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FLOOR AND ROOF CASSETTE SYSTEMS

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Wood Processors & Manufacturers
Association of New Zealand

NZ Wood Design Guides

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Each title has been written by experts in the field and is the accumulated result of years of experience in working with wood and wood products.

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- Designing for Prefabrication
- Cassette Panels for Floors, Roofs and Walls
- Standard Connection Details
- Acoustical Design and Detailing
- Fire Safety Design in Timber Buildings

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NZ Wood Design Guides is a Wood Processors and Manufacturers (WPMA) initiative designed to provide independent, non-proprietary information about timber and wood products to professionals and companies involved in building design and construction.

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1. Introduction

Traditionally buildings are constructed in their intended location. More recently it has become popular to prefabricate all or parts of a building off site. There are disadvantages to building on site, like inclement weather and limitations on machinery available. There are efficiencies that can be gained by prefabricating some of the building elements or even the entire building off site, in a factory environment. There are also disadvantages and limitations to prefabrication that ought to be considered. The most obvious ones are transportation and lifting.

Cassettes panels are a built up element than can be prefabricated off site to speed up on-site construction time, improve site safety and utilise materials more efficiently.

The advantage this system has over a solid floor panel is that most of the wood fibre is located at the extreme tension/compression regions to get maximal contribution to the panels stiffness and strength. Conversely a minimal amount of material is used around the neutral axis where it makes little contribution to the overall stiffness and strength of the panel.

Example of a boxed flooring cassette panel.

About the Author

Gavin Robertson BE, CPEng, MIPENZ.

Gavin has been a structural engineer in his own practice since 2002 and owner of Potius Building Systems Ltd, which develops and manufactures stressed skin panels and more recently expanded its operation to produce roof and wall panels. While having a broad understanding of steel and concrete, Gavin has a deeper knowledge of timber structures, particularly engineered wood structures using LVL and CLT. Gavin has recently been on the design team for high profile timber buildings including the NMIT Arts and Media building, the Kaikoura District Council Civic Building, the Nelson Boy's College's teaching block and the Plant and Food Research building at Port Nelson. He has also developed a building system over the last few years to provide low cost social housing for Housing New Zealand.

2. Floor Panels

2.1. Floor Cassette

A floor cassette is typically made up of a top skin, web(s) and a bottom skin or flange (refer Figure 1). Assuming the three elements are suitably connected then they form an composite 'I' section. Alternatively the bottom skin can be left off resulting in a "T" section instead.

The top skin will act as a flooring surface spanning between webs, perpendicular to the main span. It may have a wearing surface, flooring or the like over the top. Where the skin is structurally connected to the web, it will also act as a flange to stiffen/strengthen the cassette in the direction of the main span. The bottom skin, where present, will act as a the bottom flange. A cassette traditionally has a bottom flange but it is not essential (It can be more economic to build a slightly deeper "T" section). Assuming the elements are structurally connected the web will truly be a web.

If there is no shear connection between the elements then, from a structural perspective, the web would more accurately be described as a joist.

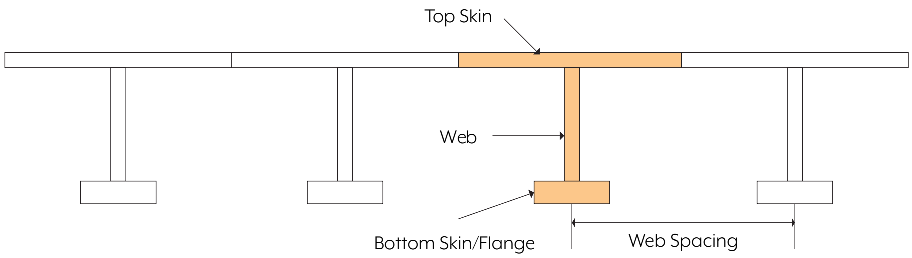


Figure 1: Typical Floor Cassette

2.2. Materials

The designer can select from a large variety of materials for the flooring, skins and webs when they design their panel. Some of the most common options are as follows;

2.2.1. Top skin/flooring

- Partical board
- Strandboard
- Plywood
- Fibre Cement Board
- Concrete (Refer to EXPAN Timber Concrete Composite (TCC) Floor Design Guide)

2.2.2. Web

- Solid Wood
- Laminated Veneer Lumber (LVL)
- Composite Joists such as 'I' joists
- Truss type assemblies including Posistrut connectors.
- Strandboard

2.2.3. Bottom Skin

- Particalboard
- Strandboard
- Plywood
- LVL

2.3. Performance requirements

A floor cassette has a number of performance requirement considerations. These can include strength, diaphram strength, stiffness , acoustic performance, fire separation, appearance and durability.

AS/NZS1170:2002 prescribes most of the structural performance requirements.

2.4. Design

A cassette can be designed as a composite 'I' or 'T' section or simply as a conventional prefabricated assembly of joists and flooring. A composite floor cassette will be utilising materials most efficiently as a composite 'I' or 'T' section. The advantage of a composite system over a non-composite assembly of flooring on top of jist is that the flooring is contributing to the stuffiness of the joist was well as spanning between them.

There are however situations where there is no advantage in providing full composite action. For these situations the designer can refer to NZS3604:2011 or design tables from Engineered Wood Product Manufacturers to select a suitable joist.

