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TIMBER ENGINEERING - VSM196

LECTURE 2

SPRING 2020

Topic

- Solid cross-sections of timber & glulam
- Design of purlins

- Literature DoTS:
  - Ch 1, Ch 2 (2.1-2.5) and Ch 3 (3.1 and 3.2)

Content

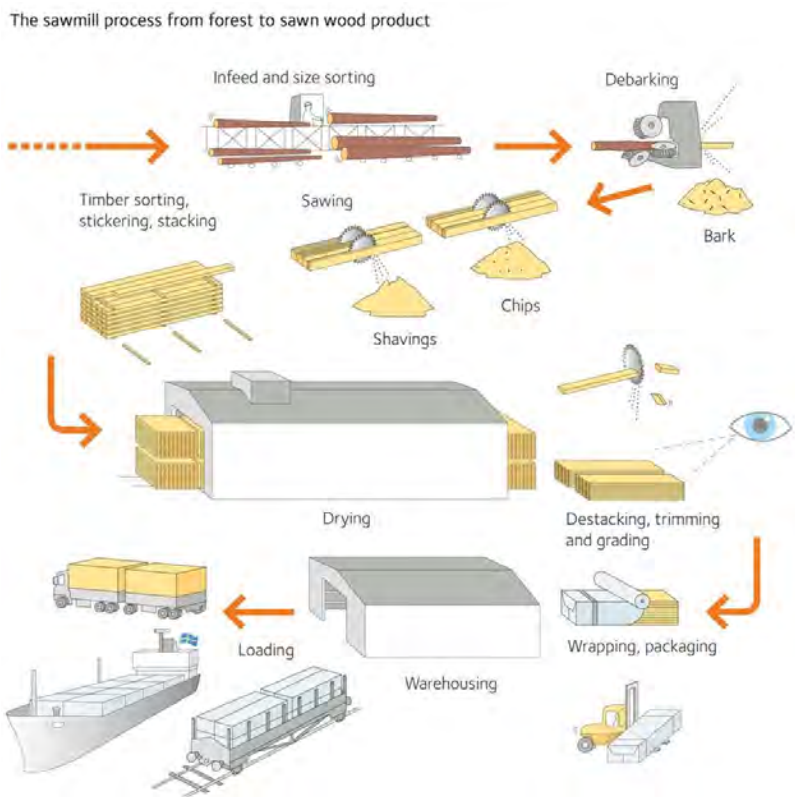
- Modern timber products
  - Production and dimensions of solid timber
  - Production and properties of glulam
- Design of linear members
  - Purlins and design of sloping members (roof joist)

Intended Learning Outcomes of this lecture

- You understand the limitations of solid timber.
- You can describe the production process of glulam.
- You can define important influences on the quality of glulam.
- You can describe the benefits of a Gerber system.

Production of solid timber

Production of solid timber



Source: Swedish Wood

Dimensions of solid timber

- Length up to 6m
- Finger jointed timber even longer

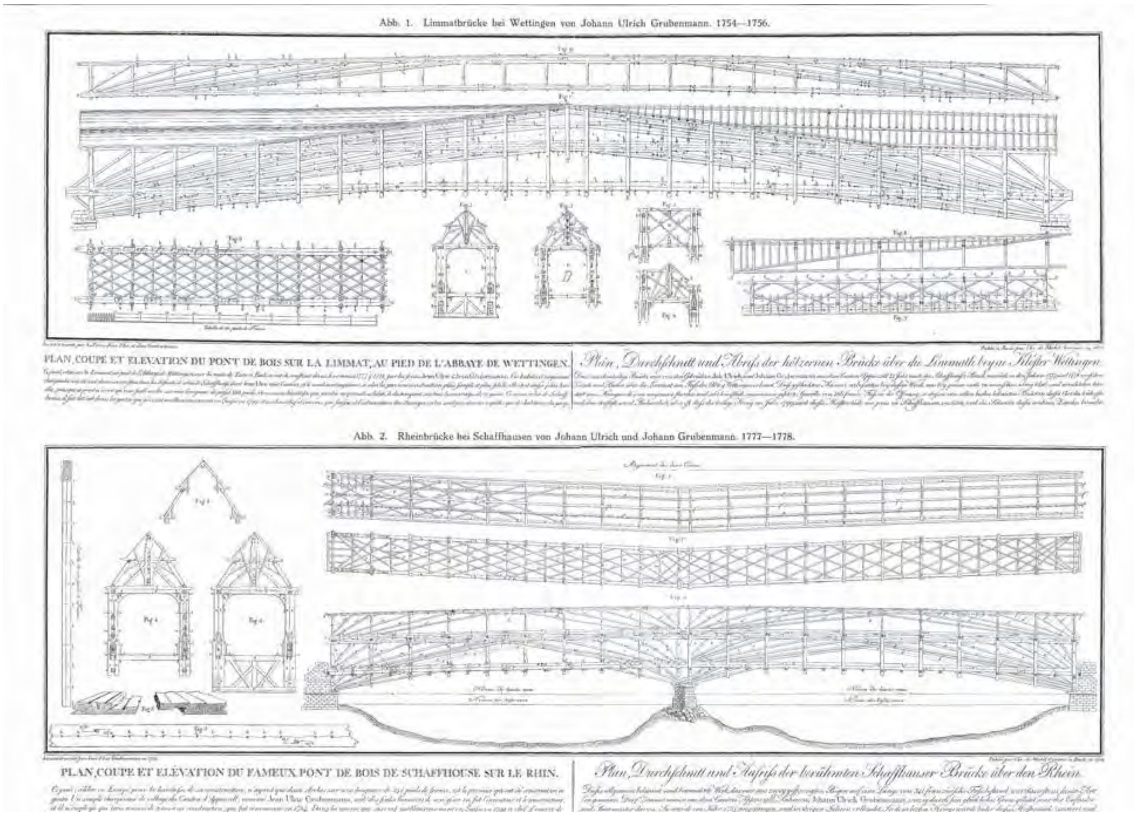
Table 31 Cross-sectional dimensions of sawn timber

Thickness (mm)	Width (mm)										
	25	38	50	75	100	125	150	175	200	225	250
12					Board	Board					
16				Board	Board	Board	Board				
19	Batten	Batten	Batten	Board	Board	Board	Board				
22		Batten	Batten	Board	Board	Board	Board	Board	Board		
25	Batten	Batten	Batten	Board	Board	Board	Board	Board	Board		
32				Board	Board	Board	Board	Board	Board		
38		Batten	Batten	Joist	Joist	Joist	Plank	Plank	Plank	Plank	Plank
44				Joist	Joist	Joist	Plank	Plank	Plank	Plank	Plank
47				Joist	Joist	Joist	Plank	Plank	Plank	Plank	Plank
50			Joist	Joist	Joist	Joist	Plank	Plank	Plank	Plank	Plank
63				Beam and post	Beam and post	Beam and post	Plank	Plank	Plank	Plank	Plank
75				Beam and post	Beam and post	Beam and post	Beam and post	Beam and post	Beam and post	Beam and post	Beam and post
100					Beam and post		Beam and post	Beam and post	Beam and post	Beam and post	Beam and post

