Eurocodes – Background and Applications
EN 1995 – Tension Perpendicular to Grain

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Timber – Strength Classes

Table 1 — Strength classes - Characteristic values

		Poplar and softwood species											
		C14	C16	C18	C20	C22	C24	C27	C30	C35	C40	C45	C50
Strength properties (in N/mm²)													
Bending	$f_{m,k}$	14	16	18	20	22	24	27	30	35	40	45	50
Tension parallel	$f_{t,0,k}$	8	10	11	12	13	14	16	18	21	24	27	30
Tension perpendicular	$f_{t,90,k}$	0,4	0,5	0,5	0,5	0,5	0,5	0,6	0,6	0,6	0,6	0,6	0,6
Compression parallel	$f_{c,0,k}$	16	17	18	19	20	21	22	23	25	26	27	29
Compression perpendicular	$f_{c,90,k}$	2,0	2,2	2,2	2,3	2,4	2,5	2,6	2,7	2,8	2,9	3,1	3,2
Shear	$f_{v,k}$	1,7	1,8	2,0	2,2	2,4	2,5	2,8	3,0	3,4	3,8	3,8	3,8
Stiffness properties (in kN/mm²)													
Mean modulus of elasticity parallel	$E_{0,mean}$	7	8	9	9,5	10	11	11,5	12	13	14	15	16
5% modulus of elasticity parallel	$E_{0,05}$	4,7	5,4	6,0	6,4	6,7	7,4	7,7	8,0	8,7	9,4	10,0	10,7
Mean modulus of elasticity perpendicular	$E_{90,mean}$	0,23	0,27	0,30	0,32	0,33	0,37	0,38	0,40	0,43	0,47	0,50	0,53
Mean shear modulus	G_{mean}	0,44	0,5	0,56	0,59	0,63	0,69	0,72	0,75	0,81	0,88	0,94	1,00

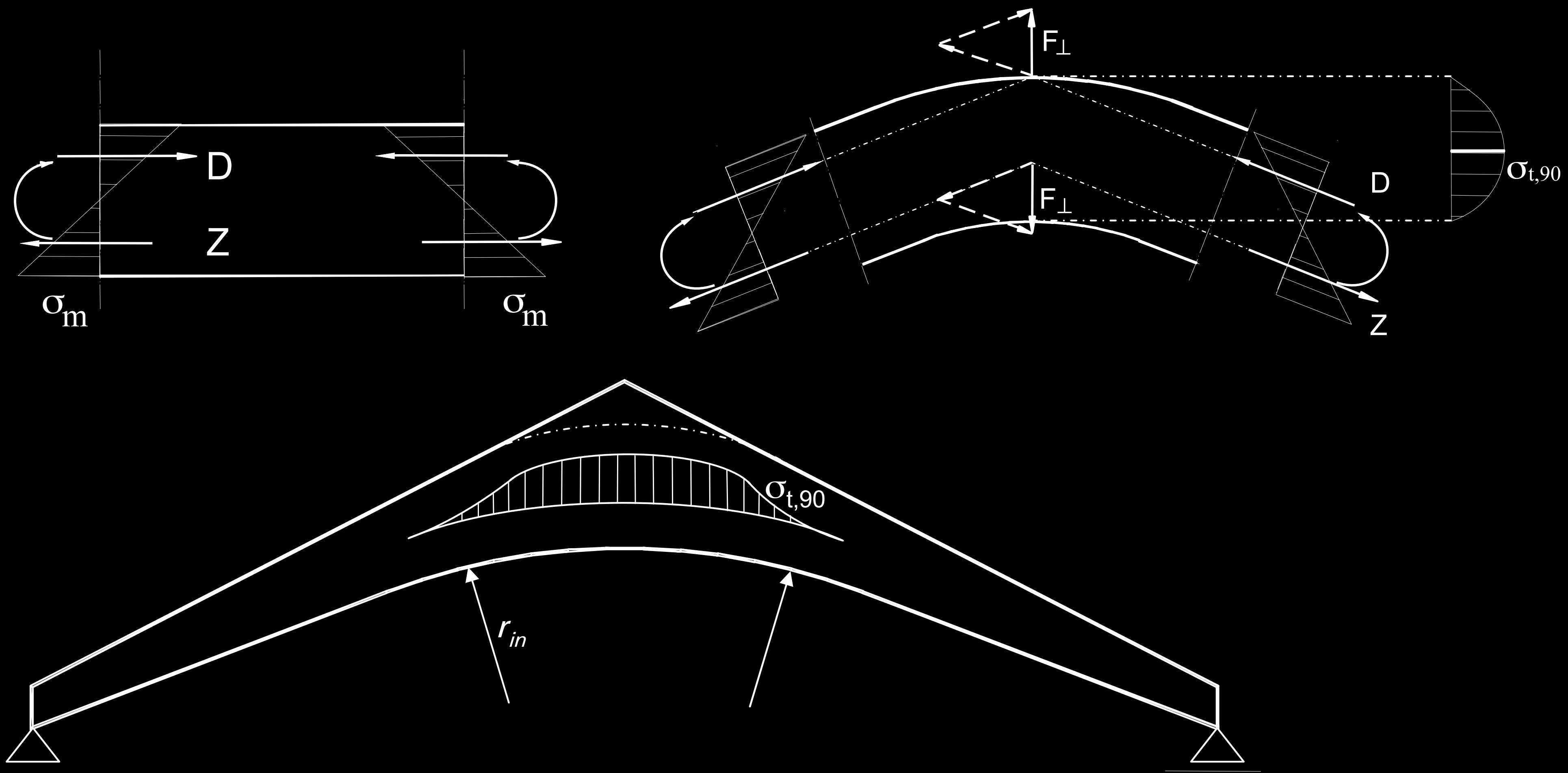
$f_{t,90,k} \approx 1/30\ f_{t,0,k}$

$f_{v,k} \approx 1/10\ f_{m,k}$

[EN 338]

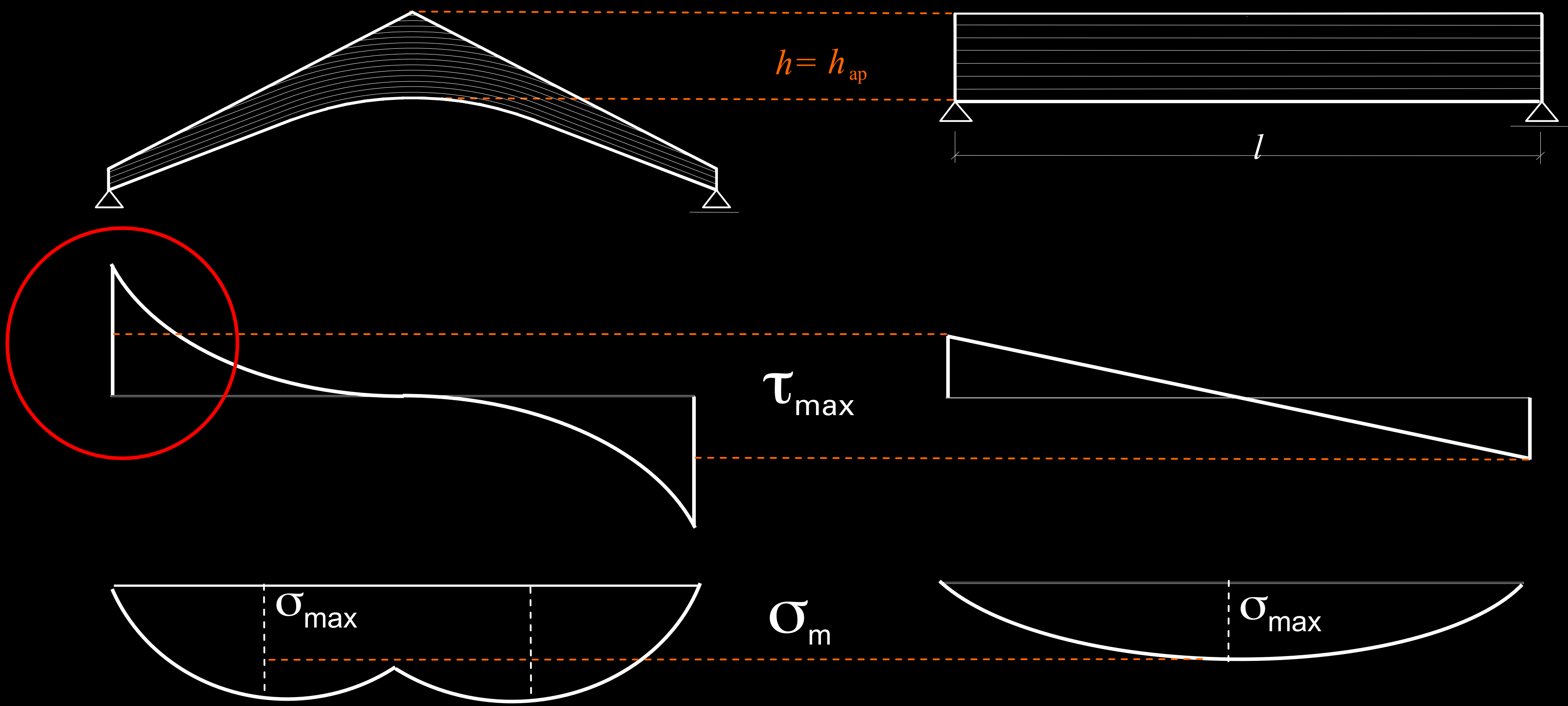
Double tapered, curved and pitch cambered Beams

Distribution of Tension Perpendicular to Grain Stresses



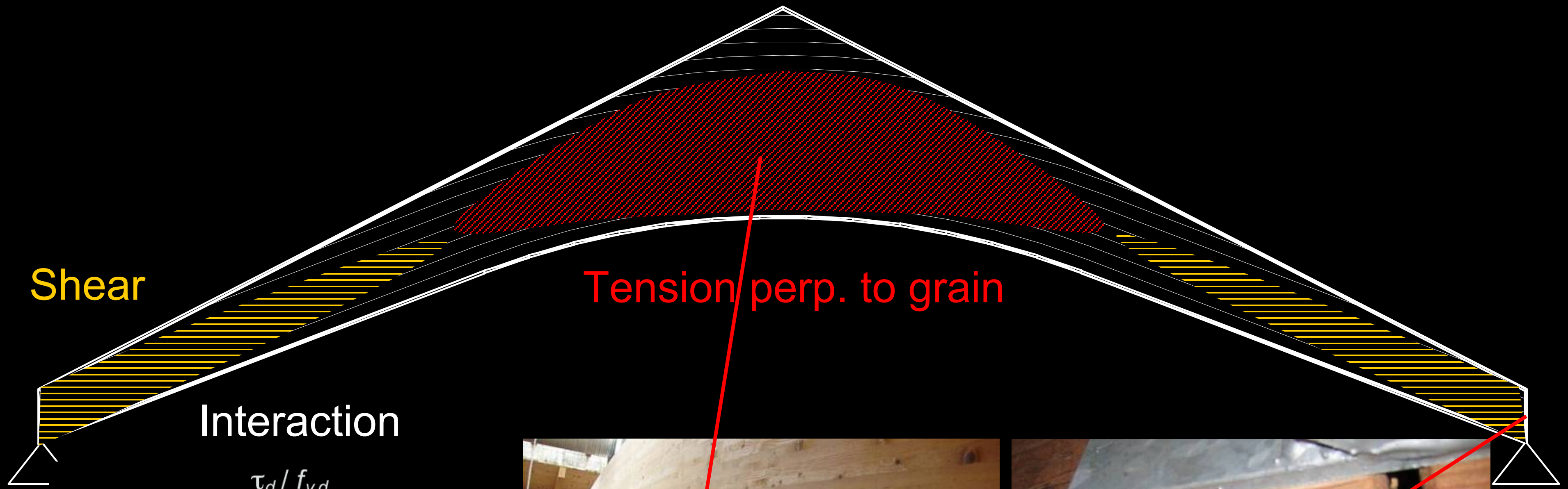
Double tapered, curved and pitch cambered Beams

Distribution of Shear Stresses

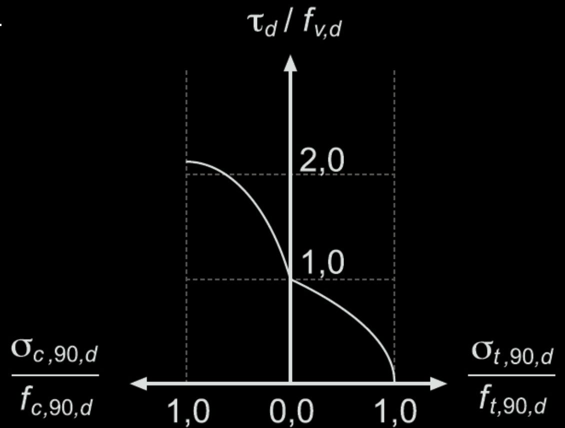


Double tapered, curved and pitch cambered Beams

Distribution of high Shear and Tension Perpendicular to Grain Stresses



Interaction



[SIA 265]

