Australia & New Zealand Structural Design Guide

Use of this Guide

Thank you for choosing to design with mass timber. XLam manufacture Cross Laminated Timber (CLT) from one hundred percent natural and renewable radiata pine. Each lamella and panel is unique, even with great care by XLam, slight deviations in grain pattern, knot location and colour will occur. By choosing to design in mass timber you are embracing the natural beauty of a renewable building material, its perfection is in its natural imperfection.

The information in this guide is based on testing methodology and certification owned by XLam. The information is provided for use in the design and specification of XLam manufactured Cross Laminated Timber (CLT) only. The guide is not intended as general information and guidance for all manufactured Cross Laminate Timber (CLT). The guide and information is specific to XLam CLT and no warranty is given to the suitability and application of the information to other manufacturers CLT.

Product Guide Description

This guide provides key information necessary for the preliminary assessment of XLam structures. It covers material properties, design principles, connections, and includes pre-analysis span tables derived from extensive product testing.

Application

This design guide has been prepared for use by suitably qualified construction professionals to assist in the design and specification of XLam panels. Products referred to in this document other than XLam panels are presented for information purposes only and due regard should be given to the relevant Australian and New Zealand Standards and other manufacturer's literature. Advice on overall building design issues including, but not limited to: stability, loading, temporary stability during construction, fixings, waterproofing, fire engineering and overall acoustic performance are not covered by this guide and advice should be sought from suitably qualified professionals.

It is the responsibility of the user to ensure that the use of this design guide is appropriate and to exercise their own professional judgement when using the document. Full responsibility for the design and compliance with the Building Codes of Australia and New Zealand (NZBC) and all relevant Australian and New Zealand Standards rests with the design professional specifying and certifying the product. XLam will not accept any liability for the failure of any other elements of the building which cause a subsequent failure of an XLam product.

Structural Design in CLT

At present there are no structural codes in use around the world which cover the design of CLT, including AS1720.1 (Timber Structures: part 1 Design Methods and NZS 3603:1993 Timber Structures Standard). Therefore, the design of CLT is not covered under the deemed-to-satisfy provisions of the BCA or NZBC, and it will be necessary for consulting engineers to design and certify the design as part of a performance solution. Performance solutions are significantly more common than many engineers might appreciate with some frequently used products, such as concrete anchors, not being covered by an Australian or New Zealand Standard.

The primary difference for many design checks will come in the calculation of the section properties of the CLT panel and more information is given later in this guide. The rest of the principles of strength and serviceability checks closely follow the provisions laid out for the design of timber in AS1720.1 and/or NZS 3603:1993.

The guide is aimed to provide a high-level overview of the structural design of a simple CLT building consisting of walls, floors and roofs and covers many standard situations. Simple indicative span tables for walls, floors, roofs and stairs have been provided to give an indication of expected panel sizes for particular applications, although project specific design checks will need to be completed for each. More detailed design information can be found in XLam Technical Notes which are available by contacting XLam's technical department.

Updates and Version Control

This design guide is identified with a version number and date of issue. The latest issue is always on the XLam website. It is the user's responsibility to ensure that the latest version is in use at all times. Unless otherwise stipulated, the XLam design guides will be provided to registered users in electronic format. Bound hard copies can be made available by XLam on request.

Structural Documentation & Certification Process

XLam strives to provide as much design and detailing assistance as our clients require. Our design phase involvement varies significantly across projects depending on our clients' preferences.

1. Concept and scoping

At the concept stage, XLam Design can carry out a scoping design for the project. This service is intended to provide high level advice on panel thicknesses and types to suit your project, as well as design considerations and where other materials will be required. Our clients are welcome to take this concept to a consulting engineer to complete the detailed design and construction documentation if preferred, the intention is to get the project off on the right foot. We encourage our clients obtain our input early to ensure the design adopted is economical, and suits both manufacturing and erection processes. The pre-analysis tables in this guide can be used at this stage to inform the concept and scoping phase of projects, however project specific design is required for all projects.

2. Detailed design and construction documentation

If the concept phase identifies CLT to be the preferred structural option, there are two options to proceed the design:

1. Engage a suitably qualified consulting structural engineer to carry out the detailed design and construction documentation for the entire project, including the CLT elements. In this instance, the structural certification would be signed by the appointed consulting engineer for all structural elements.
2. Engage a suitably qualified consulting structural engineer to carry out the detailed design and construction documentation for any non-timber elements in the project, and engage XLam Design to carry out the design and documentation of the timber and CLT elements. This is common practice, and we work in conjunction with your consulting engineer to ensure a fully coordinated package. Two structural certifications would be issued, one by the consulting engineer covering the elements they have designed, and one by XLam Design to cover the CLT and other timber elements on the project.

The team at XLam Design has a vast background of CLT experience not only in Australia and New Zealand but internationally. We strive to produce economical and buildable design solutions, leveraging off a comprehensive understanding of the manufacturing and installation process. This understanding of the manufacturing and installation process allows XLam Design to detail panels and connections in the most efficient way possible, reducing machining time and hence project CLT supply costs.

3. Shop detailing and supply of panels

After detailed design is completed, should the client wish to proceed with XLam for supply of panels, an agreement would be entered into. This agreement would cover shop drawings and associated detailing based on the construction documentation. In some instances, if XLam Design are engaged for the detailed design phase, the detailed design process may overlap with the shop drawing phase, allowing us to expedite the program. This will depend on terms of engagement, and should be discussed with your sales representative.

XLam Panel Properties

XLam manufacture all panels in Australia from locally grown plantation pine. All material is supplied to XLam pre-graded but we also conduct our own in house testing of the timber to ensure that the specifications below are met. XLam use two different timber grades to make the best use of the log. Outer layers are the most critical for panel performance and we use a higher grade of timber for these, while the inner layers can be a lower grade of timber.

CLT Section Properties

Structural Properties (Timber Grade XLam Proprietary method)	**XLG1**	**XLG2**
Structural Property	External Lamellas	Internal Lamellas
Modulus of Elasticity (parallel to grain)	10000 MPa	6000 MPa
Bending Strength (parallel to grain) $f_{b,0}$	17 MPa	10.0 MPa
Compression Strength (parallel to grain) $f_{c,0}$	18.0 Mpa	15.0 MPa
Compression Strength (perpendicular to grain) $f_{c, 90}$	10 MPa	8.9 MPa
Tension Strength (parallel to grain) $f_{t,0}$	7.7 MPa	4.0 MPa
Shear Strength (parallel to grain) $f_{s,0}$	3.8 MPa	3.8 MPa
Rolling Shear Strength (perpendicular to grain) $f_{s,90}$	1.2 Mpa	1.2 MPa
Shear Modulus (parallel to grain) G_0	670 MPa	400 MPa
Rolling Shear Modulus (perpendicular to grain) G_R	45 MPa	29 MPa
Mean Density ρ	500 kg/m^3	480 kg/m^3
Available lamella sizes	85(w) x 42.5(t) 85(w) x 32.5(t)	195(w) x 45(t) 145(w) x 35 (t) 145(w) x 20 (t)

Note: Strength properties are given as a characteristic value, while stiffness and densities are given as mean values as defined in AS/NZS 4063.

