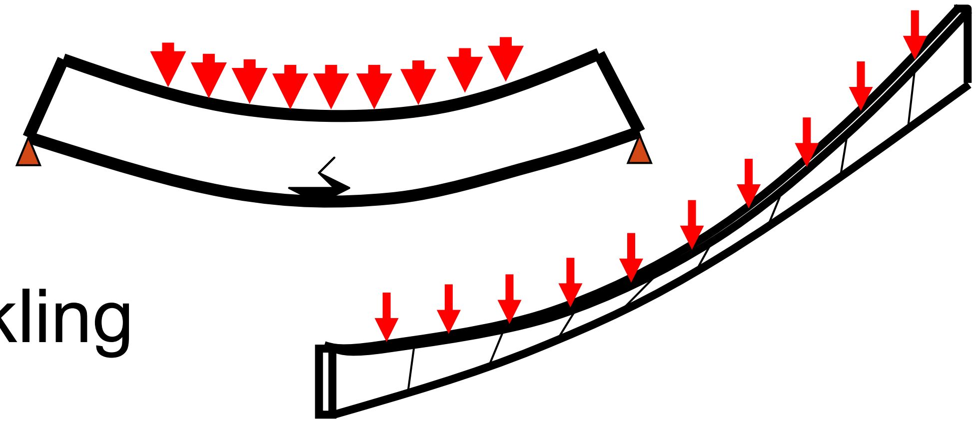
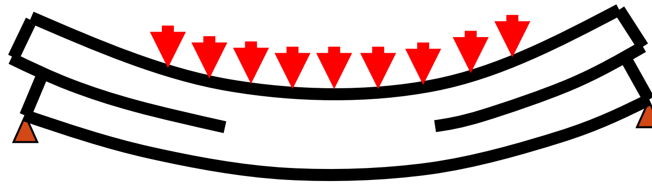
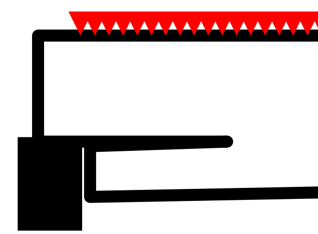
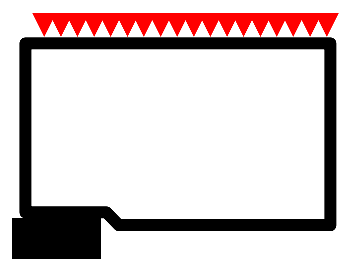
TIMBER BEAMS:

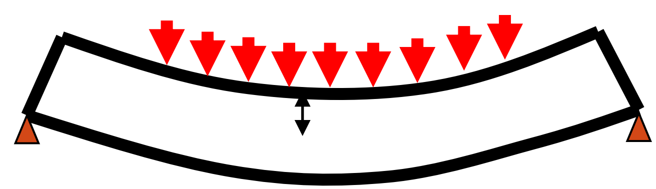
- Bending failure
- Lateral torsional buckling
- Shear failure
- Notch failure
- Bearing failure
- Excessive deflections





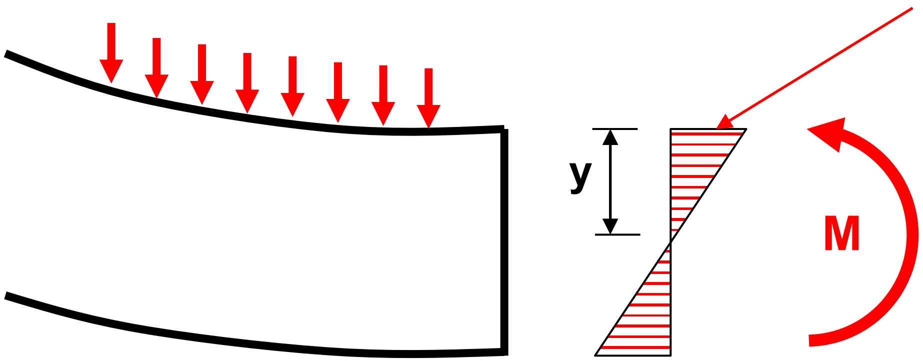






Bending Strength

Linear elastic stresses



$$\sigma_{\max} = \frac{My}{I} = \frac{M}{S}$$

$$M = \sigma_{\max} S$$

for rectangular sections

$$S = \frac{bh^2}{6}$$

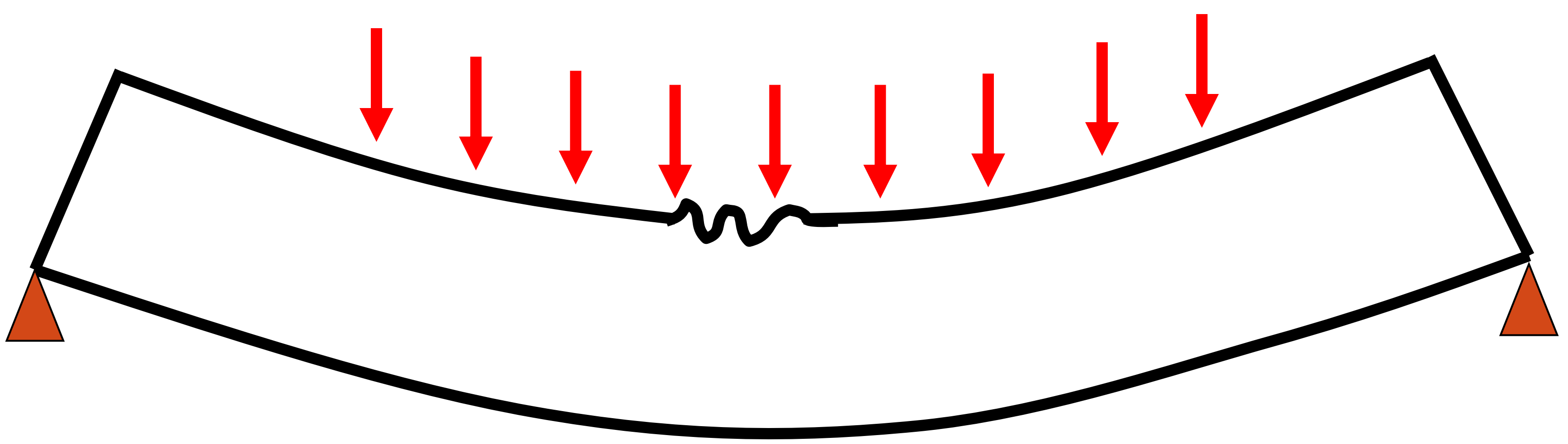
Design Equation:

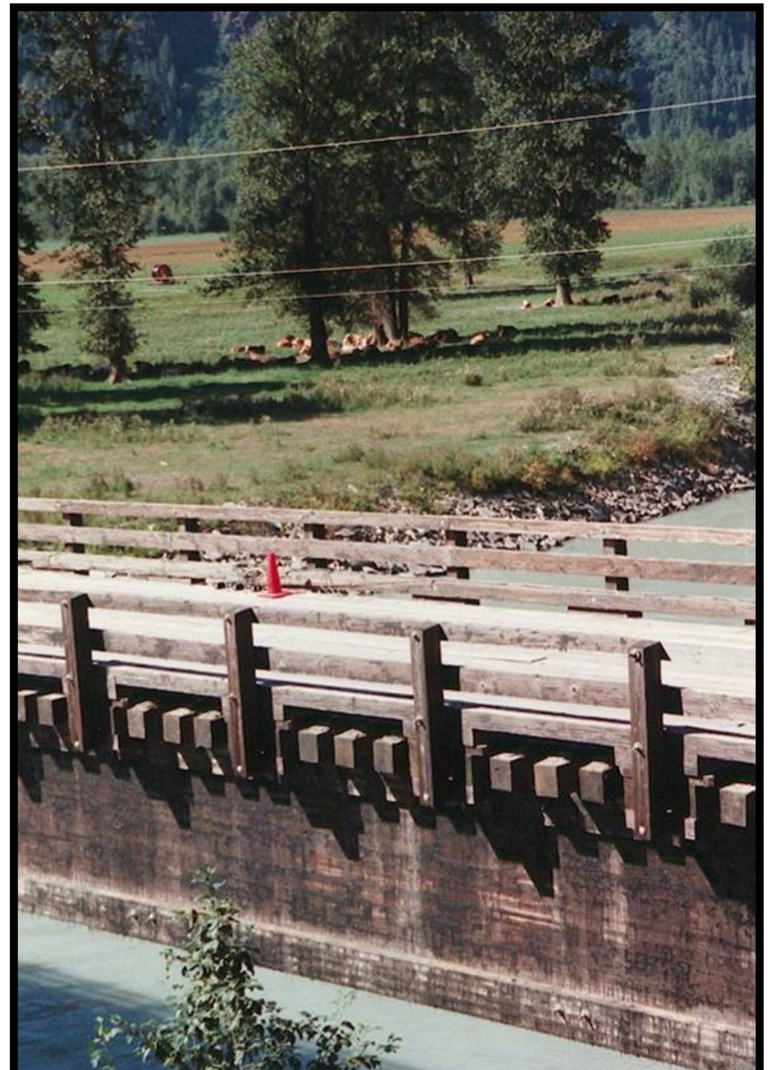
$$M_r = \varphi F_b S$$

Where F_b is the characteristic bending strength
For timber it is $F_b = f_b (K_D K_H K_{Sb} K_T)$