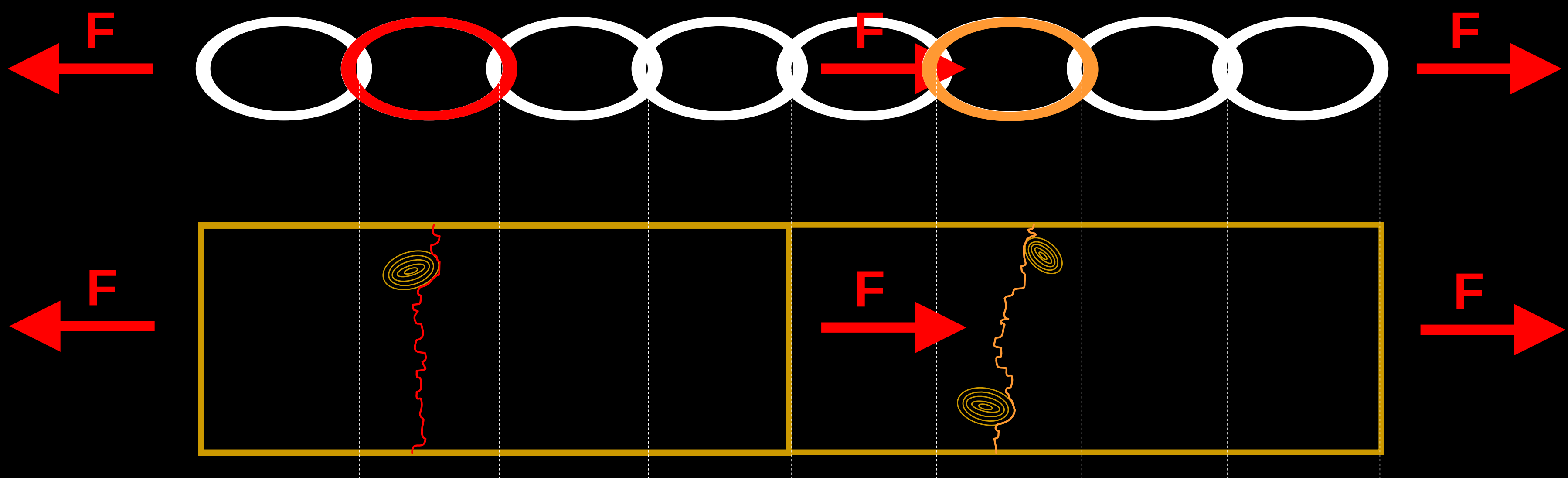
(Kirchanschöring, MPA BAU)

(Neuburg on the Danube, MPA BAU)

Double tapered, curved and pitch cambered Beams

Brittle materials – Size Effect

„A member under tension stress is only as strong as the weakest link“



The strength of a brittle material is a function of its volume under uniform stress.

$$\frac{f_i}{f_j} = \left(\frac{V_j}{V_i}\right)^m$$

Double tapered, curved and pitch cambered Beams in EC 5

6.4.3 Double tapered, curved and pitched cambered beams

⋮

(6) In the apex zone the greatest tensile stress perpendicular to the grain, $\sigma_{t,90,d}$, should satisfy the following expression:

$$\sigma_{t,90,d} \leq k_{dis}\, k_{vol}\, f_{t,90,d} \tag{6.50}$$

with

$$k_{vol} = \begin{cases} 1{,}0 & \text{for solid timber} \\ \left(\dfrac{V_0}{V}\right)^{0{,}2} & \text{for glued laminated timber and LVL with all veneers parallel to the beam axis} \end{cases} \tag{6.51}$$

$$k_{dis} = \begin{cases} 1{,}4 & \text{for double tapered and curved beams} \\ 1{,}7 & \text{for pitched cambered beams} \end{cases} \tag{6.52}$$

where:

k_{dis} is a factor which takes into account the effect of the stress distribution in the apex zone;

k_{vol} is a volume factor;

$f_{t,90,d}$ is the design tensile strength perpendicular to the grain;

V_0 is the reference volume of $0{,}01\,m^3$;

V is the stressed volume of the apex zone, in m^3, (see Figure 6.9) and should not be taken greater than $2V_b/3$, where V_b is the total volume of the beam.

[EN 1995-1-1:2004; 6.4.3, p. 48ff]

Double tapered, curved and pitch cambered Beams in EC 5

6.4.3 Double tapered, curved and pitched cambered beams

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(8) The greatest tensile stress perpendicular to the grain due to the bending moment should be calculated as follows:

$$\sigma_{t,90,d} = k_p \frac{6 M_{ap,d}}{b h_{ap}^2} \quad (6.54)$$

where:

p_d is the uniformly distributed load acting on the top of the beam over the apex area;

b is the width of the beam;

$M_{ap,d}$ is the design moment at apex resulting in tensile stresses parallel to the inner curved edge;

with:

$$k_p = k_5 + k_6 \left(\frac{h_{ap}}{r}\right) + k_7 \left(\frac{h_{ap}}{r}\right)^2 \quad (6.56)$$

$$k_5 = 0{,}2 \tan\alpha_{ap} \quad (6.57)$$

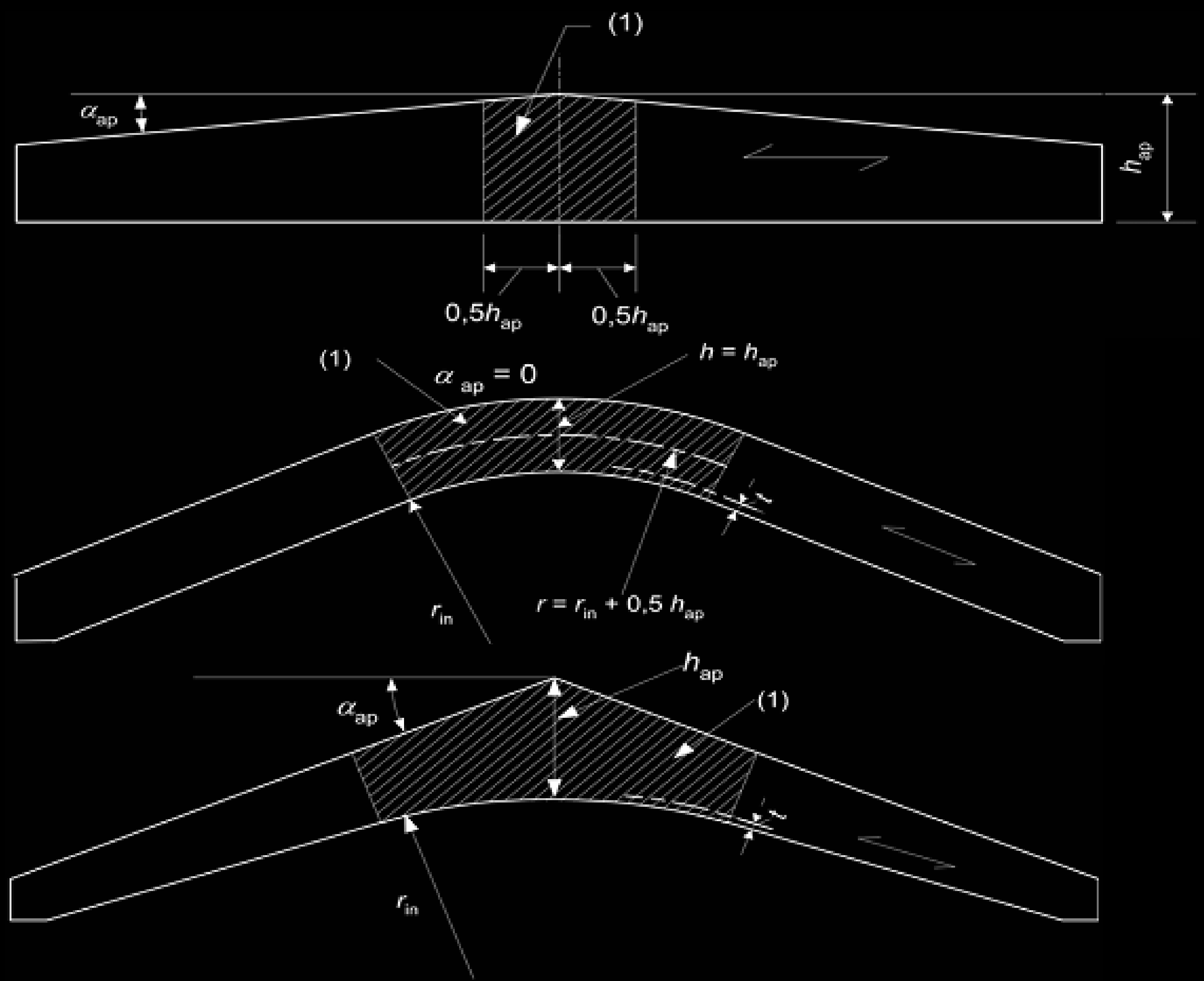
$$k_6 = 0{,}25 - 1{,}5 \tan\alpha_{ap} + 2{,}6 \tan^2\alpha_{ap} \quad (6.58)$$

$$k_7 = 2{,}1 \tan\alpha_{ap} - 4 \tan^2\alpha_{ap} \quad (6.59)$$

[EN 1995-1-1:2004; 6.4.3, p. 48ff]

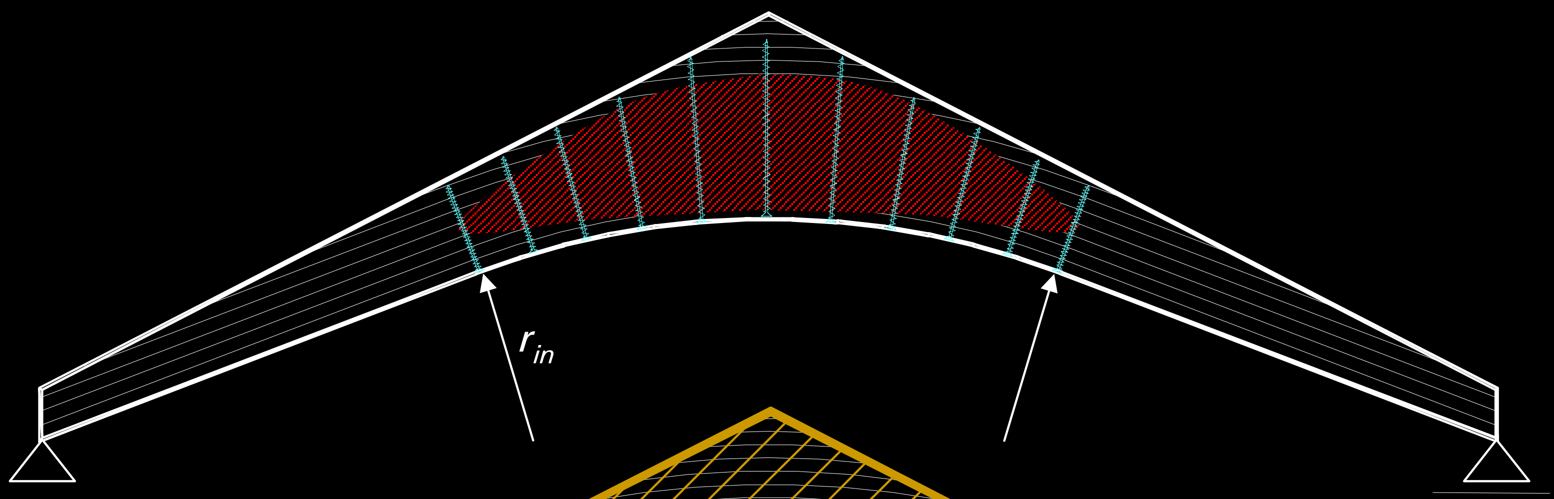
Double tapered, curved and pitch cambered Beams in EC 5

6.4.3 Double tapered, curved and pitched cambered beams

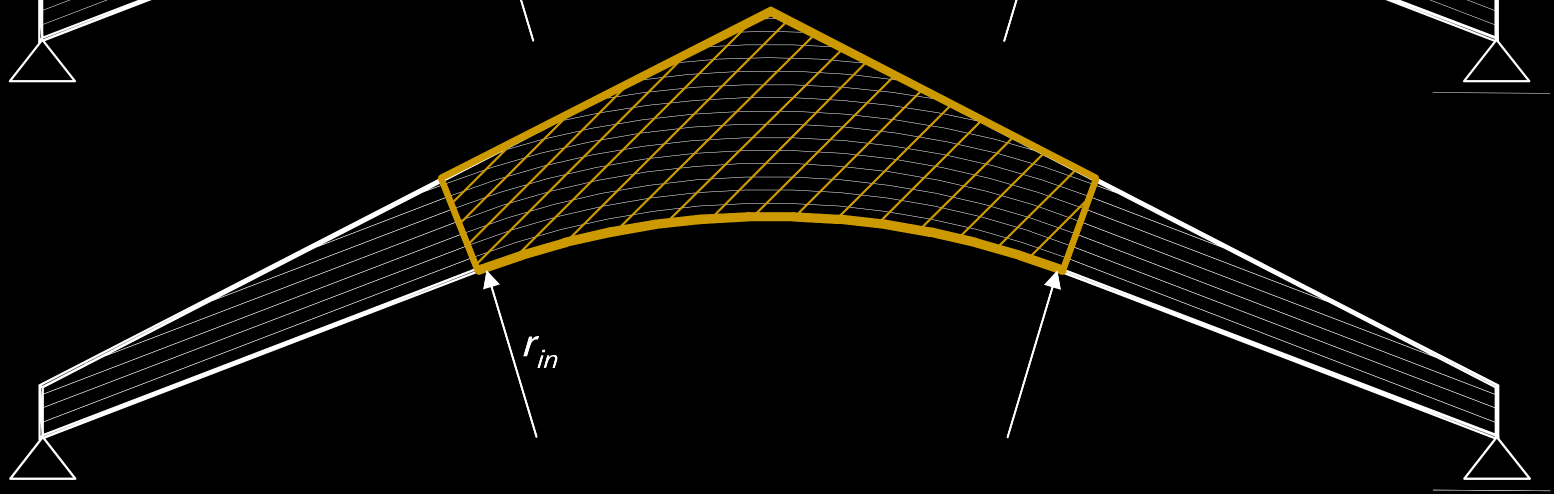


Double tapered, curved and pitch cambered Beams

Strengthening Measures



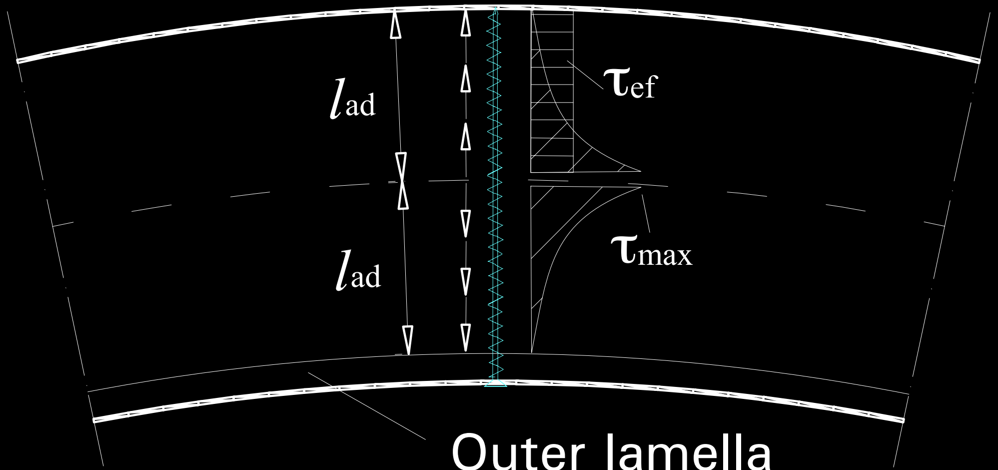
Self-tapping screws with continuous threads or threaded rods

