EN 1995-2

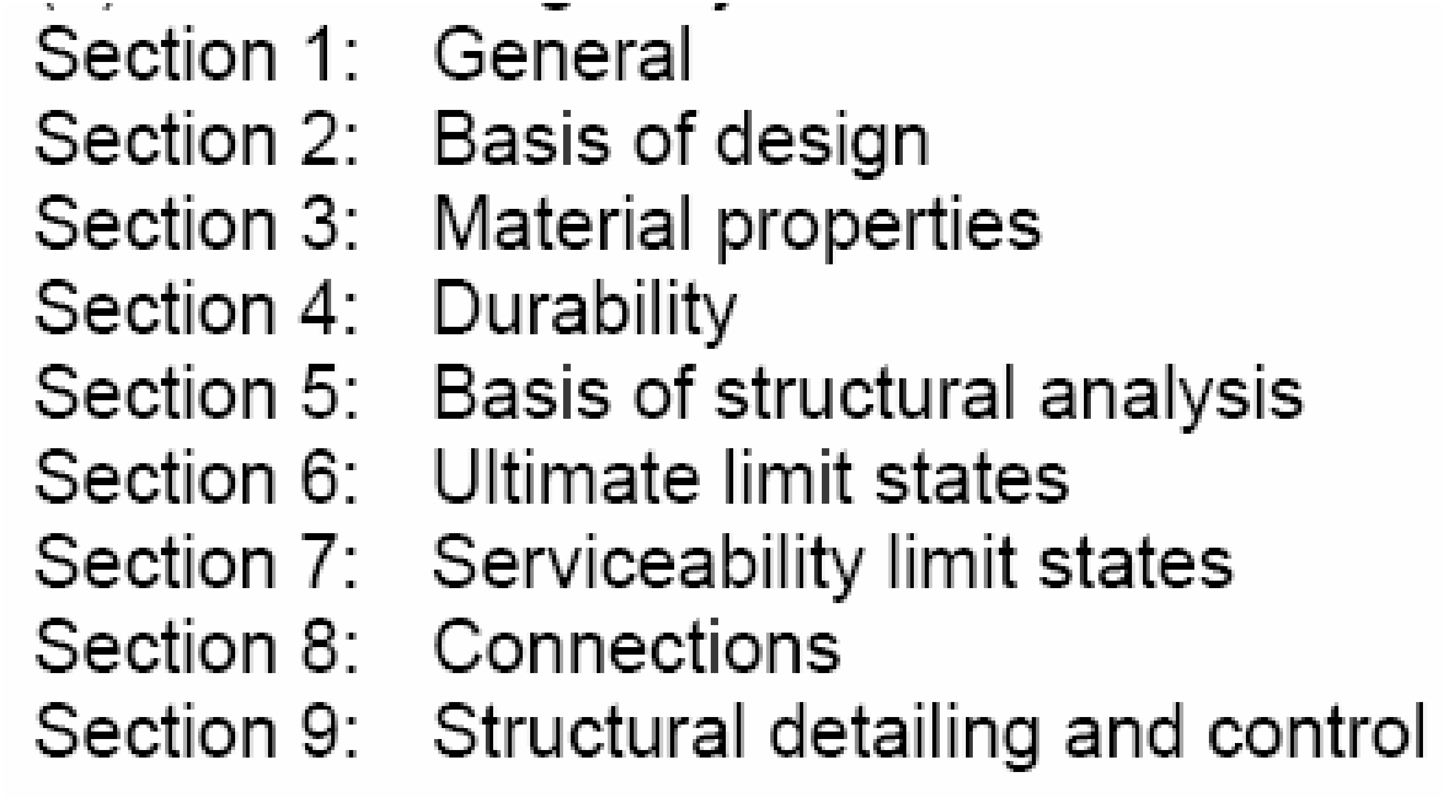
Eurocode 5 – Design of timber structures

Part 2: Bridges

Chair of Timber Structures
and Building Construction

Flisa, Norwegen

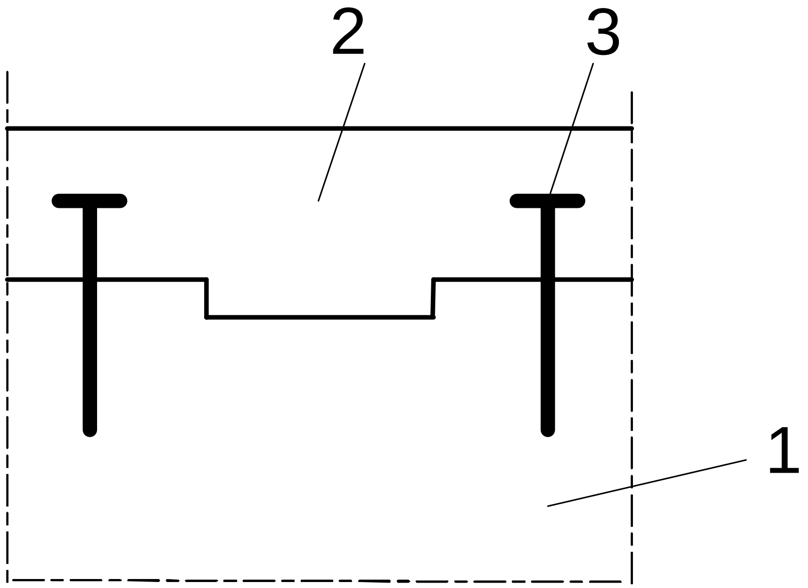
Bridge over river Saalach Bavaria - Salzburg, 70m span



Section 1: General
Section 2: Basis of design
Section 3: Material properties
Section 4: Durability
Section 5: Basis of structural analysis
Section 6: Ultimate limit states
Section 7: Serviceability limit states
Section 8: Connections
Section 9: Structural detailing and control

Rules given in EC5 part 2 are supplements and should be added to the rules given in EC5 part 1

