NRC Research Update on Mid-Rise Wood Construction

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Outline

• Benefits and uses of wood structures
• Code developments to permit midrise
• R&D for solutions and performance data
• Tall wood building demonstration projects
Use and Benefits

• Increasing demand for 5 to 12 storey buildings
• Low carbon footprint and sustainable development
• Manufacturers, builders and owners want better solutions
  – lighter and faster
  – validated performance
  – cost-effective
National Building Code of Canada

Objective-based code (since 2005)

• Acceptable solutions
  Height and area limits for sprinklered wood buildings
    ➢ 4 storeys for residential/business/retail (Group C/D/E) with floor area ≤ 1800/3600 m²
    ➢ 2 storeys for assembly (Group A-Div 2) with floor area ≤ 2400 m²

• Alternative solutions
  Allowing higher and larger
    ➢ But burden of proof
Changing Building Codes

To allow 5-6 storey wood frame construction

- British Columbia Building Code amended in 2009
- Quebec Building Regulations amended Fall 2013
- Ontario Building Code proposals under review
- NBCC proposed to change in 2015 (final approval pending)
Changing Building Codes

Proposed changes in *Acceptable Solutions*

- 6 storeys Groups C/D with floor area $\leq 1500/3000$ m$^2$
  - 18 m to uppermost floor; 25 m to highest point on roof
  - Facing 1 street if $\geq25\%$ of perimeter within 15 m of street
  - Occupancy combinations (some require higher (i.e. 2-h) FRR)

- Compensatory measures
  - NFPA 13 sprinklers + in concealed space and on balconies
  - Improved fire blocking
  - Noncombustible/limited combustible cladding 90% on exterior
  - Improved safety/security and firefighter access at construction and demolition sites
Funders
• Natural Resources Canada
• Governments of Ontario, Quebec and British Columbia

Collaborators
• National Research Council of Canada
• Canadian Wood Council
• FPInnovations
• Network for Engineered Wood-based Building Systems

Providing technical info and innovative solutions to
• Support code changes to allow mid-rise wood buildings
• Facilitate use of wood structure in mid-rise buildings
• Develop performance based requirements
• Support design and construction of demo buildings
Research Objectives

• Short term – technical data for 2015 codes
  – Alternative solutions for wood structures in midrise buildings currently prescribed as noncombustible construction
  – Facilitating informed decisions
• Mid and long term – performance data
  – Height and area re-evaluation
  – Re-evaluation of types of construction
  – Performance-based requirements
Noncombustible Construction

- NBC requires noncombustible construction for buildings based on height/area.
  - To limit the probability that combustible construction materials within a storey of a building will be involved in a fire, which could lead to the growth of fire, which could lead to the spread of fire within the storey during the time required to achieve occupant safety and for emergency responders to perform their duties, which could lead to harm to persons.

- Noncombustible structural elements.
Approaches

- Encapsulation to limit susceptibility of wood-based structures to burning in fire
- Performance of fire safety, acoustic and building envelope
- Technical solutions for design/construction
Fire Research Activities

- Fire resistive assemblies
- Generic exterior wall assemblies meeting requirements CAN/ULC-S134 (to evaluate vertical spread of flame)
- Alternative solution: encapsulation of wood structural elements to delay ignition
  - Cone calorimeter
  - Intermediate-scale tests
  - Data mining
  - Apartment tests
Fire Resistive Assemblies

LWF wall assemblies for 1\textsuperscript{st}-2\textsuperscript{nd} storeys
• Fire resistance requirements
• Acoustic requirements

CLT wall/floor assemblies
• Developed FRR with FPInnovations
## Fire Resistance LWF Wall Assemblies
*(Staggered Studs with 2 Layers 12.7 mm Type X Gypsum Board)*

<table>
<thead>
<tr>
<th>Wall Assembly</th>
<th>Stud Size</th>
<th>Stud Spacing (mm o.c.)</th>
<th>OSB Shear Membrane Layer (11.1 mm thick)</th>
<th>Resilient Metal Channels @ 600 mm o.c.</th>
<th>Glass Fibre Thickness (mm)</th>
<th>Applied Load (kN)</th>
<th>Fire Endurance Period (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td># 1</td>
<td>38 mm x89 mm (2x4)</td>
<td>400</td>
<td>unexposed side</td>
<td>-</td>
<td>90</td>
<td>170</td>
<td>92</td>
</tr>
<tr>
<td># 2</td>
<td>38 mm x89 mm (2x4) triple stud</td>
<td>400</td>
<td>-</td>
<td>exposed side only</td>
<td>90</td>
<td>456</td>
<td>90</td>
</tr>
<tr>
<td># 3</td>
<td>38 mm x89 mm (2x4)</td>
<td>100</td>
<td>-</td>
<td>exposed side only</td>
<td>90</td>
<td>624</td>
<td>75</td>
</tr>
<tr>
<td># 4</td>
<td>38 mm x89 mm (2x4)</td>
<td>400</td>
<td>-</td>
<td>-</td>
<td>90</td>
<td>170</td>
<td>87</td>
</tr>
<tr>
<td># 5</td>
<td>38 mmx140mm (2x6)</td>
<td>400</td>
<td>unexposed side</td>
<td>-</td>
<td>140</td>
<td>506</td>
<td>81</td>
</tr>
<tr>
<td># 6</td>
<td>38 mmx140mm (2x6) (blocking)</td>
<td>400</td>
<td>unexposed side</td>
<td>-</td>
<td>140</td>
<td>506</td>
<td>98</td>
</tr>
</tbody>
</table>
### WALL ASSEMBLIES

