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TIMBER ENGINEERING - VSM196

LECTURE 4 –

EWP: PLYWOOD, BOARDS AND PANELS, I-BEAMS

SPRING 2020

Topic

- Engineered Wood Products (EWP):
  - Structural Composite Lumber (SCL), beams, boards and panels, plywood, Cross-laminated timber (CLT) and I-beams
- [DoTS: (2.6) 2.7 and 5.1]

Content

- Introduction (what are EWP?)
- Types used as beams and panels
- Some facts related to properties of common EWP
- Plywood – an specific example of layered board
- Cross-laminated timber (CLT)
- I-beams from different wood-based materials

- Design exercises C2 & C3 (Homework C1)

Intended Learning Outcomes of this lecture

- You understand the benefits of Engineered Wood Production (EWP)
- You can distinguish and describe different EWPs
- You can describe the production of EWPs
- You can determine the stress distribution and capacities of EWPs
- You know the possible failure modes of different EWPs
- You can choose an adequate EWP

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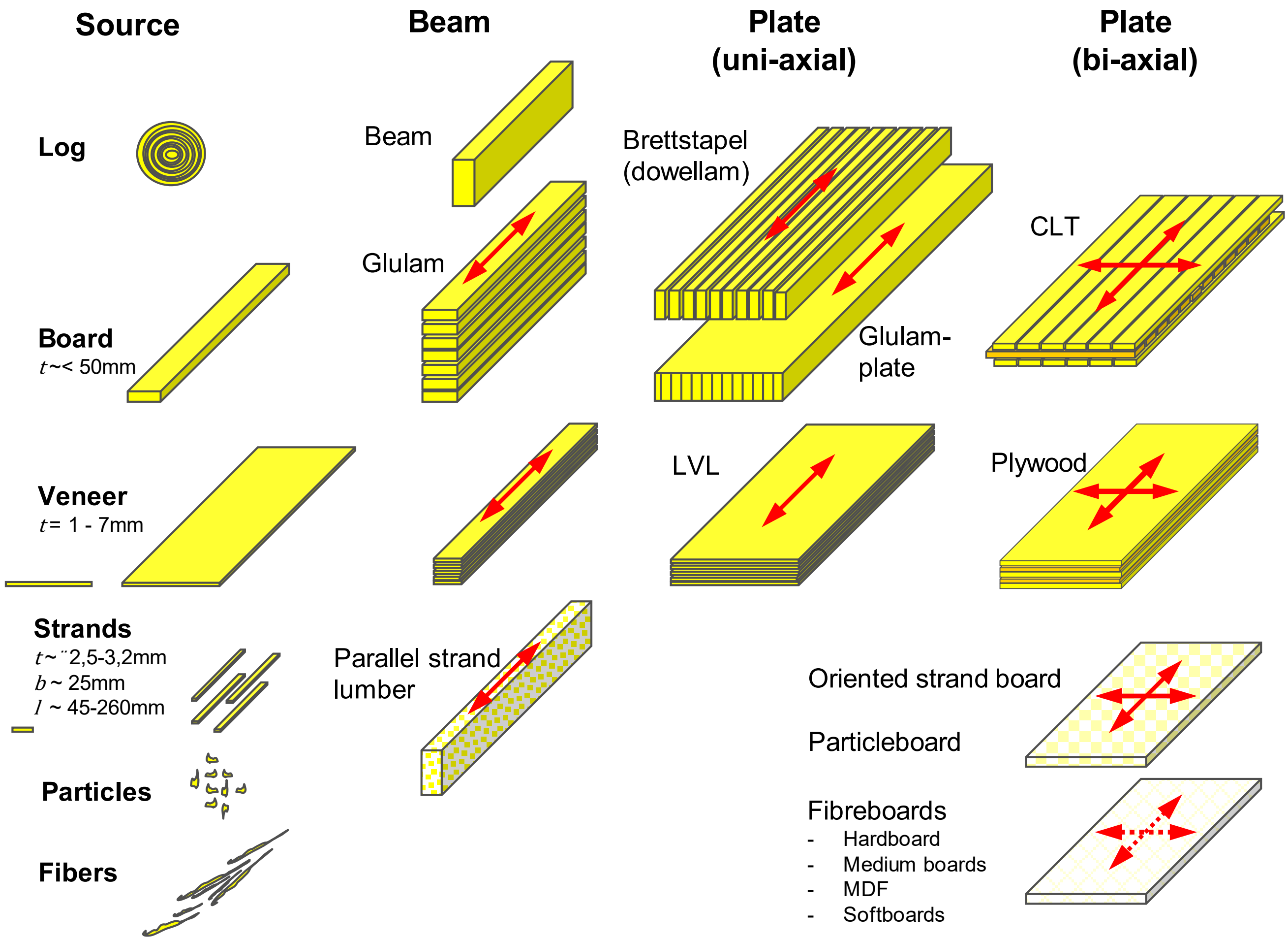
Engineered wood products - EWP

Why EWP? ⇨ to overcome the limitation of sawn timber

- Better use of the raw material
  - Using small dimensional logs
  - Making use of low quality material and residuals
  - Make use of larger portion of the log material
- Overcoming the dimensional limitations
  - Larger sections and length
  - Plates and panels
  - Conversion and size effect
- Improved material properties
  - Overcoming the anisotropy
  - Less variability in properties and removal of defects
  - Higher strength and stiffness
- Higher dimensional stability
  - less shrinkage, less distortion etc.

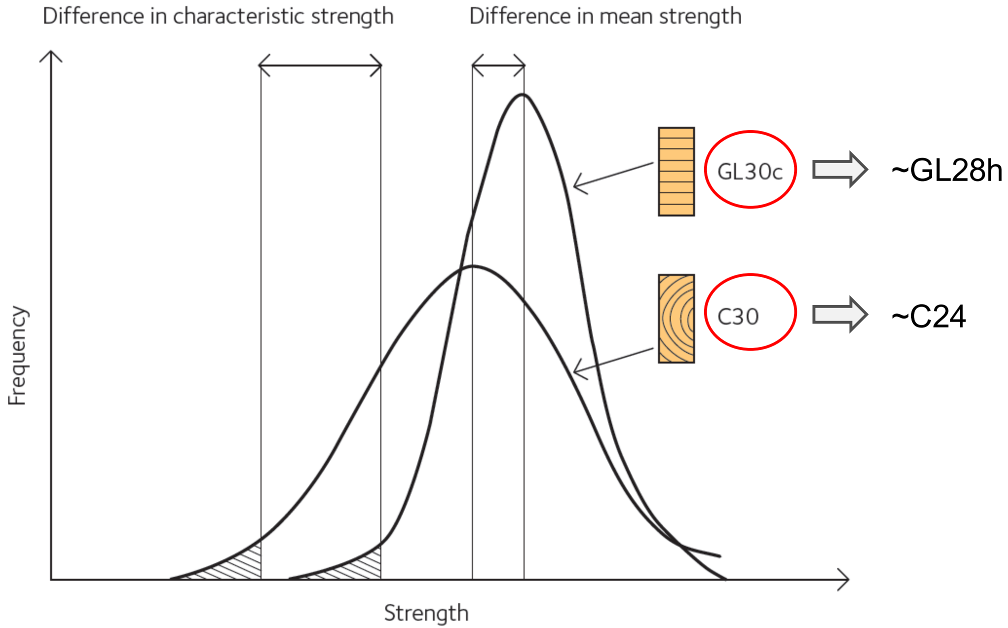

Source
Beam
Plate
(uni-axial)
Plate
(bi-axial)
Log
Beam
Brettstapel
(dowellam)
Glulam
CLT
Board
t~< 50mm
Glulam-
plate
Veneer
t= 1 - 7mm
LVL
Plywood
Strands
t~¨2,5-3,2mm
b ~ 25mm
l ~ 45-260mm
Parallel strand
lumber
Oriented strand board
Particleboard
Particles
Fibreboards
- Hardboard
- Medium boards
- MDF
- Softboards
Fibers

Engineered Wood Products – EWP

- Examples

Less variability

- Figure 2.31 in DoTS is not quite correct!
  The strength class of the solid timber and glulam is not the same!



(DoTS: 2.7.2.1.1), cf. Fig 2.31

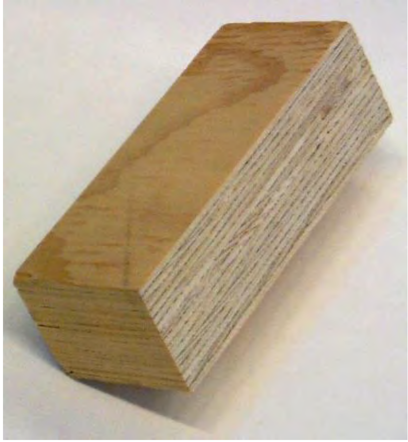
Engineered Wood Products – EWP

Beams, joists, studs

- **Glulam** – Glued Laminated timber
- **LVL** – Laminated Veneer Lumber (Kerto®)
- PSL – Parallel Strand Lumber (Parallam®)
- Intrallam® - combination of LVL & Parallam
- LSL – Long Strand Lumber (Timberstrand®)
- **I-beams** – combinations of different products

Engineering Wood Products (EWP)

Glulam

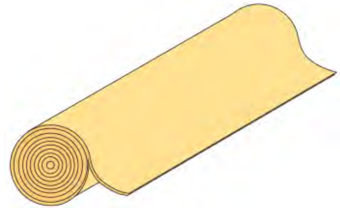


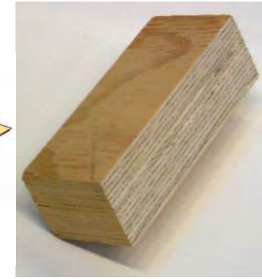
LVL - ”Kerto”

Parallam
- PSL

Laminated Veneer Lumber (Kerto®)

- Made from spruce or pine
- Veneers with normal thickness of 3 mm





- Kerto-S
  - Thickness from 21 to 90 mm
  - All veneers parallel to the grain
  - E_{mean} = 13800 Mpa
- Kerto-Q (Plywood)
  - Thickness from 21 to 69 mm
  - Some veneers are cross-grained
  - E_{mean} = 10000 MPa (for 21-24 mm)

KERTO ® S

KERTO ® Q

Structural Composite Lumber (SCL)

- SCL products (in North America) include:
  - Laminated Veneer Lumber (LVL),
  - Parallel Strand Lumber (PSL) - (Parallam®)
  - Laminated Strand Lumber (LSL) (TimberStrand®) and
  - Oriented Strand Lumber (OSL)

- Used as rafters, headers, beams, joists, rim boards, studs and columns.
- SCL products are also used for wood I-joist flanges and truss chords.