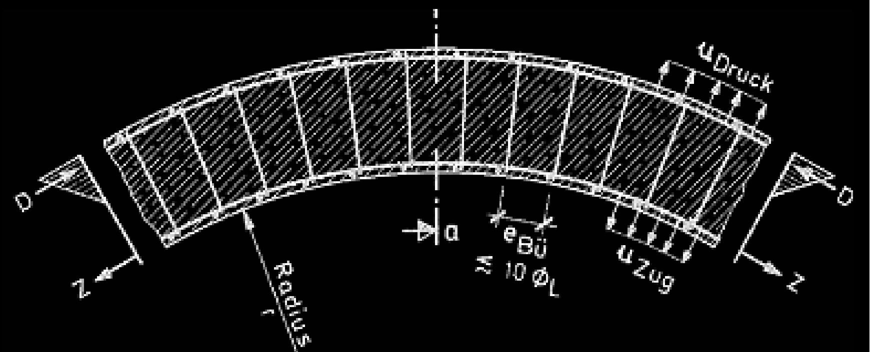


Plywood / Laminated Veneer Lumber

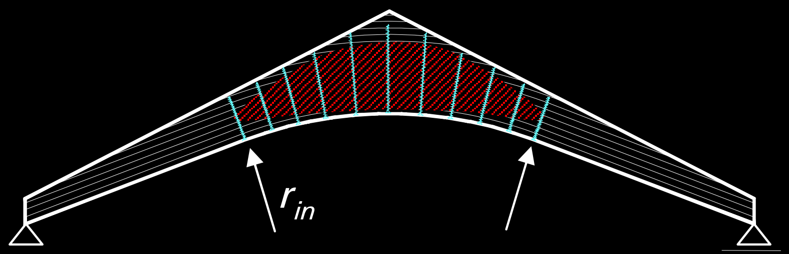
Double tapered, curved and pitch cambered Beams

Strengthening Measures – Screws or threaded Rods



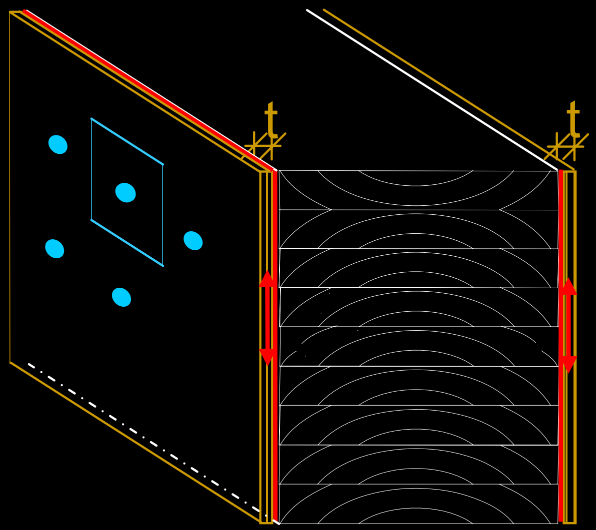


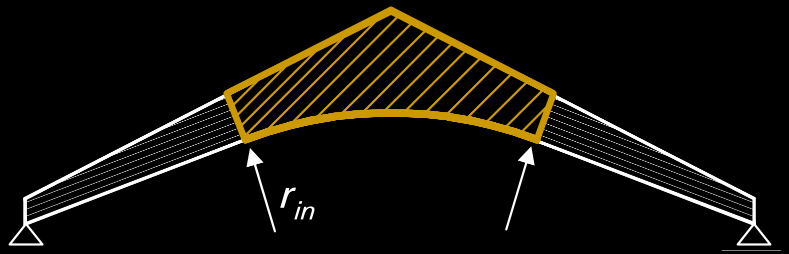
Fritz Leonhardt, Vorlesungen über Massivbau



Double tapered, curved and pitch cambered Beams

Strengthening Measures – Plywood / Laminated Veneer Lumber glued to Timber Member



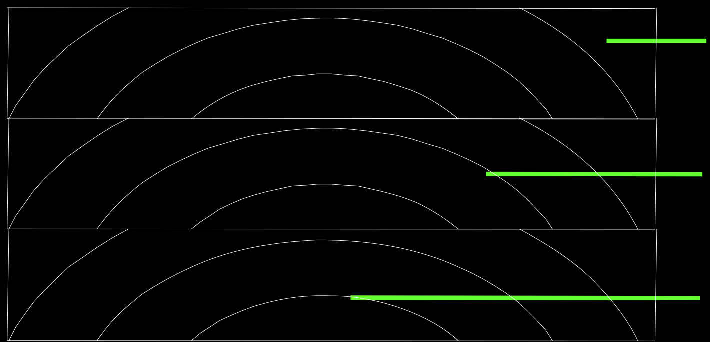


Strengthening measures (screws / plates) should be designed to carry full tension perpendicular to grain stresses and should cover the entire area under tension perp. to grain stresses (curved area)

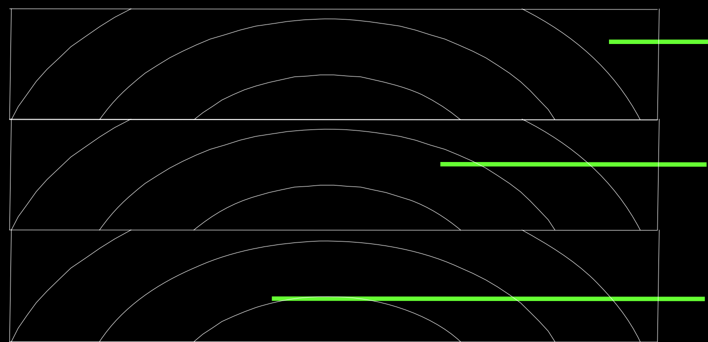
Moisture Conditions

Ice-rink arena
(Ingolstadt, MPA BAU)

Gymnasium with skylights
(Benediktbeuern, MPA BAU)



20 mm
= 25,1 %
55 mm
= 18,9 %
95 mm
= 19,1 %

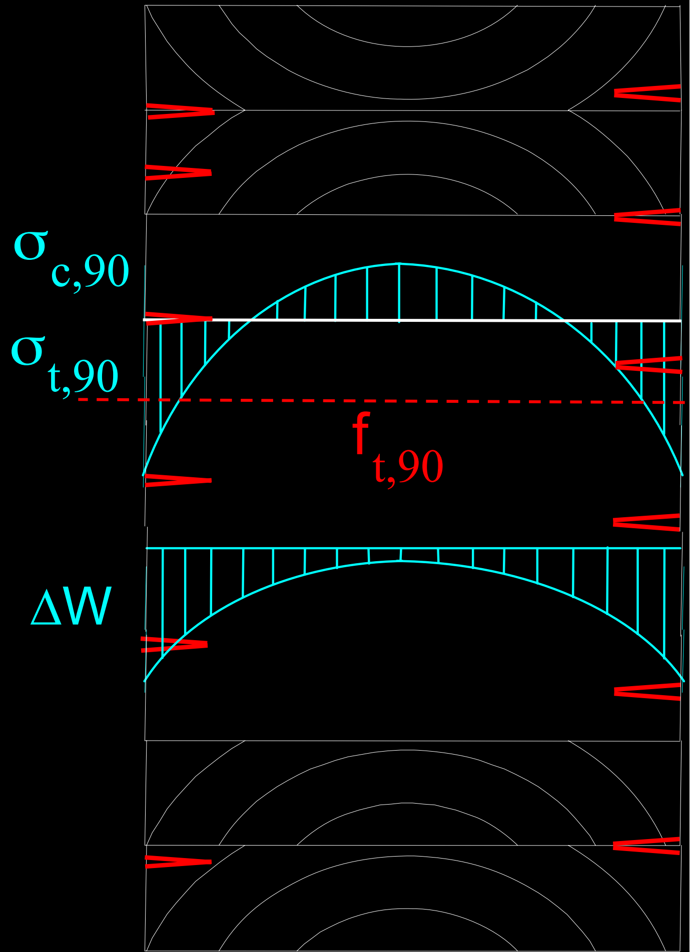


10 mm
= 7,5 %
70 mm
= 10,5 %
120 mm
= 11,7 %

Moisture Conditions – Cracks caused by Shrinking

In Glulam Beams – Crack Distribution enabled

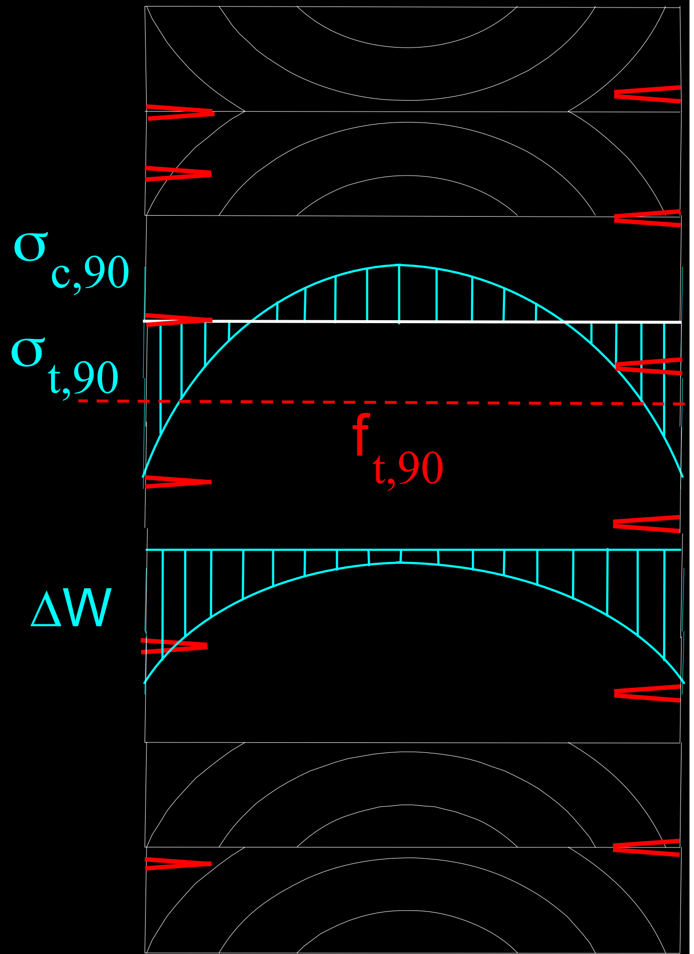
©Stefan Kühn



Moisture Conditions – Cracks caused by Shrinking

In Glulam Beams – Crack Distribution enabled

(Benediktbeuern, MPA BAU)



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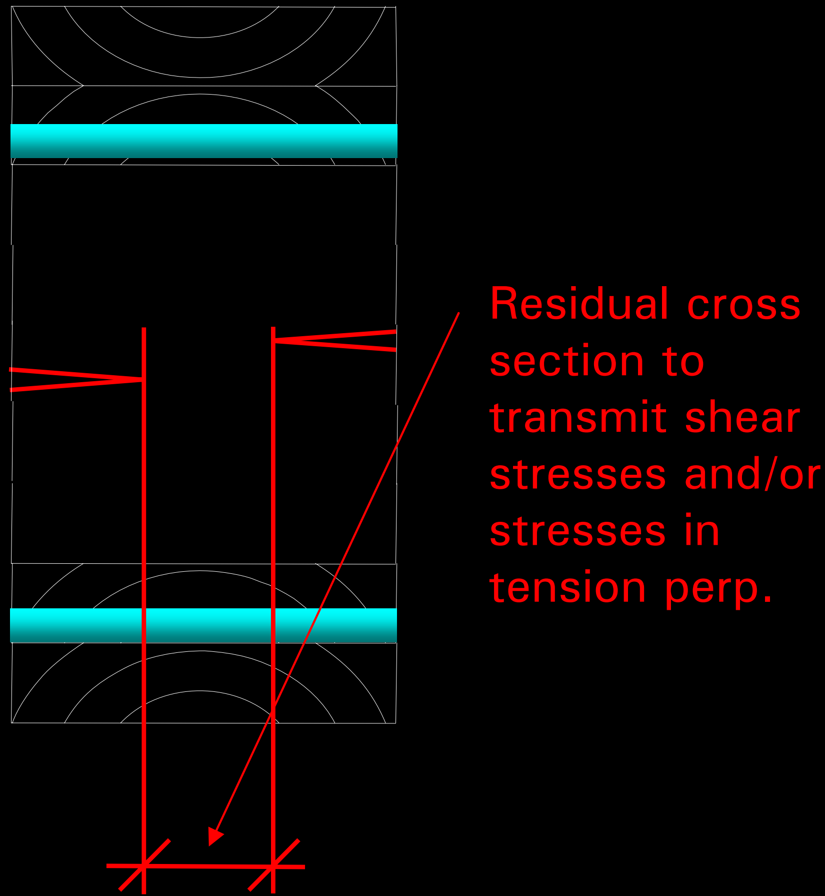
Moisture Conditions – Cracks caused by Shrinking