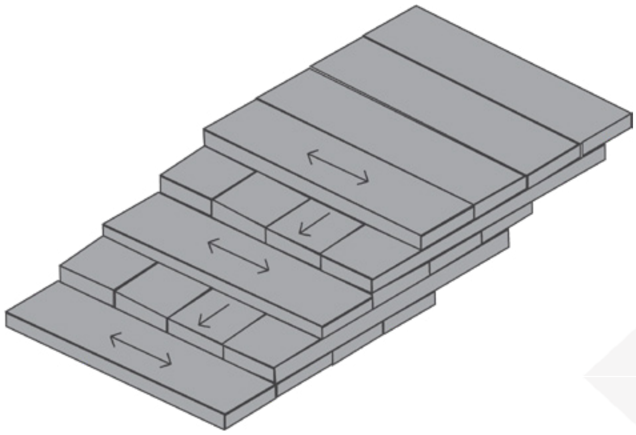
XLam Standard Panel Sizes

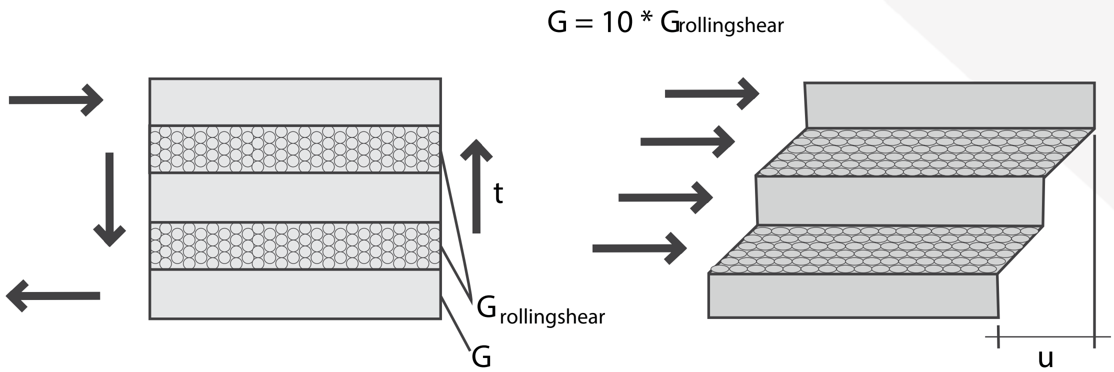
Panel Designation	Layer 1 (mm)	Layer 2 (mm)	Layer 3 (mm)	Layer 4 (mm)	Layer 5 (mm)	Layer 6 (mm)	Layer 7 (mm)	Total Thickness (mm)	Selfweight (kg/m2)
3 Layer Panels									
CL3/90	30	30	30					90	45
CL3/100	32.5	35	32.5					100	50
CL3/110	32.5	45	32.5					110	55
CL3/120	42.5	35	42.5					120	60
CL3/130	42.5	45	42.5					130	65
5 Layer Panels									
CL5/140	32.5	20	35	20	32.5			140	70
CL5/155	32.5	35	20	35	32.5			155	78
CL5/170	32.5	35	35	35	32.5			170	85
CL5/190	42.5	35	35	35	42.5			190	95
CL5/200	42.5	35	45	35	42.5			200	100
CL5/220	42.5	45	45	45	42.5			220	110
7 Layer Panels									
CL7/240	32.5	35	35	35	35	35	32.5	240	120
CL7/260	42.5	35	35	35	35	35	42.5	260	130
CL7/270	42.5	35	35	45	35	35	42.5	270	135
CL7/290	42.5	35	45	45	45	35	42.5	290	145
CL7/310	42.5	45	45	45	45	45	42.5	310	155

These represent our standard range of panels recommended for most structural applications. We have some capability to offer custom buildups for specific needs but these may attract a cost premium. Please consult with your local XLam representative to discuss in detail if required.

The structural performance of CLT is relatively unique due to the deformation caused by the cross-layers' relative shear stiffness. This phenomenon, known as rolling shear, reduces the effectiveness of the outer layers and hence the section properties of CLT panels. It is crucial that this is accounted for in the design of CLT.

There are several different methods of calculating the section properties of a CLT panel adopted around the world, most of which end up at an answer within a few percent of each other. XLam has used the Shear Analogy Method in the development of the span tables contained in this document and more information on this model and others can be obtained through XLam's technical department.





Floor and Roof Design

The design of most CLT floors will be governed by serviceability requirements (typically deflection and vibration) and it is rare for a design to push the structural capacity of the panels unless there are large openings or notches. The choice of appropriate limits for deflections or vibration performance will be subjective and dependent on project specific requirements. It is important for designers to be aware of the limits chosen to produce the span tables contained in this guide so that designers can make judgements on their suitability for specific projects. For floor and roof panels, the outer layers need to be oriented in the direction of the span. Panels do have minor direction bending stiffness, however this bending stiffness is greatly reduced.

Vibration

The dynamic performance of a floor is governed by three factors: stiffness (stiffer floors perform better), mass (heavier floors perform better) and damping (floors with additional layers, furniture etc. perform better). Timber is a relatively lightweight form of construction and therefore requires more consideration of vibration in design than a more conventional concrete floor. In most commercial scale buildings CLT floor design will be governed by vibration so these checks are important to carry out to ensure the performance of the floor meets client expectations.

Human perception of vibration is a subjective issue and different people will experience varied responses to the same floor vibration, particularly depending on what activity they are engaged in. Different criteria will apply to residential buildings when compared to offices, for example, and various parameters are well published across the world.

The pre-analysis tables contained within this document have been prepared using the following vibration criteria based on research into long span timber floors carried out in Europe. Further references and information can be made available for designers wishing to understand these checks in more detail. It should be noted that these checks are relatively stringent and another set of tables with more relaxed limits is published in XLam Technical Note XLTN-5.3.

1. The natural frequency of the floor is checked based on the dead load of the floor (including super-imposed dead loads). If the natural frequency is greater than 8Hz then skip to step 3.

