EN 1995-1-1

Design of timber structures

Storage building in Japan 4 Jh. v. Ch.

Stave church in Norway 13th century

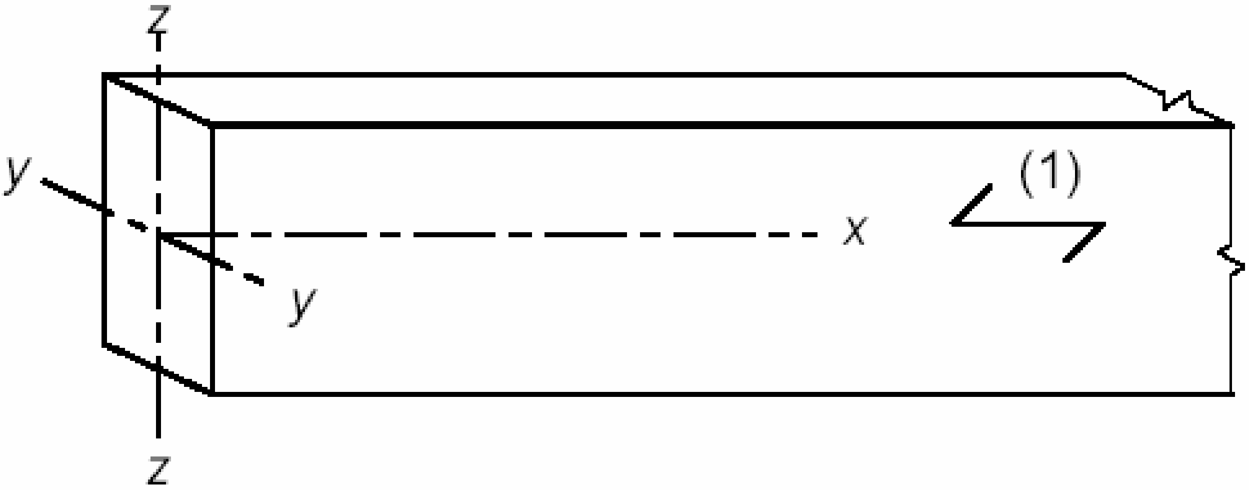
Bridge across river Sinne (Switzerland)

Faculty of architecture (Lyon)

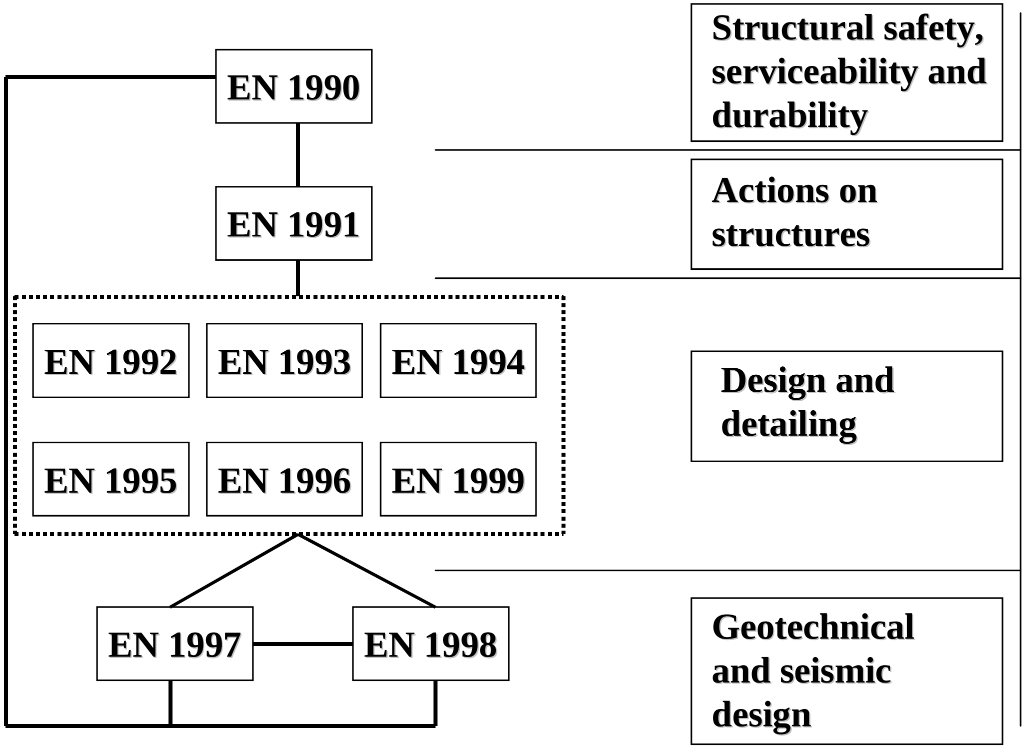
EN1995-1-1 Scope and structure

- **Section 1:** General definitions, terminology
- **Section 2:** Basis of design: Timber specific supplement to EN1990
- **Section 3:** Material properties to be used for design
- **Section 4:** Durability concept
- **Section 5:** Basis of structural analysis
- **Section 6:** Ultimate limit state design principles
- **Section 7:** Serviceability limit states
- **Section 8:** Fasteners
- **Section 9:** Design of components and assemblies
- **Section 10:** Workmanship, structural detailing and control

EN1995-1-1 - Definition of axes



Link of EN 1995-1-1 to EN1990 and EN1991



EN 1990

EN 1991

EN 1992

EN 1993

EN 1994

EN 1995

EN 1996

EN 1999

EN 1997

EN 1998

Structural safety, serviceability and durability

Actions on structures

Design and detailing

Geotechnical and seismic design

National Annex

- Contains nationally determined parameters
- These override EN1995-1-1 values
- Take account of national conditions, such as geographical or workmanship differences
- Are yet not published in all countries

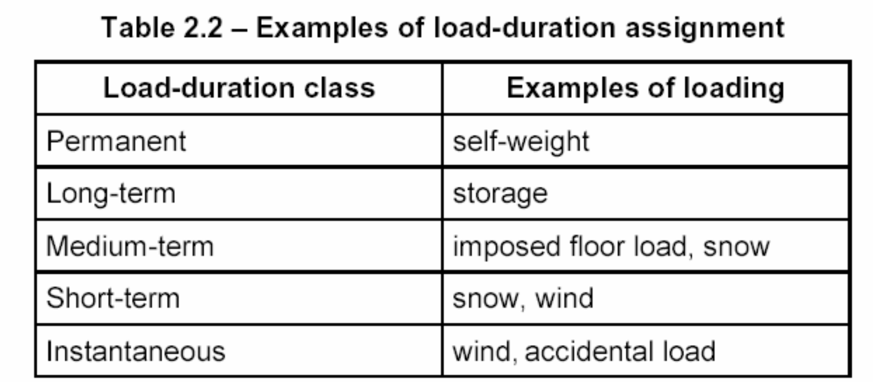
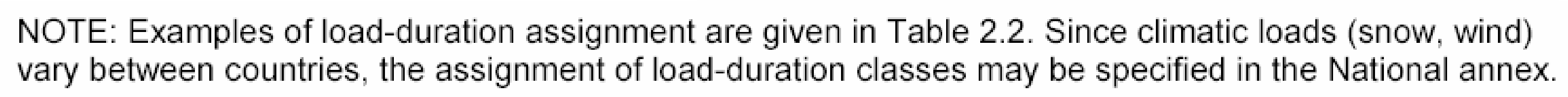


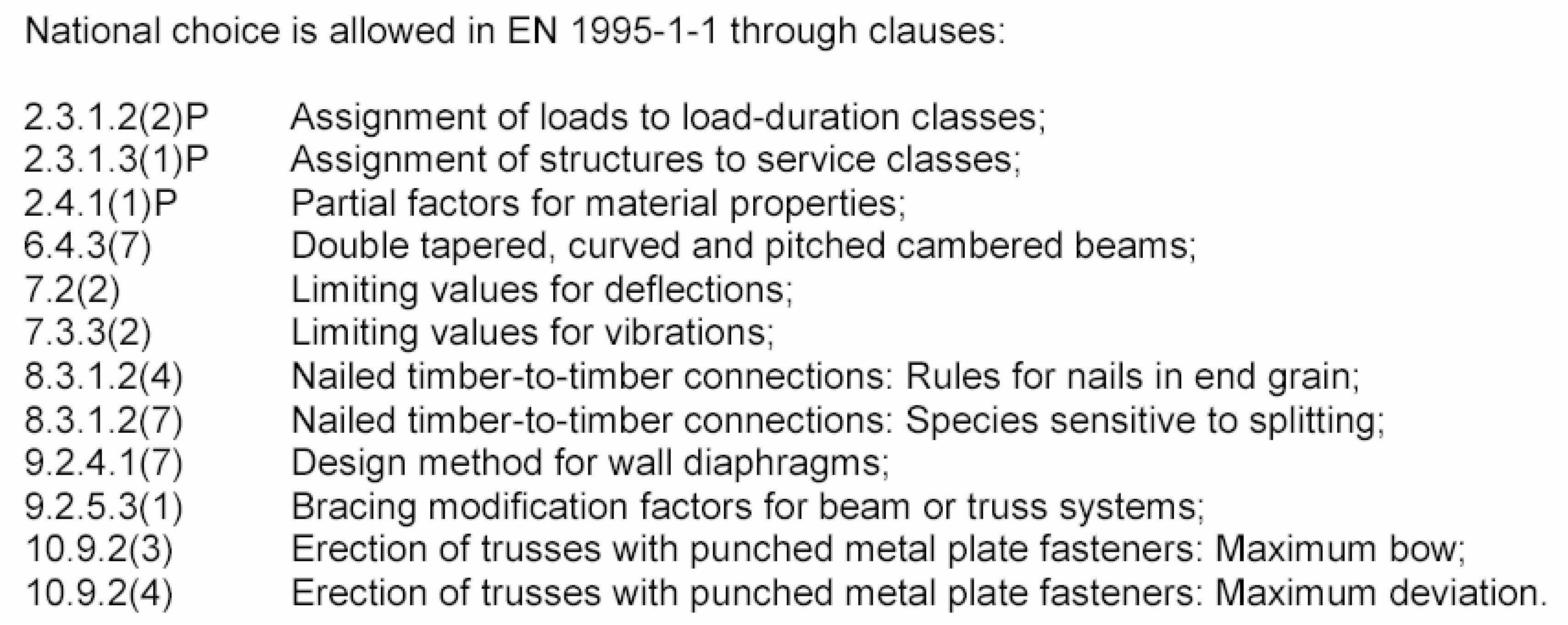
Table 2.2 – Examples of load-duration assignment

Load-duration class	Examples of loading
Permanent	self-weight
Long-term	storage
Medium-term	imposed floor load, snow
Short-term	snow, wind
Instantaneous	wind, accidental load



NOTE: Examples of load-duration assignment are given in Table 2.2. Since climatic loads (snow, wind) vary between countries, the assignment of load-duration classes may be specified in the National annex.

National choices overview



National choice is allowed in EN 1995-1-1 through clauses:

2.3.1.2(2)P	Assignment of loads to load-duration classes;
2.3.1.3(1)P	Assignment of structures to service classes;
2.4.1(1)P	Partial factors for material properties;
6.4.3(7)	Double tapered, curved and pitched cambered beams;
7.2(2)	Limiting values for deflections;
7.3.3(2)	Limiting values for vibrations;
8.3.1.2(4)	Nailed timber-to-timber connections: Rules for nails in end grain;
8.3.1.2(7)	Nailed timber-to-timber connections: Species sensitive to splitting;
9.2.4.1(7)	Design method for wall diaphragms;
9.2.5.3(1)	Bracing modification factors for beam or truss systems;
10.9.2(3)	Erection of trusses with punched metal plate fasteners: Maximum bow;
10.9.2(4)	Erection of trusses with punched metal plate fasteners: Maximum deviation.

General concept

Semi-probalistic safety concept

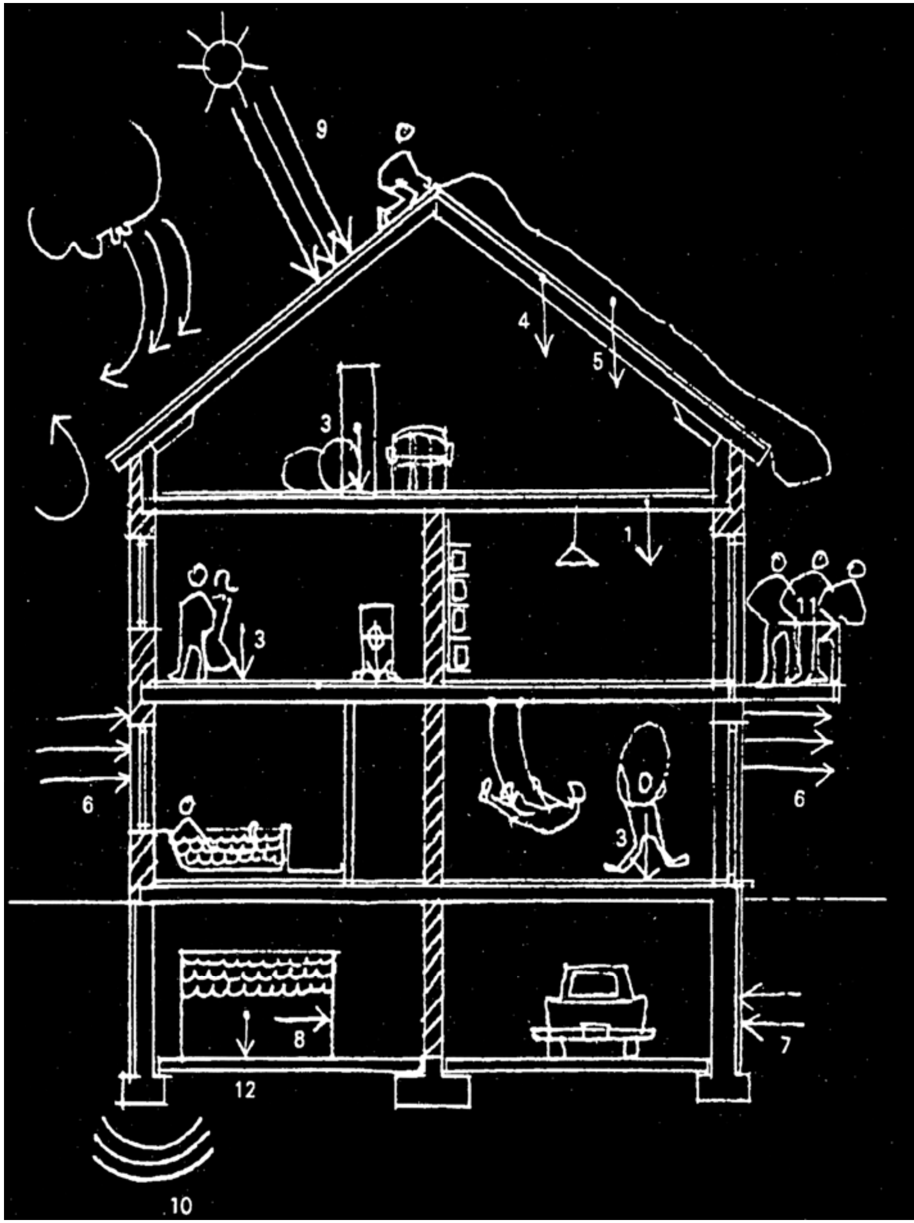
$$E_d \quad \leq \quad R_d$$

Effect of Actions:

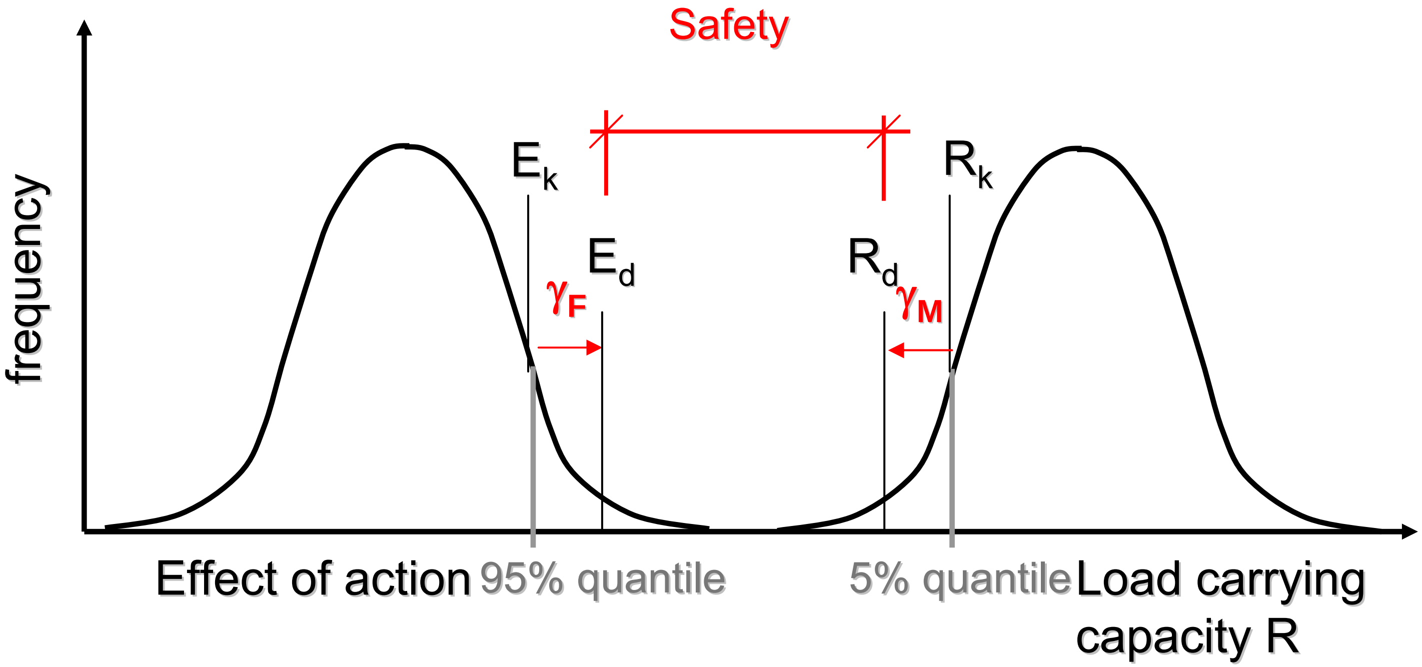
Self-Load
Wind
Snow
Variable loads
Temperature
Fire
....

