.

Sought: $n_{ef,ges} \cdot l_{Stoß,1/2}$

based on Table 41, column 2:

$$a_1 = (4 + 1)d = 5d$$

$$a_2 = 3d$$

$$a_{3,t,1/2} = (7 + 5)d = 12d$$

$$a_{4,c} = 3d$$

based on Eq. (4.18), (4.19) and Table 38:

$$n_{ef,0} = n_0^{k_{ef}} = 3^{0,57} = 1,87$$

$$n_{ef,90} = n_{90} = 2$$

$$n_{ef,ges} = n_{ef,90} \cdot n_{ef,0} = 1,87 \cdot 2 = 3,74$$

$$\begin{aligned} l_{Stoß,1/2} &= (n_0 - 1) \cdot a_1 + 2 \cdot a_{3,t,1/2} \\ &= 2 \cdot 40 \text{ mm} + 2 \cdot 96 \text{ mm} \\ &= 272 \text{ mm} \end{aligned}$$

Comparison of Examples 1 and 2

	Screws	n_{ges}	n_{ef}	$l_{Stoß}$ in mm	Offset arrangement	Fastener costs	Installation time	Connection surface	Splitting risk
Example 1	6 x 240 PT	6	5.56	324	No	-	-	+	+
Example 2	8 x 240 PT*	6	3.74	272	No	+	+	-	-

* With drill tip

+ = increase; - = decrease

For screws with drill tips, the minimum spacings for pre-drilled members can be used. The equations for non pre-drilled members is required to determine the embedment strength of screws with drill tips (see Section 4.3).

Example 3: 2 x 3 ASSY®plus 4 CSMP 8.0 x 240/100.5 mm screws, arrangement offset by d

Pre-determined:

- Arrangement offset by d
- Installation without pre-drilling

$$\rho_{k,1} = 350 \text{ kg/m}^3 \text{ (see table 58)}$$

$$\rho_{k,2} = 365 \text{ kg/m}^3$$

$$\alpha = 0^\circ \text{ (} \cos 0^\circ = 1; \sin 0^\circ = 0 \text{)}$$

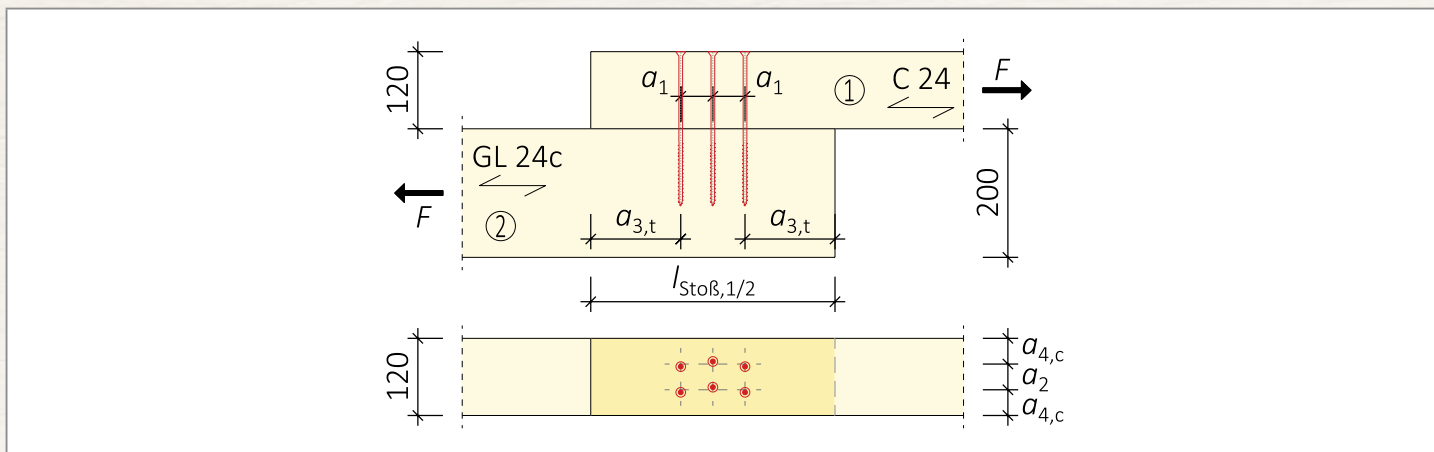


Figure 48: Butt strap joint, spacings not pre-drilled, with drill tip, arrangement offset by d .

Sought: $n_{ef,ges} \cdot l_{Stoß,1/2}$

based on Table 41, column 2:

$$a_1 = (4 + 1)d = 5d$$

$$a_2 = 3d$$

$$a_{3,t,1/2} = (7 + 5)d = 12d$$

$$a_{4,c} = 3d$$

based on Eq. (4.18), (4.19) and Table 38 (where $a_1 = 10d$ due to the offset arrangement and therefore $k_{ef} = 0.85$):

$$n_{ef,0} = n_0^{k_{ef}} = 3^{0.85} = 2,54$$

$$n_{ef,90} = n_{90} = 2$$

$$n_{ef,ges} = n_{ef,0} \cdot n_{ef,90} = 2,54 \cdot 2$$

$$= 5,09 \text{ Schrauben}$$

$$l_{Stoß,1/2} = (n_0 - 1)a_1 + 2a_{3,t,1/2}$$

$$= 2 \cdot 40 \text{ mm} + 2 \cdot 96 \text{ mm}$$

$$= 272 \text{ mm}$$

Comparison of Examples 2 and 3

	Screws	n_{ges}	n_{ef}	$l_{Stoß}$ in mm	Offset arrangement	Fastener costs	Installation time	Connection surface	Splitting risk
Example 2	8 x 240 PT*	6	3.72	272	No	0	0	0	+
Example 3	8 x 240 PT*	6	5.09	272	Yes	0	0	0	-

* With drill tip

0 = same; + = increase; - = decrease

Example 4: 1 x 4 ASSY® plus 4 CSMP 6.0 x 200/70 mm screws, arrangement offset by d

Pre-determined:

- Arrangement offset by d
- Installation without pre-drilling

$$\rho_{k,1} = 350 \text{ kg/m}^3; \rho_{k,2} = 365 \text{ kg/m}^3$$

$$\alpha_1 = 0^\circ (\cos 0^\circ = 1; \sin 0^\circ = 0)$$

$$\alpha_2 = 90^\circ (\cos 90^\circ = 0; \sin 90^\circ = 1)$$

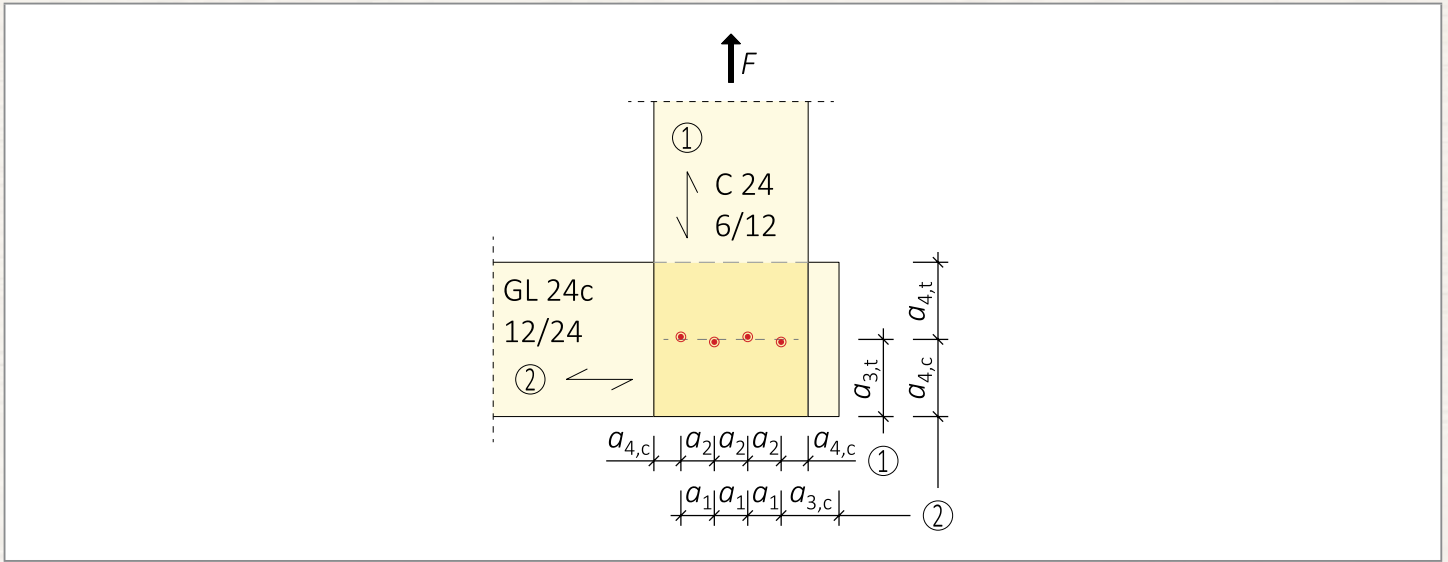


Figure 49: Butt strap joint less than 90° .

Sought: $n_{ef,ges}$

based on Table 41, column 2:

$a_{1,1} = (4 + 1)d = 5d$	$a_{1,2} = (4 + 0)d = 4d$
$a_{2,1} = 3d$	$a_{2,2} = 4d$
$a_{3,t,1} = (7 + 5)d = 12d$	$a_{3,c,2} = 7d$
$a_{4,t,1} = \text{n. def.}$	$a_{4,t,2} = (3 + 4)d = 7d$
$a_{4,c,1} = 3d$	$a_{4,c,2} = 3d$

based on Eq. (4.18), (4.19):

$n_{ef,0,1} = n_0 = 1$	$n_{ef,0,2} = n_0 = 4$
$n_{ef,90,1} = n_{90} = 4$	$n_{ef,90,2} = n_{90} = 1$
$n_{ef,ges} = n_{ef,0} \cdot n_{ef,90,2} = 1 \cdot 4 \text{ (oder } 4 \cdot 1)$	
$= 4 \text{ Schrauben}$	

Example 5: 3 x 2 ASSY® plus 4 CSMP 6.0 x 120/70 mm screws

Pre-determined:

- Arrangement not offset
- Installation without pre-drilling

$$\rho_{k,1} = 350 \text{ kg/m}^3; \rho_{k,2} = 365 \text{ kg/m}^3$$

$$\alpha_1 = 0^\circ (\cos 0^\circ = 1; \sin 0^\circ = 0)$$

$$\alpha_2 = 45^\circ (\cos 45^\circ = \sin 45^\circ = \frac{1}{\sqrt{2}})$$

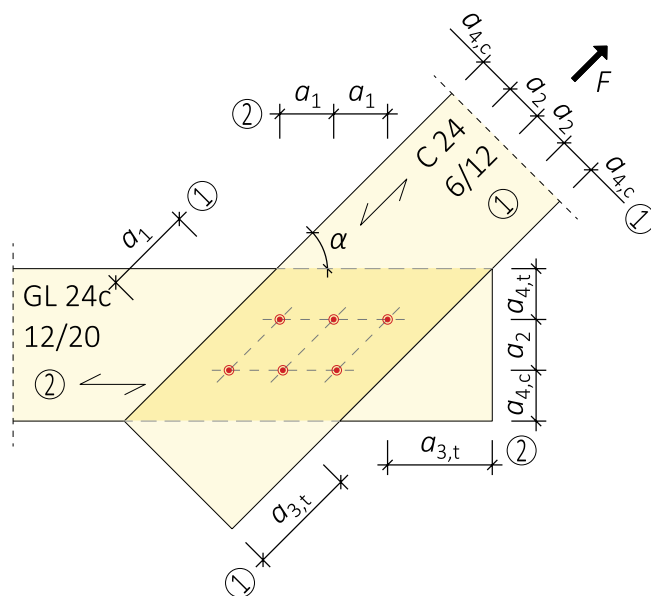


Figure 50: Butt strap joint less than 45°.

Sought: $n_{ef,min}$

Spacing selection based on Table 41, column 2:

$$a_{3,t,1} = (7 + 5)d = 12d$$

$$a_{4,t,2} = (3 + 4 \cdot \frac{1}{\sqrt{2}})d = 5,8d$$

$$a_{4,c,1} = 3d$$

$$a_{4,c,2} = \frac{a_{3,t,1} - a_{4,c,1}}{\sqrt{2}} = 6d$$

$$a_{2,1} = \frac{b_1 - 2 \cdot a_{4,c,1}}{n_{90,1} - 1} = \frac{20d - 2 \cdot 3d}{2} = 7d$$

$$\begin{aligned} a_{2,2} &= b_2 - a_{4,t,2} - a_{4,c,2} - d \\ &= 20d - 5,8d - 6d - d \\ &= 7,2d \end{aligned}$$

$$a_{1,1} = a_{2,2} \cdot \sqrt{2} = 10,2d$$

$$a_{1,2} = a_{2,1} \cdot \sqrt{2} = 9,9d$$

$$a_{3,t,2} = (7 + 5 \cdot \frac{1}{\sqrt{2}})d = 10,5d$$

$$a_{4,t,1} = n. \text{ def.}$$

Spacing verification:

$$a_{4,c,2ist} \geq a_{4,c,2min}$$

$$a_{2,2ist} \geq a_{2,2min}$$

$$a_{1,2ist} \geq a_{1,2min}$$

$$6d > 3d \checkmark$$

$$7.2d > 3.7d \checkmark$$

$$9.9d > 4.7d \checkmark$$

$$a_{2,1ist} \geq a_{2,1min}$$

$$a_{1,1ist} \geq a_{1,1min}$$

$$7d > 3d \checkmark$$

$$10.2d > 5d \checkmark$$

Effective number of screws:

based on Eq. (4.18), (4.19) and Table 38 and Eq. (4.22):

Member 1:

$$n_{\text{ef},0,1} = n_0^{\text{k}_{\text{ef}}} = 2^{0,85} = 1,8; n_{\text{ef},90,1} = n_{90} = 3$$

$$n_{\text{ef},1} = n_{\text{ef},0,1} \cdot n_{\text{ef},90,1} = 1,8 \cdot 3 = 5,4$$

Member 2:

$$n_{\text{ef},0,2} = n_0^{\text{k}_{\text{ef}}} = 3^{0,85} = 2,54; n_{\text{ef},90,2} = n_{90} = 2$$

$$n_{\text{ef},45,2} = n_{\text{ef},90,2} \cdot \min\{n_{\text{ef},0,2} \cdot \sqrt{2}; n_{0,2}\} = 2 \cdot \min\{2,54 \cdot \sqrt{2}; 3\} = 6,0$$

$$\underline{n_{\text{ef},\text{min}}} = \min\{n_{\text{ef},1}; n_{\text{ef},45,2}\} = \underline{5,4}$$

Example 7: 2 x 2 ASSY® 4 CSMP 8.0 x 200/80.5 mm screws

Pre-determined:

- Arrangement not offset
- Installation without pre-drilling

$$\rho_{k,1} = 380 \text{ kg/m}^3 \text{ (see table 58)}$$

$$\rho_{k,2} = 365 \text{ kg/m}^3$$

$$\alpha = 0^\circ \text{ (} \cos 0^\circ = 1; \sin 0^\circ = 0 \text{)}$$

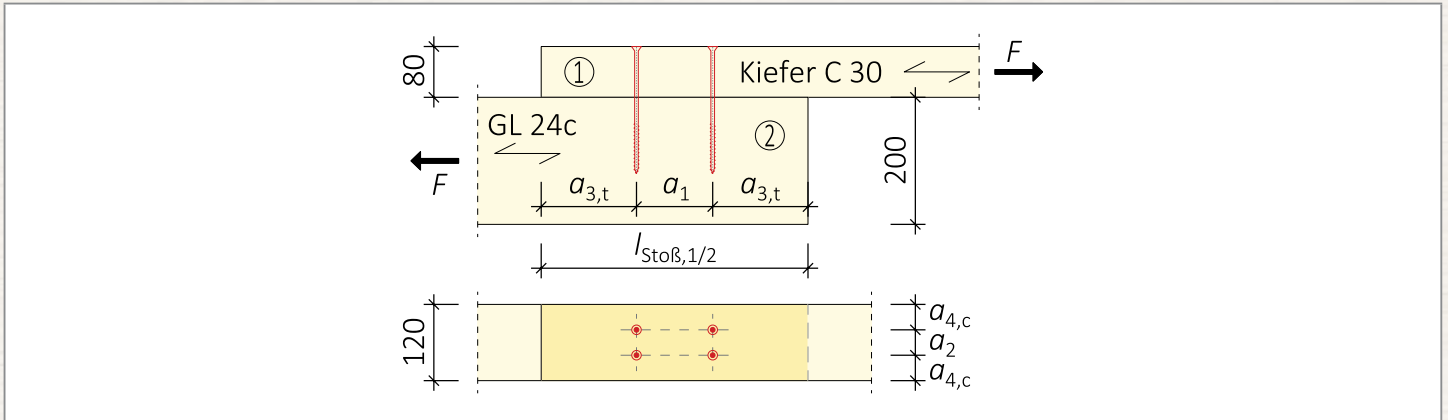


Figure 52: Butt strap joint with C 30 and size 8 screws.

Sought: $n_{ef,ges}$; $l_{Stoß,1/2}$

based on Table 41, column 2:

$$a_{1,1/2} = 12d \quad a_{2,1/2} = 5d$$

$$a_{3,t,1/2} = 15d \quad a_{4,c,1/2} = 5d$$

based on Eq. (4.24), (4.18) and (4.19):

$$n_{ef,ges} = n_{ef,0} \cdot n_{ef,90} = 2^{0,925} \cdot 2 = 1,9 \cdot 2 = 3,8 \text{ Schrauben}$$

$$t_{min,1} = \max \left\{ \begin{array}{l} 7d \\ (13d - 30) \cdot \frac{\rho_{k,1}}{400} \end{array} \right.$$

$$= \max \left\{ \begin{array}{l} 7 \cdot 8 \\ (13 \cdot 8 - 30) \cdot \frac{380}{400} \end{array} \right. = 70,3 \text{ mm}$$

$$l_{Stoß,1/2} = (n_0 - 1)a_1 + 2 \cdot a_{3,t}$$

$$= 1 \cdot 96 \text{ mm} + 2 \cdot 120 \text{ mm}$$

$$= 336 \text{ mm}$$

Width and height verification:

$$b = 2 \cdot a_{4,c} + a_{2,b} = 2 \cdot 5d + 5d = 120 \text{ mm}$$

$$b_{min} = b_{ist} \checkmark$$

$$t_{min,1} = 70,3 \text{ mm}; t_{min,2} = 135 \text{ mm}; t_{min} < t_{ist} \checkmark$$

Example 8: 3 x 3 ASSY® 4 CSMP 6.0 x 240/70 mm screws

Pre-determined:

- Arrangement not offset
- Installation without pre-drilling

$$\rho_{k,1} = 350 \text{ kg/m}^3 \text{ (see table 58)}$$

$$\rho_{k,2} = 365 \text{ kg/m}^3$$

$$\alpha = 0^\circ \text{ (} \cos 0^\circ = 1; \sin 0^\circ = 0 \text{)}$$

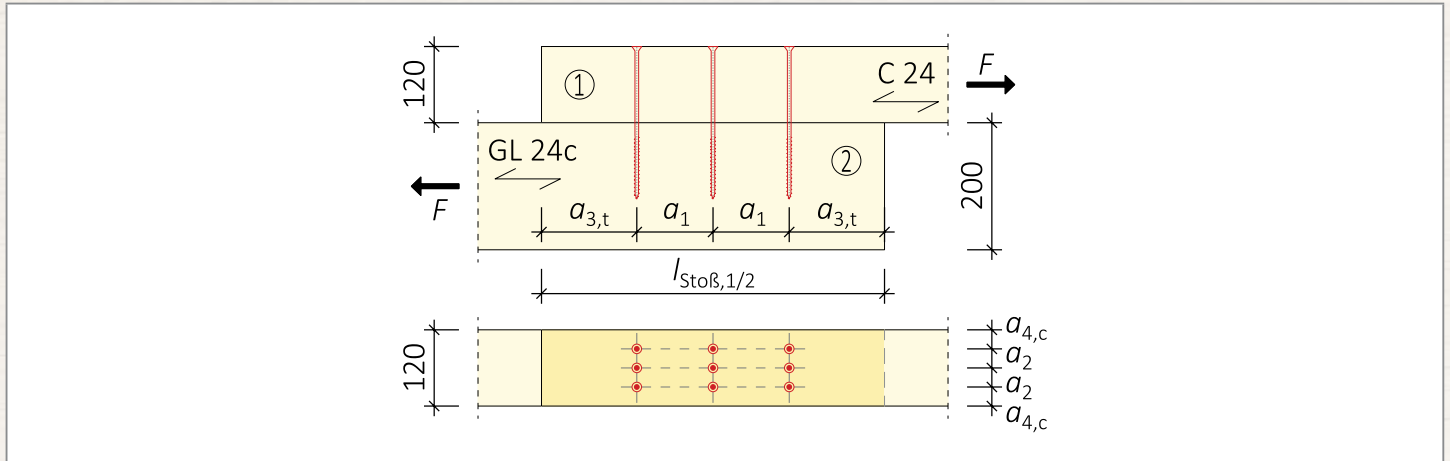


Figure 53: Butt strap joint with C 24 and size 6 screws.

Sought: $n_{ef,ges}$; $l_{Stoß,1/2}$

based on Table 41, column 2:

$$a_{1,1/2} = 12d \quad a_{2,1/2} = 5d$$

$$a_{3,t,1/2} = 15d \quad a_{4,c,1/2} = 5d$$

$$t_{min,pk,1} = 84 \text{ mm}$$

based on Eq. (4.18), (4.19) and Table 38:

$$n_{ef,0} = n_0^{k_{ef}} = 3^{0,93} = 2,78$$

$$n_{ef,90} = n_{90} = 3$$

$$n_{ef,ges} = n_{ef,0} \cdot n_{ef,90} = 2,78 \cdot 3$$

$$= 8,34 \text{ Schrauben}$$

$$l_{Stoß,1/2} = (n_0 - 1)a_1 + 2 \cdot a_{3,t}$$

$$= 2 \cdot 72 \text{ mm} + 2 \cdot 90 \text{ mm}$$

$$= 324 \text{ mm}$$

Width and height verification:

$$b = 2 \cdot a_{4,c} + 2 \cdot a_2 = 120 \text{ mm}$$

$$b_{min} = b_{ist} \checkmark$$

$$t_{min} = 84 \text{ mm}; t_{min} < t_{ist} \checkmark$$

Example 9: 2 x 3 ASSY®plus VG 4 CSMP 8.0 x 340 mm screws

Pre-determined:

- Member 1: CLT 4-2-4-2-4
- Member 2: CLT 4-2-4-2-4
- Arrangement not offset
- Installation without pre-drilling

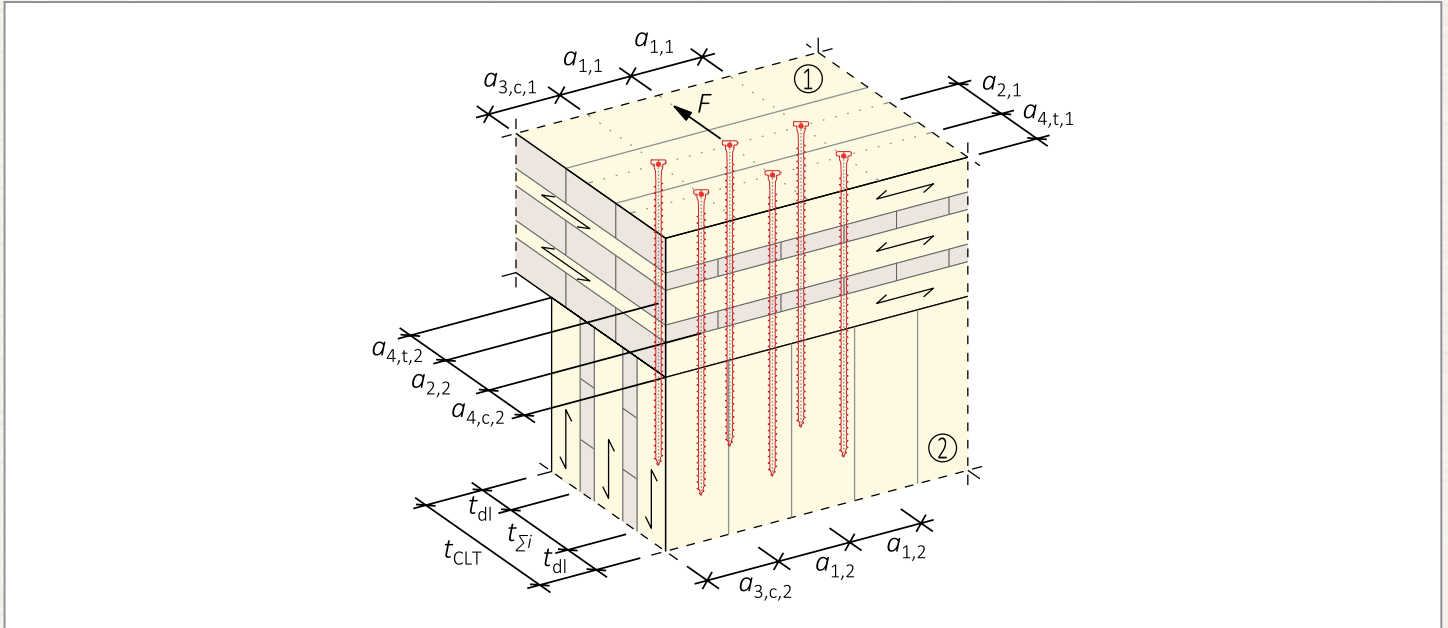


Figure 54: Spacings in cross-laminated timber (CLT).

Sought: $n_{ef,ges}$

Based on Table 46, columns 2 and 3:

$$\begin{aligned} a_{1,1} &= 4d & a_{1,2} &= 10d \\ a_{2,1} &= 2,5d & a_{2,2} &= 4d \\ a_{3,c,1} &= 6d & a_{3,c,2} &= 7d \\ a_{4,t,1} &= 6d & a_{4,t,2} &= 6d \\ a_{4,c,1} &= 2,5d & a_{4,c,2} &= 3d \end{aligned}$$

based on Eq. (4.19):

$$\begin{aligned} n_{ef,ges} &= n_{ef,0} \cdot n_{ef,90} = 2 \cdot 3 \\ &= 6 \text{ Schrauben} \end{aligned}$$

Verification that screws engage in the outer layers:

$$t_{\Sigma i} = 2 + 4 + 2 = 8 \text{ cm}$$

$$t_{\Sigma i} > a_2 \quad \checkmark$$

$$t_{dl} = 4 \text{ cm}; t_{dl} < a_{4,t} \quad \checkmark$$

$$\begin{aligned} t_{CLT} &= 4 + 2 + 4 + 2 + 4 \\ &= 16 \text{ cm} \end{aligned}$$

$$t_{CLT} > a_2 + a_{4,c} + a_{4,t} \quad \checkmark$$

$$t_{dl} < a_{4,t} \quad \checkmark$$

→ The spacings in the narrow face are decisive.

4.8 Screw-induced failure mechanisms in the affected members – block shear

4.8.1 General information

Screw-induced loads acting parallel to the grain can lead to brittle timber failure in structural members. A distinction is made between two block shear cases (see Figure 55).

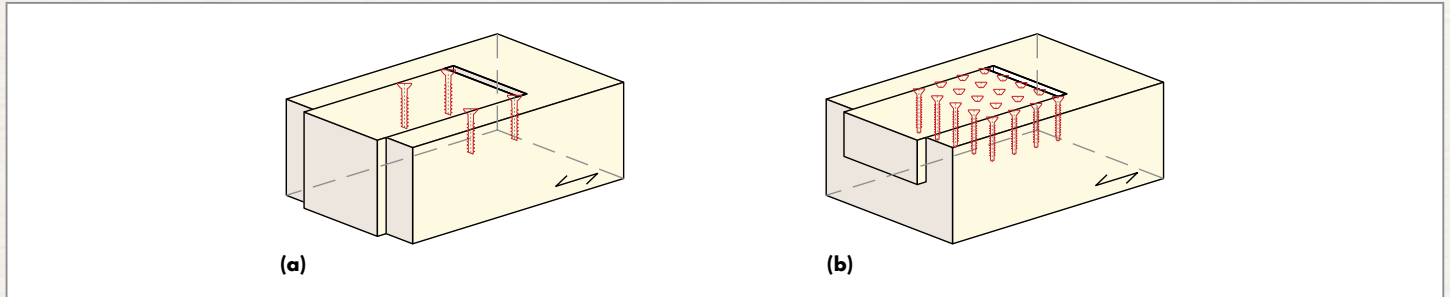


Figure 55: Brittle failure mechanisms in accordance with EC 5.

(a) Case 1: Block shear failure over the entire cross-sectional height

(b) Case 2: Block shear failure over part of the cross-sectional height

The member splits open and partial sections are sheared or torn off. The calculation of the characteristic block shear capacity $F_{bs,Rk}$ is explained in the following section.

4.8.2 Block shear failure in accordance with EC 5

Block shear failure occurs when the block surrounded by the screws shears off on two (Case 1) or three faces (Case 2) and the rear net tensile area tears off parallel to the grain.

It can be assumed that either the shear planes or the net tensile area has failed. Therefore, the characteristic block shear capacity $F_{bs,Rk}$ (in accordance with EC 5 Part 1-1, Annex A) is derived from the maximum load-bearing capacity of the two faces using Eq. (4.25). The characteristic block shear capacity is determined for both failure cases and the smaller value is decisive.

$$F_{bs,Rk} = \max \left\{ \begin{array}{l} 0,7 \cdot A_{net,v} \cdot f_{v,k} \\ 1,5 \cdot A_{net,t} \cdot f_{t,0,k} \end{array} \right. \quad (4.25)$$

Where:

$f_{v,k}$ Characteristic value of the shear strength of the timber

$f_{t,0,k}$ Characteristic value of the tensile strength of the timber parallel to the grain direction

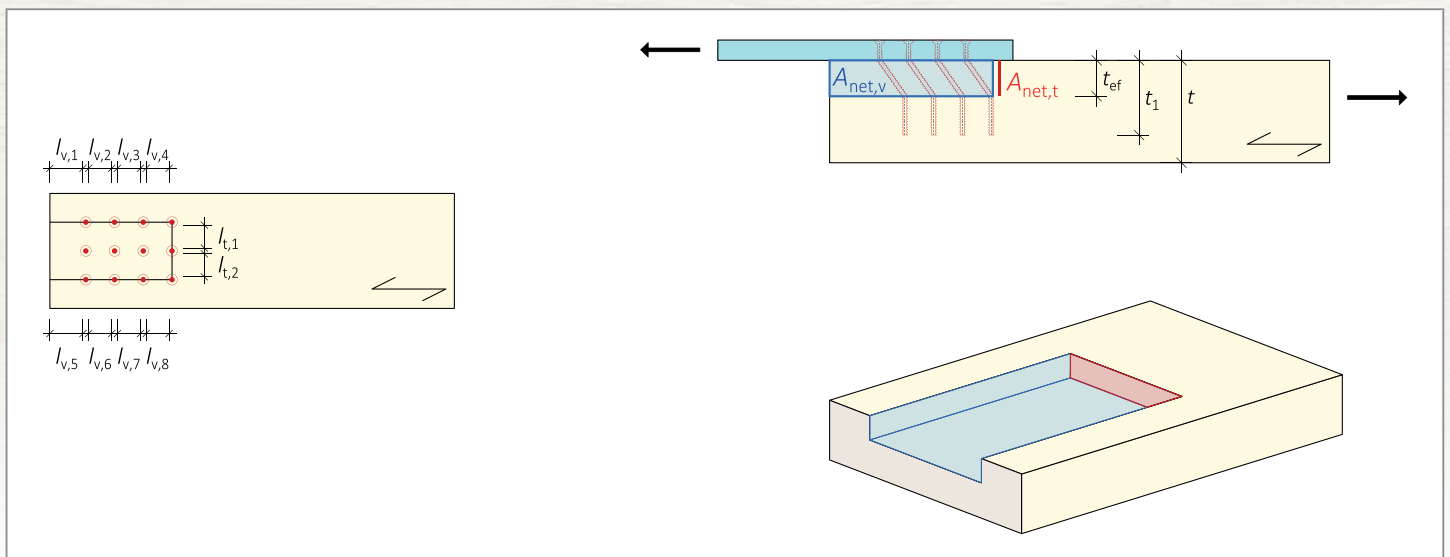


Figure 56: Block shear failure in accordance with EC 5 Part 1-1, Annex A. Left: top view; top-right: the fastener penetrates the timber member and two plastic hinges form; bottom-right: residual cross-section after failure in Case 2.

When determining the applicable areas, the penetration depth and the failure mechanism of the fasteners are taken into account. The net shear plane $A_{\text{net},v}$ (blue area in Figure 56) is designed using Eq. (4.26) and the net tensile area $A_{\text{net},t}$ (red area in Figure 56) using Eq. (4.27) for the respective failure cases. To calculate the net tensile area in Case 2, the minimum embedment depth t_1 and the effective embedment depth t_{ef} should be used. If the fastener fully penetrates the member and the decisive failure mechanism of the screw corresponds to Figure 34 (c) or Figure 35 (f), Case 2 does not need to be considered.

$$A_{\text{net},v} = \begin{cases} \sum_i l_{v,i} \cdot t & \text{Fall 1} \\ \frac{\sum_i l_{v,i}}{2} \cdot \left(\sum_i l_{t,i} + 2 \cdot \min(t_{\text{ef}}, t_1) \right) & \text{Fall 2} \end{cases} \quad (4.26)$$

$$A_{\text{net},t} = \begin{cases} \sum_i l_{t,i} \cdot t & \text{Fall 1} \\ \sum_i l_{t,i} \cdot \min(t_{\text{ef}}, t_1) & \text{Fall 2} \end{cases} \quad (4.27)$$

The effective embedment depth t_{ef} results from the screw failure mechanism contained in the brackets, which is decisive for the calculation of the load-bearing capacity (see Section 4.2, Eq. [4.5] and [4.6], Figures 33 to 35).

$$t_{\text{ef}} = \begin{cases} 0,4 \cdot t_1 & \text{(a)} \\ 1,4 \cdot \sqrt{\frac{M_{y,k}}{f_{h,k} \cdot d}} & \text{(b)} \\ 2 \cdot \sqrt{\frac{M_{y,k}}{f_{h,k} \cdot d}} & \text{(e),(h)} \\ t_1 \cdot \left[\sqrt{2 + \frac{4 \cdot M_{y,k}}{f_{h,k} \cdot d \cdot t_1^2}} - 1 \right] & \text{(d),(g)} \end{cases} \quad (4.28)$$

For thin sheet steel (for the failure mechanisms inside the brackets)

For thick sheet steel (for the failure mechanisms inside the brackets)

Where:

t	Thickness of the timber member
t_1	Embedment depth of a screw
$M_{y,k}$	Characteristic yield moment of a screw
$f_{h,k}$	Characteristic embedment strength of the timber

4.9 Screwed connections with an interlayer

4.9.1 General information

Screwed connections with interlayers that are subjected to shear cannot be designed as described in the general regulations of EC 5. If interlayers are present in a connection, extended Johansen equations as provided by Blaß and Laskewitz (2003) can be used to design the contact ratio $F_{D,k}$. These design equations are also included in Draft EC 5.

A distinction must be made between connections with moveable and immovable interlayers. An interlayer is considered immovable if it is force-locked to one of the two members being connected, either by adhesion or mechanical fasteners.

The load-bearing capacities with a movable interlayer can be designed for timber-to-timber connections using Eq. (4.30). For timber-to-steel connections with movable interlayer, Eq. (4.31) and (4.32) are used.

If an immovable interlayer is ensured by the structural design, Eq. (4.33) is used for timber-to-timber connections and Eq. (4.34) to (4.35) for timber-to-steel connections.

In addition to the equations listed here, the load-bearing capacity of each joint (steel/interlayer, wood/interlayer) must be determined using the Johansen equations provided in Section 4.3. The embedment strengths of the individual members or the interlayer must be used. In the extreme case that the interlayer is made of steel, $f_{h,k} = \infty$. The rope effect $F_{rp,k}$ should only be considered if the members are in contact with each other and any existing interlayer is sufficiently stiff to ensure a constant spacing between the members. Air interlayers can be taken into account with $f_{h,k} = 0$ and $F_{rp,k} = 0$.

When calculating the shear load-bearing capacity without taking into account rope effect, it must be noted that the modification factors k_{mod} have already been accounted in the embedment strengths. Instead of using Eq. (4.1), (4.7) and (4.16), the design value of the load-bearing capacity per screw and shear plane is therefore determined using Eq. (4.29).

$$F_{v,d} = F_{D,d} + F_{rp,d} = \frac{F_{D,k}}{\gamma_M} + \min \left\{ 1, 0 \cdot \frac{F_{D,k}}{\gamma_M} \right. \\ \left. 0,25 \cdot F_{ax,t,d} \right\} \quad (4.29)$$

The following conventions apply to all subsequent equations in this section:

$$\beta = \frac{k_{\text{mod},2} \cdot f_{h,k,2}}{k_{\text{mod},1} \cdot f_{h,k,1}}$$

$$\delta = \frac{k_{\text{mod},il} \cdot f_{h,k,il}}{k_{\text{mod},1} \cdot f_{h,k,1}}$$

$k_{\text{mod},1/2/il}$	Modification factor for member 1, member 2 or the interlayer
$f_{h,k,1/2/il}$	Characteristic embedment strength of member 1, member 2 or the interlayer
$t_{h,1/2/il}$	Embedment depth in member 1, member 2 or the interlayer
d	Outer thread diameter
$M_{y,k}$	Characteristic yield moment of a screw
$\rho_{\text{mean},1/2/il}$	Medium bulk density of member 1, member 2 or the interlayer in kg/m ³

4.9.2 Load-bearing capacity of a screw in a moveable interlayer

The load-bearing capacity of a screw in timber-to-timber connections with a moveable interlayer is determined by Eq. (4.30):

$$F_{D,k} = \min \begin{cases} k_{\text{mod},1} \cdot f_{h,k,1} \cdot t_{h,1} \cdot d & \text{(a)} \\ k_{\text{mod},2} \cdot f_{h,k,2} \cdot t_{h,2} \cdot d & \text{(b)} \\ k_{\text{mod},1} \cdot f_{h,k,1} \cdot b_1 \cdot d & \text{(c)} \end{cases} \quad (4.30)$$

Where:

$$b_1 = \min \begin{cases} \frac{\beta}{1+\beta} \cdot \left(-2 \cdot t_{h,il} - t_{h,1} - t_{h,2} + \sqrt{\left(4 + \delta + \frac{\delta}{\beta}\right) \cdot t_{h,il}^2 + \left(2 + \frac{1}{\beta}\right) \cdot t_{h,1}^2 + (2 + \beta) \cdot t_{h,2}^2 + 4 \cdot t_{h,il} \cdot t_{h,1} + 4 \cdot t_{h,il} \cdot t_{h,2} + 2 \cdot t_{h,1} \cdot t_{h,2}} \right) \\ \frac{2 \cdot \beta}{2 + \beta} \cdot \left(-t_{h,il} - \frac{t_{h,1}}{2} + \sqrt{\frac{t_{h,il}^2 + t_{h,il} \cdot t_{h,1} + \frac{t_{h,1}^2}{2} + \frac{\delta \cdot t_{h,il}^2}{2 \cdot \beta} + \frac{t_{h,1}^2}{2 \cdot \beta} + \frac{2 \cdot M_{y,k}}{k_{\text{mod},1} \cdot f_{h,1,k} \cdot \beta \cdot d}}{\frac{\delta \cdot t_{h,il}^2}{4} + \frac{M_{y,k}}{k_{\text{mod},1} \cdot f_{h,1,k} \cdot d}} \right) \\ \frac{\beta}{\frac{1}{2} + \beta} \cdot \left(-t_{h,il} - \frac{t_{h,2}}{2} + \sqrt{\frac{\left(1 + \frac{\delta}{4 \cdot \beta} + \frac{\delta}{2}\right) \cdot t_{h,il}^2 + \left(\frac{1}{2} + \frac{1}{2} \cdot \beta\right) \cdot t_{h,2}^2 + t_{h,il} \cdot t_{h,2} + \frac{M_{y,k}}{k_{\text{mod},1} \cdot f_{h,1,k} \cdot \beta \cdot d} + \frac{2 \cdot M_{y,k}}{k_{\text{mod},1} \cdot f_{h,1,k} \cdot d}} \right) \\ \frac{1}{1 + \beta} \cdot \left(-\beta \cdot t_{h,il} + \sqrt{\beta^2 \cdot t_{h,il}^2 + 4 \cdot \beta \cdot (\beta + 1) \cdot \frac{M_{y,k}}{k_{\text{mod},1} \cdot f_{h,1,k} \cdot d} + \frac{\beta \cdot (\beta + 1)}{2} \cdot \delta \cdot t_{h,il}^2} \right) \end{cases}$$

The load-bearing capacity of a screw in timber-to-steel connections with a moveable interlayer and thick sheet steel is determined using Eq. (4.31).

$$F_{D,k} = \min \begin{cases} k_{\text{mod},1} \cdot f_{h,k,1} \cdot t_{h,1} \cdot d & \text{(a)} \\ 2 \cdot k_{\text{mod},1} \cdot f_{h,k,1} \cdot b_1 \cdot d - k_{\text{mod},1} \cdot f_{h,k,1} \cdot t_{h,1} \cdot d & \text{(b)} \\ k_{\text{mod},1} \cdot f_{h,k,1} \cdot b_2 \cdot d & \text{(c)} \end{cases} \quad (4.31)$$

Where:

$$b_1 = -t_{h,il} + \sqrt{t_{h,il}^2 + \frac{M_{y,k}}{k_{\text{mod},1} \cdot f_{h,k,1} \cdot d} + \frac{\delta \cdot t_{h,il}^2}{4} + t_{h,1} \cdot t_{h,il} + \frac{t_{h,1}^2}{2}}$$

$$b_2 = -t_{h,il} + \sqrt{t_{h,il}^2 + \frac{4 \cdot M_{y,k}}{k_{\text{mod},1} \cdot f_{h,k,1} \cdot d} + \frac{\delta \cdot t_{h,il}^2}{2}}$$

For a screw in timber-to-steel connections with thin sheet steel, Eq. (4.32) is used.

$$F_{D,k} = \min \begin{cases} 2 \cdot k_{\text{mod},1} \cdot f_{h,k,1} \cdot b_1 \cdot d - k_{\text{mod},1} \cdot f_{h,k,1} \cdot t_{h,1} \cdot d & \text{(a)} \\ k_{\text{mod},1} \cdot f_{h,k,1} \cdot b_2 \cdot d & \text{(b)} \end{cases} \quad (4.32)$$

Where:

$$b_1 = -t_{h,il} + \sqrt{t_{h,il}^2 + \frac{\delta \cdot t_{h,il}^2}{4} + t_{h,1} \cdot t_{h,il} + \frac{t_{h,1}^2}{2}}$$

$$b_2 = -t_{h,il} + \sqrt{t_{h,il}^2 + \frac{2 \cdot M_{y,k}}{k_{mod,1} \cdot f_{h,k,1} \cdot d} + \frac{\delta \cdot t_{h,il}^2}{2}}$$

4.9.3 Load-bearing capacity of a screw in an immovable interlayer

The load-bearing capacity of a screw in timber-to-timber connections with an immovable interlayer is determined by Eq. (4.33):

$$F_{D,k} = \min \begin{cases} k_{mod,1} \cdot f_{h,k,1} \cdot t_{h,1} \cdot d + k_{mod,il} \cdot f_{h,k,il} \cdot t_{h,il} \cdot d & (a) \\ k_{mod,2} \cdot f_{h,k,2} \cdot t_{h,2} \cdot d & (b) \\ k_{mod,1} \cdot f_{h,k,1} \cdot b_1 \cdot d + k_{mod,il} \cdot f_{h,k,il} \cdot t_{h,il} \cdot d & (c) \end{cases} \quad (4.33)$$

Where:

$$b_1 = \min \begin{cases} \frac{\beta}{1+\beta} \cdot \left[-t_{h,il} \cdot \left(\frac{\delta}{\beta} + 2 \right) - t_{h,1} - t_{h,2} + \sqrt{\frac{1}{\beta} \cdot \left(2 \cdot t_{h,il}^2 \cdot \left(\delta - \frac{\delta^2}{2} + 2 \cdot \beta - \delta \cdot \beta \right) + t_{h,1}^2 \cdot (2 \cdot \beta + 1) + \beta \cdot t_{h,2}^2 \cdot (2 + \beta) + 2 \cdot t_{h,1} \cdot t_{h,2} \cdot \beta + 2 \cdot t_{h,il} \cdot t_{h,1} \cdot (\delta + 2 \cdot \beta) + 2 \cdot \beta \cdot t_{h,il} \cdot t_{h,2} \cdot (2 - \delta) \right)} \right] \\ -\delta \cdot t_{h,il} + \frac{\beta}{2+\beta} \cdot \left[t_{h,il} \cdot (\delta - 2) - t_{h,1} + \sqrt{\left(4 - 2 \cdot \delta + 4 \cdot \frac{\delta}{\beta} - 2 \cdot \frac{\delta^2}{\beta} \right) \cdot t_{h,il}^2 + \left(2 + \frac{2}{\beta} \right) \cdot t_{h,1}^2 + \left(4 + 4 \cdot \frac{\delta}{\beta} \right) \cdot t_{h,il} \cdot t_{h,1} + \frac{4 \cdot M_{y,k}}{k_{mod,1} \cdot f_{h,k,1} \cdot d} \cdot \left(\frac{2}{\beta} + 1 \right)} \right] \\ -\delta \cdot t_{h,il} + \frac{\beta}{1+2 \cdot \beta} \cdot \left[t_{h,il} \cdot (2 \cdot \delta - 2) - t_{h,2} + \sqrt{\left(4 - 4 \cdot \delta + 2 \cdot \frac{\delta}{\beta} - \frac{2 \cdot \delta^2}{\beta} \right) \cdot t_{h,il}^2 + (2 + 2 \cdot \beta) \cdot t_{h,2}^2 + (4 - 4 \cdot \delta) \cdot t_{h,il} \cdot t_{h,2} + \frac{4 \cdot M_{y,k}}{k_{mod,1} \cdot f_{h,k,1} \cdot d} \cdot \left(\frac{1}{\beta} + 2 \right)} \right] \\ -\delta \cdot t_{h,il} + \frac{\beta}{1+\beta} \cdot \left[t_{h,il} \cdot (\delta - 1) + \sqrt{\left(1 - \delta + \frac{\delta}{\beta} - \frac{\delta^2}{\beta} \right) \cdot t_{h,il}^2 + \frac{4 \cdot M_{y,k}}{k_{mod,1} \cdot f_{h,k,1} \cdot d} \cdot \left(1 + \frac{1}{\beta} \right)} \right] \end{cases}$$

For screws in timber-to-steel connections with an immovable interlayer and thick sheet steel, the load-bearing capacity is determined using Eq. (4.34).

$$F_{D,k} = \min \begin{cases} k_{mod,1} \cdot f_{h,k,1} \cdot t_{h,1} \cdot d + k_{mod,il} \cdot f_{h,k,il} \cdot t_{h,il} \cdot d & (a) \\ 2 \cdot k_{mod,1} \cdot f_{h,k,1} \cdot b_1 \cdot d - k_{mod,1} \cdot f_{h,k,1} \cdot t_{h,1} \cdot d + k_{mod,il} \cdot f_{h,k,il} \cdot t_{h,il} \cdot d & (b) \\ k_{mod,1} \cdot f_{h,k,1} \cdot b_2 \cdot d + k_{mod,il} \cdot f_{h,k,il} \cdot t_{h,il} \cdot d & (c) \end{cases} \quad (4.34)$$

Where:

$$b_1 = -t_{h,il} + \sqrt{t_{h,il}^2 + \frac{M_{y,k}}{k_{mod,1} \cdot f_{h,k,1} \cdot d} - \frac{\delta \cdot t_{h,il}^2}{2} + t_{h,1} \cdot t_{h,il} + \frac{t_{h,1}^2}{2}}$$

$$b_2 = -t_{h,il} + \sqrt{t_{h,il}^2 + \frac{4 \cdot M_{y,k}}{k_{mod,1} \cdot f_{h,k,1} \cdot d} - \delta \cdot t_{h,il}^2}$$

The load-bearing capacity of a screw in timber-to-steel connections with thin sheet steel is designed using Eq. (4.35).

$$F_{D,k} = \min \begin{cases} 2 \cdot k_{\text{mod},1} \cdot f_{h,k,1} \cdot b_1 \cdot d - k_{\text{mod},1} \cdot f_{h,k,1} \cdot t_{h,1} \cdot d + k_{\text{mod},il} \cdot f_{h,k,il} \cdot t_{h,il} \cdot d & \text{(a)} \\ k_{\text{mod},1} \cdot f_{h,k,1} \cdot b_2 \cdot d + k_{\text{mod},il} \cdot f_{h,k,il} \cdot t_{h,il} \cdot d & \text{(b)} \end{cases} \quad (4.35)$$

Where:

$$b_1 = -t_{h,il} + \sqrt{t_{h,il}^2 - \frac{\delta \cdot t_{h,il}^2}{2} + t_{h,1} \cdot t_{h,il} + \frac{t_{h,1}^2}{2}}$$

$$b_2 = -t_{h,il} + \sqrt{t_{h,il}^2 + \frac{2 \cdot M_{y,k}}{k_{\text{mod},1} \cdot f_{h,k,1} \cdot d} - \delta \cdot t_{h,il}^2}$$

4.10 Multi-shear connections

4.10.1 General information

For multi-shear connections, the total load-bearing capacity should be determined as the sum of the minimum load-bearing capacities of all shear planes, with each shear plane considered as part of a series of double-shear connections. The plausible sequence of potential failure types for a multi-shear connection must be considered over the length of the pin. As the connections are generally symmetrical, only half of the shear planes need to be examined.