2. If natural frequencies are lower than 8Hz then a more detailed determination of the acceleration is made based on the following equation

$$a = 0.4\frac{P_0\alpha_1(f_1)}{M_{gen}}\frac{1}{\sqrt{\left[\left(\frac{f_1}{f_F}\right)^2-1\right]^2+\left(2D\frac{f_1}{f_F}\right)^2}} \leq 0.05m/s^2$$

Where:

- P_0 = 700N (mass of one person)
- α = Fourier coefficient
- f_1 = natural frequency
- f_F = forcing frequency
- D = Damping (taken as 1.5% for a lightly finished floor)
- M_{gen} = Generalised mass $M_{gen} = m\,{}^{L}/_{2}\,b_{eff}$

Fundamental Frequency, f_1 Hz	Fourier Coefficients $alpha_1$	Forcing Frequency f_F Hz
$3.4 < f_1 < 4.6$	0.2	f_1
$4.6 < f_1 < 5.1$	0.2	f_1
$5.1 < f_1 < 6.9$	0.06	f_1
$f_1 > 6.9$	0.06	6.9

3. Check the deflection of the floor under a 1kN point load is less than 1mm based on an effective floor width of b_{eff}

$$b_{eff} = \frac{L}{1.1}\sqrt[4]{\frac{EI_T}{EI_L}}$$

Where:

- EI_T = Transverse stiffness of panel
- EI_L = Longitudinal stiffness of panel

For Cantilevers, the pre-analysis tables provide cantilever spans that satisfy both of these requirements:

1. Natural frequency of floor is checked based on the dead load of the floor (including super-imposed dead loads). The natural frequency must be greater than 8Hz.

2. The cantilever is checked for a 1kN point load on its tip, and a maximum 1.5mm deflection is allowed for.

Deflection

The allowable deflection of floor and roof panels is dependent on the application, type of finishes and any other building elements supported by them. These requirements need to be understood prior to the design. The shear deformation of timber can be a significant proportion of the overall deflection of a floor or roof and this therefore needs to be considered. The Shear Analogy Method used by XLam to develop the tables in this document includes this within its calculation method.

Similarly to concrete, timber is a material which creeps over time and the long term deflection of a floor should be calculated. Both the duration of loading and moisture content of the timber is important to the long-term deflection of the panel. AS1720.1 and NZS 3603:1993 use a modification factor for the long-term deflection of timber, j_2 (NZ referred as K_{21} this document will use j_2 to denote this factor from now on), which provides a multiplier for use in calculations. For timber with a moisture content of 15% or less, the maximum j_2 factor is 2, which has been used in the development of all span tables contained in this document. XLam does not recommend the use of their panels in any environments where the moisture content is greater than 15%.

Refer to the "CLT and Other Structural Materials" section for deflection considerations when using CLT with other structural materials.

Pre-Analysis Span Tables

Floor Table Notes

Terminology

G = Dead Load (inclusive of superimposed dead load and panel self-weight)

G_{SDL} = Superimposed dead load (floor finishes / ceiling etc.)

Q = Live Load

Wu = Wind ultimate

Ws = Wind service

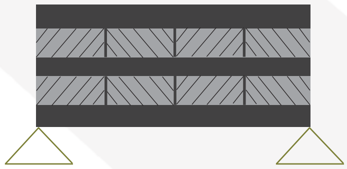
- Self-weight of the panels is included within the tables. All additional applied dead loads should be included in the value chosen for $G_{SDL.}$
- Span tables assume uniformly distributed loads across the whole panel and no pattern loading has been accounted for.
- Any penetrations or routing of panels could reduce the allowable spans in these tables.
- The cantilever design assumes a backspan of 1.5 times the cantilever length. Different backspan lengths can have a large effect on the cantilever span.
- Pattern live loading on the cantilever and backspan has not been considered in these tables. These tables account only for the uniform load on both cantilever and backspan.
- Long term deflection factors are taken as j_2 = 2 for all situations.
- These tables assume panels are supported on walls, and do not consider compound deflections if panels are supported on beams or spanning elements. Refer to "CLT and Other Structural Materials" section for limitations when using with other structural materials.

Floor deflection checks included for in the tables:

Case	Span	Cantilever
Short-term dead, δ_G	Span/200	Span/200
Short-term live, δ_Q	Span/360	Span/200
Long-term dead and live j_2(G+0.4Q), $\delta_{LT:G+Q}$	Span/300 or 25mm	Span/200

Pre-Analysis Span Tables

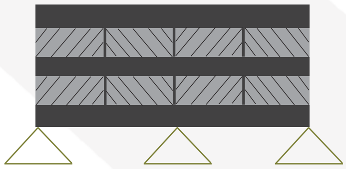
Floor Simply-Supported [maximum panel span in metres]



Floor - Simply Supported												
Panel Designation	Q = 2kPa				Q = 3kPa				Q = 5kPa			
	SDL				SDL				SDL			
	0kPa	0.5kPa	1kPa	2kPa	0kPa	0.5kPa	1kPa	2kPa	0kPa	0.5kPa	1kPa	2kPa
3 Layer Panels												
CL3/90	2.90	2.90	2.90	2.60	2.90	2.90	2.80	2.50	2.70	2.70	2.60	2.30
CL3/100	3.40	3.40	3.30	2.90	3.40	3.40	3.10	2.80	3.00	3.00	2.80	2.60
CL3/110	4.20	3.90	3.60	3.10	4.00	3.60	3.40	3.00	3.30	3.20	3.10	2.80
CL3/120	4.30	4.30	4.00	3.50	4.30	4.00	3.70	3.30	3.60	3.60	3.40	3.10
CL3/130	5.10	4.60	4.20	3.70	4.70	4.30	4.00	3.60	3.90	3.80	3.60	3.30
5 Layer Panels												
CL5/140	5.30	4.80	4.40	3.90	4.90	4.50	4.20	3.80	4.20	4.00	3.80	3.50
CL5/155	5.60	5.00	4.60	4.10	5.10	4.70	4.40	4.00	4.50	4.30	4.10	3.70
CL5/170	5.90	5.30	4.90	4.40	5.50	5.10	4.80	4.30	4.80	4.60	4.40	4.00
CL5/190	6.40	5.80	5.40	4.90	6.30	5.80	5.40	4.90	5.60	5.30	5.00	4.60
CL5/200	6.60	6.00	5.60	5.00	6.50	6.00	5.60	5.00	5.80	5.50	5.20	4.80
CL5/220	6.90	6.30	5.90	5.30	6.90	6.30	5.90	5.30	6.20	5.90	5.60	5.20
7 Layer Panels												
CL7/240	7.00	6.40	6.00	5.50	7.00	6.40	6.00	5.50	6.40	6.10	5.80	5.30
CL7/260	7.50	6.90	6.50	5.90	7.50	6.90	6.50	5.90	7.10	6.70	6.40	5.90
CL7/270	7.60	7.00	6.60	6.00	7.60	7.00	6.60	6.00	7.30	6.90	6.60	6.00
CL7/290	7.90	7.30	6.90	6.30	7.90	7.30	6.90	6.30	7.60	7.30	6.90	6.30
CL7/310	8.10	7.50	7.10	6.50	8.10	7.50	7.10	6.50	7.80	7.50	7.10	6.50

Pre-Analysis Span Tables

Floor Continuous [maximum panel span in metres, double equal span]

