31

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Timber Cassette Floors

Technical Design Guide issued by Forest and Wood Products Australia

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Authors: Prof Keith Crews, Dr Rijun Shrestha

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Contents

1

Introduction

This Design Guide complements WoodSolutions Design Guide #30: *Timber Concrete Composite Floors.* Timber cassette floor systems are well established in Australia, but are mainly used for residential floor loads comprised of either seasoned sawn timber or engineered wood products (EWP) such as I-joists, in conjunction with sawn and dressed timber, particle board or plywood flooring between 17 and 22 mm in thickness.

This Guide presents a design procedure based on *AS 1720.1: 2010 Timber structures Part 1: Design methods* for composite timber floor structures, manufactured using EWPs such as LVL and glulam and fabricated into 'T or box beam 'cassettes'. The notations throughout this document are based on AS 1720.1.

Timber cassette floors consist of a timber joist (LVL or glulam beam) sandwiched between two timber sheathing layers. The sheathing is rigidly connected to the beams by a combination of adhesives and mechanical fasteners to ensure composite action.

Extensive laboratory testing has been undertaken to validate the design assumptions within this Guide. The results of this testing program have confirmed that, provided the flange to web connections meet the prescriptive requirements contained within this Guide, the floor can be designed using the existing provisions of AS 1720.1 as a fully composite section, with linear elastic behaviour in resisting load actions predicted using AS 1170 Structural Design Action series.

The design of timber concrete composite is covered in WoodSolutions Technical Design Guide *#30: Timber Concrete Composite Floors* for use in commercial and multi-residential timber buildings.

The design of floor diaphragms for wind loading has been described in detail in WoodSolutions Technical Design Guide *#35: Floor Diaphragms*.

Fire resistance design is not covered in this Design Guide, for further information on fire design, please refer to WoodSolutions Technical Design Guide *#15: Fire Design.*

Related publications are listed under References at the end of this Guide.

2 Design Requirements

The design procedure addresses performance requirements for the strength (normative) and serviceability (advisory or informative) limit states. Load type and intensity, load combinations and modification factors for both the ultimate and the serviceability limit states have been defined in accordance with the AS 1170 standards.

The limit states that require checking are:

1. **Short-term ultimate limit state**, where the response of the structure to the maximum load is analysed. It generally corresponds to short-term exertion of the structure.
2. **Long-term ultimate limit state**, where the analysis focuses on the response of the structure to a quasi-permanent loading and avoiding failure due to creep of the timber member in particular. (Checking the end-of-life ultimate limit states corresponds to analysis and assessment of the durability/reliability of the structure.)
3. **Short-term serviceability limit state**, which corresponds to the instantaneous response of the structure to an imposed load.
4. **Long-term serviceability limit state** analysis considers time-dependent variations of the material properties; particularly creep, to identify the service life behaviour.
5. **1.0-kN serviceability limit state**: the instantaneous response to and imposed load of 1.0 kN at mid-span provides an indication of dynamic behaviour. This can be replaced with a dynamic analysis if available.

Unless noted otherwise in Figures 2.1 and 2.2, all symbols and letters used in the design procedure conform to those in AS 1720.1.

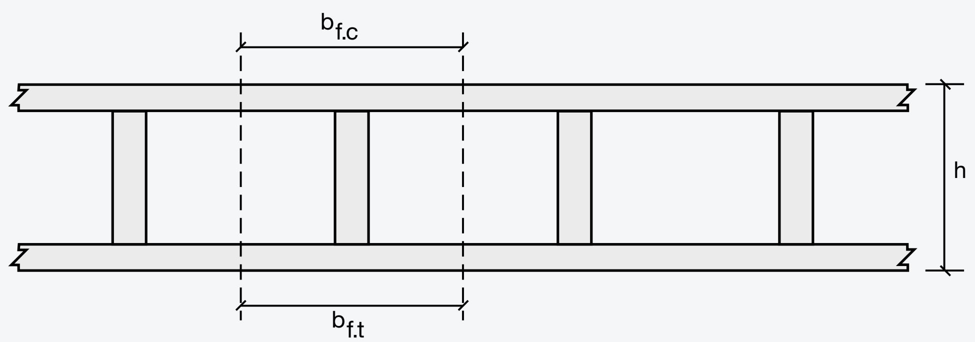

Figure 2.1: Notation for a typical composite timber floor system.

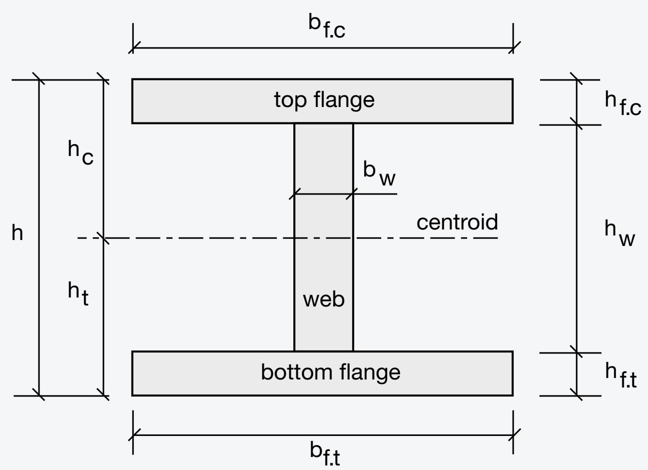

Figure 2.2: Notation for an individual 'cassette' in a typical composite timber floor design procedure.