Batten
Board
Joist
Plank
Beam and post

Source: Swedish Wood

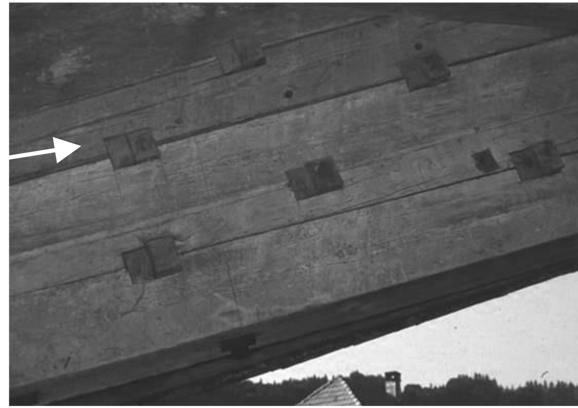
Historic structures from solid timber

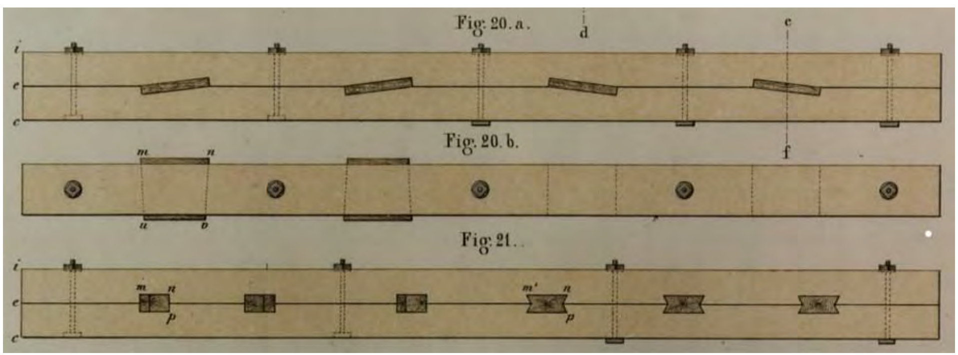


Modern structures from solid timber

Source: ETH Zurich

Challenge: Efficient connection of solid timber





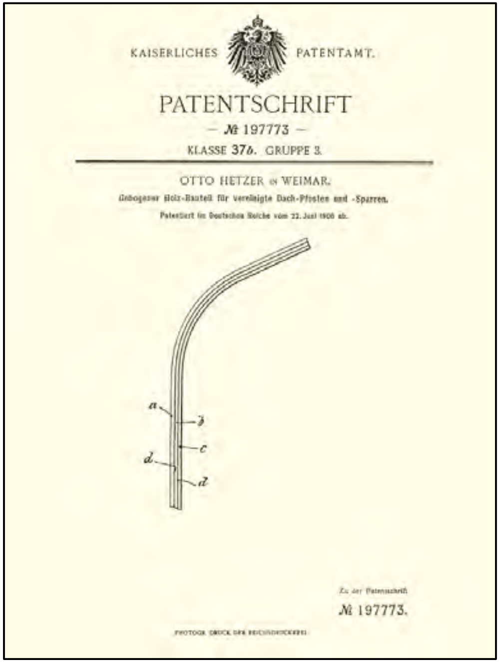
Historic glued laminated structure

- Hall – King Edward College (Southampton) 1860

Source: Müller (2000), Holzleimbau, Birkhäuser Verlag Basel/Berlin/Bosten

”Invention” of glued laminated timber

- Otto Hetzer (1846-1911)
- 1906 – ”Deutsche Reichspatent Nr. 197773 für gebogene, verleimte Brettschichtträger aus zwei oder mehr Lamellen“
(*Patent for curved, glued lamniated beams made of two or more lamellae*)


KAISERLICHES PATENTAMT.

PATENTSCHRIFT

— № 197773 —

KLASSE 37*b*. GRUPPE 3.

OTTO HETZER in WEIMAR.

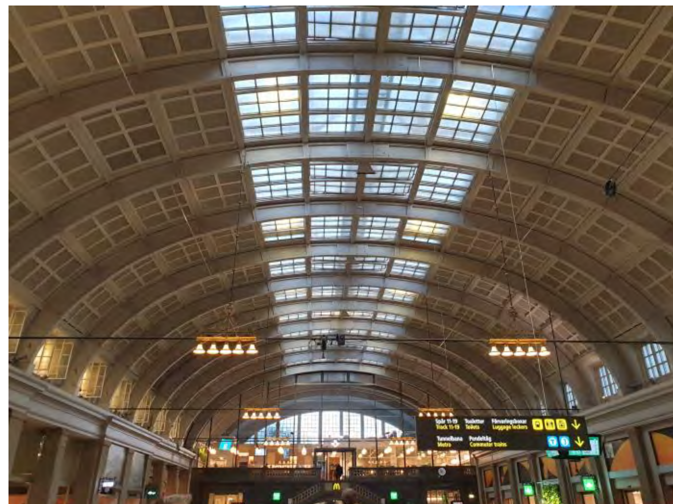
Gebogener Holz-Bauteil für vereinigte Dach-Pfosten und -Sparren.

Patentiert im Deutschen Reiche vom 22. Juni 1906 ab.

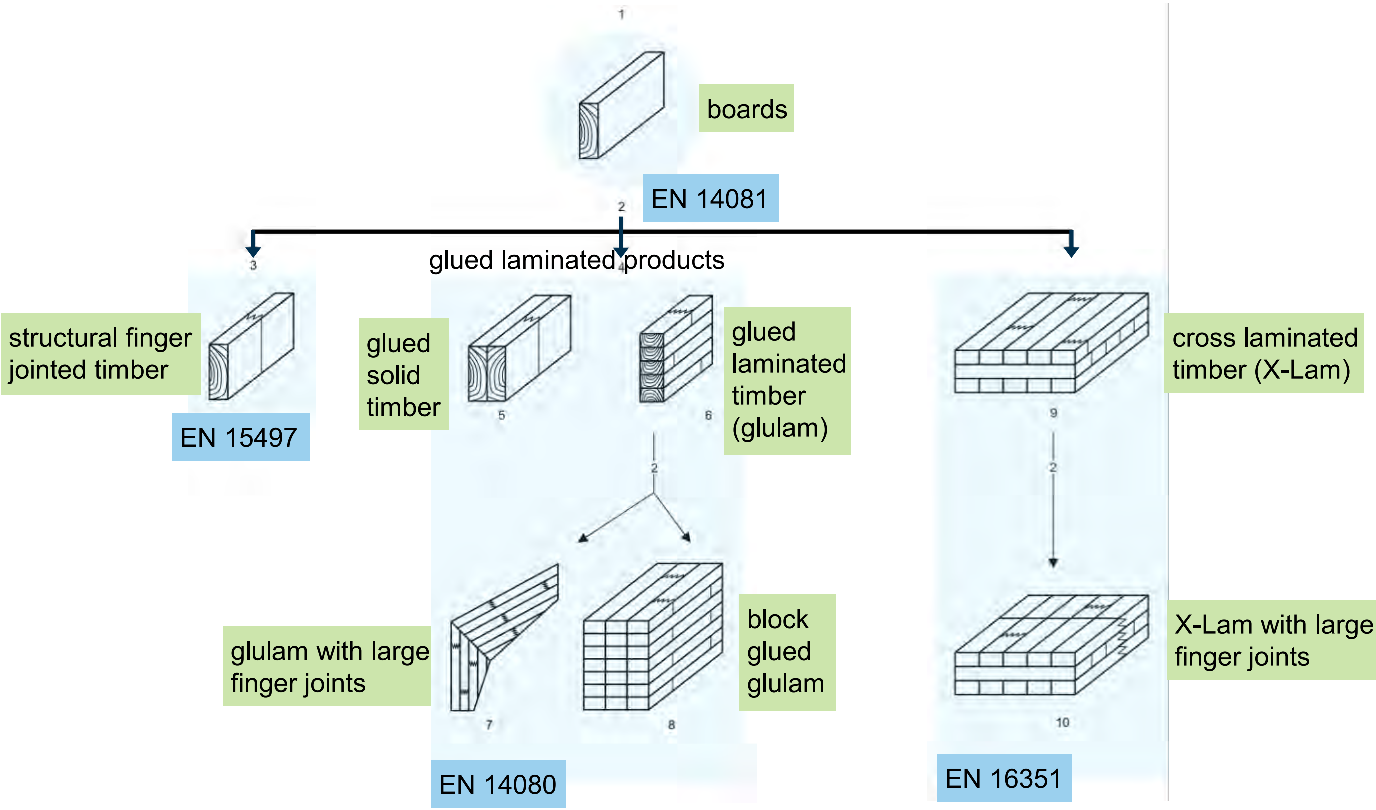
№ 197773.

