Timber Engineering Notebook series

No. 3: Timber frame structures – platform frame construction (part 1)

This series is authored by the UKTFA

The UK Timber Frame Association (UKTFA) represents over 85% of the UK's timber structural frame supply industry and is a trade organisation that provides business and technical support to the industry. The Association provides peer reviewed outputs on subjects related to the timber industry such as health and safety, fabric and technical performance, fire safety, promotion and training. These documents and other information are available at www.uktfa.com

Introduction

The platform frame method of building timber frame structures is suited to both low-rise and medium-rise buildings. Many buildings up to six and seven storeys in height have been constructed over recent years typically for residential, institutional and hotel uses.

There are a number of different conditions that need to be satisfied by the structural engineer during the engineering of a multi-storey timber frame building, including:

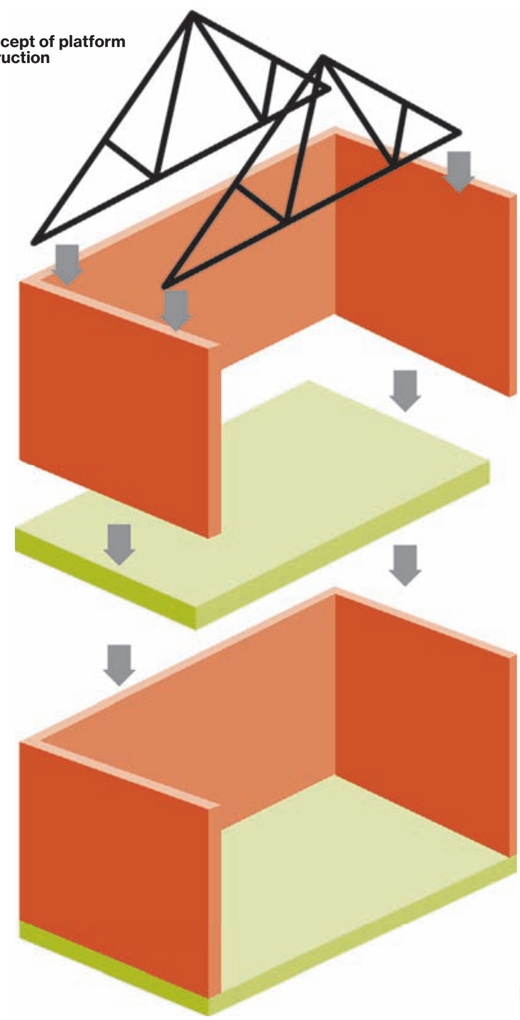
- The adequacy of vertical load paths
- The strength and stiffness of the individual framing members
- Overall building stability and stability of the individual elements
- Robustness of the framing and connections
- Disproportionate collapse design

This article introduces the composition and terminology used for platform timber frame building structures and describes the structural engineering checks which are required to verify the adequacy of the vertical load paths and the strength and stiffness of the individual framing members. There are several parts to the Timber Engineering Notebook for platform timber frame structures. Part 2 will cover horizontal stability, while part 3 will cover robustness and disproportionate collapse design.

Structural form

The term 'platform frame' derives from the method of construction where floor structures bear onto loadbearing wall panels, thereby creating a 'platform' for construction of the next level of wall panels, as indicated in Figure 1.

Figure 1 Structural concept of platform timber frame construction



UKTFA

Platform frame construction is particularly suited to buildings that have a cellular plan form. Internal walls may be used to contribute to this cellular layout and are used as loadbearing elements for resistance to both vertical and horizontal loads.

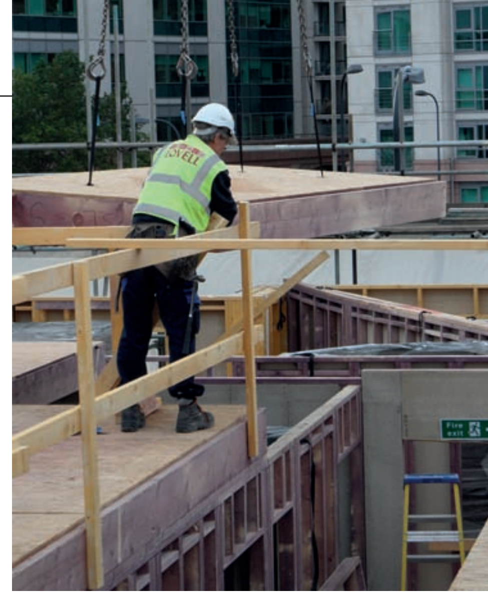
Vertical actions from walls, floors and roofs are supported by timber wall panels comprised of vertical studs at regular centres (typically 600mm centres or closer) that act as vertical columns. An example calculation can be found in the 'Worked example' section.