Resistance:

Structure
Structural Elements
Materials, E-Modulus etc.
cross sections, Area, Moment of Inertia



Safety


Safety
frequency
E_k
E_d
γ_F
R_k
R_d
γ_M
Effect of action
95% quantile
5% quantile
Load carrying capacity R

Design situations

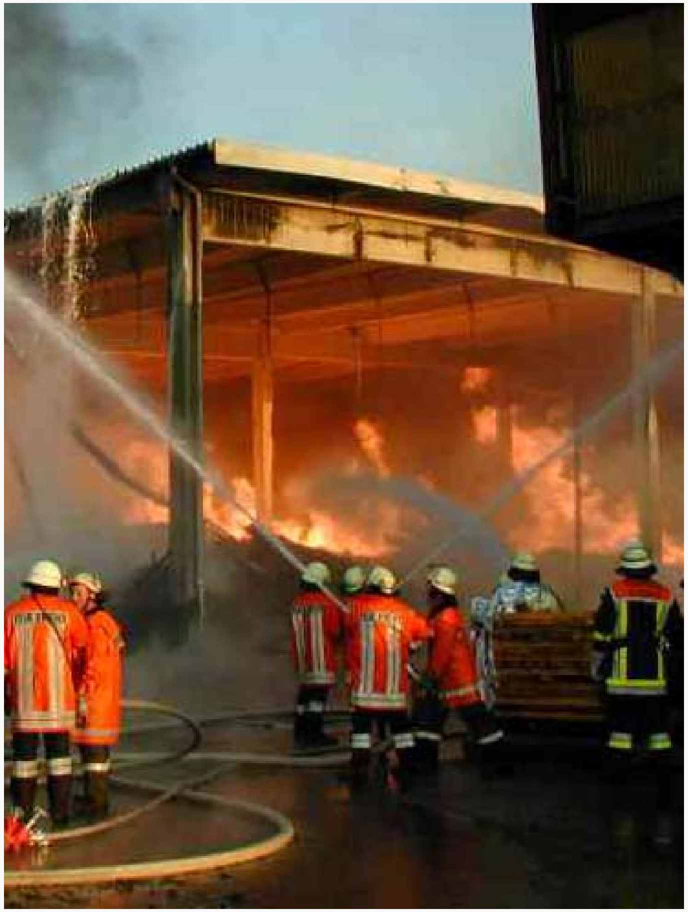
- Permanent situation (after erection of the structure)

Design situations

- temporary situation (during erection)

Design situations

- Accidential situation (impact, fire)



Limit states

- Ultimate limit states
- Serviceability limit states

For all design situations the limit states shall not be exceeded.

Limit state design

- Limit states are functional levels beyond which the structure no longer satisfies the performance criterias.

- Ultimate limit state:
  - Safety level
  - Concerns safety of people
  - Integrity of structure

- Serviceability limit state
  - Comfort of building user
  - No excessive deflection, vibration, cracks
  - Negotiable from project to project

Actions

- Characteristic Actions according to EN 1991

  G_k e.g. self-weight

  Q_k e.g. wind, snow, traffic

  A_k e.g. impact

Ultimate limit state

Design values of actions

Basic combination:

$$\Sigma\gamma_{G,j} \cdot G_{k,j} + \gamma_{Q,1} \cdot Q_{k,1} + \Sigma\gamma_{Q,i} \cdot \psi_{0,i} \cdot Q_{k,i}$$

e.g. $1{,}35 \cdot G_k + 1{,}5 \cdot W_k + 1{,}5 \cdot 0{,}5 \cdot S_k$

simplified:

Most unfavourable variable action:

$\Sigma\gamma_{G,j} \cdot G_{k,j} + \gamma_{Q1} \cdot Q_{k,1}$ $\quad$ $1{,}35 \cdot G_k + 1{,}5 \cdot W_k$

All unfavourable variable actions:

$\Sigma\gamma_{G,j} \cdot G_{k,j} + 1{,}35 \cdot \Sigma Q_{k,i}$ $\quad$ $1{,}35 \cdot (G_k + W_k + S_k)$

Design values of actions; coefficient for representative values of actions:

From a statistic point of view it´s unlikely that all actions/loads act at the same time with their fully values.

⇒ Coefficient for represantative values of actions ψ

(for exact national data see: National Annexes)

ψ_0	**combination coefficient (in fundamental design situations)**
ψ_1	**frequent coefficient (in accidential design situations and servicability calculations)**
ψ_2	**quasi-permanent coefficient (in servicability calculations)**

Principle rule:

$$\boxed{\gamma_G \cdot G_K + \gamma_{Q,1} \cdot Q_{K,1} + \sum_{i \geq 2} \psi_{0,i} \cdot \gamma_{Q,i} \cdot Q_{K,i}}$$

Use of ψ_0 from the second variable action/load.

Combination factors

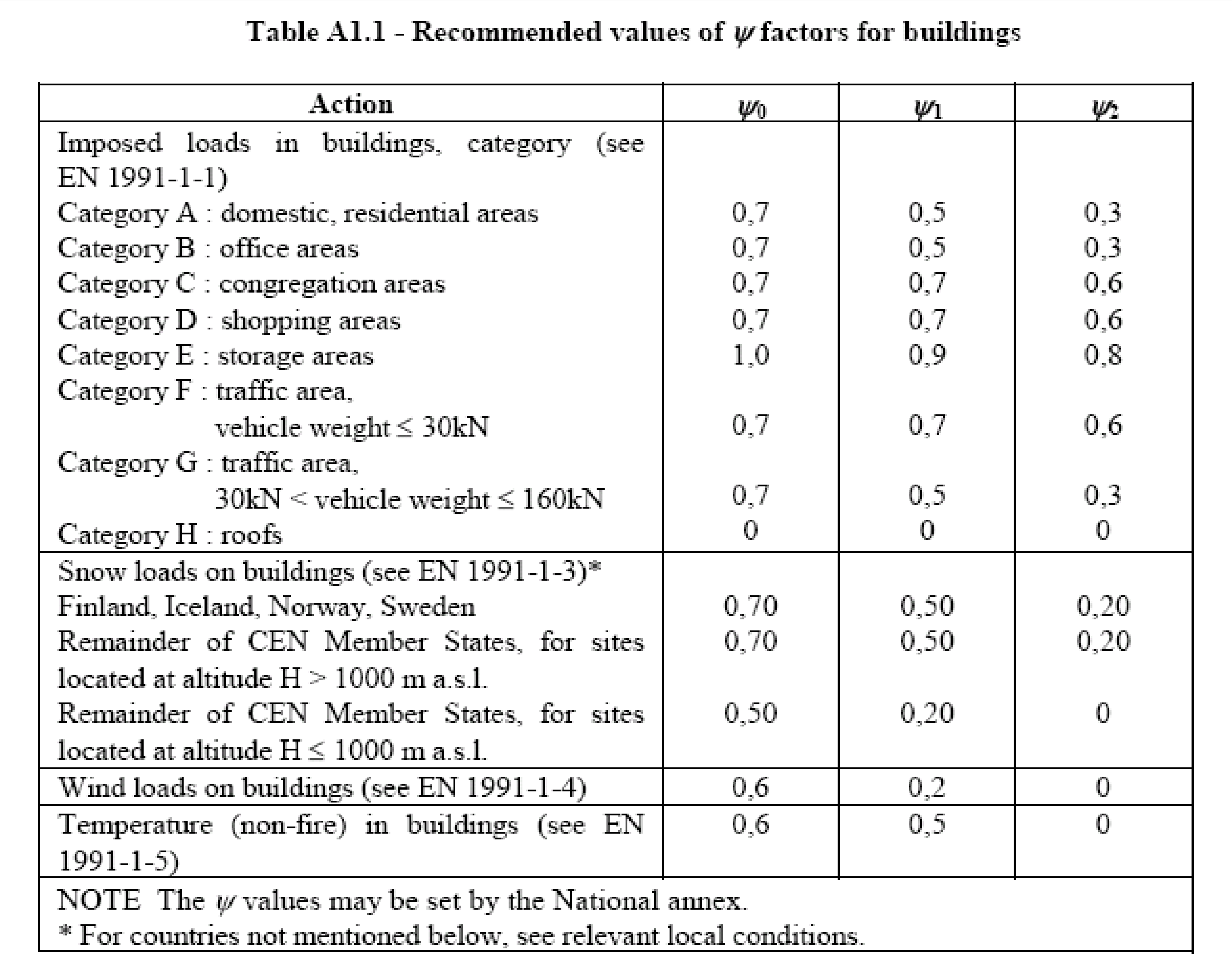


Table A1.1 - Recommended values of ψ factors for buildings

Action	ψ_0	ψ_1	ψ_2
Imposed loads in buildings, category (see EN 1991-1-1)			
Category A : domestic, residential areas	0,7	0,5	0,3
Category B : office areas	0,7	0,5	0,3
Category C : congregation areas	0,7	0,7	0,6
Category D : shopping areas	0,7	0,7	0,6
Category E : storage areas	1,0	0,9	0,8
Category F : traffic area, vehicle weight ≤ 30kN	0,7	0,7	0,6
Category G : traffic area, 30kN < vehicle weight ≤ 160kN	0,7	0,5	0,3
Category H : roofs	0	0	0
Snow loads on buildings (see EN 1991-1-3)*			
Finland, Iceland, Norway, Sweden	0,70	0,50	0,20
Remainder of CEN Member States, for sites located at altitude H > 1000 m a.s.l.	0,70	0,50	0,20
Remainder of CEN Member States, for sites located at altitude H ≤ 1000 m a.s.l.	0,50	0,20	0
Wind loads on buildings (see EN 1991-1-4)	0,6	0,2	0
Temperature (non-fire) in buildings (see EN 1991-1-5)	0,6	0,5	0

NOTE The ψ values may be set by the National annex.
* For countries not mentioned below, see relevant local conditions.

Combination factors

Action	ψ_0	ψ_1	ψ_2
Domestic residential areas	0,7	0,5	0,3
Congregation areas	0,7	0,7	0,6
Storage areas	1,0	0,9	0,8
Wind	0,6	0,5	0,0
Snow (≤ 1000 m)	0,5	0,2	0,0

Partial safety factors for actions (EN 1990)

Action	permanent	variable
favourable	$\gamma_G = 1,0$	$\gamma_Q = 0$
unfavourable	$\gamma_G = 1,35$	$\gamma_Q = 1,5$

Safety Concept - simplified

Partial Safety Factors $\gamma_F (\gamma_G, \gamma_Q), \gamma_M$

$G_k \times \gamma_G + Q_k \times \gamma_Q \quad \leq \quad k_{mod} \times R_k / \gamma_M$ (timber: $\gamma_M = 1,3$)

Safety factors in case of fire or other accidental situations: $\gamma = 1,0$

Serviceability limit states

Calculation of

- deformations
- vibrations

. the combination of actions under consideration

Increase the actions/load by partial safety factors γ (gamma factors)

$$\boxed{G_d = \gamma_G \cdot G_k}$$

$$\boxed{Q_d = \gamma_Q \cdot Q_k}$$

Design situation	γ_G	γ_Q
Structural design calculation		
favourable effect	***1,0***	**-**
unfavourable effect	*1,35*	*1,5*
Check at servicability limit state	*1,0*	*1,0*

less safety risks

Serviceability limit states

Design values of actions

characteristic (rare) combination:

$\Sigma G_{k,j} + Q_{k,1} + \Sigma \psi_{0,i} \cdot Q_{k,i}$

$G_k + W_k + 0{,}5 \cdot S_k$

quasi-permanent combination:

$\Sigma G_{k,j} + \Sigma \psi_{2,i} \cdot Q_{k,i}$

$G_k + 0{,}0 \cdot W_k + 0{,}0 \cdot S_k$

Comparison of safety concepts

	Taking into account	Semi-probalistic method	Concept of permissible stresses
Action	combinations	Combination factor ψ	
	Safety factor		
timber	Load duration - and service-class		
	Safety factor		

Comparison of safety concepts

	Taking into account	Semi-probalistic method	Concept of permissible stresses
Action	combinations	Combination factor ψ	w+s/2 or s+w/2
	Safety factor		
timber	Load duration - and service-class		
	Safety factor		

Comparison of safety concepts

	Taking into account	Semi-probalistic method	Concept of permissible stresses
Action	combinations	Combination factor ψ	w+s/2 or s+w/2
	Safety factor	γ = 1,35 (G) γ = 1,50 (Q)	
timber	Load duration - and service-class		
	Safety factor		

Comparison of safety concepts

	Taking into account	Semi-probalistic method	Concept of permissible stresses
Action	combinations	Combination factor ψ	w+s/2 or s+w/2
	Safety factor	γ = 1,35 (G) γ = 1,50 (Q)	γ = ? (permissible stress)
timber	Load duration - and service-class		
	Safety factor		

Comparison of safety concepts

	Taking into account	Semi-probalistic method	Concept of permissible stresses
Action	combinations	Combination factor ψ	w+s/2 or s+w/2
	Safety factor	γ = 1,35 (G) γ = 1,50 (Q)	γ = ? (permissible stress)
timber	Load duration - and service-class	k_{mod} 0,6 permanent,SC 1 0,9 short, SC 1 0,5 permanent, SC 3 0,7 short, SC 3	
	Safety factor		

Comparison of safety concepts

	Taking into account	Semi-probalistic method	Concept of permissible stresses
Action	combinations	Combination factor ψ	w+s/2 or s+w/2
	Safety factor	γ = 1,35 (G) γ = 1,50 (Q)	γ = ? (permissible stress)
timber	Load duration - and service-class	k_{mod} 0,6 permanent,SC 1 0,9 short, SC 1 0,5 **permanent, SC 3** 0,7 short, SC 3	? (permissible stress) Reduction of 1/6 (SC 3)
	Safety factor		

Comparison of safety concepts

	Taking into account	Semi-probalistic method	Concept of permissible stresses
Action	combinations	Combination factor ψ	w+s/2 or s+w/2
	Safety factor	γ = 1,35 (G) γ = 1,50 (Q)	γ = ? (permissible stress)
timber	Load duration - and service-class	k_{mod} 0,6 permanent,SC 1 0,9 short, SC 1 0,5 **permanent, SC 3** 0,7 short, SC 3	? (permissible stress) Reduction of 1/6 (SC 3)
	Safety factor	γ = 1,3 (5%-Quantil)	

Comparison of safety concepts

	Taking into account	Semi-probalistic method	Concept of permissible stresses
Action	combinations	Combination factor ψ	w+s/2 or s+w/2
	Safety factor	γ = 1,35 (G) γ = 1,50 (Q)	γ = ? (permissible stress)
timber	Load duration - and service-class	k_{mod} 0,6 permanent,SC 1 0,9 short, SC 1 0,5 **permanent, SC 3** 0,7 short, SC 3	? (permissible stress) Reduction of 1/6 (SC 3)
	Safety factor	γ = 1,3 (5%-Quantil)	γ = ? (permissible stress)

Materials and service classes

Steps for the designer

- Identify material strength and stiffness properties in supporting standard
- Establish modification factors
  - Material
  - Load
  - Service class
- Determine material resistance for calculation

Design value of material properties X_d

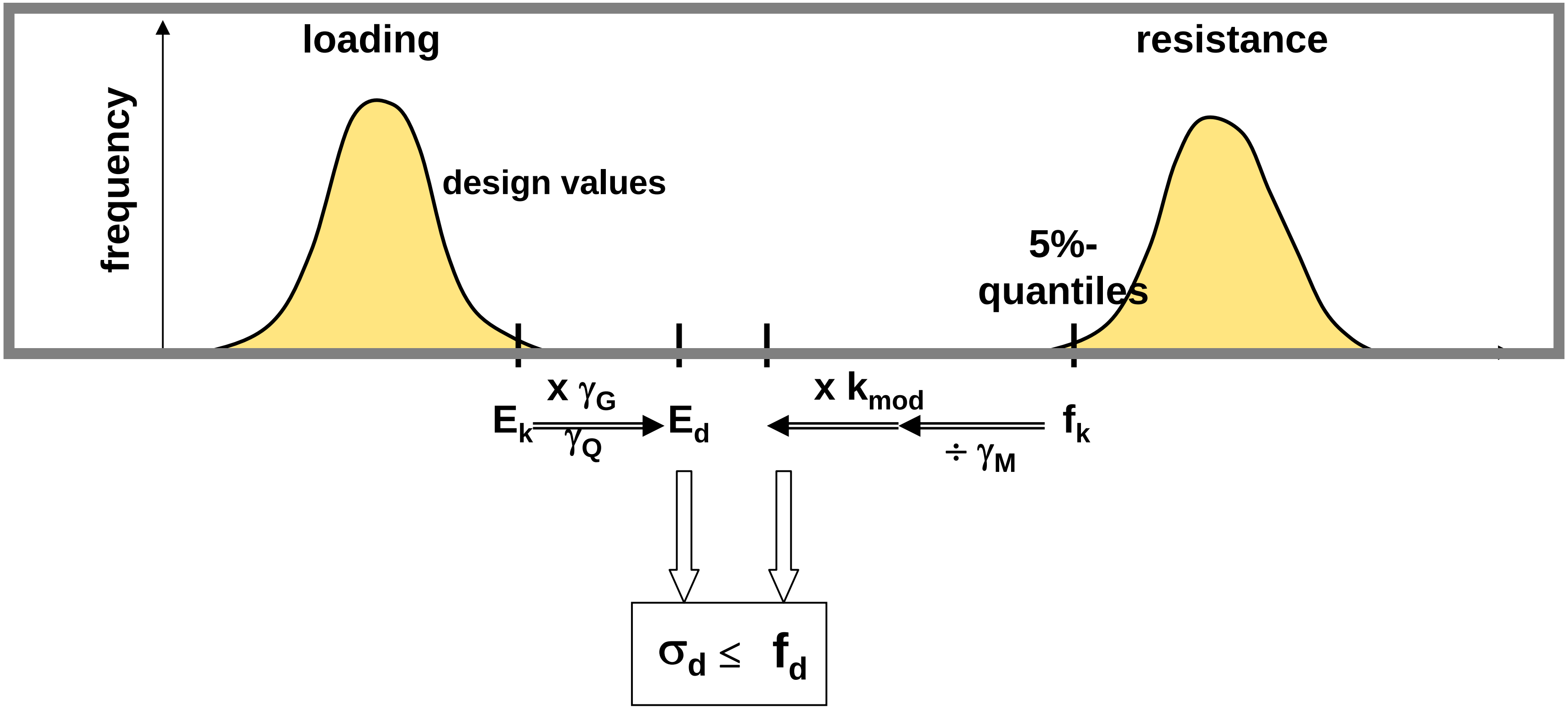
$$X_d = \frac{k_{mod} \cdot X_k}{\gamma_M}$$

