CLT – European Experience

Properties & Design
Research & Testing

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Presentation in the frame of the
CLT Forum 2013 in TOKYO

Tokyo, 24nd October 2013

- **Properties & Design**
  - Modification Factors and Characteristic Values
  - Methods of Design
- **Research & Testing**
  - Material
  - Connections
  - Structures
- **Conclusions**

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Characteristic values of CLT | introduction

- reference cross-section
- partial factor
- modification factor
- deformation factor
- shrinkage and swelling
- strength
- stiffness

- **current regulations**
  - national and international technical approvals
  - development of a standard for CLT (prEN 16351)
- **approach for determining material properties acc. to EN 1995-1-1**
  - EN 1995-1-1 - 3.1.1 Strength and stiffness parameters: *"(1)P Strength and stiffness parameters shall be determined*
    - *on the basis of tests for the types of action effects to which the material will be subjected in the structure, or*
    - *on the basis of comparisons with similar timber species and grades or wood-based materials, or*
    - *on well established relations between the different properties."*
- **definition of strength classes with consideration of a reference cross section for CLT (similar to GLT)**
- **definition of standardized test configurations to compare determined material properties**

Characteristic values of CLT | selected properties

reference cross-section

partial factor

modification factor

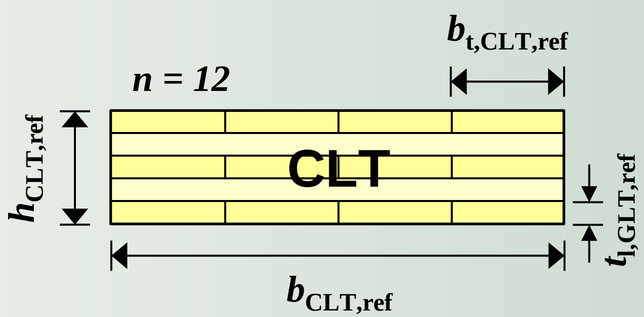
deformation factor

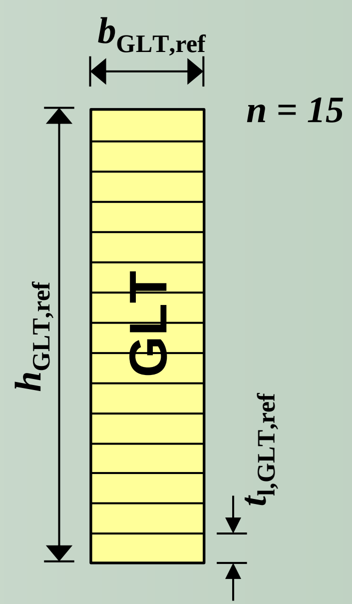
shrinkage and swelling

strength

stiffness

	height/depth/ thickness	width
GLT	$h_{GLT,ref}$ = 600 mm	$b_{GLT,ref}$ = 150 mm
basic material – boards	$t_{l,GLT,ref}$ = 40 mm	$b_{l,GLT,ref}$ = 150 mm
CLT	$h_{CLT,ref}$ = 150 mm	$b_{CLT,ref}$ = 600 mm
basic material – boards	$t_{l,CLT,ref}$ = 30 mm	$b_{l,CLT,ref}$ = 150 mm





→ bearing models for **CLT** mostly based on **GLT**

→ comparability of the demanded reference volumes

→ $n_{top\ layer}$ ≥ 4 for consideration of the system effect

Characteristic values of CLT | selected properties

reference cross-section

partial factor

modification factor

deformation factor

shrinkage and swelling

strength

stiffness

Fundamental combinations	γ_M
Solid timber	1.3
Glued laminated timber	1.25
Cross laminated timber	1.25
LVL, plywood, OSB	1.2

→ classification like **GLT**

→ **lower dispersion** of material data in comparison to basic material (boards)

Characteristic values of CLT | selected properties

reference cross-section

partial factor

modification factor

deformation factor

shrinkage and swelling

strength

stiffness

Material	Standard	SC	k_{mod} - Load-duration class				
			Perm.	Long	Medium	Short	Inst.
ST GLT	EN 14081-1 EN 14080	1	0.60	0.70	0.80	0.90	1.10
		2	0.60	0.70	0.80	0.90	1.10
		3	0.50	0.55	0.65	0.70	0.90
CLT[1)]	prEN 16351	1	0.60	0.70	0.80	0.90	1.10
		2	0.60	0.70	0.80	0.90	1.10

[1)] It is proposed, that the use of CLT in service class 3 is not allowed.

→ classification like **GLT**

Characteristic values of CLT | selected properties

- reference cross-section
- partial factor
- modification factor
- **deformation factor**
- shrinkage and swelling
- strength
- stiffness

Material	Standard		k_{def} - Service class 1	2	3
ST GLT	EN 14081-1 EN 14080		0.60	0.80	2.00
Plywood	EN 636	type EN 636-1 type EN 636-2 type EN 636-3	0.80 0.80 0.80	- 1.00 1.00	- - 2.50
CLT[1)]	prEN 16351	> 7s	0.80	1.00	-
		≤ 7s	0.85	1.10	-

[1)] It is proposed, that the use of CLT in service class 3 is not allowed.

→ classification as **plywood** due to crossed lay-up and stress towards rolling shear

→ consideration of the lay-up is necessary: >7s | ≤ 7s

→ for simplification: classification as plywood, type 2

Characteristic values of CLT | selected properties

reference cross-section

partial factor

modification factor

deformation factor

shrinkage and swelling

strength

stiffness

Material		Shrinkage and swelling coef. in % per % change in the m. c. below fibre saturation
CLT	in plane (IP)	0.02-0.04
	out of plane (OP)	0.24

→ coefficient in-plane is depending on the CLT lay-up

→ ratio of layers in and perpendicular to span with regard to the CLT thickness

Characteristic values of CLT | selected properties

reference cross-section

partial factor

modification factor

deformation factor

shrinkage and swelling

strength

stiffness

base material	T14	
CV [ft,0,l]	25 % ± 5 %	35 % ± 5 %
	CLT strength class	
property	**CL 24h**	**CL 28h**
$f_{m,CLT,k}$	24	28

Characteristic values of CLT | selected properties

reference cross-section

partial factor

modification factor

deformation factor

shrinkage and swelling

strength

stiffness

base material	T14	
CV [ft,0,l]	25 % ± 5 %	35 % ± 5 %
	CLT strength class	
property	**CL 24h**	**CL 28h**
$f_{m,CLT,k}$	24	28

$$f_{m,CLT,k} = k_{m,CLT} \cdot f_{t,0,l,k}{}^{0,8}$$

$k_{m,CLT}$	*CV [ft,0,l]*
3.0	25 % ± 5 %
3.5	35 % ± 5 %

Characteristic values of CLT | selected properties

reference cross-section

partial factor

modification factor

deformation factor

shrinkage and swelling

strength

stiffness

base material	T14	
$CV\ [ft,0,l]$	25 % ± 5 %	35 % ± 5 %
	CLT strength class	
property	**CL 24h**	**CL 28h**
$f_{m,CLT,k}$	24	28
$f_{t,0,CLT,net,k}$	16	18
$f_{t,90,CLT,k}$	0.5	
$f_{c,0,CLT,net,k}$	24	28
$f_{c,90,CLT,k}$	2.85	
$f_{v,CLT,IP,k}$	5.5	
$f_{T,node,k}$	2.5	
$f_{v,CLT,OP,k}$	3.0	
$f_{r,CLT,k}$ – $b/t \geq 4:1$	1.25	
$f_{r,CLT,k}$ – $b/t < 4:1$	0.70	

... research work is needed

Characteristic values of CLT | selected properties

- **reference cross-section**
- **partial factor**
- **modification factor**
- **deformation factor**
- **shrinkage and swelling**
- **strength**
- **stiffness**

base material	T14	
CV [ft,0,l]	25 % ± 5 %	35 % ± 5 %
	CLT strength class	
property	**CL 24h**	**CL 28h**
$E_{0,CLT,mean}$	11,000	
$E_{0,CLT,05}$	9,167	
$E_{90,CLT,mean}$	300	
$E_{90,CLT,05}$	250	
$E_{c,90,CLT,mean}$	450	
$E_{c,90,CLT,05}$	375	
$G_{CLT,mean}$	650	
$G_{CLT,05}$	540	
$G_{r,CLT,mean}$	65	
$G_{r,CLT,05}$	54	

... research work is needed

- **Properties & Design**
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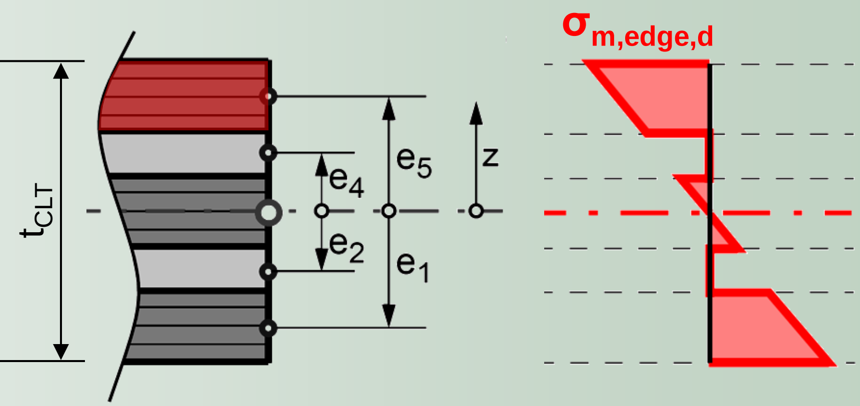
Methods of Design | selected verifications

Ultimate Limit State
ULS

Bending

e.g.: 5-layered CLT element [assumption : $E_{90}=0$]

ES	α			
#5	0	E_0	G_0	t_5
#4	90	E_{90}	G_{90}	t_4
#3	0	E_0	G_0	t_3
#2	90	E_{90}	G_{90}	t_2
#1	0	E_0	G_0	t_1



'saw tooth' - like stress distribution

$$\sigma_{m,i=5,edge,d} = \frac{M_{max,d}}{K_{CLT}} \cdot \frac{t_{CLT}}{2} \cdot E_{i=5}$$

$$K_{CLT} = \sum_{i=1}^{n} \left(J_i \cdot E_i \right) + \sum_{i=1}^{n} \left(A_i \cdot e_i^2 \cdot E_i \right)$$

$$\frac{\sigma_{m,edge,d}}{f_{m,clt,d}} \leq 1.0$$

normally very low utilization ratio → seldom relevant

Serviceability Limit State
SLS

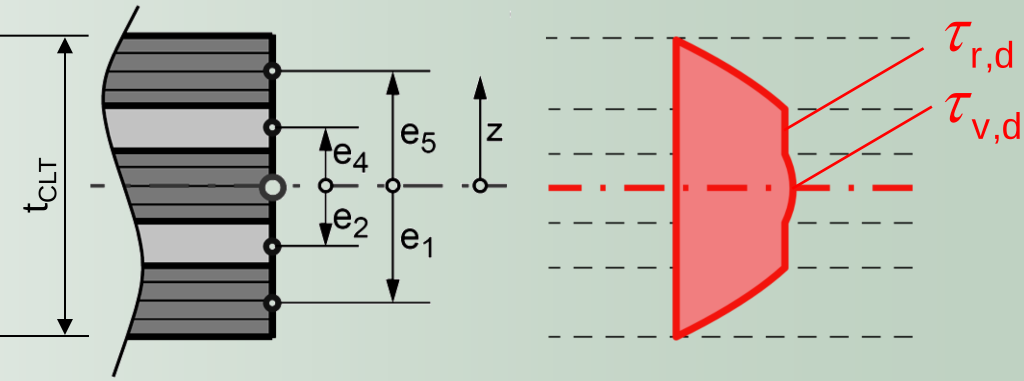
Methods of Design | selected verifications