3 Design Procedure

The design procedure has three fundamental stages:

1. Identifying the cross-sectional characteristics of the cross-section of the composite beam.
2. Evaluation of the strength capacity.
3. Assessment of the serviceability limit states.

3.1 Cross-section Characteristics

In cases where the flanges and webs have differing properties (such as the use of cross-laminated timber), it is necessary to determine the modular ratio and apply this to determine effective widths of members, prior to determination of the section properties.

For irregular sections (e.g. where the top and bottom flanges are different), the location of the centroid must be determined to enable the relevant section properties to be calculated.

It is strongly recommended that the c/c web spacing be such that shear lag effects do not occur in the flanges. This is normally met by satisfying Equations (3-1) to (3-3):

$$b_{f.t} = b_w + 0.1 \times span \qquad \text{for bottom flange} \quad (3\text{-}1)$$

$$b_{f.t} = b_w + 20 \times h_{f.t} \qquad \text{for bottom flange} \quad (3\text{-}2)$$

The minimum value of Equations (3-1) and (3-2) is used for $b_{f,t}$.

$$b_{f.c} \leq (b_w + 0.1 \times span) \qquad \text{for top flange} \quad (3\text{-}3)$$

where $b_{f.c}$ and $b_{f.t}$ are width of the top (compressive) and bottom (tension) flanges, respectively, while b_w and $h_{f.t}$ are width (thickness) of the web and height of the bottom (tension) flange, respectively.

3.2 Design for Flexural Effects

The imposed uniformly distributed load (UDL) induces flexure in the webs and a combination of flexural and axial load effects in the flanges. This requires satisfying the requirements of Clause 3.5 of AS 1720.1, for combined bending and axial load effects.

The following equations apply to a simply supported beam and would need to be interpreted correctly for use with continuous beams.

Bending capacity of the section below the centroid is given by:

$$M_d = \phi k_1 k_4 k_6 k_9 k_{12}\, f'_b Z_{bot} \qquad (3\text{-}4)$$

where f'_b is characteristic bending strength of timber while Z_{bot} and Z_{top} represent section moduli below and above the centroid. Moreover, Φ and ki are capacity and modification factors defined in AS 1720.1 as:

Φ is capacity and modification factors (Section 2, AS 1720.1).

k_1 is modification factor for duration of load (Section 2, AS 1720.1).

k_4 is modification factor for moisture condition (Section 2, AS 1720.1).
In this Guide, seasoned timber is allowed hence, $k_4 = 1$.

k_6 is modification factor for temperature (Section 2, AS 1720.1).
For covered timber structures under ambient conditions $k_6 = 1$.

k_9 is modification factor for strength sharing between parallel members factor Section 2, AS 1720.1). For glulam and LVL used in parallel systems shall be taken as unity, $k_9 = 1$.

k_{12} is stability factor (Section 3, AS 1720.1).

Axial capacity (compression) of the top flange, N_{d_top} is given by:

$$N_{d-top} = \phi \, k_1 k_4 k_6 k_{12} \, f'_c A_{f.c} \tag{3-5}$$

Axial capacity (tension) of the bottom flange, N_{d_bot} is given by:

$$N_{d-bot} = \phi \, k_1 k_4 k_6 k_{11} \, f'_t A_{f.t} \tag{3-6}$$

where f'_c and f'_t are characteristic axial strength of timber in compression and tension, respectively, while k_i and Φ are modification and capacity factors as defined in AS 1720.1. $A_{f.c}$ and $A_{f.t}$ represent cross-sectional areas of the top (compressive) and bottom (tension) flanges, respectively.

The axial force induced in each flange as a result of the bending action is calculated using the following equations:

Axial load induced (compression) in the top flange, N^*_c is given by:

$$N_c^* = \frac{M^*(h - h_{centroid} - \frac{h_{f.c}}{2})}{I} A_{f.c} \tag{3-7}$$

Axial load induced (tension) in the bottom flange, N_t^* is given by:

$$N_t^* = \frac{M^*(h_{centroid} - \frac{h_{f.t}}{2})}{I} A_{f.t} \tag{3-8}$$

where $h_{f.c}$ and $h_{f.t}$ are heights of the top (compressive) and bottom (tension) flanges, respectively, while $h_{centroid}$ and M^* represent distance from the centroid to the top of the top flange and bending action due to the factored loads specified in AS1170. I is second moment of inertia of the composite section.

Combined bending and compression – top flange:

$$(\frac{M^*}{M_d})^2 + \frac{N_c^*}{N_{d\_top}} \leq 1.0 \tag{3-9}$$

$$\frac{M^*}{M_d} + \frac{N_c^*}{N_{d\_top}} \leq 1.0 \tag{3-10}$$

Combined bending and tension – bottom flange:

$$k_{12} \frac{M^*}{M_d} + \frac{N_t^*}{N_{d\_bot}} \leq 1.0 \tag{3-11}$$

$$\frac{M^*}{M_d} - \frac{N_t^*}{N_{d\_bot}} \frac{Z}{A} \leq 1.0 \tag{3-12}$$

where Z and A are section modulus and section area of the timber module while k_{12} is AS 1720.1 stability factor used in bending strength calculation. M^* and N^* are bending and axial actions due to the factored loads specified in AS 1170.

3.3 Design for Shear Effects

Shear is generally not a limiting state for strength in these types of floor beams.
However, a check of the web for shear is recommended:

$$V_d = \phi\ k_1 k_4 k_6 f'_S A_S \qquad (3\text{-}13)$$

where f'_s and A_s are characteristic shear strength timber parallel to the grain and area corresponding to shear (A_s=2/3A) while k_i and Φ are modification and capacity factors as defined in AS 1720.1.