X_k - characteristic value of a strength property

γ_M – partial factor for a material property

k_{mod} – modification factor, taking into account duration of load and moisture content

Structural design calculation



Characteristic values of material properties

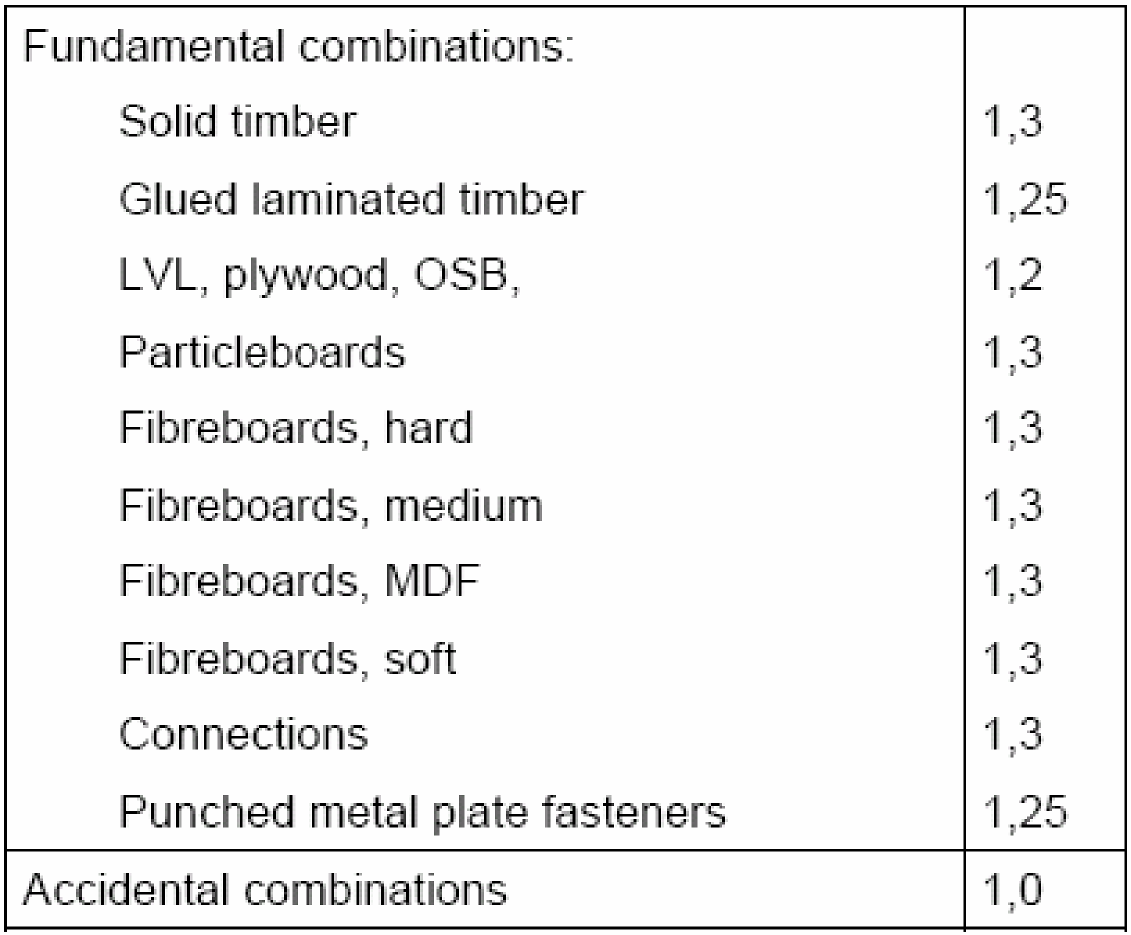
- 5%-Quantil of strength properties, e.g.

  Bending strength
  Tension strength
  Capacity of a connection

- Mean value of stiffness properties, e.g.

  Modulus of Elasticity
  (exceptions: Theory of second order, buckling)

Partial safety factor γ_M

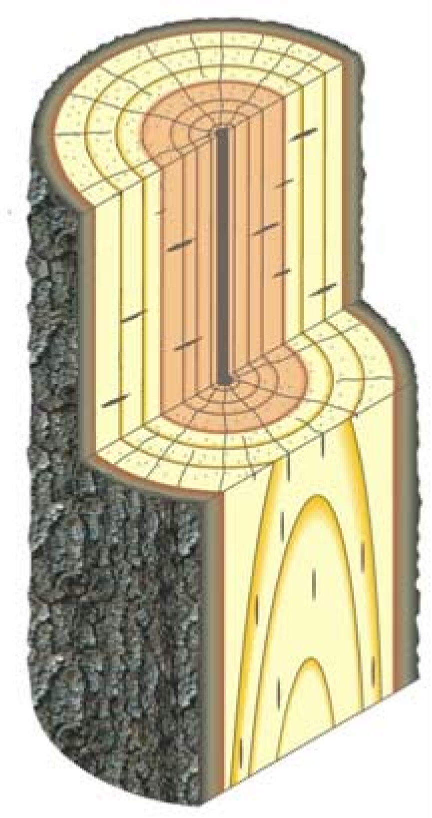


Fundamental combinations:	
Solid timber	1,3
Glued laminated timber	1,25
LVL, plywood, OSB,	1,2
Particleboards	1,3
Fibreboards, hard	1,3
Fibreboards, medium	1,3
Fibreboards, MDF	1,3
Fibreboards, soft	1,3
Connections	1,3
Punched metal plate fasteners	1,25
Accidental combinations	1,0

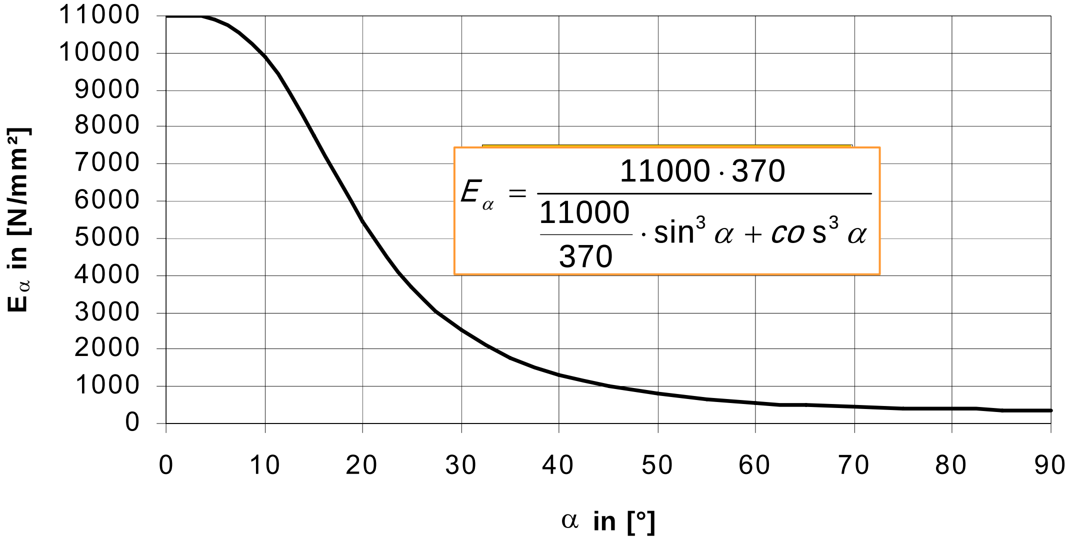
Recommended material safety factor $\gamma_M = 1,3$

Mechanical properties in general

- Different in growth directions



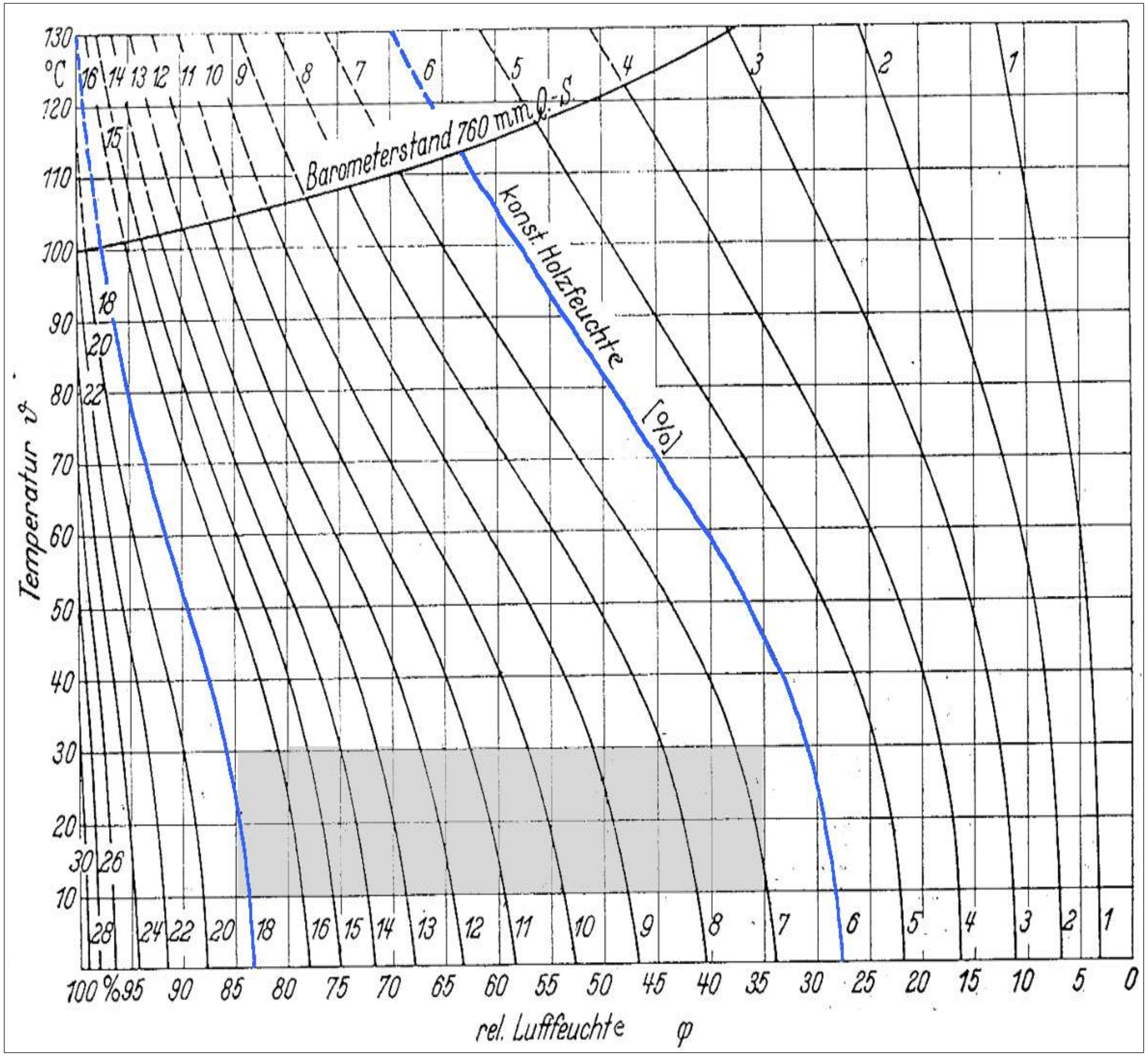
- **Modulus of elasticity**



$$E_{\alpha} = \frac{11000 \cdot 370}{\frac{11000}{370} \cdot \sin^3 \alpha + \cos^3 \alpha}$$

- **Mechanical properties are related to the density**

Hygroscopisc isotherms for fir timber by W.K. Loughborough, R. Keylwerth



Effect of moisture content

- The mechanical properties of timber are moisture dependend!

  <u>Example</u>

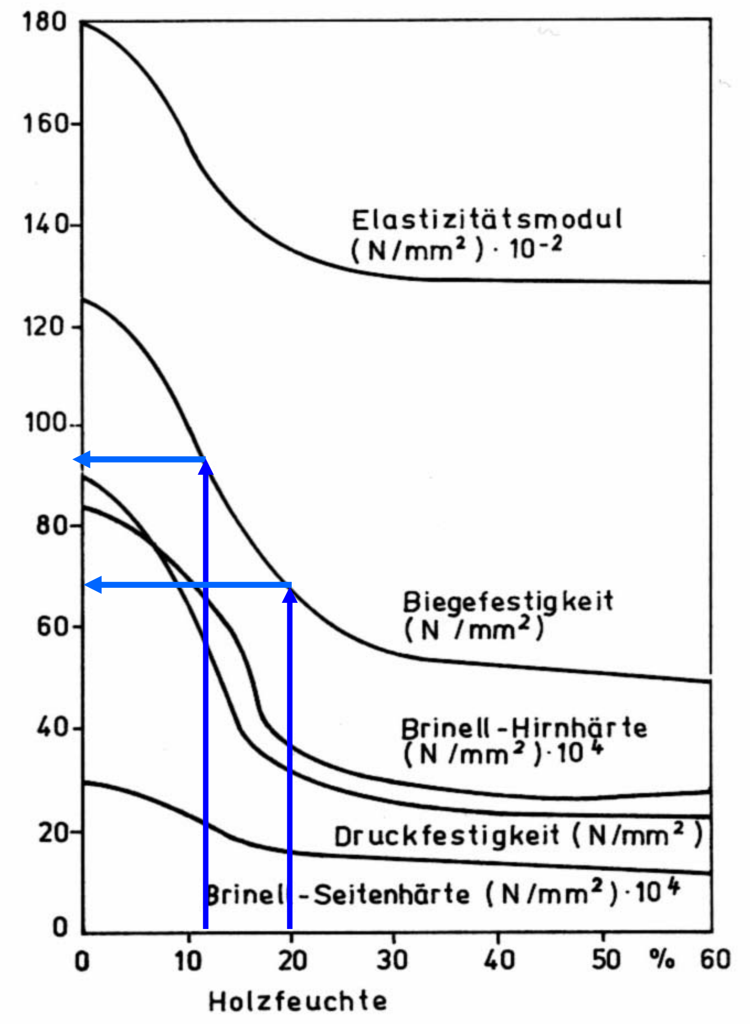
  Change of moisture content from 12% to 20%

  leads to a significant reduction

68 N/mm²

= 0,7391

92 N/mm²

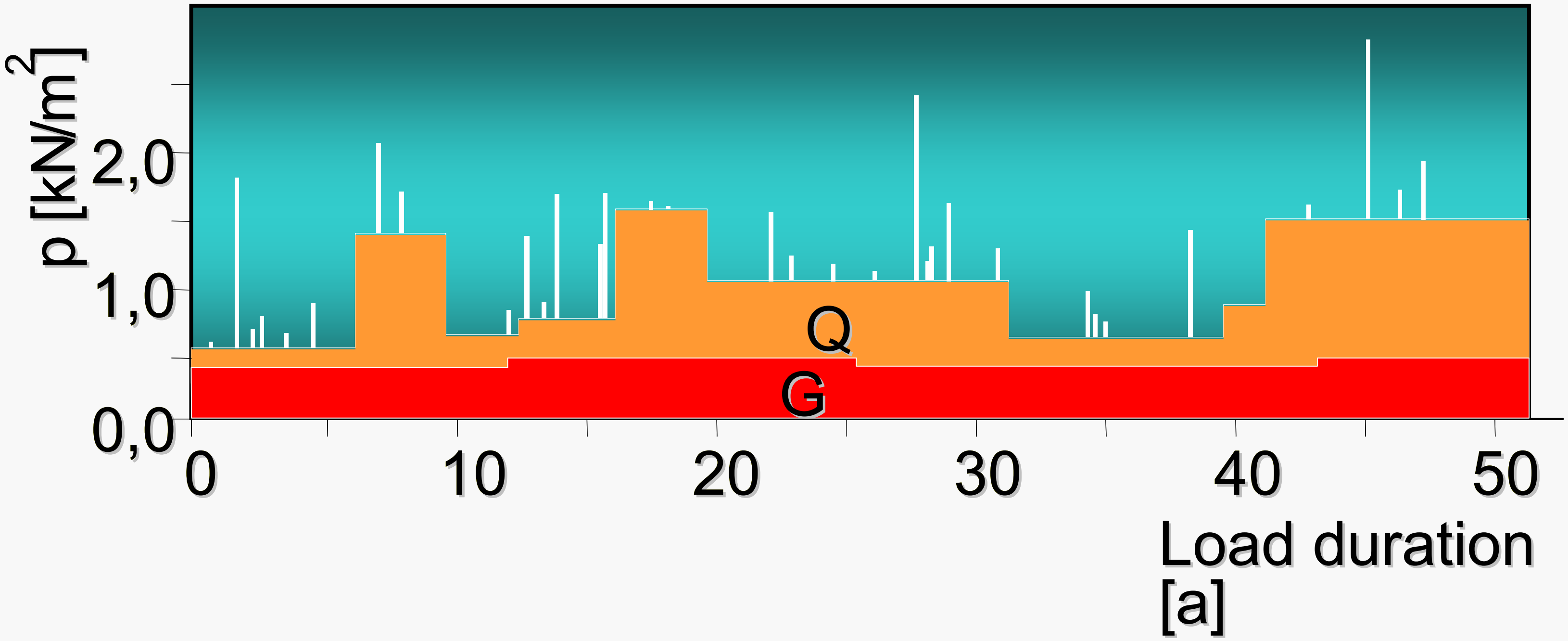


Moisture dependend strength properties are leading to

Service Classes

Service Class	Average moisture content u_m	Environmental conditions
1	$u \leq 12\%$	20°C und 65% rel. humidity
2	$u \leq 20\%$	20°C und 85% rel. humidity
3	$u > 20\%$	Higher humidity compared to SC 2