Procedure:

- Divide the multi-shear connections into single-shear connections. Only members adjacent to the shear plane should be considered.
- Determine the design values of the load-bearing capacity $F_{v,d}$ using Eq. (4.16) for each shear plane, taking into account the plausibility criteria.
- The design value of the total load-bearing capacity of the connection is assumed as the sum of the minimum load-bearing capacities of all shear planes

The use of ASSY® screws in accordance with ETA-11/0190 in multi-shear connections with internal sheet steel is not recommended, as the manufacture, fitting accuracy and slip-free load transfer between the screw shank or screw thread and the sheet steel cannot be guaranteed in such connections.

4.10.2 Calculation of the load-bearing capacity of a screw in multi-shear connections

The directions of the forces in the shear planes are determined based on the known direction of force in the connected timbers, as the embedment strength of the timber members is dependent on the force/grain angle.

For each shear plane in the connection, the load-bearing capacity of a hypothetical single-shear connection is determined by adjusting the widths of the adjacent members A and B to the shear plane according to the arrangement of the respective shear plane in the connection, see Figure 57. The hypothetical member widths correspond to half the actual widths for internal members and the full actual width for external members.

4.10.3 Plausibility criteria

The compatibility of the failure modes of the successive shear planes must also be verified. It is important to note that for internal members, it is not permitted for the fasteners to be inclined at the edge of the hypothetical member, as the fasteners must run continuously through the connection (horizontal tangent at the transitions of the hypothetical connections).

For the outermost shear planes (shear planes I and IV in Figure 57), failure modes (c) (inclination) and (e) (plastic hinge in member 1) as shown in Figure 31 are excluded due to this boundary condition. For the internal shear planes (shear planes II and III in Figure 57), failure modes (c) (inclination), (d) (plastic hinge in member 2) and (e) (plastic hinge in member 1) as shown in Figure 31 are excluded.

Finally, the load-bearing capacities of the individual shear planes can be determined according to Johansen's theory and added together.

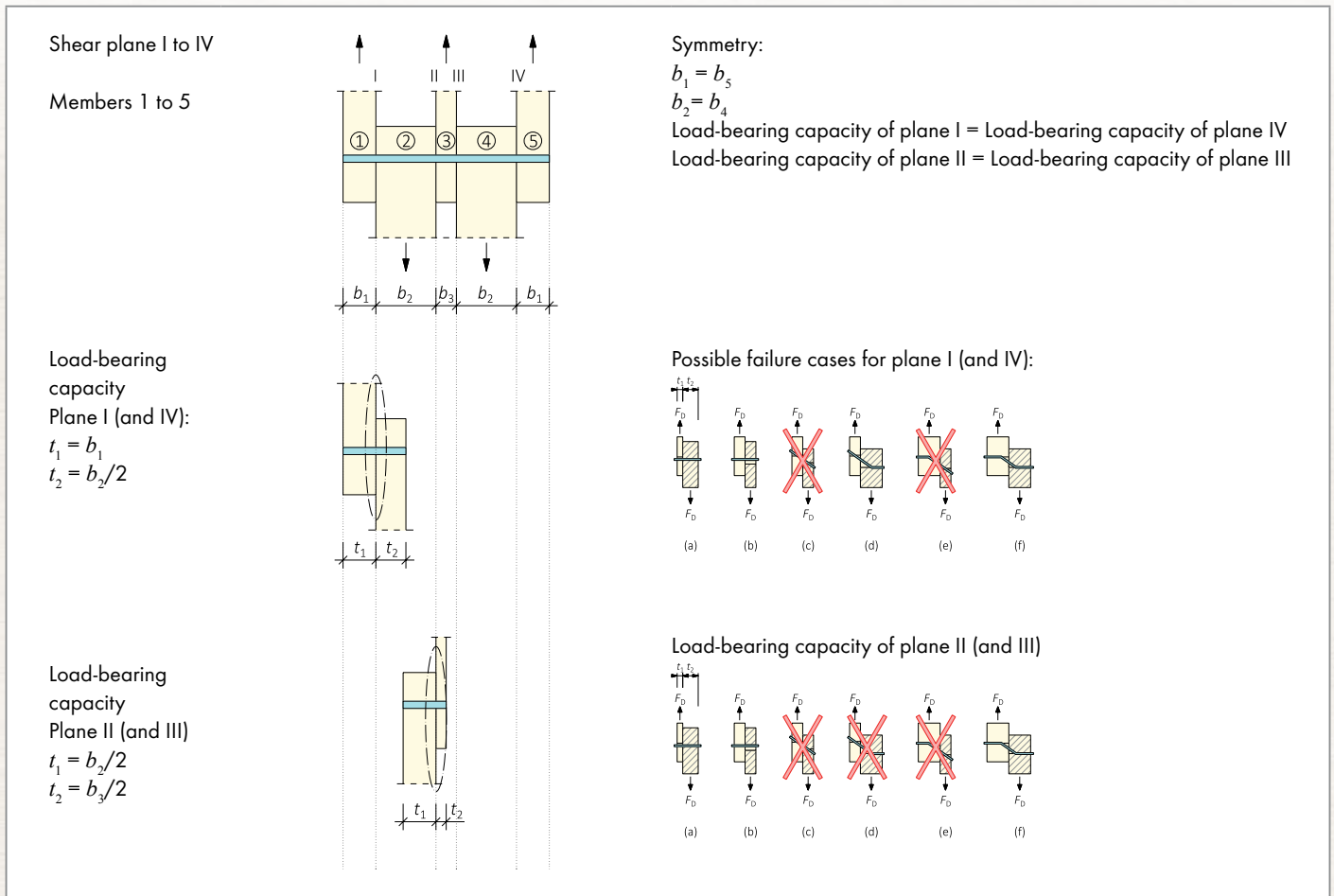


Figure 57: Step-by-step procedure for determining the load-bearing capacities of a screw in a four-shear timber-to-timber connection.

4.11 Fire design of screwed connections subjected to shear stress in accordance with EC 5 Part 1-2

4.11.1 Simplified rules for unprotected connections

Unprotected timber-to-timber connections with screws $d \geq 3.5$ with edge and hole spacings in accordance with Section 4.7 generally have a fire resistance period of 15 minutes. For screw connections with non-protruding heads, fire resistance periods of 30 minutes can be achieved if the thicknesses and widths of the side members and the end and edge spacings are increased by the value a_{fi} ; see Figure 58. Eq. (4.36) is used to calculate a_{fi} . When cold, the part of the connection increased by a_{fi} must not be used to calculate the load-bearing capacity.

$$a_{fi} = \beta_n \cdot k_{flux} \cdot (t_{req} - t_{d,fi}) \quad (4.36)$$

Where:

β_n	Ideal charring rate of the timber
$k_{flux} = 1,5$	Coefficient to account for the increased heat flow through the screw
t_{req}	Required fire resistance period with standard fire exposure, ≤ 30 min
$t_{d,fi}$	Fire resistance period of the unprotected connection, for screwed connections 15 min

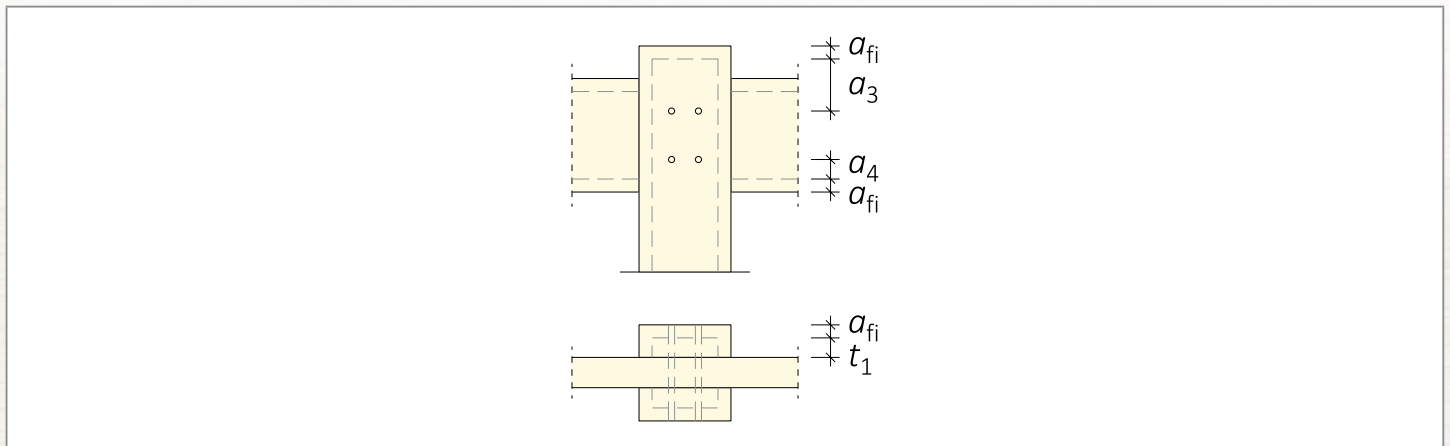


Figure 58: Increase of the timber dimensions using the simplified method.

4.11.2 Simplified rules for protected connections

If the connection is protected by additional cladding made of timber, engineered wood or gypsum boards of type A or H, the time until the start of charring is determined using Eq. (4.37). If the connection is protected by type F gypsum boards, the factor 0.5 can be replaced with 1.2.

$$t_{ch} \geq t_{req} - 0,5 \cdot t_{d,fi} \quad (4.37)$$

Where:

t_{ch}	Period until the start of charring for a protected member
t_{req}	Required fire resistance period for standard fire exposure
$t_{d,fi}$	Fire resistance period of the unprotected connection, for screwed connections 15 min

For connections in which the screws are protected by glued wooden dowels, the length of the wooden dowels should be determined using Eq. (4.36).

4.11.3 Simplified rules for connections with internal sheet steel

For connections with internal sheet steel with thicknesses $t \geq 2$ mm where the steel plate does not protrude beyond the edges of the timber, the width of the sheet steel b_{st} should fulfil the conditions described in Table 48.

Table 48: Widths of sheet steel with unprotected edges.

Boundary conditions		b_{st}
Unprotected edges in general	R 30	≥ 200 mm
	R 60	≥ 280 mm
Unprotected edges on one or two sides	R 30	≥ 120 mm
	R 60	≥ 280 mm

Regulation: EC 5 Part 1-2

Sheet steel with a smaller width than that of the timber members can be considered protected in the following cases (see Figure 59):

- Sheet steels with thickness $t \leq 3$ mm and gap depth d_g larger than 20 mm for a fire resistance period of 30 minutes or d_g greater than 60 mm for a fire resistance period of 60 minutes.
- Connections with glued covering strips or protective engineered wood boards and gap depth d_g or panel thickness h_p greater than 10 mm for a fire resistance period of 30 minutes, or greater than 30 mm for a fire resistance period of 60 minutes

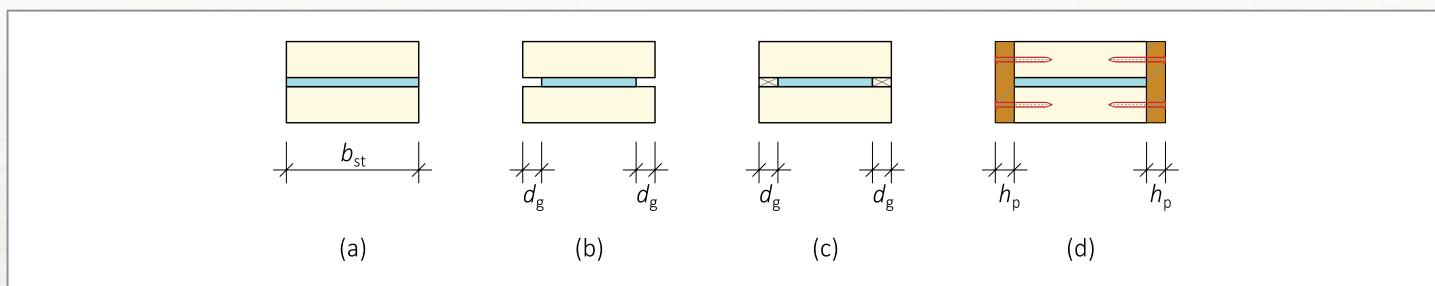


Figure 59: Protection of sheet steel edges (fasteners not shown).

(a) unprotected, (b) protected by a gap, (c) protected by glued strips, (d) protected by cladding.

4.11.4 Start of charring

For fire protection claddings consisting of one or more layers of timber or engineered wood, the period to the start of charring t_{ch} of the protected connection is determined using Eq. (4.38).

$$t_{ch} = \frac{h_p}{\beta_0} \quad (4.38)$$

Where:

h_p Thickness of the cladding; total thickness in the case of multiple layers
 β_0 One-dimensional charring rate

For single-layer claddings with gypsum board of type A, F or H in accordance with EN 520, the period to the start of charring t_{ch} outside of the joint areas or in areas with filled joints or open joints with a width ≤ 2 mm should be determined using Eq. (4.39). For areas with open joints, Eq. (4.40) is used.

For claddings consisting of two layers of gypsum boards of type A or H, the period to the start of charring should be determined by Eq. (4.38), with h_p used as the thickness of the outer layer plus 50 % of the inner layer.

For claddings consisting of two layers of type F gypsum boards, the period to the start of charring should be determined by Eq. (4.38), with h_p used as the thickness of the outer layer plus 80 % of the inner layer.

$$t_{ch} = 2,8 \cdot h_p - 14 \quad (4.39)$$

$$t_{ch} = 2,8 \cdot h_p - 23 \quad (4.40)$$

4.11.5 Charring rates

EC 5 Part 1-2 regulates the charring rates as shown in Table 49.

Table 49: Mass burning rates for different engineered wood.

Material	β_0	β_n
Softwood and beech		
Glued laminated timber (GL) with a characteristic bulk density ≥ 290 kg/m ³	0.65	0.70
Solid timber (ST/ FST) with a characteristic bulk density ≥ 290 kg/m ³	0.65	0.80
Hardwood		
Solid timber or glued laminated timber with a characteristic bulk density ≥ 290 kg/m ³	0.65	0.70
Solid timber or glued laminated timber with a characteristic bulk density ≥ 450 kg/m ³	0.50	0,55
Laminated veneer lumber (LVL)		
With a characteristic bulk density ≥ 480 kg/m ³	0.65	0.70
Boards		
Timber cladding	0.9 ^{a)}	-
Plywood (PW)	1.0 ^{a)}	-
Engineered wood board excluding plywood	0.9 ^{a)}	-
^{a)} The values are valid for a characteristic bulk density of 450 kg/m ³ and a material thickness of 20 mm. For other configurations, see EC 5 Part 1-2.		
Regulation: EC 5 Part 1-2		

4.11.6 Connections with external sheet steel

The load-bearing capacity of unprotected sheet steel should be determined in accordance with EC 3 Part 1-2. For the calculation of the section factor of the sheet plate, it can be assumed that the steel surfaces in contact with timber are not exposed to fire.

External sheet steel is considered protected if it is completely covered by a cladding made of timber or engineered wood with a minimum thickness a_{fi} as determined by Eq. (4.36), where $h_{e,fi} = 5$ min. An evaluation of Eq. (4.36) is provided in Table 50. Other fire protection measures should be assessed in accordance with EC 3 Part 1-2.

Table 50: Timber covering a_{fi} in mm for connections with external sheet steel as determined by Eq. (4.36).

t_{req}	30	60	90
Softwood and beech			
GL, $\rho_k \geq 290 \text{ kg/m}^3$	26.3	57.8	89.3
ST/FST, $\rho_k \geq 290 \text{ kg/m}^3$	30.0	66.0	102
Hardwood			
ST/FST or GL, $\rho_k \geq 290 \text{ kg/m}^3$	26.3	57.8	89.3
ST/FST or GL, $\rho_k \geq 450 \text{ kg/m}^3$	20.6	45.4	70.1
Laminated veneer lumber			
LVL, $\rho_k \geq 480 \text{ kg/m}^3$	26.3	57.8	89.3

Regulation: EC 5 Part 1-2

4.12 Slip modulus of screws subjected to shear stress

4.12.1 Slip modulus of timber-to-timber, engineered timber-to-timber and timber-to-steel connections

The mean slip modulus in the serviceability limit state $K_{SLS,v}$ can be designed for non-pre-drilled screws subjected to shear per shear plane for two timber members with the same density using Eq. (4.41) (with d in mm and ρ_{mean} in kg/m^3). For pre-drilled screws, Eq. (4.42) is applied in the same way. The slip modulus of all ASSY®plus screws should also be designed using Eq. (4.41), provided the screw is not pre-drilled.

$$K_{SLS,v} = \rho_{mean}^{1,5} \cdot \frac{d^{0,8}}{30} \text{ N/mm} \quad (4.41)$$

$$K_{SLS,v} = \rho_{mean}^{1,5} \cdot \frac{d}{23} \text{ N/mm} \quad (4.42)$$

If two connected engineered wood components have different mean bulk densities $\rho_{mean,1}$ and $\rho_{mean,2}$, ρ_{mean} should be designed using Eq. (4.43).

$$\rho_{mean} = \sqrt{\rho_{mean,1} \cdot \rho_{mean,2}} \quad (4.43)$$

For sheet timber-to-steel and concrete/wood connections where the fastener is sufficiently secured against rotation in the steel or concrete, the slip modulus $K_{SLS,v}$ determined through Eq. (4.41) and Eq. (4.42) must be doubled.

If the angle between the force direction and grain direction $\alpha = 90^\circ$, the slip modulus $K_{SLS,v}$ determined through Eq. (4.41) or Eq. (4.42) should be halved. If the force/grain angle is $0^\circ < \alpha < 90^\circ$, the slip modulus should be linearly interpolated.

4.13.1.2 Axial load-bearing capacity

To account for the rope effect, the axial load-bearing capacity of the screw must first be designed.

$$F_{ax,t,k} = \min \begin{cases} F_{w,k} = \frac{k_{ax} \cdot f_{ax,k} \cdot d \cdot l_w}{k_{\beta}} \cdot \left(\frac{\rho_k}{\rho_{ref,k}} \right)^{0,8} = \frac{1,0 \cdot 12,0 \cdot 8,0 \cdot 101}{1,0} \cdot \left(\frac{365}{350} \right)^{0,8} = 10,0 \text{ kN} \\ F_{pull,k} = f_{head,k} \cdot d_{head}^2 \cdot \left(\frac{\rho_k}{\rho_{ref,k}} \right)^{0,8} = 14 \cdot 15,0^2 \cdot \left(\frac{350}{350} \right)^{0,8} = 3,15 \text{ kN} \\ F_{t,k} = f_{tens,k} = 21,5 \text{ kN} \end{cases}$$

$$F_{ax,t,d} = \frac{k_{mod}}{\gamma_M} \cdot F_{ax,t,k} = \frac{0,8}{1,3} \cdot 3,15 \text{ kN} = 1,94 \text{ kN}$$

4.13.1.3 Shear load-bearing capacity

Effective number of fasteners

Since the fasteners are arranged offset parallel to the grain direction and the force is applied in the grain direction, Eq. (4.18), (4.19) and Table 38 are used as in Example 3: $n_{ef,1} = n_{ef,2} = 5,09$ screws

Calculation of embedment strengths

Since the connected members have different bulk densities, two embedment strengths must be determined. Although the screws have a drill tip, they are not pre-drilled. Therefore, the embedment strength must be designed for non-pre-drilled screws. The angle between the screw axis and grain direction ε is 90° .

$$f_{h,0,k,1}(C24) = \frac{0,082 \cdot \rho_k \cdot d^{-0,3}}{2,5 \cdot \cos^2 \varepsilon + \sin^2 \varepsilon} = \frac{0,082 \cdot 350 \cdot 8^{-0,3}}{2,5 \cdot \cos^2 90^\circ + \sin^2 90^\circ} = 15,4 \text{ N/mm}^2$$

$$f_{h,0,k,2}(GL 24c) = \frac{0,082 \cdot 365 \cdot 8^{-0,3}}{2,5 \cdot \cos^2 90^\circ + \sin^2 90^\circ} = 16,0 \text{ N/mm}^2$$

The ratio of the embedment strength β is determined as follows:

$$\beta = \frac{16,0}{15,4} = 1,04$$

Calculation of the load-bearing capacity in accordance with the Johansen cases

This case concerns a single-shear timber-to-timber connection. Therefore, failure cases (a) to (f) described in Section 4.3 must be taken into account. The rope effect contribution $F_{rp,k}$ must be limited for screwed connections as follows:

$$F_{rp,k} = \min \begin{cases} 1,0 \cdot F_{D,k,i} \\ 0,25 \cdot F_{ax,t,k} \end{cases}$$

The load-bearing capacities for the individual failure cases are designed as follows (the term $t_{h,2}/t_1 = 120/120 = 1.0$ is used here).

$$F_{D,k,a} = f_{h,0,k,1} \cdot t_1 \cdot d = 15,4 \cdot 120 \cdot 8 = 14,8 \text{ kN}$$

$$F_{D,k,b} = f_{h,0,k,2} \cdot t_{h,2} \cdot d = 16,0 \cdot 120 \cdot 8 = 15,4 \text{ kN}$$

$$\begin{aligned} F_{D,k,c} &= \frac{f_{h,0,k,1} \cdot t_1 \cdot d}{1 + \beta} \left[\sqrt{\beta + 2 \cdot \beta^2 \left[1 + \frac{t_{h,2}}{t_1} + \left(\frac{t_{h,2}}{t_1} \right)^2 \right] + \beta^3 \cdot \left(\frac{t_{h,2}}{t_1} \right)^2} - \beta \cdot \left(1 + \frac{t_{h,2}}{t_1} \right) \right] \\ &= \frac{15,4 \cdot 120 \cdot 8}{1 + 1,04} \left[\sqrt{1,04 + 2 \cdot 1,04^2 \left[1 + 1,0 + (1,0)^2 \right] + 1,04^3 \cdot (1,0)^2} - 1,04 \cdot (1 + 1,0) \right] \\ &= 6,24 \text{ kN} \end{aligned}$$

$$\begin{aligned} F_{D,k,d} &= 1,05 \cdot \frac{f_{h,0,k,1} \cdot t_1 \cdot d}{2 + \beta} \left[\sqrt{2 \cdot \beta \cdot (1 + \beta) + \frac{4 \cdot \beta \cdot (2 + \beta) \cdot M_{y,k}}{f_{h,0,k,1} \cdot d \cdot t_1^2}} - \beta \right] \\ &= 1,05 \cdot \frac{15,4 \cdot 120 \cdot 8}{2 + 1,04} \left[\sqrt{2 \cdot 1,04 \cdot (1 + 1,04) + \frac{4 \cdot 1,04 \cdot (2 + 1,04) \cdot 23.000}{15,4 \cdot 8 \cdot 120^2}} - 1,04 \right] \\ &= 5,41 \text{ kN} \end{aligned}$$

$$\begin{aligned} F_{D,k,e} &= 1,05 \cdot \frac{f_{h,0,k,1} \cdot t_{h,2} \cdot d}{1 + 2 \cdot \beta} \left[\sqrt{2 \cdot \beta^2 (1 + \beta) + \frac{4 \cdot \beta \cdot (1 + 2 \cdot \beta) \cdot M_{y,k}}{f_{h,0,k,1} \cdot d \cdot t_{h,2}^2}} - \beta \right] \\ &= 1,05 \cdot \frac{15,4 \cdot 120 \cdot 8}{1 + 2 \cdot 1,04} \left[\sqrt{2 \cdot 1,04^2 (1 + 1,04) + \frac{4 \cdot 1,04 \cdot (1 + 2 \cdot 1,04) \cdot 23.000}{15,4 \cdot 8 \cdot 120^2}} - 1,04 \right] \\ &= 5,53 \text{ kN} \end{aligned}$$

$$\begin{aligned} F_{D,k,f} &= 1,15 \cdot \sqrt{\frac{2 \cdot \beta}{1 + \beta}} \cdot \sqrt{2 \cdot M_{y,k} \cdot f_{h,0,k,1} \cdot d} \\ &= 1,15 \cdot \sqrt{\frac{2 \cdot 1,04}{1 + 1,04}} \cdot \sqrt{2 \cdot 23.000 \cdot 15,4 \cdot 8} \\ &= \underline{\underline{2,76 \text{ kN}}} \end{aligned}$$

The rope effect can be considered for the following failure cases by using Eq. (4.7):

- For timber-to-timber connections in failure cases (c), (d), (e), (f), (i) and (k).

Thus, the following characteristic load-bearing capacities are determined:

$$F_{v,k,a} = 14,8 \text{ kN}$$

$$F_{v,k,b} = 15,4 \text{ kN}$$

$$F_{v,k,c} = 6,24 + 0,788 = 7,03 \text{ kN}$$

$$F_{v,k,d} = 5,41 + 0,788 = 6,20 \text{ kN}$$

$$F_{v,k,e} = 5,53 + 0,788 = 6,32 \text{ kN}$$

$$F_{v,k,f} = 2,76 + 0,788 = \underline{\underline{3,55 \text{ kN}}}$$

In cases (c) to (f) with rope effect:

$$F_{rp,k} = \min \begin{cases} 1,0 \cdot F_{D,k} \\ 0,25 \cdot F_{ax,t,k} \end{cases} = \min \begin{cases} 1,0 \cdot 2,76 \\ 0,25 \cdot 3,15 \end{cases} = 0,788 \text{ kN}$$

The decisive factor for the load-bearing capacity is failure case (f) with two plastic hinges per shear plane. The design value of the load-bearing capacity per fastener and shear plane is therefore:

$$F_{v,d} = \frac{k_{mod}}{\gamma_M} \cdot F_{v,k,f} = \frac{0,8}{1,3} \cdot 3,55 = 2,18 \text{ kN}$$

The total load-bearing capacity of the connection $F_{v,Rd}$ for a shear load is therefore:

$$F_{v,Rd} = n_{ef} \cdot F_{v,d} = 5,09 \cdot 2,18 = 11,1 \text{ kN}$$

4.13.1.4 Fire design

A fire resistance of R 30 ($t_{req} = 30 \text{ min}$) is required for the connection.

The minimum edge and hole spacings given in Section 4.7.2 are used. The screw heads are screwed in flush with the surface. The simplified procedure in EC 5 Part 2 (see Section 4.11.1) can be applied.

Specifications:

Required fire resistance period t_{req}	30 min
Fire resistance period of the unprotected connection $t_{d,fi}$	15 min
Member 1, solid timber C24	
Charring rate $\beta_{n,1}$	0.8 mm/min
Member 2, glued laminated timber GL 24c	
Charring rate $\beta_{n,2}$	0.7 mm/min

The fire resistance period can be increased to up to 30 minutes using the simplified procedure by increasing the edge distances and member thicknesses by the value a_{fi} . Since timbers of different strength classes are used for the connection, the following a_{fi} values apply:

$$a_{fi,1} = \beta_{n,1} \cdot k_{flux} \cdot (t_{req} - t_{d,fi}) = 0,80 \cdot 1,5 \cdot (30 - 15) = 18 \text{ mm}$$

$$a_{fi,2} = \beta_{n,2} \cdot k_{flux} \cdot (t_{req} - t_{d,fi}) = 0,70 \cdot 1,5 \cdot (30 - 15) \approx 16 \text{ mm}$$

For member 1 or member 2, the thickness and the edge and end distances must be increased by 18 mm and 16 mm respectively. Since the edge distance $a_{4,c}$ for both members is 40 mm and therefore greater than the required minimum spacing of $3 \cdot d = 24 \text{ mm}$, an increase of $24 + 18 - 40 = 2 \text{ mm}$ in each direction is sufficient. Since the spacing a_2 with the selected value of 40 mm is also greater than the required minimum dimension of 24 mm and the block shear verifications are not decisive for the load-bearing capacity of the connection, the spacing a_2 can be reduced by $2 \cdot 2 = 4 \text{ mm}$, meaning that a timber width of 120 mm is sufficient. The load-bearing capacity for the brittle failure mechanisms must be verified again. The end distances $a_{3,t}$ must be increased as follows:

$$a_{3,t,1} = a_{3,t} + a_{fi,1} = 96 + 18 = 114 \text{ mm}$$

$$a_{3,t,2} = a_{3,t} + a_{fi,2} = 96 + 16 = 112 \text{ mm}$$

The screw can be countersunk into the timber. Alternatively, a longer screw must be selected so that the shear load capacity can be maintained. The increase in the load-bearing capacity of the cold design due to the greater embedment depth in member 1 must not be taken into account in the calculation. The thickness of member 2 does not need to be adjusted, as the screws are only partially embedded in member 2. The existing timber covering provides adequate fire protection.

This results in the connection shown in Figure 61 with increased dimensions and an adjusted ASSY®plus 4 CSMP 8.0 x 260/100.5 mm screw compared to the cold design shown in Figure 60.

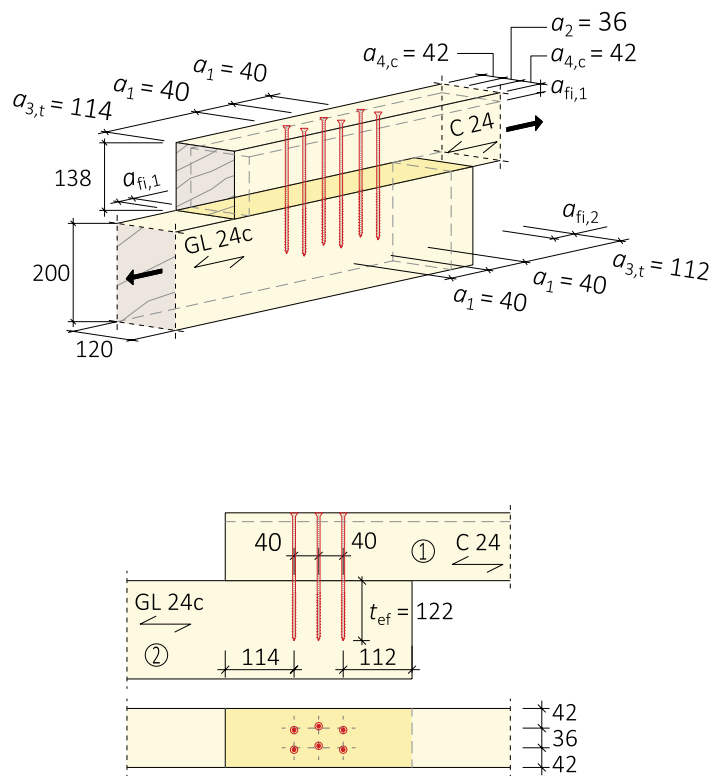


Figure 61: Calculation example – modified connection for fire design.

4.13.2 Timber-to-steel connection with laterally loaded screws

4.13.2.1 General information

This section considers the connection shown in Figure 62 to assess its load-bearing capacity with respect to shear and brittle failure in the timber. Based on the calculation example in Section 3.12.1, identical cross-sections and an approximately identical connection area have been selected.

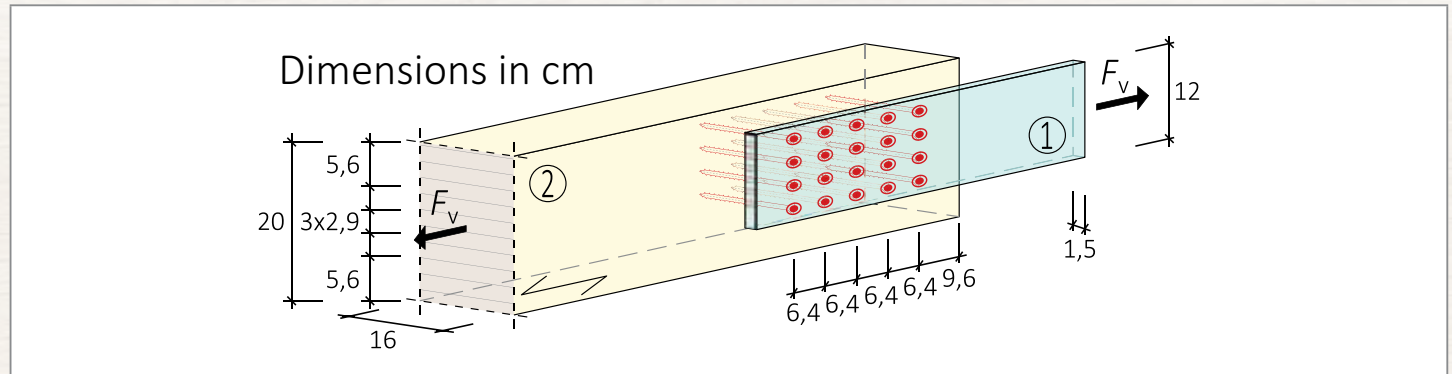


Figure 62: Calculation example – timber-to-steel connection with laterally loaded screws.

The following specifications apply:

Geometry and material

Member 1			
Material, steel grade			S235
Thickness/height	t_s/h_1	=	1.5 cm/12.0 cm
Yield strength	$f_{y,k}$	=	235 N/mm ²
Member 2			
Material, strength class			GL 28h
Thickness/height	t_2/h_2	=	16.0 cm/20 cm
Force/grain angle	α	=	0°
Raw density	ρ_k	=	425 kg/m ³
Modification factor	k_{mod}	=	0.80
Tensile strength	$f_{t,0,k}$	=	22.3 N/mm ²
Shear strength	$f_{v,k}$	=	3.5 N/mm ²
Action			
Service class	SC		1
Load duration class			Medium
Fasteners			
	ASSY®plus 4 CSMP 8.0 x 140/80.5		
Diameter	d	=	8.0 mm
Head diameter	d_{head}	=	15.0 mm
Length	l	=	140 mm
Withdrawal parameter	$f_{ax,k}$	=	12.0 N/mm ²
Tensile resistance	$f_{tens,k}$	=	21.5 kN
Partial safety factor	γ_M	=	1.3
Screw/grain angle	ε	=	90°
Spacings			
	Yes	Minimum value	
a_1	64 mm	$\geq 4 \cdot d$	✓
a_2	29 mm	$\geq 2.1 \cdot d$	✓
$a_{3,t}$	96 mm	$\geq 12 \cdot d$	✓
$a_{4,c}$	56 mm	$\geq 3 \cdot d$	✓

Note: Based on Table 42, $k_a = 0.7$ can be used for a_1 and a_2 in timber-to-steel connections. For a_1 , this results in $3.5 \cdot d$. However, spacings $a_1 < 4d$ are not permitted, since according to Table 38 (cross-reference) no k_{ef} can be determined for smaller a_1 values.

4.13.2.2 Axial load-bearing capacity

The thread dimensions of the screw and the material properties determine the characteristic axial load-bearing capacity of the screw in the timber member $F_{ax,t,k}$

Where:

$$k_{ax} = 1,0 \text{ für } 45^\circ \leq \varepsilon \leq 90^\circ$$

$$k_\beta = 1,0 \text{ für GL zu:}$$

$$F_{ax,t,k} = \min \begin{cases} F_{w,k} = \frac{k_{ax} \cdot f_{ax,k} \cdot d \cdot l_w}{k_\beta} \cdot \left(\frac{\rho_k}{\rho_a} \right)^{0,8} = \frac{1,0 \cdot 12,0 \cdot 8,0 \cdot 80,5}{1,0} \cdot \left(\frac{425}{350} \right)^{0,8} = 9,03 \text{ kN} \\ F_{t,k} = f_{tens,k} = 21,5 \text{ kN} \end{cases}$$

4.13.2.3 Shear load-bearing capacity

Calculation of embedment strengths

An embedment strength must be determined for the timber-to-steel connection. The screws have a drill tip and are screwed in without pre-drilling. Therefore, the embedment strength must be designed for non-pre-drilled screws. The screw/grain angle ε is 90° .

$$f_{h,0,k}(\text{GL 28h}) = \frac{0,082 \cdot \rho_k \cdot d^{-0,3}}{2,5 \cdot \cos^2 \varepsilon + \sin^2 \varepsilon} = \frac{0,082 \cdot 425 \cdot 8^{-0,3}}{2,5 \cdot \cos^2 90^\circ + \sin^2 90^\circ} = 18,7 \text{ N/mm}^2$$

Calculation of the load-bearing capacity in accordance with the Johansen cases

This case concerns a single-shear timber-to-steel connection with thick sheet metal. Therefore, failure cases (c), (d) and (e) as described in Section 4.3.2 must be examined (Eq. [4.5], Figure 34). The rope effect contribution $F_{rp,k}$ must be limited for screwed connections as follows:

$$F_{rp,k} = \min \begin{cases} 1,0 \cdot F_{D,k,i} \\ 0,25 \cdot F_{ax,t,k} \end{cases}$$

The load-bearing capacities of the individual failure cases can be designed as follows using $t_1 = \min(l - t_s; t_2) = 125 \text{ mm}$:

$$F_{D,k,c} = f_{h,0,k} \cdot t_1 \cdot d = 18,7 \cdot 125 \cdot 8 = 18,7 \text{ kN}$$

$$F_{D,k,d} = f_{h,0,k} \cdot t_1 \cdot d \cdot \left[\sqrt{2 + \frac{4M_{y,k}}{f_{h,0,k} \cdot d \cdot t_1^2}} - 1 \right] = 18,7 \cdot 125 \cdot 8 \cdot \left[\sqrt{2 + \frac{4 \cdot 23.000}{18,7 \cdot 8 \cdot 125^2}} - 1 \right] = 8,0 \text{ kN}$$

$$F_{D,k,e} = 2,3 \cdot \sqrt{M_{y,k} \cdot f_{h,0,k}} \cdot d = 2,3 \cdot \sqrt{23.000 \cdot 18,7 \cdot 8} = \underline{\underline{4,26 \text{ kN}}}$$

The rope effect can be considered for the following failure cases by using Eq. (4.7):

- For timber-to-steel connections in failure cases (b), (d), (e), (g), (h); this leaves (d) and (e).

The following characteristic load-bearing capacities are determined:

$$F_{v,k,c} = 18,7 \text{ kN}$$

$$F_{v,k,d} = 8,0 + 2,26 = 10,26 \text{ kN}$$

$$F_{v,k,e} = 4,26 + 2,26 = \underline{\underline{6,52 \text{ kN}}}$$

In cases (d) to (e) with rope effect:

$$F_{rp,k} = \min \begin{cases} 1,0 \cdot F_{D,k} \\ 0,25 \cdot F_{ax,t,k} \end{cases} = \min \begin{cases} 1,0 \cdot 4,26 \\ 0,25 \cdot 9,03 \end{cases} = 2,26 \text{ kN}$$

The decisive factor for the load-bearing capacity is failure case (e) with two plastic hinges per shear plane. The design value of the load-bearing capacity per fastener and shear plane is:

$$F_{v,d} = \frac{k_{mod}}{\gamma_M} \cdot F_{v,k,e} = \frac{0,8}{1,3} \cdot 6,52 = 4,01 \text{ kN}$$

The total load-bearing capacity of the connection $F_{v,Rd}$ for a shear load is determined with $a_1 = 8 \cdot d$, a non-offset arrangement and loading parallel to the grain direction (for k_{ef} see Table 38):

$n_0 = 5$	Number of fastener rows parallel to the grain direction
$n_{90} = 4$	Number of fastener rows perpendicular to the load
$n_{ef,0} = n_0^{k_{ef}} = 5^{0,75} = 3,34$	Effective number of fasteners parallel to the grain direction and load
$n_{ef} = n_{ef,0} \cdot n_{90} = 3,34 \cdot 4 = 13,4$	Effective number of screws in the connection as determined by Eq. (3.29)

Therefore:

$$F_{v,Rd} = n_{ef} \cdot F_{v,d} = 13,4 \cdot 4,01 = \underline{\underline{53,7 \text{ kN}}}$$

4.13.2.4 Block shear capacity in accordance with EC 5

Since the screws subjected to shear are located in the end grain area and subjected to stress in the direction of the end grain, brittle failure of the connection (see Section 4.8) must be taken into account.

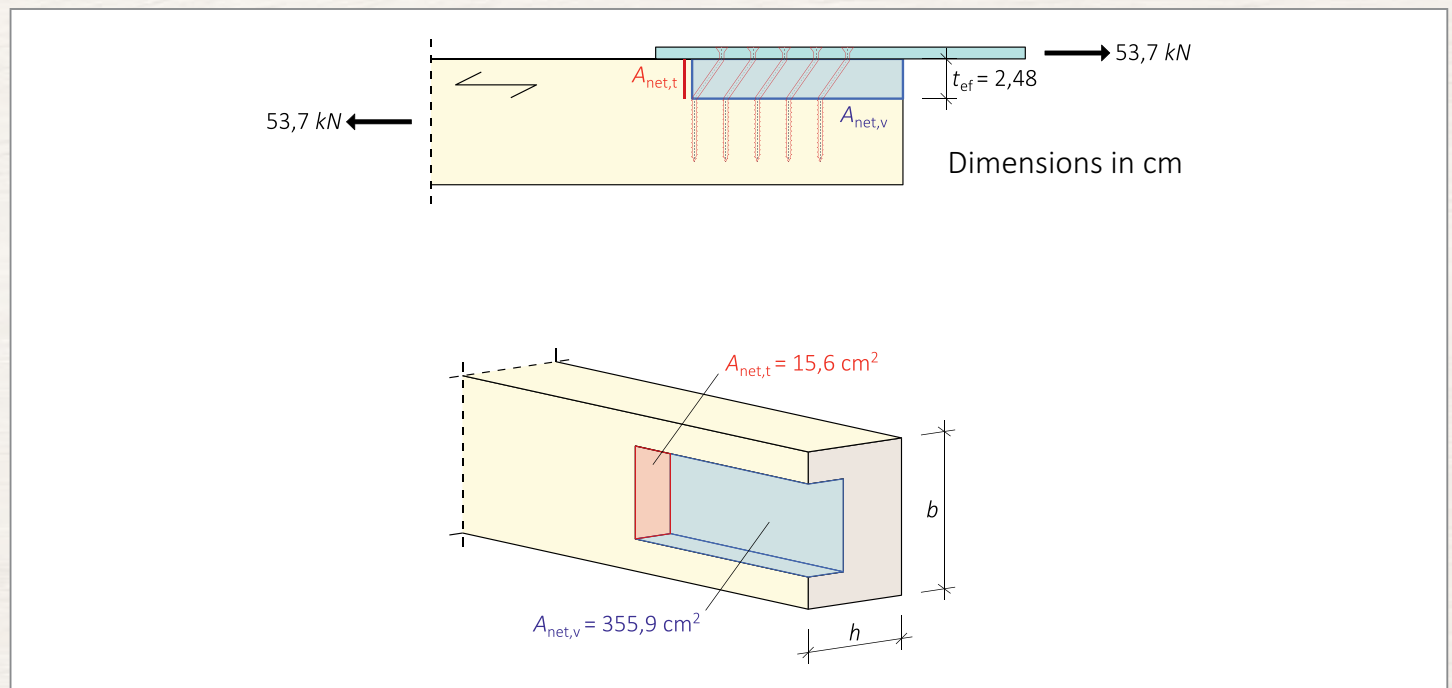


Figure 63: Calculation example - block shear failure and contributing areas.

First, the net embedment depth t_{ef} is designed as an input variable. Using case *e* as the decisive Johansen case and based on Eq. (4.29):

$$t_{ef,e} = 2 \cdot \sqrt{\frac{M_{y,k}}{f_{h,k} \cdot d}} = 2 \cdot \sqrt{\frac{23.000}{18,7 \cdot 8}} = 24,8 \text{ mm}$$

The net tensile area $A_{net,t}$ and the net shear plane $A_{net,v}$ with the required specifications:

$$l_{t,i} = a_2 - d = 21 \text{ mm} \quad \text{Partial lengths of } i \text{ lengths of the net tensile area (see Figure 56, left)}$$

$$l_{v,1/6} = a_{3,t} - \frac{d}{2} = 96 - \frac{8}{2} = 92 \text{ mm} \quad \text{Partial lengths 1 and 6 of the net shear plane (see Figure 56, left)}$$

$$l_{v,2-5,7-10} = a_1 - d = 64 - 8 = 56 \text{ mm} \quad \text{Partial lengths 2 to 5 and 7 to 10 of the net shear plane (see Figure 56, left)}$$

are designed for **Case 1**:

$$A_{\text{net},t,1} = \sum_i l_{t,i} \cdot t = (n_{90} - 1) \cdot l_{t,i} \cdot t = (4 - 1) \cdot 21 \cdot 160 = 10.080 \text{ mm}^2$$

$$A_{\text{net},v,1} = \sum_i l_{v,i} \cdot t$$

$$= (2 \cdot l_{v,1/6} + 8 \cdot l_{v,2-5,7-10}) \cdot t = (2 \cdot 92 + 8 \cdot 56) \cdot 160$$

$$= 101.120 \text{ mm}^2$$

are designed for **Case 2**:

$$A_{\text{net},t} = \sum_i l_{t,i} \cdot t_{\text{ef}} = (n_{90} - 1) \cdot l_{t,i} \cdot t_{\text{ef}} = (4 - 1) \cdot 21 \cdot 24,8 = 1.563 \text{ mm}^2$$

$$A_{\text{net},v} = \frac{\sum_i l_{v,i}}{2} \cdot \left(\sum_i l_{t,i} + 2 \cdot t_{\text{ef}} \right)$$

$$= \left(\frac{2 \cdot l_{v,1/6} + 8 \cdot l_{v,2-5,7-10}}{2} \right) \cdot (3 \cdot l_{t,i} + 2 \cdot t_{\text{ef}}) = \left(\frac{2 \cdot 92 + 8 \cdot 56}{2} \right) \cdot (3 \cdot 21 + 2 \cdot 24,8)$$

$$= 35.582 \text{ mm}^2$$

The design value of the tensile strength $f_{t,0,d}$ and the shear strength $f_{v,d}$ are:

$$f_{t,0,d} = \frac{k_{\text{mod}}}{\gamma_M} \cdot f_{t,0,k} = \frac{0,8}{1,3} \cdot 22,3 = 13,7 \text{ N/mm}^2$$

$$f_{v,d} = \frac{k_{\text{mod}}}{\gamma_M} \cdot f_{v,k} = \frac{0,8}{1,3} \cdot 3,5 = 2,15 \text{ N/mm}^2$$

The design value of the block shear capacity $F_{\text{bs,Rd}}$ is given by:

$$F_{\text{bs,ax,Rd}} = \min \left\{ \begin{array}{l} F_{\text{bs,ax,Rd},1} \\ F_{\text{bs,ax,Rd},2} \end{array} \right. = \min \left\{ \begin{array}{l} 207 \\ 53,6 \end{array} \right. = 53,6 \text{ kN}$$

$$F_{\text{bs,ax,Rd},1} = \max \left\{ \begin{array}{l} 0,7 \cdot A_{\text{net},v,1} \cdot f_{v,d} \\ 1,5 \cdot A_{\text{net},t,1} \cdot f_{t,0,d} \end{array} \right. = \max \left\{ \begin{array}{l} 0,7 \cdot 101.120 \cdot 2,15 = 152 \text{ kN} \\ 1,5 \cdot 10.080 \cdot 13,7 = 207 \text{ kN} \end{array} \right.$$

$$F_{\text{bs,ax,Rd},2} = \max \left\{ \begin{array}{l} 0,7 \cdot A_{\text{net},v,2} \cdot f_{v,d} \\ 1,5 \cdot A_{\text{net},t,2} \cdot f_{t,0,d} \end{array} \right. = \max \left\{ \begin{array}{l} 0,7 \cdot 25.582 \cdot 2,15 = 53,6 \text{ kN} \\ 1,5 \cdot 1.563 \cdot 13,7 = 32,1 \text{ kN} \end{array} \right.$$

Case 2 (failure over part of the cross-sectional height) is decisive for the block shear capacity. The design value of the load-bearing capacity $F_{\text{bs,Rd}} = 53.6 \text{ kN}$ of the block surrounded by screws in this example is greater than the design value of the shear load-bearing capacity $F_{v,Rd} = 53.7 \text{ kN}$ of the screwed connection. Consequently, for this connection (in this example), the block shear capacity and the shear load-bearing capacity are decisive, i.e. the member fails along the shear plane $A_{\text{net},v}$ as the steel plate moves due to the formation of plastic hinges in the screws.

5 COMBINED LOADS



If a connection is subjected to both axial loading and loading perpendicular to the fastener axes, thus resulting in shear force, a combined verification using Eq. (5.1) must be carried out in addition to the verifications in Sections 3 and 4.

$$\left(\frac{F_{ax,Ed}}{F_{ax,c/t,Rd}} \right)^2 + \left(\frac{F_{v,Ed}}{F_{v,Rd}} \right)^2 \leq 1,0 \quad (5.1)$$

Where:

$F_{ax,Ed}$	Design value of the axial action
$F_{ax,c/t,Rd}$	Design value of the axial load-bearing capacity in accordance with Section 3.7
$F_{v,Ed}$	Design value of the acting shear force
$F_{v,Rd}$	Design value of the shear load-bearing capacity in accordance with Section 4.6

6 TRANSVERSE TENSION REINFORCEMENT



6.1 General information

Transverse tension reinforcement with wood screws is similar to non-prestressed reinforcement in concrete. Due to the low strength of timber across the grain, which is prone to cracking, the transverse tensile strength is neglected in the design of reinforced members.