UKTFA

Figure 2
Lintels in an open panel timber frame wall panel

Figure 3
Sheathed timber frame closed panel with service battens

UKTFA



MILNER ASSOCIATES

Figure 4
Erection of a prefabricated flame retardant floor cassette

Figure 5
CLT wall panel construction

MILNER ASSOCIATES

Typically external wall studs are 140mm x 38mm (the 140mm dimension often being required to accommodate the minimum building regulation thermal insulation, although other means of achieving this with small depth studs are available) and internal wall studs 89mm x 38mm. These studs may be structurally connected to provide columns of wider sections or replaced by larger timber sections such as glulam posts (or in some cases steel posts) to resist high point loads.

Resistance to horizontal actions is provided by the in-plane shear resistance (or racking resistance) of sheathed wall panels which are connected together to act as contiguous wall diaphragms. Racking resistance is covered in part 2.

Common terms

Timber frame constructions can utilise factory assembled wall panels together with floor and roof panels often referred to as 'cassettes'. Where off-site manufacturing of panels and cassettes are used, UKTFA quality approval (leading to CE marking where appropriate) is required. The off-site assembled panels and cassettes may be made with joists or studs partially or fully clad, with solid panels such as cross laminated timber or composite insulation/timber structurally insulated panels.

Open panels are timber frame wall panels comprising studs, rails, sheathing on one face and breather membrane (Figure 2).

Closed panels are timber frame wall panels comprising studs, rails and insulation with sheathings and/or linings on the faces of the panel; a vapour barrier is provided on the warm side of the insulation and a breather membrane on the outer face of the panel (Figure 3). Closed panels may also include fitted windows and internal service zone battens.

Floor cassettes are fully assembled groups of joists, rimboards or rimjoists with structural subdeck fitted to enable lifting as a completed assembly (Figure 4). Treatments to the timbers are often coloured for differentiation. Floor cassettes may also include fitted insulation and lining materials.

Cross laminated timber (CLT) is a solid panel product made by laminating small lengths of timber, usually kiln-dried spruce, with adjacent layers having their grain direction at right angles to one another. These large solid panels can be used to form beams, columns, walls, roofs, floors and even lift shafts and stairs. CLT is a solid panel, capable of resisting comparatively high racking and vertical loads (Figure 5).

Structural insulated panels (SIPs) are factory-produced, prefabricated building products that can be used as load bearing or infill wall panels, floor and roof components in platform frame-type construction. The benefit of the system is that the structural support and the insulation are incorporated into a single system during manufacture. This results in material efficiency but care is need for concentrated loading on the panels.

Timber frame wall panels and floor cassettes are usually obtained from a specialist manufacturer such as a member of the UKTFA (www.uktfa.com)

Elements of a timber frame

Components of timber floors

Floor joists in platform timber frame structures (Figure 6a and b) can be either softwood joists or a range of engineered wood products. More detail on EWPs can be found in *Timber Engineering Notebook No. 2*. Examples of typical floor zone details are shown in Fig 6.

Components of timber frame wall panels

The loadbearing elements of a timber frame wall panel (Figure 7) typically comprise the following components:

- **Wall studs** which are vertical timber members carrying axial loads and lateral loads from wind pressures
- **Top and bottom wall panel rails** (usually of the same section size as the studs) which connect the studs together as a 'panel'
- **Soleplates or 'starter plates'** which are fixed to the foundation or subdeck to provide a locating position for the wall panel
- **Headbinders or 'header plates'** which connect together adjacent wall panels to enable them to function as a continuous wall diaphragm and, in combination with the top wall panel rails, act as 'spreader' beams to distribute floor joist loads to the wall studs where the joists are not aligned (noded) with the studs. Headbinders are usually site-fitted
- **Lintels, cripple studs and opening studs** which transfer vertical and horizontal loads around openings in the wall panels. The studs are typically arranged so that their stronger axis (y-y) is parallel to the face of the wall (Figure 8).

Principle design code references

The limit state codes for timber engineering are BS EN 1995-1-1 Eurocode 5: Design of Timber Structures – Part 1-1, together with the UK National Annex to Eurocode 5: BS EN 1995-1-1: Design of Timber Structures – Part 1-1 and PD6693-1:2012 UK Non-Contradictory Complementary Information (NCCI) to Eurocode 5.

BS 5268-2:2002 and both BS 5268-6.1 (wall panels up to 2.7 m height) and BS 5268-6.2 (wall panels up to 4.8m height) have been used to design timber structures in the UK on a permissible stress basis, though they are limited to seven and four storeys respectively.

