Steel Wood Course Hybrid

Module 1: Introduction to Timber

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Hybrid Course Outline

WeekDes	Planned Content
1	Module 1 Introduction – Limit states
2	Module 2 Tension
3	Module 3 Compression
4	Module 4 Corrosion and Software
5	Module 6 Beams
6	Module 7 Beam Columns and Plate Girders
7	Module 7 Steel Connections
8	Module 8 Composite Steel Design
9	Module 1a Introduction to Timber
10	Module 2a Design of Timber 2

This module series can be used with 3rd/4th year steel design providing these listed topics are discussed.

The module series takes approximately 4 50 minute lectures. It is based on the construct of :

***Chorlton, B., Mazur, N** and Gales, J. (June 2019) Incorporating Timber Education into Existing Accredited Engineering Programs. 10th Canadian Engineering Education Association's Annual Conference., Ottawa, Canada. 8pp.*

This module can be used in the second year materials curriculum

Typical Timber Undergraduate Course Outline

Introduction
- Wood as a green building material
- History of wood structures

Physical and mechanical properties of wood
- Molecular and cell structure
- Physical properties
- Mechanical properties

Structural wood products & structural forms

Strength and modification factors
- Specified strength of wood, size, use, species and grades
- Modification Factors
- Shrinkage calculation
- Modification factors

Fire Safety

Design Process
- Limit States Design – Ultimate & Serviceability Limit States

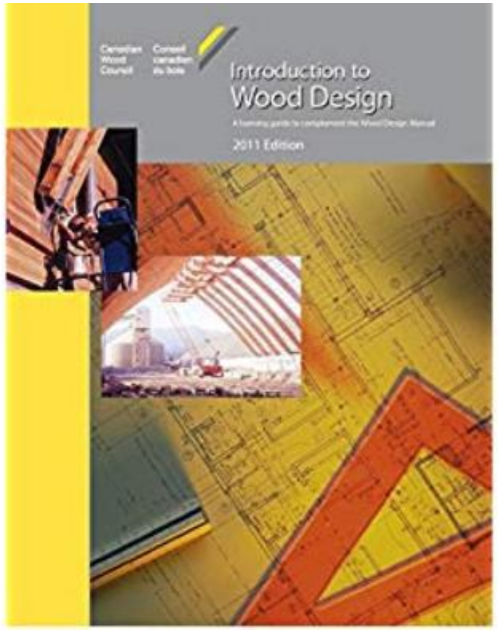
Design of Tension Members

Design of Compression Members

Design of Bending Members

Combined bending and axial load

Connections



Red we will cover in module 1.
Blue is covered elsewhere in Steel Design.
Purple covered elsewhere in Module 2.
Diaphragms are not covered herein

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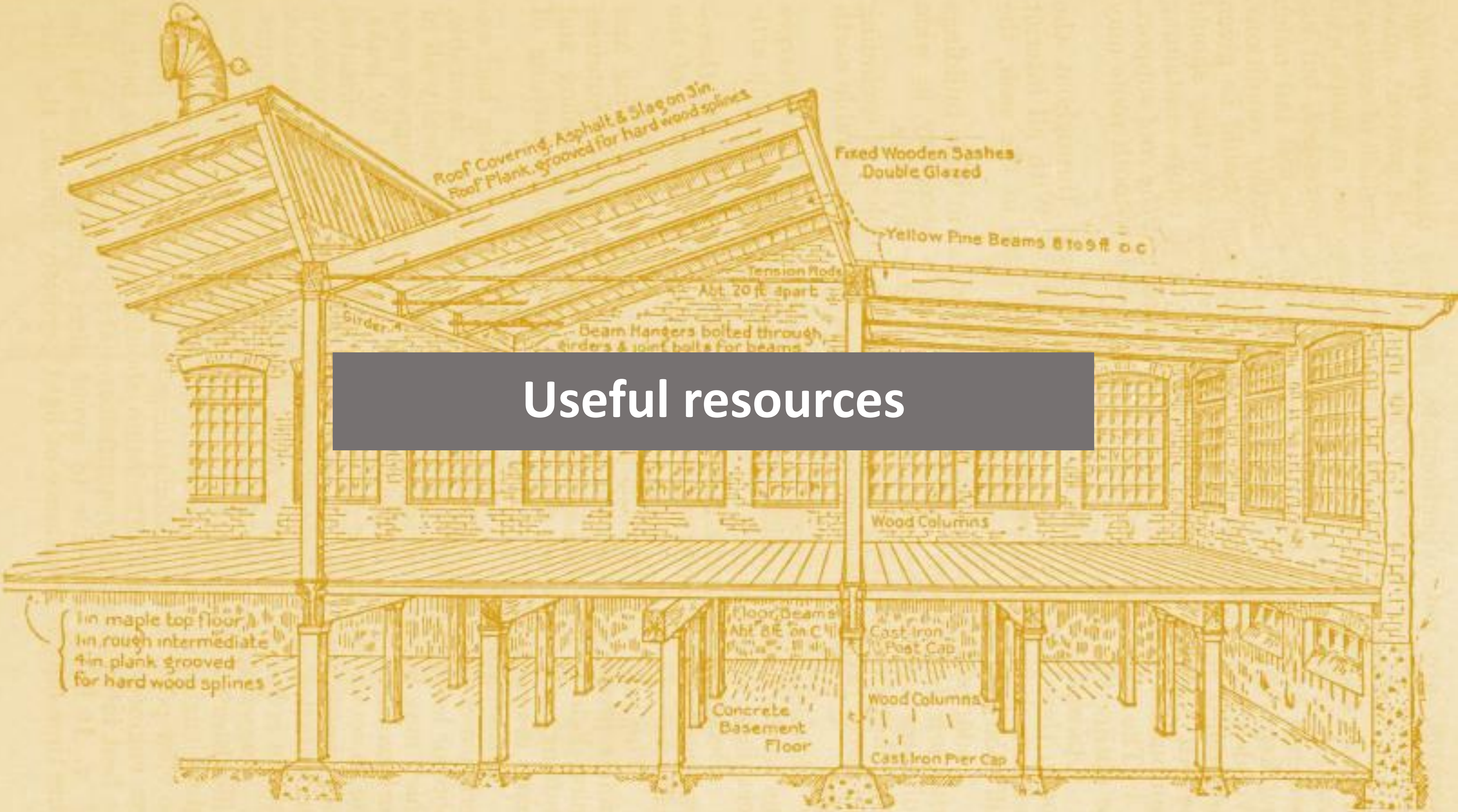
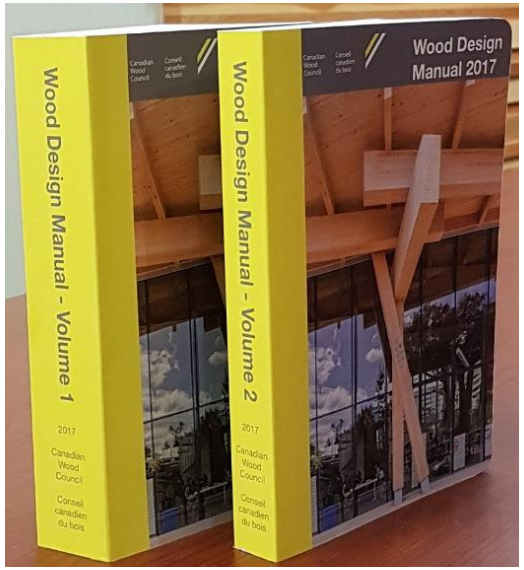
Useful resources



Useful Reading Materials



1. CWC. 2017. Wood Design Manual vol. 1 & 2. Contains CSA O86-14 with Updates 1 & 2. Canadian Wood Council. (Available for purchase w/ student discount)

2. CWC. 2018. Introduction to Wood Design. Canadian Wood Council. (Available for purchase w/ student discount)

3. Carla Dickof, Nick Bevilacqua, Reed Kelterborn. 2020. Low-Rise Commercial Mass Timber Design Example. Fast + Epp, Canadian Wood Council. (PDF is provided)


Low-Rise Commercial Mass Timber Design Example

Fast + Epp
201 - 1672 West 1st Avenue
Vancouver BC V6J 1G1
mail@fastepp.com
604.731.7412

April 20, 2020

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Wood Design Manual

Ordering a Wood Design Manual

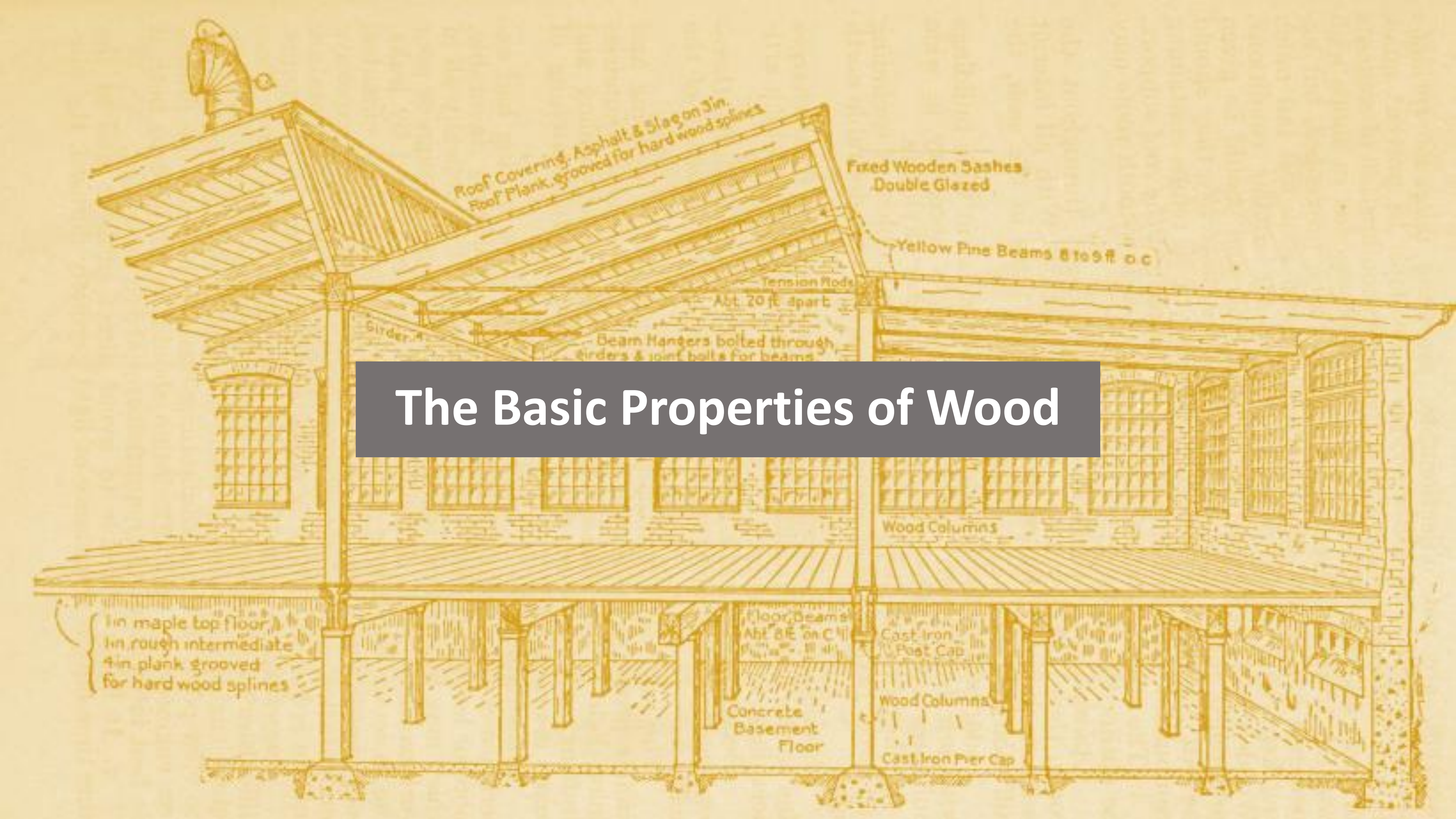
-Can be purchased from the Canadian Wood Council

https://webstore.cwc.ca/

-Student discounts available (see https://webstore.cwc.ca/student-promotion/)

1. Create an account or sign in at webstore.cwc.ca
2. Select your items (e.g., Wood Design Manual) and View Cart
3. Enter Coupon Code 'Student'
4. Place your order – on the checkout page, upload an image of the front and back of your student id card (alternatively, after placing the order, email the images to orders@cwc.ca - your order will be on hold until they receive this)
5. You will then receive an order confirmation

The Basic Properties of Wood



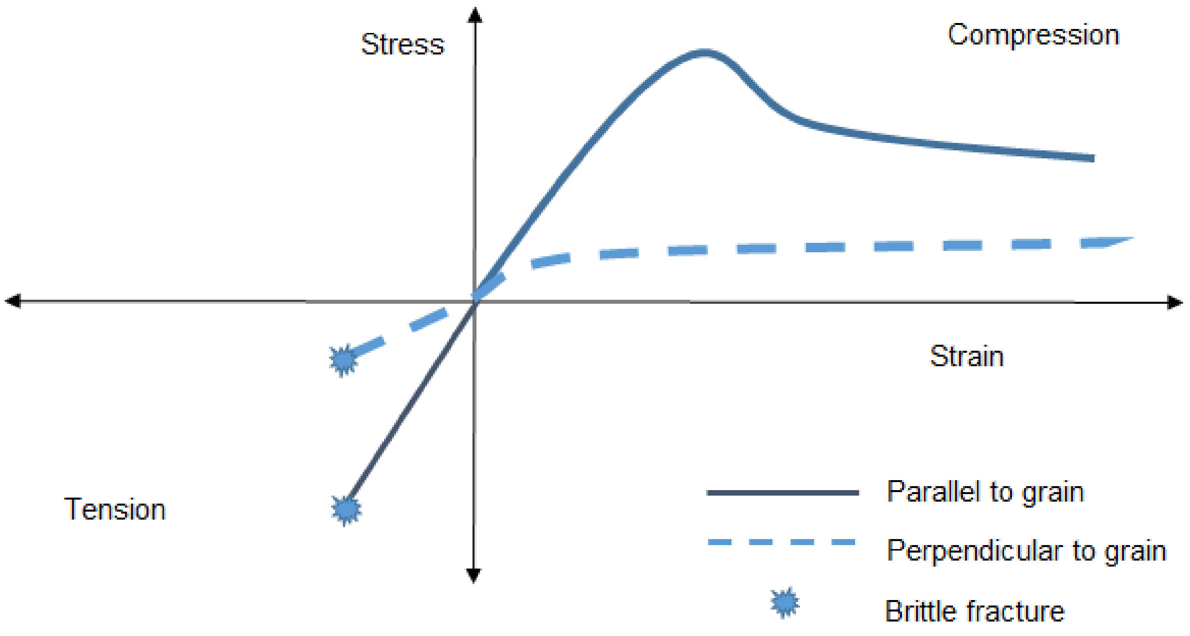
Why Wood? - BioPhilia

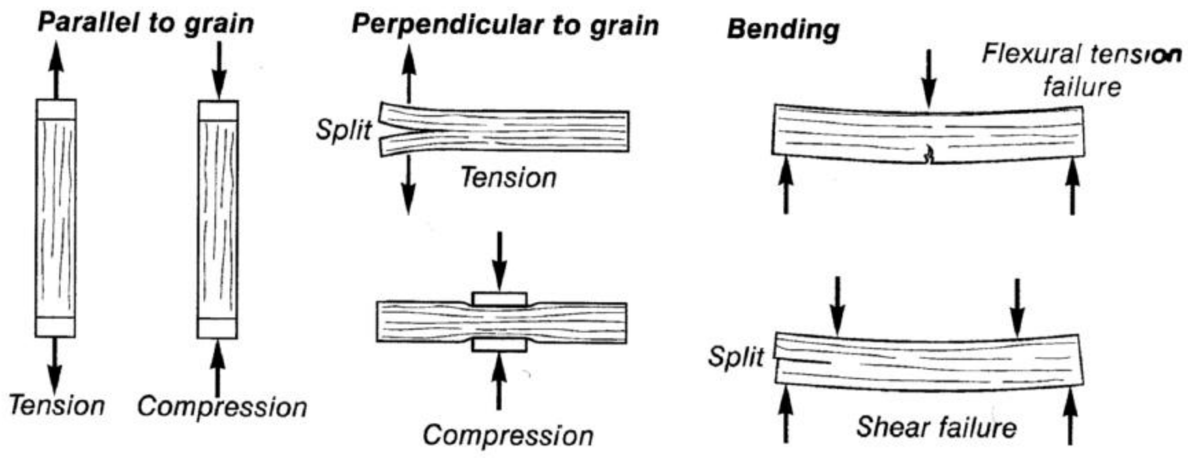
Introduction

- Wood is one of the oldest structural material for construction.
- There are approximately 30,000 species of wood.
- Civil engineering uses : natural wood and engineered wood.

- Wood is one of the most widely used building materials because of its:
  - Natural beauty
  - Availability
  - Relatively low cost
  - Ease of production
  - Ease of use
  - Low density
  - Biodegradable
  - Sustainable (e.g. renewable)
  - Durability (if used properly)

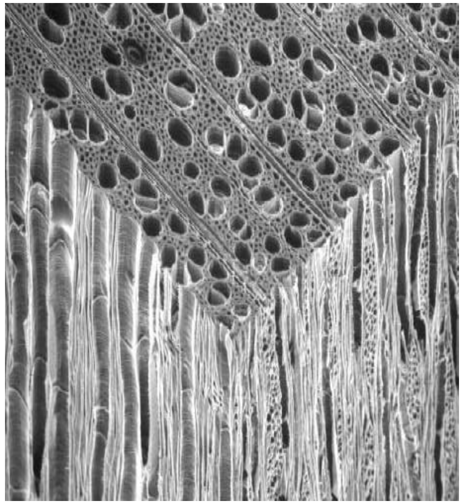
Response of Wood to Load





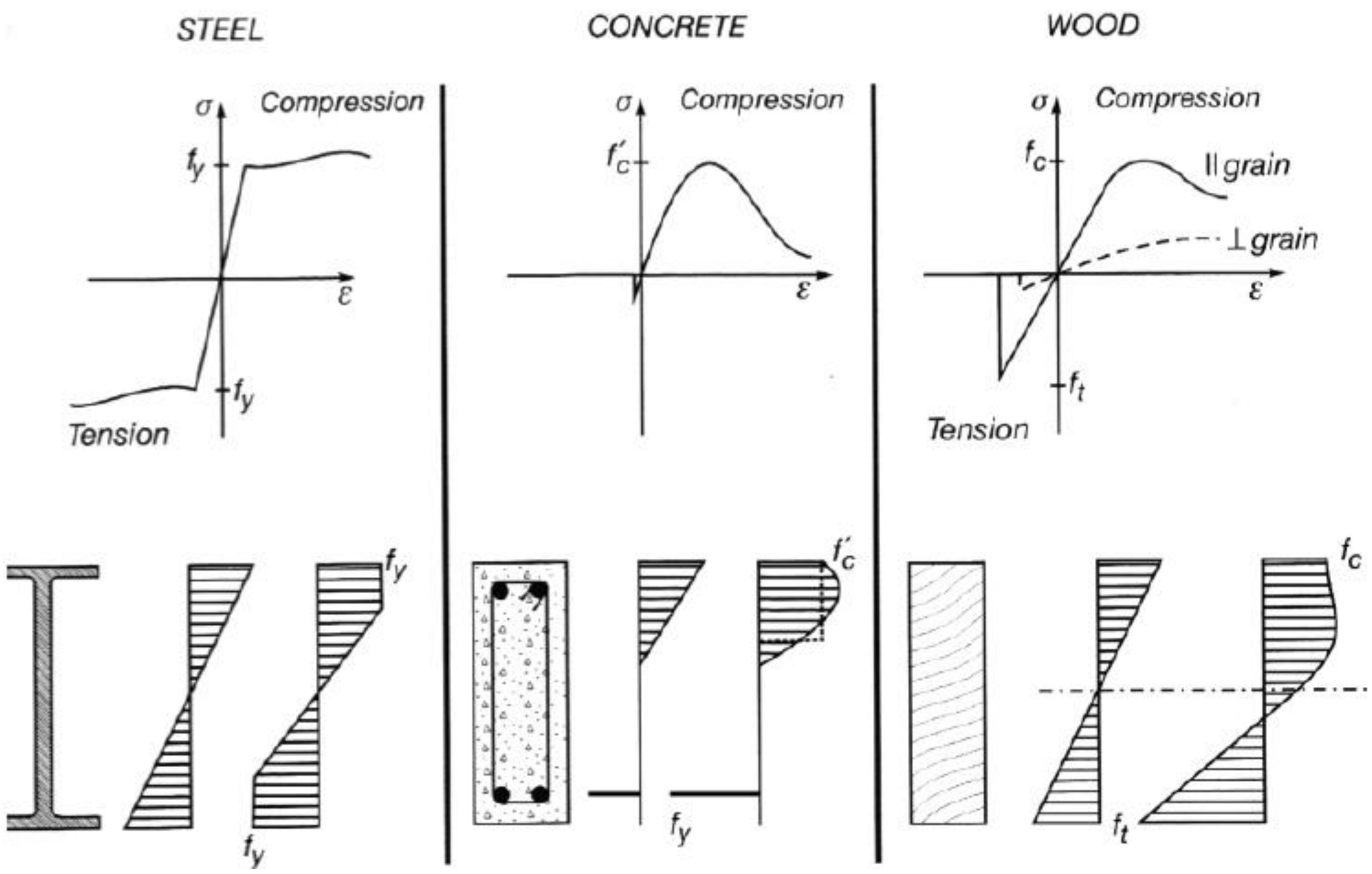
•The behavior of timber is based upon how load is applied to the orientation of the grain. This is critical in how to maximize the performance of the material.

Exercise: Response of Wood to Load



•As an illustration, obtain a bundle of paper straws. Bundle these and restrain on each end an elastic. Now regarding the previous slide, apply force to the bundle by compressing at both ends, then apply force perpendicular (the side of the bundle). This is no different to how timber in general handles loading cases. Strong compression parallel to the grain, Weak in compression perpendicular the grain. In this case the grain direction is the straw length. This is an effect called Anistropy.

Response of Wood to Load compared to other common materials



Classification of Wood

Softwood

- Evergreen or conifers.
- **Keeps needles all year round.**

Softwoods

- Douglas Fir
- Redwood
- Balsam Fir
- **Eastern White Pine**
- Sitka Spruce
- Eastern Hemlock
- etc…

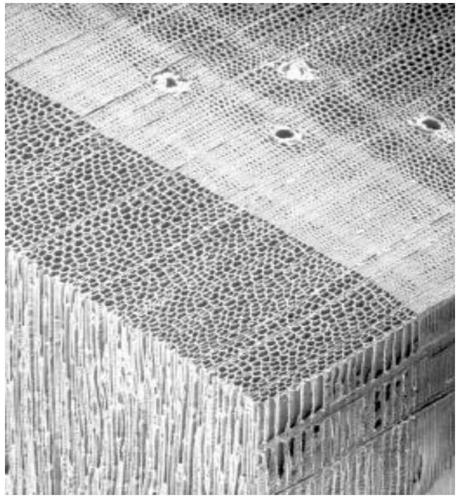
Hardwood

- Deciduous or broad-leaved.
- **Leaves change color and shed in the fall.**

Hardwoods

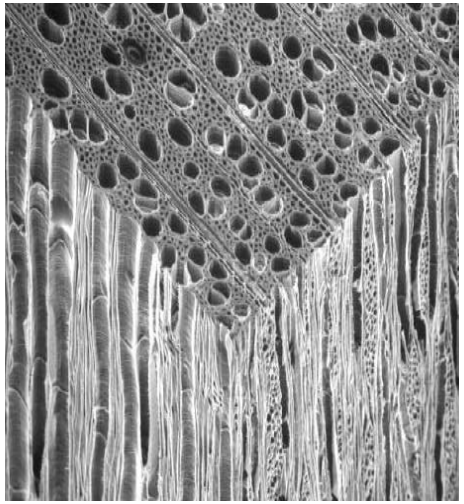
- Ash
- Basswood
- Birch
- Elm
- Oak
- **Maple**
- etc…

Softwood-Short Leaf Pine



Hardwood-Black Cherry



Softwood

- Conifers grow in large strands and **mature rapidly**, making them **economical to harvest**.
- They also grow more **uniformly** than hardwoods making them somewhat more homogenous (although they are still **anisotropic!).**
- About **20 different species** of conifers are harvested in North America and these **are widely used in structural applications**.

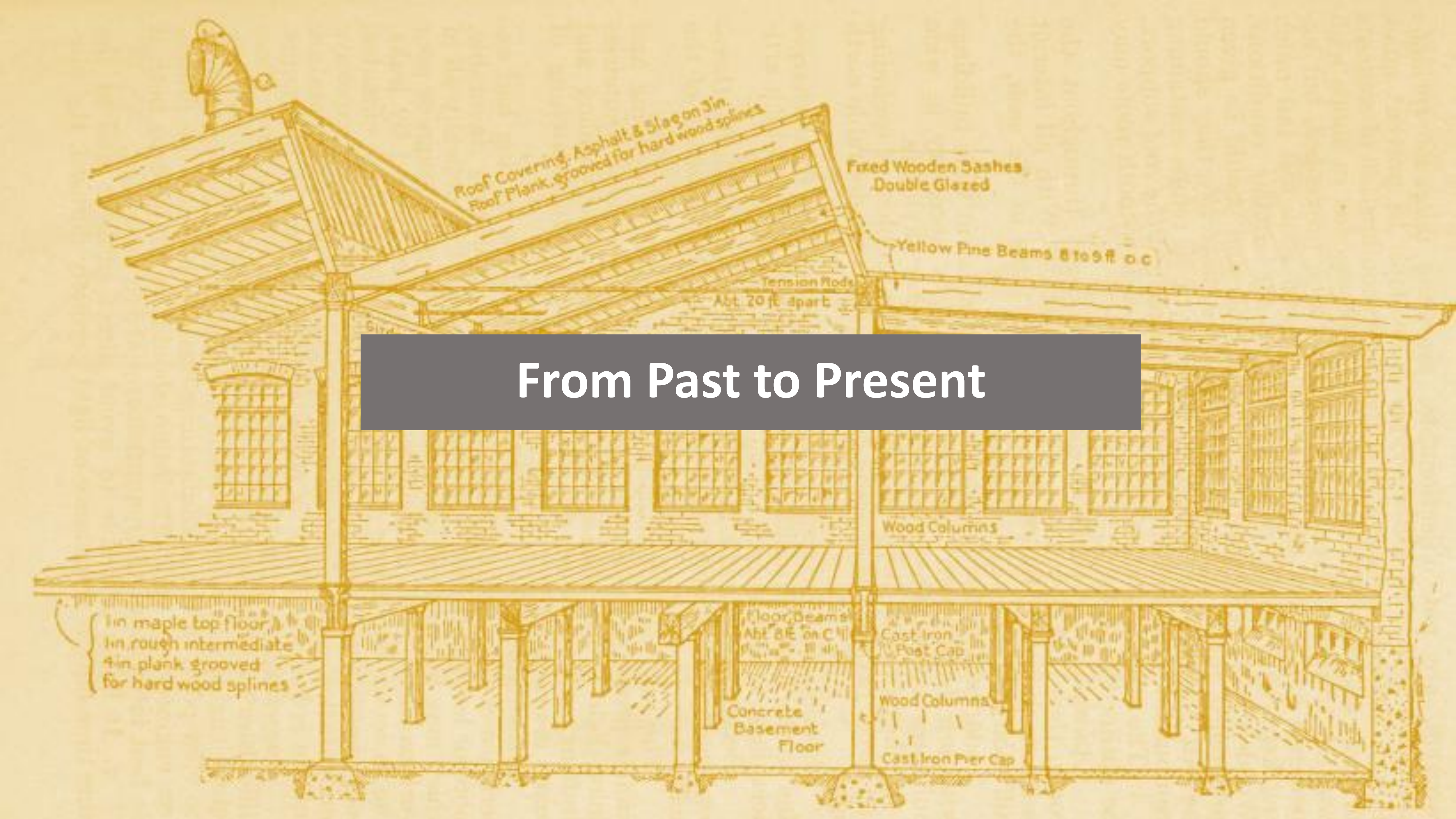
Typical Species in Construction

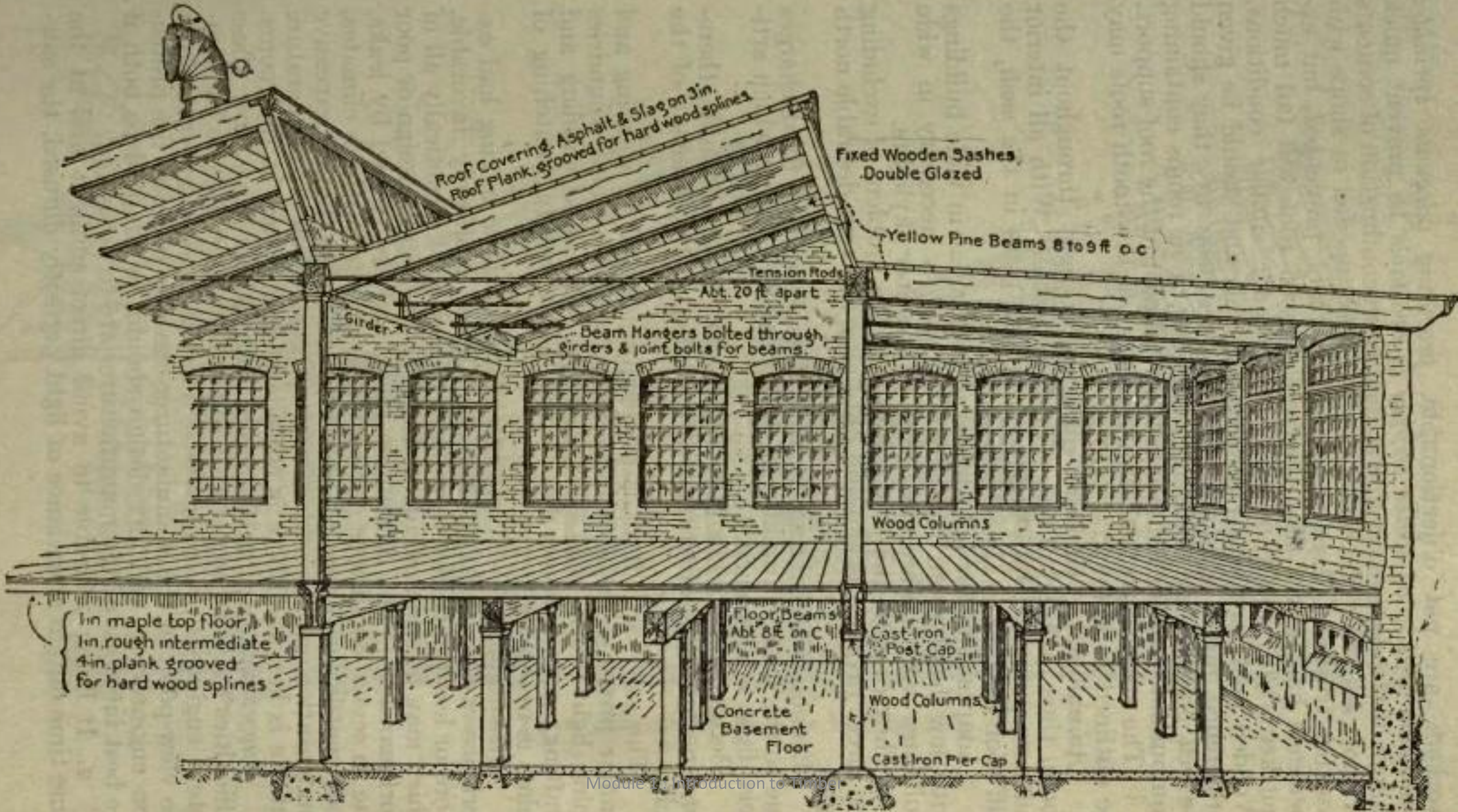
Species combinations	Stamp identification	Species included in the combination
Douglas Fir-Larch	D Fir-L (N)	Douglas fir, western larch
Hem-Fir	Hem-Fir (N)	Pacific coast hemlock, amabilis fir
Spruce-Pine-Fir	S-P-F	Spruce (all species except coast Sitka spruce), Jack pine, lodgepole pine, balsam fir, alpine fir
Northern Species	North Species	Any Canadian species graded in accordance with the NLGA rules

Hardwood

- About 40 different species of trees are exploited commercially in North America. Due to the **relative expense of hardwood**, its application is generally restricted to the manufacture of furniture and decorative veneers. **Very little hardwood is used for structural applications.**

From Past to Present



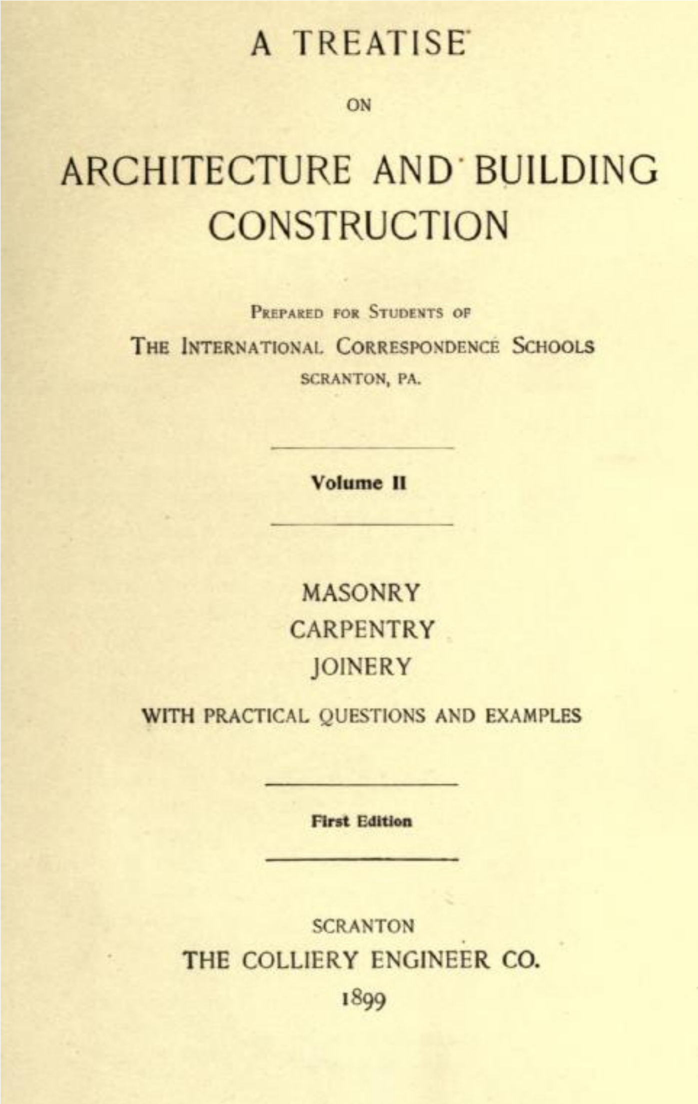

Roof Covering. Asphalt & Slag on 3in.
Roof Plank, grooved for hard wood splines
Fixed Wooden Sashes
Double Glazed
Yellow Pine Beams 8 to 9 ft o.c
Tension Rods
Abt. 20 ft apart
Girder
Beam Hangers bolted through
girders & joint bolts for beams.
Wood Columns
1in maple top floor,
1in. rough intermediate
4in. plank grooved
for hard wood splines
Floor Beams
Abt 8ft on C
Cast Iron
Post Cap
Concrete
Basement
Floor
Wood Columns
Cast Iron Pier Cap

Structures you will encounter in Canada

- Most heritage structures in Canada still existing today are made using timber. Typically hard woods as these were in abundance at the time of construction. So there is a necessity to understand their construction.
- By the late 1800s timber was recognized as ‘slow burning’ construction due to its size up effect and a predominate choice of material in industrial design such as mills.
- These structures are commonly in need of understanding because of the adaptive re-use aspects (commonly called brick and beam).

Structures you will encounter in Canada

- Scranton wrote in 1899 “ A Treatise on Architecture and Building Construction” volume 2.
- The document exemplifies the design process (Carpentry) of the time and was the go to text book for engineers building timber structures in the late 19th century.
- It is useful because it describes the load paths efficiently of these early structures and the explanation for various design decisions of the time.


A TREATISE

ON

ARCHITECTURE AND BUILDING CONSTRUCTION

PREPARED FOR STUDENTS OF

THE INTERNATIONAL CORRESPONDENCE SCHOOLS

SCRANTON, PA.

Volume II

MASONRY

CARPENTRY

JOINERY

WITH PRACTICAL QUESTIONS AND EXAMPLES

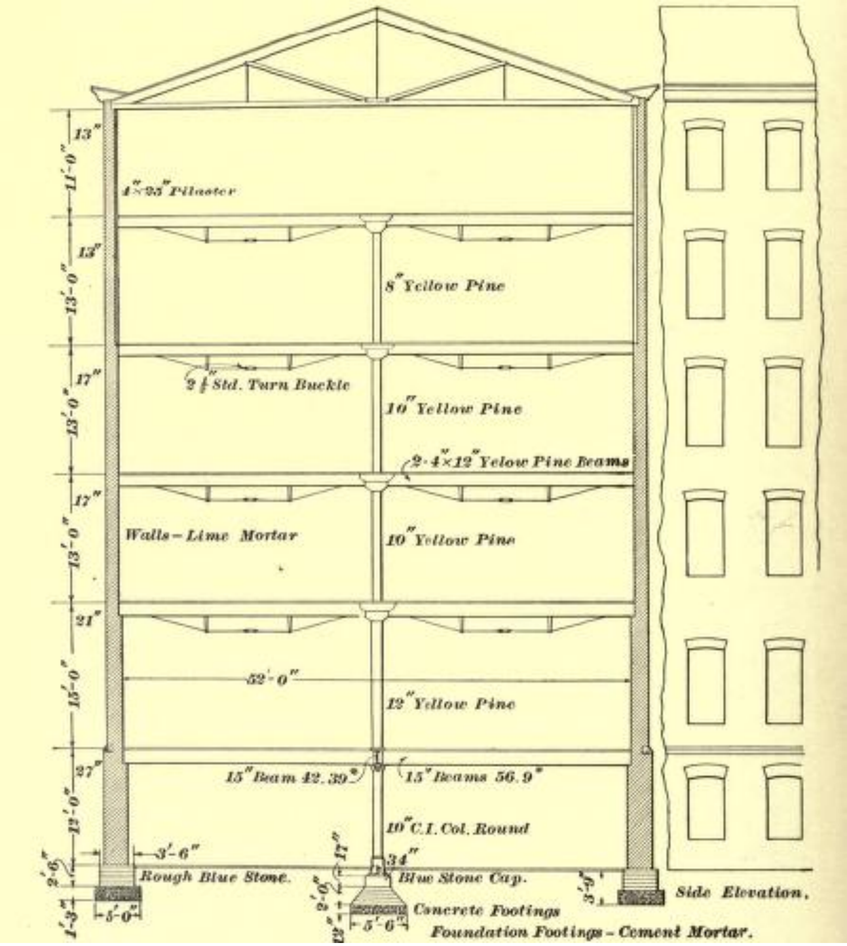
First Edition

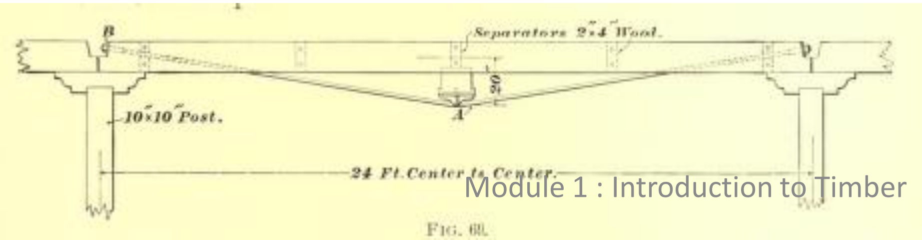
SCRANTON

THE COLLIERY ENGINEER CO.

1899

Structures you will encounter in Canada





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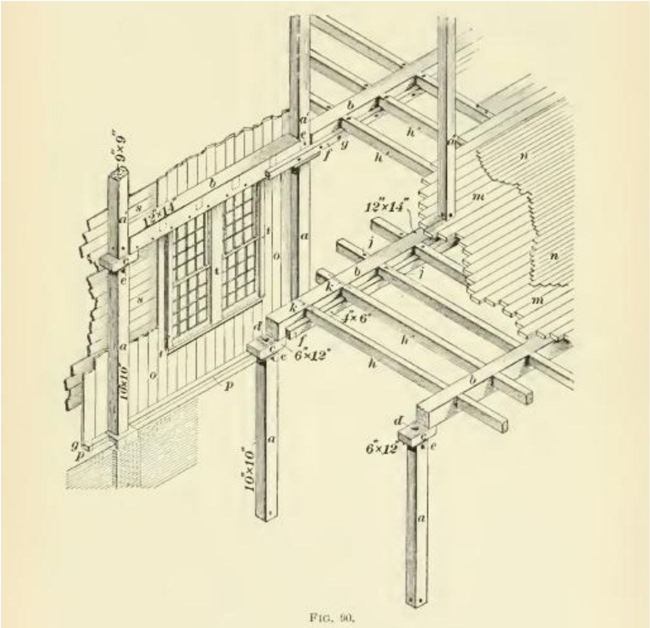
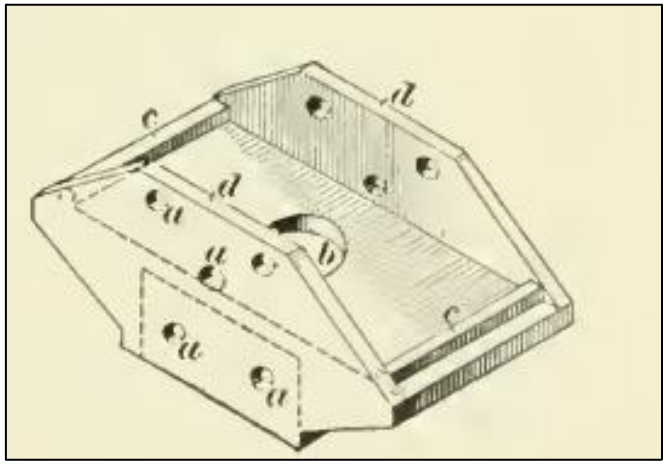
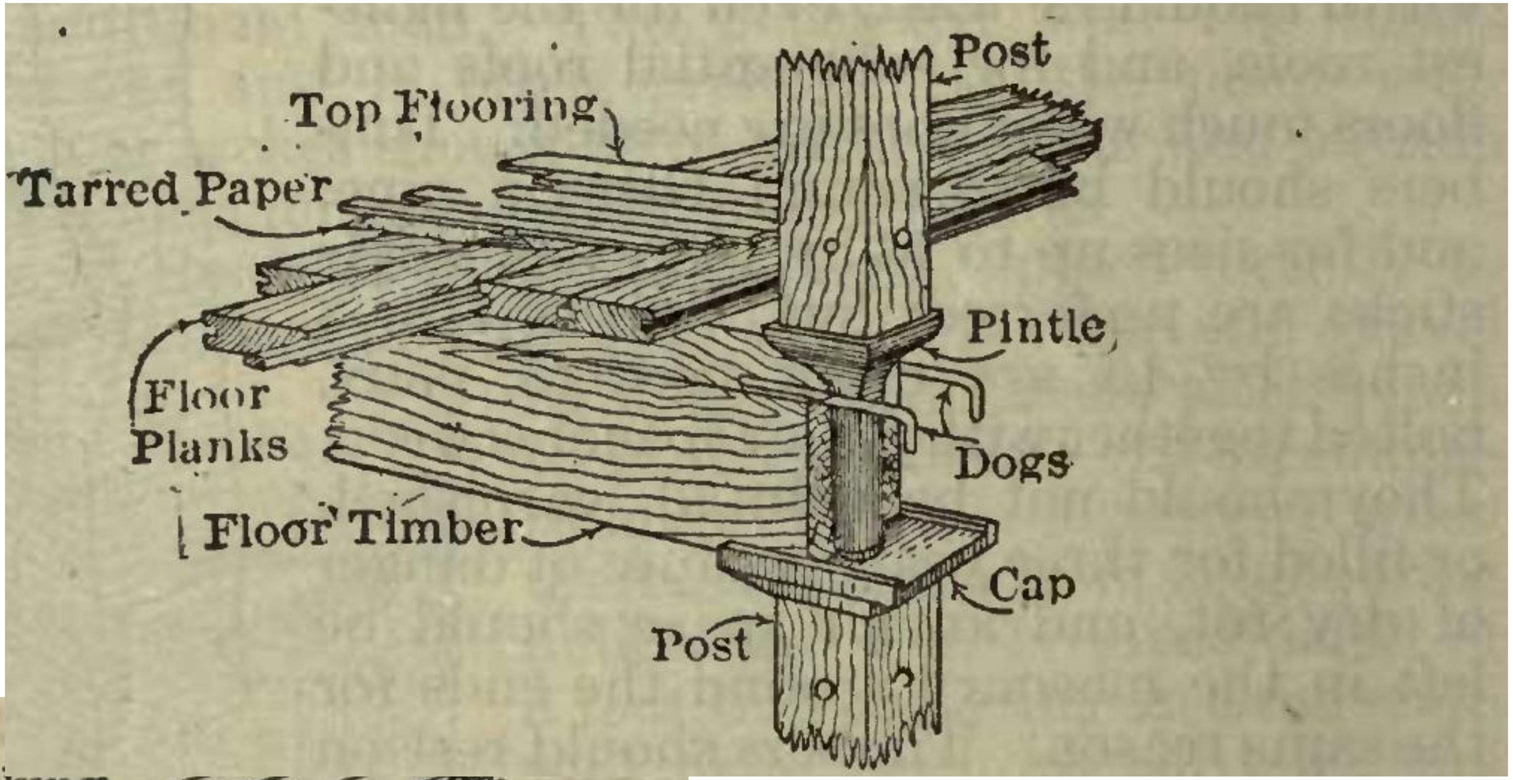
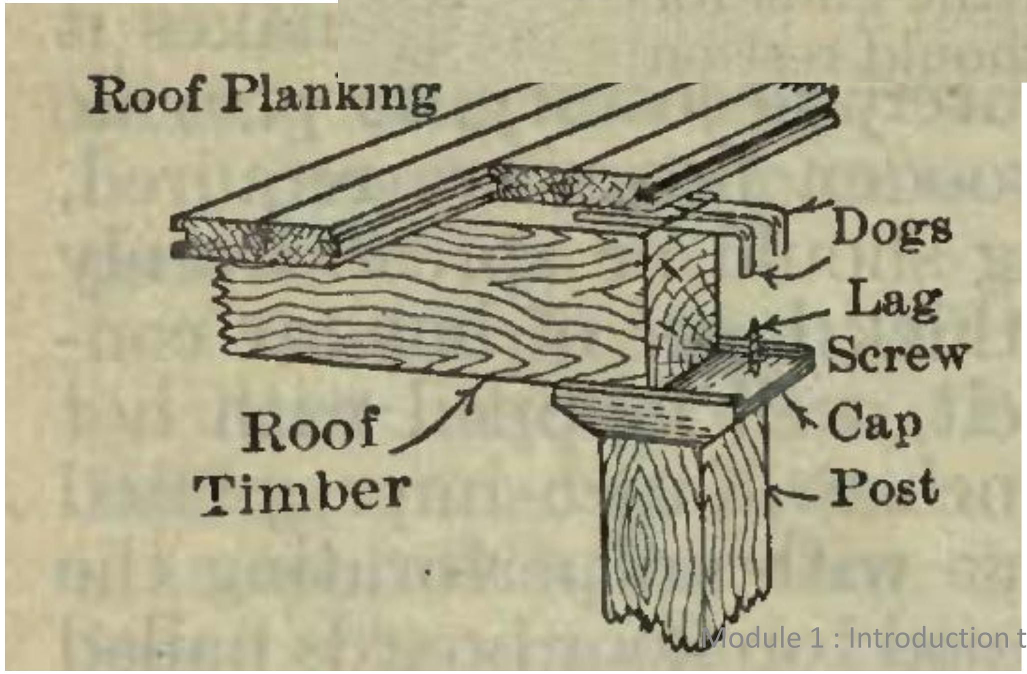
Structures you will encounter in Canada

- Classical construction is either by braced, balloon framed (assembled and locked versus nailed) or slow burning construction (members enlarged).
- Slow burning construction is quite common to see in heritage buildings (industrial, houses and barns)









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Structures you will encounter in Canada

- Typical sizing to expect per below

	Balloon-Frame Building Not Over 1,500 Sq. Ft. Area.	Balloon-Frame Building Over 1,500 Sq. Ft. Area.	Braced-Frame Building Not Over 1,500 Sq. Ft. Area.	Braced-Frame Building Over 1,500 Sq. Ft. Area.	Slow-Burning Construction.
Corner posts......	2″ × 4″ and 4″ × 6″	2″ × 6″ and 6″ × 8″	2″ × 6″ and 4″ × 8″	2″ × 6″ and 6″ × 8″	10″ × 10″
Sill..............	4″ × 6″	4″ × 8″	4″ × 10″	4″ × 10″	6″ × 10″
Plate	3″ × 8″	4″ × 10″	6″ × 8″	6″ × 10″	6″ × 10″
Interties.........			4″ × 8″	6″ × 8″	8″ × 10″
Ledger boards....	1″ × 4″	1½″ × 4″			
Double studs.....	3″ × 4″	4″ × 6″	4″ × 6″	6″ × 6″	2″ or 3″ plank
Single studs......	2″ × 4″	2″ × 6″	2″ × 4″	4″ × 6″	
Braces...........	2″ × 4″	2″ × 6″	4″ × 6″	6″ × 6″	6″ × 8″
Sheathing........	1″ × 9″	1″ × 9″	1″ × 9″	1″ × 9″	1½″ plank, 2 thicknesses
Rough floor	1″ × 6″	1″ × 6″	1″ × 6″	1″ × 6″	3″ to 4½″ plank
Finished floor.....	⅞″ × 4″	⅞″ × 4″	⅞″ × 4″	⅞″ × 4″	⅞″ to 1½″ plank
Floorbeams.......	2″ × 8″ to 3″ × 10″	3″ × 9″ to 3″ × 12″	3″ × 8″ to 3″ × 12″	3″ × 9″ to 3″ × 12″	4″ × 6″ to 10″ × 12″

Structures you will encounter in Canada

- Safe guards against decay

Dry Rot in Timbers. — In describing the construction of a modern slow-burning mill building, attention has been called to the necessity of boring 1½-inch holes through the centers of wood columns, also to the fact that such columns should not be painted until thoroughly seasoned. This is to prevent dry rot in the timbers — a decay or disease which may cause serious failure, as is proven by the sudden collapse of a factory building in New York City, after a fire in the building in question was well under control by the fire department. An examination made by Prof. Ira H. Woolson demonstrated the fact that the collapse resulted from dry rot which had seriously weakened the wooden columns.

