Cross Laminated Timber (CLT)

Fire Testing Overview
Ray O'Brocki
Manager- Fire Service Relations
Disclaimer

Required by our lawyers

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Learning Objectives

• Discuss the History of CLT
• Learn about the Tall Wood Building Ad Hoc Committee
• Review the ATF Fire Tests
• Outline the Recent CLT Fire Testing at RISE
Cross-Laminated Timber
Recently-Developed Forms of Mass Timber:

Cross-Laminated Timber (CLT)

- 1985 1st CLT patent - France
- 1993 1st CLT projects - Switzerland and Germany
- 1995-1996 Improved press technology
- 1998 1st multi-story res building - Austria
- Early 2000’s
- CLT use (Europe) increased significantly
  - Green building movement driven
  - Better efficiencies, product approvals, improved marketing and distribution channels
  - Over 500 CLT buildings in England
- Recent - US and Canadian use of CLT
Project Scope

In December 2015, the ICC Board established the ICC Ad Hoc Committee on Tall Wood Buildings noting the purpose of the ad hoc committee was to

1. Explore the science of tall wood buildings
2. Investigate the feasibility, and
3. Take action on developing code changes for tall wood buildings.

This scope required further refinement by the committee.
TWB AD HOC OBJECTIVES

• TWB identified performance objectives to be met:
  • No collapse under reasonable scenarios of complete burn-out of fuel without automatic sprinkler protection being considered
  • No unusually high radiation exposure from the subject building to adjoining properties to present a risk of ignition under reasonably severe fire scenarios
  • No unusual response from typical radiation exposure from adjacent properties to present a risk of ignition of the subject building under reasonably severe fire scenarios
TWB AD HOC OBJECTIVES (Con’t)

• No unusual fire department access issues
• Egress systems designed to protect building occupants during design escape time, plus a factor of safety
• Highly reliable fire suppression systems to reduce risk of failure during reasonably expected fire scenarios. Degree of reliability proportional to evacuation time (height) and risk of collapse.
ATF Compartment Fire Test
Fire Work Group created fire test scenarios to study and validate the TWB code change proposals.

- Test structure represented multi-story condo
- 30 ft x 30 ft interior dimensions
- Corridor and stair included in the structure
- UL “modern furnishings” fuel load imposed: 570 MJ/m²

Fuel load was approximately 85th percentile of Group R fuel loads from survey of Group R’s
Two-Story Fire Test

Purpose: Perform tests of realistic fire scenarios applicable to tall wood construction in order to evaluate occupant and firefighter tenability for egress and suppression efforts, and to provide data necessary to guide further development of relevant code and standard provisions

• Conducted at U.S. government facilities (ATF)
• Supervised by U.S. Forest Product Laboratory staff
**Test Structure Floor Plan**

**Fire Work Group Plan**

- One bedroom apartment
- 30 feet X 30 feet interior dimensions.
- UL “modern furnishings” fuel load imposed 570 mj/m2
- Fuel load was approximately 95 percentile of Group R
- 20-minute rated door between compartment and corridor
- 90-minute rated door between corridor and stairwell
Two-Story Structure

- Ceiling height: 9 ft (2.7 m)
- 5-ply CLT
  - Douglas-Fir – Larch species group
  - Lamination Thickness: 1.375 inches (35 mm)
  - CLT Thickness: 6.875 inches (175 mm)
  - Polyurethane Adhesive
- Corridor around each apartment and a stairwell
- Ceiling loaded to 20 PSF
# Fire Test Scenarios

<table>
<thead>
<tr>
<th>Test</th>
<th>Description</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test 1</td>
<td>All mass timber surfaces protected with 2 layers of 5/8” Type X GWB</td>
<td>5/23/17</td>
</tr>
<tr>
<td>Test 2</td>
<td>30% of CLT ceiling area in living room and bedroom exposed</td>
<td>5/31/17</td>
</tr>
<tr>
<td>Test 3</td>
<td>Two opposing CLT walls exposed – one in bedroom and one in living room (there is a partition wall)</td>
<td>6/20/17</td>
</tr>
<tr>
<td>Test 4</td>
<td>All mass timber surfaces fully exposed in bedroom and living room. Sprinklered – normal activation</td>
<td>6/27/17</td>
</tr>
<tr>
<td>Test 5</td>
<td>All mass timber surfaces fully exposed in bedroom and living room (except bathroom). Sprinklered – 20 min delayed activation</td>
<td>6/29/17</td>
</tr>
</tbody>
</table>
Apartment Furnishings – Kitchen & Living Room

Photos provided by U.S. Forest Products Laboratory, USDA
Apartment furnishings – Bedroom & Bath

Photos provided by U.S. Forest Products Laboratory, USDA
Test #1 – All Mass Timber Protected