Bending failure in compression

- Only likely for very high grade material
- Benign failure mode



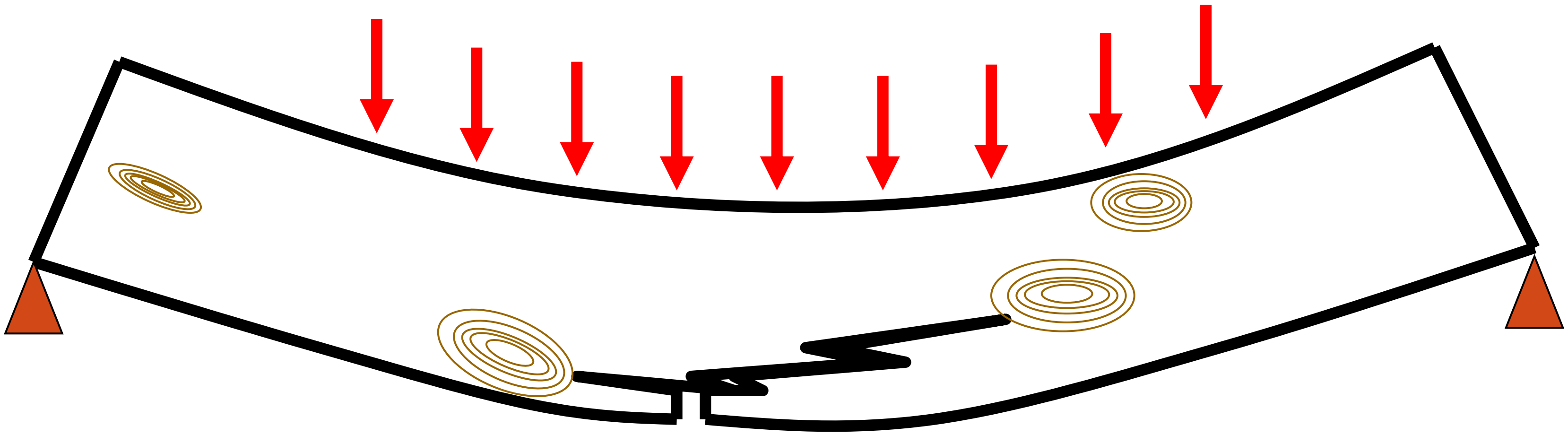


Logging bridge
near Pemberton, BC

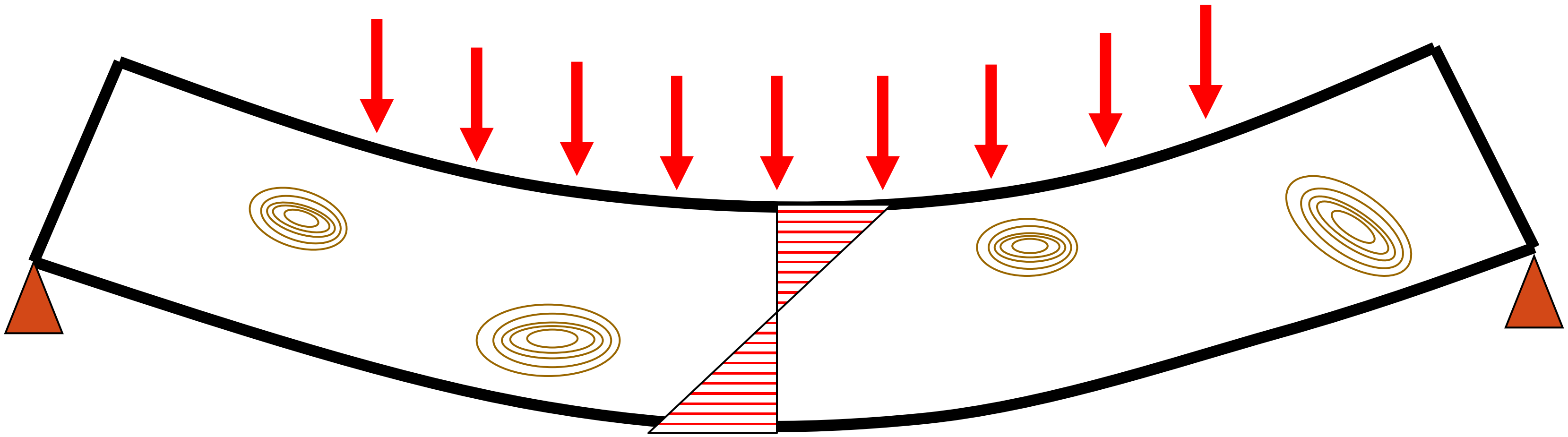
Glulam I-beam

Bending failure in tension

- Most likely failure mode
- Brittle
- Combination of tension and shear, although tension fracture is the initiating mode



Bending capacity



$$M_r = \varphi F_b S K_{Zb} K_L$$

Lateral torsional buckling

where $\varphi = 0.9$

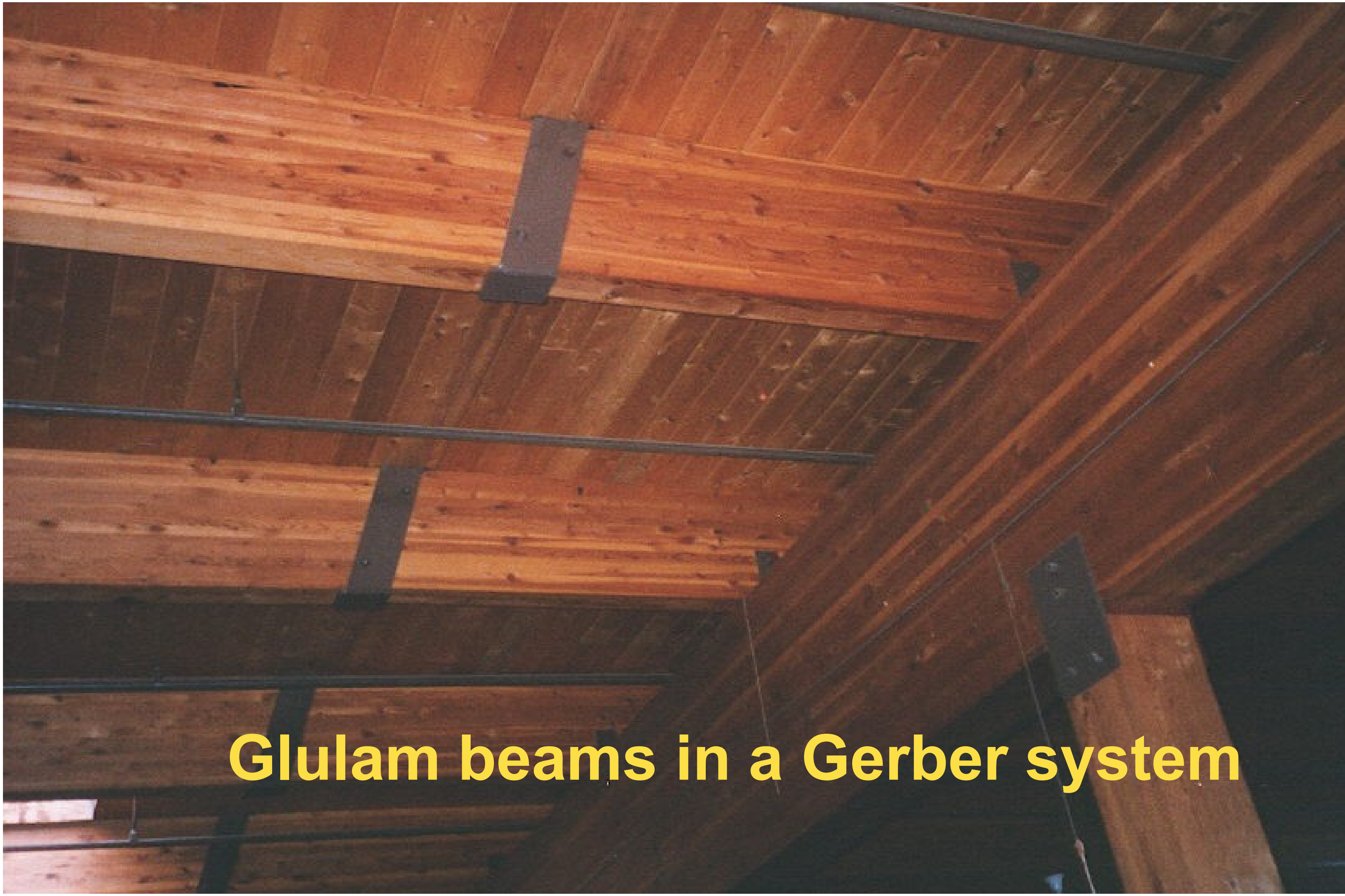
and $F_b = f_b (K_D K_H K_{Sb} K_T)$

Table 5.3.1C
Specified Strengths and Modulus of Elasticity for Beam and Stringer Grades (MPa)