Structures you will encounter in Canada

- Vancouver

Structures you will encounter in Canada

- Toronto

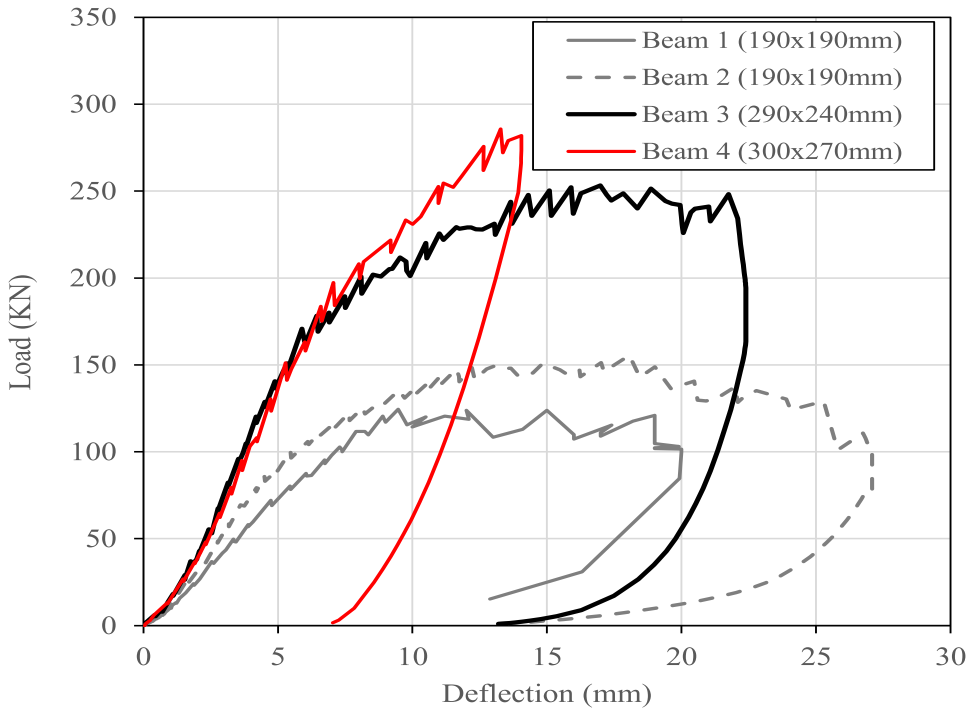
Illustrative example to try on your own

The following figures illustrate the load deflections of four heritage (Spruce) beams taken from a building constructed in 1880 in Cornwall Ontario.

On the basis of these beams performance under applied load (four point bending, equi distance application of load, 1m total span), and assuming that the timber was also locally harvested softwood in Ontario, estimate the appropriate grade of these beams on the basis of this strength alone with proper reference to the handbook.

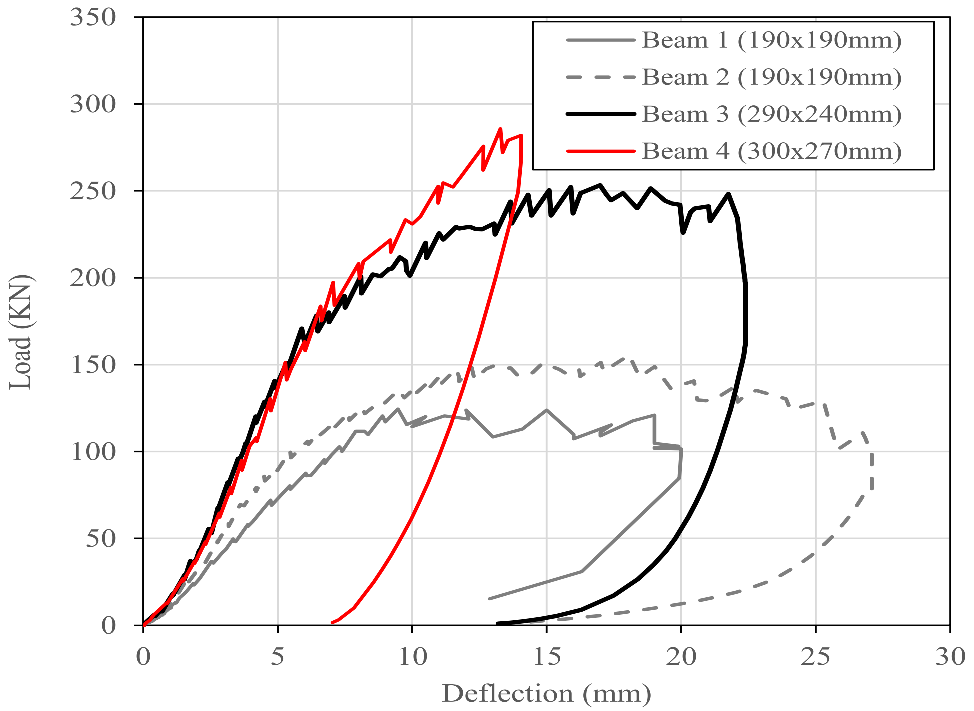
Assume each beam was bored at the centre of typical diameter through its entire length. State all limitations to your grading estimate and show relevant calculations to justify your grading estimate decision

Illustrative example to try on your own



You have to be careful in re-using wood in other applications, as you need to have a confirmed grading associated to the members

Illustrative example to try on your own



You have to be careful in re-using wood in other applications, as you need to have a confirmed grading associated to the members

Illustrative example to try on your own

Some Hints:

Table 6.2.2.1
Visual grades and their dimensions

Grade category	Smaller dimension, mm	Larger dimension, mm	Grades
Light framing	38 to 89	38 to 89	Construction, Standard
Stud	38 to 89	38 or more	Stud
Structural light framing	38 to 89	38 to 89	Select Structural No. 1, No. 2, No. 3
Structural joists and planks	38 to 89	114 or more	Select Structural No. 1, No. 2, No. 3
Beam and stringer	114 or more	Exceeds smaller dimension by more than 51	Select Structural No. 1, No. 2
Post and timber	114 or more	Exceeds smaller dimension by 51 or less	Select Structural No. 1, No. 2
Plank decking	38 to 89	140 or more	Select, Commercial

Table 6.3.1C
Specified strengths and modulus of elasticity for beam and stringer grades, MPa

				Compression				
Species identification	Grade	Bending at extreme fibre, f_b*	Longi-tudinal shear, f_v	Parallel to grain, f_c	Perpen-dicular to grain, f_{cp}	Tension parallel to grain, f_t	Modulus of elasticity E*	E_{05}*
D Fir-L	SS	19.5	1.5	13.2	7.0	10.0	12 000	8 000
	No. 1	15.8		11.0		7.0	12 000	8 000
	No. 2	9.0		7.2		3.3	9 500	6 000
Hem-Fir	SS	14.5	1.2	10.8	4.6	7.4	10 000	7 000
	No. 1	11.7		9.0		5.2	10 000	7 000
	No. 2	6.7		5.9		2.4	8 000	5 500
Spruce-Pine-Fir	SS	13.6	1.2	9.5	5.3	7.0	8 500	6 000
	No. 1	11.0		7.9		4.9	8 500	6 000
	No. 2	6.3		5.2		2.3	6 500	4 500
Northern	SS	12.8	1.0	7.2	3.5	6.5	8 000	5 500
	No. 1	10.8		6.0		4.6	8 000	5 500
	No. 2	5.9		3.9		2.2	6 000	4 000

Illustrative example to try on your own

Some Hints:

Table 6.3.1C
Specified strengths and modulus of elasticity for beam and stringer grades, MPa

Species identification	Grade	Bending at extreme fibre, f_b*	Longi-tudinal shear, f_v	Compression: Parallel to grain, f_c	Compression: Perpen-dicular to grain, f_{cp}	Tension parallel to grain, f_t	Modulus of elasticity: E*	Modulus of elasticity: E_{05}*
D Fir-L	SS	19.5	1.5	13.2	7.0	10.0	12 000	8 000
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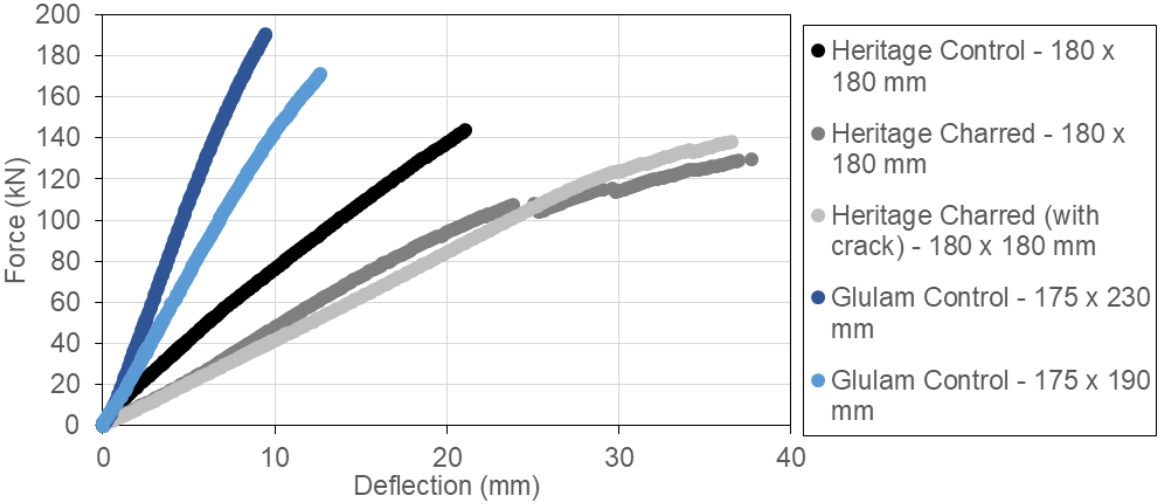
Spruce-Pine-Fir	SS	13.6	1.2	9.5	5.3	7.0	8 500	6 000
	No. 1	11.0		7.9		4.9	8 500	6 000
	No. 2	6.3		5.2		2.3	6 500	4 500
Northern	SS	12.8	1.0	7.2	3.5	6.5	8 000	5 500
	No. 1	10.8		6.0		4.6	8 000	5 500
	No. 2	5.9		3.9		2.2	6 000	4 000

- Beam 1: σ=16.0 MPa
- Beam 2: σ= 21.9 MPa
- Beam 3: σ= 12.4 MPa
- Beam 4: σ= 11.5 MPa
- Based on these results for bending and specified strengths from Table 6.3.1C, the timber is close to Select Structural in grade
- Alternative method could have theoretically used total deflection; however deflections reported from loading actuators may have low accuracy and linear potentiometer below the beam was at an angle. Therefore using deflection for this analysis may not give representative results.

This is an illustrative example, we will come back to grading, selection and mechanics in future modules. The point is, the timber is often very good quality in these buildings if it is taken care of.

In comparison to modern counterparts

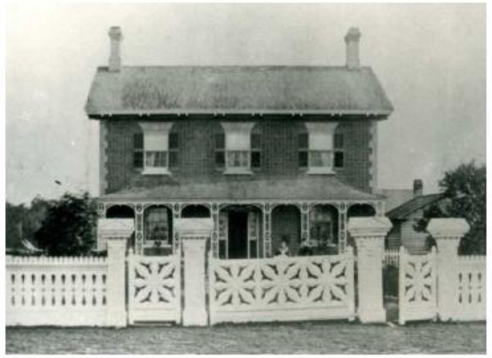
- In this example, a structure built in 1930 had its members compared in bending to contemporary glulam members
- Members were lightly fire exposed (return at Module 10)



Type	Beam Dimensions (mm)	Char depth (mm)
Pine	185x185	22.71
Pine	185x185	26.27
Douglas Fir	175x190	15.83
Douglas Fir	175x228	16.69

Modern Construction - Light frame

Multi-story apartment under construction



Single family house

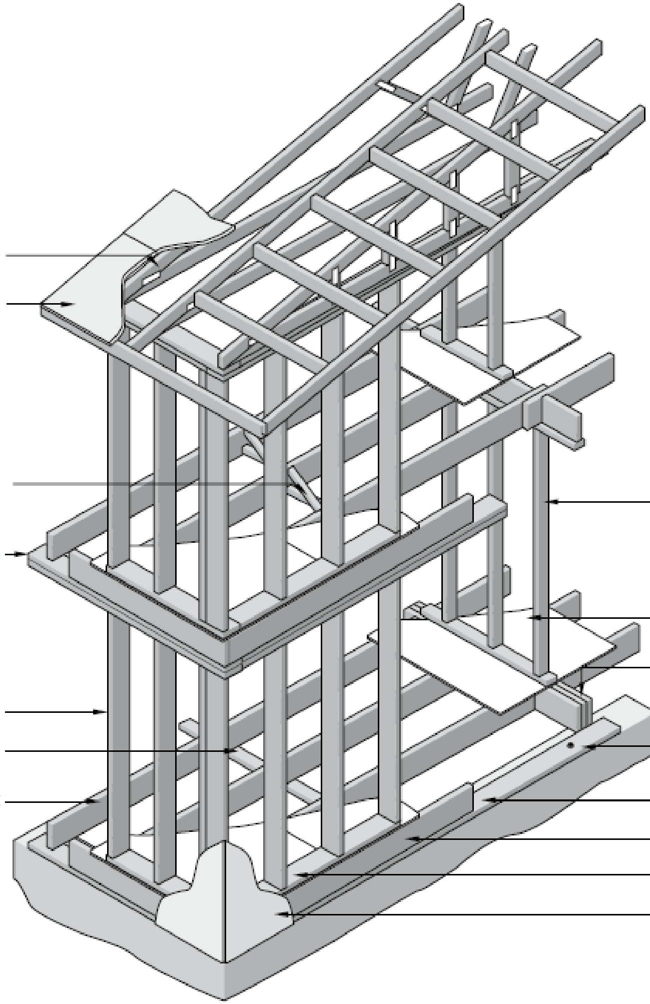
Modern Construction - Light frame

These lumber members are spaced closely together in a load-sharing arrangement to afford structural resistance. In this configuration the main structural member is the lumber, the secondary members are the sheathing (in module 6 we will discuss the additional role of sheathing for integrity). Members are connected by fasteners, usually nails. This configuration gives a high strength-to-weight ratio.

There are two types of framing Platform and Balloon:
Platform: the floor assembly is built separately from the wall, and is a working surface for next floor.

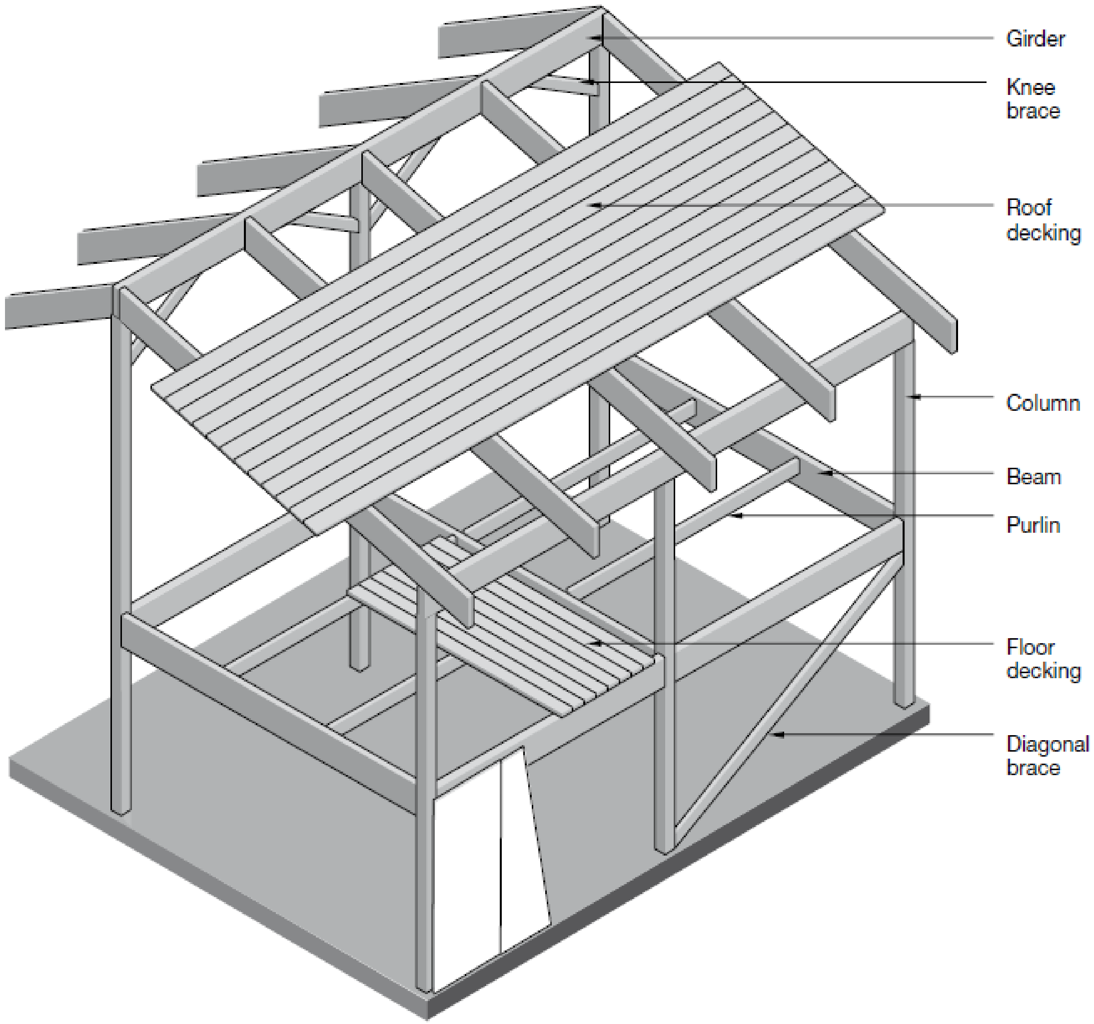
Balloon: exterior walls (studs used) are continuous from the foundation to the top below the roof framing

Modern Construction - Light frame



- Platform frame construction
  - Advantages:
    - Ease of construction
  - Disadvantages:
    - settlement issues with shrinkage and structural deformation
- Balloon frame construction
  - Advantages:
    - Less settlement issues
  - Disadvantages:
    - Requires longer studs
    - fire-stopping considerations

Modern Construction - Heavy (Post and Beam construction)



Timber members spaced far apart. in a non load-sharing arrangement.

Main members are usually connected with fasteners, e.g. steel dowels, bolts and lag screws, and steel plates.

Secondary members often are designed as stand-alone members e.g. purlins, floor/roof decking

Modern Construction - Mass Timber

CLT paneling combined with glulam

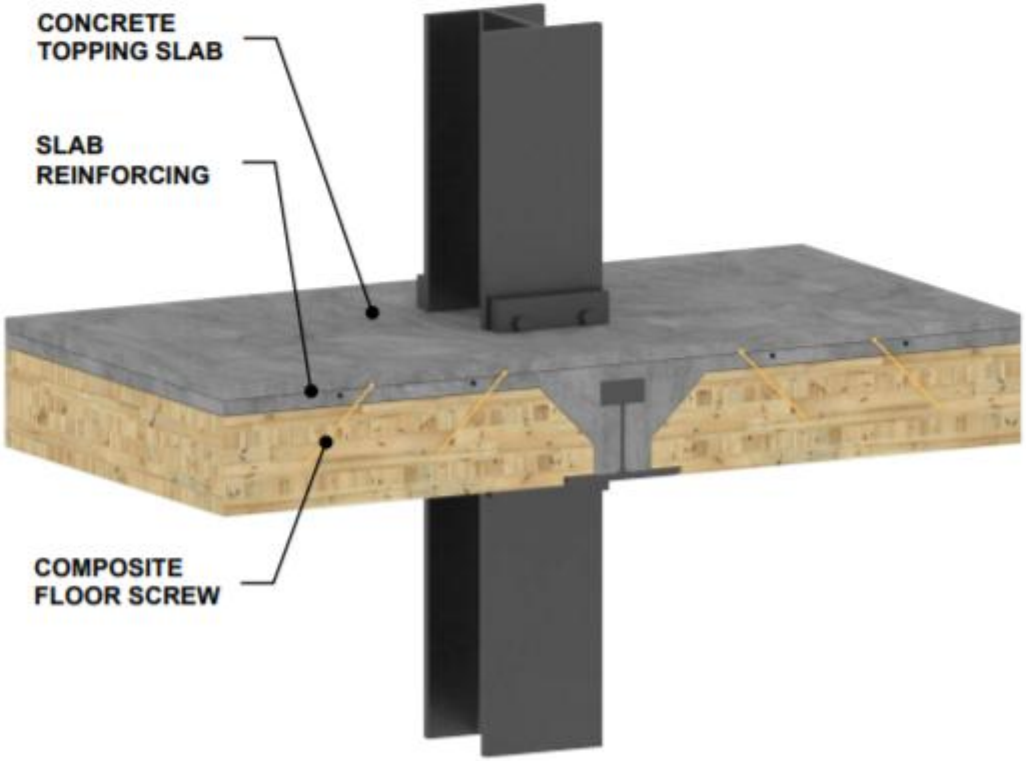
Panelized construction for floor, wall, elevator shaft and roof. Common to see CLT /NLT

Hybrid formulation allows longer spans to be achieved compared with mass timber panels alone. The material used will be the same in whole building

Modern Construction - Hybrid

(Liz Brown)

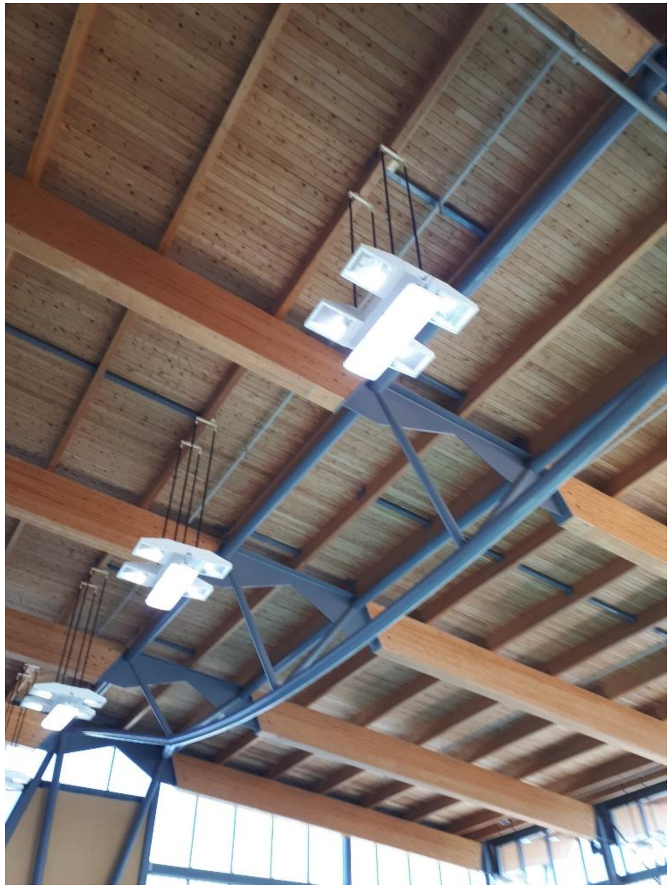
Concrete Podium and core, with CLT an glulam (Brock commons)



Steel frame and timber floor *SOM (2017)*

Modern Construction - Hybrid

Steel column and timber floor

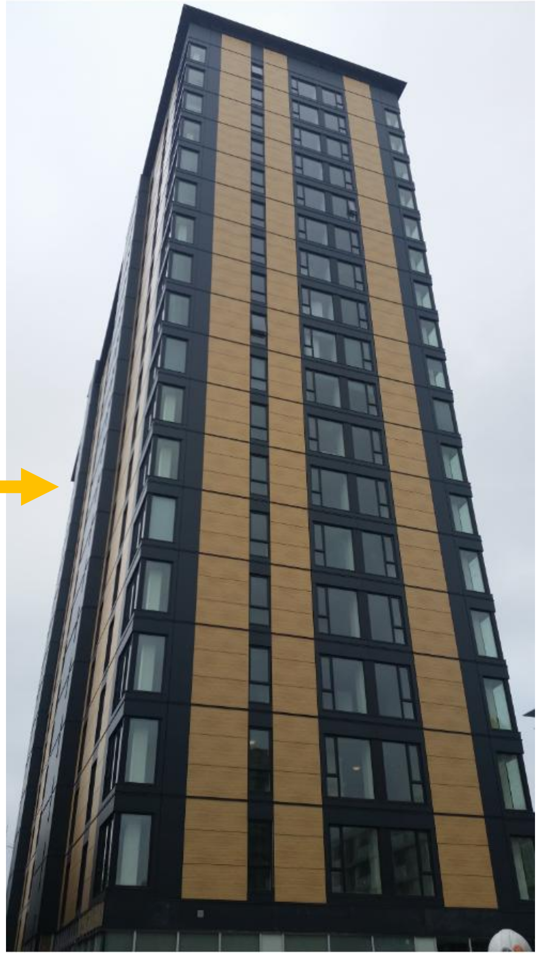


Steel truss and timber roof

An emerging trend:

(Will Pryce)

9-storey, Murray Grove, London, 2009



Brock Commons, BC, 2018

An emerging trend: Addressing the ‘Missing Middle’

Some city’s will either have high rise, or small dwellings, not structures in between.

With experience, construction can be more facilitated in more densely built regions. This has an advantage for prefabricated structures and scheduling. With advances in Building information Sciences, and advancements in mid rise clauses in codes to allow these structures there is much potential for mid rise timber

This allows cities to meet favorable sustainabity objectives

Toronto

Toronto area housing market has a 'missing middle,' new report says

Research on housing affordability suggests GTHA lacks mid-level housing like 'townhouses, duplexes, triplexes'

Shannon Martin · CBC News · Posted: May 23, 2017 9:00 AM ET | Last Updated: May 23, 2017

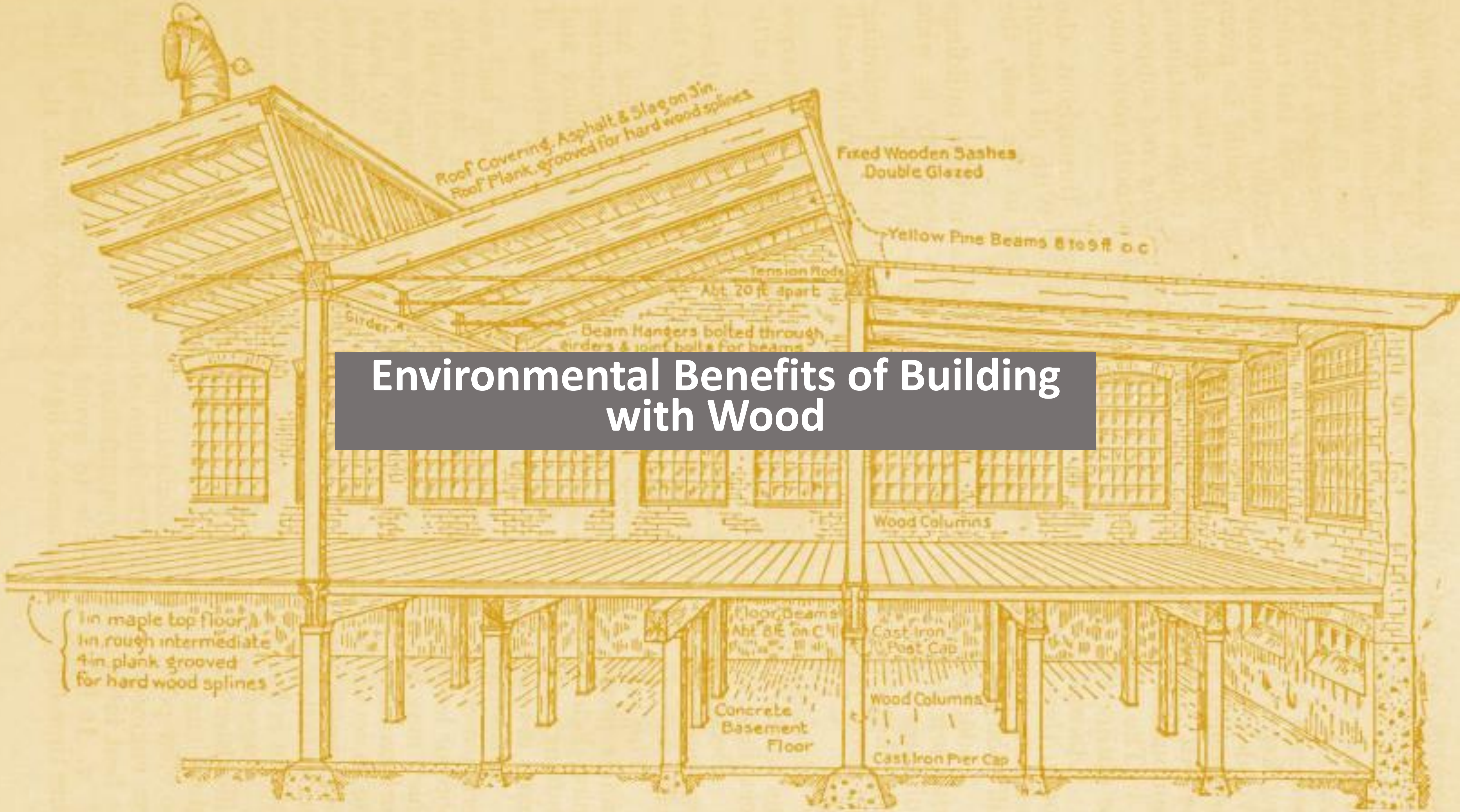
A new housing report by the Canadian Centre for Economic Analysis estimates 45 per cent of GTHA households live in detached homes, 35 per cent live in apartment buildings. That leaves about 20 per cent living in the so-called 'missing middle.' (Courtesy: Q4 Architects Inc.)

128 comments

Call it the tale of Toronto's two housing markets: on one side are the million-dollar-plus single-detached homes, and on the other, those tiny boxes in the sky.

What's missing, is everything in the middle.

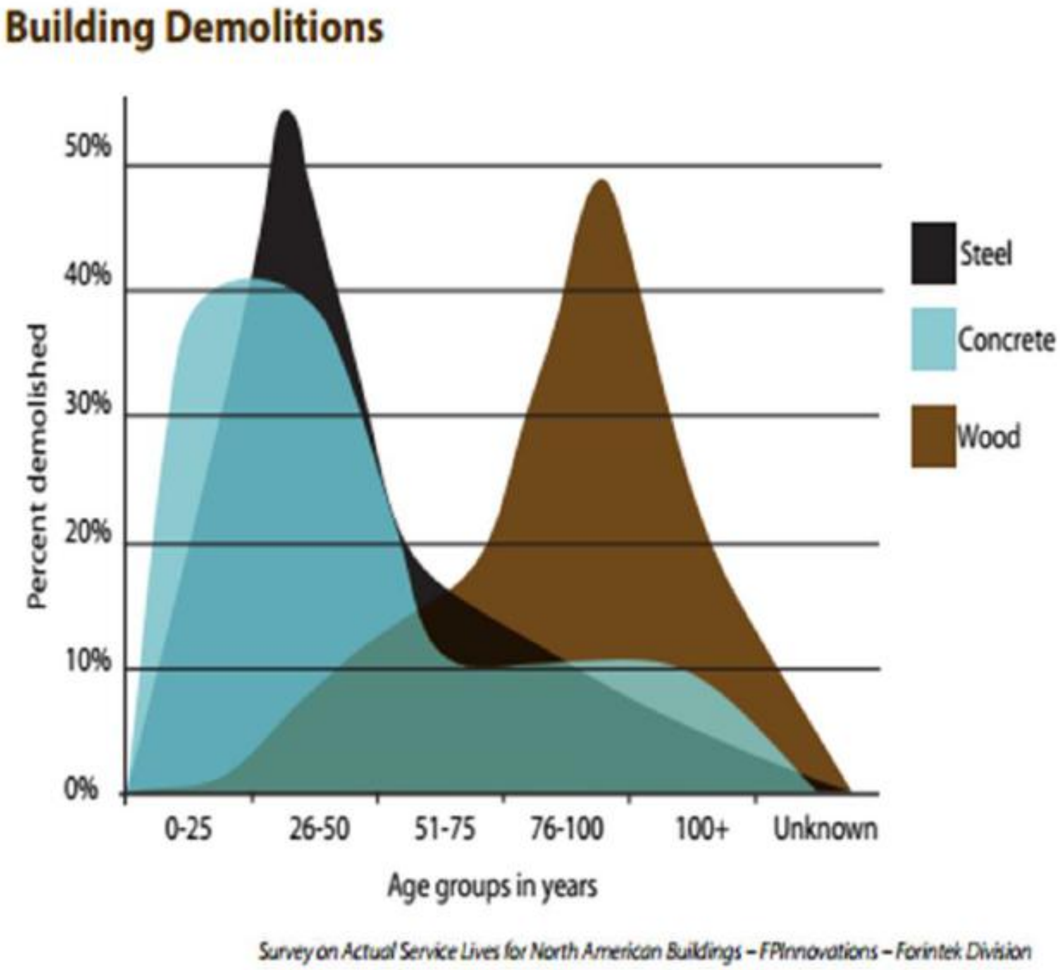
Environmental Benefits of Building with Wood



Lifecycle

Generally speaking if a timber building is well cared and maintained (which we will discuss how in this course) the final life of the building will exceed that of steel and concrete.

Shown here are compiled statistics illustrating building demolition related to the predominate material contained.



Environmental Sustainability

Is the practice of using of a renewable recourses at a rate that allows it time replenish

Wood products provides the building sector with a renewable option compared to steel and concrete which both come from finite sources

However, wood is only sustainable if harvested responsibly, with considerations given to reforestation and protecting eco systems

Harvesting legislation and standards are used throughout Canada to ensure the practise stays sustainable

Old Vines Restaurant at Quails' Gate Estate Winery West Kelowna, BC

Social Sustainability

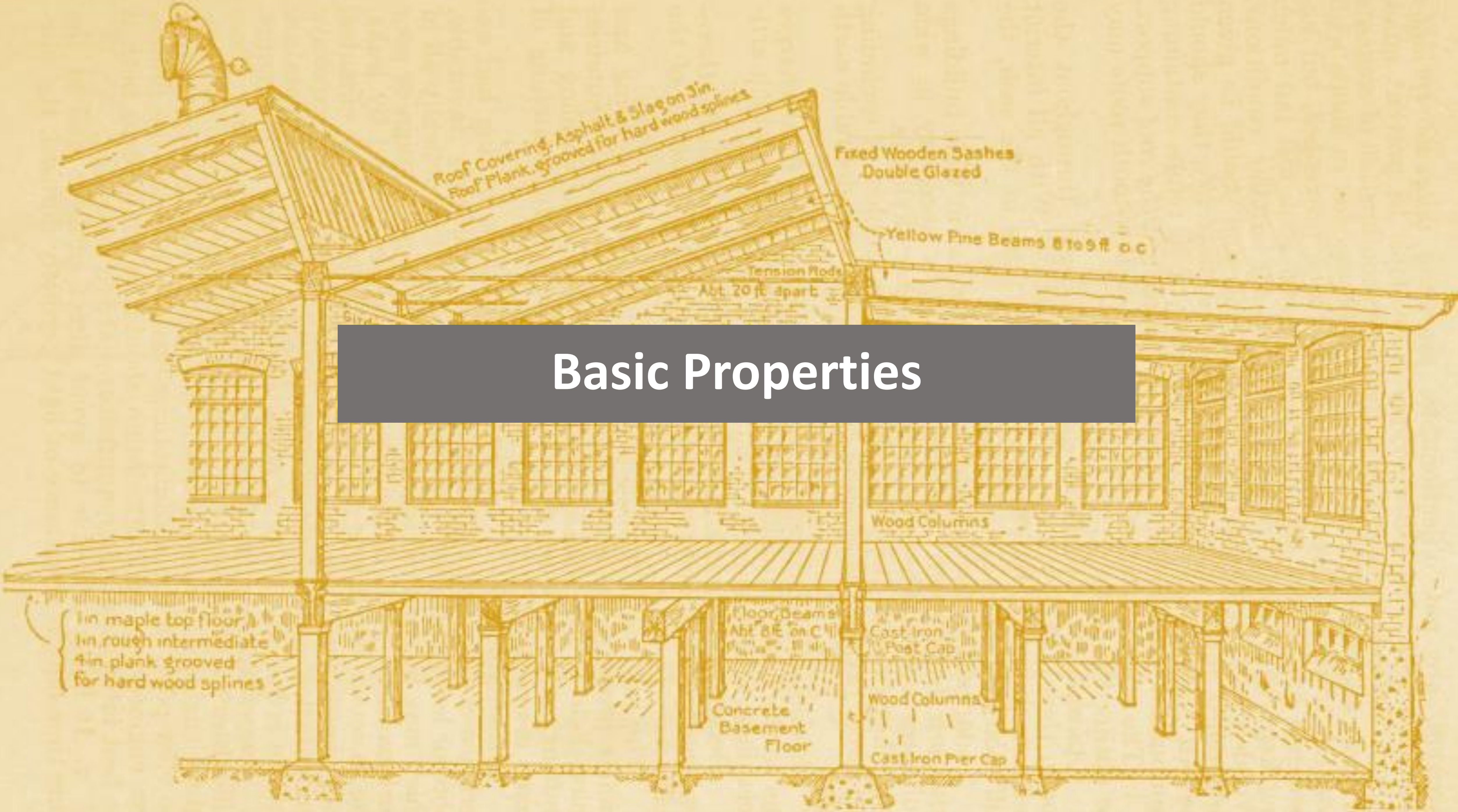
Looks at the human interaction part of a system

In addition to being home for wildlife, forests have multiple uses which need to be considered to ensure they are not also disturbed

Training and outreach are also part of sustainability to ensure there will be a skilled workforce for future generations

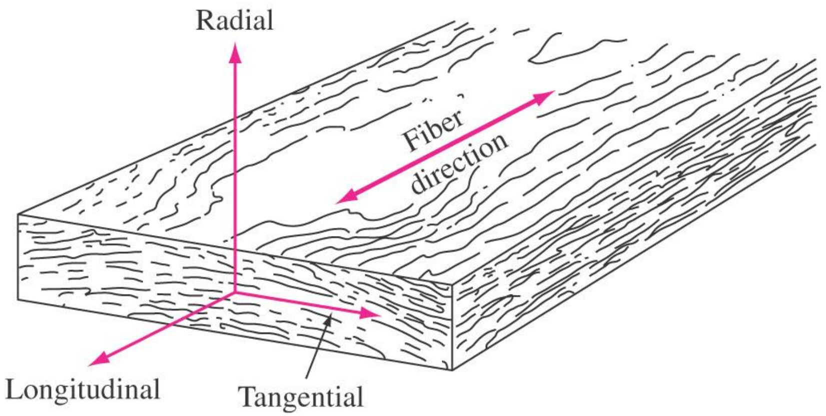
Forests are part of a complex system with multiple stakeholders

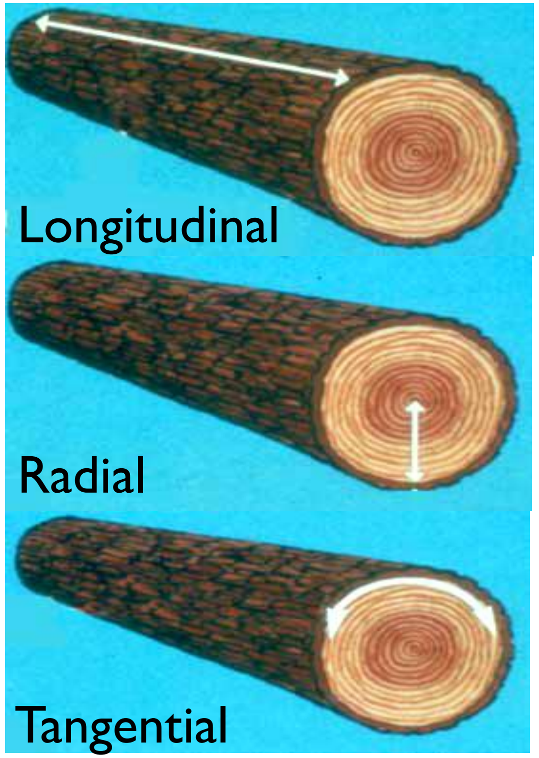
Basic Properties



Principle Planes of Wood

- Wood has 3 axes (X-longitudinal, R-radial and T-tangential).
- Anisotropic material (strongest in the X-direction, R and T strength vary slightly).
- Different species poses different strength due to their anatomical variations.





Anisotropic nature of wood affects mechanical properties such as shrinkage, stiffness and strength.

Parts of a Tree Trunk: Macro-Structure

Outer bark

- Protects the wood from insects, extreme temperatures and injury.

Inner bark

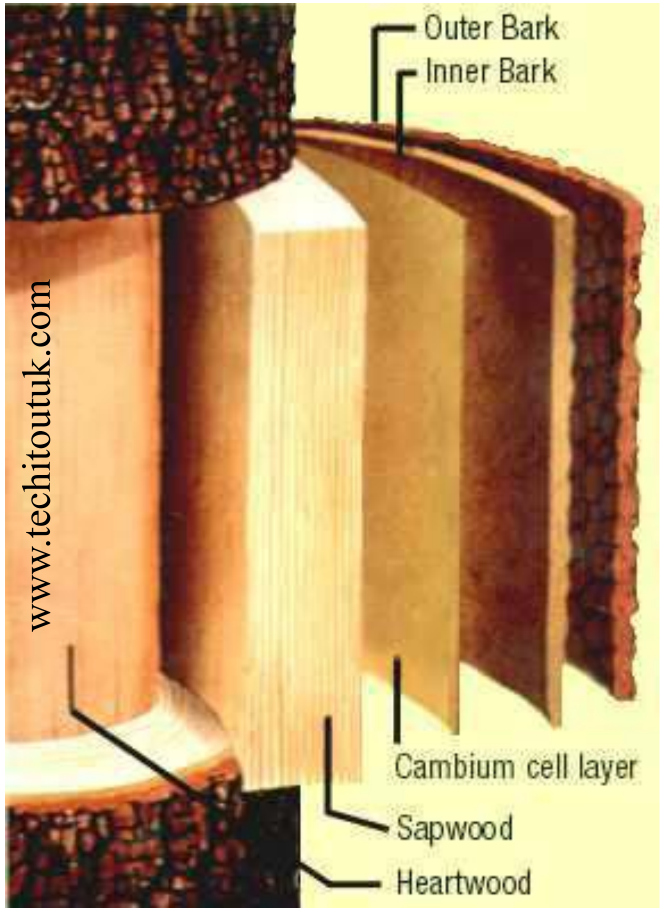
- Allows sap movement down the tree.

