University of Ljubljana
Structural Seminar – 1 February 2007

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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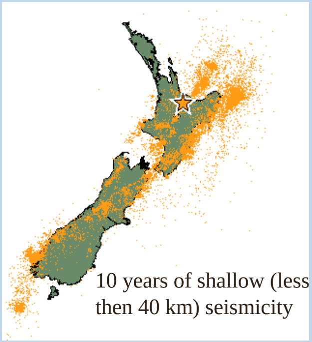


Use of timber for buildings

INTRODUCTION: NEW ZEALAND

EXPORT:

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

Use of timber for buildings

INTRODUCTION: NEW ZEALAND

Kauri trees: 2 m diameter, 600 years old

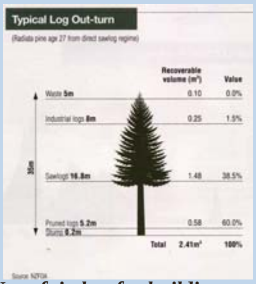
Use of timber for buildings

INTRODUCTION: NEW ZEALAND

Use of timber for buildings

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

	Steel	Timber, kiln dried	Glulam	LVL
Embodied energy [MJ/kg]	10.1	2.5	4.6	7.9
Embodied energy [MJ/m]	222		98	145

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SUSTAINABILITY:

Embodied effects summary: *(Canadian Wood Council)*

Environmental effect	Timber	Steel	Concrete
Embodied energy	1	1.26	1.57
GHG emissions	1	1.34	1.81
Air pollution	1	1.24	1.47
Water pollution	1	4.00	3.50
Resources	1	1.11	1.81
Solid waste	1	1.08	1.23

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TIMBER PROPERTIES:

PROPERTY	TIMBER	STEEL	CONCRETE
Permissible stress (compr.) σ_{adm} [MPa]	10	160	10
Density ρ_m [daN/m^3]	600	7850	2400
Ratio ρ_m/σ_{adm}	60	50	240
Elastic modulus [GPa]	8	210	30
Tensile strength	Yes	Yes	No
Ductility	No	Yes	No
Time dependent behaviour	Yes	No	Yes
Hygroscopic behaviour	Yes	No	No
Isotropy	No	Yes	Yes
Omogeneity	No	Yes	Yes
Combustibility	Yes	No	No

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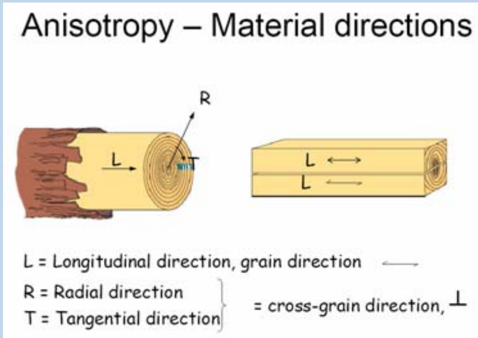
ANISOTROPY:



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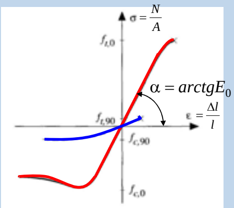
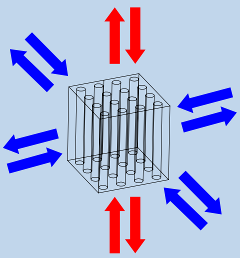
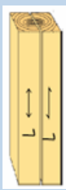
ANISOTROPY:







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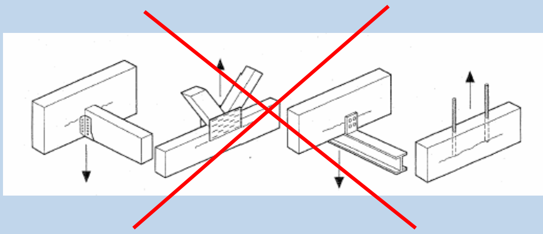
ANISOTROPY:

Be careful of the connection design!!!



