Tall Wood: A Viable Option for Today's Building Designers

Structural Systems and Approaches

Presented by Scott Breneman, PhD, PE, SE
Scott.Breneman@woodworks.org

University Laval Soccer Stadium, Quebec City
Architect: ABCP Architecture + urbanisme

216 ft span
Photos courtesy Nordic Engineered Wood Products
Raleigh Durham International Terminal 2
Lead Architect: Fentress Architects
Lead Structural: ARUP
Photos courtesy Structurlam Products

Up to 136 ft spans
Hybrid Glulam Truss
Completed 2010

Forte
Melbourne, Australia
10 Stories
2014

Cenni De Cambiamento
Milan, Italy
9 Stories
2013
**IBC Allowed Building Heights (Prescriptive Limits)**

<table>
<thead>
<tr>
<th>Occupancy</th>
<th>IIA</th>
<th>IIIB</th>
<th>IV</th>
<th>VA</th>
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<td>B</td>
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<td>4</td>
<td>3</td>
<td>5</td>
<td>4</td>
<td>2</td>
</tr>
</tbody>
</table>

**Mid-Rise vs. High-Rise Definition – IBC 202**

If this dimension exceeds 75 feet, building is considered a high rise.

Determination of high-rise building

10' floor to floor

Lowest Level of Fire Dept. Vehicle Access
Wood Building Systems

- Post and Beam
- Light Frame
- Mass Timber
Solid Timber Panel Products

Considerations:

- Gap panels for dimensional change
- Need Wood Structural Panel for diaphragm capacity
- Inconsistent lamination grades
- Manufacturers everywhere

Graphic Credit: StructureCraft
Solid Timber Panel Products

Considerations:

• Requires accommodation for dimensional change
• Need wood structural panel for diaphragm capacity
• Recognized as a heavy timber floor system
• Long history of use
Mass timber products
Nail-laminated timber (NLT) panels

NLT shrinkage/expansion design:
Consider leaving one ply out per 8'-10’ wide panel
Mass timber products
Nail-laminated timber (NLT) panels

NLT panels can be built on-site/in-place or pre-fabricated offsite

Solid Timber Panel Products

Considerations:
- Established design properties
- Specially ordered but multiple domestic manufacturers
- Horizontal applications don’t take advantage of the strength direction
- Relatively dimensionally stable
- Limited Thicknesses
Solid Timber Panel Products

Considerations:
- Established design properties
- Specially ordered but multiple domestic manufacturers
- Relatively dimensionally stable

Laminated Strand Lumber

Graphic Credit: StructureCraft
Solid Timber Panel Products

Considerations:

- Span usually governed by vibrations
- Dimensionally stable
- Recognized by 2015 codes and standards
- High in plane shear capacity
- Dual Directional span capabilities

Cross Laminated Timber

Graphic Credit: StructureCraft
Mass timber products
Cross-laminated timber (cLT)

What is CLT?

Solid wood panel
3+ layers of solid sawn lams
90 deg. cross-lams

4 1/8” to 19 1/2”
24 TO 60’
8’ TO 10’
Common CLT Layups

- 3-ply 3-layer
- 5-ply 5-layer
- 7-ply 7-layer
- 9-ply 9-layer

CLT Product Standardization

ANSI / APA PRG 320  Standard for Performance Rated Cross-Laminated Timber
PRG 320 Defined Layups

<table>
<thead>
<tr>
<th>CLT Grade</th>
<th>CLT [lt]</th>
<th>Lamination Thickness [in]</th>
<th>$R_{L}$ (lb/in²)</th>
<th>$R_{M}$ (lb/in²)</th>
<th>$R_{L}$ (psi)</th>
<th>$R_{M}$ (psi)</th>
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<tr>
<td>E1</td>
<td>6 x 6</td>
<td>1.25</td>
<td>1.25</td>
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<td>1.25</td>
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<td>E3</td>
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</tbody>
</table>

CLT Product Reports

Structurium CrossLam
Structurium Products LP
PR-L314
Revised May 9, 2016

Products: Structurium Cross-Laminated Timber Products LP
2178 Government Street
Vancouver, British Columbia, Canada V5A 9B5
www.structured.com

1. Basis of the product report:
   - 2015 and 2009 IBC Section 104.11 Aluminum
   - AAMA 2111, Aluminum Association
   - APA MR320-2012
   - APA MR320-2012
   - APA MR320-2012

2. Product description:
   - Structurium CrossLam is a cross-laminated timber (CLT) that is engineered to meet ASHRAE 730, 2013 edition, and is used in residential and commercial applications.