All ASSY® fully threaded screws can be used as transverse tension reinforcement in members with notches, openings or transverse connections.

In accordance with ETA-11/0190, the provisions for the reinforcement of timber members subjected to tensile stress perpendicular to the grain apply to members made of the following materials:

- Solid timber (ST/FST) made of softwood or beech, oak or ash hardwood
- Glued solid timber (GST) made of softwood or beech, oak or ash hardwood
- Glued laminated timber (GL, BGL) made of softwood or beech, oak or ash hardwood
- Laminated veneer lumber (LVL-P, GLVL-P) made of softwood or beech, excluding: Reinforcing screws embedded parallel to the face layer, i.e. with $\beta = 0^\circ$
- Cross-laminated timber (CLT) made of softwood.

According to Dietsch (2017), reinforcing screws installed at an angle $\varepsilon = 90^\circ$ over larger beam areas prevent the timber members from shrinking and swelling freely. This is known as the restraining effect and leads to cracks in the timber member, particularly in the event of shrinkage due to stresses acting perpendicular to the grain, which can reduce the load-bearing capacity. Based on these findings, the following construction recommendations according to Danzer et al. (2022) have been derived, which should be considered where possible:

- Larger spacings between the reinforcing screws
- Reduction of the height of the reinforced area in the timber member
- Inclined arrangement of the reinforcing screws at $\varepsilon \neq 90^\circ$ where possible

Generally, the following equation must be fulfilled for the transverse tension reinforcement:

$$\frac{F_{t,90,Ed}}{F_{t,90,Rd}} \leq 1,0 \quad (6.1)$$

The below equation applies to the load-bearing capacity of ASSY® fully threaded screws in accordance with EC 5 and Section 3.7.1 of this document

$$F_{t,90,Rd} = F_{ax,Rd} = n_{ef} \cdot \min \left\{ \begin{matrix} f_{ax,d} \cdot d \cdot l_{w,min} \\ f_{tens,d} \end{matrix} \right. \quad \text{mit} \quad l_{w,min} = \min \left\{ \begin{matrix} l_{w,1} \\ l_{w,2} \end{matrix} \right. \quad (6.2)$$

For all ASSY® fully threaded screws used for transverse tension reinforcement, $n_{ef} = n$ applies. For $l_{w,*}$ see Figures 65, 70, 73 and 78.

Further recommendations according to Dietsch (2019):

1. For timber members in permanently dry or frequently changing climates, fully bonded reinforcement elements are recommended (slower drying, lower stiffness ratio).
2. Members in dry environments should be dried to the equilibrium moisture content prior to installation (e.g. softwood in insulated, heated buildings: 7 % to 10 % with an annual fluctuation of ± 3 %).

Further details can be found in Dietsch (2019).

6.2 Notches

6.2.1 General information

In beams with notches, very high transverse tensile and shear stresses (stress concentrations) develop at the re-entrant corners, which can lead to failure of unreinforced beams even under low loads. The transverse tensile stresses decrease rapidly as the distance from the notch corner increases. Dietsch and Brandner (2015) therefore recommend placing reinforcements as close as possible to the notch corners. For notched beams, the effect of the stress concentration in the notch generally has to be taken into account in the verification of the load-bearing capacity. Fluctuating ambient humidity can cause additional climate-related transverse tensile stresses, which combine with the transverse tensile stresses caused by external loads. Notches without reinforcement should only be used in service classes 1 and 2. Notches in service class 3 must always be reinforced.

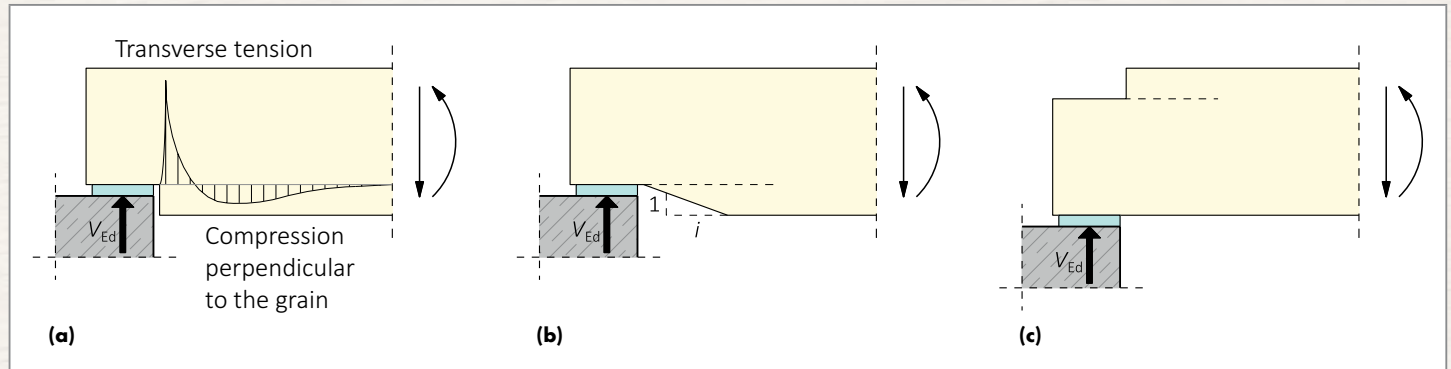


Figure 64: Types of notches.

6.2.2 Unreinforced notches

Verification of unreinforced notches using Eq. (6.60) in accordance with EC 5

$$\tau_d = 1,5 \cdot \frac{V_{Ed}}{b_{ef} \cdot h_{ef}} \leq k_{v,n} \cdot f_{v,d} \quad (6.3)$$

where $k_{v,n} = 1$ for notches of type (c) as depicted in Figure 64 and beams with compressive stresses in the notch corner. For notches of type (a) or (b) as shown in Figure 64, the following applies

$$k_{v,n} = \min \left\{ \begin{array}{l} 1 \\ \frac{k_n \left(1 + \frac{1,1 \cdot i^{1,5}}{\sqrt{h}} \right)}{\sqrt{h} \cdot \left(\sqrt{\alpha \cdot (1-\alpha)} + 0,8 \cdot \frac{x}{h} \cdot \sqrt{\frac{1}{\alpha} - \alpha^2} \right)} \end{array} \right. \quad \text{mit } k_n = \begin{cases} 4,5 & \text{für LVL}_{\text{flatwise}} \\ 5 & \text{für ST/FST, GST, LVL-P, GLVL-P} \\ 6,5 & \text{für GL/BGL} \\ 15 & \text{für LVL-C}_{\text{edgewise}}, \text{ GLVL-C}_{\text{edgewise}} \end{cases}$$

Where:

- i Inclination of the notch; see Figure 64 (b). For 90° notches: $i = 0$
- $i = \frac{l_{\text{Voute}}}{h - h_{\text{ef}}}$ where l_{Voute} is the length of the haunch
- h Height of the beam in mm
- x Distance between the line of action of the bearing force and the notch corner in mm
- $\alpha = \frac{h_{\text{ef}}}{h}$ Quotient of the residual beam height h_{ef} and the beam height h

6.2.3 Reinforcement

Notches can be reinforced with fully threaded screws arranged perpendicular or inclined to the grain (see Figure 65, [a] and [b]). A board attached to the end grain as shown in Figure 65 (c) should be verified in the same way as a notch.

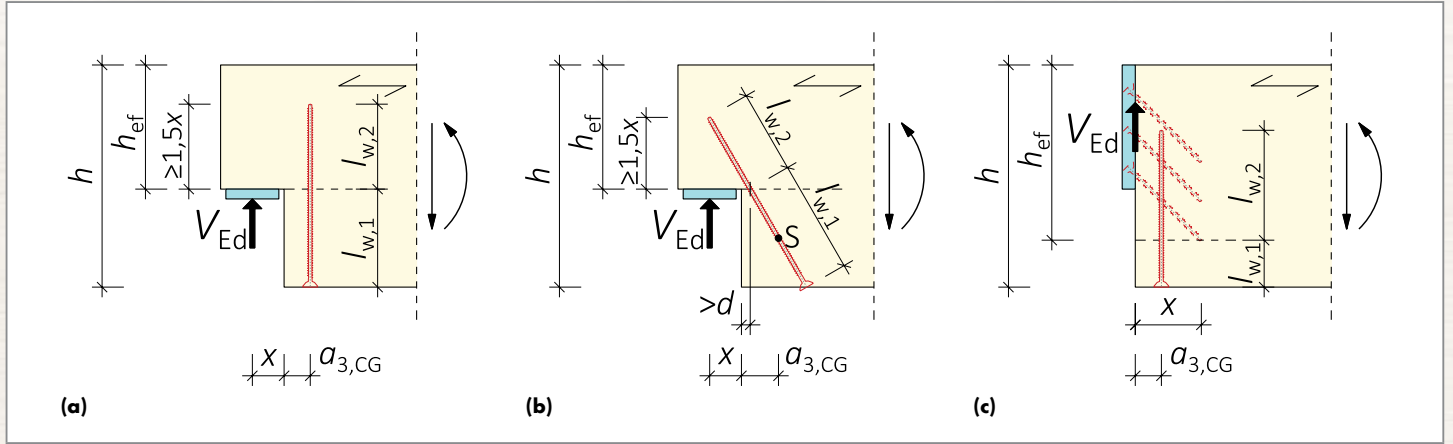


Figure 65: Notch reinforcements.

Notch reinforcements should be designed for the following tensile force action:

$$F_{t,90,Ed} = 1,3 \cdot V_{Ed} \cdot \left[3 \cdot (1-\alpha)^2 - 2 \cdot (1-\alpha)^3 \right] \quad (6.4)$$

The following equation is used for the load-bearing capacity:

$$F_{t,90,Rd} = F_{ax,t,Rd} = n \cdot F_{ax,t,d}, \text{ see Eq. (3.22) and (3.24)}$$

The following condition must be fulfilled for the reinforcement:

$$\frac{F_{t,90,Ed}}{F_{t,90,Rd}} \leq 1,0, \text{ see Eq. (6.1)}$$

Further construction and design rules:

- In the longitudinal direction of the beam, only the first screw or row of screws near the notch corner should be considered in the calculations.
- The following geometric recommendations provided in DIN 1052 and Holzbau Handbuch 2-1-2 (2016) apply:
 $\frac{h_{ef}}{h} \geq 0,5$; $\frac{x}{h} \leq 0,4$
- The reinforcing screws should be embedded such that the transverse tensile force acting upwards is anchored in the upper third of the cross-section. If the reinforcing screw ends below this limit, additional transverse tension verifications must be carried out.

Construction and design rules in accordance with Draft EC 5:

- If $l_{w,1} < h - h_{ef}$, then an additional verification is required for the unreinforced area of the notch.
- The reinforcing screws should be sufficiently embedded above the notched area $l_{w,2} \geq 1,5 \cdot x$
- The load-bearing capacity of the reinforced notch with fasteners arranged perpendicular to the grain direction is limited to twice the load-bearing capacity of the unreinforced notch (see Eq. [6.3]) $F_{t,90,Rd, \text{verstärkt}} \leq 2 \cdot F_{t,90,Rd, \text{unverstärkt}}$

6.2.4 Calculation example

6.2.4.1 General information

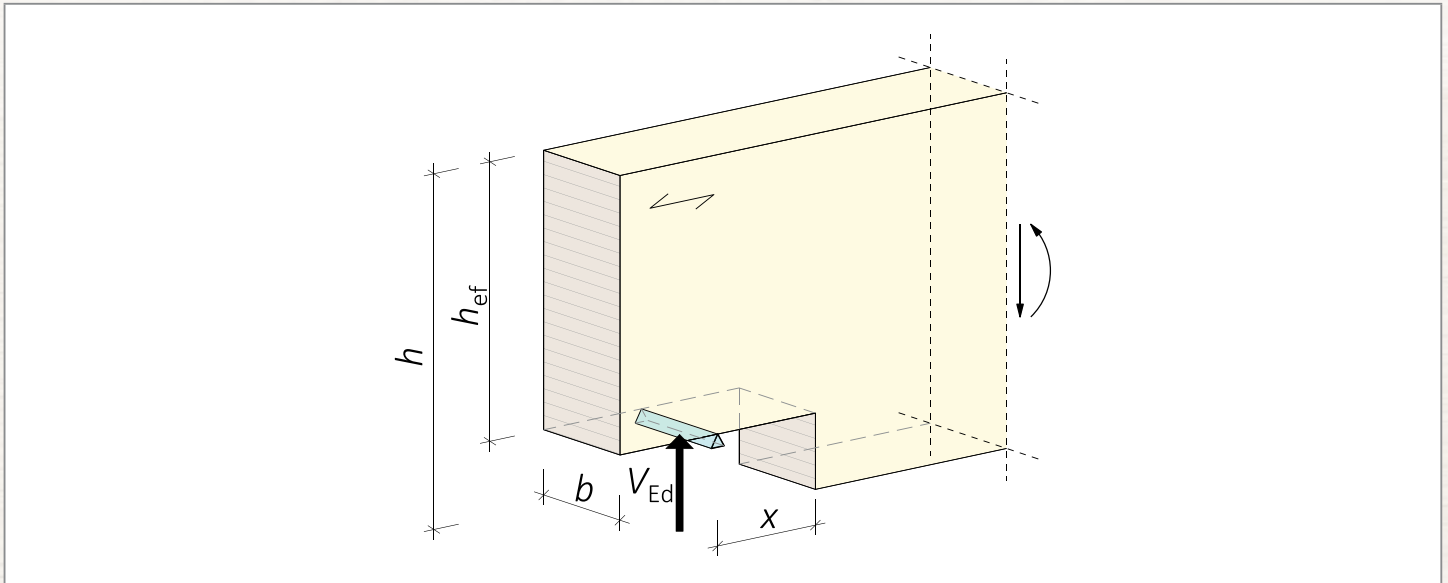


Figure 66: Calculation example – unreinforced notch.

Geometry and material

Cross-sectional width	$b = 120 \text{ mm}$
Cross-sectional height	$h = 560 \text{ mm}$
Material	GL 24c
Characteristic bulk density	$\rho_k = 365 \text{ kg/m}^3$
Characteristic value of the shear strength	$f_{v,k} = 3.50 \text{ N/mm}^2$
Design factor	$k_{cr} = 2.5/3.5$
Partial safety factor	$\gamma_M = 1.3$
Residual beam height	$h_{ef} = 440 \text{ mm}$
Support centre to notch edge	$x = 200 \text{ mm}$
Notch inclination	$i = 0 \text{ (inclination} = 90^\circ \text{)}$

Verification of the geometric recommendations:

$$\frac{h_{ef}}{h} = \frac{44}{56} = 0,79 > 0,5 \quad \checkmark$$

$$\frac{x}{h} = \frac{20}{56} = 0,36 > 0,4 \quad \checkmark$$

Action

Design load	$V_{Ed} = 46.1 \text{ kN}$
Service class	1
Load duration class	Medium
Modification factor	$k_{mod} = 0.8$

6.2.4.2 Verification of the shear stress in the residual cross-section

Where $k_{mod} = 0.8$; $\gamma_M = 1.3$ and $k_{cr} = 2.5/3.5$

$$F_{v,Rd} = \frac{k_{mod}}{\gamma_M} \cdot k_{cr} \cdot b \cdot h_{ef} \cdot \frac{f_{v,k}}{1,5} = \frac{0,8}{1,3} \cdot \frac{2,5}{3,5} \cdot 120 \cdot 440 \cdot \frac{3,5}{1,5}$$

$$F_{v,Rd} = 54,2 \text{ kN}$$

$$\eta = \frac{V_{Ed}}{F_{v,Rd}} = \frac{46,1}{54,2} = 0,85 < 1,0 \quad \checkmark$$

6.2.4.3 Verification of the unreinforced notch

$$V_{Rd} = \frac{k_{mod}}{\gamma_M} \cdot k_{cr} \cdot b \cdot h_{ef} \cdot k_{v,n} \cdot \frac{f_{v,k}}{1,5} = \frac{0,8}{1,3} \cdot \frac{2,5}{3,5} \cdot 120 \cdot 440 \cdot 0,428 \cdot \frac{3,5}{1,5} = 23,2 \text{ kN}$$

$$\eta = \frac{V_{Ed}}{V_{Rd}} = \frac{46,1}{23,2} = 1,99 > 1,0 \quad \text{⚡}$$

→ Load-bearing capacity of the residual cross-section exceeded by 99 %
→ Reinforcement required!

Where:

$$k_{v,n} = \frac{k_n \left(1 + \frac{1,1 \cdot i^{1,5}}{\sqrt{h}} \right)}{\sqrt{h} \cdot \left(\sqrt{\alpha \cdot (1 - \alpha)} + 0,8 \cdot \frac{x}{h} \cdot \sqrt{\frac{1}{\alpha} - \alpha^2} \right)} = \frac{6,5 \cdot \left(1 + \frac{1,1 \cdot 0^{1,5}}{\sqrt{560}} \right)}{\sqrt{560} \cdot \left(\sqrt{0,786 \cdot (1 - 0,786)} + 0,8 \cdot \frac{200}{560} \cdot \sqrt{\frac{1}{0,786} - 0,786^2} \right)} = 0,428$$

$$i = 0$$

$$h = 560$$

$$x = 200$$

$$\alpha = \frac{h_{ef}}{h} = \frac{440}{560} = 0,786$$

$$k_n = 6,5 \text{ (siehe Abschnitt 6.2.2)}$$

→ **The load-bearing capacity of the residual cross-section is exceeded by 99 %. Reinforcement is required.**

6.2.4.4 Verification of the reinforced notch

For the selected ASSY®plus VG 4 CH 8.0 x 420 mm fully threaded screws, the characteristic tensile resistance is $F_{t,k} = f_{tens,k} = 22 \text{ kN}$ (see Section 3.4). The characteristic pull-out resistance is designed above and below the crack plane:

$$F_{w,k} = \frac{k_{ax} \cdot f_{ax,k} \cdot d \cdot l_w}{k_{\beta}} \cdot \left(\frac{\rho_k}{\rho_{ref,k}} \right)^{0,8} \text{ (see Section 3.3)}$$

Member	1	2	
Anchorage length	$l_{w,i} = 120$	300	mm
Angle factor	$k_{ax,i} = 1,0$	$1,0$	-
Angle factor	$k_{\beta,i} = 1,0$	$1,0$	-
Characteristic bulk density	$\rho_{k,i} = 365$	365	kg/m ³
Reference bulk density	$\rho_{ref,k,i} = 350$	350	kg/m ³
Withdrawal parameter	$f_{ax,k} = 12,0$	$12,0$	N/mm ²



ASSY®plus
VG 4 CH 8.0 x 420

$$F_{w,k,1} = \frac{k_{ax,1} \cdot f_{ax,k,1} \cdot d \cdot l_{w,1}}{k_{\beta,1}} \cdot \left(\frac{\rho_{k,1}}{\rho_{ref,k,1}} \right)^{0,8} = \frac{1,0 \cdot 12,0 \cdot 8,0 \cdot 120}{1,0} \cdot \left(\frac{365}{350} \right)^{0,8} = 11,9 \text{ kN}$$

$$F_{w,k,2} = \frac{k_{ax,2} \cdot f_{ax,k,2} \cdot d \cdot l_{w,2}}{k_{\beta,2}} \cdot \left(\frac{\rho_{k,2}}{\rho_{ref,k,2}} \right)^{0,8} = \frac{1,0 \cdot 12,0 \cdot 8,0 \cdot 300}{1,0} \cdot \left(\frac{365}{350} \right)^{0,8} = 29,8 \text{ kN}$$

Characteristic load of the axial load-bearing capacity as determined by Eq. (3.18):

$$F_{ax,t,k} = \min \{ F_{w,k,1}; F_{w,k,2}; F_{t,k} \} = \min \{ 11,9; 29,8; 22,0 \} = 11,9 \text{ kN}$$

Design value of the axial load-bearing capacity as determined by Eq. (3.19):

$$F_{ax,t,d} = \min \left\{ \frac{k_{mod,1} \cdot F_{w,k,1}; k_{mod,2} \cdot F_{w,k,2}; F_{t,k}}{\gamma_M} \right\} = \min \left\{ \frac{0,8 \cdot 11,9; 0,8 \cdot 29,8; 22,0}{1,3} \right\} = 7,33 \text{ kN}$$

Forces acting on the notch:

$$F_{t,90,Ed} = 1,3 \cdot V_{Ed} \cdot \left[3 \cdot (1-\alpha)^2 - 2 \cdot (1-\alpha)^3 \right] = 1,3 \cdot 46,1 \cdot \left[3 \cdot (1-0,786)^2 - 2 \cdot (1-0,786)^3 \right] = 7,07 \text{ kN}$$

$$F_{t,90,Rd} = F_{ax,t,Rd} = n \cdot F_{ax,t,d} = 2 \cdot 7,33 = 14,7 \text{ kN} \quad \text{Berücksichtigung der Abstände!}$$

$$\begin{aligned} a_2 &\geq 2,5d \\ a_{3,CG} &\geq 5d \\ a_{4,CG} &\geq 3d \end{aligned}$$

$$\eta = \frac{F_{t,90,Ed}}{F_{t,90,Rd}} = \frac{7,07}{14,7} = 0,48 < 1,0 \quad \checkmark$$

Width and criteria verification:

$$b_{\min} = 2 \cdot a_{4,CG} + 1 \cdot a_2 = 2 \cdot 24 + 20 = 64 \text{ mm}$$

$$b_{\min} < b_{\text{ist}} \quad \checkmark$$

$$\Rightarrow a_{2,\text{gewählt}} = 60 \text{ mm}; a_{4,CG,\text{gewählt}} = 30 \text{ mm}$$

- Spacings adhered to $\checkmark$
- One row of screws $\checkmark$
- Geometric recommendations of DIN 1052 fulfilled $\checkmark$
- Reinforcing screws embedded in the top third of the cross-section $\checkmark$
- Support with reinforced notch transfers less than twice the load of the beam with an unreinforced notch $\checkmark$

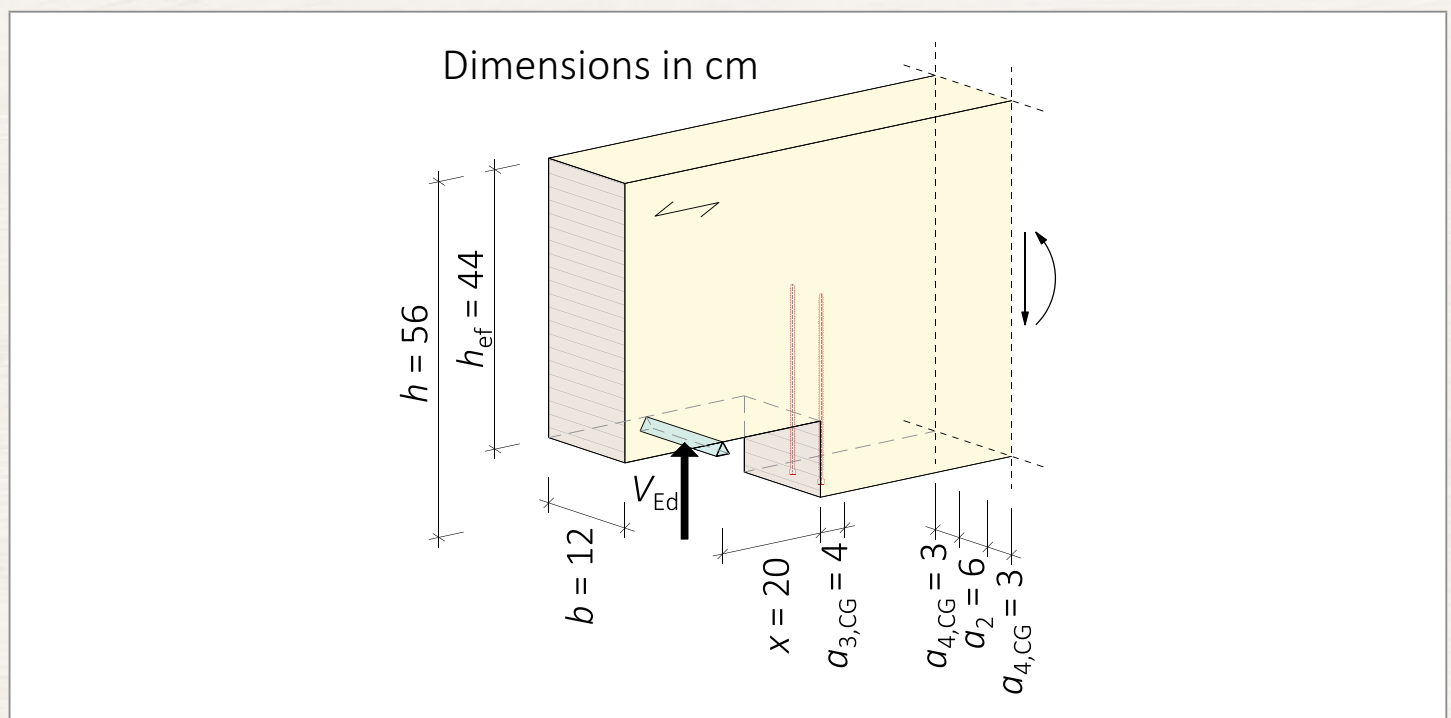


Figure 67: Calculation example – reinforced notch.

Further notes on the example:

As a precaution, fully threaded screws with length $l = h - h_{ef} + 1,5 \cdot x = 420 \text{ mm}$ were selected (recommendation from Draft EC 5: 8.3.5.2 [3]).

The embedment depth can be increased by adopting an inclined arrangement. The screws can be placed closer to the base of the notch, which reduces the restraining effect. The distance from the screw axis to the notch corner should be $> d$, see Figure 65.

6.3 Openings

Figure 68 depicts beams with openings of different shapes (circular and rectangular) and different effects of action. The dotted lines represent the brittle fractures that arise from stress redistribution. (see Figure 68 [b]). The transverse tensile force $F_{t,90,Ed}$ resulting from deflection forces consists of a shear force and moment contribution, see Eq. (6.6). Figure 68 (a) depicts fracture lines that form under high shear stresses ($F_{t,90,V,Ed} > F_{t,90,M,Ed}$). Figure 68 (c) depicts fracture lines that form under predominant bending stresses ($F_{t,90,M,Ed} >> F_{t,90,V,Ed}$). Table 51 specifies ultimate limit values for the positioning of openings. Openings in SC 3 must be reinforced. For the dimensions, refer to Figure 69.

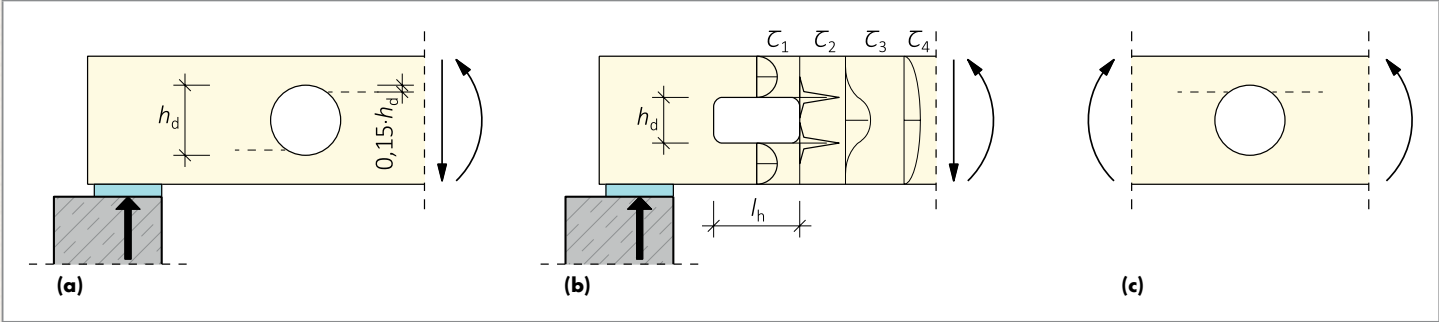


Figure 68: Unreinforced openings.

Table 51: Geometric boundary conditions for unreinforced/reinforced openings.

Boundary conditions	Unreinforced	Reinforced
Minimum spacings	$l_v \geq h$ $l_z \geq \max \begin{cases} 1,5 \cdot h \\ 300 \text{ mm} \end{cases}$ $l_A \geq h / 2$ $h_{ro(ru)} \geq 0,35 \cdot h$	$l_v \geq h$ $l_z \geq \max \begin{cases} 1,0 \cdot h \\ 300 \text{ mm} \end{cases}$ $l_A \geq h / 2$ $h_{ro(ru)} \geq 0,25 \cdot h$
Maximum dimensions	$l_h \leq 0,4 \cdot h$ $h_d \leq 0,15 \cdot h$	$l_h \leq h$ und $l_h / h_d \leq 2,5$ $h_d \leq 0,3 \cdot h$
Where:		
l_v	Length of the overhang	
l_A	Distance from the bearing force to the edge of the opening	
l_h bzw. d	Length or diameter of the opening	
l_z	Distance between two openings	
h	Cross-sectional height	
h_{ro}, h_{ru}	Height of the residual cross-section above or below the opening	
h_d	Opening height	
Regulation: EC 5		

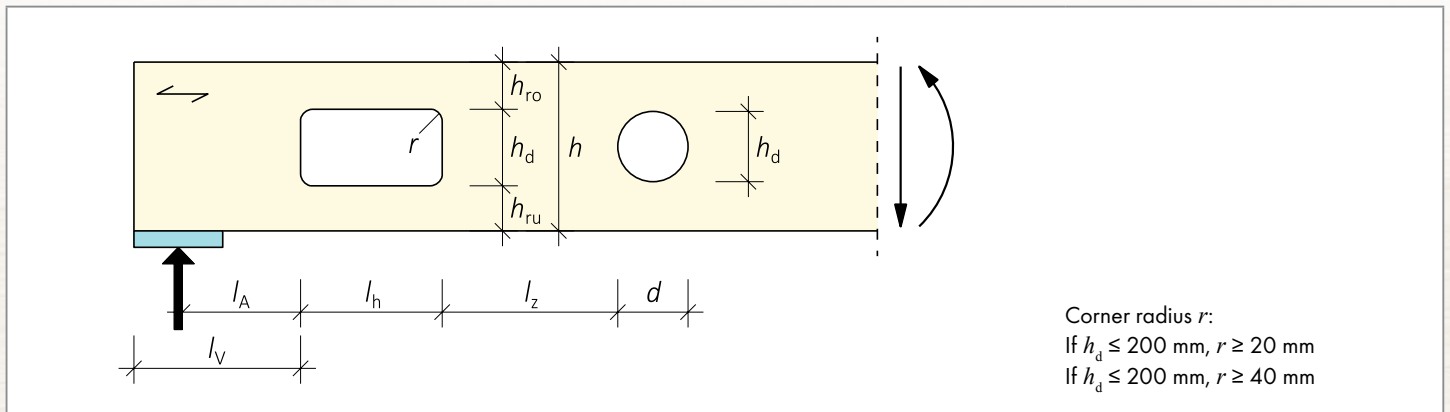


Figure 69: Definition of dimensions with an opening.

6.3.1 Verifications for unreinforced openings

For unreinforced openings, the following conditions must be met:

$$\frac{F_{t,90,Ed}}{0,5 \cdot l_{t,90} \cdot b \cdot k_{t,90} \cdot f_{t,90,d}} \leq 1,0 \quad (6.5) \text{ see EC 5, NA.6.7 (NA.63)}$$

Where:

b	Beam width at the opening
$f_{t,90,d}$	Design value of the tensile strength of GL or LVL perpendicular to the grain direction
$k_{t,90} = \min\{1; (450/h)^{0,5}\}$	h in mm
$l_{t,90} = 0,5 \cdot (h_d + h)$	Distribution length for rectangular openings
$l_{t,90} = 0,353 \cdot h_d + 0,5 \cdot h$	Distribution length for circular openings

For the design value of the force components generating transverse tension, the following equations are used:

$$F_{t,90,Ed} = F_{t,90,V,Ed} + F_{t,90,M,Ed} \quad (6.6) \text{ see EC 5, NA.6.7 (NA.66)}$$

$$F_{t,90,V,Ed} = \frac{V_{Ed} \cdot h_d \cdot k_o}{4 \cdot h} \cdot \left(3 - \frac{(h_d \cdot k_o)^2}{h^2} \right) \quad (6.7) \text{ see EC 5, NA.6.7 (NA.67)}$$

$$F_{t,90,M,Ed} = 0,008 \cdot \frac{M_{Ed}}{h_r} \quad (6.8) \text{ see EC 5, NA.6.7 (NA.68)}$$

Where:

$F_{t,90,V,Ed}$	Acting shear force created by shear stresses at the opening
$F_{t,90,M,Ed}$	Acting shear force created by bending stresses at the opening
V_{Ed}	Design value of the acting shear force
M_{Ed}	Design value of the acting bending moment
h	Cross-sectional height
h_d	Opening height
h_r	Height of the residual cross-section above or below the opening (for circular + $0,15h_d$, see Section 6.3.3)
k_o	Form factor 1.0 for rectangular, 0.7 for circular openings

6.3.2 Verifications for reinforced openings

$$\frac{F_{t,90,Ed}}{F_{t,90,Rd}} \leq 1,0$$

, see Eq. (6.1)

Where:

$$F_{t,90,Rd} = F_{ax,t,Rd} = n \cdot F_{ax,t,d}, \text{ see Eq. (3.22) and (3.24)}$$

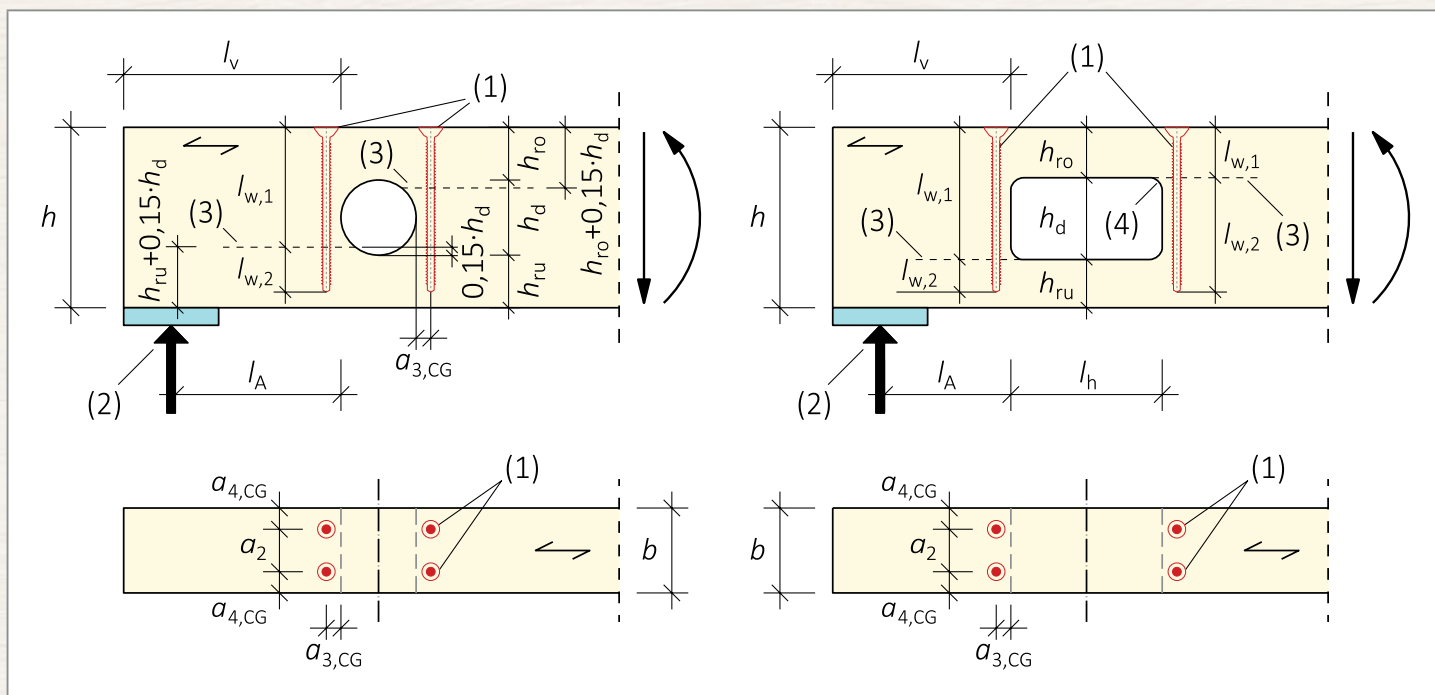


Figure 70: Reinforced openings. (1) reinforcing screws, (2) bearing force, (3) fracture line, (4) corner radius.

6.3.3 Calculation example

The load-bearing capacity of an opening can be designed using the **opening module**.

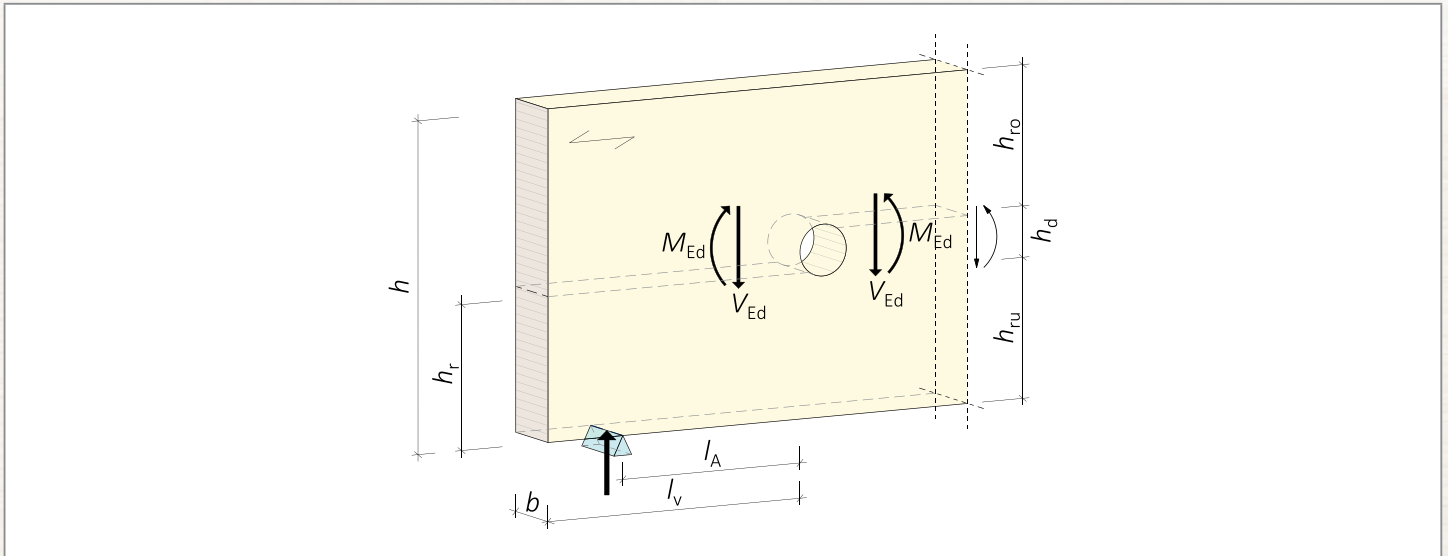


Figure 71: Calculation example - unreinforced opening.

Geometry, material and load

Cross-sectional width	b	= 160 mm
Cross-sectional height	h	= 800 mm
Material		GL 28c
Characteristic bulk density	ρ_k	= 390 kg/m ³
Characteristic value of the shear strength	$f_{v,k}$	= 3.50 N/mm ²
Design factor	k_{cr}	= 2.5/3.5
Partial safety factor	γ_M	= 1.3
Edge distance	l_v	= 850 mm
Opening distance	l_z	= 825 mm
Support distance	l_A	= 600 mm
Residual height above/below	$h_{ro/ru}$	= 312.5 mm
Opening diameter	d	= 175 mm
Design value of the acting shear force	V_{Ed}	= 45 kN
Design value of the acting bending moment	M_{Ed}	= 100 kNm
Service class		2
Load duration class		Permanent
Modification factor	k_{mod}	= 0.6

Verification of geometric boundary conditions (BC):

- $l_v = 850 \text{ mm} > h = 800 \text{ mm}$ ✓
- $l_z = 825 \text{ mm} < 1,5 \cdot h = 1200 \text{ mm}$ ✗
- $l_A = 600 \text{ mm} > h / 2 = 400 \text{ mm}$ ✓
- $l_{ro(ru)} = 312 \text{ mm} > 0,35 \cdot h = 280 \text{ mm}$ ✓
- $l_h = 175 \text{ mm} < 0,4 \cdot h = 320 \text{ mm}$ ✓
- $h_d = 175 \text{ mm} > 0,15 \cdot h = 120 \text{ mm}$ ✗

→ **Reinforcement required!**

Verification of geometric boundary conditions (BC) (reinforced):

- $l_h / h = 0,219 < 1,0$ ✓
- $h_d / h = 0,153 < 0,3$ ✓

Determination of the action

$$h_r = \min\{h_{ro}; h_{ru}\} + 0,15h_d = 339 \text{ mm}$$

$$F_{t,90,V,Ed} = \frac{V_{Ed} \cdot h_d \cdot k_o}{4 \cdot h} \cdot \left(3 - \frac{(h_d \cdot k_o)^2}{h^2}\right) = \frac{45 \cdot 123}{4 \cdot 800} \cdot \left(3 - \frac{123^2}{800^2}\right) = 5,13 \text{ kN}$$

$$F_{t,90,M,Ed} = 0,008 \cdot \frac{M_{Ed}}{h_r} = 0,008 \cdot \frac{100}{0,339} = 2,36 \text{ kN}$$

$$F_{t,90,Ed} = F_{t,90,V,Ed} + F_{t,90,M,Ed} = 5,13 + 2,36 = 7,49 \text{ kN}$$

Determination of the axial load-bearing capacity

For the selected ASSY®plus VG 4 CSMP 8.0 x 450 mm fully threaded screws, the characteristic tensile resistance is $F_{t,k} = f_{tens,k} = 22 \text{ kN}$ (see Section 3.4).

The characteristic pull-out resistance is designed above and below the crack plane:

$$F_{w,k} = \frac{k_{ax} \cdot f_{ax,k} \cdot d \cdot l_w}{k_{\beta}} \cdot \left(\frac{\rho_k}{\rho_{ref,k}}\right)^{0,8} \quad (\text{see Section 3.3})$$

Area		1	2	
Thread length	$l_{w,i}$	= 339	111	mm
Angle factor	$k_{ax,i}$	= 1.0	1.0	-
Angle factor	$k_{\beta,i}$	= 1.0	1.0	-
Characteristic bulk density	$\rho_{k,i}$	= 390	390	kg/m ³
Reference bulk density	$\rho_{ref,k,i}$	= 350	350	kg/m ³
Withdrawal parameter	$f_{ax,k}$	= 12.0	12.0	N/mm ²



2 x 2 ASSY®plus
VG 4 CSMP 8.0 x 450

$$F_{w,k,1} = \frac{k_{ax,1} \cdot f_{ax,k,1} \cdot d \cdot l_{w,1}}{k_{\beta,1}} \cdot \left(\frac{\rho_{k,1}}{\rho_{ref,k,1}}\right)^{0,8} = \frac{1,0 \cdot 12,0 \cdot 8,0 \cdot 339}{1,0} \cdot \left(\frac{390}{350}\right)^{0,8} = 35,5 \text{ kN}$$

$$F_{w,k,2} = \frac{k_{ax,2} \cdot f_{ax,k,2} \cdot d \cdot l_{w,2}}{k_{\beta,2}} \cdot \left(\frac{\rho_{k,2}}{\rho_{ref,k,2}}\right)^{0,8} = \frac{1,0 \cdot 12,0 \cdot 8,0 \cdot 111}{1,0} \cdot \left(\frac{390}{350}\right)^{0,8} = 11,6 \text{ kN}$$

The characteristic load-bearing capacity as determined by Eq. (3.18)

$$F_{ax,t,k} = \min\{F_{w,k,1}; F_{w,k,2}; F_{t,k}\} = \min\{35,5; 11,6; 22,0\} = 11,6 \text{ kN}$$

The design value of the load-bearing capacity as determined by Eq. (3.19)

$$F_{ax,t,d} = \min\left\{\frac{k_{mod,1} \cdot F_{w,k,1}}{\gamma_M}; \frac{k_{mod,2} \cdot F_{w,k,2}}{\gamma_M}; \frac{F_{t,k}}{\gamma_M}\right\} = \min\left\{\frac{0,6 \cdot 35,5}{1,3}; \frac{0,6 \cdot 11,6}{1,3}; \frac{22,0}{1,3}\right\} = 5,35 \text{ kN}$$

Verification for one side of the reinforced opening

$$\eta = \frac{F_{t,90,Ed}}{n \cdot F_{ax,t,d}} = \frac{7,49}{2 \cdot 5,35} = 0,70 < 1,0 \quad \checkmark$$

Verification of increased shear stresses in the at-risk areas

$$\tau_{max} = \kappa_{max} \cdot \frac{1,5 \cdot V_{Ed}}{k_{cr} \cdot b \cdot (h - h_d)} = 1,54 \cdot \frac{1,5 \cdot 45 \cdot 10^3}{2,5/3,5 \cdot 160 \cdot (800 - 175)} = 1,46 \text{ N/mm}^2$$

6.3.4 Design variants

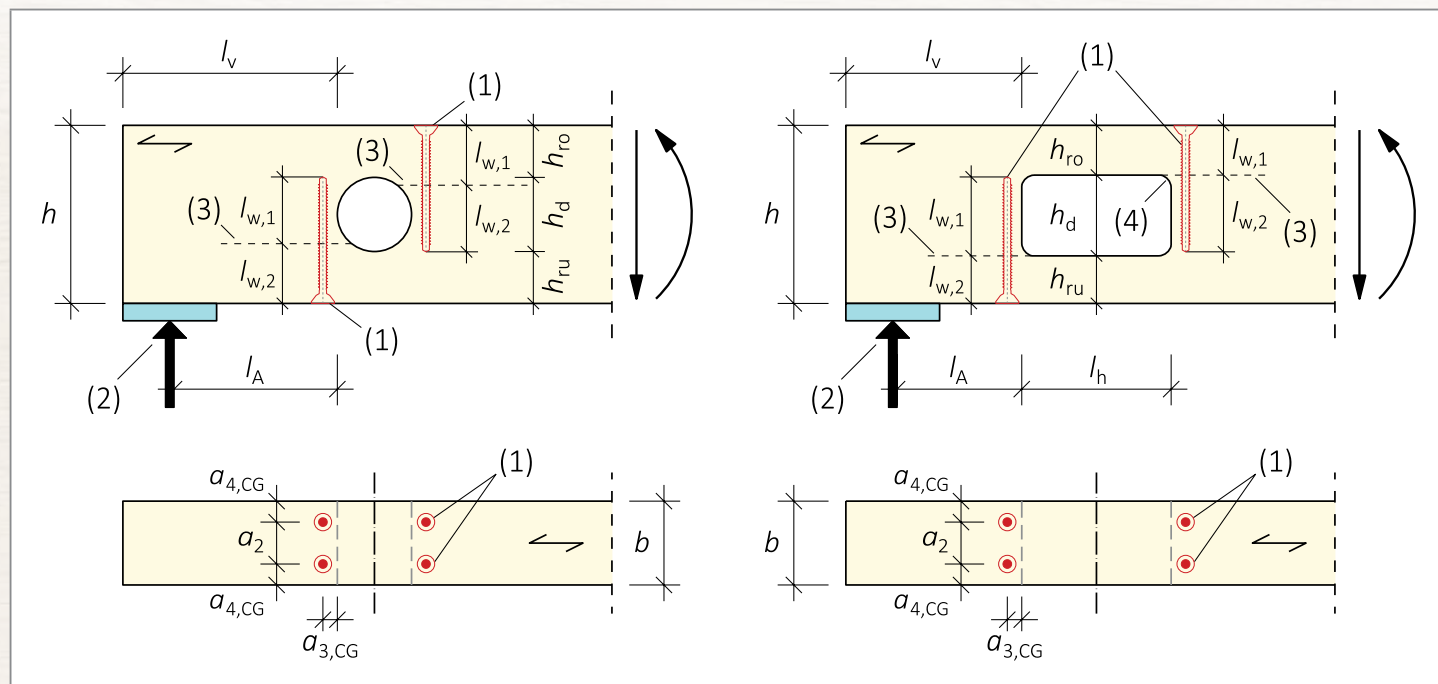


Figure 73: Other possible reinforcing screw arrangements. (1) reinforcing screws, (2) bearing force, (3) fracture line, (4) corner radius.