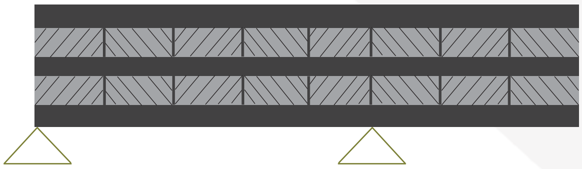


Floor - Double Span												
Panel Designation	Q = 2kPa				Q = 3kPa				Q = 5kPa			
	SDL				SDL				SDL			
	0kPa	0.5kPa	1kPa	2kPa	0kPa	0.5kPa	1kPa	2kPa	0kPa	0.5kPa	1kPa	2kPa
3 Layer Panels												
CL3/90	4.50	3.80	3.40	2.90	4.30	3.80	3.40	2.90	3.50	3.50	3.30	2.90
CL3/100	4.80	4.00	3.60	3.10	4.80	4.00	3.60	3.10	3.90	3.90	3.60	3.10
CL3/110	5.00	4.20	3.80	3.30	5.00	4.20	3.80	3.30	4.20	4.20	3.80	3.30
CL3/120	5.30	4.50	4.10	3.60	5.30	4.50	4.10	3.60	4.80	4.50	4.10	3.60
CL3/130	5.50	4.70	4.30	3.70	5.50	4.70	4.30	3.70	5.10	4.70	4.30	3.70
5 Layer Panels												
CL5/140	5.60	4.80	4.40	3.90	5.60	4.80	4.40	3.90	5.50	4.80	4.40	3.90
CL5/155	5.70	5.00	4.60	4.10	5.70	5.00	4.60	4.10	5.70	5.00	4.60	4.10
CL5/170	5.90	5.30	4.90	4.40	5.90	5.30	4.90	4.40	5.90	5.30	4.90	4.40
CL5/190	6.40	5.80	5.40	4.90	6.40	5.80	5.40	4.90	6.40	5.80	5.40	4.90
CL5/200	6.60	6.00	5.60	5.00	6.60	6.00	5.60	5.00	6.60	6.00	5.60	5.00
CL5/220	6.90	6.30	5.90	5.30	6.90	6.30	5.90	5.30	6.90	6.30	5.90	5.30
7 Layer Panels												
CL7/240	7.00	6.40	6.00	5.50	7.00	6.40	6.00	5.50	7.00	6.40	6.00	5.50
CL7/260	7.50	6.90	6.50	5.90	7.50	6.90	6.50	5.90	7.50	6.90	6.50	5.90
CL7/270	7.60	7.00	6.60	6.00	7.60	7.00	6.60	6.00	7.60	7.00	6.60	6.00
CL7/290	7.90	7.30	6.90	6.30	7.90	7.30	6.90	6.30	7.90	7.30	6.90	6.30
CL7/310	8.10	7.50	7.10	6.50	8.10	7.50	7.10	6.50	8.10	7.50	7.10	6.50

Pre-Analysis Span Tables

Floor Cantilever [maximum cantilever in metres]

[No allowance for any point load on cantilever]



Floor - Cantilever												
Panel Designation	Q = 2kPa				Q = 3kPa				Q = 5kPa			
	SDL				SDL				SDL			
	OkPa	0.5kPa	1kPa	2kPa	OkPa	0.5kPa	1kPa	2kPa	OkPa	0.5kPa	1kPa	2kPa
3 Layer Panels												
CL3/90	1.20	1.20	1.10	1.00	1.20	1.10	1.10	1.00	1.10	1.00	1.00	0.90
CL3/100	1.40	1.30	1.20	1.10	1.30	1.20	1.20	1.00	1.20	1.10	1.10	1.00
CL3/110	1.50	1.40	1.30	1.10	1.40	1.30	1.20	1.10	1.20	1.20	1.10	1.00
CL3/120	1.60	1.50	1.40	1.20	1.50	1.40	1.30	1.20	1.30	1.30	1.20	1.10
CL3/130	1.70	1.50	1.40	1.30	1.60	1.50	1.40	1.30	1.40	1.30	1.30	1.20
5 Layer Panels												
CL5/140	1.80	1.60	1.50	1.40	1.60	1.50	1.50	1.30	1.50	1.40	1.40	1.30
CL5/155	1.80	1.70	1.60	1.40	1.70	1.60	1.50	1.40	1.50	1.50	1.40	1.30
CL5/170	1.90	1.80	1.70	1.50	1.80	1.70	1.60	1.50	1.60	1.50	1.50	1.40
CL5/190	2.10	1.90	1.80	1.70	2.00	1.80	1.70	1.60	1.80	1.70	1.60	1.50
CL5/200	2.10	2.00	1.90	1.70	2.00	1.90	1.80	1.70	1.80	1.80	1.70	1.60
CL5/220	2.20	2.10	2.00	1.80	2.10	2.00	1.90	1.70	1.90	1.80	1.80	1.60
7 Layer Panels												
CL7/240	2.30	2.10	2.00	1.80	2.10	2.00	1.90	1.80	2.00	1.90	1.80	1.70
CL7/260	2.40	2.30	2.10	2.00	2.30	2.20	2.10	1.90	2.10	2.00	1.90	1.80
CL7/270	2.40	2.30	2.20	2.00	2.30	2.20	2.10	1.90	2.10	2.10	2.00	1.90
CL7/290	2.50	2.40	2.30	2.10	2.40	2.30	2.20	2.00	2.20	2.20	2.10	1.90
CL7/310	2.60	2.40	2.30	2.20	2.50	2.40	2.30	2.10	2.30	2.20	2.10	2.00

Pre-Analysis Span Tables

Roof Table Notes

Terminology

G = Dead Load (inclusive of superimposed dead load and panel self-weight)

G_{SDL} = Superimposed dead load (floor finishes / ceiling etc.)

Q = Live Load

Wu = Wind ultimate

Ws = Wind service

Ss + Serviceability snow load

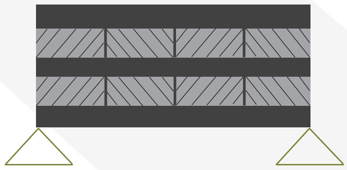
- Selfweight of the panels is included within the tables. All additional applied dead loads should be included in the value chosen for $G_{SDL.}$
- All roof tables assume a live load of Q=0.25 kPa.
- Roof snow loads of 1kPa and 3kPa have been assumed with corresponding serviceability snow loads of 0.68kPa and 2.04kPa respectively.
- Snow loads assume a constant snow distribution shape factor. No account has been made for the accumulation of snow on lower roofs abutting upper walls.
- Span tables assume uniformly distributed loads across the whole panel and no pattern loading has been accounted for.
- Any penetrations or routing of panels could reduce the allowable spans in these tables.
- The cantilever design assumes a backspan of 1.5 times the cantilever length. Different backspan lengths can have a large effect on the cantilever span.
- Long term deflection factors are taken as j_2 = 2 for all situations.
- Roof tables include for the following:
    - Ultimate wind loads of 1.3kPa (uplift) and 0.55kPa (down).
    - Serviceability wind loads of 0.9kPa (uplift) and 0.4kPa (down).
    - Refer to "CLT and Other Structural Materials" section for limitations when using other structural materials. Floor panels are assumed to be supported on walls.

