Learning Objectives

- Become familiar with current wood frame construction
- Become familiar with new wood frame construction
- Recognize advantages and disadvantages to various wood framing methods

Where does INNOVATION come from?

1. Rethinking Traditional Construction
   - Mid-Ply Shear Walls

2. Existing Techniques – New Applications
   - Heavy Timber Braced Frame
   - Panelized Components

3. Pre-fabrication
   - Structural Insulated Panels
   - Life Cycle Tower
   - Wood-concrete Composites

4. Newly Engineered Products
   - Cross Laminated Timber
   - Fiber Reinforced Polymers
Where does INNOVATION come from?

1. Rethinking Traditional Construction
   - Mid-Ply Shear Walls

NEESWood Capstone, National Research Institute for Earth Science and Disaster Prevention

- 6-story wood over 1 story steel MF
- 6-story wood over 1 story steel BF
NEESWood Capstone, National Research Institute for Earth Science and Disaster Prevention

• 1994 Northridge earthquake in California
  • approx. 1.16 times the intensity
  • 1.5 times the intensity
• Damage was minimal and non-structural
Concept of Midply Shear Wall

Standard shear wall
- Stud spaced at 16" o.c.
- Sheathing on one or both sides of the studs
- Sheathing fastened to the narrow face of framing members

Midply™ shear wall
- Sheathing at the center of the wall and possibly at faces as well
- Stud rotated 90 degree to those in standard shearwall
- Sheathing fastened to the wide face of framing members through stud and sheathing and into stud on the other side

How do Mid-Ply Shear Walls Work?

- Nails work in double shear thus increasing the lateral load capacity
- Greater edge distance - panel chip out failure is reduced
- Nail head away from panel surface - nail pull through failure is prevented
- Capable of accommodating additional sheathing
Midply Walls used in NEESWood Project

- **Nail spacing**
  - 3” in 1 - 3 stories
  - 4” in 4th storey
  - 6” in 5th storey

- **Framing**
  - 2 x 4 lumber for top and bottom plates
  - 2 x 6 lumber intermediate studs
  - 2 x 8 lumber for end studs

A total of fourteen 2 x 8 studs were used at the ends of the wall to meet the bearing capacity of plates.

Midply Shear Walls

- 4-story residential building in Vancouver
- Midply used in corridor and party walls
- Steel rods used to resist up-lift forces
Midply Shear Wall Resources

https://circle.ubc.ca/handle/2429/10422


Midply Shear Wall Resources


Where does INNOVATION come from?

- Existing Techniques – New Applications
  - Heavy Timber Braced Frame
  - Panelized Components

Concept of Heavy Timber Braced Frames (HTBF)

Why does steel have a monopoly on the braced frame vertical/lateral resisting system market?
How to Design a HTBF

Simpson Strong-Tie Demo Lab
1 story w/mezzanine
5000 square feet

How to Design a HTBF

• ASCE – Non-prescribed LFRS
  • Analytical & Test Data
  • Equivalency
    • Response Modification
    • System Overstrength
    • Deflection Amplification Factor

Table 1: EQUIVALENT LATERAL FORCE PROCEDURE DESIGN VALUES

| Importance Factor (ASCE 7-05, §11.5) | 1.25 |
| Response Modification Factor, R         | 3.0  |
| Overstrength Factor, \( \Omega_a \) - System | 2.0  |
| Overstrength Factor, \( \Omega_b \) - Braces | 2.5  |
How to Design a HTBF

Simpson Strong Tie Materials Demo Lab - 1st Approved HTBF
Approved under 2007 CBC and ASCE7-05
Simpson Strong Tie Materials Demo Lab – 1st Approved HTBF
Approved under 2007 CBC and ASCE7-05

- SEAOC 2010 Convention paper:
- Structure Magazine Article:
  http://www.structuremag.org/article.aspx?articleID=1221

HTBF Resources

Where does INNOVATION come from?

2. Existing Techniques – New Applications
   - Heavy Timber Braced Frame
   - Panelized Components
Panelized Walls

- Prefabricated or Factory Manufactured
- Lumber components cut & pre-assembled
- Delivered to building site.
COMPONENT ASSEMBLY TABLE

INTERIOR WALLS REMOVED FROM WALL LINE IMMEDIATELY AFTER FRAMING TABLE
Panelized Walls

WSP located on panel for automatic nailing

WSP automatically nailed @ 6”o.c.