Ref: Stark, Cai and Carll, FPL–GTR–190

Laminated strand lumber (LSL)

- LSL and oriented strand lumber (OSL) products are an extension of the technology used to produce oriented strandboard (OSB) structural panels, early 1990
- Common in US and Canada
- LSL is sold as TimberStrand®
- Small strands
- (waste or from fast-grown trees)
- High density
- Used often as studs (framing)

LSL in wall studs and timber framing

- USA and Canada

SP Technical Research Institute of Sweden

Parallel Strand Lumber (PSL)

- Common in Canada and US
- Establ. ~1986
- Large strands cut from veneers
- High density
- Characteristic surface
- Used for large and small members
- Possible to treat with preservatives due to voids in the structure
- Fire: comparable to sawn timber

Courtesy of Charlotte Bengtsson

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Engineered Wood Products – EWP

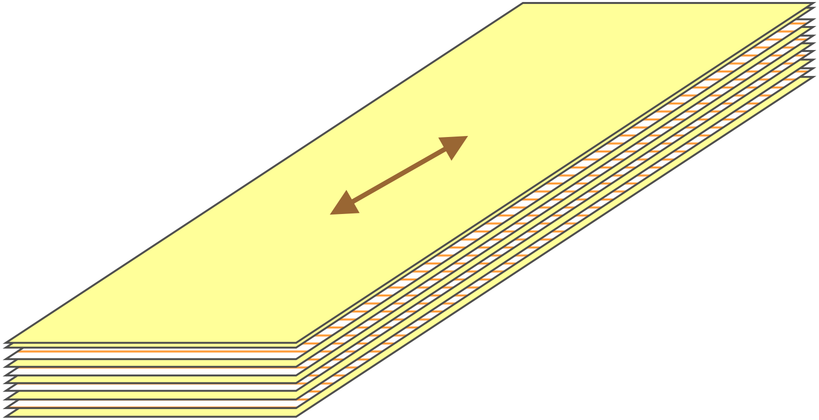
Boards and panels

- **Plywood** – boards of layered plies or veneers
- **OSB** – Oriented Strand Board - boards of large particles known as waferboards or flakeboards
- **Particleboard or chipboard** – heated particles from waste wood, flakes, chips or dust glued under pressure
    - Cement bonded particleboards
- **Fibreboards** – seven different board types of different densities and properties - wet and dry process A11/4

Common fibres are:
shavings, sawdust, fibre,
large particles, wafers, and strands

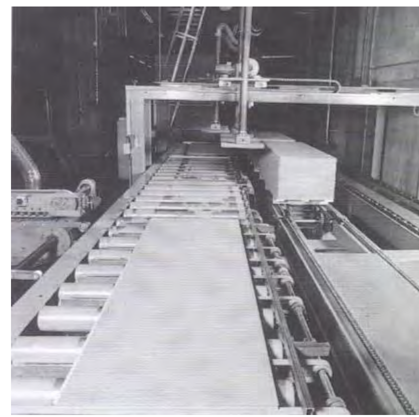
Plywood

- Glued to the odd number of plies or veneers
  - Veneer thickness $t \approx 3mm$



Oriented Strand Board (OSB)

- To replace plywood as panel product
- Flakes (or wafers) from fast-growing hardwood (aspen-poplar in USA, Scots pine in Europe)
- Production:
  - flakes: 50 to 75 mm long and 0.4 to 0.6 mm thick cut tangentially from wood
  - Resin (2-4%) by weight: phenol-formaldehyde and/or MDI (Methane Diphenyl Isocyanate)
  - under heat and pressure to form panels (like chipboards)
  - three orthogonal layers; face layers aligned parallel to the longitudinal axis of the panel, core layer aligned perpendicular to the long axis or randomly deposited (core to face = 60:40)



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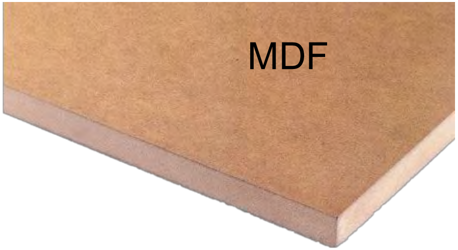
Fibreboard

According to EN 622

- Hardboards (HB)
- Mediumboards (MBL & MBH)
- Softboards (SB)
- MDF (dry process boards)



Fibreboard - differences

Manufacturing process	Board density		
	Low $< 400\ kg/m^3$	Medium $\geq 400\ kg/m^3$, $< 900\ kg/m^3$	High $\geq 900\ kg/m^3$
Wet	Softboard (SB)	Low Density Mediumboard (MBL)	Hardboard (HB)
	Impregnated Softboard (SB.I)	High Density Mediumboard (MBH)	Tempered Hardboard (HB.I)
Dry		Medium Density Fibreboard (MDF)	

Note: Board symbols shown in brackets; I means "with additional properties".

Ref: STEP1-A11, 1995

Dimension stability of timber and panels

- Percentage change in dimension from 65% to 85% RH

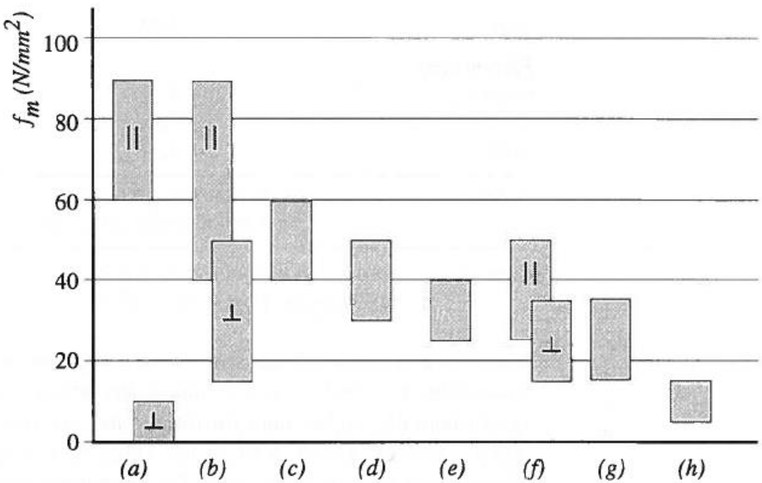
Timber or wood-based panel type	Percentage change in dimension		
	Parallel to grain or board length	Perpendicular to board length	Through thickness
Solid Timber			
Douglas Fir	<0,10	0,80 (R)	1,00 (T)
Beech	<0,10	1,20 (R)	2,00 (T)
Plywood			
Douglas Fir	0,15	0,15	2,00
Chipboard			
Loadbearing dry	0,25	0,25	7,00
Loadbearing humid	0,20	0,20	4,00
Cement Bonded Particleboard	0,18	0,18	0,50
OSB	0,20	0,20	10,00
Fibreboards			
Hardboard	0,15	0,15	3,50
Tempered Hardboard	0,15	0,15	3,50
MDF	0,20	0,20	3,50

Notes: R is radial direction.
T is tangential direction.

Ref: STEP1-A11, 1995

EWP – increased strength properties

- Comparison of bending strengths f_m of sawn timber and wood-based panels



(a) Softwood (b) Softwood Plywood
(c) Tempered Hardboard (d) Hardboard
(e) MDF (f) OSB
(g) Chipboard (h) Cement Bonded Particleboard
$\parallel$ Parallel to grain or strong direction
$\perp$ Perpendicular to grain or weak direction

Ref: STEP1-A11, 1995

EWP – increased creep

- Creep as defined in EC5 with k_{def} factor

$$E_t = \frac{E}{1+\varphi_t} = \frac{E}{1+k_{def}}$$

Material	Service class		
	1	2	3
Timber, glulam, LVL	0,60	0,80	2,00
Plywood	0,80	1,00	2,50
OSB	1,50	2,25	-
Particleboard	2,25	3,00	-
Fibreboard, hard	2,25	3,00	-
Fibreboard, medium	3,00	4,00	-
Fibreboard, MDF	2,25	3,00	-

EC5: Table 3.2

Cross-Laminated Timber (CLT) - sv: korslimmat trä (KL-trä)

Replacement of beams, joists, studs and thin panels

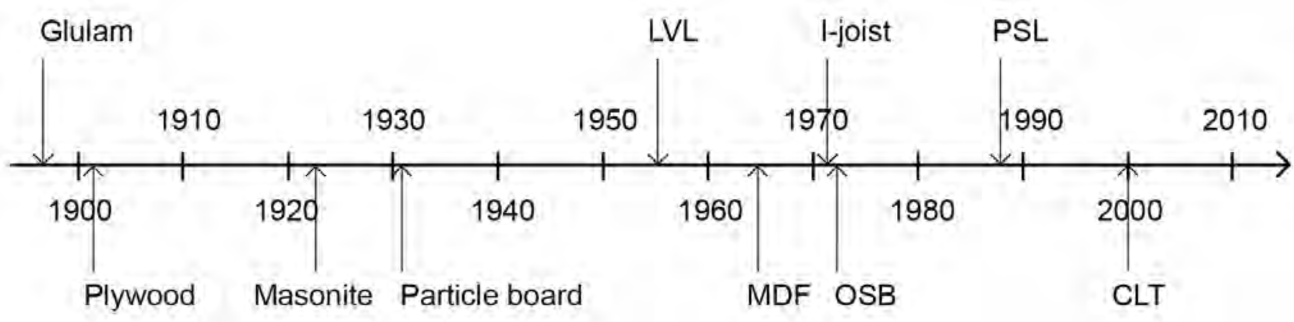
- CLT is also called solid wood panel, X-Lam, XLAM,

- CLT is made from three or more layers of solid-sawn timber that are orthogonally bonded together with structural adhesives to form a solid, straight rectangular-shaped panel

- CLT is becoming increasingly popular as an alternative to conventional structural materials in multi-storey buildings and commercial construction

DoTS, Chapters 2.7.1.2 and 8.1.1.2.

Development and commercial introduction of EWP



- LVL – laminated veneer lumber,
- MDF – medium density fibreboard,
- OSB – oriented strand board,
- PSL – parallel strand lumber,
- CLT – cross laminated timber

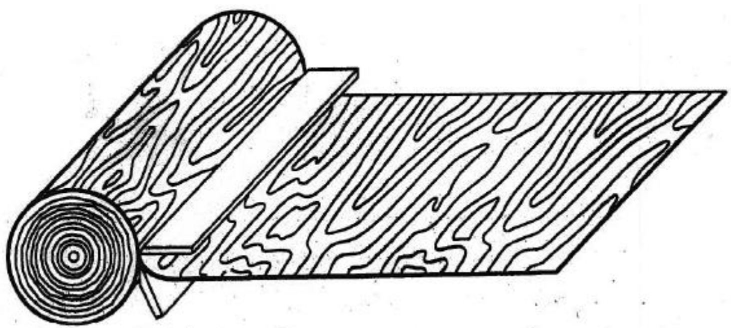
(DoTS: 2.7)

Rehearsal question

- **A8**
  - Name three most common (in Sweden and Europe) engineered wood-based products used for load-bearing purposes and what are they made up of?
  - What are the most important properties do they have that make them preferable to the solid timber in many situations?
  - What is the main difference between LVL Kerto Q and Kerto S? How are they commonly used?

Plywood

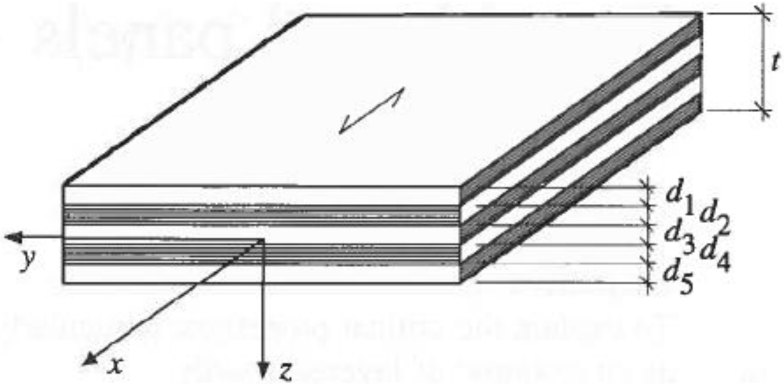
- Wood in thin layers, known as plies or veneers
- Production of an ”endless” ply ribbon by rotary peeling



- Unwinding of a log to obtain a wooden ribbon of about 2 mm to 4 mm thickness
- Dried and bonded with an angle of 90° between the grain direction in adjacent layers

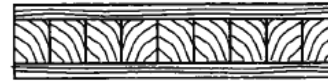
(DoTS: 2.7.2.2)

5 layers cross-section

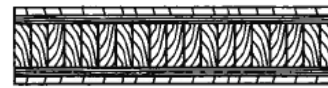


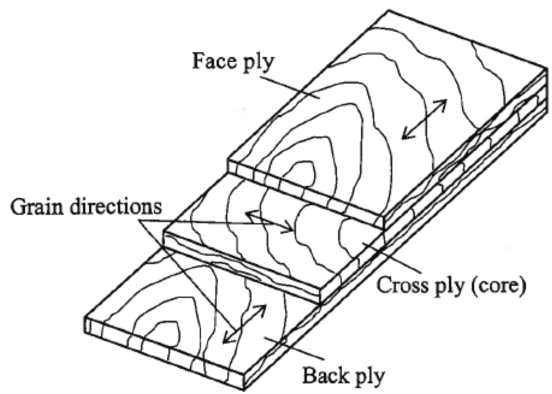
- grain direction of the face veneer
- d_i thickness of each veneer