Roof deflection checks included for in the tables:

Case	Span	Cantilever
Short-term dead, δ_G	Span/300	Span/150
Short-term live, δ_Q	Span/300	Span/150
Wind load (uplift), δ_{ws}	Span/300	Span/150
Long-term dead and live j_2(G+0.4Q), $\delta_{LT:G+Q}$	Span/300 or 25mm	Span/150
Short-term dead and wind (G+0.7W_s), δ_{G+Ws}	Span/300	Span/150
Long-term dead and snow j_2(G+S_s), dLT:G=S^s	Span/300 or 25mm	Span/150

Pre-Analysis Span Tables

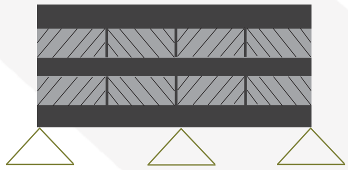
Roof Simply-Supported [maximum panel span in metres]



Roof - Simply Supported									
	No Snow			Snow= 1kPa			Snow= 1kPa		
Panel Designation	SDL			SDL			SDL		
	0kPa	0.5kPa	1kPa	0kPa	0.5kPa	1kPa	0kPa	0.5kPa	1kPa
3 Layer Panels									
CL3/90	4.80	4.00	3.50	4.30	3.70	3.30	3.40	3.10	2.80
CL3/100	5.30	4.30	3.80	4.60	4.00	3.50	3.70	3.40	3.10
CL3/110	5.60	4.60	4.10	4.90	4.30	3.80	4.00	3.60	3.40
CL3/120	6.10	5.10	4.50	5.40	4.70	4.20	4.40	4.00	3.70
CL3/130	6.40	5.40	4.80	5.70	5.00	4.50	4.70	4.30	4.00
5 Layer Panels									
CL5/140	6.60	5.60	5.00	5.90	5.20	4.70	4.90	4.50	4.20
CL5/155	6.80	5.80	5.20	6.20	5.50	5.00	5.10	4.70	4.40
CL5/170	7.30	6.30	5.60	6.60	5.90	5.40	5.50	5.10	4.80
CL5/190	7.90	7.00	6.40	7.40	6.60	6.10	6.30	5.80	5.50
CL5/200	8.10	7.30	6.60	7.60	6.90	6.30	6.50	6.00	5.70
CL5/220	8.30	7.60	7.00	7.90	7.30	6.70	6.90	6.40	6.10
7 Layer Panels									
CL7/240	8.40	7.70	7.20	8.00	7.40	6.90	7.10	6.60	6.30
CL7/260	9.00	8.30	7.80	8.50	8.00	7.60	7.70	7.30	6.90
CL7/270	9.10	8.40	7.90	8.70	8.10	7.70	7.90	7.50	7.10
CL7/290	9.40	8.80	8.30	9.00	8.40	8.00	8.20	7.80	7.50
CL7/310	9.60	8.90	8.50	9.20	8.60	8.20	8.40	8.00	7.70

Pre-Analysis Span Tables

Roof Continuous [maximum panel span in metres]

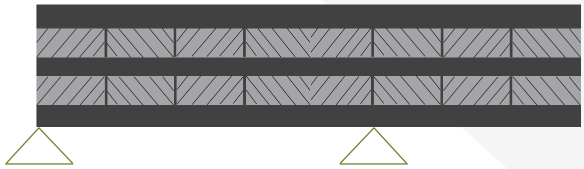


Roof - Double Span									
	No Snow			1kPa Snow			3kPa Snow		
Panel Designation	SDL			SDL			SDL		
	0kPa	0.5kPa	1kPa	0kPa	0.5kPa	1kPa	0kPa	0.5kPa	1kPa
3 Layer Panels									
CL3/90	6.40	5.30	4.60	5.70	4.80	4.30	4.50	4.00	3.70
CL3/100	7.00	5.70	5.00	6.10	5.20	4.60	4.80	4.40	4.10
CL3/110	7.50	6.10	5.30	6.50	5.60	5.00	5.20	4.70	4.40
CL3/120	7.90	6.70	5.90	7.10	6.20	5.50	5.80	5.30	4.90
CL3/130	8.20	7.10	6.30	7.50	6.50	5.90	6.10	5.60	5.20
5 Layer Panels									
CL5/140	8.40	7.40	6.60	7.70	6.90	6.20	6.40	5.90	5.50
CL5/155	8.60	7.60	6.90	8.00	7.20	6.50	6.80	6.20	5.80
CL5/170	9.00	8.10	7.40	8.40	7.70	7.00	7.30	6.70	6.30
CL5/190	9.70	8.80	8.10	9.10	8.30	7.80	8.00	7.60	7.10
CL5/200	9.90	9.00	8.40	9.30	8.60	8.10	8.30	7.80	7.40
CL5/220	10.20	9.30	8.70	9.70	8.90	8.40	8.60	8.10	7.80
7 Layer Panels									
CL7/240	10.30	9.50	8.90	9.80	9.10	8.60	8.80	8.30	8.00
CL7/260	11.00	10.10	9.50	10.50	9.80	9.20	9.40	9.00	8.60
CL7/270	11.20	10.30	9.70	10.60	9.90	9.40	9.60	9.10	8.70
CL7/290	11.50	10.70	10.10	11.00	10.30	9.80	10.00	9.50	9.10
CL7/310	11.50	10.90	10.30	11.20	10.50	10.00	10.20	9.70	9.30

Pre-Analysis Span Tables

Roof Cantilever [maximum cantilever in metres]

[No allowance for any point load on cantilever]