Actions on a floor



Load duration classes

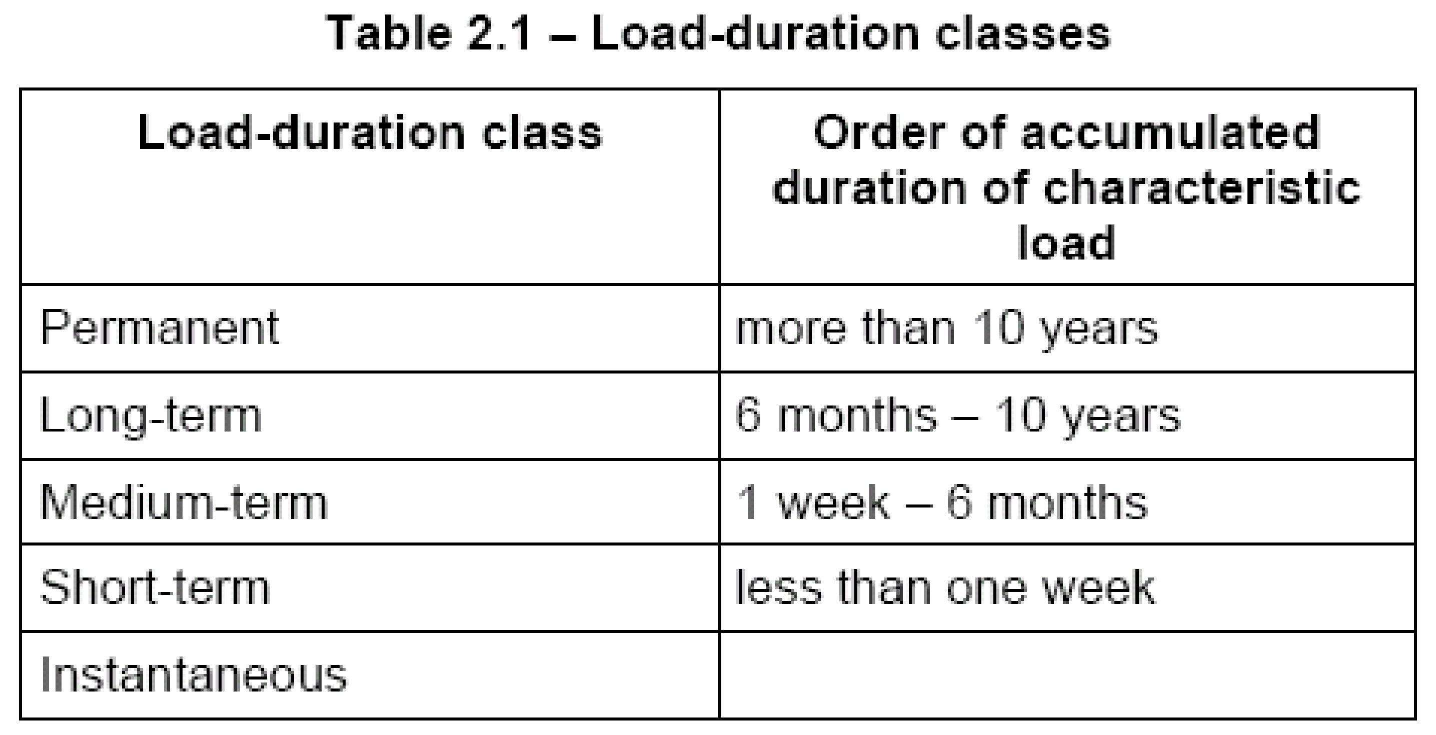


Table 2.1 – Load-duration classes

Load-duration class	Order of accumulated duration of characteristic load
Permanent	more than 10 years
Long-term	6 months – 10 years
Medium-term	1 week – 6 months
Short-term	less than one week
Instantaneous	

Influence of service classes and duration of load

Ultimate limit state: $\mathbf{k_{mod} \cdot f_k}$ **k_{mod} for the action/load with shortest design situation**

Serviceability limit state:
$$\left\{ \begin{array}{l} \dfrac{E}{1+k_{def}} \\ \mathbf{w_{el} \cdot (1+ k_{def})} \end{array} \right.$$
separate for each action/load

Strength properties for timber (Tab. F. 5 DIN 1052)

(for exact national data see: National Annexes)

Festigkeitsklasse (Sortierklasse nach DIN 4074-1)			**C16**	**C24**	C30	C35	C40
Festigkeitskennwerte in N/mm²							
Biegung		$f_{m,k}$ 2)	16	24	30	35	40
Zug	parallel	$f_{t,0,k}$ 2)	10	14	18	21	24
	rechtwinklig	$f_{t,90,k}$	0,4	0,4	0,4	0,4	0,4
Druck	parallel	$f_{c,0,k}$	17	21	23	25	26
	rechtwinklig	$f_{c,90,k}$	2,2	2,5	2,7	2,8	2,9
Schub und Torsion		$f_{v,k}$ 3) 6)	2,7	2,7	2,7	2,7	2,7
Steifigkeitskennwerte in N/mm²							
Elastizitätsmodul	parallel	$E_{0,mean}$ 4)	8000	11000	12000	13000	14000
	rechtwinklig	$E_{90,mean}$ 4)	270	370	400	430	470
Schubmodul		G_{mean} 4) 5)	500	690	750	810	880
Rohdichtekennwerte in kg/m³							
Rohdichte		ρ_k	310	350	380	400	420

1) Nur maschinen sortiert

2) Nadelrundholz geschält ohne angeschnittene Faser: +20%

3) Beim Nachweis von Querschnitten die mindestens 1,50 m vom Hirnholz entfernt liegen, darf $f_{v,k}$ um 30 % erhöht werden.

4) Für die charakteristischen Steifigkeitskennwerte $E_{0,05}$, $E_{90,05}$ und G_{05} gelten die Rechenwerte:
$E_{0,05} = 2/3 \cdot E_{0,mean}$ $E_{90,05} = 2/3 \cdot E_{90,mean}$ $G_{05} = 2/3 \cdot G_{mean}$

5) Der zur Rollschubbeanspruchung gehörende Schubmodul darf mit $G_{R,mean} = 0,10 \cdot G_{mean}$ angenommen werden.

6) Als Rechenwert für die charakteristische Rollschubfestigkeit des Holzes darf für alle Festigkeitsklassen mit $f_{R,k} = 1,0$ N/mm² angenommen werden.

Strength properties for glulam (Tab. F. 9 DIN 1052)

(for exact national data see: National Annexes)

Festigkeitsklasse des Brettschichtholzes			**GL 24**		**GL 28**		**GL 32**		**GL 36**	
h = homogen c = kombiniert			h	c	h	c	h	c	h	c
Festigkeitskennwerte in N/mm²										
Biegung		$f_{m,y,k}$ 1)	24	24	28	28	32	32	36	36
		$f_{m,z,k}$ 2)	28,8	24	33,6	28	38,4	32	43,2	36
Zug	parallel	$f_{t,0,k}$	16,5	14	19,5	16,5	22,5	19,5	26	22,5
	rechtwinklig	$f_{t,90,k}$	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5
Druck	parallel	$f_{c,0,k}$	24	21	26,5	24	29	26,5	31	29
	rechtwinklig	$f_{c,90,k}$	2,7	2,4	3,0	2,7	3,3	3,0	3,6	3,3
Schub und Torsion		$f_{v,k}$ 3)	3,5	3,5	3,5	3,5	3,5	3,5	3,5	3,5
Steifigkeitskennwerte in N/mm²										
Elastizitätsmodul	parallel	$E_{0,mean}$ 4)	11600	11600	12600	12600	13700	13700	14700	14700
	rechtwinklig	$E_{90,mean}$ 4)	390	320	420	390	460	420	490	460
Schubmodul		G_{mean} 4) 5)	720	590	780	720	850	780	910	850
Rohdichtekennwerte in kg/m³										
Rohdichte		ρ_k	380	350	410	380	430	410	450	430

1) Bei Brettschichtholz mit liegenden Lamellen und einer Querschnitthöhe $H \leq 600$ mm darf $f_{m,y,k}$ mit folgendem Faktor multipliziert werden: $(600 / H)^{0,14} \leq 1,1$

2) Brettschichtholz mit mindestens 4 hochkant stehenden Lamellen

3) Als Rechenwert für die charakteristische Rollschubfestigkeit des Holzes darf für alle Festigkeitsklassen $f_{R,k} = 1,0$ N/mm² angenommen werden.

4) Für die charakteristischen Steifigkeitskennwerte $E_{0,05}$, $E_{90,05}$ und G_{05} gelten die Rechenwerte:
$E_{0,05} = 5/6 \cdot E_{0,mean}$ $E_{90,05} = 5/6 \cdot E_{90,mean}$ $G_{05} = 5/6 \cdot G_{mean}$

5) Der zur Rollschubbeanspruchung gehörende Schubmodul darf mit $G_{R,mean} = 0,10 \cdot G_{mean}$ angenommen werden.

k_{mod}- und k_{def}-values

- Modification value k_{mod} und deformation value k_{def} taking into account service class and load duration

k_{mod}	Modification value for ultimate limit state design
k_{def}	Deformation value for serviceability limit state design

k_{mod}- values

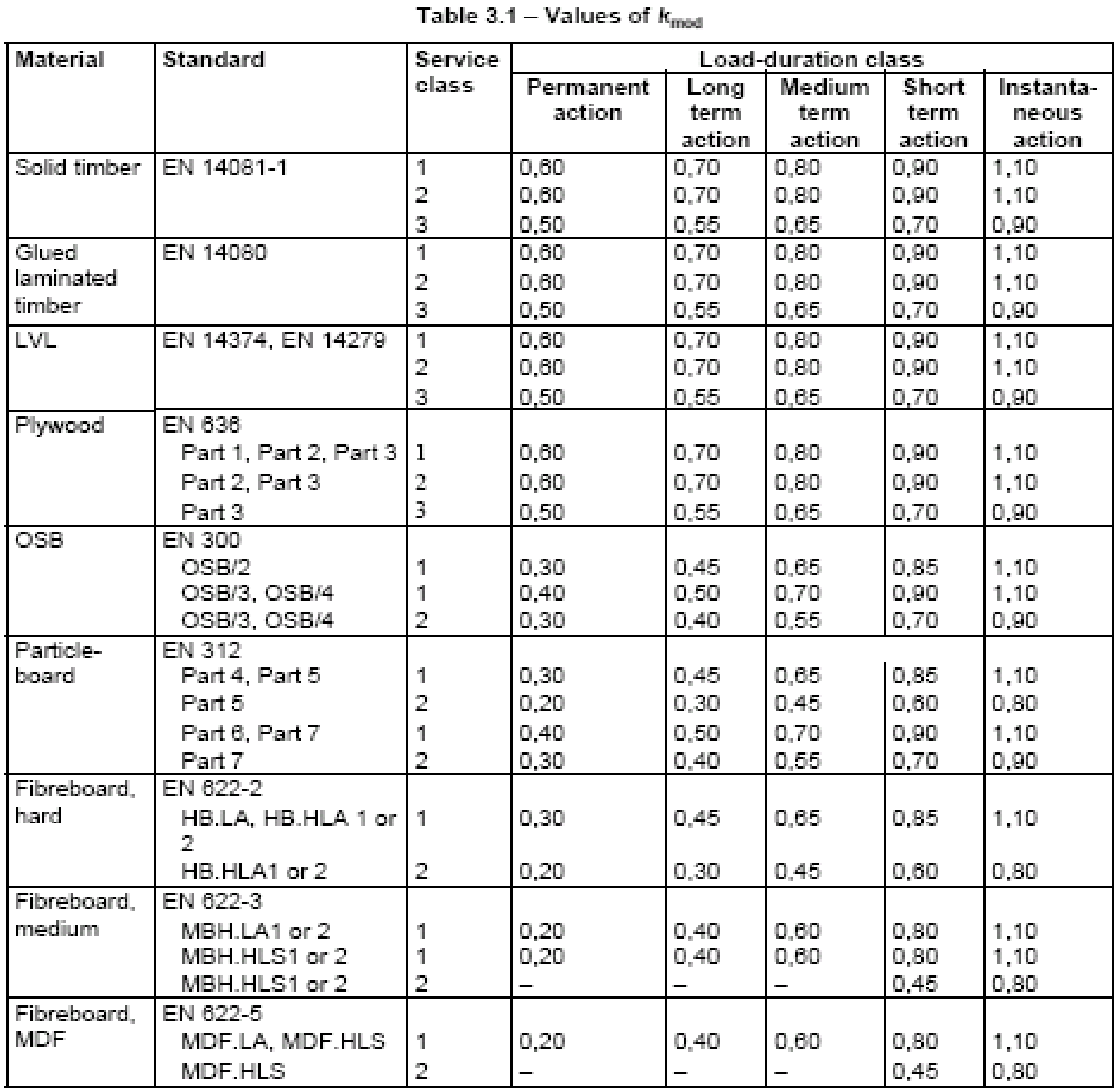


Table 3.1 – Values of k_{mod}

Material	Standard	Service class	Load-duration class				
			Permanent action	Long term action	Medium term action	Short term action	Instantaneous action
Solid timber	EN 14081-1	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
Glued laminated timber	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
LVL	EN 14374, EN 14279	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
Plywood	EN 636						
	Part 1, Part 2, Part 3	1	0,60	0,70	0,80	0,90	1,10
	Part 2, Part 3	2	0,60	0,70	0,80	0,90	1,10
	Part 3	3	0,50	0,55	0,65	0,70	0,90
OSB	EN 300						
	OSB/2	1	0,30	0,45	0,65	0,85	1,10
	OSB/3, OSB/4	1	0,40	0,50	0,70	0,90	1,10
	OSB/3, OSB/4	2	0,30	0,40	0,55	0,70	0,90
Particle-board	EN 312						
	Part 4, Part 5	1	0,30	0,45	0,65	0,85	1,10
	Part 5	2	0,20	0,30	0,45	0,60	0,80
	Part 6, Part 7	1	0,40	0,50	0,70	0,90	1,10
	Part 7	2	0,30	0,40	0,55	0,70	0,90
Fibreboard, hard	EN 622-2						
	HB.LA, HB.HLA 1 or 2	1	0,30	0,45	0,65	0,85	1,10
	HB.HLA1 or 2	2	0,20	0,30	0,45	0,60	0,80
Fibreboard, medium	EN 622-3						
	MBH.LA1 or 2	1	0,20	0,40	0,60	0,80	1,10
	MBH.HLS1 or 2	1	0,20	0,40	0,60	0,80	1,10
	MBH.HLS1 or 2	2	–	–	–	0,45	0,80
Fibreboard, MDF	EN 622-5						
	MDF.LA, MDF.HLS	1	0,20	0,40	0,60	0,80	1,10
	MDF.HLS	2	–	–	–	0,45	0,80