2.4.1. Panel Properties

Effective Width

Due to shear lag the designer must first determine the effective width of the skins or flanges before the strength or stiffness of the panel can be calculated. In reality the stresses in the unsupported area of the skins (or flanges) are not uniformly distributed. Rather than deal with the complicated stress distribution acting on the actual width of skin/flange an equivalent width upon which a constant maximum stress acts is used.

The effective width of a flange or skin can be determined as the minimum of;

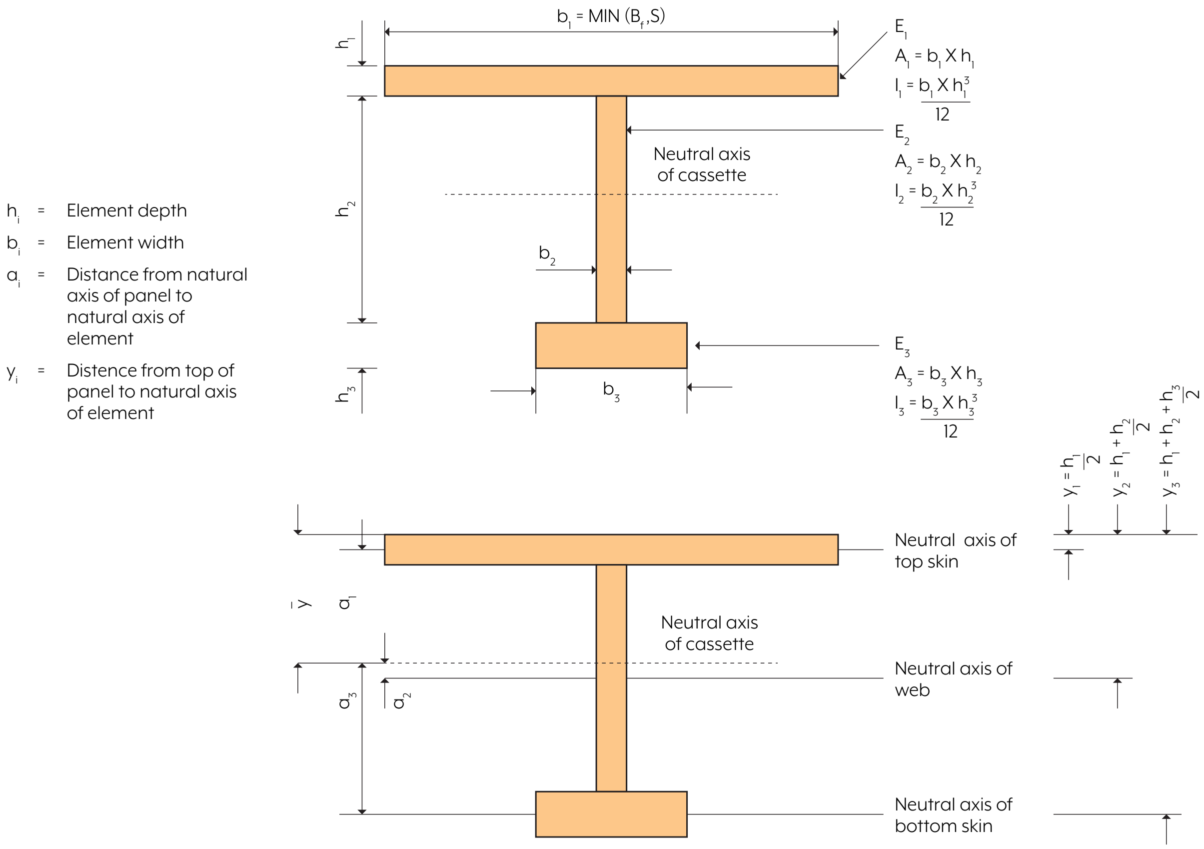


Figure 2. Panel geometry and terms

s = The web/joist spacing (mm)

For flanges in tension the effective width b_1 equals the lesser of;

$b1 = b_{t,ef} + b_2$ or S

For flanges in compression the effective width is the lesser of;

$b_i = b_{c,ef} + b_2$ or S

B_2 is the web thickness

$b_{t,ef}$ and $b_{c,ef}$ can be obtained from the table 9.1 in Eurocode 5

For $b_{c,ef}$ use the minimum value for shear lag or plate buckling

For $b_{t,ef}$ use the value for shear lag

Some of the values from Table 9.1 in Eurocode 5 are given in the following Table (Note that the notation in Eurocode is different)

Table 1. Extract from Table 9.1 in Eurocode 5.

Flange Material	Shear Lag	Plate Buckling
Plywood with grain oriented parallel to webs	0.1L	25dn
Plywood with grain oriented perpendicular to webs	0.1L	25dn
Particleboard with random fibre orientation	0.2L	30dn

L = panel span and dn = depth of element being considered (d_1 for top skin and d_3 for bottom skin).

Panel Stiffness

The cassette panel stiffness must be determined in order to check the deflection under Servicability Limit State (SLS) loading. This value can be used in the usual deflection equations for distributed and/or point loads.

Panel Flexural Stiffness – Rigid Connection.

