# Structural Design of CLT Stability Systems

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# Introduction

1. Introduction
   - Example projects
   - Basic challenges of stability for timber buildings
   - Structural testing and behaviour
2. Bracing walls and cores
3. Diaphragms
4. Modelling
5. Design
6. Further Information

# Project Examples

Aveo Norwest

10 Stories

MacArthur Gardens

6, 7, 8 Stories

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# Project Examples

Forte

10 Stories

Oakleigh Childcare Centre

1 Storey

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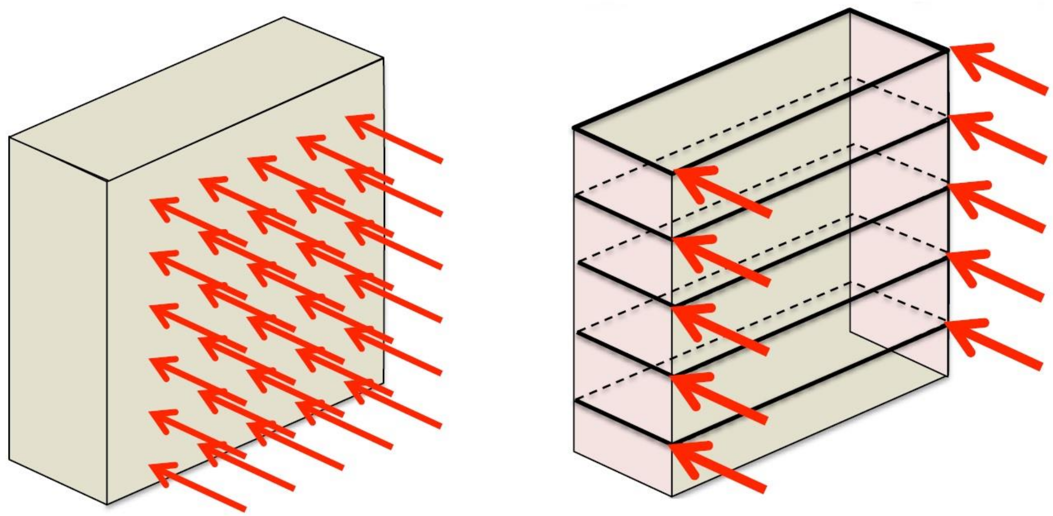
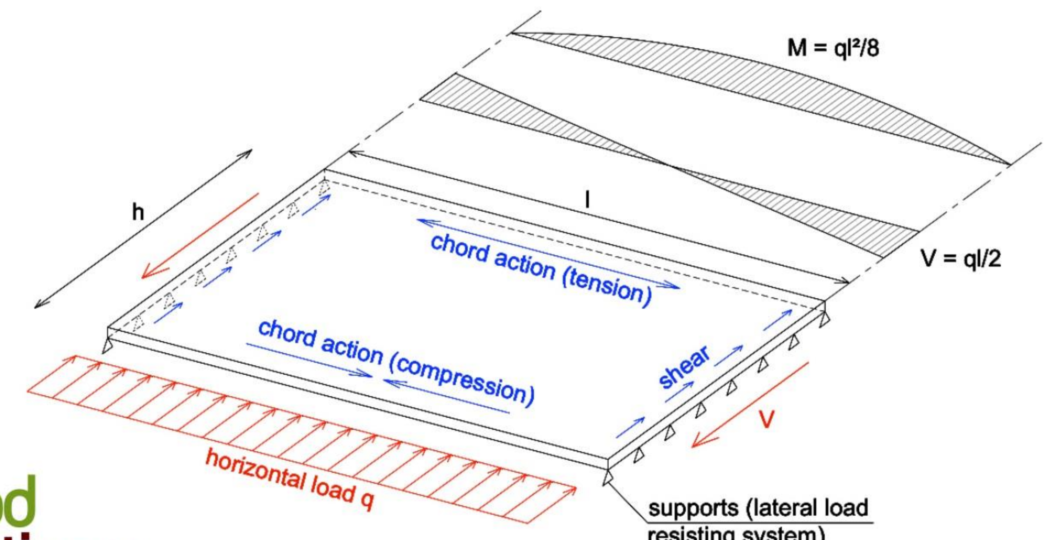
# Stability Systems



Load to bracing walls




Diaphragm transfer

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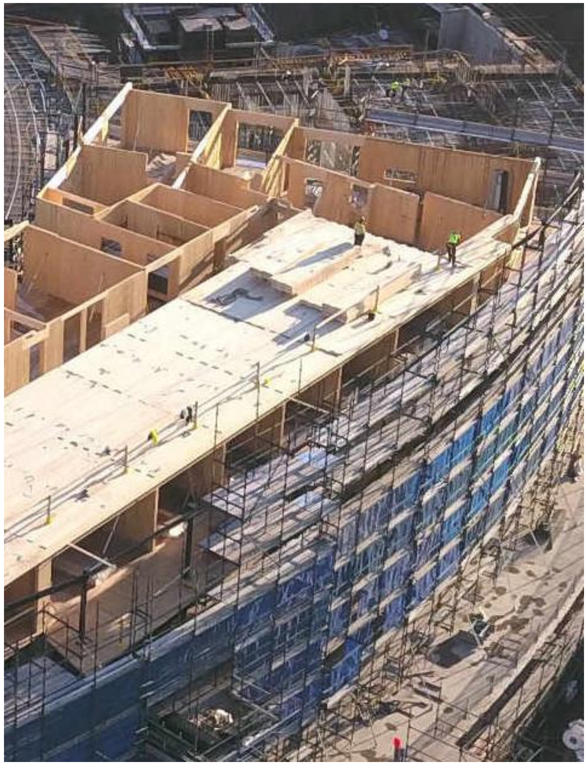
Credit: Wood Solutions