Roof - Cantilever

Panel Designation	No Snow SDL			1kPa Snow SDL			3kPa Snow SDL		
	0kPa	0.5kPa	1kPa	0kPa	0.5kPa	1kPa	0kPa	0.5kPa	1kPa
3 Layer Panels									
CL3/90	2.20	1.80	1.60	1.90	1.70	1.50	1.50	1.40	1.30
CL3/100	2.30	2.00	1.80	2.00	1.80	1.60	1.60	1.50	1.40
CL3/110	2.40	2.10	1.90	2.10	1.90	1.80	1.80	1.60	1.50
CL3/120	2.60	2.20	2.00	2.30	2.10	1.90	1.90	1.80	1.70
CL3/130	2.70	2.30	2.10	2.40	2.20	2.00	2.00	1.90	1.80
5 Layer Panels									
CL5/140	2.70	2.40	2.20	2.50	2.20	2.10	2.10	2.00	1.90
CL5/155	2.80	2.50	2.30	2.60	2.30	2.20	2.20	2.10	2.00
CL5/170	2.90	2.60	2.40	2.70	2.50	2.30	2.30	2.20	2.10
CL5/190	3.20	2.80	2.60	2.90	2.70	2.50	2.50	2.40	2.30
CL5/200	3.20	2.90	2.70	3.00	2.80	2.60	2.60	2.50	2.40
CL5/220	3.30	3.00	2.80	3.10	2.90	2.70	2.70	2.60	2.50
7 Layer Panels									
CL7/240	3.40	3.10	2.90	3.10	2.90	2.80	2.80	2.60	2.50
CL7/260	3.60	3.30	3.10	3.40	3.10	3.00	3.00	2.80	2.70
CL7/270	3.60	3.40	3.20	3.40	3.20	3.00	3.00	2.90	2.80
CL7/290	3.80	3.50	3.30	3.50	3.30	3.20	3.20	3.00	2.90
CL7/310	3.80	3.60	3.40	3.60	3.40	3.20	3.20	3.10	3.00

Wall Design

Vertical Load Design

CLT walls have high vertical load capacity when compared to more traditional timber structures and this has enabled the construction of otherwise not possible tall timber buildings. In the majority of cases the CLT wall should be designed so that the outer layers are vertical and the grain of the majority of the cross-section is running in the direction of the applied load. The cross-layers running perpendicular to the load are ignored in the axial design checks for the wall, although they can be useful to form lintel or header panels above doors and windows.

Section properties can again be calculated through several methods and the design checks are covered in detail in the FP Innovations guide. The capacity of the walls is governed by their slenderness which can be calculated through the equations for composite cross-sections in AS1720.1, E4.4. The design capacities presented in this guide have been calculated using these methods. Slender walls will naturally be more sensitive to issues like eccentric loading and construction imperfections and a suitable allowance for these should be made in the design.

When designing a multi-storey building for vertical loads consideration must be given to the floor connection and how loads are transferred through the floor. The most common form of CLT construction (known as platform construction) uses wall panels measuring a storey in height, and the floor is continuous over the top of them. This will cause compression across the grain in the floor panels, and this is significantly weaker and less stiff than the walls. For high loads or buildings more than five stories in height, we recommend the stiffness be calculated. A significant proportion of the overall shortening of the building could come from the floor and this may need to be controlled through detailing during the structural design process. XLam have developed and tested our own proprietary methods for the reinforcement of the floor under concentrated load - for more information please contact the technical team.

Lateral Load Design

The light weight and high shear resistance of CLT panels enable CLT buildings to be designed for excellent resistance to earthquakes. As with other materials in moderate or high seismic regions, it is essential to carry out "capacity design" to ensure that the brittle elements of the structure are never loaded to their full capacity, and that inelastic deformations occur in selected ductile elements; the weak links in the overall structure.

For CLT structures, it is essential to design the connections between panels as the ductile weak links. A hierarchy of strength can be applied between the various connections to ensure that the desired failure mechanism is achieved. Diaphragm capacity must also be checked to ensure the load can be sufficiently distributed to the lateral load resisting system.

Ductility in the connections comes from ductile behaviour of the fasteners themselves, which are the nails, screws or rivets used to connect the CLT panels together. These fasteners have a reasonable level of ductility, but their capacity can drop suddenly after the individual fasteners fail and crushing of wood occurs behind the individual fasteners during cyclic loading. This results in a very pinched hysteresis loop. Design for a higher level of ductility may be possible with ductile yielding of specialised hold-downs rather than relying on yielding of the nail or screw fixings. However, until further testing is carried out, it is suggested the designer uses conventional connection details which have been well tested for ductility (e.g. nails, dowels or rivets).

Depending on the support conditions and location of the wall, the reduction on axial capacity can be significant with combined axial and bending actions. The axial capacity span tables apply an accidental eccentricity of 10% of the wall thickness. Although the capacity tables provide guidance, CLT wall structures must be subject to specific engineering design.

Pre-Analysis Axial Capacity Tables

Wall Capacity [maximum axial capacity in kN per metre]

Wall Capacity ØNc				
Panel Designation	Wall Height			
	2.8m	3m	3.5m	4m
3 Layer Panels				
CL3/90	169	151	116	91
CL3/100	220	198	154	122
CL3/110	270	245	192	154
CL3/120	349	319	254	205
CL3/130	403	374	304	248
5 Layer Panels				
CL5/140	443	414	344	283
CL5/155	475	450	391	334
CL5/170	551	525	462	402
CL5/190	713	684	613	546
CL5/200	769	739	667	598
CL5/220	827	802	734	668
7 Layer Panels				
CL7/240	822	807	747	686
CL7/260	988	973	924	857
CL7/270	1008	993	955	890
CL7/290	1107	1092	1053	995
CL7/310	1126	1113	1077	1037

Note: The combined loading check completed in calculating the values in the table above allows for moment induced by eccentricity in addition to a simultaneous wind load of 0.5kPa.

CLT Connections

Much of the engineering in a CLT building is focussed on the connections between panels. XLam is committed to assisting where possible and have made available on their website a set of their most used typical details in both CAD and Revit format. These details are based on XLam's depth of experience on past projects and are intended to streamline the manufacturing and installation process. Utilising these details will ensure economical manufacturing costs for our clients and ease of assembly on-site. There are many suppliers who have developed products tailor-made for CLT and mass timber construction and have some excellent technical literature available which makes design simpler for the engineer. XLam can procure proprietary fixings from these suppliers and can also arrange for the fabrication of other custom brackets and fixings if the project requires them.

Common proprietary mass timber fixing suppliers in Australia and New Zealand:
1. Rothoblaas
2. Spax
3. Simpson Stongtie

Screw Connections

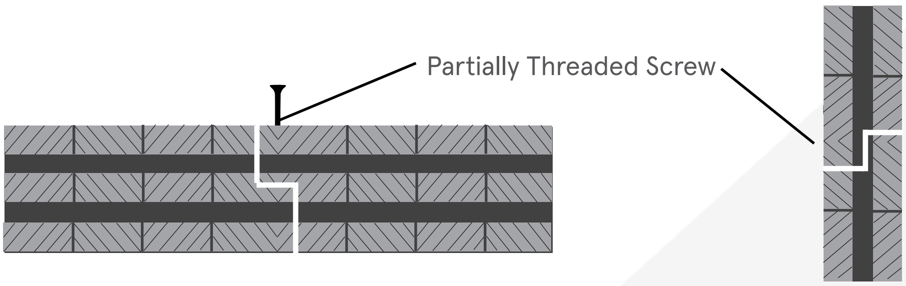
The capacity of screw connections is calculated using the European Yield Method (EYM) in Eurocode 5. The EYM considers a number of different failure mechanisms based on the shear capacity of the timber and the yield strength of the fastener.