Ultimate Limit State
ULS

Shear

e.g.: 5-layered CLT element [assumption : $E_{90}=0$]

ES	α			
#**5**	0	E_0	G_0	t_5
#4	90	E_{90}	G_{90}	t_4
#3	0	E_0	G_0	t_3
#2	90	E_{90}	G_{90}	t_2
#1	0	E_0	G_0	t_1



Serviceability Limit State
SLS

$$\tau(z_0)_d = \frac{V_{z,d} \cdot \int_{A_0} E(z) \cdot z \cdot dA}{K_{clt} \cdot b(z_0)}$$

$\tau_{v,d}$ (longitudinal) und $\tau_{r,d}$ (transverse)

$$\frac{\tau_{v,d}}{f_{v,clt,d}} \leq 1.0$$

$$\frac{\tau_{r,d}}{f_{r,clt,d}} \leq 1.0$$

Methods of Design | selected verifications

Ultimate Limit State **ULS**

Serviceability Limit State **SLS**

Deflections (loads out-of-plane)

$$w_{ges} = \frac{1}{K_{CLT}} \int \left(M \cdot \overline{M} \right) dx + \frac{1}{S_{CLT}} \int \left(V \cdot \overline{V} \right) dx$$

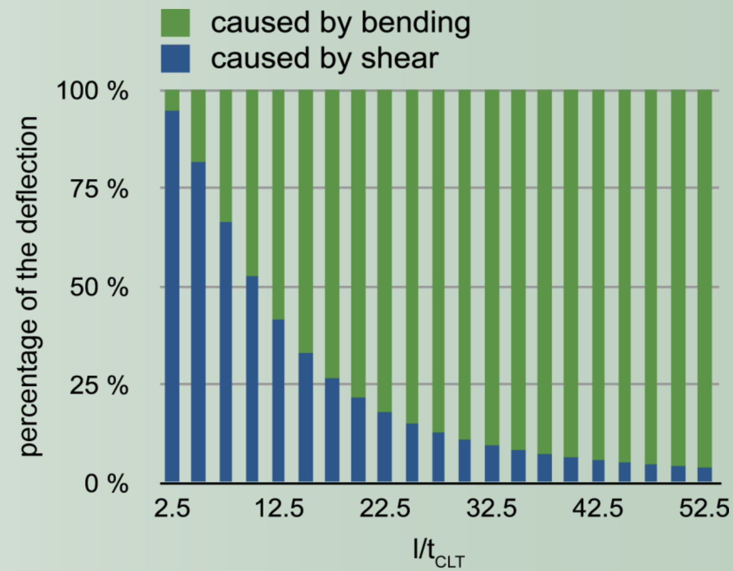
single-span beam

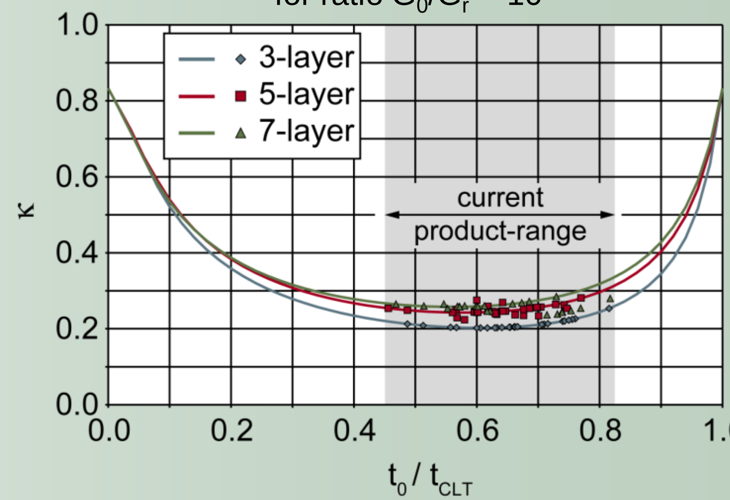
$$w(l/2) = \frac{5 \cdot q \cdot l^4}{384 \cdot K_{CLT}} + \frac{q \cdot l^2}{8 \cdot S_{CLT}}$$

Shear Stiffness

$$S_{CLT} = \kappa \cdot S_{tot} = \kappa \cdot \sum (G_i \cdot b_i \cdot t_i) = \kappa \cdot \sum (G_i \cdot A_i)$$

For G_0/G_r = 10 nearly constant and about ¼ of an unidirectional rectangular cross section.





Methods of Design | selected verifications

Ultimate Limit State **ULS**

Serviceability Limit State **SLS**

Deflections (loads out-of-plane)

Long-term effects due to creep

- due to the cross layers (rolling shear) higher values than for solid timber or glued laminated timber
- combinations of actions for instantaneous (t = 0), final and net final (t = ∞) deflections from EN 1990 and EN 1995-1-1

			combination	w_{lim}
instantaneous	t = 0	w_{inst}	$w_{inst,G} + w_{inst,Q}$	l/300
final	t = ∞	w_{fin}	$w_{inst} + w_{creep}$	l/150
net final	t = ∞	$w_{net,fin}$	$w_{fin} + w_c$	l/250

$$\frac{w_{inst}}{w_{lim,inst}} \leq 1.0 \qquad \frac{w_{fin}}{w_{lim,fin}} \leq 1.0 \qquad \frac{w_{net,fin}}{w_{lim,net,fin}} \leq 1.0$$

Methods of Design | selected verifications

Ultimate Limit State ULS

Serviceability Limit State SLS

Vibration verification according to Eurocode 5: EN 1995-1-1

1st natural frequency: $f_1 \geq 8$ Hz → NO → special investigation

YES ↓

specification of performance

↓

limits for w and v

↓

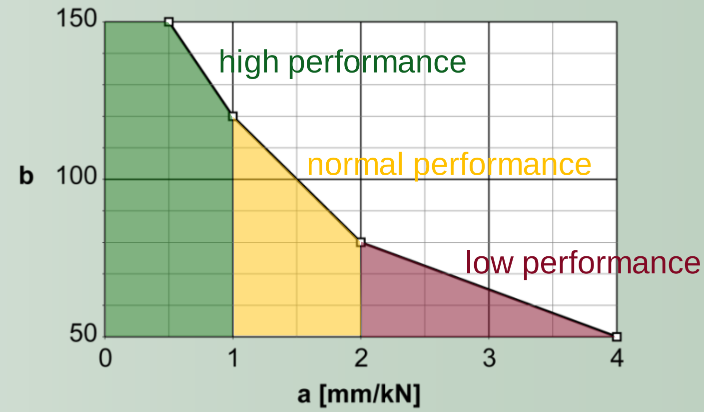
stiffness: $w(1kN) \leq w_{crit} = a$ → NO → verification not fulfilled

YES ↓

vibration velocity: $v \leq v_{crit} = b^{(f_1\zeta-1)}$ → NO → verification not fulfilled