A rigid connection will be achieved by an elastomeric glue bond between the elements. Typically this would be polyurethane (PU) or phenolic type adhesives. Flexural stiffness of a cassette that has a rigid connection between the elements can be determined using the Transformed section method whereby;

$$(EI)_{eff} = \sum_{(n=1,2,3)} (E_i I_i + E_i A_i a_i^2)$$

Where;

E_i is the Modulus of Elasticity of element (MPa)

I_i is the Moment of element (mm^4)

A_i is the area of element (mm^2)

a_2 is equal to $\dfrac{E_1 A_1 (h_1+h_2) - E_3 A_3 (h_2+h_3)}{2 \sum_{n=1,2,3} (A_i E_i)}$

a_1 is equal to $\dfrac{h_1+h_2}{2} - a_2$

a_3 is equal to $\dfrac{h_3+h_2}{2} + a_2$

Note: The distance from the top of the cassette to the neutral axis of the cassette can be determined by the equation;

Where;

$$\bar{y} = \frac{\sum_{n=1,2,3}(E_i A_i x_i)}{\sum_{n=1,2,3}(E_i A_i)}$$

x_i is the distance from the top of the cassette to the neutral axis of element i.

Panel Flexural Stiffness – Flexible Connection.

A flexible connection will be achieved by an mechanical connections like between the elements. Typically this would be nails. Flexural stiffness of a cassette that has a flexible connection between the elements can be determined using the Transformed section method whereby;

$$(EI)_{eff} = \sum_{(n=1,2,3)} (E_i I_i + \gamma_i E_i A_i a_i^2)$$

Where;

E_i, I_i and A_i as defined previously.

γ_i is equal to $[\,1 + \pi^2 E_i A_i s_i / (K_i l^2)\,]^{-1}$ for i = 1 and i = 3

s_i is equal to fastener spacing for i=1 (top skin to web fasteners) and i=3 (bottom skin to web fasteners)

K_i = $K_{ser,i}$ for SLS calculations = $\dfrac{\rho_m^{\,1.5}\, d^{0.8}}{30}$ for nails without predrilled holes.

K_i = K_{ui} for ULS calculations = $\frac{3}{2} K_{ser,i}$

ρ_m is the density of the wood.

d is the fastener diameter.

γ_2 is equal to 1

a^2 is equal to $\dfrac{\gamma_1 E_1 A_1 (h_1+h_2) - \gamma_3 E_3 A_3 (h_2+h_3)}{2\sum_{n=1,2,3}(\gamma_i E_i A_i)}$

a_1 is equal to $\dfrac{h_1+h_2 - a_2}{2}$

a_3 is equal to $\dfrac{h_3+h_2+a_2}{2}$

2.4.2. Design Actions

The conventional design method of determining the Shear Force and Bending Moment capacity of the floor unit and ensuring this is less than the applied design actions does not apply for cassette floor panels. For cassette floors the design Bending Moment and Axial compression/tension on each element from which the panel is fabricated is derived from the design actions on the floor.

A moment applied to a cassette will result in a moment and axial action on the top skin, web and bottom skin of the cassette. The design actions applied to the different elements will depend on the type of connection between the elements.

The designer should then check the design actions on each element do not exceed the capacity of that element.

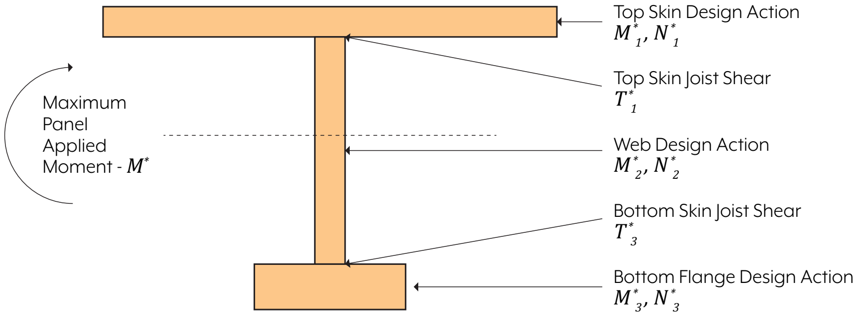


Figure 3. Panel component design actions

Design Actions – Rigid Connection

The design action on each element of a floor cassette with rigid connections between the elements can be determined by the following equations;

$$N_1^* = \frac{E_i A_i a_i}{(EI)_{eff}} M^*$$

$$M_1^* = \frac{E_i I_i}{(EI)_{eff}} M^*$$

E_i is the Modulus of Elasticity of element i (MPa)

I_i is the Moment of element i (mm^4)

A_i is the area of element i (mm^2)

a_2 is equal to $\dfrac{E_1 A_1 (h_1+h_2) - E_3 A_3 (h_2+h_3)}{2\sum\limits_{n=1,2,3}(E_i A_i)}$

a_1 is equal to $\dfrac{h_1+h_2}{2} - a_2$

a_3 is equal to $\dfrac{h_3+h_2}{2} + a_2$

Design Actions – Flexible Connection

The design action on each element of a floor cassette with flexible connections between the elements can be determined by the following equations;

$$N_i^* = \frac{\gamma_i E_i A_i a_i}{(EI)_{eff}} M^*$$

$$M_i^* = \frac{\gamma_i E_i I_i}{(EI)_{eff}} M^*$$

E_i, I_i and A_i as defined above.