Cambium

- Produces new wood cells on both the inside as a growth ring and outside, as the inner bark.

Sapwood and heartwood

- Both make up the wood section of the tree.



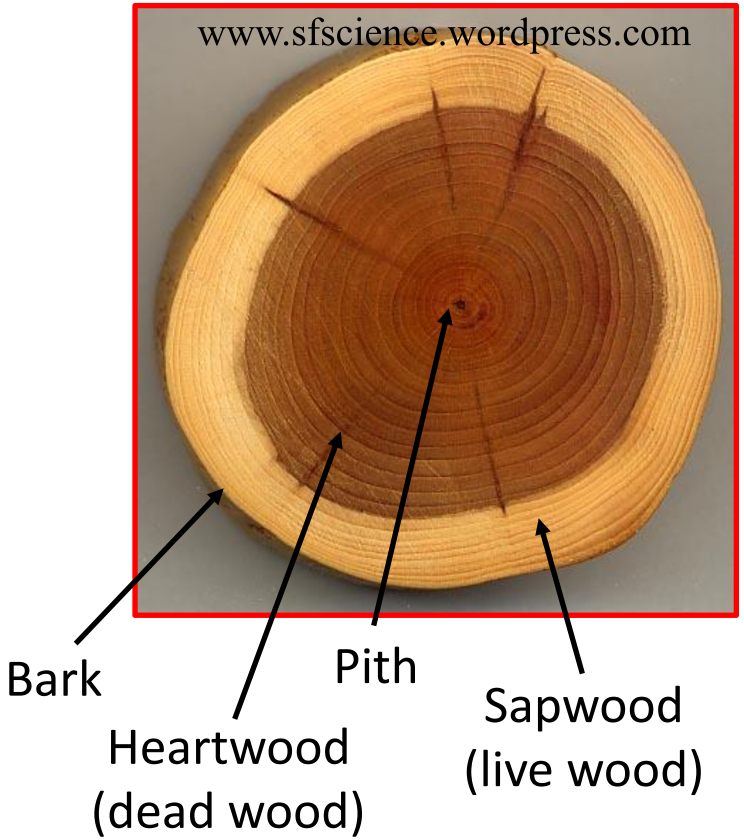
Wood Macro-Structure

Sapwood transports the sap up the tree.

- Lighter color.
- Has living cells.
- Not durable, may decay.
- Over a period of time sapwood becomes heartwood.

Heartwood provides mechanical support to the tree.

- Darker color (not all species).
- Is not a living part of the tree (contains dead cells).
- Resistant to decay.



- The pith is located at the centre of the trunk and is a small cylinder of primary tissue around which the annual rings form.

Wood Growth Rings

Growth rings (tree or annual rings):

• Occurs in seasonal climates.

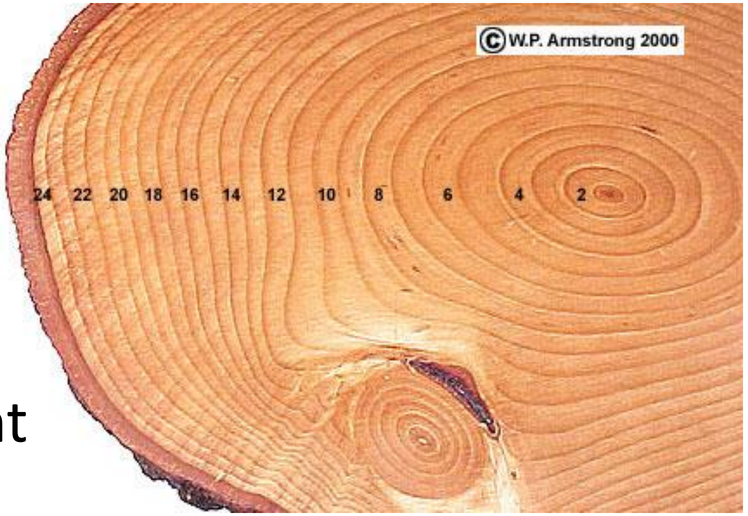
• Produced by the cambium in a single growing season.

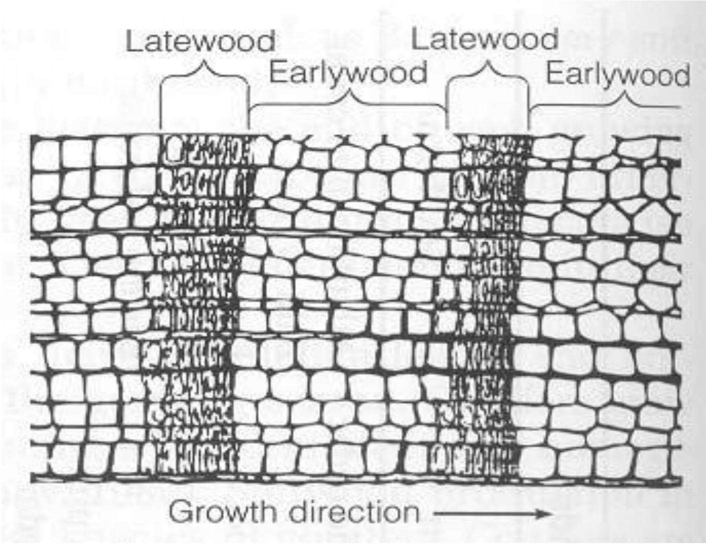
• Wood produced at beginning of growing season is different than later in season.

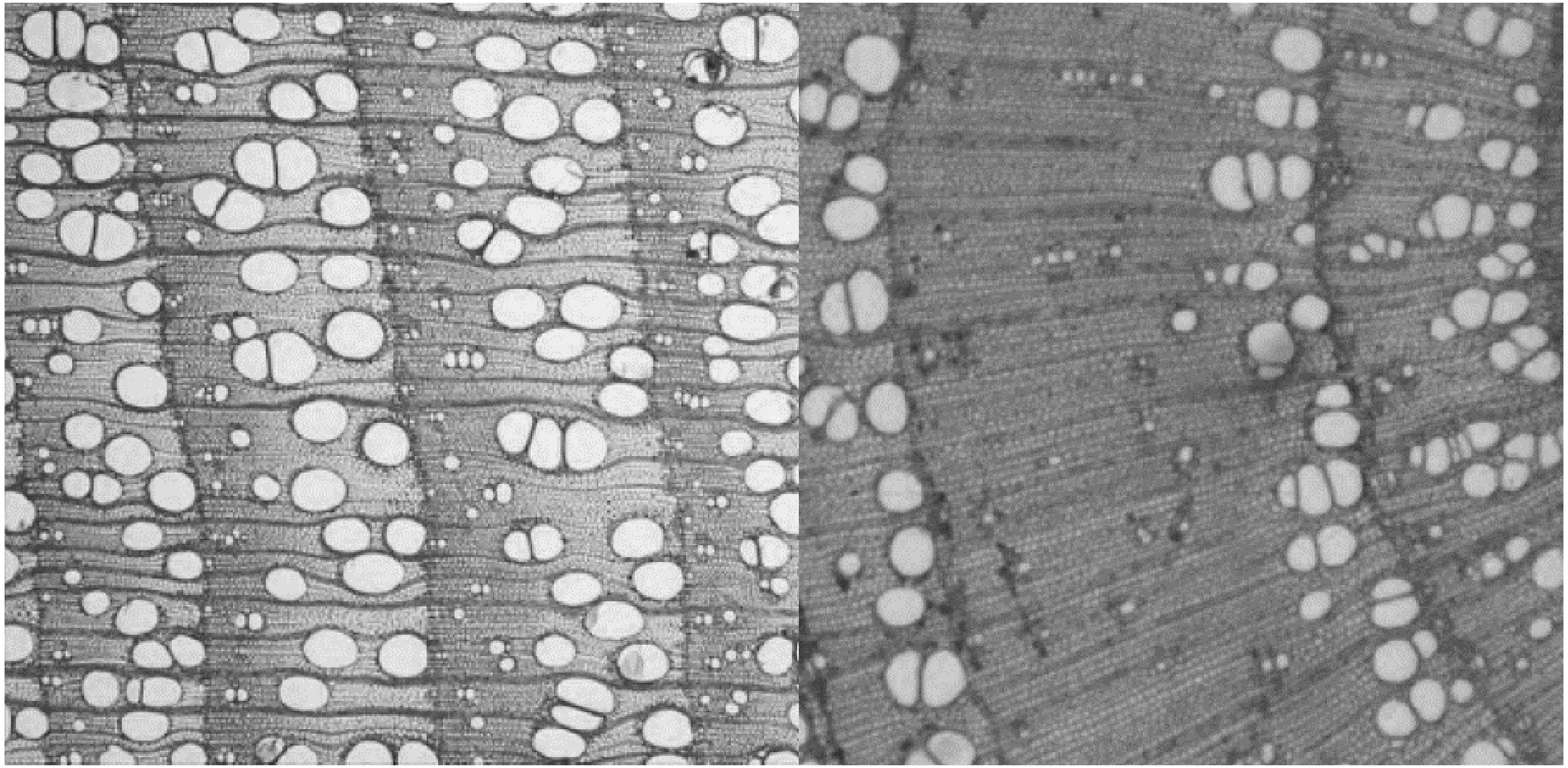
Can calculate the age of a tree:

• 1 early wood (light color) ring +1 late wood (darker color) ring =1 year's growth.

• But in tropical regions, growth rings are indistinct.







Softwood (left) ; Hard wood (right)

Trees can absorb 2 tonnes of CO2 to create 1 tonne of their own mass. In the spring, they add large cells to carry water up the trunk for quick growth. In the summer, the cells become smaller as the emphasis changes to producing wood for strength.

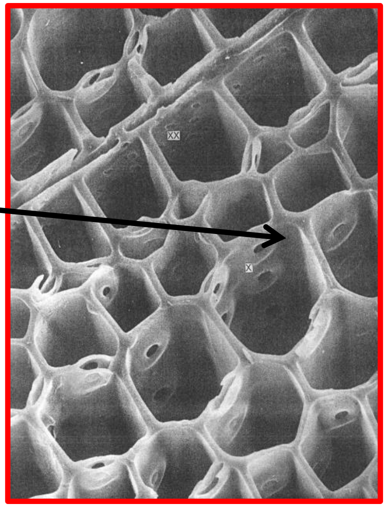
Using the rings for age…

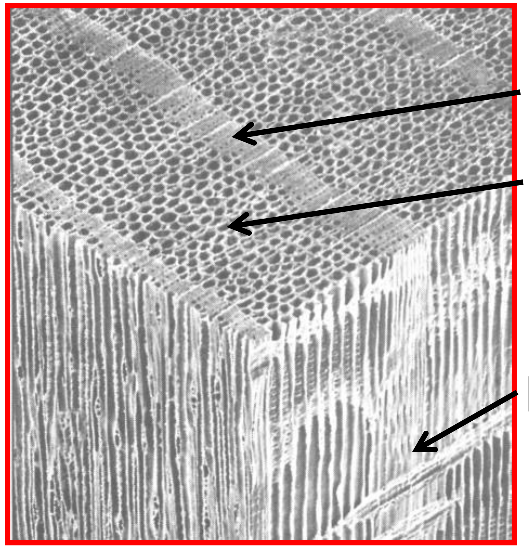
Pore Distribution

• Wood is made up of millions and millions of tubular cells bound together.

• Majority of cells oriented vertically in the tree. Ray cells run radially from the center to the outside of the trunk. Used for storage and horizontal transportation of water/sap; think of it like a vein.

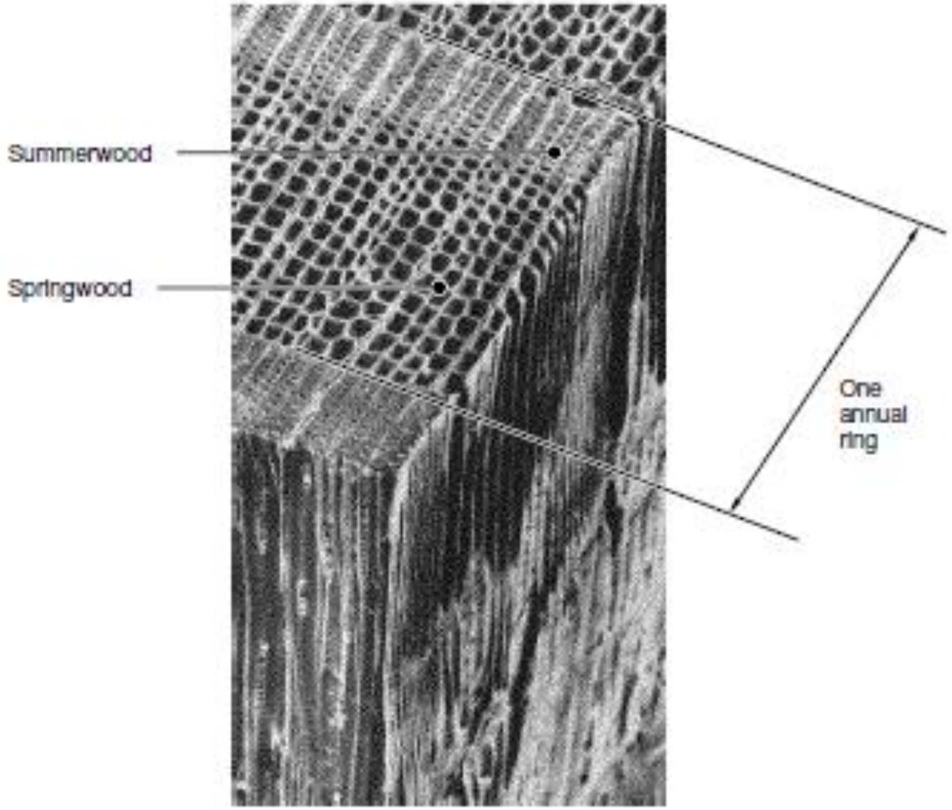
Softwood: *pore distribution is more uniform than hardwoods (e.g. Pine*)





Scanning electron micrograph (SEM) showing microstructure of pine wood.

Pore Distribution

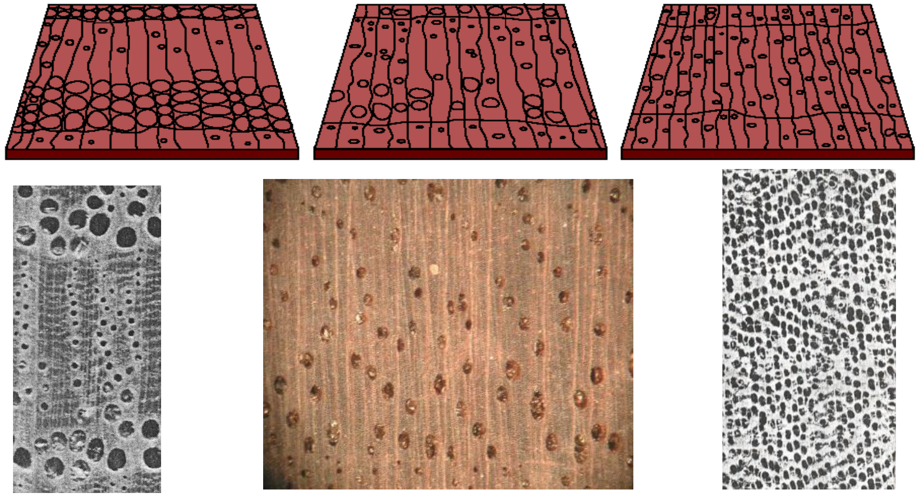


Scanning electron micrograph (SEM) showing annual rings of wood.

Pore Distribution

Hardwood:

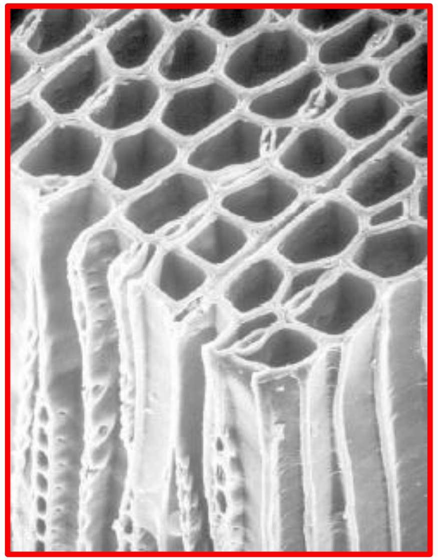
- Ring porous: for the same growth ring, early wood has larger diameter vessels than late wood.
- Semi-ring porous: the vessel diameters have a gradual change from early wood to latewood.
- Diffuse porous: have a uniform vessel diameter across the growth ring.

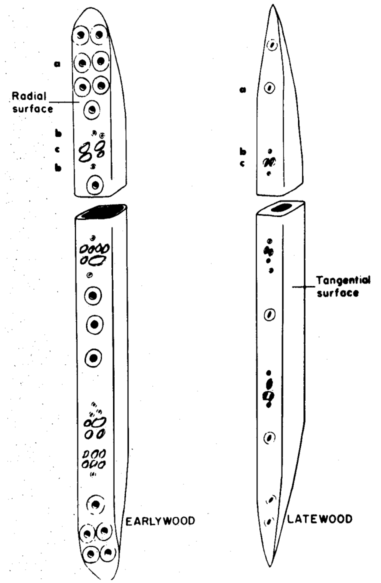


Ring porous (White oak) | Semi-ring porous (Walnut) | Diffuse porous (Yellow poplar)

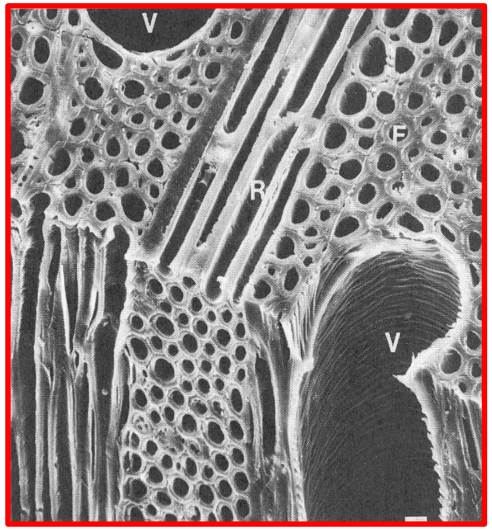
Wood Micro-Structure

The longitudinally aligned cells are called tracheids in softwoods and fibers or vessels in hardwood. These cells are responsible for mechanical support and the transport of water & sap.

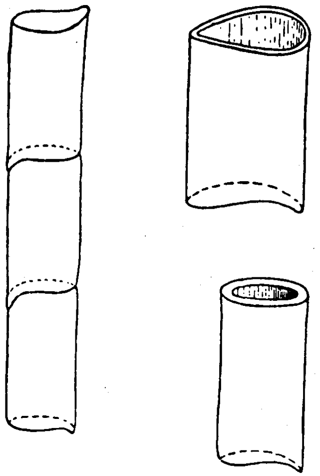




Eastern Spruce



Maple



Latewood Earlywood

- Tracheids have a hollow center closed at the ends and openings (pits) in the sidewall.

- Vessels form a pipe-like conducting tube.
- Fibers for mechanical strength not fluid transport.

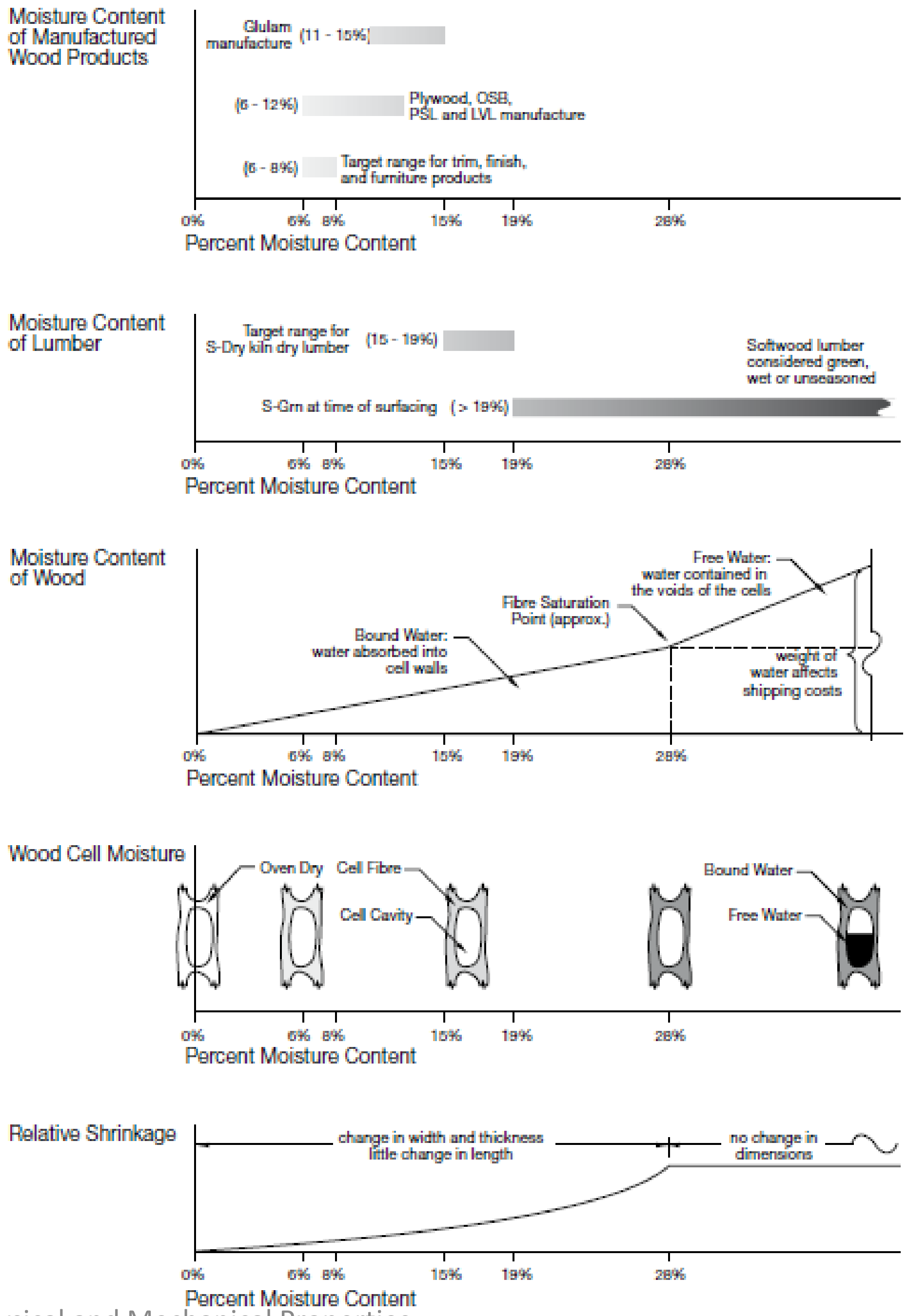
Chemical Composition of Wood

Wood substance is composed of:

- **Cellulose** (micro-fibrils):
  - 41-55% on a dry weight basis for both softwoods & hardwoods.
  - Provides tensile strength.
- **Lignin** (matrix):
  - 23-33% for softwoods.
  - 16-25% for hardwoods.
  - Binds the wood cells together.
  - Provides rigidity and compressive strength.
- **Hemicellulose** (matrix):
  - 23-30% for both softwood and hardwood.
  - Binds the cells together.

Moisture Content (MC)

- Moisture content is quite important to how the wood retains mechanical properties and undergoes very specific dimensional changes
- This can be very controlled during construction if proper care is taken.



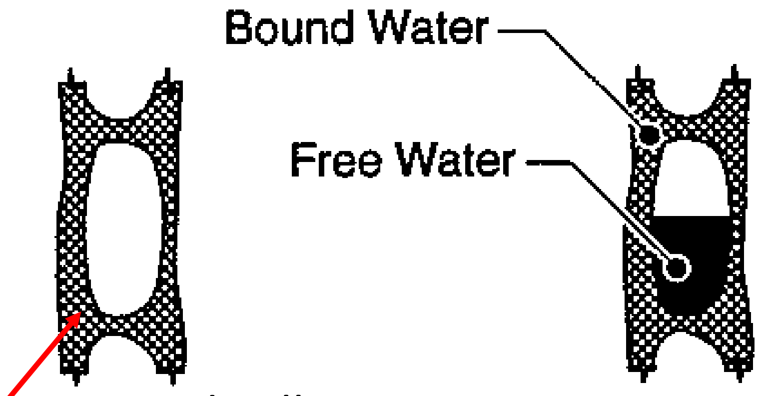
Moisture Content (MC)

- Newly felled trees contain bound and free water.
- Wood is said to be at its fibre-saturation point (FSP) when no free water in cell cavities, but the cell walls are saturated (e.g., 21-32% MC)-avg. 28%.
  - If MC > FSP, wood is *dimensionally stable* (bound and free water).
  - If MC < FSP, *shrinkage occurs* (bound water begins to evaporate).
- Wood must be seasoned before it is suitable for structural use.
- Achieved by forced air kiln-drying or by natural air-drying.

Moisture Content (MC)

$$MC\% = \frac{initial\ wt. - oven\ dry\ wt.}{oven\ dry\ wt.} x100$$

Oven-dry = wood dried at ~100°C, until there is no weight change.



Saturated cell wall, 28% MC

Seasoning

- Framing lumber is seasoned to an MC of 12-15%.
- Air seasoning: lumber dries naturally, the process can take 3 to 4 months.
- Kiln seasoning: Warm air circulates through the pieces of lumber at 20 to 50°C, 4 to 10 days.

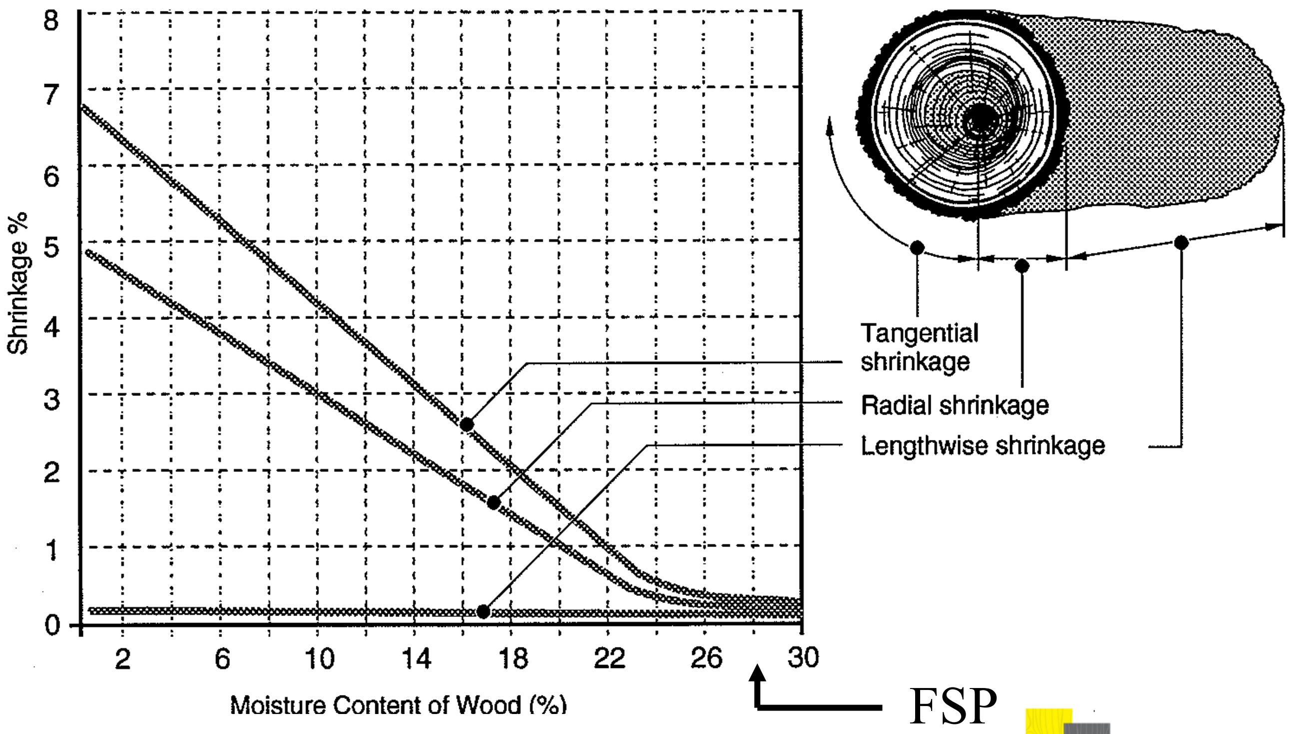
Natural drying

Kiln drying

Drying lumber to an MC content it will experience in service minimizes change in dimensions (interior of buildings in Canada rarely exceeds MC of 12%).

Seasoning

- During seasoning there is no volume change in the wood until the MC drops below the FSP (~28% MC).
- As the cell walls release moisture, the wood shrinks.
- Amount of shrinkage depends on orientation of grain.



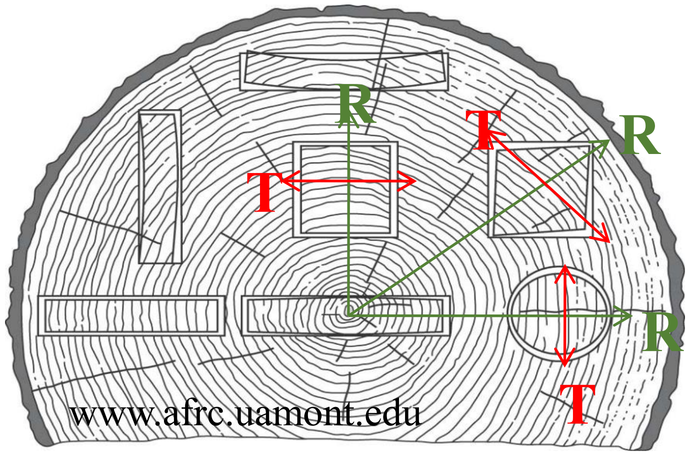
Shrinkage

Wood shrinks during drying:

• Very little along the grain (longitudinal direction)-considered negligible.

• Largest in the direction of annual growth rings (tangentially) and 1/2 as much across growth rings (radially).

• The difference in shrinkage between the radial and tangential directions can cause distortion (warping, twisting).

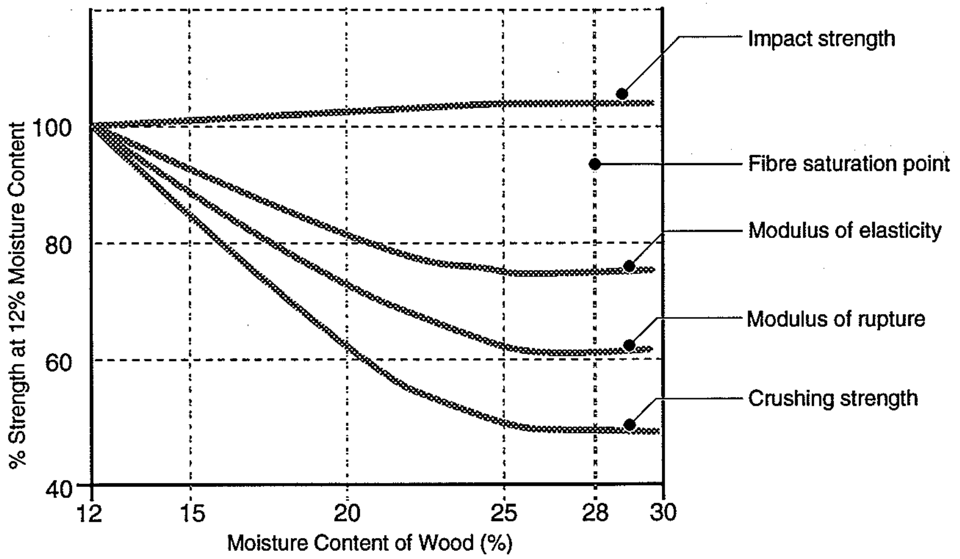


Tangential shrinkage-along growth rings
Radial shrinkage- across growth ring

Extent of distortion depends on how the timber was cut in relation to the grain.

Effect of MC on Mechanical Properties

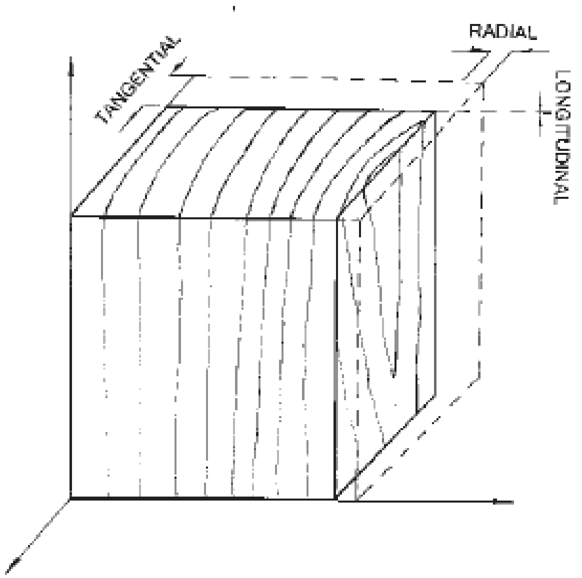
- Moisture content also affects the engineering properties of wood.
- Variation of a number of properties with MC is shown below.
- Properties of wood are highly sensitive to moisture condition.



Structural wood recommended moisture content 12-15%.

Typical Swelling/Shrinkage of Wood Species

Species	*Tangential (%)*	*Radial (%)*
American Elm	9.5	4.2
Sugar Maple	9.9	4.8
Black Oak	11.1	4.4
Red Oak	8.9	4.2
White Oak	10.5	5.6
Black Walnut	7.8	5.5
Yellow Poplar	8.2	4.6
Black Cherry	7.1	3.7
Sweetgum	10.2	5.3
Eastern Redcedar	4.7	3.1
Western Redcedar	5.0	2.4
White Fir	7.1	3.2
Eastern Hemlock	6.8	3.0
White Pine	7.4	4.1
Ponderosa Pine	6.2	3.9
Redwood	4.5	2.5
Spruce	7.5	4.3
Balsa	7.6	3.0
Ramin	8.7	3.9
Teak	4.0	2.2
Mahogany	5.1	3.7



Swelling of a wooden block in 3-D

- Shrinkage (SV) from green to oven dry.
- Tangential and radial shrinkage (or swelling).

Dimensional Change

Dimensional change can be estimated using the following equation:

$$DC = OD \times SV \times (CMC \div FSP)$$

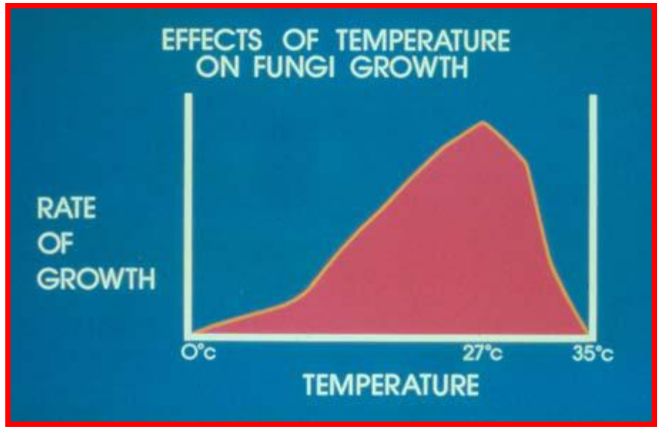
DC, dimensional change
OD, original dimension
CMC, change in moisture content
SV, shrinkage from green to oven dry moisture content (table or given)

Dimensional change can be expressed as a percent:

$$\text{Shrinkage or swelling \%} = \left\{ \frac{\text{Change in dimension or volume}}{\text{Initial dimension or volume}} \ast 100 \right\}$$

Wood Decay

- Caused by a form of plant life known as fungi, which feed upon the wood substance (cellulose & lignin) of the cell walls.
- Wood-destroying fungi require:
  - Adequate moisture content (20-60 %).
  - Supply of air to furnish oxygen.
  - Favorable temperature (20-30 ˚C).
  - Food.
- At moisture contents below 20%, growth of fungi is completely inhibited.

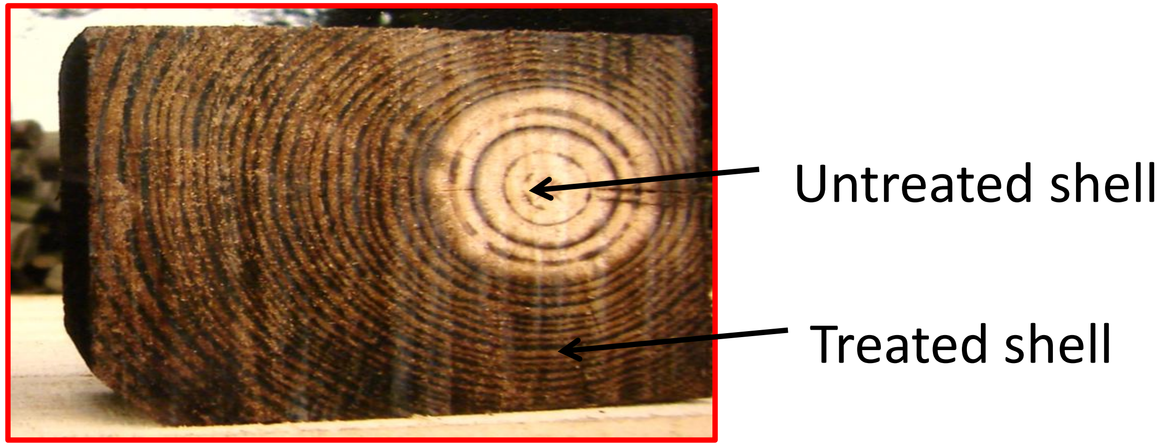


Decay organisms thrive in a wide range of temperature, but develop best at around 27°C. At low temperatures they become dormant but resume activity as temperature rises.

Wood Decay

Pressure Treated Wood

- Decay is prevented by treating wood with preservatives.
- Properly treated wood has 5 to 10 times the service life of untreated wood.
- Treated lumber has a shell of preserved wood surrounding an untreated core.



Pressure treated wood-interior is never fully infiltrated

e.g. If cut a piece of pressure treated wood to make a fence or porch post and cut ends are not protected with preservative or paint the interior of the wood post canrot.

Pressure Treated Wood

- Pressure treatment is applied to wood by injecting chemicals under pressure into the wood cells (forced penetration of the chemical).
- This is more effective than surface application (brushing, spraying or dipping).
- The process provides a shell which is toxic to fungi and insects.

Pressure Treated Wood

Wood preservative chemicals:

- Until 2004 chromated (funghicide) copper (binding agent) arsenate (insecticide) (CCA) was the chemical used-found to be toxic- banned for residential use. *(why you don’t see as many wooden play grounds anymore)*
- CCA replaced by amone copper quat (ACQ)-contains copper as the primary fungicide and a quaternary ammonium compound (‘quat’) as the secondary fungicide. Suitable for inside residential buildings, patios or decks, its clean, odor free and paintable.
- Creosote (coal tar derivative) and Pentachlorophenol are most suitable for contact with ground (e.g. utility poles, railroad ties and wharf pilings).

Pressure Treated Wood

- **Precautions** with pressure treated wood:
  - No arsenic-based treatment allowed in residential construction.
  - Avoid inhaling sawdust during cutting of wood.
  - Wash hands after handling.
  - Treated wood should not be burned-produces toxic chemical-landfill disposal is permitted.
  - May promote corrosion in steel fasteners.
- Creosote or pentachlorophenol should not be used:
  - Indoors (interior of residential or commercial buildings).
  - Where intimate human contact may occur (furniture or deckings).

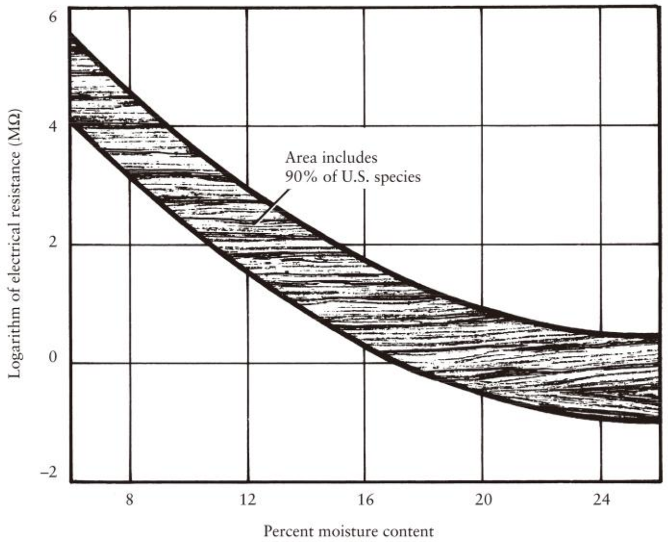
Railroad ties being unloaded from a pressure treating cylinder

Measuring Moisture Content

- Several different methods with various degrees of accuracy and interpretation. Most follow the below procedure

$$MC\ (\%) = \frac{mass\ of\ \ water\ in\ wood}{mass\ of\ \ ovendry\ wood} \times 100$$

- Other methods include consideration of electrical resistance this tends to have a higher degree of inaccuracy (3-5%) owing that surface conditions will not reflect interior conditions:

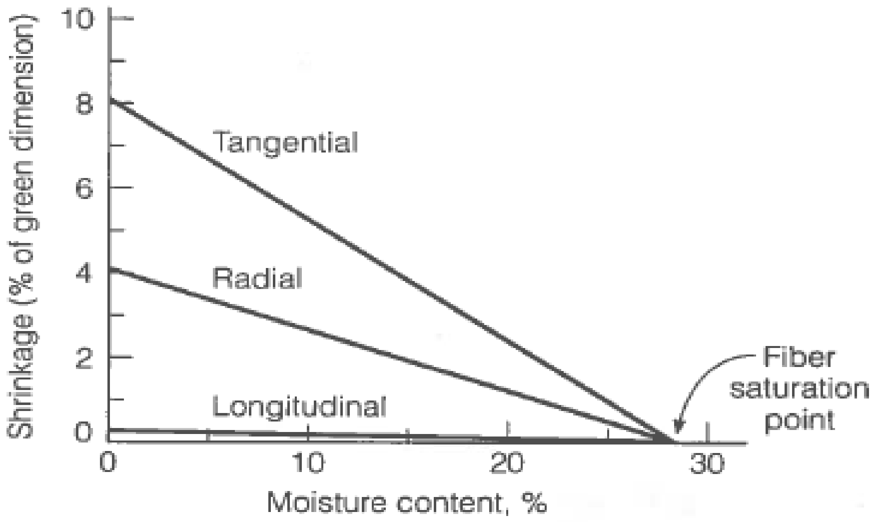


(Source: Glass and Zelinka 2010)

High Speed Production technologies may assume Infrared/radio frequency/microwave technologies.

Example

A stud had dimensions of 38 mm x 89 mm x 2.438 mm and a moisture content of 150% when it was prepared. After seasoning, the moisture content was reduced to 7%. If the tangential, radial and longitudinal directions of the grains are on the same order as the dimensions indicated above, what are the dimensions of the seasoned stud if the moisture-shrinkage relation follows the below figure. Assume the FSP is 28%.



Example

The changes in dimensions are due to the reduction of moisture below the FSP. From Figure 1 the percentage of shrinkage due the changes of moisture from 28% to 7% are as follows: tangential = 6 %, radial = 3.1 %, and longitudinal = 0.23 %. The new dimensions will be:

$$DC = OD \times SV \times (CMC \div FSP)$$

Example

Tangential:

DC = 38 mm x 0.06 x [(28 -7) ÷ 28] = 1.71 mm

Change in dimension = 38 mm – 1.71 = 36.29 mm

Radial:

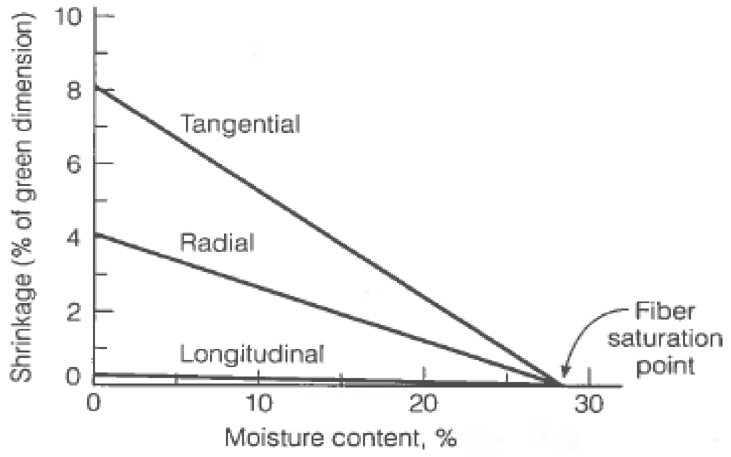
DC = 89 mm x 0.031 x [(28 -7) ÷ 28] = 2.06 mm

Change in dimension = 89 mm – 2.06 = 86.94 mm

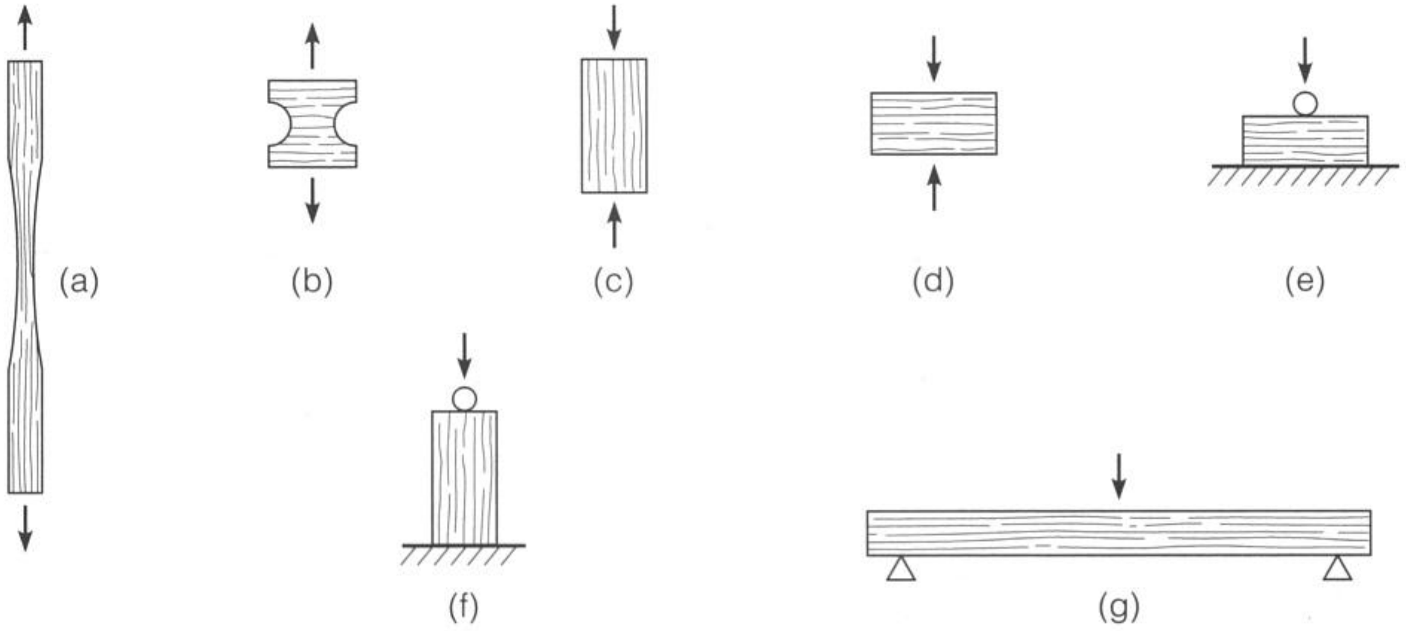
Longitudinal:

DC = 2.438 mm x 0.0023 x [(28 -7) ÷ 28] = 0.0042 mm

Change in dimension = 2.438 mm – 0.0042 = 2.433 mm



Test Specimens of Wood



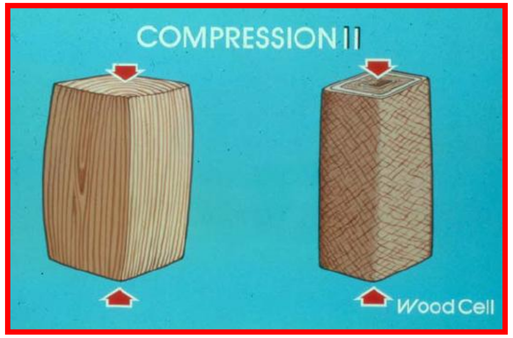
(a) Tension parallel to grain, (b) tension perpendicular to grain, (c) compression parallel to grain, (d) compression perpendicular to grain, (e) hardness perpendicular to grain, (f) hardness parallel to grain, (g) bending

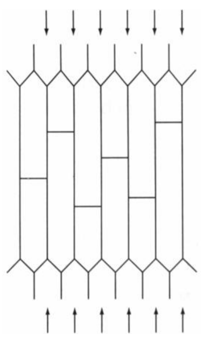
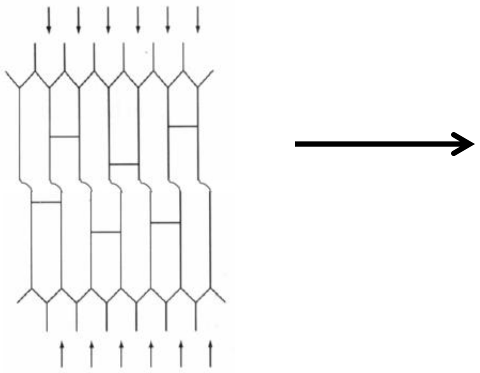
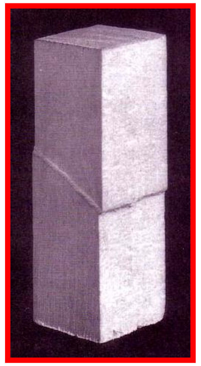
ASTM D143 provides methods for various tests on wood specimens.