(b) Five-ply plywood


(c) Three-ply blockboard


(d) Five-ply blockboard


(e) Laminboard



(a) The structure of a three-ply plywood

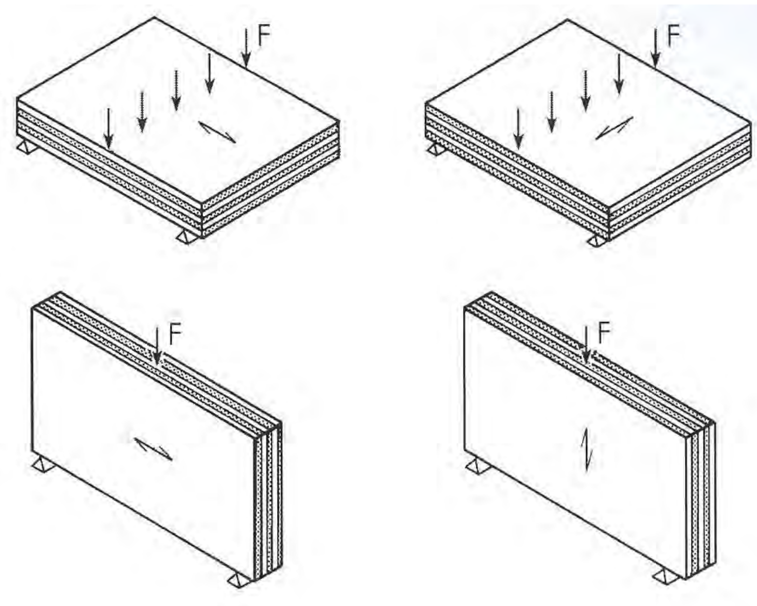
Plywood – structural properties

Affected by the following parameters:

- Geometrical factors (no. of veneers, composition)
- Material factors (wood species, moisture content)
- Load factors (type of stresses, direction of stress related to the grain direction of the face veneer, load duration)

Plywood – axes of bending

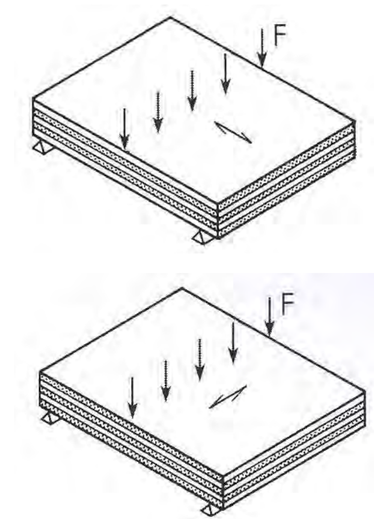
- Bending about an axis in the plane of the board
- Bending about an axis perp. to the plane of the board



Plywood in bending - bending perpendicular to the plane

- Stiffness in dependency of the orientation:
  a) Parallel to the grain of face veneer
  b) Perpendicular to the grain of face veneer

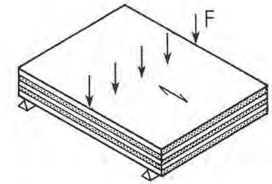
$\Rightarrow$ $EI = \sum E_i I_i$



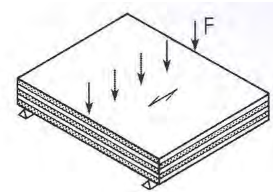
(DoTS: 2.7.2.2)

Bending perpendicular to the plane

$E_{\parallel}$



$E_{\perp}$



- Difference in stiffness between $E_{\parallel}$ and $E_{\perp}$
- Examples with 5 veneers:
- Assume: $E_{90,mean} = 0$ for the layers
- $E_{0,mean} = E_0$ and $b = 1$ gives
  - for σ_m parallel to grain of face veneer
  - $E_{\parallel} I = E_0 \left(3 \frac{d^3}{12} + 2d(2d)^2 \right) = 33 \frac{E_0 d^3}{4}$
  - for σ_m perpendicular to grain of face veneer
  - $E_{\perp} I = E_0 \left(2 \frac{d^3}{12} + 2d\, d^2 \right) = 13 \frac{E_0 d^3}{6}$

$$E_{\parallel} = \frac{33 E_0 d^3 12}{4 \cdot (5d)^3} = 0{,}79 E_0$$

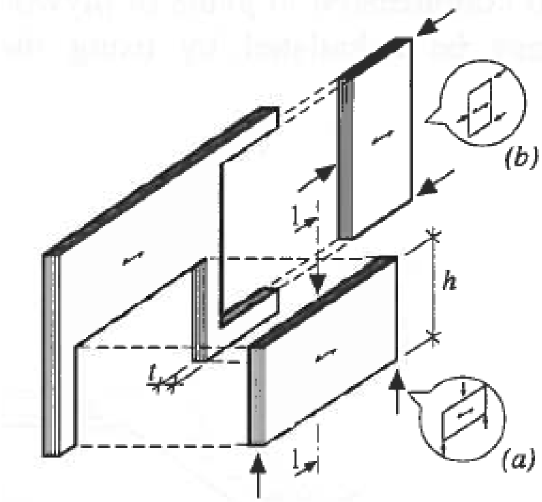
$$E_{\perp} = \frac{13 E_0 d^3 12}{6 \cdot (5d)^3} = 0{,}21 E_0$$

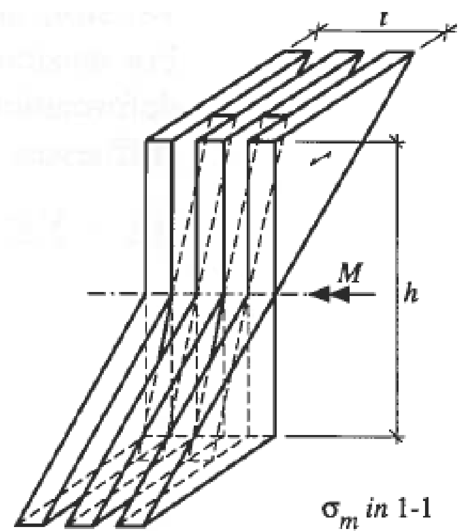
- $E_{90,mean}$ is taken as $\frac{1}{30} E_{0,mean}$, as would be typical for softwood veneers, the improvements in moduli are:
  - $E_{\parallel} = 0{,}80 E_0$ for $\sigma_m \parallel$ grain of face veneer
  - $E_{\perp} = 0{,}24 E_0$ for $\sigma_m \perp$ grain of face veneer

Ref: STEP1-A10, 1995

Plywood - in plane bending

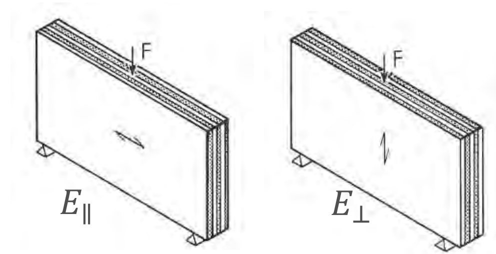
- Orientation:
  a) Parallel to the grain of face veneer
  b) Perpendicular to the grain of face veneer





(DoTS: 2.7.2.2)
Ref: STEP1-A10, 1995

Plywood - in plane bending



- Difference in stiffness between $E_{\parallel}$ and $E_{\perp}$
- Examples with 5 veneers:
- Assume: $E_{90,mean} = 0$ for the layers
- $E_{0,mean} = E_0$ and $b = 1$ gives
  - $E_{\parallel} I = 3\frac{dh^3}{12}E_0$ for σ_m ∥ grain of face veneer
  - $E_{\perp} I = 2\frac{dh^3}{12}E_0$ for σ_m ⊥ grain of face veneer

$$E_{\parallel} = \frac{dh^3 E_0 12}{4 \cdot 5dh^3} = 0{,}60E_0$$

$$E_{\perp} = \frac{dh^3 E_0 12}{6 \cdot 5dh^3} = 0{,}40E_0$$

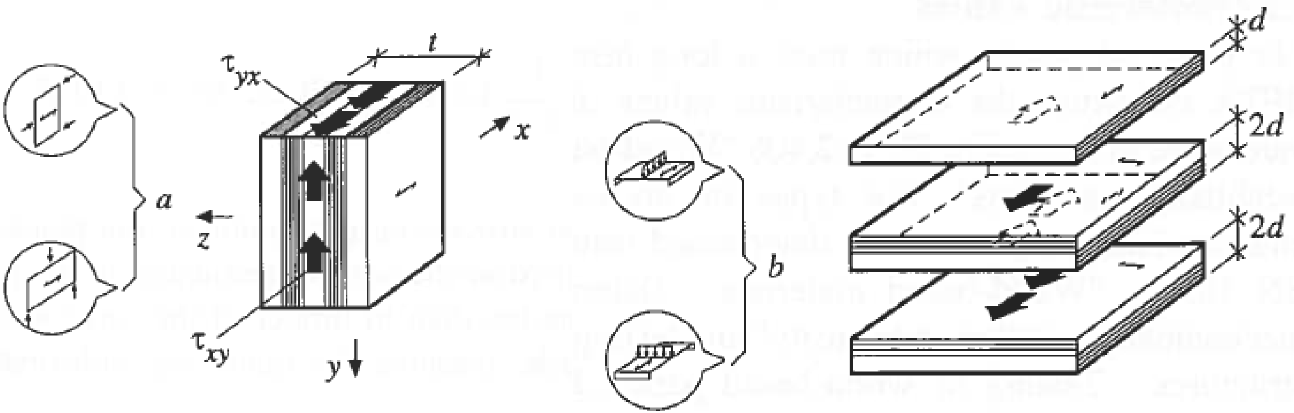
- If $E_{90,mean} = \frac{1}{30}E_{0,mean}$
  - $E_{\parallel} = 0{,}61E_0$ for σ_m ∥ grain of face veneer
  - $E_{\perp} = 0{,}41E_0$ for σ_m ⊥ grain of face veneer

Ref: STEP1-A10, 1995

Plywood – in shear

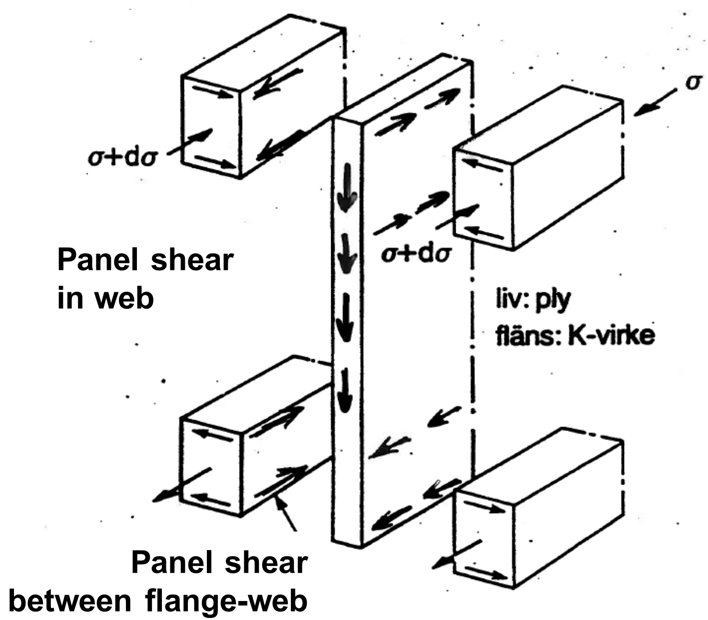
a) panel shear

b) planar (rolling) shear



Ref: STEP1-A10, 1995

Panel & rolling (planar) shear in an I-beam

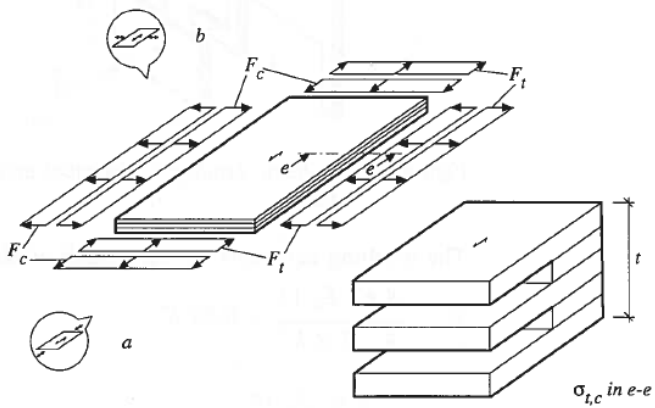


Plywood – tension and compression

a) parallel

b) perpendicular to the grain of the face veneer

$EA = \sum E_i A_i$

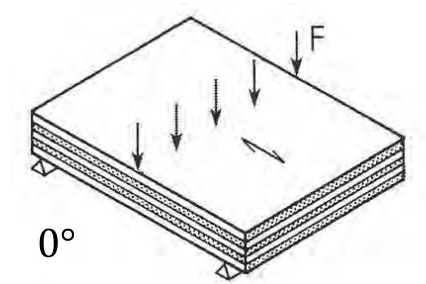


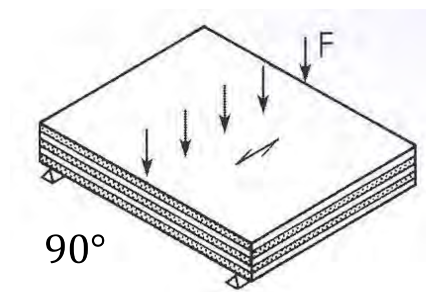
- $E_{\parallel} = \frac{1}{5d}(3dE_0 + 2d \cdot 0) = 0{,}60E_0$ for σ_m ∥ grain of face veneer
- $E_{\perp} = \frac{1}{5d}(2dE_0 + 3d \cdot 0) = 0{,}40E_0$ for $\sigma_m \perp$ grain of face veneer