# Challenges of Stability



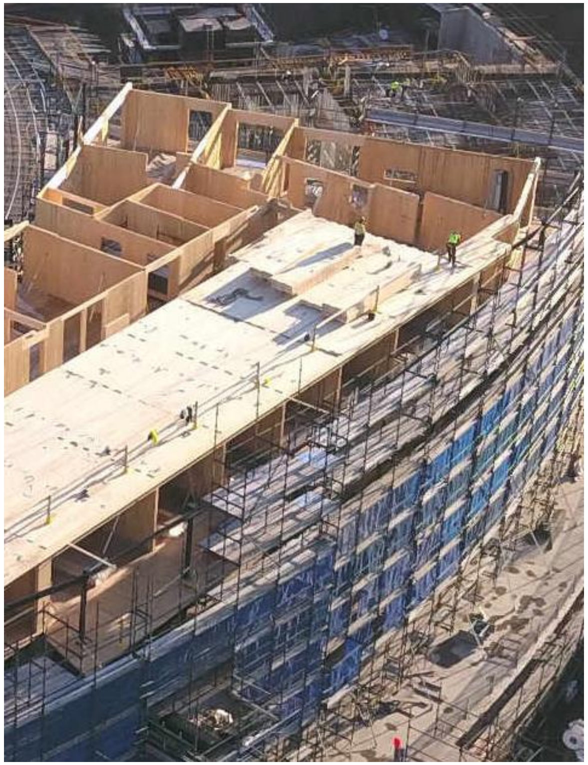
**Lightweight** - hold down and uplift is important

**One-way spanning** floors - affects distribution of gravity loads

**Connections** govern behaviour of shear walls - cannot use conventional analysis methods

**Diaphragms** not always rigid - affects distribution of lateral load

# Challenges of Stability



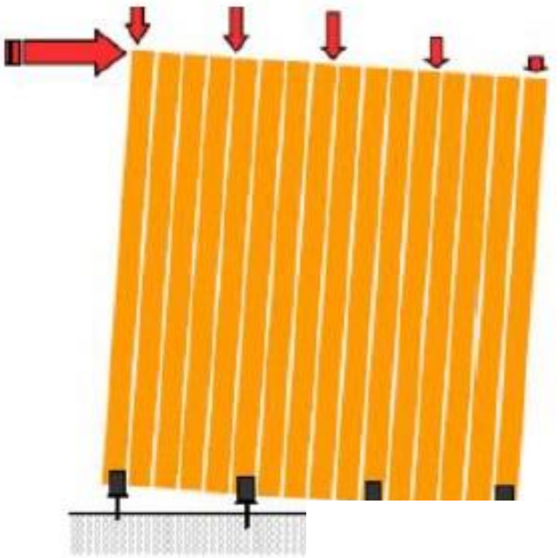
Presence and location **of vertical joints** in walls matter - manufacturing and transportation limits may affect design

Panelised design and connection details affect **buildability** and cycle time - critical to the success of a CLT project

Also have **shortening effects, floor crushing** and potential **frame elongation** to consider

# General CLT Wall Performance

- CLT wall panels behaved almost as rigid bodies during the testing
- Although slight shear deformations in the panels were measured, most of the panel deflections occurred as a result of the yielding deformation in the joints connecting the walls to the foundation
- In case of multi-panel walls deformations in the half-lap joints also had significant contribution to the overall wall deflection



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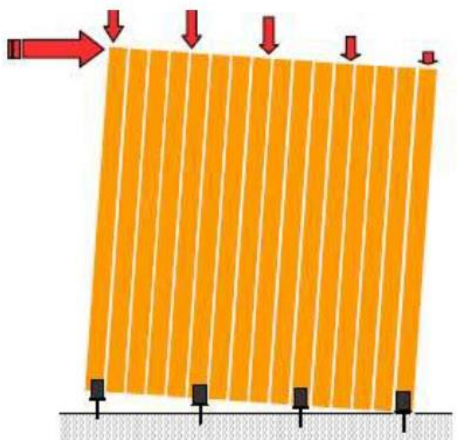
Credit: Popovski, M (FPInnovations)

Seismic performance of CLT walls is governed by connections

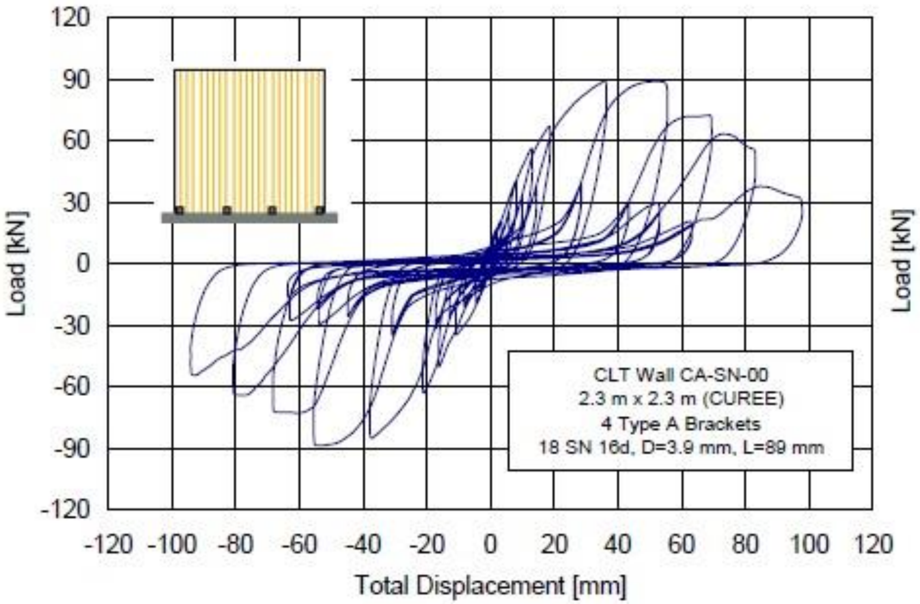


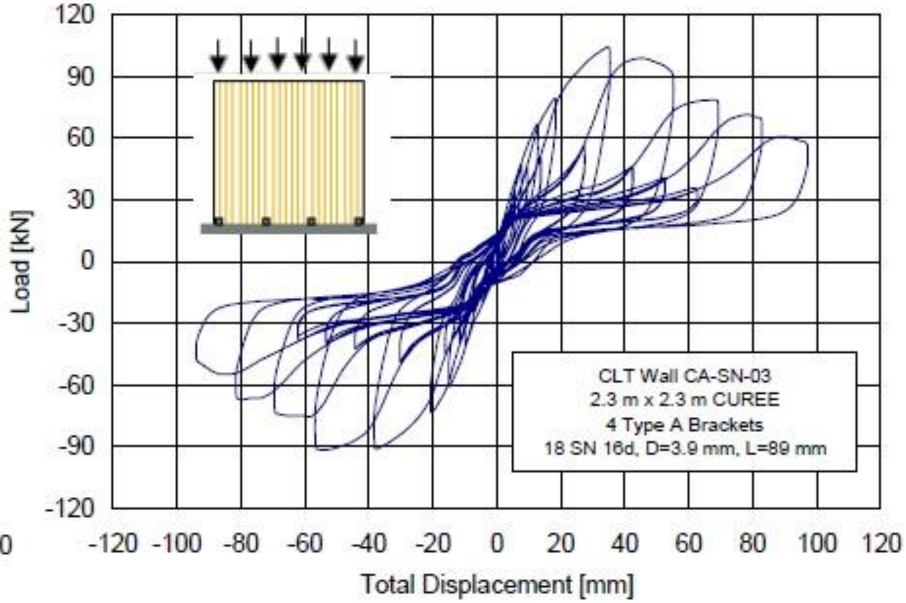


Credit: Popovski, M (FPInnovations)