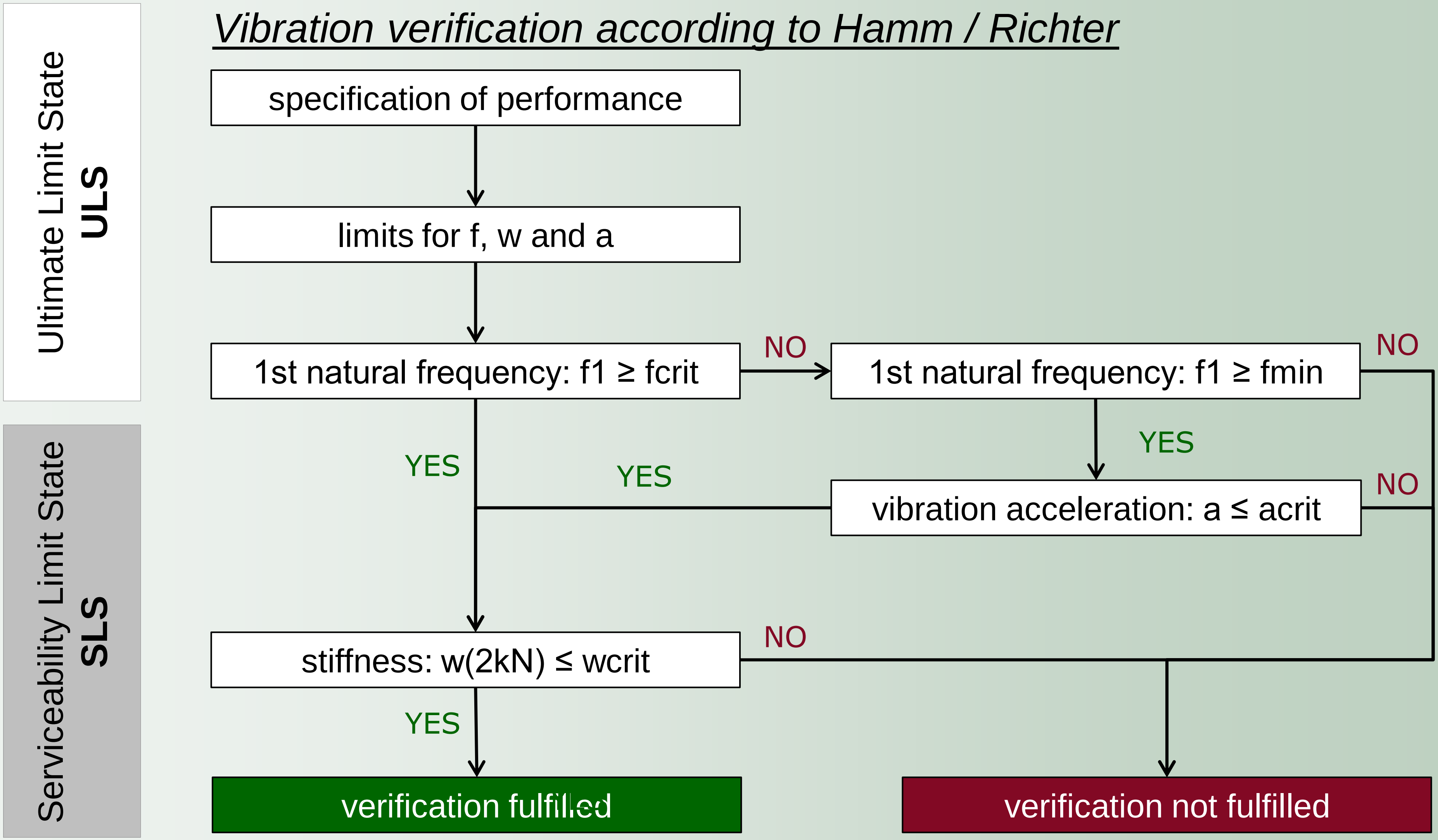
YES ↓

verification fulfilled



Methods of Design | selected verifications

Vibration verification according to Hamm / Richter



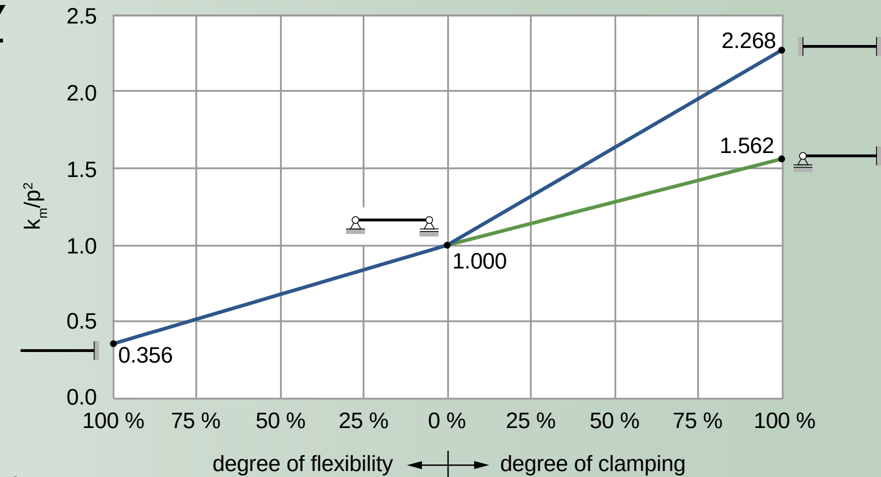
Methods of Design | selected verifications

Ultimate Limit State ULS

Fundamental natural frequency

- single span beam

$$f_{1,beam} = \left(\frac{k_m}{2\pi \cdot l^2}\right)\sqrt{\frac{(EI)_{l,ef}}{\bar{m}}}\;[\text{Hz}]$$



Serviceability Limit State SLS

Stiffness criterion

- deflection of a single span girder with a single force F at midspan

$$w(F,b_F) = \frac{F \cdot l^3}{48 \cdot (EI)_{l,ef} \cdot b_F} + \frac{F \cdot l}{4 \cdot (GA)_{ef} \cdot b_F}$$

- effective width b_F

$$b_F = \frac{l}{1.1} \cdot \sqrt[4]{\frac{(EI)_{b,ef}}{(EI)_{l,ef}}}$$

Methods of Design | selected verifications

Ultimate Limit State **ULS**

Serviceability Limit State **SLS**

Vibration acceleration

$$a = \frac{0.4 \cdot \left(\frac{F_0 \cdot a_{i,f_1}}{M_{gen}} \right)}{\sqrt{\left(\left(\frac{f_1}{f_f} \right)^2 - 1 \right)^2 + \left(2 \cdot z \cdot \frac{f_1}{f_f} \right)^2}} \quad \left[m/s^2 \right]$$

$$M_{gen} = \bar{m} \cdot \frac{l}{2} \cdot b_F \quad \left[kg/m^2 \right] \qquad \text{with } b_F \le \frac{b}{2}$$

Fourier coefficient
mass and self weight of excitatory person
span and effective width
frequeny and frequency of excitation
damping ratio

frequency [Hz]	**Fourier coefficient $\alpha_{i,f1}$** [-]	**frequency of excitation f_f** [Hz]
$4.5 < f_1 \le 5.1$	0.20	f_1
$5.1 < f_1 \le 6.9$	0.06	f_1
$6.9 < f_1 < 8.0$	0.06	6.9

type of floor construction	**damping ratio ζ** supported on 2 sides	supported on 4 sides
CLT floors with a light or without floor construction	2.0 %	2.5 %
CLT floors with heavy floor construction	2.5 %	3.0 %

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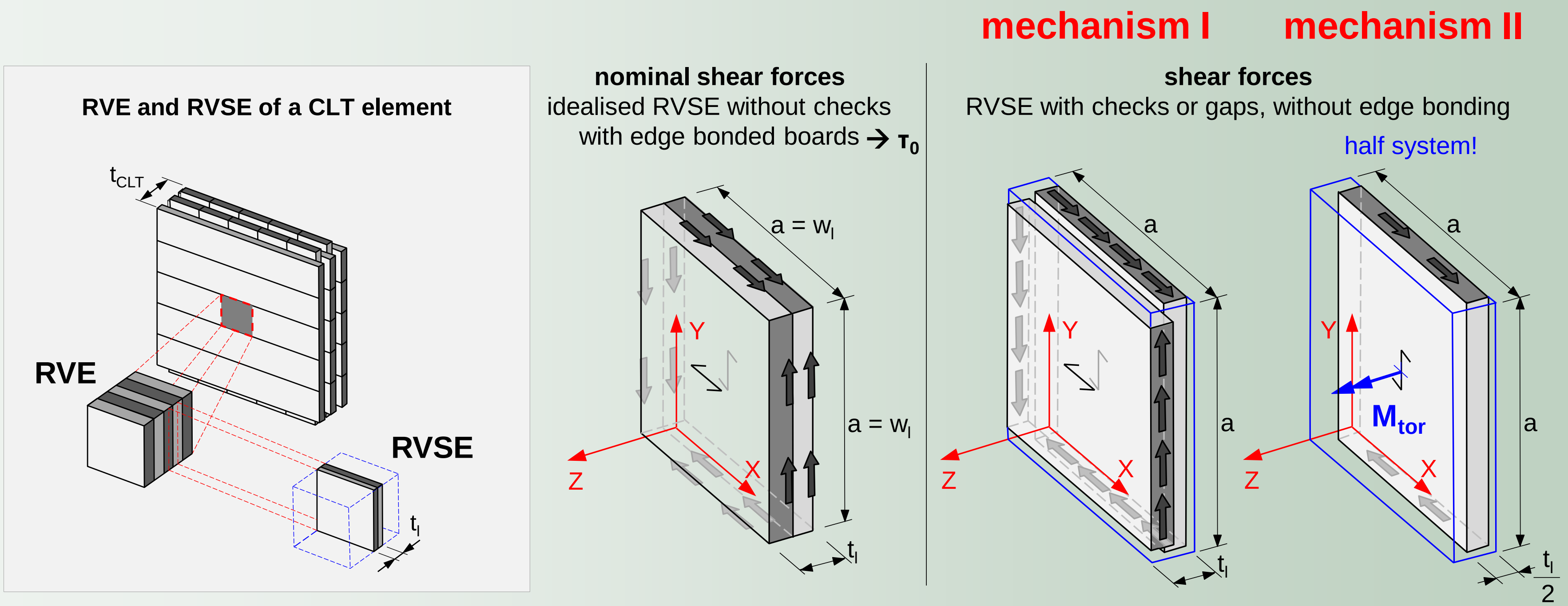
Shear Mechanisms on a RVSE

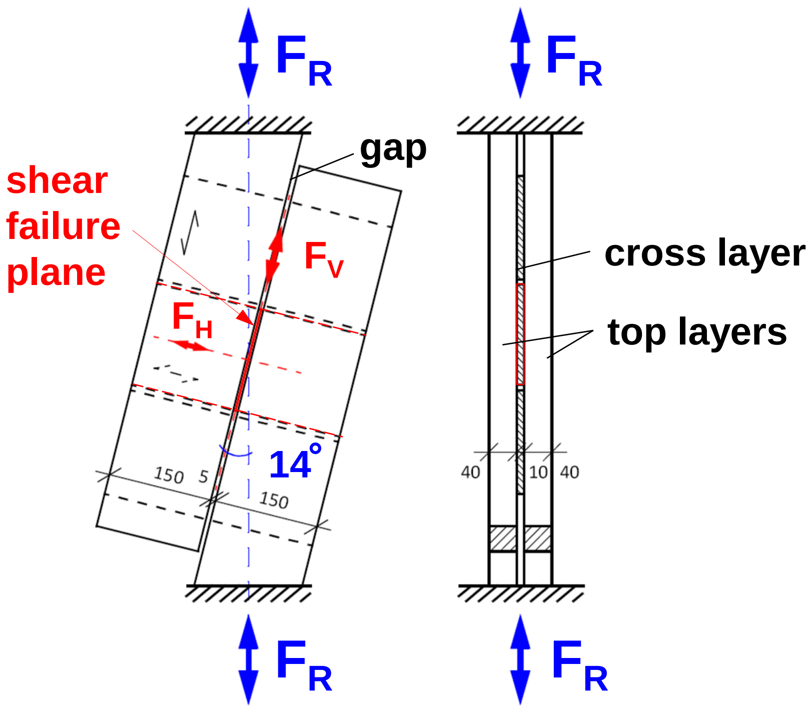
- **Mechanism I „net-shear“**
  transfer of shear via board‘s cross sections $\boldsymbol{\tau_{net} = 2 \cdot \tau_0}$
- **Mechanism II „torsion“**
  torsional shear stresses in gluing interface $\boldsymbol{\tau_{tor} = 3 \cdot \tau_0 \cdot (t_l / a)}$

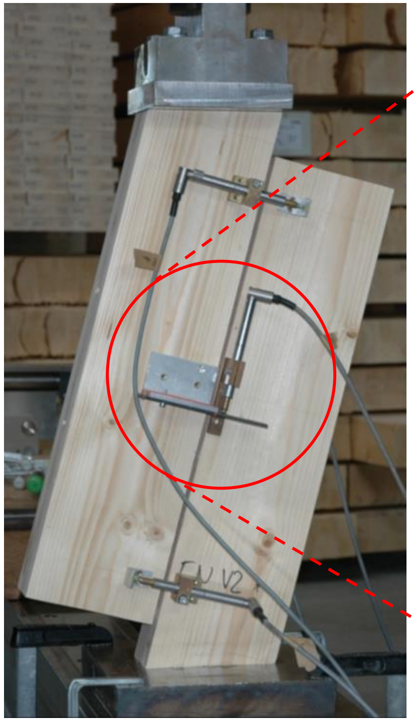


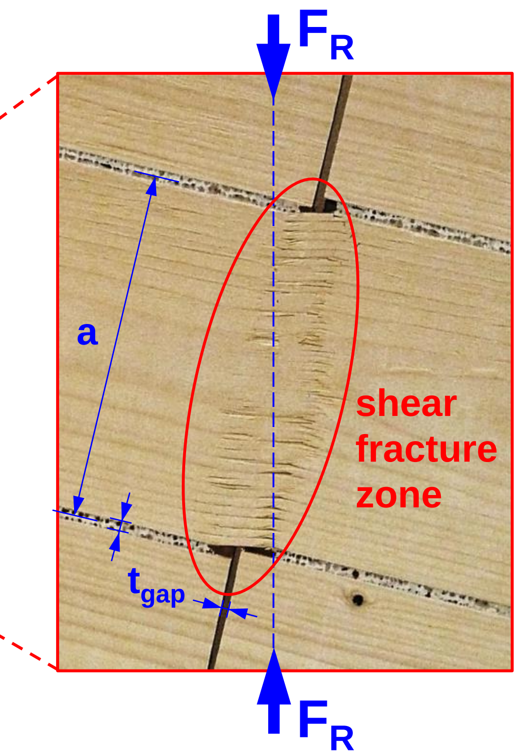
Shear Strength Test – [Mechanism I `Shear´]