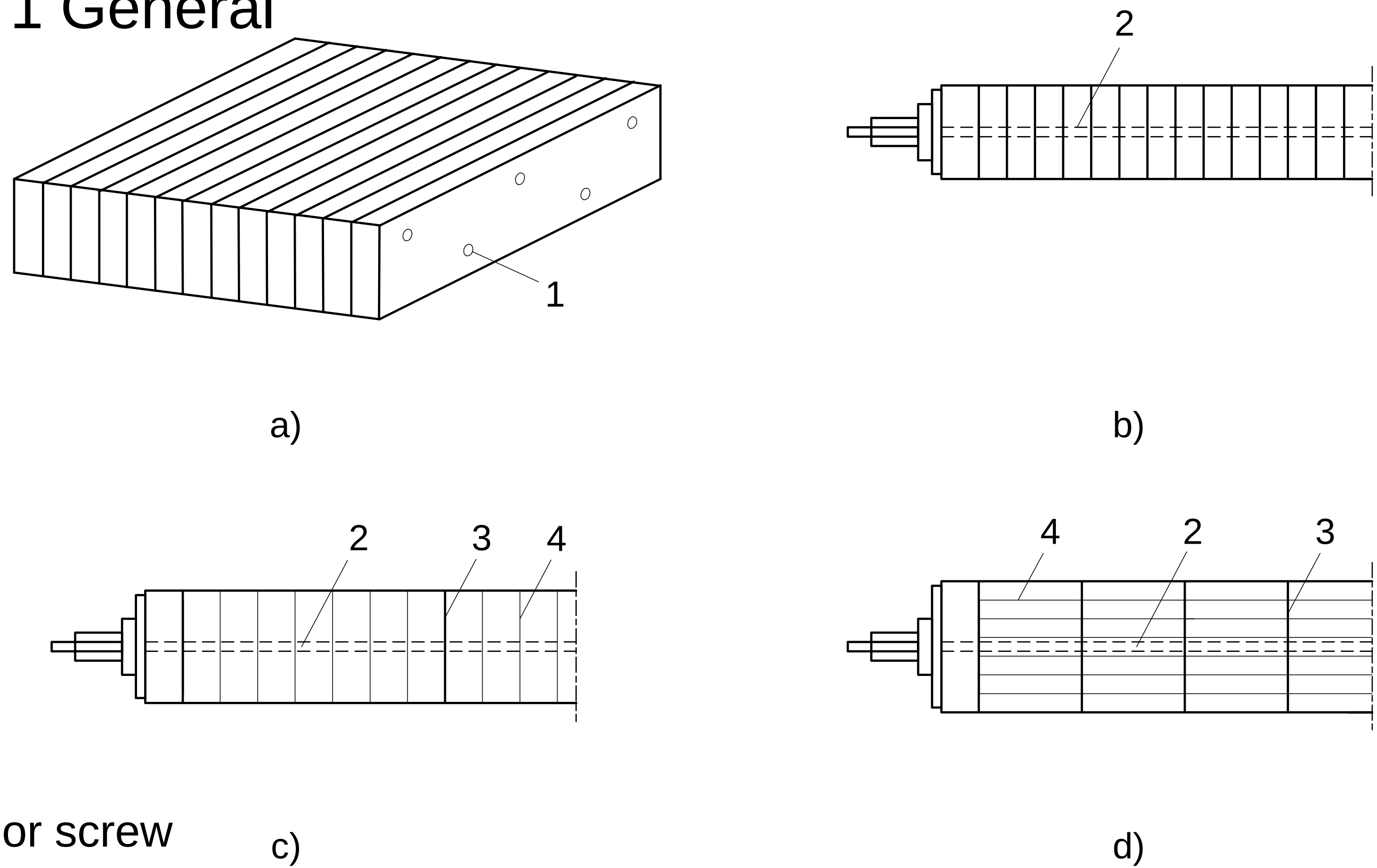
Section 1 General



1 Timber
2 Concrete
3 Fastener

Example of grooved connection

Section 1 General

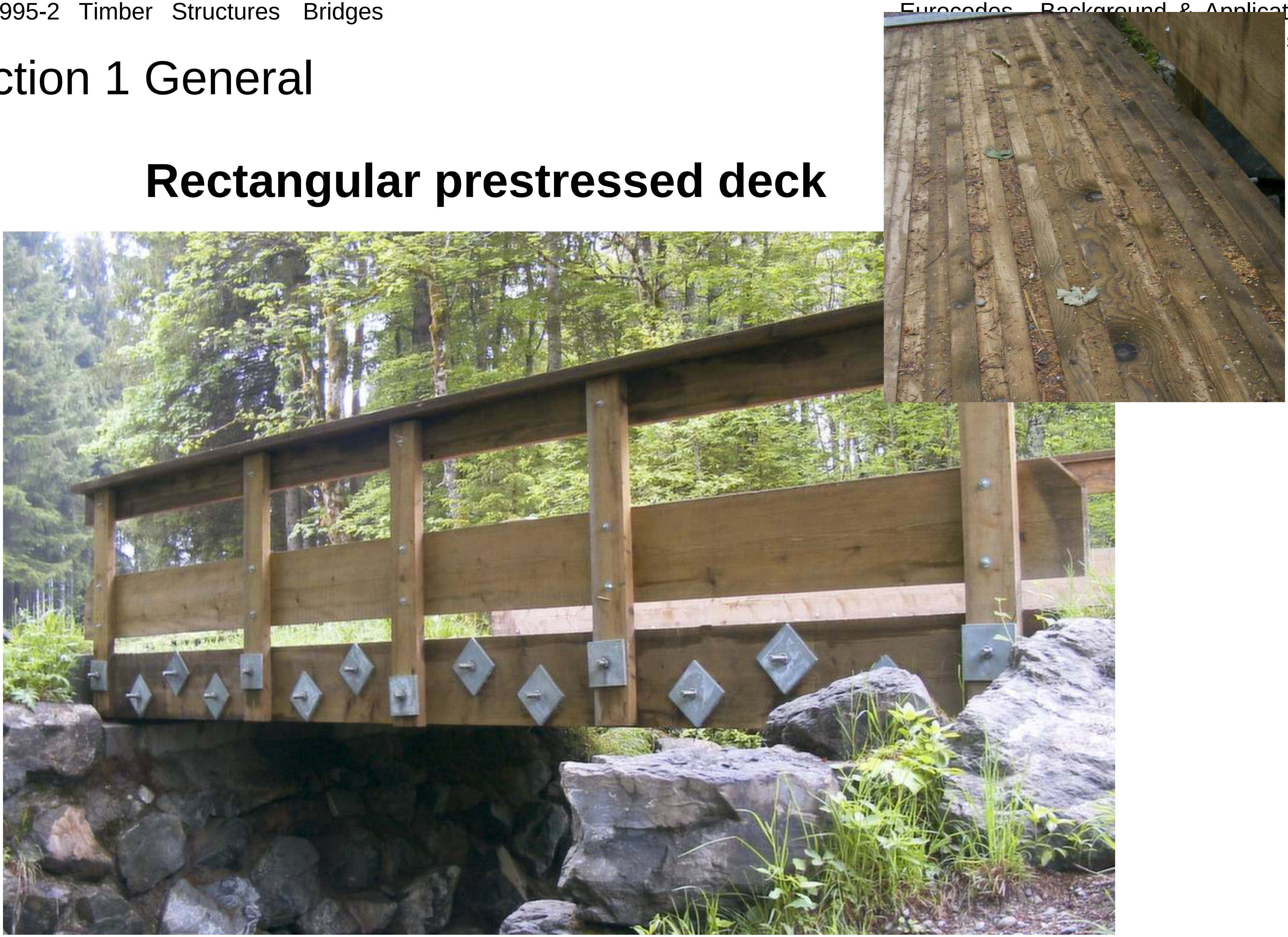


1 Nail or screw
2 Pre-stressing bar or tendon
3 Glue-line between glued laminated members
4 Glue-line between laminations in glued laminated members

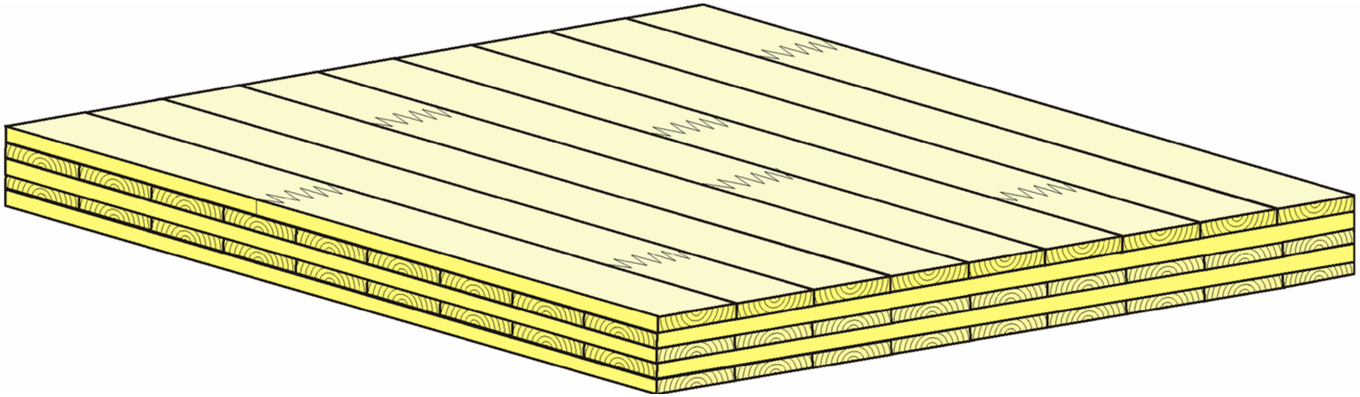
Figure 1.2 – Examples of deck plates made of laminations