Compression Strength

Compression parallel:

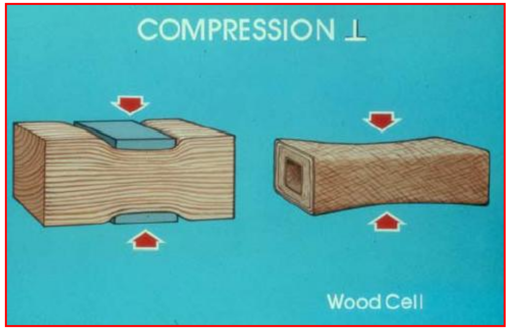
- Each cell acts as a hollow column, braced against buckling by neighboring cells.

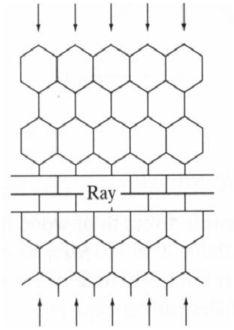


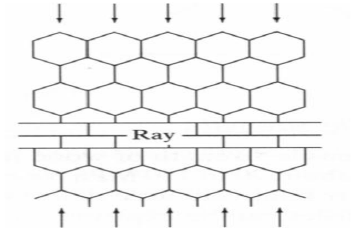




Compressive strength **30 to 70 MPa** for common structural species *(Concrete is about the same).*

Compression perpendicular:





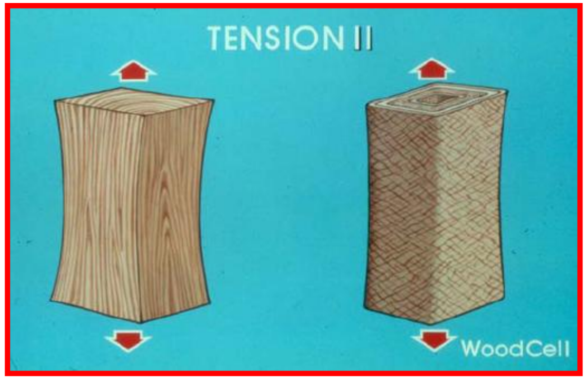


Compressive strength 3 to 7 MPa for common structural species.

Tension Strength

Tension parallel:

• Stress concentration effects of holes, notches and cuts must be considered.



Tensile strength **70 to 150 MPa** for common structural species. (steel can be about 400 MPa)

Tension perpendicular:

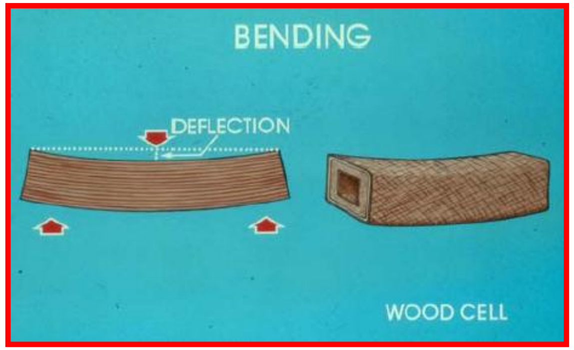
• Relatively weak in tension perpendicular to grain, but wood is rarely loaded in that manner.

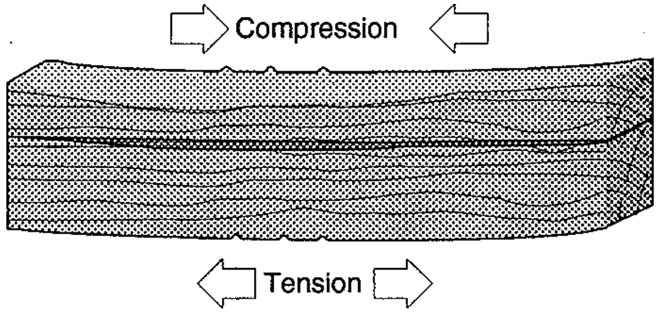
Tensile strength 2 to 9 MPa for common structural species.

Bending and Shear Strength

Bending:

• Very strong in bending along the grain.

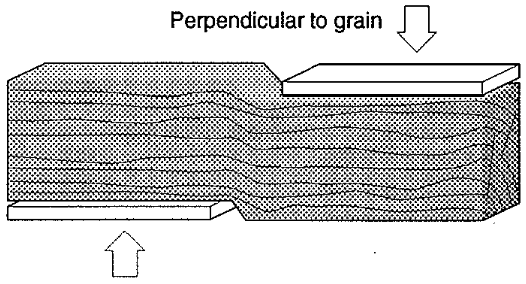


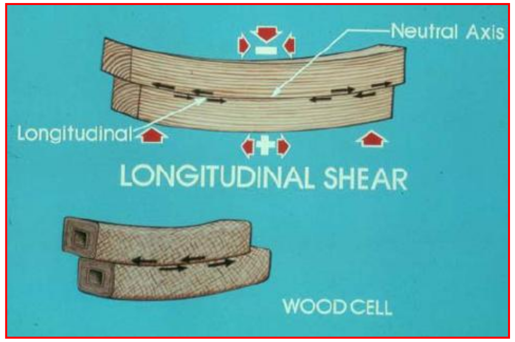


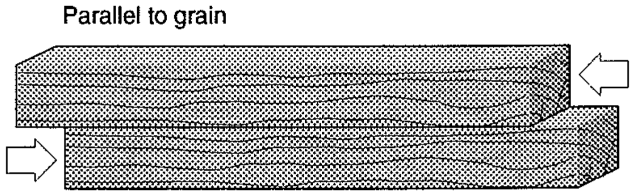
Flexural strength **40 to 100 MPa**.

Shear:

• Very strong in shear perpendicular to the grain (vertical shear), but relatively weak in shear parallel to the grain (longitudinal shear).

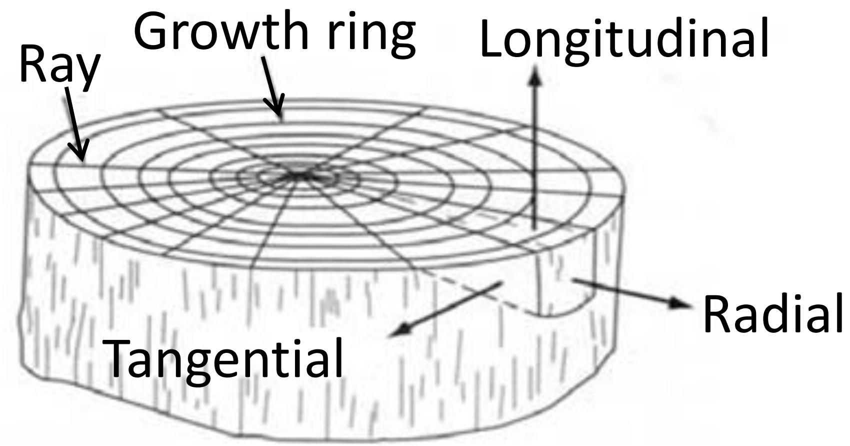


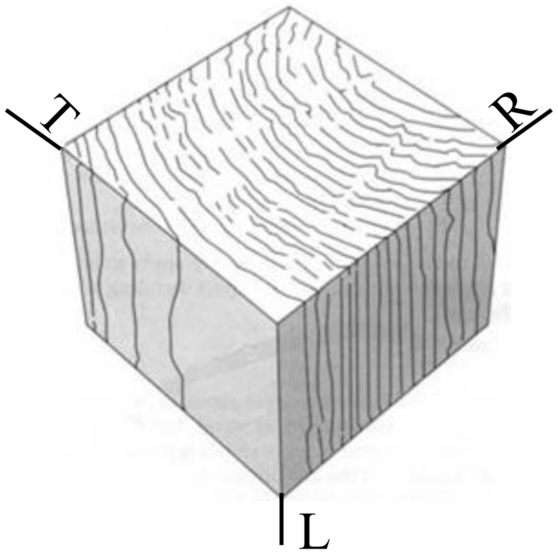




Shear strength parallel to the grain is in the range of **5 to 15 MPa.**

Anisotropic Axes of Wood

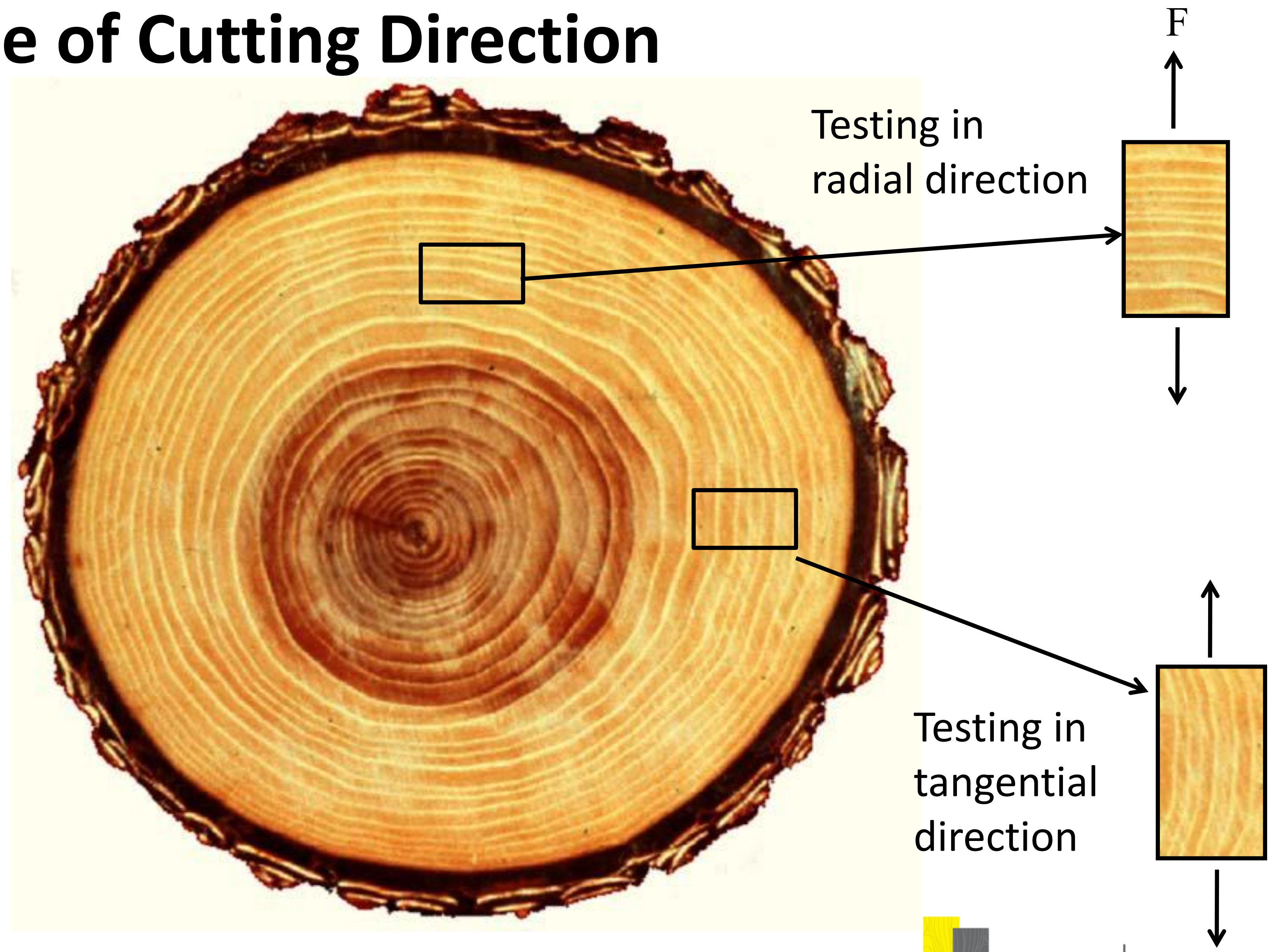




Wood is an orthotropic material with very different properties in different directions; we define three principal axes as follows:

Longitudinal axis (L) -parallel to direction of growth.
Radial axis (R) -perpendicular to growth rings.
Tangential axis (T) -tangential to growth rings.

Importance of Cutting Direction



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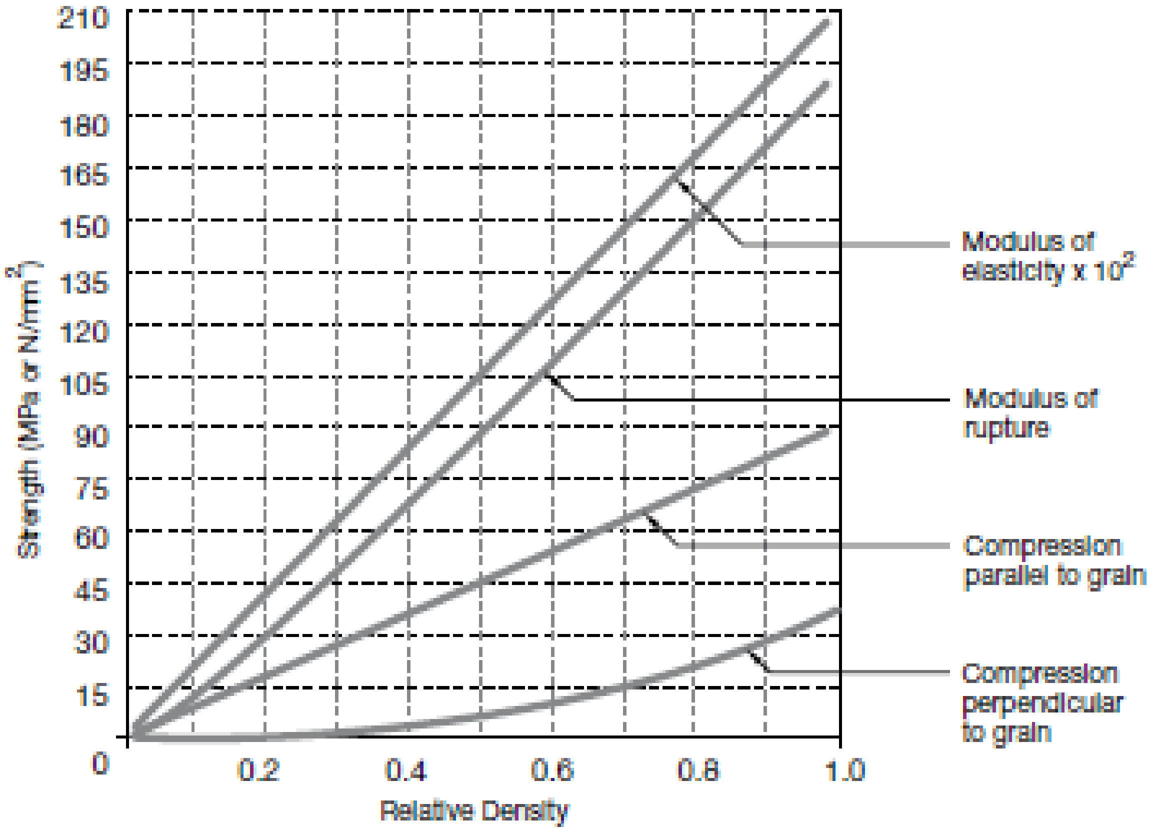
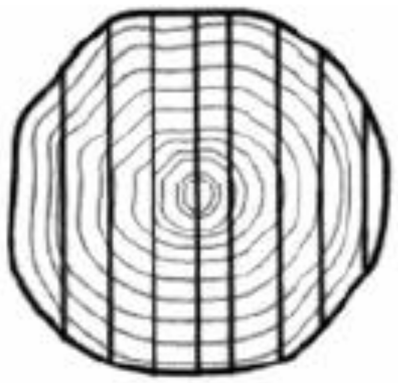
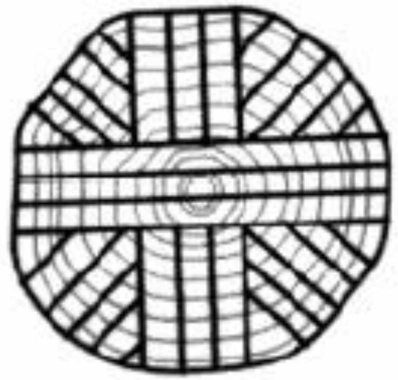
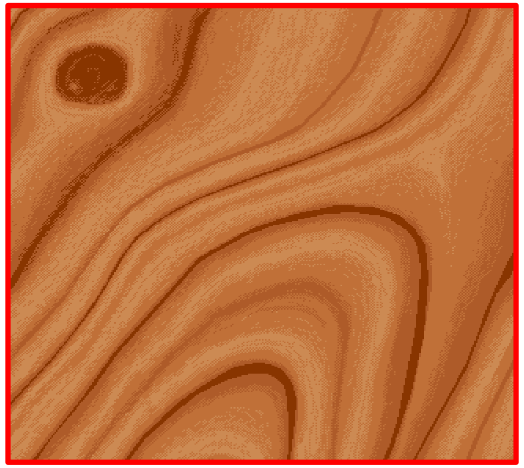
Importance of Cutting Direction



Conversion of Logs to Lumber







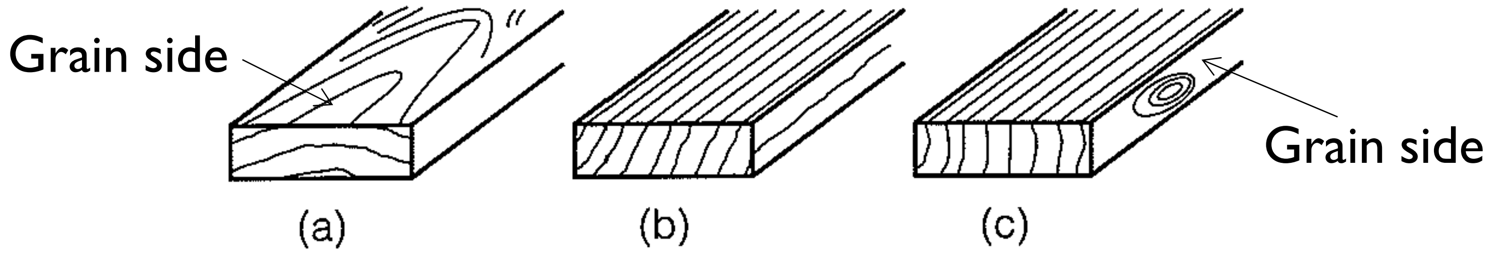
Grain exposure

- Flat sawing:
    - Is quick and economical (e.g. framing lumber).
    - Has grain exposure, desirable for decorative applications.

- Quarter sawing:
    - More complex and usually more wasteful.
    - More dimensionally stable (e.g. used in high grade flooring).

Types of Board Cut

Three types of boards produced:

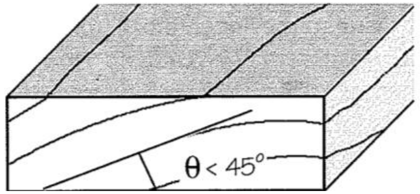


(a) Flat sawn lumber: (grain) angle is less than 45º.

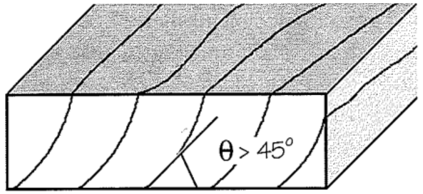
Quarter sawn lumber: angle is greater than 45º and is divided into two types:

(b) Rift sawn: angle is 45º to 80º.

(c) Vertical or edge sawn: angle is 80º to 90º.



Flat sawn



Quarter sawn

Types of Defects

- Size & location of knots-remainder of a branch.
- Amount of wane-bark remnant left on the edge of the board.
- Size of shakes-lengthwise separation in the wood that occur between annual rings (can be caused by strong wind prior to harvest).
- Size of checks-ruptures in wood along the grain, caused by uneven drying of wood.

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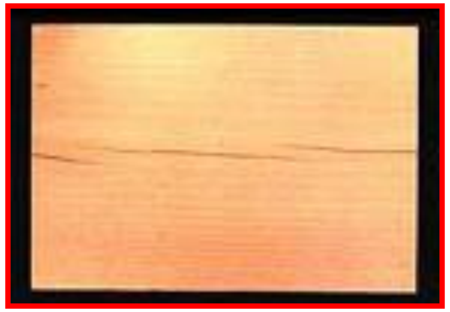
Tight knot

Loose knot

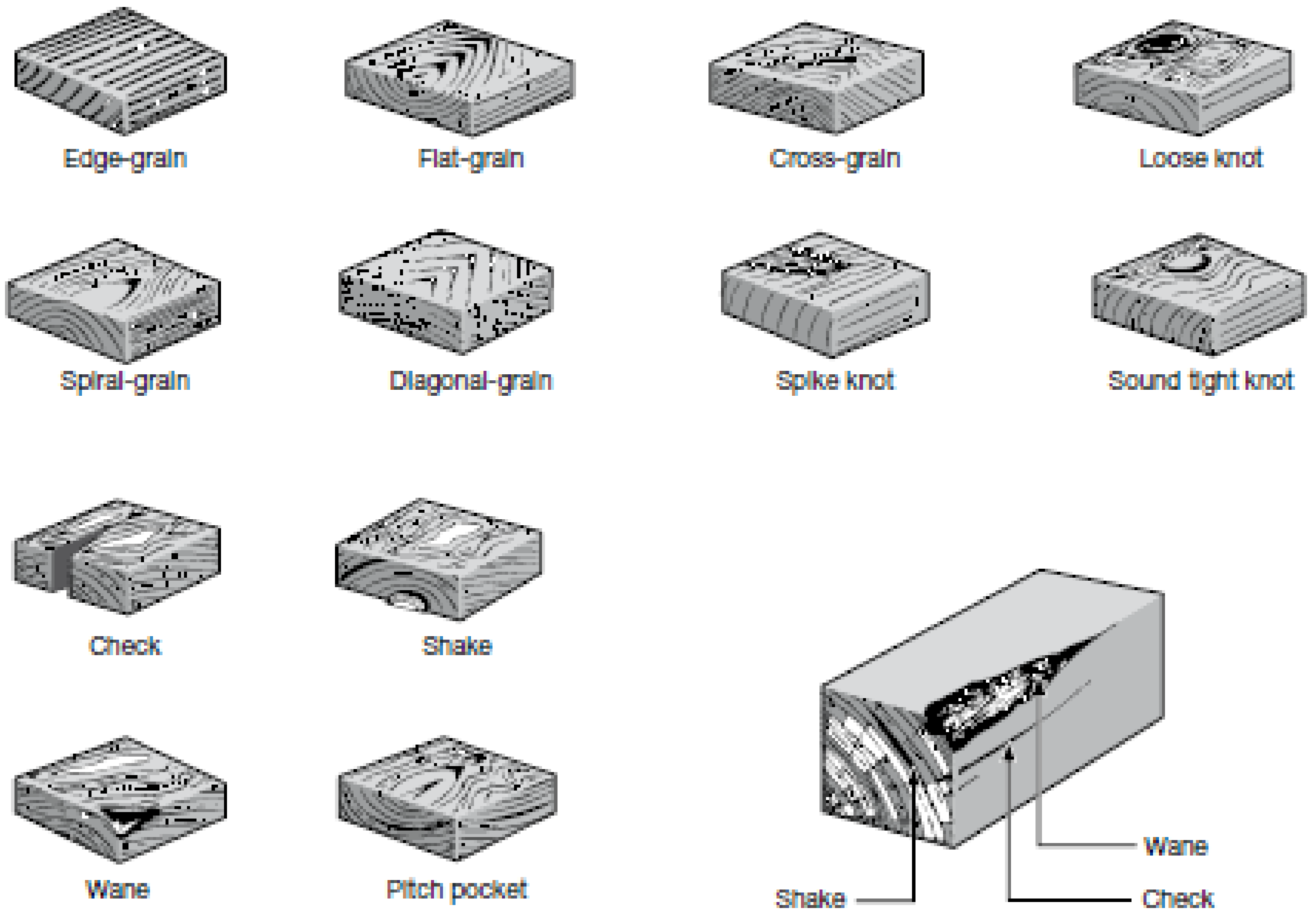
Check



Shake

Wane

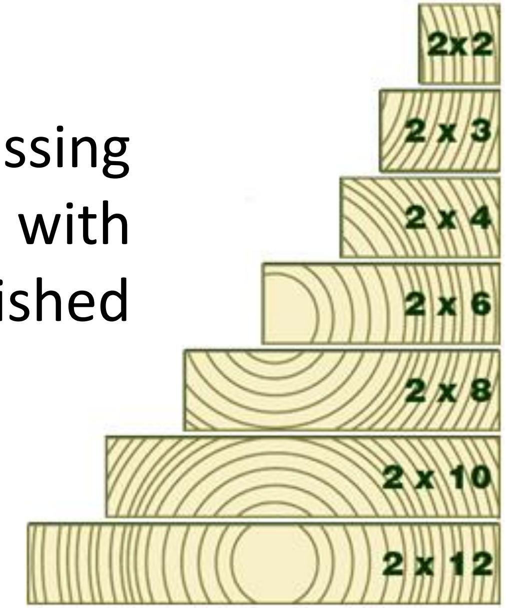
Types of Defects



Dimensional Shapes

Dimensional lumber

- Available sizes are (inches): 2 x 2 ("two-by-two"), 4, 6, 8, 10, 12
  3 x 3, 4, 6, 8, 10, 12
  4 x 4, 6, 8, 10, 12
- Available in lengths of 8, 10, 12, 14 & 16 feet.
- These sizes refer to the rough-sawn sizes in inches. Planing (dressing surface) removes 5 to 10 mm (3/8-in.) per side. Thus a section with nominal dimensions of 2 x 4 inches (50 x 100 mm) actually has finished dimensions of 1½ x 3½ inches (38 x 89 mm).



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Grading

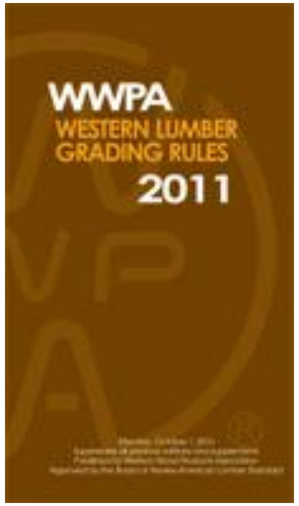
- Final step in wood production involves grading the lumber.
- Pieces of lumber are graded by visual inspection or mechanically (MSR).
- Grades identified according to size, location and number of knots, grain texture (slope), wane, shakes and checks.

Visual grading:

- The inspector gives the lumber a grade based on quality.
- Each specie of wood has a pre-defined table for relating the assigned grade to the allowable stress.

Visual grading-accomplished by certified graders.

The National Lumber Grades Authority (NLGA) for Canadian lumber.



Visual Grading

TABLE 10.4 Example of Design Values of Eastern White Pine[1,4]

Grade Designation	Size Classification	Design Values,[2] psi: Bending[3]	Tension Parallel to Grain	Shear Parallel to Grain	Compression perpendicular to Grain	Compression Parallel to Grain	Modulus of Elasticity	Minimum Modulus of Elasticity
Select Structural		1,250	575	135	350	1,200	1,200,000	440,000
No. 1		775	350	135	350	1,000	1,100,000	400,000
No. 2	2" & wider	575	275	135	350	825	1,100,000	400,000
No. 3		350	150	135	350	475	900,000	330,000
Stud	2" & wider	450	200	135	350	525	900,000	330,000
Construction		675	300	135	350	1,050	1,000,000	370,000
Standard	2"–4" wide	375	175	135	350	850	900,000	330,000
Utility		175	75	135	350	550	800,000	290,000

Grade designation:

Select Structural -highest strength and quality appearance

No. 1, No. 2 and No. 3 -most commonly available timber for structural application (e.g. trusses, rafters and joists)

Stud -principle use is in vertical wall members

Construction, Standard and Utility -permitted for use only where strength is not important-for general light framing (e.g. sill plate and blockings)

Visual Grading

- After logs are sawn into lumber, a lumber inspector examines each piece individually and assigns a grade which is then marked on the piece.
- A grade stamp indicates the grade marking agency, species group, assigned grade and method of manufacture, such as surfaced green or dry.

Grading agency: Canadian Lumbermen's Association

Assigned grade

Mill identification number

Species group: Spruce-Pine- Fir

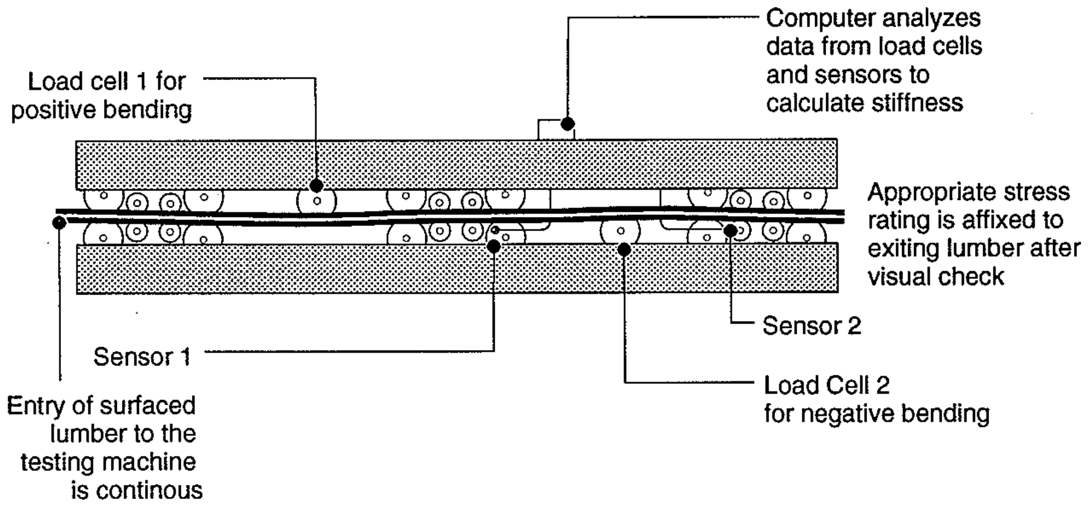
Moisture content: Surface dry

S-P-F: Three species have been grouped together because they are equivalent in appearance and performance.

Machine Stress-Rated (MSR)

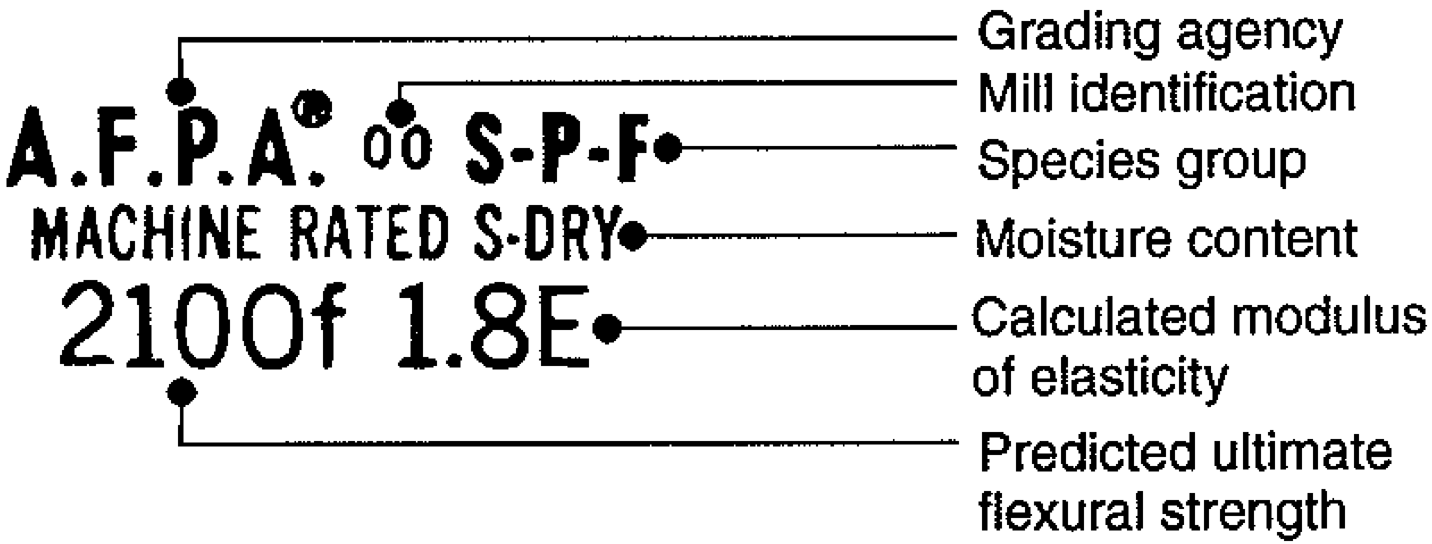
In a MSR machine:

- The wood is first visually inspected for imperfections/defects.
- Then subjected to a mechanical bend stress. Computer automatically determines the modulus of elasticity and bend strength of lumber.
- The lumber can be processed at speeds up to 365 m/minute, including being stamped with an MSR grade mark.



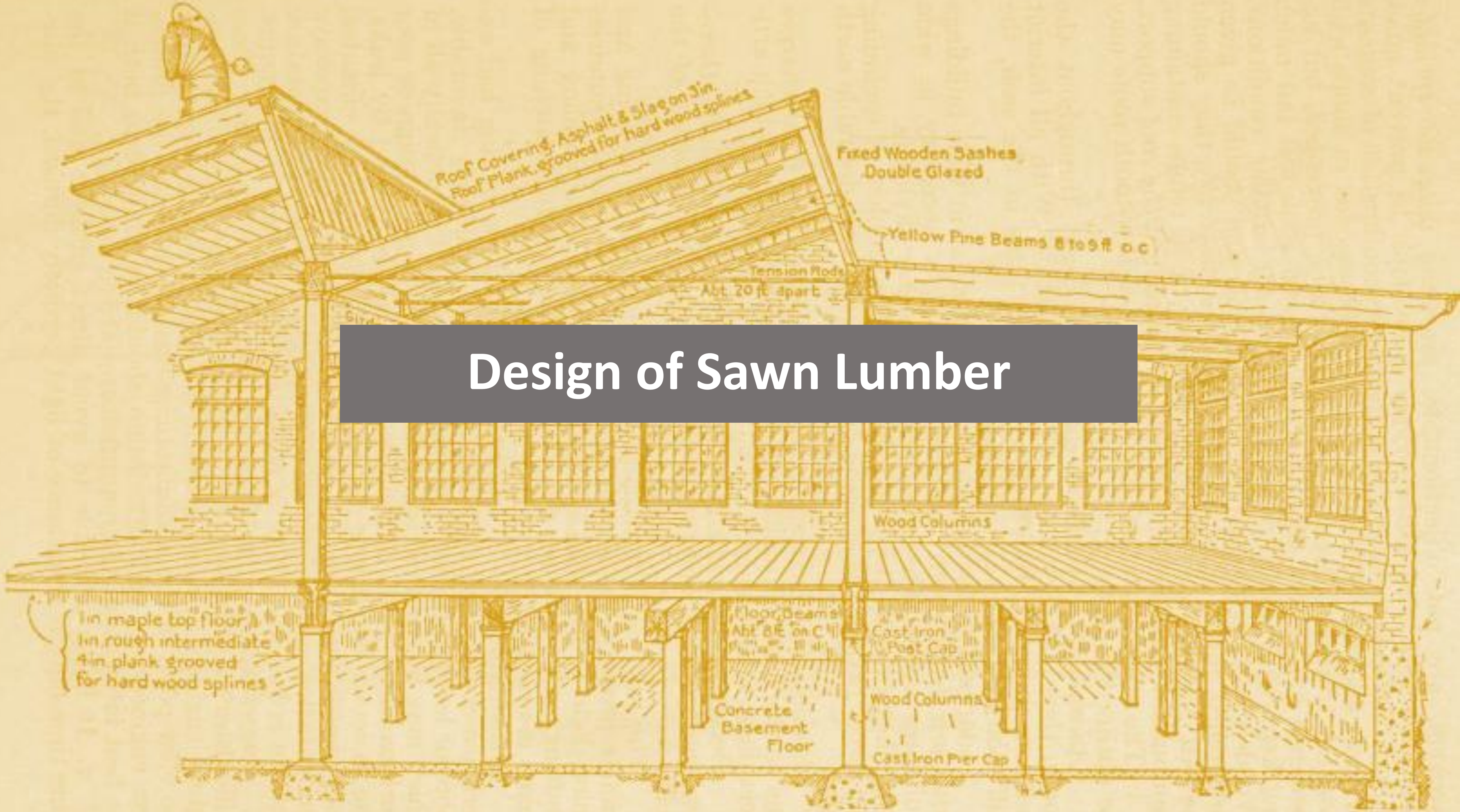
Schematic of mechanical evaluating equipment for MSR lumber.

MSR-Grading Stamp



A.F.P.A→ Alberta Forest Products Association
2100f→allowable bending stress is 2100 psi
1.8E→ modulus of elasticity is $1.8*10^6$ psi

Design of Sawn Lumber



Modification Factors

- Specified strengths should be multiplied by the following factors:
  - Load Duration Factor, K_D
  - System Factor, K_H
  - Service Condition Factor, K_S
  - Treatment Factor, K_T
  - Size Factor, K_Z

e.g. For Bend strength: $F_b = f_b(K_D \cdot K_H \cdot K_S \cdot K_T \cdot K_Z)$;
where;
F_b = factored bend strength (MPa)
f_b = bend strength of the timber (MPa)

For Es = E $(K_S \cdot K_T)$
Es= Factored modulus of elasticity (Mpa)

Other formulas exist for:
- Shear
- Compression
- Tensile strength, etc..

Modification Factors

Duration of Load K_D: *(more explanation in Table 5.3.2.2 of CSA 086-14)*

Wood has the ability to carry short-term loads of a higher magnitude than those it will support for a long time.

K_D =1.15 Short term loads (wind, earthquake, impact).

K_D =1.0 Standard duration (snow, occupancy).

K_D = 0.65 Permanent loads (continuous load due to weight of material in tanks, machinery, fixed in place, earth pressure on retaining walls).

K_D can be calculated directly for standard term loads (Pl>Ps) *(less conservatively though)* *Noted in CL 5.3.2.3 O86*

$$K_D = 1.0 - 0.50 \log (P_L/P_S) \geq 0.65$$

where

P_L = specified long-term load

P_S = specified standard-term load based on S and L loads acting alone or in combination
= S, L, $S + 0.5L$, or $0.5S + L$, determined using importance factors equal to 1.0

Combined loading, must be the most severe loading combination and K_D can be short term see CL 5.3.2.4 O86. For example

1.25D+1.4W+0.5L Use K_D = 1.15 as wind is the most dominate

Modification Factors

Duration of Load K_D: *(more explanation in Table 5.3.2.2 of CSA 086-14)*

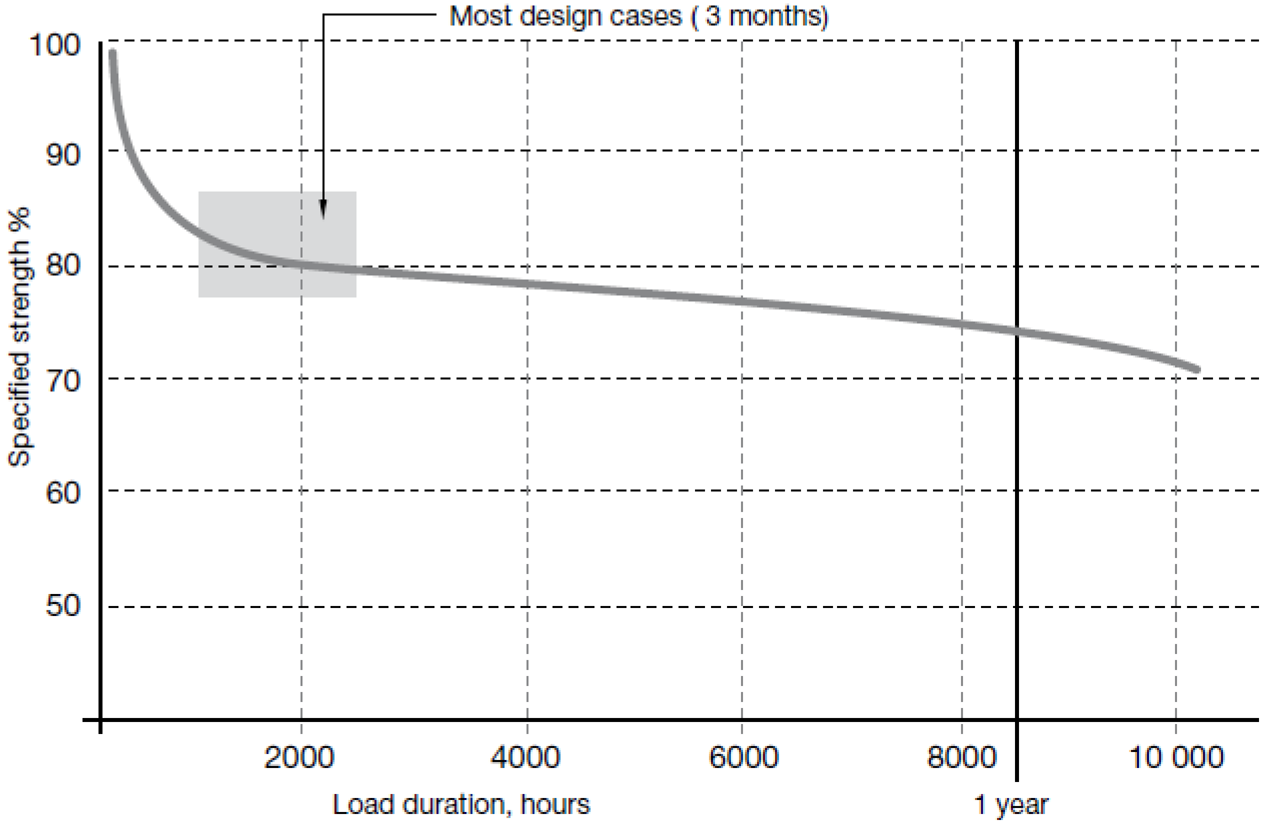
Table 5.3.2.2
Load duration factor, K_D

Load duration	K_D	Explanatory notes
Short term	1.15	Short-term loading means the condition of loading where the duration of the specified loads is not expected to last more than 7 days continuously or cumulatively throughout the life of the structure. Examples include wind loads, earthquake loads, falsework, and formwork, as well as impact loads.
Standard term	1.00	Standard term means the condition of loading where the duration of specified loads exceeds that of short-term loading, but is less than long-term loading. Examples include snow loads, live loads due to occupancy, wheel loads on bridges, and dead loads in combination with all of the above.
Long term	0.65	Long-term duration means the condition of loading under which a member is subjected to more or less continuous specified load. Examples include dead loads or dead loads plus live loads of such character that they are imposed on the member for as long a period of time as the dead loads themselves. Such loads include those usually occurring in tanks or bins containing fluids or granular material, loads on retaining walls subjected to lateral pressure such as earth, and floor loads where the specified load can be expected to be continuously applied, such as those in buildings for storage of bulk materials. Loads due to fixed machinery should be considered to be long term.

Note: *Load duration requires professional judgment by the designer. Explanatory notes in this Table provide guidance to designers about the types of loads and load combinations for which each modification factor should be applied.*

Modification Factors

Duration of Load K_D: *(more explanation in Table 5.3.2.2 of CSA 086-14)*



Notes:

1. Specified strengths in CSA O86 have incorporated a factor of 0.8 to account for load duration.
2. This curve is derived assuming the wood members are fully stressed to their short term resistance for the cumulative period shown.

Modification Factors

System Factor K_H: *(more explanation in Table 6.4.4 of CSA 086-14)*

Some wood constructed "systems" allow the load to be distributed over several adjacent framing members (e.g. a number of closely spaced parallel floor joists). This factor reduces the chances of any one member being deficient.

