USE OF TIMBER FOR SINGLE- AND MULTI-STOREY BUILDINGS

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SUMMARY:

• Introduction on New Zealand
• Main properties of timber (sustainability, anisotropy, shrinkage, mech. properties)
• Sawn timber, glulam, LVL, plywood
• Single-storey industrial buildings:
  ➢ Portal frames, arches, truss systems

SUMMARY:

➢ Column-to-foundation, rafter-to-column, and apex joints
➢ Bracing systems (in timber or steel)
➢ Erection
  • One- and two-storey houses

SUMMARY:

• Multistorey buildings:
  ➢ Ply shear walls
  ➢ Traditional floor systems and diaphragm action
  ➢ Innovative systems for walls and floors
• Some construction and design mistakes
• Examples of timber buildings

INTRODUCTION: NEW ZEALAND

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10 years of shallow (less than 40 km) seismicity

Use of timber for buildings

INTRODUCTION: NEW ZEALAND

EXPORT:

- **wool** (40 millions of sheep with 4 millions of residents)
- **milk, meet** and **dairy products**
- **wood** and wood-based materials

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INTRODUCTION: NEW ZEALAND

**Kauri** trees: 2 m diameter, 600 years old

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INTRODUCTION: NEW ZEALAND

**Radiata pine**: 1-2 cm thick growth rings per year. Harvest after 25-30 years

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PROS AND CONS OF TIMBER:

**PROS:**
- aesthetic appearance
- natural and sustainable material
- high strength-to-density ratio

**CONS:**
- cost
- anisotropy
- durability, if not adequately protected by the water

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**SUSTAINABILITY:**

Why to use timber? Because it is a **sustainable material** and **renewable resource**.

**Embodied energy**: energy consumed in the acquisition of raw materials, processing, manufacturing, transport to site & construction

<table>
<thead>
<tr>
<th></th>
<th>Steel</th>
<th>Timber, kiln dried</th>
<th>Glulam</th>
<th>LVL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Embodied energy [MJ/kg]</td>
<td>10.1</td>
<td>2.5</td>
<td>4.6</td>
<td>7.9</td>
</tr>
<tr>
<td>Embodied energy [MJ/m]</td>
<td>222</td>
<td>98</td>
<td>145</td>
<td></td>
</tr>
</tbody>
</table>

**Embodied effects summary**: (Canadian Wood Council)

<table>
<thead>
<tr>
<th>Environmental effect</th>
<th>Timber</th>
<th>Steel</th>
<th>Concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Embodied energy</td>
<td>1</td>
<td>1.26</td>
<td>1.57</td>
</tr>
<tr>
<td>GHG emissions</td>
<td>1</td>
<td>1.34</td>
<td>1.81</td>
</tr>
<tr>
<td>Air pollution</td>
<td>1</td>
<td>1.24</td>
<td>1.47</td>
</tr>
<tr>
<td>Water pollution</td>
<td>1</td>
<td>4.00</td>
<td>3.50</td>
</tr>
<tr>
<td>Resources</td>
<td>1</td>
<td>1.11</td>
<td>1.81</td>
</tr>
<tr>
<td>Solid waste</td>
<td>1</td>
<td>1.08</td>
<td>1.23</td>
</tr>
</tbody>
</table>

**TIMBER PROPERTIES:**

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>TIMBER</th>
<th>STEEL</th>
<th>CONCRETE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permissible stress (compr.) $\sigma_{adm}$ [MPa]</td>
<td>10</td>
<td>160</td>
<td>10</td>
</tr>
<tr>
<td>Density $\rho_m$ [daN/m³]</td>
<td>600</td>
<td>7850</td>
<td>2400</td>
</tr>
<tr>
<td>Ratio $\rho_m/\sigma_{adm}$</td>
<td>60</td>
<td>50</td>
<td>240</td>
</tr>
<tr>
<td>Elastic modulus [GPa]</td>
<td>8</td>
<td>210</td>
<td>30</td>
</tr>
<tr>
<td>Tensile strength</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Ductility</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Time dependent behaviour</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Hygroscopic behaviour</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Isotropy</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Omogeneity</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Combustibility</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

**ANISOTROPY:**

Be careful of the connection design!!!
**ANISOTROPY:**

**SHRINKAGE/SWELLING:**

\[ Shr = (\Delta L/L)100 \]

by drying the specimen from 30% to 12% of moisture content

- Tangential: \( Shr = 3.9\% \)
- Radial: \( Shr = 2.1\% \)
- Longitudinal: \( Shr = 0.1\% \)

**Use of timber for buildings**

**SHRINKAGE/SWELLING:**

Most shrinkage problems occur when timber movement is prevented by stiffer elements:

- Longitudinal: \( Shr = 0.1\% \)
- Radial: \( Shr = 2.1\% \)
- Tangential: \( Shr = 3.9\% \)

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**SAWN TIMBER:**

**GLULAM:**

Glue-laminated timber (glulam) is a solid wood member manufactured by gluing smaller pieces (planks) together.

