Determination of Shear Strength of Structural and Glued Laminated Timber

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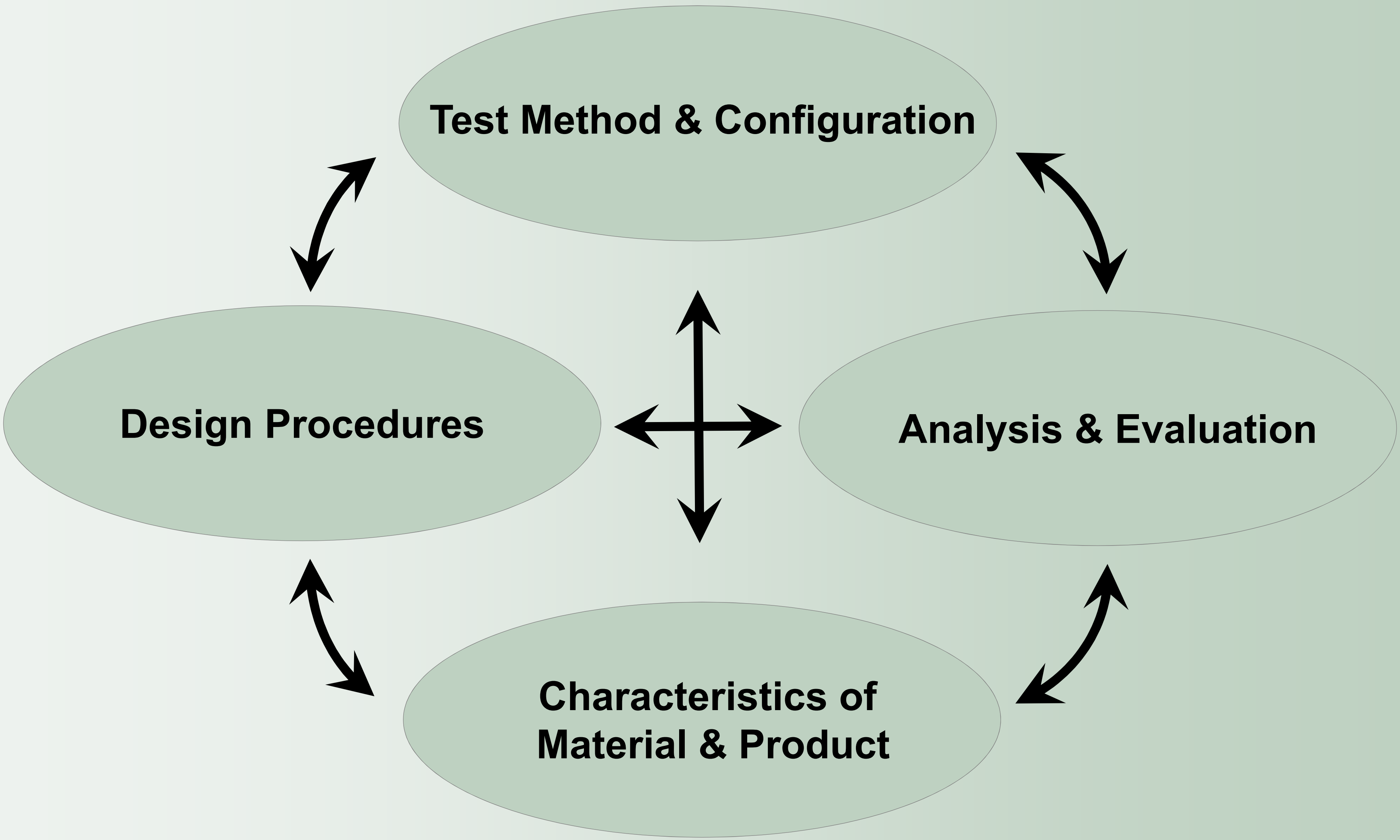
Linnaeus University | Växjö | Sweden

- General Thoughts
- Test Program & Results
- Conclusions

- **General Thoughts**
- Test Program & Results
- Conclusions


Test Method & Configuration
Design Procedures
Analysis & Evaluation
Characteristics of Material & Product

Main Influences (generally and on Shear Characteristics)

(i) Climatic Conditions

(ii) Material Structure (Relationships; Size & Scale Effects)

(iii) Test Method & Configuration

(iv) Duration of Load & Cyclic and / or Dynamic Loading

Ad (i) Climatic Conditions

Literature source (f_v)	Moisture Content (u)	Temperature (T)
Pine [Kollmann, 1951]	~2.4% / 1% Δ MC	--
Southern Pine [Kretschmann & Green, 1994]	~2.7% / 1% Δ MC	--
Douglas Fir & Southern Pine [Rammer & McLean, 1996]	~5.3% / 1% Δ MC	--
[Gerhards, 1980]	~2.6% / 1% Δ MC	0.4% / Δ 1 C

PROPOSAL

➔ **u_{ref} = 12% | T_{ref} = 20°C**

➔ **f_v –3% / +1% u, for 8% ≤ u ≤ 20% | -- / ±1°C, for 15°C ≤ T ≤ 25°C**

➔ **G_{090} –1% / +1% u, for 8% ≤ u ≤ 20%**

Ad (ii) Material Structure (Relationships; Size & Scale Effects)

- **$f_{v,RL}$ positively correlated with ρ_{12}; $f_{v,TL} \neq f\,\{\rho_{12}\}$**
  → in TL failure in earlywood; in RL shearing of early- and latewood!

