STRUCTURAL TIMBER ASSOCIATION
Building solutions in timber

Glued laminated timber structures. Part 2: construction and connection details

Introduction

In Engineering Bulletin No. 8 the engineering principles of open frame forms of construction, including post and beam and rigid frame construction, were presented. The most common timber material used – glued laminated timber (glulam), was introduced.

This Engineering Bulletin introduces the construction and connection details appropriate to open frame construction and provides a worked example for a dowelled glulam portal haunch connection.

The determination of individual fastener capacities for nails, screws and bolts is not covered here, and reference should be made to the 'References and further reading' section for further guidance on the structural design of these components. However, to illustrate the design of a dowelled portal haunch, the derivation of characteristic dowel capacities loaded in double shear is presented in the 'Structural notes' section.

For information regarding the design of connections for resistance to fire, reference should be made to Engineering Bulletin No. 7.

Detailing considerations

Construction and connection details

Proper connection details are important for the structural performance and serviceability of any timber structure. While this is true for solid sawn as well as glued laminated timber (glulam), the larger sizes and longer spans made possible with glulam components make the proper detailing of connections even more critical.

Careful consideration of moisture-related expansion and contraction characteristics of wood is essential in detailing glulam connections, to prevent induced tension perpendicular to grain stresses; which can lead to splitting of members parallel to the grain and corresponding signifi cant reductions in member capacities.

Connections must be designed to transfer design loads to and from a structural glulam member, without causing localised stress concentrations beyond the capacity of either the connector or the timber member.

Connections should be designed to prevent the build-up of moisture that could lead to decay of the timber e.g. allow for drainage holes in shoes. Refer to Engineering Bulletin No. 1 for more information on the durability of timber.

Structural effects of shrinkage and improper detailing

As described in Engineering Bulletin No. 1, wood expands and contracts as a result of changes in its internal moisture content. While expansion in the direction parallel to the grain is minimal, dimensional change in the direction perpendicular to the grain can be significant and must be considered in connection design and detailing. It is important to design and detail connections so that moisture movements of the timber are not restrained - with possible splitting of the timber as a consequence.

Account should be taken of other situations that can create tension perpendicular to the grain and possible splitting of the timber e.g. notching of the section, insuffi cient edge distance for actions applied close to the tension face of a member (important in the shoe connections of beam-to-beam connections where bolts carrying shear force at the end of a beam load the supporting beam perpendicular to the grain), eccentric (out of plane) loading of truss connections and loading beams from the tension side.

Effects of moisture accumulation

As most connections occur at the ends of members where the wood end grain is exposed, it is critical that these connections are designed to prevent moisture accumulation. This can usually be accomplished by detailing drain holes or slots and by maintaining a gap between the wood and concrete or masonry construction.

For external use, the foot of a timber column should be located at least 150mm above external fi nished ground level by the provision of a suitable elevated post base.

Pin-joints and eccentricity

The simplest kind of connection is the direct bearing of one component onto another (such as a glulam purlin bearing onto a glulam rafter) where dowels, gussets or housing in a mortise are provided to hold the members in position relative to each other but not to transfer any direct loading.

Alternatively, pinned joints can be formed by joining components together with mechanical fastenings (e.g. bolts) which are confined to a relatively small bearing area at the connection (Figures 1 and 2). The use of brackets or shoes such as joist or beam hangers can create eccentricities that must be allowed for in the design of the connection.