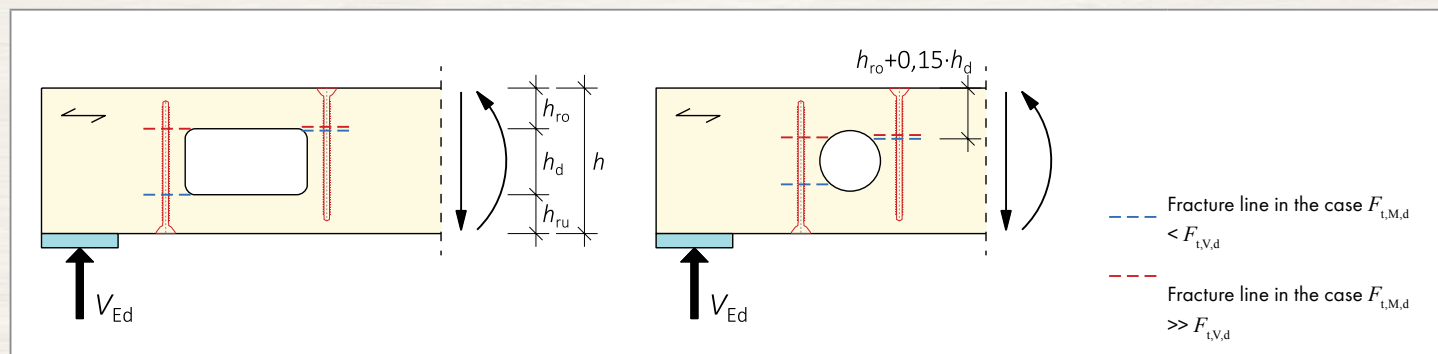


Figure 74: Location of the potential crack plane.

6.4 Transverse connections

The load-bearing capacity of unreinforced transverse connections is generally determined by the load-bearing capacity of the fasteners used. This load-bearing capacity may be limited by the transverse tensile stresses occurring in these connections.

6.4.1 Verification for unreinforced transverse connections

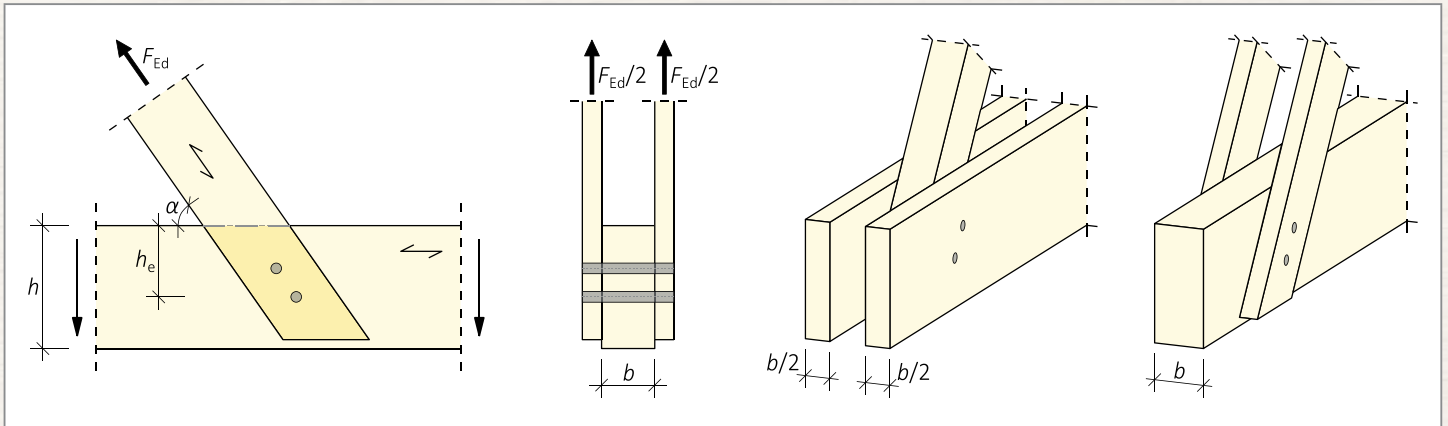


Figure 75: Transverse connection with a fastener gap ($n_0 = 1$; in accordance with EC 5).

$$\frac{F_{90,Ed}}{F_{90,Rd}} \leq 1,0 \quad (6.9) \text{ see EC 5, (8.2)}$$

Where:

$$F_{90,Ed} = F_{Ed} \cdot \sin \alpha$$

$$F_{90,Rd} = \frac{k_{mod}}{\gamma_M} 14 \cdot b \cdot w \cdot \sqrt{\frac{h_e}{\left(1 - \frac{h_e}{h}\right)}} \quad (6.10) \text{ see EC 5, (8.4)}$$

$$w = \begin{cases} \max \left\{ \left(\frac{w_{pl}}{100} \right)^{0,35} \right. & \text{für Nagelplatten} \\ 1 & \text{für alle anderen Verbindungen} \end{cases}$$

w_{pl} Width of the nail plate parallel to the grain direction in mm

6.4.2 Transverse connection with multiple fastener gaps

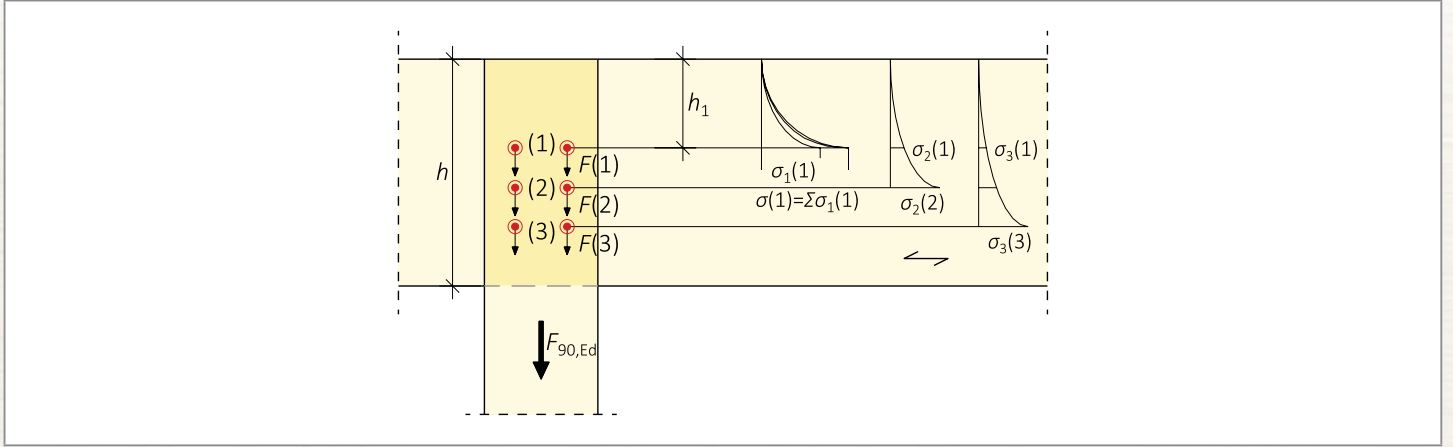


Figure 76: Transverse connection with multiple fastener gaps ($n_0 = 2$; in accordance with EC 5, NCI to 8.1.4).

The shorter the distance h_1 of the uppermost fastener row from the unloaded edge, the lower the risk of transverse tensile failure. Therefore, the decisive factor for verifying the transverse tensile stresses is always the fastener row with the greatest distance from the loaded beam edge h_e , since the sum of the stress contributions from all fastener rows is at the maximum at this location.

General conditions

- $h_e / h \geq 0,7 \rightarrow$ No further transverse tensile verification required
- $h_e / h < 0,7 \rightarrow$ Transverse tensile verification required

Further conditions

- $h_e / h < 0,2 \rightarrow$ Only permitted for loads of load duration classes (LDC) "short" or "very short"
- $a_r / h > 1,0 \rightarrow$ Transverse tensile reinforcement required
- $F_{90,Ed} > 0,5 \cdot F_{90,Rd} \rightarrow$ Transverse tensile reinforcement required
- Clear spacing between the fastener groups $l_g \geq 2h$
 $\rightarrow$ Load-bearing capacity $F_{90,Rd}$ can be determined separately for each fastener group
- Clear spacing between the fastener groups $l_g \leq 0,5h$
 $\rightarrow$ The fasteners in these groups should be considered as a single fastener group
- Clear spacing between the fastener groups $0,5h < l_g < 2h$
 $\rightarrow$ Load-bearing capacity $F_{90,Rd}$ per fastener group should be reduced by the factor k_g
where $k_g = \left(\frac{l_g}{4h} + 0,5 \right)$
- More than two fastener groups placed side by side where $l_g < 2h$ and $F_{90,Ed} \geq 0,5 \cdot k_g \cdot F_{90,Rd}$
 $\rightarrow$ Transverse tensile reinforcement required

$$\frac{F_{90,Ed}}{F_{90,Rd}} \leq 1,0 \quad (6.11) \text{ see EC 5, NCI to 8.1.4, (NA.103)}$$

Where:

$$F_{90,Ed} = F_{Ed} \cdot \sin \alpha$$

$$F_{90,Rd} = \frac{k_{mod}}{\gamma_M} \cdot k_s \cdot k_r \cdot \left(6,5 + \frac{18 \cdot h_e^2}{h^2} \right) \cdot (t_{ef} \cdot h)^{0,8} \cdot f_{t,90,k} \quad (6.12) \text{ see EC 5, NCI to 8.1.4, (NA.104)}$$

$$k_s = \max \left\{ \begin{array}{l} 1 \\ 0,7 + \frac{1,4 \cdot a_r}{h} \end{array} \right. \quad \text{Factor to account for multiple fasteners arranged side by side.}$$

$$k_r = \frac{n_{90}}{\sum_{i=1}^{n_{90}} \left(\frac{h_1}{h_i} \right)^2}$$

Factor to account for multiple fasteners arranged one above the other
For connections with axially loaded wood screws (or other internal, axially loaded profiled rods), the following applies:

$$k_r = \frac{h}{h_1}$$

n_{90}

Number of fasteners perpendicular to the grain direction (for the member subjected to transverse tension)

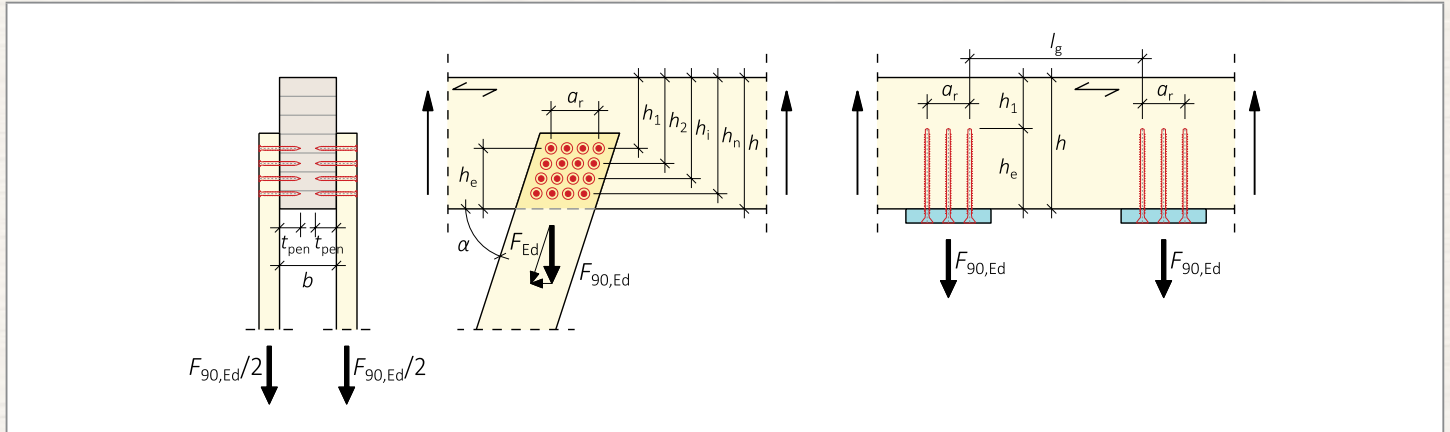


Figure 77: Transverse connection with multiple fasteners and a beam with two transverse connections.

Table 52: Effective embedment depth t_{ef} for **double-sided or central** transverse connections.

$t_{ef} = \min\{b; 2t_{pen}; 24d\}$	For timber-to-timber or engineered timber-to-timber connections with nails or wood screws
$t_{ef} = \min\{b; 2t_{pen}; 30d\}$	For sheet timber-to-steel nail connections
$t_{ef} = \min\{b; 2t_{pen}; 12d\}$	For dowel and bolted connections
$t_{ef} = \min\{b; 100 \text{ mm}\}$	For connections with special dowel types
$t_{ef} = \min\{b; 6d\}$	For connections with axially loaded wood screws
Regulation: EC 5	

Table 53: Effective embedment depth t_{ef} for **single-sided** transverse connections.

$t_{ef} = \min\{b; 2t_{pen}; 12d\}$	For timber-to-timber or engineered timber-to-timber connections with nails or wood screws
$t_{ef} = \min\{b; 2t_{pen}; 15d\}$	For sheet timber-to-steel nail connections
$t_{ef} = \min\{b; 2t_{pen}; 6d\}$	For dowel and bolted connections
$t_{ef} = \min\{b; 50 \text{ mm}\}$	For connections with special dowel types
Regulation: EC 5	

6.4.3 Reinforcement of transverse connections with fully threaded screws

General information for the design of the transverse tension reinforcement:

- The tensile strength of the timber is not considered when determining the load on the reinforcement.
- The reinforcing screws should be embedded such that the transverse tensile force acting upwards is anchored in the upper third of the cross-section. If the reinforcing screws end below this limit, additional transverse tension verifications must be carried out.

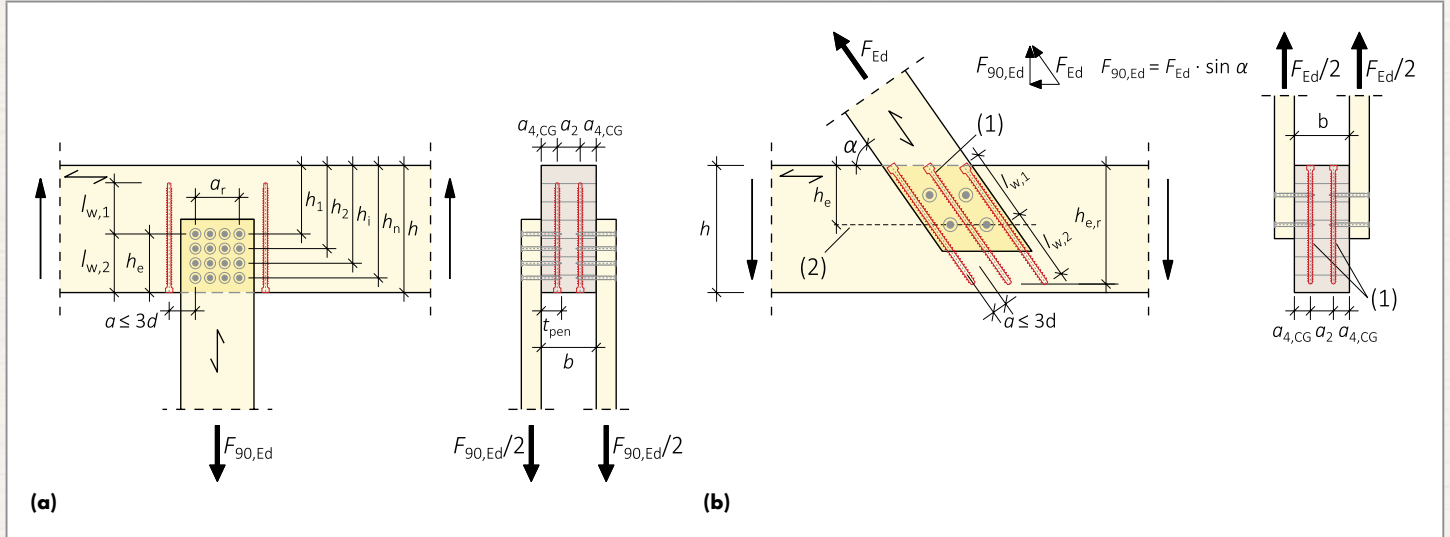


Figure 78: Transverse connection with reinforcement with load acting downwards (a) or upwards (b).

(1) reinforcing screw, (2) fracture line.

For the design value of the force components generating transverse tension, the following equations are used:

$$F_{t,90,Ed} = [1 - 3 \cdot \alpha^2 + 2 \cdot \alpha^3] \cdot F_{90,Ed} \quad (6.13)$$

Where:

α Ratio h_e / h

$F_{90,Ed}$ Design value of the tensile action effect perpendicular to the grain direction

The following equation is used for the verification of the reinforcement of the transverse connection:

$$\frac{F_{t,90,Ed}}{F_{t,90,Rd}} \leq 1,0 \text{ see Eq. (6.1)}$$

Where:

$$F_{t,90,Rd} = n \cdot F_{ax,Rd}$$

$F_{ax,Rd}$ Design value of the axial load-bearing capacity, see Eq. (3.22)

6.4.4 Calculation example

The load-bearing capacity of a transverse connection can be designed using the **transverse connection module**.

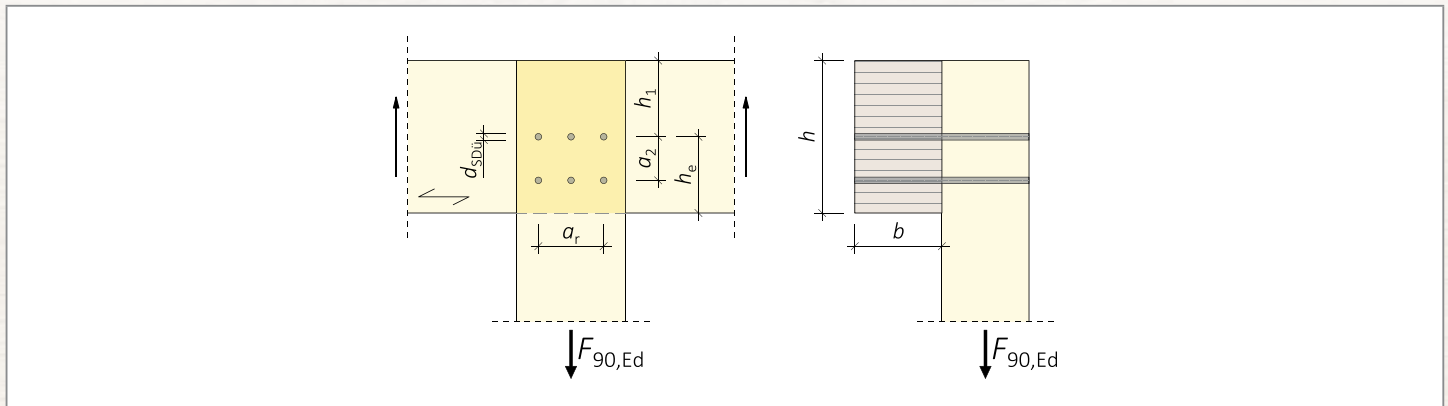


Figure 79: Calculation example – unreinforced transverse connection.

- **Connection: 2 x 3 dowel $d_{SDü} = 12$ mm**
- **90° screws as reinforcement**

Geometry and material

Cross-sectional width	b	= 160 mm
Cross-sectional height	h	= 280 mm
Material		GL 24c
Characteristic bulk density	ρ_k	= 365 kg/m ³
Characteristic transverse tensile strength	$f_{t,90k}$	= 0.50 N/mm ²
Partial safety factor	γ_M	= 1.3
Diameter of the dowel connection	$d_{SDü}$	= 12 mm
Embedment depth of the dowel connection	$t_{SDü}$	= 160 mm
Distance between the top dowel row and the top edge $h_1 = h - h_e$	h_1	= 140 mm
Number of vertical dowel rows	n_{90}	= 2
Distance between the top dowel row and the bottom edge	h_e	= 140 mm
Width of the transverse connection	a_r	= 120 mm
Distance between the bottom dowel row and the top edge	h_2	= 220 mm

Action:

Design load	$F_{90,Ed}$	= 33.9 kN
Service class		1
Load duration class		Medium
Modification factor	k_{mod}	= 0.8

Verification of the geometric boundary conditions:

- $h_e / h = 0,5 < 0,7$ → Unreinforced verification required
- $h_e / h = 0,5 > 0,2$ → LCD "short" or "very short" not required
- $a_r / h = 0,43 < 1,0$ → Reinforcement not required

Load-bearing capacity of the unreinforced connection:

$$F_{90,Rd} = \frac{k_{mod}}{\gamma_M} \cdot k_s \cdot k_r \cdot \left(6,5 + \frac{18 \cdot h_e^2}{h^2} \right) \cdot (t_{ef} \cdot h)^{0,8} \cdot f_{t,90,k}$$

Where:

$$k_s = \max \left\{ 1, 0,7 + \frac{1,4 \cdot a_r}{h} \right\} = \max \left\{ 1, 0,7 + \frac{1,4 \cdot 120}{280} \right\} = 1,3$$

$$k_r = \frac{n_{90}}{\sum_{i=1}^{n_{90}} \left(\frac{h_i}{h} \right)^2} = \frac{2}{1^2 + \left(\frac{140}{220} \right)^2} = 1,42$$

$$t_{ef} = \min \left\{ \frac{b}{t_{VM}}, \frac{b}{6 \cdot d_{VM}} \right\} = \min \left\{ \frac{160}{160}, \frac{160}{6 \cdot 12} \right\} = 72 \text{ mm}$$

$$F_{90,Rd} = \frac{0,8}{1,3} \cdot 1,3 \cdot 1,42 \cdot \left(6,5 + \frac{18 \cdot 140^2}{280^2} \right) \cdot (72 \cdot 280)^{0,8} \cdot 0,5 = 17,4 \text{ kN}$$

Verification

$$\frac{F_{90,Ed}}{F_{90,Rd}} = \frac{33,9}{17,4} = 1,95 > 1,0 \quad \rightarrow \text{Transverse tensile reinforcement required}$$

Load-bearing capacity of the reinforced connection:

Design value of the action on the transverse tensile reinforcement

$$F_{t,90,Ed} = \left[1 - 3 \cdot \left(\frac{h_e}{h} \right)^2 + 2 \cdot \left(\frac{h_e}{h} \right)^3 \right] \cdot F_{90,Ed} = \left[1 - 3 \cdot \left(\frac{140}{280} \right)^2 + 2 \cdot \left(\frac{140}{280} \right)^3 \right] \cdot 33,9 = 17,0 \text{ kN}$$

Based on Eq. (3.18) and (3.19) and the selected ASSY®plus VG 4 CH 6.0 x 240 mm fully threaded screws, the following must be designed for the reinforcement above and below the crack plane:

Characteristic tensile resistance

$$F_{t,k} = f_{tens,k} = 12,5 \text{ kN} \quad (\text{see Section 3.4})$$



2 x 2 ASSY®plus
VG 4 CH 6.0 x 240

Characteristic pull-out resistance

$$F_{w,k} = \frac{k_{ax} \cdot f_{ax,k} \cdot d \cdot l_w}{k_{\beta}} \cdot \left(\frac{\rho_k}{\rho_{ref,k}} \right)^{0,8} \quad (\text{see Section 3.3}):$$

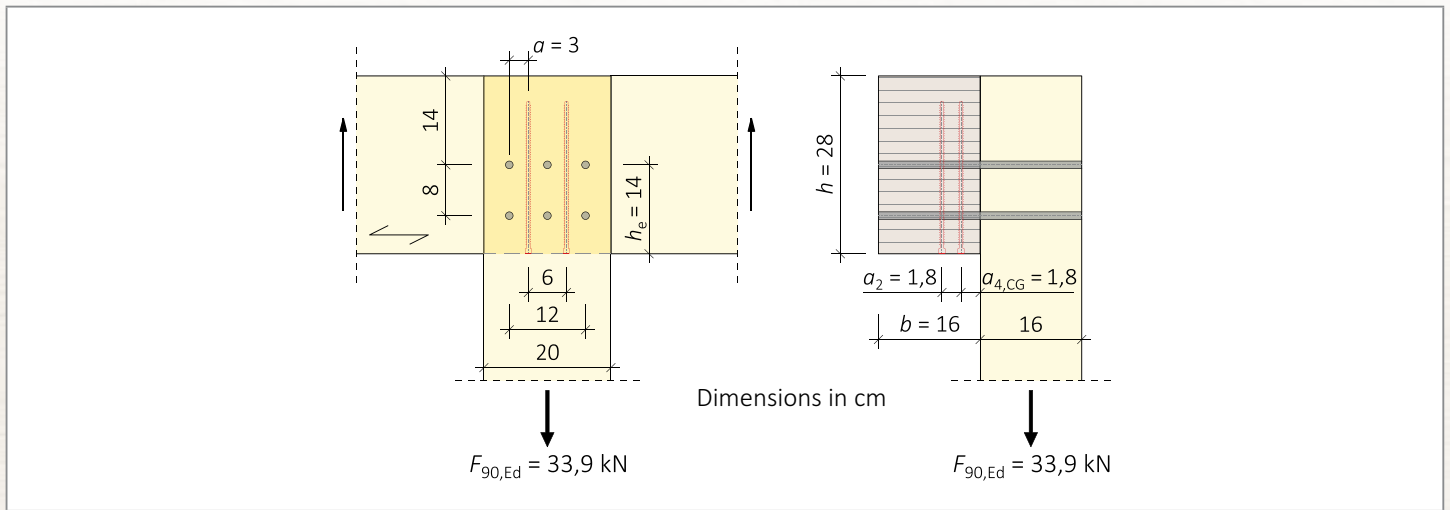


Figure 81: Calculation example – transverse connection with four fully threaded screws at the point of crack development.

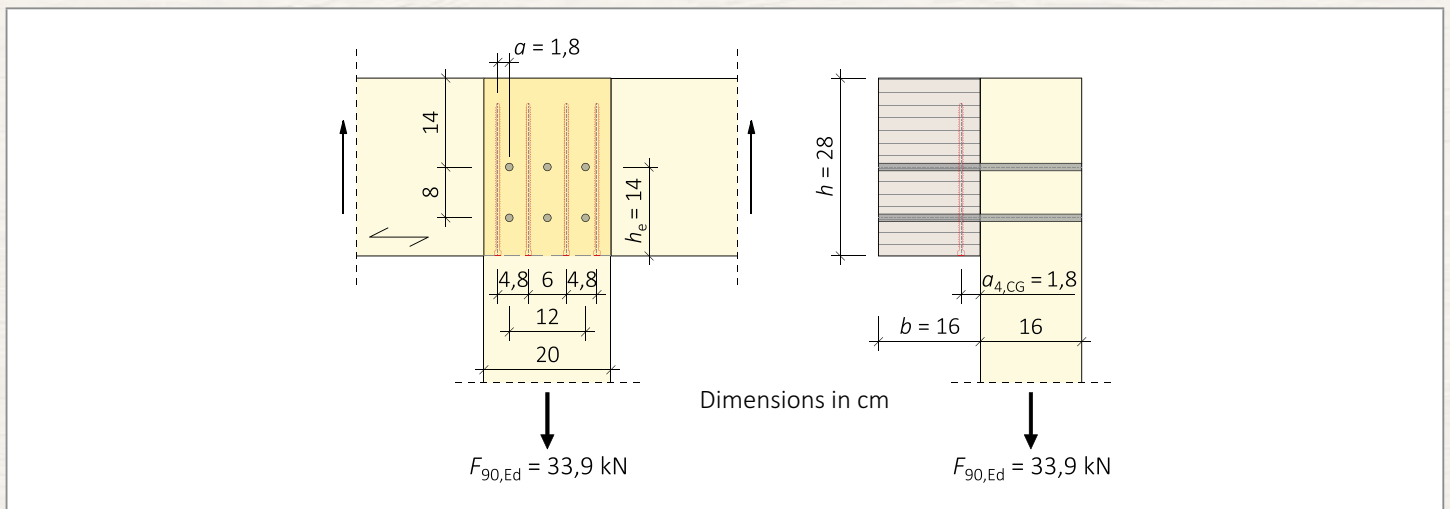
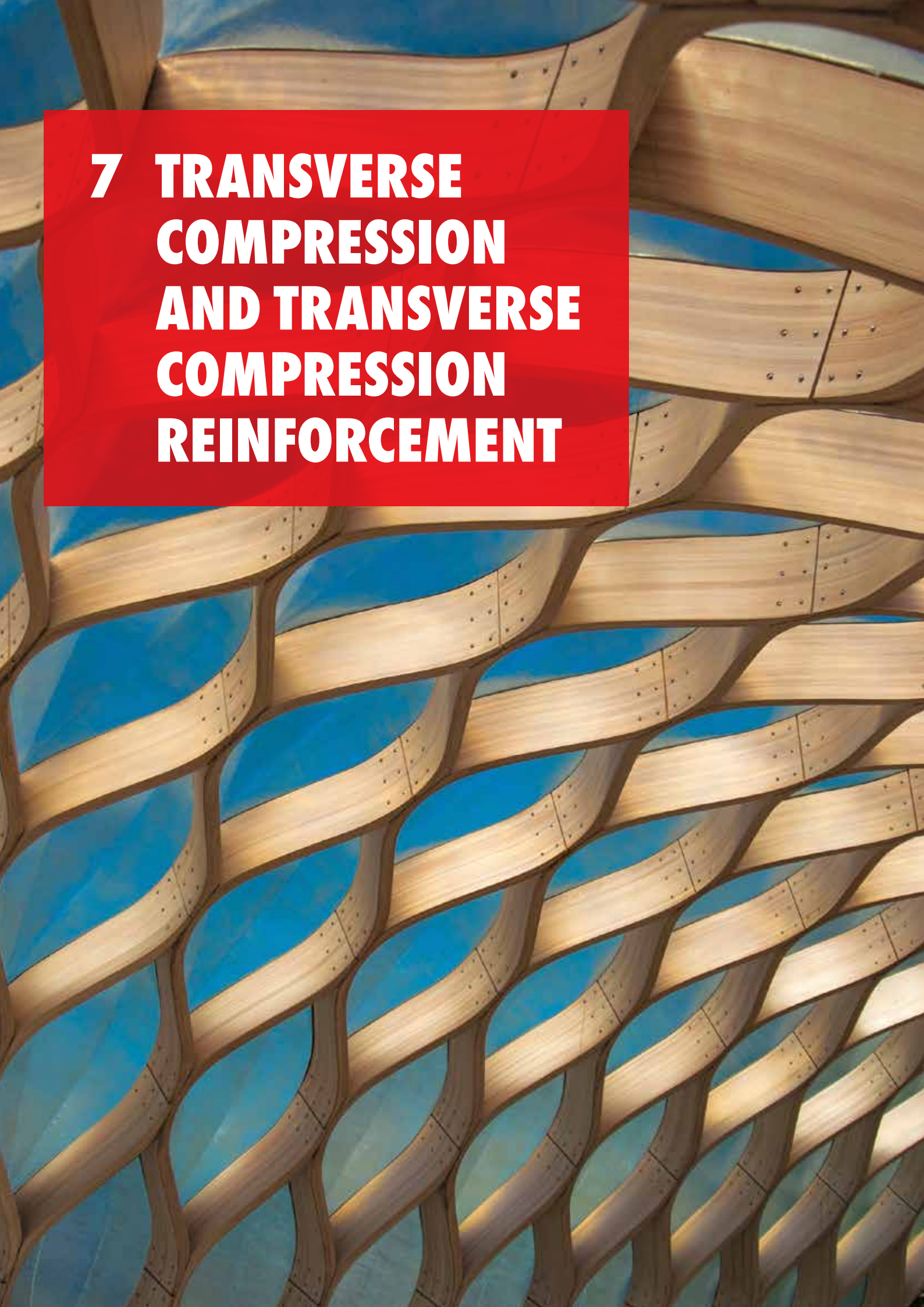


Figure 82: Calculation example – transverse connection with four fully threaded screws as close as possible to the shear plane.

Notes:

- In Figure 80, the reinforcing screws are arranged in the direction of the grain in front of and behind the connection and close to the shear plane, since the development of cracks is expected in the area of high bearing stress.
- If the connection layout is known, the reinforcing screws can be installed even closer to the location where cracks are expected to develop, see Figure 81 and Figure 82.
- The reinforcing screws must be placed close to the connection in all cases.

In addition to the arrangements of the reinforcing screws shown above, it should be noted that, according to the standard, a uniform distribution of the reinforcing screws over the cross-section is permitted.



7 TRANSVERSE COMPRESSION AND TRANSVERSE COMPRESSION REINFORCEMENT

7.1 Transverse compression verification in accordance with EC 5 (unreinforced)

Areas subjected to transverse compression must be verified using Eq. (7.1). The factor $k_{c,90}$ accounts for the different load-bearing behaviour of members made of solid timber (ST/FST) and glued laminated timber (GL) that are subjected to transverse compression. A distinction is made between sill compression and support compression, as well as full-area and partial-area loading of the members. Detailed explanations of the influence of these factors can be found in Blaß and Görlacher (2004) and Neuhaus (2017). Relevant examples can also be found in Neuhaus (2017). Additional factors such as the length $l_{c,90}$ of the compression area and the spacing l_s of the shear loads are also considered in the transverse compression verification.

$$\frac{\sigma_{c,90,d}}{k_{c,90} \cdot f_{c,90,d}} \leq 1 \quad (7.1)$$

Where:

$$\sigma_{c,90,d} = \frac{F_{c,90,d}}{A_{ef}} \quad \text{Design value of the compressive stress in the contact area} \quad (7.2)$$

$F_{c,90,d}$ Design value of the compressive force perpendicular to the grain direction

A_{ef} Effective contact area taking into account the effective contact length

$k_{c,90}$ Factor to account for the type of action, the splitting risk and the degree of compressive deformation, see Table 54.

$$f_{c,90,d} = \frac{k_{mod} \cdot f_{c,90,k}}{\gamma_M} \quad \text{Design value of the compressive strength perpendicular to the grain direction} \quad (7.3)$$

For compression acting perpendicular to the grain direction, the actual contact area length $l_{c,90}$ can be increased by 30 mm on each side parallel to the grain direction, but not by more than l_e , $l_{c,90}$ or $l_s/2$. Figure 83 below shows a member with continuous support (left) and a member with point support (right).

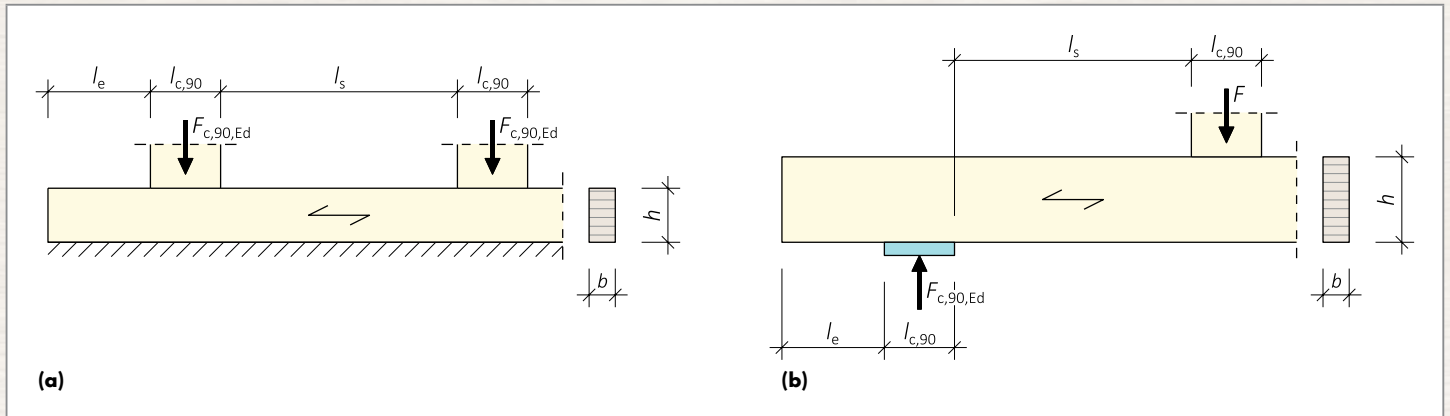


Figure 83: Sill (a) and beam (b) with transverse compressive load.

Factor $k_{c,90}$ is generally 1.0. Depending on the support conditions, the values in Table 54 can be assumed:

Table 54: Applicable values for $k_{c,90}$.

For sill compression (continuous support), if $l_s \geq 2h$ (Figure 83 [a])	$k_{c,90} = 1,25$	For solid timber (ST/FST) made of softwood
	$k_{c,90} = 1,20$	For glued laminated timber (GL) made of softwood
For support compression (point support), if $l_s \geq 2h$ (Figure 83 [b])	$k_{c,90} = 1,50$	For solid timber (ST/FST) made of softwood
	$k_{c,90} = 1,75$	For glued laminated timber (GL) made of softwood
Regulation: EC 5		

Especially for laminated veneer lumber, the product approval must be taken into account when determining factor $k_{c,90}$.

7.2 Support reinforcement

7.2.1 Design

Requirements for the reinforcement of timber members subjected to compression perpendicular to the grain direction:

- Fully threaded screws (FTS) perpendicular to the surface with an angle to the grain of $45^\circ \leq \varepsilon \leq 90^\circ$
- Uniform force transfer across the entire bearing area
- The requirement for uniform force transfer is fulfilled by:
 - A sufficiently stiff bearing plate, see Eq. (7.5)
 - Uniform distribution of the screws across the bearing area
 - Screws inserted with the screw heads flush with the timber surface (socket head and countersunk head screws)
 - A sufficient rotational capacity of the support, see Figure 85 This is ensured if the support rotations induced by deflections are accommodated by a suitable elastomeric bearing (where $\Delta w_{c,90} > 1 \text{ mm}$).
- The rules for minimum member thicknesses and spacings as specified in Section 3.7.3 apply
- The reinforcement of members made of hardwood is not regulated

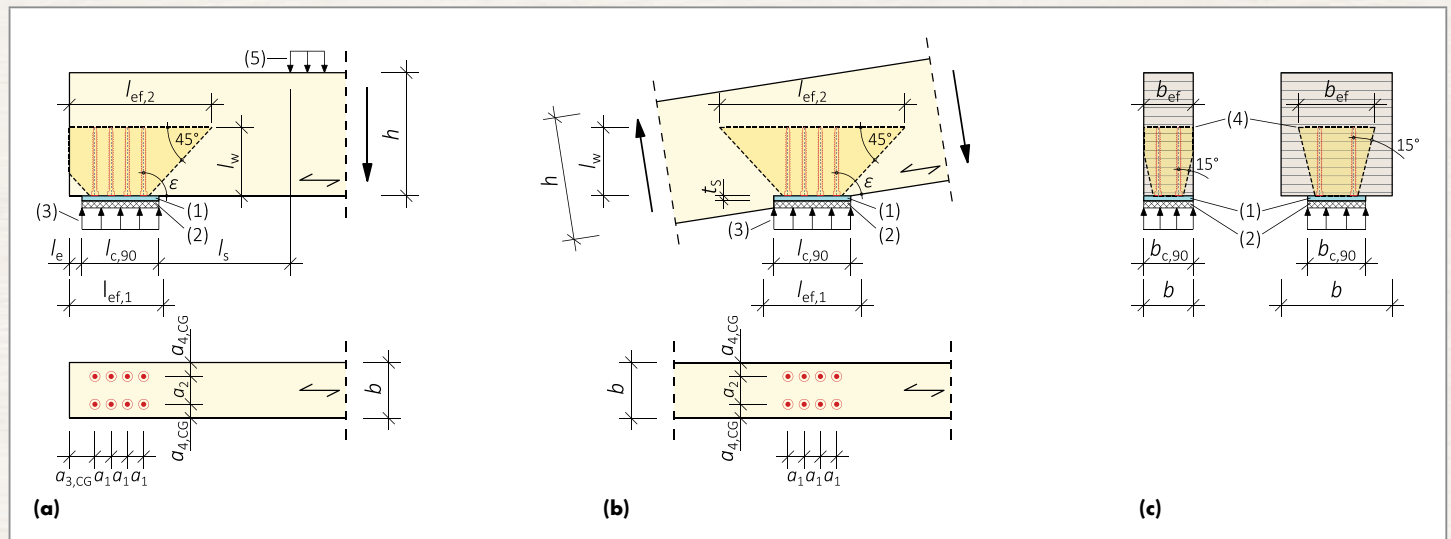


Figure 84: Reinforcement on the end support (a), intermediate support (b) and in the cross-section (c).

(1) steel plate, (2) elastomer, (3) compressive force, (4) plane of the fully activated member width, (5) compressive force.

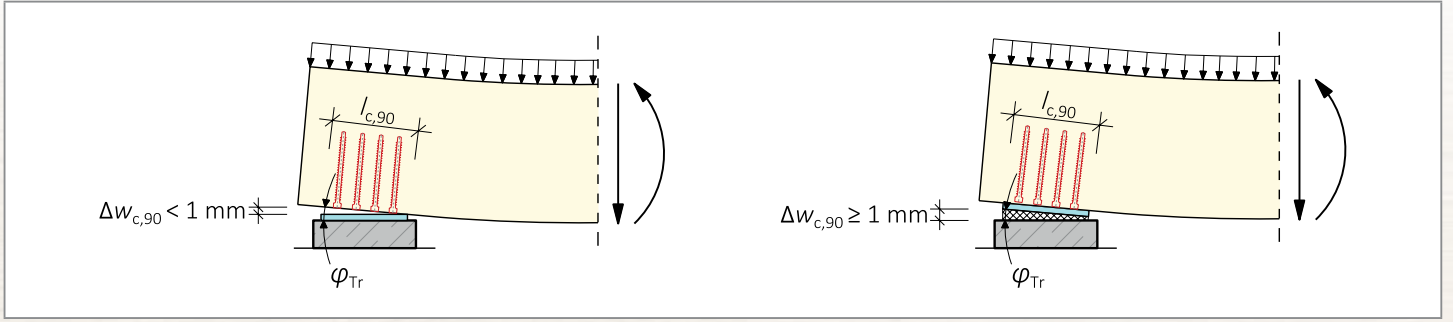


Figure 85: Illustration of $\Delta w_{c,90}$ (exaggerated representation).

The load capacity of a reinforced timber member is designed using Eq. (7.4). Eq. (7.4) (a) is the verification of the transverse compressive stresses in the plane of the screw heads combined with the compressive load capacity of the reinforcing screws. Eq. (7.4) (b) describes the verification of the transverse compressive stresses in the plane of the screw tips.

$$F_{c,90,Rk} = \min \left\{ \begin{array}{l} k_{c,90} \cdot b_{c,90} \cdot l_{ef,1} \cdot f_{c,90,k} + n \cdot \min \{ F_{w,k}; F_{c,k} \} \\ b_{ef} \cdot l_{ef,2} \cdot f_{c,90,k} \end{array} \right. \quad \begin{array}{l} \text{(a)} \\ \text{(b)} \end{array} \quad (7.4)$$

Where:

$$l_{ef,1} = l_{c,90} + \min \{ 30 \text{ mm}; l_e; l_s / 2 \} + \min \{ 30 \text{ mm}; l_s / 2 \}$$

for end support, FTS head

$$l_{ef,1} = l_{c,90} + \min \{ 30 \text{ mm}; l_s / 2 \} + \min \{ 30 \text{ mm}; l_s / 2 \}$$

for intermediate support, FTS head

$$l_{ef,2} = l_w + (n_0 - 1) \cdot a_1 + \min \{ l_w; a_{3,CG} \}$$

for end support, FTS tip

$$l_{ef,2} = 2 \cdot l_w + (n_0 - 1) \cdot a_1$$

for intermediate support, FTS tip

$$f_{c,90,k} = \begin{cases} 2,5 & \text{C24, GL 24c - 32h} \\ 1,8 & \text{LVL-P}^{1), 4)}_{\text{flat}} \\ 2,2 & \text{LVL-P}^{1), 4)}_{\text{flat}} \\ 3,0 & \text{LVL-P}^{2)}_{\text{flat}} \\ 4,0 & \text{LVL-P}^{2), 3)}_{\text{flat}} \\ 3,6 & \text{LVL-P}^{3)}_{\text{flat}} \end{cases}$$

in N/mm²

1) LVL in accordance with Z-9.1-847

2) LVL in accordance with Z-9.1-842

3) LVL in accordance with Z-9.1-890

4) LVL in accordance with Z-9.1-880

$$n = n_0 \cdot n_{90} \quad \text{taking into account the minimum spacings in Section 3.7.3}$$

Recommendation for the steel plate thickness t_s in mm with any screw spacing, see also Figure 86:

$$t_s \geq \sqrt{\frac{F_{c,Ed} \cdot (L_x + L_y)}{\pi \cdot d_{\text{head}} \cdot f_{y,d}}} \quad (7.5)$$

Where:

$$F_{c,Ed} \quad \text{Design value of the acting compressive force in a reinforcing screw in N}$$

$$L_x = \min \left\{ a_1; 2 \cdot \max \left\{ a_{3,S}; \frac{a_1}{2} \right\} \right\} \quad \text{Calculated penetration depth parallel to the grain direction in mm} \quad (7.6)$$

$$L_y = \min \left\{ a_2; 2 \cdot \max \left\{ a_{4,S}; \frac{a_2}{2} \right\} \right\} \quad \text{Calculated penetration depth perpendicular to the grain direction in mm} \quad (7.7)$$

$$d_{\text{head}} \quad \text{Head diameter of the reinforcing screws in mm (d1 for load transfer with cut-off through screws, see Figure 91)}$$

$$f_{y,d} = \frac{f_{y,k}}{\gamma_{M0}} \quad \text{Design value of the yield strength of the steel where } \gamma_{M0} = 1,0 \text{ (in accordance with EC 3) in N/mm}^2 \quad (7.8)$$

For a_1 , a_2 , $a_{3,S}$ and $a_{4,S}$, the values from the transverse compression verification must be used; see Sections 7.2.2 and 7.3.2.

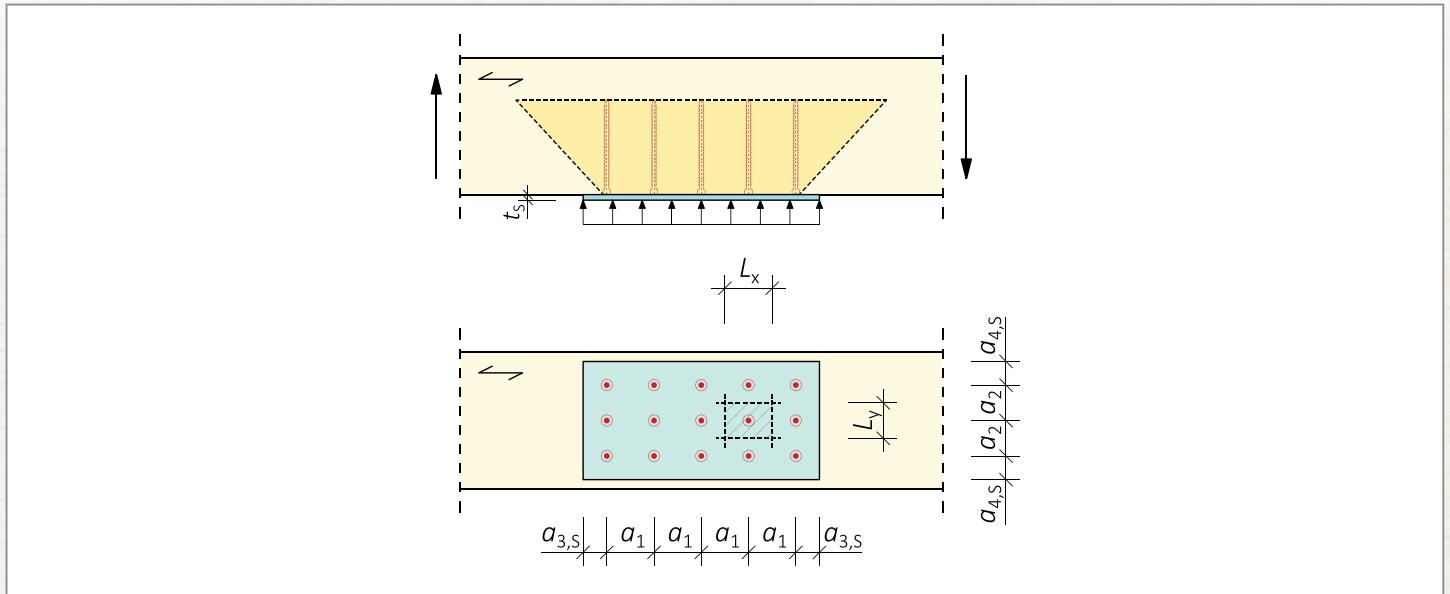


Figure 86: Spacing designations on the bearing plate.

Recommendation for the steel plate thickness t_s in mm in accordance with Draft EC 5 with fixed fastener spacings, see also Figure 86:

$$t_s \geq \max \left\{ 5,0 \right. \\ \left. 1,45 \cdot \sqrt{\frac{F_{c,Ed}}{f_{y,d}}} \right\} \quad (7.9)$$

Assuming that:

$$a_1 = a_2 = 5 \cdot d \text{ and } a_{3,S} = a_{4,S} = 2,5 \cdot d$$

Where:

$F_{c,Ed}$	Design value of the acting compressive force in a reinforcing screw in N
$f_{y,d}$	Design value of the yield strength of the steel where $\gamma_{M0} = 1,0$ (in accordance with EC 3) in N/mm ²

7.2.2 Calculation example

The load-bearing capacity in the support area of a beam with regard to transverse compression and any transverse compression reinforcement that may be required in this case can be designed using the **transverse compression verification and transverse compression reinforcement module**.