Master Thesis B. Hirschmann (2011)

- **based on Jöbstl et al. (2008), EN 789 & EN 408**
- **loading in compression or tension (14° angle) → no significant influence!**







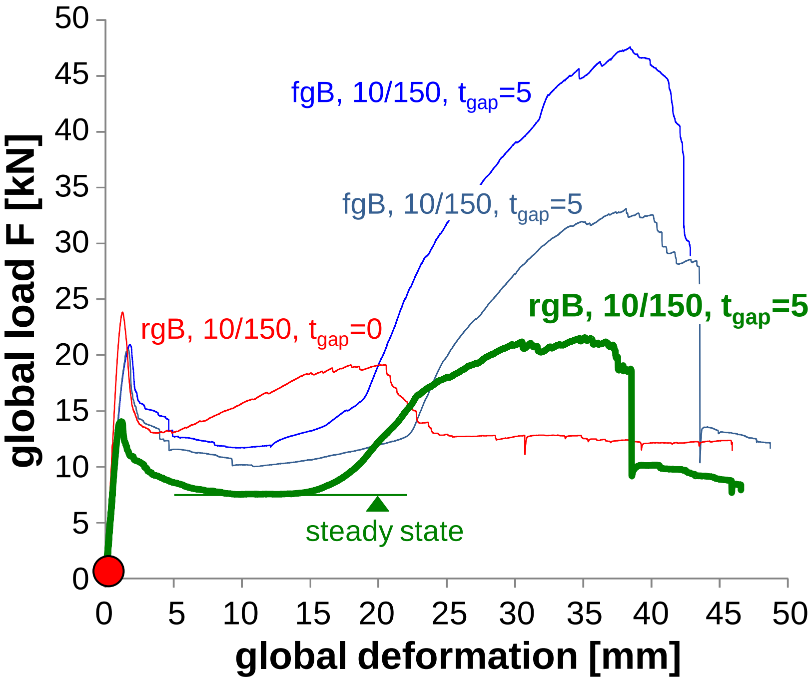
Failure Process – Sequence of Fracturing

I **linear elastic (≈ 20 to 80 % of F_{max})**

II **regressive, non-linear until F_{max} → locally mech. I & II**

III **softening, steady state (≈ 40 to 50 % of F_{max}) ➔ loading in bending & tension**

➔ shearing parallel to grain & successive dissolution by separation of annual rings



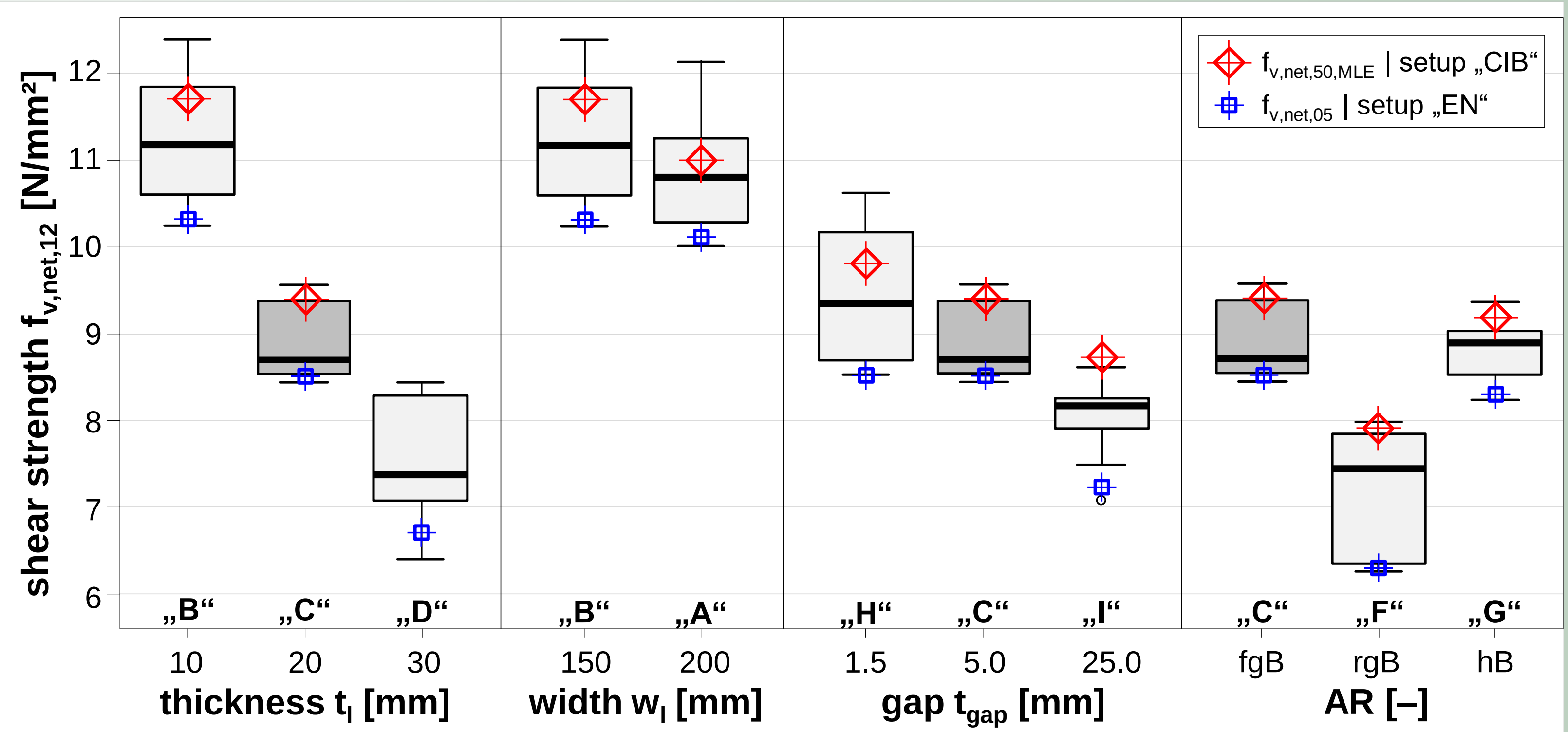
Failure Process

- **shear forces perpendicular to grain lead to shear failures parallel to grain!**
- **F_{max} (1st peak) governed by interacting mech. I & II**
  ➔ confirmed by numerical model
- **tremendous possibilities for load redistribution (steady state)**
- **successive dissolution, separation of annual rings at transition zone of early- and latewood → fixed-end beams active in bending & tension**
  ➔ confirmed by simple engineering model

Tests

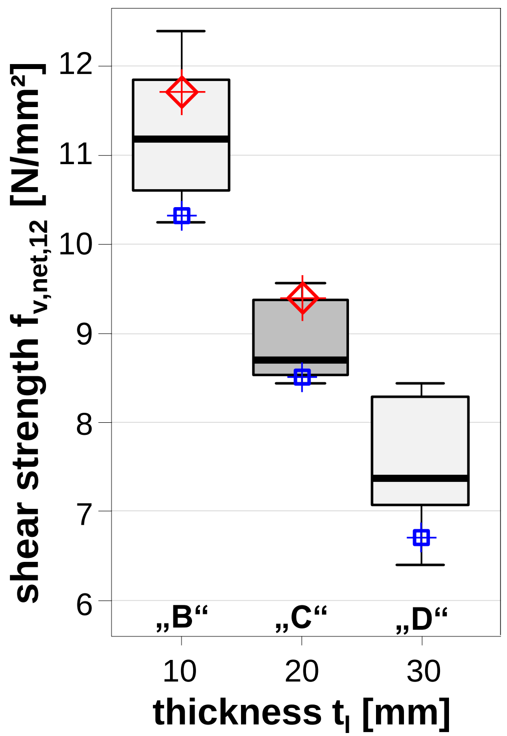
- **Norway spruce | C24 | u = 12 % | density matched samples**
- **top layers w_l x t_l = 150 x 40 mm²**
- **fracture zones free of knots, checks, reaction wood, …**
- **test parameters (core layers)**
  - **width w_l 150 mm** vs. 200 mm
  - **thickness t_l** 10 mm vs. 20 mm vs. **30 mm**
  - **annual ring orientation AR flat grain (fgB)**, rift grain (rgB), heart boards (hB)
  - **gap width t_{gap}** 1.5 mm vs. **5.0 mm** vs. 25.0 mm
- **10 tests per series**
- **comparison of configurations „EN“ (Hirschmann, 2011) and „CIB“ (Jöbstl et al., 2008)**

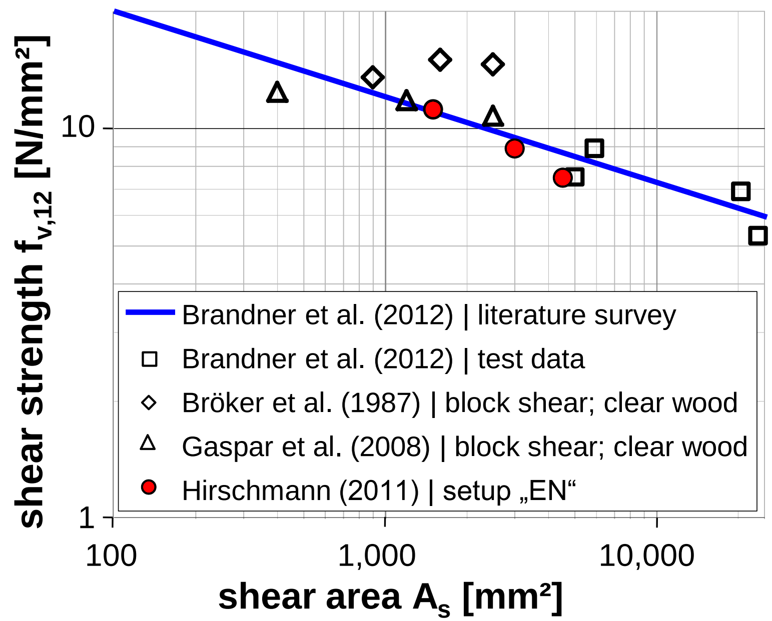
RESULTS „EN“



constant base parameters	w_l = 150 | t_{gap} = 5 fgB			t_l = 10 | t_{gap} = 5 fgB		w_l = 150 | t_l = 20 fgB			w_l = 150 | t_l = 20 t_{gap} = 5		
ρ_{mean} [kg/m³]	401	399	395	401	396	413	399	419	399	397	443
$f_{v,net,mean}$ [N/mm²]	**11.2**	**8.9**	**7.5**	**11.2**	**10.8**	**9.5**	**8.9**	**8.0**	**8.9**	**7.2**	**8.8**
CV[$f_{v,net}$] [%]	6.3	4.9	9.3	6.3	6.0	8.5	4.9	5.6	4.9	10.1	4.2
$f_{v,net,05}$ [N/mm²]	10.3	8.5	6.7	10.3	10.1	8.5	8.5	7.2	8.5	6.3	8.3