3. Design properties:
   - Design values for CLT shall be determined with the allowable load factor provided by the manufacturer.

SmartLam Cross-Laminated Timber
PR-L319
Issued August 16, 2016

Products: SmartLam Cross-Laminated Timber
SmartLam, LLC
2006 107th Street
Columbus, Ohio 43212
www.merlina.com

1. Basis of the product report:
   - 2015 International Residential Code (IRC)
   - AAMA 2111, Aluminum Association
   - APA MR320-2012
   - APA MR320-2012

2. Product description:
   - SmartLam Cross-Laminated Timber (CLT) is a cross-laminated composite material that is designed to meet the requirements of ASHRAE 730, 2013 edition, and is used in residential and commercial applications.
CLT Product Reports

Table 1. Allowable Design Properties\(^{12}\) for Nordic X-Lam (for use in the U.S.)

<table>
<thead>
<tr>
<th>CLT Grade</th>
<th>Major Strength Direction</th>
<th>Minor Strength Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(F_{0.97}) (psi)</td>
<td>(F_{0.97}) (psi)</td>
</tr>
<tr>
<td>E1</td>
<td>1.950</td>
<td>1.7</td>
</tr>
</tbody>
</table>

For SI 1 psi = 0.006895 MPa
\(^{12}\) Tabulated values are allowable design values and not permitted to be increased for the lumber size adjustment factor in accordance with the NDS. The design values shall be used in conjunction with the section properties provided by the CLT manufacturer based on the actual layup used in manufacturing the CLT panel (see Table 2).

Table 2. The Allowable Bending Capacities\(^{13}\) for Nordic X-Lam Listed in Table 1 (for use in the U.S.)

<table>
<thead>
<tr>
<th>CLT Grade</th>
<th>Lamination Thickness (in)</th>
<th>CLT Layup</th>
<th>Major Strength Direction</th>
<th>Minor Strength Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(F_{0.97}) (psi)</td>
<td>(F_{0.97}) (psi)</td>
<td>(E_0) (10^3 psi)</td>
<td>(E_0) (10^3 psi)</td>
</tr>
</tbody>
</table>

For SI 1 psi = 0.006895 MPa
\(^{13}\) Tabulated values are allowable design values and not permitted to be increased for the lumber size adjustment factor in accordance with the NDS.

Structural Design Standardization

National Design Specification for Wood Construction
2015 Edition
Model Building Code Acceptance

Highlights of CLT Provisions in IBC 2015

- CLT is generally available for use in Type III, IV and V construction.

- IBC Chapter 6 defines minimum dimensions of CLT to qualify as Heavy Timber (Type IV Construction)
  - 6” Walls
  - 4” Floors
  - 3” Roofs
  - non Fire-Retardant Treated CLT allowed in Exterior Walls of Type IV construction in many conditions.
ICC-ES Acceptance Criteria AC 455

Standardizes In-plane Panel Shear Strength for use in Floor and Roof Decks

Product Availability

- Producers of structural CLT certified to the APA 320 standard:
  - DR Johnson Lumber, Riddle, Oregon
  - Nordic Structures in Quebec, Canada
  - SmartLam, Columbia Fall, Montana
  - Structurlam in Penticton British Columbia, Canada
CLT Prefabrication
• Finished panels are planed, sanded, cut to size. Then openings are cut with precise CNC routers.
• Third party inspection at factory
• Custom engineered for material efficiency
• Custom designed for project
• Each panel numbered, delivered & installed in predetermined sequence

Outline
• Introduction
• Mass Timber Products (Including CLT)
• Strategies for Tall Wood
  • Gravity Systems
  • Lateral/Seismic Systems
Tall Wood Structural Systems

- Tall Wood Structural Systems
  - Gravity Framing Styles
  - Lateral Force Systems

Tall Wood Framing Styles

- Gravity Framing Styles
  - Post & Beam
  - Two-Way Panel Deck
  - “Honeycomb”
Tall Wood Framing Styles

- Gravity Framing Styles
- Post & Beam
- Two-Way Panel Deck
- “Honeycomb”

framework
Portland, OR

Photo: joshua jay elliot
framework
Portland, OR

4 stories of wood (office) over 1 story of concrete (retail & parking)
6,800 sf
Completed 2015