Ref: STEP1-A10, 1995

Plywood – general classification

- Strength and stiffness in bending parallel and perpendicular to the grain of face veneer





- Example:
  - F 50/25 E70/25

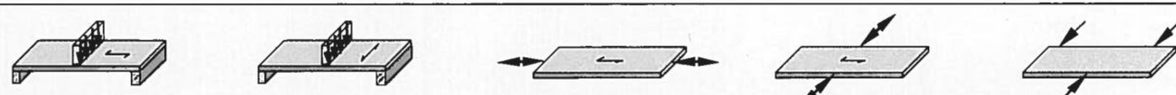
$$f_{m,0,k} = 50N/mm^2$$
$$f_{m,90,k} = 25N/mm^2$$
$$E_{m,0,mean} = 7000N/mm^2$$
$$E_{m,90,mean} = 2500N/mm^2$$

Plywood – special grades

Table 1.7 Strength and stiffness properties and density values of selected American and Swedish structural plywoods

Section properties		Characteristic strength (N/mm²)								Density (kg/m³)		Mean modulus of rigidity (N/mm²)	Mean modulus of elasticity (N/mm²)			
		Bending		Compression		Tension		Panel shear	Planar (rolling) shear	Characteristic	Mean	Panel shear	Bending		Tension and compression	
Plywood type	Nominal thickness (mm)	$f_{m,0,k}$	$f_{m,90,k}$	$f_{c,0,k}$	$f_{c,90,k}$	$f_{t,0,k}$	$f_{t,90,k}$	$f_{v,k}$	$f_{r,k}$	ρ_k	ρ_{mean}	$G_{v,mean}$	$E_{m,0,mean}$	$E_{m,90,mean}$	$E_{t/c,0,mean}$	$E_{t/c,90,mean}$
American plywood	12.5	23.5	12.2	13.9	8.1	13.6	7.2	3.2	0.9	410	460	500	10300	2500	6800	4600
Grade: C-D	21	14.8	10.1	10.6	7.7	10.5	6.9	3.2	0.9	410	460	500	7800	2500	5200	3900
Exposure 1 (CDX)																
Swedish plywood	12	23.0	11.4	15.0	12.0	15.0	12.0	2.9	0.9	410	460	500	9200	4600	7200	4800
Grade: P30	24	21.6	12.4	15.4	11.4	15.4	11.4	2.9	0.9	410	460	500	8700	5000	7400	4600

Note: 1. Characteristic value of modulus of elasticity, $E_{i,k} = 0.8 \times E_{i,mean}$.
2. Number of plies ≥ 5.



Bending parallel to grain: $f_{m,0,k}$ and $E_{m,0,mean}$
Planar shear: $f_{r,0,k}$

Bending perpendicular to grain: $f_{m,90,k}$ and $E_{m,90,mean}$
Planar shear: $f_{r,90,k}$

Tension or compression parallel to grain: $f_{t,0,k}$, $f_{c,0,k}$ and $E_{t,0,mean}$, $E_{c,0,mean}$

Tension or compression perpendicular to grain: $f_{t,90,k}$, $f_{c,90,k}$ and $E_{t,90,mean}$, $E_{c,90,mean}$

Panel shear: $f_{v,k}$

Product specific properties of Kerto-S and Kerto-Q

Property	Kerto-S Thickness 21–90 mm	Kerto-Q Thickness 21–24 mm	Kerto-Q Thickness 27–69 mm
Strength values			
Bending edgewise $f_{m,0,edge,k}$	44	28	32
– Size effect parameter s	0,12	0,12	0,12
Bending flatwise, parallel to grain $f_{m,0,flat,k}$ (thickness 21–90 mm)	50	32	36
Bending flatwise, perpendicular to grain $f_{m,90,flat,k}$	-	8,0 [2)]	8,0
Tension parallel to grain $f_{t,0,k}$	35	19	26
Tension edgewise, perpendicular to grain $f_{t,90,edge,k}$	0,8	6,0	6,0
Tension flatwise, perpendicular to grain $f_{t,90,flat,k}$	-	-	-
Compression parallel to grain $f_{c,0,k}$	35	19	26
Compression edgewise, perpendicular to grain $f_{c,90,edge,k}$	6	9	9
Compression flatwise, perpendicular to grain $f_{c,90,flat,k}$	1,8	2,2	2,2
Shear edgewise $f_{v,0,edge,k}$	4,1	4,5	4,5
Shear flatwise, parallel to grain $f_{v,0,flat,k}$	2,3	1,3	1,3
Shear flatwise, perpendicular to grain $f_{v,90,flat,k}$	-	0,6	0,6

Swedish Wood

Product specific properties of Kerto-S and Kerto-Q

Property	Kerto-S Thickness 21–90 mm	Kerto-Q Thickness 21–24 mm	Kerto-Q Thickness 27–69 mm
Stiffness values for capacity analysis			
Elastic modulus			
– parallel to grain, along $E_{0,k}$	11 600	8 300	8 800
– parallel to grain, across $E_{90,k}$	–	1 000 [2)]	1 700
– edgewise, perpendicular to grain $E_{90,edge,k}$	350	2 000	2 000
– flatwise, perpendicular to grain $E_{90,flat,k}$	100	100	100
Shear modulus			
– edgewise $G_{0,edge,k}$	400	400	400
– flatwise, parallel to grain $G_{0,flat,k}$	400	60	100
– flatwise, perpendicular to grain $G_{90,flat,k}$	–	16	16
Stiffness values for deformation calculations, mean values			
Elastic modulus			
– parallel to grain, along $E_{0,mean}$	13 800	10 000	10 500
– parallel to grain, across $E_{90,mean}$	–	1 200 [2)]	2 000
– edgewise, perpendicular to grain $E_{90,edge,mean}$	430	2 400	2 400
– flatwise, perpendicular to grain $E_{90,flat,mean}$	130	130	130
Shear modulus			
– edgewise $G_{0,edge,mean}$	600	600	600
– flatwise, parallel to grain $G_{0,flat,mean}$	600	60	120
– flatwise, perpendicular to grain $G_{90,flat,mean}$	–	22	22
Density			
Density ρ_k	480	480	480
Density ρ_{mean}	510	510	510

Swedish Wood

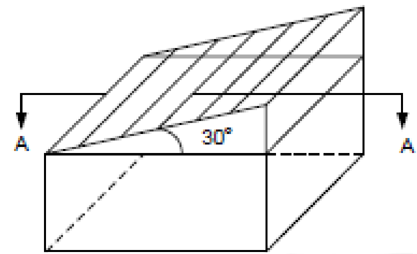
Rehearsal questions

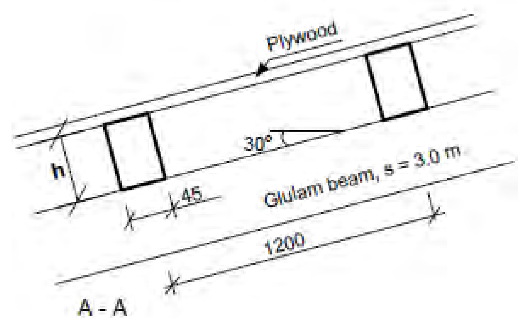
- **A6.** In which case (a) or (b) is the modulus of elasticity of plywood $E_{\parallel}$ (outer ply parallel to main plate direction) with the same number of veneers larger and why? Derive the values for 5 plies plywood.
  a) Bending perpendicular to the plate
  b) In-plane bending

- **A7.** In which case (a) or (b) is the modulus of elasticity of plywood $E_{\perp}$ (outer ply perpendicular to main plate direction) with the same number of veneers larger and why? Derive the values for 5 plies plywood.
  a) Bending perpendicular to the plate
  b) In-plane bending

Example C3 Roof cover made of plywood

- Design (ULS) the plywood cladding (in the central part of the building) for the load combination of wind and snow load, with *snow as the main load*. Plywood panels (12 x 1200 x 2400 mm) is a continuous panel with tongued-and-grooved joints between the panels.
- Location Göteborg
- Primary beams - spacing 3m, purlins - spacing 1.2m
- Roof angle 30º.
- Service class 2
- Design snow load: 0.58 kN/m² ($\psi_0 = 0,7$)
- design wind load: 0.25 kN/m² ($\psi_0 = 0,3$)
- Roof cover 0.1 kN/m²
- Self-weight of the purlin: 0.03 kN/m



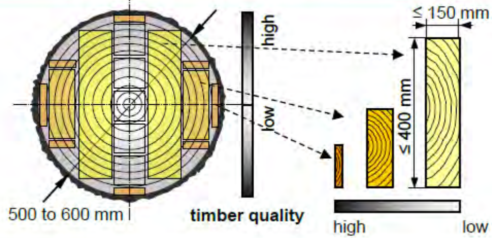


Cross-laminated timber (CLT)

Cross Laminated Timber (CLT) – Production

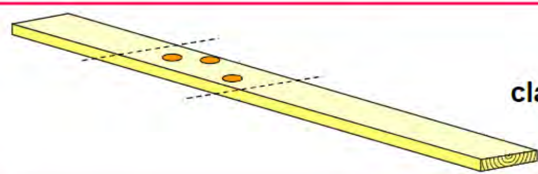
STEPs | **intermediate products | steps in production**

STEP I
log



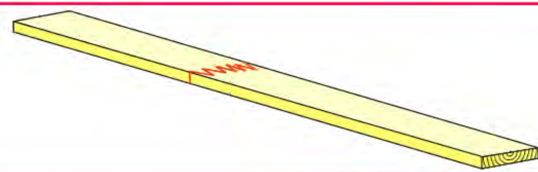
breakdown

STEP II
board



classification / grading
trimming

STEP III
finger jointed
lamella



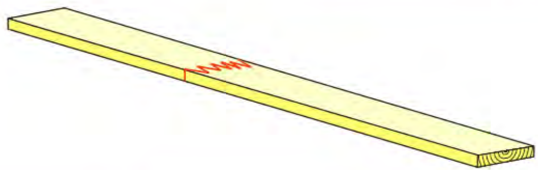
finger jointing

Courtesy of R. Brandner & G. Schickhofer

Cross Laminated Timber (CLT) – Production

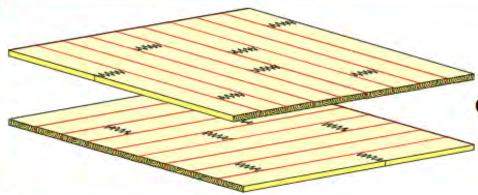
STEPs | **intermediate products | steps in production**