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Figure 1

Glulam pin-jointed connections

Figure 2

Bolted glulam beam-to-column connection

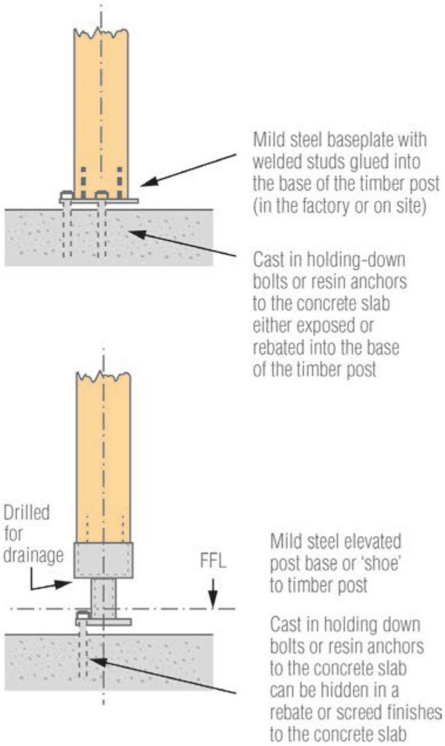


Figure 3a

Correct detailing of connection of glulam column to concrete base

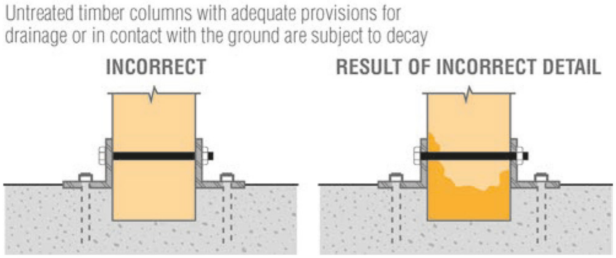


Figure 3b

Incorrect detailing of connection of glulam column to concrete base

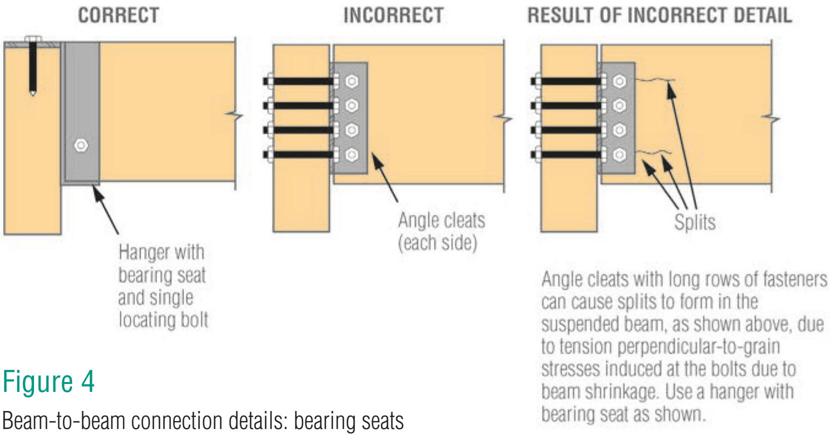


Figure 4

Beam-to-beam connection details: bearing seats

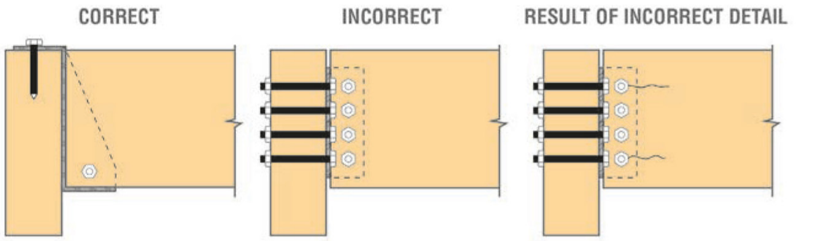


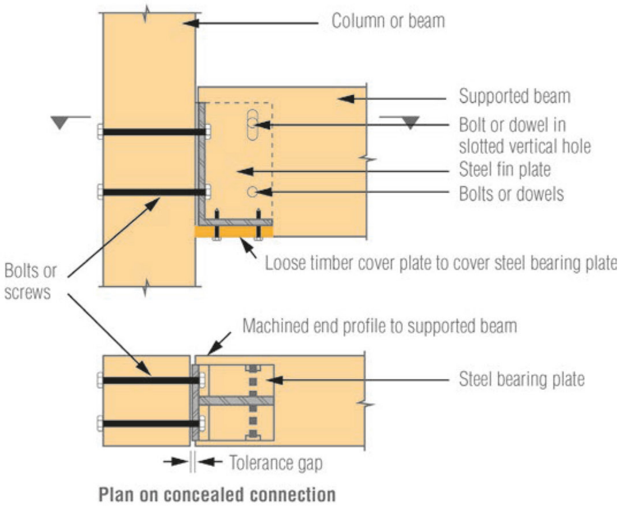
Figure 5

Beam-to-beam connection details: partially concealed beam hangers

Concealed plate with long row of fasteners can cause splits to form in suspended beam, as shown above. Use a concealed plate with bearing seat, as shown above left.