• 3 Stories
• 25’x25’ Grid
• 15’-18’ floor to floor heights
• Composite floor: 2x4 and 2x6 NLT floor panels with 3 ½” reinforced concrete topping
• All MEP exposed
Type IV Construction
7 stories (6 Timber on 1 Concrete)
234,000 sf
2x8 NLT Floor Panels w/3" Concrete Topping
Glulam Beam and Column Frame
20’x25’ Grid
T3 Minneapolis
Minneapolis, MN

Image Credit: Blaine Brownell

ARCHITECT: Lever Architecture
Photo: Scott Breneman

ALBINA YARD
PORTLAND, OR

stories
6,000 sf
Green Roof

ARCHITECT: Lever Architecture
Photo: Scott Breneman
The Bullitt Center
Seattle, WA
Architect: Miller Hull Partnership

Tall Wood Framing Styles

- Post & Beam
  - Horizontal Deck
  - Primary Frame
    - CLT
    - NLT
    - GLT
    - LVL
    - T&G Decking
Tall Wood Framing Styles

Post & Beam
- Horizontal Deck
- Primary Frame
- Solid-Sawn Lumber
- Glulam Lumber
- Structural Composite Lumber
- Other Materials

---

Example Floor Framing Design

Assumptions:
DL = 30 psf
LL = 65 psf

<table>
<thead>
<tr>
<th>X</th>
<th>S</th>
<th>Mass Timber Panel</th>
<th>Glulam Purlin 24F-V4</th>
<th>Glulam Girder 24F-V4</th>
<th>Approx. Cost</th>
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<tbody>
<tr>
<td>20'</td>
<td>20'</td>
<td>2x6 NLT or 7-Ply CLT</td>
<td>None</td>
<td>5-1/8&quot;x24&quot;</td>
<td>$25/SF</td>
</tr>
<tr>
<td>25'</td>
<td>12.5'</td>
<td>2x6 NLT or 5-Ply CLT</td>
<td>5-1/8&quot;x24&quot;</td>
<td>6-3/4&quot;x30&quot; or 8-3/4&quot;x27&quot;</td>
<td>$23/SF</td>
</tr>
<tr>
<td>30'</td>
<td>10'</td>
<td>2x6 NLT or 3-Ply CLT</td>
<td>5-1/8&quot;x28-1/2&quot;</td>
<td>8-3/4&quot;x36&quot; or 10-3/4&quot;x33&quot;</td>
<td>$18/SF</td>
</tr>
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</table>

Note: All member sizing needs to be confirmed by a licensed engineer for conditions of your project.
Innovative Floor Systems

Considerations:
• Connection needs to be carefully designed
• Difficult to ensure design capacity if concrete is poured on site
• Detail needs to accommodate the moisture conflict between the materials

Timber Concrete Composites

Graphic Credit: StructureCraft
MyTiCon Timber Composite System
OFFICE BUILDING
LCT ONE
Dornbirn, Austria
Height: 8 stories
FA: app. 17,000 ft²

ARCHITECT: Hermann Kaufmann
ENGINEER: Merz Kley Partner
PHOTO CREDIT: CREE

Life Cycle Tower
Wood Innovation Design Center
Prince George, British Columbia
8 Levels/6 Stories
97 feet tall
Completed Fall 2014

Architect: Michael Green Architecture
Structural Engineer: Equilibrium Consulting
Contractor: PCL Constructors Westcoast
Photos: Ema Peter Photography
WIDC Floor System
Staggered 5 Ply over 3 Ply CLT Panels

Rocky Mountain Institute Innovation Center
Basalt, CO

Photo Credit: Rocky Mountain Institute, Tim Griffith
Tall Wood Framing Styles

Gravity Framing Styles

- Post & Beam
- Two-Way Panel Deck
- “Honeycomb”
5 PLY CLT PANELS, 2-WAY SPAN
~9'X13' GRID OF COLUMNS

Chicago Horizon Pavilion
Chicago, IL

56' square kiosk
2 Layers of 3-ply, 4-1/8" CLT roof panels in opposite directions, each panel 8' x 56', creating 2 way spanning plate
Tall Wood Framing Styles

- Post & Beam
- Two-Way Panel Deck
- “Honeycomb”
Candlewood Suites
Redstone Arsenal, AL

62,600 sf, 4 story hotel, 92 private rooms
CLT utilized for walls, roof panels, and floor panels
1,557 CLT Panels; Typical floor panel is 8’x50’ & weighs 8,000 lbs
Completed Late 2015
Stadhaus at Murray Grove
London

Waugh Thistleton Architects
9 Story
97 Ft Tall Residential
Completed 2009

Photo credit: Waugh Thistleton Architects

2010
BRIDPORT HOUSE,
HACKNEY LONDON, UK
8 STORIES
87 FT
~17K SF

ARCHITECT: Karakusevic Carson
ENGINEER: Peter Brett Associates
Question: What is the *Structural* limit on the height of a wood gravity framing system in our building codes and standards?