STEP III
finger jointed lamella



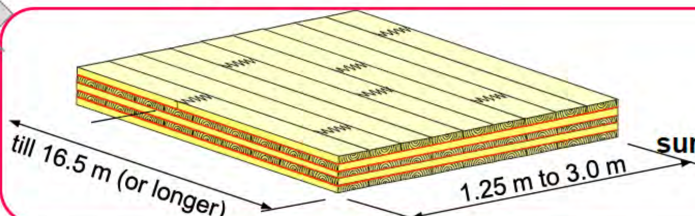
finger jointing

intermediate STEP
single-layer panel



edge bonding

STEP IV
cross laminated timber (CLT)



surface bonding

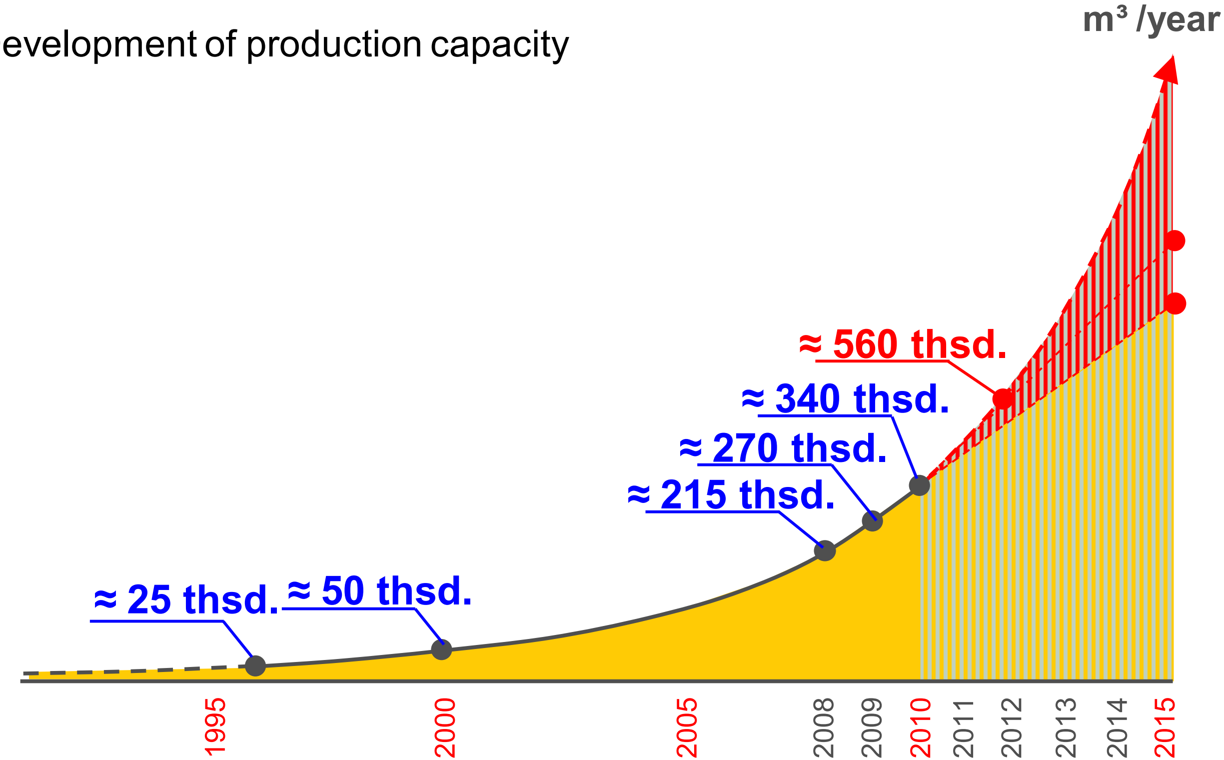
Courtesy of R. Brandner & G. Schickhofer

Cross-Laminated Timber (CLT)

- Late 90's: first products in Austria and Germany
- Developed in Austria (Technical University of Graz)
- 1998: first austrian product certification
- Layer of structural materials are glued crossed to each other
- Same glued adopted for glulam (PRF, MUF, PUR)
- Structural optimisation is possible

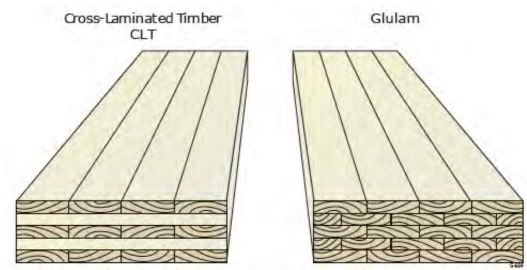
Cross-Laminated Timber (CLT)

- Development of production capacity

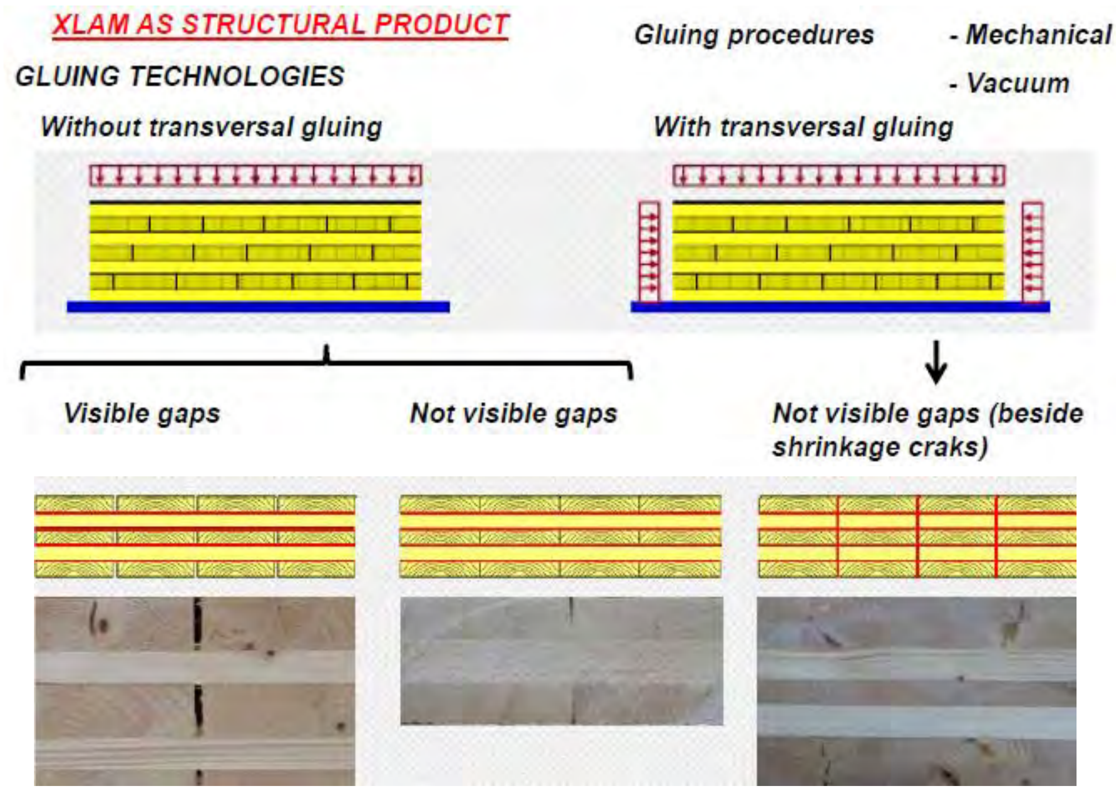


Modern production of CLT, cf. glulam

- Kiln-dry boards to 12% MC (but range 8 to 15% ±2%)
- Strength grading (tensile strength ex. T14),
- Finger jointing lamellas tB (boards)
  - Thickness $t_B = $ (12 to 45 mm)
  - Width $w_B = $ (40 to 300 mm)
  - $w_B/t_B > 4$, due to rolling shear stresses between the layers
- Four-side planing
- Surface bonding
  - (bond line thickness of the gluline is within 0.1 to 0.3 mm)



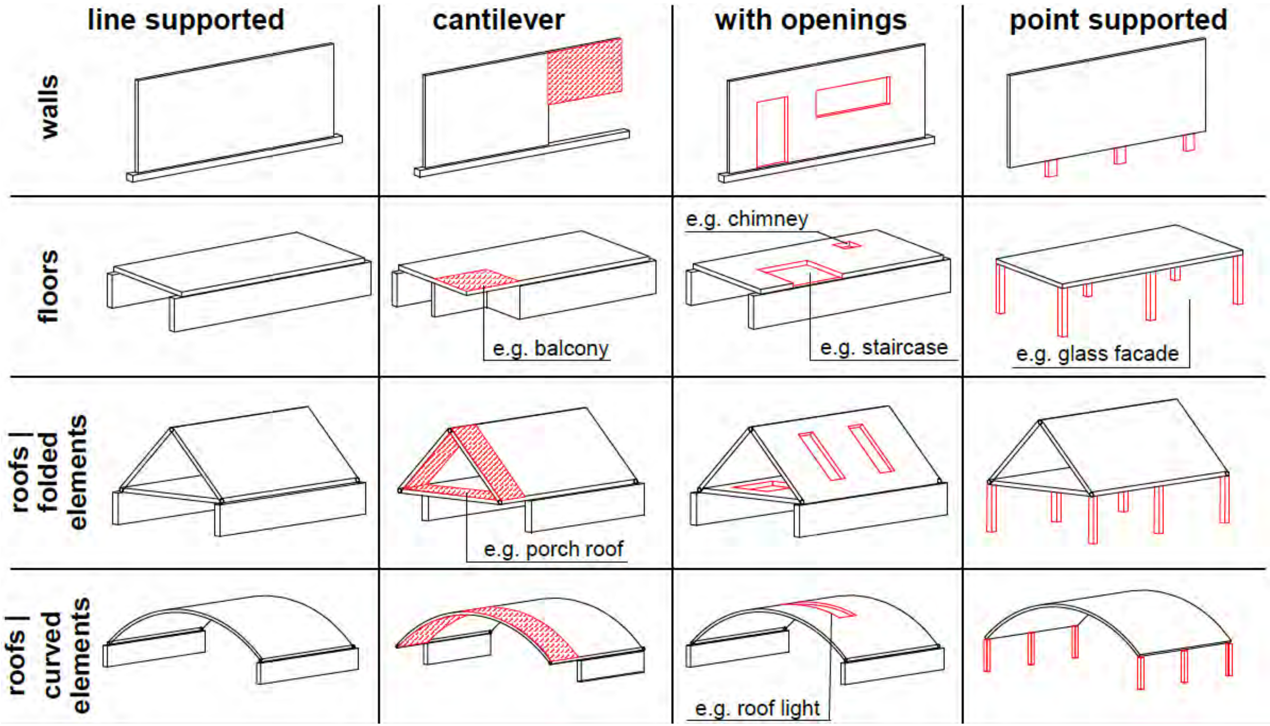
Cross-Laminated Timber (CLT)



Courtesy of Roberto Tomasi

Cross-Laminated Timber (CLT)

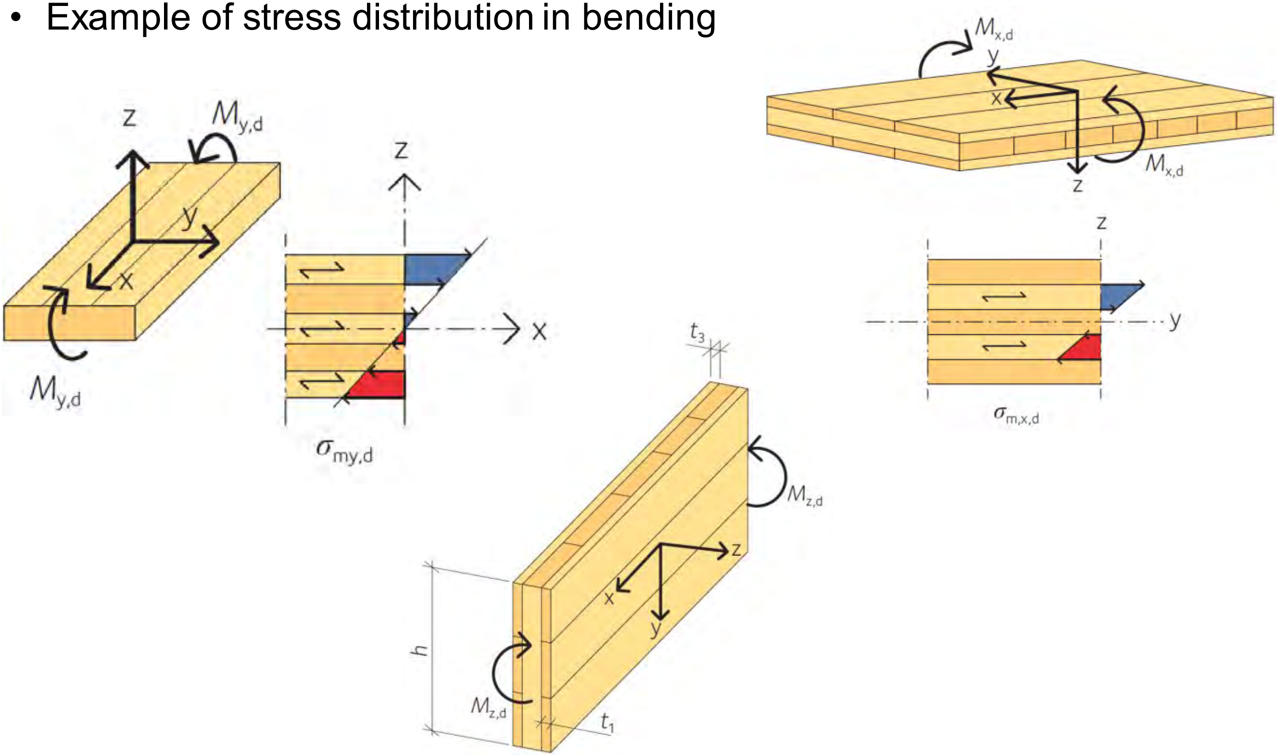
- Examples of application



Schickhofer G (2012) Presentation, Edinburgh, Scotland, 30th October 2012; adapted