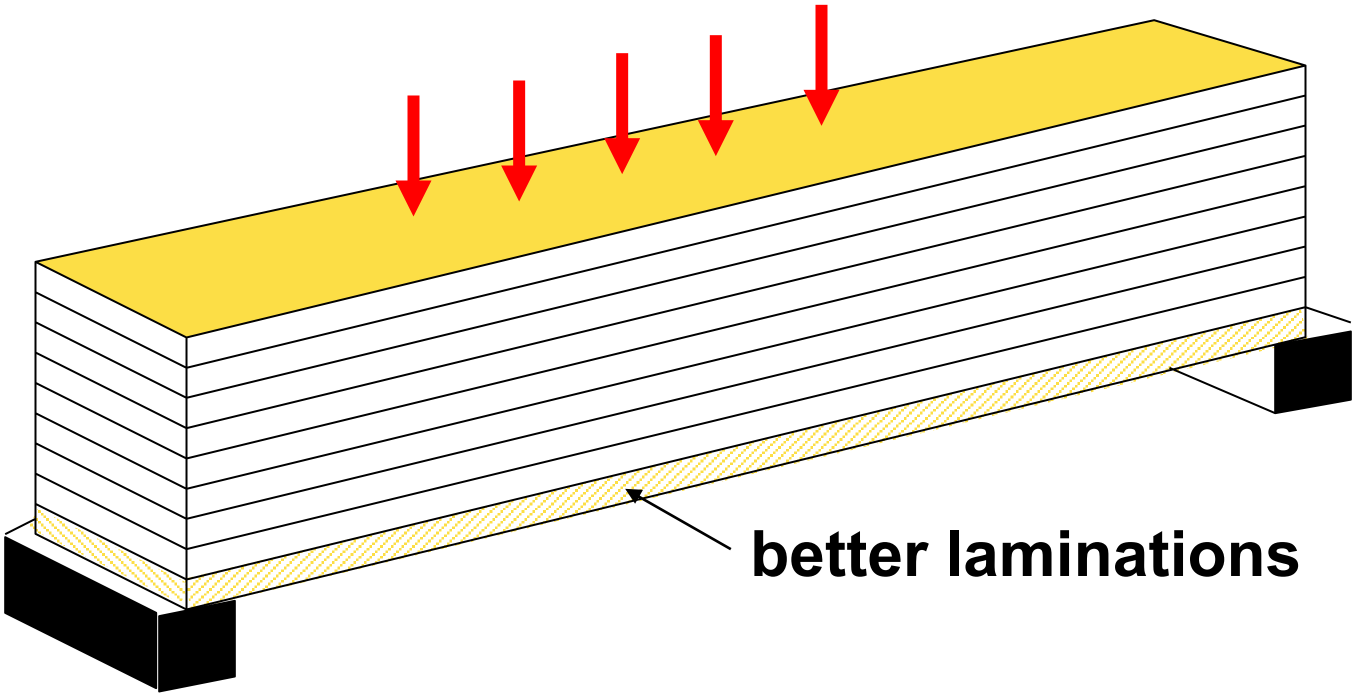
Species identification	Grade	Bending at extreme fibre,* f_b	Longitudinal shear, f_v	Compression: Parallel to grain, f_c	Compression: Perpendicular to grain, f_{cp}	Tension parallel to grain, f_t	Modulus of elasticity: E	Modulus of elasticity: E_{05}
D Fir-L	SS	19.5		13.2		10.0	12 000	8 000
	No. 1	15.8	0.9	11.0	7.0	7.0	12 000	8 000
	No. 2	9.0		7.2		3.3	9 500	6 000
Hem-Fir	SS	14.5		10.8		7.4	10 000	7 000
	No. 1	11.7	0.7	9.0	4.6	5.2	10 000	7 000
	No. 2	6.7		5.9		2.4	8 000	5 500
S-P-F	SS	13.6		9.5		7.0	8 500	6 000
	No. 1	11.0	0.7	7.9	5.3	4.9	8 500	6 000
	No. 2	6.3		5.2		2.3	6 500	4 500
Northern	SS	12.8		7.2		6.5	8 000	5 500
	No. 1	10.8	0.6	6.0	3.5	4.6	8 000	5 500
	No. 2	5.9		3.9		2.2	6 000	4 000

**Specified strengths for beams and stringers are based on loads applied to the narrow face. When beams and stringers are subject to loads applied to the wide face, the specified strength for bending at the extreme fibre and the specified modulus of elasticity shall be multiplied by the following factors:*

	f_b	E or E_{05}
Select Structural	0.88	1.00
No. 1 or No. 2	0.77	0.90

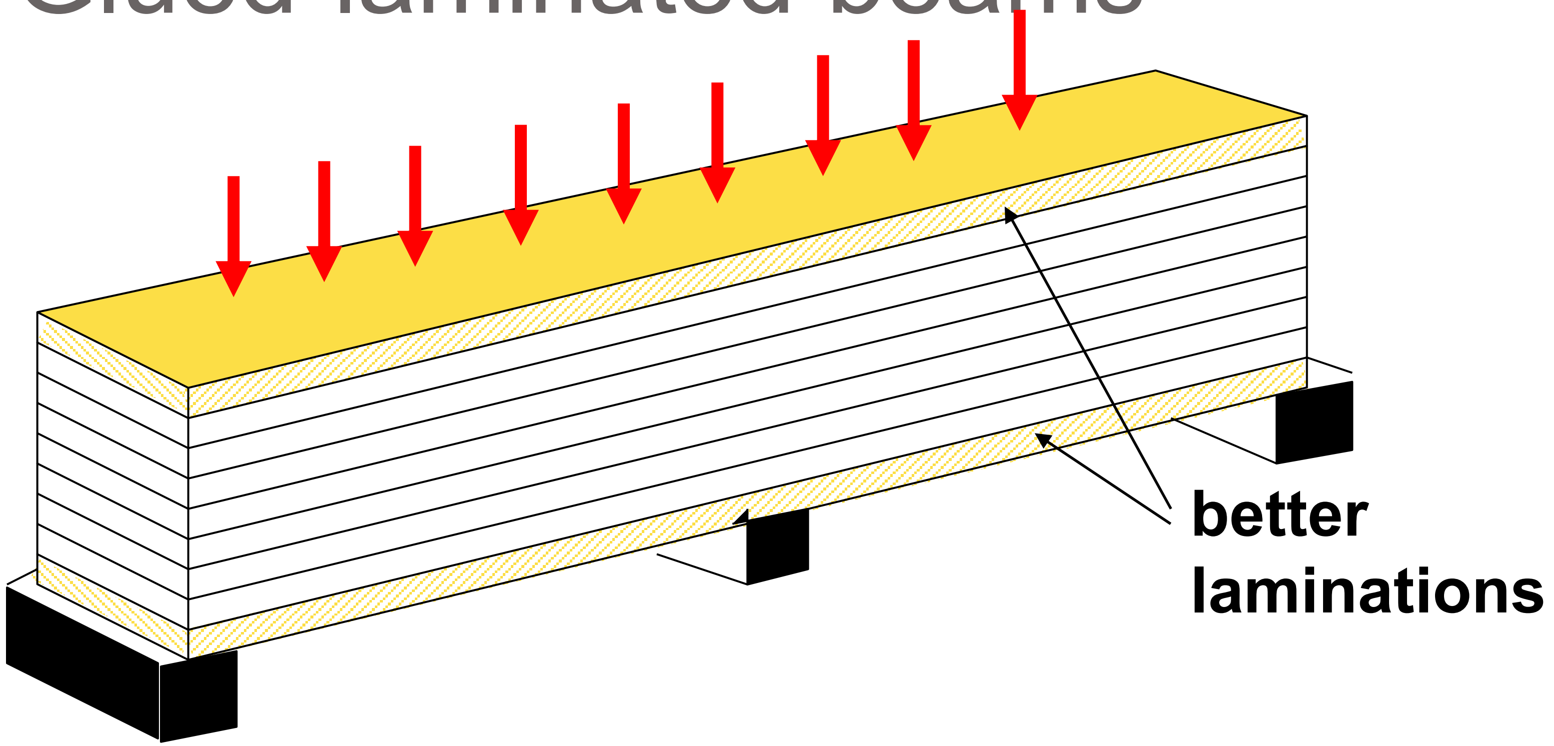

Glulam beams in a Gerber system

Glued-laminated beams



20f-E and 24f-E grades

Glued-laminated beams



20f-EX and 24f-EX grades

Table 6.3
Specified Strengths and Modulus of Elasticity for Glued-Laminated Timber (MPa)