Section 1 General

Rectangular prestressed deck



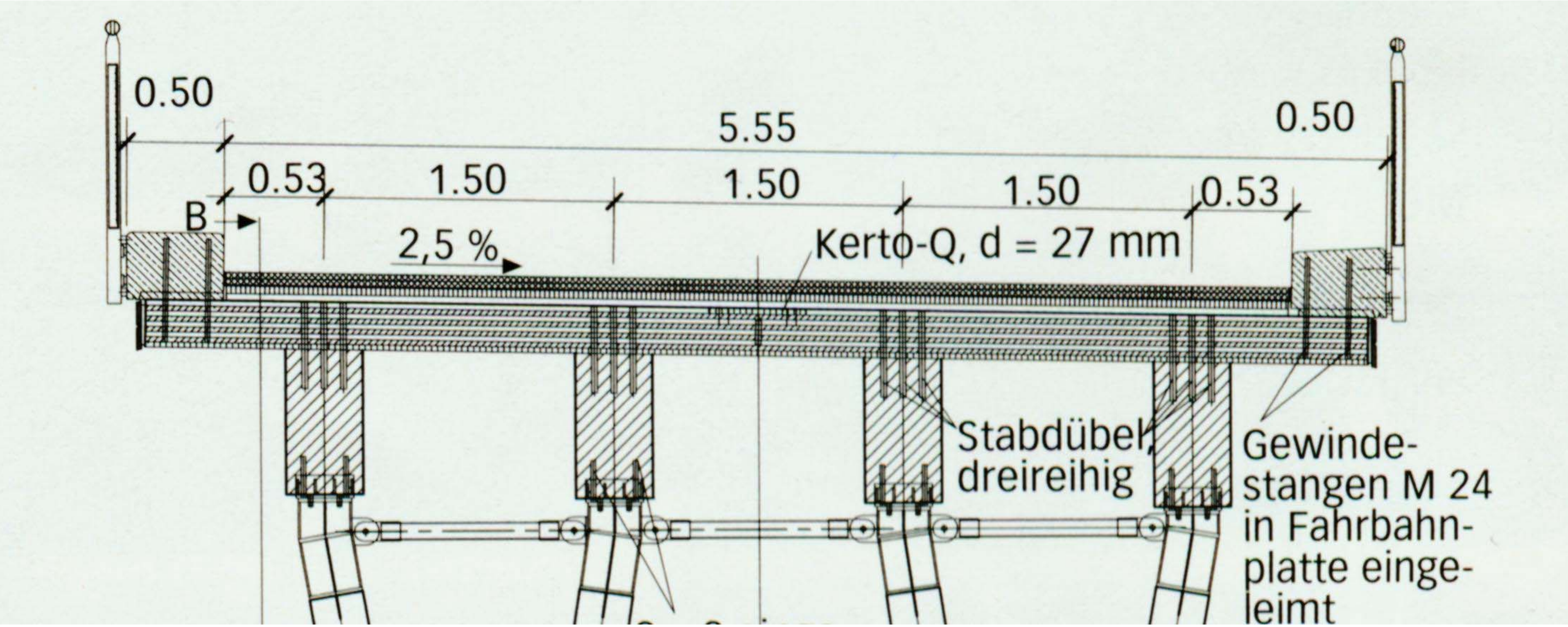
Section 1 General



Example of cross-laminated deck plate

Section 1 General

Ruderting



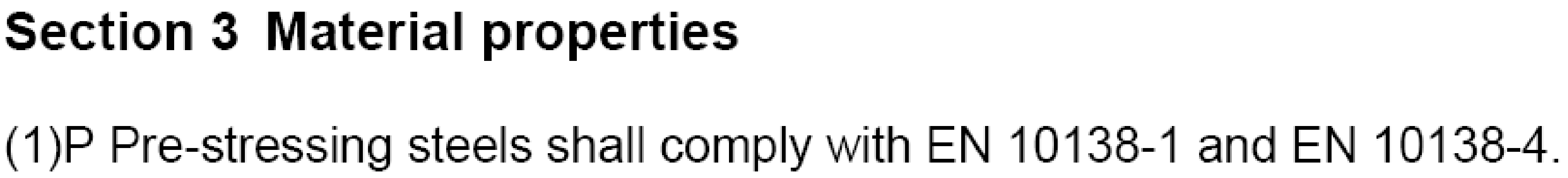
Section 2 Basis of design

$$R_d \leq \frac{k_{mod} \cdot R_k}{\gamma_M}$$

Section 2 Basis of design

1. Timber and wood-based materials	
–normal verification –solid timber –glued laminated timber –LVL, plywood, OSB –fatigue verification	 γ_M = ***1,3*** γ_M = ***1,25*** γ_M = ***1,2*** γ_M = ***1,0***
2. Connections - normal verification – fatigue verification	 γ_M = ***1,3*** γ_M = ***1,0***
3. Steel used in composite members	γ_M = ***1,15***
4. Concrete used in composite members	γ_M = ***1,5***
5. Shear connectors between composite members – normal verification – fatigue verification	 γ_M = ***1,25*** γ_M = ***1,0***
6.Pre-stressing steel elements	γ_M = ***1,15***

Section 3 Material properties



Section 3 Material properties

(1)P Pre-stressing steels shall comply with EN 10138-1 and EN 10138-4.

Section 4 Durability

Section 4 Durability

4.1 Timber

(1)The effect of precipitation,
wind and solar should be taken into account

4.2 Resistance to corrosion

4.3 Protection of timber decks from water by sealing

Section 4 Durability

Roof = constructive protection

Alternatives?

Chemical treatment

Section 4 Durability

Constructive protection

Bridge in Eching

Section 4 Durability

Constructive protection

Section 4 Durability

South-west-side, roof to small?

Section 4 Durability

Chemical treatment

Section 4 Durability

Theoretical costs for bridges (Ablöserichtlinien):

Timber bridges:	**theoretical time of duration**	**50 years**
	cost per year	
	actual :	**2%**
	New proposal:	
	protected bridges	**1,0 %**
	unprotected bridges	**1,8 %**

To compare:

Steel bridges:	**Theoretical time of duration**	**100 years**
	costs per year	**0,8 %**

Section 4 Durability

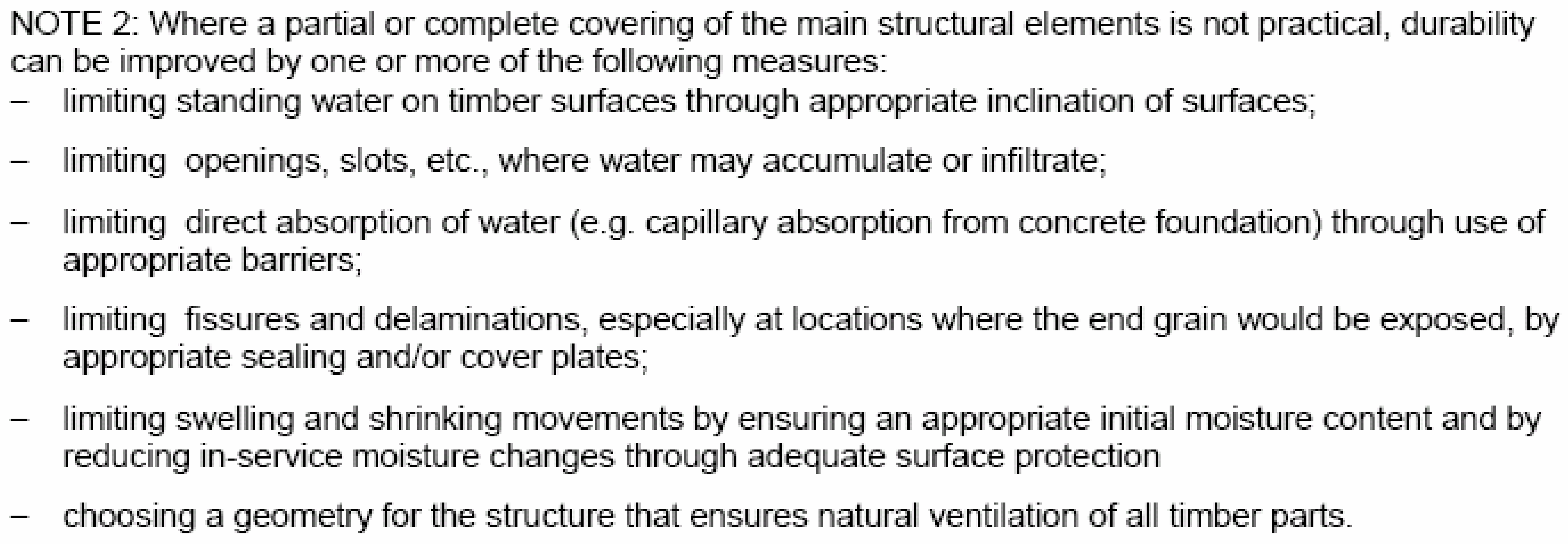
Timber protection:

Essential task

Documentation in drawings and documents

Part of structural calculation!!

Section 4 Durability



NOTE 2: Where a partial or complete covering of the main structural elements is not practical, durability can be improved by one or more of the following measures:

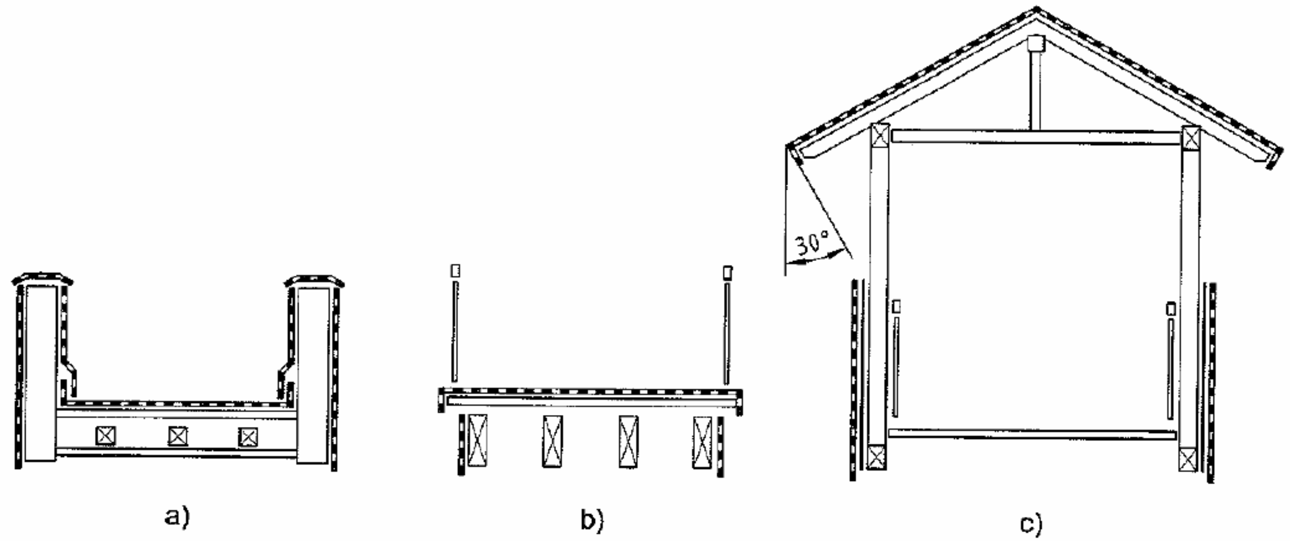
- limiting standing water on timber surfaces through appropriate inclination of surfaces;
- limiting openings, slots, etc., where water may accumulate or infiltrate;
- limiting direct absorption of water (e.g. capillary absorption from concrete foundation) through use of appropriate barriers;
- limiting fissures and delaminations, especially at locations where the end grain would be exposed, by appropriate sealing and/or cover plates;
- limiting swelling and shrinking movements by ensuring an appropriate initial moisture content and by reducing in-service moisture changes through adequate surface protection
- choosing a geometry for the structure that ensures natural ventilation of all timber parts.