Connection details recommended for achieving fully composite design behaviour are specified in Chapter 4. The first moment of shear area (Q_{top} and Q_{bot}) and hence the shear flow (q_{top} and q_{bot}) at the interface between the web and the flanges can be checked using the following equations:

$$Q_{top} = A_{f.c}(h_c - \frac{h_{f.c}}{2}) \qquad (3\text{-}14)$$

$$Q_{bot} = A_{f.t}(h_t - \frac{h_{f.t}}{2}) \qquad (3\text{-}15)$$

$$q_{top} = \frac{Q_{top} V^*}{I} \qquad (3\text{-}16)$$

$$q_{bot} = \frac{Q_{bot} V^*}{I} \qquad (3\text{-}17)$$

where h_c and h_t are distances from the centroid to the top of the top flange and the bottom of the bottom flanges, respectively, while (V^*) is the acting shear force at the distance of 1.5d from the supports of the LVL modules.

3.4 Shear Strength at Glue Line

In the case of composite timber section, to ensure there is no failure in the glue line at the interfaces of LVL modules, the shear stress at the interfaces between the flange and the web must be checked according to:

$$\frac{QV^*}{I(2b_w)} \leq \text{Min } (f'_s),\ (f'_{s,glue}) \qquad (3\text{-}18)$$

V^* is the acting shear force at the distance of 1.5d from the supports of the LVL modules and Q is the first moment of area of the LVL cross section at the interface between the flange and the web. d is total depth of the timber cross section. $f'_{s,glue}$ is given by adhesive manufacturers.

3.5 Bearing Strength

The design capacity in bearing must satisfy the condition given in:

$$\phi N_p \geq N_P^* \qquad (3\text{-}19)$$

$$\phi N_p = \phi\ k_1 k_4 k_6 k_7 f'_P A_P \qquad (3\text{-}20)$$

where, N^*_p is the design load in bearing, f'_p is the bearing strength of the bottom flange, and A_p is the bearing area. k_7 represents modification factor of length and position of bearing as specified in Section 2 AS 1720.1.

3.6 Serviceability – Deflection

Limits on the deflection behaviour need to be determined to suit the functional requirements of the flooring system, in accordance with Guidelines presented in Appendix B of AS 1720.1.

Serviceability of the timber floor is assessed by checking the deflections against the limits defined to suit the functional requirements of the building being designed as:

$$\Delta = \frac{5(W^*)L^4}{384(EI)_{ef}} = \frac{5(\mathrm{G}+0.7\mathrm{Q})L^4}{384(EI)_{ef}} \leq \frac{Span}{300} \quad (3\text{-}21)$$

$$\Delta = \frac{5(W^*)L^4}{384(EI)_{ef}} = \frac{5(\mathrm{G}+0.4\mathrm{Q})L^4}{384(EI)_{ef}} \leq \frac{Span}{400} \quad (3\text{-}22)$$

where G is the self-weight plus the permanent loading and Q is the imposed loading. L is the span of the modules and EI_{ef} is the flexural stiffness of the modules. G+0.7Q is the short-term serviceability load combination and G+0.4Q is the long-term serviceability load combination. The minimum required flexural stiffness of the modules can be calculated from:

$$EI_{ef} = \frac{300 \times 5(W^*)L^3}{384} = \frac{300 \times 5(\mathrm{G}+0.7\mathrm{Q})L^3}{384} \quad (3\text{-}23)$$

$$EI_{ef} = \frac{400 \times 5(W^*)L^3}{384} = \frac{400 \times 5(\mathrm{G}+0.4\mathrm{Q})L^3}{384} \quad (3\text{-}24)$$

The serviceability load combinations and deflection limits are presented in Table 3.1.

The minimum required EI_{ef} due to different loading condition shall be less than EI_{ef} of the section.

G	self-weight & permanent loading (permanent)	Span/400
G+Q	imposed loading (instantaneous)	Span/300
G+ 0.7Q	imposed loading (short-term)	Span/300
G+ 0.4Q	imposed loading (long-term)	Span/400
1.0 kN	imposed 'impact' loading (vibration)	1-2 mm

Table 3.1: Load combinations and deflection limit for serviceability limit state design.

Load combination	
1.35G	self-weight & permanent loading (permanent)
1.2G+(1.5ψ)Q,ψ=0.4	imposed loading (long-term)
1.2G+1.5Q	imposed loading (short-term)
1.0 kN	imposed 'impact' loading (vibration)

Table 3.2: Load combinations and deflection limit for ultimate limit state design.

Table 3.2 lists the ultimate load combinations. To consider the long-term deformation of a structure to satisfy a specific serviceability limit state, an appropriate modification factor for creep (see Table 3.3) should be applied to the deformation as specified by AS 1720.1. To consider the creep deformation of the timber modules, the creep factor is applied for the portion of the serviceability load that is permanently applied. Therefore, the minimum required EI_{ef} of timber modules needs to be calculated based on some modification to Equations (3-24) and (3-25) by:

$$EI_{ef} = \frac{300 \times 5(j_2\mathrm{G}+0.7\mathrm{Q})L^3}{384} \quad (3\text{-}25)$$

$$EI_{ef} = \frac{300 \times 5 \times j_2(\mathrm{G}+0.4\mathrm{Q})L^3}{384} \quad (3\text{-}26)$$

where the values of j_2 are presented in Table 3.3.

Loading	j_2
Instantaneous Live load	1.0
Long-term loads in a controlled environment	2.0
Long-term loads in a variable environment	3.0

Table 3.3: Rigorous Method - Recommended Values of the Creep Factor j_2.