All mass timber surfaces protected with 2 layers of 5/8” Type X GWB
TEST #1 - 2 LAYERS GWB
Test #1 – All Mass Timber Protected

Photos provided by U.S. Forest Products Laboratory, USDA
Test #2 – 30% CLT Ceilings Exposed

30% of CLT ceiling area in living room and bedroom exposed

Live load applied using water barrels
ATF Fire Test #2 – 30% Exposed
Test #2 – 30% CLT Ceilings Exposed

Photos provided by U.S. Forest Products Laboratory, USDA
Post-Fire Condition of Glulam After Gypsum Removal

- Fire intensity decreased subsequent to consumption of furnishings and contents (known as decay phase)
- Exposed mass timber surfaces self-extinguished in the decay phase
- Mass timber surfaces protected with 2 layers of 5/8” Type X GWB remained mostly uncharred
Section of Exposed Ceiling (90º Angle)
Test #3 – Exposed Walls

Two opposing CLT walls exposed one in bedroom and one in living room
Test #3 – Exposed Walls

Photos provided by U.S. Forest Products Laboratory, USDA
Test #4 – Sprinkler Protected, Exposed
Test #4 – Sprinklers Protected, Exposed

All mass timber surfaces fully exposed in bedroom and living room.

Sprinkler – normal activation

Photos provided by U.S. Forest Products Laboratory, USDA
Test #5- Delayed Sprinkler
Test #5 – Delayed Sprinklers

All mass timber surfaces fully exposed in bedroom and living room.

Sprinkler – water delayed for 20 minutes after sprinkler activation within the test compartment...approximately 23 minutes from ignition

Flashover conditions were reached in the kitchen, and the bedroom was very near reaching flashover

The sprinkler system effectively suppressed the fire

Photos provided by U.S. Forest Products Laboratory, USDA
# Results – Event Log

<table>
<thead>
<tr>
<th>Test No.</th>
<th>1st floor</th>
<th>2nd floor</th>
<th>2nd floor</th>
<th>2nd floor</th>
<th>1st floor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Living Room</td>
<td>Bedroom</td>
<td>Living Room</td>
<td>Bedroom</td>
<td>Living Room</td>
</tr>
<tr>
<td>1</td>
<td>Flashover (600°C)</td>
<td>Flashover (600°C)</td>
<td>Flames in Hallway</td>
<td>Compartment door Fails</td>
<td>Sprinkler Activation</td>
</tr>
<tr>
<td></td>
<td>13:27</td>
<td>17:20</td>
<td>26:51</td>
<td>57:46</td>
<td>N/A</td>
</tr>
<tr>
<td>2</td>
<td>11:42</td>
<td>17:20</td>
<td>30:38</td>
<td>63:59</td>
<td>N/A</td>
</tr>
<tr>
<td>3</td>
<td>12:37</td>
<td>17:00</td>
<td>13:06 (door frame installation error)</td>
<td>29:42 (door frame installation error)</td>
<td>N/A</td>
</tr>
<tr>
<td>4</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2:37</td>
</tr>
<tr>
<td>5</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>23:00</td>
</tr>
</tbody>
</table>
ATF Fire Tests

Full Report on FPL Website:


Fire Test Videos on AWC Website:

www.awc.org/tallmasstimmer
Link to you tube videos available on this page
Research at RISE

Similar to ATF compartment tests in 2018, **EXCEPT:**

- PRG 320-18 compliant CLT
- Increased areas of exposed mass timber
Reason for Additional Testing

- **Tests performed at ATF used previous generation of CLT**
  - PRG 320-18 – compliant CLT not available at the time
  - Type IV-B exposed mass timber limits based on these tests
- **2021 IBC requires compliance with PRG 320-18**
  - Mismatch between the material requirements for CLT vs. the exposed mass timber area limits in 2021 IBC
  - Additional testing on PRG 320-18-compliant CLT needed to determine appropriate area limits
Research at RISE

Objective:
- Determine whether increased areas of exposed mass timber are justifiable using CLT compliant with PRG 320-18
Objectives

**Primary**

- Design and perform 5 compartment fire tests with **PRG 320-2018 compliant CLT** & varying amounts of exposed mass timber areas.

- Assess against performance criterion: decay of the fire is required to be continuous until 4 hours after ignition.

**Secondary**

- Design and test **intersections between exposed mass timber members**

- **Record façade exposure** allowing for comparisons with standard façade testing methods.