Section 4 Durability

DN 1074 Dauerhaftigkeit

Anhang A (informativ)

Empfehlungen zur Dauerhaftigkeit von Holz und Holzwerkstoffen



Legende

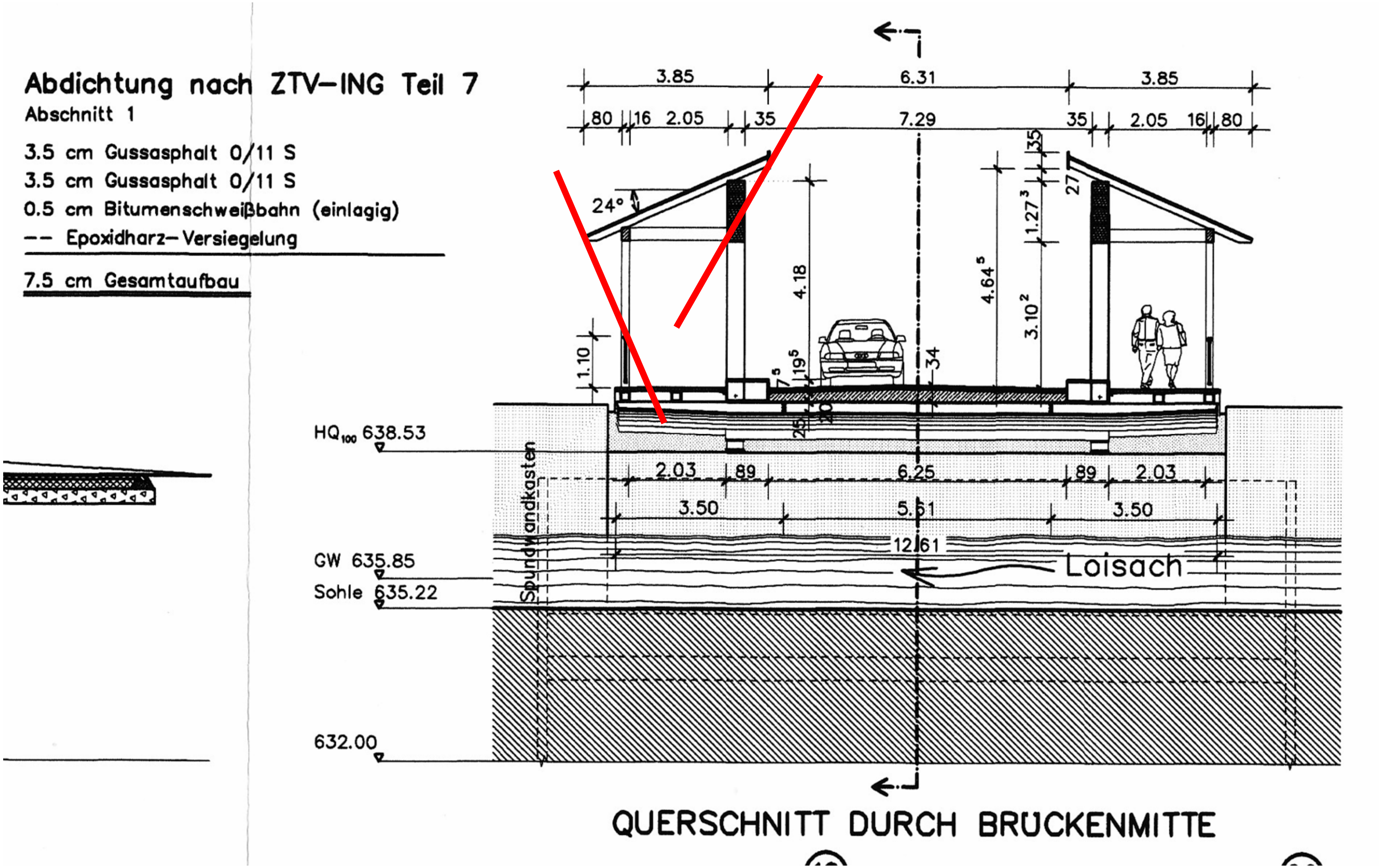
a Brücke mit unten liegender Verkehrsbahn
b Brücke mit oben liegender Verkehrsbahn
c gedeckte Brücke

Bild A.1 — Geschützte Brückenbauteile

Sonne, Regen

Section 4 Durability

DIN 1074



Abdichtung nach ZTV–ING Teil 7

Abschnitt 1

3.5 cm Gussasphalt 0/11 S
3.5 cm Gussasphalt 0/11 S
0.5 cm Bitumenschweißbahn (einlagig)
–– Epoxidharz– Versiegelung

7.5 cm Gesamtaufbau

QUERSCHNITT DURCH BRÜCKENMITTE

Section 4 Durability

Dauerhaftigkeit

Architekt: Dietrich, Tragwerksplanung: Sues, Staller, Schmitt
Prüfung: Albrecht/Kreuzinger

Section 5 Basis of structural analysis

Section 5 Basis of structural analysis

5.1 Laminated deck plates

5.1.1 General

(1) The analysis of timber deck plates should be based upon:
- the orthotropic plate theory;
- modelling the deck plate by a grid
- a simplified method according to 5.1.3