<table>
<thead>
<tr>
<th># of Plies</th>
<th>CLT Thickness (mm)</th>
<th>Gypsum Board Protection</th>
<th>Load (kN/m)</th>
<th>Load Ratio (%)</th>
<th>Failure Mode</th>
<th>Fire Resistance (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>114</td>
<td>2 x 12.7 mm (1/2&quot;)</td>
<td>333</td>
<td>76</td>
<td>Structural</td>
<td>106</td>
</tr>
<tr>
<td>5</td>
<td>175</td>
<td>Unprotected</td>
<td>333</td>
<td>37</td>
<td>Structural</td>
<td>113</td>
</tr>
<tr>
<td>5</td>
<td>105</td>
<td>Unprotected</td>
<td>72</td>
<td>34</td>
<td>Structural</td>
<td>57</td>
</tr>
</tbody>
</table>

### FLOOR ASSEMBLIES

<table>
<thead>
<tr>
<th># of Plies</th>
<th>CLT Thickness (mm)</th>
<th>Gypsum Board Protection</th>
<th>Load (kPa)</th>
<th>Load Ratio (%)</th>
<th>Failure Mode</th>
<th>Fire Resistance (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>114</td>
<td>2 x 12.7 mm (1/2&quot;)</td>
<td>2.7</td>
<td>36</td>
<td>No failure *</td>
<td>77 *</td>
</tr>
<tr>
<td>5</td>
<td>175</td>
<td>Unprotected</td>
<td>11.8</td>
<td>59</td>
<td>Integrity</td>
<td>96</td>
</tr>
<tr>
<td>3</td>
<td>105</td>
<td>1 x 15.9 mm (5/8&quot;)</td>
<td>2.4</td>
<td>75</td>
<td>Integrity</td>
<td>86</td>
</tr>
<tr>
<td>5</td>
<td>175</td>
<td>1 x 15.9 mm (5/8&quot;)</td>
<td>8.1</td>
<td>101</td>
<td>Integrity</td>
<td>124</td>
</tr>
<tr>
<td>7</td>
<td>245</td>
<td>Unprotected</td>
<td>14.6</td>
<td>101</td>
<td>Structural</td>
<td>178</td>
</tr>
</tbody>
</table>

* Test was stopped due to equipment safety concerns. Failure was not reached.
Exterior Wall Assemblies

Wood-based assemblies (LWF, CLT)

- Limit fire spread on exterior
- Meet hygrothermal performance
Exterior Walls

- Generic wall assemblies meeting CAN/ULC S134
- Lightweight wood frame with spray polyurethane
  - Exterior gypsum sheathing (Passed)
  - Interior FRT plywood (Passed)
- CLT with outboard polystyrene insulation
  - Exterior gypsum sheathing (Passed)
  - Interior FRT plywood (Failed approximately 20 min)
Exterior Walls and CAN/ULC S134 Test

LWF/spray polyurethane
- gypsum
- FRT plywood
- Passed

CLT/outboard polystyrene
- gypsum
- FRT plywood
- Passed
- Passed
- Failed
Rainscreen Wall Assembly

- Screening test with predrilled cement panels
- 12.7 mm gap at 0.6 and 3.0 m
- 12.7 mm spacing behind panels
- Passed – (Problems with larger spacing)
Delay ignition and limit contribution of wood structural elements to fire severity using thermal barrier materials

- Type X gypsum board
- Cement board with fibreglass
- Gypsum concrete
Cone Calorimeter Tests

- Tests with acoustic insulation materials for floors.
- Tests with encapsulation materials to determine:
  - encapsulation time
  - ignition time
  - ignition temperature for plywood substrate.
Intermediate Scale Furnace
Standard Time-Temperature Curve

- Encapsulation Materials
  - 12.7 mm and 15.9 mm thick Type X gypsum board
  - 12.7 mm thick cement board with fibre glass
  - 25 mm and 38 mm thick gypsum concrete

- 2 layers of 15.9 mm thick plywood as substrate.
Intermediate Scale Furnace
(standard time-temperature curve)