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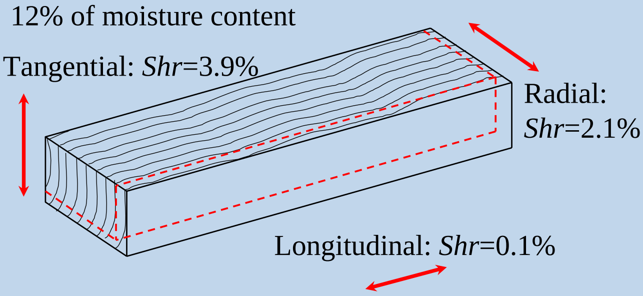
ANISOTROPY:

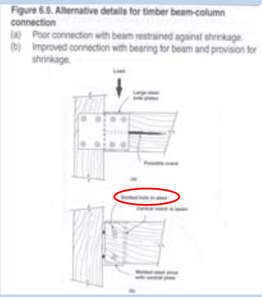
SHRINKAGE/SWELLING:

Shr=(ΔL/L)100 by drying the specimen from 30% to 12% of moisture content

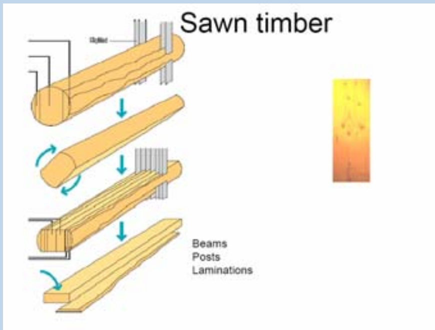


SHRINKAGE/SWELLING:

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



SAWN TIMBER:



GLULAM:

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

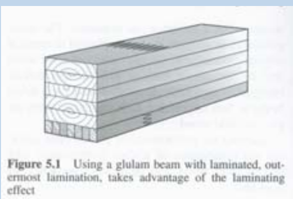
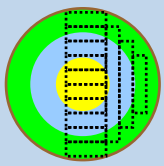


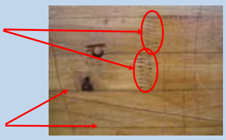
Figure 5.1 Using a glulam beam with laminated, outermost lamination, takes advantage of the laminating effect

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.



HOW IS GLULAM MANUFACTURED?

Jigs and pressing devices for straight members

Use of timber for buildings

HOW IS GLULAM MANUFACTURED?

Jigs and pressing devices for curved members

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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.

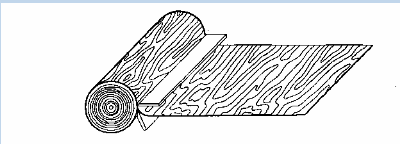

Figure 1 Production of an "endless" ply ribbon by rotary peeling.

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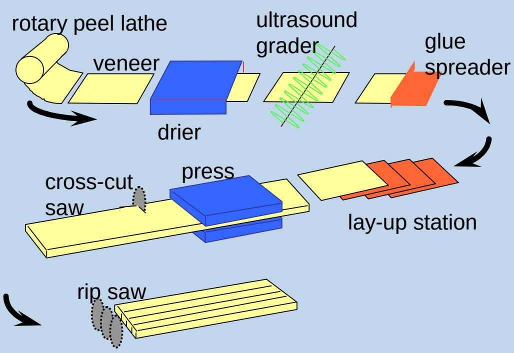
HOW IS IT PRODUCED?



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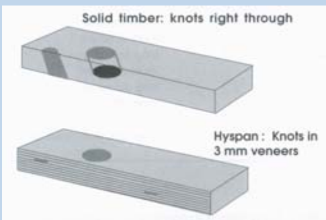
WHY IS IT PRODUCED?

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.



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COMPARISON AMONG STRENGTHS:

	Sawn timber m/c=16%	Glulam GL8	LVL (Hyspan)	Concrete Grade 25
Compression strength [MPa]	15	24	34	25
Bending strength [MPa]	10	19	42	3
Modulus of Elasticity [GPa]	6	8	13.2	28.8

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PLYWOOD:

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

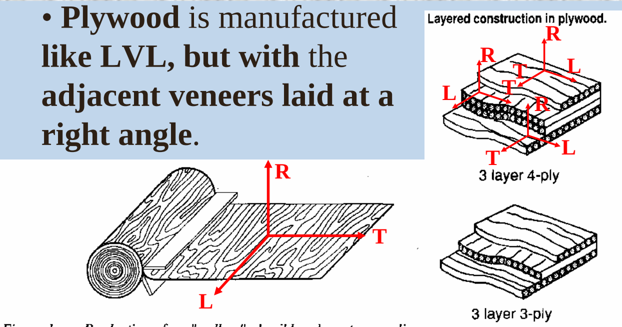

Figure 1 Production of an "endless" ply ribbon by rotary peeling.