K_H =1.1 to 1.4, larger values are when the load is shared amongst more members in the "system."

		Case 2†		
For specified strength in	Case 1*	Visually graded	MSR	Built-up beams
Bending	1.10	1.40	1.20	1.10
Longitudinal shear	1.10	1.40	1.20	1.10
Compression parallel to grain	1.10	1.10	1.10	1.00
Tension parallel to grain	1.10	—	—	1.00
All other properties	1.00	1.00	1.00	1.00

Modification Factors

System Factor K_H: *(more explanation in Table 6.4.4 of CSA 086-14)*

Are you Case 1 or Case 2?

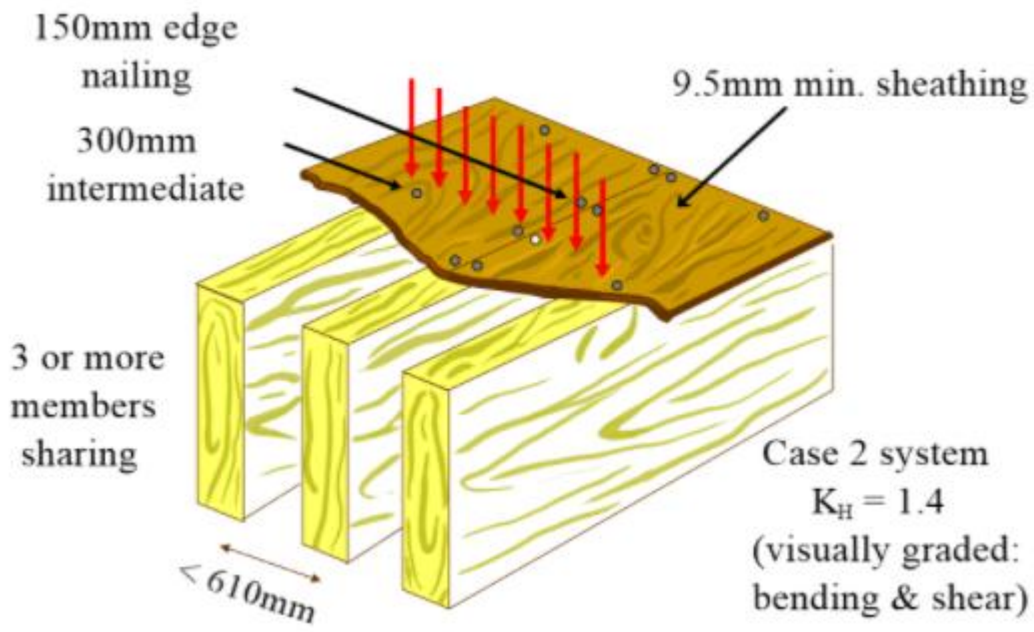
The system factor implies load redundancy based upon a member failing. In Case 1, there must be three or more parallel members spaced not more that 610mm apart (2ft).

In Case 2, you need to show composite action and load sharing in the system. Basic sheathing fastening etc. Typical to see in slid lumber joists, rafters and stud systems. Trusses however are not applicable though case 1 may apply based on the configuration of the framing, sheathing and fastenings.

Modification Factors

System Factor K_H: *(more explanation in Table 6.4.4 of CSA 086-14)*

Are you Case 1 or Case 2?



Modification Factors

Service Condition Factor K_S: *(more explanation in Table 6.4.2 of CSA 086-14)*

Member capacities and stiffness are generally higher for dry service conditions than for wet service conditions. Effect of moisture can reduce strength properties . Being dry is not to assume there is know moisture. There will always be an inherent amount its basically reference to a threshold

Conservative to assume K_S = 0.67

K_S	Property	Dry service conditions	Wet service conditions: sawn lumber, piling, and poles of least dimension	
			89 mm or less	Over 89 mm
K_{Sb}	Bending at extreme fibre	1.00	0.84	1.00
K_{Sf}	Fracture shear	1.00	0.70	0.70
K_{Sv}	Longitudinal shear	1.00	0.96	1.00
K_{Sc}	Compression parallel to grain	1.00	0.69	0.91
K_{Scp}	Compression perpendicular to grain	1.00	0.67	0.67
K_{St}	Tension parallel to grain	1.00	0.84	1.00
K_{SE}	Modulus of elasticity	1.00	0.94	1.00

Modification Factors

Timber roof on swimming pool in Toronto

Service Condition Factor K_S: *(more explanation in Table 6.4.2 of CSA 086-14)*

Dry conditions refer to where the timber will have an average equilibrium moisture content over a year of 15% and not exceeding 19%. Hence if you can control the humidity in the system you can rely more on dry conditions. A common misconception pertaining to using timber for swimming pools is that they are always wet, there are ways to control the moisture environment

Note also that conditions can differ for different properties and wood products (lumber, glulam, plywood, fastenings etc, in bending, shear and compression

Modification Factors

Treatment Factor K_T: *(more explanation in Table 6.4.3 of CSA 086-14)*

Preservative treatments themselves appear to have little effect on structural properties. However, when members are incised (sharp point penetrating into the surface) and then treated and re-dried significant structural property decreases can occur:

K_T = 0.90 for strength of dimension lumber incised with preservatives.

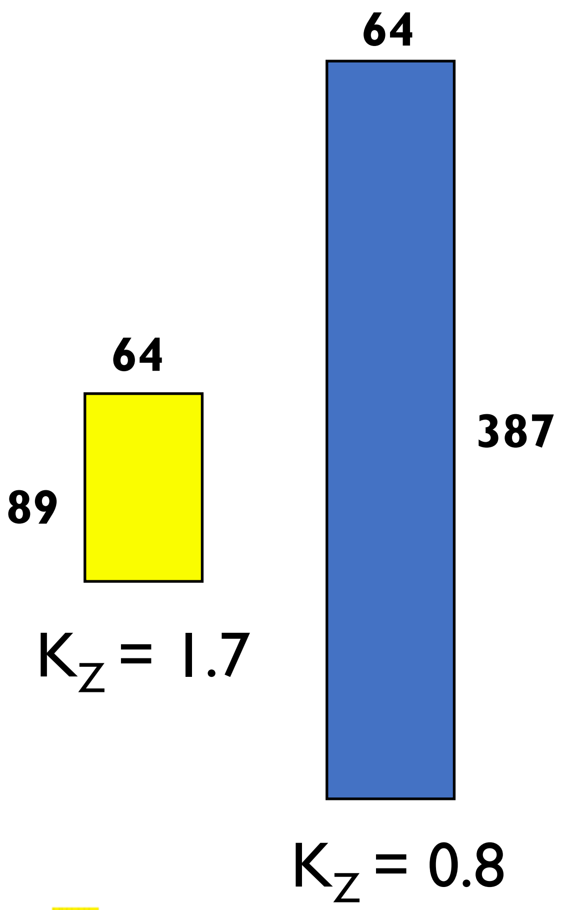
Fire retardant treatment requires specific evaluation

Product	Dry service conditions	Wet service conditions
Untreated lumber	1.00	1.00
Preservative-treated unincised lumber	1.00	1.00
Preservative-treated incised lumber of thickness 89 mm or less		
Modulus of elasticity	0.90	0.95
Other properties	0.75	0.85
Fire-retardant-treated lumber	See Clause 6.4.3.2 for effects of fire-retardant treatment.	

Modification Factors

Size Factor K_Z: *(more explanation in Table 5.4.5 of CSA 086-14)*

- Strength properties may vary with member size.
- Strength is limited to the weakest part of a structure, so larger members will have more probability to have 'weak links'
- Larger members have lower strength properties.
- Values of K_z for bending and shear in visually graded sawn lumber range from 1.7 to 0.8.



Explanation:

•For a Kz of 1.7, it is assumed the strength is increased by 70% for a short member (less defects in a short member).

• For a Kz of 0.8, it is assumed the strength is decreased by 20% for a long member (more chances of defects in a longer member).

Modification Factors

Larger dimension, mm	Bending and shear K_{Zb}, K_{Zv} — Smaller dimension, mm: 38 to 64	89 to 102	114 or more	Tension parallel to grain, K_{Zt} — All	Compression perpendicular to grain, K_{Zcp} — All	Compression parallel to grain, K_{Zc} — All	All other properties — All
38	1.7	—	—	1.5	See Clause 6.5.7.5	Value computed using formula in Clause 6.5.6.2.3	1.0
64	1.7	—	—	1.5			1.0
89	1.7	1.7	—	1.5			1.0
114	1.5	1.6	1.3	1.4			1.0
140	1.4	1.5	1.3	1.3			1.0
184 to 191	1.2	1.3	1.3	1.2			1.0
235 to 241	1.1	1.2	1.2	1.1			1.0
286 to 292	1.0	1.1	1.1	1.0			1.0
337 to 343	0.9	1.0	1.0	0.9			1.0
387 or larger	0.8	0.9	0.9	0.8			1.0

Member Dimensions

Grade category	Smaller dimension, mm	Larger dimension, mm	Grades
Light framing	38 to 89	38 to 89	Construction, Standard
Stud	38 to 89	38 or more	Stud
Structural light framing	38 to 89	38 to 89	Select Structural No. 1, No. 2, No. 3
Structural joists and planks	38 to 89	114 or more	Select Structural No. 1, No. 2, No. 3
Beam and stringer	114 or more	Exceeds smaller dimension by more than 51	Select Structural No. 1, No. 2
Post and timber	114 or more	Exceeds smaller dimension by 51 or less	Select Structural No. 1, No. 2
Plank decking	38 to 89	140 or more	Select, Commercial

Specified strengths

Table 6.3.1A
Specified strengths and modulus of elasticity for structural joist and plank, structural light framing, and stud grade categories of lumber, MPa

Species identification	Grade	Bending at extreme fibre, f_b	Longi-tudinal shear, f_v	Compression: Parallel to grain, f_c	Compression: Perpen-dicular to grain, f_{cp}	Tension parallel to grain, f_t	Modulus of elasticity: E	Modulus of elasticity: E_{05}
D Fir-L	SS	16.5		19.0		10.6	12 500	8 500
	No. 1/No. 2	10.0	1.9	14.0	7.0	5.8	11 000	7 000
	No. 3/Stud	4.6		7.3		2.1	10 000	5 500
Hem-Fir	SS	16.0		17.6		9.7	12 000	8 500
	No. 1/No. 2	11.0	1.6	14.8	4.6	6.2	11 000	7 500
	No. 3/Stud	7.0		9.2		3.2	10 000	6 000
Spruce-Pine-Fir	SS	16.5		14.5		8.6	10 500	7 500
	No. 1/No. 2	11.8	1.5	11.5	5.3	5.5	9 500	6 500
	No. 3/Stud	7.0		9.0		3.2	9 000	5 500
Northern	SS	10.6		13.0		6.2	7 500	5 500
	No. 1/No. 2	7.6	1.3	10.4	3.5	4.0	7 000	5 000
	No. 3/Stud	4.5		5.2		2.0	6 500	4 000

Note: *Tabulated values are based on the following standard conditions:*
(a) 286 mm *larger dimension;*
(b) dry service conditions; and
(c) standard-term duration of load.

Table 6.3.1B
Specified strengths and modulus of elasticity for light framing grades, MPa, applicable to sizes 38 by 38 mm to 89 by 89 mm

Species identification	Grade	Bending at extreme fibre, f_b	Longi-tudinal shear, f_v	Compression: Parallel to grain, f_c	Compression: Perpen-dicular to grain, f_{cp}	Tension parallel to grain, f_t	Modulus of elasticity: E	Modulus of elasticity: E_{05}
D Fir-L	Const.	13.0	3.2	16.0	7.0	6.6	10 000	5 500
	Stand.	7.3		13.1		3.7	9 000	5 000
Hem-Fir	Const.	14.3	2.7	16.9	4.6	7.0	10 000	6 000
	Stand.	8.0		13.9		3.9	9 000	5 500
Spruce-Pine-Fir	Const.	15.3	2.6	13.1	5.3	6.2	9 000	5 500
	Stand.	8.6		10.8		3.5	8 000	5 000
Northern	Const.	9.9	2.2	11.9	3.5	4.5	6 500	4 000
	Stand.	5.5		9.8		2.5	6 000	3 500

Table 6.3.1C
Specified strengths and modulus of elasticity for beam and stringer grades, MPa

Species identification	Grade	Bending at extreme fibre, f_b*	Longi-tudinal shear, f_v	Compression: Parallel to grain, f_c	Compression: Perpen-dicular to grain, f_{cp}	Tension parallel to grain, f_t	Modulus of elasticity: E*	Modulus of elasticity: E_{05}*
D Fir-L	SS	19.5	1.5	13.2	7.0	10.0	12 000	8 000
	No. 1	15.8		11.0		7.0	12 000	8 000
	No. 2	9.0		7.2		3.3	9 500	6 000
Hem-Fir	SS	14.5	1.2	10.8	4.6	7.4	10 000	7 000
	No. 1	11.7		9.0		5.2	10 000	7 000
	No. 2	6.7		5.9		2.4	8 000	5 500
Spruce-Pine-Fir	SS	13.6	1.2	9.5	5.3	7.0	8 500	6 000
	No. 1	11.0		7.9		4.9	8 500	6 000
	No. 2	6.3		5.2		2.3	6 500	4 500
Northern	SS	12.8	1.0	7.2	3.5	6.5	8 000	5 500
	No. 1	10.8		6.0		4.6	8 000	5 500
	No. 2	5.9		3.9		2.2	6 000	4 000

Table 6.3.1D
Specified strengths and modulus of elasticity for post and timber grades, MPa

Species identification	Grade	Bending at extreme fibre, f_b	Longi-tudinal shear, f_v	Compression: Parallel to grain, f_c	Compression: Perpen-dicular to grain, f_{cp}	Tension parallel to grain, f_t	Modulus of elasticity: E	Modulus of elasticity: E_{05}
D Fir-L	SS	18.3	1.5	13.8	7.0	10.7	12 000	8 000
	No. 1	13.8		12.2		8.1	10 500	6 500
	No. 2	6.0		7.5		3.8	9 500	6 000
Hem-Fir	SS	13.6	1.2	11.3	4.6	7.9	10 000	7 000
	No. 1	10.2		10.0		6.0	9 000	6 000
	No. 2	4.5		6.1		2.8	8 000	5 500
Spruce-Pine-Fir	SS	12.7	1.2	9.9	5.3	7.4	8 500	6 000
	No. 1	9.6		8.7		5.6	7 500	5 000
	No. 2	4.2		5.4		2.6	6 500	4 500
Northern	SS	12.0	1.0	7.5	3.5	7.0	8 000	5 500
	No. 1	9.0		6.7		5.3	7 000	5 000
	No. 2	3.9		4.1		2.5	6 000	4 000

Table 6.3.2
Specified strengths and modulus of elasticity for machine stress-rated grades 38 mm wide by all depths, MPa

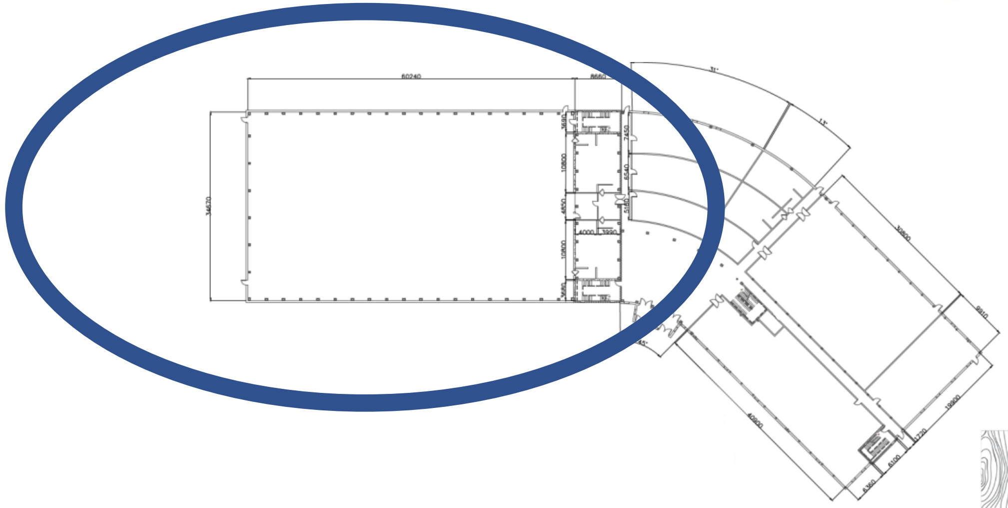
Grade	Bending at extreme fibre, f_b	Modulus of elasticity, E	Tension parallel to grain, ft: 89 to 184 mm	Tension parallel to grain, ft: >184 mm*	Compression: Parallel to grain, f_c	Compression: Perpendicular to grain, f_{cp}†
1200F_b -1.2E	17.4	8 300	6.7	—	15.1	5.3
1350F_b -1.3E	19.5	9 000	8.4	—	16.9	5.3
1450F_b -1.3E	21.0	9 000	9.0	—	17.3	5.3
1500F_b -1.4E	21.7	9 700	10.1	—	17.5	5.3
1650F_b -1.5E	23.9	10 300	11.4	—	18.1	5.3
1800F_b -1.6E	26.1	11 000	13.2	—	18.7	5.3
1950F_b -1.7E	28.2	11 700	15.4	—	19.3	5.3
2100F_b -1.8E	30.4	12 400	17.7	—	19.9	6.5
2250F_b -1.9E	32.6	13 100	19.6	—	20.5	6.5
2400F_b -2.0E	34.7	13 800	21.6	—	21.1	6.5
2550F_b -2.1E	36.9	14 500	23.0	—	21.7	6.5
2700F_b -2.2E	39.1	15 200	24.1	—	22.3	6.5
2850F_b -2.3E	41.3	15 900	25.8	—	22.9	6.5
3000F_b -2.4E	43.4	16 500	26.9	—	23.5	6.5

The following MSR grades provide a modulus of elasticity with higher corresponding strengths. For these MSR grades, qualification and daily quality control for tensile strength are required.

Table 6.3.3
Specified strengths and modulus of elasticity for machine evaluated lumber grades 38 mm wide by all depths, MPa

Grade	Bending at extreme fibre, f_b	Modulus of elasticity, E	Tension parallel to grain, f_t	Compression	
				Parallel to grain, f_c	Perpendicular to grain, f_{cp}*
M-10	20.3	8 300	9.0	17.1	5.3
M-11	22.4	10 300	9.5	17.7	5.3
M-12	23.2	11 000	9.5	17.9	5.3
M-13	23.2	9 700	10.7	17.9	5.3
M-14	26.1	11 700	11.2	18.7	5.3
M-15	26.1	10 300	12.3	18.7	5.3
M-18	29.0	12 400	13.5	19.5	6.5
M-19	29.0	11 000	14.6	19.5	5.3
M-21	33.3	13 100	15.7	20.7	6.5
M-22	34.0	11 700	16.8	20.9	5.3
M-23	34.7	12 400	21.3	21.1	6.5
M-24	39.1	13 100	20.2	22.3	6.5
M-25	39.8	15 200	22.4	22.5	6.5
M-26	40.6	13 800	20.2	22.7	6.5

This scenario is a swimming pool. You are being asked to specify the species and grade of a timber joist in Ontario (*assume SPF only available for economic and availability considerations*) that can meet an 8MPa Bending stress. Assume the roof supports long term machinery, untreated and members are arranged in such a way to assume case 2 system conditions.



This scenario is a swimming pool. You are being asked to specify the species and grade of a timber joist in Ontario (*assume SPF only available for economic and availability considerations*) that can meet an 8MPa Bending stress. Assume the roof supports long term machinery, untreated and members are arranged in such a way to assume case 2 system conditions.

Joist specified strengths are found in Table 6.3.1A (note this table assumes unity in K factors). In this problem, which is purely illustrative with limitations (many assumptions are simplified here), but we must specify the appropriate member. The solution here is more detailed and there are more efficient calculation procedures.

You have 7 potential options. Though access to only SPF limits you to two : SS or No.1/No.2

Table 6.3.1A
Specified strengths and modulus of elasticity for structural joist and plank, structural light framing, and stud grade categories of lumber, MPa

Species identification	Grade	Bending at extreme fibre, f_b	Longitudinal shear, f_v	Compression: Parallel to grain, f_c	Compression: Perpendicular to grain, f_{cp}	Tension parallel to grain, f_t	Modulus of elasticity: E	Modulus of elasticity: E_{05}
D Fir-L	SS	16.5		19.0		10.6	12 500	8 500
	No. 1/No. 2	10.0	1.9	14.0	7.0	5.8	11 000	7 000
	No. 3/Stud	4.6		7.3		2.1	10 000	5 500
Hem-Fir	SS	16.0		17.6		9.7	12 000	8 500
	No. 1/No. 2	11.0	1.6	14.8	4.6	6.2	11 000	7 500
	No. 3/Stud	7.0		9.2		3.2	10 000	6 000
Spruce-Pine-Fir	SS	16.5		14.5		8.6	10 500	7 500
	No. 1/No. 2	11.8	1.5	11.5	5.3	5.5	9 500	6 500
	No. 3/Stud	7.0		9.0		3.2	9 000	5 500
Northern	SS	10.6		13.0		6.2	7 500	5 500
	No. 1/No. 2	7.6	1.3	10.4	3.5	4.0	7 000	5 000
	No. 3/Stud	4.5		5.2		2.0	6 500	4 000

Note: *Tabulated values are based on the following standard conditions:*
(a) 286 mm *larger dimension;*
(b) dry service conditions; and
(c) standard-term duration of load.

This scenario is a swimming pool. You are being asked to specify the species and grade of a timber joist in Ontario (*assume SPF only available for economic and availability considerations*) that can meet an 8MPa Bending stress. Assume the roof supports long term machinery, untreated and members are arranged in such a way to assume case 2 system conditions.

- Required Factored bend strength = 8 MPa
- Bend strength is either 16.5 or 11.8 MPa before modification

Bend strength: $F_b = f_b \cdot (K_D \cdot K_H \cdot K_S \cdot K_T \cdot K_Z)$;
where;
F_b = factored bend strength (MPa) = 8MPa (min)
f_b= bend strength of the timber (MPa) = either 16.5 or 11.8MPa

This scenario is a swimming pool. You are being asked to specify the species and grade of a timber joist in Ontario (*assume SPF only available for economic and availability considerations*) that can meet an 8MPa Bending stress. Assume the roof supports long term machinery, untreated and members are arranged in such a way to assume case 2 system conditions.

- Required Factored bend strength = 8 MPa
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Bend strength: $F_b = f_b \cdot (K_D \cdot K_H \cdot K_S \cdot K_T \cdot K_Z)$;
where;
F_b = factored bend strength (MPa)
f_b = bend strength of the timber (MPa)

In this case I have 4 modification factors needed; Kd- load duration; Kh- system, Ks- Service, and Kz- size

This scenario is a swimming pool. You are being asked to specify the species and grade of a timber joist in Ontario (*assume SPF only available for economic and availability considerations*) that can meet an 8MPa Bending stress. Assume the roof supports long term machinery, untreated and members are arranged in such a way to assume case 2 system conditions.

Which K factors you assume will require justification. Specific detailing to the swimming pool complex can alleviate the Ks reduction. If you aren't detailing this you will drop your capacities by 33%. Here this is shown as 0.67 to be conservative but will likely be unity. I have also more conservatively specked Kz as its uncertain the size 0.8. Case 2 would mean the system factor is 1.4. There is no treatment so this is 1. Lastly because of mechanical equipment on the roof this will penalize us and need long term loading of 0.65. Detailing here so that the load is taken elsewhere can also be performed.

Bend strength: $F_b = f_b \cdot (K_D \cdot K_H \cdot K_S \cdot K_T \cdot K_Z)$;
where;
F_b = factored bend strength (MPa)
f_b = bend strength of the timber (MPa)

$$F_b = f_b(K_D \cdot K_H \cdot K_S \cdot K_T \cdot K_Z);$$
$$= 11.8(0.65*1.4*0.67*1*0.8)$$
$$= 5.75 \text{ MPa}$$

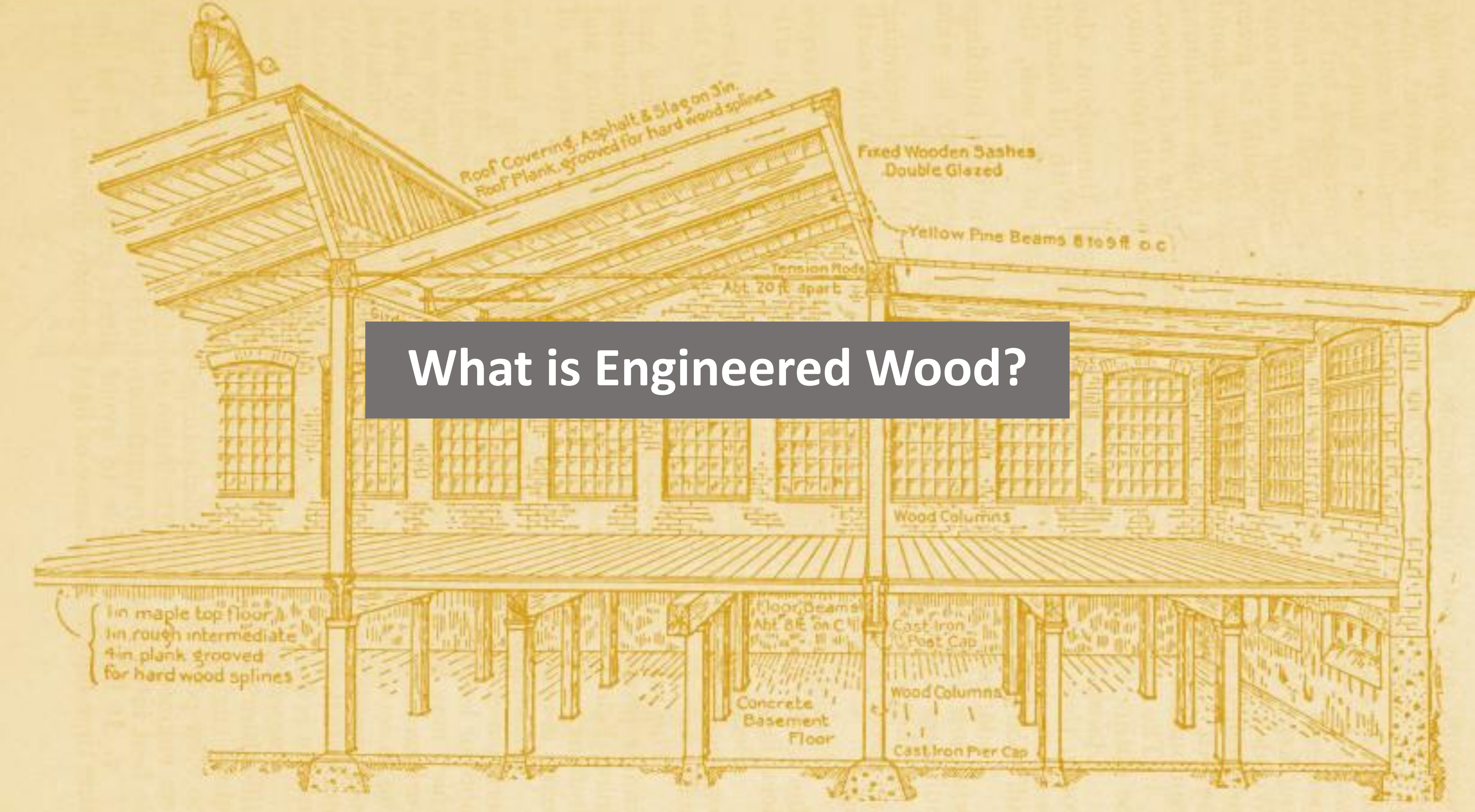
Re-calculating to the new member shows that the select structural grade just meets the problem definition. Recall the question and solution makes a series of approximations in reality each modification will need justification. Try redoing the problem assuming that the Ks factor is unity and compare the section sizes available to you.

Bend strength: $F_b = f_b \,(K_D \cdot K_H \cdot K_S \cdot K_T \cdot K_Z)$;
where;
F_b = factored bend strength (MPa)
f_b= bend strength of the timber (MPa)

$F_b = f_b(K_D \cdot K_H \cdot K_S \cdot K_T \cdot K_Z)$;
$= 16.5(0.67*1.4*0.65*1*0.8)$
$= 8.04\ MPa$

In this case ill specify SPF –select structural for my timber.

What is Engineered Wood?



Engineered Wood: Composite a union of materials

Engineered Wood Products

Engineered wood consists of bonding together wood strands, veneers, lumber and fibres with adhesives to form composite materials.

Advantages over solid wood are:

- Large panels can be manufactured from small diameter trees unsuitable for solid lumber.
- Wood waste and defective wood, can be used to produce particle and fiber-based boards.
- Produce stronger, stiffer and more homogeneous material than lumber.

Adhesives

Adhesives used in glulam, plywood and other laminated products are typically thermosetting resins that require heat or catalysts to work and are irreversible once hardened.

Their chemical composition consists of **P**henol, **R**esorcinol, **F**ormaldehyde, **M**elamine and **U**rea.

Typical combination are **PRF** , **RF**, **MUF** and **UF**.

Additionally one(**1**)-**C**omponent **P**oly**U**rethane **R**eactive (**1C-PUR**) and **E**mulsion **P**olymerized **I**socyanate (**EPI**) adhesives can be used which reduce the effects of Formaldehyde.

IC-PUR is common in CLT production but the others can also be used.

All of the adhesives listed above have shown minimal strength loss when exposed to high temperatures and are developed according to specific standards.

However epoxy resins used for connecting steel to wood and **P**oly**V**inyl **A**cetate (**PVA**) also known as “wood glue” fail when exposed to high temperatures.

Example of an epoxy resins Steel- Timber connection

Engineered Wood Products

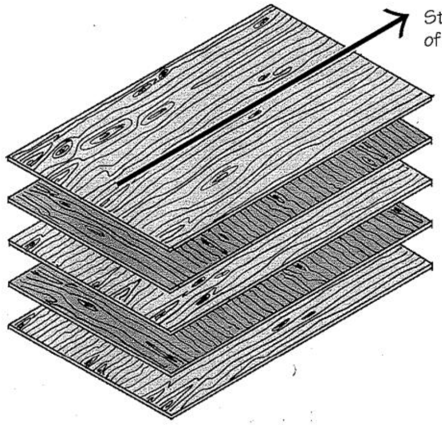
Types of engineered wood:

- Glulam (glued-laminated wood).
- Plywood.
- Oriented Strandboard (OSB) and Waferboard.
- Laminated Veneer Lumber (LVL).
- Parallel Strand Lumber (PSL).
- Prefabricated Wood I-Joists.
- Structurally Insulated Panels (SIP)
- Cross Laminated Timber (CLT)

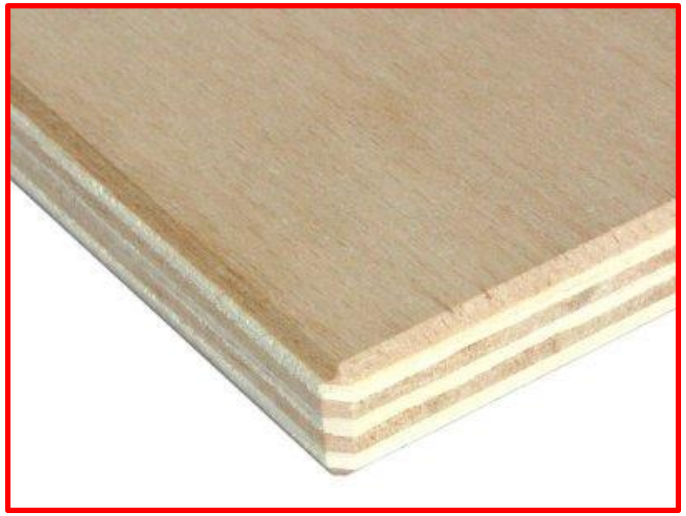
Plywood

Plywood is made from layers of thin sheets of wood veneer glued together, each with its grain at right angles to adjacent layers.

• There are usually an odd number of plies, so that the grain on the outside plies runs in the same direction.



Orientation of veneers in a plywood panel.



www.winwood-products.com

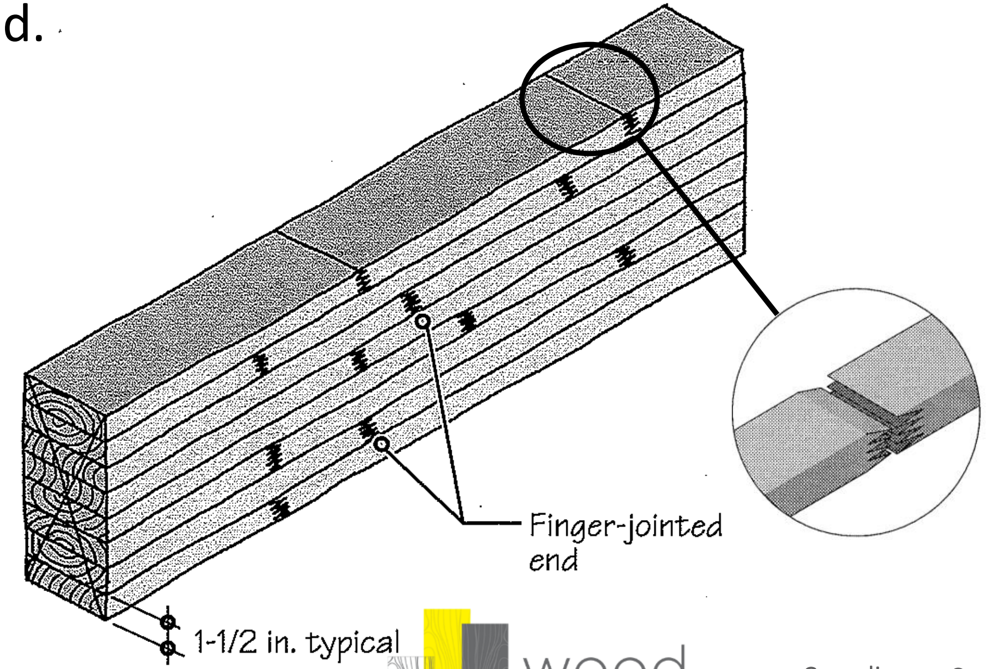
Available in 1220mm (4feet) x 2440mm (8feet) sheets of various thickness from 6mm to 30mm

Glulam

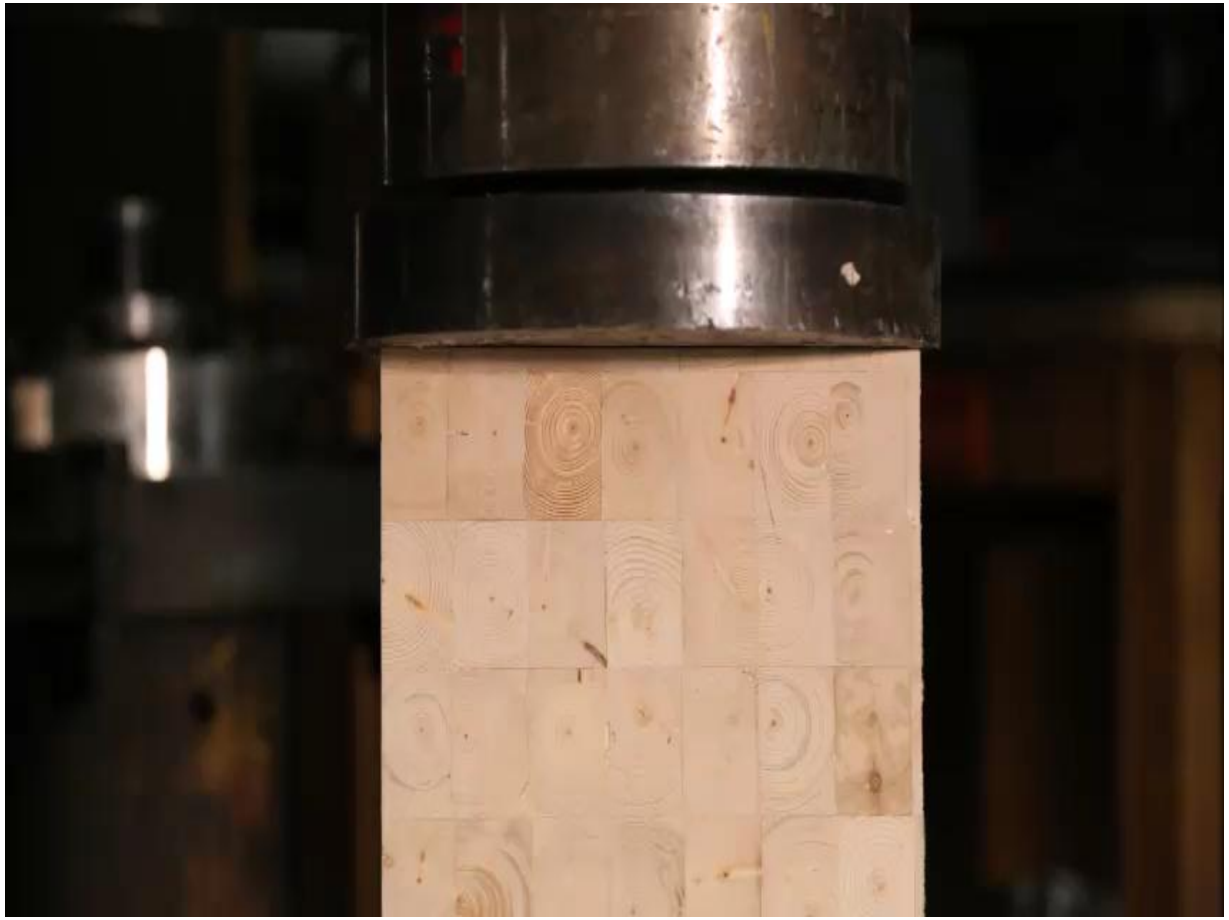
Glulam is a structural timber product manufactured by gluing together individual pieces of dimensional lumber.

- Produces large structural members from standardized commercial lumber.
- Beams and columns made with curves and tapered sections.
- Low quality and high quality wood can be used.
- Connected by scarf or finger type joints.

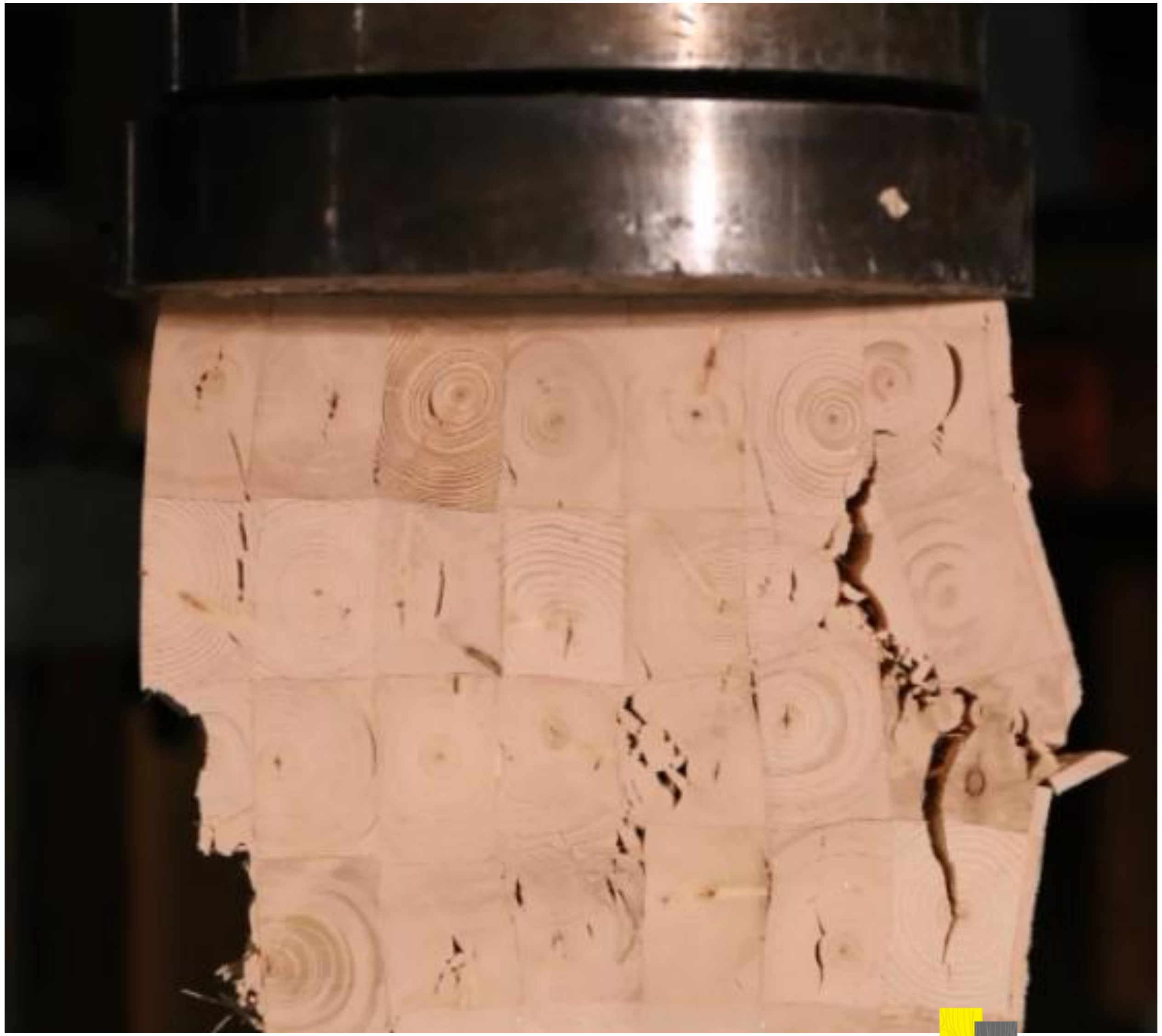
Floor beams



Response of Glulam to Load (video)



Response of Glulam to Load



Structural Composite Lumber (SCL)

- Structural composite lumber (SCL) encompasses laminated veneer lumber (LVL) and parallel strand lumber (PSL), laminated strand lumber (LSL) and oriented strand lumber (OSL)
- Typically has 3 times the bending strength and is 30% stiffer compared to a similar size piece of lumber
- Produced at a low moisture content to minimize shrinkage after installation
- Unlike timber and glulam, SCL is proprietary which means that these products do not have a common standard of production and the design values are often derived from test results in accordance with CSA 086

Structural Composite Lumber (SCL)

- Panel size can be up to 3m x 20m
- Thickness of PSL can be up to 175mm however, most common thickness is 38-45mm
- Thickness of other types of SCL is typically 75mm
- Commonly ripped into one-dimensional members for use as beams and columns

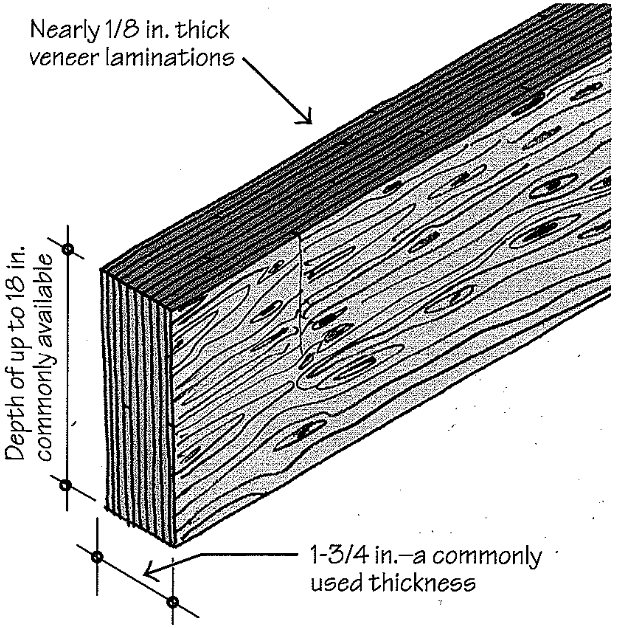
Structural Composite Lumber (SCL)

Principal Applications	Beams, Columns, Joists
Applicable Manufacturing Standards	Proprietary products — Check with the manufacturer
Applicable Service Conditions	Dry or Wet — Check with the manufacturer
Treatability With Wood Preservatives	Some products are treatable — Check with the manufacturer
Applicable Fastenings	Nails, Bolts, Joist Hangers, Framing Anchors, Heavy Duty Hangers

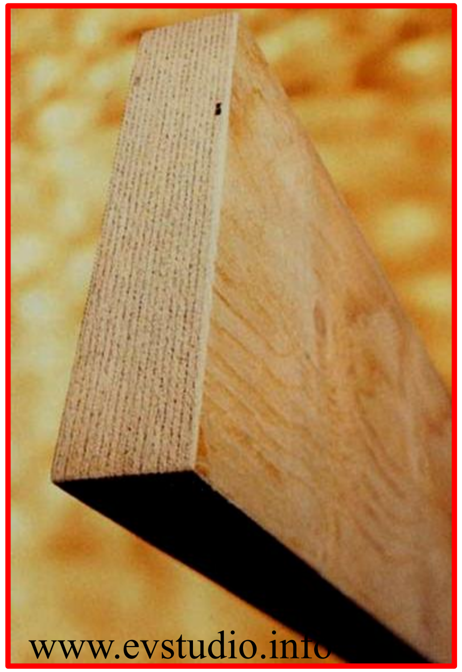
Structural Composite Lumber (SCL): Laminated Veneer Lumber (LVL)

LVL is a layered composite of wood veneers adhesively bonded.

- Differs from plywood, grain in each layer runs in same direction rather than at 90˚.
- Fabricated into billets of approx. 2 ft x 4 ft in cross-section and 80 ft long.
- Billets sawn to custom lengths and widths.
- Used primarily as floor joists and rafters.