# Influence of Vertical Load on the Resistance

- Cyclic behavior of CLT wall panels is not degraded by the presence of axial load
- Walls with axial load had increased initial stiffness and shear capacity but almost similar ductility
- Slight change in hysteresis loop shape

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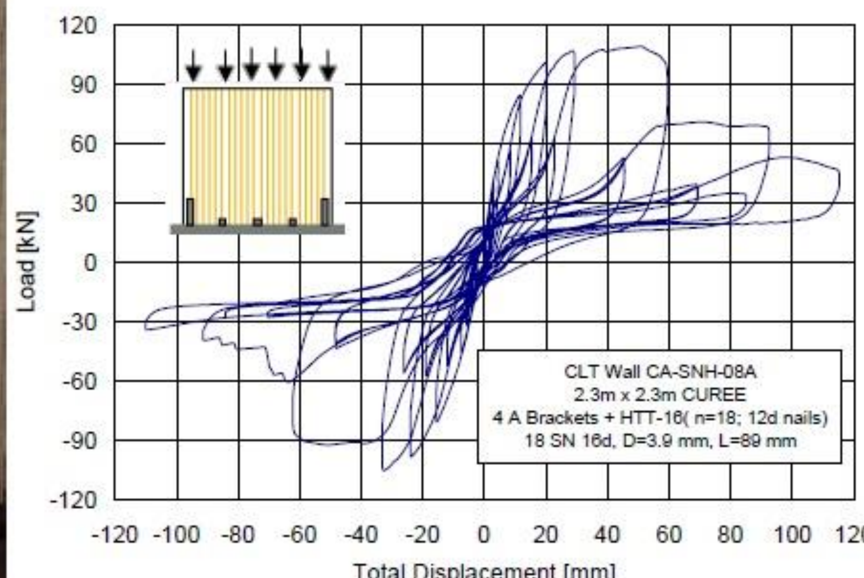
Credit: Popovski, M (FPInnovations)

# CLT Walls with Brackets and Hold-downs

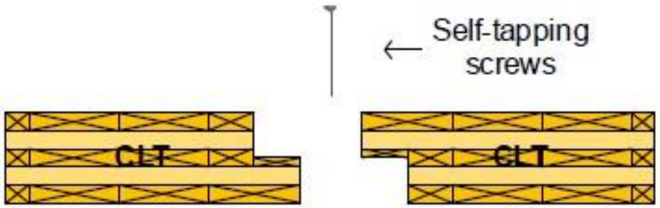
- With increased stiffness, strength and ductility values this configuration is one of the best for use in high seismic regions

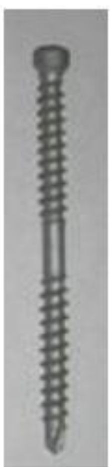



Credit: Popovski, M (FPInnovations)

# Walls with Half Lap Joints

- Wall behaviour was influenced by the type of fasteners in the brackets and in the wall lap joint



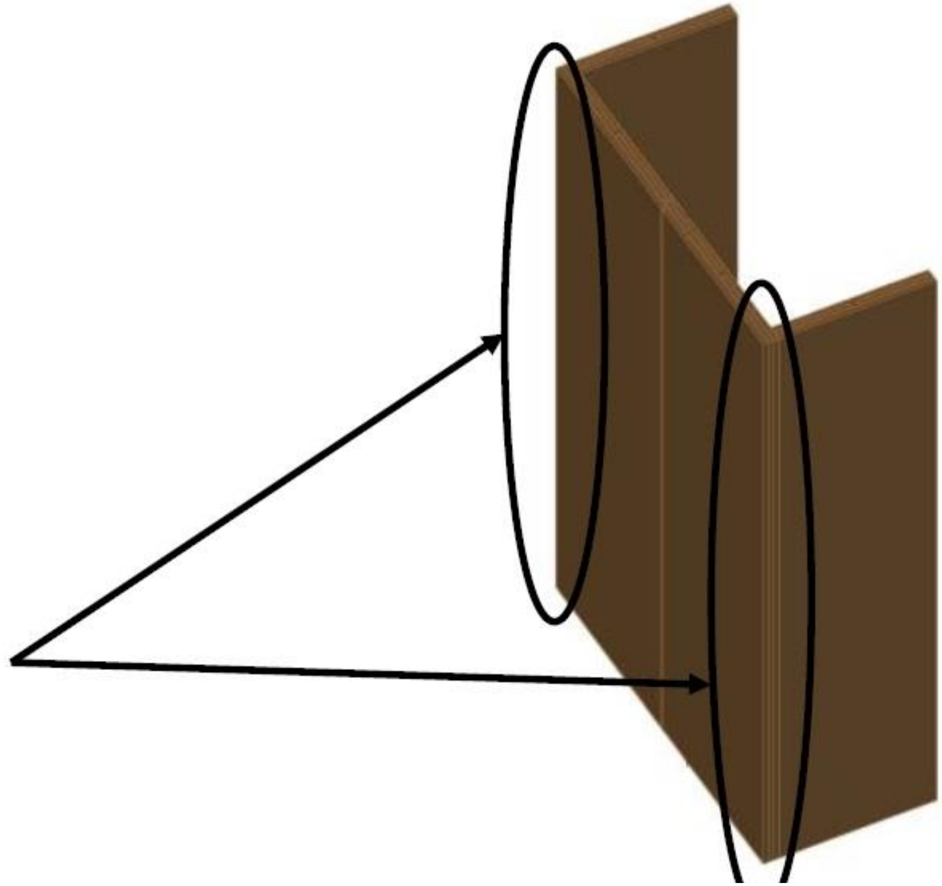





Credit: Popovski, M (FPInnovations)