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PLYWOOD:

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.

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USE OF TIMBER:

For **different types of buildings**:

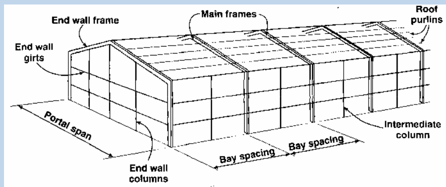
- **Single-storey industrial** (and swimming pool) buildings
- Single- and two-storey **houses**
- **Multistorey** buildings



Use of timber for 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)

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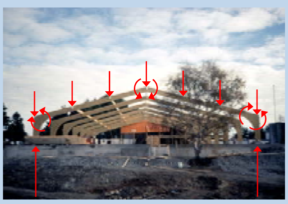
MAIN FRAMES:

Portal frames: members and joints mainly subjected to **bending**

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MAIN FRAMES:

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


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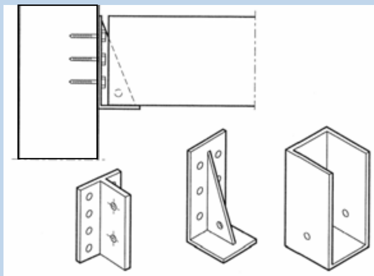
MAIN FRAMES:

Arches: member mainly subjected **to compression**

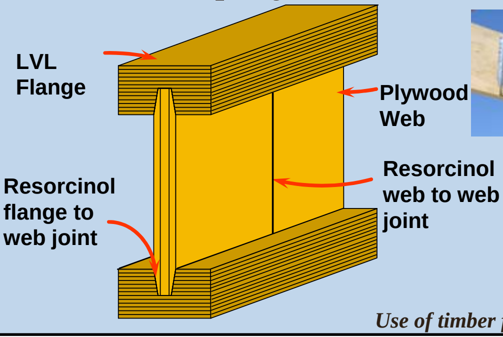

INDUSTRIAL BUILDINGS:

Purlins: in Glulam/LVL

INDUSTRIAL BUILDINGS:

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

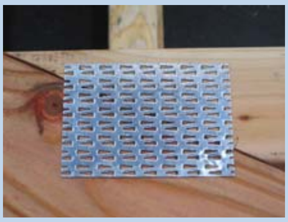


INDUSTRIAL BUILDINGS:

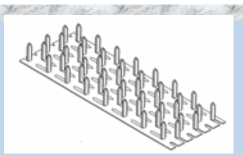
Purlins: in truss systems


INDUSTRIAL BUILDINGS:

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

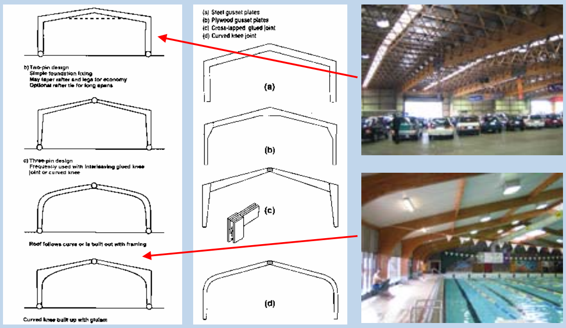



INDUSTRIAL BUILDINGS:



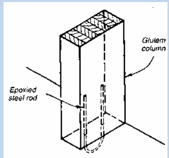
Punched metal plate fasteners: machine pressed on the timber members

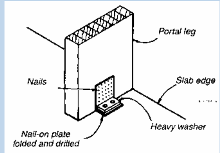

TIMBER FRAMES:



RESTRAINTS:

Pinned connection

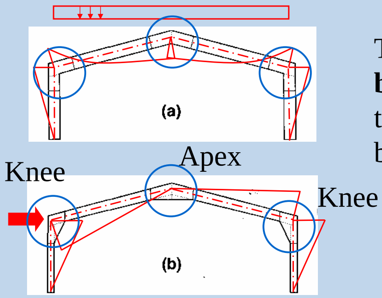




RESTRAINTS:

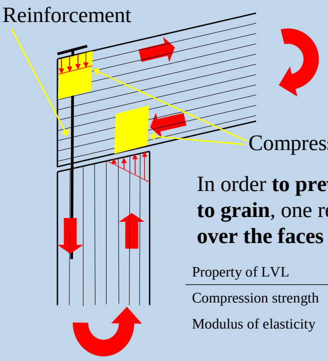
Fixed connection

KNEE AND APEX JOINTS



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

RIGID JOINTS:



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

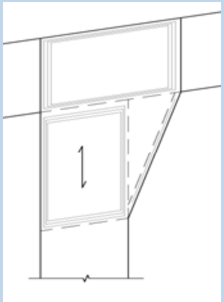
In order **to prevent crushing perpendicular to grain**, one remedy is **to distribute load over the faces** of the members

Property of LVL	Parallel to grain	Perp. to grain
Compression strength	45 MPa	12 MPa
Modulus of elasticity	10 to 13 GPa	1.0 GPa

RIGID JOINTS:

Nailed steel gusset plates

RIGID JOINTS:



Nailed plywood gussets

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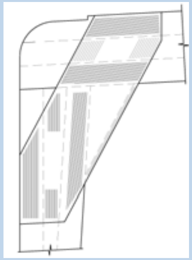
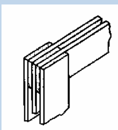
RIGID JOINTS:



X-band LVL gusset for large moments

Use of timber for buildings

RIGID JOINTS:



Cross lapped glued joint

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RIGID JOINTS:

Joint reinforced with a steel profile

Dowelled cross lapped joint

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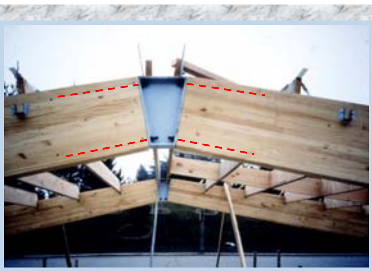
RIGID JOINTS:



Joints with steel plates and epoxied rods

Use of timber for buildings

RIGID JOINTS:

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

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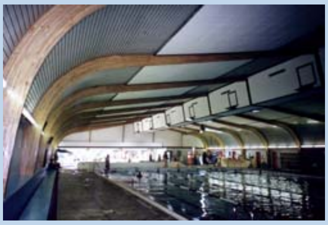
RIGID JOINTS:

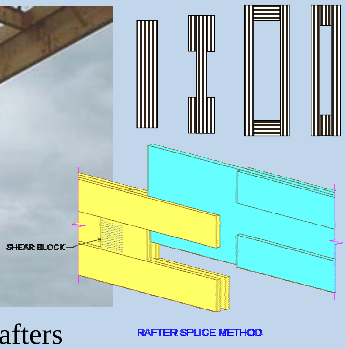



Curved knee joint

RIGID JOINTS:

Splicing I-beam rafters

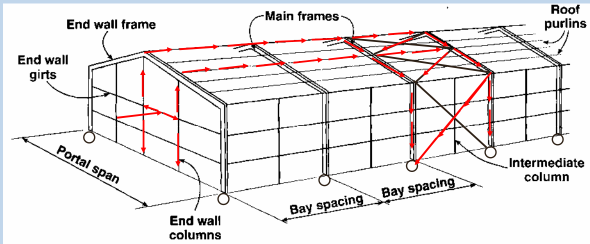
RIGID JOINTS:

Splicing I-beam rafters

LATERAL RESISTANCE:

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



STEEL BRACINGS:


Designed as tension-only!

TIMBER BRACINGS:


Designed in tension and compression!