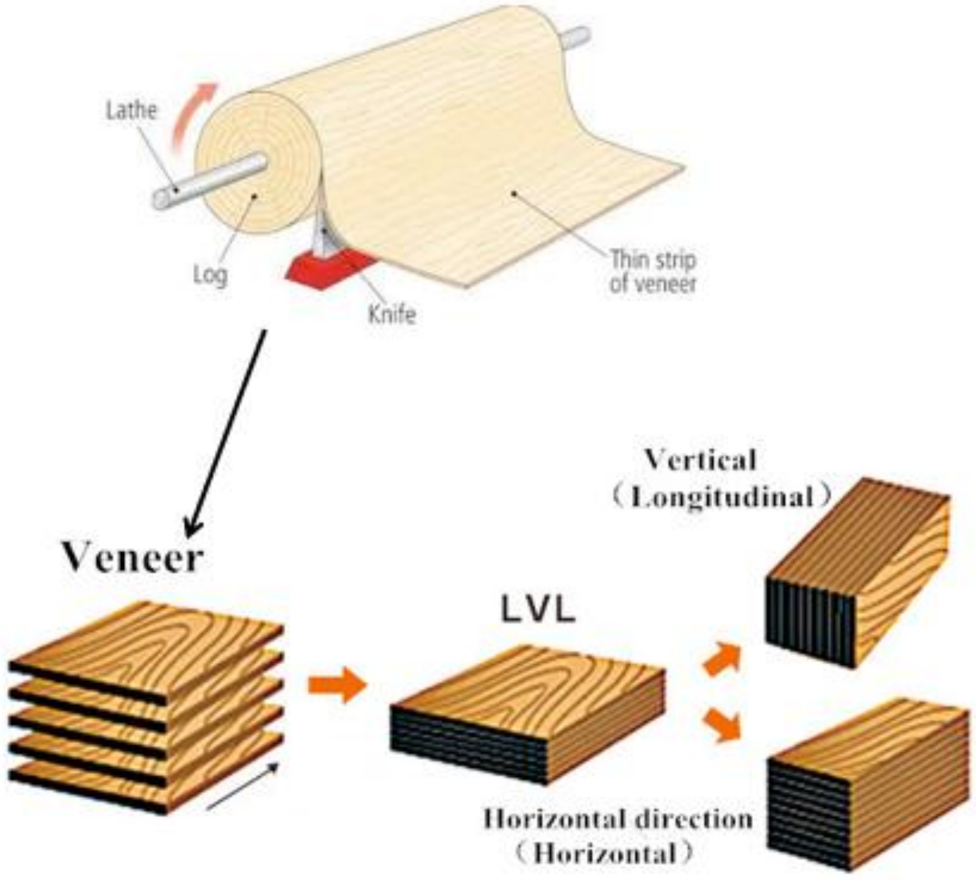


LVL-direction of **grain in all plies is the same**



LVL beams

Structural Composite Lumber (SCL): Laminated Veneer Lumber (LVL)



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Wood
Council

Conseil
canadien
du bois

Structural Composite Lumber (SCL): Oriented Strandboard & Waferboard

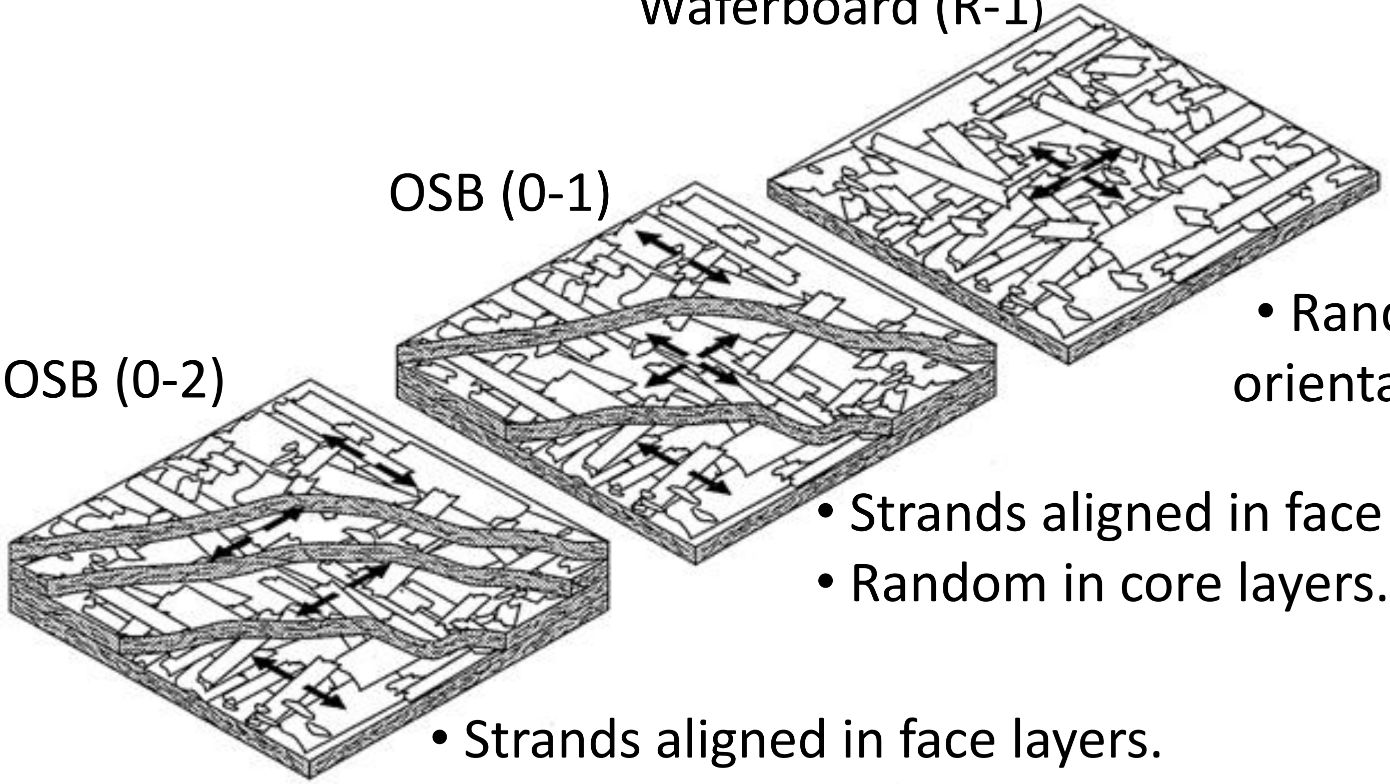
Panels made of shredded wood strands bonded together under heat and pressure using a waterproof adhesive.

- OSB is **three layers** of strands oriented at right angles to each other.
- Waferboard is **one layer** of randomly oriented strands.

• Available in same size as plywood, less expensive but cannot be painted or treated with preservatives and does not have a smooth surface finish.

Use of OSB

Structural Composite Lumber (SCL): Oriented Strandboard & Waferboard



Waferboard (R-1)

- Random orientation.

OSB (0-1)

- Strands aligned in face layers.
- Random in core layers.

OSB (0-2)

- Strands aligned in face layers.
- Perpendicular to face in core layers.

Produced from small trees, branches **& waste from lumber manufacturing.**

Structural Composite Lumber (SCL): Parrel Strand Lumber (PSL)

PSL is a layered composite of narrow strands of wood veneers.

- Strands are made by chopping 3 mm (1/8in) thick veneer sheets into 2.4m (8ft) long by 13 mm (1/2in) wide strips.
- Manufactured by aligning in grain direction and gluing strands of wood together under pressure.
- Made into large billets, then sawn to required dimensions.
- Use as beams and columns.
- It is a proprietary product marketed under the trade name Parallam®.

www.unitized.ca

www.finehomebuilding.com

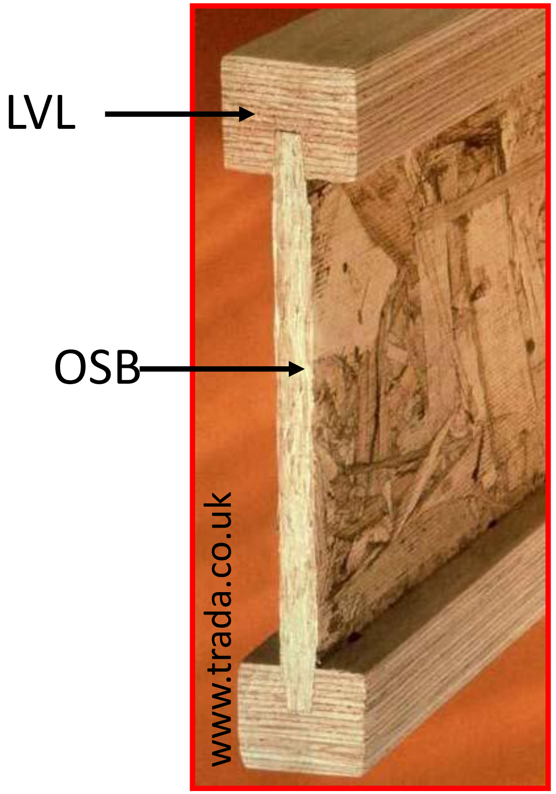
www.leelumber.myeshowroom.com

Prefabricated Wood I-Joists

An alternative to solid lumber framing which uses expensive and difficult to sources 10” or 12” members.

Wooden I –Joists are made by gluing smaller solid lumber or LVL flanges to a plywood or OSB panel web.

Available in a variety of sizes with depths ranging from 241mm to 610mm (9.5” to 24”)



Flange sizes are 63.5 mm or 88.9 mm by 38.1mm (Nominal 3” by 2” or 4” by 2”)

www.studyblue.com

Prefabricated Wood I-Joists

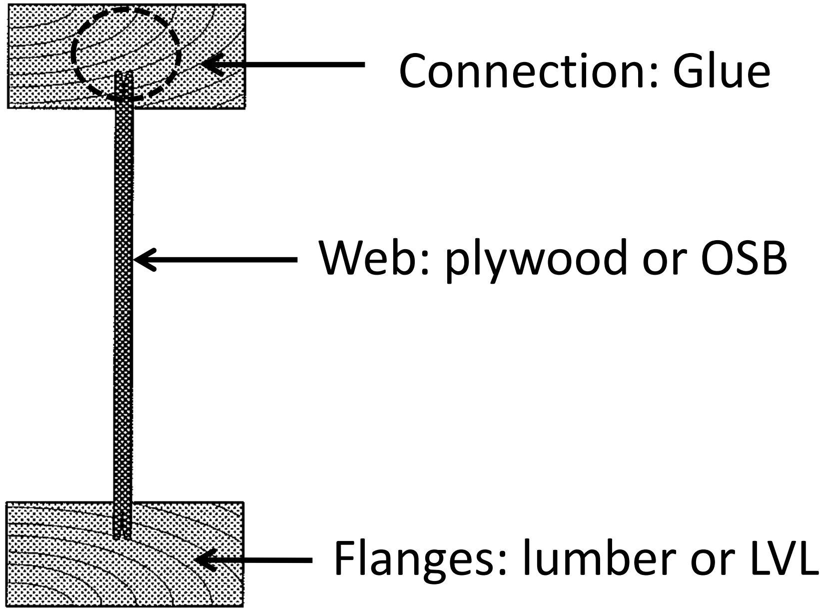
As the members are fabricated in a facility moisture and quality of can be better controlled.

Critical to the members strength is the connection between the web and flanges.

Both the joint and glue are proprietary and will vary with manufactures.

Designers should refer to the manufacture's specifications for strength and stiffness values.

In Canada, all wooden I-joist are registered with the Canadian Construction Materials Centre (CCMC).



Cross Laminated Timber

Cross Laminated Timber (CLT) like Glulam is dimensional lumber glued together, however this time in alternate directions.

By alternating the orientation of the lumber, the CLT panel can support loading in both directions.

Panels dimensions range from

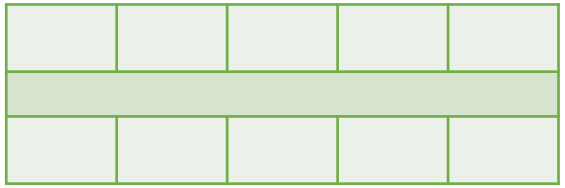
Thickness (m)	0.1	0.5
Width (m)	1.3	3
Length (m)	5	15

Ideal for floors, walls and roofs but is limited to dry service conditions only

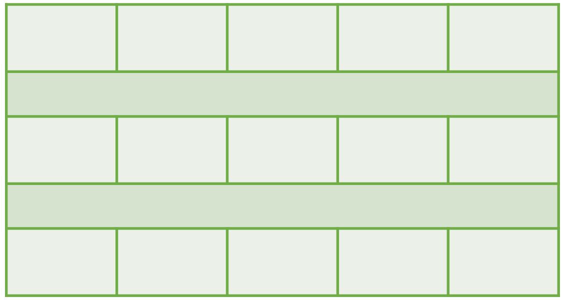
structurlam.com

Cross Laminated Timber

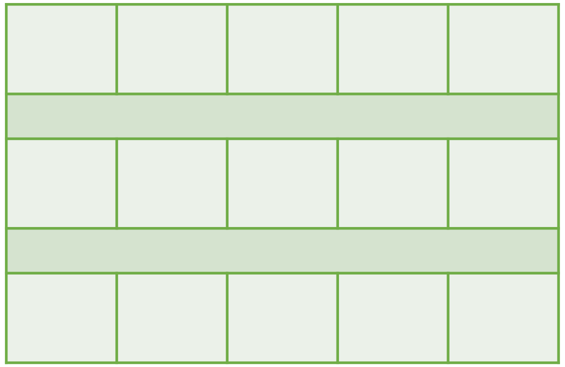
Available in in a variety of configurations with only a sample shown below:



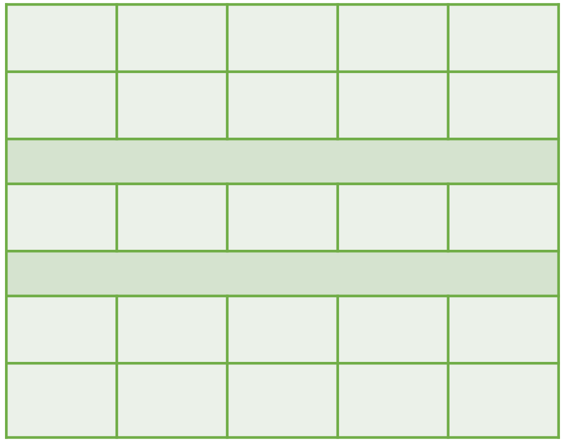
3-layer equal depth



5-layer equal depth



5-layer unequal depth



5-layer equal depth with double outer layer

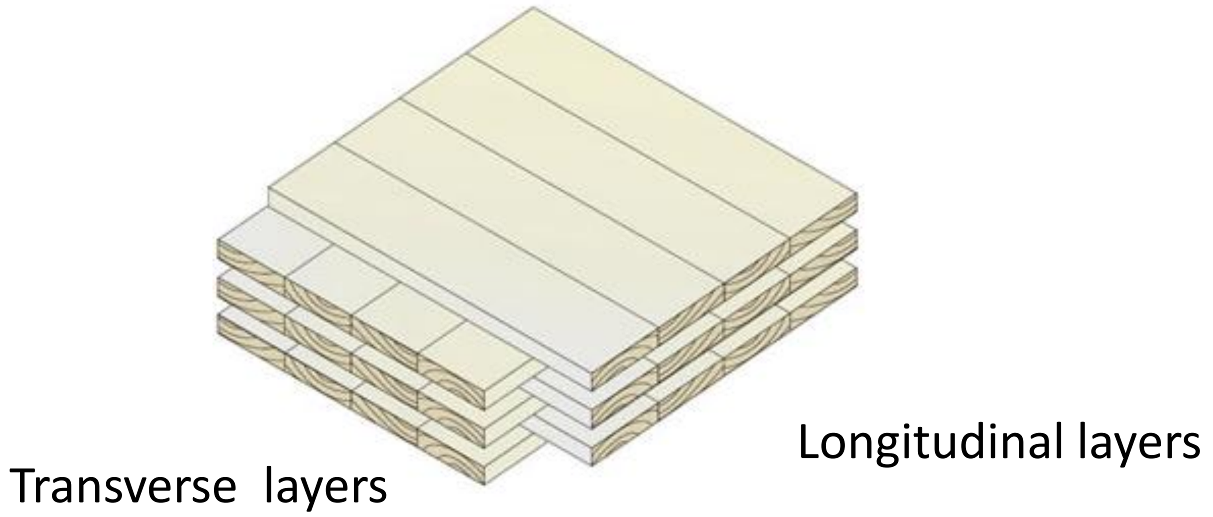
Double outer layer configurations increase the bending resistance in the major direction.

While traditional used for One-Way slabs, Two-Way slabs are limitedly available.

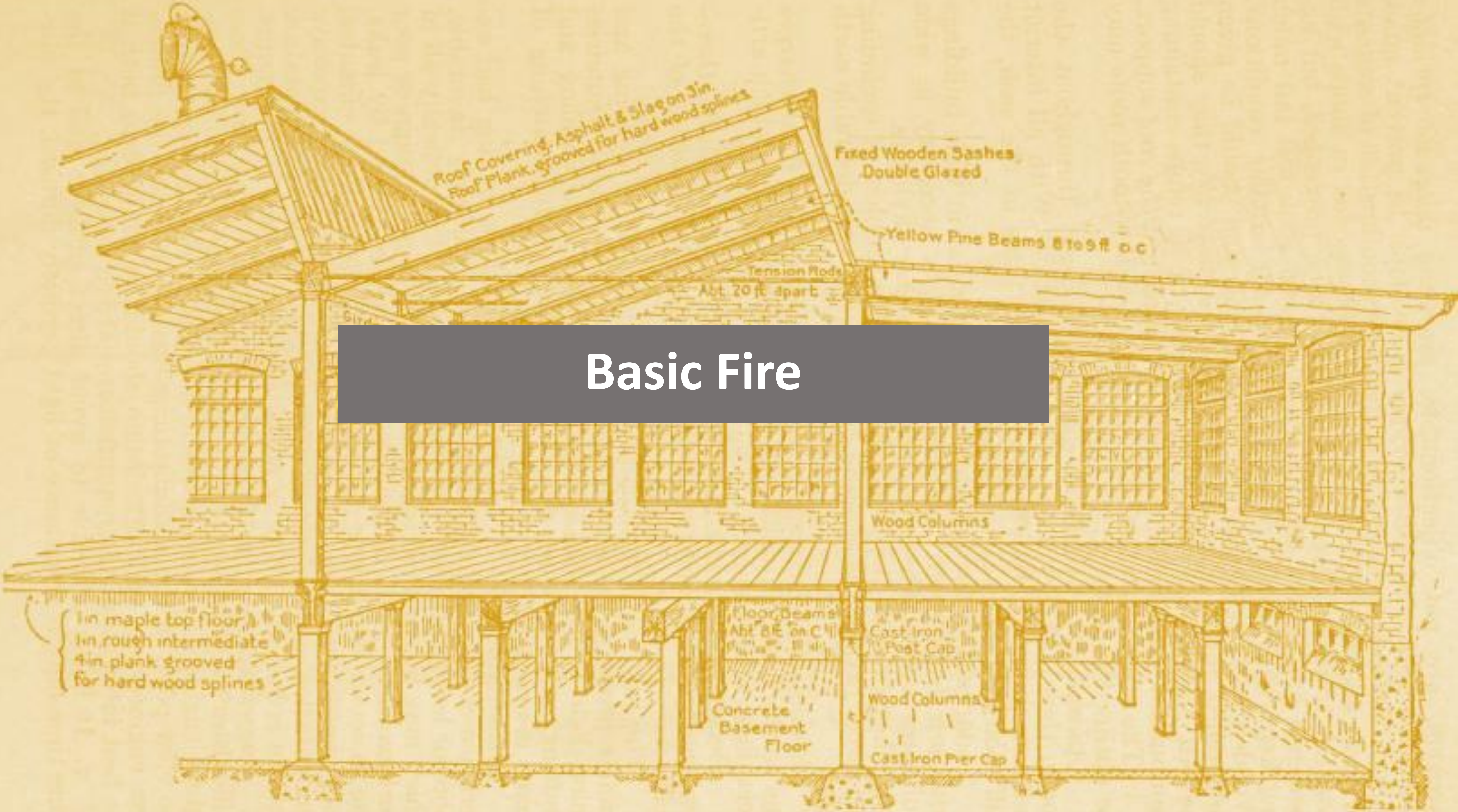
Cross Laminated Timber

In Canada, the lumber used for CLT is softwood with the same or similar species in each layer.

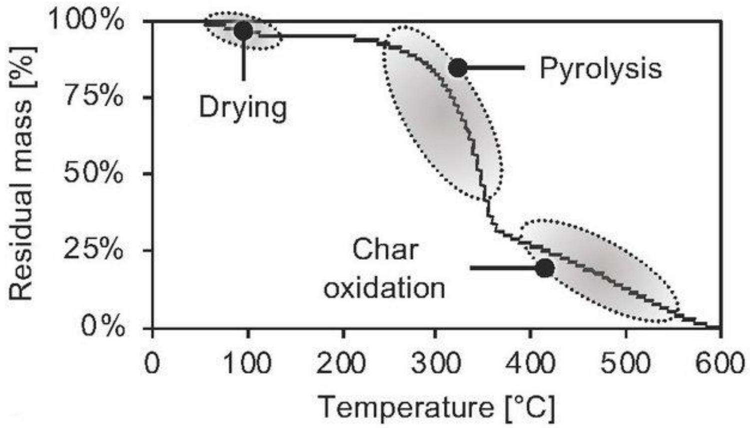
The longitudinal layer must have a minimum visual grade No.2 and No.3 in the transverse layer. Machine Stress Rated (MSR) equivalents may also be used.

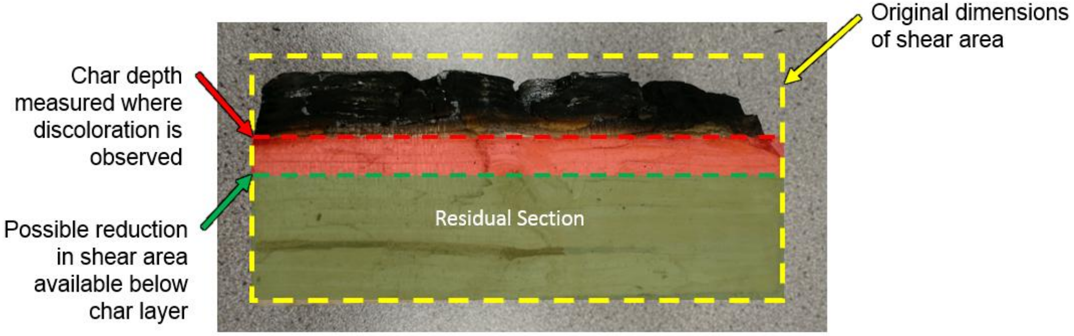


Basic Fire


Roof Covering, Asphalt & Slag on 3in.
Roof Plank, grooved for hard wood splines
Fixed Wooden Sashes
Double Glazed
Yellow Pine Beams 8 to 9 ft o.c
Tension Rods
Abt. 20 ft apart
Wood Columns
1in maple top floor
1in rough intermediate
4in plank grooved
for hard wood splines
Floor Beams
Abt. 8 ft on C
Cast Iron
Post Cap
Concrete
Basement
Floor
Wood Columns
Cast Iron Pier Cap

How wood degrades at elevated temperature - Drying

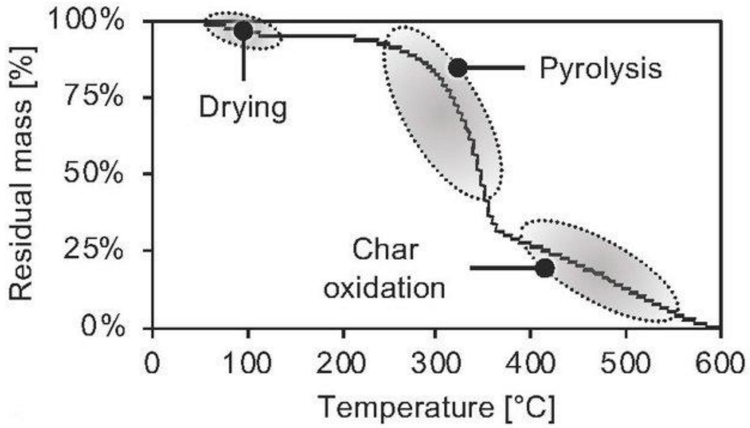


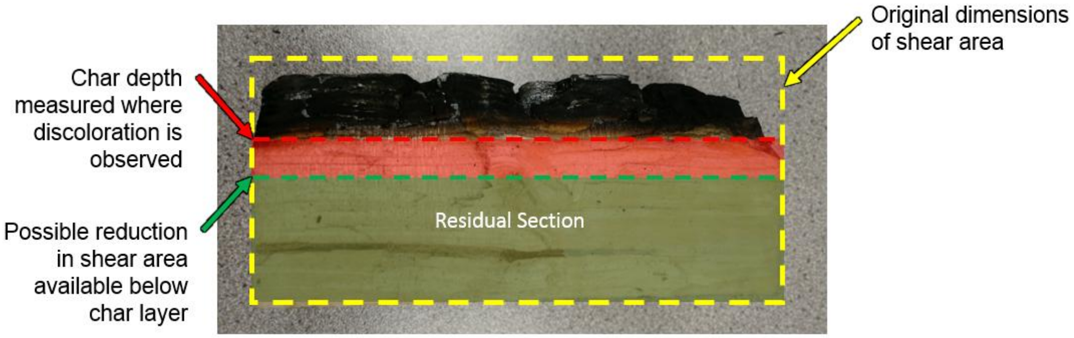


- Timber undergoes three stages when heated. The first being a drying phase, where the material dehydrates at the source of local exposure. Note that in this phase the relative size of the member and moisture content is very critical. This is where the saying sticks versus trees is very applicable.

Canadian Wood Council
Conseil canadien du bois

How wood degrades at elevated temperature - Pyrolysis





- Timber undergoes three stages when heated. The second phase is pyrolysis. Simply stated this is essential where the structure of the timber begins to undergoe a chemical change leaving it in the form of a carbon residual in the last stage. At this stage there is a rapid degradation of mass.

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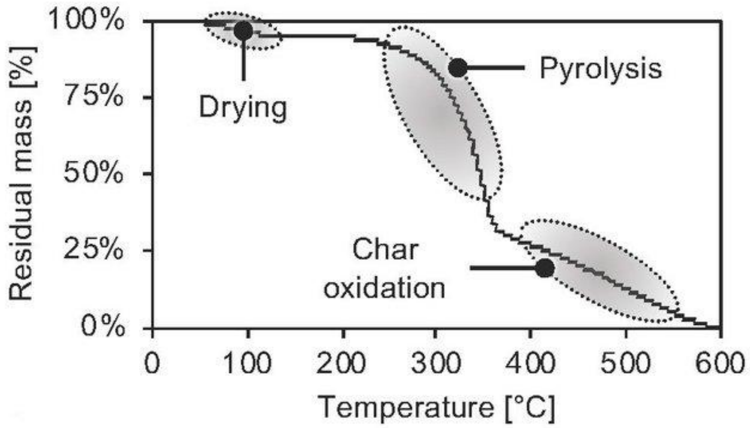
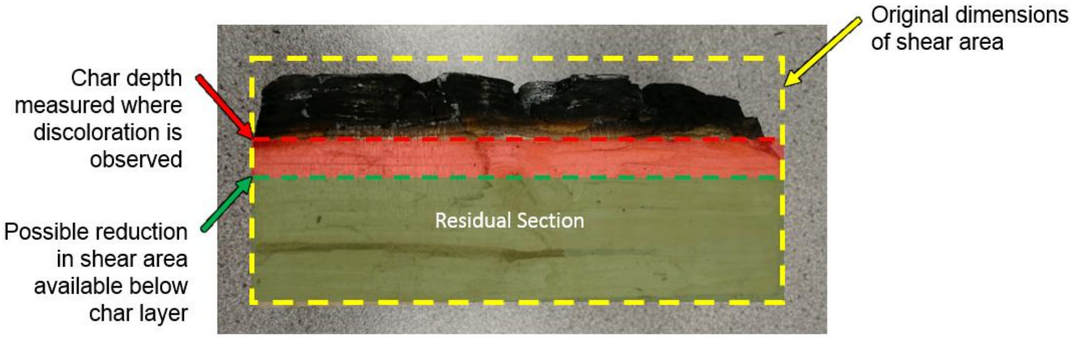
How wood degrades at elevated temperature - Char





- Timber undergoes three stages when heated. The last stage is char. This is not a bad thing, the thickness of the char layer actually can provide a very porous layer to protect the inner portion of the timber from additional heat. The deeper this layer the more resistance.

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How wood degrades at elevated temperature - Char

What you see here is an older style timber structure. These were called slow –burning because the size of the timber is provided at about 30% more than what it needs to be to undertake normal loading,

How wood degrades at elevated temperature - Char

This was an attempted arson where allegedly the perpatrators attempted to start a fire in this structure. This was the result after about 1 hour of attempt and about 20 minutes of burning. The structure was undergoing adaptative re-sue so the sprinkler system was not yet activated.

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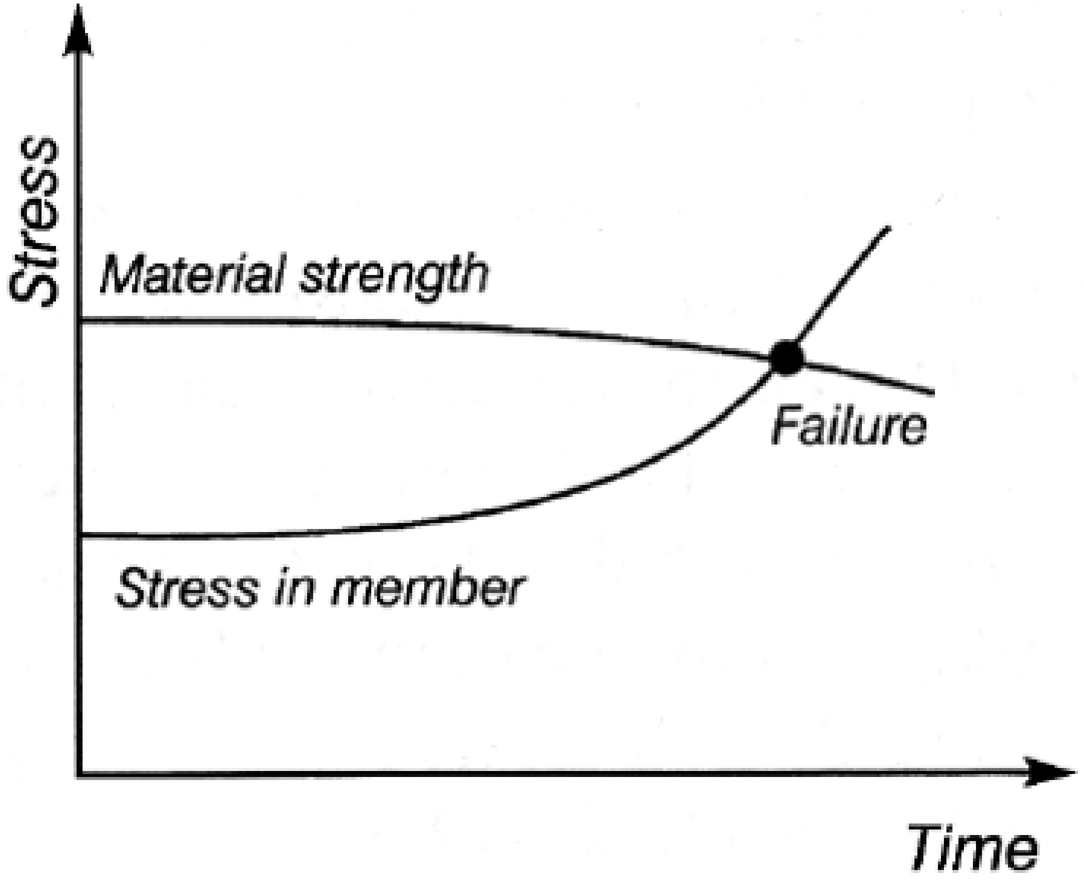
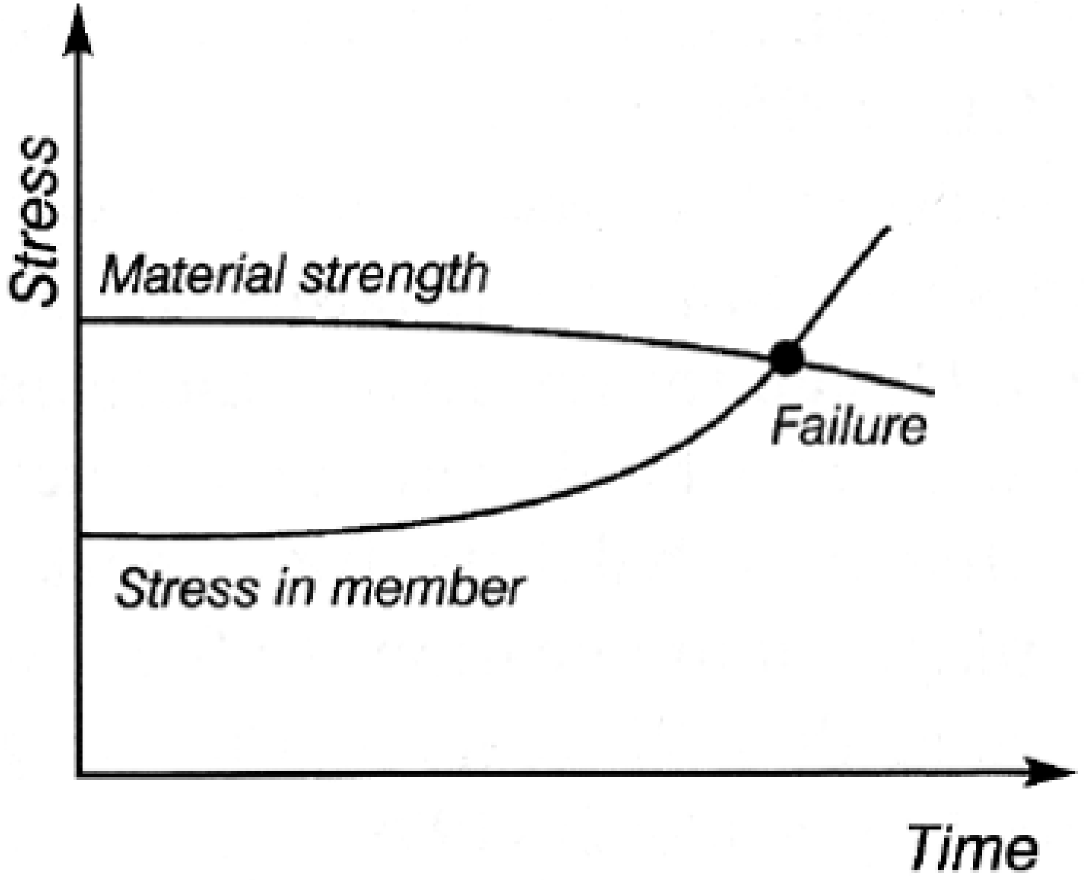
How wood degrades at elevated temperature – Mechanical behaviour



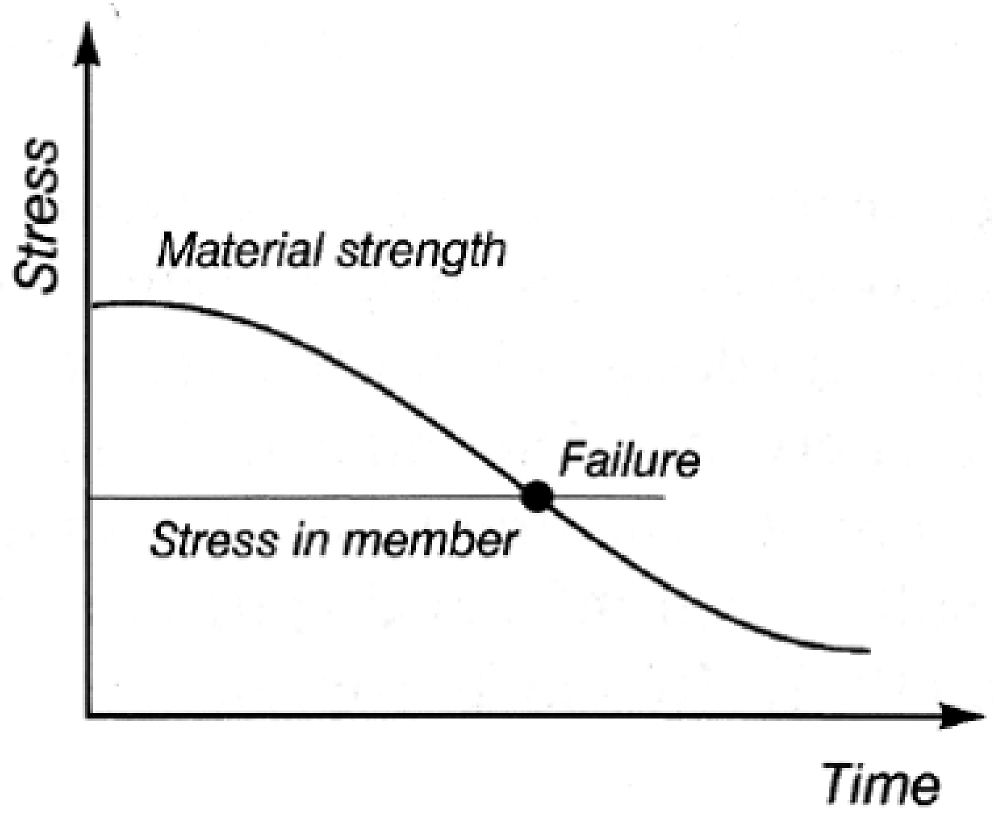
With temperature increase, the unaffected timber regains most strength with temperature rise (<300C). The dehydration effect is quite minimal, but once pyrolysis occurs strength reduces rapidly to the effected layer, and there is minimal strength left in the char layer.

How wood degrades at elevated temperature – Mechanical behaviour



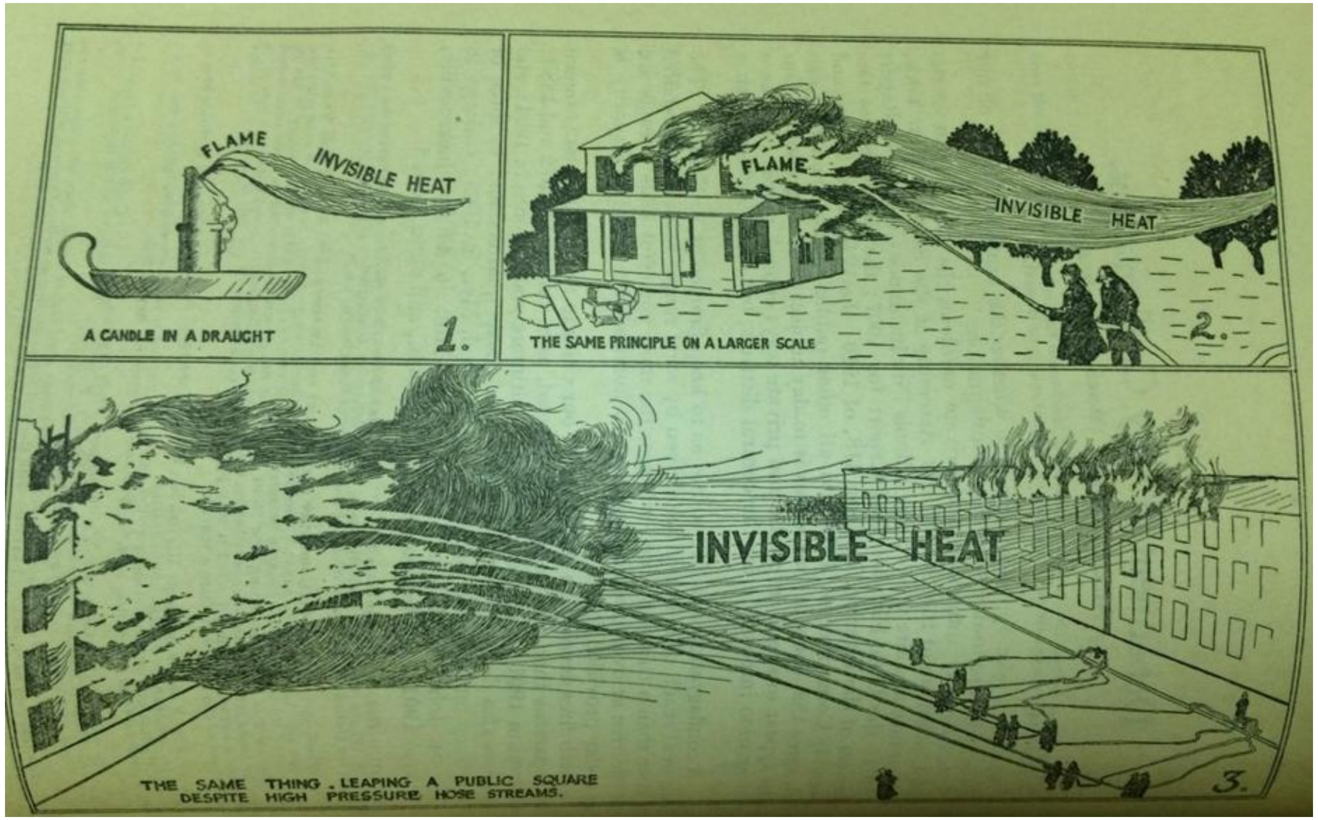
Because you are effectively losing cross section, and the applied loading is largely the same, the stress in the member will increase and this is what can lead to failure of the members.

How wood degrades at elevated temperature – Mechanical behaviour



Steel on the otherhand is very different. With increasing temperature the chemical composition of the member changes. The cross section does not change largely but the strength degradation is rapid. Note also that steel will be a conductor of heat. Which has important implications in exposed steel connections

What is Fire?

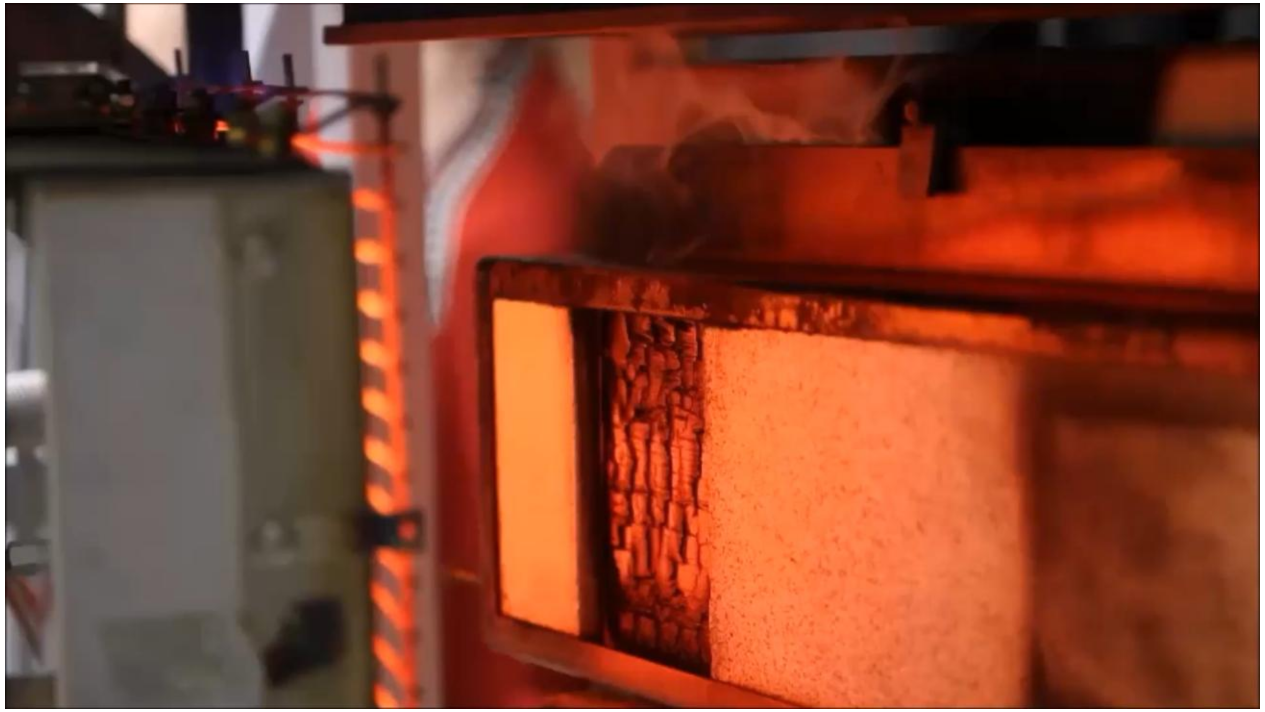


There is a very simple way to look at what fire is. Basically the idea behind this is that it is a chemical reaction, where a material beginning as a solid when exposed to heat because to convert in the presence of oxygen to a gas. The gas when heated high enough, gives off light. That is fire. The reaction produces a large amount of heat in the form of convection and radiation. Classically the later called invisible heat

What is Fire?

A tiny experiment with a candle illustrates this behaviour very well on a small scale. See how once extinguished a heat source is added into the candle igniting its smoke trail. (*don’t do this at home for safety reasons)

What is Fire?



In this video the same effect is being seen with a piece of charred timber. Instead of a match, a spark is introduced that ignites the surface between the gypsum boards (we will come back to gypsum later).

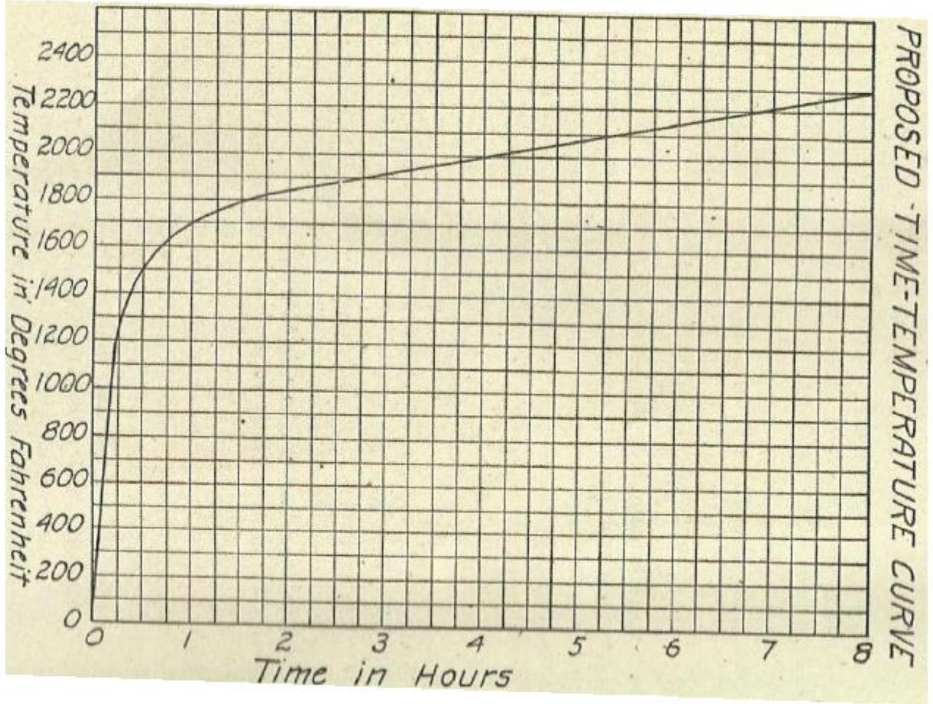
(heat soure – radiant heaters) at about 1100C

Just how hot does a real fire get?