Source: www.brettschichtholz.de

Glulam in Sweden: Station Malmö and Stockholm



Overview and standards for structural timber products



(Source: EN 14080)

Production of glulam

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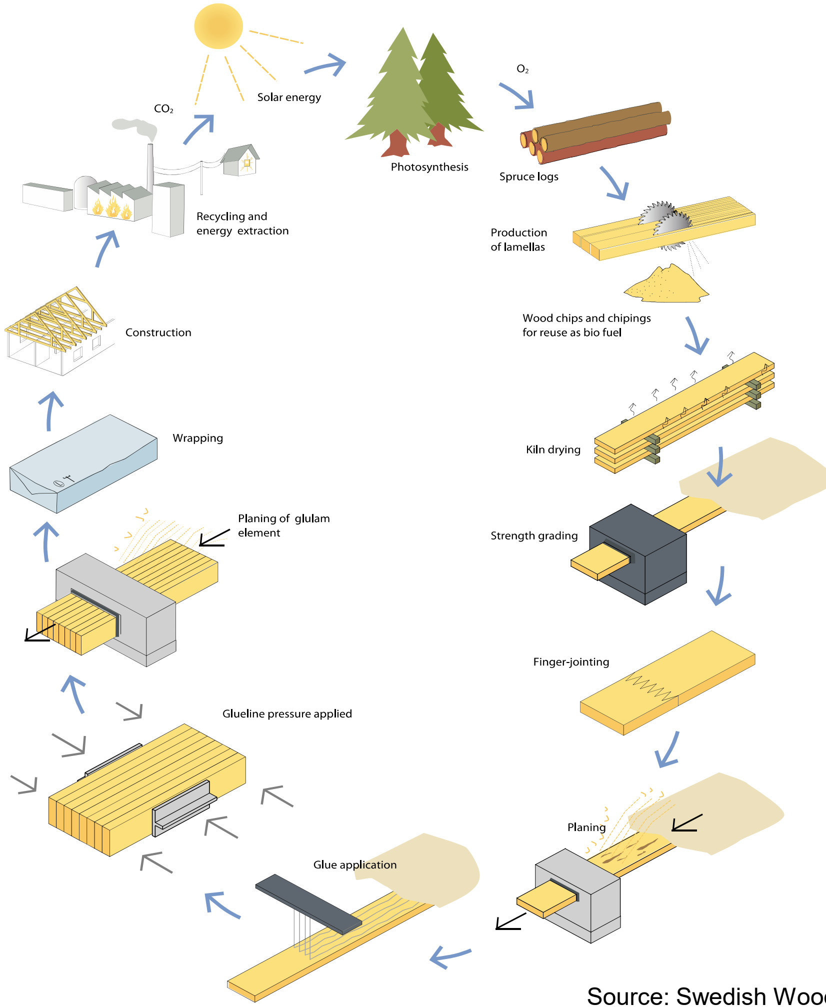

Source: Swedish Wood


KSR
DEMAG

Predifined cutting

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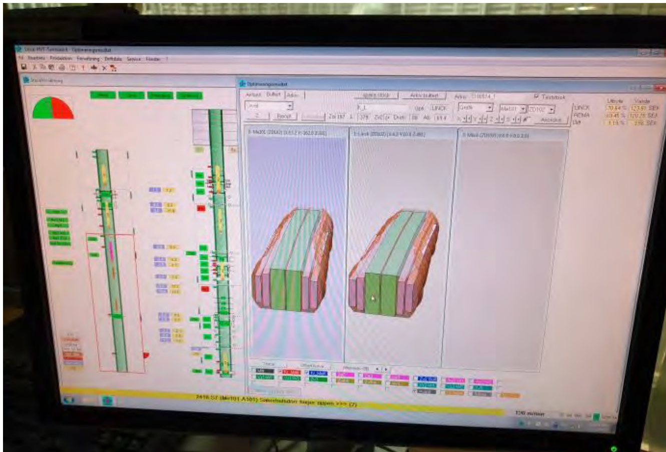
Optimized cutting



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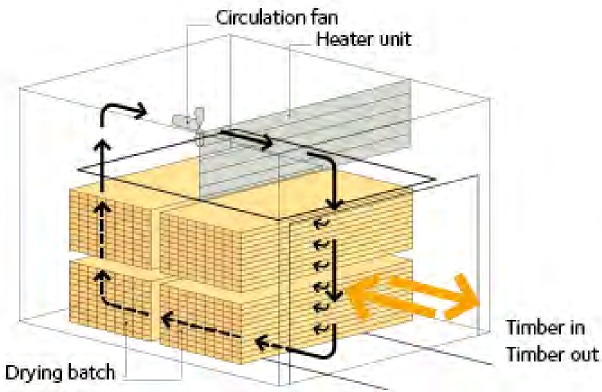
Kiln drying



www.swedishwood.com

Grading

Grading techniques

- Machine grading by means of
  - Mechanical techniques: Stress grading, proof loading
  - Dynamic methods: Eigenfrequency, Ultrasonic speed
  - Radiographic: X-ray, Microwave
  - Optical techniques: Surface scanning, Laser scanning, etc.

- Examples
  - Dynalyse
    - Precigrade: measurement of dynamic MOE https://youtu.be/zbpFLABn7cE
  - Microtec
    - Goldeneye: X-ray, dynamic MOE, and more

www.dynalyse.com

www.microtec.eu

Grading classes of boards

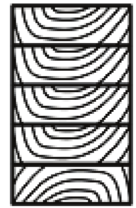
Table 1 — Characteristic strength and stiffness properties for T-classes in N/mm² and densities in kg/m³ for boards or planks for glued laminated timber

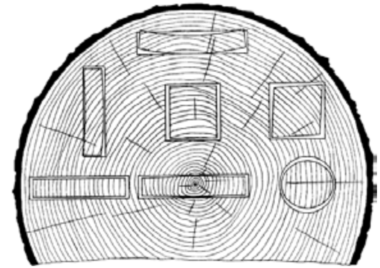
T - class of boards[a]	$f_{t,0,l,k}$	$E_{t,0,l,mean}$	$\rho_{l,k}$
T8 (C14)	8	7 000	290
T9	9	7 500	300
T10 (C16)	10	8 000	310
T11 (C18)	11	9 000	320
T12 (C20)	12	9.500	330
T13 (C22)	13	10 000	340
T14 (C24)	14	11 000	350
T14,5	14,5	11 000	350
T15	15	11 500	360
T16 (C27)	16	11 500	370
T18 (C30)	18	12 000	380
T21 (C35)	21	13 000	390
T22	22	13 000	390
T24 (C40)	24	13 500	400
T26	26	14 000	410
T27 (C45)	27	15 000	410
T28	28	15 000	420
T30 (C50)	30	15 500	430

[a] The C-Classes according to EN 338:2009 meet at least the required values of the respective T-classes.