The mid-span deflection under a point load imposed 'impact' loading for vibration is assessed by:

$$\Delta = \frac{P^* L^3}{48(EI)_{ef}} \tag{3-27}$$

where p^* is design action for point load action, for which the value of ψ and $(EI)_{ef}$ are defined to suit the loading condition and duration. The mid-span deflection under a point load imposed 'impact' loading should be less than 2 mm.

3.7 Serviceability – Dynamic Behaviour

In addition to the 1 kN point load vibration check, a more rigorous dynamic assessment can be carried out based on the first fundamental frequency of the timber cassette floor. Note that this formula (above) predicts the behaviour of a simply supported single span beam.

The first natural frequency of the floor systems is generally recommended to be more than 10 Hz, while natural frequencies below 3 Hz and between 5 Hz to 8 Hz should be avoided to prevent walking resonance and human discomfort, respectively. There are several prediction formulas proposed to calculate the first natural frequency of the structure. In this Design Guide, the proposed formula in Eurocode 5, BS EN 2004[1] is used to predict the dynamic behaviour of the timber floor modules:

$$f_1 = \frac{\pi}{2l^2}\left(\frac{EI_{ef}}{m}\right)^{0.5} \tag{3-28}$$

where f_1 is the fundamental frequency of the floor modules, EI_{ef} is the equivalent bending stiffness of the floor modules in the perpendicular to the beam direction (kNm²), L is the floor span (m) and m is the mass per unit area (kg/m²). The mass includes self-weight of the floor and other permanent actions, such as imposed dead load.

4

Manufacturing Provisions

The recommended procedure for connecting flanges to webs is 'gluing and screwing'. The design philosophy is that the glue creates an infinitely stiff bond to resist serviceability load events, while the screws provide a mechanical connection so composite action occurs at the design ultimate load events.

In research by the University of Technology Sydney for the Structural Timber Innovation Company, the glue bond was a PURBOND polyurethane glue, fastened using 14G Type 17 screws (see Figure 4.1) at nominal centres of 400 mm c/c along the entire length of the web. It is recommended this method be a starting point for design. Reference should always be made to timber fabricators for their preferred 'gluing and screwing' method.

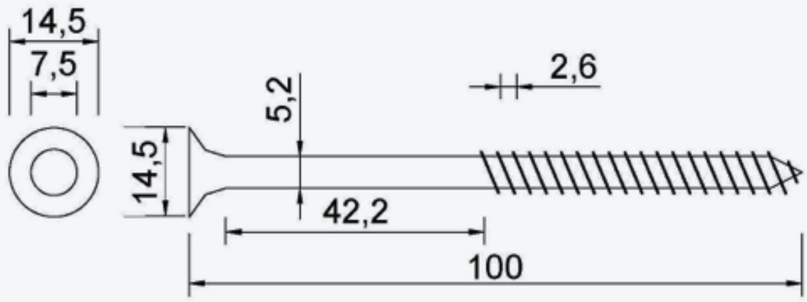

Figure 4.1: Dimensions of the Type 17 screws used for manufacture.

5 Acoustic Performance

From a review of existing knowledge on acoustic performance of timber floors, it is clear that both airborne and impact sound insulation requirements can be fulfilled by applying suitable treatments and proper detailing to timber floors. It is important to understand the difference in the factors affecting the airborne and impact sound insulation to address the acoustic performance of a floor.

A number of best practice guidelines based on existing knowledge on acoustic performance of timber floors are summarised below:

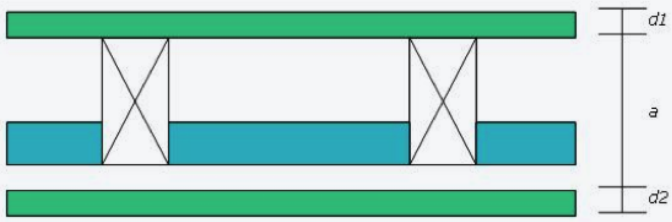

Figure 5.1: Double layer floor with good acoustic properties.

5.1 Guidance on Improving the Airborne Sound Insulation

1. Larger spacing and separated layers of double layer floor: The ceiling boards should not be directly connected to the floor joists. Ceiling should be separated from the floor joists (distance a in Figure 5.1) by providing either resilient support for the ceiling board or separate joists for ceiling boards supported on the walls.
2. The ceiling boards should have a minimum density of 10 kg/m^2. Although single layer ceiling boards provide adequate airborne sound insulation, it is preferable to use two ceiling boards with staggered joints for better sound insulation performance.
3. The floor cavity between the subfloor and ceiling should be filled with sound absorbing material (mineral fibre). The material's type and density is dependent on the floor's construction. The BCA may require the mineral wool to be non-combustible.
4. Increasing the mass of the joist may not improve the airborne sound insulation of timber floors. The thickness of sound absorbing material, arrangement of resilient channels and depth and spacing of joist has some effect on the airborne sound insulation behaviour, but it is not as significant as the effect of having ceiling boards separated from the joists.
5. A combination of sub-floor with a mass of 20 kg/m^2 and 150 mm thick sound absorbing material with ceiling boards supported on resilient metal channels has been reported to give good airborne sound insulation for timber floors.
6. Thin, heavyweight, and non-rigid layers, or asymmetric construction (d_1/d_2 = about 2 in Figure 5.1) options, are suitable for satisfactory acoustic properties.[2]