Panelized Walls
Panelized Walls

Most panels can be handled by two men

Panelized Walls

- Benefits
  - Reduced on-site construction time
  - Reduced labor costs
  - Increased product consistency
  - Potential resistance to moisture
Panelized Walls

Benefits
- Provides increased sound proofing
- Provides decreased noise pollution
- Optimizes stud design
- Sheathing applied in factory
- Proper nailing of panels

Panelized Walls

Drawbacks
- Material costs are higher
  - Higher up-front cost
- Changes in layout and openings are difficult and costly
Panelized Walls

Bottom Line Savings:

<table>
<thead>
<tr>
<th>Description</th>
<th>Stick Frame</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Man Hours to Construct</td>
<td>401 man hours</td>
</tr>
<tr>
<td>Total Man Hour Cost @ $20/hr for Average Framing Crew Labor (Components used Cranes @ $500)</td>
<td>$6,020.00</td>
</tr>
<tr>
<td>Total Board Footage Lumber (Sheathing Panels Same for Both)</td>
<td>20,400 bd. ft.</td>
</tr>
<tr>
<td>Total Cost of Lumber @ $450/1000 bd. ft., Sheathing @ $3748.00 (same for both) and Components at Truss Manf. Bailing Price (Components include panel corners)</td>
<td>$12,628.00</td>
</tr>
<tr>
<td>Total Lumber and Panel Scrap Generated</td>
<td>17 yards</td>
</tr>
<tr>
<td>Total Scrap Cost @ $15/yd dumpster cost and 1/2 man-hour/yd to pick up</td>
<td>$425.00</td>
</tr>
<tr>
<td>Total Framing Cost for This Example</td>
<td>$21,373.00</td>
</tr>
</tbody>
</table>

- 16% Cost savings by using Components
- 26% Less wood fiber used
- 37% Less construction time

Source: NAHB

Panelized Walls

Commercial project Crozet, Virginia

Copyright © 2014 American Wood Council
Panelized Walls

Commercial project
Blacksburg, Virginia

Multi-family project built with wall panels

Panelized Walls Systems Resources

Panelized Walls Systems Resources

http://www.pathnet.org/sp.asp?id=1029

Panelized Floors

Mid-rise Construction - Arlington, VA
Panelized Floors

Mid-rise Construction - Arlington, VA

Panelized Floors

Mid-rise Construction - Arlington, VA
Panelized

• Benefits
  • Increased product consistency
  • Optimizes floor design
  • Proper nailing of panels
  • Increased speed of Construction
  • Increase job site safety

Panelized

• Drawbacks
  • Staging area required
  • Requires modular floor system
  • Changes in layout and openings are difficult and costly
Where does INNOVATION come from?

3. Pre-fabrication
   • **Structural Insulated Panels**
   • Life Cycle Tower
   • Wood-concrete Composites
Energy Efficient Products

- Structural Insulated Panels
  - 8’x24’ jumbo panels available
  - Faster erection time
  - Higher “R” values

Structural Insulated Panels (SIPs)

- Often available in 8’x4’ to 8’x24’ dimensions
- Benefits include
  - Energy efficiency
  - Ease of Construction
- Limited use in high seismic areas (335plf max)
Structural Insulated Panels (SIPs)

- Now can be used in SDC D, E, and F!
- Approved with NTA report

5.8.2. Seismic Design Categories D, E and F. The shear wall configurations in Table 10 are permitted in Seismic Design Categories D, E and F. Such walls shall be designed using the seismic design coefficients and limitations provided in ASCE 7-05 for light-framed walls sheathed with wood structural panels rated for shear resistance (SFRS A13). These SIPs shall use the following factors for design: Response Modification Coefficient, $R = 6.5$; System Overstrength Factor, $O_2 = 3.0$; Deflection Amplification Factor, $C_D = 4.0$. The maximum panel height-to-width ratio of such walls shall be 2:1 for Type L panels and 1:1 for Type S panels.