Glulam lay-up

- Homogeneous lay-up: GL XX**h**
    - laminations are a single strength class

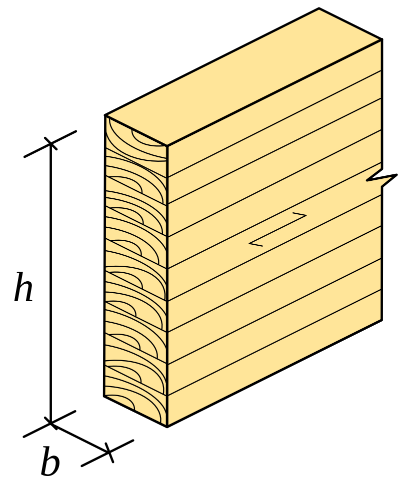




FPL Wood Handbook (2010)

Table 3 — Beam lay-up of homogeneous glued laminated timber and minimum values for bending strength of finger joints in laminations in N/mm^2

Strength class glued laminated timber	Strength class laminations	$f_{m,j,k}$
GL 20h	T10	25
GL 20h	T11	22
GL 22h	T13	25
GL 24h	T14	30
GL 26h	T16	33
GL 28h	T18	36
GL 30h	T21	38
GL 30h	T22	37
GL 32h	T24	41
GL 32h	T26	38

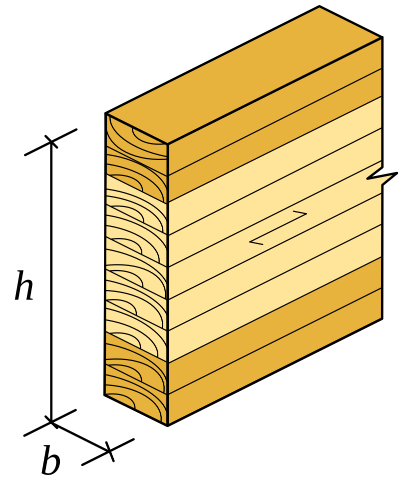


Glulam lay-up

- Combined lay-up: GL XX**c**
    - inner and outer laminations of different strength classes

Table 2 — Beam lay-up of combined glued laminated timber and minimum values for bending strength of finger joints in laminations in N/mm^2

Glued laminated timber	Outer zones of laminations			Intermediate zones of laminations			Inner zone of laminations		
Strength class	Strength class	Propor-tion [%]	$f_{m,j,k}$ [N/mm^2]	Strength class	Propor-tion [%]	$f_{m,j,k}$ [N/mm^2]	Strength class[a]	Propor-tion [%]	$f_{m,j,k}$ [N/mm^2]
GL 20c	T13	2x33	21	-	-	-	T8	34	18
GL 22c	T13	2x33	26	-	-	-	T8	34	18
GL 24c	T14	2x33	31	-	-	-	T9	34	19
GL 26c	T16	2x33	34	-	-	-	T11	34	22
GL 28c	T18	2x25	37	-	-	-	T14	50	28
GL 28c	T21	2x17	36	-	-	-	T14	66	26
GL 28c	T21	2x17	38	-	-	-	T13	66	25
GL 28c	T21	2x25	35	-	-	-	T11	50	22
GL 28c	T21	2x20	35	T14	2x20	28	T11	20	22
GL 28c	T22	2x20	35	-	-	-	T13	60	25
GL 30c	T22	2x17	40	-	-	-	T15	66	27
GL 30c	T22	2x17	41	-	-	-	T14	66	28
GL 30c	T22	2x20	40	T14	2x20	30	T11	20	22
GL 30c	T22	2x17	42	T14	2x23	31	T11	20	22
GL 32c	T24	2x17	44	-	-	-	T18	66	31
GL 32c	T26	2x17	45	-	-	-	T14	66	26
GL 32c	T26	2x10	48	T18	2x20	32	T11	40	22



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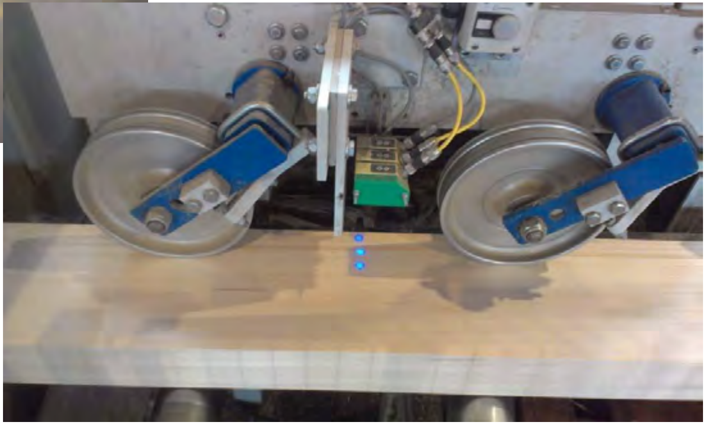
Cutting process



Source: Gerhard Fink

Finger jointing

Source: Gerhard Fink

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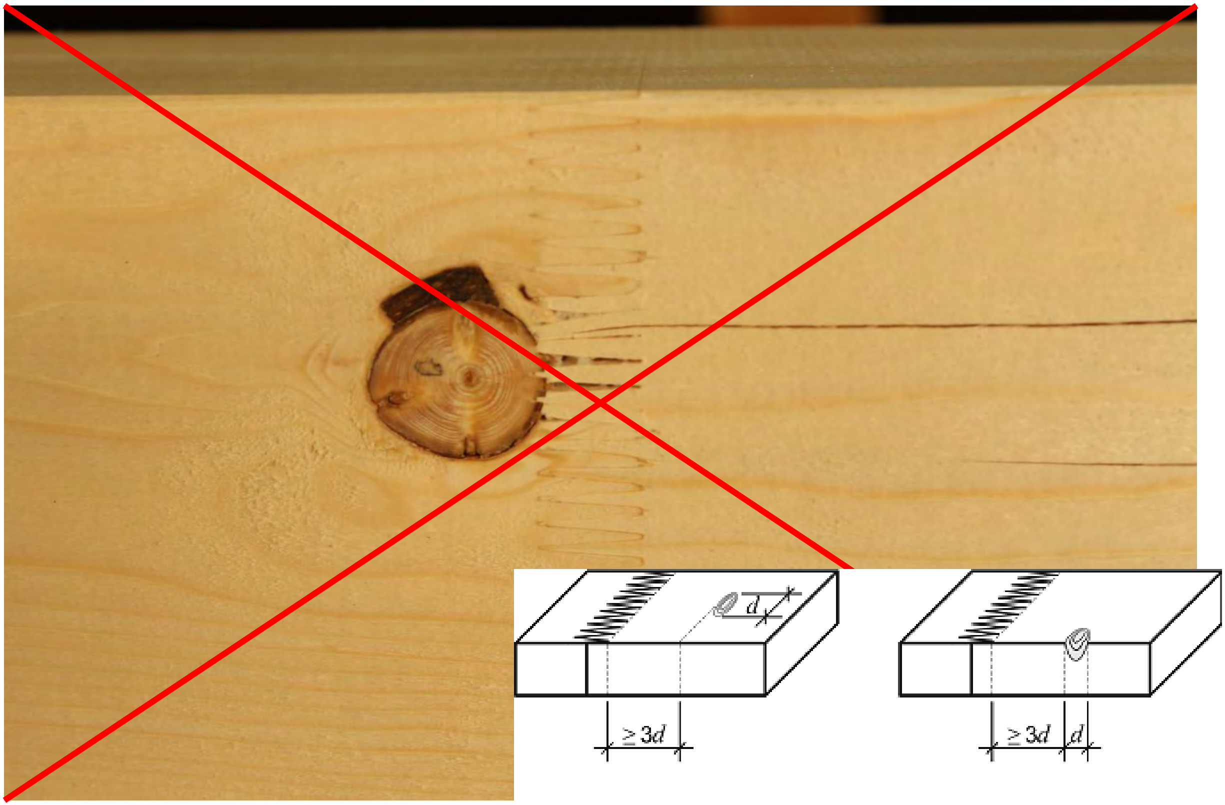
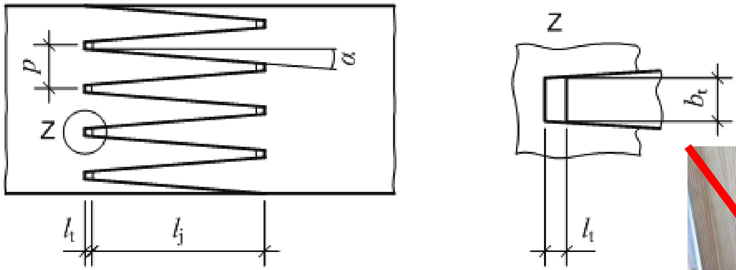
Finger jointing