RESULTS „EN“





constant base parameters	w_l = 150 | t_{gap} = 5 fgB		
ρ_{mean} [kg/m³]	401	399	395
$f_{v,net,mean}$ [N/mm²]	11.2	8.9	7.5
CV[$f_{v,net}$] [%]	6.3	4.9	9.3
$f_{v,net,05}$ [N/mm²]	10.3	8.5	6.7

✓

- **high significant influence!**
- **two reasons**
  - size effect on shear strength (+)
  - locking effect (+)
- **decrease with power ≥ 0.2**

Results

- **significantly influencing parameters**
  - **lamella thickness t_l** → decreasing $f_{v,net}$ with increasing t_l
  - **gap width t_{gap}** → decreasing $f_{v,net}$ with increasing t_{gap}
  - **annual ring orientation AR** → $f_{v,net,\mathbf{rgB}} \leq f_{v,net,\mathbf{hB}} \leq f_{v,net,\mathbf{fgB}}$
- **not significant parameter**
  - **lamella width w_l** → 150 mm ≤ w_l ≤ 200 mm

Proposed Reference Material and Geometric Parameters

- **$t_{l,ref}$ = 30 mm** ($t_{l,st}$ = 20, 30, 40 mm)
- **$w_{l,ref}$ = 150 mm** (100 mm ≤ w_l ≤ 240 mm)
- **t_{gap} ≤ 5 mm** (0 mm ≤ t_{gap} ≤ 4 (6) mm)
- **AR = fgB**

Results

- **proposal for test configuration net-shear on single nodes**

- **shear perpendicular to grain …**
  - failure in shear parallel to grain | interaction mech. I & II
  - high potential of load redistribution
  - analogies with shear parallel to grain, e.g. AR, t_l, w_l

- **proposal for net-shear of single nodes for …**
  - $t_l \leq 40$ mm, $w_l = 150$ mm, AR = fgB, $t_{gap} \leq 6$ mm
  - assuming $CV[f_{v,net}] = 15$ %, $f_{v,net}$ ~ 2pLND

➔ **$f_{v,net,05} = 5.5$ N/mm²**

<u>latest series 2013 (12 #)</u>
30 x 150 mm², fgB, $t_{gap} = 0$ mm, $\rho_{12,mean} = 438$ kg/m³ → **$f_{v,net,05} = 6.4$ N/mm²**

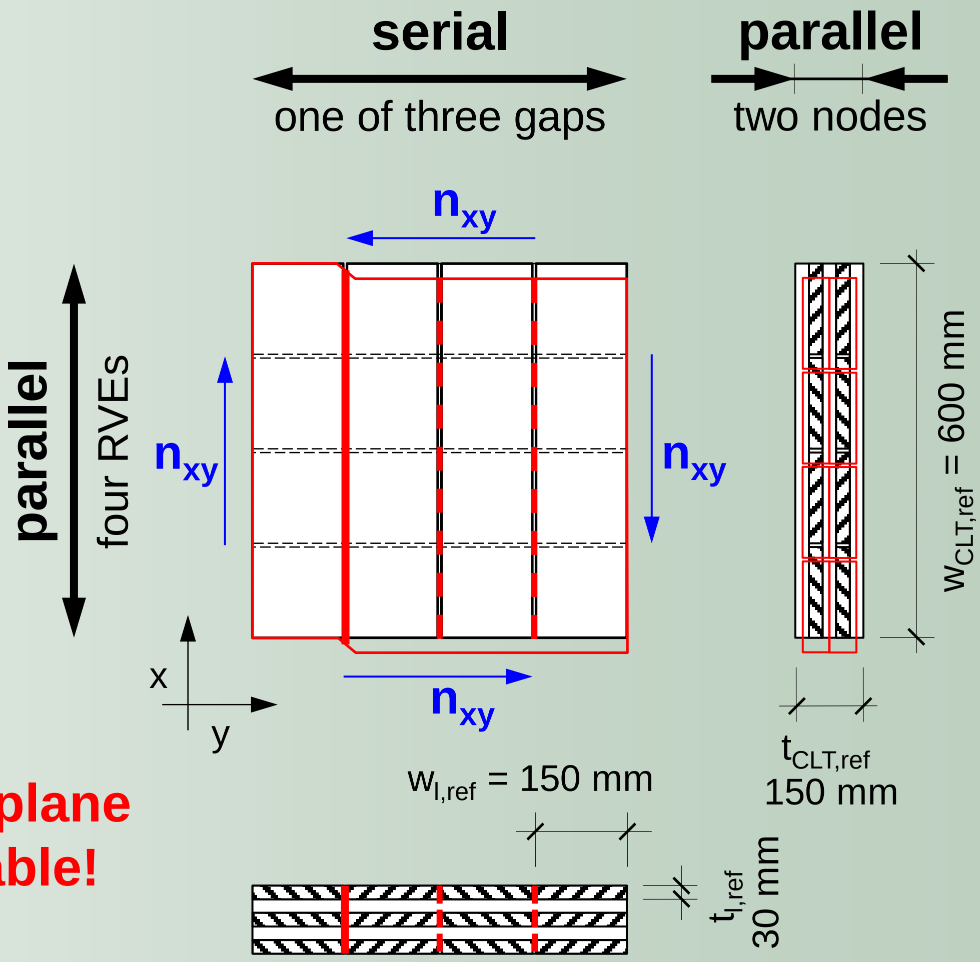
Proposed Reference CLT Diaphragm

- reference lamella w_l x t_l = 150 x 30 mm²
- reference CLT element
  - 5 layers | t_{CLT} = 150 mm
  - 4 x 4 nodes | w_{CLT} = 600 mm

Net Shear in CLT Element

- net shear failure only if all nodes in x-direction fail (parallel)
- serial system action in y-direction
- high potential for load transfer

➔ current verification of shear in plane on single nodes judged as reliable!



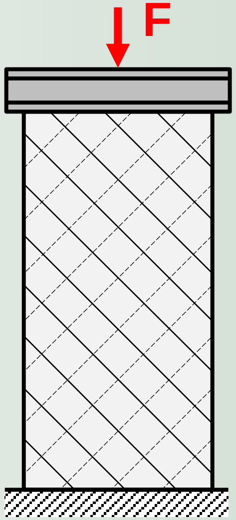
3 Tests on CLT Elements

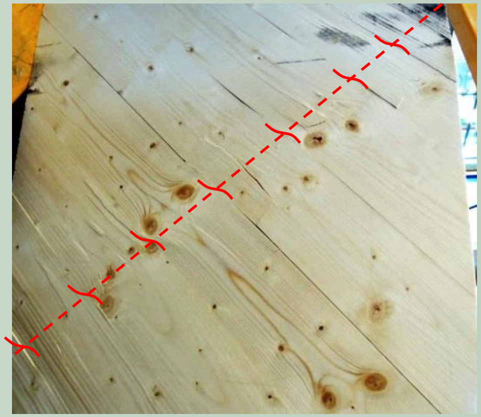
- **Norway spruce C24**
- **w_l = 105 mm | layup 20 | 30 | 20 | 30 | 20 mm**
- **CLT element 120 x 600 x 1,200 mm³**
- **config. & analysis acc. to Kreuzinger (2013)**

➔ failure acc. to mechanism I „net-shear“

➔ interaction compression perp. to grain and shear considered

	$\tau_{gross,12}$ [N/mm²]	$f_{v,net,12}$ [N/mm²]
test 1	3.95	**7.89**
test 2	4.16	**8.32**
test 3	4.20	**8.40**





Shear Strength Test – [Mechanism II `Torsion´]

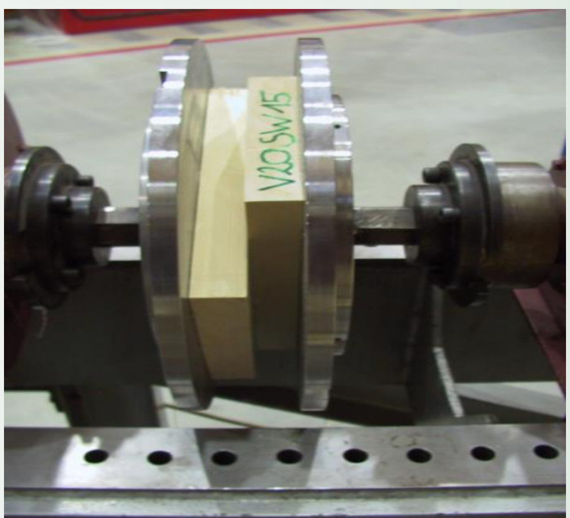
Diploma Thesis G. Jeitler (2004)

torsional shear stresses in the gluing interface

$$\tau_{T,max} = \frac{M_T}{I_P} \cdot \frac{1}{2} \cdot a = \frac{3 \cdot M_T}{a^3}$$

with $J_P = \frac{a^4}{6}$

M_T … torsional moment
J_P … polar sectional moment
… of gluing interface
a … dimension of RVE

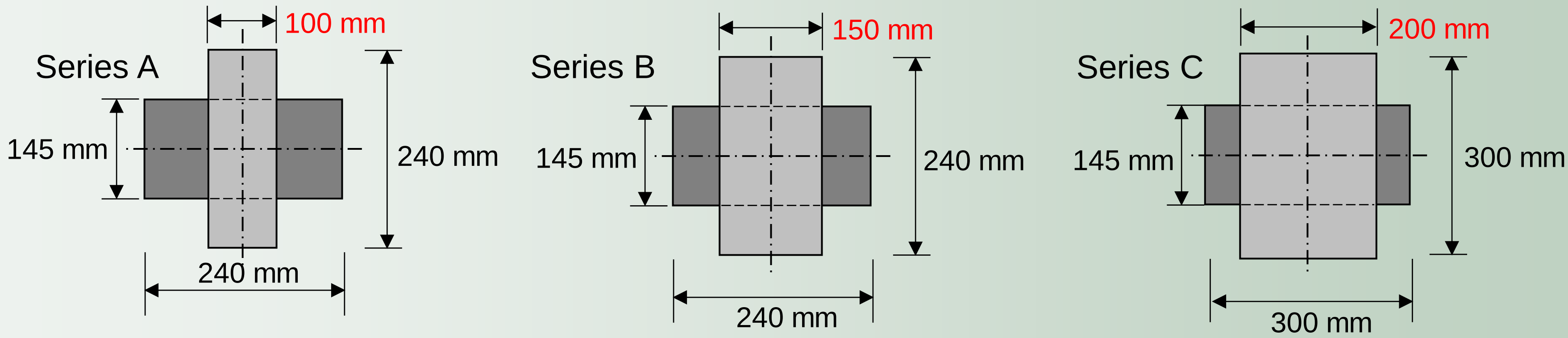


test specimen

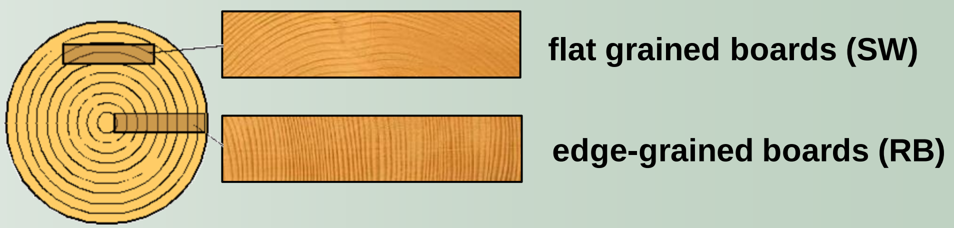
torsional test configuration

Shear Strength Test – [Mechanism II `Torsion´]

Diploma Thesis G. Jeitler (2004)



annual ring gradient
spruce



shear stresses in the gluing interface

series	annual ring orientation	5%-quantile [N/mm²]
A	edge grained	3.67
A	flat grained	2.79
B	edge grained	3.20
B	flat grained	2.69
C	edge grained	2.98
C	flat grained	3.10

$$\tau_{T,max} = \frac{3 \cdot M_T}{a^3}$$

$$f_{T,clt,k} = 2.5 \;\; N/mm^2$$

remark:
Value generally accepted!