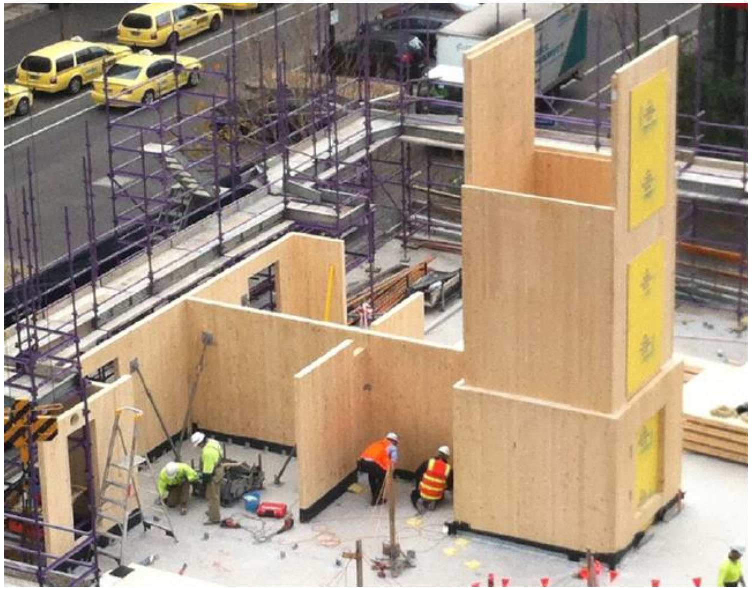
# C-shaped Cores

- Hold-down Connections
- Screw Connections
- Castellated Connections



Credit: Brown, J. (University of Canterbury)

# Design of bracing walls and cores



Overturning

Stiffness

Compound sections

Other considerations

# Bracing walls

Establish loads at bottom of walls, and at each floor level (above and below slab)

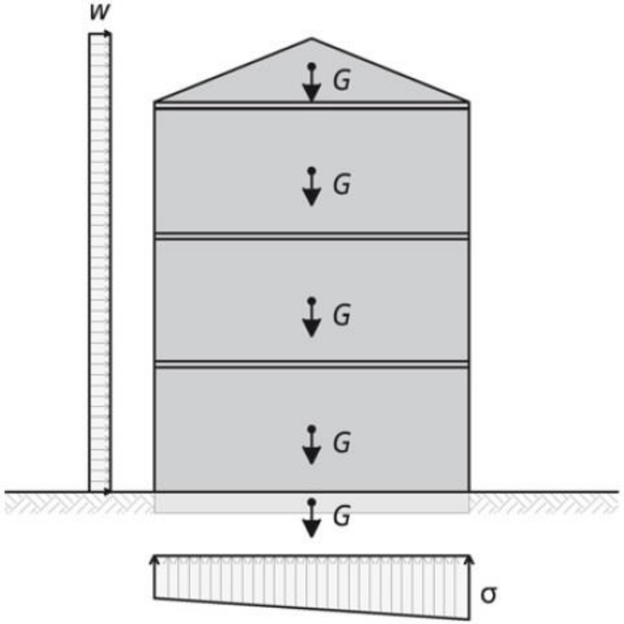



**Figure 10-4: Impacts and distribution of the contact pressure**

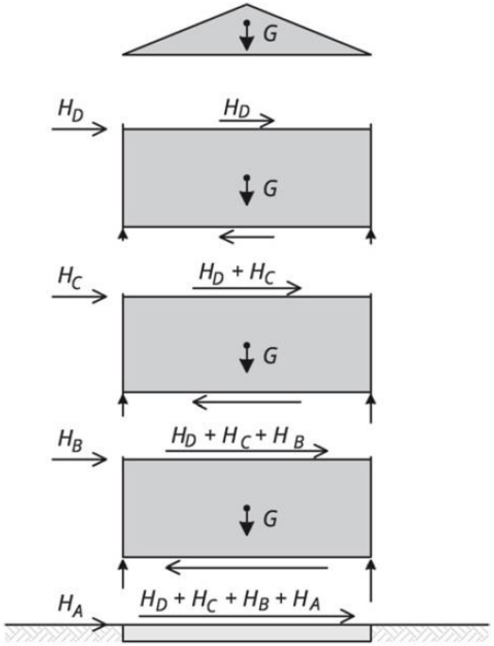



**Figure 10-6: Force progression per storey with vertical loads**

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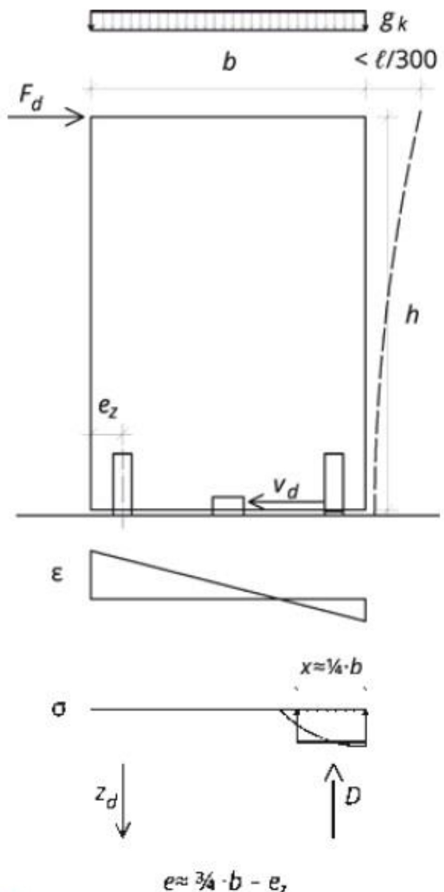
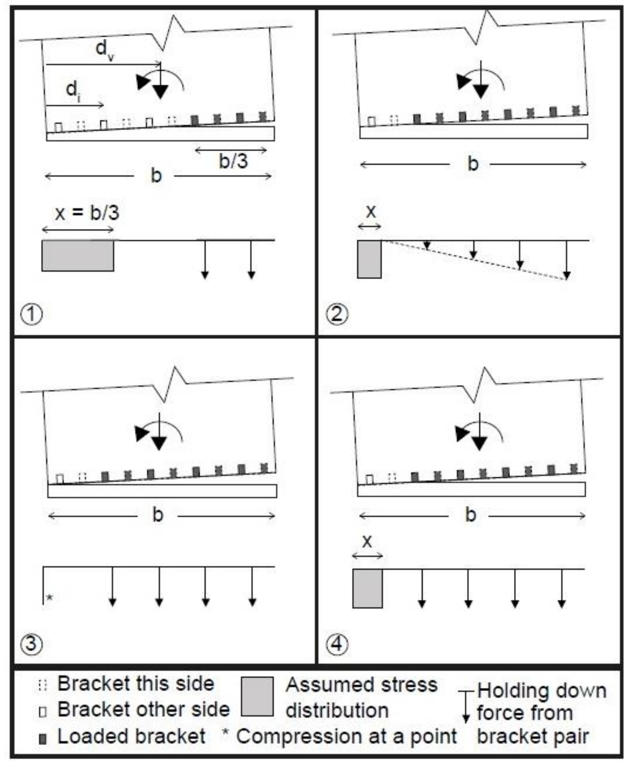
Credit: ProHolz guide