Finger joint geometry in EN 14080

- The geometry of the fingers shall permit the joint to be self-interlocking after pressing.



- The finger length l_j, the pitch p, the tip width b_t, the reduction factor $v = b_t/p$ and the finger angle α shall fulfil:
  - $l_j \geq 4p(1 - 2v)$
  - $\alpha \leq 7{,}1°$

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Finger-jointed lamellae

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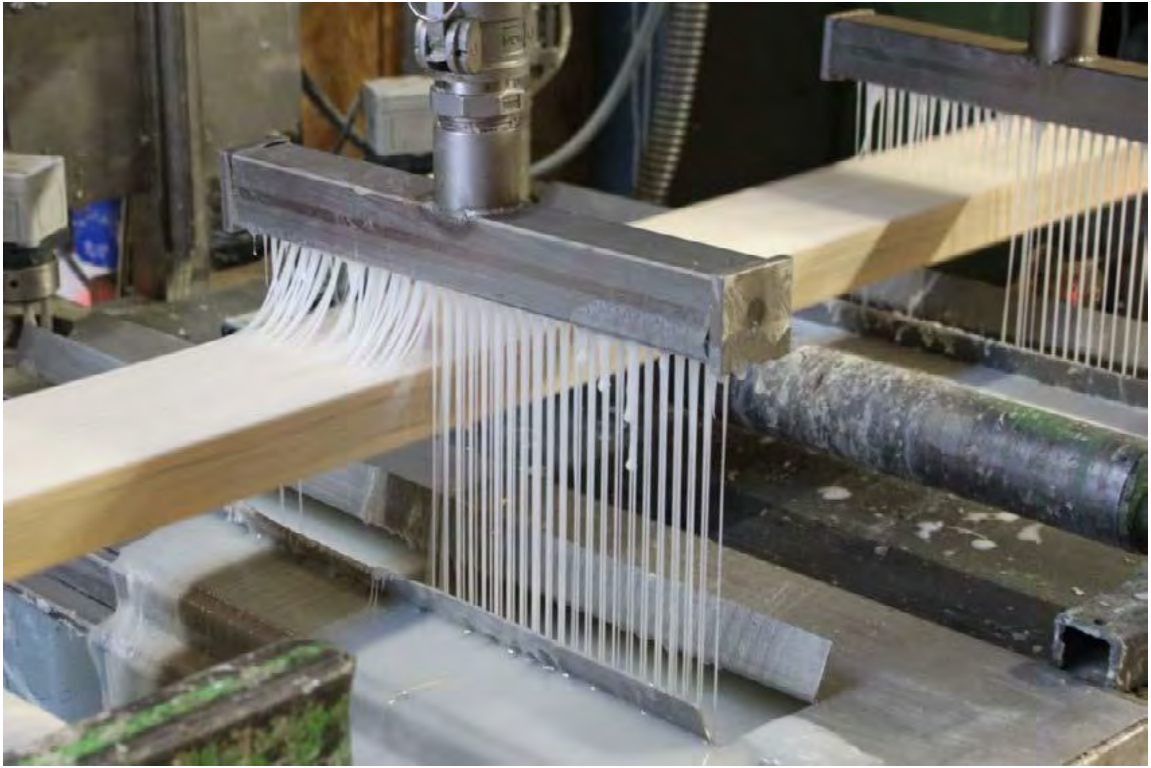
Application of adhesive for surface gluing



Source: Gerhard Fink

Assembly

Source: Gerhard Fink

Pressing

Variety in geometry

Curved beam after pressing

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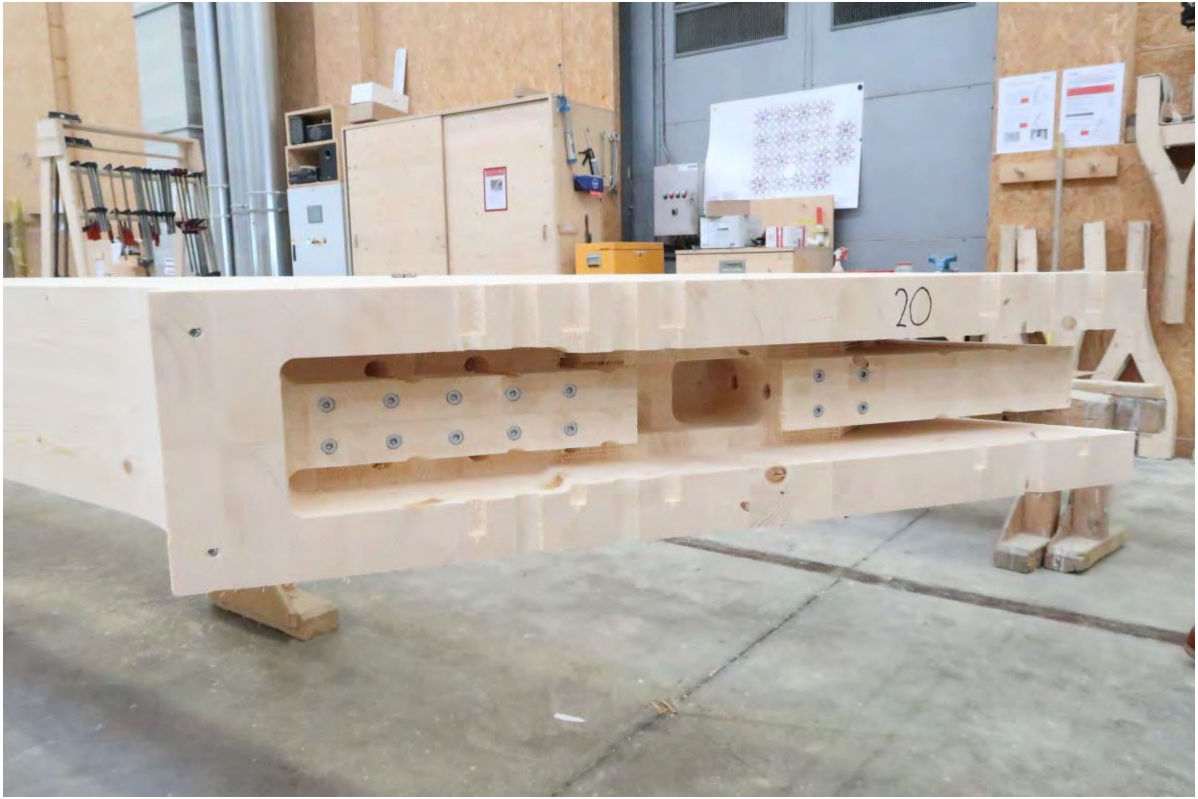
Planing and processing