- **f_v positively correlated with G_{090}**

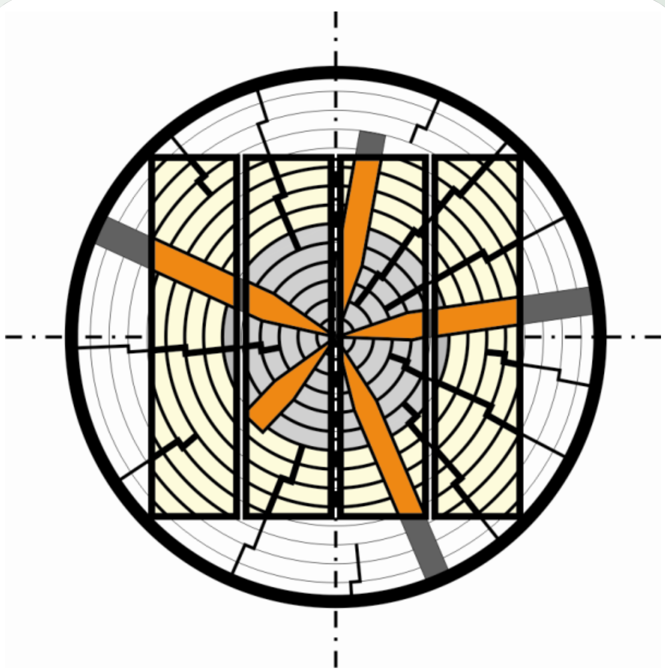
- **$f_{v,RL}$ significantly affected by σ_{90}; $f_{v,TL}$ minor!** (Keenan, 1973 & 1974)

Ad (ii) Material Structure (Relationships; Size & Scale Effects)

- contrary to EN 338 (ST) & EN 1194 (GLT)
  f_v is not or solely minor positively correlated with f_m!
  ➔ **f_v not significantly influenced by timber quality!**
  (e.g. Denzler & Glos, 2007; Gatternig, 2012; Schickhofer, 2001 (GLT); Rammer & Soltis, 1994)

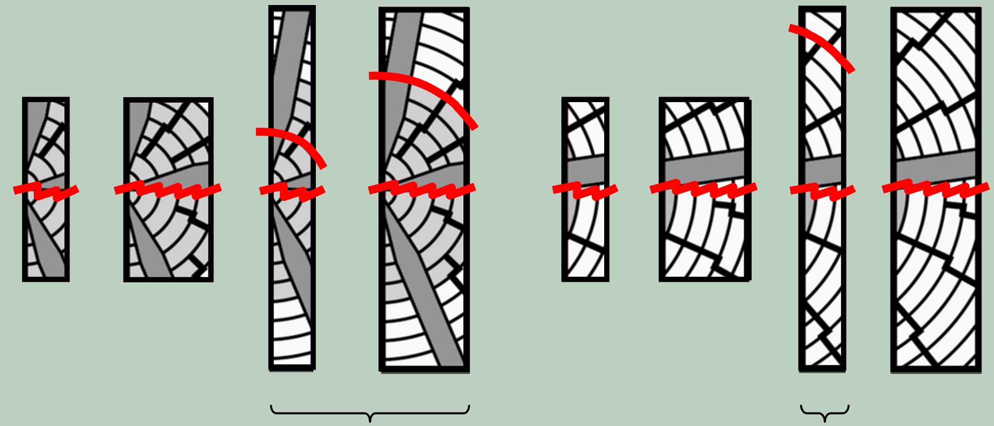
- **checks reduce f_v in RL; no or only minor effect on $f_{v,TL}$!**

- **knots increase f_v in TL; no or even a negative effect on $f_{v,RL}$!**
  ➔ **f_v = f {radial position within the log; shear plane}**



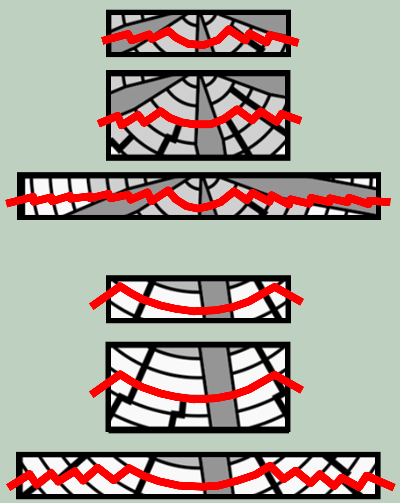
ST EDGEWISE

→ shear failure mainly in RL!
→ reduction of f_v by knots & checks!



increase in depth raises failure causes & planes!

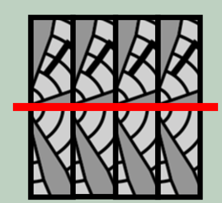
ST FLATWISE



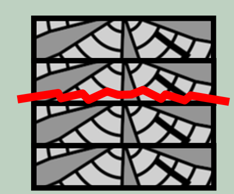
→ shear failure mainly in TL & TL/RL!
→ knots reinforce!