**WHAT IS GLULAM?**

The idea is to:

- cut some planks (33 mm thick, 1500 to 5000 mm long) from a tree;
- join them lengthwise (finger joints);
- glue the laminations together.

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HOW IS GLULAM MANUFACTURED?

Jigs and pressing devices for straight members

HOW IS GLULAM MANUFACTURED?

Jigs and pressing devices for curved members

WHAT IS LVL?

• LVL is Laminated Veneer Lumber

• LVL is obtained by gluing together under pressures veneers of wood 2 to 4 mm thick produced by the rotary peeling of steamed logs.

HOW IS IT PRODUCED?

rotary peel lathe
veneer
drier
ultrasound grader
liner spreader
lay-up station
press
cross-cut saw
ripper saw

WHY IS IT PRODUCED?

The better properties are achieved because the defects such as knots are smaller and spread throughout the beam volume. Therefore each defect is less critical compared to the case of sawn timber. LVL behaves almost as clear wood.

COMPARISON AMONG STRENGTHS:

<table>
<thead>
<tr>
<th></th>
<th>Sawn timber m/c=16%</th>
<th>Glulam GL8</th>
<th>LVL (Hyspan)</th>
<th>Concrete Grade 25</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compression strength [MPa]</td>
<td>15</td>
<td>24</td>
<td>34</td>
<td>25</td>
</tr>
<tr>
<td>Bending strength [MPa]</td>
<td>10</td>
<td>19</td>
<td>42</td>
<td>3</td>
</tr>
<tr>
<td>Modulus of Elasticity [GPa]</td>
<td>6</td>
<td>8</td>
<td>13.2</td>
<td>28.8</td>
</tr>
</tbody>
</table>
PLYWOOD:

- Plywood is manufactured like LVL, but with the adjacent veneers laid at a right angle.

Unlike LVL, Plywood experiences strength and stiffness comparable in any in-plane direction. It is produced in panels which are mainly used for 2D members such as floor deckings and shear walls.

USE OF TIMBER:

For different types of buildings:
- Single-storey industrial (and swimming pool) buildings
- Single- and two-storey houses
- Multistorey buildings

INDUSTRIAL BUILDINGS:

How are they constructed?

Typically, as a series of main frames (in glulam or LVL) linked by longitudinal beams (purlins and girts).

MAIN FRAMES:

Portal frames: members and joints mainly subjected to bending

Truss systems: global bending resistance of the structure achieved through axial resistance of single members
**MAIN FRAMES:**

*Arches:* member mainly subjected to compression

**INDUSTRIAL BUILDINGS:**

*Purlins:* in Glulam/LVL

**INDUSTRIAL BUILDINGS:**

*Purlins:* I-shaped joists in LVL and plywood

**INDUSTRIAL BUILDINGS:**

*Purlins:* in truss systems

**INDUSTRIAL BUILDINGS:**

*Truss systems* in sawn timber and punched metal plate fasteners:

**INDUSTRIAL BUILDINGS:**

*Punched metal plate fasteners:* machine pressed on the timber members
TIMBER FRAMES:

RESTRAINTS:

- Pinned connection

KNEE AND APEX JOINTS

The joints need to be rigid, in order to transmit the bending moments

RIGID JOINTS:

- Compression perpendicular to grain

<table>
<thead>
<tr>
<th>Property of LVL</th>
<th>Parallel to grain</th>
<th>Perp. to grain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compression strength</td>
<td>45 MPa</td>
<td>12 MPa</td>
</tr>
<tr>
<td>Modulus of elasticity</td>
<td>10 to 13 GPa</td>
<td>1.0 GPa</td>
</tr>
</tbody>
</table>

For joints, the vastly different strength and stiffness parallel and perpendicular to the grain is the major issue.

Compression perpendicular to grain

In order to prevent crushing perpendicular to grain, one remedy is to distribute load over the faces of the members.