< Figure 6

Glulam beam-to-column connection showing partially concealed beam hanger



< Figure 7

Glulam beam-to-column connection using fully concealed beam hangers

Connection examples

This section provides some indicative details of various connection types. Figures 3-9 show correct connection details along with examples of poor connection detailing and the likely failures that may occur as a result.

All connections must be designed to effectively transfer the ultimate limit state (design) loads imposed on the connection. The detailing must also address the aesthetic and serviceability requirements of the connection, for example limiting rotation in a moment-resisting connection.

In addition to the bespoke details shown, STA member companies can also provide pre-engineered metal connectors such as beam hangers, post bases and concealed beam connectors that have been specifically designed for use in glulam framing.

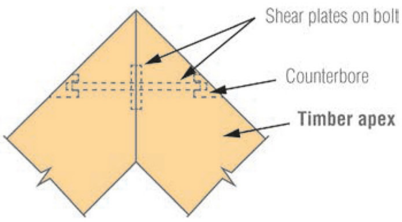
In summary, the principles of connection design are:

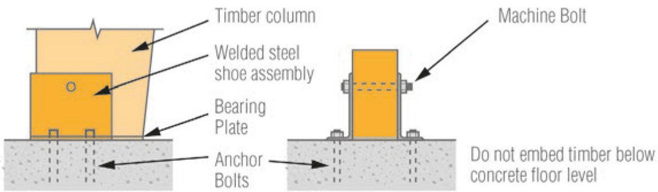
- Transfer loads in compression bearing wherever possible
- Allow for dimensional changes in glulam due to potential in-service moisture cycling
- Avoid the use of details that induce tension perpendicular to grain stresses in a member
- Avoid moisture entrapment at connections
- Do not place glulam in direct contact with masonry or concrete
- Design the joints to minimise eccentricity in the connection
- Minimise exposure of end grain

Figure 8

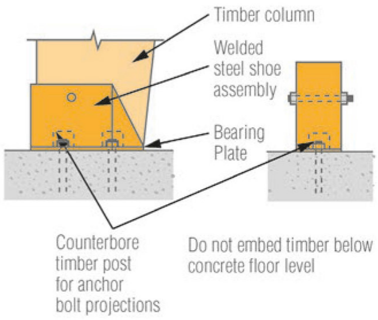
Pinned portal frame connections – post base and apex connections

Portal apex connection - this connection will transfer both vertical forces (shear) and horizontal forces (tension and compression)





Portal column shoe with exposed anchor bolts



Portal column shoe with concealed anchor bolts

Structural detailing and control of connections

BS EN 1995-1-1: Eurocode 54 provides a number of rules for connections with mechanical fasteners:

- Wane, splits and knots or other defects in the timber should be limited in the vicinity of connections (Clause 10.4.1 (1))
- Nails should typically be driven at right angles to the grain and to such depth that the surfaces of the nail head are fl ush with the timber surface (Clause 10.4.2 (1))
- The diameter of predrilled holes for nails should not exceed 0.8d where d is the nail diameter (Clause 10.4.2 (3))
- Bolt holes in timber should have a diameter not more than 1mm larger than the bolt. Bolt holes in steel plates should have a diameter not more than 2mm or 0.1d (whichever is the greater) larger than the bolt diameter (Clause 10.4.3 (1))
- Bolts should be provided with washers with a side length or diameter of at least 3d and a thickness of at least 0.3d under the head and nut (Clause 10.4.3 (2))
- Bolts and lag screws (coach screws) should be tightened so that members fi t closely and they should be retightened if necessary when the timber has reached its equilibrium moisture content (Clause 10.4.3 (3))
- The dowel diameter should be greater than 6mm and less than 30mm. Pre-bored holes in the timber members should have a diameter not greater than the dowel (Clause 10.4.4)
- Pre-drilling for screws with a smooth shank diameter less than 6mm is not required in softwoods. For all screws in hardwoods and for screws with a diameter greater than 6mm in softwoods, predrilling is required (Clause 10.4.5 (1))

In some instances it may be necessary to use concealed or semi-concealed connections to achieve architectural requirements or to provide fire resistance[2].