GANTRY CRANE:

Factory glued corbel for gantry

Use of timber for buildings

ERECTION:

Use of timber for buildings

ERECTION:

Use of timber for buildings

ERECTION:

Use of timber for buildings

ERECTION:

Use of timber for buildings

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Use of timber for buildings

ERECTION:

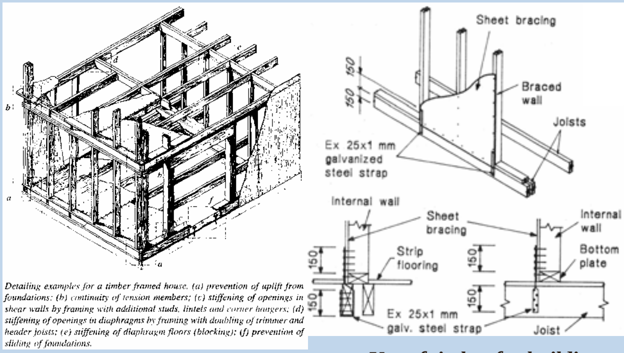
SINGLE- AND MULTISTOREY HOUSES:

- **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:

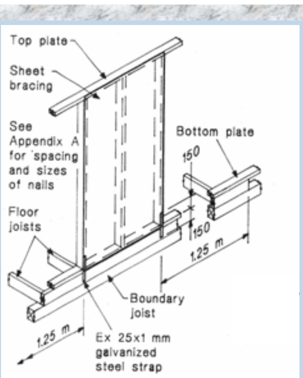
In some countries such as Canada and New Zealand, timber is used in 90% of the one- and two-storey houses

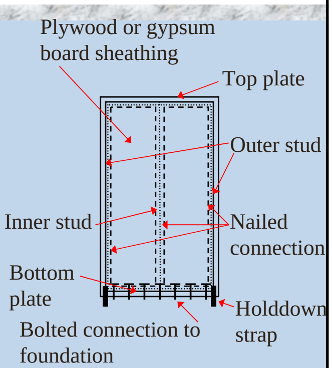
TIMBER FRAMED HOUSES:



Detailing examples for a timber framed house. (a) prevention of uplift from foundations; (b) continuity of tension members; (c) stiffening of openings in shear walls by framing with additional studs, lintels and corner hangers; (d) stiffening of openings in diaphragms by framing with doubling of trimmer and header joists; (e) stiffening of diaphragm floors (blocking); (f) prevention of sliding of foundations.

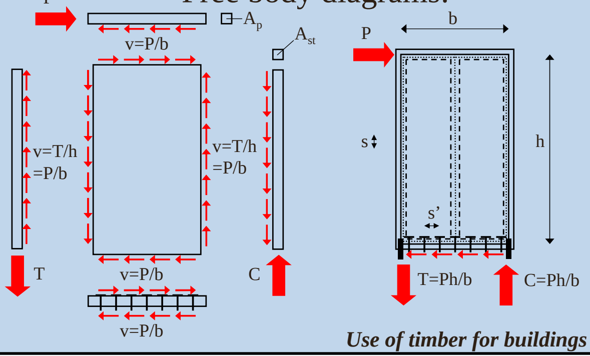
SHEAR WALLS:



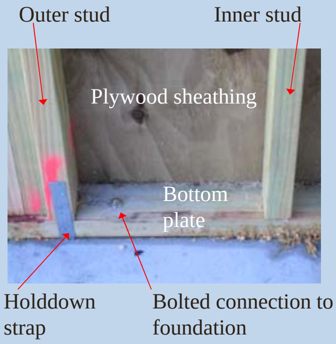


SHEAR WALLS:

Free body diagrams:



SHEAR WALLS:



SHEAR WALLS:

Shear walls subjected to lateral load behave like a cantilevered **deep beam** where:

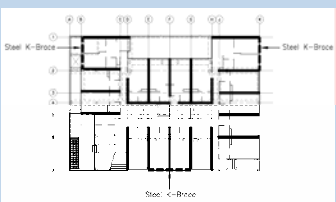
- **shear** is **resisted by** the panel **sheathing and** nailed **connection** to outer studs and plates
- **bending** is **resisted by** the **lateral chords** in tension and compression
- **inner studs and nailed connection** with sheathing **prevent buckling of** the **sheathing**

TIMBER FRAMED HOUSES:

TIMBER FRAMED HOUSES:

MULTISTOREY BUILDINGS:

Traditional solution: **ply shear walls and joisted floors.** Suitable for apartment blocks, motel, hotel and youth hostels. Maximum height: 5-8 floors.