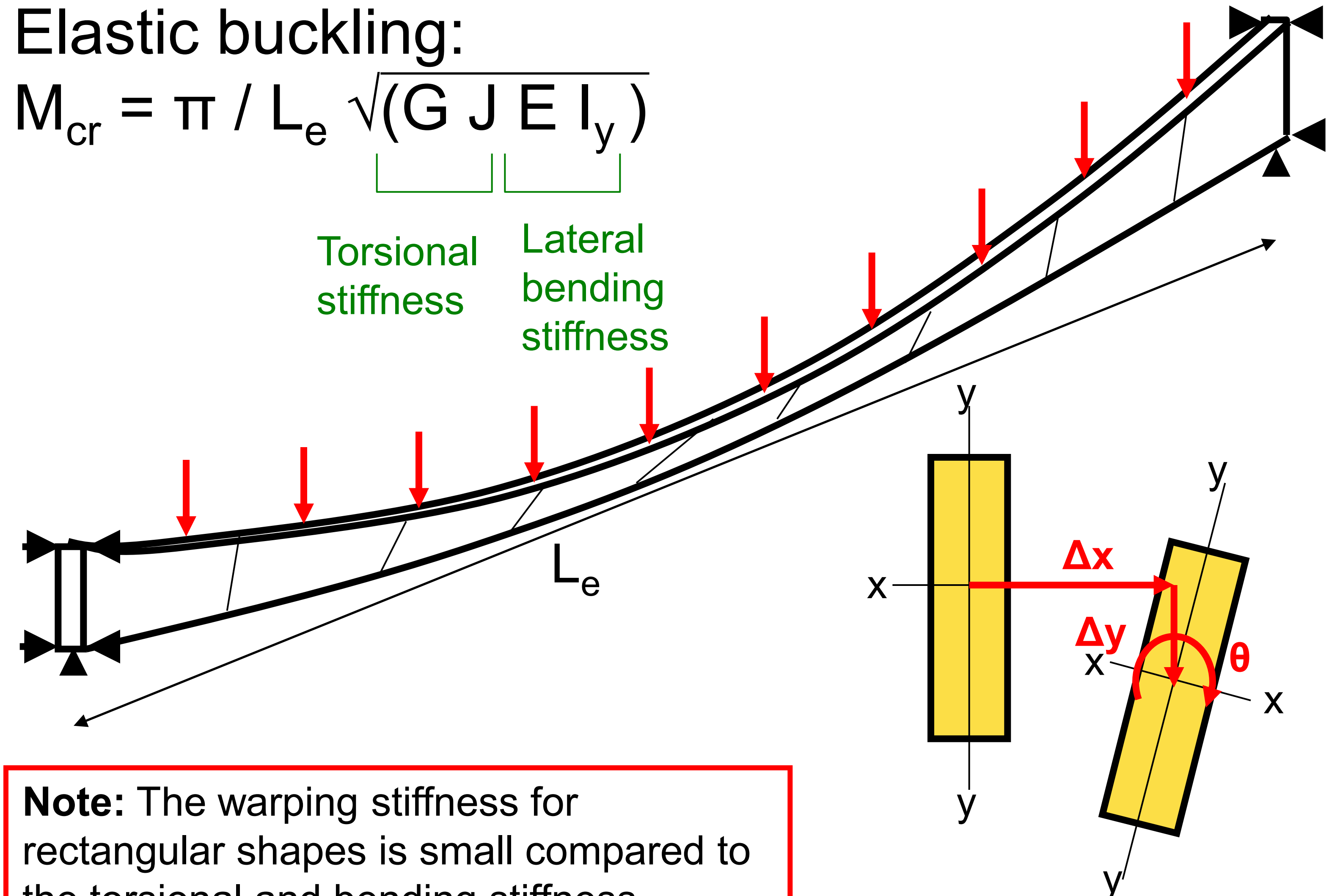
		Douglas Fir-Larch					
		24f-E	24f-EX	20f-E	20f-EX	18t-E	16c-E
Bending moment (pos.)	f_b	30.6	30.6	25.6	25.6	24.3	14.0
Bending moment (neg.)	f_b	14.0	30.6	14.0	25.6	24.3	14.0
Longitudinal shear	f_v	2.0	2.0	2.0	2.0	2.0	2.0
Compression parallel	f_c	30.2*	30.2*	30.2*	30.2*	30.2	30.2
Compression parallel combined with bending	f_{cb}	30.2*	30.2	30.2*	30.2	30.2	30.2
Compression perpendicular	f_{cp}						
— compression face bearing		7.0	7.0	7.0	7.0	7.0	7.0
— tension face bearing		7.0	7.0	7.0	7.0	7.0	7.0
Tension net section (See Clause 6.5.11)	f_{tn}	20.4*	20.4	20.4*	20.4	23.0	20.4
Tension gross section	f_{tg}	15.3*	15.3	15.3*	15.3	17.9	15.3
Tension perpendicular to grain	f_{tp}	0.83	0.83	0.83	0.83	0.83	0.83
Modulus of elasticity	E	13 100	13 100	12 400	12 400	13 800	12 400

Lateral torsional buckling of timber beams

Elastic buckling:

$$M_{cr} = \pi / L_e \sqrt{(G\,J\,E\,I_y)}$$

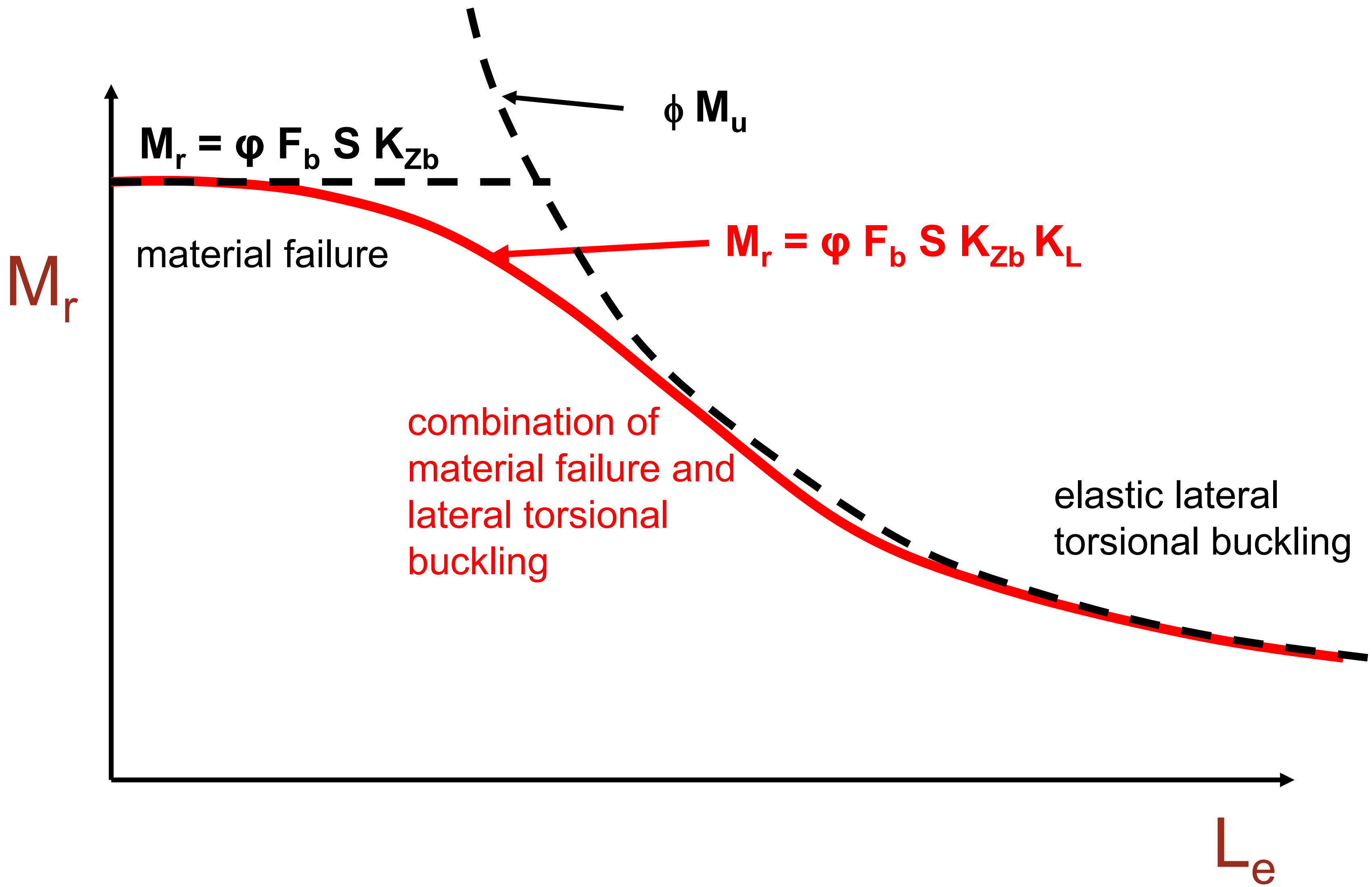
Torsional stiffness — Lateral bending stiffness