Figure 6a
Floor joists perpendicular to external wall panel

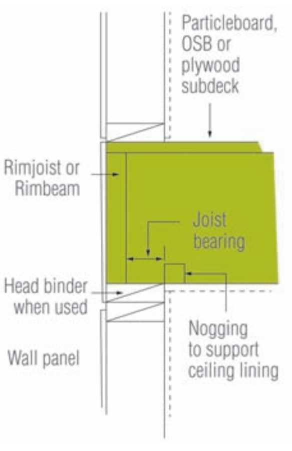
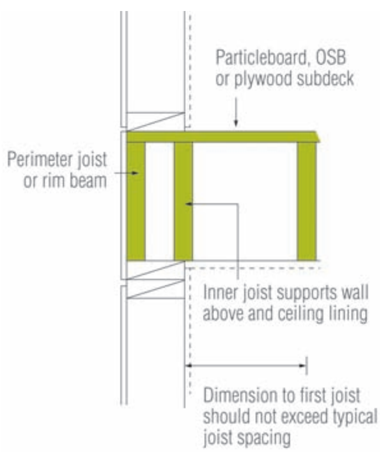


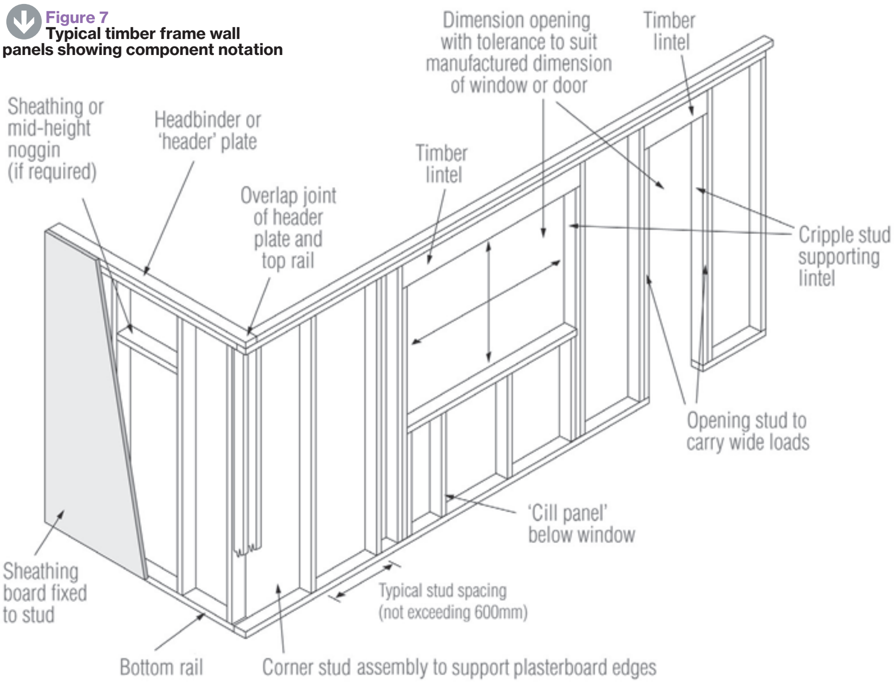
Figure 6b
Floor joists parallel to external wall panel



(Joist shown as sawn softwood (SW), but can be other engineered wood products such as I-joists, Open-web joists or glue laminated timber or LVL)

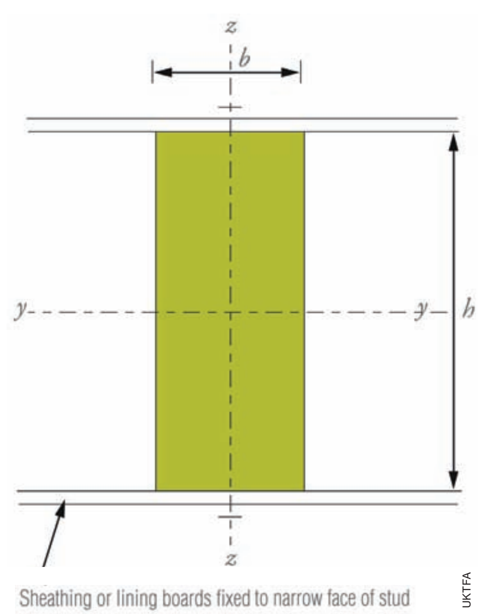
UKTFA

Figure 7
Typical timber frame wall panels showing component notation



UKTFA

Figure 8
Wall stud plan view and nomenclature



UKTFA

Table 1: Typical platform frame materials

Element	Common sizes	Common materials
Studs & rails	38 x 89,114,140,184 Canadian lumber size(CLS)	C16,C24 (BS EN 338:2003)
	47 (T1) x 97, 145,195 (T2) (BS EN 336:2003)	
Sheathing boards	9mm,11mm OSB	OSB 3 / 4 (BS EN 300)
	9mm Plywood	Plywood (BS EN 636)
	9mm Magnesium Oxide (MgO) boards	Non-combustible board to BS EN ISO 1182 Euroclass A1 and tested to EN 594 and UKTFA product paper 3
Structural subdeck	15mm OSB	OSB 3 / 4 (BS EN 300)
	18mm Plywood	Plywood (BS EN 636)
	22mm Particleboard	P5 particleboard (BS EN 312)

This Notebook concentrates only on the use of Eurocode 5 for the design of platform frame constructions, as the British Standard has now been superseded by the Eurocode.