- This depends completely on what is inside the building and what is the source of a fire. Typically the source of the flame for a candle is about 1000C. Most room fires show temperatures of about 1000 to 1300 C at peak exposures – if and only if there is no active suppression.
- In engineered design in canada fire can be viewed as if it were a load persay- like the building code the most simple procedure is to use what is called a prescriptive approach or standard fire. However if you are fortunate enough to have expertise within a company you can perform alternative solutions to this approach and use different design fires (these are beyond the scope of this course to describe).

What is a standard fire

- A standard fire is a prescribed temperature for a predetermined period. It takes the form seen here.
- Through years performance of various materials in simulated furnace tests have been catalogued. This performance is called a fire resistance rating and takes the form of an hourly rating



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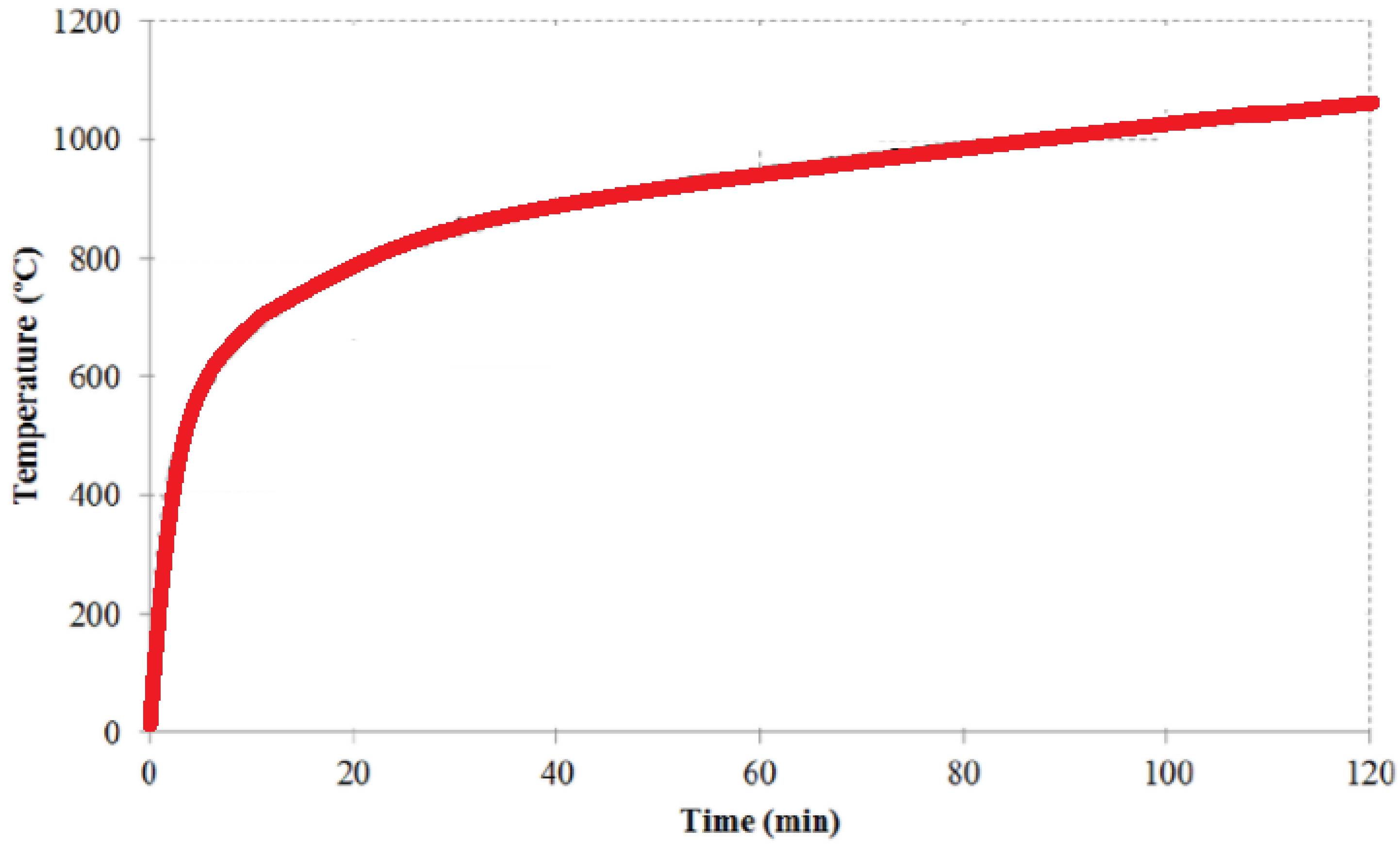
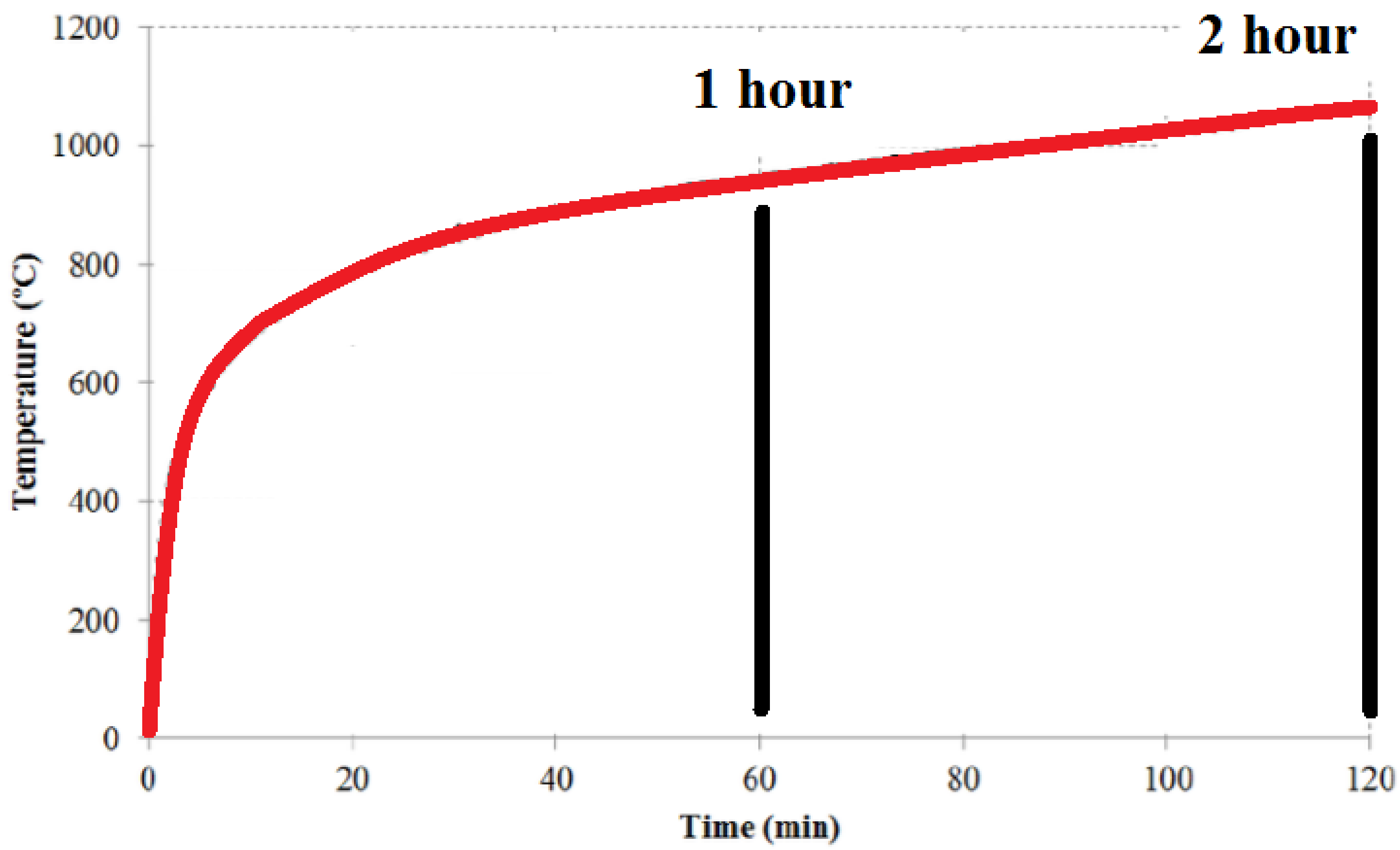
What is a fire resistance rating?



What is a fire resistance rating?



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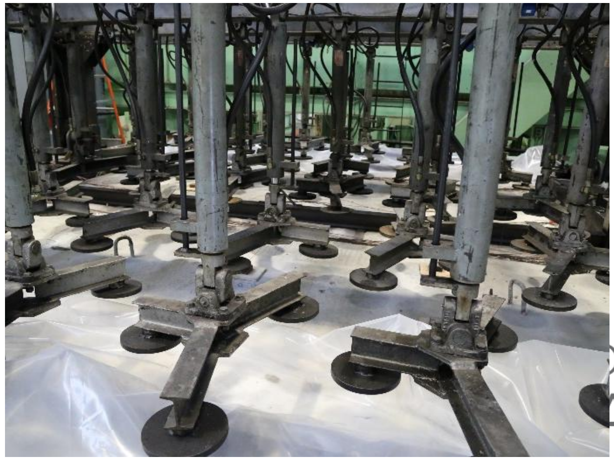
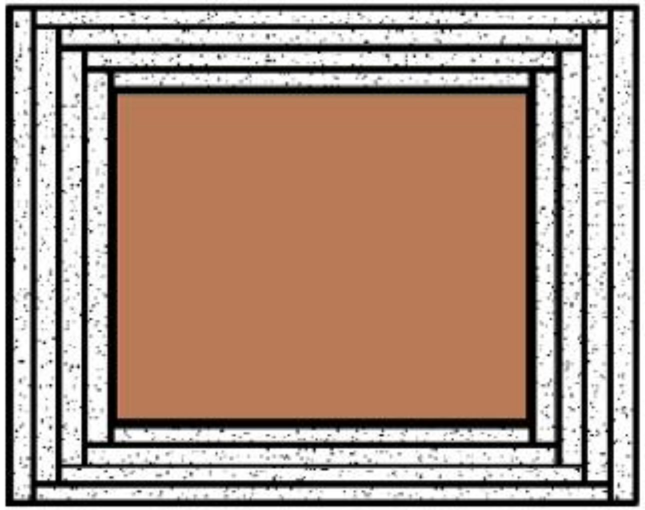
What is a furnace test

- Seen here is a video fo the end of a standard fire furnace test performed on a CLT flooring system after 2 hours of exposure.
- Below is a typical furnace used for testing



Additive Rules

- After decades of testing it became very accepted in practice to use additive rules of fire protection (known as the component additive method). That is to say if you were trying to increase the resistance rating of a building what you do is add layers of protection that in themselves each have a rating. Below is a scematic of the columns at Brock columns. In this case multiple layers are used to cover the timb



Additive Rules - Tables

- In the hand book Tables 10.2- 6 give a series of tabulated ratings for different components and different applications (pay careful attention to notes. (ex;)

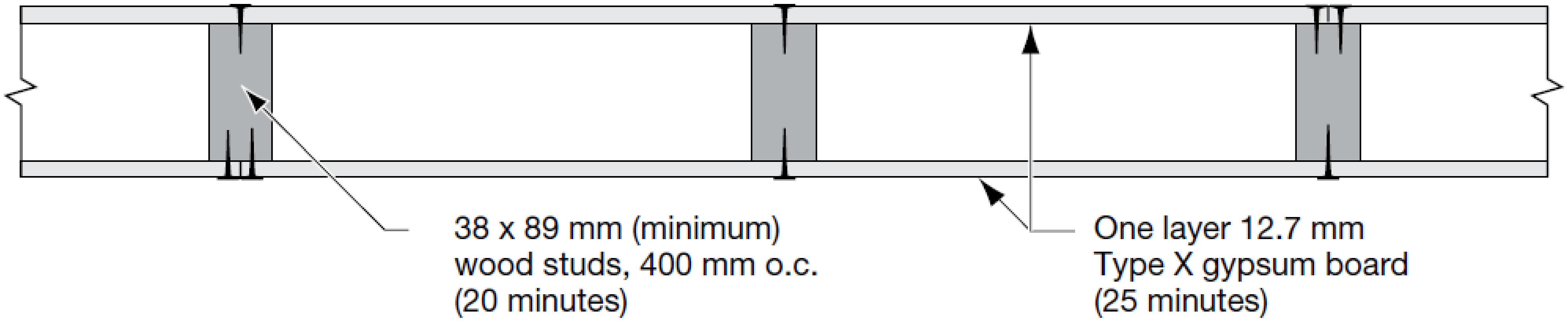
Table 10.2a
Time assigned for the contribution of protective membranes on the fire-exposed side of wood-framed walls

Description of finish	Time, minutes	
	Loadbearing Walls	Non-loadbearing Walls
11.0 mm Douglas Fir plywood phenolic bonded	-	10[1]
14.0 mm Douglas Fir plywood phenolic bonded	-	15[1]
12.7 mm Type X gypsum wallboard	25[2]	25
15.9 mm Type X gypsum wallboard	40[2]	-
Double 12.7 mm Type X gypsum board[3]	50	80

Note:
1. Applies to stud cavities filled with mineral wool conforming to CAN/ULC-S702, "Mineral Fibre Thermal Insulation for Buildings", and having a mass per unit area of not less than 2 kg/m^2, with no additional credit for insulation according to Table D-2.3.4.G in Appendix D of the *NBC*.
2. If resilient metal channels are installed with a single layer of gypsum board, the fire-resistance rating determined using this method for loadbearing walls is to be reduced by 10 minutes.
3. Resilient metal channels are permitted to be installed at a spacing of 400 mm o.c. with no effect on the rating of the walls assembly.

Additive Rules Example

- Determine the fire-resistance rating of an interior partition (i.e., interior nonloadbearing wall assembly) with 12.7 mm Type X gypsum board (GB) on both sides of wood studs spaced at 400 mm on centre.



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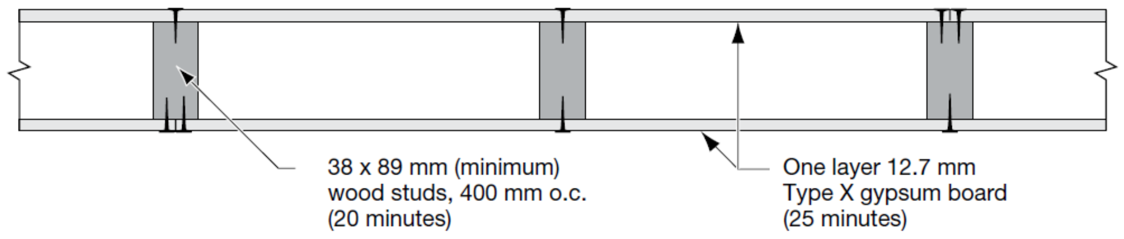
Additive Rules Example

- Determine the fire-resistance rating of an interior partition (i.e., interior nonloadbearing wall assembly) with 12.7 mm Type X gypsum board (GB) on both sides of wood studs spaced at 400 mm on centre.



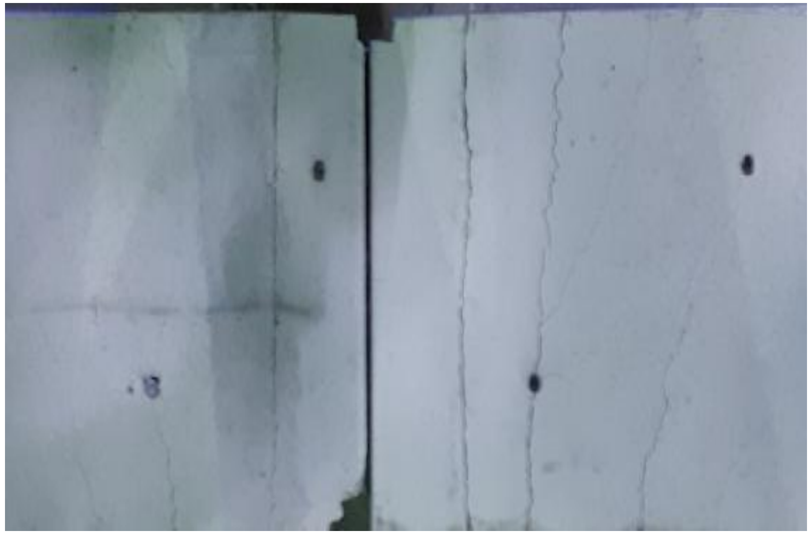
Time assigned to 12.7 mm Type X GB - 25 minutes
Time assigned to wood studs at 400 mm o.c. - 20 minutes

Total Fire-resistance rating of interior partition: 45 minutes

Important notes: These times are not real fire times or times of failure in a real fire, the times are a relative performance rating to the standardized fire. This is why these times should not be used for time of evacuation in a real fire.

Gypsum board performance

- Type X Gypsum board (or an adaptive form of dry wall) is a calcium based material retaining approximately 20% moisture. As the material is exposed to temperature it dehydrates protecting layers beneath. While fall off in fire may be a concern, if appropriate nail spacing is accounted for the material rarely degrades to falling off.



Chemistry of Gypsum

The manufacturing process of Gypsum involves driving the moisture out of the gypsum rock to create the powdery white material of calcium sulphate hemihydrate $CaSO_4 \cdot 2H_2O$, which is an endothermic decomposition reaction occurring between 100°C and 120°C.

$$CaSO_4 \cdot 2H_2O \rightarrow CaSO_4 \cdot \frac{1}{2}H_2O + \frac{3}{2}H_2O$$

When the powder is mixed with water and formed into flat sheets of gypsum plaster, the reaction is reversed to become a hydration reaction:

$$CaSO_4 \cdot \frac{1}{2}H_2O + \frac{3}{2}H_2O \rightarrow CaSO_4 \cdot 2H_2O$$

Chemistry of Gypsum

- Moisture in gypsum plaster contributes to the fire resistance behaviour
- Dehydration reaction occurs when gypsum plaster is heated in fire, converting solid gypsum into a powdery form
- Complete dehydration occurs at temperatures between 200°C and 300°C
- Gypsum plaster can be easily recycled since both the dehydration and hydration reactions can be repeated indefinitely

Annex B (informative)

Fire resistance of large cross-section wood elements

Notes:

(1) *This informative (non-mandatory) Annex has been written in normative (mandatory) language to facilitate adoption where users of the Standard or regulatory authorities wish to adopt it formally as additional requirements to this Standard.*

(2) *When this informational (non-mandatory) Annex is not otherwise adopted formally by building regulatory authorities as additional requirements to this Standard, the methodology presented provides information that may be useful to users of the Standard in the development of a proposal for an alternative solution to meet the objectives of the* National Building Code of Canada *(NBC).*

B.1 Scope

B.1.1

The design tables, data and methods specified in Annex B provide a design methodology to develop fire-resistance ratings of large cross-section wood elements based on structural criteria.

B.1.2

The design methodology is intended to be used as an alternative approach for determining fire-resistance ratings for establishing compliance to the *National Building Code of Canada* (NBC), as determined by testing in conformance with CAN/ULC-S101.

Note: *The fire performance criteria for evaluating the separating function of building elements related to the passage of flames or hot gases and transmission of heat through the assembly, as defined in CAN/ULC-S101, are outside the scope of Annex B, except as otherwise noted.*

B.1.3

The structural resistance of a wood element reduces as a function of time when exposed to fire. A structural element is deemed to possess a fire-resistance rating for a particular duration of fire exposure provided the reduced structural resistance of the element, after the specified exposure time, is greater than the specified load effects.

B.1.4

The methodology in Annex B is an engineering approach, intended to predict the structural fire resistance of large cross-section wood elements exposed to the standard fire-resistance test, CAN/ULC-S101. The standard test method requires loadbearing elements to be tested with a superimposed load that represents a full specified load condition or a restricted load use condition. When calculating the fire-resistance rating using the methodology in Annex B, the actual specified gravity loads are used (i.e., D + L).

Note: *When a performance-based fire safety design approach is used in which the specific fire scenario(s) has a design fire(s) having time-temperature relationships other than that specified in the standard CAN/ULC-S101 fire-resistance test, additional analysis may be required. For example, a heat transfer analysis may be needed in order to determine an appropriate charring rate and zero-strength layer depth. In this case, it may also be appropriate to use the load factors suggested in Paragraph 25 of the Structural Commentary A of the* National Building Code of Canada*. Such fire scenarios can be evaluated as an alternative solution to meet the objectives of the* National Building Code of Canada *(NBC).*

B.8.1 Gypsum board

Provided that surfaces are protected from fire exposure by fire-rated Type X gypsum board, the assigned fire-resistance duration calculated in accordance with Clause B.7 can be increased by the following times:

(a) 15 min when one layer of 12.7 mm Type X gypsum board is used;

(b) 30 min when one layer of 15.9 mm Type X gypsum board is used;

(c) 60 min when two layers of 15.9 mm Type X gypsum boards are used; or

(d) 60 min when two layers of 12.7 mm Type X gypsum boards are applied to CLT.

Acceptable Charring Rates

Table B.4.2
Design charring rates for wood and wood-based products, mm/min

	β_o	β_n
Timber and plank decking	0.65	0.80
Glued-laminated timber	0.65	0.70
Structural Composite Lumber	0.65*	0.70*
Cross-laminated timber	0.65	0.80

**Values are only applicable to wood-based structural composite lumber products.*

B.4.3 One-dimensional char depth

The char depth for one-dimensional charring, $x_{c,o}$ (mm), shall be taken as follows:

$$x_{c,o} = \beta_o t$$

where

β_o = one-dimensional charring rate, mm/min

t = fire exposure duration, min

Acceptable Charring Rates

B.5.1 Zero-strength layer depth

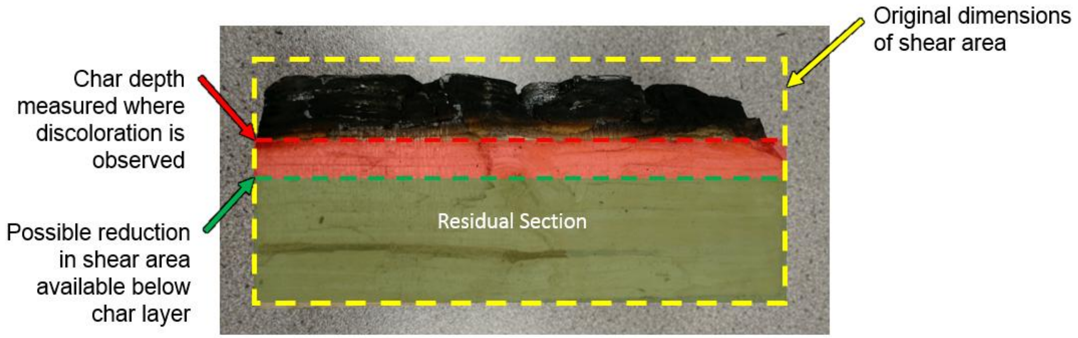
A zero strength layer shall further reduce the cross-section (beyond the char depth determined in Clause B.4.3 or B.4.4) in order to account for a reduction in strength of the heated wood beyond the char front. This additional reduction in cross-section, x_t (mm), depends on the fire exposure duration and shall be taken as follows:

$$x_t = \left(\frac{t}{20}\right) \times 7 \text{ (for } t < 20)$$

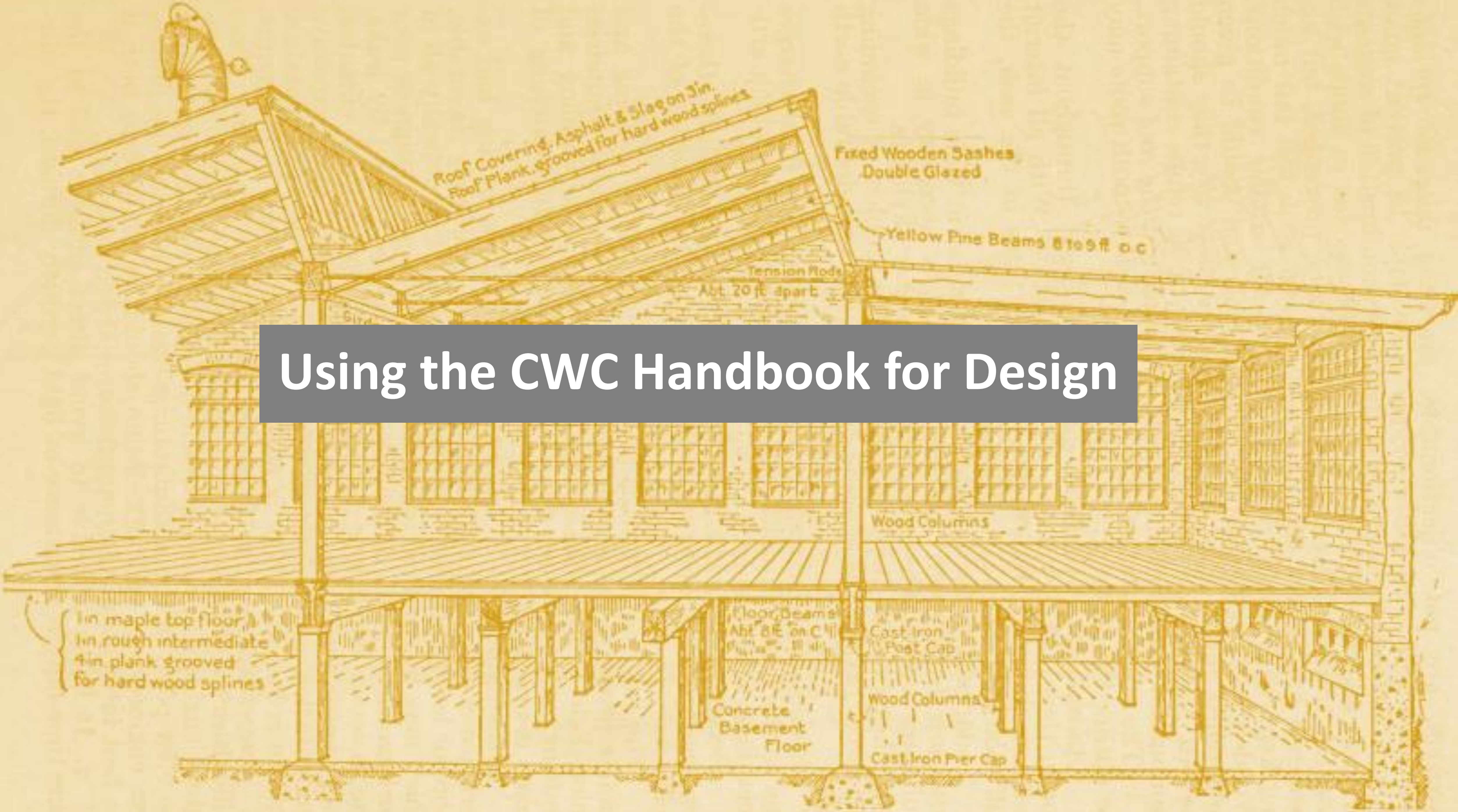
$$x_t = 7 \text{ (for } t \geq 20)$$

where

t = fire exposure duration, min



Using the CWC Handbook for Design



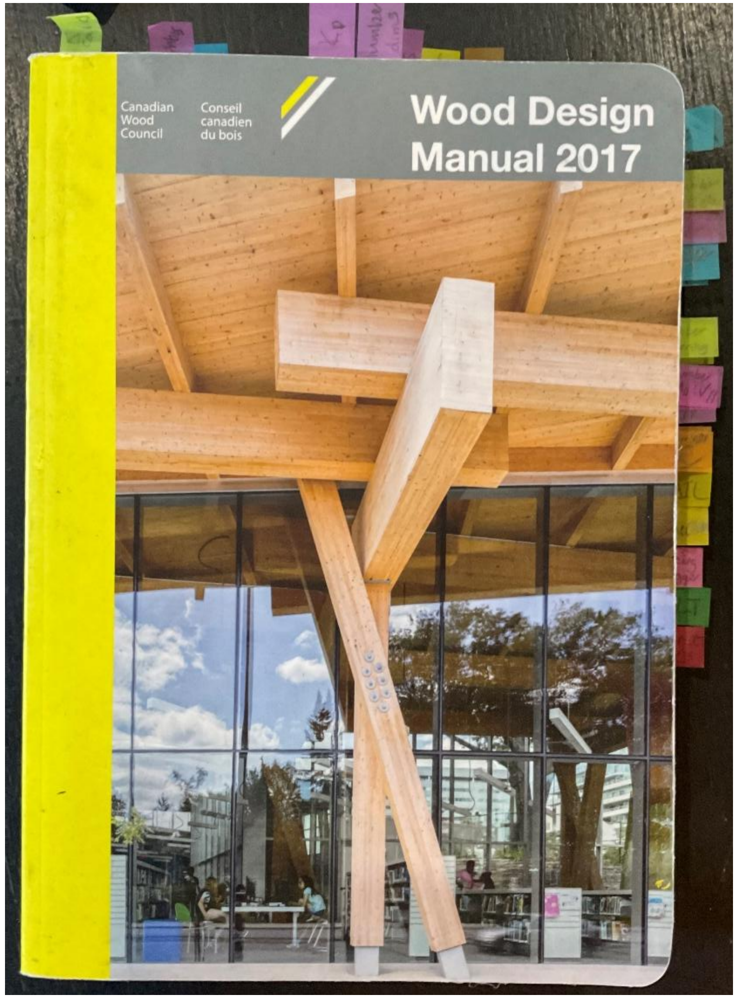
Wood Design Manual Indexing

Indexing the Wood Design Manual and CSA O86

– Quickly find where to look when working on designs, etc.

– It’s a physical and traditional document that without proper indexing applied can be difficult to use.

– The following slides are suggestions of useful sections to index; but may not be comprehensive of everything you need to index depending on your services.



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Wood Design Manual

CSA O86 Standard

– Outlines the minimum requirements that must be met

Wood Design Manual

- Contains explanatory information/Commentary for using CSA O86
- Provides solved examples
- Includes selection tables where factored
- Other additional information that can be useful in design

Wood Design Manual

Volume 1

– Explanatory information to different types of member design

Volume 2

– Includes reference information and commentary to CSA-O86

– CSA O86 and Appendices

Wood Design Manual

Volume 1

Topic	Page
Introduction	3
Bending Members	17
Compression Members	143
Tension Members	211
Combined Loads	233
Bearing	295
Connections	321
Shearwalls and Diaphragms	563
Applications	671
Design for Fire Safety	753

Wood Design Manual

Volume 1

-Most sections focus on design for a specific loading condition (indicated on the right side of the page)

Typically:

-Sections usually start off with general information for all types of timber, and then move to specific information for Lumber, Glulam, CLT, and other types of timber

-For each type of timber - explanatory notes, examples, and selection tables are given

2.9 Cross-Laminated Timber

General

This section covers the design of Cross-Laminated Timber (CLT) panels as flexural members. CLT is a part of a broader mass timber category of products, which also includes products such as Glued-Laminated Timber and Nail-Laminated Timber. CLT panels consist of several layers of lumber, laid flat-wise, and glued together on their wide faces. Panels typically consist of 3 to 9 alternating layers. CLT was introduced into the O86 in the 2014 edition update 1.

The CSA O86 design provisions apply to sawn lumber panels manufactured in accordance with ANSI/APA PRG 320 *Standard for Performance-Rated Cross-Laminated Timber* with balanced layups. A balanced layup is one in which all laminations oriented in the same direction are made of the same grade and species of sawn lumber. CSA O86 includes a table of specified strengths and moduli of elasticity of laminations for primary CLT stress grades. The design provisions and formulas may also be applied to custom stress grades specified by the manufacturer, provided the CLT layup is balanced, manufactured with sawn lumber and the panels are of constant width. The provisions contained within Clause 8 of the CSA O86 are intended for design of CLT in compression and out-of-plane bending applications. The PRG 320 stipulates that the net thickness of laminations for all directions at the time of gluing should not be less than 16 mm or more than 51 mm.

2 Bending Members

Wood Design Manual

Volume 2

Topic	Page
Reference Information	895
Commentary to CSA O86	961
CSA O86	Grey pages
Appendix	A-3

Wood Design Manual

Volume 2

Reference Information (Page 895)

-Information regarding species and grading

-Connection fastener dimensions

-Miscellaneous information regarding load durations, service conditions, preservatives, etc.

-Beam diagrams – Page 930

Commentary to CSA O86 (Page 961)

-Proceeds clause by clause with further explanations and diagrams

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General

Cl 5.2.4 Load Combinations (Page 16 of Grey pages/GP)

-Load combinations for ultimate and serviceability limit states

5.2.4 Load combinations

5.2.4.1 Load combinations for ultimate limit states

The effect of factored principal plus companion loads shall be determined in accordance with the load combinations in Table 5.2.4.1. The applicable combination shall be that which results in the most unfavourable effect.

Table 5.2.4.1
Load combinations for ultimate limit states

Case	Principal loads*	Companion loads
1	1.4*D*	—
2	(1.25*D*† or 0.9*D*) + 1.5*L*‡	1.0*S*§ or 0.4*W*
3	(1.25*D*† or 0.9*D*) + 1.5*S*	1.0*L*§** or 0.4*W*
4	(1.25*D*† or 0.9*D*) + 1.4*W*	0.5*L*** or 0.5*S*
5	1.0*D* + 1.0*E*	0.5*L*§** + 0.25*S*§

*Refer to the National Building Code of Canada for loads due to lateral earth pressure (H), prestress (P), and imposed deformation (T).
†Refer to the National Building Code of Canada for a dead load (D) for soil.
‡The principal load factor of 1.5 for a live load (L) may be reduced to 1.25 for liquids in tanks.
§Refer to the National Building Code of Canada for loads on exterior areas.
**The companion load factor for a live load (L) shall be increased by 0.5 for storage occupancies, equipment areas, and service rooms.

5.2.4.2 Load combinations for serviceability limit states

The effect of principal plus companion loads shall be determined in accordance with the load combinations in Table 5.2.4.2. The applicable combination shall be that which results in the most unfavourable effect.

Table 5.2.4.2
Load combinations for serviceability limit states

Case	Principal loads	Companion loads
1	1.0*D**	—
2	1.0*D** + 1.0*L*	0.5*S*† or 0.4*W*
3	1.0*D** + 1.0*S*	0.5*L*†‡ or 0.4*W*
4	1.0*D** + 1.0*W*	0.5*L*‡ or 0.5*S*

*Dead loads include permanent loads due to lateral earth pressure (H) and prestress (P).
†Refer to the National Building Code of Canada for loads on exterior areas.
‡The companion load factor of 0.5 for a live load (L) shall be increased to 1.0 for storage occupancies, equipment areas, and service rooms.

General

Cl 5.4 Serviceability Requirements (Page 19 GP)

-Includes information regarding the Modulus of Elasticity and Deflection

5.4 Serviceability requirements

5.4.1 Modulus of elasticity

The modulus of elasticity for stiffness calculations, E_S, shall be taken as follows:

$$E_S = E\,(K_{SE} K_T)$$

where

E = specified modulus of elasticity, MPa

K_{SE} = service condition factor

K_T = treatment factor

5.4.2 Elastic deflection

The elastic deflection of structural members under the load combinations for serviceability limit states shall not exceed 1/180 of the span. For members having cambers equaling at least dead load deflection, the additional deflection due to live, snow, and wind loads shall not exceed 1/180 of the span. Deflection under the load combinations for serviceability limit states shall be limited to avoid damage to structural elements or attached non-structural elements.

Note: *See Clause A.5.4.2 for additional information on deflection of a wood frame system under static loads.*

5.4.3 Permanent deformation

Structural members that support long term loads in excess of 50% of the load combinations for serviceability limit states shall be designed to limit permanent deformation. In lieu of a more accurate evaluation of acceptable deflection limits, an upper limit of 1/360 of the span shall be imposed on the elastic deflection due to long term loads.

General

Wood Design Manual (WDM) page 17 – suggested deflection limits

Table 2.1
Deflection Criteria

		Serviceability Load	Δ_{max}	Limitation
Roofs and floors		Total	L/180[1]	CSA O86
Plastered or gypsum ceilings:	Glulam NLT, CLT	Live	L/360	Suggested
	Lumber	Total	L/360[2]	Suggested
Roofs		Snow	L/240[3]	Suggested
Floors		Live[4]	L/360	Suggested
Wind columns		Wind	L/180	Suggested

Notes:

1. L/180 will control immediate deflection under total serviceability loads. L/360 will control the elastic deflection under long term loads in cases where long term loads exceed 50% of total serviceability loads. Refer to Clause 5.4.2 and 5.4.3 of CSA O86. For CLT, a creep adjustment factor (K_{creep} = 2) is applied to the instantaneous elastic deflection due to long term loads, in accordance with Clause A.8.5.2 of CSA O86. The application of the creep adjustment factor satisfies the permanent deformation provision of Clause 5.4.3, therefore eliminating the need to meet the additional requirements of Clause 5.4.3 for CLT.
2. Part 9 of the NBC permits L/360 deflection limitation based on live load for all roofs and floors with plaster or gypsum board.
3. In Part 9, this is required for roofs with ceilings other than plaster or gypsum. Where no ceilings exist, L/180 based on live load is permitted.
4. For floor beams supporting floors with concrete topping, L/360 based on total specified load is recommended.
5. For curved glulam members, refer to Section 9.2 and Clause 5.4.2 of CSA O86.

General

Cl 5.3.2 Load Duration Factor (Page 17 GP)

-Defines load duration factor K_D for given loading conditions

Table 5.3.2.2
Load duration factor, K_D

Load duration	K_D	Explanatory notes
Short term	1.15	Short-term loading means the condition of loading where the duration of the specified loads is not expected to last more than 7 days continuously or cumulatively throughout the life of the structure. Examples include wind loads, earthquake loads, falsework, and formwork, as well as impact loads.
Standard term	1.00	Standard term means the condition of loading where the duration of specified loads exceeds that of short-term loading, but is less than long-term loading. Examples include snow loads, live loads due to occupancy, wheel loads on bridges, and dead loads in combination with all of the above.
Long term	0.65	Long-term duration means the condition of loading under which a member is subjected to more or less continuous specified load. Examples include dead loads or dead loads plus live loads of such character that they are imposed on the member for as long a period of time as the dead loads themselves. Such loads include those usually occurring in tanks or bins containing fluids or granular material, loads on retaining walls subjected to lateral pressure such as earth, and floor loads where the specified load can be expected to be continuously applied, such as those in buildings for storage of bulk materials. Loads due to fixed machinery should be considered to be long term.

Note: *Load duration requires professional judgment by the designer. Explanatory notes in this Table provide guidance to designers about the types of loads and load combinations for which each modification factor should be applied.*

Lumber Grading + Strengths

Cl 6.2.2 & 6.3 Lumber Grading (Page 21/23 GP)

-Table 6.2.2.1 – Dimensional lumber grades and dimensions

-Tables 6.3.1A-6.3.1D – Specified strengths and moduli of elasticity

Table 6.2.2.1
Visual grades and their dimensions

Grade category	Smaller dimension, mm	Larger dimension, mm	Grades
Light framing	38 to 89	38 to 89	Construction, Standard
Stud	38 to 89	38 or more	Stud
Structural light framing	38 to 89	38 to 89	Select Structural No. 1, No. 2, No. 3
Structural joists and planks	38 to 89	114 or more	Select Structural No. 1, No. 2, No. 3
Beam and stringer	114 or more	Exceeds smaller dimension by more than 51	Select Structural No. 1, No. 2
Post and timber	114 or more	Exceeds smaller dimension by 51 or less	Select Structural No. 1, No. 2
Plank decking	38 to 89	140 or more	Select, Commercial

Glulam Grading + Strengths

Table 7.3 Glulam (Page 46 GP)

- Strengths and modulus of elasticity for Glulam

Table 7.3
Specified strengths and modulus of elasticity for glued-laminated timber, MPa
(See Clauses 7.5.9.3, 10.5.3, 10.5.4, 10.5.5, 10.6.3.1, 10.6.3.6, 10.6.3.7, A.6.5.6.3.6.)

	Douglas Fir-Larch					
	24f-E	24f-EX	20f-E	20f-EX	18t-E	16c-E
Bending moment (pos.), f_b	30.6	30.6	25.6	25.6	24.3	14.0
Bending moment (neg.), f_b	23.0	30.6	19.2	25.6	24.3	14.0
Longitudinal shear, f_v	2.0	2.0	2.0	2.0	2.0	2.0
Compression parallel, f_c	30.2*	30.2*	30.2*	30.2*	30.2	30.2
Compression parallel combined with bending, f_{cb}	30.2*	30.2	30.2*	30.2	30.2	30.2
Compression perpendicular, f_{cp} Compression face bearing	7.0	7.0	7.0	7.0	7.0	7.0
Tension face bearing	7.0	7.0	7.0	7.0	7.0	7.0
Tension net section, f_{tn} (see Clause 7.5.11)	20.4*	20.4	20.4*	20.4	23.0	20.4
Tension gross section, f_{tg}	15.3*	15.3	15.3*	15.3	17.9	15.3
Tension perpendicular to grain, f_{tp}	0.83	0.83	0.83	0.83	0.83	0.83
Modulus of elasticity, E	12 800	12 800	12 400	12 400	13 800	12 400

	Spruce-Lodgepole Pine-Jack Pine				Hem-Fir and Douglas Fir-Larch	
	20f-E	20f-EX	14t-E	12c-E	24f-E	24-EX
Bending moment (pos.), f_b	25.6	25.6	24.3	9.8	30.6	30.6
Bending moment (neg.), f_b	19.2	25.6	24.3	9.8	23.0	30.6
Longitudinal shear, f_v	1.75	1.75	1.75	1.75	1.75	1.75
Compression parallel, f_c	25.2*	25.2*	25.2	25.2	—	—
Compression parallel combined with bending, f_{cb}	25.2*	25.2	25.2	25.2	—	—
Compression perpendicular, f_{cp} Compression face bearing	5.8	5.8	5.8	5.8	4.6	7.0
Tension face bearing	5.8	5.8	5.8	5.8	7.0	7.0
Tension net section, f_{tn} (see Clause 7.5.11)	17.0*	17.0	17.9	17.0	20.4*	20.4
Tension gross section, f_{tg}	12.7*	12.7	13.4	12.7	15.3*	15.3
Tension perpendicular to grain, f_{tp}	0.51	0.51	0.51	0.51	0.83	0.83
Modulus of elasticity, E	10 300	10 300	10 700	9 700	13 100	13 100

**The use of this stress grade for this primary application is not recommended.*

Notes:

(1) *Designers should check the availability of grades before specifying.*

(2) *Tabulated values are based on the following standard conditions:*
  (a) dry service conditions; and
  (b) standard term duration of load.

CLT Grading + Strengths

Table 8.2.3 – Primary CLT Stress Grades

(Page 64 GP)

Table 8.2.3
Primary CLT stress grades

Stress grade	Species combinations and grades of laminations
E1	1950 F_b-1.7E Spruce-Pine-Fir MSR lumber in all longitudinal layers and No. 3/Stud Spruce-Pine-Fir lumber in all transverse layers
E2	1650 F_b-1.5E Douglas fir-Larch MSR lumber in all longitudinal layers and No. 3/Stud Douglas fir-Larch lumber in all transverse layers
E3	1200 F_b-1.2E Northern Species MSR lumber in all longitudinal layers and No. 3/Stud Northern Species lumber in all transverse layers
V1	No. 1/No. 2 Douglas fir-Larch lumber in all longitudinal layers and No. 3/Stud Douglas fir-Larch lumber in all transverse layers
V2	No. 1/No. 2 Spruce-Pine-Fir lumber in all longitudinal layers and No. 3/Stud Spruce-Pine-Fir lumber in all transverse layers

Table 8.2.4 – Strengths and modulus of elasticity

(Page 64A GP)

Table 8.2.4
Specified strengths and moduli of elasticity of laminations in primary CLT stress grades, MPa

Stress grade	Longitudinal layers						Transverse layers					
	f_b	E	f_t	f_c	f_s	f_{cp}	f_b	E	f_t	f_c	f_s	f_{cp}
E1	28.2	11700	15.4	19.3	0.50	5.3	7.0	9000	3.2	9.0	0.50	5.3
E2	23.9	10300	11.4	18.1	0.63	7.0	4.6	10000	2.1	7.3	0.63	7.0
E3	17.4	8300	6.7	15.1	0.43	3.5	4.5	6500	2.0	5.2	0.43	3.5
V1	10.0	11000	5.8	14.0	0.63	7.0	4.6	10000	2.1	7.3	0.63	7.0
V2	11.8	9500	5.5	11.5	0.50	5.3	7.0	9000	3.2	9.0	0.50	5.3

Notes:

(1) *Tabulated values are based on the following standard conditions:*
(a) dry service; and
(b) standard-term duration of load.

(2) *The specified values are taken from Table 6.3.2 for MSR lumber and Table 6.3.1A for visually stress-graded lumber. The specified strength in rolling shear, f_s, is taken as approximately 1/3 of the specified strength in shear, f_v, for the corresponding species combination. See Figure 8.2.4 for clarification of rolling shear.*

(3) *The transverse modulus of elasticity, $E_\perp$, may be estimated as E/30.*

(4) *The shear modulus, G, may be estimated as E/16.*

(5) *The rolling shear modulus, $G_\perp$, may be estimated as G/10. See Figure 8.2.4 for clarification of rolling shear.*

(6) *The modulus of elasticity for design of compression members, E_{05}, shall be taken form Table 6.3.1A for visually stress-graded lumber and 0.82E for MSR lumber.*

Table A.12.1 Relative density values

(Page 225 GP)

Lumber Modification Factors

Cl 6.4 Modification Factors (Page 28 GP)

-Modification factors for K_S, K_T, K_H, K_Z for lumber

-Includes Tables 6.4.2, 6.4.3, 6.4.4, and 6.4.5

Table 6.4.2
Service condition factors, K_S

K_S	Property	Dry service conditions	Wet service conditions: sawn lumber, piling, and poles of least dimension: 89 mm or less	Over 89 mm
K_{Sb}	Bending at extreme fibre	1.00	0.84	1.00
K_{Sf}	Fracture shear	1.00	0.70	0.70
K_{Sv}	Longitudinal shear	1.00	0.96	1.00
K_{Sc}	Compression parallel to grain	1.00	0.69	0.91
K_{Scp}	Compression perpendicular to grain	1.00	0.67	0.67
K_{St}	Tension parallel to grain	1.00	0.84	1.00
K_{SE}	Modulus of elasticity	1.00	0.94	1.00

Table 6.4.3
Treatment factor, K_T

Product	Dry service conditions	Wet service conditions
Untreated lumber	1.00	1.00
Preservative-treated unincised lumber	1.00	1.00
Preservative-treated incised lumber of thickness 89 mm or less		
Modulus of elasticity	0.90	0.95
Other properties	0.75	0.85
Fire-retardant-treated lumber	See Clause 6.4.3.2 for effects of fire-retardant treatment.	