5.2 Guidance on Improving the Impact Sound Insulation

1. Increasing the mass or separating the ceiling from the floor joists can improve impact sound insulation of timber floors.
2. Good impact sound insulation can be achieved for floors constructed with a sub-floor layer (e.g. particleboard, gypsum board), separated ceiling using resilient channels and sound absorbing material in the floor cavity. The requirements for the density of floor boards and insulation material are same as that for airborne sound insulation.
3. A floor with a mass of at least 200 kg/m^3 has been reported to have adequate impact sound insulation. However, mass alone may not be sufficient and attention also needs to be given to the floor finish and ceiling treatment.
4. Providing soft floor topping can reduce high frequency impact sound transmission. Hard floor toppings such as concrete, marble, tile and hardwood lead to problems with high frequency impact noise. If a hard floor topping is unavoidable, a floating floor on a resilient layer should be used.
5. A top floor layer should be installed with a resilient under layer and should not be screwed directly to the timber joist (Figure 5.2) or in direct connection with walls or columns. Place a resilient under layer between the floor covering and any walls or columns.
6. The addition of transverse stiffeners can improve the high frequency impact insulation of the floor but reducing the joist spacing may not always improve this.

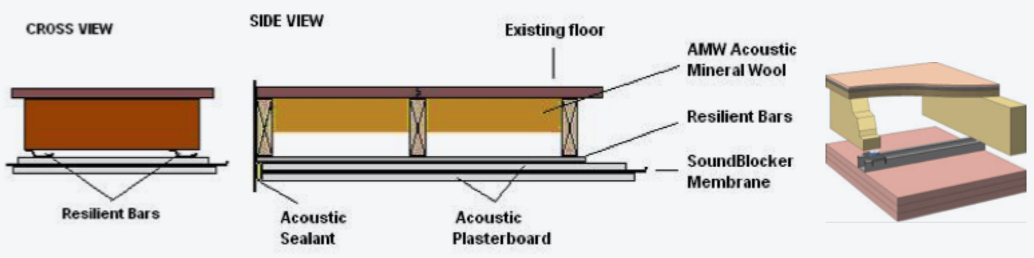

Figure 5.2: Acoustic improvement methods.

Appendix A: Worked Example – 8.5 m Timber Floor Span

In this section, the serviceability and ultimate capacities of a timber cassette floor are calculated in accordance with this Guide. As shown in Figure A1.1, LVL 11 was used for the timber cassette floor. The different stages of calculations are summarised in the following sections.

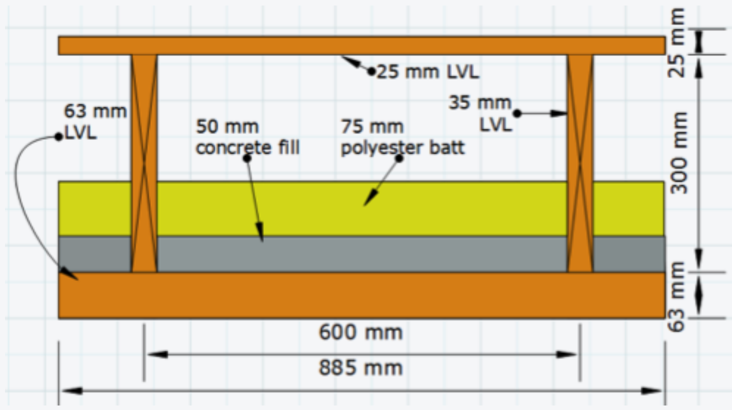

Figure A1.1: Dimensions of 8.5 m timber modules.

A1.1 Material Properties

Material Properties of the timber module based on manufacturer's data are:

- Timber type — LVL 11
- Timber modulus — $E_t = 11000$ MPa
- Timber density — $\rho = 620$ kg/m^3
- Timber bending strength — $f'_b = 38$ MPa
- Timber compression strength — $f'_c = 38$ MPa
- Timber tensile strength — $f'_t = 26$ MPa
- Timber shear strength — $f'_s = 5.3$ MPa

A1.2 Section Properties

$$b_{f.t} \leq \mathrm{Min}\begin{cases} b_w + 0.1 \times span \\ b_w + 20 \times h_{f.t} \end{cases}$$ for bottom flange

$b_{f.t}$ = minimum of (35+0.1 x 8500) and (35+20 x 25) = 885 mm (width of the bottom flange)

b_w = 35 mm (thickness of the web)

$h_{f.t}$ = 63 mm (height of the bottom flange)

$b_{f.c} \leq$ (b_w+0.1 x *span*) for top flange

$b_{f.c}$ = 35+0.1 x 8500 = 885 mm (width of the top flange)

Neutral axis (from bottom to centroid):

y_c = 147.85 mm

A_c = 37175 mm^2

A_t = 61635 mm^2

The calculation of moment of inertia of the timber floor section is given in Table A1.1.
The equivalent section of timber floor is used for the calculation as shown in Figure A1.2.

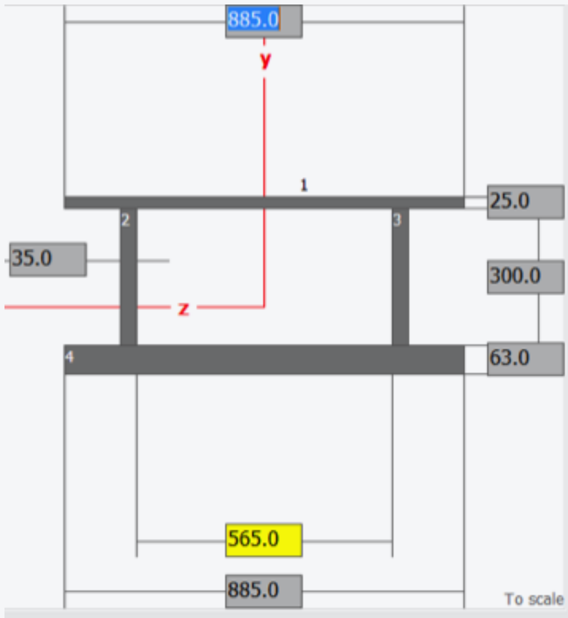

Figure A1.2: Equivalent section of timber floor (mm).