C

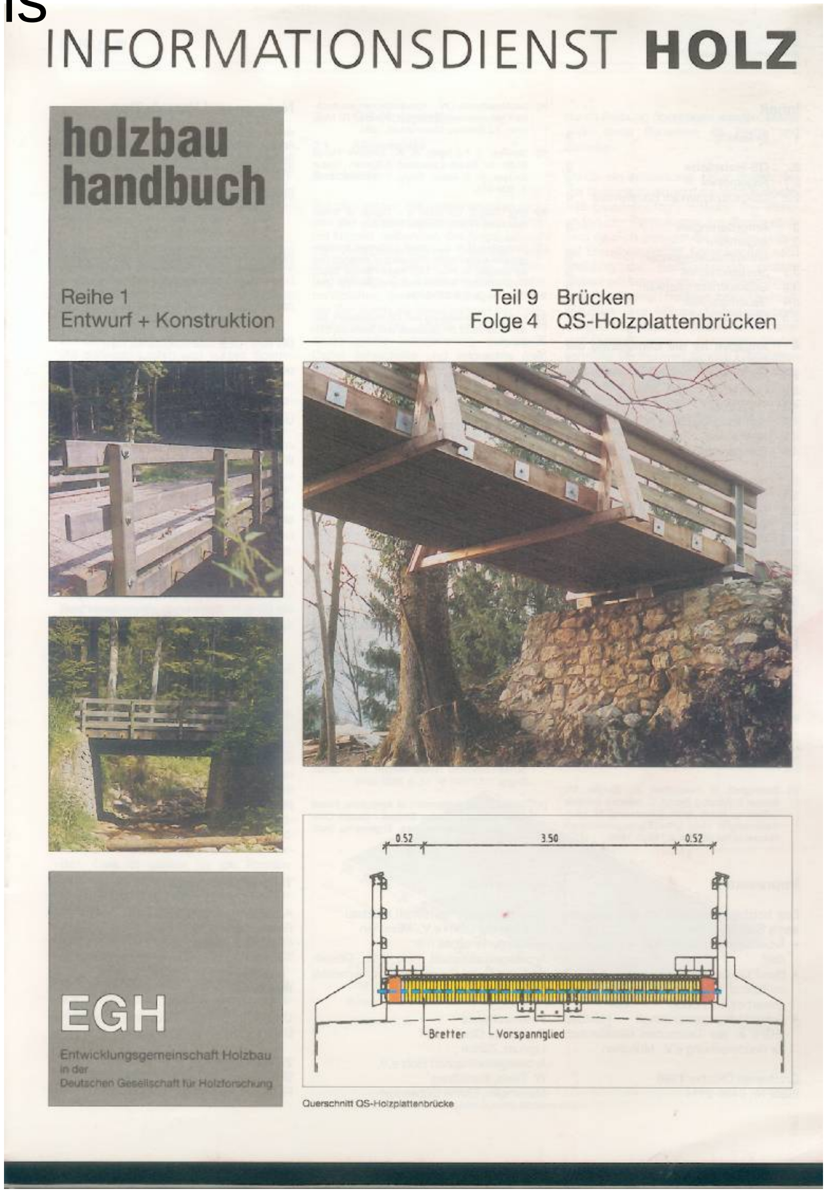
Section 5 Basis of structural analysis

Section 5 Basis of structural analysis

Table 5.1 – System properties of laminated deck plates

Type of deck plate	$E_{90,\text{mean}}/E_{0,\text{ mean}}$	$G_{0,\text{mean}}/E_{0,\text{mean}}$	$G_{90,\text{mean}}/G_{0,\text{mean}}$
Nail-laminated	0	0,06	0,05
Stress-laminated			
–sawn sawn			
–planed planed	0,015	0,06	0,08
Glued-laminated	0,020	0,06	0,10
	0,030	0,06	0,15

Section 5 Basis of structural analysis



INFORMATIONSDIENST **HOLZ**

holzbau handbuch

Reihe 1
Entwurf + Konstruktion

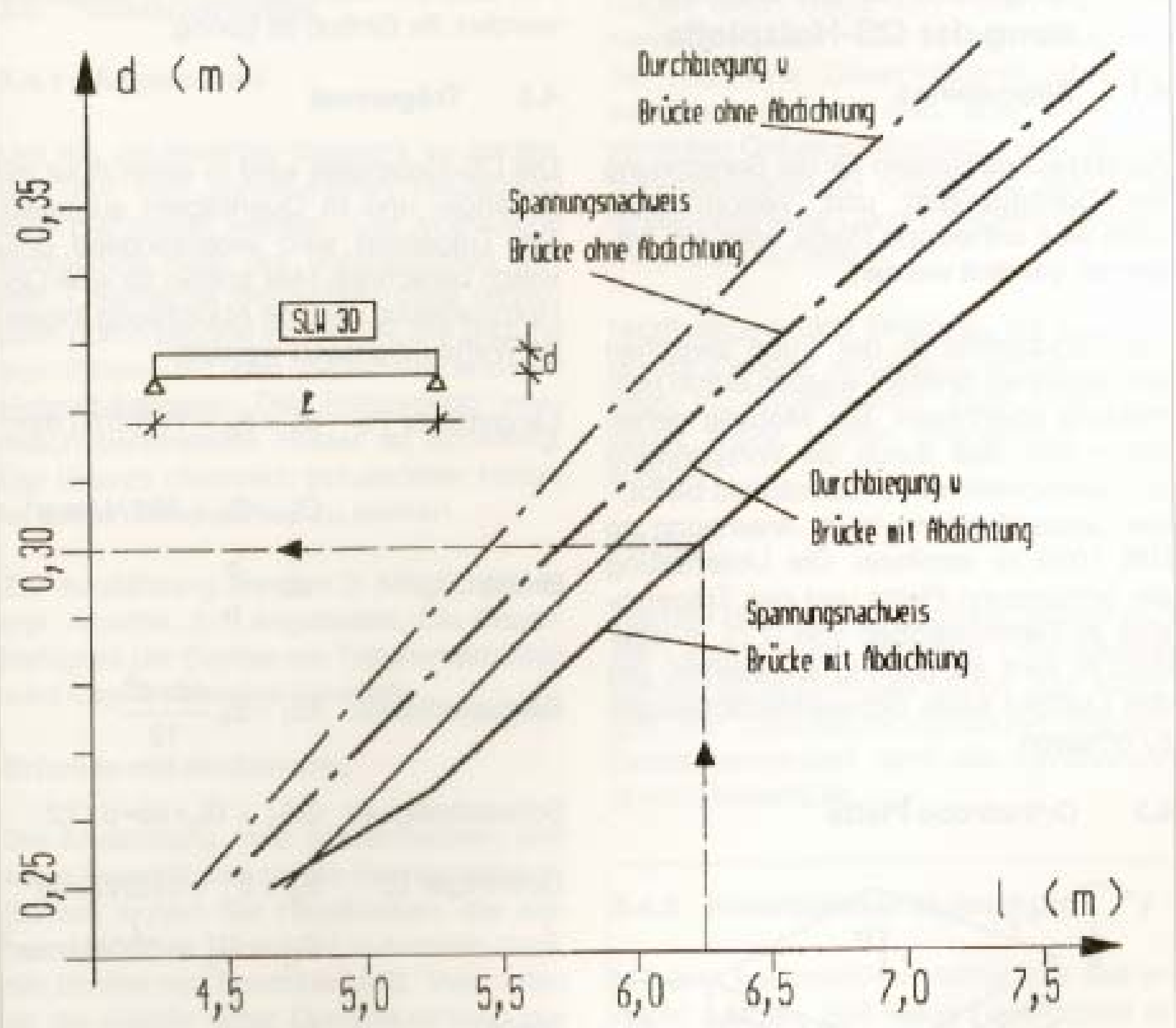
Teil 9 Brücken
Folge 4 QS-Holzplattenbrücken

Querschnitt QS-Holzplattenbrücke

EGH

Entwicklungsgemeinschaft Holzbau
in der
Deutschen Gesellschaft für Holzforschung

Section 5 Basis of structural analysis



Section 5 Basis of structural analysis

5.1.2 Concentrated vertical loads

1900

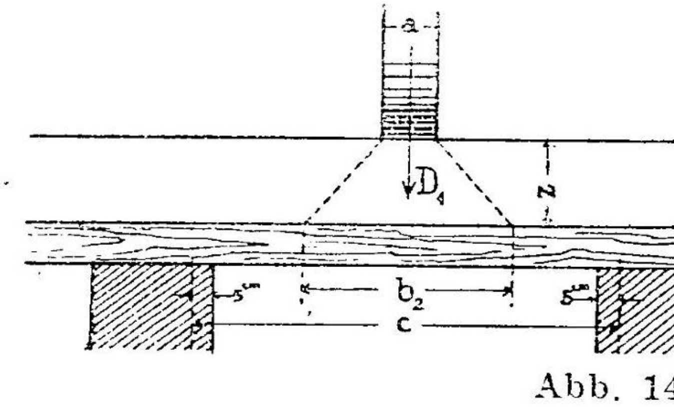
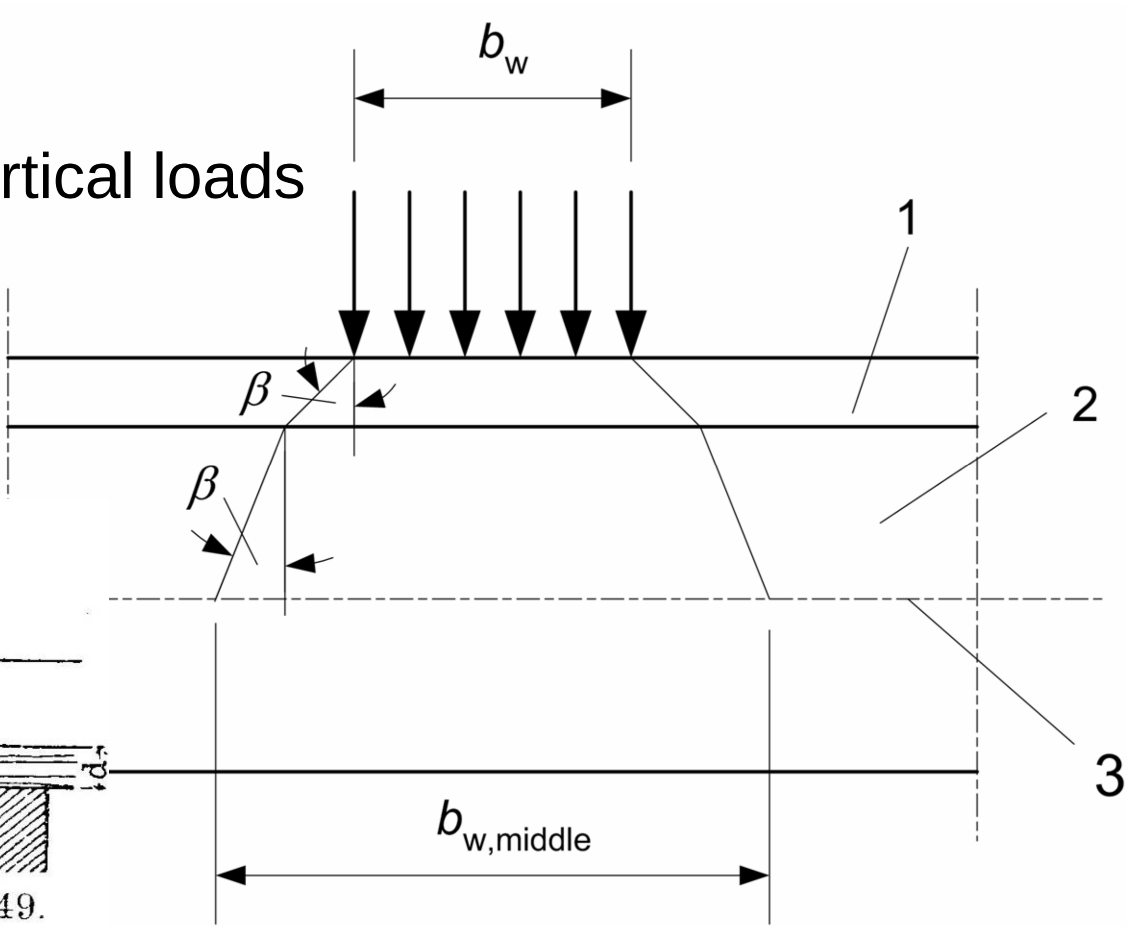


Abb. 149.