γ_i is equal to $[1+\pi^2 A_i s_i / (K_i l_2)]^{-1}$ for i=1 and i=3

s_i is equal to fastener spacing for i=1 (top skin to web fasteners) and i=3 (bottom skin to web fasteners)

$K_i = K_{ser,i}$ for SLS calculations = $\dfrac{\rho_m^{1.5} d^{0.8}}{30}$ for nails without predrilled holes.

ρ_m is the density of the wood.

d is the fastener diameter.

$K_i = K_{u,i}$ for ULS calculations = $\dfrac{3}{2} K_{ser,i}$

γ_2 is equal to 1

a_2 is equal to $\dfrac{\gamma_1 E_1 A_1 (h_1+h_2) - \gamma_3 E_3 A_3 (h_2+h_3)}{2\sum\limits_{n=1,2,3} (\gamma_i E_i A_i)}$

a_1 is equal to $\dfrac{h_1+h_2 - a_2}{2}$

a_3 is equal to $\dfrac{h_3+h_2+a_2}{2}$

2.4.3 Shear Stress Between Elements

The shear stress in a web between cassette members is a function of the vertical shear stress acting on the beam. For a simply supported cassette supporting a uniformly distributed load the maximum vertical stress will occur at the supports and there will be zero shear force at the midspan. The maximum shear stress in the connection will also occur at the support and be zero at the midspan. The relationship between the two will depend on the type of connection.

Connection Design – Rigid Connection

For cassettes with a rigid connection between members the shear stress in the connection can determined from the equation;

$$\tau_x = \frac{E_i A_i a_i}{(EI)_{eff}\, b_2} V_x$$

Where;

i = 1 for top skin/web connection, i = 3 for bottom skin/web connection.

τ_x is the Shear stress in the connection at location x along the panel.

V_x is the Shear force acting on the cassette at location x along the panel.

The maximum shear stress in the connection τ^* will coincide with the maximum shear force acting on the panel V^*.

The designer must check that the capacity of the glue and the wood fibre exceeds this shear stress. Note that particular attention should be given to rolling shear in the ply.

$\tau^* \leq \varnothing k_1 k_{14} k_{15} k_{17} f_{sh}$

Refer to NZS3603 and/or manufacturers specifications for values above. Note that for rolling shear k_{17} should be taken as 0.5 and f_{sh} should be the characteristic rolling shear capacity stress (Refer table 6.1, NZS3603, for ply).

Also check the web shear capacity

$\tau^* \leq k_1 k_{14} f_s$

The designer must also ensure the glue joint is adequate. This is likely to require physical testing of the glued joint. Refer to appendix B in NZS 1170.0:2002.

Connection Design – Flexible connection

For cassettes with a flexible connection between members the shear stress in the connection can determined from the equation;

$$S_x^* = \frac{\gamma_i E_i A_i a_i s}{(EI)_{eff}\, b_2} V_x$$

Where

i=1 for top skin/web connection, i=3 for bottom skin/web connection.

S_x^* is the Shear force in the connector at location x along the panel.

V_x is the Shear force acting on the cassette at location x along the panel.

Other parameters are defined above.

The maximum shear force in the connector S_x^* will coincide with the maximum shear force acting on the panel V_x. For a simply supported cassette supporting a uniformly distributed load the maximum shear force will occur at the supports and will reduce linearly to zero and the midspan of the cassette. To optimise the design the spacing of the fasteners can therefore be adjusted accordingly, increasing the spacing as the shear force is reduced. Alternatively the designer can set a constant nail spacing and assume that there will be adequate slip in the nails to redistribute the shear between the fasteners. This approach seems reasonable for a nailed connection but is not recommended with a screwed connection. A screwed connection is more likely to “unzip” with successive screw failures.

2.5 Dynamic Performance

The design of cassette floors are often governed by dynamic performance. This is a subjective phenomena relating to how bouncy a floor feels or how much it vibrates.

There are several methods of assessing the performance of cassette panel. The following methods can be adopted by the designer in order of complexity (least to most complex).

- AS/NZS1170 Table C1 requires a floor deflection to be no more than 1-2mm under a point load of 1kN applied at the midspan of the panel.

$$\Delta = \frac{1000 \times L^3}{48(EI)_{eff}} \leq 1 \text{ to } 2mm$$

- Some designers prefer to set the maximum deflection under a 1kN point load to;

$$\Delta = \frac{1000 \times L^3}{48(EI)_{eff}} \leq \frac{2.55}{L^{0.63}}$$

- People are more sensitive to lover frequency vibration. A floor that has a resonant frequency greater that 8Hz will generally be acceptable. The frequency of a floor can be calculated by the following formula.

$$f = \frac{\pi}{2L^2}\left(\frac{(EI)_{eff}}{M}\right)^{0.5} > 8Hz$$

Where

f is the Frequency (Hz)

M is the mass per unit length of the cross section being considered (kg/m). The mass should include the self-weight of the cassette and any superimposed dead load. It may also be appropriate to include a percentage of the live load where the designer considers it reasonable to do so.

Note the units in this equation should be L (m), $(EI)_{eff}$ (Nm^2),

There are more sophisticated computer modelling techniques that are outside the scope of this guide. Particular care need to be taken when floor cassettes are supported on beams and the liveliness will depend of the properties of the overall system.

'T' panel configuration used for a residential floor in Nelson.

'T' panels in an educational building. In this case the webs are sized to provide fire rating.