	$I = 1/12bh^3$ (mm^4)	A (mm^2)	d (mm)	$I+Ad^2$ (mm^4)
Top Flange	1152343.75	22125	228.5	1156348375
Webs	157500000	21000	66	248976000
Bottom Flange	18440966.25	55755	115.5	762226605
I_{tot}				2167550980

Table A1.1: Calculation of second moment of area for the timber floor.

where d is the distance between centroid of each component and the whole section.

$I_{ef} = \Sigma\ (I+Ad^2) = 21.68 \times 10^8$ mm^4

Section Modulus (top): $Z_{top} = 8.99 \times 10^6$ mm^3

Section Modulus (bottom): $Z_{bot} = 14.74 \times 10^6$ mm^3

$EI_{ef} = 23.84 \times 10^{12}$ N.mm^2

A1.3 Action Loads

The loading input is according to AS 1170 and it includes 2.5 kPa permanent action (DL), 3.0 kPa imposed action (LL) and the self-weight:

Super imposed dead load, SDL = 2.5 kPa

Permanent Load (allows concrete topping, services and partitions): 2.5 (kPa)(b_{tf}) = 2.21 kN/m

Self–Weight:

Timber:

$[(b_{tf})(d_{tf}) + 2(b_w)(d_w) + (b_{bf})(d_{bf})] \text{ x}(\rho_{\text{timber}})$

$= [0.885 \text{ x } 0.063+0.885 \text{ x } 0.025 +2 \text{ x } 0.3 \text{ x } 0.035] \text{ x } 620=0.098 \text{ x } 620\text{x}10^{-4}=0.61$ kN/m

Spacing (S) = 0.89 m

Self weight of concrete and insulation is included in the SDL.

Self-weight total = 0.61 kN/m

G = (SDL+ Self-weight/S) G = (0.613/0.885+2.5)0.885 = 2.83 kN/m

Live Load (LL) = 3 kPa

Q=LL(btf) = 3x0.885=2.66 kN/m

$M^* = w^*L^2/8$

$V^* = w^*L/2$

Different combinations and the deflection limit for ultimate limit state design are listed in Table A1.2.

A1.4 Serviceability Checks

The load combinations and the deflection criteria for serviceability check are presented in this Guide.

According to AS 1170 and AS 1720.1, Equations (3-22) and (3-23) must be satisfied to check the serviceability performance of timber modules.

Since the moisture of content of timber module (LVL) is less than 15%, the creep factor, j_2 is equal to 1 and 2 for short-term and long-term serviceability check, respectively (Table 1.3).

To consider the creep deformation of the timber modules, the creep factor is applied for the portion of the serviceability load that is permanently applied. Hence, the minimum required short- and long-term EI_{eff} of timber modules need to be calculated based on Equations (3-24) and (3-25), respectively:

$$EI_{ef} = \frac{300 \times 5(j_2 G + 0.7Q)L^3}{384} = 1.13 \times 10^{13} \text{Nmm}^2$$ short-term EI_{ef} (Equation [3-24])

$$EI_{ef} = \frac{300 \times 5 \times j_2 (G + 0.4Q)L^3}{384} = 1.87 \times 10^{13} \text{Nmm}^2$$ short-term EI_{ef} (Equation [3-25])

Comparing minimum required EI_{ef} (obtained from Equations (3-24) and (3-25) and EI_{ef} of the section (23.8x10^{-13} Nmm^2), the specified section satisfied the minimum EI_{ef} requirement.

Considering the effect of creep factor, the short- and long-term deflections of the 8.5 m LVL modules (Equations [3-24] and [3-25]) are equal to 13.4 mm and 11.1 mm, respectively, which are less than Span/300 (or 28.3 mm) and Span/400 (or 21.3 mm), respectively.

$$\Delta = \frac{5(W^*)L^4}{384(EI_{ef})} = \frac{5(G+0.7Q)L^4}{384(EI_{ef})} = \frac{5(2.83+0.7\times 2.66)8500^4}{384(23.8\times 10^{12})} \le \frac{Span}{300}$$ 13.4 < 28.3 mm OK

$$\Delta = \frac{5(W^*)L^4}{384(EI)_{ef}} = \frac{5(G+0.4Q)L^4}{384(EI)_{ef}} = \frac{5(2.83+0.4\times 2.66)8500^4}{384(23.8\times 10^{12})} \le \frac{Span}{400}$$ 11.1 < 21.3 mm OK

Now consider the short-term deflection check for 1 kN point load – Equation (3-28).

$$\Delta = \frac{PL^3}{48(EI)_{ef}} = \frac{1\times 8500^3}{48\times 1.06\times 10^{13}} \le 2 \text{ mm}$$ 0.54 < 2 mm OK

Short-term deflection check for 1 kN point load) is also equal to 0.54 mm which is smaller than the deflection limit (2 mm).

A1.5 Strength Checks

Characteristic values for structural LVL shall be obtained from the manufacturer. Characteristic values for LVL shall include consideration of the section sizes to which they are intended to apply. Unless otherwise specified by the manufacturer, the characteristic values for LVL for bending and tension shall be modified using Equations specified in Section 8.3 AS 1720.1.