Table 6.4.4
System factor, K_H

For specified strength in	Case 1*	Case 2† Visually graded	MSR	Built-up beams
Bending	1.10	1.40	1.20	1.10
Longitudinal shear	1.10	1.40	1.20	1.10
Compression parallel to grain	1.10	1.10	1.10	1.00
Tension parallel to grain	1.10	—	—	1.00
All other properties	1.00	1.00	1.00	1.00

*See Clause 6.4.4.1 for conditions applying to Case 1.
†See Clause 6.4.4.2 for conditions applying to Case 2.

Table 6.4.5
Size factor, K_Z, for visually stress-graded lumber

Larger dimension, mm	Bending and shear K_{Zb}, K_{Zv} — Smaller dimension, mm: 38 to 64	89 to 102	114 or more	Tension parallel to grain, K_{Zt} — All	Compression perpendicular to grain, K_{Zcp} — All	Compression parallel to grain, K_{Zc} — All	All other properties — All
38	1.7	—	—	1.5	See Clause 6.5.7.5	Value computed using formula in Clause 6.5.6.2.3	1.0
64	1.7	—	—	1.5			1.0
89	1.7	1.7	—	1.5			1.0
114	1.5	1.6	1.3	1.4			1.0
140	1.4	1.5	1.3	1.3			1.0
184 to 191	1.2	1.3	1.3	1.2			1.0
235 to 241	1.1	1.2	1.2	1.1			1.0
286 to 292	1.0	1.1	1.1	1.0			1.0
337 to 343	0.9	1.0	1.0	0.9			1.0
387 or larger	0.8	0.9	0.9	0.8			1.0

Glulam Modification Factors

Cl 7.4 Modification Factors (Page 47 GP)

-Modification factors for K_S, K_T, K_H for Glulam

-Includes Table 7.4.2

7.4 Modification factors

7.4.1 Load duration factor, K_D

The specified strength shall be multiplied by a load duration factor, K_D, in accordance with Clause 5.3.2.

7.4.2 Service condition factor, K_S

7.4.2.1

The specified strengths for glued-laminated timber are tabulated for dry service conditions. For wet service conditions, tabulated values shall be multiplied by a service condition factor, K_S, in accordance with Table 7.4.2.

7.4.2.2

Where glued-laminated members that could be exposed to free moisture are adequately protected, an intermediate value of K_S between 1.00 and that listed in Table 7.4.2 may be used.

7.4.3 System factor, K_H

The specified strengths for glued-laminated timber members in a system consisting of three or more essentially parallel members spaced not more than 610 mm apart and so arranged that they mutually support the applied load may be multiplied by a system factor, K_H, equal to 1.00 for tension parallel to grain and 1.10 for all other strength properties.

7.4.4 Treatment factor, K_T

For preservative treatment, the treatment factor for unincised glued-laminated timber may be taken as unity. For glued-laminated timber treated with fire-retardant or other potentially strength-reducing chemicals, strength and stiffness capacities shall be based on documented results of tests that shall take into account the effects of time, temperature, and moisture content in accordance with Clause 4.3.2. Glued-laminated members shall not be treated with water-borne chemicals after gluing.

Δ

Table 7.4.2
Service condition factors, K_S

		Glued-laminated timber	
K_S	Property	Dry service conditions	Wet service conditions
K_{Sb}	Bending at extreme fibre	1.00	0.80
K_{Sf}	Fracture shear	1.00	0.85
K_{Sv}	Longitudinal shear	1.00	0.87
K_{Sc}	Compression parallel to grain	1.00	0.75
K_{Scp}	Compression perpendicular to grain	1.00	0.67
K_{St}	Tension parallel to grain	1.00	0.75
K_{Stp}	Tension perpendicular to grain	1.00	0.85
K_{SE}	Modulus of elasticity	1.00	0.90

CLT Modification Factors

Cl 8.3 Modification Factors (Page 64A GP)

-Modification factors for K_S, K_T, K_H for CLT

8.3 Modification factors

8.3.1 Load duration factor, K_D

The specified strength shall be multiplied by a load duration factor, K_D, in accordance with Clause 5.3.2.

8.3.2 Service condition factors, K_S

CLT shall only be used in dry service conditions for which $K_{Sb} = K_{Sc} = K_{Scp} = K_{St} = K_{Sv} = K_{SE} = 1.0$.

Note: *CLT structures may be used in wet service conditions only if specifically permitted by the manufacturer based on documented test data in accordance with Clause 4.3.2 and is approved by the certification organization.*

8.3.3 Treatment factor, K_T

For CLT treated with fire-retardant or other potentially strength-reducing chemicals, strength and stiffness shall be based on documented results of tests that shall take into account the effects of time, temperature, and moisture content in accordance with Clause 5.3.4; otherwise, K_T shall be equal to 1.0. CLT shall not be treated with water-borne preservatives after gluing.

8.3.4 System factor, K_H

K_H shall be equal to 1.0 for all strength properties of CLT.

Shrinkage Calculations

Cl A5.4.6 Building Movement due to Moisture Content Change (Page 201 GP)

Δ **A.5.4.6 Building movements due to moisture content change**

Most buildings are able to accommodate small amounts of movement due to moisture content change in wood members. However, if insufficient considerations are taken during design and construction, differential movements can become visible or even cause structural or serviceability problems. The considerations for differential movements become more critical for higher buildings due to the cumulative effect of movement.

Shrinkage can contribute to overall lateral drift calculations but can be mitigated using shrinkage compensators and materials subject to less dimensional change.

Attention should be paid to the following areas to avoid potential shrinkage and swelling related problems in the design, where:

(a) non-uniform movements could occur;
(b) metal connectors are used to support large sawn and glulam timber components;
(c) differential movements could cause distress in the finish materials or building envelope; and
(d) differential movements could cause distress in plumbing, electrical and mechanical systems.

Compatibility with other materials considered in the design detailing. Assuming similar members are exposed to the same environmental conditions, it is reasonable to assume the same degree of shrinkage or swelling will occur along each load path. Where wood members are exposed to different environmental conditions (e.g., some members are located in a conditioned space while others are in an unconditioned space), a more detailed analysis is warranted. Similarly, expected movement in non-wood members, such as contraction or expansion due to temperature changes should be considered.

The shrinkage or swelling of a wood member between the initial and final moisture content may be estimated using the following equation:

$$S = D \times (M_i - M_f) \times c$$

where

S = shrinkage or swelling in the dimension being considered (thickness, width, or length) (mm)

D = actual dimension (thickness, width, or length) (mm)

M_i = the lesser of the initial moisture content or the fibre saturation point (28%)

M_f = the final moisture content

c = shrinkage coefficient*

For lumber

= 0.002 for shrinkage or swelling perpendicular to the grain

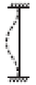
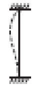
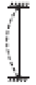
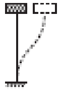
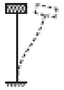
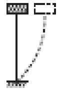
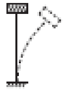
= 0.00005 for shrinkage or swelling parallel to the grain

**More information on shrinkage coefficients for individual wood species can be found in the CWC Wood Design Manual. For other wood products refer to published literature.*

Effective Length Factors

A.6.5.6.1 Effective length factor, K_e

Table A.6.5.6.1
Minimum design values of effective length factor, K_e, for compression members

Degree of end restraint of compression member	Effective length factor, K_e	Symbol
Effectively held in position and restrained against rotation at both ends	0.65	
Effectively held in position at both ends and restrained against rotation at one end	0.80	
Effectively held in position at both ends but not restrained against rotation	1.00	
Effectively held in position and restrained against rotation at one end, and at the other end restrained against rotation but not held in position	1.20	
Effectively held in position and restrained against rotation at one end, and at the other partially restrained against rotation but not held in position	1.50	
Effectively held in position at one end but not restrained against rotation, and at the other end restrained against rotation but not held in position	2.00	
Effectively held in position and restrained against rotation at one end but not held in position or restrained against rotation at the other end	2.00	

Note: *Effective length $L_e = K_eL$, where L is the distance between centres of lateral supports of the compression member in the plane in which buckling is being considered. At a base or cap detail, the distance shall be measured from the outer surface of the base or cap plate. The effective length factor, Ke , shall be not less than what would be indicated by rational analysis. Where conditions of end restraint cannot be evaluated closely, a conservative value for K_e shall be used.*

Lumber: Tension and Compression

Lumber in Compression and Tension

- Cl 6.5.6: Compression Parallel to the Grain (Page 35 GP)
- Cl 6.5.7: Compression Perpendicular to the Grain (Page 38 GP)
- Cl 6.5.9: Tension Parallel to the Grain (Page 40 GP)

6.5.6.2 Simple compression members

6.5.6.2.1 General
The factored compressive resistance parallel to grain for sawn lumber, P_r, shall be checked for both axes.

6.5.6.2.2 Constant rectangular cross-section
The slenderness ratio, C_C, of simple compression members of constant rectangular section shall not exceed 50 and shall be calculated for both axes as follows:

$$C_C = \frac{\text{effective length associated with width}}{\text{member width}}$$

$$C_C = \frac{\text{effective length associated with depth}}{\text{member depth}}$$

6.5.6.2.3 Factored compressive resistance parallel to grain
The factored compressive resistance parallel to grain, P_r, shall be taken as follows:

$$P_r = \phi F_C A K_{Zc} K_C$$

where
ϕ = 0.8
$F_C = f_c (K_D K_H K_{Sc} K_T)$
where
f_c = specified strength in compression parallel to grain, MPa (Tables 6.3.1A to 6.3.1D, 6.3.2, and 6.3.3)
$K_{Zc} = 6.3\,(dL)^{-0.13} \le 1.3$
where
d = dimension in direction of buckling (depth or width), mm
L = length associated with member dimension, mm

6.5.6.2.4 Slenderness factor, K_C
For both axes, the slenderness factor, K_C, shall be taken as follows:

$$K_C = \left[1.0 + \frac{F_C K_{Zc} C_c^3}{35 E_{05} K_{SE} K_T}\right]^{-1}$$

where
E_{05} = $0.82E$ for MSR lumber
= $0.75E$ for MEL lumber
= as specified in Tables 6.3.1A to 6.3.1D for visually graded lumber

6.5.6.3 Spaced compression members
Spaced compression members shall be designed using the specified strengths and adjustment factors for sawn lumber.
Note: *Spaced compression members may be designed in accordance with the provisions of Clause A.6.5.6.3.*

6.5.6.4 Built-up compression members

6.5.6.4.1 General
Built-up rectangular compression members shall consist of two to five individual members of at least 38 mm thickness joined with nails or bolts, or bolts and split ring connectors. The factored compressive

Glulam: Tension and Compression

Glulam in Tension and Compression

- Cl 7.5.8: Compression Parallel to the Grain (Page 60 GP)
- Cl 7.5.9: Compression Perpendicular to the Grain (Page 61 GP)
- Cl 7.5.11: Tension Parallel to the Grain (Page 63 GP)

7.5.8.4.2

The factored compressive resistance parallel to grain, P_r, shall be taken as follows:

$$P_r = \phi F_c A K_{Zcg} K_C$$

where

ϕ = 0.8

$F_c = f_c(K_D K_H K_{Sc} K_T)$

where

f_c = specified strength in compression parallel to grain, MPa (Table 7.3)

$K_{Zcg} = 0.68(Z)^{-0.13} \le 1.0$

where

Z = member volume, m^3

K_C = slenderness factor (Clause 7.5.8.5)

7.5.8.5 Slenderness factor, K_C

The slenderness factor, K_C, shall be taken as follows:

$$K_C = \left[1.0 + \frac{F_c K_{Zcg} C_c^3}{35 E_{05} K_{SE} K_T}\right]^{-1}$$

where

E_{05} = 0.87E

Δ **7.5.11 Tensile resistance parallel to grain**

The factored tensile resistance parallel to grain, T_r, shall not be less than the maximum factored tensile force, T_f, and shall be calculated as the lesser of

$$T_r = \phi F_{tn} A_n$$

or

$$T_r = \phi F_{tg} A_g$$

where

ϕ = 0.9

$F_{tn} = f_{tn}(K_D K_H K_{St} K_T)$

where

f_{tn} = specified strength in tension parallel to grain at net section, MPa (Table 7.3)

A_n = net area of cross-section, mm^2

$F_{tg} = f_{tg}(K_D K_H K_{St} K_T)$

where

f_{tg} = specified strength in tension parallel to grain at gross section, MPa (Table 7.3)

A_g = gross area of cross-section, mm^2

CLT: Compression

CLT in Compression

- Cl 8.4.5: Axial compression (Page 64E GP)
- Cl 8.4.7: Bearing (compression perpendicular to the face of the panel) (Page 64 G GP)

8.4.5.4.2
The factored compressive resistance of CLT panels under axial load shall be calculated as follows:

$$P_r = \phi F_c A_{eff} K_{Zc} K_C$$

where
ϕ = 0.8
$F_c = f_c(K_D K_H K_{Sc} K_T)$

where
f_c = specified strength in compression parallel to grain of the laminations oriented parallel to the axial load, MPa (Clause 8.2.4)

$$K_{Zc} = 6.3\left(\sqrt{12}\ r_{eff}\ L\right)^{-0.13} \le 1.3$$

$$K_C = \left[1.0 + \frac{F_c K_{Zc} C_c^3}{35 E_{05}(K_{SE} K_T)}\right]^{-1}$$

where
E_{05} = modulus of elasticity for design of compression members, only for the laminations oriented parallel to the axial load, MPa (Clause 8.2.4)
L = height of the panel, mm

Compression Member Selection Tables

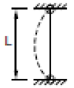
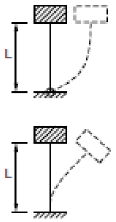
Compression Members

- Sawn Timbers and Glulam: WDM Page 169
- CLT Walls: WDM Page 201

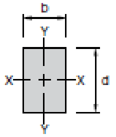
Column Selection Tables

DF-L Sel

Sawn Timbers

D.Fir-L Select Structural		Square timbers				Rectangular timbers					
	b (mm)	140	191	241	292	140		191		241	
	d (mm)	140	191	241	292	191		241		292	
	L m	P_r kN	P_r kN	P_r kN	P_r kN	P_{rx} kN	P_{ry} kN	P_{rx} kN	P_{ry} kN	P_{rx} kN	P_{ry} kN
 K_e = 1.0	2.0	227	447	714	1040	328	309	566	564	856	865
	2.5	194	411	675	992	301	265	535	519	819	817
	3.0	162	373	634	947	273	220	502	470	782	768
	3.5	132	333	590	902	244	180	468	420	744	715
	4.0	106	293	545	854	215	145	432	369	705	660
	4.5	85.3	255	498	804	187	116	395	321	663	603
	5.0	68.5	219	452	752	161	93.5	358	277	620	547
	5.5	55.3	188	406	699	138	75.4	322	238	577	492
	6.0	44.9	161	364	646	118	61.3	288	203	533	440
	6.5	36.8	138	324	595	101	50.2	257	174	491	392
	7.0	30.4	118	287	545	86.3	41.5	228	149	449	348
	7.5		101	255	497	74.1		202	127	410	308
	8.0		86.9	225	452	63.7		179	110	373	273
	8.5		75.1	200	411	55.1		158	94.8	339	242
	9.0		65.1	177	372	47.7		140	82.2	307	214
 K_e = 2.0	2.0	110	311	585	920	228	151	464	392	763	709
	2.5	70.3	230	480	810	168	95.9	380	290	667	582
	3.0	45.7	167	382	688	122	62.4	303	210	568	463
	3.5	30.8	121	299	575	88.6	42.0	237	152	474	362
	4.0		88.6	233	473	65.0		184	112	391	282
	4.5		66.1	181	387	48.4		144	83.4	319	220
	5.0			142	315			113		260	173
	5.5			113	258			89.5		213	137
	6.0			90.5	212			71.7		175	110
	6.5				175					144	
	7.0				145					120	

Notes:
1. P_{rx} is the factored resistance to buckling about the x-x (strong) axis.
   P_{ry} is the factored resistance to buckling about the y-y (weak) axis.
2. For L ≤ 2.0 m, use P_r for L = 2.0 m.
   Where P_r values are not given, the slenderness ratio exceeds 50 (maximum permitted).
3. Tabulated values are valid for the following conditions:
   - standard term load (dead plus snow or occupancy loads) (K_D = 1.0)
   - dry service conditions (K_S = 1.0)
   - no fire-retardant treatment (K_T = 1.0)
   - K_e = 1.0 or K_e = 2.0
   - concentrically loaded (e = 0).



Tension Member Selection Tables

Tension Members

- Sawn Timbers and Glulam: WDM Page 220

Tension Member Selection Tables

38 mm **Sawn Lumber**

Factored tensile resistance based on gross area, T_r (kN)

Species	Size (b x d) mm	Visually graded Select Structural	No.1/ No.2	No.3/ Stud	Machine Stress-Rated (MSR) 1450F_b-1.3E	1650F_b-1.5E	1800F_b-1.6E	2100F_b-1.8E	2400F_b-2.0E
D.Fir-L	38 x 89	48.4	26.5	9.59	27.4	34.7	40.2	53.9	66.1
	38 x 140	66.0	36.1	13.1	43.1	54.6	63.2	84.7	104
	38 x 184	80.0	43.8	15.9	56.6	71.7	83.1	111	137
	38 x 235	93.7	51.3	18.6					
	38 x 286	104	56.7	20.5					
Hem-Fir	38 x 89	44.3	28.3	14.6	27.4	34.7	40.2	53.9	66.1
	38 x 140	60.4	38.6	19.9	43.1	54.6	63.2	84.7	104
	38 x 184	73.2	46.8	24.2	56.6	71.7	83.1	111	137
	38 x 235	85.8	54.8	28.3					
	38 x 286	94.9	60.6	31.3					
S-P-F	38 x 89	39.3	25.1	14.6	27.4	34.7	40.2	53.9	66.1
	38 x 140	53.5	34.2	19.9	43.1	54.6	63.2	84.7	104
	38 x 184	64.9	41.5	24.2	56.6	71.7	83.1	111	137
	38 x 235	76.0	48.6	28.3					
	38 x 286	84.1	53.8	31.3					
Northern	38 x 89	28.3	18.3	9.13	27.4	34.7	40.2	53.9	66.1
	38 x 140	38.6	24.9	12.4	43.1	54.6	63.2	84.7	104
	38 x 184	46.8	30.2	15.1	56.6	71.7	83.1	111	137
	38 x 235	54.8	35.4	17.7					
	38 x 286	60.6	39.1	19.6					

Lumber: Bending and Shear

Cl 6.5.4: Bending (Page 32 GP)

6.5.4 Bending moment resistance

Δ **6.5.4.1 General**

The factored bending moment resistance, M_r, of sawn lumber members shall be taken as follows:

$$M_r = \phi F_b S K_{Zb} K_L$$

where

ϕ = 0.9

F_b = $f_b(K_D K_H K_{Sb} K_T)$

where

f_b = specified strength in bending, MPa (Tables 6.3.1A to 6.3.1D, 6.3.2, and 6.3.3)

K_{Zb} = size factor in bending (Clause 6.4.5)

K_L = lateral stability factor (Clause 6.5.4.2)

Cl 6.5.5: Shear (Page 33 GP)

6.5.5.2 Shear resistance

The factored shear resistance, V_r, shall not be less than the maximum factored shear force, V_f, and shall be taken as follows:

$$V_r = \phi F_v \frac{2A_n}{3} K_{Zv}$$

where

ϕ = 0.9

F_v = $f_v (K_D K_H K_{Sv} K_T)$

where

f_v = specified strength in shear, MPa (Clause 6.3)

A_n = net area of cross-section, mm^2 (Clause 5.3.8)

K_{Zv} = size factor in shear (Clause 6.4.5)

Cl 6.5.10: Resistance to Bending and Axial Load (Page 40 GP)

Glulam: Bending and Shear

Cl 7.5.6.5: Moment Resistance

(Page 50 GP)

Cl 7.5.7: Shear

(Page 55 GP)

Cl 7.5.12: Combined bending and axial load (Page 63 GP)

7.5.6.5 Moment resistance

7.5.6.5.1
Except as provided for in Clauses 7.5.6.5.3 and 7.5.6.6, the factored bending moment resistance, M_r, of glued-laminated timber members shall be taken as the lesser of M_{r1} or M_{r2}, as follows:

$$M_{r1} = \phi F_b S K_x K_{Zbg}$$

$$M_{r2} = \phi F_b S K_x K_L$$

where

ϕ = 0.9

$F_b = f_b(K_D K_H K_{Sb} K_T)$

where

f_b = specified strength in bending, MPa (Table 7.3)

K_X = curvature factor (Clause 7.5.6.5.2)

$$K_{Zbg} = \left(\frac{130}{b}\right)^{\frac{1}{10}}\left(\frac{610}{d}\right)^{\frac{1}{10}}\left(\frac{9100}{L}\right)^{\frac{1}{10}} \le 1.3$$

where

b = beam width (for single-piece laminations) or the width of widest piece (for multiple-piece laminations), mm

d = beam depth, mm

L = length of beam segment from point of zero moment to point of zero moment, mm

K_L = lateral stability factor (Clause 7.5.6.4)

Note: *For beams with one or more points of inflection (i.e., multi-span beams and cantilevered beams), the size factor is calculated for each beam segment. The moment resistance for each beam segment, as modified by the appropriate size factor, is then compared to the maximum factored moment within that segment.*

7.5.7.2 Shear resistance at locations other than end notches

The factored shear resistance of glued-laminated members shall be determined as follows:

(a) For beams of any volume, the total factored loading, W_f, acting normal to a member shall not exceed the total factored shear resistance, W_r, calculated as follows:

$$W_r = \phi F_v 0.48 A_g C_V Z^{-0.18} \ge W_f$$

Note: *As an alternative for beams less than 2.0 m³ in volume, the factored shear resistance may be calculated using the equation in Item (b).*

(b) For members other than beams, the factored shear resistance, V_r, shall not be less than the maximum factored shear force, V_f, and shall be taken as follows:

$$V_r = \phi F_v \frac{2A_g}{3}$$

where

ϕ = 0.9

$F_v = f_v(K_D K_H K_{Sv} K_T)$

where

f_v = specified strength in shear, MPa (Table 7.3)

$A_g = b \times d$ = gross cross-sectional area of member, mm^2 (Clause 5.3.8)

C_V = shear load coefficient (Clause 7.5.7.5)

Z = beam volume, m^3

Note: *The shear resistance requirements of this clause are additional to those applicable to notched members (Clauses 7.5.7.3 and 7.5.7.4).*

CLT: Bending and Shear

Cl 8.4.3: Moment Resistance (Page 64B GP)

8.4.3.1 General

The out-of-plane factored bending moment resistance, M_r, of CLT panels shall be calculated as follows:

(a) for the major strength axis (Figure 8.4.3.2a):

$$M_{r,y} = \phi F_b S_{eff,y} K_{rb,y}$$

where

ϕ = 0.9

$F_b = f_b (K_D K_H K_{Sb} K_T)$

Cl 8.4.4: Shear (Page 64D GP)

8.4.4.2 Factored shear resistance

The factored shear resistance, V_r, of CLT panels shall be calculated as follows:

(a) for the major strength axis:

$$V_{r,zy} = \phi F_s \frac{2A_{g,zy}}{3}$$

where

ϕ = 0.9

$F_s = f_s(K_D K_H K_{Sv} K_T)$

where

f_s = specified strength in rolling shear of laminations in the transverse layers, MPa (Clause 8.2.4)

$A_{g,zy}$ = gross cross-sectional area of the panel for the major strength axis, mm^2

(b) for the minor strength axis:

$$V_{r,zx} = \phi F_s \frac{2A_{g,zx}}{3}$$

where

ϕ = 0.9

$F_s = f_s(K_D K_H K_{Sv} K_T)$

where

f_s = specified strength in rolling shear of laminations in the longitudinal layers, MPa (Clause 8.2.4)

$A_{g,zx}$ = gross cross-sectional area of the panel for the minor strength axis, mm^2

Cl 8.4.6: Combined Bending and Axial Compression (Page 64F GP)

Bending Members Selection Tables

Bending Members

- Joists: WDM Page 41
- Sawn Timbers, Glulam and Structural Composite Lumber: WDM Page 66
- CLT: WDM Page 115

Panel Selection Tables

35 mm plies

CLT (Strength)

Grade	Number of Plies	Panel Thickness (mm)	Strength Axis: Major $M_{r,y}$ kN•m/m	Major $V_{r,zy}$ kN/m	Minor $M_{r,x}$ kN•m/m	Minor $V_{r,zx}$ kN/m
E1	3	105	38.2	31.5	1.29	10.5
	5	175	87.8	52.5	11.2	31.5
	7	245	155	73.5	25.8	52.5
	9	315	240	94.5	45.6	73.5
E2	3	105	32.4	39.7	0.845	13.2
	5	175	74.5	66.2	7.34	39.7
	7	245	132	92.6	16.9	66.2
	9	315	204	119	29.9	92.6
E3	3	105	23.6	27.1	0.827	9.03
	5	175	54.2	45.2	7.18	27.1
	7	245	95.7	63.2	16.6	45.2
	9	315	148	81.3	29.3	63.2
V1	3	105	13.6	39.7	0.845	13.2
	5	175	31.2	66.2	7.34	39.7
	7	245	55.1	92.6	16.9	66.2
	9	315	85.5	119	29.9	92.6
V2	3	105	16.0	31.5	1.29	10.5
	5	175	36.8	52.5	11.2	31.5
	7	245	65.1	73.5	25.7	52.5
	9	315	101	94.5	45.5	73.5

Note:
Values are per metre width of panel.

Combined Loading Selection Tables

Combined Loading (Axial and Bending)

- Sawn Timbers and Glulam: WDM Page 244
- CLT Wall Panels: WDM Page 270

Wall Panel Selection Tables (Combined Loading)

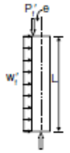
E1
35 mm plies

CLT Wall

Maximum combined compressive resistance P'_r (kN /m) and Lateral resistance w'_r (kPa)

L (m)	3-ply 105 mm P'_r (kN/m)	w'_r (kPa) (e=0)	w'_r (kPa) (e=d/6)	w'_r (kPa) (e=d/2)	5-ply 175 mm P'_r (kN/m)	w'_r (kPa) (e=0)	w'_r (kPa) (e=d/6)	w'_r (kPa) (e=d/2)
2.5	93.0	46.5	45.5	43.4	186	110	107	100
	186	37.7	35.6	31.4	372	93.0	86.1	72.2
	279	29.8	26.6	20.4	558	76.9	66.5	45.6
	372	22.8	18.6	10.3	744	62.0	48.1	
	465	16.7	11.5		931	48.5	31.1	
	558	11.5	5.28		1120	36.2		
	651	7.27			1300	25.2		
	744	3.93			1490	15.5		
3.0	71.8	32.2	31.6	30.5	167	76.0	73.9	69.5
	144	25.9	24.8	22.6	334	63.4	59.0	50.4
	215	20.3	18.7	15.3	502	51.8	45.3	32.3
	287	15.4	13.2	8.74	669	41.2	32.5	
	359	11.2	8.41		836	31.7	20.9	
	431	7.63	4.28		1000	23.3		
	503	4.73	0.816		1170	15.9		
	574	2.48			1340	9.53		
3.5	54.7	23.6	23.3	22.7	148	55.4	54.0	51.2
	109	19.0	18.4	17.2	295	45.8	43.0	37.3
	164	15.0	14.0	12.1	443	37.0	32.8	24.3
	219	11.3	10.1	7.59	591	29.1	23.5	
	274	8.23	6.67	3.54	738	22.1	15.0	
	328	5.61	3.73		886	15.9	7.47	
	383	3.47	1.28		1030	10.6		
	438	1.83			1180	6.21		
4.0	41.7	18.1	18.0	17.6	129	42.2	41.2	39.4
	83.4	14.7	14.3	13.6	257	34.6	32.7	28.9
	125	11.6	11.0	9.92	386	27.7	24.9	19.3
	167	8.82	8.09	6.63	514	21.6	17.8	10.3
	209	6.44	5.53	3.71	643	16.2	11.5	
	250	4.43	3.33	1.14	771	11.5	5.85	
	292	2.78	1.50		900	7.52		
	334	1.49	<0.1		1030	4.28		
4.5	32.0	14.4	14.3	14.1	111	33.2	32.5	31.3
	64.0	11.7	11.5	11.0	221	27.1	25.8	23.2
	96.0	9.28	8.94	8.28	332	21.6	19.6	15.8
	128	7.13	6.69	5.80	443	16.7	14.1	9.01
	160	5.26	4.70	3.60	553	12.4	9.18	
	192	3.66	2.99	1.67	664	8.68	4.86	
	224	2.33	1.56		774	5.60		
	256	1.28	0.396		885	3.13		
Q_r (kN/m)	445				742			
$V_{r,zy}$ (kN/m)		31.5				52.5		
$(EI)_{eff,y} \times 10^9$ (N•mm²/m)		1090				4170		
$(GA)_{eff,zy} \times 10^6$ (N/m)		7.31				14.6		

Notes:
1. P'_r is based on the major strength axis. Values of P'_r range from 0.1 to 0.8 of the maximum compressive resistance, and are based on short-term load duration (K_D = 1.15).
2. w'_r is the maximum factored uniform wind resistance that satisfies the interaction equation for a given P'_r value.
3. The eccentricity calculations assume that the panel is loaded eccentrically at the top and concentrically at the bottom. Calculations consider eccentric loading at the top of the wall and the mid-height of the wall.
4. Where values are not provided, the slenderness ratio C_c exceeds 43 or the combination of P'_r value and e exceeds capacity.



Lateral Load Resisting Systems

Cl 11 – Lateral Load Resisting Systems

Potentially useful clauses include:

- Cl 11.4 Modification factors (Page 90 GP)
- Cl 11.5 Strength and resistance of shear walls and diaphragms (Page 93 GP)
- Cl 11.7 Deflection of shear walls and diaphragms (Page 103 GP)
- Cl 11.8 Seismic design (Page 104 GP)
- Cl 11.9 Design of CLT Shear walls and diaphragms (Page 108 GP)

11.9 Design of CLT shearwalls and diaphragms

Note: *The provisions in this Clause should be used in conjunction with the CWC* Commentary on CSA O86.

11.9.1 General

11.9.1.1

Clause 11.9 shall apply to platform-type constructions not exceeding 30 m in height. For high seismic zones (i.e., $I_E F_a S_a(0.2) > 0.75$), the height shall be limited to 20 m. Alternative systems shall be designed in accordance with Clause 4.3.2 of this Standard and *NBC* subsection 4.1.8.

11.9.1.2

The factored shear resistance of CLT shearwalls shall be governed by the resistance of connections between the shearwalls and the foundations or floors, and connections between the individual panels, calculated using methods of mechanics, assuming each individual panel acts as a rigid body.

11.9.1.3

The factored shear resistance of the diaphragms shall be governed by the resistance of the connections between the diaphragms and the supporting structure and the connections between the individual panels, calculated using methods of mechanics, assuming each individual panel acts as a rigid body.

Shear Walls and Diaphragms Selection

Diaphragms

- Design procedure: WDM Page 572
- Selection tables: WDM Page 580

Shear walls

- Design procedure: WDM Page 607
- Selection tables: WDM Page 623

Shearwall Selection Tables

Wood-based Panel: DFP — **Factored Shear Resistance v_{rs}[1,2,8] (kN/m)**

Stud species	Common nail size		Panel thickness (mm)	Panels applied directly to framing Nail spacing at panel edges (mm)				
D.Fir-L	Length (in.)	Diameter (mm)		150	125	100	75	50**
	2-1/4	2.52++	7.5	3.34	4.01	4.96	5.21*	5.21*
			9.5	3.65	4.37	5.42	6.90	8.95
			12.5	4.11	4.93	6.10	7.77	10.1
			15.5	4.38	5.26	6.51	8.29	10.8
	2	2.84	7.5	3.96	4.75	5.21*	5.21*	5.21*
			9.5	4.29	5.15	6.37	8.12	9.36*
			12.5	4.79	5.74	7.11	9.05	11.8
			15.5	5.28	6.34	7.85	9.99	13.0
	2	2.87++	7.5	4.02	4.82	5.21*	5.21*	5.21*
			9.5	4.35	5.22	6.47	8.23	9.36*
			12.5	4.85	5.82	7.21	9.18	11.9
			15.5	5.35	6.42	7.95	10.1	13.1
	2-1/2	3.25	7.5	4.80	5.21*	5.21*	5.21*	5.21*
			9.5	5.15	6.18	7.65	9.36*	9.36*
			12.5	5.69	6.82	8.45	10.8	14.0
			15.5	6.22	7.46	9.24	11.8	15.3
	2-1/2	3.33++	7.5	4.96	5.21*	5.21*	5.21*	5.21*
			9.5	5.32	6.38	7.91	9.36*	9.36*
			12.5	5.86	7.03	8.71	11.09	14.4
			15.5	6.41	7.68	9.51	12.1	15.7
	3	3.66+	7.5	5.21*	5.21*	5.21*	5.21*	5.21*
			9.5	6.04	7.24	8.97	9.36*	9.36*
			12.5	6.60	7.92	9.81	12.5	16.2
			15.5	7.17	8.60	10.7	13.6	17.6

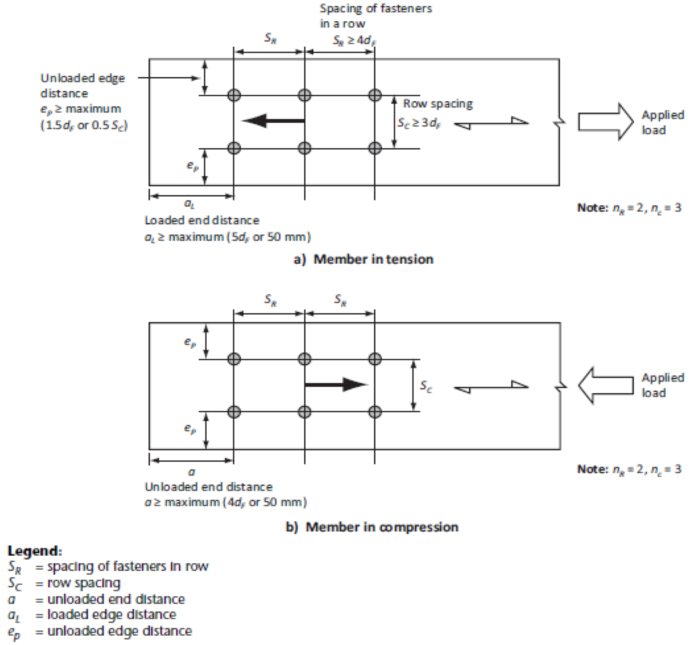
Connection Design

Cl 12.2 General Requirements (Page 110 GP)

- Shear resistance, modification factors

Cl 12.4 Bolts and dowels (Page 126 GP)

- 12.4.3 Placement of fasteners (Page 127 GP)
- 12.4.4 includes Lateral and Yielding Resistance, Embedment Strength, Tension resistance (Page 130 GP)



Δ **Figure 12.4.3.1**
Placement of bolts and dowels in a connection loaded parallel to grain

Connection Design

Cl 12.6 Lag Screws (Page 139 GP)

Cl 12.9 Nails and Spikes (Page 166 GP)

- 12.9.4 Lateral resistance (Page 169 GP)
- 12.9.5 Withdrawal resistance (Page 171 GP)
- Table A.12.9.5.2 Nail and spike characteristics (Page 233 GP)

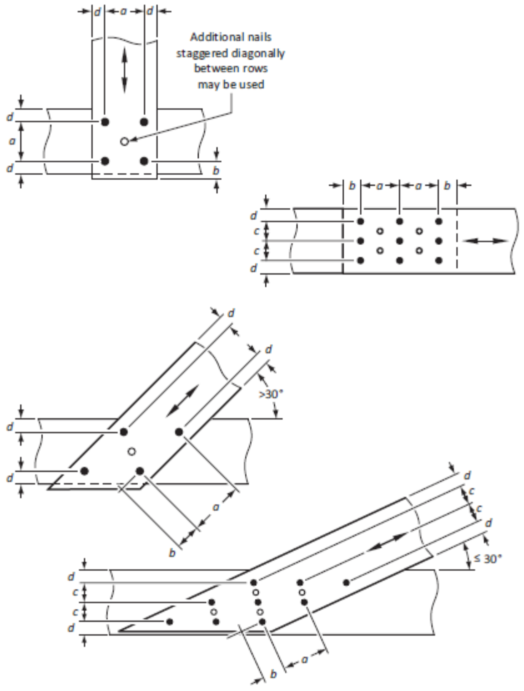


Figure 12.9.2.1
Nail spacings for wood-to-wood connections

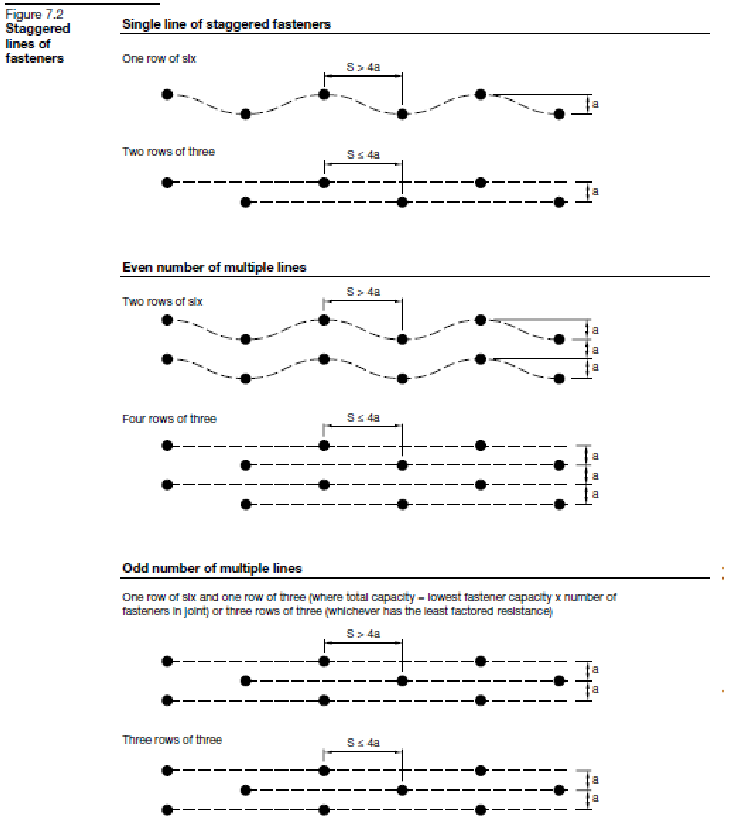
WDM Connections

WDM Page 321

- Visualization of spacing requirements and genera design considerations

Nails and Spikes: WDM Page 327

- Selection Tables: WDM Page 332



WDM Connections

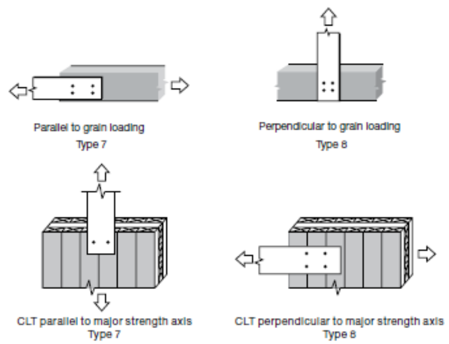
Bolts and Dowels: Page 383

- Bolt Joint Configurations: WDM Page 395
- Bolts and Dowels Selection Table: WDM Page 398

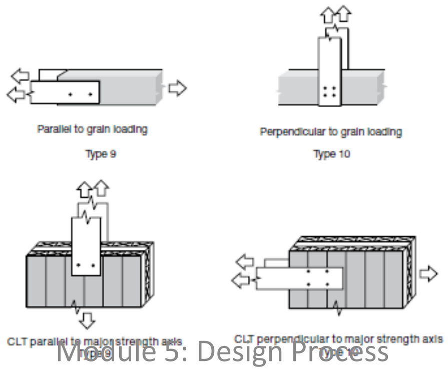
Bolt Selection Tables

Joint Configurations

Single Shear, Steel Side Plates



Double Shear, Steel Side Plates



WDM Connections

Lag Screw: Page 459

- Lag screw selection tables: WDM Page 467

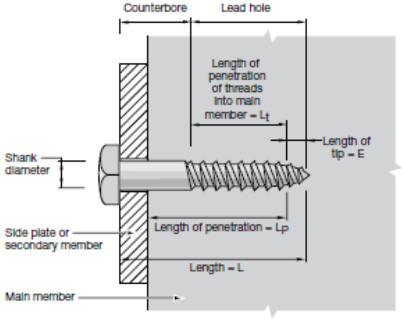
7.6 Lag Screws

General

Lag screws may be used alone or with timber connectors in situations where through bolts are undesirable or impractical (Detail 7.24a). Lag screw materials and dimensions are specified in ASME Standard B18.2.1 *Square and Hex Bolts and Screws (Inch Series)*. The steel must meet or exceed the properties of SAE J429 Grade 1.

Usually lag screws are manufactured with regular square heads and cone points, but they can be obtained with hexagon heads and gimlet points. A typical lag screw joint is shown in Figure 7.9.

Figure 7.9
Typical lag screw joint



Lag screws may be used with wood or steel side plates. Since lag screws are threaded, they may be designed to resist withdrawal loads as well as lateral loads.

For lag screw connections into CLT panels, the embedment strength equations are factored by J_x=0.9. The factored lateral resistances parallel (P'_r) and perpendicular (Q'_r) to the grain for CLT selection tables incorporate J_x=0.9.

Availability

Lag screws are generally available in imperial sizes. Typical sizes range from 3" to 12" in length and from 1/4" to 1" in diameter. However, the availability of long lengths should be confirmed before specifying. Chapter 11 contains information on standard lag screw dimensions.

Fire Safety

Annex B (Page 235 GP)

- B.3 – Resistance factors (Page 236 GP)
- B.4/5 – Char depths (Page 237/239 GP)

Table B.4.2
Design charring rates for wood and wood-based products, mm/min

	β_o	β_n
Timber and plank decking	0.65	0.80
Glued-laminated timber	0.65	0.70
Structural Composite Lumber	0.65*	0.70*
Cross-laminated timber	0.65	0.80

**Values are only applicable to wood-based structural composite lumber products.*

- B.6 – Reduced cross section resistances (Page 239 GP)
- B.8 – Surfaced protected by gypsum board (Page 240 GP)

B.8 Surfaces protected by gypsum board

B.8.1 Gypsum board

Provided that surfaces are protected from fire exposure by fire-rated Type X gypsum board, the assigned fire-resistance duration calculated in accordance with Clause B.7 can be increased by the following times:

(a) 15 min when one layer of 12.7 mm Type X gypsum board is used;
(b) 30 min when one layer of 15.9 mm Type X gypsum board is used;
(c) 60 min when two layers of 15.9 mm Type X gypsum boards are used; or
(d) 60 min when two layers of 12.7 mm Type X gypsum boards are applied to CLT.

B.8.2 Gypsum board fasteners

The values in Clause B.8.1 shall only apply where the fasteners used to attach the gypsum board penetrate the wood element a minimum of 25 mm and are spaced a maximum of 300 mm on centre and each length of gypsum board is attached by a minimum of two rows of fasteners that are off-set by half the fastener spacing if row spacing is less than 300 mm.

Note: *Steel or wood furring providing a gap between the gypsum board and wood member will not reduce the additional fire-resistance attributed to the gypsum board provided the gypsum board fastener spacing requirements in Clause B.8.2 are met, and the fasteners used to attach the furring elements to the wood structural elements penetrate the wood structural elements a minimum of 25 mm.*

B.8.3 Joints

The values in Clause B.8.1 shall only apply where the exposed joints of the gypsum board are taped and finished. When multiple layers of 15.9 mm Type X gypsum board described in Clause B.8.1 are used, the joints shall be off-set between the base layer and face layer.

Fire Design

Fire resistance ratings

- Pre-assigned ratings: WDM Page 767
- NBC Division B Appendix D method for Glulam: WDM Page 773

Beams

- CSA-O86 Annex B method (large cross section): WDM Page 775
- Beam selection tables for fire resistance ratings: WDM Page 784

Columns

- CSA-O86 Annex B method (large cross section) WDM Page 805
- Column selection tables for fire resistance ratings: WDM Page 816

Fire Design

CLT Floor and Roof Panels

- CSA-O86 Annex B method (large cross section): WDM Page 857
- Floor panel selection tables for fire resistance ratings: WDM Page 864

CLT Wall Panels

- CSA-O86 Annex B method (large cross section): WDM Page 866
- Wall panel selection tables for fire resistance ratings: WDM Page 873

Solid Wall Panel Selection Tables for Fire Resistance

E1 **35** mm plies **CLT** **30** min

	Major Strength Axis				Minor Strength Axis			
Number of plies	3	5	7	9	3	5	7	9
Panel thickness (mm)	105	175	245	315	105	175	245	315
L m	P_r kN	P_r kN	P_r kN	P_r kN	P_r kN	P_r kN	P_r kN	P_r kN
2.0	706	2190	3380	4420		940	1530	2010
2.5	464	1880	3140	4210		793	1420	1920
3.0	308	1570	2880	3990		649	1320	1840
3.5	210	1280	2610	3770		522	1200	1750
4.0		1040	2340	3540		415	1080	1650
4.5		835	2070	3290		329	967	1550
5.0		672	1810	3040		262	855	1450
5.5		543	1580	2790			751	1350
6.0		442	1370	2550			656	1250
6.5		363	1180	2310			571	1140
7.0			1020	2090			497	1050
7.5			887	1880			433	954
8.0			770	1690			377	867
8.5			669	1520			329	787
9.0			584	1360				713

Structural Analysis

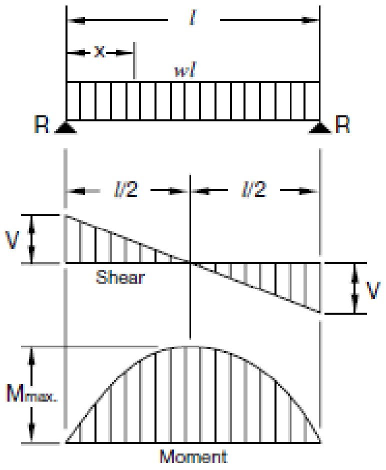
Shear, Bending and deflection Diagrams (WDM Pg 930)

- Often overlooked but most cases are there. Chapter 11 also provides specific guidance to modifying deflection approaches.

Beam Diagrams and Formulae*

Simple Beam

1.
Uniformly distributed load



R = V . . . . = $\frac{wl}{2}$

V_x . . . . = $w\left(\frac{l}{2} - x\right)$

M max. (at center) . . . . = $\frac{wl^2}{8}$

M_x . . . . = $\frac{wx}{2}(l - x)$

Δ max. (at center) . . . . = $\frac{5wl^4}{384EI}$

Δ_x . . . . = $\frac{wx}{24EI}(l^3 - 2lx^2 + x^3)$

Next Module:

Steel Wood Course Hybrid Module 2