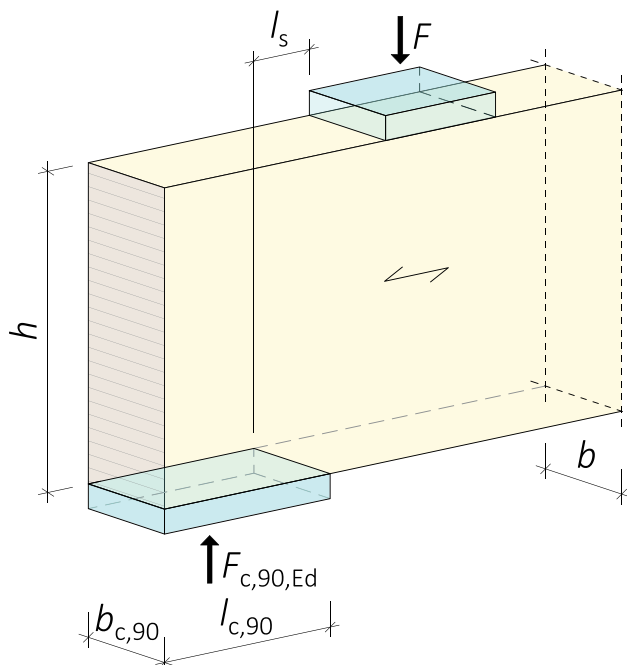


Figure 87: Calculation example – unreinforced support.

Geometry and material

Cross-sectional width	b	= 120 mm
Cross-sectional height	h	= 560 mm
Material		GL 24c
Characteristic bulk density	ρ_k	= 365 kg/m ³
Characteristic shear strength	$f_{t,90k}$	= 2.50 N/mm ²
Partial safety factor	γ_M	= 1.3
Support width	$b_{c,90}$	= 120 mm
Support length	$l_{c,90}$	= 240 mm
Distance to the load at the top	l_s	= 45 mm
Support type		End support

Action

Design load	$F_{c,90,Ed}$	= 91.0 kN
Service class		1
Load duration class		Permanent
Modification factor	k_{mod}	= 0.6

Load capacity of the unreinforced support based on Eq. (7.1); $k_{c,90} = 1.0$ because $l_s < 2h$:

$$F_{c,90,Rd} = k_{c,90} \cdot b_{c,90} \cdot l_{ef,1} \cdot f_{c,90,d} = 1,0 \cdot 120 \cdot (240 + 30) \cdot 1,15 = 37,3 \text{ kN}$$

Where:

$$l_{ef,1} = l_{c,90} + 30 + 0 = 240 + 30 = 270 \text{ mm}$$

$$f_{c,90,d} = \frac{k_{mod} \cdot f_{c,90,k}}{\gamma_M} = \frac{0,6 \cdot 2,5}{1,3} = 1,15 \text{ N/mm}^2$$

Verification for unreinforced

$$\frac{F_{c,90,Ed}}{F_{c,90,Rd}} = \frac{91,0 \text{ kN}}{37,3 \text{ kN}} = 2,44 \gg 1,0 \quad \rightarrow \text{Reinforcement required!}$$

Verification of the reinforced support based on Eq. (7.4):

Based on Eq. (3.20) and (3.21) and the selected ASSY®plus VG 4 CH 8.0 x 530 mm

fully threaded screws, the following values apply for the reinforcing screws:

$$f_{ax,k} = 12 \text{ N/mm}^2 \text{ (see Table 8).}$$



3 x 2 ASSY®plus
VG 4 CH 8.0 x 530

The load-bearing capacity of the reinforcement

$$F_{w,k} = \frac{k_{ax} \cdot f_{ax,k} \cdot d \cdot l_w}{k_{\beta}} \cdot \left(\frac{\rho_k}{\rho_{ref,k}} \right)^{0,8} \text{ (see Section 3.3)} \text{ must be designed at the screw tip:}$$

Anchorage length	l_w	=	530	mm
Angle factor	k_{ax}	=	1.0	-
Angle factor	k_{β}	=	1.0	-
Characteristic bulk density	ρ_k	=	365	kg/m ³
Reference bulk density	$\rho_{ref,k}$	=	350	kg/m ³
Withdrawal parameter	$f_{ax,k}$	=	12.0	N/mm ²

Verification of the screw spacings (Table 30):

$$a_{1,min} = 5d = 40 \text{ mm} < a_{1,ist} = 80 \text{ mm} \quad \checkmark$$

$$a_{2,min} = 2,5d = 20 \text{ mm} < a_{2,ist} = 56 \text{ mm} \quad \checkmark$$

$$a_{3,CG,min} = 5d = 40 \text{ mm} = a_{3,CG,ist} = 40 \text{ mm} \quad \checkmark$$

$$a_{4,CG,min} = 3d = 24 \text{ mm} < a_{4,CG,ist} = 32 \text{ mm} \quad \checkmark$$

$$a_{1,ist} \cdot a_{2,ist} \geq 25d^2 = 1.600 \text{ mm}^2$$

$$80 \cdot 56 = 4.480 \text{ mm}^2 > 1.600 \text{ mm}^2 \quad \checkmark$$

$$F_{w,k} = \frac{k_{ax} \cdot f_{ax,k} \cdot d \cdot l_w}{k_{\beta}} \cdot \left(\frac{\rho_k}{\rho_{ref,k}} \right)^{0,8} = \frac{1,0 \cdot 12,0 \cdot 8,0 \cdot 530}{1,0} \cdot \left(\frac{365}{350} \right)^{0,8} = 52,6 \text{ kN}$$

Characteristic load-bearing capacity where $F_{c,k} = 11.4 \text{ kN}$ as per Table 19:

$$F_{ax,c,k} = \min \{ F_{w,k}; F_{c,k} \} = \min \{ 52,6; 11,4 \} = 11,4 \text{ kN}$$

Design value of the axial load-bearing capacity - because $F_{c,k}$ is the buckling resistance of the steel screw, the following applies:

$$F_{ax,c,d} = \min \left\{ \frac{k_{mod} \cdot F_{w,k}}{\gamma_M}, \frac{F_{c,k}}{\gamma_{M1}} \right\} = \min \left\{ \frac{0,6}{1,3} \cdot 52,6, \frac{11,4}{1,1} \right\} = \min \{ 24,3; 10,4 \} = 10,4 \text{ kN}$$

Verifications of the reinforcement in the plane of the screw head and screw tip, see Eq. (7.4) (a) and (b):

$$\begin{aligned} F_{c,90,Rd,(a)} &= k_{c,90} \cdot b_{c,90} \cdot l_{ef,1} \cdot f_{c,90,d} + n \cdot F_{ax,c,d} \\ &= 1,0 \cdot 120 \cdot (240 + 30) \cdot 1,15 + 6 \cdot 10,400 \\ &= 37,260 + 62,400 = 99,7 \text{ kN} \end{aligned}$$

→ **With a single load acting close to the support**, $k_{c,90} = 1.0$; $n = n_0 \cdot n_{90}$

$$F_{c,90,Rd,(b)} = b_{ef} \cdot l_{ef,2} \cdot f_{c,90,d} = 120 \cdot 730 \cdot 1,15 = 100,7 \text{ kN}$$

Where:

$$b_{ef} = b_{c,90} = 120 \text{ mm}$$

$$l_{ef,2} = l_w + (n_0 - 1) \cdot a_1 + \min \{ l_w; a_{3,CG} \} = 530 + 2 \cdot 80 + 40 = 730 \text{ mm}$$

Verification of the transverse compression reinforcement

$$\frac{F_{c,90,Ed}}{F_{c,90,Rd}} = \frac{91,0 \text{ kN}}{99,7 \text{ kN}} = 0,91 < 1,0 \quad \checkmark$$

→ **Verification of the deflection:** $\Delta w_{c,90} < 1,0 \text{ mm} \quad \checkmark$

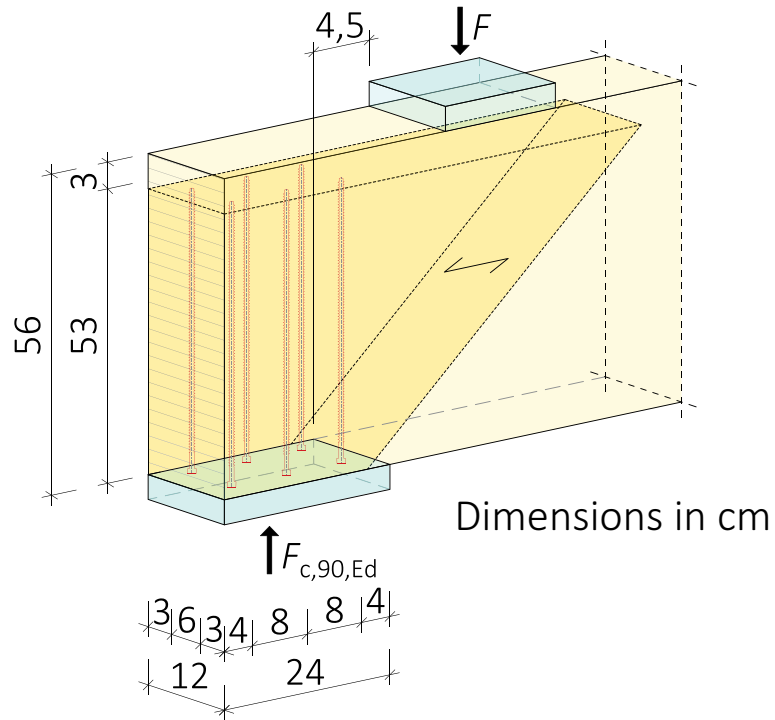


Figure 88: Calculation example – reinforced support.

Design of the steel plate thickness t_s in steel grade S235 with any screw spacing using Eq. (7.5):

$$\begin{aligned} t_s &\geq \sqrt{\frac{F_{c,Ed} \cdot (L_x + L_y)}{\pi \cdot d_{head} \cdot f_{y,d}}} \\ &\geq \sqrt{\frac{15200 \cdot (80 + 60)}{\pi \cdot 10 \cdot 235}} = 17,0 \text{ mm} \end{aligned}$$

Where

$$F_{c,Ed} = \frac{F_{c,90,Ed}}{n} = \frac{91}{6} = 15,2 \text{ kN}$$

$$d_{head} = 10 \text{ mm} \quad (\text{siehe Tabelle 1})$$

$$f_{y,d} = \frac{f_{y,k}}{\gamma_{M0}} = \frac{235}{1,0} = 235 \text{ N/mm}^2$$

$$L_x = \min \left\{ a_1; 2 \cdot \max \left\{ a_{3,S}; \frac{a_1}{2} \right\} \right\}$$

$$= \min \left\{ 80; 2 \cdot \max \left\{ 40; \frac{80}{2} \right\} \right\} = 80 \text{ mm}$$

$$L_y = \min \left\{ a_2; 2 \cdot \max \left\{ a_{4,S}; \frac{a_2}{2} \right\} \right\}$$

$$= \min \left\{ 60; 2 \cdot \max \left\{ 30; \frac{60}{2} \right\} \right\} = 60 \text{ mm}$$

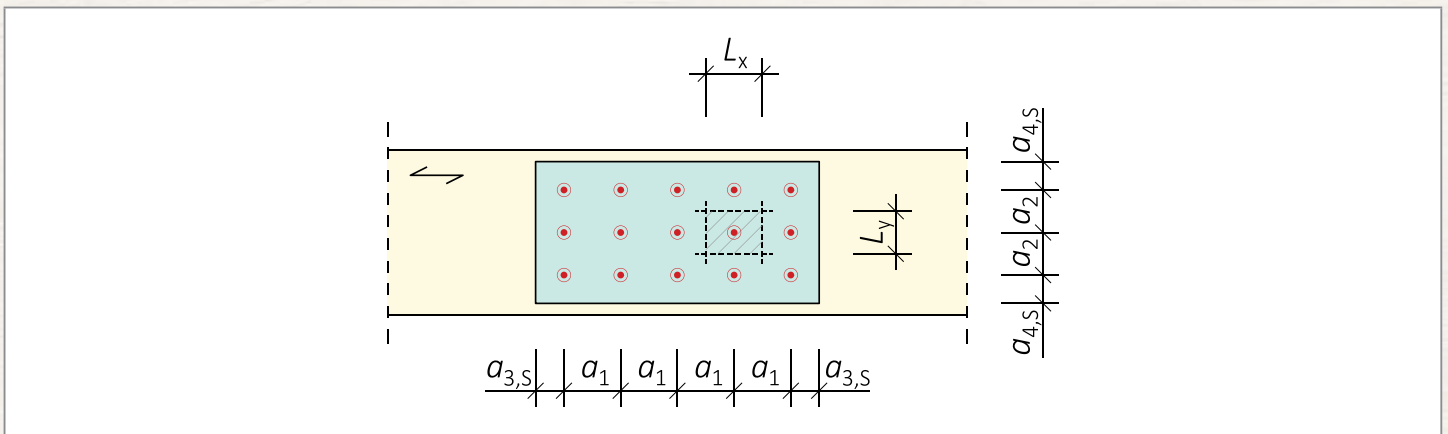


Figure 89: Spacing designations on the bearing plate.

Flat steel with thickness $t_s = 20,0 \text{ mm}$ in steel grade S235 has been selected.

7.3 Load transfer

7.3.1 Design

According to Draft EC 5, double-sided reinforcement of the timber members for load transfer is permitted under the following conditions:

- All requirements defined for transverse compression reinforcement apply here as well.
- The minimum spacings between the overlapping fully threaded screws must be maintained.
- The opposing support surfaces should be arranged axially symmetrical to each other.

The load capacity for each support surface can be determined at follows, see Eq. (7.4) (a). The verification of the transverse compressive stresses in the plane of the screw tips can be omitted, see Eq. (7.4) (b).

$$F_{c,90,Rk} = k_{c,90} \cdot b_{c,90} \cdot l_{ef,1} \cdot f_{c,90,k} + n \cdot \min \{ F_{w,k}; F_{c,k} \} \quad \text{see Eq. (7.4) (a)}$$

Where:

$$k_{c,90} = 1,0$$

Each of the two support surfaces must be verified for the load acting on it. If a difference arises between surface 1 and surface 2 (see Figures 90 and 91) due to an acting shear force, a larger number of screws may be required on the side with the higher load. The arrangement and overlap length must be

designed such that the force transfer is ensured (Figure 91: a greater number of screws is required in surface 2; fully threaded screws [FTS] are used first in this surface; screws are arranged alternately.)

The following geometric boundary conditions must be observed:

$$l_1 \geq 15d ; l_2 \geq 15d ; l_{1,2} \geq \max\{10 \cdot d; 2 \cdot a_1\} ; a_{1,\max} = 5d ; a_1 \times a_2 \geq 25d^2$$

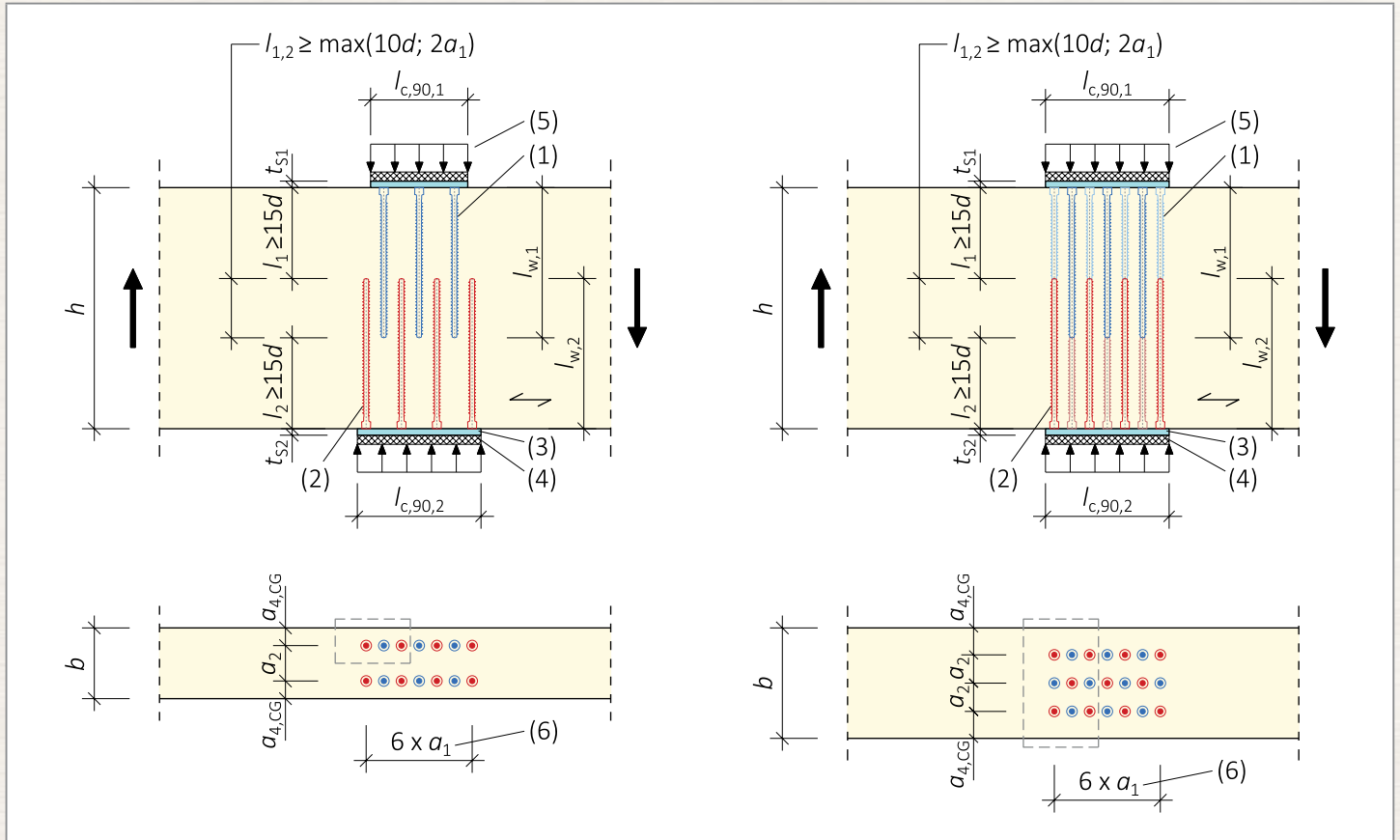


Figure 90: Arrangement and depiction of load transfer. (1) FTS surface 1, (2) FTS surface 2, (3) sheet steel, (4) elastomer, (5) compressive force on the beam, (6) FTS spacing parallel to the grain direction $a_1 = 5d$.

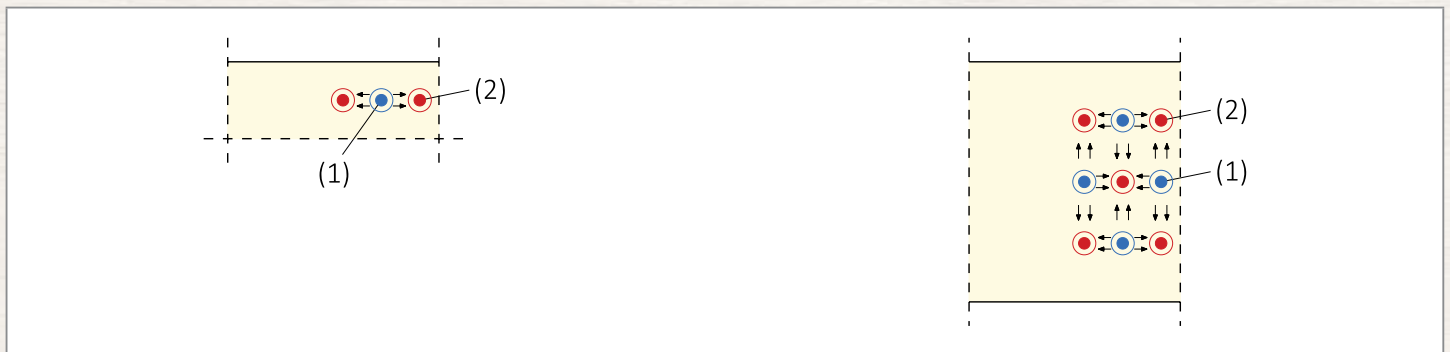


Figure 91: Force flow through the overlapping screws. (1) FTS surface 1, (2) FTS surface 2.

The maximum screw length for overlapping screws can be designed using Eq. (7.10).

$$l_{s,\max} = l_{w,\max} = h - 15 \cdot d \quad (7.10)$$

Table 55: Minimum screw lengths and minimum beam heights for load transfers (values in mm).

Outer thread diameter d	6	8	10	12
Fixed screw spacing parallel to the grain direction a_1	30	40	50	60
Minimum embedment depth without overlap at member edge 1 $l_{1,min}$	90	120	150	180
Minimum embedment depth without overlap at member edge 2 $l_{2,min}$	90	120	150	180
Minimum overlap length $l_{1,2,min}$	60	80	100	120
Minimum screw length $l_{s,min} = l_{w,min} = l_{1,min} + l_{1,2,min}$	150	200	250	300
Maximum screw length $l_{s,max} = h_{min} - 15 \cdot d$	150	200	250	300
Minimum beam height $h_{min} = l_{1,min} + l_{2,min} + l_{1,2,min}$	240	320	400	480
Regulation: Draft EC 5				

As an alternative to the system described above for load transfer using opposing and overlapping fully threaded screws, ASSY®plus VG and ASSY® fully threaded screws can also be screwed in from a single side flush with the timber surface, similar to transverse compression reinforcement. Only the screws should be considered in the verification. The absorption or transfer of the loads through transverse compression in the timber must not be taken into account. The verification must always be carried out using the larger of the two load components. Screws slightly longer than the corresponding member height should be selected. The protruding screw tips must then be cut flush with the timber surface using a suitable tool.

Notes:

- It is recommended to pre-drill the members for the screws to ensure that they are screwed in at the correct location.
- In the case of identical loads, the core diameter of the screw d_1 is the decisive factor for the design of the steel plate as determined by Eq. (7.5).

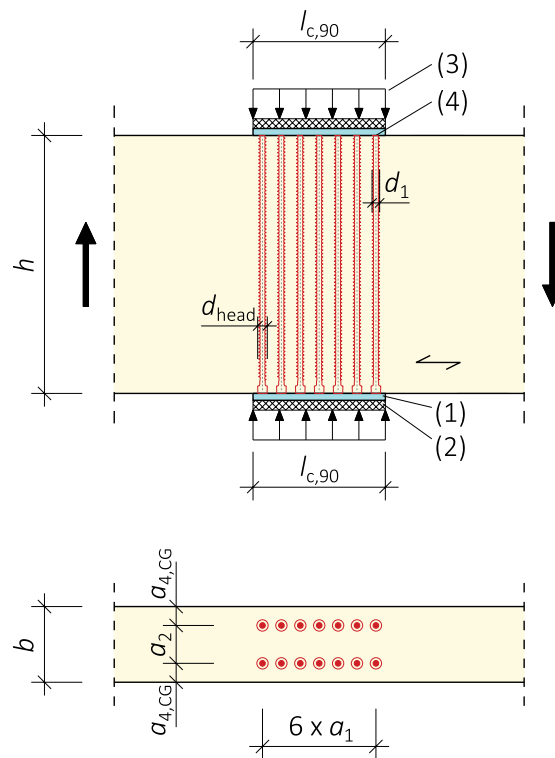


Figure 92: Alternative system to load transfer. (1) steel plate, (2) elastomer, (3) compressive force on the beam, (4) cut screws.

7.3.2 Calculation examples

7.3.2.1 Load transfer with overlapping screws

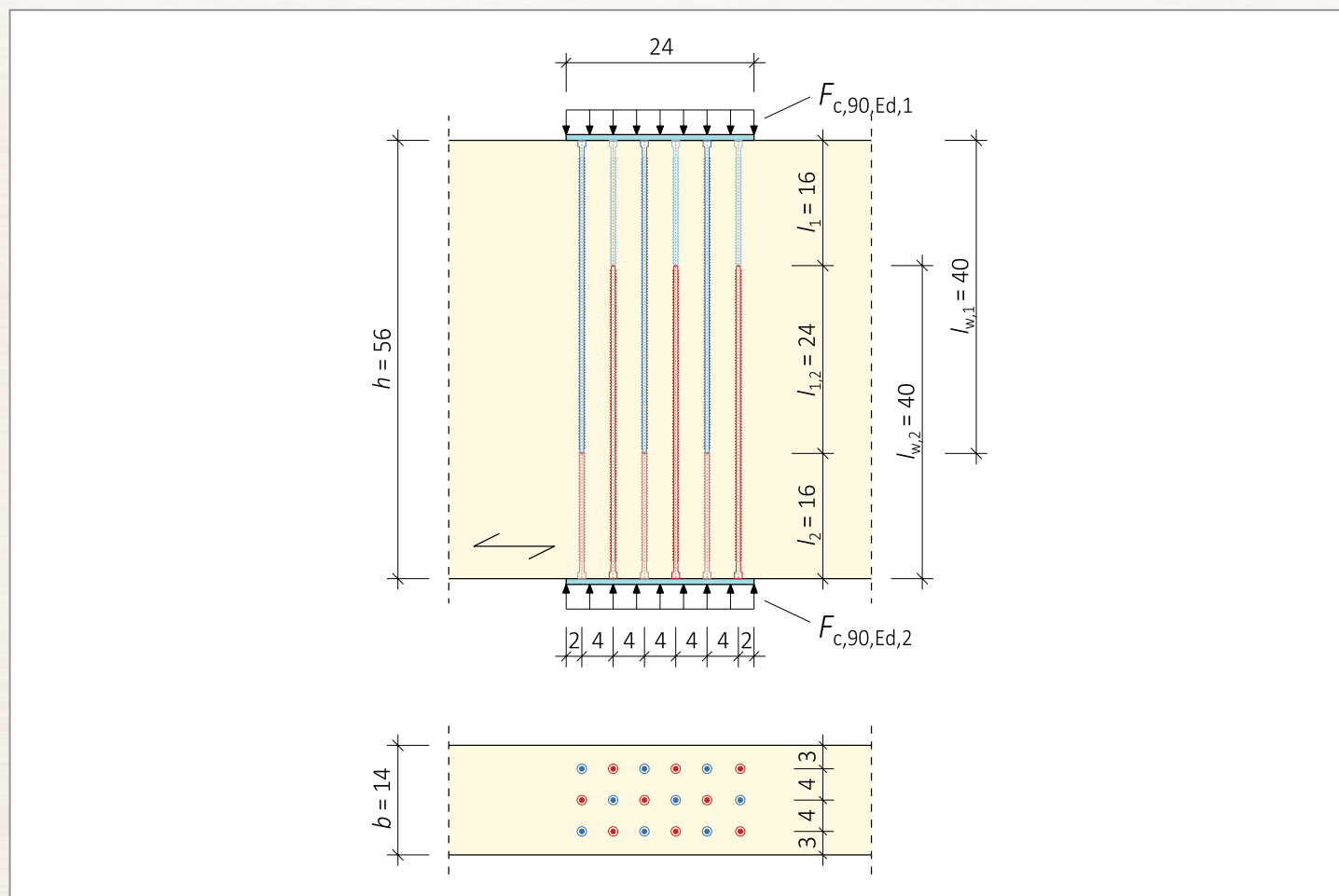


Figure 93: Calculation example – load transfer with overlapping screws. Dimensions in cm.

Geometry and material

Cross-sectional width	b	= 140 mm
Cross-sectional height	h	= 560 mm
Material		GL 24c
Characteristic bulk density	ρ_k	= 365 kg/m ³
Transverse compressive strength	$f_{t,90k}$	= 2.50 N/mm ²
Partial safety factor	γ_M	= 1.3
Support width	$b_{c,90}$	= 140 mm
Support length	$l_{c,90}$	= 240 mm
Support type		Intermediate support
Service class		1
Load duration class		Permanent
Modification factor	k_{mod}	= 0.6
Screw type		ASSY®plus VG 4 CH
		8.0 x 400 mm
Number of screws	n_1	= 9
	n_2	= 9

Determination of the load-bearing capacity of an ASSY®plus VG 4 CH 8.0 x 400 mm screw

The following applies to the characteristic pull-out resistance of a screw when pressed in:

$$F_{w,k} = \frac{k_{ax} \cdot f_{ax,k} \cdot d \cdot l_w}{k_{\beta}} \cdot \left(\frac{\rho_k}{\rho_{ref,k}} \right)^{0,8} \quad (\text{see Section 3.3})$$

Where:

$$k_{ax} = 1,0$$

$$k_{\beta} = 1,0$$

$$f_{ax,k} = 12,0 \text{ N/mm}^2$$

$$d = 8,0 \text{ mm}$$

$$l_w = 400 \text{ mm}$$

$$\rho_k = 365 \text{ kg/m}^3$$

$$\rho_{ref,k} = 350 \text{ kg/m}^3$$

$$\Rightarrow F_{w,k} = \frac{1,0 \cdot 12,0 \cdot 8,0 \cdot 400}{1,0} \cdot \left(\frac{365}{350} \right)^{0,8} = 39,7 \text{ kN}$$

For the characteristic value of the buckling resistance of the screw, as stipulated in Table 19:

$$F_{c,k} = 11,4 \text{ kN} \quad \text{see Section 3.5.1}$$

Therefore, the design value of the load-bearing capacity of a screw is obtained as follows:

$$F_{ax,c,d} = \min \left\{ \frac{k_{mod}}{\gamma_M} \cdot F_{w,k}; \frac{F_{c,k}}{\gamma_{M1}} \right\} = \min \left\{ \frac{0,6}{1,3} \cdot 39,7; \frac{11,4}{1,1} \right\} = 10,4 \text{ kN}$$

Verification of the geometric boundary conditions:

$$l_1 \geq 15d = 120 \text{ mm}; l_1 = 160 \text{ mm} \quad \checkmark$$

$$l_2 \geq 15d = 120 \text{ mm}; l_2 = 160 \text{ mm} \quad \checkmark$$

$$l_{1,2} \geq \max \{ 10 \cdot d; 2 \cdot a_1 \} = 80 \text{ mm};$$

$$l_{1,2} = h_{Träger} - l_1 - l_2 = 240 \text{ mm} \quad \checkmark$$

$$a_1 \times a_2 = 1.600 \geq 1.600 = 25d^2 \quad \checkmark$$

In this case, with an equal number of screws $n_1 = n_2 = 9$ and equal bearing surface lengths $l_{c,90,1} = l_{c,90,2} = 240 \text{ mm}$, the load-bearing capacity for load transfer is the same on beam sides 1 and 2.

Calculation of the maximum load-bearing capacity with nine ASSY®plus VG 4 CH 8.0 x 400 mm screws

$$F_{c,90,Rk,1} = k_{c,90} \cdot b_{c,90,1} \cdot l_{ef,1,1} \cdot f_{c,90,k} + n_{ef,1} \cdot F_{ax,c,k}$$

Where:

$$l_{ef,1,1} = l_{c,90,1} + \min\{30; l_s / 2\} + \min\{30; l_s / 2\}$$

$$l_{ef,1,1} = 240 + \min\{30; 0 / 2\} + \min\{30; 0 / 2\} = 240 + 0 + 0 = 240 \text{ mm}$$

$$f_{c,90,d} = \frac{k_{mod} \cdot f_{c,90,k}}{\gamma_M} = \frac{0,6 \cdot 2,5}{1,3} = 1,15 \text{ N/mm}^2$$

$$k_{c,90} = 1,0 \quad \text{Lastdurchleitung}$$

$$n_{ef,1} = n_1 = 9 \quad \text{siehe Gl. (3.24)}$$

$$F_{c,90,Rd,1} = 1,0 \cdot 140 \cdot 240 \cdot 1,15 + 9 \cdot 10.400 = 38.640 + 93.600 = 132,2 \text{ kN}$$

Design of the steel plate thickness t_s in steel grade S235 with any screw spacing using Eq. (7.5):

Note:

- For the design of the steel plate with maximum load-bearing capacity, $F_{c,Ed} = F_{c,Rd}$ is used.

$$\begin{aligned} t_s &\geq \sqrt{\frac{F_{c,Ed} \cdot (L_x + L_y)}{\pi \cdot d_{head} \cdot f_{y,d}}} \\ &\geq \sqrt{\frac{14.690 \cdot (80 + 80)}{\pi \cdot 10 \cdot 235}} = 17,8 \text{ mm} \end{aligned}$$

Where:

$$F_{c,Ed} = \frac{F_{c,90,Ed}}{n} = \frac{F_{c,90,Rd,1}}{n_1} = \frac{132,2}{9} = 14,69 \text{ kN}$$

$$a_1 = 40 + 40 = 80 \text{ mm}$$

$$a_2 = 40 + 40 = 80 \text{ mm}$$

$$a_{3,S} = 20 + 40 = 60 \text{ mm}$$

$$a_{4,S} = 30 + 40 = 70 \text{ mm}$$

$$\begin{aligned} L_x &= \min \left\{ a_1; 2 \cdot \max \left\{ a_{3,S}; \frac{a_1}{2} \right\} \right\} \\ &= \min \left\{ 80; 2 \cdot \max \left\{ 40; \frac{80}{2} \right\} \right\} = 80 \text{ mm} \end{aligned}$$

$$\begin{aligned} L_y &= \min \left\{ a_2; 2 \cdot \max \left\{ a_{4,S}; \frac{a_2}{2} \right\} \right\} \\ &= \min \left\{ 80; 2 \cdot \max \left\{ 70; \frac{80}{2} \right\} \right\} = 80 \text{ mm} \end{aligned}$$

$$d_{head} = 10 \text{ mm} \quad (\text{siehe Tabelle 1})$$

$$f_{y,d} = \frac{f_{y,k}}{\gamma_{M0}} = \frac{235}{1,0} = 235 \text{ N/mm}^2$$

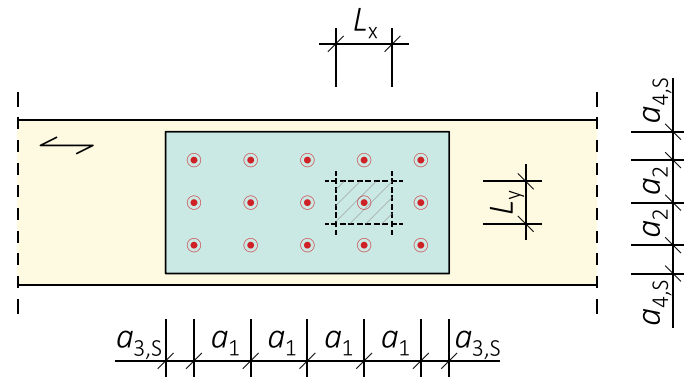


Figure 94: Spacing designations on the bearing plate.

Flat steel with thickness $t_s = 20,0$ mm in steel grade S235 has been selected.

7.3.2.2 Load transfer with through screws

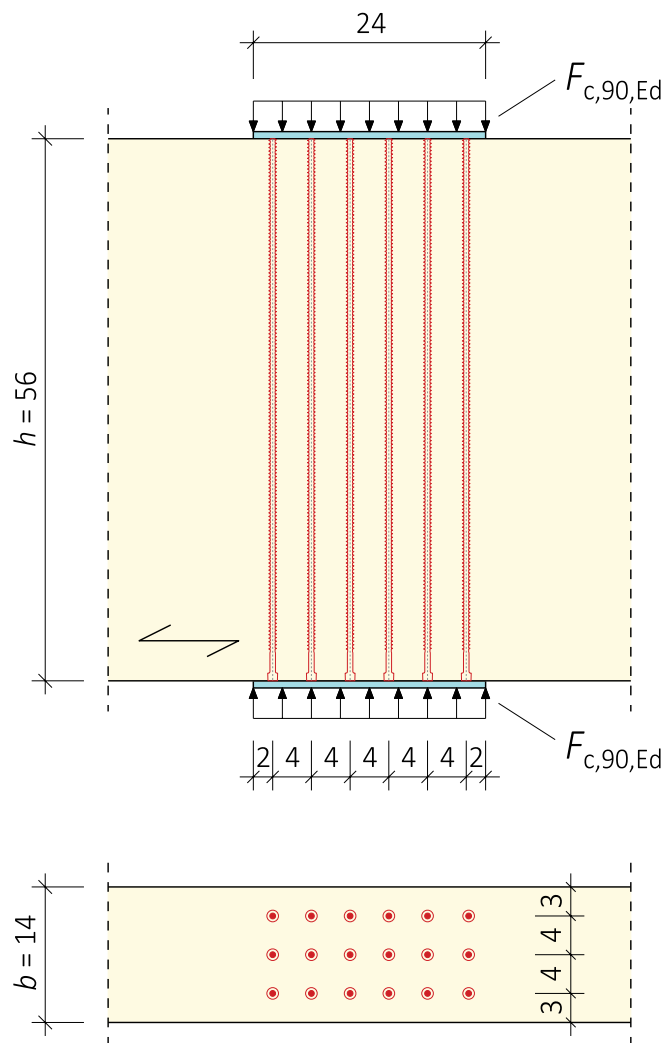


Figure 95: Calculation example - load transfer with through screws.

Geometry and material

Cross-sectional width	b	= 140 mm
Cross-sectional height	h	= 560 mm
Material		GL 24c
Characteristic bulk density	ρ_k	= 365 kg/m ³
Partial safety factor	γ_M	= 1.3
Support width	$b_{c,90}$	= 140 mm
Support length	$l_{c,90}$	= 240 mm
Support type		Intermediate support
Service class		1
Load duration class		Permanent
Modification factor	k_{mod}	= 0.6
Screw type		ASSY®plus VG 4 CH
		8.0 x 580 mm
Number of screws	$n_1 = n_2$	= 18

Execution note for the pilot hole:

- Nominal diameter of the drill bit in accordance with Table 11: 5 mm

Determination of the load-bearing capacity of an ASSY®plus VG 4 CH 8.0 x 580 mm screw (cut to 560 mm)

As in the previous example, the buckling resistance is the decisive factor; see above.

Therefore, the design value of the load-bearing capacity of a screw is obtained as follows:

$$F_{ax,c,d} = \min \left\{ \frac{k_{mod}}{\gamma_M} \cdot F_{w,k}, \frac{F_{c,k}}{\gamma_{M1}} \right\} = \min \left\{ \frac{0,6}{1,3} \cdot 55,6; \frac{11,4}{1,1} \right\} = 10,4 \text{ kN}$$

Load-bearing capacity verification for load transfer with 3 x 5 ASSY®plus VG 4 CH 8.0 x 580 mm screws (cut to 560 mm)

$$F_{c,90,Rd} = F_{ax,Rd} = n_{ef} \cdot F_{ax,c,d}$$

Where:

$$n_{ef} = n_1 = 18 \quad \text{see Eq. (3.24)}$$

$$F_{c,90,Rd} = 18 \cdot 10.400 = 187,2 \text{ kN}$$

Design of the steel plate thickness t_s in steel grade S235 with any screw spacing using Eq. (7.5)

Notes:

- For the design of the steel plate with maximum load-bearing capacity, $F_{c,Ed} = F_{c,Rd}$ is used.
- Since the design is carried out at the screw tips which are cut flush with the timber surface, d_{head} is replaced with d_1 .

$$\begin{aligned} t_s &\geq \sqrt{\frac{F_{c,Ed} \cdot (L_x + L_y)}{\pi \cdot d_1 \cdot f_{y,d}}} \\ &\geq \sqrt{\frac{10.400 \cdot (40 + 40)}{\pi \cdot 5 \cdot 235}} = 15,0 \text{ mm} \end{aligned}$$

Where:

$$F_{c,Ed} = \frac{F_{c,90,Ed}}{n} = \frac{F_{c,90,Rd}}{n_1} = \frac{187,2}{18} = 10,4 \text{ kN}$$

$$L_x = \min \left\{ a_1; 2 \cdot \max \left\{ a_{3,S}; \frac{a_1}{2} \right\} \right\}$$

$$= \min \left\{ 40; 2 \cdot \max \left\{ 20; \frac{40}{2} \right\} \right\} = 40 \text{ mm}$$

$$L_y = \min \left\{ a_2; 2 \cdot \max \left\{ a_{4,S}; \frac{a_2}{2} \right\} \right\}$$

$$= \min \left\{ 40; 2 \cdot \max \left\{ 30; \frac{40}{2} \right\} \right\} = 40 \text{ mm}$$

$d_1 = 5 \text{ mm}$ (siehe Tabelle 2, Spalte 3 – Bohrspitze)

$$f_{y,d} = \frac{f_{y,k}}{\gamma_{M0}} = \frac{235}{1,0} = 235 \text{ N/mm}^2$$

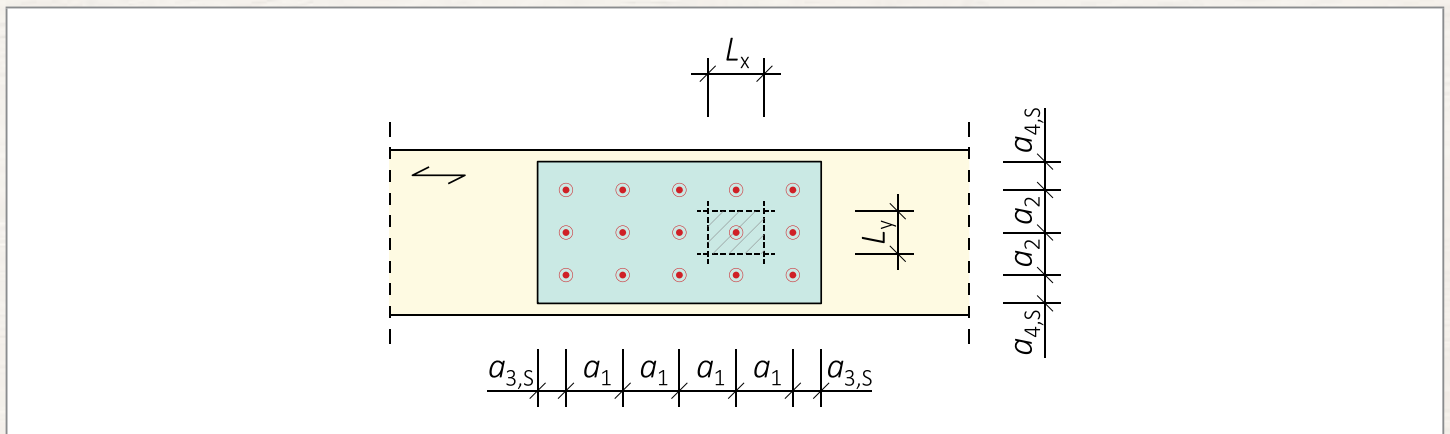


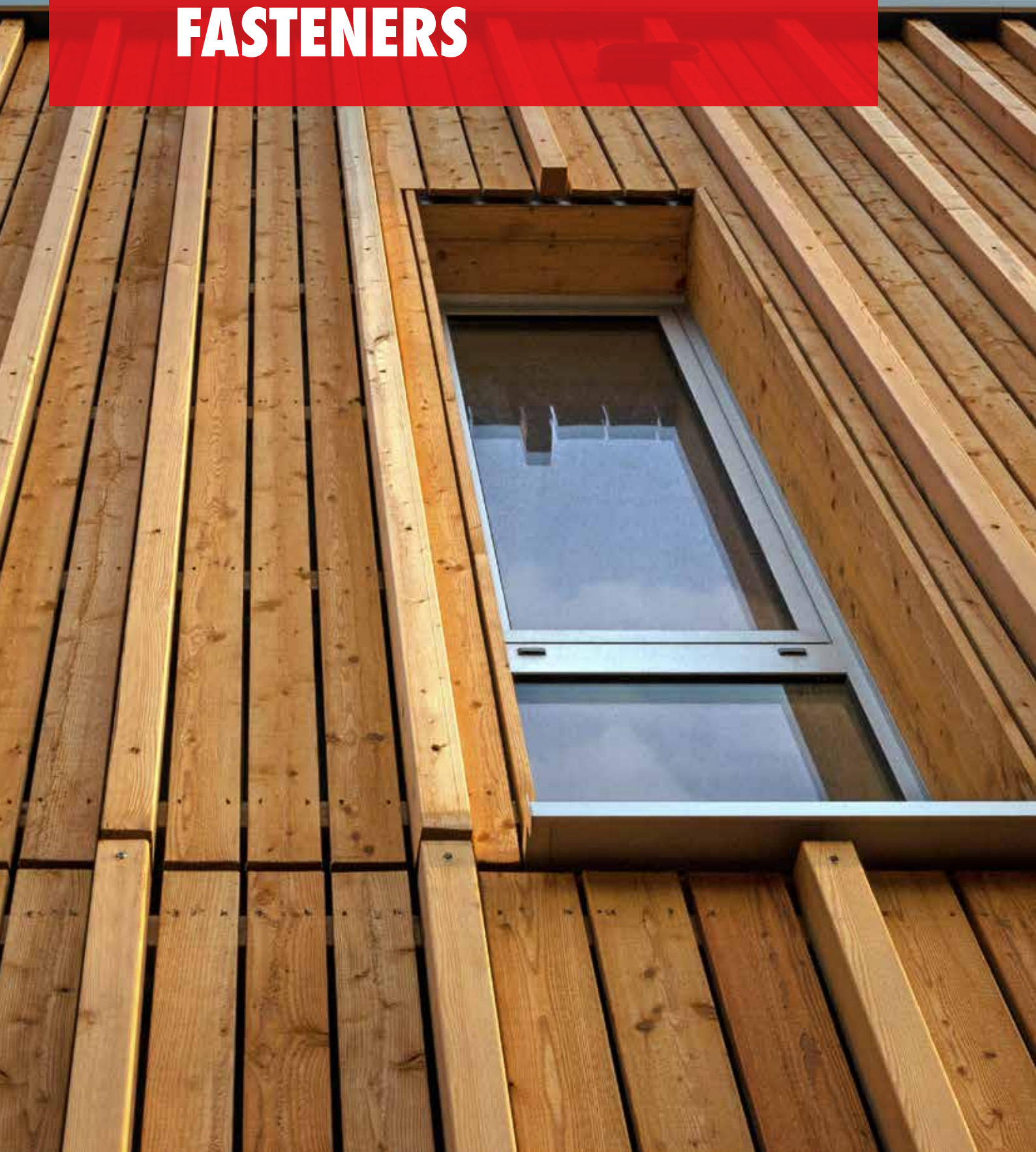
Figure 96: Spacing designations on the bearing plate.

A thick plate (DIN EN 10025-2-S235JR) with thickness $t_s = 15,0 \text{ mm}$ has been selected.

Comparison

In the example with through screws, approximately 40 % more load can be transferred compared to the load transfer with overlapping screws with the same support and beam geometry.

8 CRACK REINFORCEMENT WITH DOWEL-TYPE FASTENERS



8.1 General information

Fully threaded screws can prevent splitting perpendicular to the grain direction in connections with laterally loaded dowel-type fasteners. To achieve this, the screws must be arranged between the dowel-type fasteners, perpendicular to the grain direction (see Figure 97).

The splitting tensile force $F_{t,90,Ed}$ perpendicular to the grain for each reinforcing screw should, according to Blaß and Bejtka (2008), be assumed as 30 % of the design shear force per fastener and shear plane $F_{v,0,Ed}$. Accordingly, the verification of the reinforcement can be carried out using Eq. (8.1).

$$\eta = \frac{F_{t,90,Ed}}{F_{ax,t,d}} = \frac{0,3 \cdot F_{v,0,Ed}}{F_{ax,t,d}} \quad (8.1)$$

Where:

$F_{v,0,Ed}$ Design value of the effect of action per fastener and shear plane parallel to the grain direction

To determine the design value of the axial load-bearing capacity $F_{ax,1,d}$, see Section 3. The effective anchorage length l_w of the threaded section of the reinforcing screws is the smaller of the anchorage lengths $l_{w,1}$ at the screw head and $l_{w,2}$ at the screw tip (see Figure 97).

If each middle and side member is reinforced below each fastener, the effective number of fasteners according to EC 5 may be assumed as $n_{ef} = n$. The spacings of the laterally loaded dowel-type fasteners can be reduced to their minimum spacings. The reinforcing fully threaded screws should be arranged as close as possible to the shear plane with $a_{4,CG} \geq 3 \cdot d_r$. Here, d_r is the outer thread diameter of the reinforcing screw.