For beam-to-beam and beam-to-column connections, steel dowels or countersunk bolts can be concealed by recessing the head of the fastener and filling the recess with a glued-in timber plug or covering a group of fasteners with a wood-based or gypsum panel.

Stiff jointing techniques - portal haunch connections

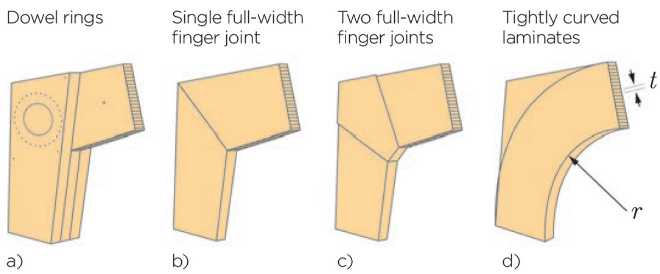
Stiff, moment-resisting connections, such as those at portal frame haunches, can be formed between timber members in a number of ways:

- Using surface-fixed gusset plates, fixed with nails, screws, bolts, dowels or adhesives
- Using let-in steel plates joined to the timber members with bolts or dowels
- Using mechanically fi xed timber lap-joints
- Using finger joints
- Using curved laminated members

In methods of jointing, BS EN 1995-1-1 Eurocode 5 allows a greater range of options compared with previous British Standards; such as the use of hidden steel dowels and plates which have been proven to be structurally efficient and give a cleaner, more aesthetically attractive final appearance for connections. Fig. 9 indicates the possible arrangements for portal haunch connections using solid LVL or glulam.

Figure 9

Portal haunch details



a) Rings or dowels are suitable for glulam or LVL. Provides a durable connection which can be site-assembled. Reinforcement of the timber may be required to avoid splitting.

b) A neat connection suitable for glulam or LVL. The tightness of the corner reduces its strength; it cannot be used in service class 3.

c) As b but with improved strength; still cannot be used in service class 3.

d) Very neat appearance and no site assembly required. Suitable only for glulam. Internal radius limited to:

$$r \geq \frac{t\,E_{mean}}{70}$$

Where:

r = radius of curvature (mm)

E_{mean} = mean modulus of elasticity (N/mm²)

t = thickness of individual glulam laminates (mm)

Structural notes

To illustrate the design of a dowelled portal haunch, the derivation of characteristic dowel capacities loaded in double shear is presented.

A dowel is a metal cylindrical fastener, typically of circular cross section, produced from steel rods in accordance with BS EN 14592:20085. Minimum spacing and edge distances for dowels are given in BS EN 1995-1-1 Table 8.5.

Derivation of characteristic shear strength of a steel dowel in double shear in accordance with BS EN 1995-1-1 Clause 8.2.2: Concise Eurocodes: Design of timber structures6 provides a simplified procedure for the derivation of fastener capacities compared to that provided in BS EN 1995-1-1 Clause 8.2.2 and it is this method which is presented here.

For fasteners of diameter d in double shear, the characteristic lateral load carrying capacity per shear plane per fastener, $F_{v,Rk}$ should be taken as:

$$F_{v,Rk} = k_{rope} f_{h,1,k} t_1 d \eta$$

Note: The design lateral load-carrying capacity for the fastener should be calculated from the characteristic lateral load carrying capacity in accordance with BS EN 1995-1-1 expression 2.17.

Characteristic embedment strength $f_{h,i,k}$

$f_{h,i,k}$ is the characteristic embedment strength in timber member i (refer to BS EN 1995-1-1 expressions 8.31 and 8.32). For woodbased materials the characteristic embedment strengths $f_{h,k}$ in N/ mm² are given in Table 1.