k_{def}-values

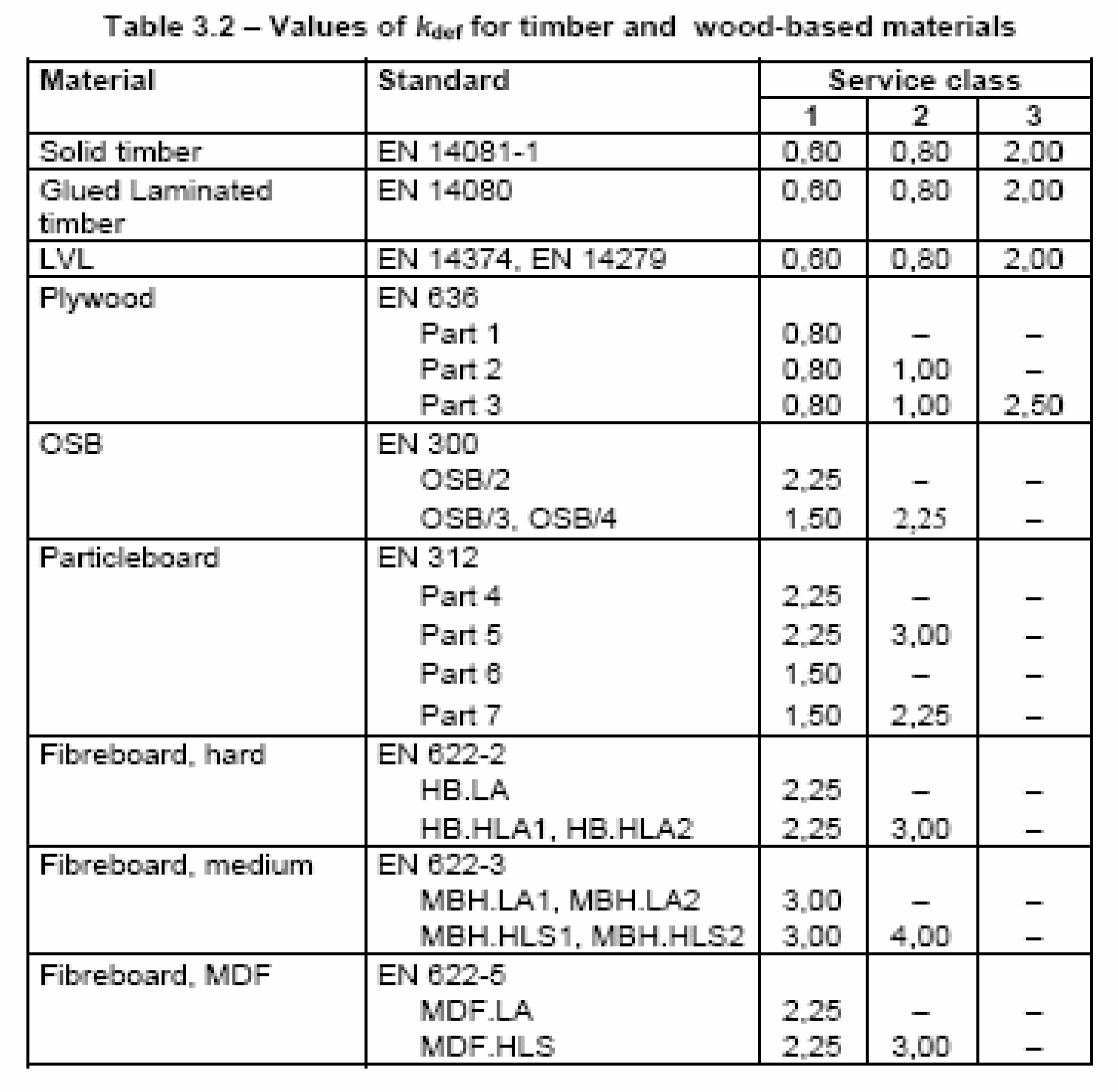


Table 3.2 – Values of k_{def} for timber and wood-based materials

Material	Standard	Service class		
		1	2	3
Solid timber	EN 14081-1	0,60	0,80	2,00
Glued Laminated timber	EN 14080	0,60	0,80	2,00
LVL	EN 14374, EN 14279	0,60	0,80	2,00
Plywood	EN 636			
	Part 1	0,80	–	–
	Part 2	0,80	1,00	–
	Part 3	0,80	1,00	2,50
OSB	EN 300			
	OSB/2	2,25	–	–
	OSB/3, OSB/4	1,50	2,25	–
Particleboard	EN 312			
	Part 4	2,25	–	–
	Part 5	2,25	3,00	–
	Part 6	1,50	–	–
	Part 7	1,50	2,25	–
Fibreboard, hard	EN 622-2			
	HB.LA	2,25	–	–
	HB.HLA1, HB.HLA2	2,25	3,00	–
Fibreboard, medium	EN 622-3			
	MBH.LA1, MBH.LA2	3,00	–	–
	MBH.HLS1, MBH.HLS2	3,00	4,00	–
Fibreboard, MDF	EN 622-5			
	MDF.LA	2,25	–	–
	MDF.HLS	2,25	3,00	–

Size factors

Size factors taking into account volume effects

k_h is a variable factor in correlation with the reference depth in bending

Solid timber

$$k_h = \min\begin{cases}\left(\dfrac{150}{h}\right)^{0,2}\\ 1,3\end{cases}$$

Glulam

$$k_h = \min\begin{cases}\left(\dfrac{600}{h}\right)^{0,1}\\ 1,1\end{cases}$$

LVL

$$k_h = \min\begin{cases}\left(\dfrac{300}{h}\right)^{s}\\ 1,2\end{cases}$$

Strength Classes – solid timber

Strength Classes – solid timber

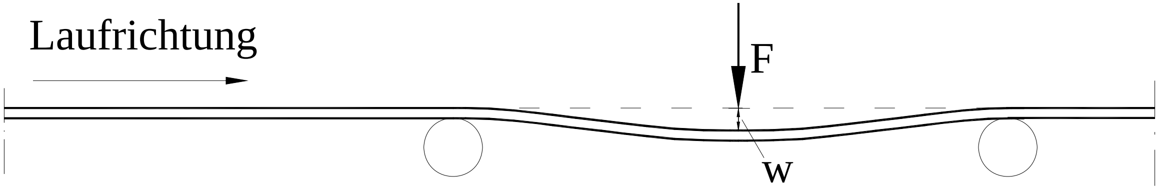
Visual grading:

Criteria: Knots, cracks, discoloration, bark etc.

Reliability ??

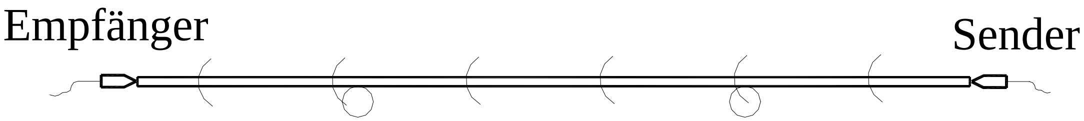
Mechanically grading:

Bending principe:

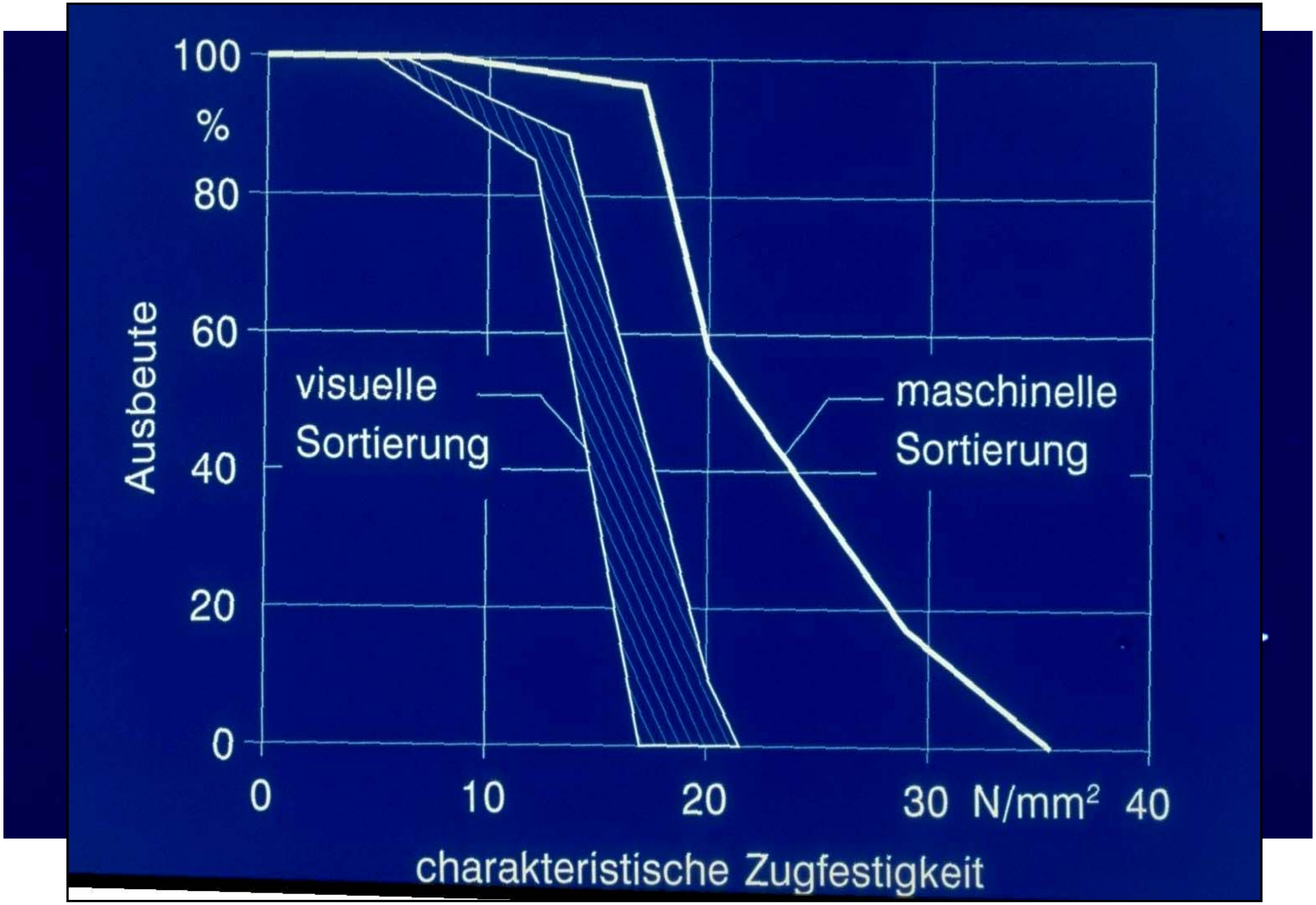


Measurement of natural frequency:

Radiation:

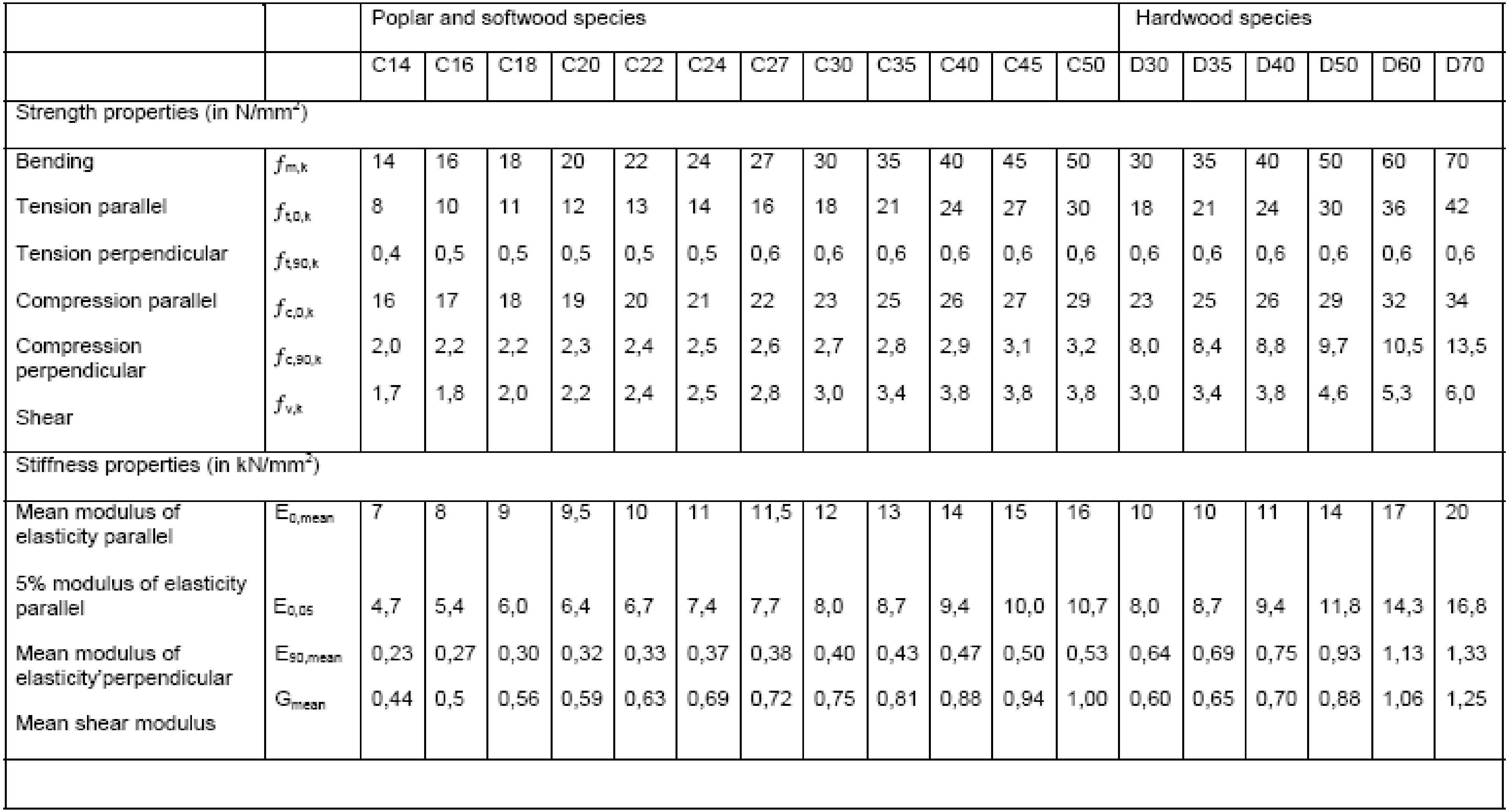


Grading


100
%
80
60
40
20
0
Ausbeute
visuelle Sortierung
maschinelle Sortierung
0
10
20
30
N/mm²
40
charakteristische Zugfestigkeit

Strength Classes – solid timber (EN 338)

Table 1 — Strength classes - Characteristic values



		Poplar and softwood species												Hardwood species					
		C14	C16	C18	C20	C22	C24	C27	C30	C35	C40	C45	C50	D30	D35	D40	D50	D60	D70
Strength properties (in N/mm^2)																			
Bending	$f_{m,k}$	14	16	18	20	22	24	27	30	35	40	45	50	30	35	40	50	60	70
Tension parallel	$f_{t,0,k}$	8	10	11	12	13	14	16	18	21	24	27	30	18	21	24	30	36	42
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	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	23	25	26	29	32	34
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	8,0	8,4	8,8	9,7	10,5	13,5
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	3,0	3,4	3,8	4,6	5,3	6,0
Stiffness properties (in kN/mm^2)																			
Mean modulus of elasticity parallel	$E_{0,mean}$	7	8	9	9,5	10	11	11,5	12	13	14	15	16	10	10	11	14	17	20
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	8,0	8,7	9,4	11,8	14,3	16,8
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	0,64	0,69	0,75	0,93	1,13	1,33
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	0,60	0,65	0,70	0,88	1,06	1,25

Strength Classes – glulam (EN 1194)

Strength Classes – glulam (EN 1194)

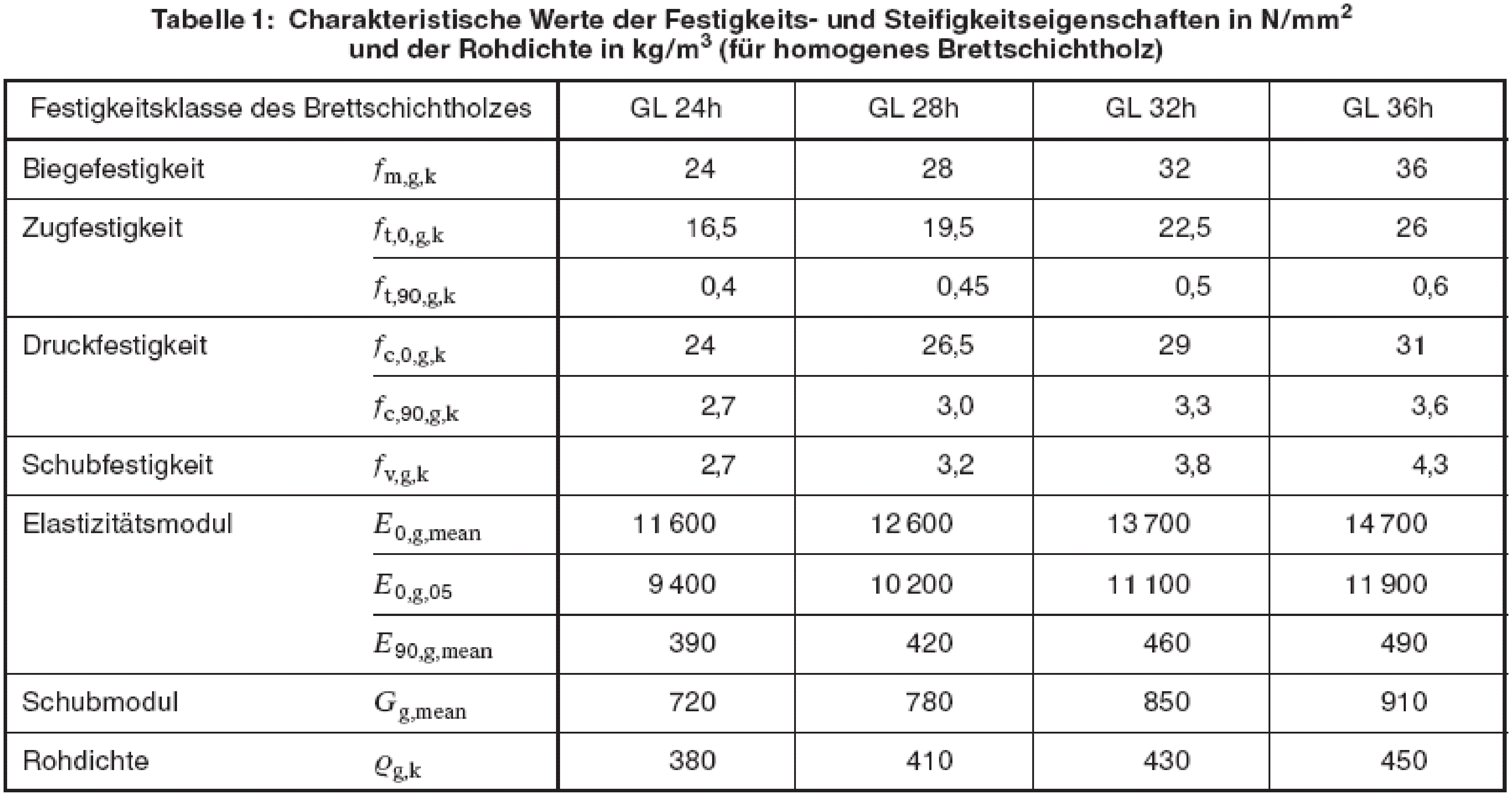


Tabelle 1: Charakteristische Werte der Festigkeits- und Steifigkeitseigenschaften in N/mm^2 und der Rohdichte in kg/m^3 (für homogenes Brettschichtholz)