Compression Perpendicular to the Grain

Design Value for Compression Stress Perp. to Grain

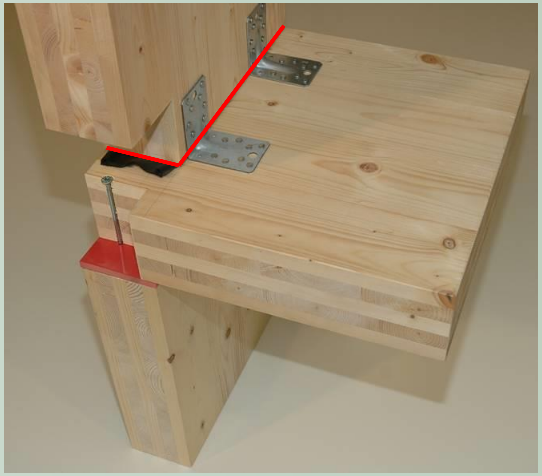
$$\sigma_{c,clt,90,d} = \frac{F_d}{A_{c,90}}$$

with: $A_{c,90}$ ... contact area

point supported | point supported | line supported

© Picture: DI R. Salzer (AUT)

© Picture: Architect Reinberg (AUT)



© Picture: TU Graz (AUT)

Compression Perpendicular to the Grain

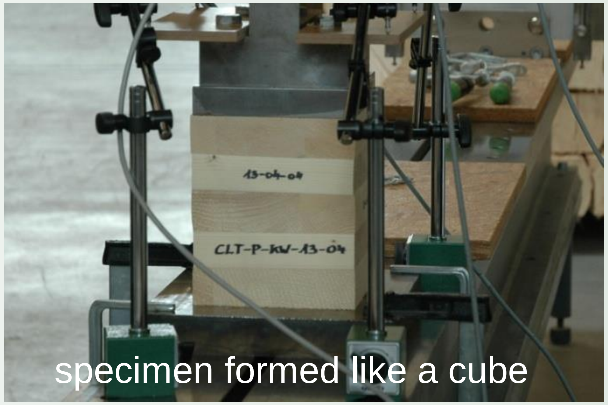
Material Resistance against Compression Perp. to Grain ($f_{c,clt,90,d}$)

publications regarding CLT:

- Y. Halili | TU Graz, 2008
- E. Serrano | Linnæus University, 2010
- C. Salzmann | TU Graz, 2010

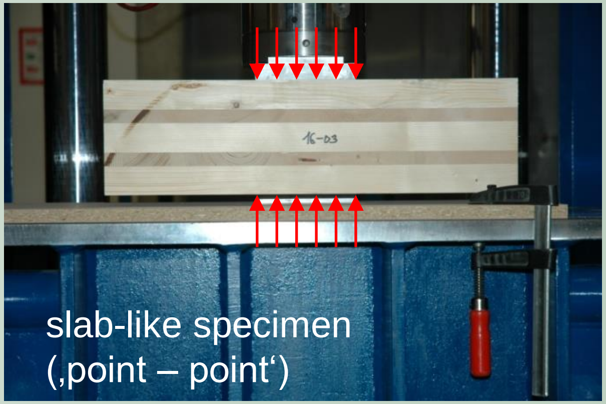
characteristic parameters:

- $f_{c,clt,90,d}$ | cube | slab-like specimen
- $k_{c,clt,90}$ (`hang-in effect´)
- $E_{c,clt,90,mean}$



specimen formed like a cube

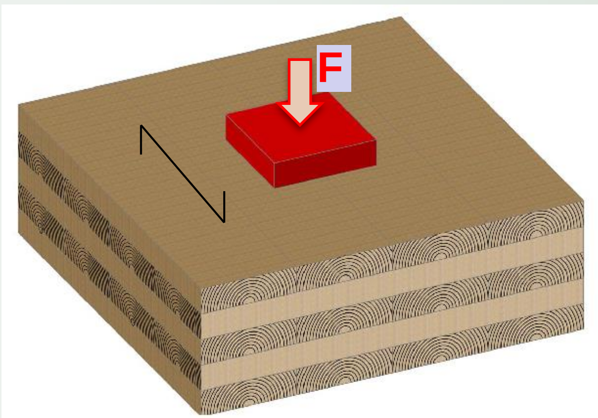

slab-like specimen


slab-like specimen (‚point – point‘)

Compression Perpendicular to the Grain

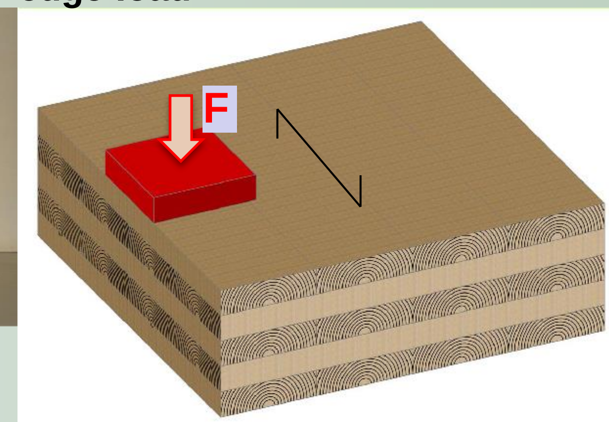
Different Loading Situations | Configurations on CLT Elements

center load

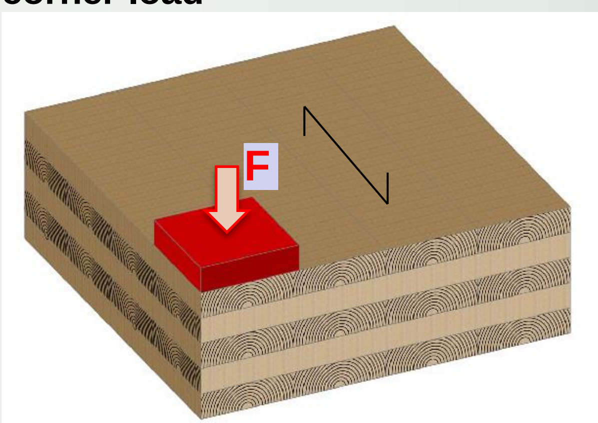


`hang-in effect´
(two sides)

edge load

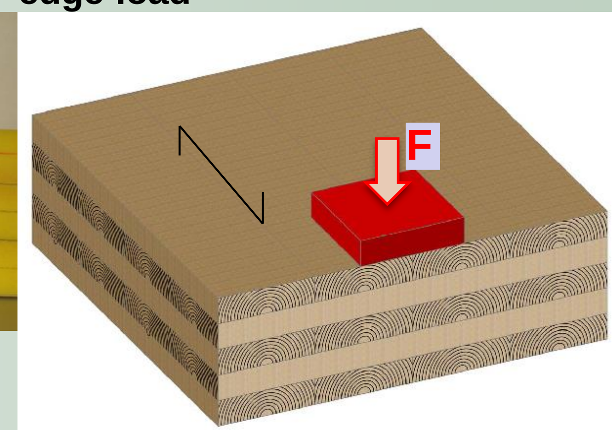


corner load



`hang-in effect´
(one side)