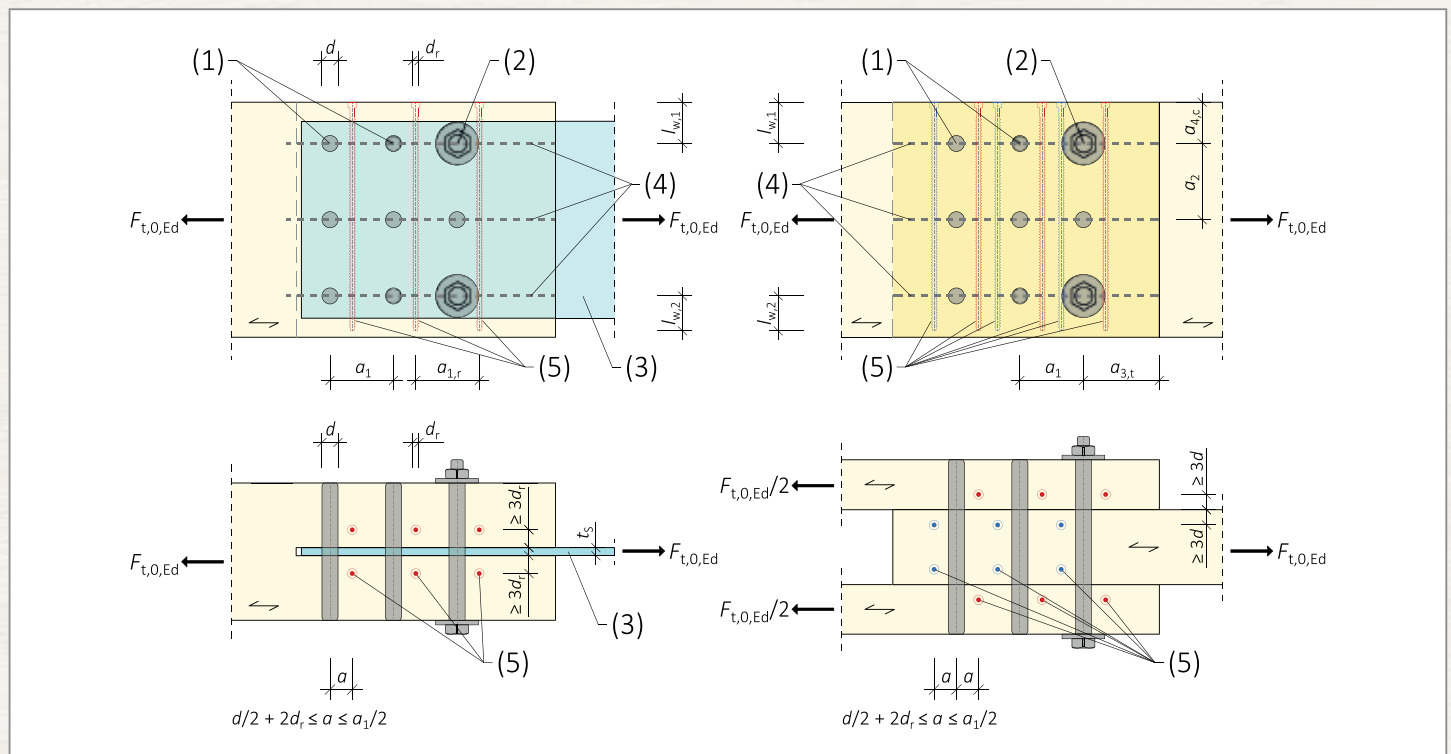


Figure 97: Dowel/bolt connection with reinforcing screws.

(1) dowel, (2) through bolt, (3) embedded sheet steel, (4) possible crack line, (5) reinforcing screw.

8.2 Calculation example

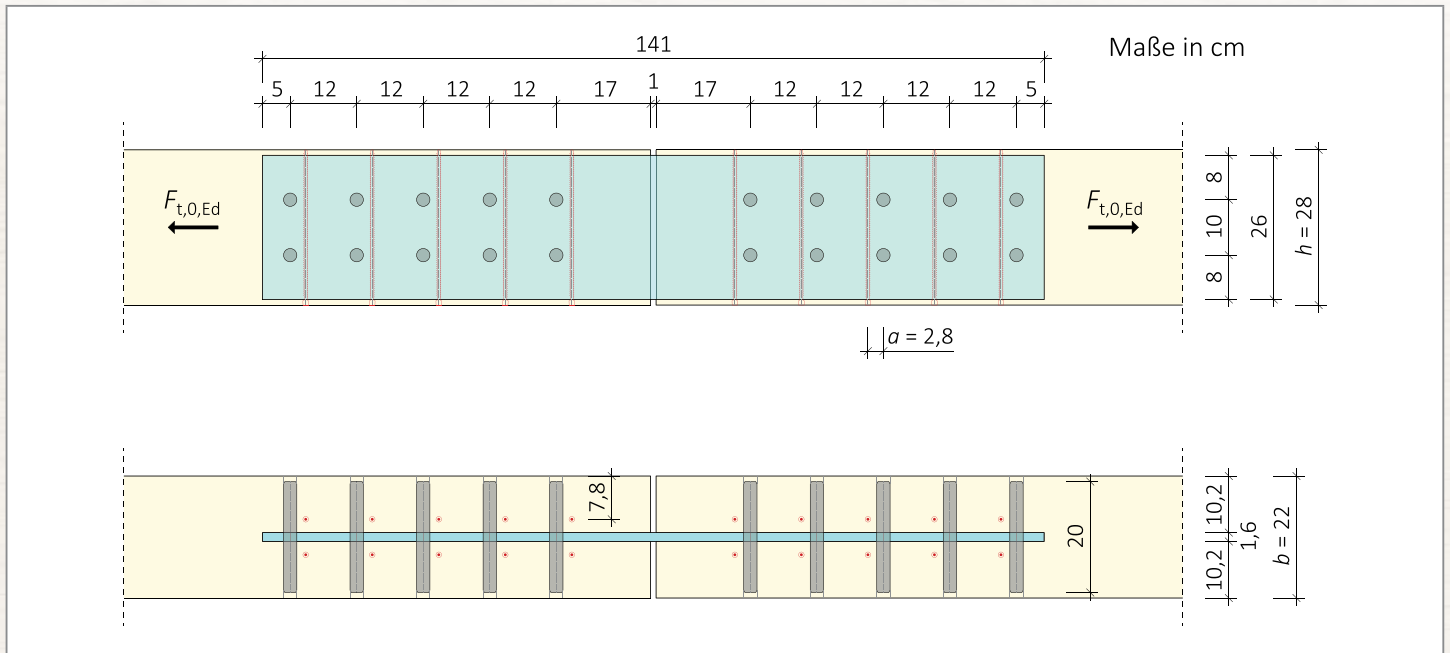


Figure 98: Dowel connection reinforced with fully threaded screws.

2 x 5 x 2 dia. 24 x 200 dowel

Cross-sectional width	$b_{1,2}$	= 220 mm
Cross-sectional height	$h_{1,2}$	= 280 mm
Material	$QS_{1,2}$	= GL 28h
Bulk density	$\rho_{k,1,2}$	= 425 kg/m ³
Embedment strength	$f_{h,k,SD\ddot{u}}$	= 26.5 N/mm ²
Tensile strength of the dowel	$f_{u,k,S235}$	= 360 N/mm ²
Sheet steel thickness	t_s	= 16 mm
Dowel embedment depth	t_1	= 92 mm

Action

Design load	$F_{t,0,Ed}$	= 410 kN
Service class		1
Load duration class		Short
Modification factor	k_{mod}	= 0.9
Partial safety factor	γ_M	= 1.3

Embedment strength of the dowel (identical to pre-drilled screw, see Section 4.3, Eq. [4.9]):

$$f_{h,k,SD\ddot{u}} = 0,082 \cdot \rho_k \cdot (1 - 0,01 \cdot d) = 0,082 \cdot 425 \cdot (1 - 0,01 \cdot 24) = 26,5 \text{ N/mm}^2$$

Yield moment of the dowel in accordance with EC 5:

$$M_{y,k} = 0,3 \cdot f_{u,k} \cdot d^{2,6} = 0,3 \cdot 360 \cdot 24^{2,6} = 418.768 \text{ Nmm}$$

Load-bearing capacity of the dowel, see Section 4.3, Eq. (4.6):

$$F_{v,k} = \min \left\{ \begin{aligned} & f_{h,k,SD\ddot{u}} \cdot t_1 \cdot d = 26,5 \cdot 92,5 \cdot 24 = 58.512 \text{ N} & (f) \\ & f_{h,k,SD\ddot{u}} \cdot t_1 \cdot d \cdot \left[\sqrt{2 + \frac{4 \cdot M_{y,k}}{f_{h,k,SD\ddot{u}} \cdot d \cdot t_1^2}} - 1 \right] + F_{rp,k} = 58.830 \cdot 0,519 = 30.441 \text{ N} & (g) \\ & 2,3 \cdot \sqrt{M_{y,k} \cdot f_{h,k,SD\ddot{u}} \cdot d} + F_{rp,k} = 2,3 \cdot \sqrt{418.768 \cdot 26,5 \cdot 24} = 37.536 \text{ N} & (h) \end{aligned} \right.$$

$$F_{v,k} = 30.441 \text{ N}$$

No axial load-bearing capacity with dowel

$$\rightarrow F_{rp,k} = \frac{F_{ax,k}}{4} = 0$$

Based on Eq. (3.22), the values for fully threaded screws
 $d = 8 \text{ mm}$ are as follows:

$$F_{t,k} = f_{tens,k} = 22,0 \text{ kN (see Section 3.4)}$$

$$f_{ax,k} = 12,0 \text{ N/mm}^2 \text{ (see Table 15)}$$



2 x 5 x 2 ASSY®plus
 VG 4 CH 8.0 x 280

The load-bearing capacity of the reinforcement (see Section 3.3)) is determined using the embedment depth above and below the dowel row for both cross-sections:

Position in member	Top	Bottom		
Anchorage length	$l_w = 90$	90	mm	In this case, l_w is identical at the screw tip (bottom) and the screw head (top).
Angle factor	$k_{ax} = 1.0$	1.0	-	
Angle factor	$k_{\beta} = 1.0$	1.0	-	Dimensions are dependent on the member height, screw length, dowel position and embedment depth!
Bulk density	$\rho_k = 425$	425	kg/m ³	
Reference bulk density	$\rho_{ref,k} = 350$	350	kg/m ³	
Withdrawal parameter	$f_{ax,k} = 12.0$	12.0	N/mm ²	

$$F_{w,k, oben/unten} = \frac{k_{ax} \cdot f_{ax,k} \cdot d_r \cdot l_w}{k_{\beta}} \cdot \left(\frac{\rho_k}{\rho_{ref,k}} \right)^{0,8} = \frac{1,0 \cdot 12,0 \cdot 8,0 \cdot 90}{1,0} \cdot \left(\frac{425}{350} \right)^{0,8} = 10,1 \text{ kN}$$

The design value of the axial resistance is obtained as:

$$F_{ax,t,d} = \min \left\{ \frac{k_{mod} \cdot F_{w,k, oben/unten}}{\gamma_M}; \frac{F_{t,k}}{\gamma_M} \right\} = \min \left\{ \frac{0,9 \cdot 10,1}{1,3}; \frac{22,0}{1,3} \right\} = 6,99 \text{ kN}$$

The effect of action on each dowel can be designed as:

$$F_{v,0,Ed} = \frac{F_{t,0,Ed}}{n_0 \cdot n_{90} \cdot n_{Scherfugen}} = \frac{410}{5 \cdot 2 \cdot 2} = 20,5 \text{ kN}$$

The effect of action on each reinforcing screw can be designed as:

$$F_{t,90,Ed} = 0,3 \cdot F_{v,0,Ed} = 0,3 \cdot 20,5 = 6,15 \text{ kN}$$

The verification is finally determined as:

$$\eta = \frac{F_{t,90,Ed}}{F_{ax,t,d}} = \frac{6,15}{6,99} = 0,88 \quad \checkmark$$

For the reinforcing screws, the spacings provided in Figure 94 apply; for the dowels pins, EC 5, Table 8.5 applies.

Additional notes:

In this example (load acting in **one direction**), the screws can be arranged according to the following recommendation:
 $0,5d + 2d_r \leq a \leq 2,5d$ (see Draft EC 5, Section 11.3.6, Figure 11.12), whereby $a \leq a_1 / 2$ is obtained.

For **alternating loads**, the reinforcing screws should be arranged centrally between the dowels with $a_{1,r} = a_{1,SD\ddot{u}}$, whereby $a = a_1 / 2$ is obtained.

The distance from the shear plane to the reinforcing screws is set to the minimum permissible with $a_{4,CG} = 3d_r$

9 MEMBER REINFORCEMENTS



9.1 Example of beam doubling

9.1.1 General information

An existing beam is subjected to additional loads due to conversion of the space. The system must be verified for the new loads and, if necessary, reinforced accordingly. The beam is depicted by the system in Figure 99. Before the reinforcement is installed, the beam must be unloaded or deformed to an appropriate extent in the opposite direction to the load. Before the insertion of the fully threaded screws, full-surface contact must be ensured, if necessary by installing structural partially threaded screws.

Beam doubling or beams with a flexible connection can be designed using the **beam doubling module**.

9.1.2 Specifications of the existing structure and reinforcement

For all specifications, index 1 is used for the reinforcement and index 2 for the existing structure.

Geometry and material		Existing structure	Reinforcement
Material		C24	GL 28h, horizontal
Cross-section	W x H	180 x 180 mm ²	280 x 80 mm ²
Elasticity modulus	E	11,000 N/mm ²	12,600 N/mm ²
Area moment of inertia	I	87.5 x 10 ⁶ N/mm ⁴	12.0 x 10 ⁶ N/mm ⁴
Section modulus	W	972,000 mm ³	-
Design value of the tensile strength	f _{t,0,d}	8.92 N/mm ²	-
Design value of the compressive strength	f _{c,0,d}	-	17.2 N/mm ²
Design value of the flexural strength	f _{m,d}	14.8 N/mm ²	17.2 N/mm ²
Design value of the shear strength	f _{v,d}	2.46 N/mm ²	2.15 N/mm ²

Fasteners			
ASSY®plus 4 VG CH 8.0 x 260			
Effective fastener spacing	s _{ef}	12.5 cm	12.5 cm
Anchorage lengths	l _w	147 mm	113 mm
Screw-in angle	ε	45°	45°

Action			
Sustained loads	g _k	0.7 kN/m	
Variable loads	q _k	1.3 kN/m	
Modification factor	k _{mod}	0.8	
Partial safety factor	γ _M	1.3	

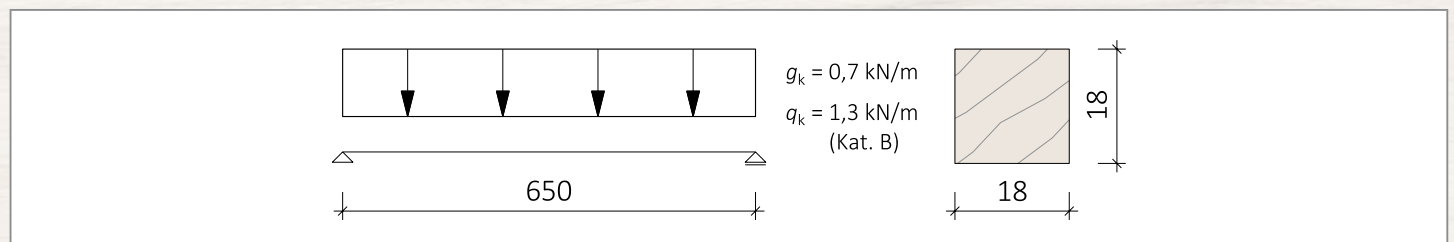


Figure 99: Calculation example – unreinforced system. Dimensions in cm.

9.1.3 Verification of the existing structure

First, it must be checked if the existing beam has sufficient load-bearing capacity for the new load in the ultimate limit state:

Design value of the action: $q_d = 1.35 \cdot 0.7 + 1.5 \cdot 1.3 = 2.90 \text{ kN/m}$

Acting moment: $M_{Ed} = \frac{q_d \cdot l^2}{8} = \frac{2.9 \cdot 6.5^2}{8} = 15.3 \text{ kNm}$

Acting shear force: $V_{Ed} = \frac{q_d \cdot l}{2} = \frac{2.9 \cdot 6.5}{2} = 9.43 \text{ kN}$

Bending stress:

$$\sigma_{m,d} = \frac{M_{Ed}}{W_2} = \frac{15,3 \cdot 10^6}{972.000} = 15,8 \text{ N/mm}^2$$

Utilisation:

$$\eta_m = \frac{\sigma_{m,d}}{f_{m,d,2}} = \frac{15,8}{14,8} = 1,06 > 1,0 \quad \text{⚡}$$

The verification in the ultimate limit state is not fulfilled. The beam must be reinforced.

9.1.4 Verification of the reinforcement

The existing beam made of C24 is reinforced with glued laminated timber in GL 28h on the top. Since the connection of the two beams is made using ASSY®plus 4 VG CH 8.0 x 260 mm screws, $s_{ef} = 12,5$ cm, a flexible connection must be assumed. Flexibly connected beams can be designed in accordance with EC 5 Part 1-1, Annex B, using the γ method. The cross-section of the reinforced system is shown on the left of Figure 100.

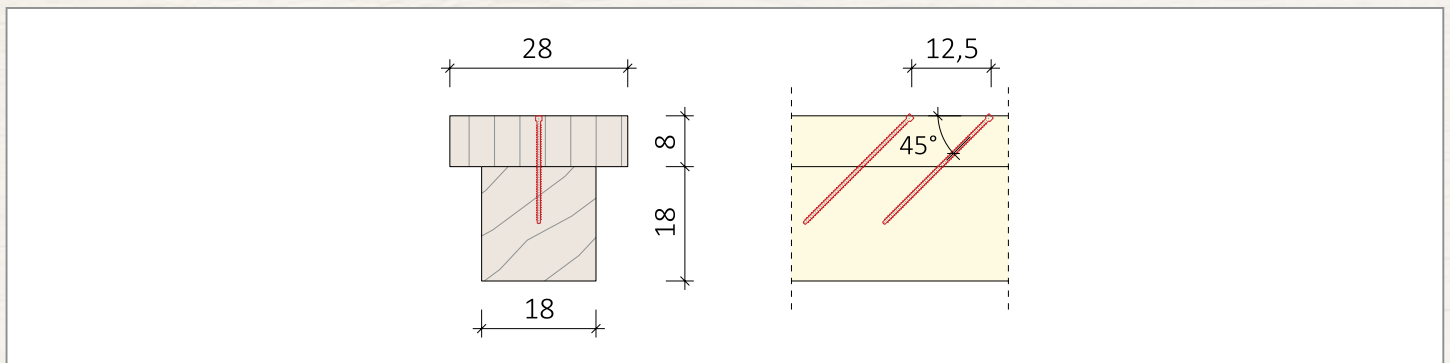


Figure 100: Calculation example – cross-section of the reinforced system. Dimensions in cm.

In the following, the time $t = 0$ in the ultimate limit state (ULS) is considered. For a complete system verification, the time $t = \infty$ in the ULS must also be considered, as well as times $t = 0$ and $t = \infty$ in the serviceability limit state (SLS).

First, the fastener stiffness parallel to the joints is designed. Since the fasteners are installed with an incline, the value $K_{ULS,ax,ges}$ is determined using the axial stiffness $K_{ULS,ax,i}$ based on Eq. (9.1) and assuming a spring connected in series:

$$K_{ULS,ax,ges} = \frac{1}{\sum_{i=1}^n \frac{1}{K_{ULS,ax,i}}} \quad (9.1)$$

Where:

$$K_{ULS,ax,i} = \frac{2}{3} \cdot \frac{K_{SLS,ax,i}}{\gamma_M}$$

The values of the axial stiffness are designed in accordance with ETA-11/0190 for softwood using Eq. (9.2).

$$\left. \begin{matrix} K_{SLS,ax,1} \\ K_{SLS,ax,2} \end{matrix} \right\} = 1.250 \cdot d^{0,2} \cdot l_{w,i}^{0,4} \cdot \rho_{mean,i}^{0,2} = \begin{cases} 1.250 \cdot 8^{0,2} \cdot 113^{0,4} \cdot 460^{0,2} = 40.511 \text{ N/mm} \\ 1.250 \cdot 8^{0,2} \cdot 147^{0,4} \cdot 350^{0,2} = 47.534 \text{ N/mm} \end{cases} \quad (9.2)$$

Based on Eq. (9.1), $K_{ULS,ax,ges}$ is designed as:

$$K_{ULS,ax,ges} = \frac{2}{3 \cdot 1,3} \cdot \frac{1}{\left(\frac{1}{40.511} + \frac{1}{47.534} \right)} = 11.216 \text{ N/mm} \quad (9.3)$$

The value for the stiffness parallel to the joint $K_{SLS,v}$ is determined as:

$$K_{SLS,v,d,1} = K_{SLS,v} = K_{ULS,ax} \cdot \cos^2 \varepsilon = 11.261 \cdot \cos^2 45^\circ = 5.610 \text{ N/mm}$$

When calculating the γ factors to determine the effective bending stiffness, the reduced stiffness $E_{d,i}$ must be taken into account in the ULS. This results in $E_{d,1}$ or $E_{d,2}$ as:

$$\left. \begin{matrix} E_{d,1} \\ E_{d,2} \end{matrix} \right\} = \frac{E_{d,i}}{\gamma_M} = \left\{ \begin{matrix} 9.692 \text{ N/mm}^2 \\ 8.462 \text{ N/mm}^2 \end{matrix} \right.$$

Subsequently, the γ_i factors are determined as:

$$\gamma_1 = \frac{1}{1 + \frac{\pi^2 \cdot E_{d,1} \cdot A_1 \cdot s_1}{K_{SLS,v,d,1} \cdot I^2}} = \frac{1}{1 + \frac{\pi^2 \cdot 9.692 \cdot 22.400 \cdot 125}{5.610 \cdot 6.500^2}} = 0,469$$

$$\gamma_2 = 1,0$$

The spacings of the neutral axes for the partial cross-sections $a_{mm,i}$ are determined as:

$$\begin{aligned} a_{mm,2} &= \frac{\gamma_1 \cdot E_{d,1} \cdot A_1 \cdot (h_1 + h_2)}{2 \cdot (\gamma_1 \cdot E_{d,1} \cdot A_1 + \gamma_2 \cdot E_{d,2} \cdot A_2)} \\ &= \frac{0,469 \cdot 9.692 \cdot 22.400 \cdot (80 + 180)}{2 \cdot (0,469 \cdot 9.692 \cdot 22.400 + 1,0 \cdot 8.462 \cdot 32.400)} \\ &= 35,2 \text{ mm} \\ a_{mm,1} &= \frac{h_1 + h_2}{2} - a_{mm,2} = \frac{80 + 180}{2} - 35,2 = 95 \text{ mm} \end{aligned}$$

The effective bending stiffness of the cross-section $(EI)_{ef}$ is determined using Eq. (9.4).

$$\begin{aligned} (EI)_{ef} &= E_{d,1} \cdot I_1 + \gamma_1 \cdot E_{d,1} \cdot A_1 \cdot a_{mm,1}^2 + E_{d,2} \cdot I_2 + \gamma_2 \cdot E_{d,2} \cdot A_2 \cdot a_{mm,2}^2 \\ &= 9.692 \cdot 12,0 \cdot 10^6 + 0,469 \cdot 9.692 \cdot 22.400 \cdot 95^2 + 8.462 \cdot 87,5 \cdot 10^6 + 1,0 \cdot 8.462 \cdot 32.400 \cdot 35,2^2 \\ &= 2,115 \cdot 10^{12} \text{ Nmm}^2 \end{aligned} \quad (9.4)$$

Using the effective bending stiffness, the normal and bending stress components acting in partial cross-sections 1 and 2 can be designed. These are then added together to design the edge stresses of the partial cross-sections.

For partial cross-section 1 (reinforcement) the following stresses and utilisation ratios are determined:

$$\begin{aligned} \sigma_{c,d,1} &= \frac{M_{Ed}}{(EI)_{ef}} \cdot \gamma_1 \cdot a_{mm,1} \cdot E_{d,1} = \frac{15,3 \cdot 10^6}{2,115 \cdot 10^{12}} \cdot 0,469 \cdot 95 \cdot 9.692 = 3,12 \text{ N/mm}^2 \\ \sigma_{m,d,1} &= \frac{M_{Ed}}{(EI)_{ef}} \cdot 0,5 \cdot h_1 \cdot E_{d,1} = \frac{15,3 \cdot 10^6}{2,115 \cdot 10^{12}} \cdot 0,5 \cdot 80 \cdot 9.692 = 2,80 \text{ N/mm}^2 \\ \sigma_{min,d,1} &= -(\sigma_{c,d,1} + \sigma_{m,d,1}) = -(3,12 + 2,80) = -5,92 \text{ N/mm}^2 \\ \eta_{c,1} &= \frac{3,12}{17,2} = 0,18 \leq 1,0 \\ \eta_{m,1} &= \frac{5,92}{17,2} = 0,34 \leq 1,0 \end{aligned}$$

For partial cross-section 2 (existing structure) the following stresses and utilisation ratios are determined:

$$\sigma_{t,d,2} = \frac{M_{Ed}}{(EI)_{ef}} \cdot \gamma_2 \cdot a_{mm,2} \cdot E_{d,2} = \frac{15,3 \cdot 10^6}{2,115 \cdot 10^{12}} \cdot 1,0 \cdot 35,2 \cdot 8,462 = 2,15 \text{ N/mm}^2$$

$$\sigma_{m,d,2} = \frac{M_{Ed}}{(EI)_{ef}} \cdot 0,5 \cdot h_2 \cdot E_{d,2} = \frac{15,3 \cdot 10^6}{2,115 \cdot 10^{12}} \cdot 0,5 \cdot 180 \cdot 8,462 = 5,51 \text{ N/mm}^2$$

$$\sigma_{max,d,2} = \sigma_{t,d,2} + \sigma_{m,d,2} = 2,15 + 5,51 = 7,66 \text{ N/mm}^2$$

$$\eta_{t,2} = \frac{2,15}{8,92} = 0,24 \leq 1,0$$

$$\eta_{m,2} = \frac{7,66}{14,8} = 0,52 \leq 1,0$$

The maximum shear stress in the partial cross-section occurs on the neutral axes. For partial cross-section 2:

$$h = \frac{h_2}{2} + a_{mm,2} = \frac{180}{2} + 35,2 = 125,2 \text{ mm}$$

$$\tau_{max,d,2} = \frac{(0,5 \cdot E_{d,2} \cdot b_2 \cdot h^2) \cdot V_{Ed}}{b_2 \cdot (EI)_{ef}} = \frac{(0,5 \cdot 8,462 \cdot 180 \cdot 125,2^2) \cdot 9,430}{180 \cdot 2,115 \cdot 10^{12}} = 0,30 \text{ N/mm}^2$$

$$\eta_{v,2} = \frac{0,30}{2,46} = 0,12 \leq 1,0$$

The fastener must also be verified. The effect of action of a screw is determined as:

$$F_{VM,d} = \frac{\gamma_1 \cdot E_1 \cdot A_1 \cdot a_{mm,1} \cdot s_1 \cdot V_{Ed}}{(EI)_{ef}} = \frac{0,469 \cdot 9,692 \cdot 22,400 \cdot 95 \cdot 125 \cdot 9,430}{2,115 \cdot 10^{12}} = 5,391 \text{ N}$$

The pull-out resistance of a screw as described in Section 3.7.1 is designed as:

$$F_{w,k} = \min \left\{ \begin{array}{l} \frac{1,0 \cdot 12,0 \cdot 8,0 \cdot 113}{1,0} \cdot \left(\frac{425}{350} \right)^{0,8} = 12,7 \text{ kN} \\ \frac{1,0 \cdot 12,0 \cdot 8,0 \cdot 147}{1,0} \cdot \left(\frac{350}{350} \right)^{0,8} = 14,1 \text{ kN} \end{array} \right.$$

$$F_{ax,t,d} = \min \left\{ \begin{array}{l} \frac{k_{mod} \cdot F_{w,k}}{\gamma_M} = \frac{0,8 \cdot 12,7}{1,3} = \underline{\underline{7,80 \text{ kN}}} \\ \frac{F_{t,k}}{\gamma_M} = \frac{22}{1,3} = 16,9 \text{ kN} \end{array} \right.$$

The axial load-bearing capacity must be converted to a load-bearing capacity acting parallel to the joint $F_{v,d}$:

$$F_{v,d} = F_{ax,t,d} \cdot (\cos \varepsilon + \mu \cdot \sin \varepsilon) = 7,8 \cdot (\cos 45^\circ + 0,25 \cdot \sin 45^\circ) = 6,89 \text{ kN}$$

The utilisation ratio of the screw is then determined as:

$$\eta_{ax} = \frac{F_{VM,d}}{F_{v,d}} = \frac{5,39}{6,89} = 0,78 \leq 1,0$$

Execution note:

- Contact must be ensured by installing structural partially threaded screws.

9.2 Example of lateral reinforcement

9.2.1 General information

The following boundary conditions must be observed when designing a system with lateral reinforcement:

- Both cross-sections are designed as single-span beams with supports in the same positions and therefore with the same span length.
- The existing cross-section can only transfer part of its load to the reinforcing member if the existing beam is unloaded before screwing in.

$$q_{d,i} = q_d \cdot \frac{E_{0,\text{mean},i} \cdot I_{y,i}}{\sum E_i \cdot I_i} \quad (9.5)$$

Where:

q_d	Design value of the load, here as the line load of the decisive combination
$E_{0,\text{mean},i}$	Mean elasticity modulus parallel to the grain direction of cross-section i
$I_{y,i}$	Area moment of inertia around the y-axis of cross-section i
$\sum E_i \cdot I_i$	Sum of all bending stiffnesses of the individual cross-section i

The verification of the serviceability limit state requires the deflection to be designed in the initial state (index *inst*, Eq. [9.6]) and the final state (index *fin*, Eq. [9.7]) in accordance with EC 5, NDP to Section 7.2(2) Ultimate limits for deflection. The total final deflection (index *net,fin*, Eq. [9.8]) must also be determined.

$$w_{\text{inst}} = w_{\text{inst}}(q_{\text{char}}) \quad (9.6)$$

$$w_{\text{fin}} = w_{\text{inst}}(q_{\text{char}}) + w_{\text{creep}}(q_{\text{qs}}) \quad (9.7)$$

$$w_{\text{net,fin}} = w_{\text{inst}}(q_{\text{qs}}) + w_{\text{creep}}(q_{\text{qs}}) \quad (9.8)$$

Where:

q_{char}	Characteristic load combination $\sum_{i \geq 1} g_k + q_{k,1} + \sum_{i > 1} \psi_0 \cdot q_{k,i}$
q_{qs}	Quasi-constant load combination $\sum_{i \geq 1} g_k + \sum_{i \geq 1} \psi_2 \cdot q_{k,i}$
$w_{\text{creep}} = w_{\text{inst}} \cdot k_{\text{def}}$	Creep deformation
k_{def}	Creep factor (see EC 5, Tab. 3.2); for ST/FST, GL, LVL: SC 1: 0.6; SC 2: 0.8; SC 3: 2.0
ψ_0, ψ_2	Combination factors in accordance with DIN EN 1990

9.2.2 Specifications of the existing structure and reinforcement

Geometry and material		Existing structure	Reinforcement
Material		D30	GLVL made of beech (ETA-14/0354)
Beam length	L_{beam}	5 m	5 m
Service class	SC	1	1
Cross-section	$W \times H$	220 x 280 mm ²	40 x 300 mm ²
Elasticity modulus	E	11,000 N/mm ²	16,800 N/mm ²
Bulk density in kg/m ³	ρ_k	530 kg/m ³	730 kg/m ³
Characteristic flexural strength	$f_{m,k}$	30 N/mm ²	75 N/mm ²
Characteristic shear strength	$f_{v,k}$	3.9 N/mm ²	4.5 N/mm ²
Crack factor	k_{cr}	0.67	+1.0

Fasteners			
Screw cross consisting of ASSY®plus VG 4 CH 6.0 x 180			
Screw cross spacing	e_{con}	1.25 m	1.25 m
Face layer/screw angle	β	45°	45°
Screw-in angle	ε	90°	90°

Action			
LC0: Permanent loads (LDC = permanent)	g_k	5.7 kN/m	
LC1: Variable loads (category B, LDC = medium)	$q_{k,1}$	4.0 kN/m	
LC2: Variable loads (snow, LDC = short)	$q_{k,2}$	2.0 kN/m	
Partial safety factor	γ_M	1.3	

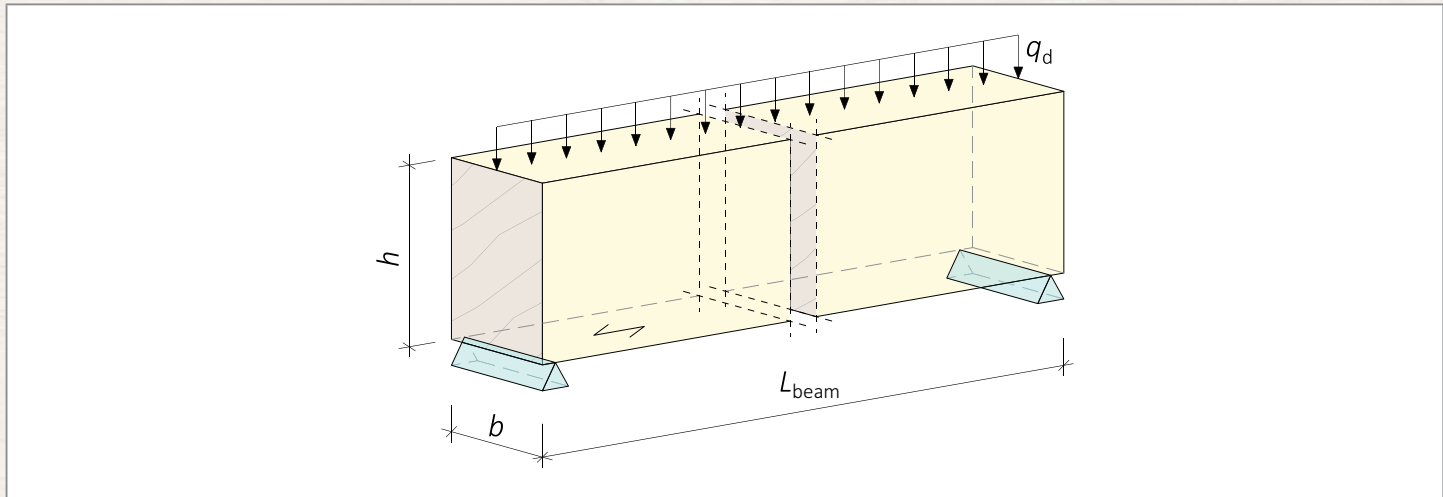


Figure 101: Calculation example – existing system.

Cross-section characteristics

Based on the geometry and material, the cross-sectional area A , the section modulus W_y and the area moment of inertia I_y are determined (index 1 for the reinforcement, index 2 for the existing structure):

$$A_1 = b_1 \cdot h_1 = 4 \cdot 30 = 120 \text{ cm}^2$$

$$A_2 = b_2 \cdot h_2 = 22 \cdot 28 = 616 \text{ cm}^2$$

$$W_{y,1} = \frac{b_1 \cdot h_1^2}{6} = \frac{4 \cdot 30^2}{6} = 600 \text{ cm}^3$$

$$W_{y,2} = \frac{b_2 \cdot h_2^2}{6} = \frac{22 \cdot 28^2}{6} = 2.875 \text{ cm}^3$$

$$I_{y,1} = \frac{b_1 \cdot h_1^3}{12} = \frac{4 \cdot 30^3}{12} = 9.000 \text{ cm}^4$$

$$I_{y,2} = \frac{b_2 \cdot h_2^3}{12} = \frac{22 \cdot 28^3}{12} = 40.245 \text{ cm}^4$$

9.2.3 Verification of the existing structure

Decisive combination

$$\begin{aligned} \text{Load case combination (LCC)} \quad q_d &= 1,35 \cdot LF_0 + 1,5 \cdot LF_1 \\ &= 1,35 \cdot 5,75 + 1,5 \cdot 4,0 = 13,8 \text{ kN/m} \end{aligned}$$

$$\text{Load duration class} \quad \text{Medium}$$

$$\text{Modification factor} \quad k_{\text{mod}} = 0,8$$

$$\text{Deformation factor} \quad k_{\text{def}} = 0,6$$

First, it must be checked based on the member verifications whether reinforcement is required:

$$M_{\text{Ed}} = q_d \cdot \frac{L_{\text{Träger}}^2}{8} = 13,8 \cdot \frac{5^2}{8} = 43,1 \text{ kNm}$$

$$V_{\text{Ed}} = q_d \cdot \frac{L_{\text{Träger}}}{2} = 13,8 \cdot \frac{5}{2} = 34,5 \text{ kN}$$

$$\sigma_{\text{m,d}} = \frac{M_{\text{Ed}}}{W_{y,2}} = \frac{43,1}{2,87} = 15,0 \text{ N/mm}^2$$

$$\tau_{\text{z,d}} = 1,5 \cdot \frac{V_{\text{Ed}}}{k_{\text{cr,2}} \cdot A_2} = 1,5 \cdot \frac{34,5}{0,67 \cdot 61,6} = 1,25 \text{ N/mm}^2$$

The following verifications are determined in the ultimate limit state (ULS):

$$f_{\text{m,d,2}} = \frac{f_{\text{m,k,2}} \cdot k_{\text{mod}}}{\gamma_{\text{M}}} = \frac{30 \cdot 0,8}{1,3} = 18,5 \text{ N/mm}^2$$

$$f_{\text{v,d,2}} = \frac{f_{\text{v,k,2}} \cdot k_{\text{mod}}}{\gamma_{\text{M}}} = \frac{3,9 \cdot 0,8}{1,3} = 2,40 \text{ N/mm}^2$$

$$\eta_{\text{m}} = \frac{\sigma_{\text{m,d}}}{f_{\text{m,d,2}}} = \frac{15,0}{18,5} = 0,81 < 1,0 \quad \checkmark$$

$$\eta_{\text{v}} = \frac{\tau_{\text{z,d}}}{f_{\text{v,d,2}}} = \frac{1,25}{2,40} = 0,52 < 1,0 \quad \checkmark$$

Using the decisive characteristic load combination, the deflections required for the verifications in the serviceability limit state are designed based on Eq. (9.6). The combination factors in accordance with DIN EN 1990 are $\psi_0 = 0,5$ (snow), $\psi_2 = 0,3$ (live load, category B) and $\psi_2 = 0$ (snow).

$$q_{\text{char}} = 5,75 + 4 + 0,5 \cdot 2 = 10,75 \text{ kN/m}$$

$$q_{\text{qs}} = 5,75 + 0,3 \cdot 4 + 0 \cdot 2 = 6,95 \text{ kN/m}$$

$$w_{\text{inst}}(q_{\text{char}}) = \frac{q_{\text{char}} \cdot L_{\text{Träger}}^4}{76,8 \cdot E_{0,\text{mean},2} \cdot I_{y,2}} = \frac{10,75 \cdot 5^4}{76,8 \cdot 11000 \cdot 40245} \cdot 10^8 = 19,8 \text{ mm}$$

The initial deformation of the quasi-permanent load component $w_{\text{inst}}(q_{\text{qs}})$ can be used to design the creep deformation w_{creep} with a creep factor $k_{\text{def}} = 0.6$ for ST/FST:

$$w_{\text{inst}}(q_{\text{qs}}) = \frac{q_{\text{qs}} \cdot L_{\text{Träger}}^4}{76,8 \cdot E_{0,\text{mean},2} \cdot I_{y,2}} = \frac{6,95 \cdot 5^4}{76,8 \cdot 11000 \cdot 40245} \cdot 10^8 = 12,8 \text{ mm}$$

$$w_{\text{creep}}(q_{\text{qs}}) = 12,8 \cdot 0,6 = 7,68 \text{ mm}$$

The final deflection w_{fin} and the total final deflection under quasi-permanent loads $w_{\text{net,fin}}$ are designed using Eq. (9.7) and (9.8):

$$w_{\text{fin}} = 19,8 + 7,68 = 27,4 \text{ mm}$$

$$w_{\text{net,fin}} = 12,8 + 7,68 = 20,5 \text{ mm}$$

Using the ultimate limits for deformation in accordance with EC 5, Section 7.2 (NDP to 7.2[2]) Ultimate limits for deflection $w_{\text{inst}} \leq L_{\text{Träger}}/300$; $w_{\text{fin}} \leq L_{\text{Träger}}/200$, $w_{\text{net,fin}} \leq L_{\text{Träger}}/300$, the following results can be obtained:

$$\eta_{\text{inst}} = \frac{w_{\text{inst}}}{L_{\text{Träger}}/300} = \frac{19,8}{5.000/300} = 1,19 > 1,0 \quad \text{✗}$$

$$\eta_{\text{fin}} = \frac{w_{\text{fin}}}{L_{\text{Träger}}/200} = \frac{27,4}{5.000/200} = 1,1 > 1,0 \quad \text{✗}$$

$$\eta_{\text{net,fin}} = \frac{w_{\text{net,fin}}}{L_{\text{Träger}}/300} = \frac{20,5}{5.000/300} = 1,23 > 1,0 \quad \text{✗}$$

The verifications in the serviceability limit state are not fulfilled. Reinforcement is required.

9.2.4 Verification of the reinforced system

For the reinforcement, a 40 mm-thick beech LVL board (ETA-14/0354) is used on one side, which is fastened using screw crosses consisting of ASSY®plus VG 4 CH 6.0 x 180 mm screws with a spacing of $e_{\text{con}} = 1.25 \text{ m}$.

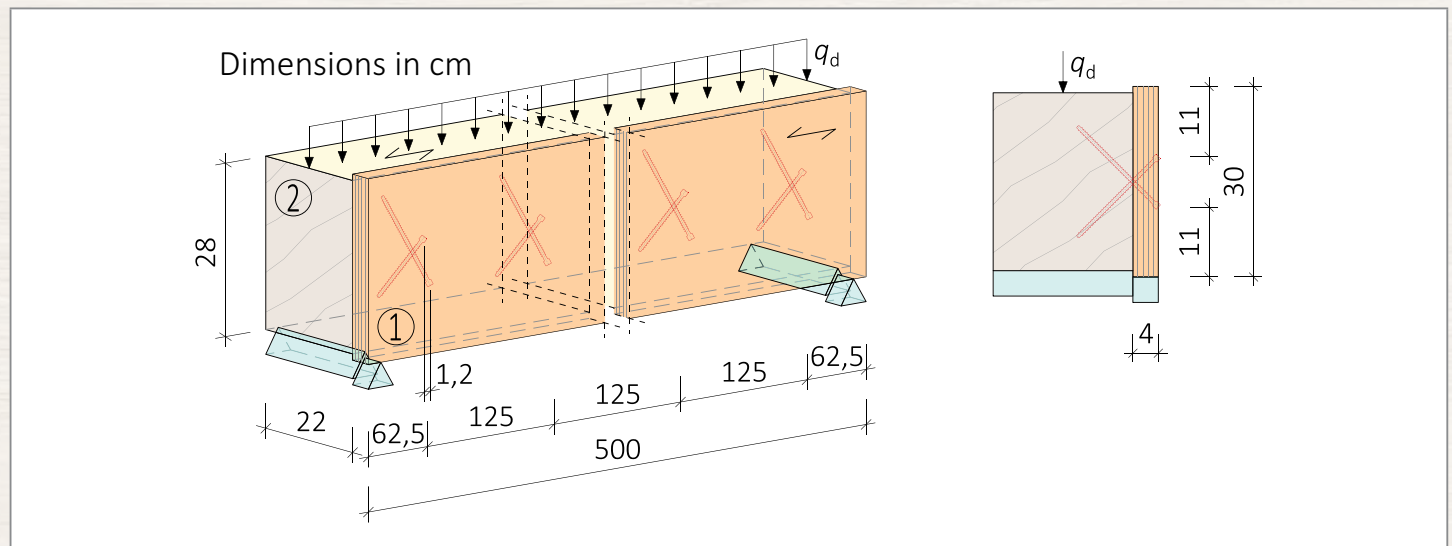


Figure 102: Calculation example – existing system with reinforcement.

Load components $q_{d,1}$ and $q_{d,2}$ as determined by Eq. (9.5)

$$q_{d,1} = q_d \cdot \frac{E_{0,\text{mean},1} \cdot I_{y,1}}{\Sigma E_i \cdot I_i} = 13,8 \cdot \frac{168 \cdot 90}{168 \cdot 90 + 110 \cdot 402,45} = 3,51 \text{ kN/m}$$

$$q_{d,2} = q_d \cdot \frac{E_{0,\text{mean},2} \cdot I_{y,2}}{\Sigma E_i \cdot I_i} = 13,8 \cdot \frac{110 \cdot 402,45}{168 \cdot 90 + 110 \cdot 402,45} = 10,3 \text{ kN/m}$$

The bending and shear stresses are designed using the design values of the moment and shear force:

$$M_{Ed,1} = q_{d,1} \cdot \frac{L_{Träger}^2}{8} = 3,51 \cdot \frac{5^2}{8} = 11,0 \text{ kNm}$$

$$M_{Ed,2} = q_{d,2} \cdot \frac{L_{Träger}^2}{8} = 10,3 \cdot \frac{5^2}{8} = 32,2 \text{ kNm}$$

$$V_{Ed,1} = q_{d,1} \cdot \frac{L_{Träger}}{2} = 3,51 \cdot \frac{5}{2} = 8,78 \text{ kN}$$

$$V_{Ed,2} = q_{d,2} \cdot \frac{L_{Träger}}{2} = 10,3 \cdot \frac{5}{2} = 25,8 \text{ kN}$$

$$\sigma_{m,d,1} = \frac{M_{Ed,1}}{W_{y,1}} = \frac{11,0}{0,6} = 18,3 \text{ N/mm}^2$$

$$\sigma_{m,d,2} = \frac{M_{Ed,2}}{W_{y,2}} = \frac{32,2}{2,87} = 11,2 \text{ N/mm}^2$$

$$\tau_{z,d,1} = 1,5 \cdot \frac{V_{Ed,1}}{k_{cr,1} \cdot A_1} = 1,5 \cdot \frac{8,78}{1,0 \cdot 12} = 1,10 \text{ N/mm}^2$$

$$\tau_{z,d,2} = 1,5 \cdot \frac{V_{Ed,2}}{k_{cr,2} \cdot A_2} = 1,5 \cdot \frac{25,8}{0,67 \cdot 61,6} = 0,94 \text{ N/mm}^2$$

The following stress verifications are obtained in the ULS:

$$f_{m,d,1} = \frac{f_{m,k,1} \cdot k_{mod}}{\gamma_M} = \frac{75 \cdot 0,8}{1,3} = 46,2 \text{ N/mm}^2$$

$$f_{m,d,2} = \frac{f_{m,k,2} \cdot k_{mod}}{\gamma_M} = \frac{30 \cdot 0,8}{1,3} = 18,5 \text{ N/mm}^2$$

$$\eta_{m,1} = \frac{\sigma_{m,d,1}}{f_{m,d,1}} = \frac{18,3}{46,2} = 0,40 < 1,0 \quad \checkmark$$

$$\eta_{m,2} = \frac{\sigma_{m,d,2}}{f_{m,d,2}} = \frac{11,2}{18,5} = 0,61 < 1,0 \quad \checkmark$$

$$\eta_{v,1} = \frac{\tau_{z,d,1}}{f_{v,d,1}} = \frac{1,10}{2,77} = 0,40 < 1,0 \quad \checkmark$$

$$\eta_{v,2} = \frac{\tau_{z,d,2}}{f_{v,d,2}} = \frac{0,94}{2,40} = 0,39 < 1,0 \quad \checkmark$$

$$f_{v,d,1} = \frac{f_{v,k,1} \cdot k_{mod}}{\gamma_M} = \frac{4,5 \cdot 0,8}{1,3} = 2,77 \text{ N/mm}^2$$

$$f_{v,d,2} = \frac{f_{v,k,2} \cdot k_{mod}}{\gamma_M} = \frac{3,9 \cdot 0,8}{1,3} = 2,40 \text{ N/mm}^2$$

Based on the deflection of the single-span beam in the initial and final state, the deformations required for the verifications in the SLS are obtained using Eq. (9.6) to (9.8):

$$w_{inst}(q_{char}) = \frac{q_{char} \cdot L_{Träger}^4}{76,8 \cdot \Sigma E_{0,mean,i} \cdot I_{y,i}} = \frac{10,75 \cdot 5^4}{76,8 \cdot (16,8 \cdot 9.000 + 11 \cdot 40.245)} \cdot 10^5 = 14,7 \text{ mm}$$

$$w_{inst}(q_{qs}) = \frac{q_{qs} \cdot L_{Träger}^4}{76,8 \cdot \Sigma E_{0,mean,i} \cdot I_{y,i}} = \frac{6,95 \cdot 5^4}{76,8 \cdot (16,8 \cdot 9.000 + 11 \cdot 40.245)} \cdot 10^5 = 9,52 \text{ mm}$$

$$w_{creep} = w_{inst}(q_{qs}) \cdot k_{def} = 9,52 \cdot 0,6 = 5,71 \text{ mm}$$

$$w_{fin} = 14,7 + 5,71 = 20,4 \text{ mm}$$

$$w_{net,fin} = 9,52 + 5,71 = 15,2 \text{ mm}$$

Using the ultimate limits for deformation in accordance with EC 5, Section 7.2 (NDP to 7.2[2]) Ultimate limits for deflection $w_{\text{inst}} \leq l_{\text{Träger}}/300$; $w_{\text{fin}} \leq l_{\text{Träger}}/200$, $w_{\text{net,fin}} \leq l_{\text{Träger}}/300$, the following verifications can be obtained:

$$\eta_{\text{inst}} = \frac{w_{\text{inst}}}{l_{\text{Träger}}/300} = \frac{14,7}{50/3} = 0,88 < 1,0 \quad \checkmark$$

$$\eta_{\text{fin}} = \frac{w_{\text{fin}}}{l_{\text{Träger}}/200} = \frac{20,4}{50/2} = 0,82 < 1,0 \quad \checkmark$$

$$\eta_{\text{net,fin}} = \frac{w_{\text{net,fin}}}{l_{\text{Träger}}/300} = \frac{15,2}{50/3} = 0,91 < 1,0 \quad \checkmark$$

The verifications of the reinforced system are fulfilled.