MULTISTOREY BUILDINGS:

LATERAL LOAD RESISTANCE:

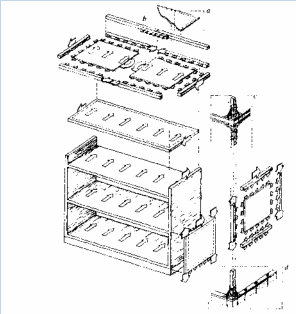
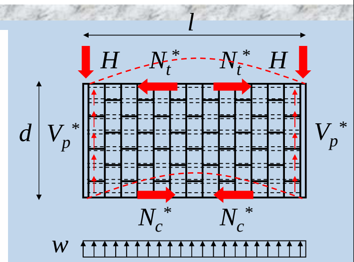


Figure 2 Details assuring structural continuity under horizontal actions. (a) corner reinforcement; (b) tension girder continuity; (c) continuity of tension studs; (d) prevention of uplifting from foundation and sliding of foundation.

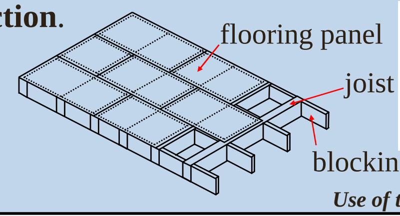


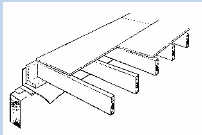
$V_p^* = \frac{wl}{2}$ (sheathing)

$N_c^* = N_t^* = \frac{M^*}{d} = \frac{wl^2}{8d}$ (top and bottom chords)

TRADITIONAL FLOORS

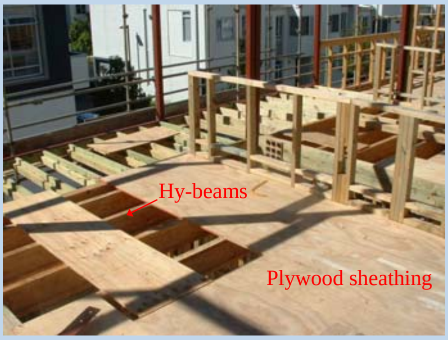
The flooring panels must be **staggered** and **nailed** (100 to 150 mm c/c on the edges, 200 to 300 mm c/c elsewhere) to the joists and blockings in order to achieve the **diaphragm action**.





Floor construction (NBI Building Details A 522.351).

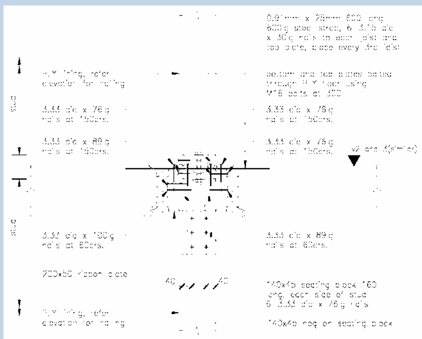
TRADITIONAL FLOORS:



TRADITIONAL FLOORS:

TRADITIONAL FLOORS:

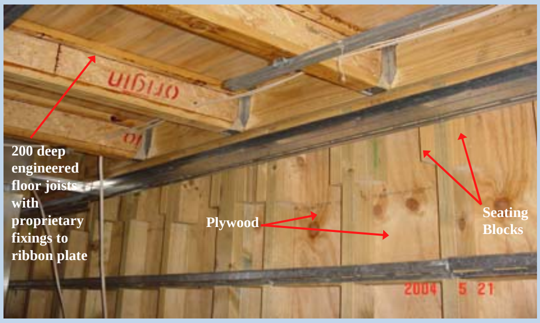
MULTISTOREY BUILDINGS



MULTISTOREY BUILDINGS

Use of timber for buildings

MULTISTOREY BUILDINGS



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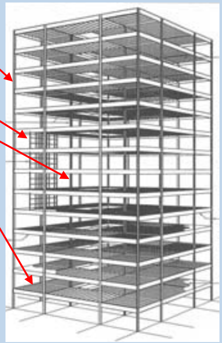
HYBRID BUILDINGS:

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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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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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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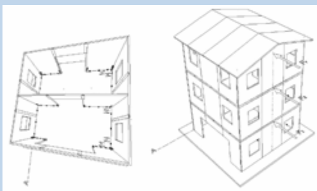
CROSS-LAMINATED PANELS:



Steel angles **Holddown anchors**

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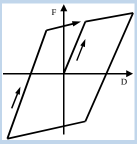
SOLID PRESTRESSED LVL WALLS

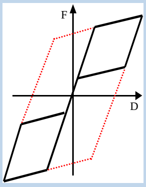
Energy dissipation



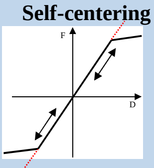
Mild Steel Yielding

(or energy dissipation devices)

+



Self-centering



Unbonded Post-tensioned (PT) tendons

(+ axial load)

Flag-Shape (FS) Hysteresis

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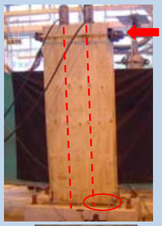
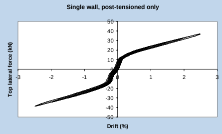
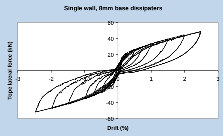
SOLID PRESTRESSED LVL WALLS







Dissipater

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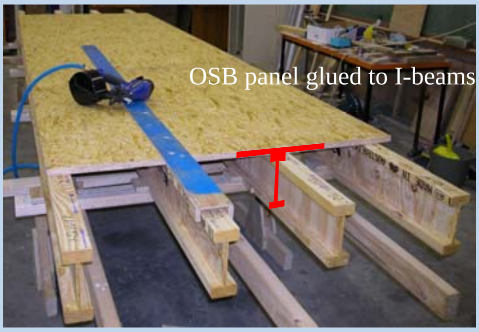
STRESSED SKIN PANELS:



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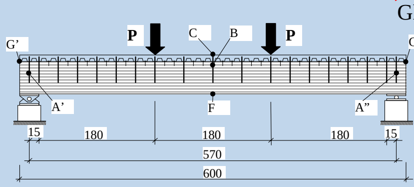
CONCRETE-TIMBER COMPOSITES:

Steel mesh

Timber flooring

Glued rebars



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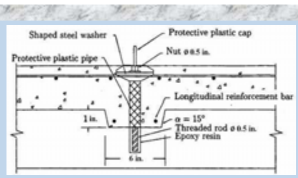
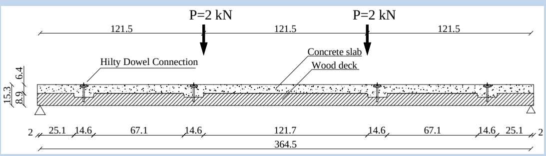
CONCRETE-TIMBER COMPOSITES:





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CONCRETE-TIMBER COMPOSITES:

“Tecnaria” stud connector

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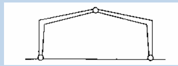
ERRORS:


Use of timber for buildings

ERRORS:





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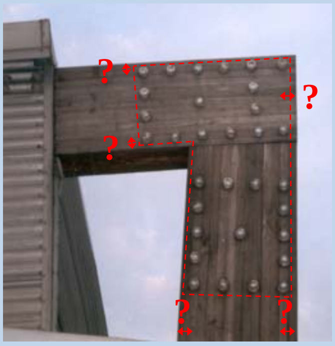
ERRORS:


Use of timber for buildings

ERRORS:



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

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ERRORS:

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

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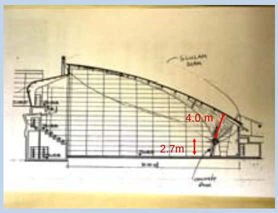
EXAMPLES:



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EXAMPLES:

Use of timber for buildings

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EXAMPLES:

Use of timber for buildings

The End

Thanks for your attention!