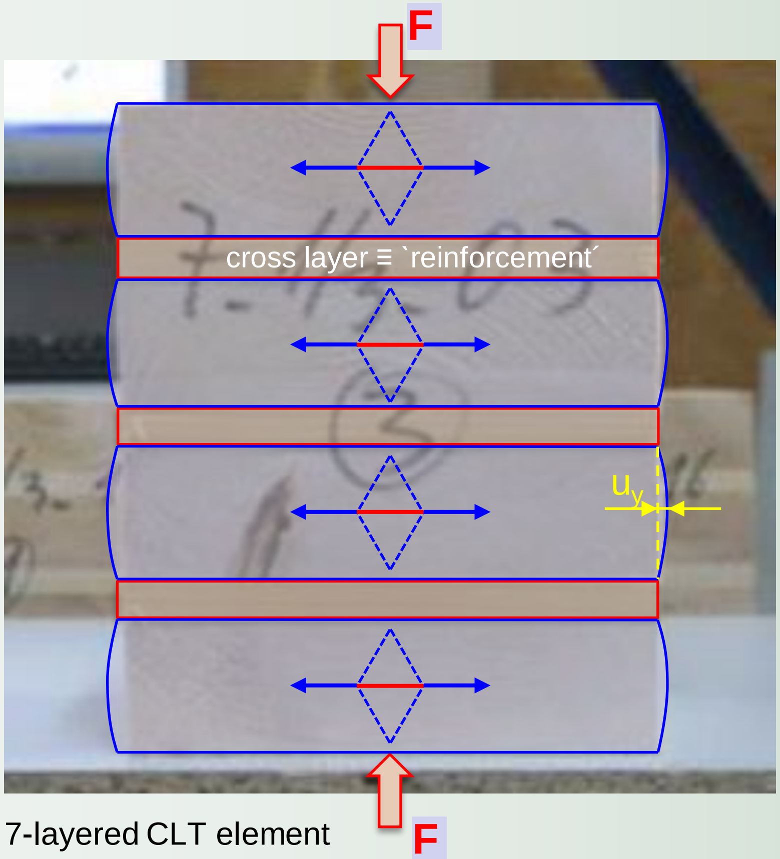
edge load



Compression Perpendicular to the Grain

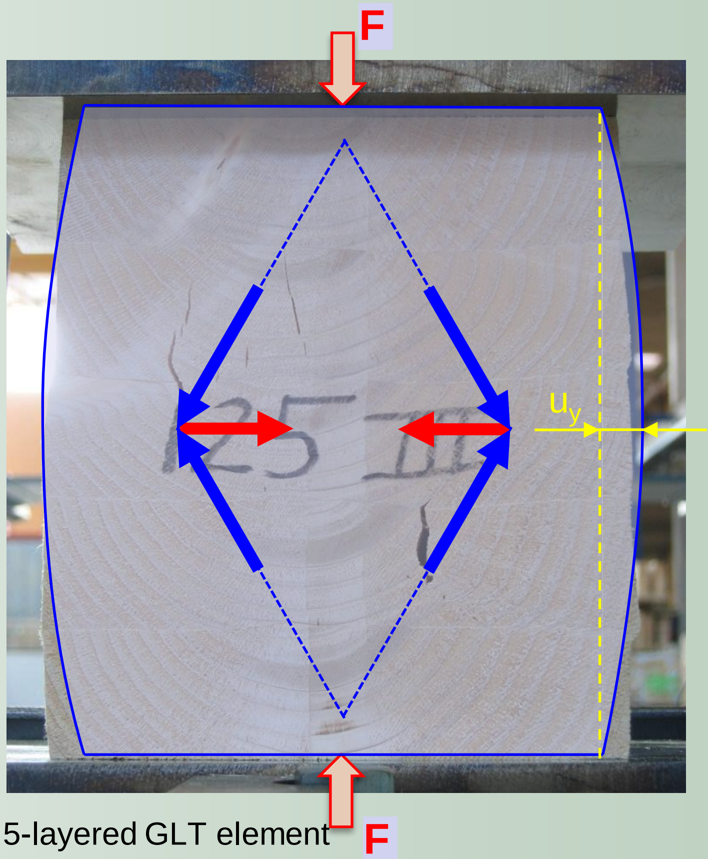
`Framework Model´

CLT cubes
failure mode:
deformation at defined failure stage



7-layered CLT element

GLT cubes
failure mode:
e.g. tension perp. to grain



5-layered GLT element

Compression Perpendicular to the Grain

The cross layers cause a `locking effect´ and therefore a reduction of deformation.

comparison of CLT to GLT at the same load level

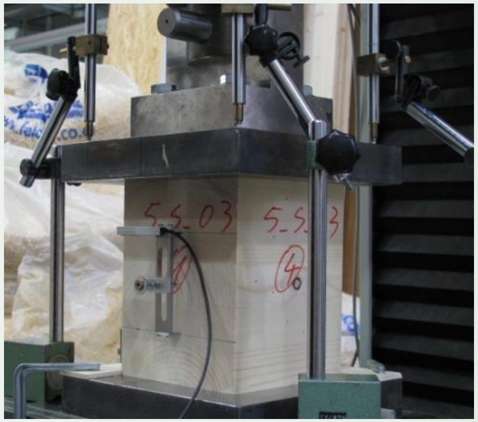
- ✓ CLT shows reduced deformation perp. to grain (u_y) concentrated on each single layer
- ✓ CLT shows higher stiffness and lower stresses in tension perp. to grain

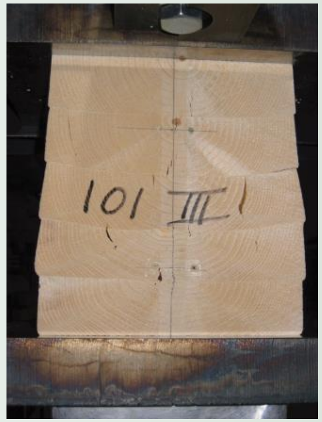
result:
lower failure probability at the same load level and **higher load bearing capacity** perpendicular to the grain

Compression Perpendicular to the Grain

Strength determined on standardised full-loaded Prismatic Specimen

GLT





CLT

$f_{c,glt,90,k}$ = 2.1 ... 2.4 N/mm² [res. publ.]

$f_{c,clt,90,k}$ = ... 3.0 ... 3.1 N/mm²

$f_{c,glt,90,k}$ = 2.5 N/mm²
(prEN 14080)

$f_{c,clt,90,k}$ = 3.0 N/mm²
(proposal TU Graz)

basic value for design

Compression Perpendicular to the Grain

Bearing Capacity in Constructions

GLT

CLT

edge
`line supported´

centric
`point supported´

proposal TU Graz

GLT

$k_{c,glt,90}$ = 1,0 ... 1,5 ... 1,75

$k_{c,clt,90}$ = ~ 1.5 = ~ 2.0

$$f_{c,glt,90,k} \cdot k_{c,glt,90} = 3.75\ N/mm^2$$

$$f_{c,clt,90,k} \cdot k_{c,clt,90} = 4.5 \ldots 6.0\ N/mm^2$$

+ 20 %

+ 60 %

- **Properties & Design**
  - Modification Factors and Characteristic Values
  - Methods of Design
- **Research & Testing**
  - Material
  - Connections
  - Structures
- **Conclusions**

Transport | Assembling

storage of CLT elements (production site)

charging and transport

discharging (building site)

mounting parts for roof elements

mounting parts for ceiling elements

mounting parts for wall elements

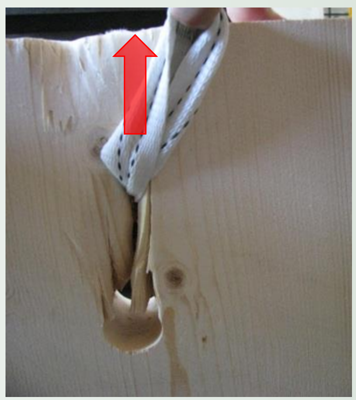
Mounting Parts for Transport and Assembling

for walls:

- ball-shaped head connected with self-tapping screws
- textile hanger with high strength and ductility

mounting part at the narrow side of a 3-layered CLT element

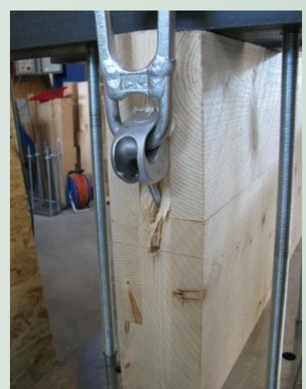
tension test configuration



failure mode with high deformation [safety factor:7]

in plane

`shear´



`pull out´

out of plane

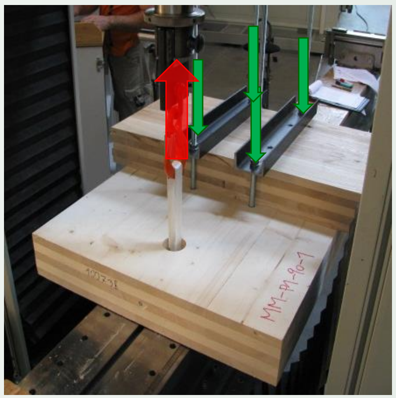
`shear´

failure modes

Mounting Parts for Transport and Assembling

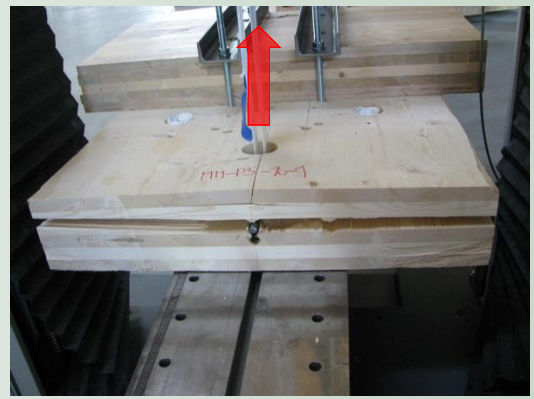
for ceiling and roof elements:

- tapped blind hole connection with dowel and textile hanger



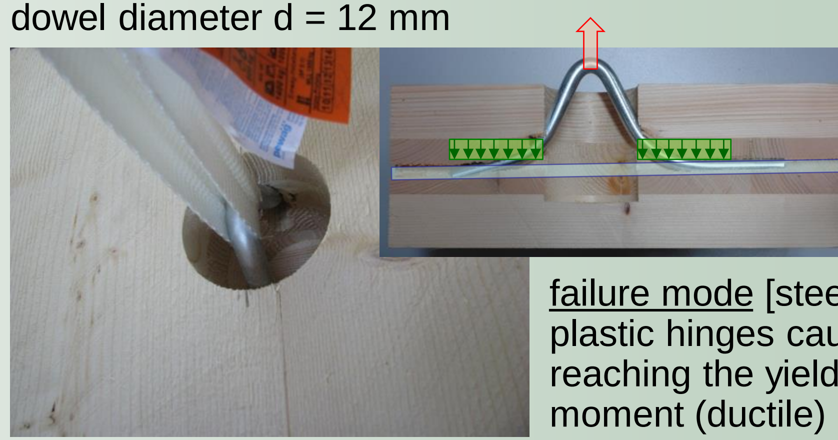
tension test configuration perp. to the grain

dowel diameter d = 16 mm



<u>failure mode</u> [timber] caused by tension perp. to the grain [rigid]

dowel diameter d = 12 mm



<u>failure mode</u> [steel dowel] plastic hinges caused by reaching the yield moment (ductile)

NOTE:

Extension of knowledge regarding the load carrying behavior of mounting parts is required! → Research activities are important!

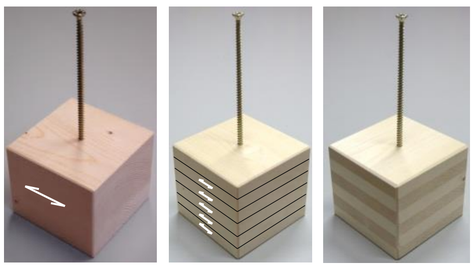
Screwed connections in CLT elements

6 main research projects

single screws

k_{sys}

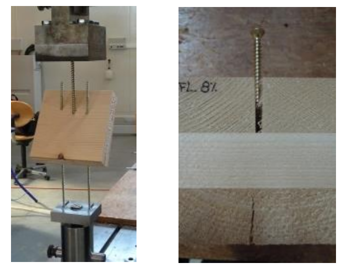
ST GLT CLT



k_{90} | k_{gap}

CLT - side face

α



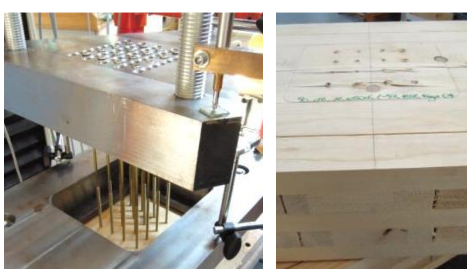
k_{90} | k_{gap}

CLT - narrow face

groups and line connections

n_{ef} | block shear

CLT - side face



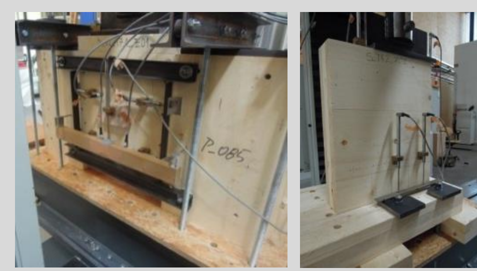
n_{ef}

CLT - narrow face

ONGOING

cyclic behaviour

CLT - side and narrow face



ONGOING

- **Properties & Design**
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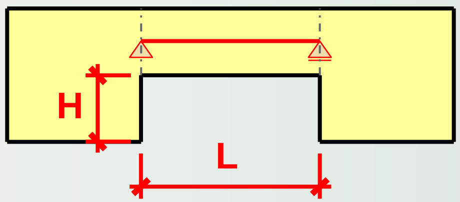
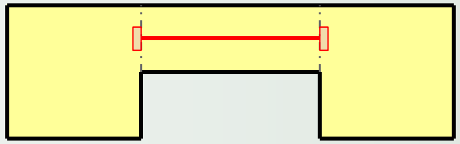
CLT Lintels