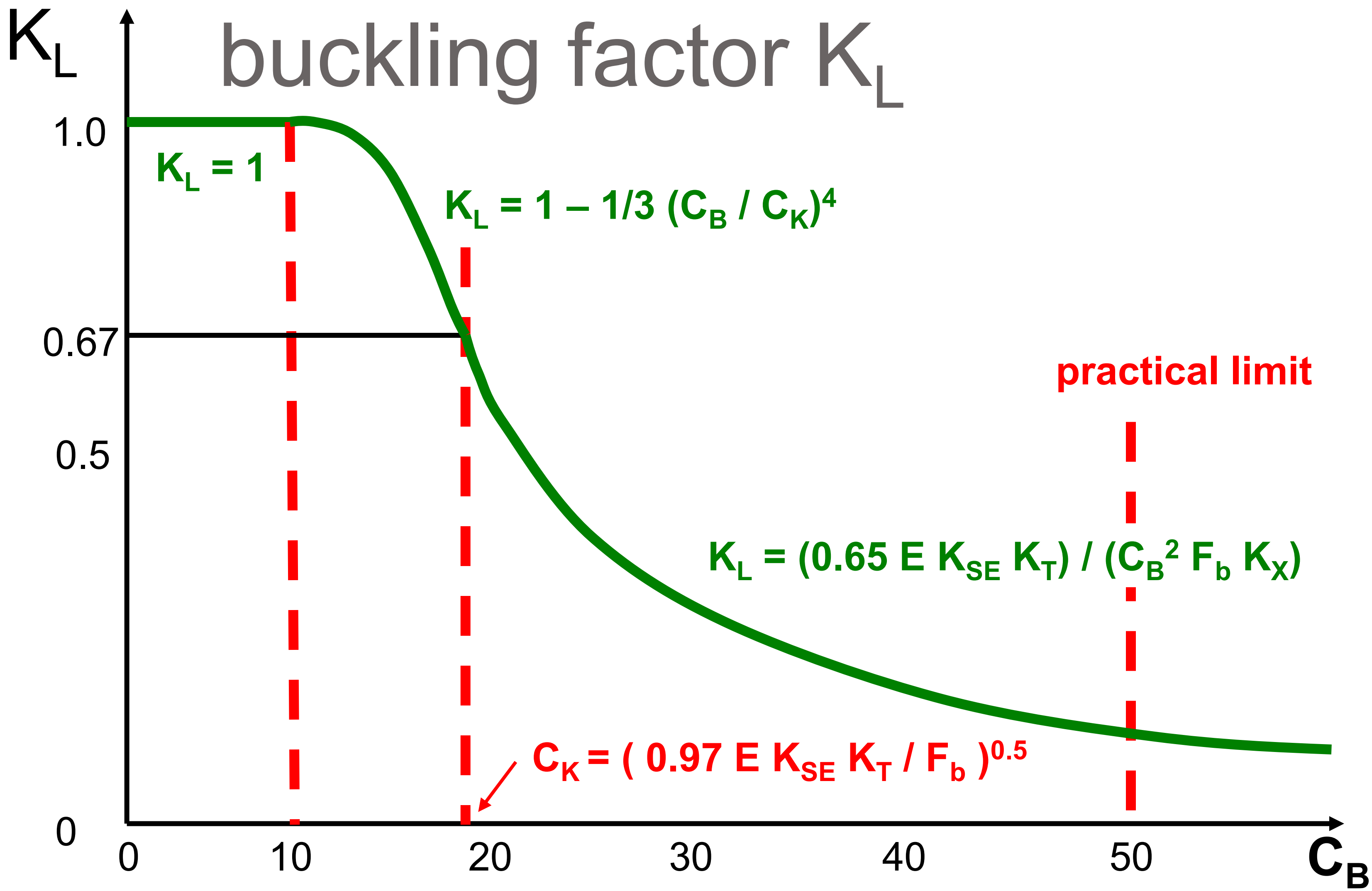
Note: The warping stiffness for rectangular shapes is small compared to the torsional and bending stiffness

Lateral torsional buckling of deep I-joists

Capacity of a timber beam subject to lateral torsional buckling

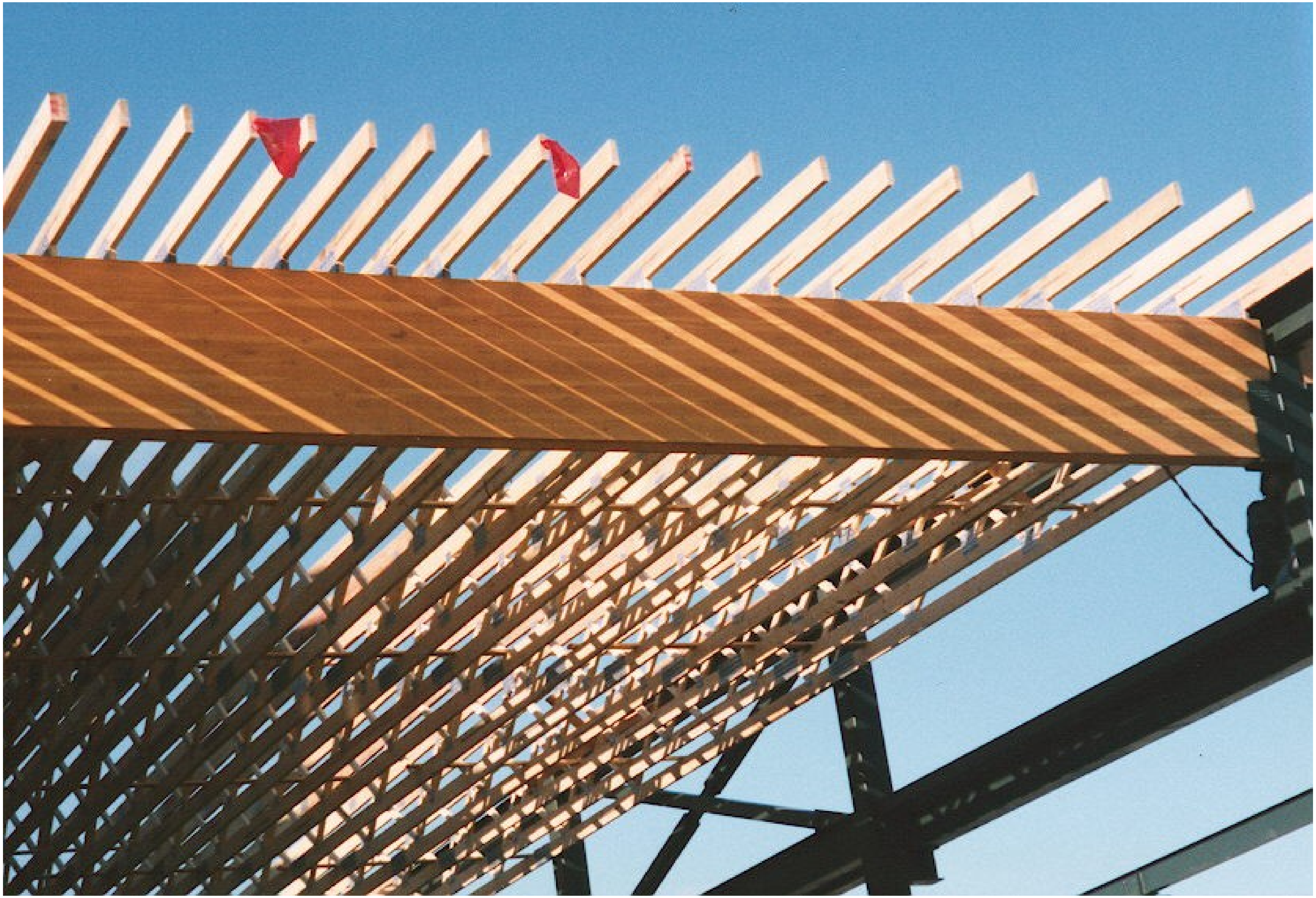


Lateral torsional buckling factor K_L



Slenderness ratio $C_B = (\ L_e\ d / b^2\ )^{0.5}$

Deep glulam beam



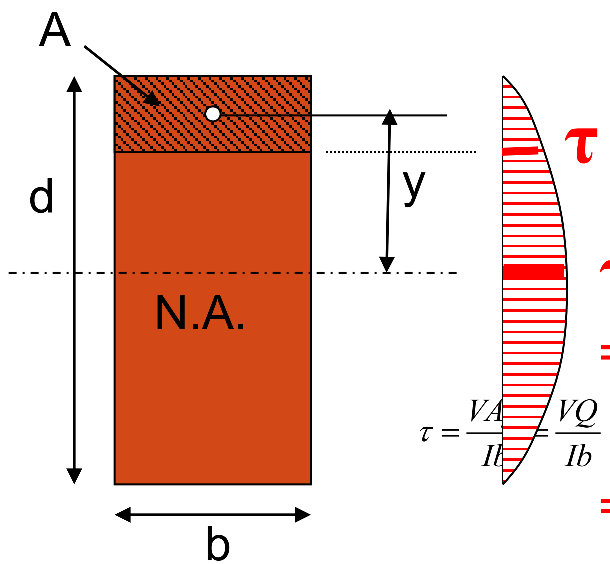
Prevention of lateral torsional buckling

$K_L = 1.0$ when lateral support is provided as shown

d/b	Lateral support at spacing:
< 4	no support
< 5	purlins or tie rods
< 6.5	< 610 mm compression edge held by decking or joists
< 7.5	< 610 mm < 8d top edge plus bridging
< 9	both edges