Where does INNOVATION come from?

3. Pre-fabrication
   - Structural Insulated Panels
   - Life Cycle Tower
   - Wood-concrete Composites
CREE Designed Structure - Dornbirn, Austria

30 stories
tallest timber structure in the world
Passivhous standard
All components local and prefabricated
Adaptive facade

Concept of Life Cycle Tower
CREE 8-Story Building - Dornbirn, Austria

Where does INNOVATION come from?

3. Pre-fabrication
   • Structural Insulated Panels
   • Life Cycle Tower
   • Wood-concrete Composites
Wood-concrete Composites

Composite action – reinforced concrete and wood

- Offers alternatives for:
  - Reinforced-concrete floors
  - Conventional steel composite systems
  - Flexural and two-way load bearing planks
  - Pre-stressed steel concrete hollow box floor

Wood-concrete Composites

EARTH SCIENCE BUILDING

Perkins+Will
Equilibrium Consulting Inc.
Bird Construction
$55 million
Wood-concrete Composites

Composite action – reinforced concrete and wood

- Offers alternatives for:  
  - Reinforced-concrete floors  
  - Conventional steel composite systems  
  - Flexural and two-way load bearing planks  
  - Pre-stressed steel concrete hollow box floor

Wood (LSL) - Concrete composite panels  
(4” conc., 1” insulation, over 3-1/2” LSL)
Wood-concrete Composites

Innovation
The ESB project includes the following critical structural elements:
- wood-concrete composite floor system;
- post and beam structure and connections;
- transfer trusses over the lecture theatres;
- exposed CLT roof and canopy;
- ductile chevron braces; and
- cantilevered atrium staircase.

Exterior construction shows the use of state-of-the-art post and beam materials along with composite and non-composite solid wood panels.
Wood-concrete Composites

Exposed glulam chevron bracings are used along the north façade of the ESB.

Wood-concrete Composites

Steel tension members support two story trusses at the ESB, showcasing the strength of glued-laminated (glulam) concrete composite tee sections.
Wood-concrete Composites

Where does INNOVATION come from?

4. Newly Engineered Products
   • Cross Laminated Timber
   • Fiber Reinforced Polymers
Concept of Cross Laminated Timber (CLT)

Photos provided by FPInnovations

Cross Laminated Timber
Murray Grove - Tallest Modern Mixed Use Timber Structure

- London infill project
- 29 flats (mixed affordable and private)
- Ground floor office
- 4x less weight than precast concrete
- ~1/2 the construction time of precast concrete
- Saves 300 metric tons of CO2
- 21 years of energy usage for the building
- 9 stories built in 9 weeks

Cross Laminated Timber
How does CLT work?
CLT Panel to Panel Connection Details
Traditional Fasteners (Screws, Nails)

- Screws
- Plywood or LVL
- Internal spline
- Plywood or LVL
- Single surface spline
- Double surface spline
- Half-lapped

Source: G. Traetta

Tightly joined
Single bead of construction adhesive

Copyright © 2014 American Wood Council
Typical Panel Connectors

Benefits of CLT

- Speed of Erection
- Overall Performance
  - Seismic (no soft story)
  - Acoustic
  - Vibrations
  - Fire
- Sustainable Benefits
  - Carbon footprint
  - Low embodied energy
  - Tight building envelope (high energy efficiency)
  - Little waste
- Cost Competitive
Shake Table Tests on 7-story Building

- Conducted at E-Defense
- Building weight 270t
  - Self weight 120t
  - Added weight 150t
- Panel thickness
  - 140 mm (5.5”) floors 1 and 2
  - 125 mm (4.9”) floors 3 and 4
  - 85 mm (3.3”) top 3 floors
- Wall panels length 2.3 m (7.5’)

![Building Image]

23.5m
77.1’

13.5m
44.3’

7.5m
24.6’
Bridport House, London Borough

- 41 Units
- 8 stories
Forte', Victoria Harbor, Melbourne, Australia
Architect: Lend Lease

Forte will have positively affected the environment by:
- Storing (sequestering) 761 tonnes CO₂ eq as an advantage of 1.461 tonnes CO₂ eq over concrete and steel construction
- Equivalent to taking 345 cars off the road for a year
- Saving 7.7 GJ of energy
- Lowering water consumption (the supply of excess nutrients to the water system) by 70%

In addition, the smart design and efficient systems of the building could save an average over $300 per year on energy and water bills.