3. Roof Panels

3.1. Roof Cassettes

A roof cassette geometry will be similar to a floor cassette. It will usually include a top skin and webs and may or may not have a bottom skin. Because the roof cassette is usually part of the building envelope there will be extra considerations. These are discussed below.

3.2. Materials

Material selections will be similar to those described in section 2.2 above noting that the designer needs to be mindful of durability requirements. Insulation may need to be incorporated into a roof panel as well.

3.3. Performance requirements

The structural performance requirements for a roof cassette are largely the same as a floor cassette. There will be additional load combinations to consider involving wind and snow design actions. There will usually be no need to consider the dynamic performance of a roof cassette and there will be additional non-structural requirements to consider because the panel will be part of the building envelope.

3.4. Thermal Performance, Treatment and Ventilation

Roof cassettes may have to incorporate insulation to achieve New Zealand Building Code compliance. This has the potential to create moisture issues due to condensation. The designer need to carefully consider where condensation may occur and how to prevent any adverse effects. This will usually be achieved by providing adequate ventilation

An increased risk of moisture within the roof cassette can sometimes necessitate increased treatment requirements.

4. Fire Performance

In non-residential applications a midfloor will be required to act as a fire separation. Fire rating can be achieved by timber charring or by a fire rated ceiling system protecting the underside of the panels. The fire resistance achieved by charring can be determined by calculation in accordance with NZS3603:1993. Special consideration needs to be given to firestopping joints and penetrations.

5. Acoustic Performance

A lightweight timber cassette will not typically provide adequate acoustic separation between floors. Acoustic performance is usually improved by introducing mass to the system. Also the transmission of sound vibration is reduced by separating ceiling and flooring linings with resilient connectors. The acoustic performance can be improved in by the following methods;

- Suspended acoustic ceiling. There are proprietary ceiling systems on the market that can be suspended from a cassette panel. They will include a dense lining, resilient clips and an acoustic blanket.
- Floating floor. A dense flooring layer on framing with cushioning to separate it from the cassette panel. For example the Batten and Cradle® floor system is one that is available on the New Zealand Market.
- Concrete topping. A concrete screed on top of the floor panel.

Foot fall noise transition can also be reduced by soft floor coverings

6. Sample Floor Span Tables

The span tables below show the maximum span for a 'T' type panel and 'I' type panel. The 'T' type panel has a 25mm plywood top skin with the face grain perpendicular to the webs, no bottom skin and a 45mm LVL13 web, of varying depth, at 600mm spacing. The 'I' has a 25mm plywood top skin with the face grain perpendicular to the webs, a 45mm LVL11 continuous bottom skin and a 45mm LVL13 web, of varying depth, at 600mm spacing. In all cases the design is limited by the dynamic criteria. In this instance the 1 kN point load dynamic calculation has been used.