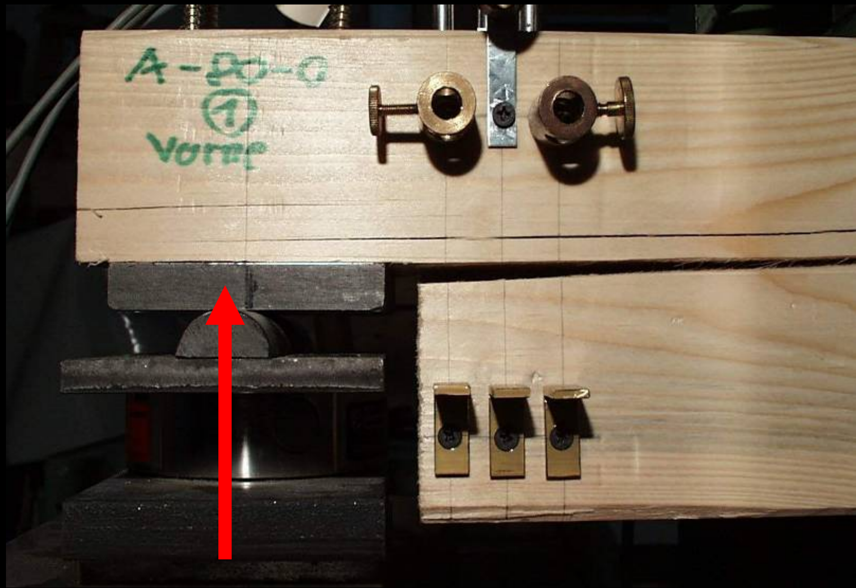
In Combination with Fasteners – Crack Distribution impeded

(Feldkirchen, Prof. Winter)



→ reduction of applicable strength values or cross sections by e.g. k_{cr}

Notched Beams



Picture: Prof. H. Blaß, TH Karlsruhe

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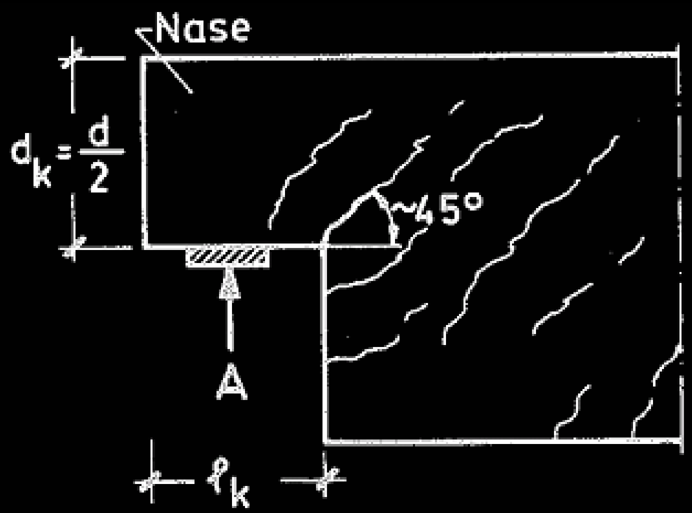
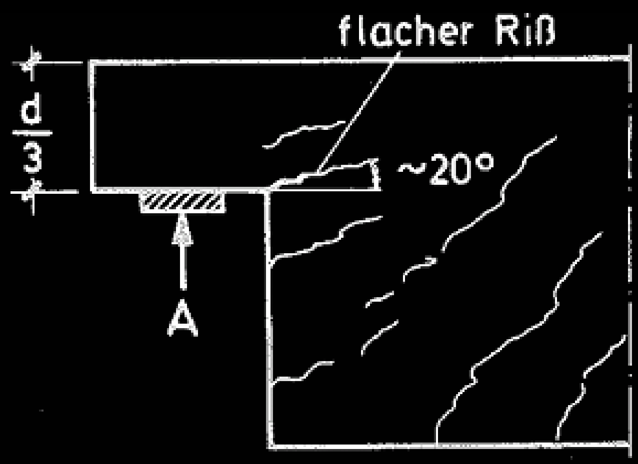
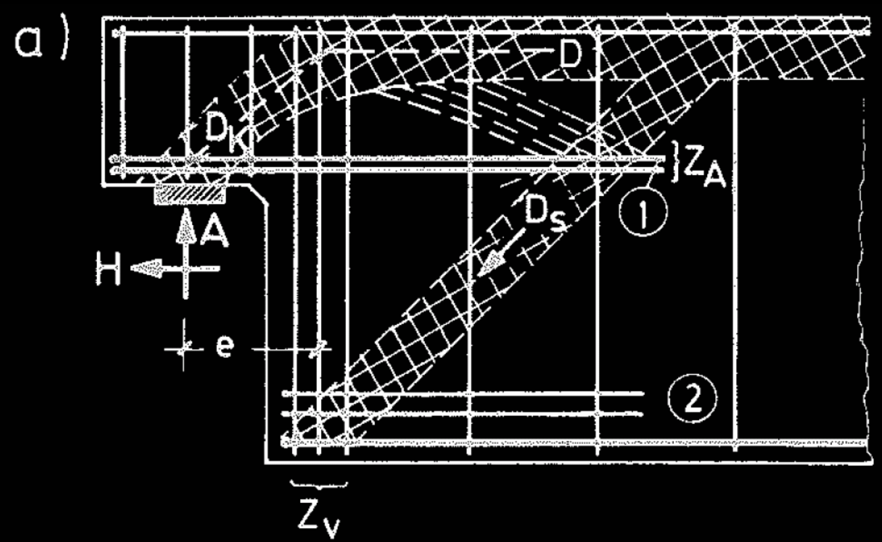
Notched Beams in Concrete



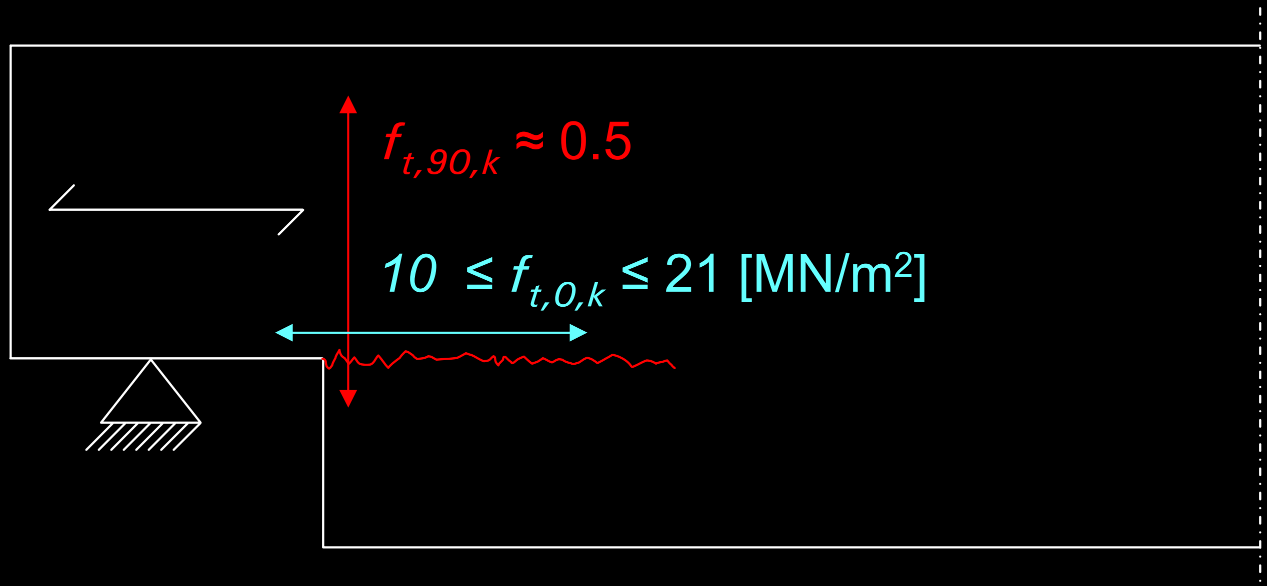


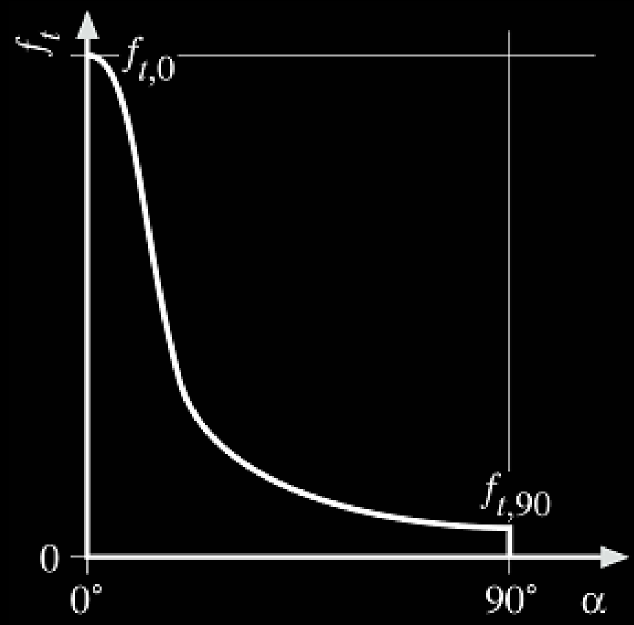
→ Constant tensile strength in all directions