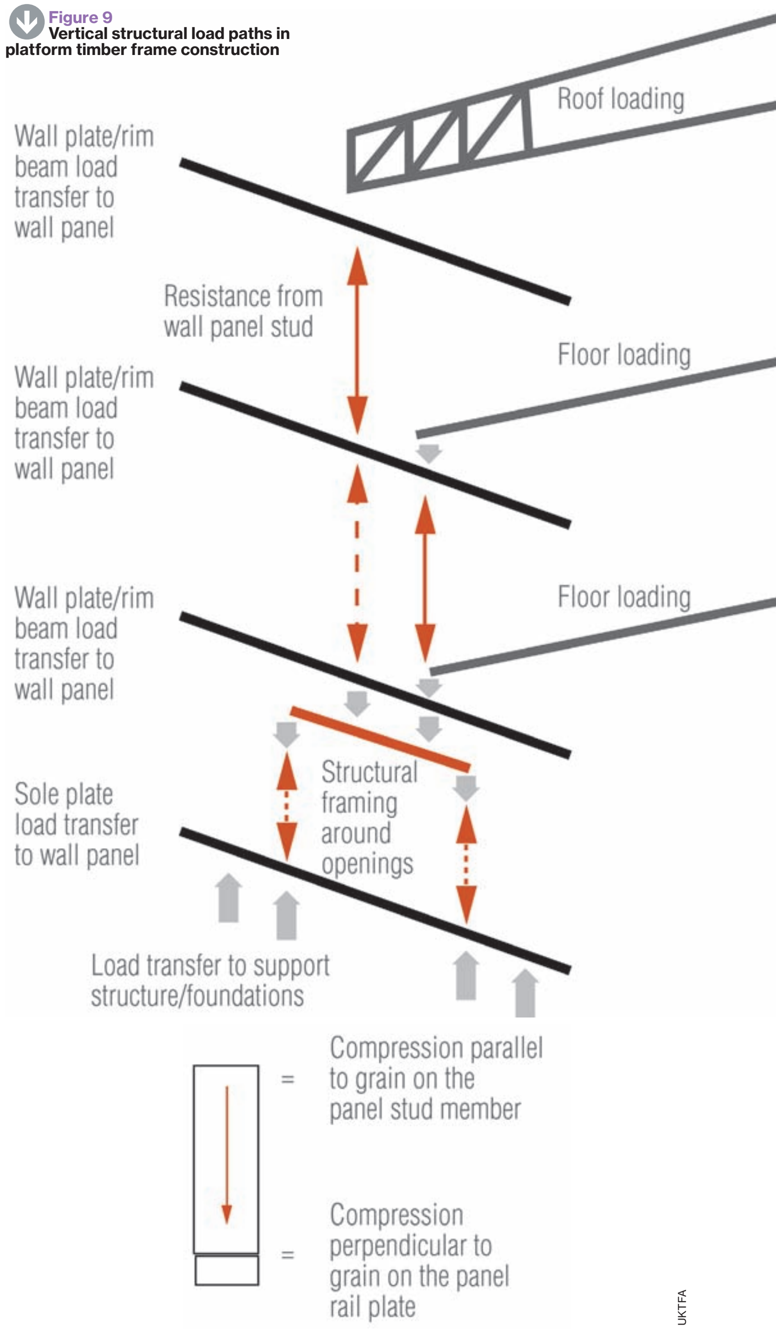
The height limit of seven storeys has, in the past, been determined by the structural robustness relating to the vertical movement and racking stiffness and serviceability design, using working stress designs. Applying the principles of Eurocode 5 and using high strength materials such as cross laminated timber (CLT) it is possible to build higher than seven storeys provided particular attention is given to connections and bearing pressures beneath wall panels. In-service fire resistance of frames increases with building height and the engineer should always consider fire resistance of the frame in the design approach. Future articles will address fire and timber construction.

When designing timber structures and carrying out code checks, care is needed to ensure that the factors used in equations are consistent with the code of practice being used. Using a combination of Eurocodes and British Standards on a structure can lead to an unsafe assessment as the two codes are based on fundamentally different principles.