Generally, self-tapping wood screws are recommended for connecting CLT floor and wall elements together. The screws come in a variety of lengths and diameters either fully threaded, or partially threaded, and do not require pre-drilling. Provided no thread extends beyond the receiving panel, partially threaded screws are able to pull the panels tight together, but fully threaded screws provide greater shear and withdrawal capacities.
If fully threaded screws are required for additional strength, it is recommended that panels be firstly pulled tight together using partially threaded screws.

The appropriate European Technical Approval (ETA) documentation specific to each screw supplier shall be used to determine the specific characteristic strengths. The capacity of each specific screw may vary slightly from each screw supplier. Higher shear capacities can be achieved using steel to timber connections, timber in double shear, or greater embedment depths.

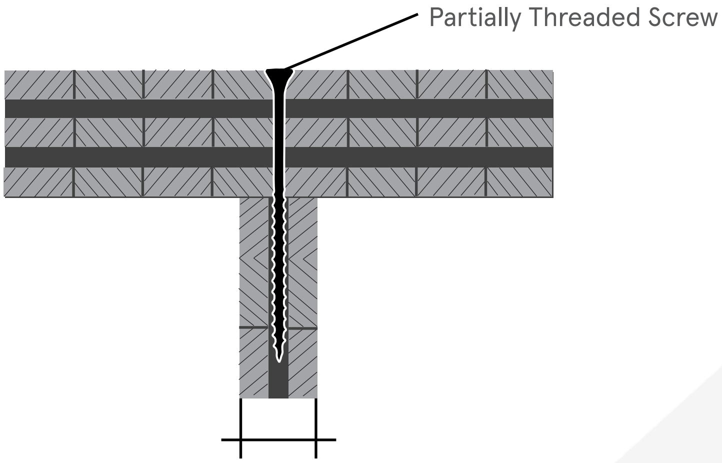
Panel to Panel Connections

Solid CLT panels are typically fixed together with a half lap joint connection. The screw spacing at the joint should be specified to resist the shear flow between panels to achieve diaphragm action. It is recommended that partially threaded screws are specified to ensure the panels are pulled tight together during site assembly. The half lap joint can resist transverse loading but is not considered to be a moment-resisting connection.



Wall and Floor Fixings

Wall-to-wall fixings and floor-to-wall fixings can also be efficiently achieved using engineered wood screws. However, the capacity of screws on the narrow edge is less than in the face grain orientation. Again it is recommended that partially threaded screws are specified to help pull the panels tight together.



Durability of Fixings

It is recommended that designers consult with the manufacturer of screws, nails and proprietary brackets to ensure they have an appropriate design life for the structure under consideration. Wood Solutions "Timber Service Life Design" publication provides very detailed information and methods to assess the suitability of fixings for durability.

Designers should pay careful attention to fixings in wet areas and fixings that are externally exposed, and design accordingly. Consideration should also be given to screws and fixings being used in treated panels. As an example, based on the Wood Solutions publication a typical screw with 12 microns of galvanic protection could have a design life of less than 5 years in treated timber panels, depending on the location in Australia or New Zealand and application. Coating technology is advancing, and some manufacturers have their own proprietary protection systems and can provide test results and advice for the design life of these products.

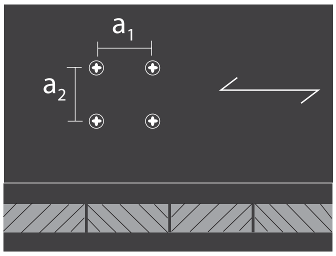
Edge Distance Diagrams

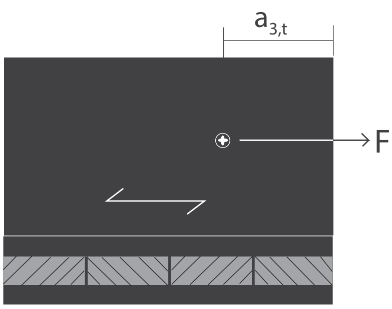
The following recommended edge distances are as specified in the Spax European Technical Approval (ETA - 12/0114) and are presented in this document for guidance only. Self tapping screws of the same length and diameter from different suppliers may have different capacities and edge distance requirements. Reference must be made to the ETA specific to each supplier.

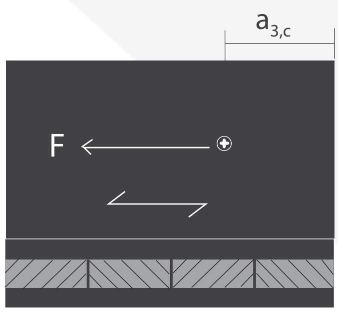
Screw Edge Distance Requirements		
	Face Grain	On Edge
Minimum panel thickness	t_{min} = 10d	t_{min} = 10d
Spacing a_1 parallel to grain	a_1 = 4d	a_1 = 10d
Spacing a_2 perpendicular to grain	a_2 = 2.5d	a_2 = 4d
Distance $a_{3,c}$ to unloaded end grain	$a_{3,c}$ = 6d	$a_{3,c}$ = 7d
Distance $a_{3,t}$ to loaded end grain	$a_{3,t}$ = 6d	$a_{3,t}$ = 12d
Distance $a_{4,c}$ to unloaded edge	$a_{4,c}$ = 2.5d	$a_{4,c}$ = 3d
Distance $a_{4,t}$ to loaded edge	$a_{4,t}$ = 6d	$a_{4,t}$ = 6d

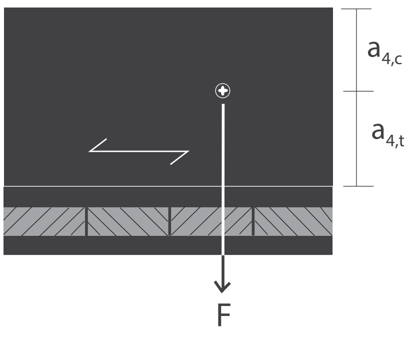
Edges Distances

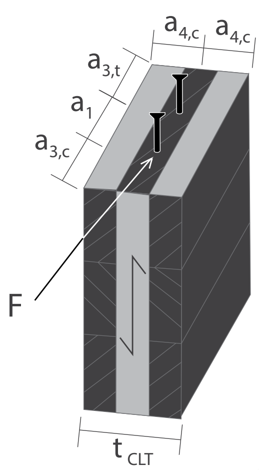
While the yielding failure mode of the fastener is a dominant failure mechanism, there is potential for brittle block tear-out failure, or tensile splitting of the timber. Care must be taken when specifying minimum edge distances of the fasteners.