Festigkeitsklasse des Brettschichtholzes		GL 24h	GL 28h	GL 32h	GL 36h
Biegefestigkeit	$f_{m,g,k}$	24	28	32	36
Zugfestigkeit	$f_{t,0,g,k}$	16,5	19,5	22,5	26
	$f_{t,90,g,k}$	0,4	0,45	0,5	0,6
Druckfestigkeit	$f_{c,0,g,k}$	24	26,5	29	31
	$f_{c,90,g,k}$	2,7	3,0	3,3	3,6
Schubfestigkeit	$f_{v,g,k}$	2,7	3,2	3,8	4,3
Elastizitätsmodul	$E_{0,g,mean}$	11 600	12 600	13 700	14 700
	$E_{0,g,05}$	9 400	10 200	11 100	11 900
	$E_{90,g,mean}$	390	420	460	490
Schubmodul	$G_{g,mean}$	720	780	850	910
Rohdichte	$\varrho_{g,k}$	380	410	430	450

Strength Classes – glulam (DIN 1052)

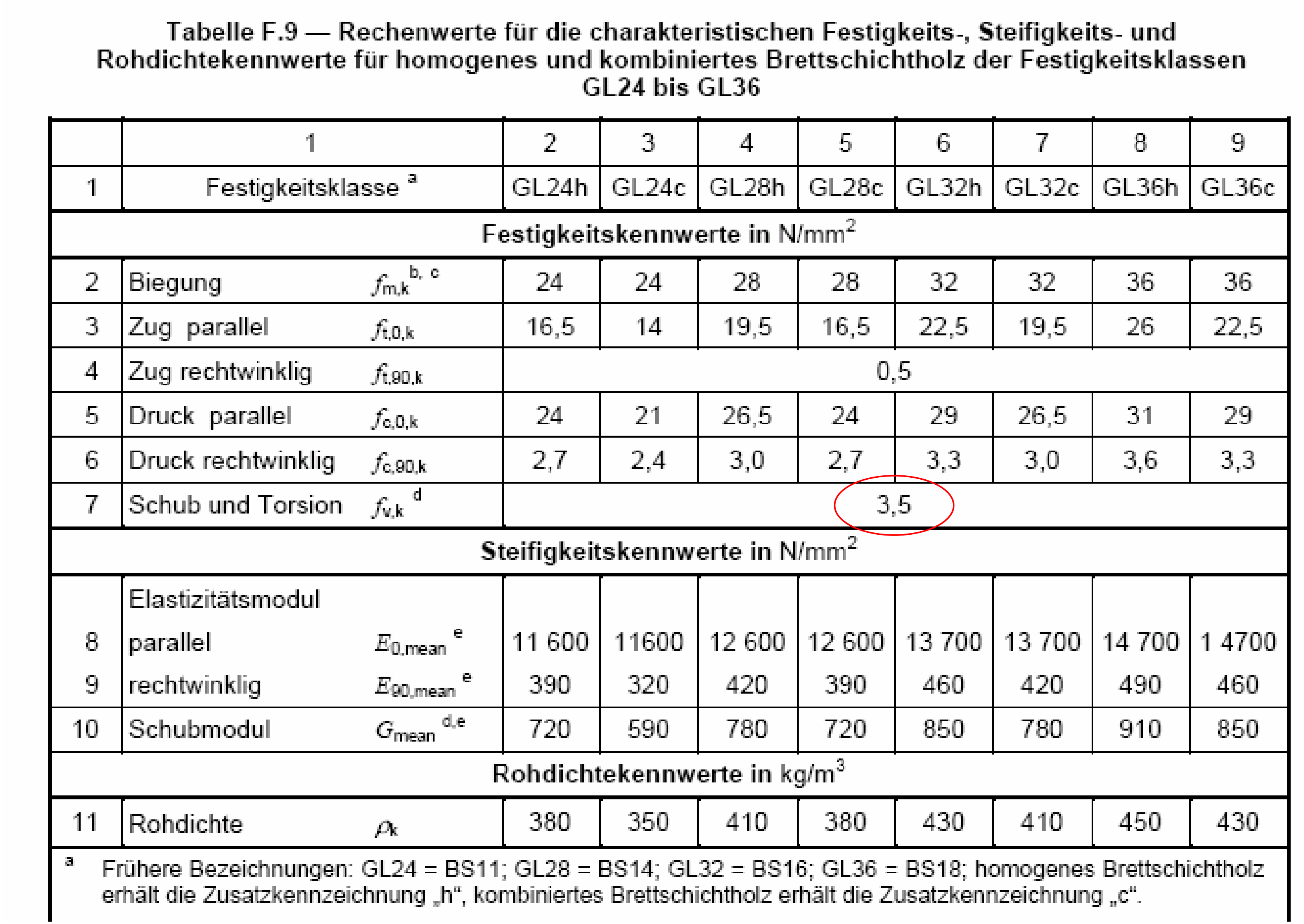


Tabelle F.9 — Rechenwerte für die charakteristischen Festigkeits-, Steifigkeits- und Rohdichtekennwerte für homogenes und kombiniertes Brettschichtholz der Festigkeitsklassen GL24 bis GL36

	1		2	3	4	5	6	7	8	9
1	Festigkeitsklasse [a]		GL24h	GL24c	GL28h	GL28c	GL32h	GL32c	GL36h	GL36c
	Festigkeitskennwerte in N/mm^2									
2	Biegung	$f_{m,k}$ [b, c]	24	24	28	28	32	32	36	36
3	Zug parallel	$f_{t,0,k}$	16,5	14	19,5	16,5	22,5	19,5	26	22,5
4	Zug rechtwinklig	$f_{t,90,k}$	0,5							
5	Druck parallel	$f_{c,0,k}$	24	21	26,5	24	29	26,5	31	29
6	Druck rechtwinklig	$f_{c,90,k}$	2,7	2,4	3,0	2,7	3,3	3,0	3,6	3,3
7	Schub und Torsion	$f_{v,k}$ [d]	3,5							
	Steifigkeitskennwerte in N/mm^2									
	Elastizitätsmodul									
8	parallel	$E_{0,mean}$ [e]	11 600	11600	12 600	12 600	13 700	13 700	14 700	1 4700
9	rechtwinklig	$E_{90,mean}$ [e]	390	320	420	390	460	420	490	460
10	Schubmodul	G_{mean} [d,e]	720	590	780	720	850	780	910	850
	Rohdichtekennwerte in kg/m^3									
11	Rohdichte	ρ_k	380	350	410	380	430	410	450	430

[a] Frühere Bezeichnungen: GL24 = BS11; GL28 = BS14; GL32 = BS16; GL36 = BS18; homogenes Brettschichtholz erhält die Zusatzkennzeichnung „h", kombiniertes Brettschichtholz erhält die Zusatzkennzeichnung „c".

Strength Classes – glulam (EN 1995-1-1)

Warning Letter !!

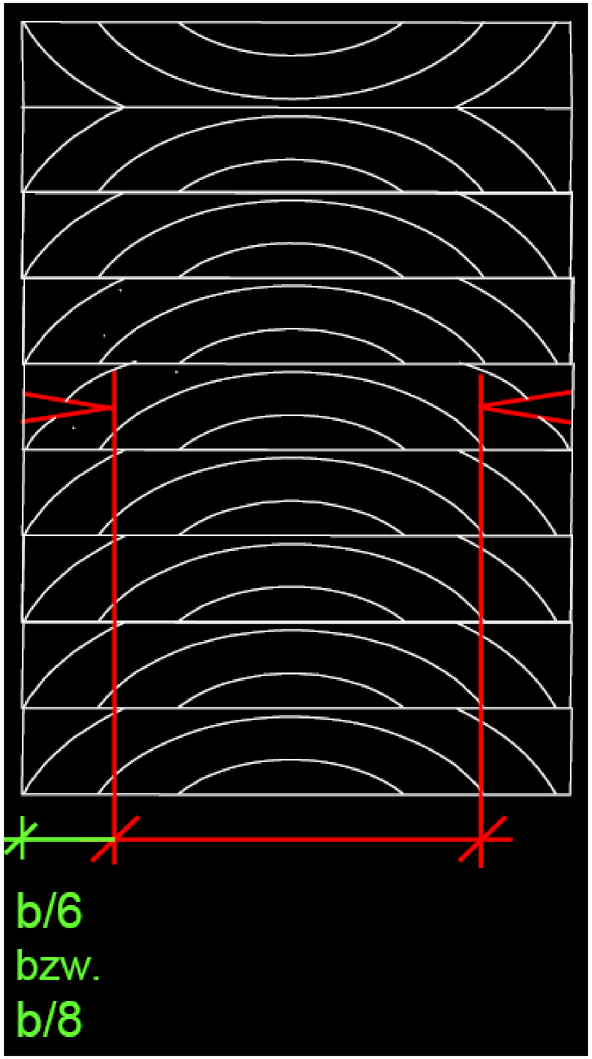
Solid timber: $f_{v.k} = 2{,}0\ \mathrm{N/mm^2}$

Glulam: $f_{v.k} = 2{,}5\ \mathrm{N/mm^2}$

will be taken into account by a factor k_{cr}

k_{crack}-value

$$f_{v,d} = \frac{k_{crack} \cdot f_{v,k} \cdot k_{\mathrm{mod}}}{\gamma_M}$$



Wood based panels

Wood based panels covered by EN 1995-1-1

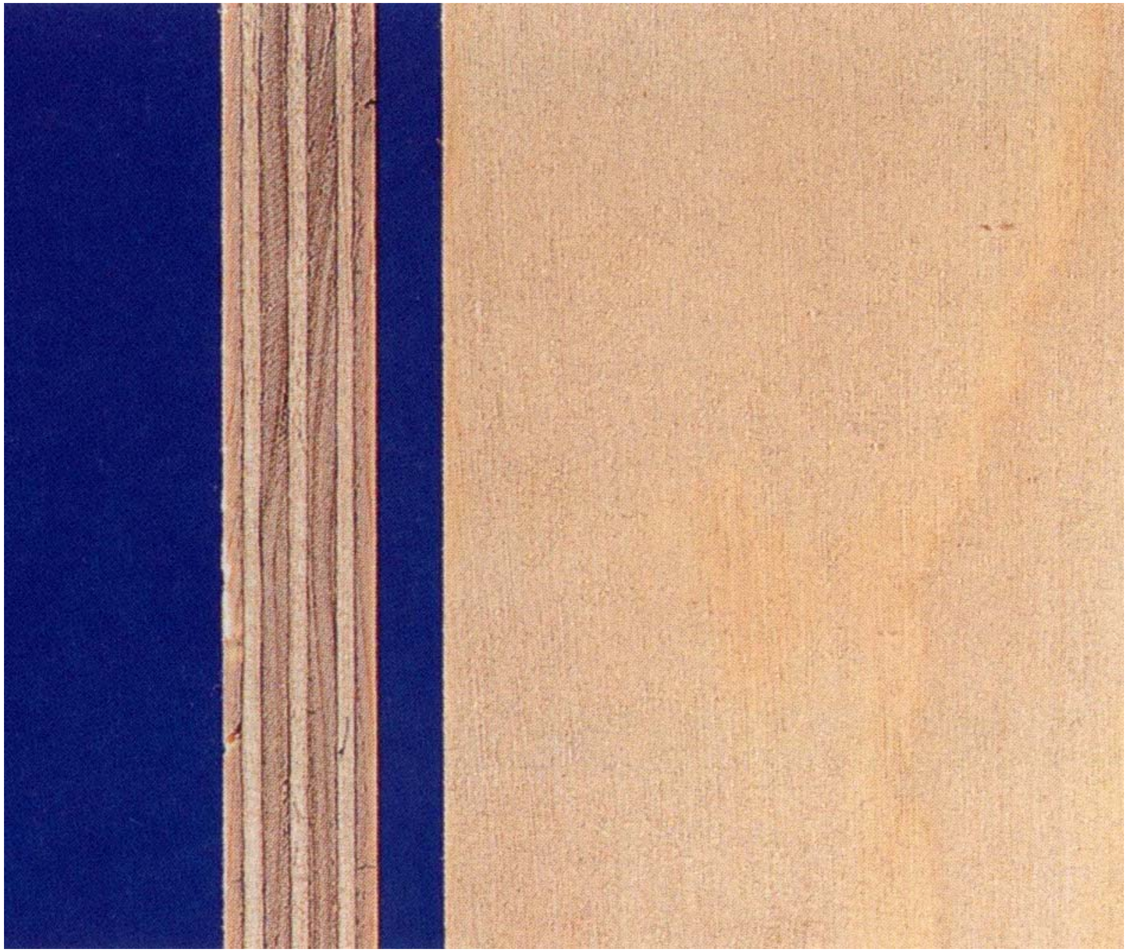
Missing materials:

Cement bonded particle board,

gypsum based panels,

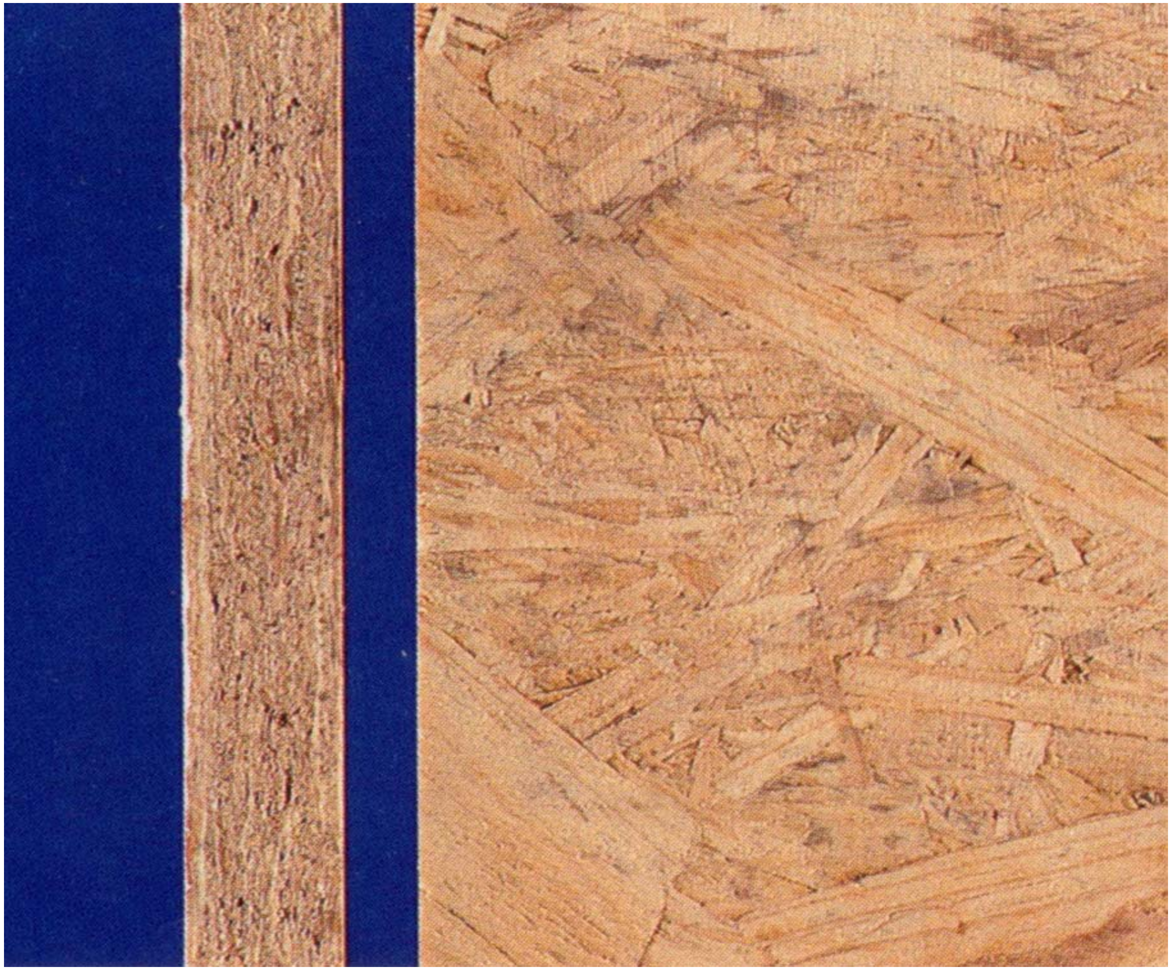
X – lam (cross laminated glulam) ….