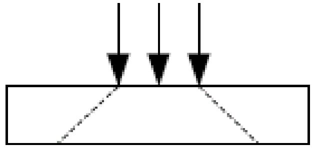
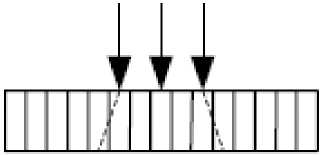


Section 5 Basis of structural analysis

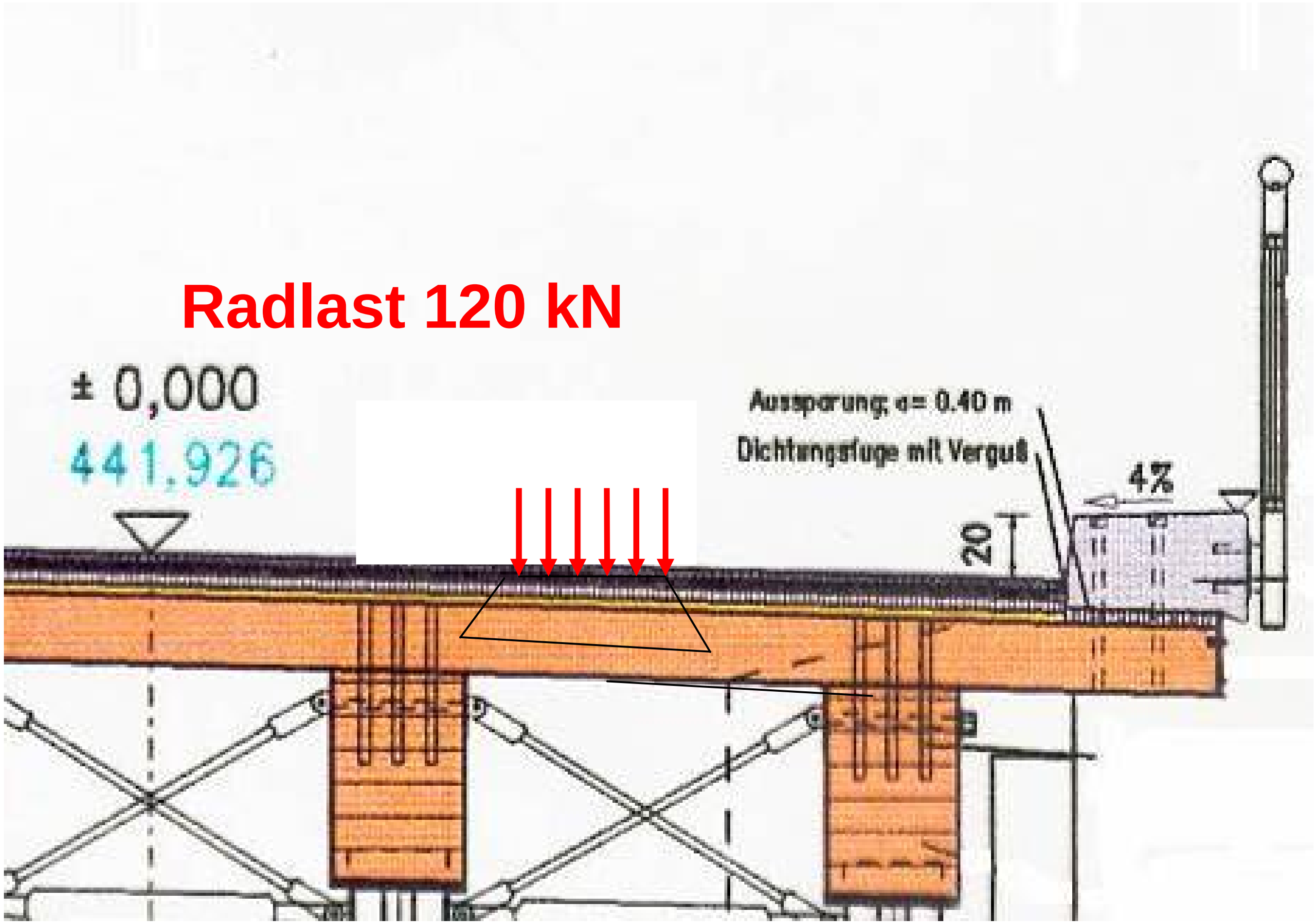
5.1.3 Simplified analysis

$$b_{ef} = b_{w,middle} + a$$

Deck plate system	a m
Nail-laminated deck plate	0,1
Stress-laminated or glued laminated	0,3
Cross-laminated timber	0,5
Composite concrete/timber deck structure	0,6

Pavement (in accordance with EN 1991-2 clause 4.3.6)		45°
Boards and planks		45°
Laminated timber deck plates:		
– in the direction of the grain		45°
– perpendicular to the grain		15°
Plywood and cross-laminated deck plates		45°

Section 5 Basis of structural analysis



Brücke Ruderting, Grossmann

Section 6 Ultimate limit states

Section 6 Ultimate limit states

Eurocode 5.1, EN 1995-1-1 !