Master Thesis A. Reichhart (2013)

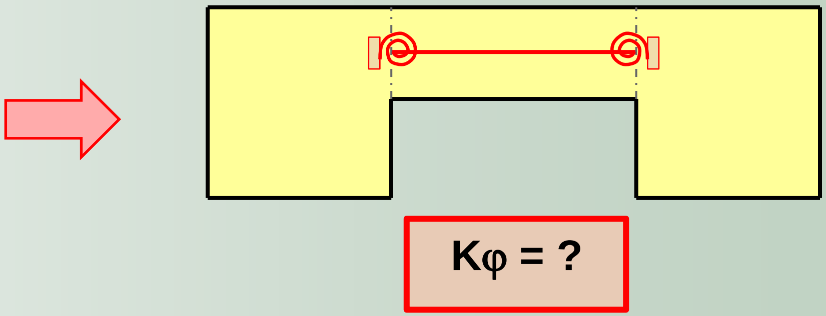
hinged support (conservative)



rigid support (progressive)



support with springs

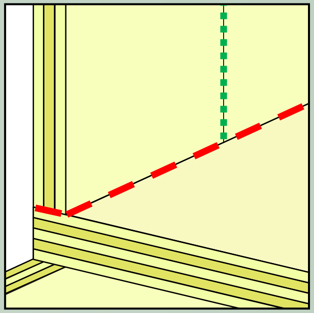


- **3-layered CLT elements**
- **tests with varying L/H ratio (5 ÷ 10)**
- **proposed degree of clamping: 65% if L/H ≥ 7.5**
- **high variance of F_{max}**
  - partially very low ultimate loads caused by knots in middle layer
    → **therefore: no high stressed lintels in 3-layered CLT elements**

Seismic Tests

3-steps

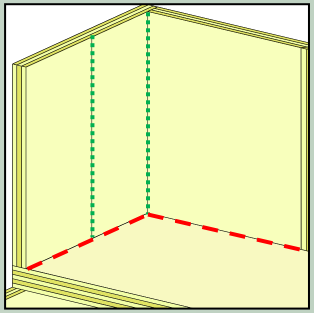
- **I – connections**
  - angle brackets, hold downs and screws
  - CLT/CLT and CLT/concrete/steel
  - shear and tension | monotonic and cyclic
  - about 200 tests



Seismic Tests

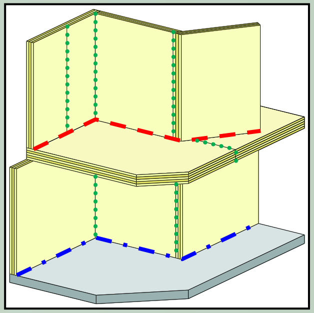
3-steps

- I – connections
- **II – walls**
  - 5 configurations – 17 tests
    - variation of connections, vertical loads and geometries
    - walls with and without vertical joints – with and without door opening



Seismic Tests

3-steps



- I – connections
- II – walls
- **III – building**
  - shaking table tests on a three-storey building
  - EU-project ‚SERIES' (***S**eismic **E**ngineering **R**esearch **I**nfrastructures for **E**uropean **S**ynergies*)

- **Properties & Design**
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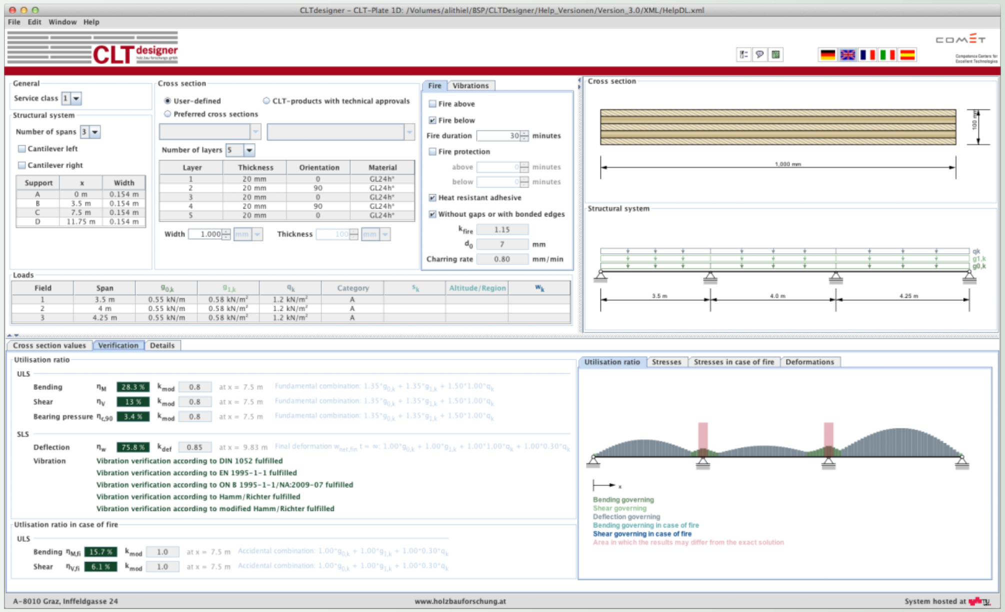
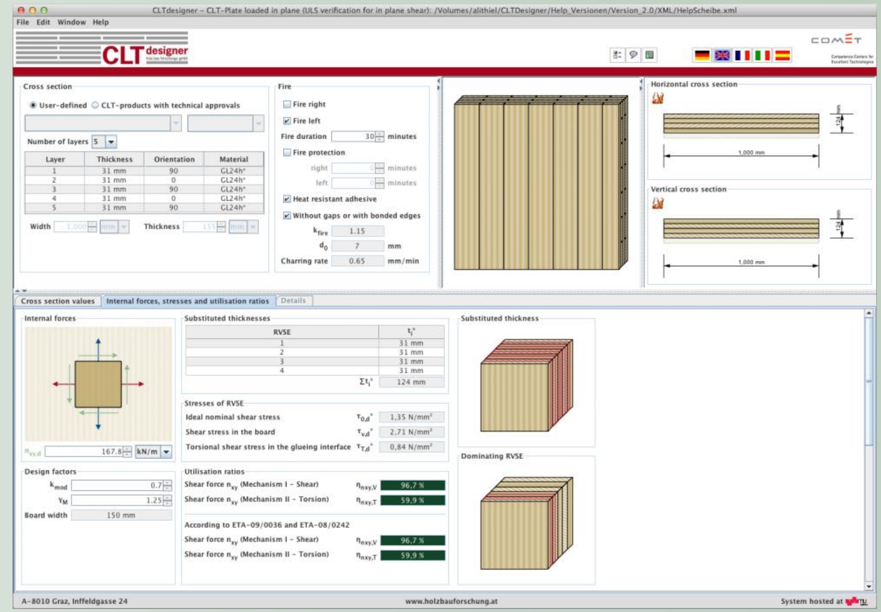
Conclusions

1. The development of CLT about 25 years ago provides a panel-like product for timber constructions. Combined with one-dimensional GLT members, it was - and still is - possible to open up new markets for timber products.
2. Enhanced by the simultaneously occurring development of screw technology for innovative connection concepts, new possibilities regarding construction and spans were created, increasing the market of timber products.
3. An ongoing trend concerning both solid timber construction with CLT and connection systems with screws is to be expected.
4. An increasing competition for resources, also affecting forest and timber industry, can be noticed too. This will lead to a selective and resource-friendly use of wood diversity.
5. An intelligent mix of solutions in solid and lightweight construction combined with the use of regionally available wood diversity, will gain more visibility in future timber engineering.

CLTdesigner – The software tool for designing cross laminated timber elements (CLT)

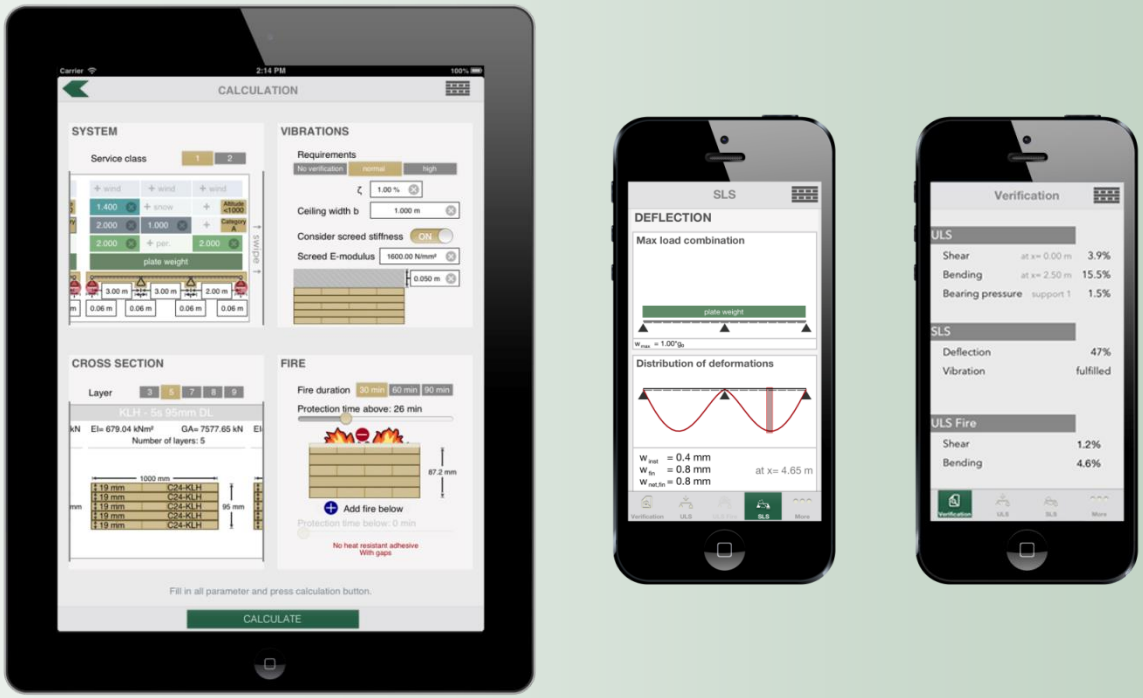




- based on the design concepts of Eurocode 5 and numerous research works
- built up of modules
- developed and provided by the Centre of Competence holz.bau forschungs gmbh and the Institute of Timber Engineering and Wood Technology of Graz University of Technology
- available in DE, EN, FR, IT and ES at **www.cltdesigner.at**

CLTcalculator - First CLT App for iPhone and iPad

developed by A. Mikara
in corp. with the
Institute of Timber Engineering and Wood Technology



Available on App Store!

THANKS FOR ATTENTION!

Contact

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