Plywood (EN 636)

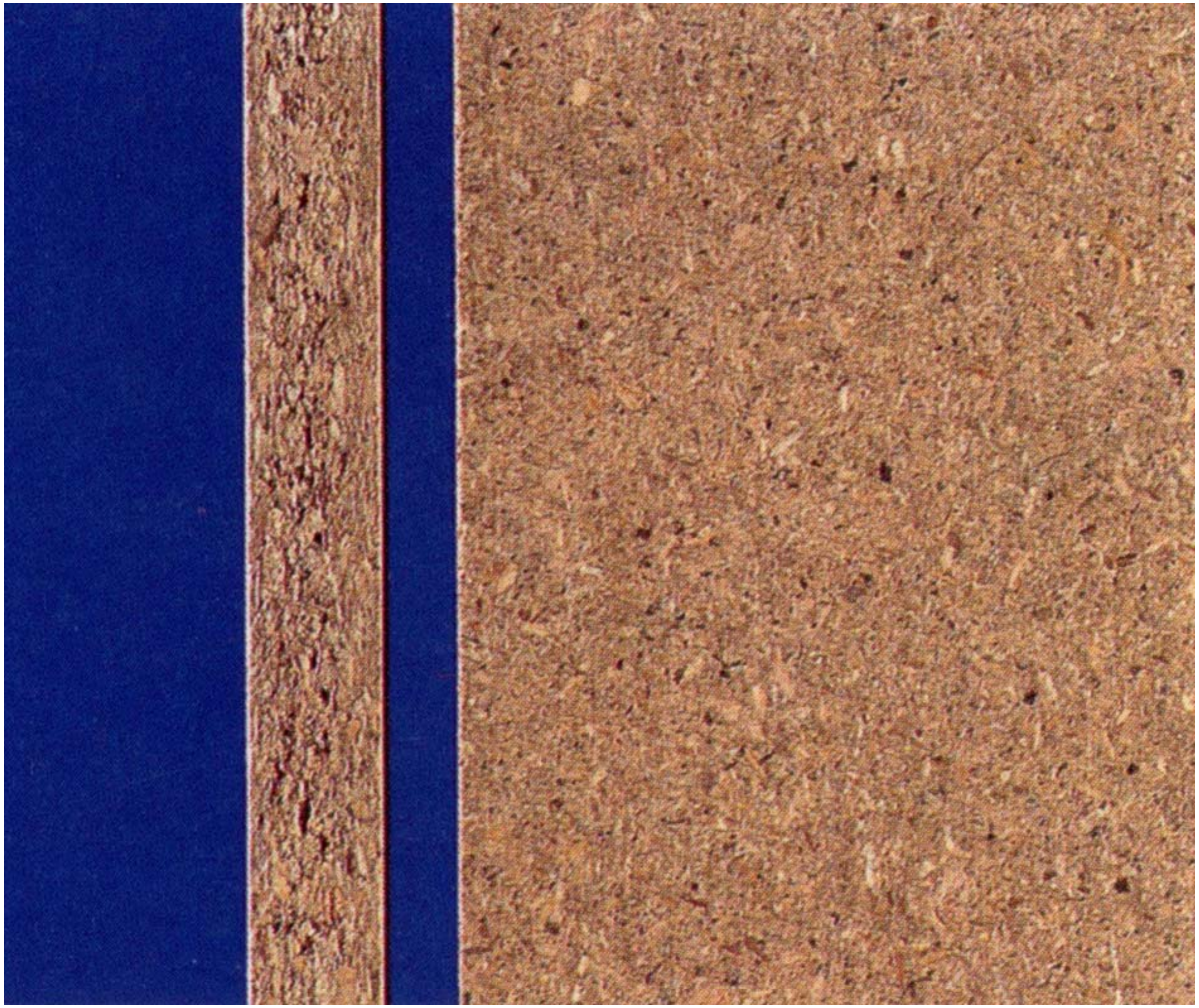


LVL (EN 14374)

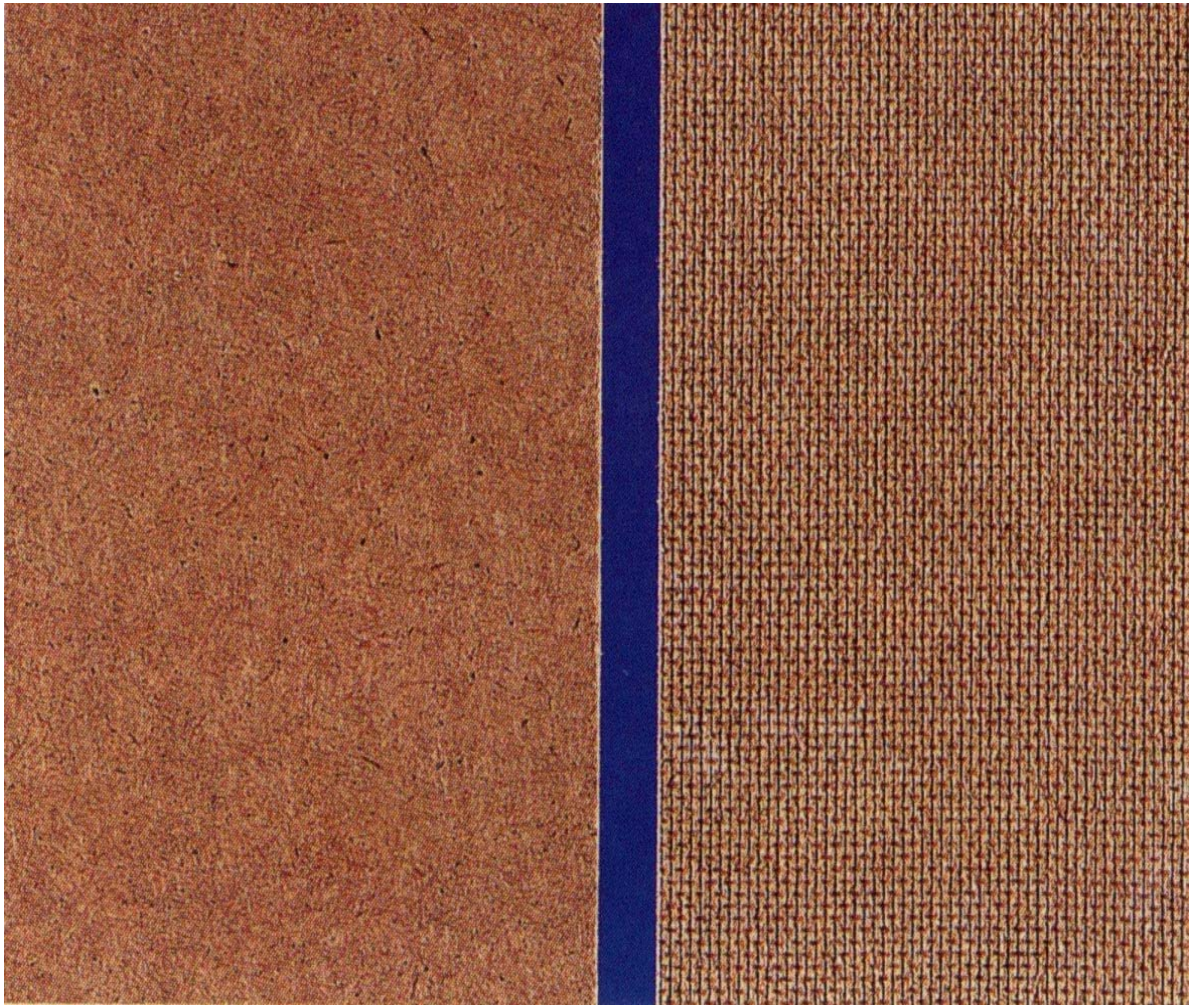
OSB (EN 300)



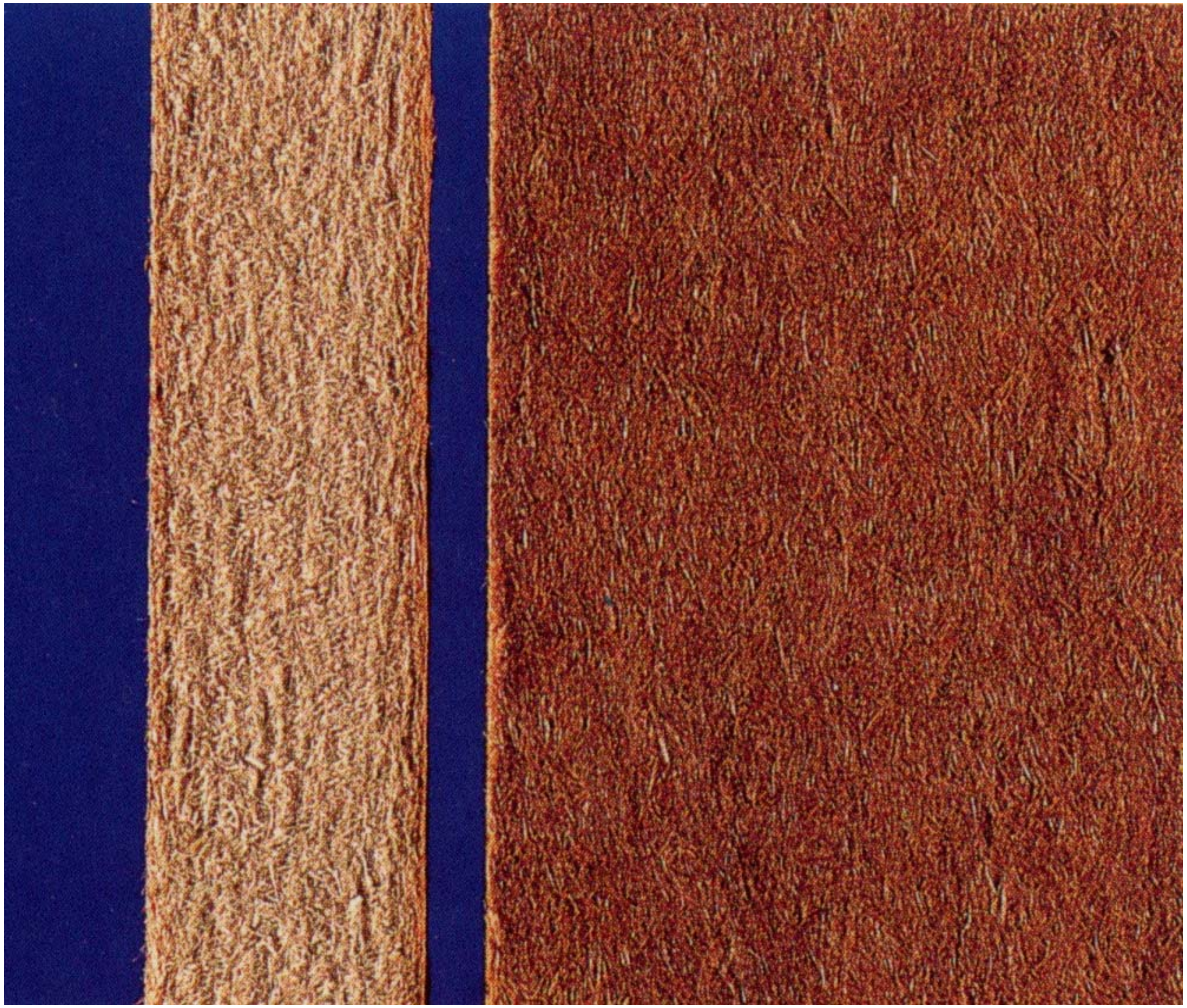
Particleboard (EN 312)



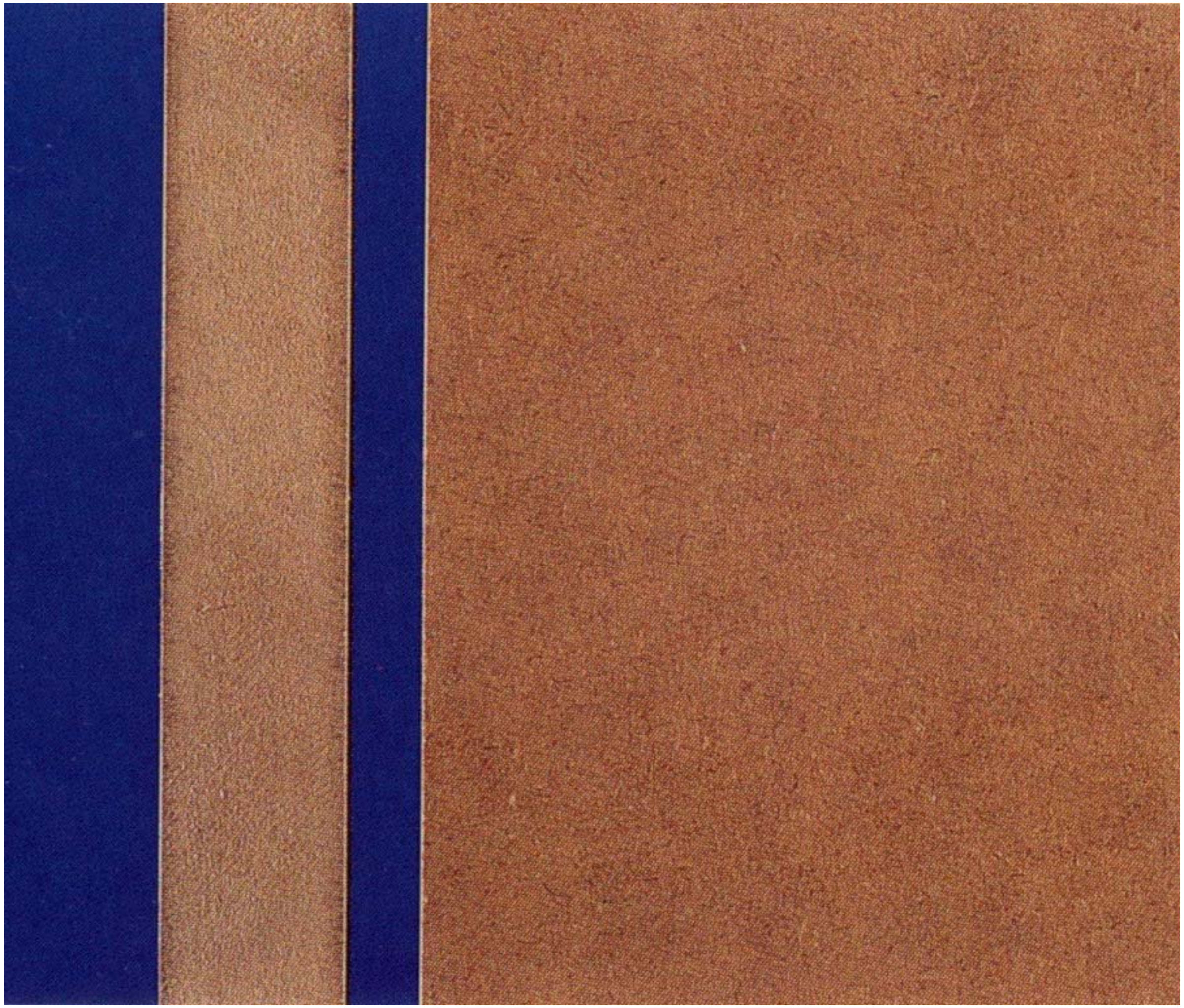
Fibreboard, hard (EN 622-2)



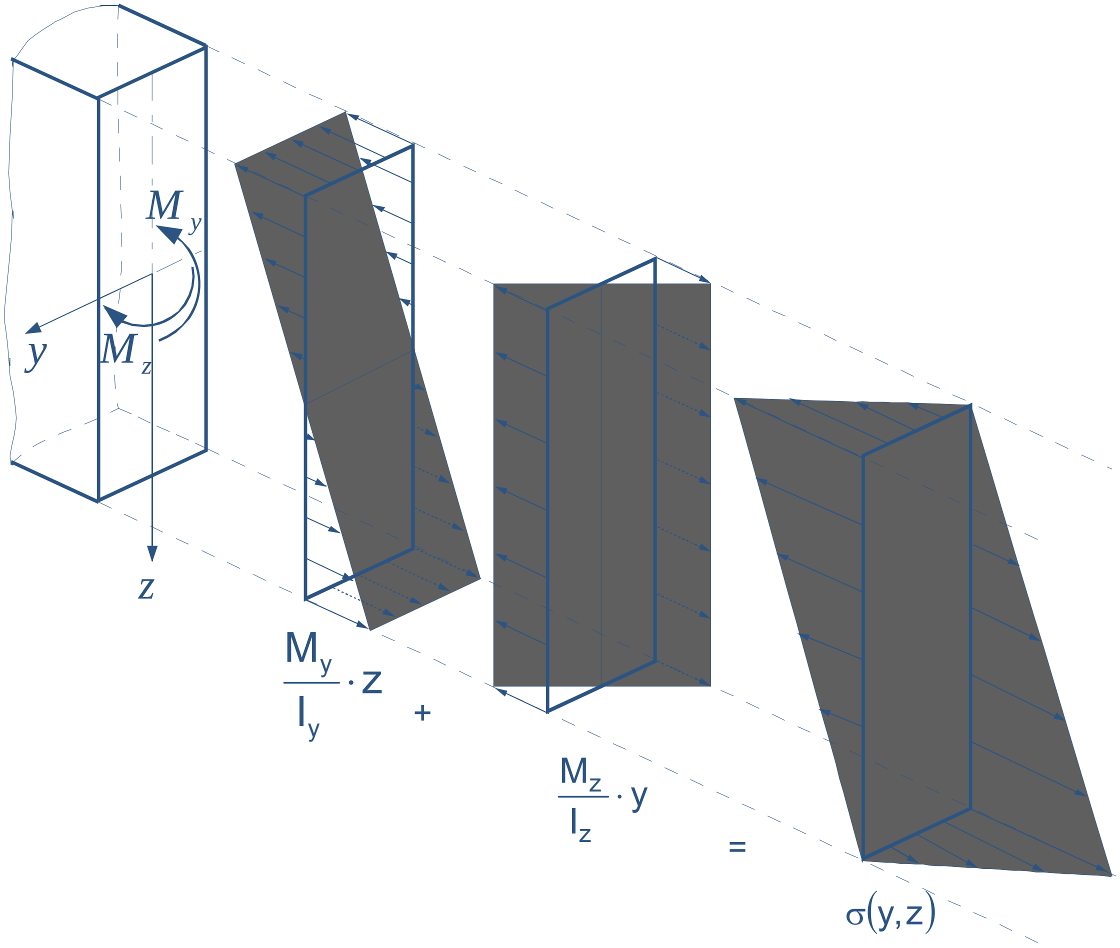
Fibreboard medium (EN 622-3)



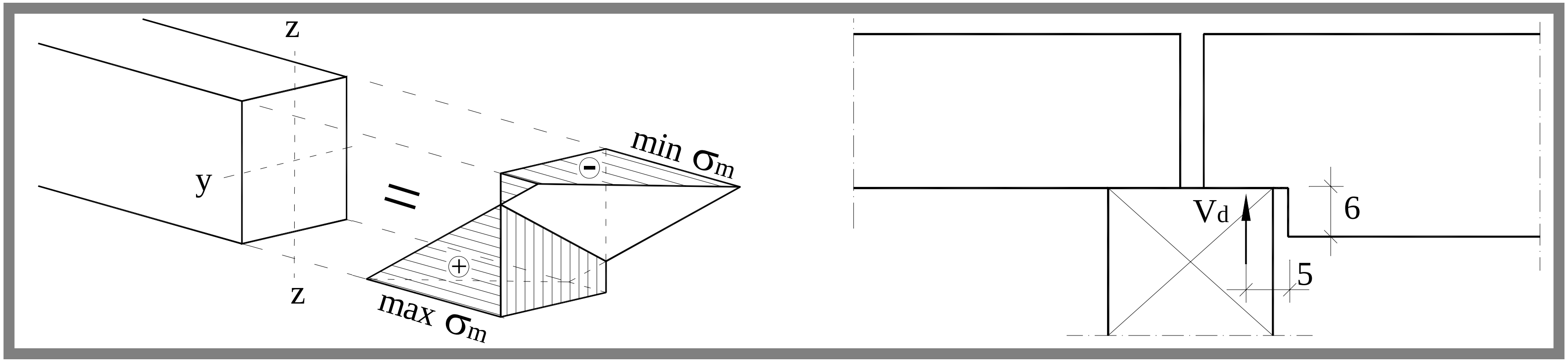
Fibreboard MDF (EN 622-5)