6.1 Deck plates

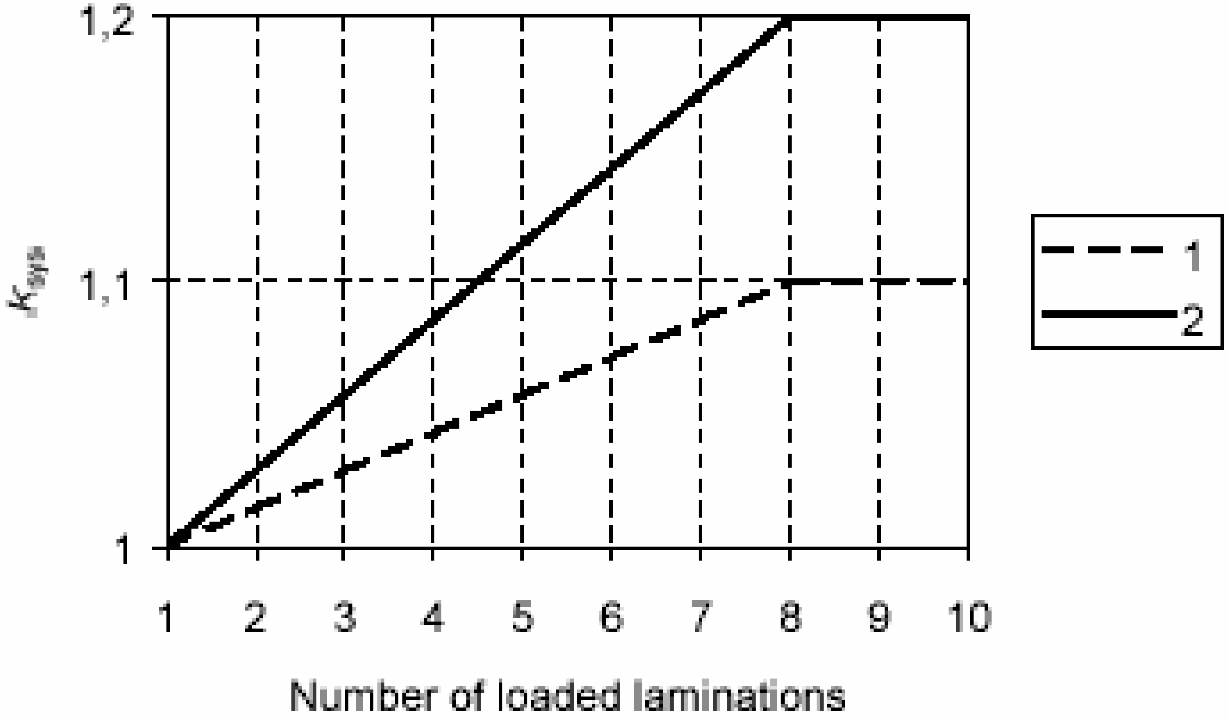
6.1.1 System strength

$$f_{\text{m,d,deck}} = k_{\text{sys}} f_{\text{m,d,lam}}$$

$$f_{\text{v,d,deck}} = k_{\text{sys}} f_{\text{v,d,lam}}$$

Section 6 Ultimate limit states

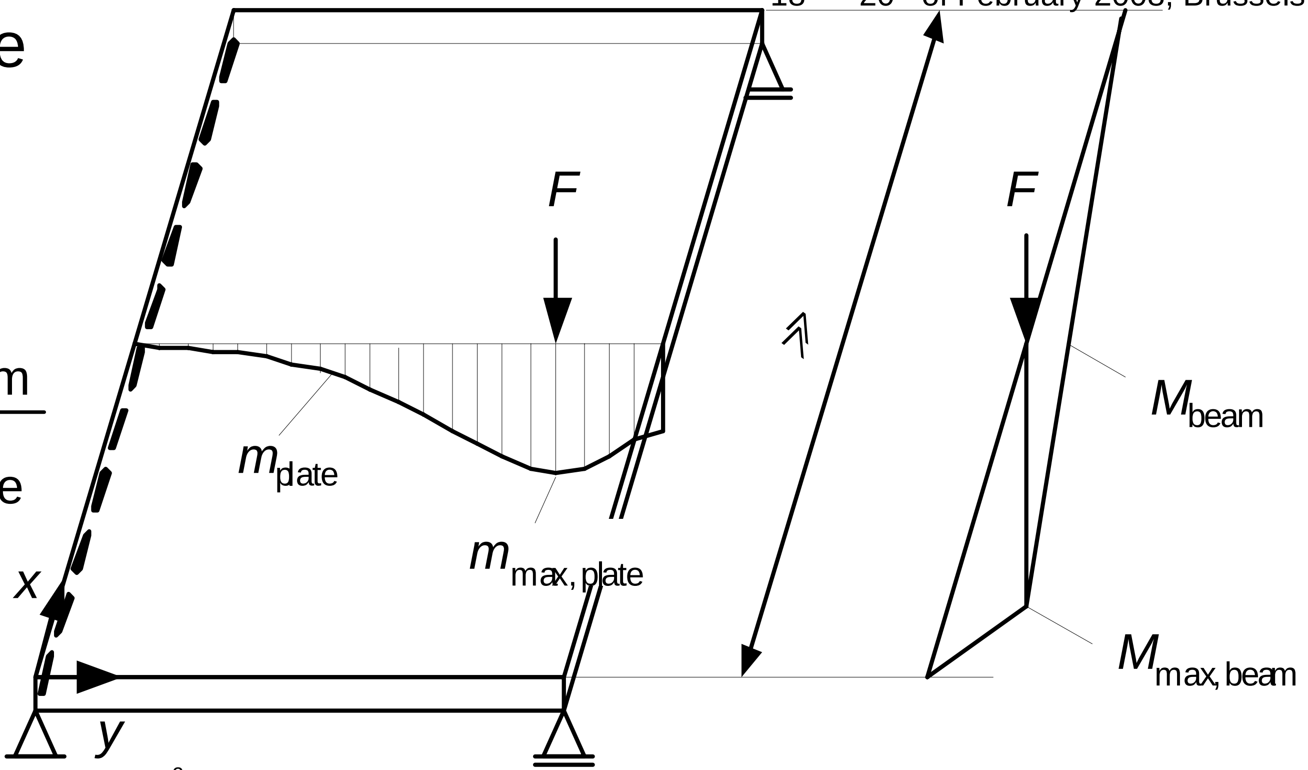
Eurocode 5-1-1, System factor

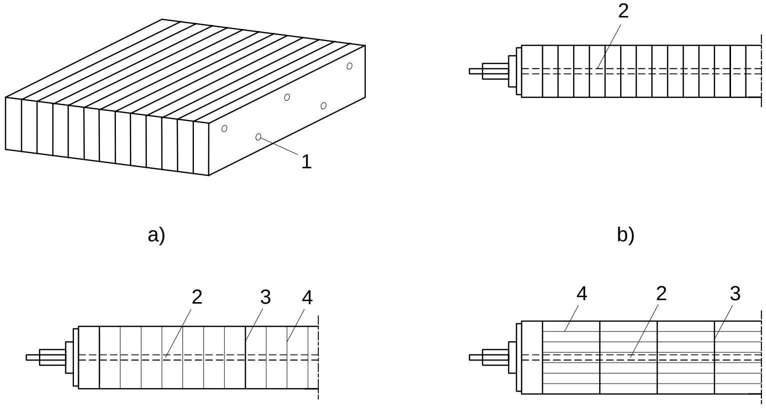


Key:
1 Nailed or screwed laminations
2 Laminations pre-stressed or glued together

Section 6 Ultimate limit states

$$b_{ef} = \frac{M_{max,beam}}{m_{max,plate}}$$





c) d)

$$n = \frac{b_{ef}}{b_{lam}}$$

Section 6 Ultimate limit states

6.1.2 Stress-laminated deck plates

$$F_{v,Ed} \leq \mu_d \cdot \sigma_{p,min} \cdot h$$

$$\sigma_{p,min} = 0{,}35 \frac{\text{N}}{\text{mm}^2}$$

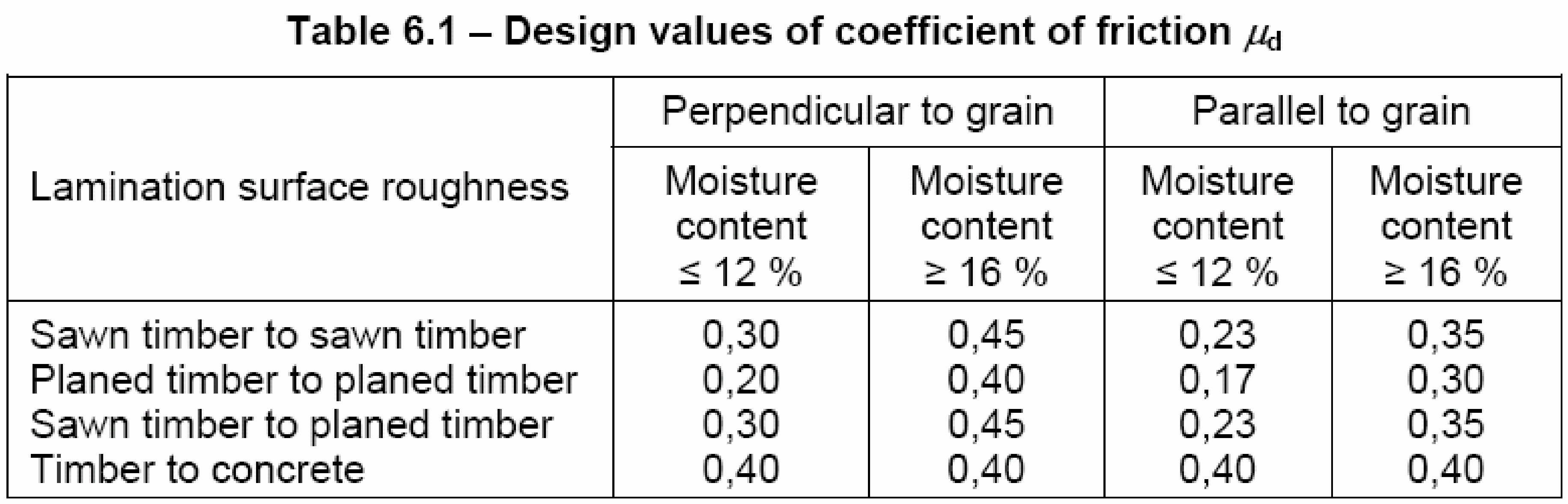
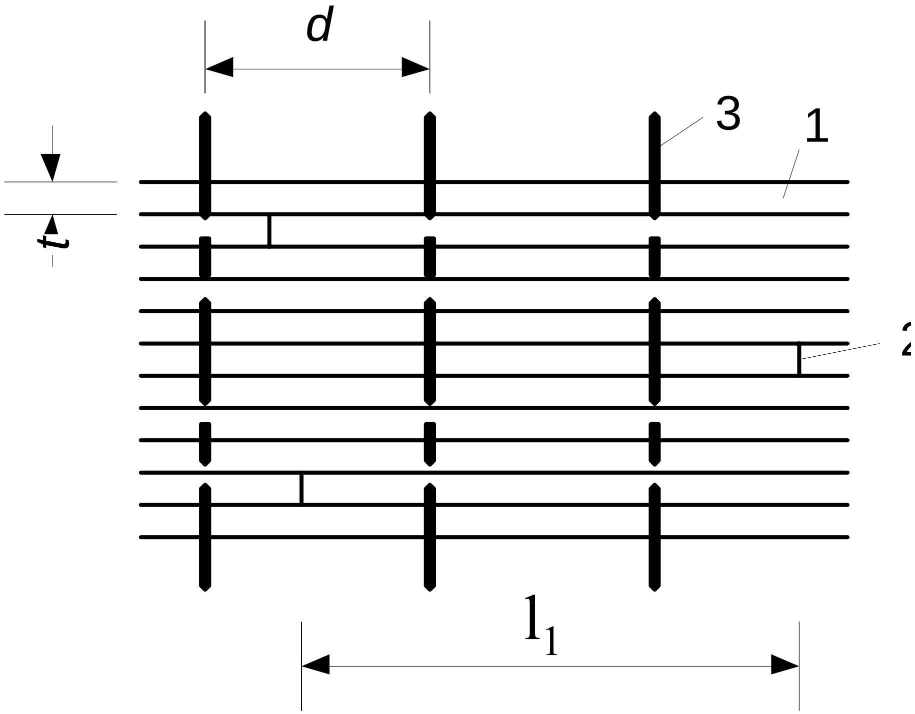