- **Predictive modeling**

- Case study for **restoring exposed CLT** members after a fire.
Test Configurations

<table>
<thead>
<tr>
<th>Test 1</th>
<th>Test 2</th>
<th>Test 3</th>
<th>Test 4</th>
<th>Test 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walls 2GB</td>
<td>Back wall 3GB</td>
<td>Back wall 3GB</td>
<td>Back wall 2GB</td>
<td>Back wall 3GB</td>
</tr>
<tr>
<td>Column 2GB</td>
<td>Column 3GB</td>
<td>Openings 3GB**</td>
<td>Openings 2GB</td>
<td>Openings 3GB**</td>
</tr>
<tr>
<td>Openings 2GB</td>
<td>Openings 2 GB sides; 3GB top</td>
<td>Openings 3GB**</td>
<td>Facade 1GB + 45mm SW</td>
<td>Facade 1GB + 50mm SW</td>
</tr>
<tr>
<td>Facade 1GB</td>
<td>Facade 1GB + 50mm SW</td>
<td>Facade 1GB + 50mm SW</td>
<td>Facade 1GB + 50mm SW</td>
<td>Facade 1GB + 50mm SW</td>
</tr>
</tbody>
</table>

Configurations based on a combination of:

- Performance of the previous test
- Modeling predictions
- Opinion of the steering group
Test videos

Test 1 - Exposed timber: 53.8 m²
Test 2 - Exposed timber: 91.2 m²
Test 3 - Exposed timber: 96.2 m²
Test 4 - Exposed timber: 77.9 m²
Test 5 - Exposed timber: 97.2 m²
Reference without PRG320(2018) compliance - Exposed: 67 m²
Test Videos

Test 1 - Exposed timber: 53.8 m²

Test 2 - Exposed timber: 91.2 m²

Test 3 - Exposed timber: 96.2 m²

Exposed walls intersecting in a corner: Yes

Test 4 - Exposed timber: 77.9 m²

Exposed walls intersecting in a corner: No

Test 5 - Exposed timber: 97.2 m²

Reference without PRG320(2018) compliance - Exposed: 67 m²
Fire Test Results

Internal plate thermometers Test 1

Temperature criterion @ 4h
Fire Test Results

![Graph showing temperature changes over time for different tests.](image)
Test Results

Mass loss of combustibles

Heat release rates - All tests

Flashover criterion @ 3 to 4h
## Fire Test Results – Char Depths

*Highlights increased uncertainty in char estimation due to unclear Resistograph curve.*

<table>
<thead>
<tr>
<th>Left Wall</th>
<th>Roof</th>
<th>Right Wall</th>
</tr>
</thead>
<tbody>
<tr>
<td>76 59 36 45*</td>
<td>44 33</td>
<td>42 52 48 81</td>
</tr>
<tr>
<td>86*58 47 49</td>
<td>43 43 45 41</td>
<td>47 44 58 76</td>
</tr>
<tr>
<td>79<em>68 54</em>45</td>
<td>44 43 39 40</td>
<td>45 58 59 73</td>
</tr>
<tr>
<td>57*71 58 46</td>
<td>41 45 49 44</td>
<td>47 49 53 69</td>
</tr>
<tr>
<td>81 74 47 48*</td>
<td>45 57</td>
<td>58 68 70 85</td>
</tr>
<tr>
<td>72*61 72 56</td>
<td></td>
<td>69 70 75 73</td>
</tr>
</tbody>
</table>
Fire Test Results – Char Depths

Char depths ceiling - All tests

NDS char depth (2h)
Fire Test Results – Char Depths

[Graph showing the relationship between height from floor and average char depth after test (mm) for different tests.]

- Test 1
- Test 4
- Test 2
- Test 5
- Test 3
- NDS char depth (2h)

Full panel thickness
Intersections

• All airtight sealed mass timber intersections were effective to prevent fire spread.

• One of the designed intersections had locally no airtight seal and led to smoke and some flaming through the intersection.

• Geometrical tolerances need to be accounted for.

• The sealing material does not have to be resistant against elevated temperatures if positioned in a well insulated location.
Secondary Objective

Record façade exposure allowing for comparisons with standard façade testing methods.
Facade Exposure

![Graphs showing temperature vs time for TC and PT comparisons.](image1)

![Image showing British BS 8414 test setup.](image2)
Secondary objective

Predictive modeling
Predictive Modeling

1. Calculate the fire temperature-time history using energy equilibrium.
2. Calculate temperatures of all timber elements & determine the char depth in time.
3. Calculate charring rate and corresponding CLT contribution.
4. Add mass timber contribution.

This can be used for structural calculations.
Secondary Objective

Case study for restoring exposed CLT members after a fire.
Rehabilitation of Charred CLT Video
Characteristics

• Flexural stiffness and bending capacity maintained
• Shear capacity reduced, but sufficient for most applications
Conclusions

- CLT is what makes Tall Mass Timber Buildings possible.
- CLT has been extensively fire tested.
- CLT performs very differently in fire conditions than lightweight wood construction.
Questions?
Thank you!