Encapsulation Time Criteria
Average $\Delta T$: $250^\circ C$
Single Point $\Delta T$: $270^\circ C$

- Encapsulation time
- Ignition time
- Ignition temperature of plywood substrate
Data Mining
1 layer 12.7 mm Type X gypsum board

Encapsulation Time Criteria

Average $\Delta T$: 250$^\circ$C
Single Point $\Delta T$: 270$^\circ$C
Data Mining
2 layers 12.7 mm Type X Gypsum Board

Encapsulation Time Criteria
Average $\Delta T$: 250°C
Single Point $\Delta T$: 270°C
Sprinkler Reliability and Effectiveness

- **Operation reliability**: The sprinkler system operates.
- **Performance reliability**: The delivered water density meets or exceeds required amount.
- **Effectiveness**: The fire is controlled or extinguished.

\[
\text{Operation reliability} \times \text{Performance reliability} = \text{Effectiveness}
\]
Sprinkler Reliability and Effectiveness

• Hall (2013) – US experience with Sprinklers
  – Based on US statistics for 2007 – 2011
  – Sprinklers **operated** in 91% of fires in structures with fires large enough for activation.
    – Wet pipe systems – 92%; Dry pipe systems – 81%
• Sprinklers **operated** and were **effective** in 87% of fires in structures with fires large enough for activation.
  – Wet pipe systems – 89%; Dry pipe systems – 76%
Effectiveness of Sprinklers

- Mid-rise wood buildings to be fully sprinklered
- Sprinklers highly effective to control or suppress fires
- The fire studies in this presentation address extreme cases
  - where sprinklers may fail to control or suppress fire
  - Fire protection measures against the extreme cases
To demonstrate effectiveness of encapsulation

- Encapsulated wood structure – LWF and CLT
- Noncombustible structure lightweight steel frame
Apartment Scale Fire Tests

• Four Tests
  – Cross-laminated timber
  – Two Light-weight wood frame
  – Noncombustible Construction
    • Light-weight steel frame (Cold-formed steel).

• Primary Measurements
  – Temperatures measured in apartment, in wall and floor assemblies and unexposed side of wall and floor assemblies
  – Heat release rate, O₂, CO, CO₂ and smoke obscuration in smoke collected by hood
CLT Apartment Test
Apt CLT – Average Room Temperatures

115 min

after test
LWF-1 Apartment Test
Apt LWF 1 – Average Room Temperatures

- **Average Room Temperatures**
  - **Time (min)**: 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100
  - **Temperature (°C)**: 0, 200, 400, 600, 800, 1000, 1200

- **Living Room - North**
- **Living Room - Center**
- **Kitchen**
- **Entryway**
- **Average**

- **PMF-03**
- **CAN/ULC-S101**

- **40 min**

**Graphs:**
- **Bedroom**
- **Living Room**

**Legend:**
- Average temperature (1.4 and 2.4 m)
- PMF-03
- CAN/ULC-S101
Noncombustible Apartment Test

• Meet minimum code requirements.
  – 60 min fire resistance time for walls and floors.
  – Exterior wall – nonloadbearing – not fire rated (regular gypsum board interior membrane)

• Structural engineering company designed test structure using lightweight (cold-formed) steel-frame.

• Structural design reviewed by second company.

• Fire protection engineering company provided fire protection based on published information (UL listed).

• Construction company built the test structure.
Lightweight Steel Apartment Test
Noncombustible – Temperatures in Room and Ceiling Joist Spaces

**bedroom**

**living room**

26 min

**ceiling joist space**
Apt LWF 2 – Average Room Temperatures

49 min

bedroom

Average temperature (1.4 and 2.4 m)
PMF-03
CAN/ULC-S101

living room

Time (min)
0 10 20 30 40 50 60 70 80 90 100
Temperature (°C)
0
200
400
600
800
1000
1200

Average
Living Room - North
Living Room - Center
Kitchen
Entryway

CAN/ULC-S101
Heat Release Rate during Apartment Tests

The graph shows the heat release rate (in MW) over time (in minutes) for different materials. The materials marked are CLT, Noncombustible, LWF 2, and LWF1 (estimated). The graph indicates distinct peaks and trends for each material, with CLT and Noncombustible materials generally releasing more heat compared to LWF 2 and LWF1 (estimated).
The effectiveness of encapsulation in delaying the time at which the wood structural elements are affected by and eventually contribute to the growth and spread of fire is demonstrated.

Generic wood-based exterior wall assemblies are developed to limit exterior fire spread.

Generic staggered stud wall assemblies are developed for high structural load applications in midrise mid-rise (5-6 storeys) wood buildings.

Research is ongoing to develop performance based solutions

- Remove technical and regulatory barriers
- Facilitate design/demonstration of mid-rise wood buildings
- Support demonstration projects in Quebec (10/14 storeys) and Ottawa (10/12 storeys)
Thank you

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