Processing by CNC



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Dimensions

- Standard dimensions

Tabell 4 Tillverkningssortiment för limträpelare och limträbalkar tillverkade i Sverige, i aktuella hållfasthetsklasser

Bredd *b* (mm)	42	56	66	78	90	115	140	160	165	190	215
Höjd *h* (mm)											
90	GL28hs	GL28hs	GL28hs	GL28hs	**GL30h**	GL30h	GL30h		GL30h	GL30h	GL30h
115						**GL30h**	GL30h		GL30h	GL30h	GL30h
135	GL28hs	GL28hs	GL28hs	GL28hs	GL30h	GL30h	**GL30h**		GL30h	GL30h	GL30h
140							**GL30h**				
160								**GL30h**			
165									**GL30h**		
180	**GL28cs**	GL28cs	GL28cs	GL28cs	**GL30c**	**GL30c**	GL30c	GL30c	GL30c	GL30c	GL30c
225	**GL28cs**	**GL28cs**	GL28cs	GL28cs	**GL30c**	**GL30c**	**GL30c**		GL30c	GL30c	GL30c
270	**GL28cs**	**GL28cs**	**GL28cs**	GL28cs	**GL30c**	**GL30c**	**GL30c**		GL30c	GL30c	GL30c
315	GL28cs	GL28cs	**GL28cs**	GL28cs	**GL30c**	**GL30c**	**GL30c**		GL30c	GL30c	GL30c
360	GL28cs*	GL28cs	GL28cs	GL28cs	**GL30c**	**GL30c**	**GL30c**		GL30c	GL30c	GL30c
405	GL28cs*	GL28cs	GL28cs	GL28cs	**GL30c**	**GL30c**	**GL30c**		GL30c	GL30c	GL30c
450		GL28cs	GL28cs	GL28cs	**GL30c**	**GL30c**	GL30c		GL30c	GL30c	GL30c
495		GL28cs*	GL28cs	GL28cs	GL30c	**GL30c**	GL30c		GL30c	GL30c	GL30c
540		GL28cs*	GL28cs*	GL28cs	GL30c	GL30c	GL30c		GL30c	GL30c	GL30c
585			GL28cs*	GL28cs	GL30c	GL30c	GL30c		GL30c	GL30c	GL30c
630			GL28cs*	GL28cs*	GL30c	**GL30c**	GL30c		GL30c	GL30c	GL30c
675				GL28cs*	GL30c	GL30c	GL30c		GL30c	GL30c	GL30c
720				GL28cs*	GL30c	GL30c	GL30c		GL30c	GL30c	GL30c
765				GL28cs*	GL30c	GL30c	GL30c		GL30c	GL30c	GL30c
810					GL30c	GL30c	GL30c		GL30c	GL30c	GL30c
855					GL30c	GL30c	GL30c		GL30c	GL30c	GL30c
900					GL30c	GL30c	GL30c		GL30c	GL30c	GL30c
945						GL30c	GL30c		GL30c	GL30c	GL30c
990						GL30c	GL30c		GL30c	GL30c	GL30c
1 035						GL30c	GL30c		GL30c	GL30c	GL30c
1 080						GL30c	GL30c		GL30c	GL30c	GL30c
1 125						GL30c	GL30c		GL30c	GL30c	GL30c
1 170							GL30c		GL30c	GL30c	GL30c
1 215							GL30c		GL30c	GL30c	GL30c
1 260							GL30c		GL30c	GL30c	GL30c
1 305							GL30c		GL30c	GL30c	GL30c
1 350							GL30c		GL30c	GL30c	GL30c
1 395							GL30c		GL30c	GL30c	GL30c
1 440									GL30c	GL30c	GL30c
1 485									GL30c	GL30c	GL30c
1 530									GL30c	GL30c	GL30c
1 575									GL30c	GL30c	GL30c
1 620									GL30c	GL30c	GL30c

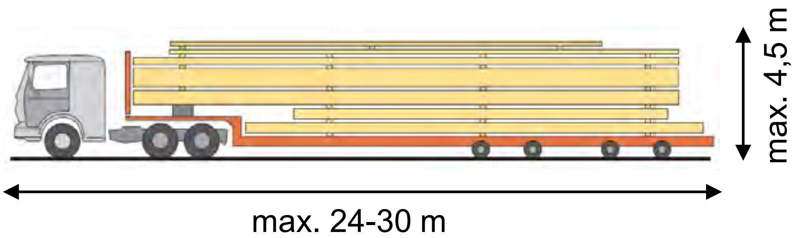
Dimensions

- Taylor made beams available in (almost) all dimensions

Transportation

Transportation length

- < 12,1 m – common truck
- > 12,1 m – lorry
- > 20,5 m – only during daytime
- > 24,5 m or width larger than 2,6 m – following car with blinking lights
- > 30 m or width larger than 4,5m in width – police escort



http//www.schneider-holz.com

Standard for Glued laminated timber EN 14080

- Production requirements, provisions for evaluation and attestation of conformity and marking of glued laminated products

EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN 14080

June 2013

ICS 79.060.99

Supersedes EN 1194:1999, EN 14080:2005, EN 385:2001, EN 386:2001, EN 387:2001, EN 390:1994, EN 391:2001, EN 392:1996

English Version

Timber structures - Glued laminated timber and glued solid timber - Requirements

Structures en bois - Bois lamellé collé et bois massif reconstitué - Exigences

Holzbauwerke - Brettschichtholz und Balkenschichtholz - Anforderungen

This European Standard was approved by CEN on 1 May 2013.

CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the CEN-CENELEC Management Centre or to any CEN member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the CEN-CENELEC Management Centre has the same status as the official versions.