Fritz Leonhardt, Vorlesungen über Massivbau

Notched Beams in Timber

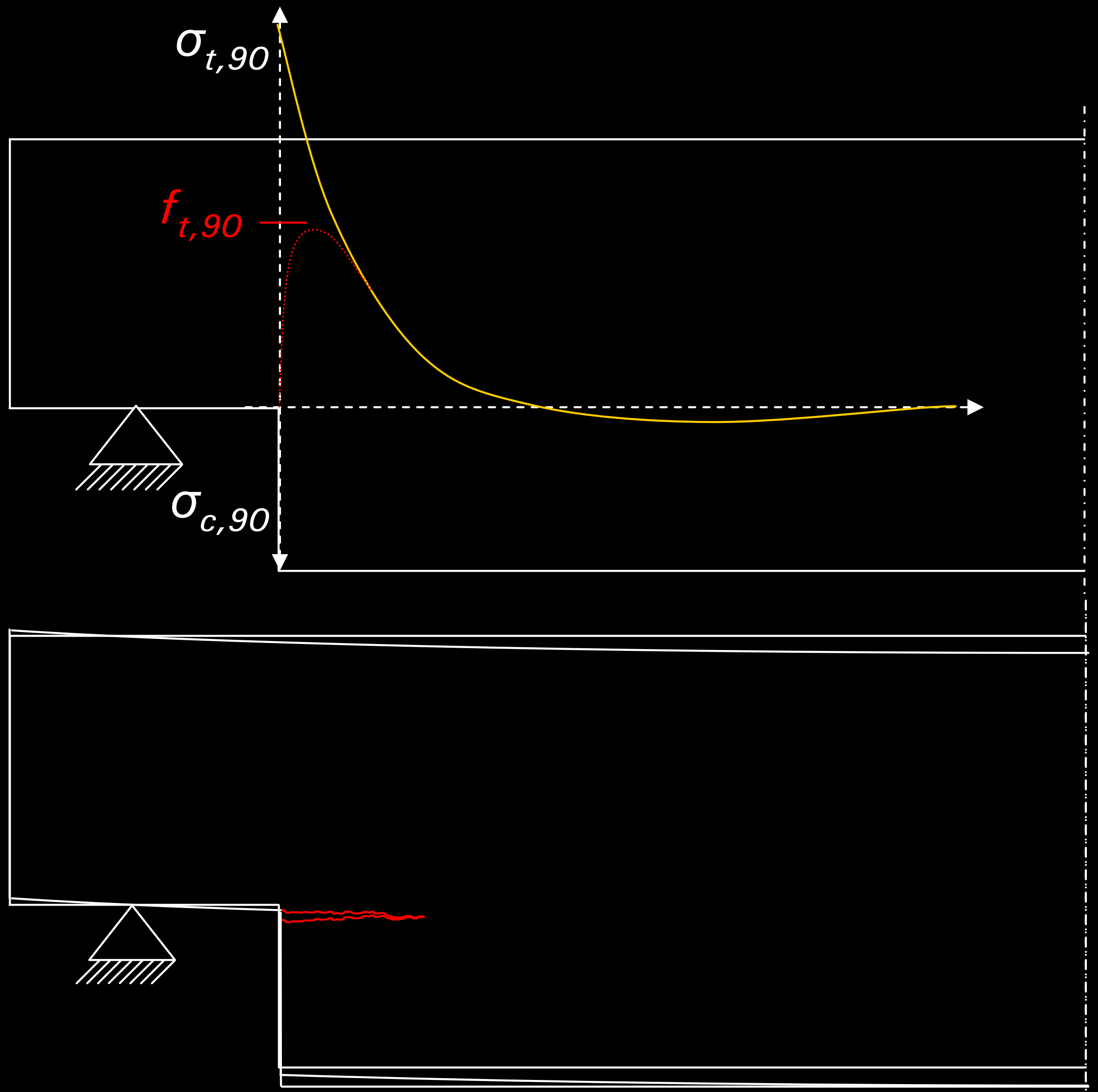


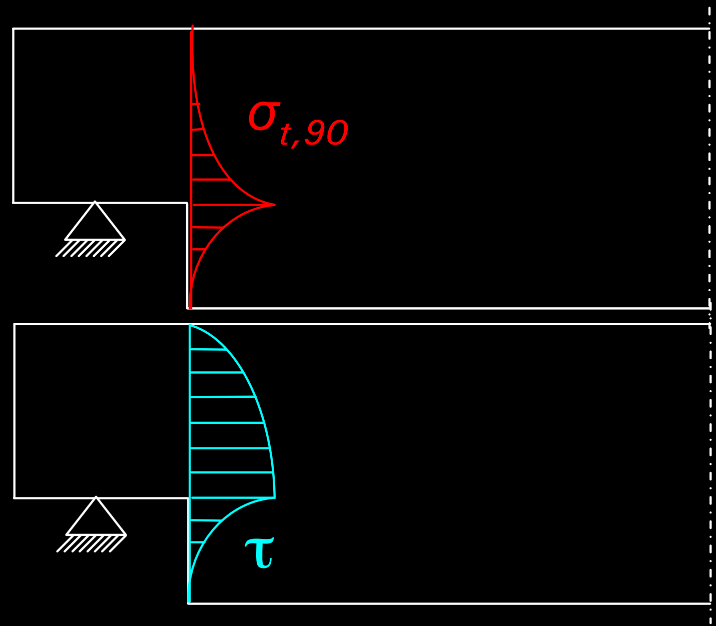


→ Tensile strength changes with varying angle between load and grain

$f_{t,90,k} \approx 1/30\ f_{t,0,k}$

Notched Beams in Timber





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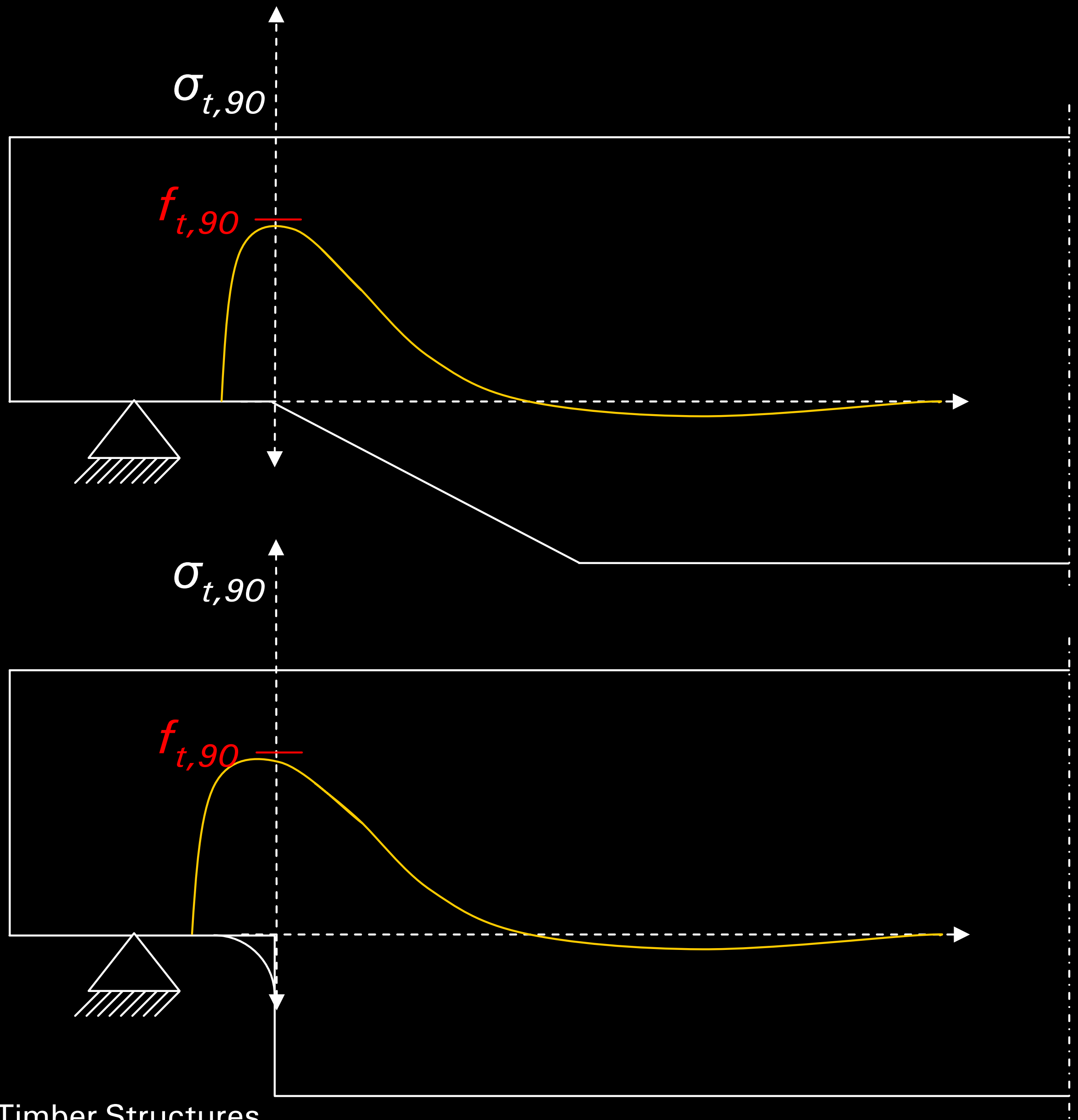
Notched Beams in Timber – Constructive Measures



Notched Beams in Timber

6.5 Notched members

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6.5.2 Beams with a notch at the support

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It should be verified that

$$= \frac{1{,}5V}{b\,h_{\mathrm{ef}}} \leq k_{\mathrm{v}} f_{\mathrm{v,d}} \quad (6.60)$$

ere k_{v} is a reduction factor defined as follows:

For beams notched at the opposite side to the support (see Figure 6.11b)

$$k_{\mathrm{v}} = 1{,}0 \quad (6.61)$$

For beams notched on the same side as the support (see Figure 6.11a)

$$k_{\mathrm{v}} = \min \begin{cases} 1 \\ \dfrac{k_{\mathrm{n}}\left(1 + \dfrac{1{,}1\, i^{1{,}5}}{\sqrt{h}}\right)}{\sqrt{h}\left(\sqrt{\alpha(1-\alpha)} + 0{,}8\dfrac{x}{h}\sqrt{\dfrac{1}{\alpha} - \alpha^2}\right)} \end{cases} \quad (6.62)$$

[EN 1995-1-1:2004; 6.5.2, p. 52ff]

Notched Beams in Timber

6.5 Notched members

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.

6.5.2 Beams with a notch at the support

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.
.

where:

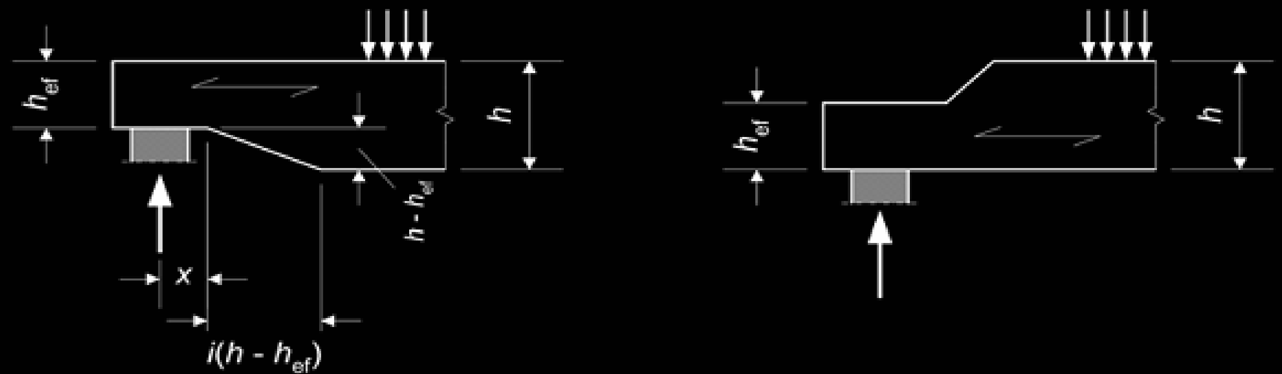
i is the notch inclination (see Figure 6.11a);

h is the beam depth in mm;

x is the distance from line of action of the support reaction to the corner of the notch;

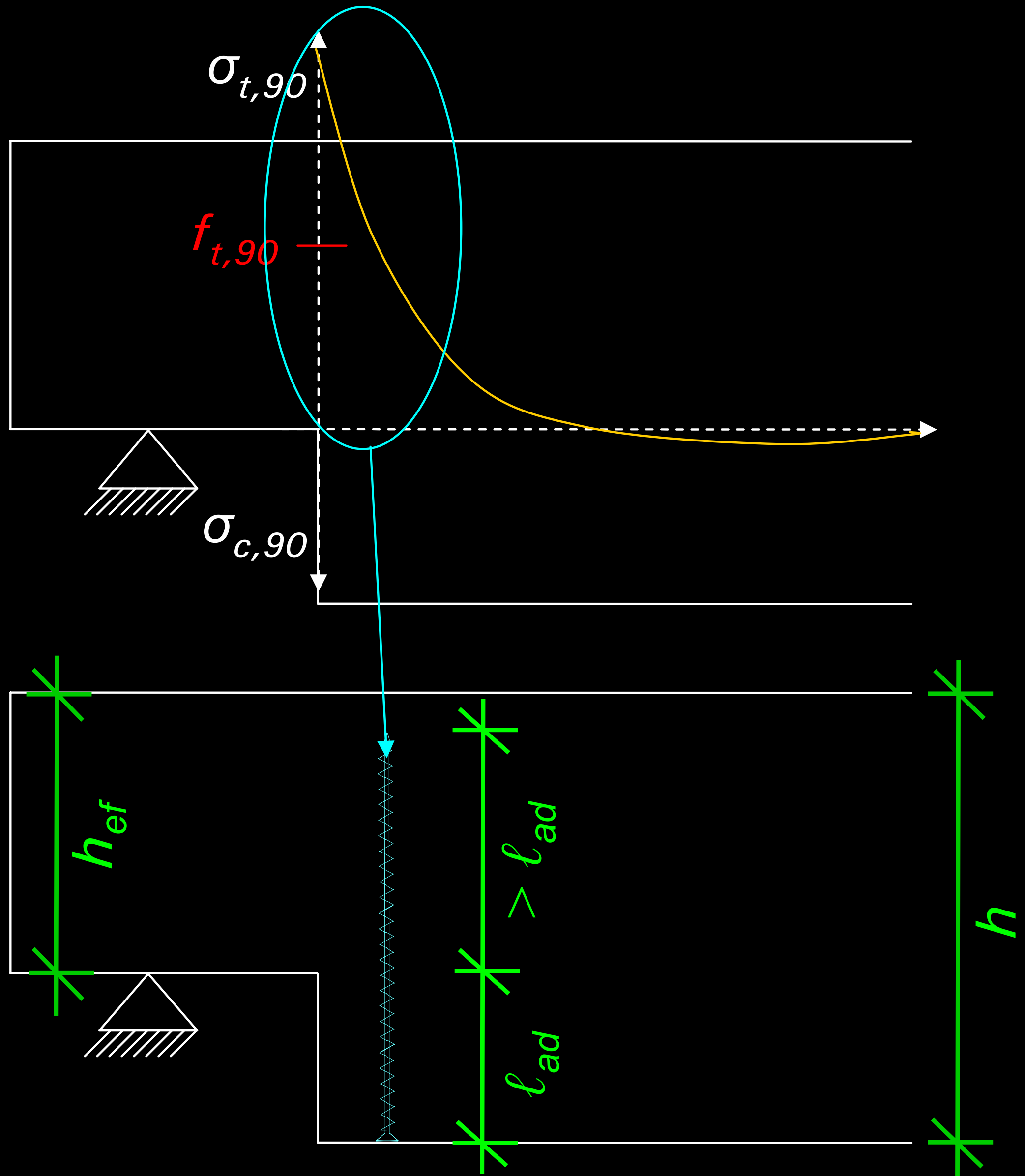
$$\alpha = \frac{h_{ef}}{h}$$

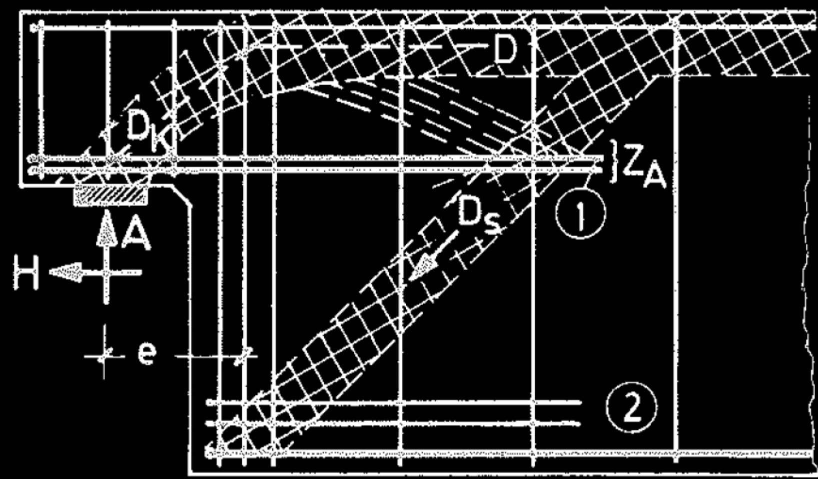
$$k_n = \begin{cases} 4,5 & \text{for LVL} \\ 5 & \text{for solid timber} \\ 6,5 & \text{for glued laminated timber} \end{cases} \qquad (6.63)$$



[EN 1995-1-1:2004; 6.5.2, p. 52ff]