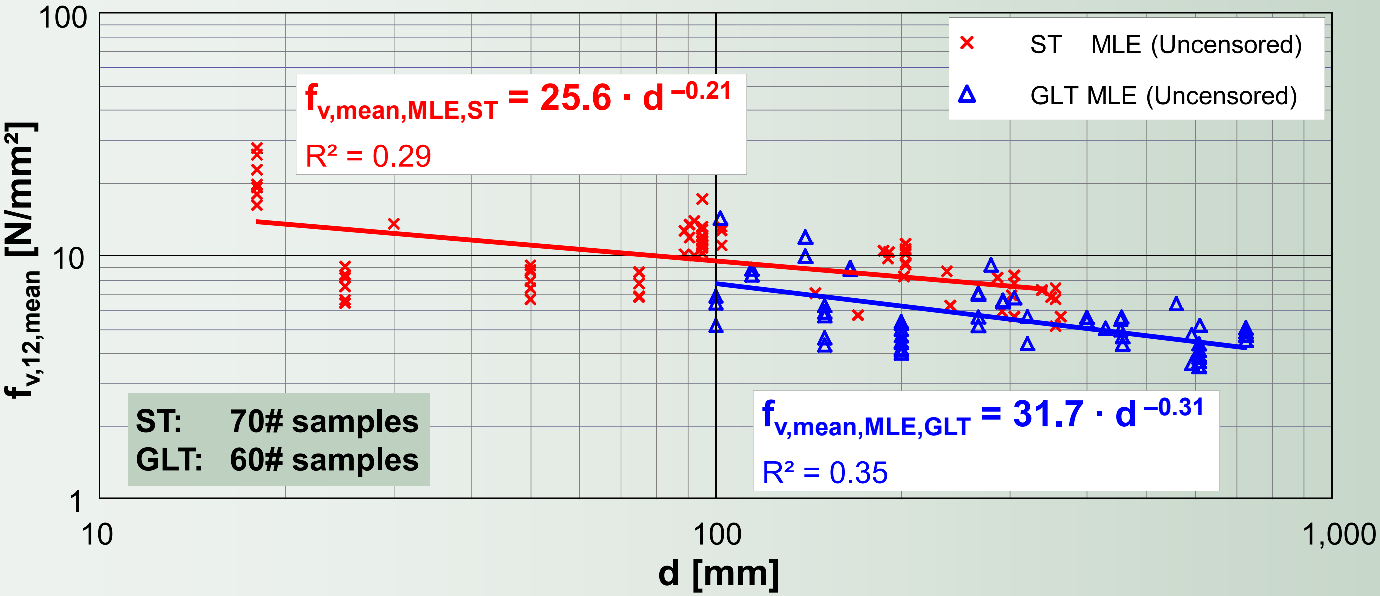
GLT FLATWISE / EDGEWISE

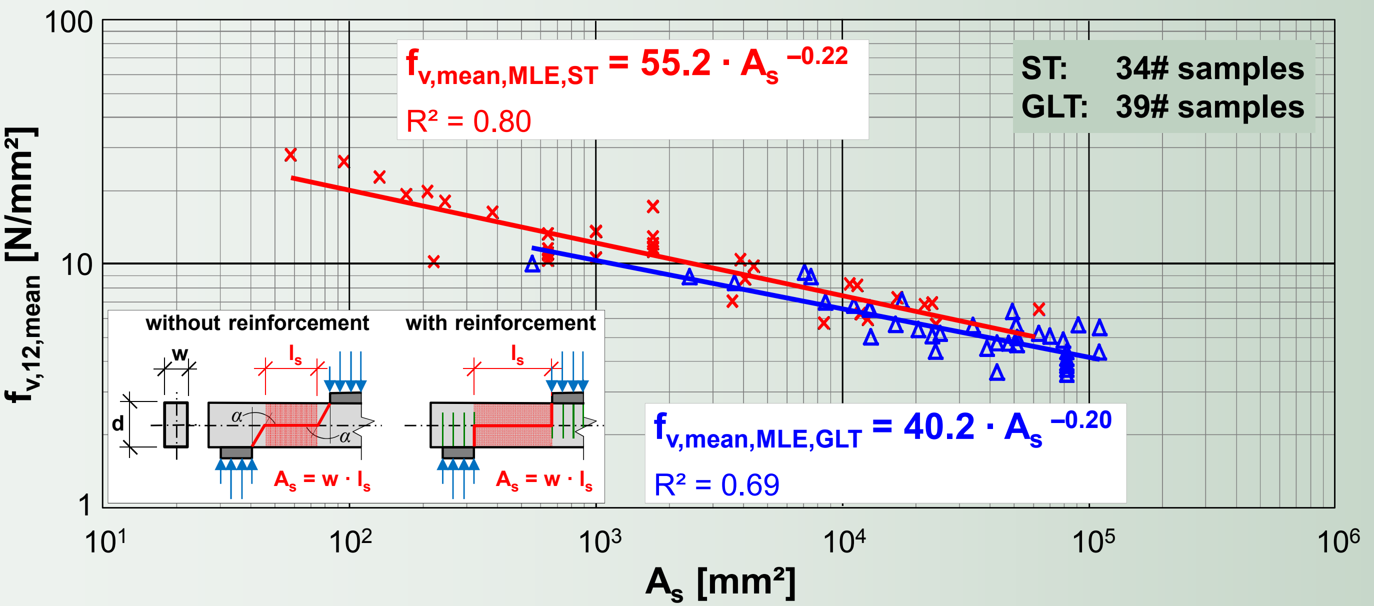
parallel



serial







Literature Survey

- bending tests only (3p, 4p, 5p)
- diverse timber species
- adapted to u_{ref} = 12%
- MLE for right censored data