**Answer:** There is no limit
Mass timber design
connections

Long self tapping screws used extensively throughout mass timber construction

Photo Credit: alex schreyer
Mass timber design connections

Beam to beam connections

Photo Credit: MyTiCon

Beam to column & column to column connections

Photo Credit: John Stamets
Mass timber design connections

Beam to column connections

Beam to column connections
Mass timber design connections

column to column connections

Mass timber design connections

column to foundation connections

Photo Credit: alex schreyer
Tall Wood Structural Systems

Gravity Framing Styles

Lateral Force Systems

Seismic Design

CLT Seismic Force Resisting Systems Not addressed In

ASCE/SEI 7-10

SDPWS 2015
“This is a terrific building that echoes the historic character of the workspaces in the Central Eastside, but takes it a step further with this incredible wood construction.”
Portland Metro Councilor Bob Stacey
The Bullitt Center
Seattle, WA
Architect: Miller Hull Partnership
Photos © Nick Lehoux for the Bullitt Center

framework
Portland, OR
4 stories of wood (office) over 1 story of concrete (retail & parking)
6,800 sf
Completed 2015
Mass timber design
Lateral framing systems

Central core – concrete shearwalls

Photo Credit: structurecraft

Tall Wood Structural Systems

Lateral Force Systems

Vertical Lateral/Seismic Force Resisting Systems

Horizontal Lateral/Seismic Force Resisting Systems

Code Recognized Seismic Force Resisting System

Innovative System via Alternative Means
### Light Frame Wood Shear Wall Seismic Height Limits

#### ASCE 7-10 Table 12.2-1

<table>
<thead>
<tr>
<th>Seismic Force-Resisting System</th>
<th>ASCE 7 Section Where Detailing Requirements Are Specified</th>
<th>Response Modification Coefficient, $R^*$</th>
<th>Overstrength Factor, $D_s^*$</th>
<th>Deflection Amplification Factor, $C_s^*$</th>
<th>Structural System Limitations Including Structural Height, $H_s$ (ft) Limits*</th>
<th>Seismic Design Category</th>
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<tbody>
<tr>
<td>A. BEARING WALL SYSTEMS</td>
<td></td>
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</tr>
<tr>
<td>15. Light frame (wood) walls sheathed with wood structural panels rated for shear resistance</td>
<td>14.5</td>
<td>6½</td>
<td>3</td>
<td>4</td>
<td>NL NL</td>
<td>65 65 65</td>
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</table>

#### ASCE 7-10 Seismic Design Category

Risk Category I-III Buildings and Site Class D (default)

ASCE 7-10 Seismic Design Category
Risk Category I-III Buildings and Site Class D (default)


ASCE 7-10 Seismic Design Category
Risk Category I-III Buildings and Site Class C

ASCE 7-10 Seismic Design Category
Risk Category I-III Buildings and Site Class B


Tall Wood Structural Systems
Code Compliance Pathway – ASCE 7-10

CLT Shear Wall Seismic Design Values

What R value can I use?
State of Oregon Statewide Alternative

ASCE 7-10 Table 12.2-1 modified by Oregon Buildings Code Division

Table 12.2-1 Design Coefficients and Factors for Seismic Force-Resisting Systems

<table>
<thead>
<tr>
<th>Seismic Force-Resisting System</th>
<th>ASCE 7 Section Where Requirements Are Specified</th>
<th>Response Modification Coefficient, $R^2$</th>
<th>Overstrength Factor, $L_h$</th>
<th>Deflection Amplification Factor, $C_2$</th>
<th>Structural System Limitations Including Structural Height, $h$, (b) Limita</th>
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<tr>
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<td>6 ½</td>
<td>3</td>
<td>4</td>
<td>NL</td>
</tr>
<tr>
<td>19. Cross-laminated timber shear walls</td>
<td>14.1 and 14.5</td>
<td>2</td>
<td>2 ½</td>
<td>2</td>
<td>NL</td>
</tr>
</tbody>
</table>
Mass timber design
Lateral framing systems