Notched Beams in Timber – Strengthening Measures

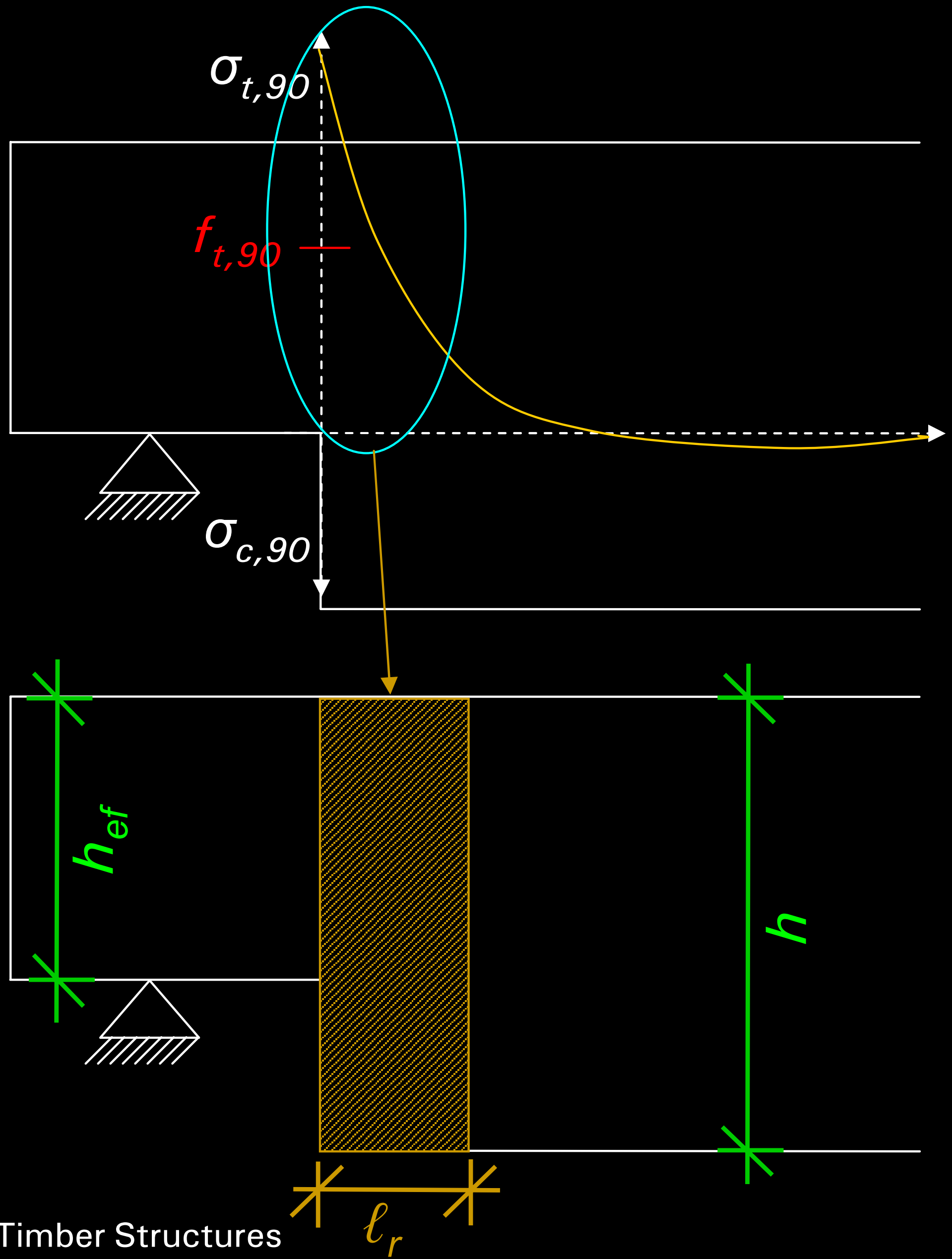


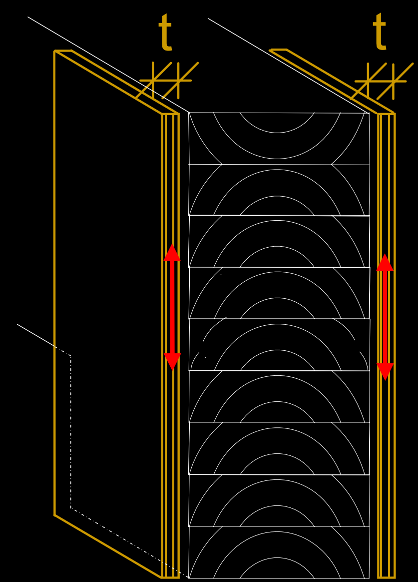


Example of reinforcement in concrete structures

Strengthening measure / reinforcement by self-tapping screws with continuous thread

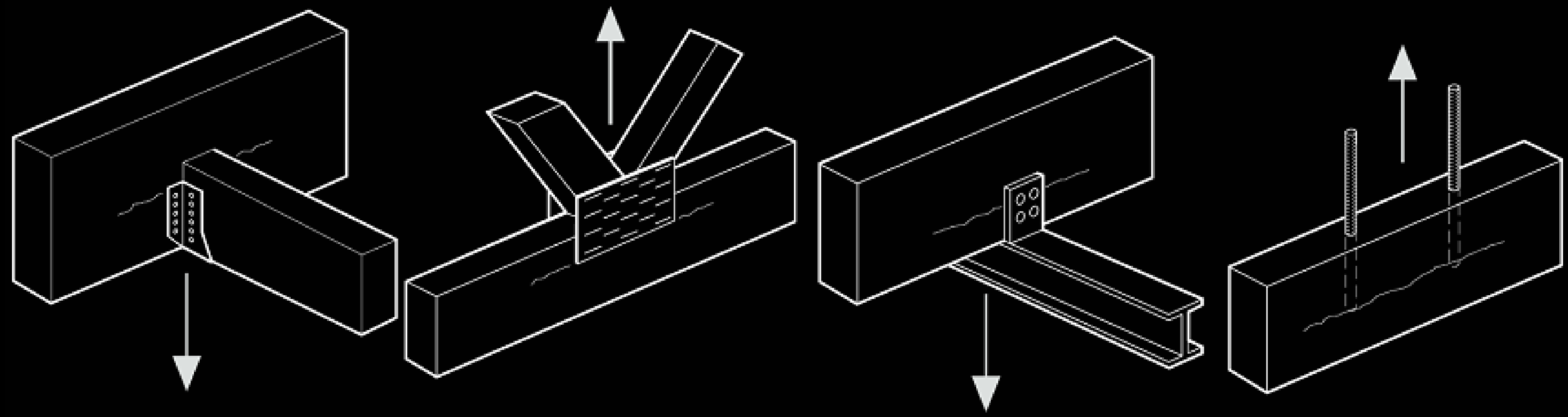
Notched Beams in Timber – Strengthening Measures

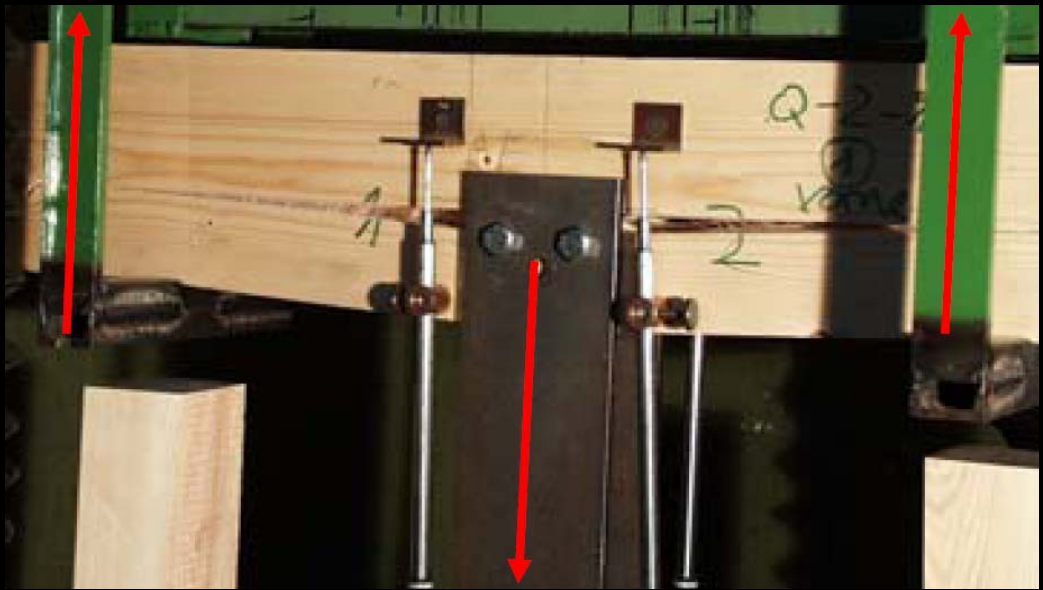


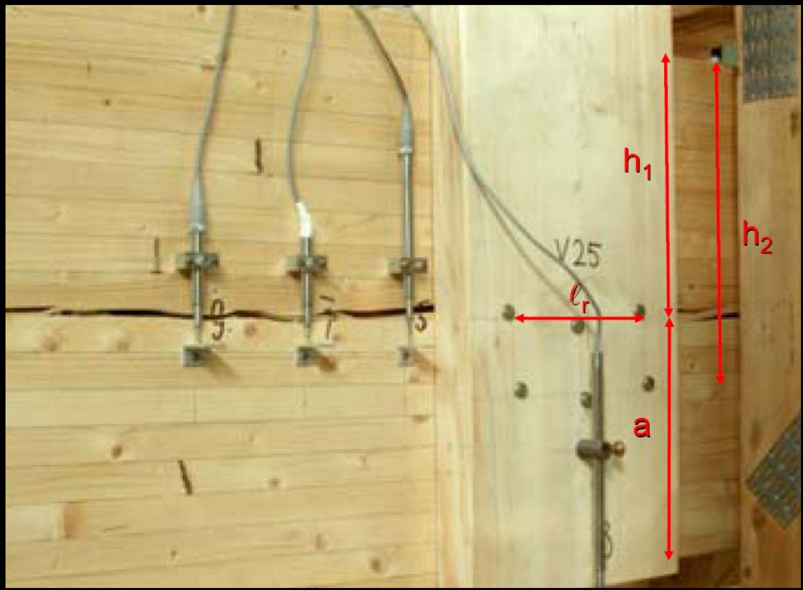


Strengthening measure / reinforcement by glueing plywood / LVL to the sides of beam, glueline pressed by screws