➔ f_v ➔ f {size}

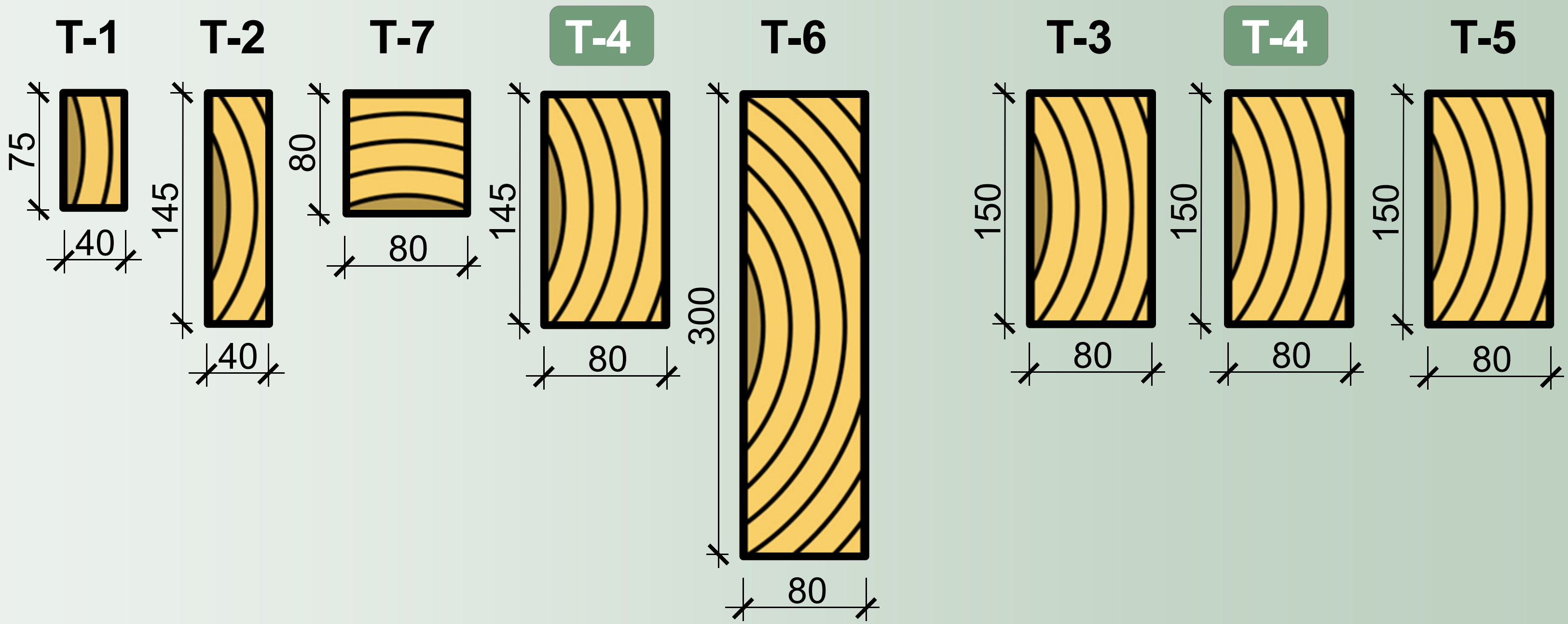
➔ power regression $\lambda \approx 0.20$

➔ $f_{v,ST} > f_{v,GLT}$

- General Thoughts
- **Test Program & Results**
- Conclusions

TEST SETUP

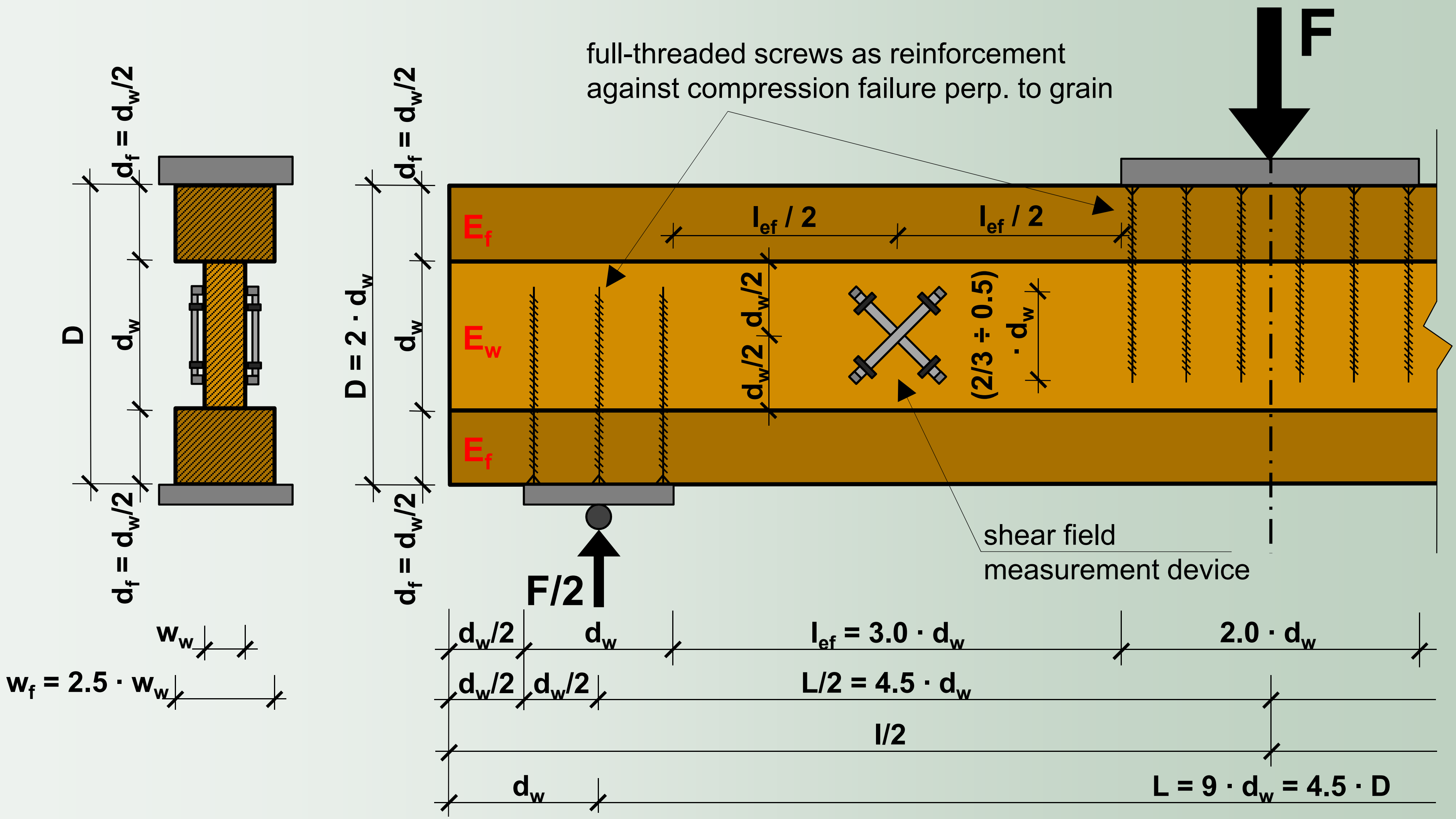
Influence of Size & Orientation of Annual Rings | Influence of Timber Quality