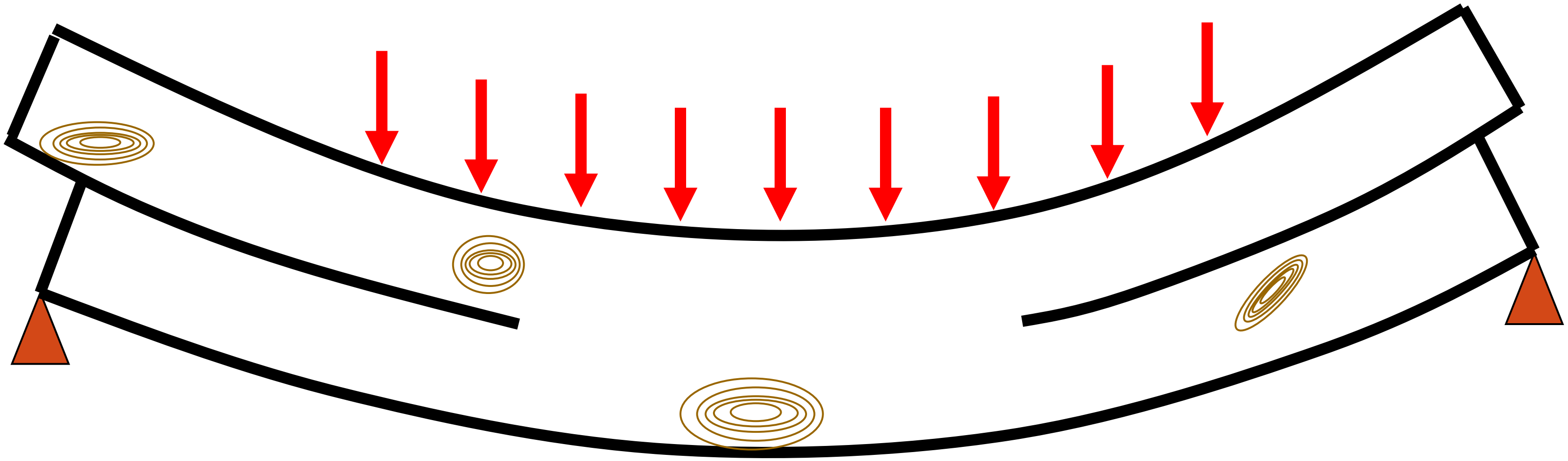
Bridging for floor joists

Shear stress in a beam



$$\tau_{max} = \frac{V(0.5A)(d/4)}{(bd^3/12)b} = 1.5\ V/A$$

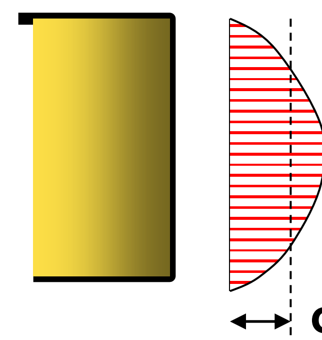
Shear in a timber beam



$$V_r = \varphi\, F_v\, \overbrace{2/3\, A}^{A_s}\, K_{Zv}$$

where φ = 0.9

and $F_v = f_v\,(K_D\, K_H\, K_{Sv}\, K_T\,)$



$\sigma_{v(max)} = 1.5\, \sigma_{v(avg)}$

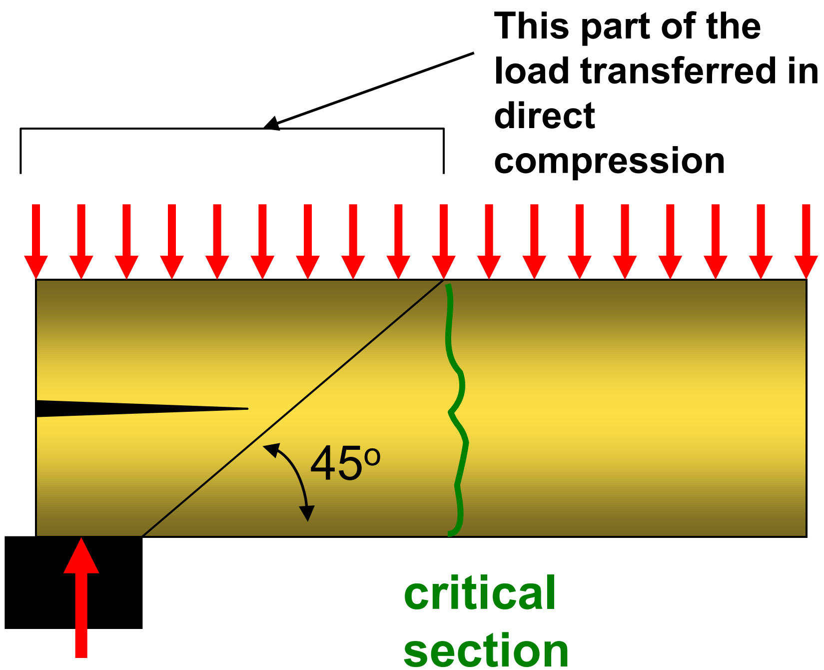
$= 1.5\, V / A$

UNBC
Prince George, BC

Shear failures

- One of the very weak properties of wood
- Shrinkage cracks often occur at the ends of beams in the zone of maximum shear stress

- **Direct compression transfer of loads in the end zones reduces the total shear force to be carried.**



Shear design of glulam beams

A simple approach for beams where the volume < 2.0 m^3:

$$V_r = \varphi F_v \, 2/3 \, A \, K_N$$

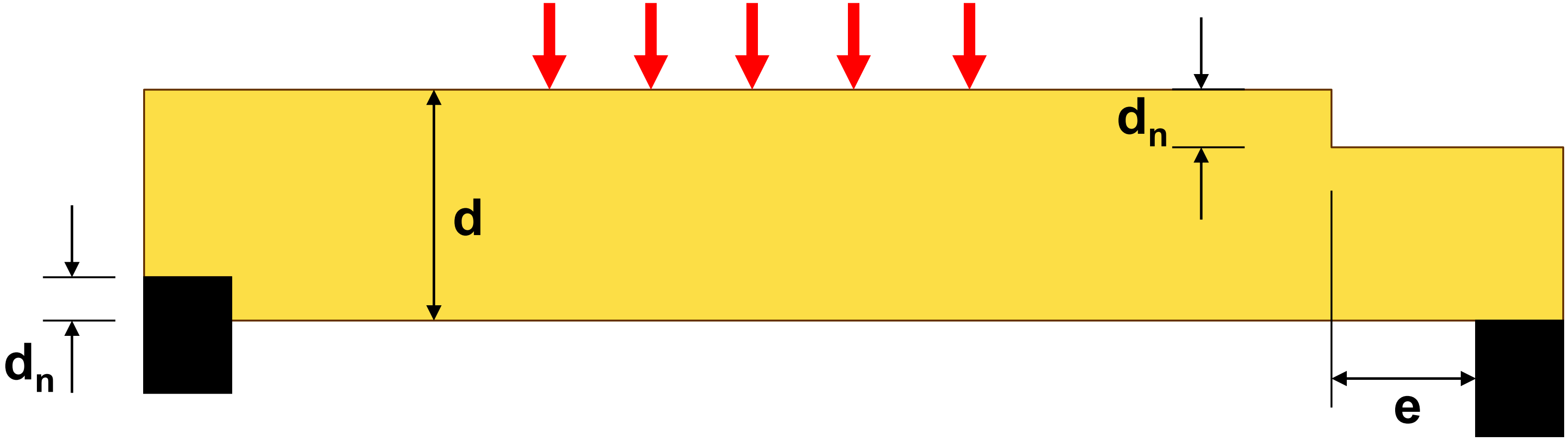
where $\varphi = 0.9$

and $F_v = f_v (K_D K_H K_{Sv} K_T)$

K_N **= notch factor (see next section)**

For larger beams this is usually quite conservative and a more sophisticated approach is used (see clause 6.5.7.3)