# Bracing walls

Check uplift in hold-down adopting suitable lever arm
Check cross-grain compression




Credit: ProHolz guide, Reynolds et. al

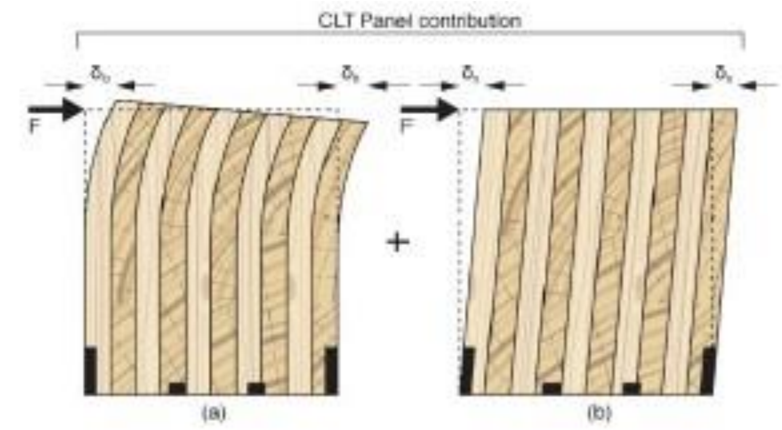
# Bracing walls

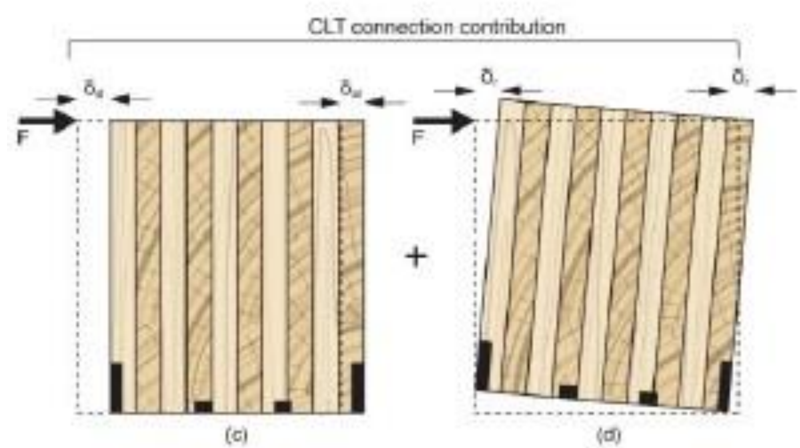
Calculate deflections based on:

- Shear and flexure of panel
- Translation and rotation due to connections

Also consider:

- Rotation due to cross-grain compression
- Rolling shear of floor
- Joint slip if panels have vertical lap joints

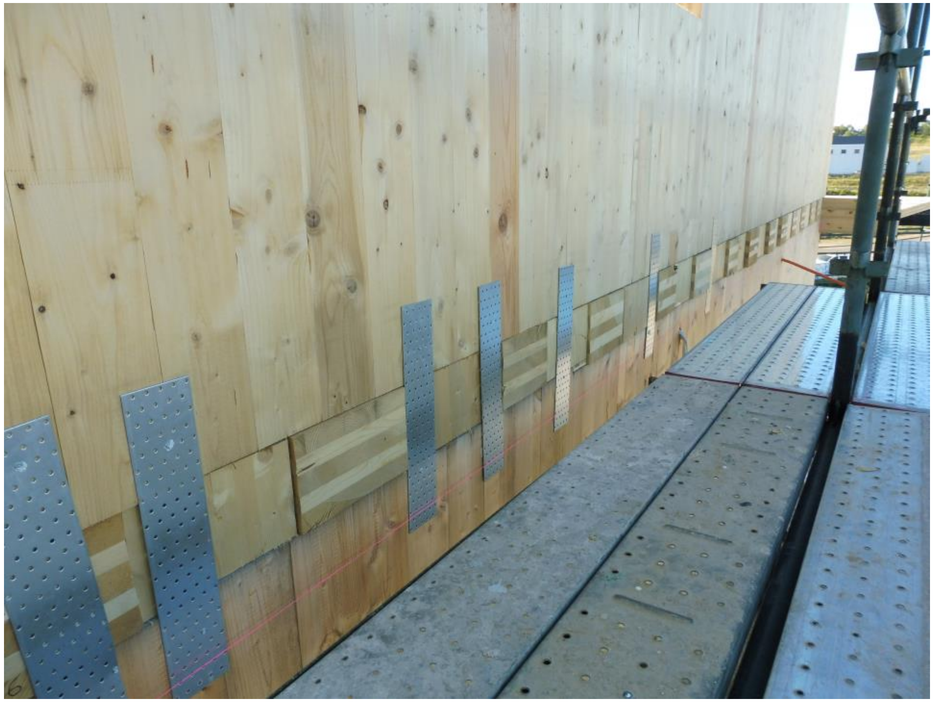


# Bracing walls

Check connections:

- Shear connections at slab connections
- Vertical joints



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# Mass timber cores

Similar checks to bracing walls, however:

- Low gravity loads mean high uplifts
- Practical aspects and spatial limitations of hold-down connections
- Shear transfer at joins must be examined, or design as discreet elements
- Ensure walls restrained by floors on all sides