	T-1	T-2	T-7	T-4	T-6	T-3	T-4	T-5
N	39#	31#	35#	40#	14#	10#	40#	38#
NGC	C24	C24	C24	C24	C24	„C16“	C24	„C40“
L / D	4.8	4.3	3.5	4.4	4.8 / 5.0	3.4	4.4	4.8
$\rho_{12,mean}$ [kg/m³]	447	449	430	414	417	389	414	467
$E_{t,0,12,est,mean}$ [N/mm²]	11,310	12,190	10,750	11,420	11,710	8,510	11,420	14,250

TEST CONFIGURATION (PROPOSED GEOMETRY)

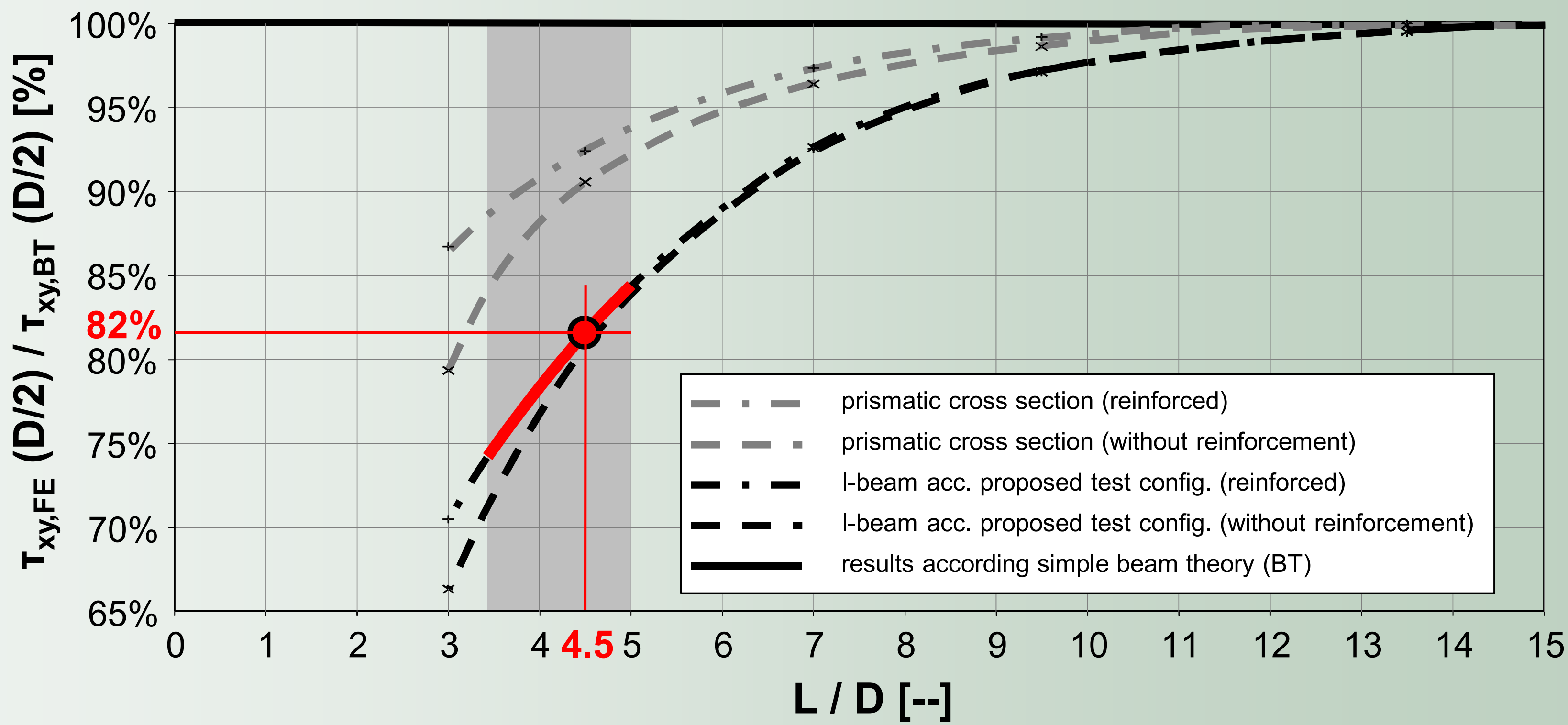
$E_w \approx E_f$ ¦ $[F \mid f_{v,95}] \geq f_{m,05}$ ¦ $\sigma_{t,0,pl,w} = [\sigma_{m,05,w} \mid \tau_{95,w} = f_{v,95,w}]$