Cross-Laminated-Timber – CLT

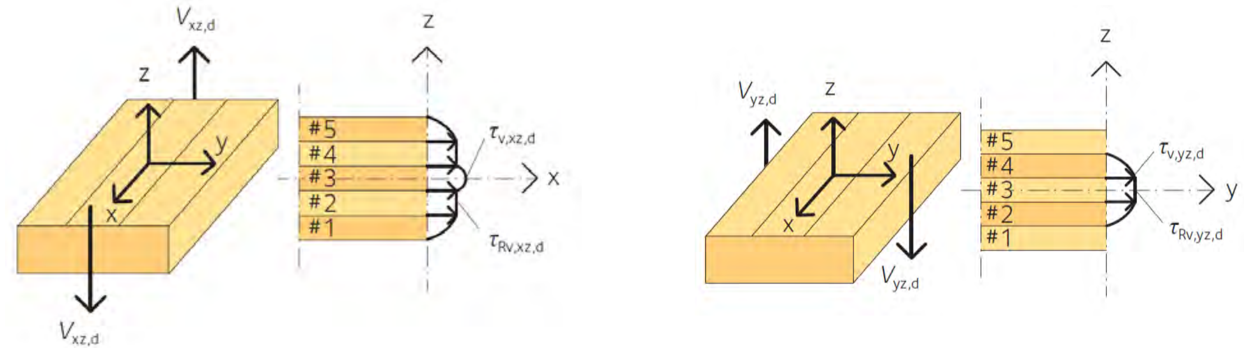
- Example of stress distribution in bending



Swedish Wood

Cross-Laminated-Timber – CLT

- Example of stress distribution in shear

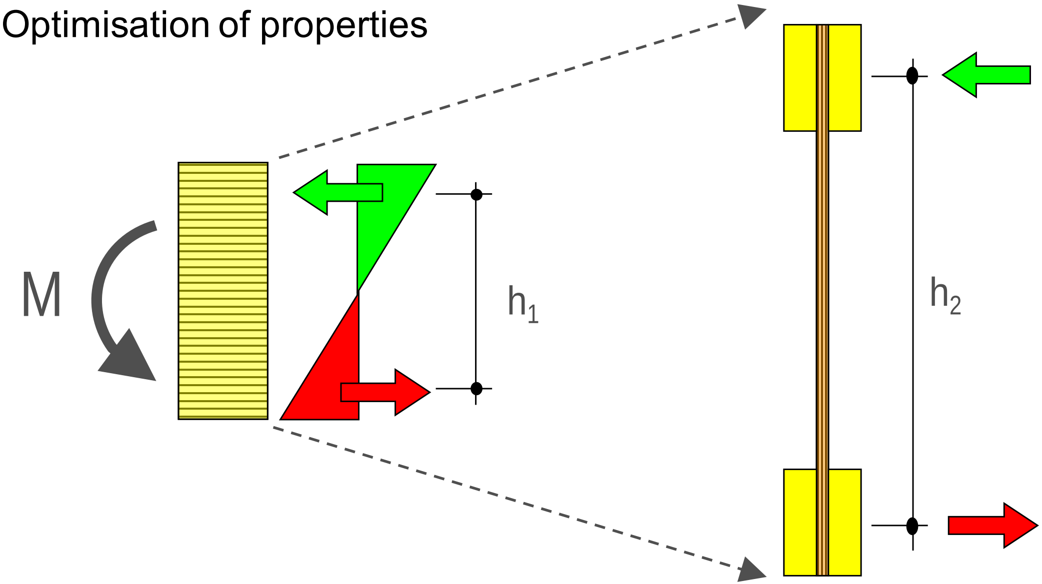


Swedish Wood

I-beams and box beams

Concept

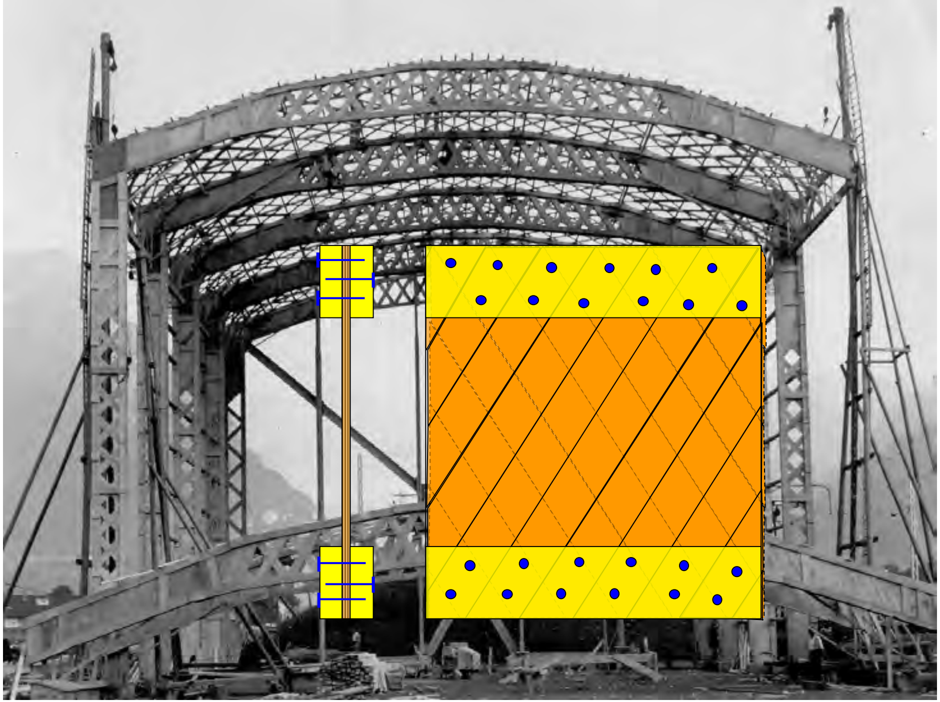
- Optimisation of properties



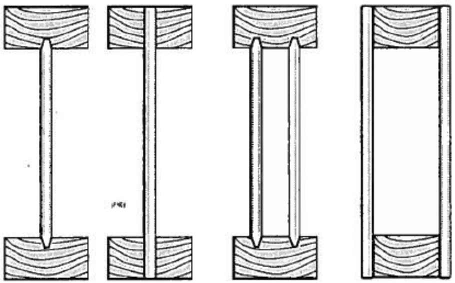
Efficient material use ⟷ higher production costs

Example

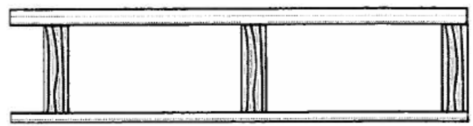
- Nailed trusses of a storage buidling Dätwyler Altdorf, Switzerland 1954
- Span 22.5m,
- Crane attached to trusses



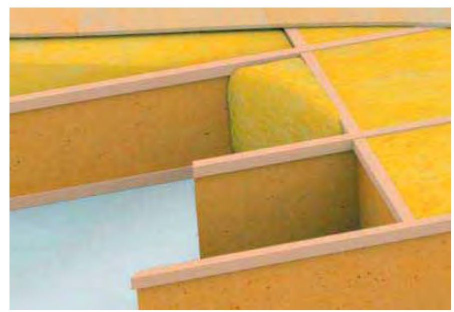
Glued thin-webbed I-beams, box beams and SSP



(a) I-beams (b) Double I-beam (c) Box beam

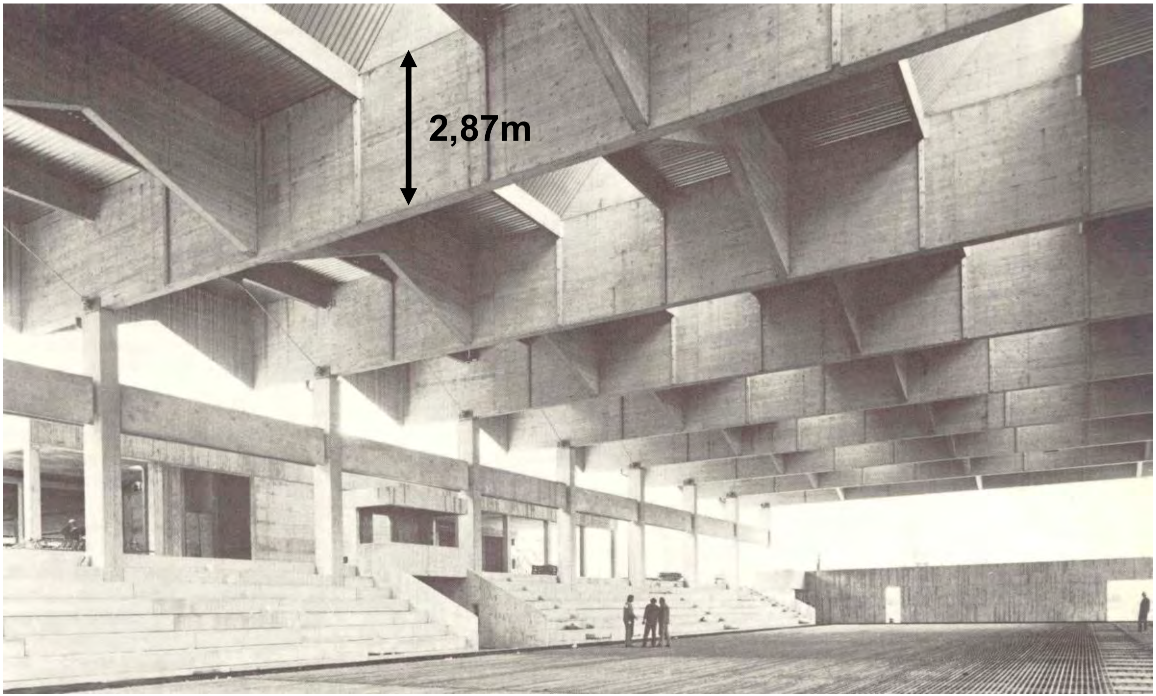


(d) Glued thin flanged beam



Examples

- Boxbeams



Examples

- Large I-beams

Examples

- I-beams with steel web

I-joists – manufacture

- Strength grading of timber (flange)
- Fingerjointing to desired length (flange)
- Cutting of groove (flange)
- Jointing and cutting of tongue for the webmaterial
- Jointing of flanges and web to a beam

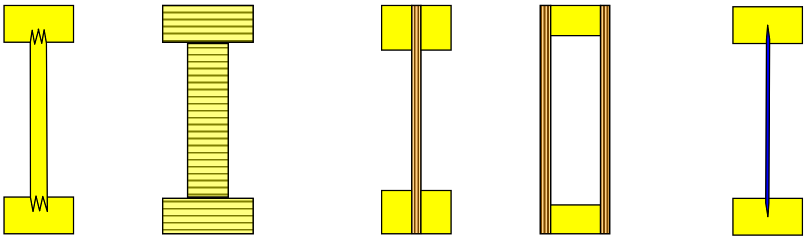
Masonite beam ®

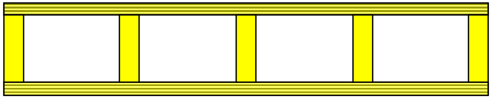
- Manufacturing varies between mills
  - Strength grading
  - Orientation of the flange