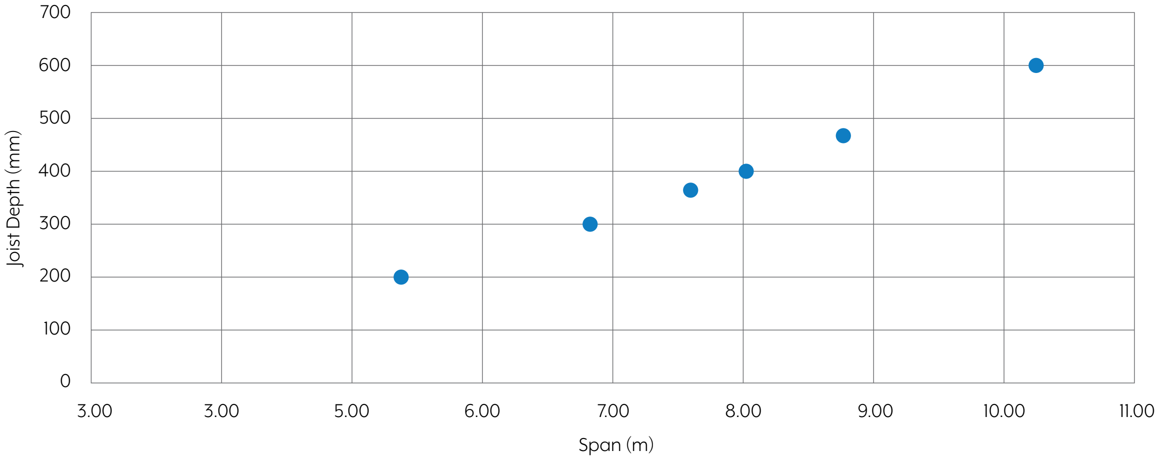


Figure 4. Span table for 'I' panel confuguration

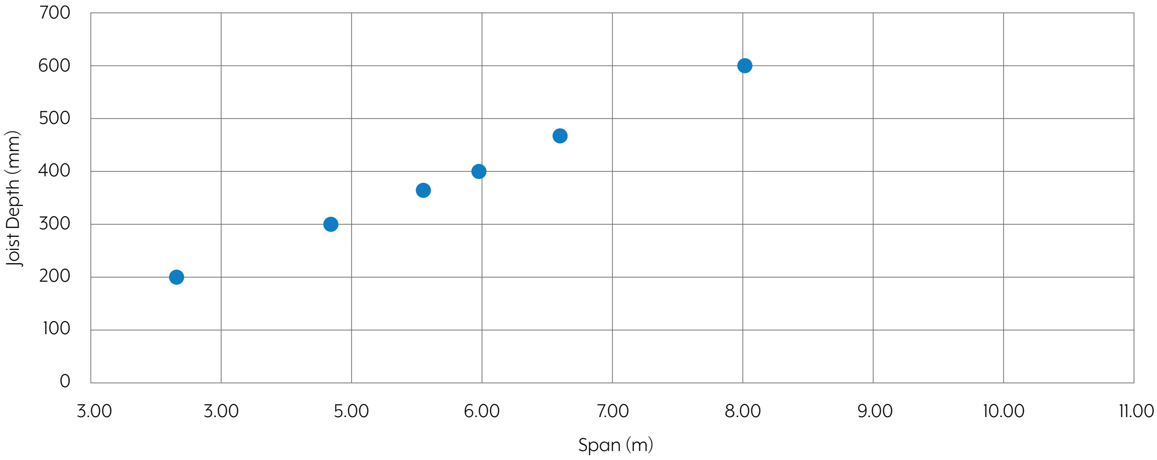


Figure 5. Span table for 'T' panel confuguration

7. Shop Drawing and Fabrication

Much like structural steel or precast concrete, prefabricated cassettes will need shop drawings. This is a critical stage in ensuring a successful erection process. The designer or detailer needs to consider the installation sequence, construction tolerances and potential conflicts with other elements. They may also need to be aware of panel handling and transport limitations (discussed below).

In practice, the total size of something will be greater than the sum of it's parts. In other words a cassette fabricated with 25mm ply on a 400mm joist and a 45mm bottom flange will probably end up being 472mm deep. In some situations this phenomena has no practical consequences; like a three story building with floors all stacked on top of walls. The building would simply be a few millimetres higher than designed. In other situations it can be quite problematic; if there was a full height column introduced to the same three story building then the walls would end up slightly higher than the top of the column, as an example.

The detailer also needs to consider how panels will be manoeuvred into position. There may be multiple column penetrations that make it impossible to manoeuvre a panel into possition

The following photo shows a roof panel, fabricated by Potius Building Systems Ltd, being lowered into position. The panel needed enough of a gap to be able to slot between the adjacent panel and the polystyrene block/reinforced concrete wall. It had 1.5 degree falls built into the panel, as there was a membrane roof being applied over the top. There is also a hip built into the panel that needed to line up within one millimetre to the hip on the adjacent panel. The panel therefore had to be drawn and built accurately to +/-1mm but with sufficient gaps to allow for installation and wriggle room on site.

Potius Building Systems roof panel being installed

8. Transport

Consideration must be given to the logistics of transporting the cassettes from where they are fabricated to the building site. There is a limit to how high a load can be on public roads. If the load is over certain width limits a pilot vehicle may be required, which can add considerable cost.

The designer should also consider the geometry of the panels in terms of how efficiently they can be loaded on a truck to minimise the amount of air being transported.

It is critical that the panels can be stacked for transport so as not to be damaged. Tiedown and bumps in the road can induce loads that the panels may not have been designed for causing damage to the panels in transit.

Potius floor panels in place. CLT walls layed out ready to be lifted into position. (Kaikoura District Council Building)

Packs of panels lifted onto beams before being unstacked and placed into final positions, minimising cranage time. (NMIT Arts and Media Building)

9. On Site Storage

If cassettes are not handled and stored carefully then the wood products can deteriorate rapidly. In an ideal world they would be stored indoors until they are installed and then enclosed as soon as they are installed. This is not usually practical and so specifiers need to prescribe methodologies to insure damage does not occur. The panels pictured in Figure 6 were stored on site, under cover, for approximately 9 months due to construction delays, moisture escaped under the wrap and was then trapped causing the LVL to swell and split, facilitating mould growth on the surface of the LVL.

Figure 6. Panels damaged by prolonged exposure to moisture in storage.

10. Quality Control and Testing

The designer, manufacturer and/or specifier of cassette panels need to be confident that the panels will perform for the contractor and throughout the life of the building. The need for fabrication accuracy is discussed already in section 7.

Particular care is need where adhesives are being relied on for composite action. Systems need to be in place to ensure the glue bond will always be achieved. The exact procedure will depend on the materials and the type of adhesive being specified but will generally include;

- Surface preparation.
- Glue mixing.
- Temperature and humidity.
- Substrate moisture content.
- Pressure on glue joint during curing.
- Glue cure time.