Cross Connections

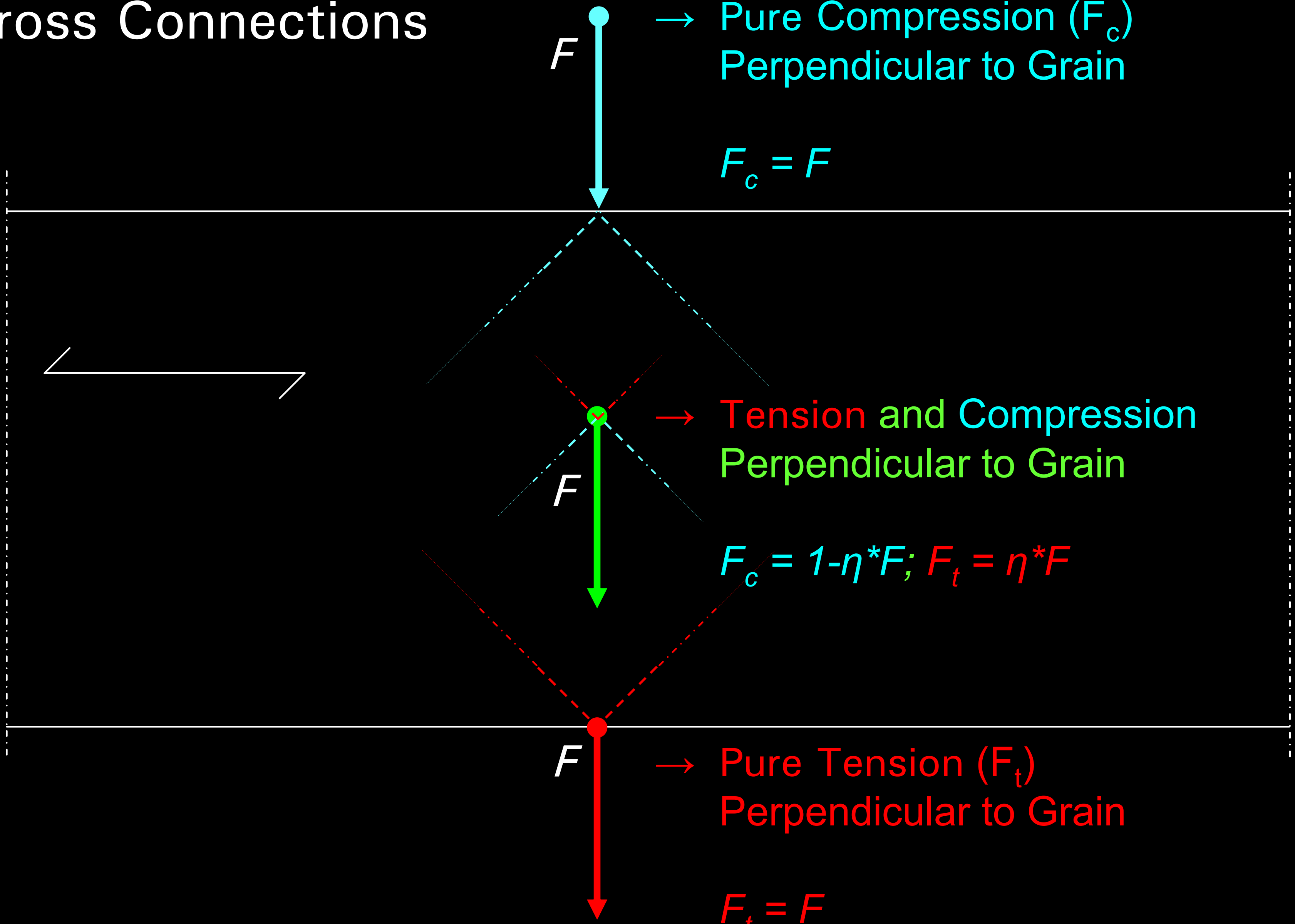




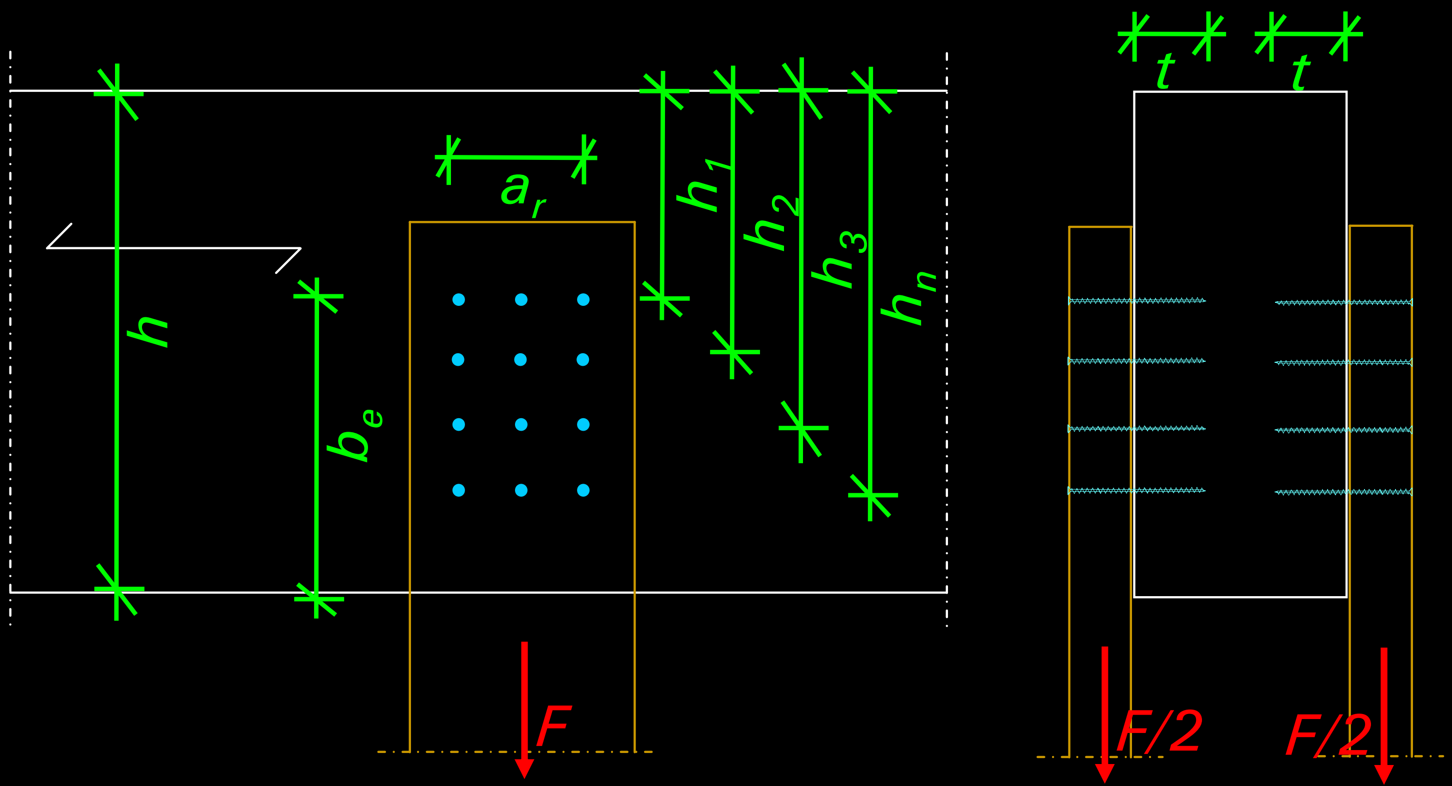


Pictures: Prof. H. Blaß, TH Karlsruhe

Cross Connections



Cross Connections – Influences on load-carrying Capacity



Load-carrying capacity depends on stressed volume and stress distribution / stress peaks and is therefore influenced by:

- Ratio between distance b_e and beam depth h
- Fastener spacing in grain direction / length a_r
- Penetration thickness t

Cross Connections

8.1.4 Connection forces at an angle to the grain

:

(3) For softwoods, the characteristic splitting capacity for the arrangement shown in Figure 8.1 should be taken as:

$$F_{90,\mathrm{Rk}} = 14\,b\,w\sqrt{\frac{h_e}{\left(1-\frac{h_e}{h}\right)}} \qquad (8.4)$$

where:

$$w = \begin{cases} \max\begin{cases}\left(\frac{w_{\mathrm{pl}}}{100}\right)^{0,35} \\ 1\end{cases} & \text{for punched metal plate fasteners} \\ 1 & \text{for all other fasteners}\end{cases} \qquad (8.5)$$

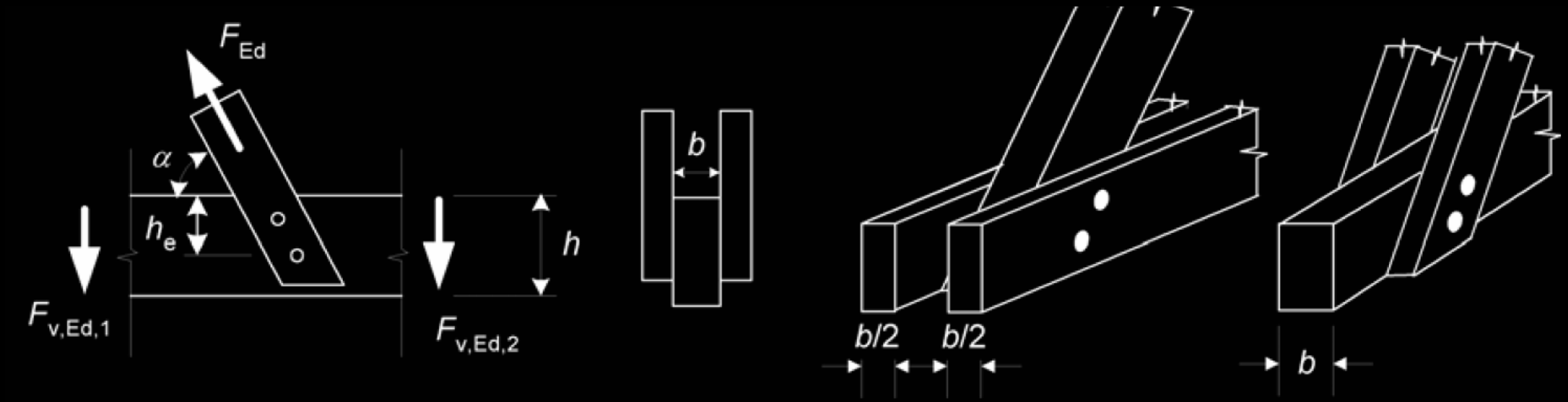
and:

$F_{90,\mathrm{Rk}}$	is the characteristic splitting capacity, in N;
w	is a modification factor;
h_e	is the loaded edge distance to the centre of the most distant fastener or to the edge of the punched metal plate fastener, in mm;
h	is the timber member height, in mm;
b	is the member thickness, in mm;
w_{pl}	is the width of the punched metal plate fastener parallel to the grain, in mm.

[EN 1995-1-1:2004; 8.1.4, p. 59ff]

Cross Connections

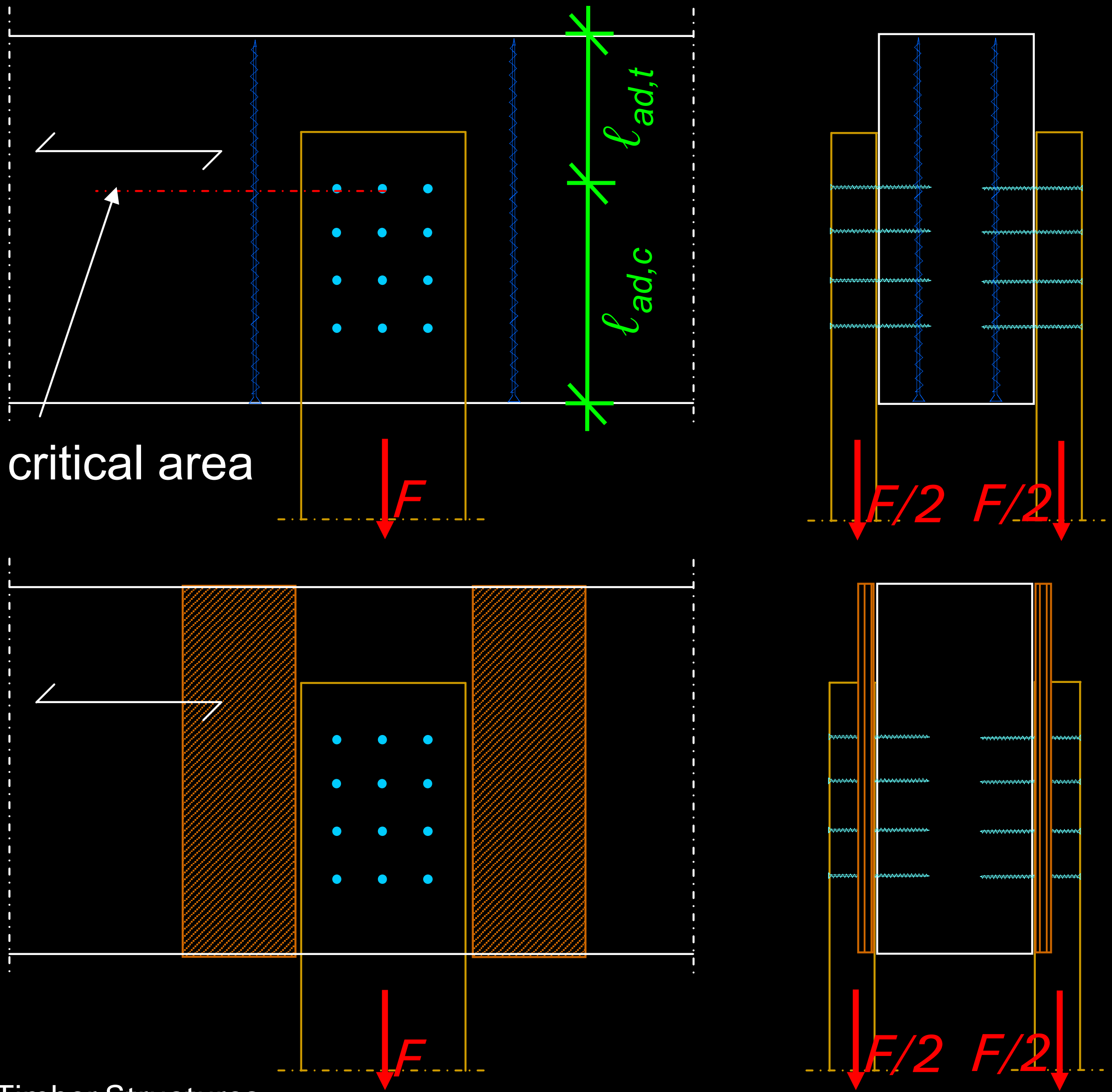
8.1.4 Connection forces at an angle to the grain



[EN 1995-1-1:2004; 8.1.4, p. 59ff]

See also STEP C2 „Tension perpendicular to the grain in joints“

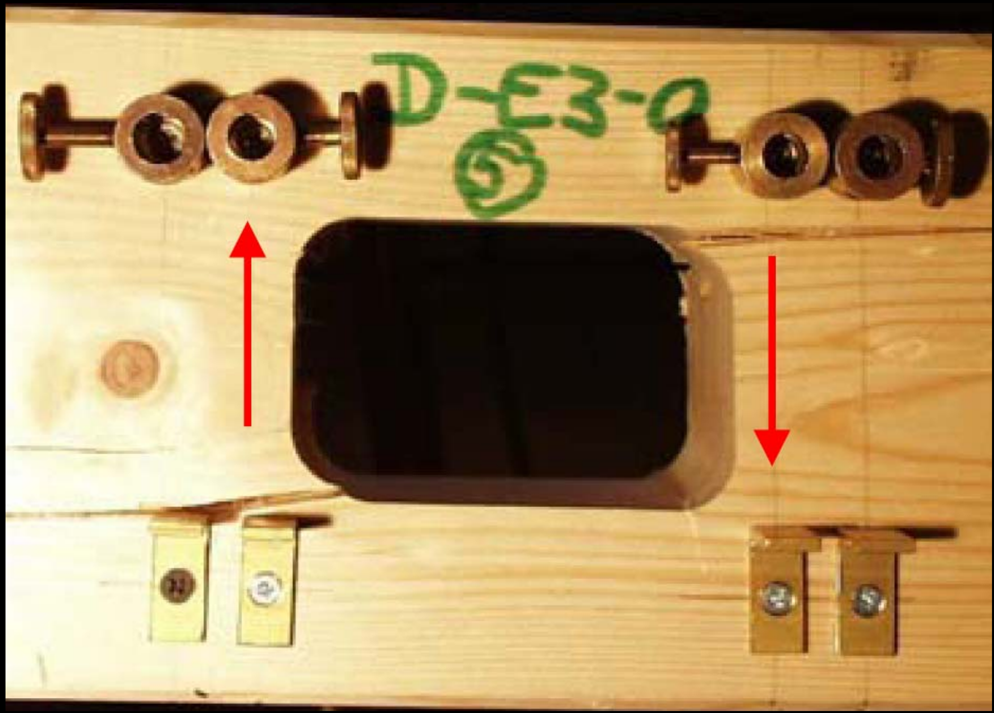
Cross Connections – Strengthening Measures