Table A1.2 shows the load combination and the maximum bending and shear force (refer Table 0.2 in body of text). The required modification factors are presented in Table A1.3 and Table A1.4 which are based on AS 1720.1.

Combination	***w* (kNm)***	***M* (kNm)***	***V* (kN)***	***N^*_c (kN)***	***N^*_t (kN)***
1.35G	3.8	34.5	16.2	80.5	185.9
1.2G + (1.5ψ)Q, ψ=0.4	5.0	45.1	21.1	105.1	242
1.2G + 1.5Q	7.4	66.7	31.4	155.5	359.4

Table A1.2: Load combinations and deflection limit for ultimate limit state design.

Force	*Φ*	k_4	k_6	k_9	k_{12}
Tension	0.9	1	1	-	-
Compression	0.9	1	1	-	1
Shear	0.9	1	1	-	-
Bending	0.9	1	1	1	1

Table A1.3: AS 1720.1 modification factors.

Load-Combination	k_1	*Comment*
Permanent	0.57	50+ years
Long-term	0.8	5 months
Short-term	0.97	5 hours
Bending	0.9	1

Table A1.4: k_1 modification factors.

Combination		M_{dtop} (kNm)	M_{dbot} (kNm)	N_{dtop} (kN)	N_{dbot} (kN)
1.35G	1-self-weight & permanent loading (permanent)	175.3	287.3	431.3	1086.9
1.2G + (1.5ψ)Q, $\psi = 0.4$	2-imposed loading (long-term)	246	403.3	605.3	1525.5
1.2G + 1.5Q	3-imposed loading (short-term)	298.2	489	734	1849.6

Table A1 5: Axial and flexural strength values.

All the results of the bending and axial ratios for top and bottom flanges are summarised in Table A1.6 for 8.5 m timber modules.

By substituting the values of material properties and the dimensions of the system into Equations (3-4) to (3-7) and considering the values of Tables A1.2 to A1.4, the bending strength ratio for top and bottom flanges and for permanent, long-term and short-term load combinations are calculated as given in Table A1.6.

Load-Comb.	*Bending: Top Flange*	*Bending: Bottom Flanges*	*Axial: Top Flange*	*Axial: Bottom Flanges*
1-Permanent	0.20 ≤ 1 OK	0.12 ≤ 1 OK	0.19≤ 1 OK	0.17 ≤ 1 OK
2-Long-term	0.18 ≤ 1 OK	0.11 ≤ 1 OK	0.17 ≤ 1 OK	0.16 ≤ 1 OK
3-Short-term	0.22 ≤ 1 OK	0.14 ≤ 1 OK	0.21 ≤ 1 OK	0.19 ≤ 1 OK

Table A1.6: Bending and axial load ratio checks.

By substituting the values of material properties and the dimensions of the system into Equations (3-10) to (3-13) – (the components of Equations (3-10) to (3-13) are precisely described in AS 1720.1) – and considering the values of Tables A1-2 to A1-4, the combined bending and axial strength ratio checks for top and bottom flanges and for permanent, long-term and short-term loading are calculated, as given in Table A1-7.

Load Comb	*Bending and Compression (Eq. 3-10)*	*Bending and Compression (Eq. 3-11)*	*Bending and Tension (Eq. 3-12)*	*Bending and Tension (Eq. 3-13)*
1	0.22 OK	0.38 OK	0.29 OK	0.10 OK
2	0.21 OK	0.36 OK	0.27 OK	0.10 OK
3	0.26 OK	0.43 OK	0.33 OK	0.12 OK

Table A1.7: Combined Bending and axial ratio checks.

The results of the shear stress ratio for top and bottom flanges interfaces are reported in Table A1.5. The Equation (3-14) and Tables A1.2 to A1.4 are used for the shear stress ratio checks. The values of shear stress ratio for permanent, long-term and short-term load combination are less than one.

Load-Combination	V_d **(kN)**	***Max Flexural Shear***
Permanent	179.1	0.09 ≤1 OK
Long-term	251.3	0.08 ≤1 OK
Short-term	304.7	0.10 ≤1 OK

Table A1.8: Shear stress ratio check.

A1.6 Dynamic Performance Check

For the dynamic performance of the LVL modules, the first natural frequency of the system is calculated according to Equation (3-29):

$$f_1 = \frac{\pi}{2l^2}\left(\frac{EI_{ef}}{m}\right)^{0.5} = \frac{\pi}{2(8.5)^2}\left(\frac{10603.25}{0.267}\right) = 4.33 \text{ Hz}$$

The first natural frequency of the system is about 4.33 Hz which is in the safe frequency zone.