11. Proprietary Systems

Existing cassette manufacturers and/or systems include (known at the time of publishing);

Concision

Based in Christchurch, Concision manufactures wall, floor and roof assemblies. Refer http://concision.co.nz/

Potius Building Systems

Potius Building Systems Ltd is a Nelson based facility that produces roof, wall and floor cassettes for residential and commercial construction. Refer https://www.potius.co.nz/

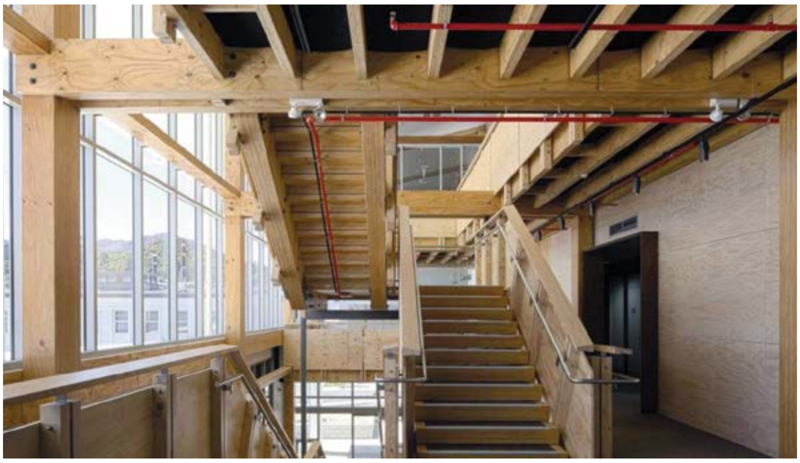
Pryda Cassette Systems

Prefabrication plants may be able to produce custom cassette panels on demand.

Mitek Cassette Systems.

Mitek has pubished a guide for the fabrication of PosiStrut Floor Cassettes.

Potius box panels seated on a corbel on the face of a beam system. (Kaikoura District Council Building)



'T' panels with a concrete screed provide a fire rated floor system. Panels are flange hung on primary beams . (NMIT Arts and Media Building)

12. Worked Examples - Member Capacities

1. Design Requirements

Panel Span (L) = 5.0m

Assumed Self Weight (G) = 0.3 kPa

Live Load (Q) = 3.0 kPa

2. Panel Load Combinations

Assume webs at 600m centres therefore determining UDL on 600 mm strip

2.1. ULS Loads

[1.35 G] s = [1.35 (0.3)] 0.6 = 0.2 kN/m

[1.2G + 1.5Q] s = [1.2 (0.3) + 1.5 (3.0)] 0.6 = 2.92 kN/m

Max ULS load = 2.92 kN/m

2.2. SLS Loads

Long term $[G+U_L Q]\ k_2\ S = [0.3 + 0.4\ (3.0)]\ 2.0\ (0.6) = 1.8\ kN/m$

K_2 = 2.0

Short term $[G + U_s Q]\ K_2 S = [0.3 + 0.7\ (3.0)]\ 1.0\ (0.6) = 1.4\ kN/m$

K_2 = 1.0

Max SLS Load = 1.8 kNm

3. Panel Properties

Assume:

- 20mm strandboard top flange
- 240 x 45 LVL8 web @ bottom 600m centers
- 45 x 140 LVL13 bottom flange @ 600m centers
- Assume ridgid connection

3.1 Effective width top flange – b_1

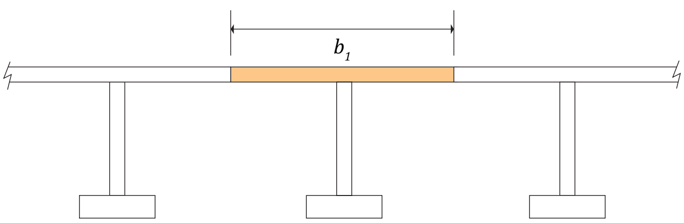
b_1 = minimum of S & $b_{c,ef} + b_2$

S = 600mm

$b_{c,ef}$ = minimum of 0.1 (L) & 25 (h_1)

L = 5000mm (span)

h_1 = 20mm (strandboard thickness)



0.1 (L) = 0.1 (5000) = 500mm }Min 500mm

25 (h_1) = 25 (20) = 500mm }Min 500mm

» $b_{c,ef}$ = 500mm = 45 = 545mm

So b_1 + 545mm

3.2 Element Properties

3.2.1 Element 1 – top flange

h_1 = 20mm b_1 = 545mm

A_1 = 10900mm2

E_1 = 4500 MPa

$I_1 = \frac{b_1 h_1^3}{12} = 0.36 \times 10^6\ mn^4$

$a_1 = \frac{(h_1+h_2)}{2} + a_2$ Refere 3.2.2 for a_2 definition

$= \frac{(20 + 240)}{2} - (-25) = 155mm$

3.2.2 Element 2 – web

h_2 = 240mm b_2 = 45mm

A_2 = 10800mm^2

E_2 = 8000 MPa

$I_2 = \frac{b_2 h_2^3}{12}$ = 51.8 x 10^{6}mm^4

$$a_2 = \frac{E_1 A_1 (h_1+h_2) - E_3 A_3 (h_2+h_3)}{2\sum_{n=1,2,3} (E_i A_i)}$$

$$= \frac{4500\ (10900)\ (20+240) - 13200\ (6300)\ (240 + 45)}{2\left[4500(10900) + 8000\ (10800) + 13200\ (6300)\right]}$$