Materials

Timber platform frame construction typically uses softwood wall studs and rails together with a wood-based sheathing board (in accordance with BS EN 13986:2004 – see *Timber Engineering Notebook No. 2* for further information) to form a structural frame which transmits all vertical and horizontal loads acting on the structure, safely to the building's foundations.

Figure 9
Vertical structural load paths in platform timber frame construction



Vertical load transfer – structural notes

Vertical load paths are to be checked for load transfer as follows:

Key items:

1. Floor joist and beam reactions to walls – Critical element check bearing of beam and joist.
2. Spread of loads from studs through rails and plates and through floor zone to wall frame below.
3. Holding down resistance due to uplift pressures on roof.
4. Wall stud design
   - Compression parallel to grain on the studs and perpendicular to grain on the panel rails
   - Combined axial and bending stresses in the studs from vertical and horizontal actions

The contribution of plasterboard to racking resistance may also be considered within the limits allowed by PD6693-1:2012.

Typical platform frame materials and the loadbearing elements of a timber frame wall panel are indicated in Table 1 and Fig. 7.

Non-combustible sheathing boards are used to provide fire resistance to a timber frame structure during construction. This topic will be discussed in future Timber Engineering Notebooks.

The exterior cladding (typically masonry or supported claddings such as boarding and rendering) is non-loadbearing (although in the case of masonry, it may contribute to wind resistance by providing shielding) thereby reducing the racking forces which the timber frame structure is required to resist.

Engineering principles

Vertical load paths

The vertical load paths that require checking by the engineer are indicated in Figure 9.

Design of timber frame wall panels

The lateral stability of the studs against buckling is provided by either a sheathing material or from the provision of timber blockings i.e. noggins or dwangs at intermediate positions in the stud height, to allow fixing of sheathings or to provide lateral restraint about the minor axis of the studs.

A wood-based board sheathing material which is directly fixed to a timber frame wall panel will provide adequate lateral resistance to stud buckling. However, if no sheathing material is present, the effective length of the stud about the minor (z-z) axis will be the distance between the plate and the noggin. A row of noggins in a wall panel must also be restrained in some way, such as back to a return wall panel. Otherwise the whole batch could buckle sideways.

Factors $k_{c,y}$ and $k_{c,z}$ are adopted in EC5 to take account of reduced axial compression strength due to lateral buckling about the principal axes. If the studs are adequately laterally restrained against both permanent and construction stage loads, then the risk of stud buckling about the minor (z-z) axis can be ignored:

For wall panel studs fully restrained in the minor (z-z) axis, the relative slenderness of the studs about the major (y-y) axis is given by:

$$\lambda_{rel,y} = \frac{\lambda_y}{\pi}\sqrt{\frac{f_{c,0,k}}{E_{0.05}}} \qquad \text{EC5 (6.21)}$$

Where:
λ_y is the slenderness ratio corresponding to bending about the y-y axis = 0.85L
$f_{c,o,k}$ is the characteristic compressive strength parallel to the grain
$E_{0.05}$ is the fifth percentile modulus of elasticity parallel to grain

The instability factor about the y-y axis $k_{c,y}$ is given by:

$$k_{c,y} = \frac{1}{k_y + \sqrt{k_y^2 - \lambda_{rel,y}^2}} \qquad \text{EC5 (6.25)}$$

Where:
$$k_y = 0.5\left(1 + \beta_c\left(\lambda_{rel,y} - 0.3\right) + \lambda_{rel,y}^2\right. \qquad \text{EC5 (6.27)}$$
and
$\beta_c =$ 0,2 for solid timber and 0,1 for glued laminated timber and LVL

Studs subjected to axial compression only

For wall panel studs fully restrained in the minor (z-z) axis, the strength condition to be satisfied for wall studs subjected to axial loading only, with no bending stresses, becomes:

$$\frac{\sigma_{c,0,d}}{k_{c,y} \cdot f_{c,0,d}} <= 1 \qquad \text{EC5 (6.23)}$$

Where:
$\sigma_{c,0,d}$ is the design compressive stress parallel to the grain
$F_{c,0,d}$ is the design compressive strength parallel to the grain

Compression perpendicular to grain

The governing failure mode for timber wall studs is often bearing of the stud onto the horizontal rails of the panel (compression perpendicular to grain).

The following expression is to be satisfied:

$$\sigma_{c,90,d} <= k_{c,90} \cdot f_{c,90,d} \qquad \text{EC5 (6.3)}$$

With:

$$\sigma_{c,90,d} = \frac{F_{c,90,d}}{A_{ef}} \qquad \text{EC5 (6.4)}$$

Where:
$\sigma_{c,90,d}$ is the compressive stress in the effective contact area perpendicular to the grain
$F_{c,90,d}$ is the design compressive load perpendicular to the grain
A_{ef} is the effective contact area in compression perpendicular to the grain
$F_{c,90,d}$ is the design compressive strength perpendicular to the grain
$K_{c,90}$ is a factor taking into account the load configuration, the possibility of splitting and the degree of compressive deformation

The effective contact area perpendicular to the grain A_{ef} should be determined by taking an effective contact length parallel to grain 30mm greater than the actual contact length when the contact length is at the end of a member – or 60mm greater than the contact length when all of the contact length is more than 30mm from the end of a member.