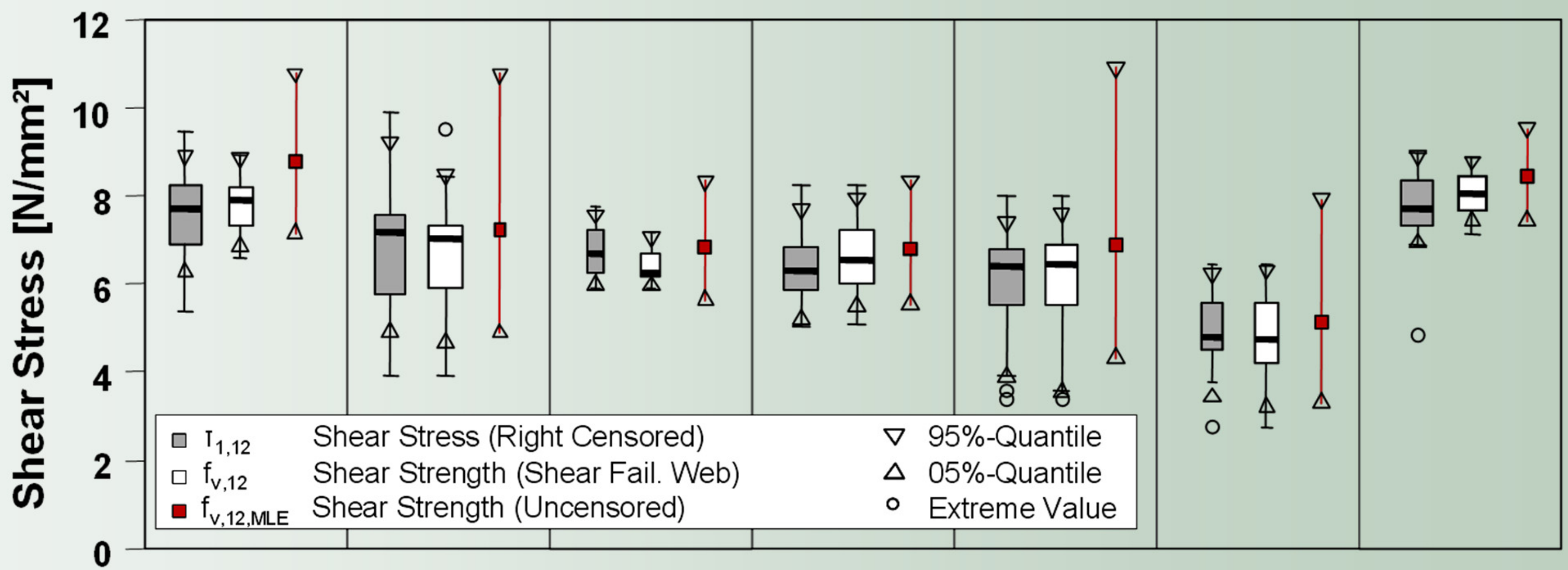


ISO/FDIS 8375:2008 (prismatic) $l_{ef} \geq 2.0 \cdot D$ | Schickhofer (2001; I-beam) $l_{ef} = 3.3 \cdot d_w$; $L = 5 \cdot D$

- FE-analysis in RFEM (4.xx): prismatic & I-beams acc. proposed test configuration
- $w_{w,ref}$ / $d_{w,ref}$ = 80mm / 150mm
- orthotropic material C24; 2D

FE – STUDY



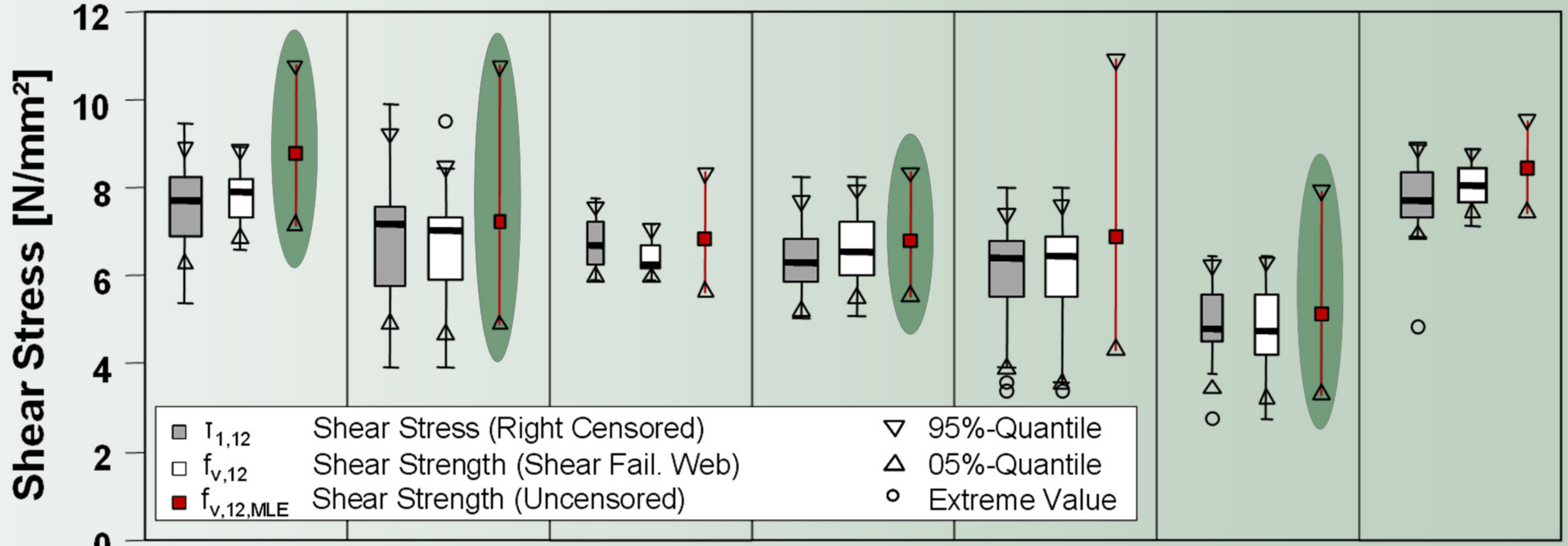


Test Series	T-1			T-2			T-3			T-4			T-5			T-6			T-7		
Depth	75			145			150			150			150			300			80		
Width	40			40			80			80			80			80			80		
Quantity	39 #	10 #	39 #	31 #	21 #	31 #	10 #	7 #	10 #	40 #	21 #	40 #	38 #	19 #	38 #	14 #	10 #	14 #	35 #	13 #	35 #

Series		T-1	T-2	T-3	T-4	T-5	T-6	T-7
$f_{v,MLE,12}$ [N/mm²]	mean	8.9	7.5	6.9	6.9	7.2	5.3	8.5
	CoV	12.5%	24.4%	11.9%	12.5%	28.6%	27.1%	7.5%
$f_{v,MLE,adj,12}$ [N/mm²]	adj.	84%	80%	74%	81%	84%	84%	75%
	mean	**7.4**	**6.0**	**5.1**	**5.6**	**6.0**	**4.5**	**6.3**
	CoV	**15.0%**	**30.4%**	**16.1%**	**15.4%**	**34.3%**	**32.1%**	**10.1%**