Courtesy of Charlotte Bengtsson

Glued thin-webbed I-beams and box beams – Performance

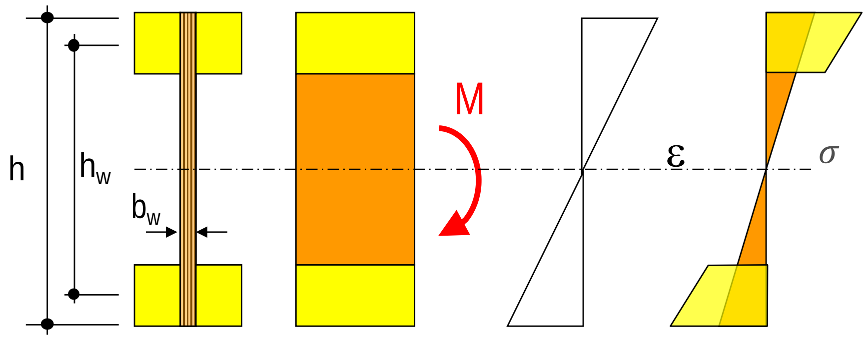
- The flanges carry the stresses caused by bending moment and axial forces
- The web (or webs) carry the stresses from shear forces
- They have a high load-carrying capacity and stiffness compared with their weight
- The dimensions of I-sections are often determined by the need for insulation and its thickness





Members with full composite action

- What is full composite action?
  - When strain compatibility applies

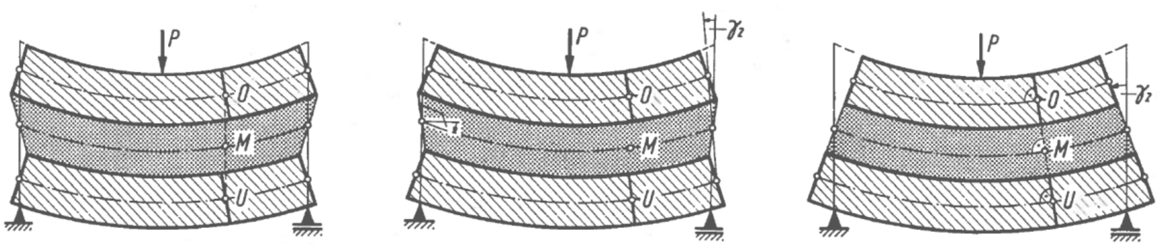


- Examples of members with full composite action
  - I- beams
  - Hollow section beams
  - Stress-skinned panels (SSP)

Conditions for composite action

- When a glued joint is used and the thickness of the glue line is small then full composite action can be assumed

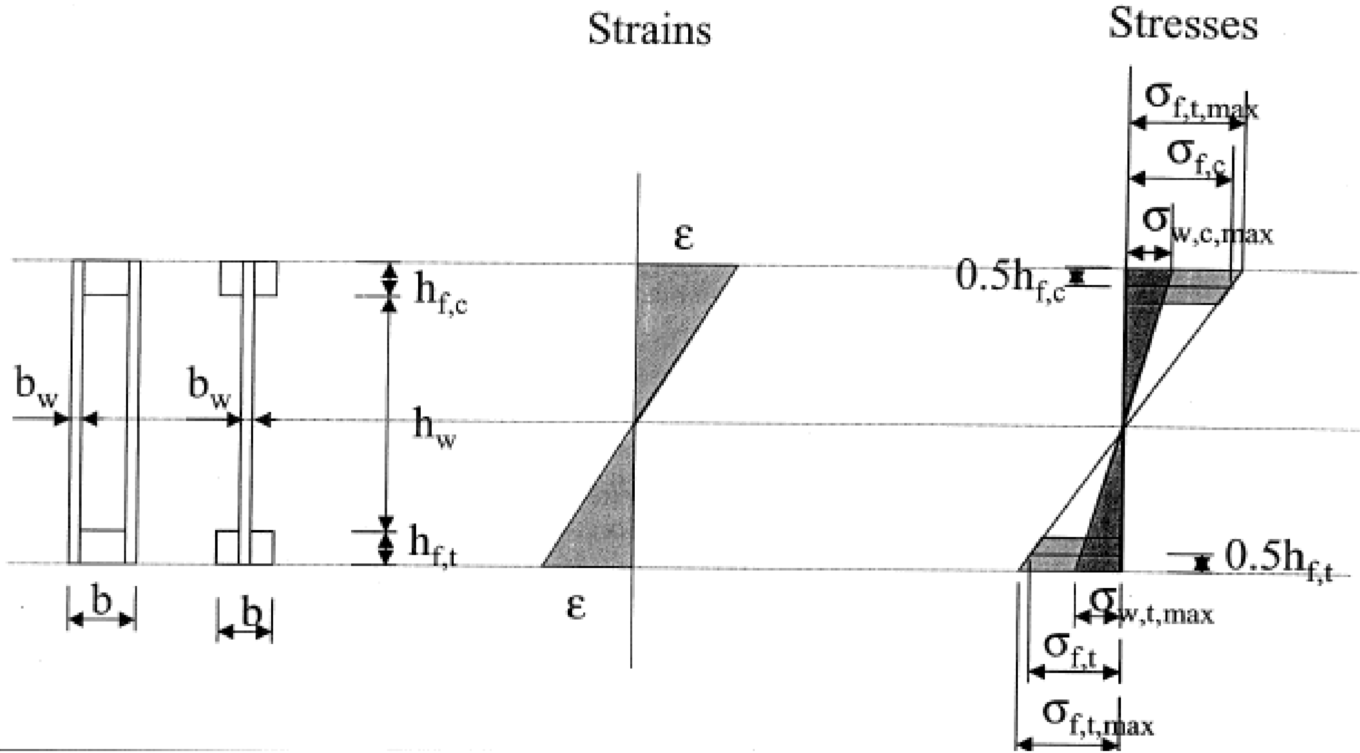
- When the connection is made by mechanical fasteners and/or a thick glue line, partial composite action should be assumed



[DoTS, Ch 5.2]

Stress distribution

- Linear strain distribution + different MOE => different stresses



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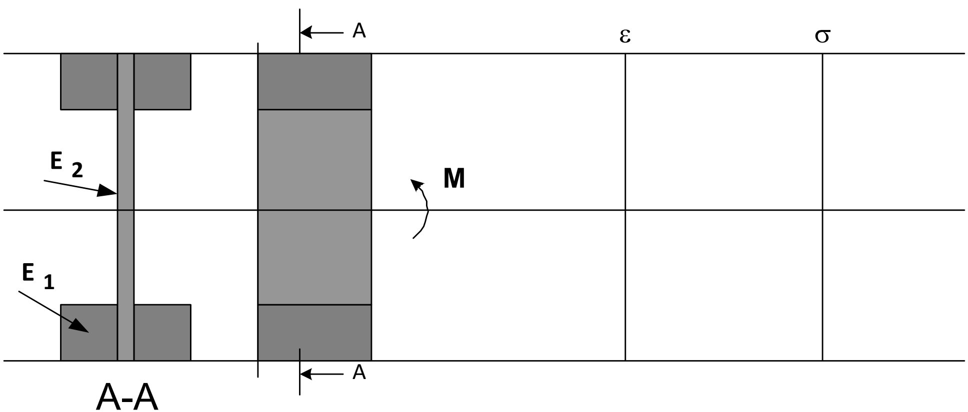
Rehearsal question

- Describe (draw) the stress and strain distribution over
- the cross-section for the glued thin-webbed I-beam.
- Complete interaction between the flanges and the web is assumed. The MOE varies for different component parts,
  - a) $E_1 = 2E_2$
  - b) $E_1 = 3E_2$



Rehearsal question

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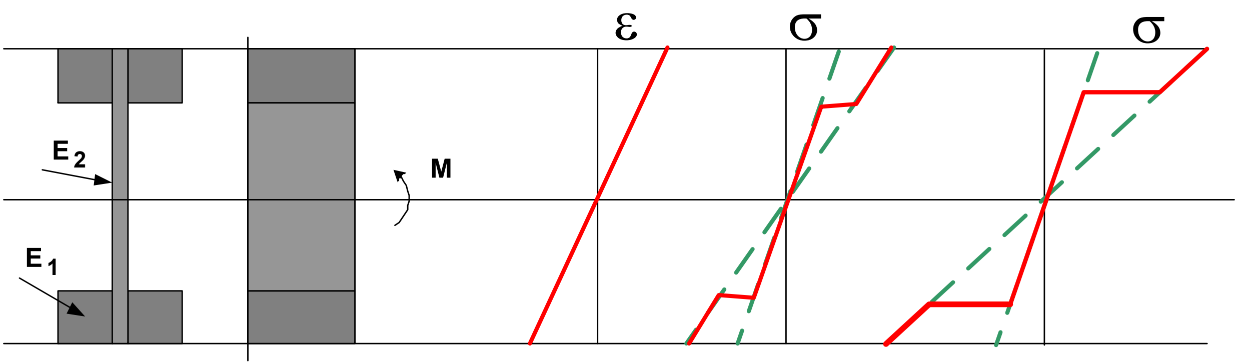
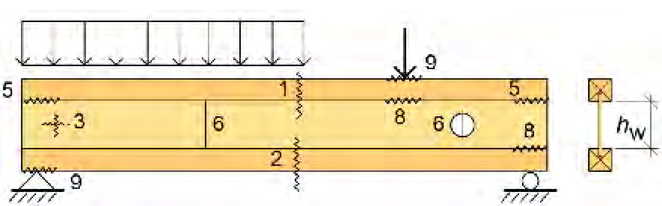
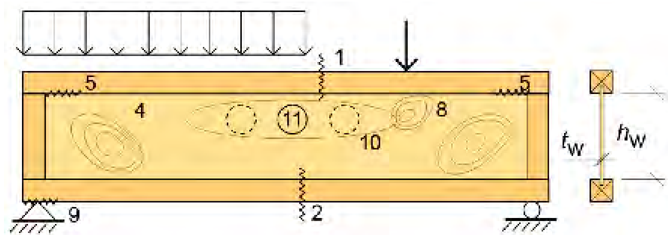


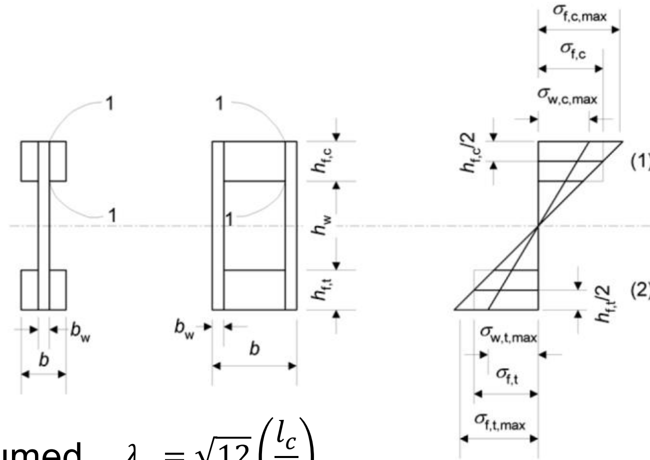
Possible failure modes and positions of failure

1. Compression failure of the compression flange
2. Tension failure of the tension flange
3. Shear failure of the web panel
4. Shear buckling failure of the web panel
5. Shear failure of the flange-to-web interface
6. Shear failure of open web panel joints and web panels with holes
7. Buckling failure due to axial loading, not shown in Figure
8. Patch loading failure, i.e. concentrated loading acting perpendicular to the flanges
9. Compression failure of the outer flange surfaces caused by concentrated forces acting perpendicular to the grain
10. Overall web buckling failure
11. Local web buckling caused by bending moments and/or axial force