Also consider:

- Fire performance
- Acoustics
- Vibration
- Coordination with lift manufacturers


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# Concrete cores

Advantages:

- Reliable stability system
- Higher capacity
- Higher stiffness

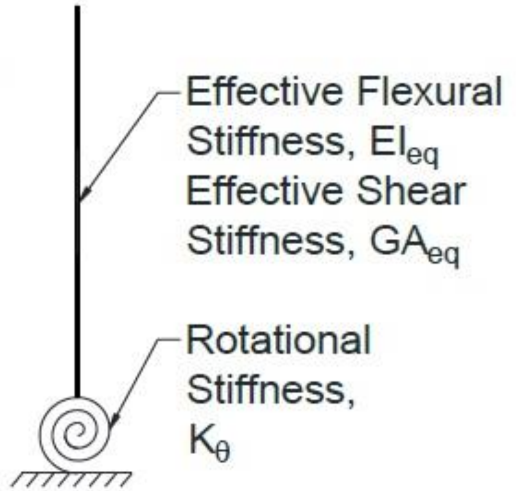
Disadvantages:

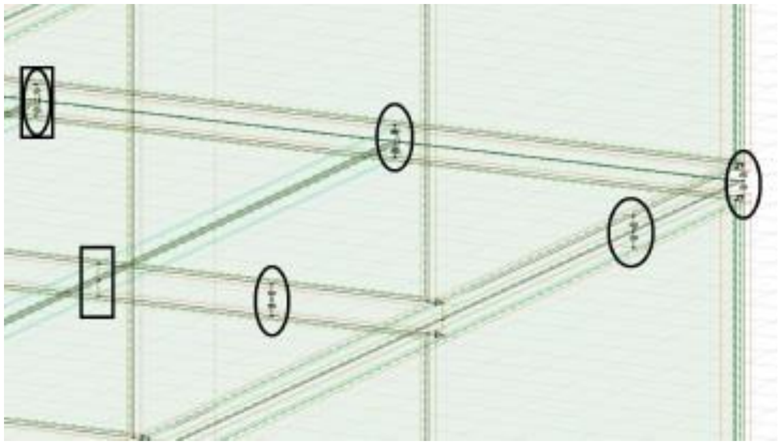
- Differential shortening effects
- Construction tolerances
- Program and construction planning
- Potentially places higher demand on floor diaphragms
- Higher localised forces

# Bracing wall modelling

Three approaches:

1. Use spreadsheet to build up horizontal load-take-down and calculate deflection components
2. Stick and spring models
3. Finite element with gap elements, tension only elements and springs



# Modelling issues

- Elements orthotropic, and effective bending thickness does not match actual thickness
- Have to incorporate connection stiffnesses based on supplier data
- Stiffnesses of HD bolts may need to be halved if continue through floors
- Set up model so forces can be extracted for connection design (more important than element design)
- Wall response is highly non-linear if modelled accurately and takes a long time to analyse
- FE good to explore shear stress over plate, explore penetrations etc. but takes much more effort
- Due to the importance of connections, highly iterative

# Rules of Thumb

G = 1kPa (NLB) or 2kPa (LB) - approx

Lever arm = Lwall - 1m

Floor rigid if span/depth < 2

Load in wall based on trib width if flexible diaphragm

Stiffness is proportional to $L^{1.5}$

Friction is ~0.3 (varies 0.2 - 0.4)

Max uplift ~40 kN per fastener

# Mass timber diaphragms

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# Mass timber diaphragms

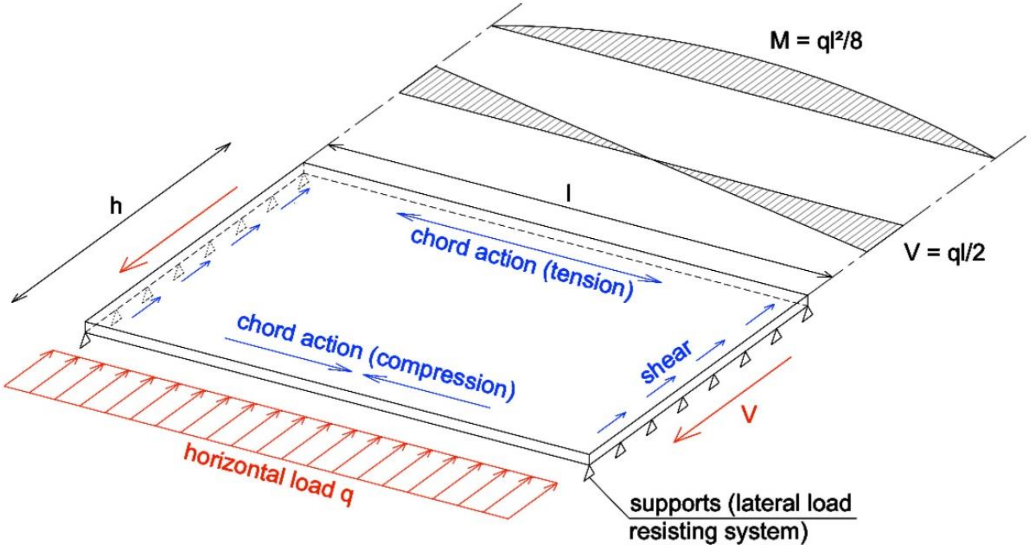
Purpose of diaphragms transfer wind and seismic loads to LLRS