RESULTS – doubling of depth

RESULTS



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Depth	75 →			145			150			150 →			150			300			80		
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Quantity	39 #	10 #	39 #	31 #	21 #	31 #	10 #	7 #	10 #	40 #	21 #	40 #	38 #	19 #	38 #	14 #	10 #	14 #	35 #	13 #	35 #

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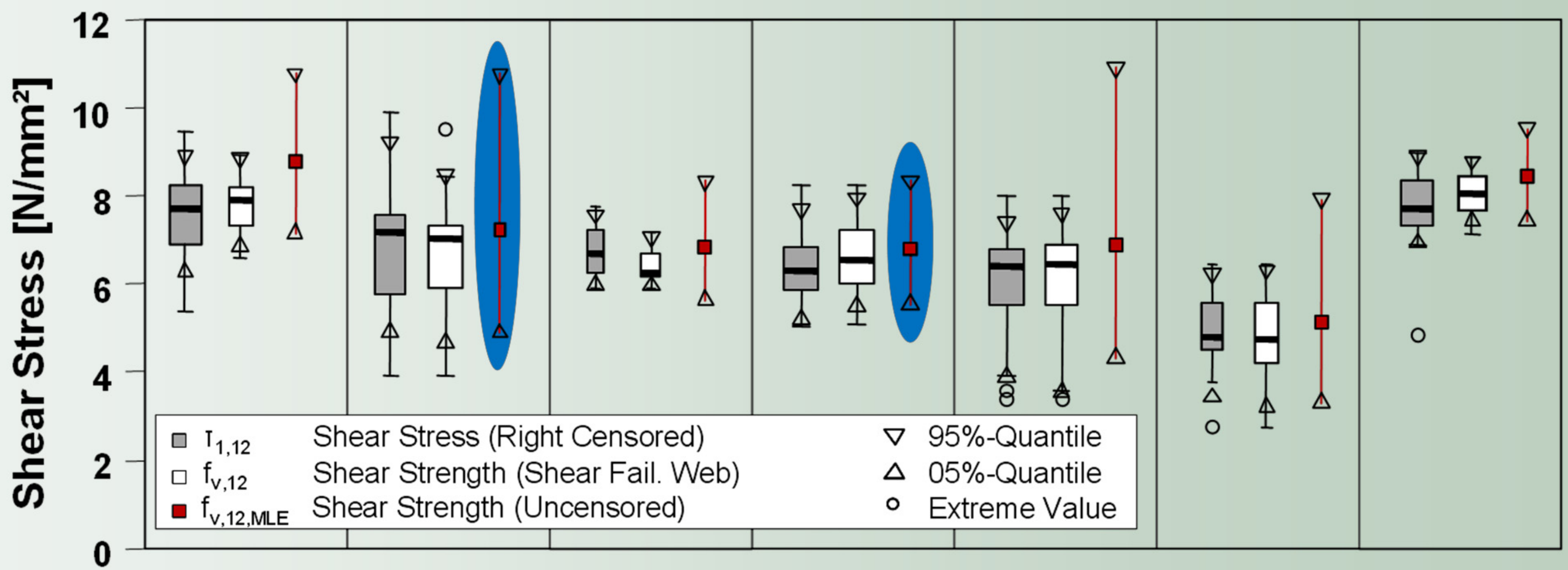
RESULTS



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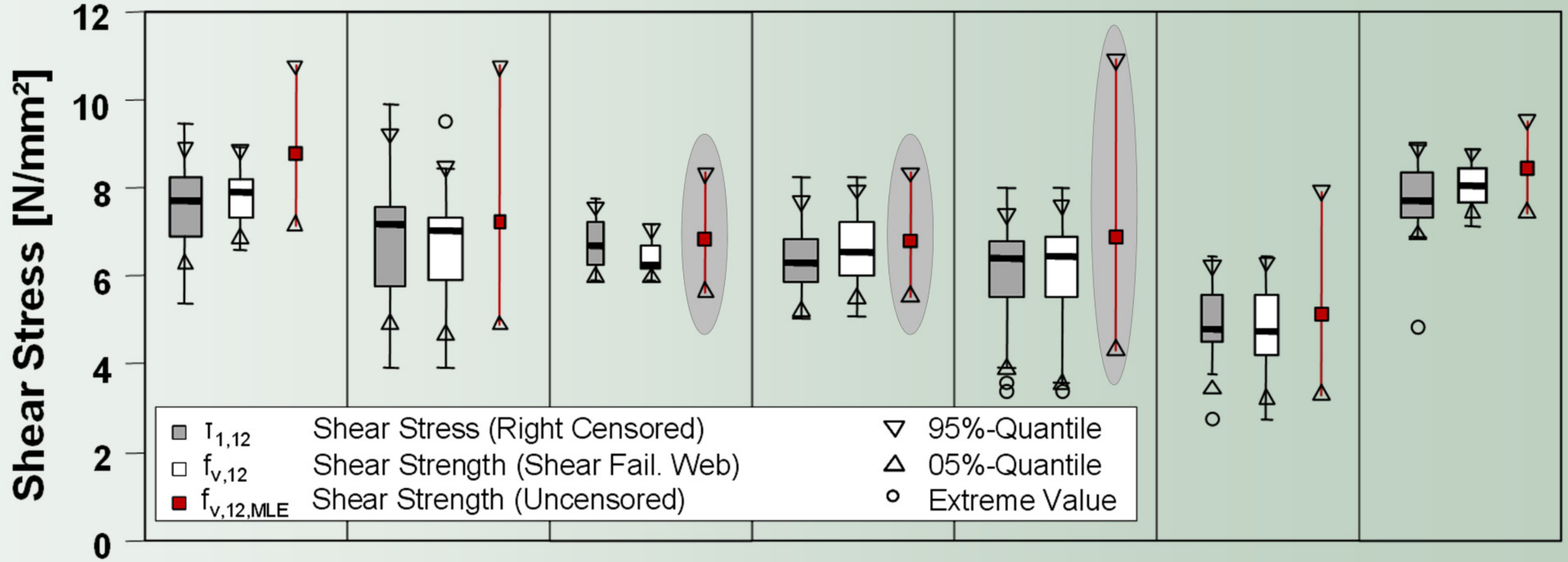
RESULTS – effect of timber quality