9.2.5 Verification of the fully threaded screws

ASSY®plus VG 4 CH 6.0 x 180 mm screws have been selected as the fasteners. Based on Eq. (3.7), the characteristic tensile resistance is obtained as:

$$F_{t,k} = f_{\text{tens},k} = 11,5 \text{ kN (see Section 3.4)}$$

and the characteristic pull-out resistance as:

$$F_{w,k} = \frac{k_{\text{ax}} \cdot f_{\text{ax},k} \cdot d \cdot l_w}{k_{\beta}} \cdot \left(\frac{\rho_k}{\rho_{\text{ref},k}} \right)^{0,8} \quad (\text{see Section 3.6}).$$

The anchorage lengths and the factor to account for the angle β (see Section 3.3) must be designed for the reinforcement and the existing structure:

$$l_1 = \frac{t_1}{\sin \beta} = \frac{40}{\sin 45^\circ} = 56,5 \text{ mm}$$

$$l_{w,1} = l_1 - k = 56,5 - 4,7 = 52 \text{ mm}$$

$$l_{w,2} = l - l_{w,1} = 180 - 57 = 123 \text{ mm}$$

$$k_{\beta,1} = 1,5 \cdot \cos^2 \beta + \sin^2 \beta = 1,5 \cdot (\cos 45^\circ)^2 + (\sin 45^\circ)^2 = 1,25$$

$$k_{\beta,2} = 1,0$$

Member		1	2	
Bulk density	$\rho_{k,i}$	= 730	530	kg/m ³
Reference bulk density	$\rho_{\text{ref},k,i}$	= 730	350	kg/m ³
Withdrawal parameter	$f_{\text{ax},k,i}$	= 35.0	13.0	N/mm ²



4 x 2 ASSY®plus
VG 4 CH 6.0 x 180

Head height $k = 4.7 \text{ mm}$
Pre-drilling dia.: 4 mm

$$F_{w,k,1} = \frac{k_{\text{ax}} \cdot f_{\text{ax},k,1} \cdot d \cdot l_{w,1}}{k_{\beta,1}} \cdot \left(\frac{\rho_{k,1}}{\rho_{\text{ref},k,1}} \right)^{0,8} = \frac{1,0 \cdot 35,0 \cdot 6,0 \cdot 52}{1,25} \cdot \left(\frac{730}{730} \right)^{0,8} = 8,71 \text{ kN}$$

$$F_{w,k,2} = \frac{k_{\text{ax}} \cdot f_{\text{ax},k,2} \cdot d \cdot l_{w,2}}{k_{\beta,2}} \cdot \left(\frac{\rho_{k,2}}{\rho_{\text{ref},k,2}} \right)^{0,8} = \frac{1,0 \cdot 13,0 \cdot 6,0 \cdot 123}{1,0} \cdot \left(\frac{530}{350} \right)^{0,8} = 13,4 \text{ kN}$$

The design value of the load-bearing capacity is obtained as:

$$\begin{aligned} F_{\text{ax},t,d} &= \min \left\{ \frac{k_{\text{mod}}}{\gamma_M} \cdot F_{w,k,1}, \frac{k_{\text{mod}}}{\gamma_M} \cdot F_{w,k,2}, \frac{F_{t,k}}{\gamma_M} \right\} \\ &= \min \left\{ \frac{0,8}{1,3} \cdot 8,71; \frac{0,8}{1,3} \cdot 13,4; \frac{11,5}{1,3} \right\} \\ &= \min \{ 5,85; 8,26; 8,85 \} \\ &= 5,85 \text{ kN} \end{aligned}$$

The design value of the load-bearing capacity in the load direction is obtained as:

$$F_{v,d} = F_{ax,t,d} \cdot \cos \varepsilon = 5,85 \cdot \cos 45^\circ = 4,14 \text{ kN}$$

Using the action $q_{d,1}$ in kN/m, the spacing of the screw crosses e_{con} in m and the number of screws per cross n_{con} , the action of each screw is obtained as:

$$F_{v,Ed} = q_{d,1} \cdot \frac{e_{con}}{n_{con}} = 3,51 \cdot \frac{1,25}{2} = 2,19 \text{ kN}$$

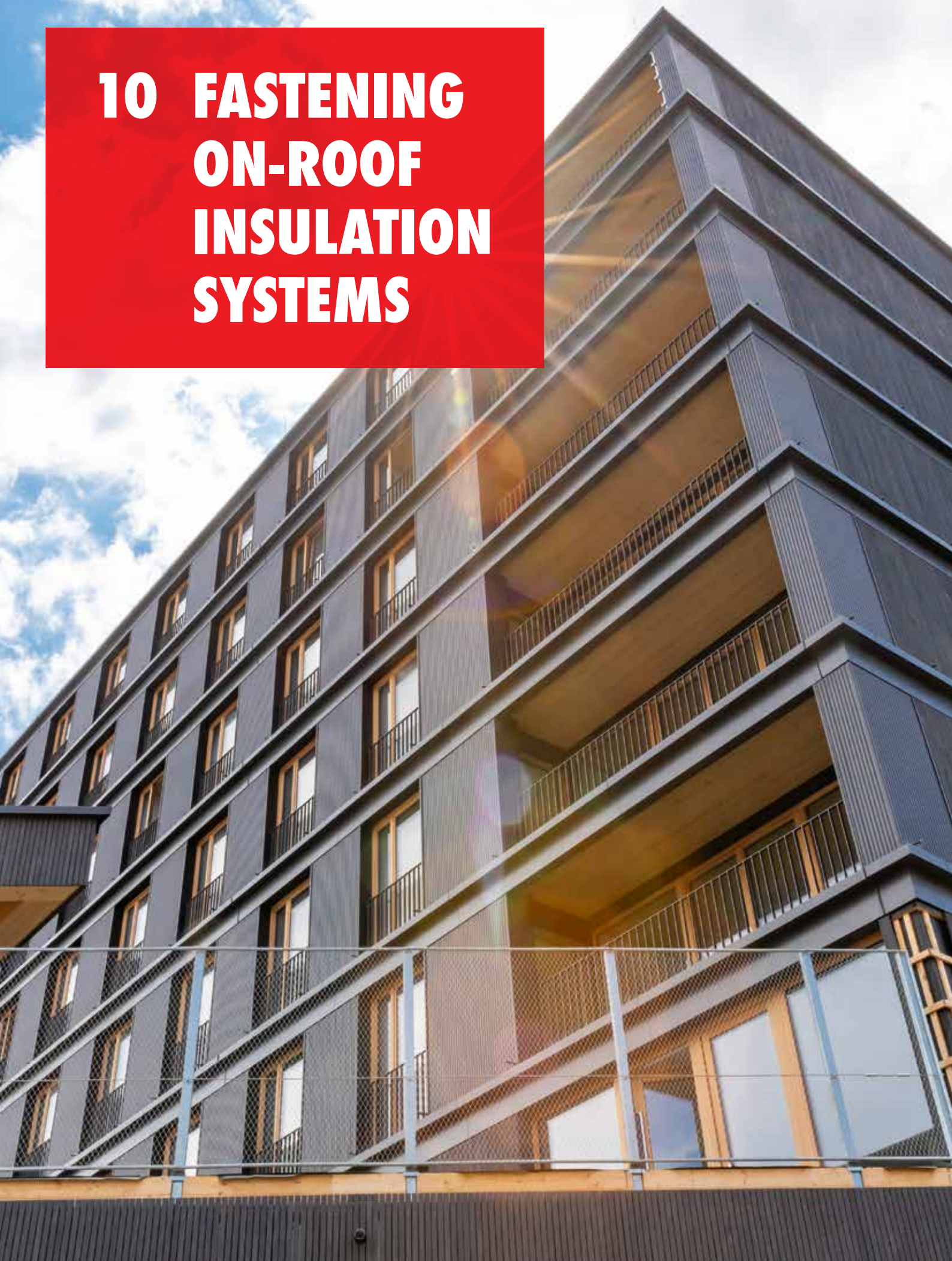
$$\eta = \frac{F_{v,Ed}}{F_{v,d}} = \frac{2,19}{4,14} = 0,53 < 1,0 \quad \checkmark$$

Width verification:

$$b_{min} = 2 \cdot a_{4,CG} = 2 \cdot 3 \cdot d = 2 \cdot 3 \cdot 6 = 36 \text{ mm}$$

$$b_{min} < b_{ist} \quad \checkmark$$

10 FASTENING ON-ROOF INSULATION SYSTEMS



10.1 General information

ASSY® screws with an outer thread diameter of at least 6 mm can be used to fasten on-roof insulation systems to rafters or timber members in vertical façades.

In the following, the term "rafter" also refers to timber members with an inclination of 0° to 90°. The thickness of the thermal insulation must not exceed 400 mm. The thermal insulation must be suitable for use as on-roof insulation in accordance with national regulations applicable at the place of installation.

The counter battens must be made of solid timber (ST/FST) in accordance with EN 338/ EN 14081-1. The minimum dimensions for the counter battens listed in Table 56 must be adhered to.

Table 56: Minimum cross-section dimensions for the battens.

Outer thread diameter d in mm	6	6.5	7	8	10	12	14
Minimum member thickness $t_{\min}$ in mm	30	30	30	30	40	80	100
Minimum member width $b_{\min}$ in mm	50	50	50	50	60	100	100
Regulation: ETA-11/0190							

The minimum width of the rafters is 60 mm. The spacing e between the screws must not exceed 1.75 m.

Friction forces must not be considered in the calculation when determining the characteristic withdrawal force of the screws.

The anchorage of the wind uplift forces and the bending stresses of the battens must be taken into account in the design of the structure. If required, additional screws can be arranged perpendicular to the longitudinal axis of the rafters (angle $\varepsilon = 90^\circ$).

In addition to the standard roof loads consisting of snow and wind, a human load of $F_{Q,k} = 1$ kN must be considered in the design of the battens.

In general, buckling of the screw can be assumed in Euler Case II with soft insulation. The load-bearing capacity of the screw is determined as the minimum load-bearing capacity of the screw when pressed into the batten or rafter and the buckling resistance of the free screw section, see Eq. (10.1).

$$F_{ax,c,d} = \min \left\{ F_{w,d, Latte}; F_{w,d, Sparren}; \frac{F_{c,k}}{\gamma_{M1}} \right\} \quad (10.1)$$

Where:

$F_{w,d, Latte}$	Load-bearing capacity of the screw when pressed into the counter batten in accordance with Section 3.6, Eq. (3.21)
$F_{w,d, Sparren}$	Load-bearing capacity of the screw when pressed into the rafter in accordance with Section 3.6, Eq. (3.21) where $l_w \geq 40$ mm
$F_{c,k}$	Characteristic buckling resistance of the screw in accordance with Section 3.5, Eq. (3.8) to (3.11) and Eq. (3.16) and (3.9), or Table 26

10.2 Parallel inclined screws – Fastening on-roof insulation systems with pressure-resistant insulation

10.2.1 Static model

The system consisting of rafter, thermal insulation on top of the rafter and counter batten parallel to the rafter (see Figure 103) can be considered as a beam on an elastic foundation. The counter batten represents the beam, and the thermal insulation on top of the rafter represents the elastic foundation as depicted in Figure 104. The thermal insulation must have a minimum compressive stress of at least $\sigma_{10\%} = 0.05 \text{ N/mm}^2$ at 10 % deformation, measured in accordance with EN 826. The batten is loaded perpendicular to the axis by point loads F_b . Further concentrated loads F_s result from the roof shear load due to sustained loads and snow loads, which are transferred to the counter battens through the screw heads.

Instead of battens, the following engineered wood can be used to cover the on-roof insulation, provided they are suitable for the intended use:

- Plywood (PW) in accordance with EN 636 and EN 13986
- Oriented-strand board (OSB) in accordance with EN 300 and EN13986
- Chipboard (RPB) in accordance with EN 312 and EN 13986
- Fibreboard (WFB) in accordance with EN 622-2, EN 622-3 and EN 13986

For screws with $\varepsilon \leq 90^\circ$, only countersunk head screws (CS) can be used for fastening the engineered wood to the rafters with insulation as an interlayer. For screws with $\varepsilon = 90^\circ$, washer head screws (WH) can also be used. The minimum thickness of the engineered wood board is 22 mm. The term "batten" includes the above-mentioned engineered wood boards in the following.

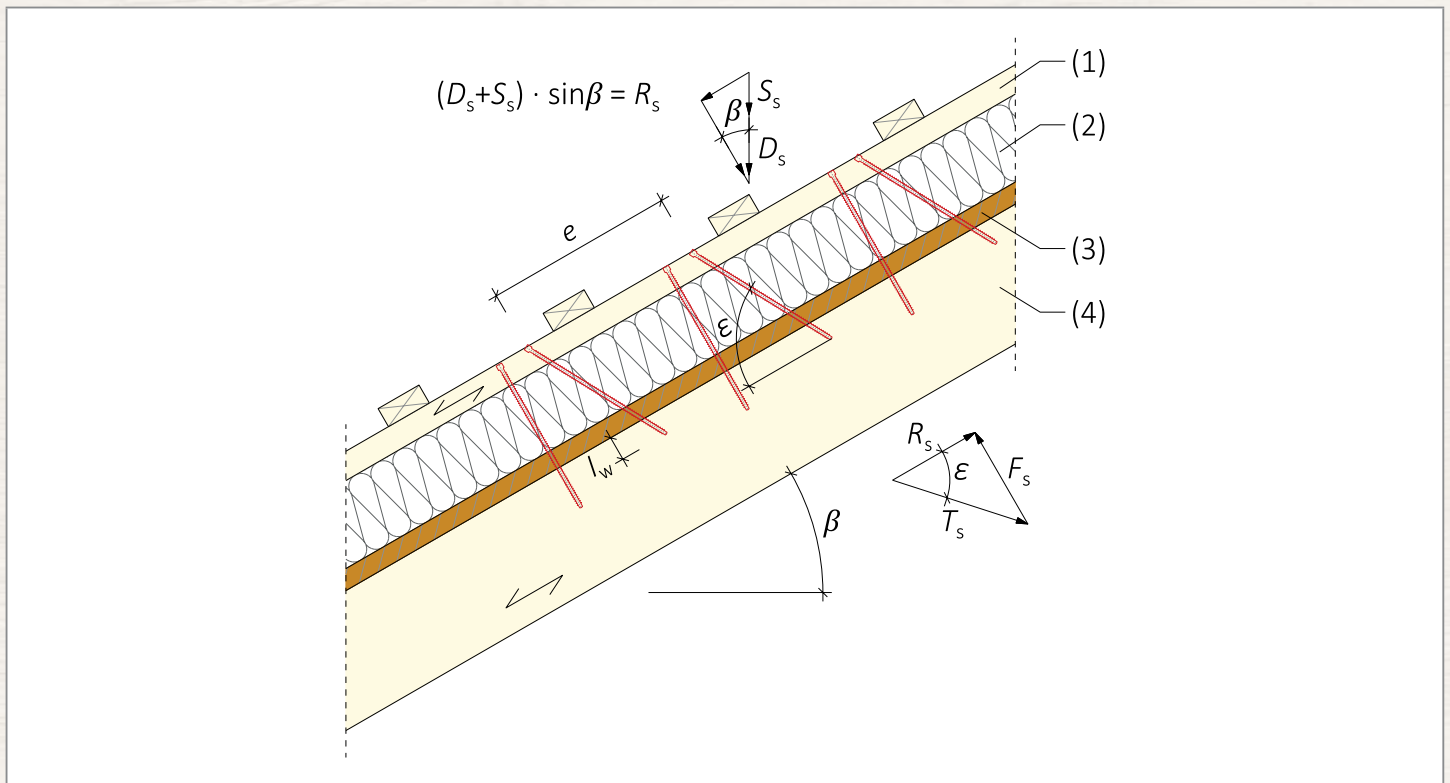


Figure 103: Arrangement of the screws for on-roof insulation with pressure-resistant insulation.

(1) counter batten, (2) insulation, (3) roof board, (4) rafter.

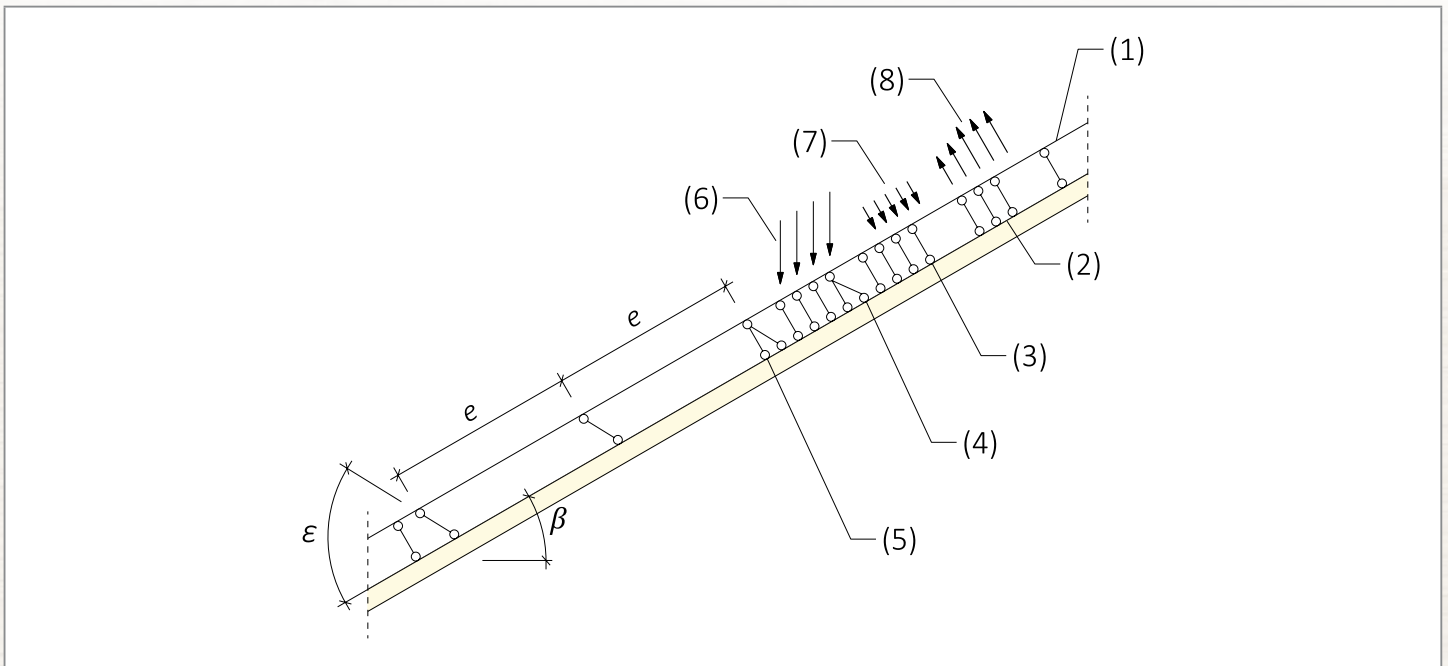


Figure 104: Mechanical system of on-roof insulation with pressure-resistant insulation.

(1) counter-batten axis, (2) rafter top edge, (3) compressive force transfer in the thermal insulation, (4) tensile force in screw axis TS, (5) concentrated compressive force transfer in the thermal insulation, (6) dead load and snow load, (7) wind pressure, (8) wind suction.

10.2.2 Design of the counter battens

It is assumed that the spacing between the counter battens exceeds the characteristic length of l_{char} . The characteristic bending moment can be designed as follows:

$$M_k = \frac{(F_{b,k} + F_{s,k}) \cdot l_{\text{char}}}{4} \quad (10.2)$$

Where:

l_{char} Characteristic length of the batten

$$l_{\text{char}} = \sqrt[4]{\frac{4 \cdot EI}{w_{\text{ef}} \cdot K}}$$

EI Bending stiffness of the batten

K Coefficient of subgrade

$$K = \frac{E_{\text{HI}}}{t_{\text{HI}}}$$

w_{ef} Effective width of the thermal insulation

$F_{b,k}$ Characteristic value of the concentrated loads perpendicular to the batten

$F_{s,k}$ Characteristic value of the concentrated loads perpendicular to the batten, load application in the area of the screw heads

The coefficient of subgrade K can be designed based on the elasticity modulus E_{HI} and the thickness t_{HI} of the thermal insulation if the effective width w_{ef} of the thermal insulation under compression is known. Due to the load extension in the thermal insulation, the effective width is greater than the width of the batten or rafter. For further calculations, the effective width w_{ef} of the thermal insulation can be determined as follows:

$$w_{\text{ef}} = w + t_{\text{HI}} / 2 \quad (10.3)$$

Where:

w Minimum width of the batten or rafter

t_{HI} Thickness of the thermal insulation

The following condition must be fulfilled:

$$\frac{\sigma_{m,d}}{f_{m,d}} = \frac{M_{Ed}}{W \cdot f_{m,d}} \leq 1 \quad (10.4)$$

The net cross-section must be considered in the calculation of the section modulus.

The characteristic value of the shear stresses must be designed as follows:

$$V_k = \frac{F_{b,k} + F_{s,k}}{2} \quad (10.5)$$

The following condition must be fulfilled:

$$\frac{\tau_d}{f_{v,d}} \leq \frac{1,5 \cdot V_{Ed}}{A \cdot k_{cr} \cdot f_{v,d}} \quad (10.6)$$

The net cross-section must be considered in the calculation of the cross-sectional area.

10.2.3 Design of the thermal insulation

The characteristic value of the compressive stress in the thermal insulation must be designed as follows:

$$\sigma_{c,k} = \frac{1,5 \cdot F_{b,k} + F_{s,k}}{2 \cdot l_{char} \cdot w} \quad (10.7)$$

The design value of the compressive stress $\sigma_{c,d}$ must not be greater than 110 % of the compressive stress at 10 % deformation (designed in accordance with EN 826):

$$\frac{\sigma_{c,d}}{1,1 \cdot \sigma_{10\%}} \leq 1 \quad (10.8)$$

10.2.4 Design of the screws

The screws are predominantly loaded in the direction of the screw axis. The characteristic value of the axial tensile force in the screw $T_{s,k}$ can be determined from the roof shear load $R_{s,k}$ using Eq. (10.9), applying the conventions shown in Figure 100.

$$T_{s,k} = \frac{R_{s,k}}{\cos \varepsilon} \quad (10.9)$$

The load-bearing capacity of the screws loaded in the axial direction is defined as the minimum from the design values of the pull-out resistance, the head pull-through resistance and the tensile resistance of the screw based on Eq. (3.19). To limit the deformation of the screw head for an insulation thickness greater than 200 mm or for a thermal insulation with a compressive strength below 0.12 N/mm², the pull-out resistance of the screws must be reduced by the factors k_1 and k_2 using Eq. (10.10). If Eq. (10.10) is used, the deformation of the battens does not need to be considered in the design of the screw load-bearing capacity.

$$F_{ax,t,d} = \min \begin{cases} F_{w,d} \cdot k_1 \cdot k_2 \\ F_{pull,d} \\ F_{t,d} \end{cases} \quad (10.10)$$

Where:

$$k_1 = \min \{1; 220 / t_{HI}\}$$

$$k_2 = \min \{1; \sigma_{10\%} / 0,12\}$$

The following verification must be carried out for the screws:

$$\eta_{ax} = \frac{T_{s,d}}{F_{ax,t,d}} \leq 1 \quad (10.11)$$

10.3 Screws with varying inclination – Fastening on-roof insulation systems with pressure-sensitive insulation

10.3.1 Mechanical model

Depending on the screw spacing and the arrangement of the tensile and compressive screws (see Figure 105) with different inclinations, the battens are significantly stressed by bending moments. The bending moments are derived based on the following assumptions:

- The tensile and compressive forces in the screws are determined based on the equilibrium conditions from the actions acting parallel and perpendicular to the roof surface. The actions are constant line loads $q_{\perp}$ and $q_{\parallel}$.
- The compressive screws are regarded as pin-ended columns with an assumed support depth of 10 mm each in the batten and the rafter. The effective pin-ended column length is therefore obtained from the free length of the screw between the batten and rafter plus 20 mm.
- The battens are considered as continuous beams with a constant span of $l_{\text{feld}} = A + B$ (see Figure 106). The compressive screws form the supports of the continuous beam, while the tensile screws transfer concentrated loads acting perpendicular to the longitudinal direction of the battens.

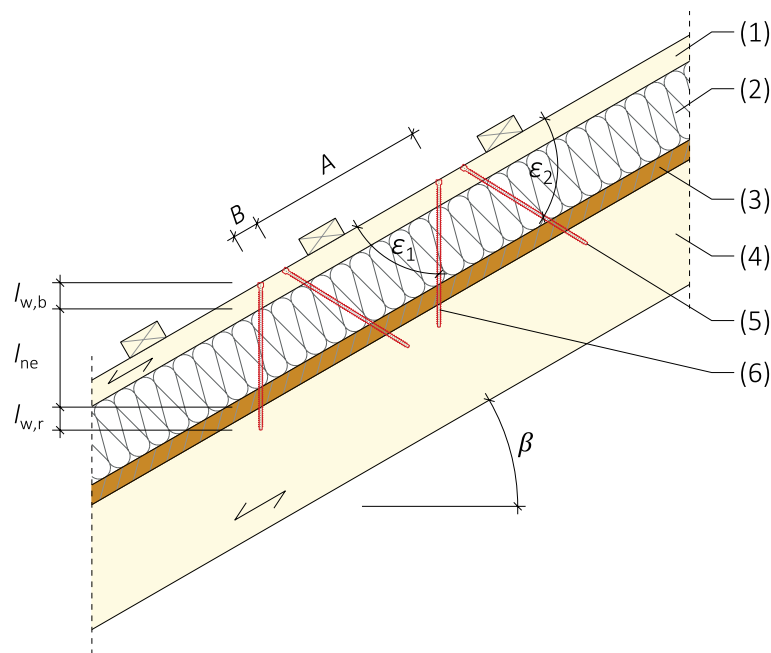


Figure 105: Arrangement of the screws for on-roof insulation with soft insulation.

(1) counter batten, (2) insulation, (3) roof board, (4) rafter, (5) tensile screw, (6) compressive screw.

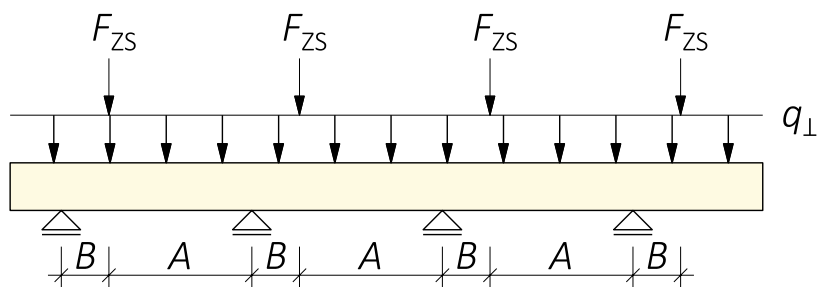


Figure 106: Mechanical system for on-roof insulation with soft insulation.

The screws are predominantly subjected to pull-out or compression. The characteristic values of the normal forces in the compressive screws $N_{c,k}$ or the tensile screws $N_{t,k}$ are determined from the actions acting parallel and perpendicular to the roof surface using Eq. (10.12) and (10.13).

$$N_{c,k} = (A + B) \cdot \left(-\frac{q_{\parallel,k}}{\cos \varepsilon_1 + \sin \varepsilon_1 / \tan \varepsilon_2} - \frac{q_{\perp,k} \cdot \sin(90^\circ - \varepsilon_2)}{\sin(\varepsilon_1 - \varepsilon_2)} \right) \quad (10.12)$$

$$N_{t,k} = (A + B) \cdot \left(\frac{q_{\parallel,k}}{\cos \varepsilon_2 + \sin \varepsilon_2 / \tan \varepsilon_1} - \frac{q_{\perp,k} \cdot \sin(90^\circ - \varepsilon_1)}{\sin(\varepsilon_1 + \varepsilon_2)} \right) \quad (10.13)$$

Where:

A	Screw spacing in mm as shown in Figure 102
B	Spacing between the screws arranged inclined to each other in mm as shown in Figure 102
$q_{\parallel,k}$	Characteristic value of the action parallel to the roof surface
$q_{\perp,k}$	Characteristic value of the action perpendicular to the roof surface
$\varepsilon_1, \varepsilon_2$	Angle between the screw axis and grain direction, $30^\circ \leq \varepsilon_1, \varepsilon_2 \leq 90^\circ$

Only screws with full thread or double thread (ASSY® Isotop) should be used.

The bending stresses in the battens result from the constant line load $q_{\perp}$ and the load components acting perpendicular to the longitudinal direction of the battens from the tensile screws. The span of the continuous beam is $(A + B)$. The characteristic value of the load components acting perpendicular to the longitudinal direction $F_{zs,k}$ from the tensile screws can be designed using Eq. (10.14).

$$F_{zs,k} = (A + B) \cdot \left(\frac{q_{\parallel,k}}{1 / \tan \varepsilon_1 + 1 / \tan \varepsilon_2} - \frac{q_{\perp,k} \cdot \sin(90^\circ - \varepsilon_1) \cdot \sin \varepsilon_2}{\sin(\varepsilon_1 + \varepsilon_2)} \right) \quad (10.14)$$

A positive value for $F_{zs,k}$ indicates a load directed towards the rafter, while a negative value indicates a load directed away from the rafter. The on-roof or façade construction attached to the timber substructure must be secured against displacement perpendicular to the load-bearing plane.

10.3.2 Design of the screws

The design values of the tensile or compressive load-bearing resistance of the screw are determined using Eq. (10.15) or (10.16).

$$F_{ax,t,d} = \min \begin{cases} F_{w,d} \\ F_{pull,d} \\ F_{t,d} \end{cases} \quad \text{see Section 3.6} \quad (10.15)$$

$$F_{ax,c,d} = \min \begin{cases} F_{w,d} \\ F_{c,d} \end{cases} \quad \text{see Section 3.6} \quad (10.16)$$

11 SHEAR REINFORCEMENT



11.1 General information

Only ASSY® and ASSY®plus VG screws with full thread and a diameter of $d \geq 8$ mm may be used for shear reinforcement of beams made of GL or GST made from softwood. Other materials and screws are not permitted. The beams must be straight and have a rectangular cross-section.

For shear reinforcement, at least four screws must be arranged in a row parallel to the grain direction and screwed in at an angle $\varepsilon = 45^\circ$ to the grain direction. The screw spacing in the grain direction must not be greater than the member height. The spacing rules in Section 3.8.2 also apply. If the screws are arranged in a single row, they must be positioned centrally relative to the member width, as shown in Figure 107.

In the areas of the member without shear reinforcement, the provisions for unreinforced timber members apply. The regulations at the place of installation apply to the design and execution of the shear reinforcements.

The following regulations apply to beams subjected to concentrated loads and/or line loads.

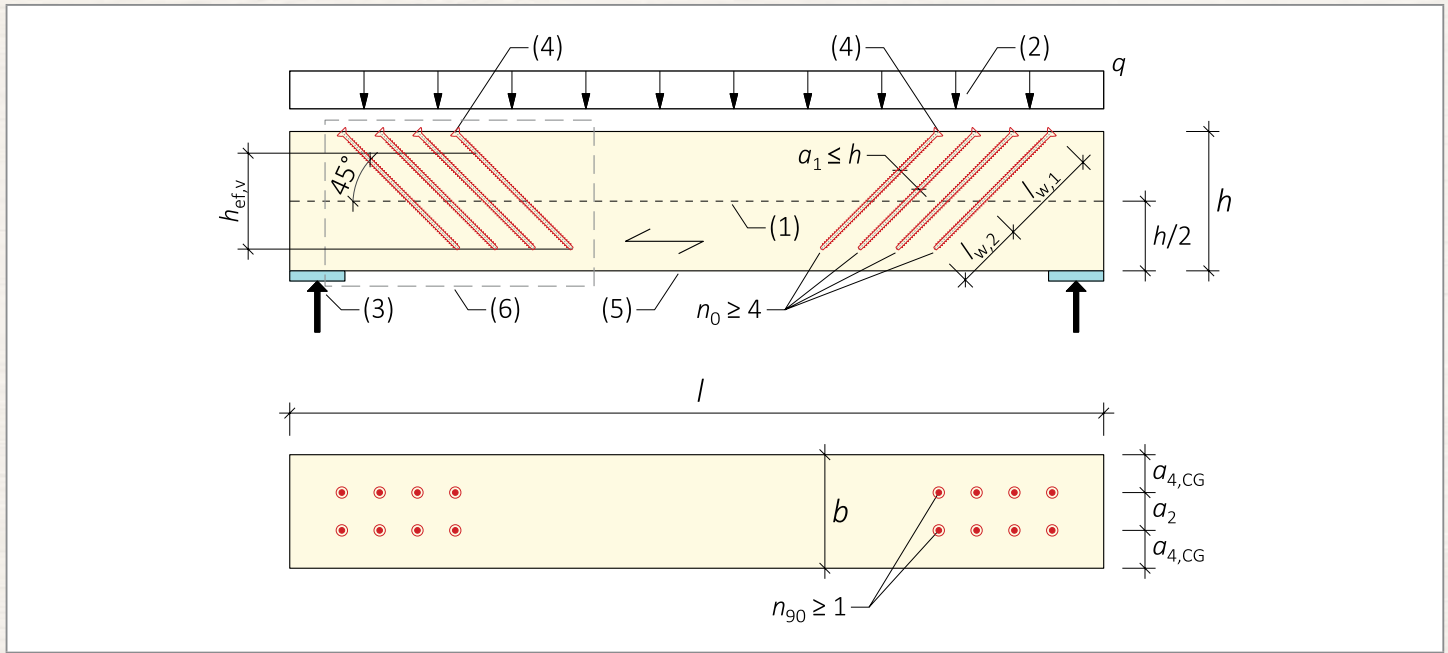


Figure 107: Schematic representation of shear reinforcement using fully threaded screws.

(1) crack line, (2) line load, (3) bearing force, (4) reinforcing screws, (5) glued laminated timber or glued solid timber made of softwood, (6) reinforced area.

11.2 Member design

In areas of reinforced timber members that are subject to shear in accordance with Section 11.1 with a stress component parallel to the grain direction, Eq. (11.1) must be fulfilled:

$$\tau_d \leq f_{v,d,mod} = f_{v,d} \cdot \min \left\{ \frac{k_{\tau}}{\eta_H}; 1,3 \right\} \quad (11.1)$$

Where:

τ_d	Design value of the shear stress in N/mm ²
$f_{v,d}$	Design value of the shear strength in N/mm ²

Where:

$$k_{\tau} = 1 - 0,46 \cdot \sigma_{90,d} - 0,052 \cdot \sigma_{90,d}^2$$

$$\eta_H = \frac{G_{\text{mean}} \cdot b}{G_{\text{mean}} \cdot b + \frac{1}{\frac{4}{n_{90}} \cdot \left(\frac{6 \cdot a_1}{\pi \cdot d \cdot h_{\text{ef,v}}^2 \cdot K_{\text{ax,vol}}} + \frac{a_1}{E_S \cdot A_S} \right)}}$$

Where:

$\sigma_{90,d}$ Design value of the stress perpendicular to the grain direction (negative value for compression)

$$\sigma_{90,d} = \frac{F_{\text{ax,Ed}}}{2 \cdot b \cdot a_1}$$

b Width of the timber member in mm

a_1 Screw spacing in a plane parallel to the grain direction and screw axis in mm

G_{mean} Mean value of the shear modulus in N/mm²

n_{90} Number of fastener rows perpendicular to the grain direction.
The rows of screws should be arranged evenly and symmetrically across the member width b .

d Outer thread diameter of the screw in mm

$h_{\text{ef,v}}$ Effective height relative to the shear-reinforcing screws in mm

$K_{\text{ax, vol}}$ Connection stiffness between the screw and timber member:

$$K_{\text{ax, vol}} = 400 \cdot d^{-0,8} \cdot l_w^{-0,6} \cdot \rho_{\text{mean}}^{0,2} \text{ in N/mm}^3$$

For fully threaded ASSY®plus VG and ASSY® screws with $d \geq 8$ mm

$E_S \cdot A_S$ Axial stiffness of a screw:

$$E_S \cdot A_S = \frac{E_S \cdot \pi \cdot d_1^2}{4}$$

E_S Elasticity modulus of the steel, $E_S = 210,000$ N/mm²

d_1 Thread core diameter in mm

The design value of the axial screw force $F_{\text{bs,Rd}}$ is given by:

$$F_{\text{ax,Ed}} = \frac{2 \cdot (1 - \eta_H) \cdot V_{\text{Ed}} \cdot a_1}{n_{90} \cdot h_{\text{ef,v}}} \quad (11.2)$$

Where:

V_{Ed} Design value of the acting shear force in N

The axial load-bearing capacity of an ASSY®plus VG or ASSY® screw must fulfil the following conditions:

$$\frac{F_{ax,Ed}}{F_{ax,t,d}} \leq 1 \quad (11.3)$$

Where:

- $F_{ax,t,d}$ Design value of the axial load-bearing capacity of a screw in accordance with Section 3.6
- $l_{w,1}; l_{w,2}$ Anchorage lengths of the screw; the values of the screw thread lengths from the crack plane in the centre of the beam to the screw head or tip in mm
- $l_w = \min \begin{cases} l_{w,1} \\ l_{w,2} \end{cases}$ Calculable anchorage length (in $K_{ax,vol}$ and F_w)

Notes:

- With a single row of screws and screw axis/grain angle $\varepsilon = 45^\circ$, only a small restraining effect can be assumed. Nevertheless, Eq. (2.1) must be taken into account.
- If an arrangement with two rows is required, Dietsch (2014) recommends a spacing to the beam side faces of $a_{4,CG} = 70$ mm.

ANNEX

Annex A – Material designations and properties

Table 57: Material designations.

Group/sub-group/product	Material designation	
	EC 5	Manual and Draft EC 5
Solid wood-based products		SWB
Structural lumber		SL
Solid timber	VH	ST
Structural timber	KVH	FST
Parallel-laminated timber		PL
Glued solid timber	BSH	GST
Glued laminated timber		GL
Block-glued glulam		BGL
Single-layer solid wood panel		SWP-P
Cross-layered timber		CL
Cross-laminated timber	BSP	CLT
Multilayer solid wood panel		SWP-C
Veneer-based wood products		VB
Laminated veneer lumber	FSH	LVL
With parallel veneer layers		LVL-P
With crossed veneer layers		LVL-C
Glued laminated veneer lumber		GLVL
With parallel veneer layers		GLVL-P
With crossed veneer layers		GLVL-C
Plywood		PW
Strand-based timber products		STB
Boards made from long, slim, aligned strands	OSB	OSB
Wood fibre-based boards		WFB
Hard fibreboard		HB
Medium-hard fibreboard		MB
Porous fibreboard (soft fibreboard)		SB
Medium-density fibreboard		MDF
Wood particle-based boards		WPB
Resin-bonded particleboard		RPB
Cement-bonded particleboard		CPB
Gypsum-based boards		GYB
Gypsum plasterboard	GKP	GPB
Gypsum fibreboard		GFB
Timber/timber composite		TTC
Beams and columns made of composite wood		

Table 58: Materials, strength classes, strength values, bulk density, source documents and material designations.

	$f_{m,k}$ in N/mm ²	$f_{t,0,k}$ in N/mm ²	$f_{t,90,k}$ in N/mm ²	$f_{c,0,k}$ in N/mm ²	$f_{c,90,k}$ in N/mm ²	$f_{v,k}$ in N/mm ²	ρ_k in kg/m ³	Regulation	k_{cr}	Material designation in Draft EC 5
Softwood										
C24	24	14.5	0.4	21	2.5	4.0	350	DIN EN 338:2016-07	$2.0/f_{v,k}$	ST, FST
C30	30	19	0.4	24	2.7	4.0	380	DIN EN 338:2016-07	$2.0/f_{v,k}$	ST, FST
GL 24c	24	17	0.5	21.5	2.5	3.5	365	DIN EN 14080:2013-09	$2.5/f_{v,k}$	GL
GL 28c	28	19.5	0.5	24.0	2.5	3.5	390	DIN EN 14080:2013-09	$2.5/f_{v,k}$	GL
GL 30c	30			24.5						
GL 24h	24	19.2	0.5	24	2.5	3.5	385	DIN EN 14080:2013-09	$2.5/f_{v,k}$	GL
GL 28h	28	22.3	0.5	28	2.5	3.5	425	DIN EN 14080:2013-09	$2.5/f_{v,k}$	GL
GL 30h	30	24	0.5	30	2.5	3.5	430	DIN EN 14080:2013-09	$2.5/f_{v,k}$	GL
LVL-P	50	35 ^{a)}	0.8 ^{b)}	35 ^{c)}	6.0 ^{d)}	2.3 ^{e)}	480	Z-9.1-847, Z-9.1-842, Z-9.1-880, Z-9.1-890	+1.0	LVL-P
LVL-C	36	21	3.5 ^{f)}	26 ^{g)}	9.0	1.3 ^{h)}				LVL-C
Hardwood										
D30	30	18	0.6	24	5.3	3.9	530	DIN EN 338:2016-07	0.67	ST
GLT Birch	32	24	0.6	30	4.5	4.9	600	ETA-19/0031	0.67	GL
GL75	75	60	0.6	59.4	14.8	4.5	730	ETA-14/0354	+1.0	GLVL
Board materials										
F20/10- E40/20, F20/15- E30/25	20/10 20/15	9.0 8.0	7.0 7.0	15 13	10 13	3.5 4.0	350	DIN EN 636:2015-05 and DIN 20000-1:2017-06	-	GPB
OSB/3, OSB/4	14.8/7.4 21/11.4	9.0 10.9	6.8 8.0	14.8 17.0	12.4 13.7	+1.0 1.1				
^{a)} Z-9.1-842: $f_{t,0,k} = 36 \text{ N/mm}^2$ ^{b)} Z-9.1-842, Z-9.1-890: $f_{t,90,edge,k} = 0.9 \text{ N/mm}^2$ ^{c)} Z-9.1-842: $f_{c,0,k} = 40 \text{ N/mm}^2$ ^{d)} Z-9.1-842: $f_{c,90,edge,k} = 7.5 \text{ N/mm}^2$; Z-9.1-890: $f_{c,90,edge,k} = 7.3 \text{ N/mm}^2$ ^{e)} Z-9.1-842, Z-9.1-890: $f_{v,0,flat,k} = 2.6 \text{ N/mm}^2$ ^{f)} Z-9.1-847, Z-9.1-880: $f_{c,90,edge,k} = 6 \text{ N/mm}^2$; Z-9.1-842: $f_{c,90,edge,k} = 5 \text{ N/mm}^2$ ^{g)} Z-9.1-842, Z-9.1-890: $f_{c,0,k} = 30 \text{ N/mm}^2$ ^{h)} Z-9.1-842: $f_{v,0,flat,k} = 1.1 \text{ N/mm}^2$										

Annex B – n_{ef} in accordance with Lantos

As an alternative to Eq. (3.29) and (3.30), the effective number of screws can also be designed based on stiffness in accordance with the approach by Lantos (1969).

For screw groups where $30^\circ \leq \varepsilon \leq 60^\circ$ (inclined, crossed or screw crosses), arranged one behind the other in the direction of the force and grain

$$n_{ef} = \frac{1}{\max\{\delta_1; \delta_2\}} \quad (11.4)$$

Where:

$$\delta_1 = 1 - m_1 \cdot (1 + \mu) + \mu + \frac{m_1 - m_2}{m_1^n - m_2^n} \cdot (m_1^n \cdot (1 + \mu) - \mu)$$

$$\delta_2 = -\mu + m_1^{n-1} \cdot (1 + \mu) - \frac{m_1^{n-1} - m_2^{n-1}}{m_1^n - m_2^n} \cdot (m_1^n \cdot (1 + \mu) - \mu)$$

$$\mu = -\frac{1}{1 + \frac{E_1 \cdot A_1}{E_2 \cdot A_2}}$$

Where:

$E_1 \cdot A_1$

Axial stiffness of side member 1

$E_2 \cdot A_2$

Axial stiffness of side or middle member 2. If member 2 is a middle member, only half of the middle member cross-section should be used for A_2 .