Beams and columns



Design resistance for cross-sections



Design value of material properties:

Ultimate limit state:

$$\boxed{X_d = k_{mod} \cdot \frac{X_{05}}{\gamma_M}}$$

Bending strength:

$$f_{m,d} = k_{mod} \cdot \frac{f_{m,k}}{\gamma_M}$$

Tensile strength:

$$f_{t,0,d} = k_{mod} \cdot \frac{f_{t,0,k}}{\gamma_M}$$

Servicability limit state:

$$\boxed{X_d = X_m}$$

Modulus of elasticity:

$$E_d = E_{0,mean}$$

Shear

$$\boxed{\tau_d = \frac{V_d \cdot S}{I \cdot b} \leq f_{v,d}}$$

$$\boxed{\frac{\tau_d}{f_{v,d}} \leq 1}$$

V_d = design value of the shear force
S = static moment (section modulus)
= $b \cdot h^2/8$ (rectangle cross-section)
I = second moment of area (moment of inertia)
= $b \cdot h^3/12$ (rectangle cross-section)
b = width
$f_{v,d}$ = design shear strength for the actual condition

$$\Rightarrow \quad \boxed{\tau_d = 1{,}5 \cdot \frac{V_d}{A} \leq f_{v,d}} \qquad \boxed{\frac{1{,}5 \cdot V_d / A}{f_{v,d}} \leq 1}$$

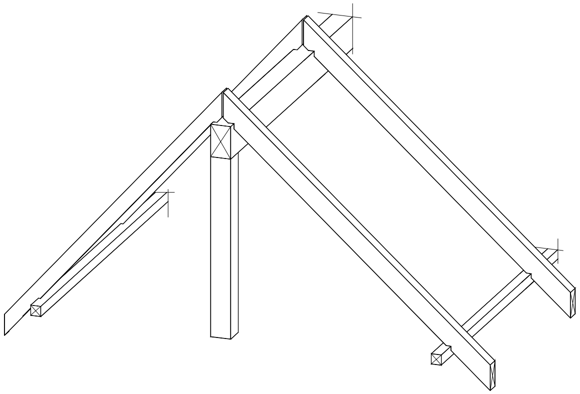
$$\boxed{\tau_d = 15 \cdot \frac{V_d}{A} \leq f_{v,d}} \qquad \boxed{15 \cdot \frac{V_d / A}{f_{v,d}} \leq 1} \qquad \left\{ \begin{array}{ll} \tau_d & \text{in [N/mm²]} \\ V_d & \text{in [kN]} \\ A & \text{in [cm²]} \\ f_{v,d} & \text{in [N/mm²]} \end{array} \right.$$

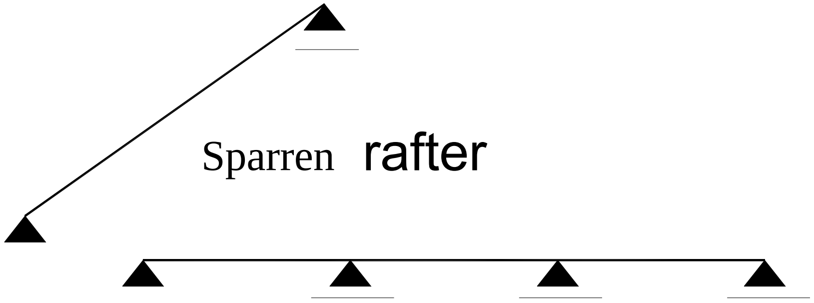
dimensioning $$\boxed{erf\, A \geq 15 \cdot \frac{V_d}{f_{v,d}} \quad with \quad \left\{ \begin{array}{ll} A & in\ [cm^2] \\ V_d & in\ [kN] \\ f_{v,d} & in\ [N/mm^2] \end{array} \right.}$$

For sawn timber C 24, service class 2 and medium term action:

$$\boxed{erf\, A \geq 9 \cdot V_d \quad with \quad \left\{ \begin{array}{ll} A & in\ [cm^2] \\ V_d & in\ [kN] \end{array} \right\}}$$

Roof construction





static systems

uniaxial bending

$$\boxed{\sigma_{m,d} = \frac{M_d}{W_n} \le f_{m,d}}$$

$$\boxed{\frac{M_d / W_n}{f_{m,d}} \le 1}$$

$\sigma_{m,d}$ = design value of bending stress
M_d = design value of bending moment
W_n = netto moment of resistance considering the cross section weaks
$f_{m,d}$ = design value of bending strength

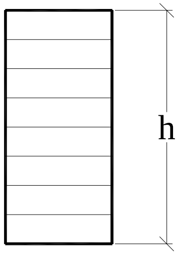
Ultimate limit state

$$\boxed{\sigma_{m,d} = 1000 \cdot \frac{M_d}{W_n} \leq f_{m,d}}$$

$$\boxed{1000 \cdot \frac{M_d / W_n}{f_{m,d}} \leq 1}$$

$\sigma_{m,d}$ in [N/mm²]
M_d in [kNm]
W_n in [cm³]
$f_{m,d}$ in [N/mm²]

Influence of height of glulam

	**$600\ \text{mm} \leq h$**	**$f_{m,y,k}$**
	$250\ \text{mm} < h < 600\ \text{mm}$	$f_{m,y,k} \cdot \left(\frac{600}{h}\right)^{0,1}$
	$h \leq 250\ \text{mm}$	**$f_{m,y,k} \cdot 1,1$**

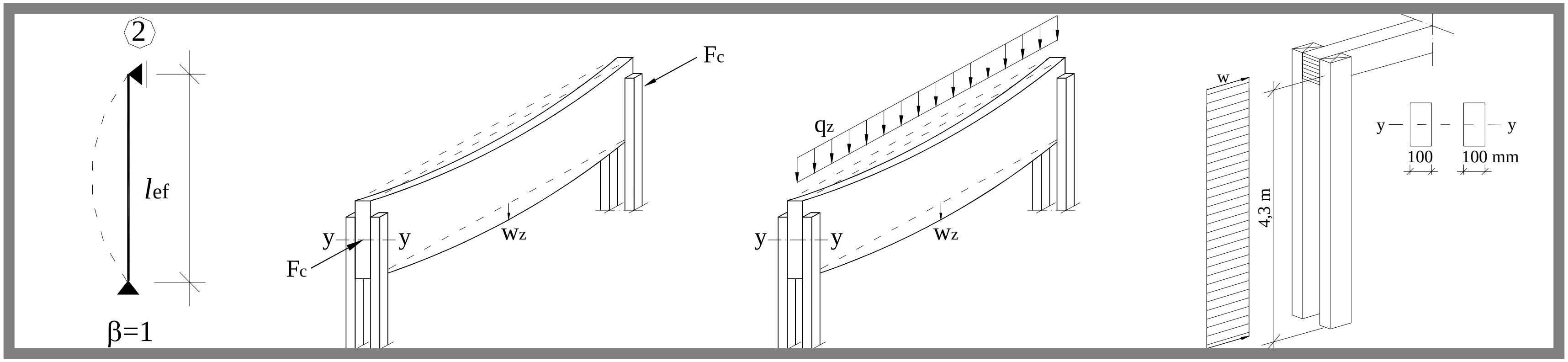
Dimensioning

$$\boxed{erf\ W_n \geq 1000 \cdot \frac{M_d}{f_{m,d}}\ mit\ \begin{cases} W_n & in\ [cm^3] \\ M_d & in\ [kNm] \\ f_{m,d} & in\ [N/mm^2] \end{cases}}$$

For sawn timber C 24, service class 2 and medium term action:

$$\boxed{erf\ W_n \geq 68 \cdot M_d\ \ with\ \left\{\begin{matrix} W_n & in\ [cm^3] \\ M_d & in\ [kNm] \end{matrix}\right\}}$$

Stability of Members



Compression members endangered by buckling

(2)P Column stability and lateral torsional stability shall be verified using the characteristic properties, e.g. $E_{0,05}$

imperfections ⇨ additional bending moment

Structural design calculation using compressive stress values and reduced compressive strength:

$$\boxed{\sigma_{c,0,d} = \frac{F_{c,0,d}}{A_n} \leq k_c \cdot f_{c,0,d}} \qquad \boxed{\frac{F_{c,0,d}/A_n}{k_c \cdot f_{c,0,d}} \leq 1}$$

A_n: local cross section weakenings might be neglected at the stress verification if they are not situated in the middle third of the buckling length.

k_c: local cross section weakenings might be neglected at the calculation of the buckling coefficient.

Buckling coefficient

$$\boxed{k_c = \frac{1}{k + \sqrt{k^2 - \lambda_{rel,c}^2}} \leq 1}$$

k = $0,5 \cdot \left[1 + \beta_c \cdot \left(\lambda_{rel,c} - 0,3\right) + \lambda_{rel,c}^2\right]$

β_c = 0,2 for solid timber
0,1 for glued laminated timber and LVL

$\lambda_{rel,c}$ = Relative Slenderness $= \frac{\ell_{ef}}{\pi \cdot i} \cdot \sqrt{\frac{f_{c,0,k}}{E_{0,05}}} = \frac{\lambda}{\pi} \cdot \sqrt{\frac{f_{c,0,k}}{E_{0,05}}}$

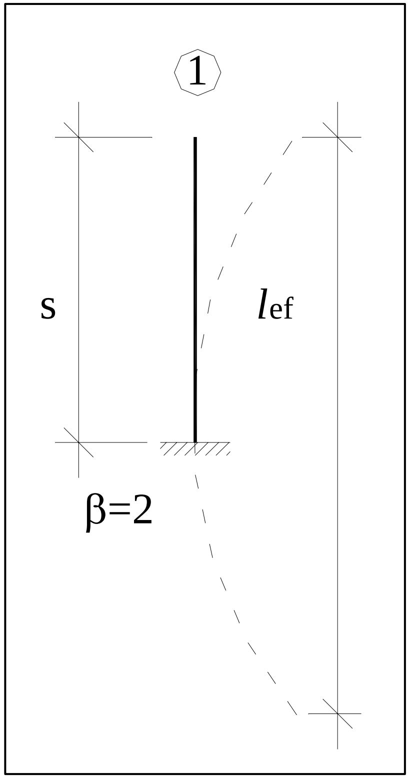
λ = $\frac{\ell_{ef}}{i}$ = Slenderness

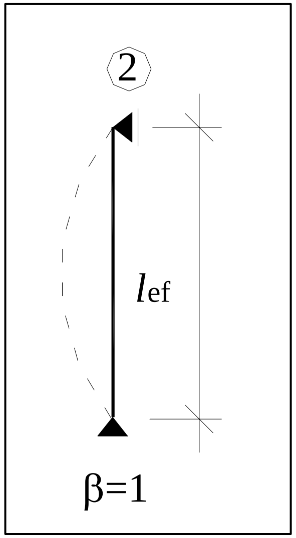
ℓ_{ef} = $\beta \cdot s$ = effective lenght

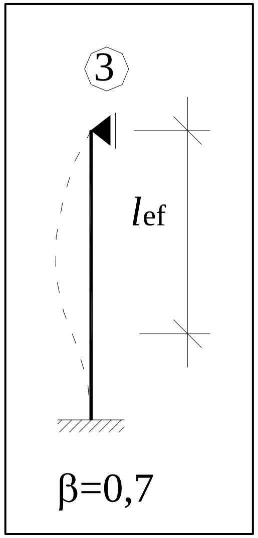
β = buckling length coefficient

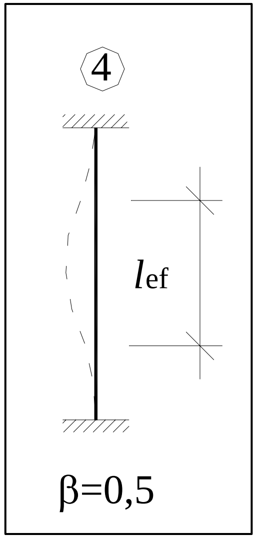
i $= \sqrt{I/A}$

Buckling length coefficient β





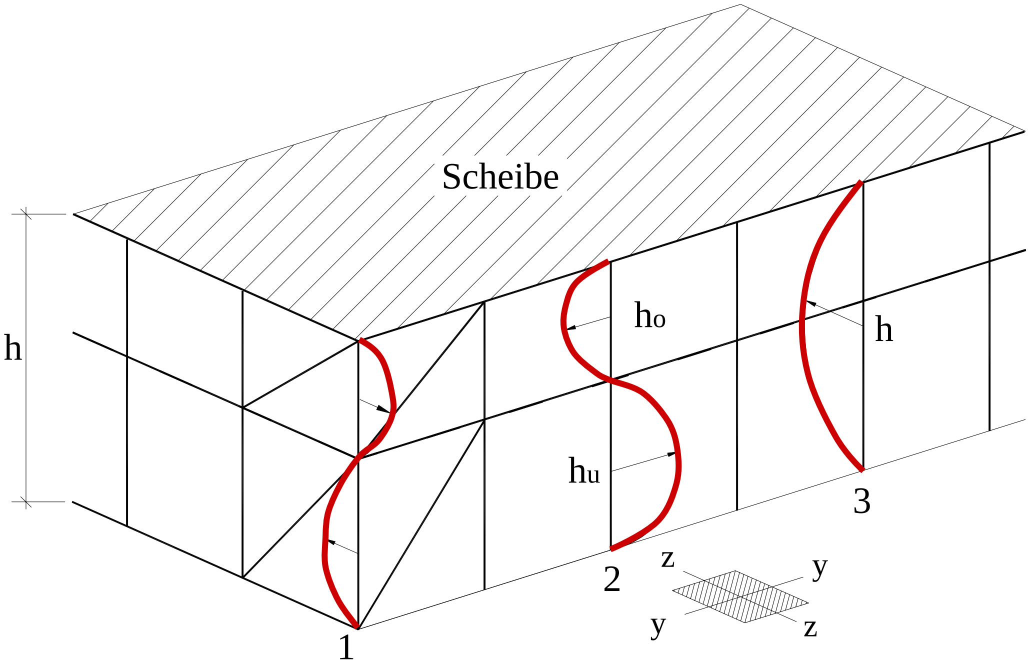




Compression member with intermediate lateral support:

⇨ **buckling length = distance of lateral support**

different buckling lengths $\ell_{ef,y}$ and $\ell_{ef,z}$:



Design calculation

$$\frac{\sigma_{\mathrm{c,0,d}}}{k_{\mathrm{c,y}} f_{\mathrm{c,0,d}}} + \frac{\sigma_{\mathrm{m,y,d}}}{f_{\mathrm{m,y,d}}} + k_{\mathrm{m}} \frac{\sigma_{\mathrm{m,z,d}}}{f_{\mathrm{m,z,d}}} \leq 1$$

$$\frac{\sigma_{\mathrm{c,0,d}}}{k_{\mathrm{c,z}} f_{\mathrm{c,0,d}}} + k_{\mathrm{m}} \frac{\sigma_{\mathrm{m,y,d}}}{f_{\mathrm{m,y,d}}} + \frac{\sigma_{\mathrm{m,z,d}}}{f_{\mathrm{m,z,d}}} \leq 1$$

Design calculation

1. **determination of buckling lengths ℓ_{ef} for buckling around the principal axis**
2. **calculation of the slenderness ratio λ_y and λ_z**

$\boxed{\lambda = \ell_{ef}/i}$ **with i = 0,289 · h resp. = 0,289 · w at rectangular cross sections**

3. **determination of instability factors $k_{c,y}$ und $k_{c,z}$**

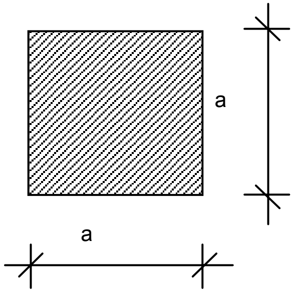
4. **verification of buckling resistance**

$$\boxed{\sigma_{c,0,d} = 10 \cdot \frac{F_{c,0,d}}{A_n} \le k_c \cdot f_{c,0,d}} \qquad \boxed{10 \cdot \frac{F_{c,0,d}/A_n}{k_c \cdot f_{c,0,d}} \le 1}$$

$\sigma_{c,0,d}$ in [N/mm²]
$F_{c,0,d}$ in [kN]
A_n in [cm²]
$f_{c,0,d}$ in [N/mm²]

Design resistance of squared columns C 24 in Service class 2 for medium action load

for axial compression



a	A	Nd, max in kN for a buckling length of lef in m										
mm	**mm²**	**2,00**	**2,50**	**3,00**	**3,50**	**4,00**	**4,50**	**5,00**	**5,50**	**6,00**	**6,50**	**7,00**
100	10000	72	50,4	36,4	27,4	21,3	17	13,9	11,5	9,7	8,3	7,2
120	14400	130	97,6	72,5	55,2	43,2	34,6	28,3	23,6	20	17,1	14,8
140	19600	202	164	127	98,7	78	62,9	51,6	43,1	36,6	31,4	27,2
160	25600	284	247	202	161	129	105	86,5	72,5	61,5	52,9	45,9
180	32400	375	340	293	243	199	163	136	114	97,1	83,6	72,7
200	40000	476	444	399	343	288	240	201	170	146	126	109
220	48400	587	557	514	459	397	337	286	244	209	181	158
240	57600	709	679	639	586	522	454	391	336	290	252	221
260	67600	841	812	773	723	660	588	515	448	390	340	299

Thank you very much for your attention!