RESULTS



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T-3 ← T-4 → T-5

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TEST METHOD & CONFIGURATION

- **3pB-test**
- **visually unchecked beams**
- **reference cross sections**

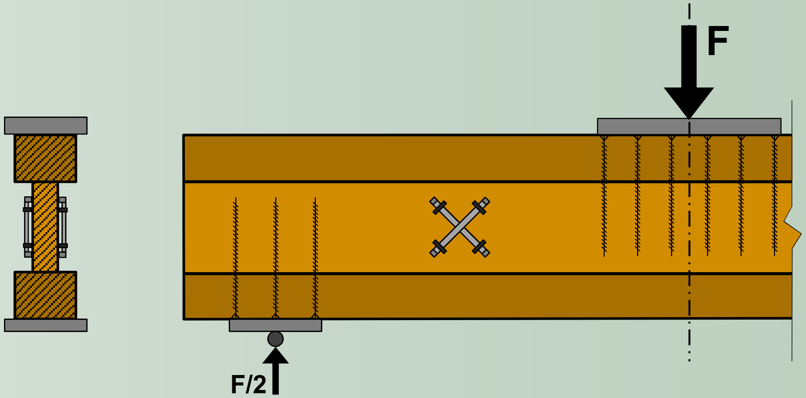
  → ST: w_{ref} / d_{ref} = 80 mm / 150 mm
  → GLT: w_{ref} / d_{ref} = 150 mm / 600 mm

- **reinforced I-beam**

  → minor conservative shear strengths
  → G_{090}

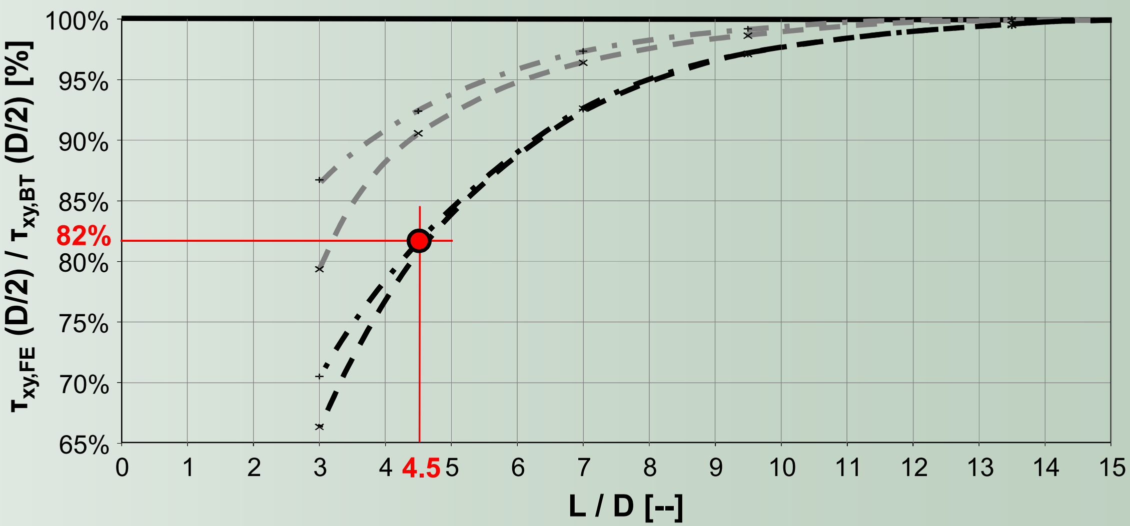
- **adaptations for climatic influences**

  → f_v –3% / +1% u, for 8% ≤ u ≤ 20%
  → G_{090} –1% / +1% u, for 8% ≤ u ≤ 20%



ANALYSIS & EVALUATION

- **registration of main failure cause & region**
- **evaluation acc. simple beam theory (BT) + correction acc. diagram**
- **MLE for right censored data**
  → only "first" shear failures within the test section as "ok"
  → assumption: f_v ~ 2pLND



CHARACTERISTICS OF MATERIAL & PRODUCT

- **f_v depends on built up & direction of loading (edgewise vs. flatwise)**
- **no significant relationship found between f_v and $f_{m,exp}$ or $E_{0,EF}$**
  → f_v constant over all strength classes of ST & GLT!
- **reference climate conditions [T = 20°C, u_{ref} = 12%] & reference dimensions**
  → CoV[f_v] = 15% (literature survey)
  → k_{size} (e.g. k_h)

ST: $$f_{v,k} = f_{v,k,ref} \cdot k_d = \min\left\{4.0 \cdot \left(\frac{150}{d}\right)^{0.2}; 4.5\right\}$$

DESIGN PROCEDURES

- **material & product characteristics (→ laboratory values)**

- **characteristic values for material & products in use (→ engineering values)**
  → climatic influences not considerable by k_{mod}
  → **need**: long term shear strengths of material & products exposed to dynamical climatic conditions!

- **k_{size} (e.g. k_h)**

ST: $$f_{v,k} = f_{v,k,ref} \cdot k_d = \min\left\{4.0 \cdot \left(\frac{150}{d}\right)^{0.2}; 4.5\right\}$$

THANK YOU FOR YOUR ATTENTION!

Contact:

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