Nailed steel gusset plates
RIGID JOINTS:

Nailed plywood gussets

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X-band LVL gusset for large moments

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RIGID JOINTS:

Cross lapped glued joint

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Joint reinforced with a steel profile

Dowelled cross lapped joint

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RIGID JOINTS:

Joints with steel plates and epoxied rods

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Dowelled or bolted joints with steel fin plates sandwiched between LVL or glulam members

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**RIGID JOINTS:**

- Curved knee joint

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**RIGID JOINTS:**

- Splicing I-beam rafters

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**RIGID JOINTS:**

- Splicing I-beam rafters

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**LATERAL RESISTANCE:**

To make the system stable, a bracing system must be added!

**STEEL BRACINGS:**

- Designed as tension-only!

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**TIMBER BRACINGS:**

- Designed in tension and compression!

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GANTRY CRANE:

Factory glued corbel for gantry

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ERECTION:

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Use of timber for buildings

Use of timber for buildings

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SINGLE- AND MULTISTOREY HOUSES:

- Timber can be used for both vertical (walls and posts) and horizontal (floors and beams) structures.
- In the traditional timber dwelling and multistorey building, the floor is made of joists and sheathing, while the vertical structure is made of shear walls.

SINGLE AND TWO-STOREY HOUSES:

In some countries such as Canada and New Zealand, timber is used in 90% of the one- and two-storey houses.

TIMBER FRAMED HOUSES:

- Plywood or gypsum board sheathing
- Top plate
- Inner stud
- Outer stud
- Nailed connection
- Holddown strap
- Bolted connection to foundation

SHEAR WALLS:

Free body diagrams:
SHEAR WALLS:

Shear walls subjected to lateral load behave like a cantilevered deep beam where:
• shear is resisted by the panel sheathing and nailed connection to outer studs and plates
• bending is resisted by the lateral chords in tension and compression
• inner studs and nailed connection with sheathing prevent buckling of the sheathing

TIMBER FRAMED HOUSES:

MULTISTOREY BUILDINGS:

LATERAL LOAD RESISTANCE:

![Diagram of Lateral Load Resistance](image)

\[
V_p^* = \frac{wL}{2} \quad \text{(sheathing)}
\]

\[
N_t^* = N_t^* = \frac{M^*}{d} + \frac{wL^2}{8d} \quad \text{(top and bottom chords)}
\]

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TRADITIONAL FLOORS:

The flooring panels must be **staggered** and **nailed** (100 to 150 mm c/c on the edges, 200 to 300 mm c/c elsewhere) to the joists and blockings in order to achieve the **diaphragm action**.

![Diagram of Traditional Floors](image)

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TRADITIONAL FLOORS:

![Image of Traditional Floors: Plywood sheathing and Hy-beams](image)

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TRADITIONAL FLOORS:

![Image of Traditional Floors: particleboard and H-beams](image)

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MULTISTOREY BUILDINGS:

![Diagram of Multistorey Buildings](image)

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MULTISTOREY BUILDINGS

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HYBRID BUILDINGS:

Structural steel perimeter moment resisting frame
Kiln dried timber wall framing
Structural steel internal gravity post and beam system
Plywood flooring over Hybeam joists

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MULTISTOREY BUILDINGS

Innovative techniques for:

Shear walls
- Cross-laminated walls
- Solid prestressed LVL walls

Floors
- Cross-laminated slabs
- Stressed skin panels
- Concrete-timber composites

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HYBRID BUILDINGS:

LVL posts and beams gravity load system, timber floors, and steel bracing and/or concrete shear walls for the lateral loads.

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CROSS-LAMINATED PANELS:

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SOLID PRESTRESSED LVL WALLS

Energy dissipation

Self-centering

Mild Steel Yielding
(or energy dissipation devices)

Unbonded Post-tensioned (PT) tendons
(+ axial load)

Flag-Shape (FS) Hysteresis

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SOLID PRESTRESSED LVL WALLS

Dissipater

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STRESSED SKIN PANELS:

OSB panel glued to I-beams

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CONCRETE-TIMBER COMPOSITES:

Steel mesh

Timber flooring

Glued rebars

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CONCRETE-TIMBER COMPOSITES:

“Tecnaria” stud connector

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ERRORS:

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ERRORS:

Use of timber for buildings

ERRORS:

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ERRORS:

• Bolt end & edge distances?
• Washer sizes? (85mm dia. for >M20 bolt)
• Timber/steel dimensional change with moisture?
• Joint durability?

Examples:

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Use of timber for buildings

Errors:

• Epoxy grouted rods in exposed environment?
• Rod edge distances?
• Timber dimensional change with moisture vs rigid steel bracket?
EXAMPLES:

Use of timber for buildings

EXAMPLES:

Use of timber for buildings

EXAMPLES:

Use of timber for buildings

EXAMPLES:

Use of timber for buildings

The End

Thanks for your attention!