Notch factor for Glulam beams



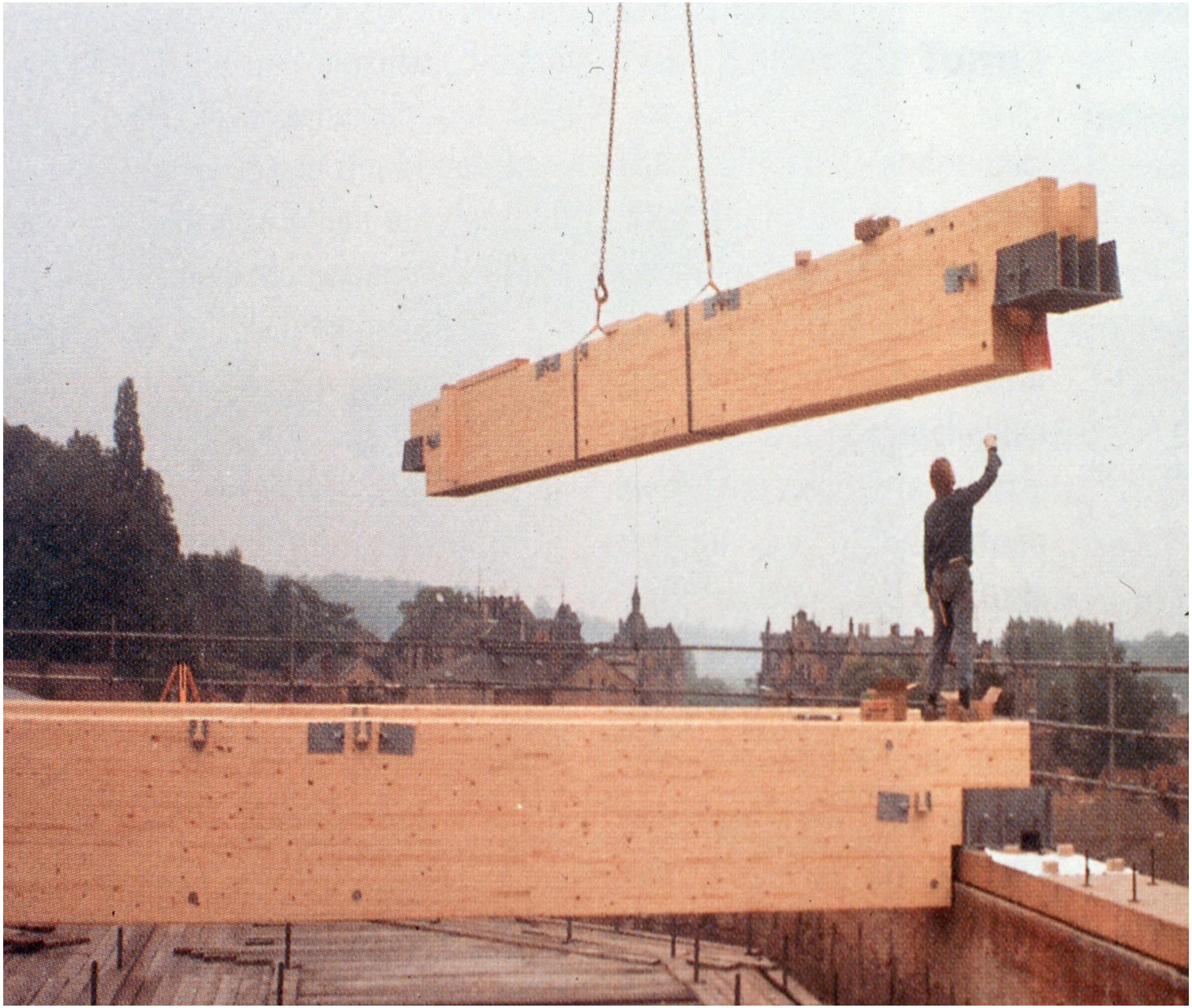
$$K_N = (1 – d_n/d)^2$$

For e > d :

$$K_N = (1 – d_n/d)$$

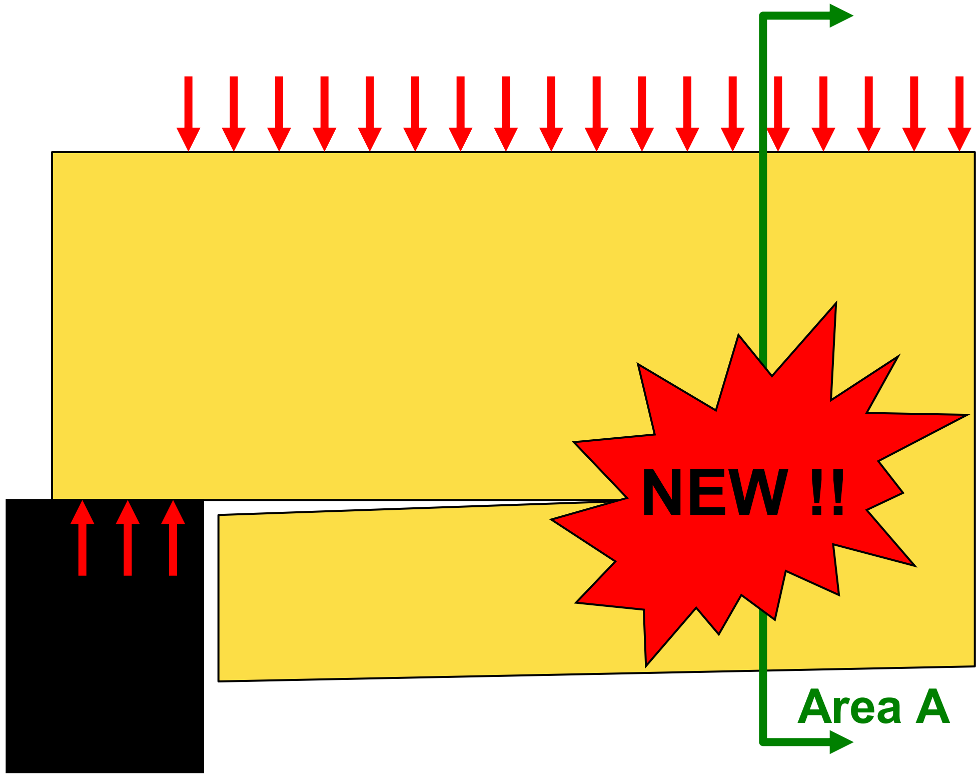
For e < d :

$$K_N = 1 – d_n e/[d(d – d_n)]$$



Notch effect in sawn lumber

- For notches on the tension side of supports (sawn lumber)
- In new code: Reaction calculation



$$F_r = \phi F_t A K_N$$

$\phi = 0.9$

$F_t = f_t (K_D K_H K_{St} K_T)$

where f_t = specified reaction force strength = 0.5 MPa for sawn lumber

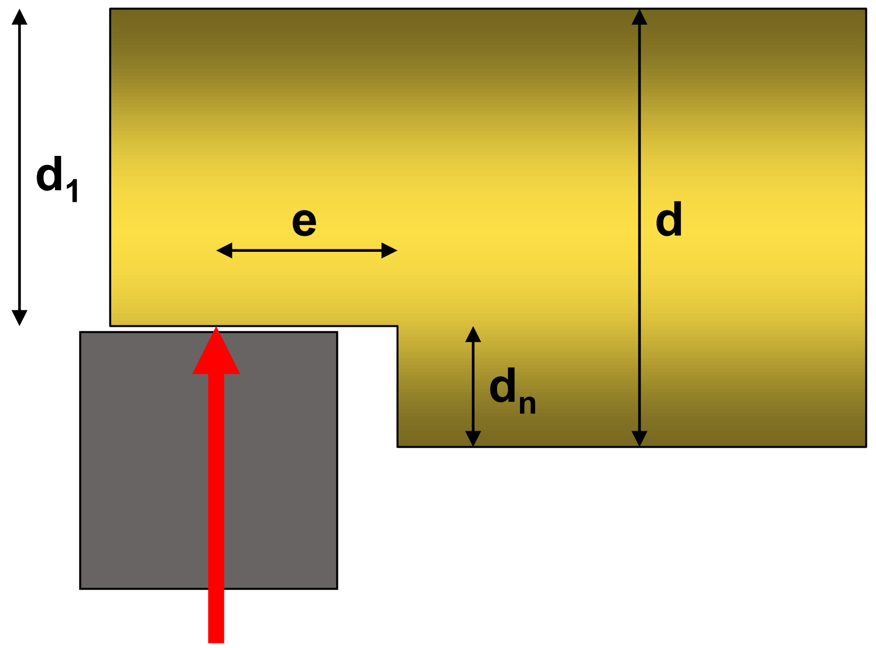
K_{St} = 1.0 for dry and 0.7 for wet service conditions

A = gross cross-section area

K_N = notch factor

Notch factor K_N

Based on Fracture Mechanics theory



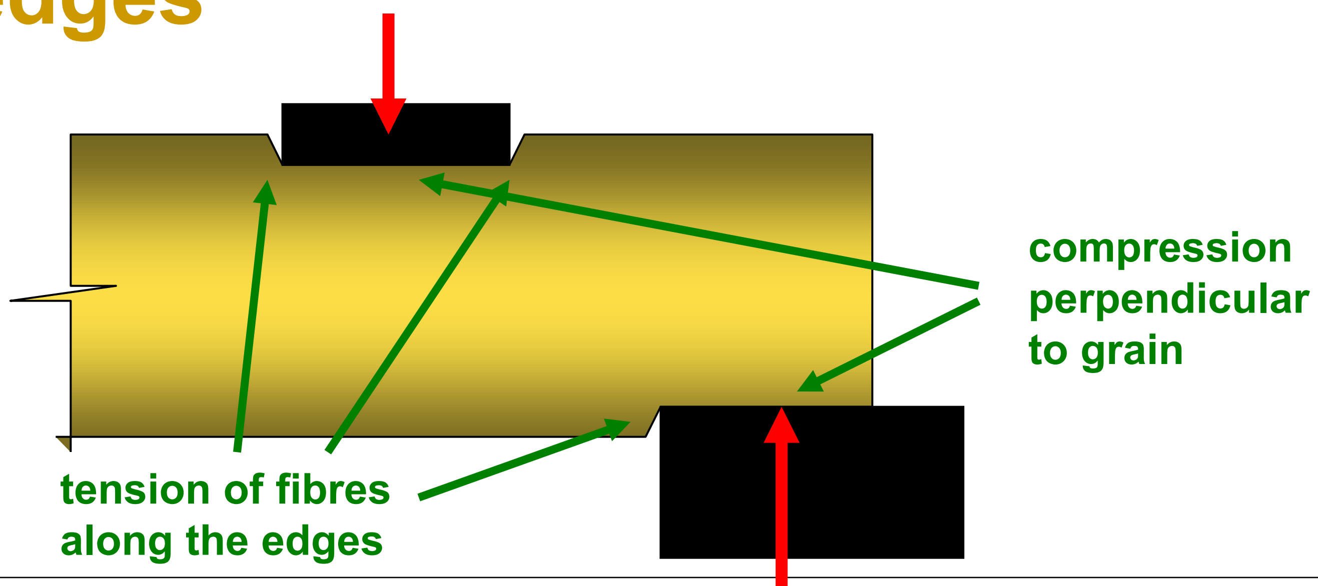
$$K_N = \left(0.006\left(1.6\left(\frac{1}{\alpha}-1\right)+\eta^2\left(\frac{1}{\alpha^3}-1\right)\right)\right)^{-0.5}$$