Also tie columns, beams together

Can be timber/concrete composites, ply sheeting, SIPS or mass timber

Comprise plate elements with chords, collectors and connections

Typically designed using the girder analogy

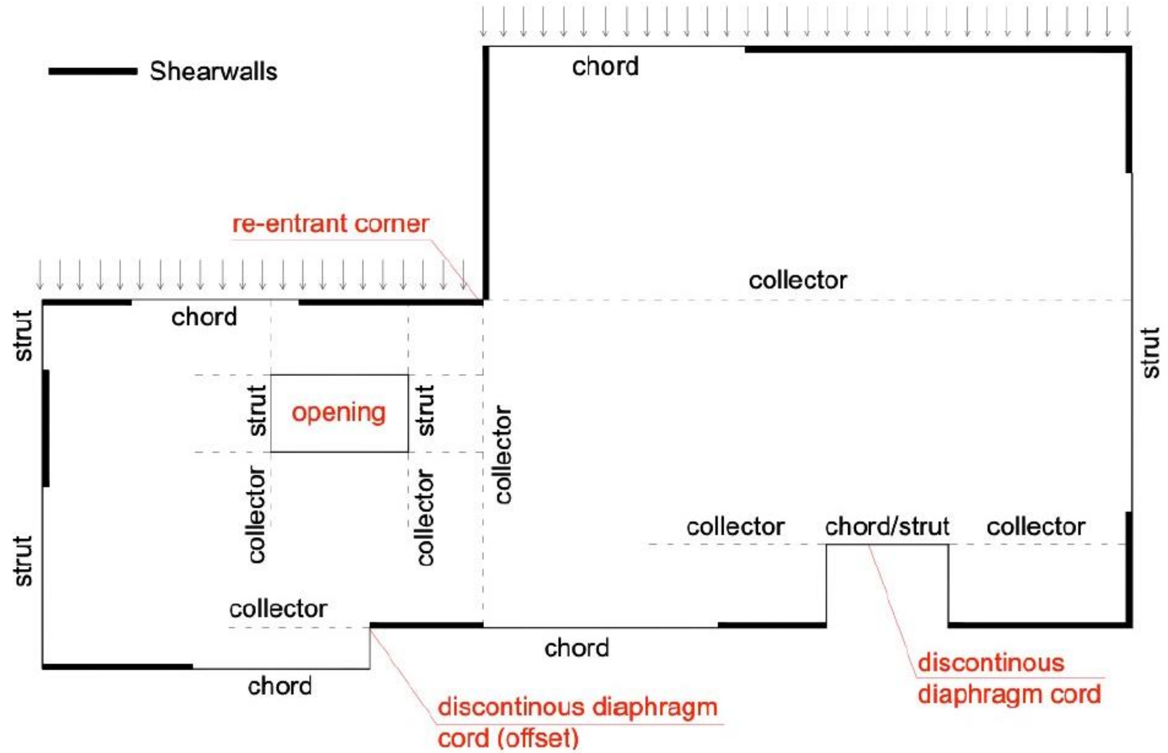


# Diaphragm design

Care with re-entrant corners, penetrations etc.

Ensure beams or walls at perimeter with continuity through connections

Consider diaphragm flexibility



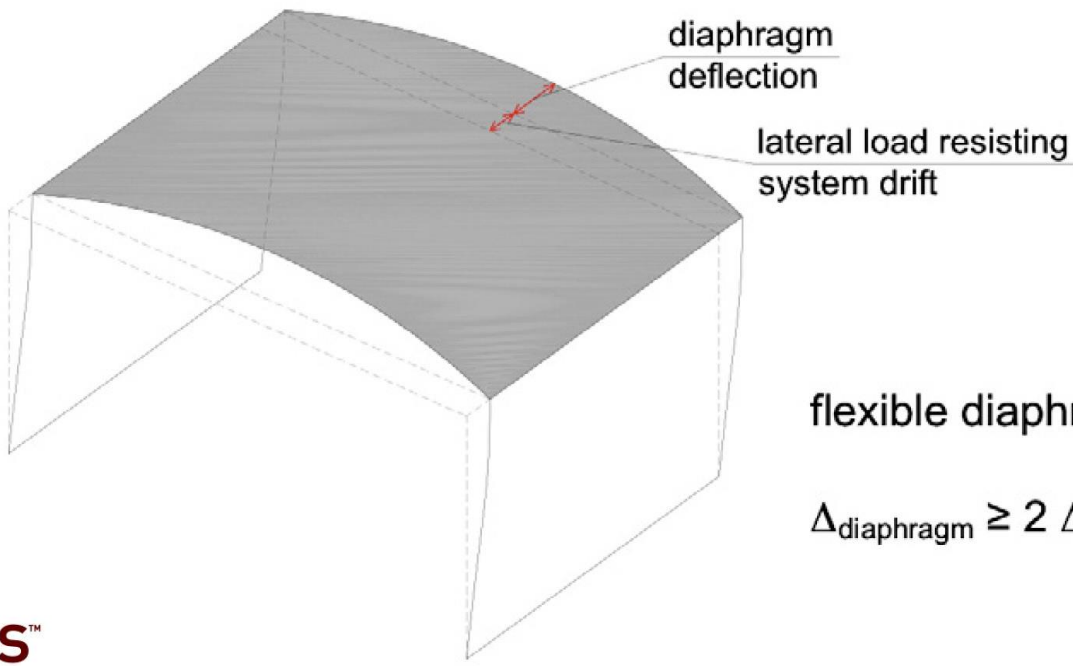
# Diaphragm design

Flexible if diaphragm deflection > 2*inter-storey drift

If **flexible -** loads distributed according to tributary width;

if **rigid**, loads distributed according to wall stiffness.

In reality, likely to be between, and an envelope of forces could be adopted




flexible diaphragm if

$\Delta_{diaphragm} \geq 2\ \Delta_{inters}$

# Diaphragm design

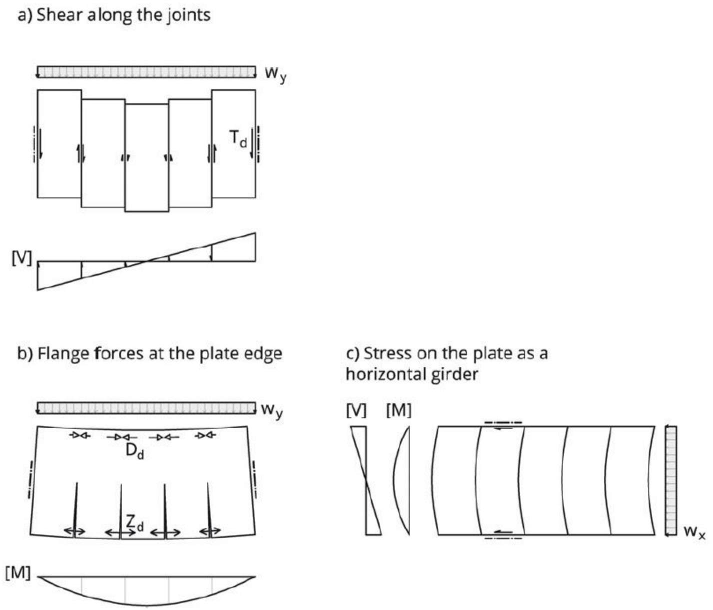
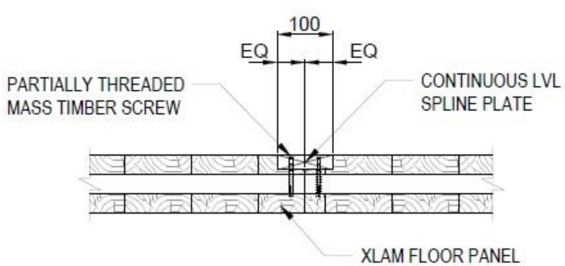
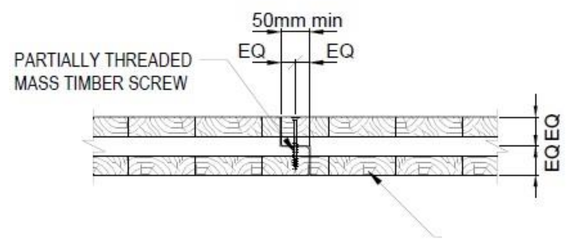