Table 1: Characteristic embedment strengths $f_{h,k}$ for wood based materials

Type of dowel-type fastener	Characteristic embedment strength $f_{h,k}$ in solid timber, glued laminated timber or LVL at following angle to grain	
	0 degrees	α degrees
Diameter 30 > d ≥ 6mm, inserted in pre-drilled holes	$0.082(1-0.01d)\rho_k$	$\dfrac{0.082(1-0.01d)\rho_k}{k_{90}\sin^2\alpha + \cos^2\alpha}$

Where:

d is the diameter of the dowel-type fastener (mm)
ρ_k is the characteristic density of the timber (kg/m3)
k_{90} is the embedment strength modification factor for all angles to grain other than 0 degrees which should be taken as:

$$k_{90} \begin{cases} 1.35+0.015d \text{ for softwoods and glulam} \\ 1.30+0.015d \text{ for LVL} \\ 0.90+0.015d \text{ for hardwoods} \end{cases}$$

The characteristic density ρ_k for LVL should be taken as: $\rho_k = \min \begin{cases} \rho_k \\ 500 \end{cases}$

Characteristic fastener yield moment $M_{y,Rk}$

$M_{y,Rk}$ is the characteristic fastener yield moment (BS EN 1995-1-1 expression 8.30). For dowel-type fasteners, unless the characteristic yield moment $M_{y,Rk}$ has been determined and declared in accordance with BS EN 4097 and BS EN 14592, the following values for characteristic yield moment should be used: $M_{y,Rk} = 0.3 f_{u,k} d^{2.6}$

Where:
d is the diameter of the dowel-type fastener (mm)
$f_{u,k}$ is the characteristic tensile strength of the fastener (N/mm²) which for bolts whose nominal diameter > 8mm should be taken as 400N/mm²

The rope efffect factor k_{rope}
k_{rope} is the rope effect modification factor. The rope effect factor is determined by the axial withdrawal capacity of a fastener. The values of krope should be taken as:
k_{rope} = 1.00 for plain dowels
k_{rope} = 1.20 for bolts with washers

Factor for the simplification of failure mode η

In Concise Eurocodes: Design of timber structures (section 8.1.2), a factor η is provided to simplify the four expressions contained in BS EN 1995-1-1 (expression 8.7) for the lateral load-carrying capacity of a fastener per shear plane as a result of the combined effects of fastener yield and timber bearing failure.

For fasteners in double shear η is the factor given in Table 2.

Table 2: Values of η factor for fasteners in double shear

K	η
≥ 0.05	$\min \begin{cases} 1.0 \\ 0.5\beta \dfrac{t_2}{t_1} \\ 0.93\beta^{0.25} K^{0.33} \end{cases}$
< 0.05	$2.3\sqrt{\dfrac{K\beta}{(1+\beta)}}$

Where:

$$K = \frac{M_{y,Rk}}{f_{h,1,k} d t_1^2}$$

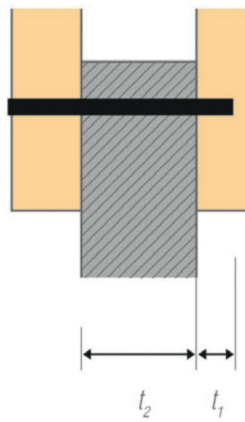
$$\beta = f_{h,2,k} / f_{h,1,k}$$

Where:
t_1 is the outer member thickness (or pointside embedment depth for a partially embedded dowel) (Figure 10)

t_2 is the central member thickness

Figure 10

Definitions of t_1 and t_2 for bolted and dowelled connections



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Worked Example

Glulam portal haunch moment connection design example to BS EN 1995-1-1 Eurocode 5:

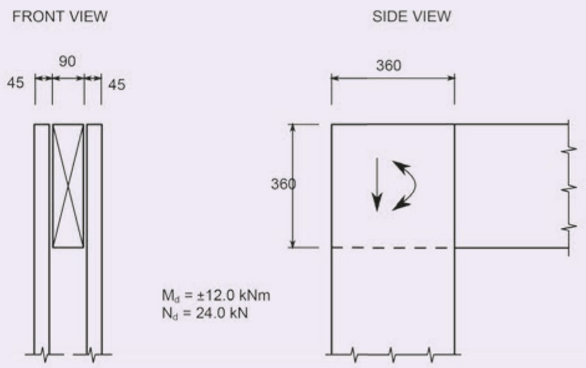
A moment-resisting connection is to be designed using 12mm diameter plain steel dowels with a minimum tensile strength of 400N/mm². The post is designed as a built up column comprising 45x360mm glulam sections, spaced apart by 90mm, and the beam section is 90x360mm. All timber members are glulam of strength class GL28h to BS EN 1194.