Canadian Projects – 1st NA Multi-family, Quebec
Condominiums – Chibougamau, QC

Actual - 22 construction days (10 hours a day) - 5 men

Long Hall Project - Whitefish, MT
Meticulous Loading in Chronological Order to Accelerate Construction on Site

Long Hall Project - Whitefish, MT

CLT Milestone in Montana

Project Overview
Where is CLT Allowed in IBC 2015?

- Code modifications to Ch. 23 Wood
  - 2303.1.4 Structural glued cross laminated timber. Cross-laminated timbers shall be manufactured and identified as required in ANSI/APA PRG 320-2011.
  - CROSS-LAMINATED TIMBER. A prefabricated engineered wood product consisting of at least three layers of solid-sawn lumber or structural composite lumber where the adjacent layers are cross-oriented and bonded with structural adhesive to form a solid wood element.

- Code modifications to Ch. 35 Wood
  - ANSI or APA
Where is CLT Allowed in IBC 2015?

Tall Wood Building
SOM Timber Tower Research Project

- 42 stories
- Concrete Jointed Timber Frame
- Reduces carbon footprint 60-75%
Resources

- Cross-Lamination Timber: A Primer - Provides background info on the European experience & identifies potential market and cost analysis for CLT in NA

Technical Support on CLT

- A series of state-of-the-art technical reports has been prepared @ FPInnovations
  - CLT Manufacturing
  - Structural Design of CLT Elements
  - Seismic Performance of CLT Buildings
  - Connections in CLT Buildings
  - Duration of Load and Creep Factors for CLT
  - Vibration Performance of CLT Floors
  - Acoustic Performance of CLT Assemblies
  - Fire Performance of CLT Assemblies
  - Building Envelope Design in CLT Construction
  - Environmental Performance of CLT

- To order a copy of the FPInnovations CLT Handbook
Where does INNOVATION come from?

4. Newly Engineered Products
   • Cross Laminated Timber
   • Fiber Reinforced Polymers
Fiber Reinforce Polymers (FRP) in Wood Construction

- Tension reinforced Glulam
- FRP reinforced shear walls
- Blast Resistant technology

Concept of Fiber Reinforced Polymer (FRP) Glulam

<table>
<thead>
<tr>
<th>Unreinforced (0%)</th>
<th>1% GFRP</th>
<th>2% GFRP</th>
<th>3% GFRP</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.75&quot; x 66&quot; DF</td>
<td>6.75&quot; x 52-1/2&quot; DF with 6.75&quot; x 0.525&quot; GFRP on tension face</td>
<td>6.75&quot; x 45&quot; DF with 6.75&quot; x 0.9&quot; GFRP on tension face</td>
<td>6.75&quot; x 43-1/2&quot; DF with 6.75&quot; x 1.3&quot; GFRP on tension face</td>
</tr>
</tbody>
</table>
How can FRP Glulams be used?

- Currently approved for bridge applications in AASHTO

- LRFD Bridge Design Specifications: Section 8, Various Articles
- Modification to adjustment factors
  - 8.4.4.5 Volume factor
  - 8.4.4.2 Format conversion factor
  - 8.4.4.3 Wet service factor
- 8.4.1.3 Tension-Reinforced Glulams defined
  - Type of reinforcement (FRP, steel, etc.)
  - Design values determined via ASTM D7199 (ReLam meets the requirements therein)

Concept FRP Reinforced Shear Walls

**Failure Mode Differences**
- Conventional OSB
  - Single nail curvature
  - Edge tear failure
  - Less ductile
  - Lower strength

**Advanced OSB (AOSB)**
- Double nail curvature
- More ductile
- 90% nail pull-out
- 39% stronger
- 249% tougher
FRP Use in Blast Resistant Testing

Blast Testing Results

Resources

- APA – G215F
Resources


Resources


https://www.som.com/publication/timber-tower-research-project