Central core – mass timber shearwalls
Photo Credit: alex schreyer

FEMA P-695 Study for CLT Shear Walls

Project Lead: John van de Lindt, Colorado State University

Design Method
Testing
Modeling
Peer Review
Report

Non-Linear Analyses
Resilient CLT Rocking Walls

Cross-Laminated Timber Post-Tensioned Rocking Shear Walls

CLT Resilient System Testing

• Resilient energy dissipating lateral CLT systems
• Testing at WSU
Structural Testing – Lateral Systems

Cross-Laminated Timber Post-Tensioned Rocking Shear Walls

CLT Post Tensioned Rocking Shear Wall
NHERI TallWood
Full Scale Shake Table Testing of A Ten-story CLT Building to Validate Resilient Seismic Design Methodology

(Project period 2016-2020)

Objective:
Develop and test-validate a seismic design methodology for 8-20 story tall wood buildings so that they can withstand large earthquakes with minimal damage.

New Mass-timber material (Cross Laminated Timber) enables building tall with wood
Sustainable solid wood material; Fast and environmental friendly construction process due to prefabrication

Actively looking for collaborators, partners, and pay-load projects.

Please Contact Dr. Shiling Pei at spei@mines.edu

Source: S. PEI et al.
Framework, Portland, OR

- Owner: Beneficial Bank & Home Forward
- Developer: Project
- Architect: Lever Architecture
- Structural: KPFF
- Fire: Arup
- Height: 130’ / 12 stories
- Total Building Area: 90,000 square feet
- Mixed Use: Retail, Office, Residential
- Materials: Cross laminated timber floors and lateral force resisting system; Glue laminated beams and columns
Framework, Portland, OR

Completed 2015
14 STORIES
173 FT
~63K SQ.FT.

Source: Toward Taller Wood Buildings Symposium 2014
Heavy Timber Buckling-Restrained Brace
Tall Wood Structural Systems

- Lateral Force Systems
  - Vertical Lateral/Seismic Force Resisting Systems
  - Horizontal Lateral/Seismic Force Resisting Systems
**Diaphragm Design**

- Diaphragm: Roof, floor transferring lateral forces to the vertical resisting elements
- Diaphragm loads are generally uniform loads, resisted by the diaphragm in bending, similar to a horizontal deep beam
- Diaphragm bending results in tension/compression in chords perpendicular to load

---

![Diagram of diaphragm design](image)

---

**One north**
Portland, OR

Structural Floor/Roof & Diaphragm: Exposed T&G Decking, Wood Structural Panels

Photo Credit: Josh Partee
NLT Diaphragm design:
Should be covered with wood structural panels for use with blocked diaphragm values in SDPWS Table 4.2A/4.2B

CLT Diaphragm Design?

Source: A Ceccotti in the US CLT Handbook
An European Approach

Fragiacomo, Vasallo et al.

Yielding Connections
Non Yielding Connections

Designed to Overstrength factor of 1.3 to 1.6 of yielding connection strength

Typical Assumption of Rigid Diaphragm Behavior for CLT wall and floor systems

US CLT Handbook Approach

Yielding Connections
• NDS Yield Modes III and IV govern.
• Strength of other (non-yielding) limit states at connection designed to nominal yielding connection capacity.  
  \( \frac{1}{\phi} = \frac{1}{0.65} = 1.54 \) overstrength factor

Non Yielding Connections
Chords and Anchorage
CLT Floors as Diaphragms

Panel In-Plane Strength:
• Panel strength generally does not govern diaphragm shear strength.
• Reference Design Values
  • Not covered by APA PRG 320-12 product standard
  • Are covered by New ICC AC455 Acceptance Criteria
  • Ask for design values from the Manufacturers

Connection Strength:
• Commodity connectors (e.g. Nails) per NDS 2015
• Proprietary Connectors (Self-Tapping Screws) per Evaluation Reports, Manufacturer’s Information and Engineering Mechanics.
• For seismic design, select connection details so ductile limit states govern capacities.

Extensive Panel to Panel Tests
• MyTiCon & University of British Columbia
• Also Colorado State, Oregon State
Diaphragm Design Example by Spickler et al.

CROSS LAMINATED TIMBER
Horizontal Diaphragm Design Example

Our aim for this white paper is to provide a practical design method to determine the strength of a Cross Laminated Timber horizontal diaphragm and deflection due to lateral wind or seismic loads.

CLT HORIZONTAL DIAPHRAGM DESIGN

The design approach is based on compliance with engineering design of CLT in accordance with the 2015 International Building Code; reference standards, and other published information including manufacturer’s literature.