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EUROPÄISCHES KOMITEE FÜR NORMUNG

Management Centre: Avenue Marnix 17, B-1000 Brussels

Ref. No. EN 14080:2013: E

CE

4321

AnyCo Ltd

13

4321-CPD-00234

EN 14080:2013

Glued laminated timber

Intended to be used in buildings and bridges

Mechanical resistance and resistance to fire as	
– geometrical data (mm)	160 x 800
– strength class	GL 24h
Bonding strength as	
– strength class	GL 24h
– bonding strength test	B
Reaction to fire	D-s2, d0
Release of formaldehyde	E1
Durability of bonding strength	
– species	*Picea abies*
– adhesive	MUF, Type IGP70S
Durability of other characteristics as	
- natural durability class(es) against wood destroying fungi	Durability class 5

Glued-laminated timber

- Modern glulam according to EN 14080
  - Wood moisture content
    - 12% ±2% at delivery
  - Gluing
    - Waterproofed adhesives for interior and exterior applications, tested in accordance with EN 301/302
  - Wood species
    - Softwood species: Spruce, Pine, Fir, Larch, Poplar, Cedar
  - Tolerances
    - Standard measurements according to EN 390 ”Glulam dimensions” at average moisture content of 15%

Dimension	Tolerance
Width	± 2 mm
Height < 400 mm	+4 / -2 mm
Height > 400 mm	+1% / -0,5%
Length < 2,0 m	± 2 mm
Length 2,0 - 20 m	± 0,1%
Length > 20 m	± 20 mm

Layup of Glulam

- Adhesives in glulam production
  - Phenol-Resorcinol-Formaldehyde resin (PRF)
    - Polycondensation adhesive with very good moisture resistance (also outdoor weathering, since largely resistant to hydrolysis).
    - Recognizable by dark glue line.
    - Glulam, boat building plywood
  - Melamine-urea formaldehyde resin (MUF)
    - Polycondensation adhesive with improved moisture resistance (but not for outdoor weathering, as not completely hydrolysis resistant)
    - Wood-based materials, plywood, load-bearing timber construction
  - Polyurethane (PUR)
    - Polyaddition adhesive with higher ductility. Since the 1990s has it been used extensively for timber construction.
    - No emission of VOCs or formaldehyde
    - Structural timber (surface gluing and finger-jointing)

Non-weather proof adhesives

Adhesives

MUF adhesive for inside application

PRF adhesive for outside application

Polyurethane

Strength classes

Table 4 — Characteristic strength and stiffness properties in N/mm² and densities in kg/m³ for combined glulam

Property[a]	Symbol	GL 20c	GL 22c	GL 24c	GL 26c	GL 28c	GL 30c	GL 32c
		Glulam strength class						
Bending strength	$f_{m,g,k}$	20	22	24	26	28	30	32
Tensile strength	$f_{t,0,g,k}$	15	16	17	19	19,5	19,5	19,5
	$f_{t,90,g,k}$	0,5						
Compression strength	$f_{c,0,g,k}$	18,5	20	21,5	23,5	24	24,5	24,5
	$f_{c,90,g,k}$	2,5						
Shear strength (shear and torsion)	$f_{v,g,k}$	3,5						
Rolling shear strength	$f_{r,g,k}$	1,2						
Modulus of elasticity	$E_{0,g,mean}$	10 400	10 400	11 000	12 000	12 500	13 000	13 500
	$E_{0,g,05}$	8 600	8 600	9 100	10 000	10 400	10 800	11 200
	$E_{90,g,mean}$	300						
	$E_{90,g,05}$	250						
Shear-modulus	$G_{g,mean}$	650						
	$G_{g,05}$	540						
Rolling shear modulus	$G_{r,g,mean}$	65						
	$G_{r,g,05}$	54						
Density[b]	$\rho_{g,k}$	355	355	365	385	390	390	400
	$\rho_{g,mean}$	390	390	400	420	420	430	440

[a] Properties given in this table have been calculated according to 5.1.5 on the basis of the layups given in Table 2. If different layups for a certain strength class lead to different characteristic values the lowest values are given here.

[b] Calculated as the weighted mean of the densities of the different lamination zones, see 5.1.5.3, 5th paragraph.

Strength classes

Table 5 — Characteristic strength and stiffness properties an N/mm² and densities in kg/m³ for homogeneous glulam

Property	Symbol	Glulam strength class GL 20h	GL 22h	GL 24h	GL 26h	GL 28h	GL 30h	GL 32h
Bending strength	$f_{m,g,k}$	20	22	24	26	28	30	32
Tensile strength	$f_{t,0,g,k}$	16	17,6	19,2	20,8	22,3	24	25,6
	$f_{t,90,g,k}$	0,5						
Compression strength	$f_{c,0,g,k}$	20	22	24	26	28	30	32
	$f_{c,90,g,k}$	2,5						
Shear strength (shear and torsion)	$f_{v,g,k}$	3,5						
Rolling shear strength	$f_{r,g,k}$	1,2						
Modulus of elasticity	$E_{0,g,mean}$	8 400	10 500	11 500	12 100	12 600	13 600	14 200
	$E_{0,g,05}$	7 000	8 800	9 600	10 100	10 500	11 300	11 800
	$E_{90,g,mean}$	300						
	$E_{90,g,05}$	250						
Shear modulus	$G_{g,mean}$	650						
	$G_{g,05}$	540						
Rolling shear modulus	$G_{r,g,mean}$	65						
	$G_{r,g,05}$	54						
Density	$\rho_{g,k}$	340	370	385	405	425	430	440
	$\rho_{g,mean}$	370	410	420	445	460	480	490

Purlin and gerber systems

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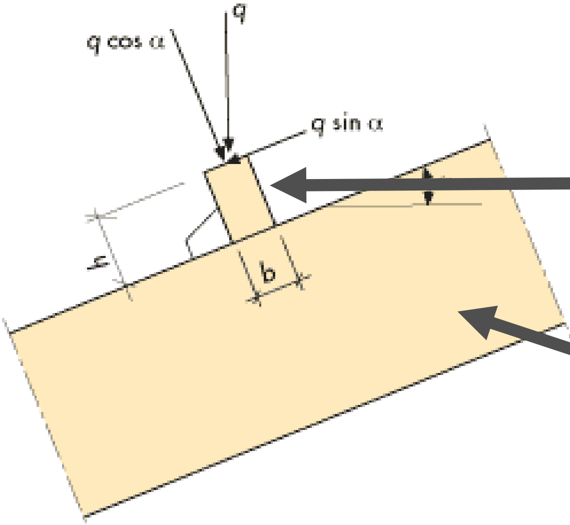
Purlins

Bi-axial bending



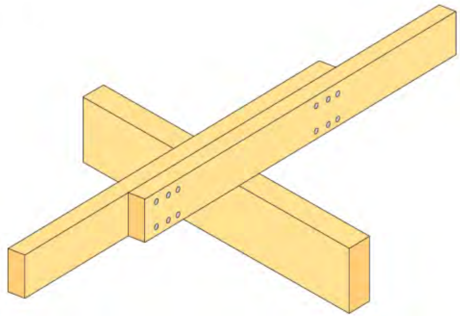
- Interaction of stresses

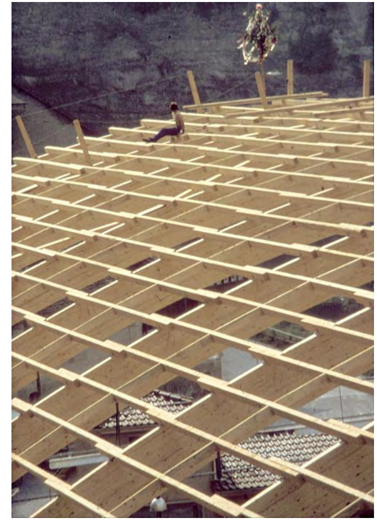
$$\frac{\sigma_{m,y,d}}{f_{m,y,d}} + k_m \frac{\sigma_{m,z,d}}{f_{m,z,d}} \leq 1$$