E_1, E_2

Mean value of the elasticity modulus of members 1 and 2

A_1, A_2

Cross-sectional area of members 1 and 2

n

Number of unidirectionally inclined screws or screw crosses per row

m

Number of rows of unidirectionally inclined screws or screw crosses per shear plane

$$m_1 = 0,5 \cdot \left(\omega + \sqrt{\omega^2 - 4} \right)$$

$$m_2 = 0,5 \cdot \left(\omega - \sqrt{\omega^2 - 4} \right)$$

$$\omega = 2 + K_u \cdot a_1 \cdot \left(\frac{m}{E_1 \cdot A_1} + \frac{m}{E_2 \cdot A_2} \right)$$

K_u

Slip modulus parallel to the shear plane per screw (unidirectionally inclined screws) or per screw cross (screws arranged in a cross) in the ultimate limit state

a_1

Screw spacing parallel to the grain direction

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Formula symbols used in the manual

Uppercase Latin letters and designations in accordance with ETA-11/0190, EC 5 and Draft EC 5

		ETA	EC 5	Draft EC 5
A	Cross-sectional area Partial load length	A A	A –	$A_{(i)}$ –
A_1	Cross-section 1	A_1	–	A_1
A_2	Cross-section 2	A_2	–	A_2
A_{ef}	Effective contact area taking into account the effective contact length	–	A_{ef}	A_{ef}
$A_{efU-Scheibe}$	Effective area of the washer	–	$A_{efU-Scheibe}$	–
$A_{net,t}$	Net tensile area	–	$A_{net,t}$	–
$A_{net,t1}$	Net tensile area in member 1	–	–	–
$A_{net,v}$	Net shear plane	–	$A_{net,v}$	–
A_s	Cross-sectional area of a screw	A_s	–	A_s
B	Partial load length	B	–	–
$W \times H$	Width times height of a cross-section	–	–	–
$E_{0,mean}$	Mean elasticity modulus parallel to the grain direction	–	$E_{0,mean}$	$E_{0,mean}$
$E_{0,mean,1}$	Mean elasticity modulus parallel to the grain direction of member 1/cross-section 1	–	–	–
$E_{0,mean,2}$	Mean elasticity modulus parallel to the grain direction of member 2/cross-section 2	–	–	–
$E_{0,mean,i}$	Mean elasticity modulus parallel to the grain direction of member i/cross-section i	–	–	$E_{(X),(i)mean}$
E_1	Elasticity modulus of member 1/cross-section 1	–	–	E_1
$E_{d,1}$	Design elasticity modulus of member 1/cross-section 1	–	–	E_1
E_2	Elasticity modulus of member 2/cross-section 2	–	–	E_2
$E_{d,2}$	Design elasticity modulus of member 2/cross-section 2	–	–	E_2
E_{HI}	Elasticity modulus of the thermal conduction (heat insulation)	E_{HI}	–	–
E_i	Elasticity modulus of member i/cross-section i	–	E_i	E_i
EI	Flexural strength of the counter batten	EI	–	–
$(EI)_{ef}$	Effective flexural strength of a member/a cross-section	–	$(EI)_{ef}$	$(EI)_{ef}$
$E_{d,i}$	Design elasticity modulus of member i/cross-section i	–	E_i	E_i
E_s	Elasticity modulus of the steel	E_s	–	E_s
$F_{0,Ed}$	Design value of the connection force parallel to the grain direction	–	–	$F_{0,Ed}$
$F_{90,Ed}$	Design value of the tensile action effect perpendicular to the grain direction	$F_{90,Ed}$	$F_{v,Ed}$	$F_{90,Ed}$
$F_{90,Rd}$	Design value of the transverse tensile load-bearing capacity	–	$F_{90,Rd}$	$(F_{90,Rd})$
$F_{ax,c,d}$	Design value of the load-bearing capacity of a compressive screw	$F_{ax,Rd}/F_{ax,\alpha,Rd}$	–	$F_{ax,c,d}$
$F_{ax,c,k}$	Characteristic load-bearing capacity of a compressive screw	–	–	$F_{ax,c,k}$
$F_{ax,c,Rd}$	Design value of the load-bearing capacity of a connection with compressive screws	–	–	–
$F_{ax,c/t,Rd}$	Design value of the axial load-bearing capacity in accordance with Section 3.7	–	$F_{ax,Rd}$	$F_{ax,c/t,Rd}$
$F_{ax,Ed}$	Design value of the axial action	$F_{ax,d}$	$F_{ax,Ed}$	$F_{ax,Ed}$
$F_{ax,Rd}$	Design value of the axial load-bearing capacity of a connection	$F_{ax,Rd}$	$F_{ax,Rd}$	$F_{ax,Rd}$
$F_{ax,t,d}$	Design value of the load-bearing capacity of a tensile screw	$F_{ax,Rd}/F_{ax,\alpha,Rd}$	$F_{ax,Rd}$	$F_{ax,t,d}$
$F_{ax,t,d,fi}$	Design value of the axial load-bearing capacity in the event of fire	–	–	–
$F_{ax,t,k}$	Characteristic load-bearing capacity of a tensile screw	$F_{ax,\alpha,Rk}$	$F_{ax,Rk}$	$F_{ax,t,k}$
$F_{ax,t,R20}$	20% fractile value of the load-bearing capacity of a screw	–	–	–
$F_{ax,t,Rd}$	Design value of the load-bearing capacity of a connection with a tensile screw	–	–	$F_{ax,t,Rd}$
$F_{ax,x,d}$	Design value of the load-bearing capacity of a screw cross	–	–	–
$F_{b,k}$	Characteristic value of the concentrated loads on the counter batten	$F_{b,k}$	–	–
$F_{bs,ax,Rd}$	Design value of the block shear capacity of a connection	–	–	–
$F_{bs,ax,Rk}$	Characteristic block shear capacity of a connection	–	$F_{bs,Rk}$	–
$F_{bs,Rd}$	Design value of the block shear capacity	–	–	$F_{bs,Rd}$
$F_{bs,Rd,1}$	Design value of the block shear capacity of a connection in member 1	–	–	–
$F_{bs,Rk}$	Characteristic block shear capacity	–	$F_{bs,Rk}$	–
$F_{c,90,d}$	Design value of the compressive force perpendicular to the grain direction	–	$F_{c,90,d}$	$F_{c,90,d}$
$F_{c,90,Ed}$	Design value of the acting compressive force perpendicular to the grain direction	–	–	–
$F_{c,90,Ed,1}$	Design value of the acting compressive force perpendicular to the grain direction at member edge 1	–	–	–

		ETA	EC 5	Draft EC 5
$F_{c,90,Ed,2}$	Design value of the acting compressive force perpendicular to the grain direction at member edge 2	-	-	-
$F_{c,90,Rd}$	Design value of the compressive force perpendicular to the grain direction	$F_{90,d}$	$F_{c,90,d}$	$F_{c,90,d}$
$F_{c,90,Rd,(a)}$	Design value of the compressive force perpendicular to the grain direction at head level	-	-	-
$F_{c,90,Rd,(b)}$	Design value of the compressive force perpendicular to the grain direction at screw level	-	-	-
$F_{c,90,Rk}$	Characteristic value of the load-bearing capacity of a reinforced timber member	-	-	-
$F_{c,d}$	Design value of the buckling resistance of a screw	-	-	-
$F_{c,Ed}$	Design value of the acting compressive force in a reinforcing screw	-	-	$F_{c,Ed}$
$F_{c,k}$	Characteristic buckling resistance of a screw	-	-	$F_{c,k}$
$F_{c,k,HT}$	Characteristic buckling resistance of a screw in the main beam	-	-	-
$F_{c,k,NT}$	Characteristic buckling resistance of a screw in the secondary beam	-	-	-
$F_{D,k}$	Characteristic value of the load-bearing capacity in accordance with Johansen's yield theory	-	$F_{v,Rk}$	$F_{D,k}$
$F_{D,k,j}$		-	-	-
F_{Ed}	Force acting on a connection	-	F_{Ed}	F_{Ed}
$F_{pull,d}$	Design value of the head pull-through resistance	-	-	-
$F_{pull,k}$	Characteristic head pull-through resistance	-	-	$F_{pull,k}$
$F_{Q,k}$	Human load	-	-	-
$F_{rp,k}$	Characteristic value of the rope effect component	-	$\Delta F_{v,Rk}$	$F_{rp,k}$
$F_{s,k}$	Characteristic value of the concentrated loads on the counter batten created by the roof shear load	$F_{s,k}$	-	-
$F_{t,0,Ed}$	Design tensile force parallel to the grain direction in the connection	F_{Ed}	$F_{t,0,d}$	$F_{t,0,Ed}$
$F_{t,90,Ed}$	Design value of the force components generating transverse tension (per reinforcing screw)	-	$F_{t,90,d}$	$F_{t,90,Ed}$
$F_{t,90,M,Ed}$	Acting shear force from bending stresses at the opening	-	$F_{t,M,d}$	$F_{t,90,m,Ed}$
$F_{t,90,Rd}$	Design value of the load-bearing capacity perpendicular to the grain direction	-	$F_{t,V,d}$	-
$F_{t,90,V,Ed}$	Acting shear force from shear stresses at the opening	-	$F_{t,V,d}$	$F_{t,90,v,Ed}$
$F_{t,d}$	Design value of the tensile resistance of a screw	-	-	-
$F_{t,k}$	Characteristic tensile resistance of a screw	-	$F_{t,Rk}$	$F_{t,Rk}/F_{t(X),(i),k}$
$F_{t,M,d}$	Acting tensile force from a bending moment	-	$F_{t,M,d}$	$F_{t,m,d}$
$F_{t,V,d}$	Acting tensile force from a shear force	-	$F_{t,V,d}$	$F_{t,V,d}$
$F_{v,0,Ed}$	Design value of the effect of action per fastener and shear plane parallel to the grain direction	$F_{v,0,Ed}$	-	-
$F_{v,d}$	Design value of the load-bearing capacity of a screw subjected to shear stress per shear plane	-	$F_{v,Rd}$	$F_{v,d}$
$F_{v,Ed}$	Design value of the acting shear force	-	$F_{v,Ed}$	$F_{v,Ed}$
$F_{v,k}$	Characteristic load-bearing capacity of a screw subjected to shear stress	-	$F_{v,Rk}$	$F_{v,k}$
$F_{v,k,a}$	Characteristic shear resistance of a screw with timber failure	-	$F_{v,Rk} (a)$	-
$F_{v,k,b}$	Characteristic shear resistance of a screw with fastener failure	-	$F_{v,Rk} (b)$	-
$F_{v,k,c}$	Characteristic shear resistance of a screw with mixed failure	-	$F_{v,Rk} (c)$	-
$F_{v,k,d}$	Characteristic shear resistance of a screw with two plastic hinges	-	$F_{v,Rk} (d)$	-
$F_{v,k,e}$	Characteristic shear resistance of a screw with timber failure and one plastic hinge	-	$F_{v,Rk} (e)$	-
$F_{v,k,f}$	Characteristic shear resistance of a screw with timber failure and two plastic hinges	-	$F_{v,Rk} (f)$	-
$F_{v,Rd}$	Design value of the shear load-bearing capacity of a connection	-	$F_{v,Rd}$	$F_{v,Rd}$
$F_{VM,d}$	Design value of the effect of action of a screw (in a flexible connection)	-	F_i	$F_i(X)$
$F_{w,c,d,HT}$	Design value of the withdrawal parameter when pressed in for a screw in the main beam	-	-	-
$F_{w,c,d,NT}$	Design value of the withdrawal parameter when pressed in for a screw in the secondary beam	-	-	-
$F_{w,c,k,HT}$	Characteristic value of the pull-out resistance when pressed in for a screw in the main beam	-	-	-
$F_{w,c,k,NT}$	Characteristic value of the pull-out resistance when pressed in for a screw in the secondary beam	-	-	-
$F_{w,d}$	Design value of the pull-out resistance	-	-	$F_{w,d}$
$F_{w,d,Latte}$	Design value of the pull-out resistance in a counter batten	-	-	-
$F_{w,d,Sparren}$	Design value of the pull-out resistance in a rafter	-	-	-
$F_{w,k}$	Characteristic pull-out resistance	$F_{ax,\alpha,Rk}$	$F_{ax,\alpha,Rk}/F_{ax,Rk}$	$F_{w,k}$
$F_{w,k,1}$	Characteristic pull-out resistance on the screw-head side/in member 1	-	-	-
$F_{w,k,2}$	Characteristic load-bearing capacity on the screw-tip side/of the thread in member 2	-	-	-
$F_{w,k,oben/unten}$	Characteristic pull-out resistance top and bottom	-	-	-
$F_{w,t,k,HT}$	Characteristic pull-out resistance of a screw in the main beam	-	-	-
$F_{w,t,k,NT}$	Characteristic pull-out resistance of a screw in the secondary beam	-	-	-

		ETA	EC 5	Draft EC 5
$F_{ZS,k}$	Characteristic value of the load components perpendicular to the longitudinal direction of the counter batten	$F_{ZS,k}$	–	–
G_{mean}	Mean value of the shear modulus	G	G_{mean}	G_{mean}
I_1	Area moment of inertia of member 1/cross-section 1	–	–	$I_{(i)}$
I_2	Area moment of inertia of member 2/cross-section 2	–	–	$I_{(i)}$
I_S	Second area moment of inertia for the circular cross-section	I_S	–	I_S
$I_{y,1}$	Area moment of inertia around the y-axis of member 1/cross-section 1	–	–	I_y
$I_{y,2}$	Area moment of inertia around the y-axis of member 2/cross-section 2	–	–	I_y
$I_{y,i}$	Area moment of inertia around the y-axis of member i/cross-section i	–	–	I_y
K	Coefficient of subgrade	K	–	–
$K_{\text{ax,vol}}$	Connection stiffness between the screw and timber member in N/mm ³	k_{ax}		
$K_{\text{SLS,ax},2}$	Mean value of the slip modulus in the serviceability limit state of the screw in the axial direction in member 2			
$K_{\text{SLS,ax},i}$	Mean value of the slip modulus in the serviceability limit state of the screw in the axial direction in member i			
$K_{\text{SLS,ax,ges}}$	Mean value of the slip modulus in the ultimate limit state of a connection with screws designed for axial loading			
$K_{\text{ULS,ax},i}$	Mean value of the slip modulus in the ultimate limit state of a connection with screws designed for axial loading in member i			
$K_{\text{ULS,ax,vol}}$	Mean value of the axial connection stiffness between the screw and timber member in the ultimate limit state			
$K_{\text{SLS,ax}}$	Mean slip modulus of screws designed for axial loading			
$K_{\text{SLS,v}}$	Mean slip modulus of screws subjected to shear stress			$K_{\text{SLS,v},i}$
$L_{\text{Träger}}$	Load length	–	l	l
L_X	Calculated penetration depth parallel to the grain direction	–	–	–
L_y	Calculated penetration depth perpendicular to the grain direction	–	–	–
M	Moment	–	–	M
$M_{A,\text{max}}$	Maximum permissible tightening torque	–	–	–
M_{Ed}	Design value of the acting bending moment	M_d	M_{Ed}	M_d
M_k	Characteristic value for the bending moment of the counter batten	M_k	–	–
M_W	Prevailing torque	–	–	–
$M_{y,k}$	Characteristic yield moment of a screw	$M_{y,k}$	$M_{y,Rk}$	$M_{y,k}$
$N_{c,k}$	Characteristic value of the normal compressive force	$N_{c,k}$	–	–
$N_{ki,k}$	Characteristic ideal elastic buckling load of a screw	$N_{ki,k}$	–	$N_{ki,k}$
$N_{pl,k}$	Characteristic value of the normal force load capacity of the net cross-section	$N_{pl,k}$	–	$N_{pl,k}$
$N_{t,k}$	Characteristic value of the normal tensile force	$N_{t,k}$	–	–
$QS_{1,2}$	Cross-sections 1 and 2	–	–	–
$R_{S,k}$	Characteristic value of the shear load of the roof	$R_{S,k}$	–	–
S	Centre of gravity of the screw in relation to the relevant cross-sectional area	–	–	S
$T_{S,d}$	Design value of the axial tensile force in the screw	–	–	–
$T_{S,k}$	Characteristic value of the axial tensile force in the screw	$T_{S,k}$	–	–
V_{Ed}	Design value of the acting shear force	V_d	V_{Ed}	V_d
V_k	Characteristic value of the shear stress	V_k	–	–
V_{Rd}	Design value of the shear capacity of an unreinforced notch	–	V_d	V_d
W	Section modulus	W	–	$W_{(X),(i)}$
W_1	Section modulus of member 1/cross-section 1	–	–	$W_{(X),(i)}$
W_2	Section modulus of member 2/cross-section 2	–	–	$W_{(X),(i)}$
W_y	Section modulus around the y-axis	–	W_y	W_y
$W_{y,1}$	Section modulus around the y-axis of member 1/cross-section 1	–	–	$W_{(X),(i)}$
$W_{y,2}$	Section modulus around the y-axis of member 2/cross-section 2	–	–	$W_{(X),(i)}$

Lowercase Latin letters and designations in accordance with ETA-11/0190, EC 5 and Draft EC 5

		ETA	EC 5	Draft EC 5
a	Material coefficient in the k_{ax} equation for small screw axis/grain angles Minimum distance between the fasteners in the connection and the reinforcing screws	a –	– –	– a
a_1	Minimum distance between two screws in a plane parallel to the grain direction and screw axis Minimum distance between two fasteners parallel to the grain direction Minimum distance between two fasteners parallel to the grain direction of the cross-laminated timber face layer	a_1 a_1 –	a_1 a_1 –	$a_{1,ct,min}$ a_1 –
$a_1 \times a_2$	Smallest free area around a screw	$a_1 \times a_2$	–	$a_1 \times a_2$
$a_{1,fi}$	Side covering of a connection in the event of fire	–	$a_{1,fi}$	–
$a_{1,i}$	Multiple spacings between fasteners parallel to the grain direction	–	$l_{v,1}/l_{v,2}/\dots$	–
$a_{1,max}$	Maximum permissible distance between two screws parallel to the grain direction	–	–	$a_{1,max}$
$a_{1,r}$	Minimum distance between two reinforcing screws parallel to the grain direction	–	–	$a_{1,r}$
$a_{1,SD0}$	Minimum distance between two dowels parallel to the grain direction	–	–	–
a_2	Minimum distance between two screws perpendicular to a plane parallel to the grain direction and screw axis Minimum distance between two fasteners perpendicular to the grain direction Minimum distance between two fasteners perpendicular to the grain direction of the CLT face layer	a_2 a_2 –	a_2 a_2 –	$a_{2,ct,min}$ a_2 –
$a_{2,fi}$	Side covering of a connection in the event of fire	–	$a_{2,fi}$	–
$a_{2,i}$	Multiple spacings between fasteners perpendicular to the grain direction	–	$l_{t,1}$ or $l_{t,2}$	–
a_3	Minimum distance between the fastener and the end of the side member	–	a_3	–
$a_{3,c}$	Minimum distance between the unloaded edge and the fastener parallel to the grain direction Minimum distance between the unloaded edge and the fastener parallel to the grain direction of the CLT face layer	$a_{3,c}$ –	$a_{3,c}$ –	$a_{3,c}$ –
$a_{3,CG}$	Minimum distance between the edge and the screw centre of gravity in the member parallel to the grain direction	–	$a_{1,CG}$	$a_{3,ct,min}$
$a_{3,CG,ist}$	Minimum distance between the edge and the screw centre of gravity in the member parallel to the grain direction of the first row of screws	–	–	–
$a_{3,fi}$	Covering of the screw tip or screw head of a connection in the event of fire	–	$a_{3,fi}$	–
$a_{3,S}$	Minimum distance between the steel plate edge and the screw axis parallel to the grain direction	–	–	–
$a_{3,t}$	Minimum distance between the loaded edge and the fastener parallel to the grain direction Minimum distance between the loaded edge and the fastener parallel to the grain direction of the CLT face layer	$a_{3,t}$ –	$a_{3,t}$ –	$a_{3,t}$ –
$a_{3,t,1}$	Distance between the loaded edge and the screw parallel to the grain direction in member 1	–	–	–
$a_{3,t,2}$	Distance between the loaded edge and the screw parallel to the grain direction in member 2	–	–	–
a_4	Minimum distance between the member edge and the fastener perpendicular to the grain direction Minimum distance between the fastener and the edge of the middle member	– –	– a_4	a_4 –
$a_{4,c}$	Minimum distance between the unloaded edge and the fastener perpendicular to the grain direction Minimum distance between the unloaded edge and the fastener perpendicular to the grain direction of the CLT face layer	$a_{4,c}$ –	$a_{4,c}$ –	$a_{4,c}$ –
$a_{4,CG}$	Minimum distance between the edge and the screw centre of gravity in the member perpendicular to the grain direction	–	$a_{2,CG}$	$a_{4,ct,min}$
$a_{4,S}$	Minimum distance between the steel plate edge and the screw axis perpendicular to the grain direction	–	–	–
$a_{4,t}$	Minimum distance between the loaded edge and the fastener perpendicular to the grain direction Minimum distance between the loaded edge and the fastener perpendicular to the grain direction of the CLT face layer	$a_{4,t}$ –	$a_{4,t}$ –	$a_{4,t}$ –
a_{fi}	Additional thickness of a member for increased mechanical strength of a connection	–	a_{fi}	–
$a_{fi,1}$	Additional thickness on member 1	–	–	–
$a_{fi,2}$	Additional thickness on member 2	–	–	–
$a_{mm,1}$	Spacing of the neutral axes for partial cross-section 1	–	–	$a_{mm,1}$
$a_{mm,2}$	Spacing of the neutral axes for partial cross-section 2	–	a_2	$a_{mm,2}$
$a_{mm,i}$	Spacing of the neutral axes for partial cross-section i	–	a_i	$a_{mm,i}$
a_x	Minimum distance between two screws in a screw cross	–	–	–
b	Material coefficient in the k_{ax} equation for small screw axis/grain angles Member width	b b	– b	– b

		ETA	EC 5	Draft EC 5
b_1	Net width of the connection Factor 1 in the extended Johansen equation Width of member 1	- - -	- - -	b_{net} b_1 -
$b_{1,2}$	Cross-sectional width of cross-sections 1 and 2	-	-	-
b_2	Factor 2 in the extended Johansen equation Width of member 2	- -	- -	b_2 -
b_3	Width of member 3	-	-	-
b_4	Width of member 4	-	-	-
b_5	Width of member 5	-	-	-
$b_{c,90}$	Width of the compressive area	B	-	$b_{90,c}$
b_{ef}	Calculable width perpendicular to grain direction (in the plane of the screw tip)	B	b_{ef}	-
b_{HT}	Width of the main beam	-	-	-
b_{ist}	Available width	-	-	-
b_{min}	Minimum width of the member	-	-	b_{min}
$b_{\text{net},1}$	Net width of member 1	-	-	-
$b_{\text{net},2}$	Net width of member 2	-	-	-
b_{NT}	Width of the secondary beam	-	-	-
b_{St}	Width of the sheet steel	-	b_{St}	-
c_h	Elastic bedding of a screw	c_h	-	c_h
d	Outer thread diameter of a screw Diameter of an opening Fastener diameter	d - -	d d d	d d d
d_l	Thread core diameter	d_l	d_l	d_l
d_g	Gap depth	-	d_g	-
d_{head}	Head diameter or outer diameter of the washer	d_h/d_{head}	d_h	d_{head}
d_r	Outer thread diameter of the reinforcing screw	-	-	d_r
d_s	Shank diameter or thread core diameter	d_s	-	d_s
d_{VM}	Diameter of the fasteners in the connection	-	-	d
e	Spacing between the screws in a continuous connection	e	-	a_1
e_{con}	Screw (cross) spacing in a continuous connection	-	-	-
$f_{\text{ax},d}$	Design value of the withdrawal parameter	$f_{\text{ax},d}$	$f_{\text{ax},d}$	-
$f_{\text{ax},k}$	Characteristic withdrawal parameter	$f_{\text{ax},k}$	$f_{\text{ax},k}$	$f_{\text{ax},k}$
$f_{\text{ax},k,1}$	Characteristic withdrawal parameter in member 1	-	-	-
$f_{\text{ax},k,2}$	Characteristic withdrawal parameter in member 2	-	-	-
$f_{\text{ax},k,i}$	Characteristic withdrawal parameter in member i	-	-	-
$f_{c,0,d,1}$	Design value of the compressive strength parallel to the grain direction of member 1	-	$f_{c,0,d}$	-
$f_{c,90,d}$	Design value of the compressive strength perpendicular to the grain direction	$f_{c,90,d}$	$f_{c,90,d}$	$f_{c,90,d}$
$f_{c,90,k}$	Characteristic value of the compressive strength perpendicular to the grain direction	-	$f_{c,90,k}$	$f_{c,90,k}$
$f_{h,0,k}$	Characteristic embedment strength parallel to the grain direction	-	$f_{h,0,k}$	$f_{h,0,k}$
$f_{h,0,k,1}$	Characteristic embedment strength parallel to the grain direction of member 1	-	-	-
$f_{h,0,k,2}$	Characteristic embedment strength parallel to the grain direction of member 2	-	-	-
$f_{h,k}$	Characteristic embedment strength	$f_{h,k}$	$f_{h,k}$	$f_{h,k}$
$f_{h,k,1}$	Characteristic embedment strength of member 1	-	$f_{h,k,1}$	$f_{h,k,1}$
$f_{h,k,1/2/il}$	Characteristic embedment strength of member 1, member 2 or the interlayer	-	-	$f_{h,k,1/2/il}$
$f_{h,k,2}$	Characteristic embedment strength of member 2	-	$f_{h,k,2}$	$f_{h,k,2}$
$f_{h,k,il}$	Characteristic embedment strength of the interlayer	-	-	$f_{h,k,il}$
$f_{h,k,SDu}$	Characteristic embedment strength of the dowel	-	-	-
$f_{\text{head},k}$	Characteristic head pull-through parameter	$f_{\text{head},k}$	$f_{\text{head},k}$	$f_{\text{head},k}$
$f_{m,d}$	Design value of the flexural strength	$f_{m,d}$	$f_{m,d}$	$f_{m,d}$
$f_{m,d,1}$	Design value of the flexural strength of member 1/cross-section 1	-	-	-
$f_{m,d,2}$	Design value of the flexural strength of member 2/cross-section 2	-	-	-
$f_{m,k}$	Characteristic value of the flexural strength	-	$f_{m,k}$	$f_{m,k}$
$f_{m,k,1}$	Characteristic value of the flexural strength of cross-section 1	-	-	-
$f_{m,k,2}$	Characteristic value of the flexural strength of cross-section 2	-	-	-

		ETA	EC 5	Draft EC 5
$f_{t,0,d}$	Design value of the tensile strength parallel to the grain direction of the timber	–	$f_{t,0,d}$	$f_{t,0,d}$
$f_{t,0,d,1}$	Design value of the tensile strength parallel to the grain direction of member 1	–	–	–
$f_{t,0,d,2}$	Design value of the tensile strength parallel to the grain direction of member 2	–	–	–
$f_{t,0,k}$	Characteristic value of the tensile strength parallel to the grain direction of the timber	–	$f_{t,0,k}$	$f_{t,0,k}$
$f_{t,90,d}$	Design value of the tensile strength perpendicular to the grain direction of the GL or LVL	–	$f_{t,90,d}$	$f_{t,90,d}$
$f_{t,90,k}$	Characteristic transverse tensile strength	–	–	$f_{t,90,k}$
$f_{tens,d}$	Design value of the tensile resistance	$f_{tens,d}$	–	–
$f_{tens,k}$	Characteristic value of the tensile resistance	$f_{tens,k}$	$f_{tens,k}$	–
$f_{tor,k}$	Characteristic value of the breaking torque	$f_{tor,k}$	–	–
$f_{u,k}$	Characteristic value of the tensile strength of the steel	–	$f_{u,k}$	$f_{u,k}$
$f_{u,k,S235}$	Characteristic value of the tensile strength of the grade S235 steel	–	–	–
$f_{v,d}$	Design value of the shear strength	$f_{v,d}$	$f_{v,d}$	$f_{v,d}$
$f_{v,d,mod}$	Design value of the modified shear strength of the shear-reinforced cross-section	$f_{v,d,mod}$	–	–
$f_{v,d,1}$	Design value of the shear strength of member 1/cross-section 1	–	–	–
$f_{v,d,2}$	Design value of the shear strength of member 2/cross-section 2	–	–	–
$f_{v,k}$	Characteristic value of the shear strength	–	$f_{v,k}$	$f_{v,k}$
$f_{v,k,1}$	Characteristic value of the shear strength of cross-section 1	–	–	–
$f_{v,k,2}$	Characteristic value of the shear strength of cross-section 2	–	–	–
$f_{y,d}$	Design value of the yield strength of the steel	–	$f_{y,d}$	$f_{y,d}$
$f_{y,k}$	Characteristic value of the yield strength of the steel	$f_{y,k}$	–	$f_{y,k}$
g_k	Distributed load of permanent actions	–	–	–
h	Member height/cross-sectional height	h	h	h
h_1	Cross-sectional height of member 1	–	–	h_1
	Distance between the first fastener row and the unloaded edge perpendicular to the grain direction	h_1	h_1	h_1
$h_{1,2}$	Cross-sectional height of cross-sections 1 and 2	–	–	–
h_2	Cross-sectional height of member 2	–	–	h_2
h_d	Opening height	–	h_d	h_d
h_e	Distance between the furthest fastener or nail plate edge and the loaded edge (short: connection height)	a	h_e	h_e
h_{ef}	Residual beam height	h_e	h_{ef}	h_{ef}
$h_{ef,v}$	Effective height relative to the shear-reinforcing screws	–	–	–
h_{HT}	Height of the main beam	–	–	–
h_i	Distance of each row of fasteners from the unloaded edge	h_i	h_i	h_i
h_{min}	Minimum beam height	–	–	–
h_n	Spacing of the fastener row nearest to the loaded edge	h_n	h_n	–
h_{NT}	Height of the secondary beam	–	–	–
h_p	Thickness of the cladding; total thickness in the case of multiple layers	–	h_p	–
h_r	Height of the residual cross-section above or below the opening	–	h_r	–
h_{ro}	Height of the residual cross-section above the opening	–	h_{ro}	h_{ru}
h_{ru}	Height of the residual cross-section below the opening	–	h_{ru}	h_{rl}
i	Inclination of the notch	–	i	i
k	Head height	–	–	l_{head}
k_1	Factor for reducing the pull-out resistance with high t_{HI} values	k_1	–	–
k_2	Factor for reducing the pull-out resistance with low $\sigma_{10\%}$ values	k_2	–	–
k_a	Factor for screw spacing in connections between different materials	–	–	–
k_{ax}	Factor to account for the angle ε between the screw axis and the grain direction	k_{ax}	–	–
$k_{ax,HT}$	Factor to account for the angle ε between the screw axis and the grain direction in the main beam	–	–	–
$k_{ax,i}$	Factor to account for the angle ε between the screw axis and the grain direction in member i	–	–	–
$k_{ax,NT}$	Factor to account for the angle ε between the screw axis and the grain direction in the secondary beam	–	–	–
$k_{c,90}$	Factor to account for the type of action, the splitting risk and the degree of compressive deformation	$k_{c,90}$	$k_{c,90}$	$k_{c,90}$
k_{cr}	Crack factor for shear resistance	–	k_{cr}	–
$k_{cr,1}$	Crack factor for cross-section 1	–	–	–

		ETA	EC 5	Draft EC 5
$k_{cr,2}$	Crack factor for cross-section 2	–	–	–
k_{def}	Creep factor	–	k_{def}	k_{def}
k_{ef}	Exponent for reducing the number of fasteners screwed in to the effective number of fasteners	–	k_{ef}	k_{ef}
k_{fi}	Conversion factor from 5 % fractile values to 20 % fractile values	–	k_{fi}	–
k_{flux}	Coefficient to account for the increased heat flow through the screw	–	k_{flux}	–
k_g	Factor to account for multiple fastener groups in defined proximity to each other	–	k_g	–
k_{mod}	Modification factor	–	k_{mod}	k_{mod}
$k_{mod,1}$	Modification factor for member 1	–	$k_{mod,1}$	$k_{mod,1}$
$k_{mod,1/2/il}$	Modification factor for member 1, member 2 or the interlayer	–	–	$k_{mod,1/2/il}$
$k_{mod,2}$	Modification factor for member 2	–	$k_{mod,2}$	$k_{mod,2}$
$k_{mod,HT}$	Modification factor of the main beam	–	–	–
$k_{mod,il}$	Modification factor of the interlayer	–	–	$k_{mod,il}$
$k_{mod,NT}$	Modification factor of the secondary beam	–	–	–
k_n	Material coefficient for notches	–	k_n	k_n
k_o	Form factor	–	–	–
k_t	Factor to account for multiple fasteners arranged one above the other	–	k_t	$k_{con,90}$
k_s	Factor to account for multiple fasteners arranged side by side	–	k_s	$k_{con,0}$
$k_{sf,i}$	Ratio of the effective number of screws to the actual number of screws parallel to the grain direction in the respective row	–	–	–
$k_{t,90}$	Factor to account for the beam height	–	$k_{t,90}$	–
k_t	Factor describing the stresses perpendicular to the grain direction	k_t	–	–
$k_{v,n}$	Shear factor for notches	–	k_v	$k_{v,n}$
k_a	Factor for the force/grain angle	k_e	–	–
k_β	Factor to account for the angle β between the screw axis and the wide face (of the laminated veneer lumber)	k_β	–	–
$k_{\beta,1}$	Factor to account for the angle β between the screw axis and the wide face of member 1	–	–	–
$k_{\beta,2}$	Factor to account for the angle β between the screw axis and the wide face of member 2	–	–	–
$k_{\beta,HT}$	Factor to account for the angle β between the screw axis and the wide face of the main beam	–	–	–
$k_{\beta,i}$	Factor to account for the angle β between the screw axis and the wide face of member i	–	–	–
$k_{\beta,NT}$	Factor to account for the angle β between the screw axis and the wide face of the secondary beam	–	–	–
k_e	Factor for the screw/grain angle	–	–	–
l	Screw length Load length	l –	– l	l_i l_i
l_1	Embedment depth without overlap at member edge 1	–	–	–
$l_{1,2}$	Overlap length	–	–	–
$l_{1,2,min}$	Minimum overlap length	–	–	–
$l_{1,min}$	Minimum embedment depth without overlap at member edge 1	–	–	–
l_2	Embedment depth without overlap at member edge 2	–	–	–
$l_{2,min}$	Minimum embedment depth without overlap at member edge 2	–	–	–
l_A	Distance from the bearing force to the edge of the opening	–	l_A	l_A
l_{aw}	Effective length in the angled washer	n	–	–
$l_{c,90}$	Length of the compressive area	–	l_A/l_A	$l_{90,c}$
$l_{c,90,1}$	Length of the compressive area, top	–	–	–
$l_{c,90,2}$	Length of the compressive area, bottom	–	–	–
$l_{c,NT}$	Anchorage length of the compressive screws in the secondary beam	–	–	–
l_{char}	Characteristic length of the timber on top of the thermal insulation	l_{char}	–	–
l_e	Distance from the free member edge to the contact area	–	a	l_e
l_{ef}	Calculated screw length	l_{ef}	–	–
$l_{ef,1}$	Calculable length parallel to the grain direction in the plane of the screw head	$l_{ef,1}$	–	$l_{1,ef}$
$l_{ef,2}$	Calculable length parallel to the grain direction in the plane of the screw tip	$l_{ef,1}$	–	$l_{2,ef}$
l_{Feld}	Span of the counter batten	l	–	–
l_g	Thread length (incl. drill tip)	l_g	–	–
l_h	Length of the opening	–	a	l_h

		ETA	EC 5	Draft EC 5
l_{ne}	Unbedded screw length	-	-	-
l_s	Spacing of the shear loads	-	l_l	l_s
$l_{s,max}$	Maximum possible screw length	-	-	-
$l_{s,min}$	Minimum screw length	-	-	-
$l_{Stoß,1/2}$	Installation length of a connection	-	-	l_{con}
$l_{t,90}$	Distribution length for rectangular/circular openings	-	$l_{t,90}$	$l_{t,90,V}$
$l_{t,i}$	Partial length of the i lengths of a net tensile area	-	$l_{t,i}$	-
l_{Voute}	Length of the haunch	-	-	-
l_v	Spacing between the edge and the centre of gravity of the first row of screws in the timber parallel to the grain direction	-	-	-
	Length of the overhang	-	l_v	l_v
$l_{v,i}$	Partial length of the i lengths of a net shear plane	-	$l_{v,i}$	-
l_w	Anchorage length of the threaded section of a screw (including the screw tip)	l_{ef}	-	l_r
$l_{w,1}$	Anchorage length in member 1/member area 1	-	l_{ad}	$l_{w,1}$
$l_{w,2}$	Anchorage length in member 2/member area 2	-	l_{ad}	$l_{w,2}$
$l_{w,c,HT}$	Anchorage length of the threaded section of a compressive screw in the main beam	-	-	-
$l_{w,c,NT}$	Anchorage length of the threaded section of a compressive screw in the secondary beam	-	-	-
$l_{w,i}$	Anchorage length in member i /member area i	-	-	$l_{w(i)}$
$l_{w,max}$	Maximum anchorage length of the threaded section of a screw (including the screw tip)	-	-	-
$l_{w,min}$	Minimum anchorage length	-	-	$l_{w,min}$
$l_{w,t,HT}$	Anchorage length of the threaded section of a tensile screw in the main beam	-	-	-
$l_{w,t,NT}$	Anchorage length of the threaded section of a tensile screw in the secondary beam	-	-	-
l_z	Distance between two openings	-	l_z	l_z
m_{HT}	Installation dimension in the main beam	-	-	-
m_{NT}	Installation dimension in the secondary beam	-	-	-
n	Number of fasteners in a connection/number of reinforcing screws	n	n	n
	Upper limit of the sum	-	-	j
n_0	Number of fasteners parallel to the load/in a row parallel to the grain direction	n_0	-	n_0
$n_{0,i}$	Number of screws in a row parallel to the grain direction (one of several rows)	-	-	-
n_1	Number of screws at member edge 1	-	-	n_1
n_2	Number of screws at member edge 2	-	-	n_2
n_{90}	Number of fastener rows perpendicular to the load/grain direction	n_{90}	-	n_{90}
n_{con}	Number of screws per screw cross	-	-	-
n_{ef}	Effective number of fasteners	n_{ef}	n_{ef}	n_{ef}
$n_{ef,0}$	Effective number of fasteners in a row parallel to the grain direction	-	-	n_{ef}
$n_{ef,0,i}$	Effective number of fasteners in a row parallel to the grain direction (one of several rows)	-	-	-
$n_{ef,1}$	Effective number of fasteners in member 1	-	-	-
$n_{ef,2}$	Effective number of fasteners in member 2	-	-	-
$n_{ef,90}$	Effective number of fasteners perpendicular to the grain direction	-	-	-
$n_{ef,ges}$	Product of the effective number of screws parallel and perpendicular to the grain direction in a connection	-	-	-
$n_{ef,\alpha}$	Effective number of fasteners with a force acting at angle α	-	-	-
$n_{ef,\alpha,i}$	Effective number of screws in one of several rows of screws arranged parallel to the grain direction with a force acting at angle α	-	-	-
$n_{ef,\alpha,j}$	Effective number of screws in a connection with variable force/grain angle α per screw	-	-	-
n_{ges}	Number of screws in a connection	-	-	-
n_j	Number of screws in a connection with variable force/grain angle α	-	-	-
$n_{Scherfugen}$	Number of shear planes	-	$n_{Schnitte}$	-
n_x	Number of screw crosses or pairs	n	-	-
q	Distributed load	-	q_i	q_{Ed}/q_z
$q_{ ,k}$	Characteristic value of the line load acting parallel to the roof plane	$q_{ ,k}$	-	-
$q_{\perp,k}$	Characteristic value of the line load acting perpendicular to the roof plane	$q_{\perp,k}$	-	-
q_{char}	Characteristic load combination	-	-	-
q_d	Design value of the acting distributed load	-	-	-
	Design value of the load, here: as the line load of the decisive combination	-	-	-

		ETA	EC 5	Draft EC 5
$q_{d,i}$	Design value of the load of cross-section i	–	–	–
q_k	Variable distributed load	–	–	–
$q_{k,1}$	Variable acting distributed load (category B)	–	–	–
$q_{k,2}$	Variable acting distributed load (snow)	–	–	–
$q_{k,i}$	Variable acting distributed load of load case i	–	–	–
q_{qs}	Quasi-constant load combination	–	–	–
r	Corner radius	–	r	r
s_l	Effective fastener spacing in cross-section 1	–	s_i	s_i
s_{ef}	Effective fastener spacing	–	s	$s_{i,ef}$
t	Member thickness/board thickness	t	t	t
t	Time	–	t	t
t_1	Embedment depth projected perpendicular to the shear plane Thickness of member 1 Embedment depth in member 1	–	t_{ef} t_1 t_1	– t_1 t_{h1}
t_2	Member thickness of the middle member Thickness of member 2 Embedment depth in member 2	– – –	– t_2 t_2	– t_2 t_{h2}
t_{ch}	Period until the start of charring for a protected member	–	t_{ch}	–
t_{CLT}	Thickness/minimum thickness of a member made of CLT	–	h	t_{CLT}
$t_{d,fi}$	Required fire resistance period in minutes Fire resistance period of the unprotected connection	– –	$t_{d,fi}$ $t_{d,fi}$	– –
t_{dl}	Thickness of the CLT face layer	–	–	–
t_{ef}	Effective embedment depth	l_{ef}	t_{ef}	t_{ef}
$t_{ef,1}$	Effective embedment depth in member 1	–	–	–
$t_{ef,2}$	Effective embedment depth in member 2	–	–	–
t_h	Embedment depth	l_{ef}	t	t_h
$t_{h,1}$	Embedment depth in member 1	–	t_1	$t_{h,1}$
$t_{h,1/2/il}$	Embedment depth in member 1, member 2 or the interlayer	–	–	$t_{h,1/2/il}$
$t_{h,2}$	Embedment depth in member 2	–	t_2	$t_{h,2}$
$t_{h,i}$	Embedment depth in member i	–	t_i	$t_{h,(i)}$
t_{HI}	Thickness of the thermal insulation	t_{HI}	–	–
t_{max}	Maximum member thickness	–	–	–
t_{min}	Minimum member thickness	–	–	t_{min}
t_{pen}	Penetration depth in the transversely loaded member	t	t_{pen}	–
t_{req}	Required fire resistance period for standard fire exposure	–	t_{req}	–
t_s	Sheet steel thickness	t	$t_i/t_{Blech}/t_s$	t/t_s
$t_{s,1}$	Sheet steel thickness, top	–	–	–
$t_{s,2}$	Sheet steel thickness, bottom	–	–	–
$t\Sigma_i$	Total thickness of the CLT inner layers	–	–	–
w	Modification factor Minimum value of the width of the counter batten and the rafter	– w	w –	– –
w_{creep}	Creep deformation	–	w_{creep}	w_2
w_{ef}	Calculable width of the thermal insulation	w_{ef}	–	–
w_{fin}	Deflection in the final state	–	w_{fin}	w_{tot}
w_{inst}	Deflection in the initial state	–	w_{inst}	–
$w_{net,fin}$	Total final deflection	–	$w_{net,fin}$	w_{max}
w_{pl}	Width of the nail plate parallel to the grain direction	–	w_{pl}	w_{pl}
x	Distance between the line of action of the bearing force and the notch corner	c	x	x

Greek letters and designations in accordance with ETA-11/0190, EC 5 and Draft EC 5

		ETA	EC 5	Draft EC 5
α	Angle between the force direction and grain direction Quotient of the residual beam height and the beam height Quotient of the connection height and beam height	ε α α	α α α	α α –
β	Angle between the screw axis and wide face Ratio of the embedment strength between two members Roof pitch angle between the shear plane and normal plane	β – β	– β –	β β –
β_0	One-dimensional charring	–	β_0	–
β_n	Ideal charring rate of the timber (taking into account corner rounding and cracks)	–	β_n	–
$\beta_{n,1}$	Ideal charring rate of member 1	–	–	–
$\beta_{n,2}$	Ideal charring rate of member 2	–	–	–
γ_1	Factor for the connection stiffness in member 1	–	γ_1	γ_1
γ_2	Factor for the connection stiffness in member 2	–	γ_2	γ_2
γ_i	Factor for the connection stiffness in member i	–	γ_i	γ_i
γ_M	Partial safety factor	–	γ_M	γ_M/γ_R
γ_{M0}	Partial safety factor for normal compressive stress	–	–	γ_{M0}
γ_{M1}	Partial safety factor for stability verification under compressive stress	γ_{M1}	–	γ_{M1}
$\gamma_{M,fi}$	Partial safety factor for timber in the event of fire	–	$\chi \gamma_{M,fi}$	–
γ_R	Partial safety factor for shear connections	–	γ_M	γ_R
$\Delta w_{c,90}$	Bearing displacement due to deflection	–	–	Δw
δ	Ratio of the modified embedment strength of the interlayer to the member on the tip side Angle between the screw axis and shear plane	– α	– –	δ δ
ε	Angle between the screw axis and grain direction	α	α	ε
ε_1	Angle between the screw axis and the grain direction on the compressive screw	α_1	–	–
ε_2	Angle between the screw axis and the grain direction on the tensile screw	α_2	–	–
ε_{HT}	Angle between the screw axis and the grain direction in the main beam	–	–	–
ε_{NT}	Angle between the screw axis and the grain direction in the secondary beam	–	–	–
η	Utilisation factor Reduction factor for reducing the axial load-bearing capacity in the event of fire	– –	η η	– –
η_{ax}	Utilisation of the screw	–	–	–
$\eta_{c,1}$	Utilisation relative to the compressive stress in member 1	–	–	–
η_{fin}	Utilisation relative to the deflection in the final state	–	–	–
η_H	Factor describing the shear force components generating shear stress	η_H	–	–
η_{inst}	Utilisation relative to the deflection in the initial state	–	–	–
η_m	Utilisation relative to the bending stress	–	–	–
$\eta_{m,1}$	Utilisation relative to the bending stress in member 1/cross-section 1	–	–	–
$\eta_{m,2}$	Utilisation relative to the bending stress in member 2/cross-section 2	–	–	–
$\eta_{t,2}$	Utilisation relative to the tensile stress in member 2	–	–	–
η_v	Utilisation of the connection	–	–	–
$\eta_{v,1}$	Utilisation relative to the shear stress in cross-section 1	–	–	–
$\eta_{v,2}$	Utilisation relative to the shear stress in member 2/cross-section 2	–	–	–
κ_{max}	Geometry factor (max. shear stress in at-risk areas)	–	–	κ_r
λ_k	Relative slenderness ratio	λ_k	$\lambda_{rel,y/z}$	λ_k
μ	Coefficient of friction	–	μ	μ
$\rho_{ref,k}$	Reference bulk density	ρ_a	ρ_a	$\rho_{ref(i),k}$
$\rho_{ref,k,1}$	Reference bulk density of member 1	–	–	–
$\rho_{ref,k,2}$	Reference bulk density of member 2	–	–	–
$\rho_{ref,k,i}$	Reference bulk density of member i	–	–	$\rho_{ref(i),k}$
ρ_k	Characteristic bulk density	ρ_k	ρ_k	$\rho_{(i),k}$
$\rho_{k,1}$	Characteristic bulk density of member 1	–	–	–
$\rho_{k,1,2}$	Characteristic bulk density of cross-sections 1 and 2	–	–	–
$\rho_{k,2}$	Characteristic bulk density of member 2	–	–	–
$\rho_{k,HT}$	Characteristic bulk density of the main beam	–	–	–
$\rho_{k,NT}$	Characteristic bulk density of the secondary beam	–	–	–

		ETA	EC 5	Draft EC 5
$\rho_{k,i}$	Characteristic bulk density of member i /cross-section i	–	–	$\rho_{(i),k}$
ρ_{mean}	Mean bulk density	–	ρ_m	ρ_{mean}
$\rho_{\text{mean},1}$	Mean bulk density of member 1	–	–	$\rho_{\text{mean},1}$
$\rho_{\text{mean},1/2/il}$	Mean bulk density of member 1, member 2 or the interlayer	–	–	$\rho_{\text{mean},1/2/il}$
$\rho_{\text{mean},2}$	Mean bulk density of member 2	–	–	$\rho_{\text{mean},2}$
$\rho_{\text{mean},i}$	Mean bulk density of member i /cross-section i	–	–	$\rho_{(i),\text{mean}}$
$\rho_{\text{mean},il}$	Mean bulk density of the interlayer	–	–	$\rho_{\text{mean},il}$
Σ	Total	–		Σ
Σ_i	Total of i	–	Σ_i/Σ_j	Σ_i
$\sigma_{10\%}$	Compressive stress at 10 % compressed thermal insulation (measured in accordance with DIN EN 826)	$\sigma_{10\%}$	–	–
$\sigma_{90,d}$	Design value of the stress perpendicular to the grain direction	$\sigma_{90,d}$	$\sigma_{90,d}$	–
$\sigma_{c,90,d}$	Design value of the compressive stress in the contact area	–	$\sigma_{c,90,d}$	$\sigma_{c,90,d}$
$\sigma_{c,d}$	Design value of the compressive stress	–	$\sigma_{c,d}$	$\sigma_{c,d}$
$\sigma_{c,d,1}$	Design value of the compressive stress in member 1	–	–	σ_i
$\sigma_{c,k}$	Characteristic value of the compressive stress	σ_k	–	–
$\sigma_{m,d}$	Design value of the bending stress	$\sigma_{m,d}$	$\sigma_{m,d}$	$\sigma_{m,i}$
$\sigma_{m,d,1}$	Design value of the bending stress in member 1/cross-section 1	–	–	$\sigma_{m,i}$
$\sigma_{m,d,2}$	Design value of the bending stress in member 2/cross-section 2	–	–	$\sigma_{m,i}$
$\sigma_{\text{max},d,2}$	Largest value of the stress in member 2	–	–	–
$\sigma_{\text{min},d,1}$	Smallest value of the stress in member 1	–	–	–
$\sigma_{t,d,2}$	Design value of the tensile stress in member 2	–	–	σ_i
τ_d	Design value of the shear stress	τ_d	τ_d	τ_d
τ_{max}	Maximum shear stress in the at-risk areas	–	–	$\tau_{\text{max},d}$
$\tau_{\text{max},d,2}$	Largest value of the shear stress in member 2	–	–	$\tau_{2,\text{max}}$
$\tau_{z,d}$	Shear stress in the z direction in the cross-section	–	–	–
$\tau_{z,d,1}$	Shear stress in the z direction in cross-section 1	–	–	–
$\tau_{z,d,2}$	Shear stress in the z direction in cross-section 2	–	–	–
ϕ	Factor	k	–	ϕ
ϕ_c	Reduction factor for screw buckling	κ_c	–	ϕ_c
ϕ_{Tr}	Bearing rotation due to beam deflection	–	–	φ
Ψ_0	Combination factor in accordance with DIN EN 1990	–	Ψ_0	Ψ_0
Ψ_2	Combination factor in accordance with DIN EN 1990	–	Ψ_2	Ψ_2
ω_{mean}	Timber equilibrium moisture content (annual average)	–	ω	ω_{mean}

Abbreviations

①	Member 1 (in a connection)
②	Member 2 (in a connection)
il	Interlayer
A2	Stainless steel (alloys: 1.4301, 1.4305 or 1.4307)
A4	Stainless steel (alloys: 1.4401)
GST	G lued S olid T imber
BFU	Plywood in accordance with DIN EN 636-1/S to -3/S (S = structural)
BGL	B lock G lued G lulam
CH	Socket head (C ylinder H ead)
CL	C ross- L ayered Timber – CLT, SWP-C
CLT	C ross- L aminated T imber
COMBI	Combination screw head (with shank reinforcement)
CPB	C ement- B onded P articleboard
CS	C ountersunk head
CSMP	C ountersunk head with M illing P ocket
CSMR	C ountersunk head with M illing R ib
CSMR-WW	Countersunk head with milling ribs (high head shape with extended drive)

CRC	C orrosion R esistance C lass
ETX	External TX
SC	S rength C lass
FST	F inger-jointed S tructural T imber
GFB	G ypsum F ibre b oard
CT IIpc	C oarse T hread II with milling pockets (pre-cut)
GL	G lued L aminated Timber
GLVL	G lued L aminated V eneer L umber – GLVL-C, GLVL-P
GLVL-C	Glued LVL – C rossband
GLVL-P	Glued LVL – P arallel
GL 75	Beams made of laminated veneer lumber from beech in accordance with ETA-1470354
GPB	G ypsum P laster b oard
GST	G lued S olid T imber
GLT Birch	Glued laminated timber made of birch in accordance with ETA-19/0031
GYB	G ypsum B ased – GPB, GFB
SLS	S erviceability L imit S tate
ULS	U ltimate L imit S tate
HB	H ard fibreboard
HCR	Steels for corrosive environments (H igh C orrosion R esistance – alloys: 1.4539, 1.4529)
HI	H eat I nsulation
MB	M ain B eam
JH	J oist H anger
LDC	L oad D uration C lass
LCC	L oad C ase C ombination
LVL	L aminated V eneer L umber – LVL-C, LVL-P
LVL-C	Laminated veneer lumber with C rossband veneer layers
LVL-P	Laminated veneer lumber with P arallel veneer layers
LVL _{edge(wise)}	Laminated veneer lumber with vertical veneers (e.g. high-edge loading)
LVL _{flat(wise)}	Laminated veneer lumber with horizontal veneers (e.g. flat-edge loading)
MB	M edium-hard fibreboard
MDF	M edium- D ensity F ibreboard
NDP	N ationally D etermined P arameter
SC	S ervice C lass
SB	S econdary B eam
OSB	O riented- S trand B oard
P	Screw with two threaded sections
PII	Screw with two threaded sections
Pan	P an H ead
Pan-JH	J oist H anger
PL	P arallel- L aminated Timber – GST, GL, BGL, SWP-P
PW	P ly w ood
QS	C ross- s ection
R 30	Fire resistance period of 30 minutes
R 60	Fire resistance period of 60 minutes
RPB	R esin-Bonded P article b oard
RW	Internal drive
SB	Porous fibreboard (S oft b oard)
SL	S tructural L umber – ST, FST
ST	S olid T imber
STB	S trand- B ased timber products
ShSt	S heet S teel
SWB	S olid W ood- B ased products
SWP	S olid- w ood p anels in accordance with DIN EN 13986
SWP-C	Multilayer solid wood panel

SWP-P	Single-layer solid wood panel
PT	P artial T hread
TTC	T imber/ T imber C omposite
VB	V eneer- B ased timber products
FT	F ull T hread
FTS	F ully T hreaded S crew
VM	Fasteners
WFB	W ood F ibre- B ased boards – HB, MB, SB, MDF
WH	W asher H ead – with domed head
WH II	Washer head II (with step and flat head)
WH _{A2}	Washer head on A2 screws
WPB	W ood P article- B ased boards – RPB, CPB)
WW	Countersunk head with milling ribs (high head shape with extended drive)



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