**Figure 10-8: Failure mechanisms of diaphragms**

- Check shear capacity of nails/screws
- Check capacity of panels
- Check T/C in chords
- Check forces in collectors and struts, and their connections
- May need to add "drag strips"
- May need sub-diaphragms to achieve acoustic performance




XLAM FLOOR TO FLOOR
HALF-LAP WITH SPLINE PLATE
CONNECTION




XLAM FLOOR TO FLOOR
HALF-LAP CONNECTION
3 LAYER PANEL

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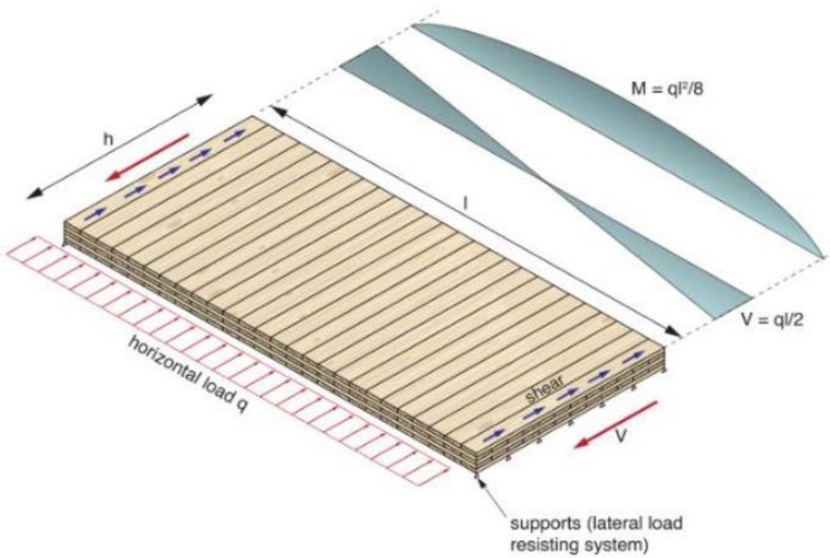
# Diaphragm modelling

Four approaches:

1. Envelope of forces based on flexible or rigid
2. Use girder analogy for beams and springs for walls if span / depth > 2
3. Truss analogy for flexible diaphragms (usually joists)
4. Finite element modelling, with connection stiffness modelled

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# Design Approach

1. Establish overall stability loads.
2. Frame up floors with repetition. Determine span direction and gravity load path, review available length of walls in each direction and consider alternating floor span direction. Decide if platform construction and examine cross-grain compression.
3. Compare lateral loads with gravity loads - how far over? Are HD forces reasonable?
4. Decide concrete core vs. bracing walls or alternatives
5. Review implications for foundation/transfer structure
6. If bracing walls, commence more detailed assessments of wall stiffness, connection designs and diaphragm performance.
7. Review assumptions with acoustic and fire consultants early.

# Optimisation

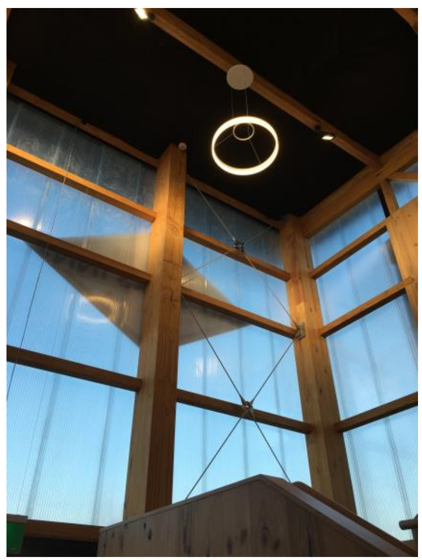
Optimisation of the no. of walls, connection details, and no. fasteners.

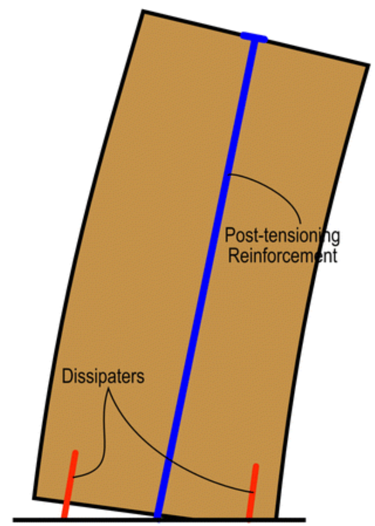
Other criteria likely to govern wall and floor thicknesses

- Configure building to make best use of gravity loads
- Increase level of certainty around diaphragm flexibility and load paths
- Adopt screw details wherever possible, whilst not undermining ductility
- Consult with supplier to select best value connectors

# Alternatives

- Consider epoxy-bonded rods and plates with dowels for the most heavily loaded tie-downs
- Post-tensioning of LVL walls (e.g. Preslam solution)
- Adopt braced or moment frames at the perimeter of the building
- Tie party walls together as large C-shaped cores






# Further Information

- Wood Solutions guide 35 – Diaphragms
- ProHolz guide, Cross-Laminated Timber Structural Design (EU)
- FPInnovations guides (US/Canada)
- TRADA guides (UK)

Forthcoming:

- Wood Solutions CLT Design Example
- Wood Solutions Structural Engineers Guide
- BRANZ guide

# Acknowledgements

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CHRISTCHURCH NEW ZEALAND

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