$$\alpha = 1-\left(d_n/d\right) \text{ and } \eta = e/d$$

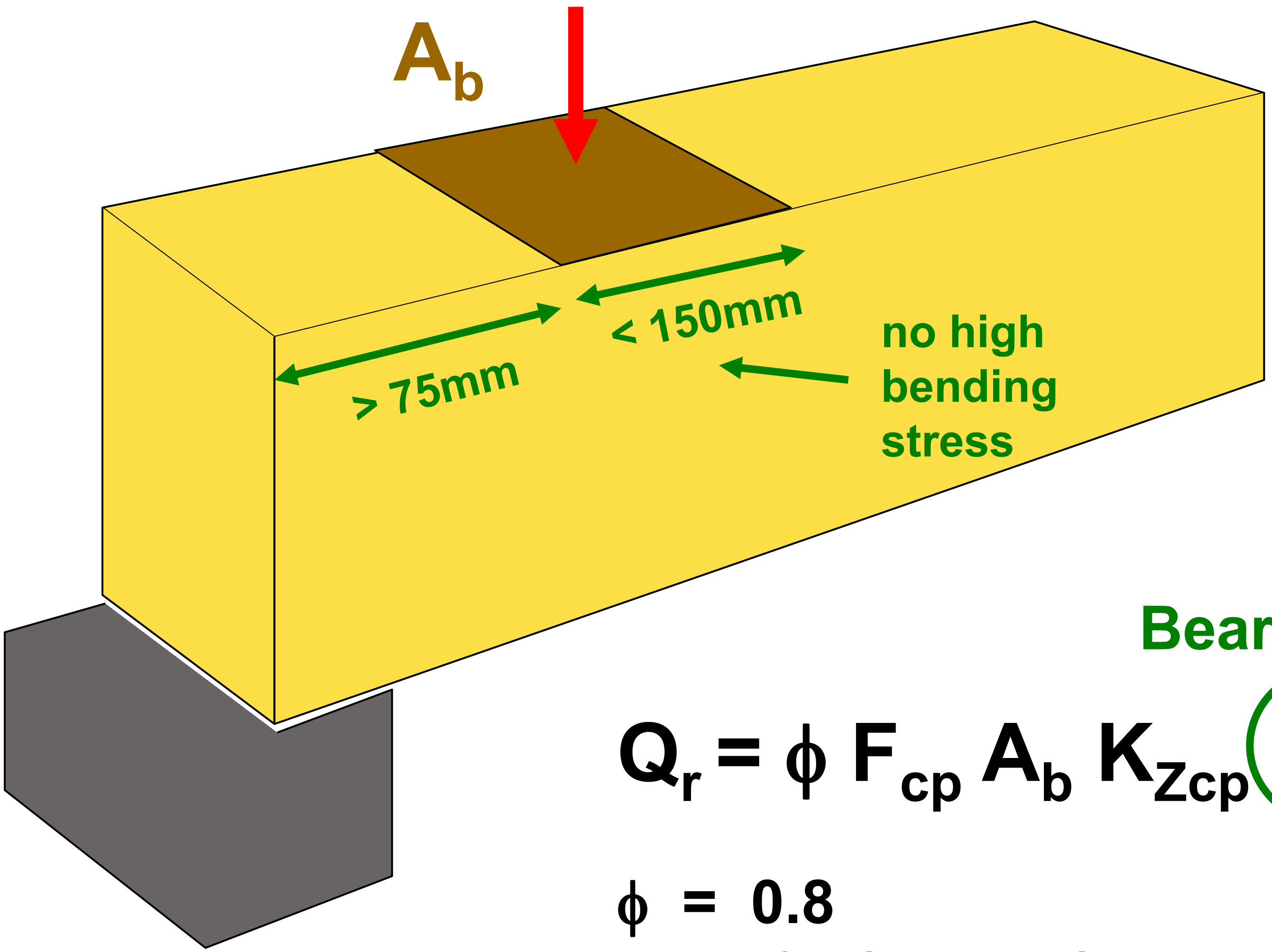
Bearing failure in a timber beam

- The "soft" property of wood
- Often governs

- **Not only compression perpendicular to grain but also tension of the fibres along edges**



Bearing resistance



Bearing factor

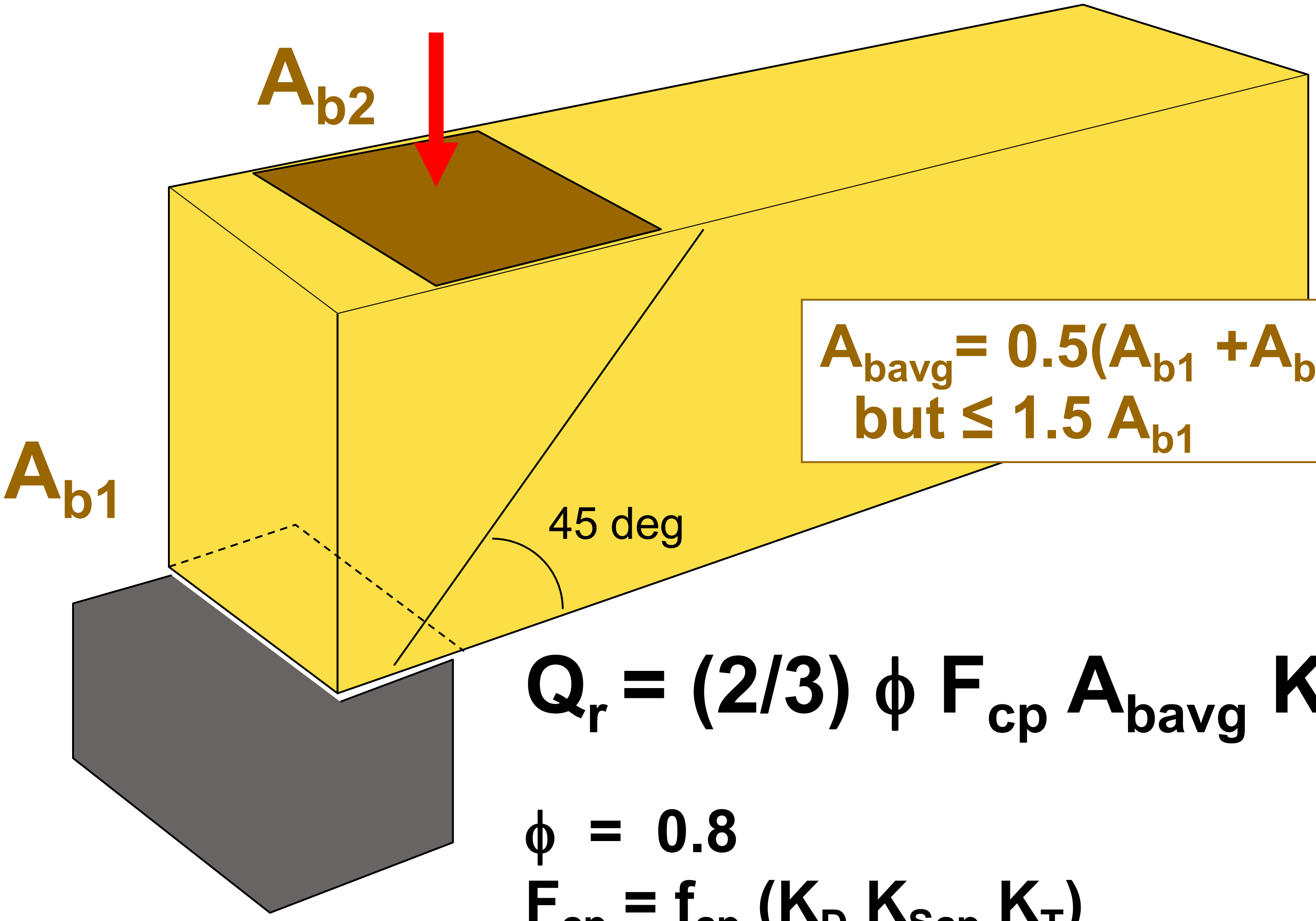
$$Q_r = \phi \, F_{cp} \, A_b \, K_{Zcp} \, K_B$$

$\phi = 0.8$

$F_{cp} = f_{cp} \, (K_{Scp} \, K_T)$

Critical bearing areas in woodframe construction

Bearing resistance (double bearing)



$A_{bavg} = 0.5(A_{b1} + A_{b2})$
but $\leq 1.5\ A_{b1}$

$$Q_r = (2/3)\ \phi\ F_{cp}\ A_{bavg}\ K_{Zcp}\ K_B$$

$\phi = 0.8$

$F_{cp} = f_{cp}\ (K_D\ K_{Scp}\ K_T)$

Bearing factor K_B

Bearing length or diameter (mm)	Bearing factor K_B
< 12.5	1.75
25	1.38
38	1.25
50	1.19
75	1.13
100	1.10
> 150	1.0

Deflections

- A serviceability criterion
  - Avoid damage to cladding etc. ($\Delta \leq L/180$)
  - Avoid vibrations ($\Delta \leq L/360$)
  - Aesthetics ($\Delta \leq L/240$)
- Use <u>unfactored</u> loads
- Typically not part of the code