Self-tapping screws with continuous thread

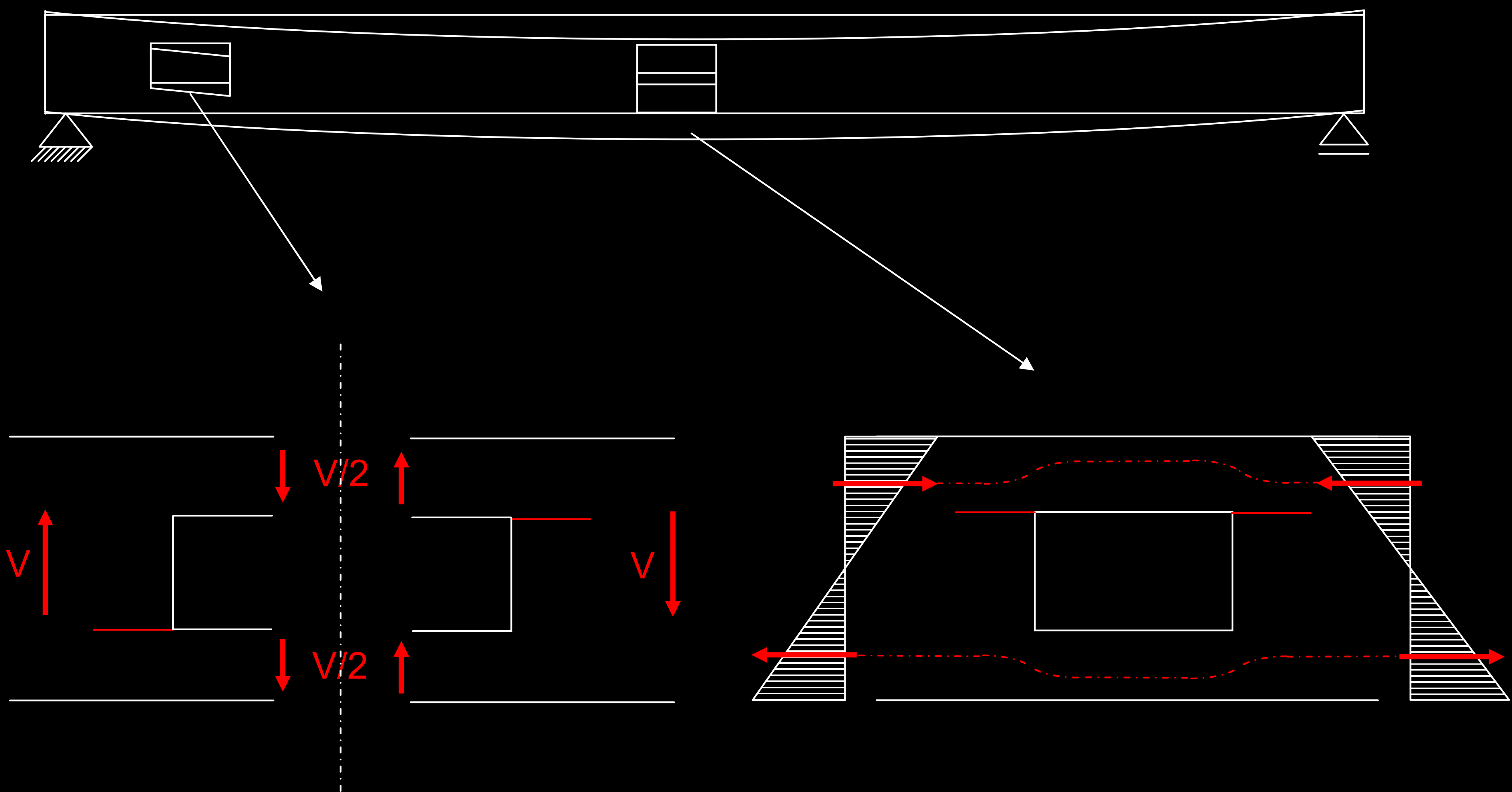
Plywood / LVL, glued, pressed by screws

Openings

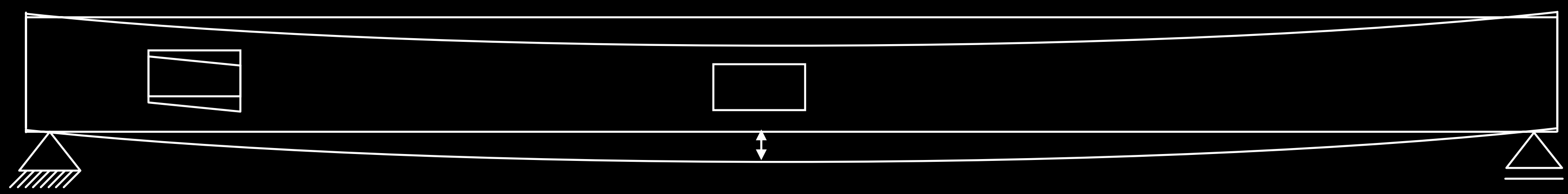


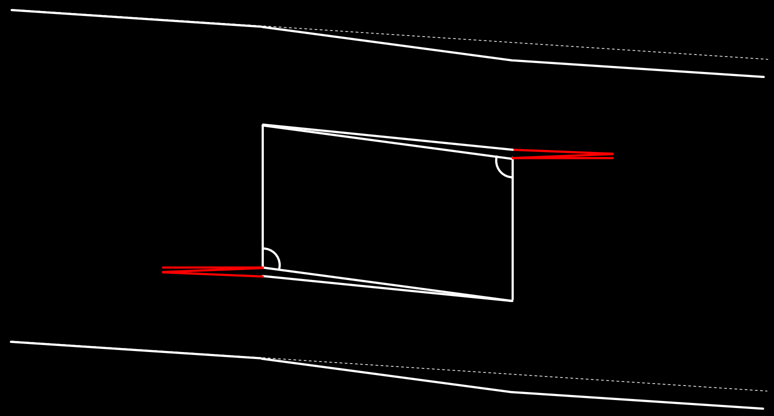
Pictures: Prof. H. Blaß, TH Karlsruhe

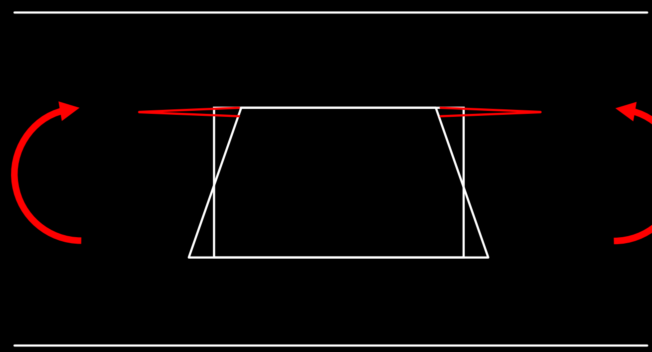
Openings



Openings

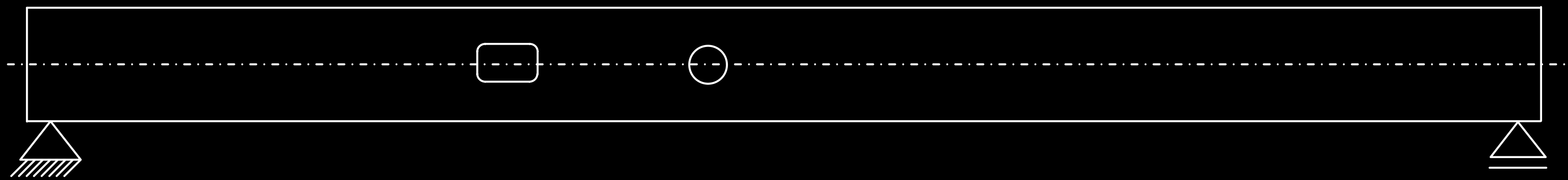




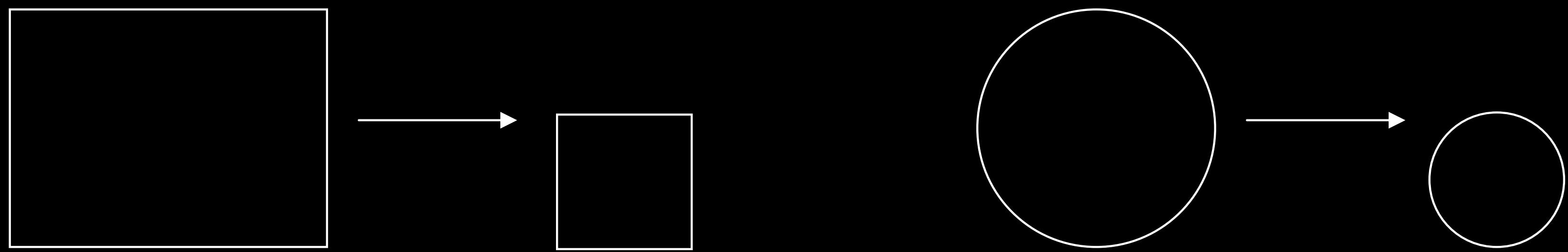


Openings - Constructive Measures

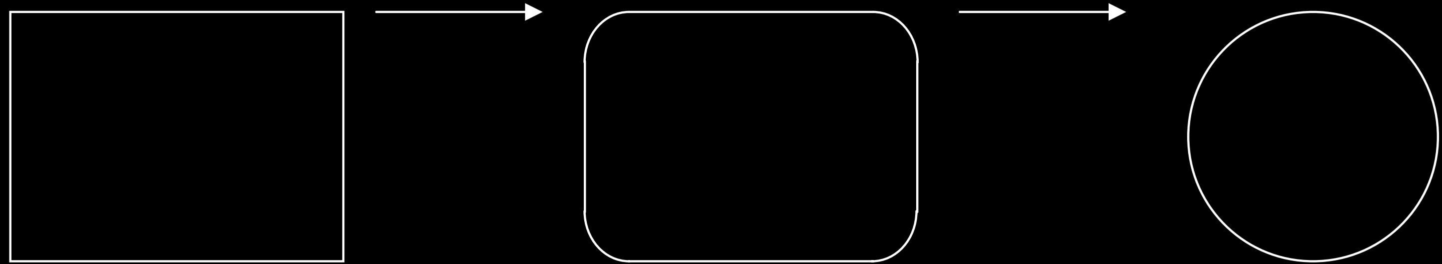
Place in center line of member, at distance from supports



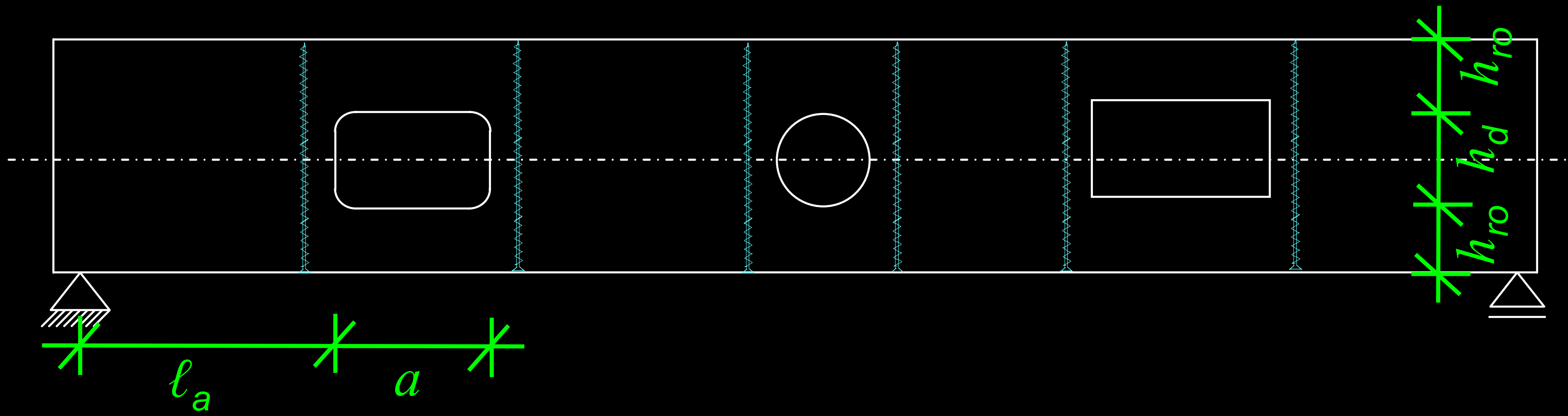
Size – as small as possible (minimize reduction in cross section)

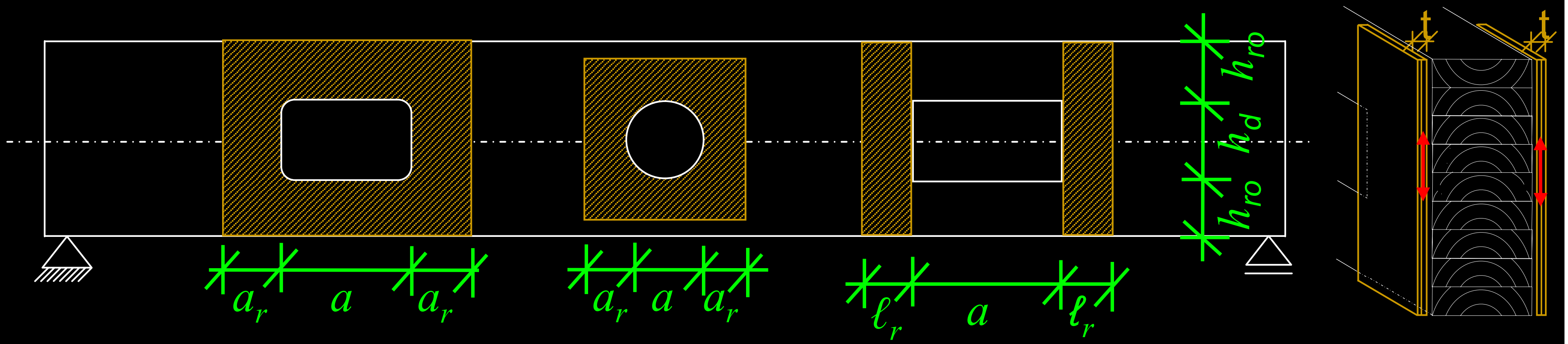


Round openings or chamfered corners (avoid stress peaks)



Openings - Strengthening Measures





Tension Perpendicular to Grain - Conclusion

- Tension perpendicular to grain strength very low
- Avoid tension perp. to grain stresses whenever possible
- Members with tension perp. to grain stresses are:
  - Double tapered, curved and pitch cambered beams
  - Notched members, members with holes or cross connctions
- Tension perp. to grain stresses also develop with changing moisture content
- Possible reinforcements are: Self-tapping screws with continuous thread, drilled or glued-in rods, plywood / LVL...
- Proposal: reinforcements should be designed to carry full tension perp. to grain stresses (cracked tension perp. to grain zone)

Literature

- Timber Engineering – STEP 1, STEP 2; Centrum Hout; The Netherlands
- Erläuterungen zu DIN 1052:2004; DGFH; Germany (in German)
- CIB – W18 Proceedings; TH Karlsruhe; Germany
- Design of Structural Timber to EC5; Palgrave; GB
- Structural Timber Design to Eurocode 5; Blackwell Publishing; GB