The connection is in service class 2 conditions and is subjected to a combination of permanent and instantaneous variable actions resulting in design actions of instantaneous duration as indicated in the diagram.

The characteristic lateral shear capacity of M12 dowels in double shear can be calculated in accordance with BS EN 1995-1-1 clause 8.2.2 or the simplified method given in the 'Structural notes' section. For simplicity the following characteristic fastener capacities are assumed in the calculations:

• Characteristic lateral shear capacity of an M12 dowel of length 180mm with full embedment of 45+90+45mm acting at 90° to the grain direction in double shear $F_{v,Rk} = 5.27kN$ per shear plane.

Design the connection to meet the ULS requirements of BS EN 1995-1-1.



Derivation of design lateral shear resistance per fastener

Duration factor for instantaneous actions

k_{mod} = 1.1 — EC5-1-1 Table 3.1

Material partial safety factor for connections

γ_M = 1.3 — NA to EC5-1-1 Table NA.3

Design lateral shear capacity per shear plane

$F_{V,Rd,1} = k_{mod} \times F_{V,Rk,1} / \gamma_M = 1.1 \times 5.27 / 1.3$ = 4.46 kN

Design lateral shear capacity per fastener

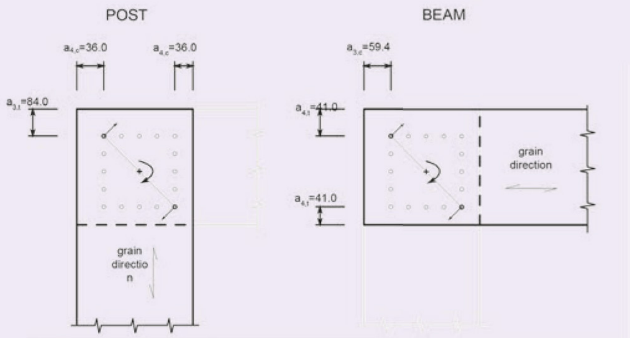
$F_{V,Rd} = 2 \times F_{V,Rd,1} = 2 \times 4.46$ = 8.92 kN

Note: The resistance of a fastener group can be increased by applying the actual angles to grain for each timber and each individual fastener.

Joint geometry

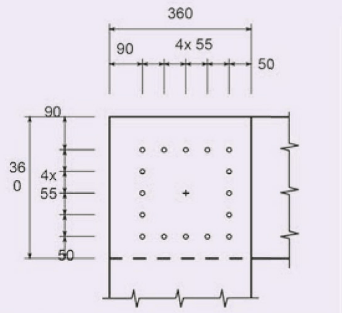
Minimum end and edge distances and spacing (EC5-1-1 Table 8.5)

spacing parallel	a_1	= (3+2|cos α|)d = (3+2x|cos 45|)x12	= 53.0 mm
spacing perp.	a_2	= 3d = 3x12	= 36.0 mm
loaded end	$a_{3,t}$	= max(7d; 80) = max(7x12; 80)	= 84.0 mm
unloaded end	$a_{3,c}$	= max($a_{3,t}$|sin α|; 3d) = max(84.0x|sin 225|; 3x12)	= 59.4 mm
loaded edge	$a_{4,t}$	= max((2+2|sin α|)d; 3d) = max((2+2x|sin 45|x12; 3x12)	= 41.0 mm
unloaded edge	$a_{4,c}$	= 3d = 3x12	= 36.0 mm



Fixing pattern

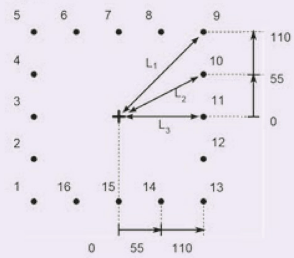
The worst case edge and end distances when considering both the post and beam geometry and possibility of bending moment reversal are taken into account:



Transfer of the design load

Bending moment (elastic analysis)

The bending moment is to be fully resolved in the fastener group. The pattern is symmetrical and all fasteners are of the same type although at different lever arms to the centroid of the fastener group e.g. L_1, L_2, L_3.