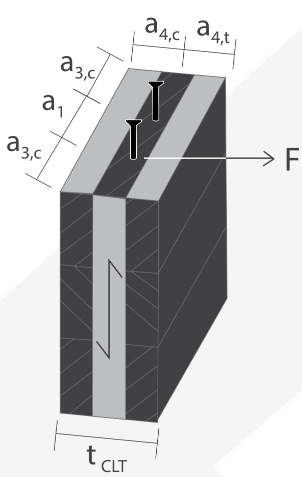






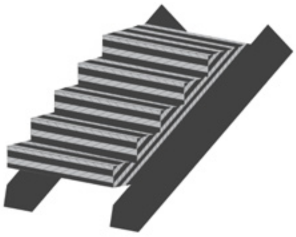






AirStair

AirStair is XLam's proprietary CLT stair system and is used in both commercial and residential construction to provide a simple and fast to install stair.



In order to simplify the manufacturing process for AirStair and reduce waste there are 5 different types which are manufactured by XLam. Each stair is created by pressing a thick billet and cutting the treads into it with a circular saw, leaving a minimum throat thickness to act as the spanning element.

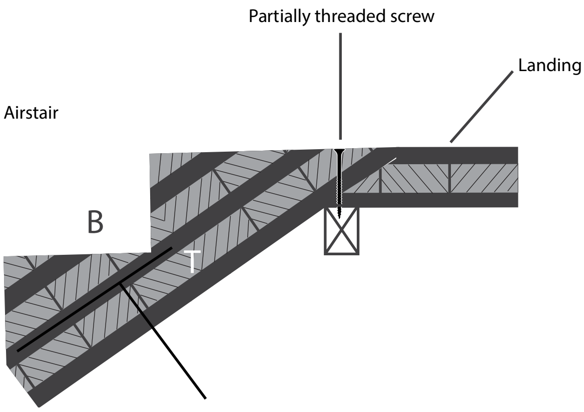
Airstair can either span from top to bottom when supported at landing levels (noted longitudinal), or span from side-to-side when supported on walls (noted transverse). The tables below note the different panel types and buildups.

The design of the AirStair follows a similar methodology to floor panels, with the exception that no long term live load is expected for stairs. The formula for deflection therefore becomes:
$j_2(G) + 0.7Q < span/400$

Where G is the self-weight of the AirStair panel, including the mass of the treads. The vibration checks are the same as outlined in the floor design section of this document.

Connection details shown are suitable for single occupancy residential dwellings only. Connection details for stairs in multistorey commercial or residential structures must take into account requirements for sliding, inter-storey drift, and construction tolerance.

AirStair Typical Connection Detail

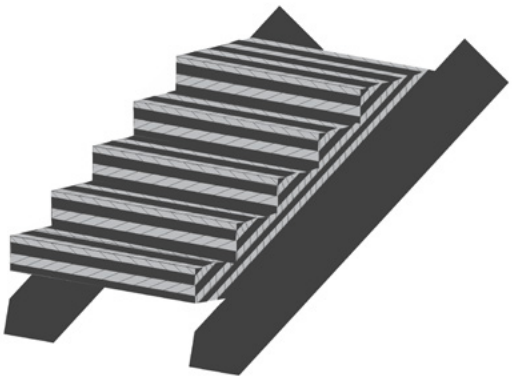


T = throat thickness
B = tread and riser thickness

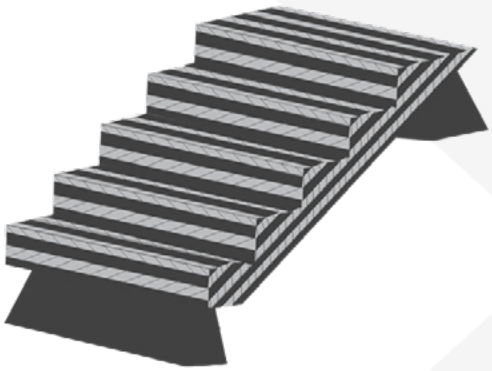
Pre-Analysis Span Tables

Airstair [maximum span on incline in metres]

AirStair								
	Q=2kPa			Q=4kPa			Throat buildup	Tread Buildup
	SDL			SDL				
	0kPa	0.25kPa	0.5kPa	0kPa	0.25kPa	0.5kPa		
Longitudinal AirStair								
AS8/263	3.8	3.6	3.5	3.4	3.2	3.1	32.5/35/32.5	32.5 x 5
AS8/293	4.8	4.6	4.4	4.3	4.1	4.0	42.5/45/42.5	32.5 x 5
AS10/333	5.7	5.4	5.2	5.1	5.0	4.8	32.5/35/35/35/32.5	32.5 x 5
Transverse AirStair								
AS7/270	3.7	3.5	3.4	3.3	3.2	3.0	32.5/35/32.5	42.5 X 4
AS7/300	4.7	4.5	4.3	4.2	4.0	3.9	42.5/45/42.5	42.5 X 4



Transverse AirStair



Longitudinal AirStair

CLT and Other Structural Materials

The use of CLT in conjunction with other structural materials is commonplace but particular consideration should be given to the interface between them. The manufacture of CLT involves tolerances to millimetre accuracy whereas tolerances for the typical construction of steel, concrete and masonry could be up to 10-15mm in certain situations. Given the shop drawings and fabrication of CLT panels takes place significantly in advance of the completion of other materials on site it is important to allow for tolerance in the connections and joints.

The speed of construction benefits of mass timber could be difficult to realise if there are significant amounts of site modifications required to panels to ensure they fit and careful detailing can assist in this. For instance, many CLT buildings sit on a concrete slab which may have a tolerance in level of +/- 10mm so it is usually sensible to set the CLT above the concrete by 15mm and pack up and grout underneath the wall. Once this initial connection has been made the building can continue swiftly with timber to timber connections fitting together accurately.

A major design consideration when considering hybrid structures is the different movement characteristics between CLT and other materials and how they behave in the long term. Timber is a material which behaves very differently to steel and concrete and issues like creep, shrinkage and thermal movements need to be calculated in many situations. For example, the axial shortening of a wall on a ten storey building could be in the order of 50mm due to creep and shrinkage and this may be very different to a steel or concrete core structure.

Consideration should also be given to compound deflections when using CLT with other structural materials. The floor pre-analysis span tables in this guide are applicable to floor panels supported on the walls. Should panels be supported on steel beams, the compounding deflection should be considered for the steel beam and the floor panels. This is outside of the scope of these pre-analysis span tables, and usually considered by the structural engineer during the design process.

Details also need to consider constructability. Understanding where screws and brackets need to be installed from and how they're accessed is important to a safe and efficient construction site. Pre-installation of brackets, plates, bolts and screws can improve efficiency on site provided the allowance for tolerances is still maintained. The long-term performance of details is also something to bear in mind, particularly with respect to moisture, and details with the potential to trap water against the timber should be avoided.

Acknowledgements

XLam would like to acknowledge the support of Vistek Structural Engineers and Engco Consulting Engineers in the review of the design guide.

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