Applicable Building Code, reference standards, and other information sources:
- IBC, 2015 International Building Code
- ANSI/AMS-AD5-2015 National Design Specification (NDS) for Wood Construction with Commentary
- AWPA EP-15 Special Design Provisions for Wind and Seismic
- AASHTO LRFD Specification for Structural Steel Buildings
- AASHTO LRFD Specification for Structural Steel Buildings

Shear Wall

3 Ply CLT Panels

Lateral load, w
1000 plf (14.6 kN/m)
CLT Diaphragms in US Seismic Applications

Calculated Diaphragm Deflections

OR

Enveloped Diaphragm Design

(check for both flexible and rigid diaphragm behavior)

(check for conservatively flexible and conservatively stiff semi-rigid behavior)

Diaphragm Design Example by Spickler et al.

- Detailed design example for simple diaphragm following NDS 2015, US CLT Handbook
- Includes approximate deflection equation:
  - Modified 4-term wood panel sheathed diaphragm equation in SDWPS 15

\[ \delta_{dia} = \frac{5vL^3}{8EAW} + \frac{vL}{4G_{e}t_{e}} + C\epsilon_{n} + \frac{\sum(x\Delta_{c})}{2W} \]

\[
C = \frac{1}{2} \left( \frac{1}{P_{L}} + \frac{1}{P_{W}} \right) \]

- \( P_{L} \) is panel length
- \( P_{W} \) is panel width
- \( \epsilon_{n} \) is connector slip at diaphragm edge
Diaphragm Design Example by Spickler et al.

\[ \delta_{\text{dia}} = \frac{5vL^3}{8EAW} + \frac{vL}{4G_v t_v} + C L e_n + \frac{\Sigma(x \Delta e)}{2W} \]

0.283 in + 0.300 in + 0.568 in + 0.199 in = 1.35 in

A Real Application: Framework 12 Story Project
A Real Application: Framework 12 Story Project

Possible Modelling Approaches

Homogenous Model

Possible source of homogenous properties

Uniform diaphragm membrane model with no explicit modeling of connection joints with properties approximating effective system behavior

\[
\delta_{\text{dia}} = \frac{5\nu L^3}{8EA W} + \frac{vL}{4G_v t_v} + C L e_n + \frac{\Sigma (x\Delta e)}{2W}
\]
Possible Modelling Approaches

Explicit model of CLT panel layout with connection in limited locations. Multi directional springs to model connections.

Different connection elements types per panel length.
Few connection elements.

Discrete Panel with Corner Connections

Areas of a connection detail represented by discrete element to element MDOF springs
FEM Modeling for Design Work

• Semi-Rigid Analysis of Diaphragm in SAP 2000
• Modelled to match design example assumptions
• Concentrated Connection Model
  • 4 Springs per corner
  • With No Chord Slip, 4% difference in deflections
  • With Chord Slip, 11% difference in deflections

Framework Walls and Framing
Framework Panel Layout

Three Panel to Panel Details

Hossain et al. Static and Cyclic Testing at the University of British Columbia, Canada

Preliminary Framework Detail
Panel Detail Conditions

Typical CLT Span Direction

CLT Panels

CLT Panels Ends Supported on Beam

Panel Detail Conditions

Typical CLT Span Direction

CLT Panel Spans Over Beam
Deflected Shape: West-East Load

0.56 in (14 mm) max deflection

Deflection Shape: South-North Load

0.60 in (15 mm) max deflection
**Ideas for Near Term Seismic Diaphragms**

Possible routes for near term CLT seismic design:

1) Elastic Design Method
   - Based on lower-bound strength of components
   - Forces from non-reduced estimate of floor accelerations:
     - Non-Linear Time History Analysis of system OR
     - Following new ASCE 7-16 alternative diaphragm method to determine elastic seismic diaphragm force demands (Rs = 1.0, 0.77)

2) Capacity-Based Design Method
   - Using designated yielding connections with overstrength design of non-desirable limit states.
   - Based on yielding connection technologies of proven cyclic behavior
     - Relatively equivalent to Wood Structural Panel diaphragm behavior OR
     - Engineering and connection testing to support ductile cyclic behavior

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**Tall Wood Structural Systems**

- Tall Wood Structural Systems
  - Gravity Framing Styles
    - Post & Beam
    - Two-Way Panel Deck
    - "Honeycomb" Bearing Walls
  - Lateral Force Systems
    - Vertical Lateral/Seismic Force Resisting Systems
    - Horizontal Lateral/Seismic Force Resisting Systems
Tall Wood: A Viable Option for Today's Building Designers

Structural Systems and Approaches

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