Fastener ID	Total no. of fasteners	x^2+y^2	Sum x^2+y^2	Lever arm (mm)
1, 5, 9, 13	4	110^2+110^2 = 24200	96'800	155.6
2, 4, 6, 8, 10, 12, 14, 16	8	110^2+55^2 = 15125	121'000	123.0
3, 7, 11, 15	4	110^2+0^2 = 12100	48'400	110.0
			Σ 266'200	max 155.6

The maximum bending moment that can be taken by the group of fasteners (disregarding vertical action) is:

$M_{Rd} = F_{V,Rd} \times \Sigma(x^2+y^2) / r_{max} = 8.92 \times 266'200 / 155.6 \times 10^3$ = 15.3 kNm

$M_d \leq M_{Rd}$

12.0 kNm ≤ 15.3 kNm — OK

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Vertical action

The vertical action can be transferred either by direct bearing contact of the beam at the post or distributed to the fasteners.

To allow for a lack of fit between the post and beam, vertical actions are to be carried by the fastener group as follows:

Design action per fastener

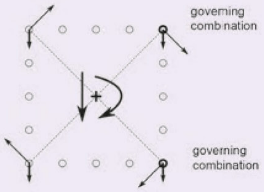
Assuming proportional distribution of the design action to each fastener.

Design action per fastener due to vertical actions:

$F_{d,V,i} = F_d \times F_{V,Rd,i} / \sum F_{V,Rd,i} = 24.0 \times 8.92 / (16 \times 8.92)$ = 1.50 kN

This is to be added to the action attracted by each fastener as a result of the bending moment.

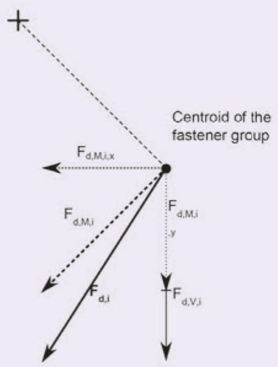
The check is carried out only for the most loaded fasteners, i.e. those that occur at the max lever arm from the centroid of the fastener group.



Design action per fastener due to bending moment:

$F_{d,M,i} = M_d \times r_i / \sum(x^2+y^2) = 12.0\times10^3 \times 155.6 / 266'200$ = 7.01 kN

Total combined design action on extreme fasteners



Resolving the fastener design actions due to bending moment into x and y directions gives:

$F_{d,M,i,x} = F_{d,M,i} \times \cos \alpha = 7.01 \times \cos 45$ = 4.96 kN

$F_{d,M,i,y} = F_{d,M,i} \times \sin \alpha = 7.01 \times \sin 45$ = 4.96 kN

Combining design actions from bending moment and vertical action gives the total design shear action on extreme fasteners:

$F_{d,i} = \sqrt{(F_{d,M,i,x}^2 + (F_{d,M,i,y} + F_{d,V,i})^2)} = \sqrt{(4.96^2 + (4.96 + 1.50)^2)}$ = 8.14 kN

Fastener design resistance check

$$F_{d,i} / F_{V,Rd} \leq 1.0$$

$$8.14 / 8.92 = 0.91 \leq 1.0$$ OK

Therefore the connection satisfies the ULS design requirements of BS EN 1995-1-1 for resistance to a combination of actions resulting from bending moment and vertical actions.

It would be prudent to prevent accidental opening of the built up section in the joint e.g. placing a bolt in the centre of the fastener group.

RELEVANT CODES OF PRACTICE

BS EN 1990:2002 Eurocode 0: Basis of structural design

BS EN 1995-1-1 Eurocode 5: Design of Timber Structures – Part 1-1: General – Common rules and rules for buildings

BS EN 1995-1-1 UK National Annex to Eurocode 5: Design of Timber Structures – Part 1-1: General – Common rules and rules for buildings

PD6693-1:2012 UK Non-Contradictory Complementary Information (NCCI) to Eurocode 5: Design of timber structures

DEFINITIONS

Portal haunch – reinforced part or enlarged section of a structural member at and close to a joint, typically at corners of a portal frame

Dowel – fastener without a distinct head and without a washer

REFERENCES AND FURTHER READING

STA Engineering Bulleting No. 1 - Timber as a structural material - an introduction

STA Engineering Bulleting No. 2 - Engineered wood products and an introduction to timber structural systems

STA Engineering Bulleting No. 3 - Timber frame structures – platform frame construction (part 1)

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