The values of $k_{c,90}$ are taken as 1.25 for solid timber and LVL and 1.5 for glued laminated timber.

Studs subjected to bending about the strong axis y-y

External wall studs also carry wind loads, transmitted to them by the cladding via wall ties or battens. These studs are therefore subjected to combined axial and bending stresses.

For wall panel studs fully restrained in the minor (z-z) axis and subject to bending about the strong (y-y) axis, the following expression should be satisfied:

$$\sigma_{m,y,d} <= k_{crit} \cdot f_{m,y,d}$$

Where:
$\sigma_{m,y,d}$ is the design bending stress about the y-y axis
$f_{m,y,d}$ is the corresponding design bending strength
k_{crit} is a factor which takes into account reduced bending strength due to lateral buckling and may be taken as 1.0 for a beam where lateral displacement of its compressive edge is prevented throughout its length and where torsional rotation is prevented at its supports (as is the case for wall studs with directly fixed sheathing and linings)

Studs subjected to combined axial compression and bending about the strong axis y-y

In addition, the strength condition to be satisfied for wall studs subjected to combined axial and bending stresses becomes:

$$\frac{\sigma_{c,0,d}}{k_{c,y} \cdot f_{c,0,d}} + \frac{\sigma_{m,y,d}}{f_{m,y,d}} \leq 1 \qquad \text{EC5 (6.23)}$$

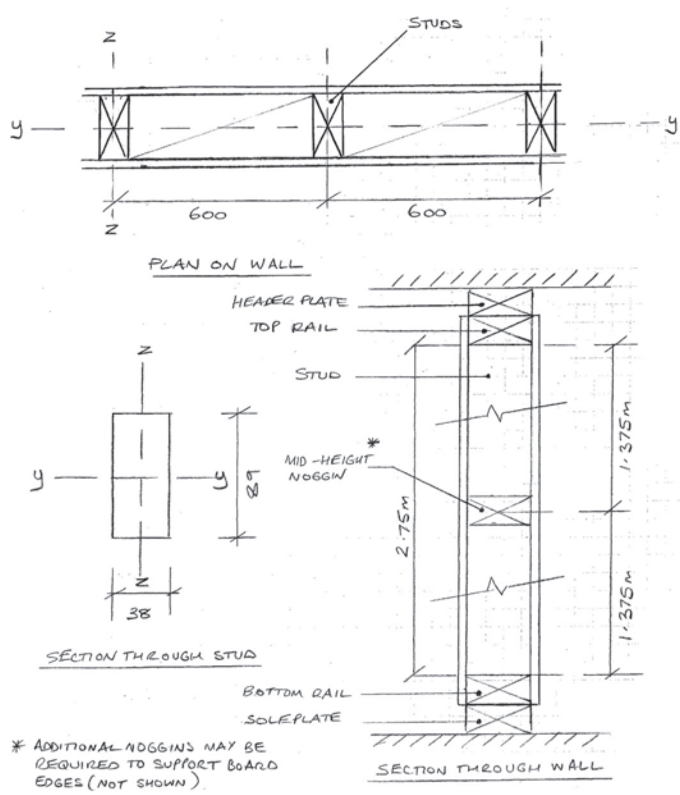
Where:
$\sigma_{c,0,d}$ is the design compressive stress parallel to the grain
$F_{c,0,d}$ is the design compressive strength parallel to the grain

Unless it can be demonstrated that the shielding effect of the cladding adequately prevents excessive stud deflection, deflection due to wind loads may be the governing load case for the design of shallow (dimension h in Fig. 8) or tall external wall studs and should be checked.

Although no specific deflection limit is given in EC5 for wall studs subjected to horizontal loads, a maximum deflection limit of l/300 might be considered appropriate, as given in EC5 section 10.2 (1) for the maximum permitted deviation from straightness of a column section, to avoid lateral instability.