Appendix B: Notation

B

Symbols and letters used in the Guide are listed below:

A	cross-sectional area of the entire section
$A_{f.c}$	cross-sectional area of the top (compressive) flange
$A_{f.t}$	cross-sectional area of the bottom (tension) flange
A_s	shear area of the web = 2/3 $b_w\, h_w$
A_w	cross-sectional area of the web
A_p	bearing area
$b_{f.t}$	width of the bottom (tension) flange
b_w	width (thickness) of the web
d	total depth of the timber cross section
h	overall depth of floor
h_c	distance from the centroid to the top of the top flange
h_t	distance from the centroid to the bottom of the bottom flange
h_w	depth of the web
$h_{f.t}$	height of the bottom (tension) flange
$h_{centroid}$	distance from the bottom of the bottom flange to the centroid = $h_{f.t}$
I	second moment of inertia of the composite section
Z_{top}	section modulus above the centroid (top flange)
Z_{bot}	section modulus below the centroid (bottom flange)
E	value of the modulus of elasticity of the timber members
f_1	fundamental frequency of the floor modules
f'_b	characteristic strength in bending
f'_c	characteristic strength in compression
f'_s	characteristic strength in shear
$f'_{s,glue}$	characteristic shear strength of the adhesive
f'_t	characteristic strength in tension
j_2	stiffness modification factor – load duration specified in AS 1720.1
k_1	duration of load (timber) specified in AS 1720.1
k_4	moisture condition (timber) specified in AS 1720.1
k_6	temperature (timber) specified in AS 1720.1
k_7	length and position of bearing (timber) specified in AS 1720.1
k_9	strength sharing between parallel members specified in AS 1720.1

k_{11}	size factor (timber) – this is normally applied to the characteristic strength property by the manufacturer
k_{12}	stability factor (timber) specified in AS 1720.1
m	mass per unit area
M^*	moment action resulting from applied loads
M_{d_top}	design moment capacity – top flange
M_{d_bot}	design moment capacity – bottom flange
N^*_c	axial force (compression) induced in top flange from bending
N^*_t	axial force (tension) induced in bottom flange from bending
N_{d_top}	design axial capacity (compression) – top flange
N_{d_bot}	design axial capacity (tension) – bottom flange
Q_{top}	first moment of shear area for top flange
Q_{bot}	first moment of shear area for bottom flange
q_{top}	shear flow at interface between web and top flange
q_{bot}	shear flow at interface between web and bottom flange
V^*	maximum shear effect
V_d	design shear capacity of the web
Φ	capacity factor

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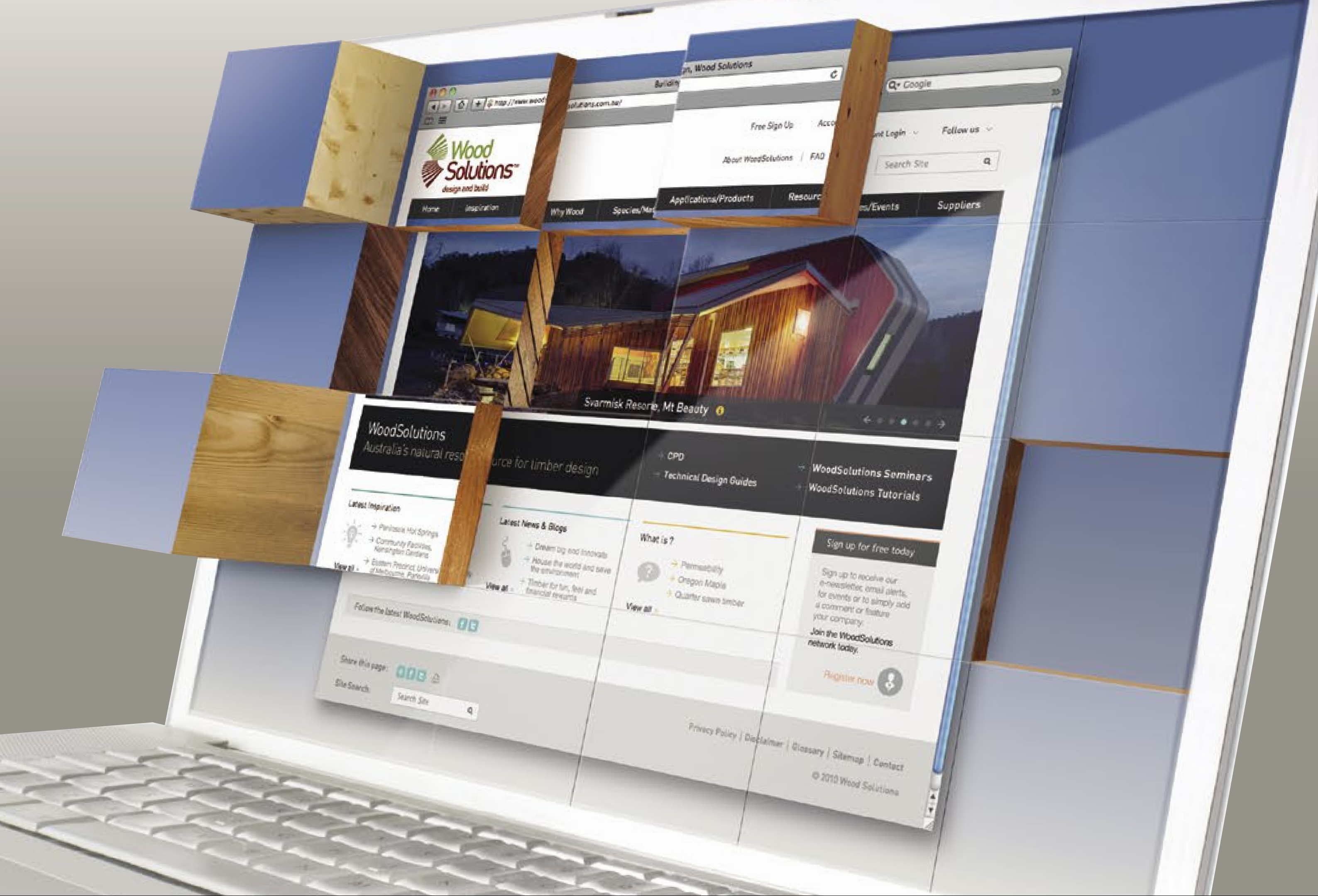

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