Verification of I-beams



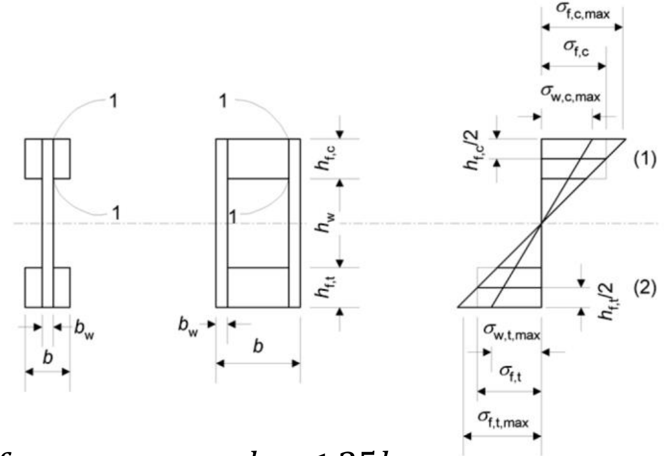
For linear strain distribution

- Flanges should satisfy
  - $\sigma_{f,c,max,d} \leq f_{m,d}$
  - $\sigma_{f,t,max,d} \leq f_{m,d}$
  - $\sigma_{f,c,d} \leq k_c \cdot f_{c,0,d}$ it may be assumed $\lambda_c = \sqrt{12}\left(\frac{l_c}{b}\right)$
  - $\sigma_{f,t,d} \leq f_{t,0,d}$

where l_c distance between lateral bracing of flange

- The web should satisfy
  - $\sigma_{w,c,d} \leq f_{c,w,d}$
  - $\sigma_{w,t,d} \leq f_{t,w,d}$

Verification of I-beams



For linear strain distribution

- Shear stresses in the web:
  - Without detailed buckling analysis: $h_w \leq 70 b_w$
  - $F_{v,w,Ed} \leq \begin{cases} b_w h_w \left(1 + \frac{0,5(h_{f,t}+h_{f,c})}{h_w}\right) f_{v,0,d} & \text{for } h_w \leq 35 b_w \\ 35 b_w^2 \left(1 + \frac{0,5(h_{f,t}+h_{f,c})}{h_w}\right) f_{v,0,d} & \text{for } 35 b_w \leq h_w \leq 70 b_w \end{cases}$
  - Local shear strength in section 1-1
  - $\tau_{mean,d} \leq \begin{cases} f_{v,r,d} & \text{for } h_f \leq 4 b_{ef} \\ f_{v,r,d} \left(\frac{4 b_{ef}}{h_f}\right)^{0,8} & \text{for } h_f > 4 b_{ef} \end{cases}$
  - Where

$$b_{ef} = \begin{cases} b_w & \text{for box beams} \\ b_w/2 & \text{for I-beams} \end{cases}$$

Load-duration and moisture influence on deformation

- (1) SLS – composites with materials having different time-dependent properties, the final mean values are:

$$E_{mean,fin} = \frac{E_{mean}}{(1 + k_{def})} \qquad G_{mean,fin} = \frac{G_{mean}}{(1 + k_{def})}$$

- (2) ULS – the distribution of member forces and moments is affected by the stiffness distribution in the structure, the final mean values are:

$$E_{mean,fin} = \frac{E_{mean}}{(1 + \psi_2 k_{def})} \qquad G_{mean,fin} = \frac{G_{mean}}{(1 + \psi_2 k_{def})}$$

- Where:
  - ψ_2 is the factor for the quasi-permanent value of the action causing the largest stress in the relation to the strength

EC5 - 2.3.2.2

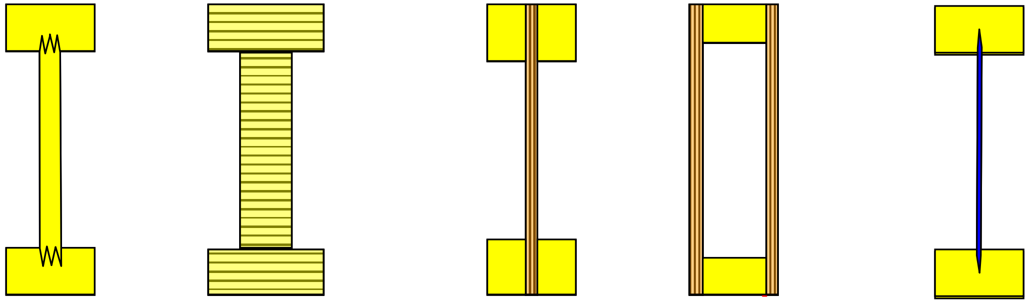
Use, advantages and failure modes

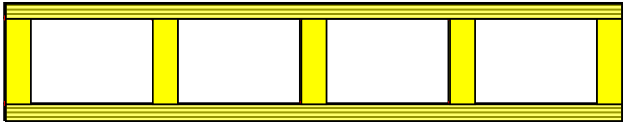
- Framing walls, floors and roofs
  - + Well insulated structures
  - + Very light structures
  - - Time-consuming connections

- Failures:
  - Tension failure in lower flange
  - Buckling of upper flange
  - Shear failure of the web

Built-up, wood-based I-beams

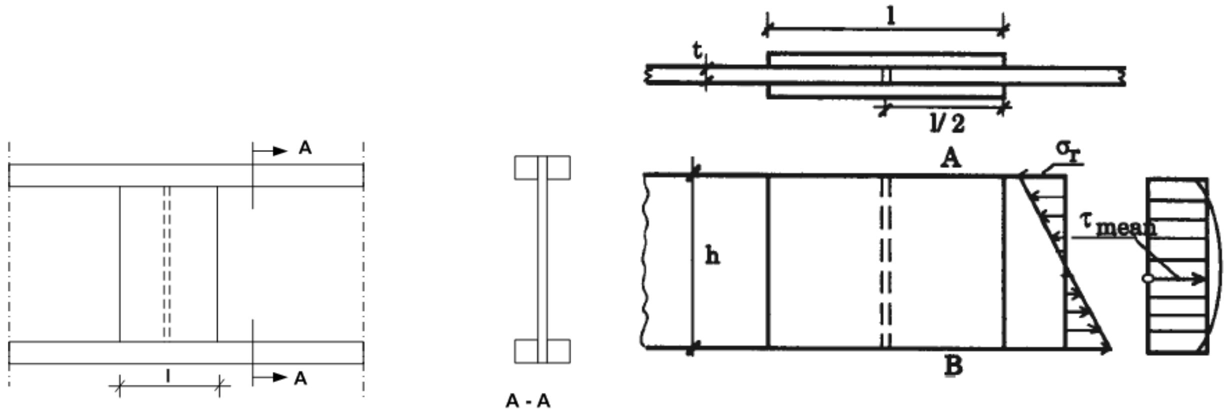
- How do we connect flanges to the web?
- How do we splice the web made of boards of short length?





Design of an overlap splice in a plywood web

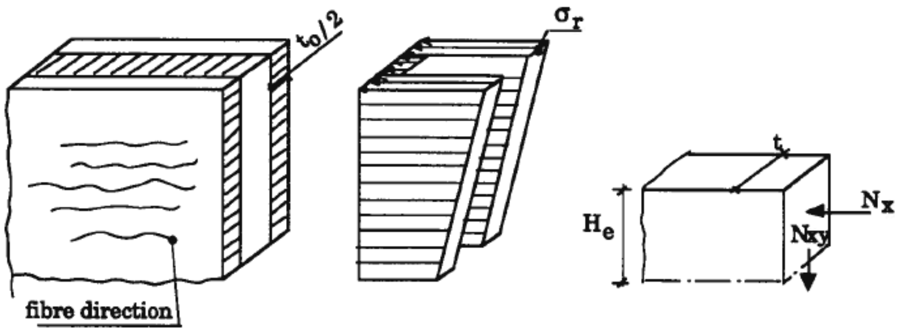
- Suggestion for how the capacity of a nail-glued overlap splice can be calculated when loaded by a moment and shear force.
- Outer veneers are horizontal (parallel with the span of the I-beam)



- Where
  - σ_r the maximum normal stress from the bending moment
  - τ_{mean} the mean shear streess

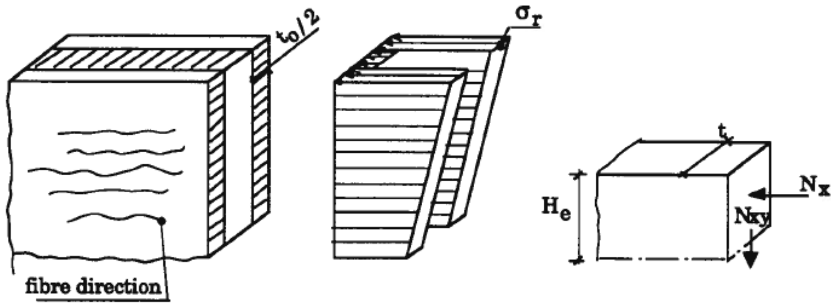
An overlap splice

- Consider a normal force on a strip with the depth H_e at the edge of the web:
  - Plywood with 3 veneers



- Normal force: $N_x = \sigma_r \sum t_{\parallel} \cdot H_e = \sigma_r \cdot t_0 \cdot H_e$
- Shear force: $N_{xy} = \tau_{mean} \cdot t \cdot H_e$
- Resultant force: $R = \sqrt{N_x^2 + N_{xy}^2} = \sqrt{(\sigma_r \cdot t_0)^2 + (\tau_{mean} \cdot t)^2} \cdot H_e$

An overlap splice



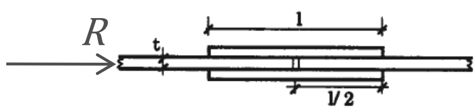
- These forces can be collected to a single resultant force which is:

$$R = \sqrt{N_x^2 + N_{xy}^2} = \sqrt{(\sigma_r \cdot t_0)^2 + (\tau_{mean} \cdot t)^2} \cdot H_e \leq l \cdot H_e \cdot f_{r,d}$$

- The resultant force R has to be transmitted to the overlap member by means of rolling shear acting on both sides of the web

$$R = f_{r,d} \cdot l \cdot H_e$$

$$f_{r,d} = \tau_{rolling}^{min} = \frac{R}{2 \cdot {}^{l}/_{2} \cdot H_e}$$



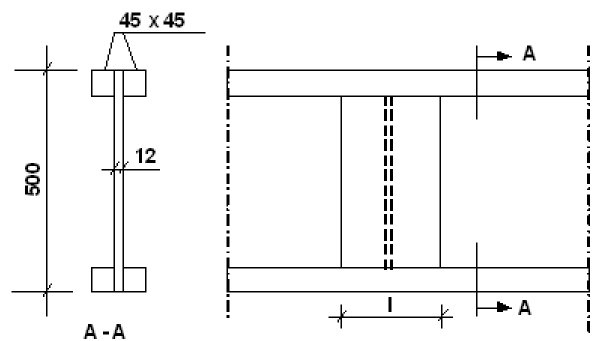
$$l \geq \frac{\sqrt{(\sigma_r \cdot t_0)^2 + (\tau_{mean} \cdot t)^2}}{f_{r,d}}$$

Example C2 Splice of the web in an I-beam

- Design (ULS) the double-sided overlap splice in the plywood I-beam. The splice in the beam is subjected to a bending moment of M_{sd} = 18 kNm and a shear force of V_{sd} = 7.8 kN (design values). Strength classes C24 and P30 for the timber flanges and the plywood web respectively.
- The beam is situated in an ordinary residential building. Service class 2. Assume that the splice is of the same material as the web

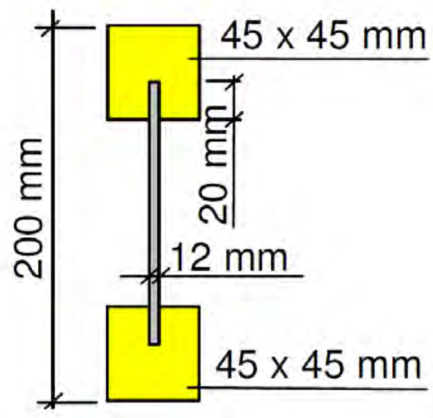
a) The outer veneers are parallel to the direction of the beam

b) The outer veneers are perpendicular to the direction of the beam



Examples C1 – Shear capacity of a I-beam

- Determine the shear capacity of the I-beam!
  - The load is of medium-term duration.
  - Service class 1 can be assumed.
  - Timber in the flanges is C24 and in the web OSB/3
  - There is full interaction between flanges and the web.



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