Worked example

The loadbearing studs within the wall panel shown below have a height of 2.75m and the studs are spaced at 600mm centre to centre with a mid-height noggin. 38mm x 89mm section CLS timber of grade C16 to BS EN 338:2009 is used for the studs, rails, header and soleplates. The wall functions in service class 1 conditions and supports a characteristic permanent action of 1.0 kN/m (inclusive of the panel self-weight) and a characteristic variable medium term action of 9.0 kN/m. For simplicity, the wall stud is not subjected to wind actions or roof actions. There is wall sheathing on one face and plasterboard on the other face which provide lateral restraint to the studs about the z-z axis. Check that the wall will meet the ULS requirements of EC5:



1. GEOMETRIC PROPERTIES

STUD LENGTH — $L = 2.75\text{m}$

EFFECTIVE LENGTH OF STUD BUCKLING ABOUT THE y-y AXIS (TABLE 4, PD 6693-1:2012) — $L_{e,y} = 0.85L$ ie $L_{e,y} = 2.34$ m

WIDTH OF EACH STUD — $b = 38\text{mm}$

DEPTH OF EACH STUD — $h = 89\text{mm}$

BEARING AREA OF EACH STUD ON THE PANEL RAILS — $A_b = 38 \times 89 = 3.38 \times 10^3 \text{ mm}^2$

SECOND MOMENT OF AREA OF STUD ABOUT THE y-y AXIS — $I_y = \frac{bh^3}{12} = 2.23 \times 10^6 \text{ mm}^4$

RADIUS OF GYRATION OF STUD ABOUT THE y-y AXIS — $i_y = \sqrt{\frac{I_y}{A}} = 25.7\text{mm}$

SLENDERNESS RATIO OF STUD ABOUT THE y-y AXIS — $\lambda_y = \frac{L_{e,y}}{i_y} = 91.0$

2. TIMBER STRENGTH PROPERTIES
(TABLE 1 BS EN 338: 2009 FOR C16 TIMBER)

CHARACTERISTIC COMPRESSION STRENGTH PARALLEL TO GRAIN — $f_{c,0,k} = 17 \text{ N/mm}^2$

CHARACTERISTIC COMPRESSION STRENGTH PERPENDICULAR TO GRAIN — $f_{c,90,k} = 2.2 \text{ N/mm}^2$

5th PERCENTILE MODULUS OF ELASTICITY PARALLEL TO GRAIN — $E_{0.05} = 5.4 \text{ kN/mm}^2$

3. PARTIAL SAFETY FACTORS
(UK NATIONAL ANNEX TO BS EN 1990: 2002 TABLE NA.A1.2(B))

PERMANENT ACTIONS — $\gamma_G = 1.35$

VARIABLE ACTIONS — $\gamma_Q = 1.50$

(UK NATIONAL ANNEX TO EUROCODE 5-1-1 TABLE NA.3)

MATERIAL PARTIAL FACTOR — $\gamma_m = 1.3$

4. ACTIONS PER STUD

CHARACTERISTIC PERMANENT COMPRESSIVE ACTION TO STUDS @ 600 cc — $G_k = 0.6\text{m} \times 1.0\text{kN/m} = 0.6 \text{ kN}$

CHARACTERISTIC VARIABLE MED TERM COMPRESSIVE ACTION ON STUDS @ 600cc — $Q_k = 0.6\text{m} \times 9.0\text{kN/m} = 5.4 \text{ kN}$

DESIGN COMPRESSIVE ACTION — $N_d = 1.35(0.6) + 1.50(5.4)$
$= 8.91 \text{ kN}$
$= 8.91 \times 10^3 \text{ N}$

5. MODIFICATION FACTORS

FACTOR FOR MEDIUM TERM DURATION LOADING AND SC1 (EC5 TABLE 3.1) — $k_{mod,med} = 0.8$

SYSTEM STRENGTH FACTOR (EC5 6.6) — $k_{sys} = 1.1$

BEARING STRENGTH FACTOR FOR CONTINUOUS SUPPORTS (EC5 6.1.5(3)) — $k_{c,90} = 1.25$

6. COMPRESSION STRENGTH OF A STUD

DESIGN COMPRESSION STRESS IN STUD $\sigma_{c,0,d} = \frac{N_d}{A} = 2.63\ N/mm^2$

DESIGN COMPRESSION STRENGTH OF C16 TIMBER $f_{c,0,d} = \frac{k_{mod,med} \cdot k_{sys} \cdot f_{c,0,k}}{\gamma_m} = 11.51\ N/mm^2$

BUCKLING RESISTANCE CONDITION (EC5, 6.3.2):

RELATIVE SLENDERNESS ABOUT THE y-y AXIS (EC5, 6.21) $\lambda_{rel,y} = \frac{\lambda_y}{\pi}\sqrt{\frac{f_{c,0,k}}{E_{0.05}}} = 1.63$

AS THE RELATIVE SLENDERNESS RATIO IS GREATER THAN 0.3, EC5 6.3.2(3) CONDITIONS APPLY:

FACTOR β_c FOR SOLID TIMBER (EC5 6.29) $\beta_c = 0.2$

FACTOR k_y (EC5 6.27) $k_y = 0.5\left[1 + \beta_c(\lambda_{rel,y} - 0.3) + \lambda_{rel,y}^2\right] = 1.96$