$= -25$

3.2.3 Element 3 – bottom flange

h_3 = 45mm b_3 = 140mm

A_3 = 6300mm^2

E_3 = 13200 MPa

$I_3 = \frac{140\ (45)^3}{12}$ = 1.1 x 10.6 mm^4

$a_3 = \frac{(h_3 + h_2)}{2} + a_2 = \frac{(45+240)}{2} + (-25)$

= 117mm

3.2.4 Effective stiffness – panel

$(E1)_{eff} = \sum_{N=1,2,3} (E_i I_i + E_i A_i a_i^2)$

$= 4500\ (0.36 \times 10^6) + 4500\ (10900)\ (155)^2$

$+ 8000\ (51.8 \times 10^6) + 8000\ (10800)\ (-25)^2$

$+ 13200\ (1.1 \times 10^6) + 13200\ (6300)\ (117)^2$

$= 2.81 \times 10^{12}$ Nmm^2

4. Design Actions – Panel Actions

$$M^*_{panel} = \frac{WL^2}{8} = \frac{2.92\,(5000)^2}{8} = 9.1 \times 10^6 \text{ Nmm}$$

$$V^*_{panel} = \frac{WL}{2} = \frac{2.92\,(5000)}{2} = 7300\text{N}$$

4.1 Design Actions – Top Skin

$$N^*_1 = \frac{E_1 A_1 a_1 M^*_{Panel}}{(EI)_{eff}} = \frac{4500\,(10900)\,(155)\,(9.1 \times 10^6)}{2.81 \times 10^{12}}$$

$= 2.4 \times 10^4$ N Check $\leq ØN_c$ for strandboard

$$M^*_1 = \frac{E_1 I_1 M^*_{Panel}}{(EI)_{eff}} = \frac{4500\,(10900)\,(155)\,(9.1 \times 10^6)}{2.81 \times 10^{12}}$$

$= 5.3 \times 10^3$ Nmm Check $\leq ØM_b$ for strandboard

4.2 Design Actions – Web

$$N^*_2 = \frac{E_2 A_2 a_2 M^*_{Panel}}{(EI)_{eff}} = \frac{8000\,(10800)\,(-25)\,(9.1 \times 10^6)}{2.8 \times 10^{12}}$$

$= -7.0 \times 10^3$ N Check $\leq ØN_c$ for 240x45 LVL8

$$M^*_2 = \frac{E_2 I_2 M^*_{Panel}}{(EI)\ eff} = \frac{8000\,(5.18 \times 10^7)\,(9.1 \times 10^6)}{2.8 \times 10^{12}}$$

$= 1.34 \times 10^6$ Nmm Check $\leq ØM_b$ for 240x45 LVL8

4.3 Design Actions – Bottom Flange

$$N^*_3 = \frac{E_3 A_3 a_3 M^*_{Panel}}{(EI)\ eff} = \frac{13200\,(6300)\,(177)\,(9.1 \times 10^6)}{2.81 \times 10^{12}}$$

$= 3.17 \times 10^4$ N Check $\leq ØN_c$ for 240x45 LVL8

$$M^*_3 = \frac{E_3 I_3 M^*_{Panel}}{(EI)_{eff}} = \frac{3200\,(1.06 \times 10^6)\,(9.1 \times 10^6)}{2.81 \times 10^{12}}$$

$= 4.55 \times 10^4$ Nmm Check $\leq ØM_b$ for 240x45 LVL8

Check Design Actions against Member Capacities.

5.0 Serviceability

Check panel deflection under UDL

$$\Delta = \frac{5}{384}\frac{WL4}{(EI)_{eff}} = \frac{5\,(1.8)\,(5000)^4}{384\,(2.81 \times 10^{12})}$$

$$= 5.2 = \frac{\text{Span}}{959}$$

5.1 Dynamic Load Check

1 kN Point Load Deflection

$$\Delta = \frac{1000\ (5000)^3}{48\ (2.81 \times 10^{12})} = 0.93m \leq 1 \text{ to } 2mm$$

$$\leq \frac{2.25}{\text{Span}^{0.63}} = 0.93mm$$

Frequency of panel

$$F = \frac{\pi}{2L^2}\left(\frac{(EI)_{eff}}{M}\right)^{0.5} = \frac{\pi}{2(5)^2}\left(\frac{2.31 \times 6^{12}}{18}\right)^{0.5} = 24\ H_2 \geq 8H_2$$

Note M = (0.3 kPa x 1000 / 9.81) 0.6 = 18kg / m

6. Connection

Connection between top skin & web

Max Stress $\tau_1 = \dfrac{E_1 A_1 a_1 V^*_{Panel}}{(EI)_{eff}\, b_2}$

$$= \frac{4500\ (10900)\ (155)\ (7300)}{2.8 \times 10^{12}\ (45)}$$

= 0.43 MPa

* For ply the designer needs to check for rolling shear in transverse ply layer

$$\theta = \emptyset\, (K_1)\ (K_{14})\ (K_{15})\ (K_{17})\ (E_{su})$$

6.1 Connection between bottom flange & web

$$\tau_2 = \frac{E_3 A_3 a_3 V^*_{Panel}}{(EI)_{eff}\ b_2}$$

$$= \frac{13200\ (6300)\ (117)\ (7300)}{2.81 \times 10^{12}\ (45)}$$

= 0.56 MPa

∴ Connection shear strength & glue bond should be designed / tested to ensure capacity exceeds 0.56MPa

13. References

AS/NZS1170 – Structural Design Actions

Eurocode 5 – Design of Timber Structures

NZS3603 – Timber Structures Standard

Stress Skin Floor Systems, Massimo Fragiacomo 2010

Timber Industry Federation, Timber Design Guide, Andy Buchanan 2007.

Cassettes with continuous top skins and bottom flange span full width of basement garage.

Prefabricated Potius wall cassettes with polyurethane spray foam insulation.

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