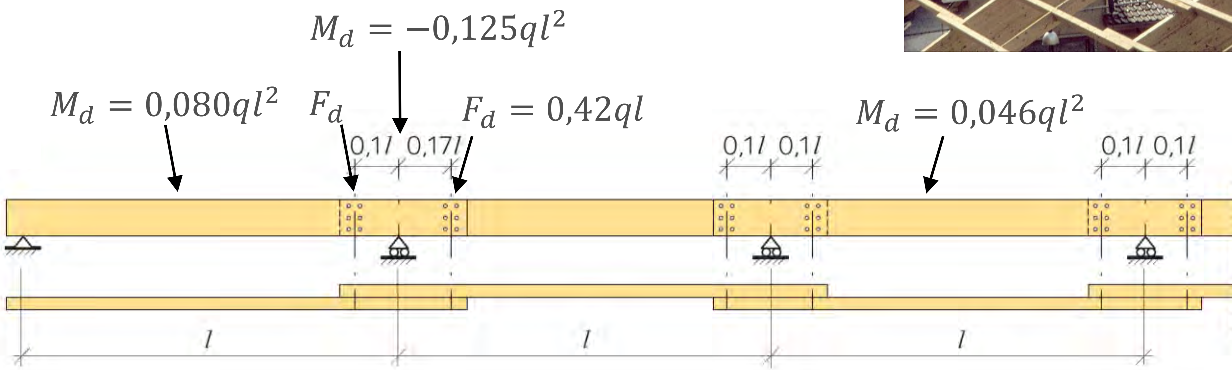
$$k_m \frac{\sigma_{m,y,d}}{f_{m,y,d}} + \frac{\sigma_{m,z,d}}{f_{m,z,d}} \leq 1$$

- k_m is a modification factor that allows for redistribution of stress in the element
  - For solid timber, glulam and LVL:
  - for rectangular sections $k_m = 0{,}7$
  - for other cross-sections $k_m = 1{,}0$

Action effects





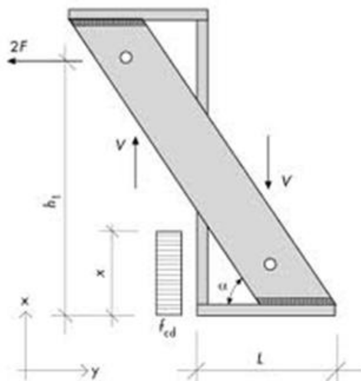


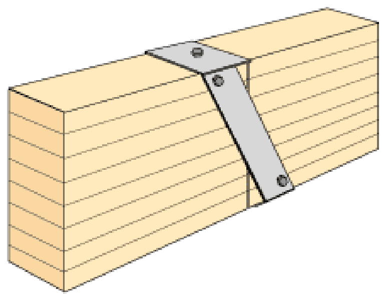
- Continuous purlin system with overlaps

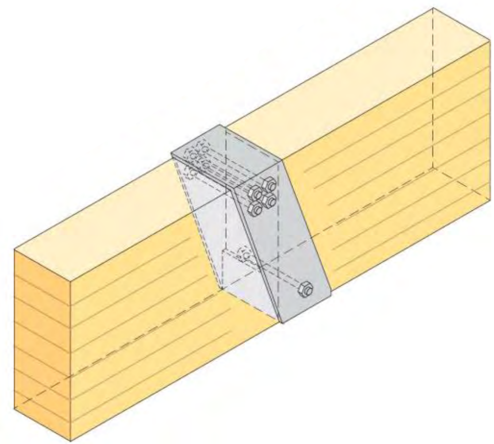
Source: Swedish Wood

Gerber system

- “The Gerber system” is designed so that moment in the field (bay) and moment over the support are equal.
- To reduce the risk of progressive collapse if one bay should collapse, the system should be designed so that every second bay is free from hinges.





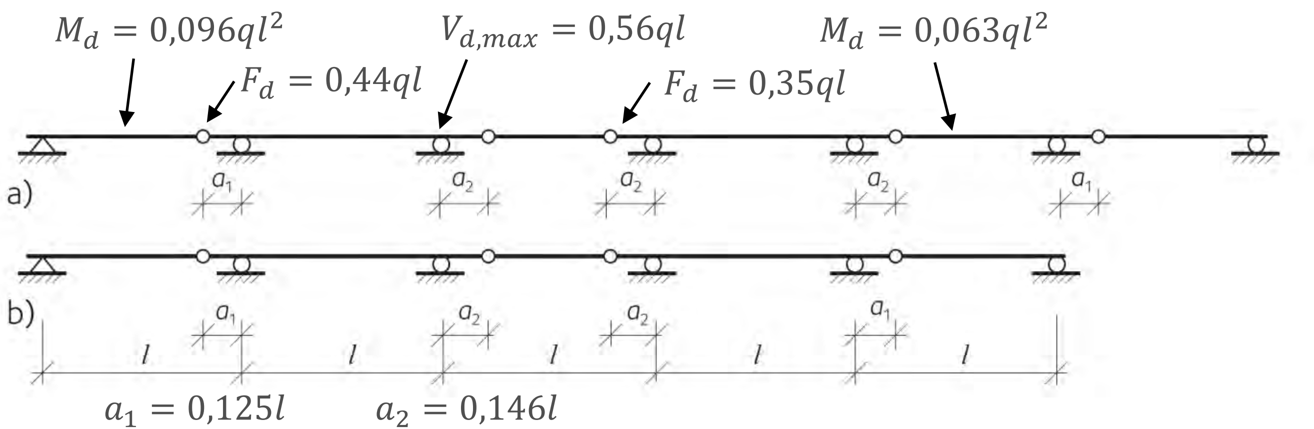


Source: Swedish Wood

Gerber systems

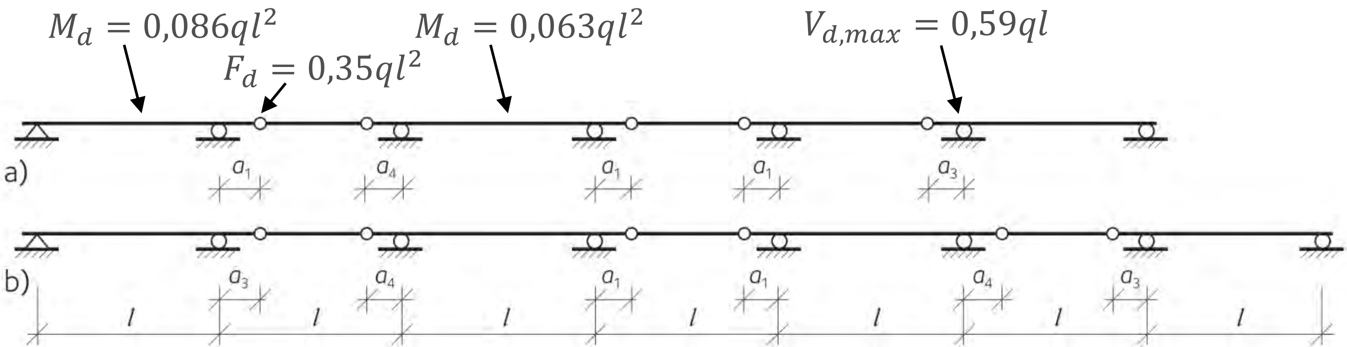
Gerber system – joint layout

- Alternative 1: Joint in end bay
  - even number of bays
  - odd number of bays



- Max. deflection (in first bay) $w = 0{,}72ql^4/100EI$

- Alternative 2: End bays without joints
    - even number of bays
    - odd number of bays



$a_3 = 0{,}204l$ $\quad a_4 = 0{,}157l$ $\quad a_1 = 0{,}146l$

- Max. deflection (in first bay) $w = 0{,}77ql^4/100EI$

Example: B1

Joist design

Example: B6

Check the design of purlin on a sloping roof joist – simply-supported

Rectangular cross-section

Homework: B7

Check the design of purlin on a sloping roof joist – Gerber system
Rectangular cross-section

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