INSTABILITY FACTOR ABOUT THE y-y AXIS (EC5 6.25) $k_{c,y} = \frac{1}{k_y + \sqrt{k_y^2 - \lambda_{rel,y}^2}} = 0.33$

STRENGTH CONDITION (EC5 6.23) $\frac{\sigma_{c,0,d}}{k_{c,y} \cdot f_{c,0,d}} = 0.70 \leq 1$

AS THE RELATIONSHIP IS LESS THAN UNITY, 38 X 89 C16 STUDS AT 600 CENTRES WILL MEET THE ULS COMPRESSION STRENGTH REQUIREMENTS OF EC5.

7. BEARING STRENGTH OF WALL PANEL RAILS

DESIGN BEARING LOAD PER STUD $N_d = 8.91 \times 10^3\ N$

EFFECTIVE CONTACT AREA PERPENDICULAR TO GRAIN (EC5 6.1.5(1)) $A_{ef} = (b + 2(30)).h = 8722\ mm^2$

DESIGN BEARING STRESS ON THE PANEL RAIL $\sigma_{c,90,d} = \frac{N_d}{A_{ef}} = 1.02\ N/mm^2$

DESIGN BEARING STRENGTH $f_{c,90,d} = \frac{k_{mod,med} \cdot k_{sys} \cdot k_{c,90} \cdot f_{c,90,k}}{\gamma_m} = 1.86\ N/mm^2$

THE BEARING STRESS IS LESS THAN THE BEARING STRENGTH, THEREFORE THE 38 X 89 C16 PLATES WILL MEET THE ULS BEARING COMPRESSION STRENGTH REQUIREMENT OF EC5.

Design of timber floor joists

The design of a softwood timber floor joist to Eurocode 5 is covered in The Institution of Structural Engineers' *Technical Guidance Note 18 (Level 1)*. Engineered timber floor joists are designed in a similar manner using the characteristic material strengths taken from the relevant material standard (see *Timber Engineering Notebook No. 2*)

The engineering design of proprietary I-joists and open-web joists are typically undertaken using proprietary software provided by the specific joist manufacturers.

Relevant codes of practice

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

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

PD 6693-1:2012 UK Non-Contradictory Complementary Information (NCCI) to Eurocode 5: Design of timber structures

Working stress codes BS 5268-2:2002: Structural use of timber – Part 2: Code of practice for permissible stress design, materials and workmanship

BS 5268-6.1-1996 Part 6: Code of practice for timber frame walls – Section 6.1 Dwellings not exceeding seven storeys

BS 5268-6.2-2001 Part 6: Code of practice for timber frame walls – Section 6.2 Buildings other than dwellings not exceeding four storeys

Definitions

Rimboards/rimjoists – timber edge members used to connect a series of timber joists into prefabricated 'cassettes' or installed loose onto wall panels to provide both vertical and horizontal load transfer through floor joist zones.

Structural subdeck – a timber-based board material fixed to the uppermost surface of joists, rimbeams and rimboards to provide a horizontal diaphragm and a surface for the application of floor finishes.

References and further reading

Porteus J. and Kermani A. (2008) *Structural Timber Design to Eurocode 5* Chichester: John Wiley & Sons

British Standards Institution (2012) *Concise Eurocodes: Design of Timber Structures BS EN 1995-1-1: Eurocode 5* London: BSI

UKTFA (2007) *Engineered Wood Products Code of Practice* [Online] Available at: www.uktfa.com/about-uktfa/uktfa-code-of-practice/ (Accessed: March 2013)

UKTFA (2008) *Structural Guidance for Platform Timber Frame* [Online] Available at: www.uktfa.com/download/uktfa_documents/ (Accessed: April 2013)

The Institution of Structural Engineers/TRADA (2007) *Manual for the design of timber building structures to Eurocode 5* London: ISE/TRADA

The Institution of Structural Engineers (2012) Technical Guidance Note 18 (Level 1): 'Design of timber floor joists', *The Structural Engineer,* 90 (11), pp. 36-39

The Institution of Structural Engineers (2013) Timber Engineering Notebook No. 2: 'Engineered wood products and an introduction to timber structural systems' *The Structural Engineer,* 91 (4), pp. 42-48

The Institution of Structural Engineers (2010) *Practical guide to structural robustness and disproportionate collapse in buildings* London: The Institution of Structural Engineers

Lewis G. (2005) 'Multi-storey timber frame construction' *The Structural Engineer,* 83 (17), pp. 26-31

UKTFA (2012) *Design guide to separating distances during construction* (Version 2) [Online] Available at: www.uktfa.com/download/uktfa_documents (Accessed: April 2013)