Table 6.1 – Design values of coefficient of friction μ_d

Lamination surface roughness	Perpendicular to grain		Parallel to grain	
	Moisture content ≤ 12 %	Moisture content ≥ 16 %	Moisture content ≤ 12 %	Moisture content ≥ 16 %
Sawn timber to sawn timber	0,30	0,45	0,23	0,35
Planed timber to planed timber	0,20	0,40	0,17	0,30
Sawn timber to planed timber	0,30	0,45	0,23	0,35
Timber to concrete	0,40	0,40	0,40	0,40

Section 6 Ultimate limit states



$$\ell_1 = \min\begin{Bmatrix} 2d \\ 30t \\ 1{,}2m \end{Bmatrix}$$

Joints of lamellas

1 lamella
2 joint
3 prestress element

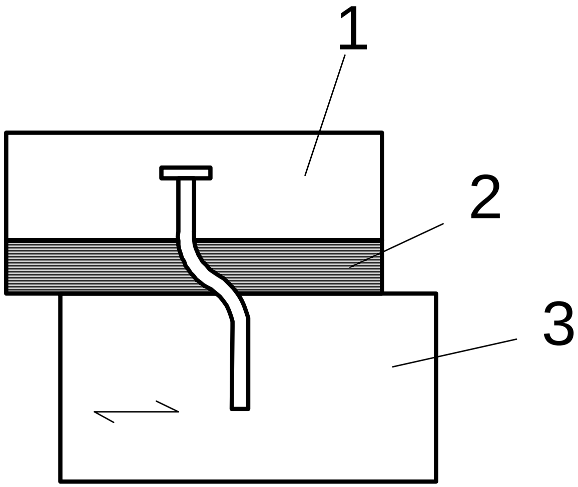
Bridge across railway, Oslo

Rectangular
prestressed deck plate

Oslo

Section 8 Connections

Not for bridges: Nails (withdrawal)
staples
Nail plates

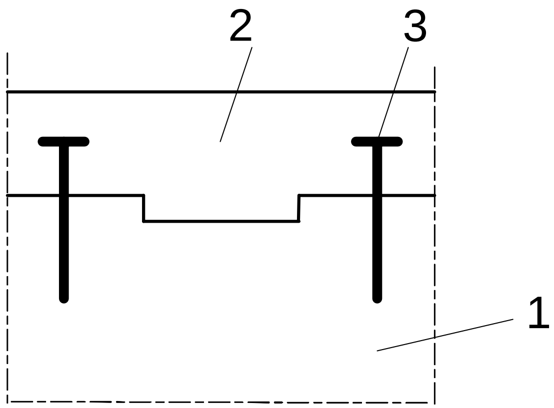


Timber-concrete composites
1 concrete
2 Additional layer
3 timber

$F_{Ed} = 0{,}1 \cdot F_{v,ED}$

Section 8 Connections

Timber – concrete - composite



$$F_{Ed} = 0{,}1 \cdot F_{V,ED}$$

Annex A (informative) Fatigue verification

(3) A fatigue verification is required if the ratio κ given by expression (A.1) is greater than:

- For members in compression perpendicular or parallel to grain: 0,6
- For members in bending or tension: 0,2
- For members in shear: 0,15
- For joints with dowels: 0,4
- For joints with nails: 0,1
- Other joints: 0,15

$$\kappa = \frac{\left|\sigma_{\mathrm{d,max}} - \sigma_{\mathrm{d,min}}\right|}{\dfrac{f_{\mathrm{k}}}{\gamma_{\mathrm{M,fat}}}} \qquad \text{(A.1)}$$

where:

$$\kappa = \frac{\left|\sigma_{\mathrm{d,max}} - \sigma_{\mathrm{d,min}}\right|}{\dfrac{f_{\mathrm{k}}}{\gamma_{\mathrm{M,fat}}}}$$

$\sigma_{\mathrm{d,max}}$	is the numerically largest design stress from the fatigue loading;
$\sigma_{\mathrm{d,min}}$	is the numerically smallest design stress from the fatigue loading;
f_{k}	is the relevant characteristic strength;
$\gamma_{\mathrm{M,fat}}$	is the material partial factor.

Annex A (informative) Fatigue verification

(1) A simplified fatigue load model is built up of reduced loads (effects of actions) compared to the static loading models. The load model should give the maximum and minimum stresses in the actual structural members.

(2) The fatigue loading from traffic should be obtained from the project specification in conjunction with EN 1991-2.

(3) The number of constant amplitude stress cycles per year, N_{obs}, should either be taken from table 4.5 of EN 1991-2 or, if more detailed information about the actual traffic is available, be taken as:

$$N_{\mathrm{obs}} = 365\, n_{\mathrm{ADT}}\, \alpha\, t_{\mathrm{L}}$$

$$N_{\mathrm{obs}} = 365 \cdot n_{\mathrm{ADT}} \cdot \alpha \cdot t_{\mathrm{L}} \qquad \text{(A.2)}$$

where:

N_{obs}	is the number of constant amplitude stress cycles per year;
n_{ADT}	is the expected annual average daily traffic over the lifetime of the structure; the value of n_{ADT} should not be taken less than 1000;
α	is the expected fraction of observed heavy lorries passing over the bridge, see EN 1991-2 clause 4.6 (e.g. $\alpha = 0{,}1$);
t_{L}	is the design service life of the structure expressed in years according to EN 1990:2002 (e.g. 100 years).

A.2 Fatigue loading

Annex A (informative) Fatigue verification

$$\sigma_{d,max} \leq f_{fat,d} = k_{fat} \cdot \frac{f_k}{\gamma_{M,fat}}$$

(4) The value of k_{fat} should be taken as:

$$k_{fat} = 1 - \frac{1-R}{a(b-R)} \log(\beta N_{obs}) \geq 0$$

(A.5)

$$k_{fat} = 1 - \frac{1-R}{a \cdot (b-R)} \cdot \log(\beta \cdot N_{OBS})$$

where:

$R = \sigma_{d,min} / \sigma_{d,max}$ with $-1 = R = 1$; (A.6)

$\sigma_{d,min}$	is the numerically smallest design stress from the fatigue loading;
$\sigma_{d,max}$	is the numerically largest design stress from the fatigue loading;
N_{obs}	is the number of constant amplitude stress cycles as defined above;
β	is a factor based on the damage consequence for the actual structural component;
a, b	are coefficients representing the type of fatigue action according to table A.1.

The factor β should be taken as:

- Substantial consequences: $\beta = 3$
- Without substantial consequences: $\beta = 1$

A.3 Fatigue verification

Annex A (informative) Fatigue verification

Table A.1 – Values of coefficients *a* and *b*

	a	*b*
Timber members in		
- compression, perpendicular or parallel to grain	2,0	9,0
- bending and tension	9,5	1,1
- shear	6,7	1,3
connections with		
- dowels with d = 12 mm [a]	6,0	2,0
- nails	6,9	1,2

[a] The values for dowels are mainly based on tests on 12 mm tight-fitting dowels. Significantly larger diameter dowels or non-fitting bolts may have less favourable fatigue properties.

$$k_{fat} = 1 - \frac{1 - R}{a \cdot (b - R)} \cdot \log(\beta \cdot N_{OBS})$$

Annex A (informative) Fatigue verification

$$\sigma_{d,\max} \leq k_{fat} \cdot \frac{f_k}{\gamma_{M,fat}}$$

$$\sigma_d \leq k_{\text{mod}} \cdot \frac{f_k}{\gamma_M}$$

Dauerfestigkeit

Dauerstandfestigkeit

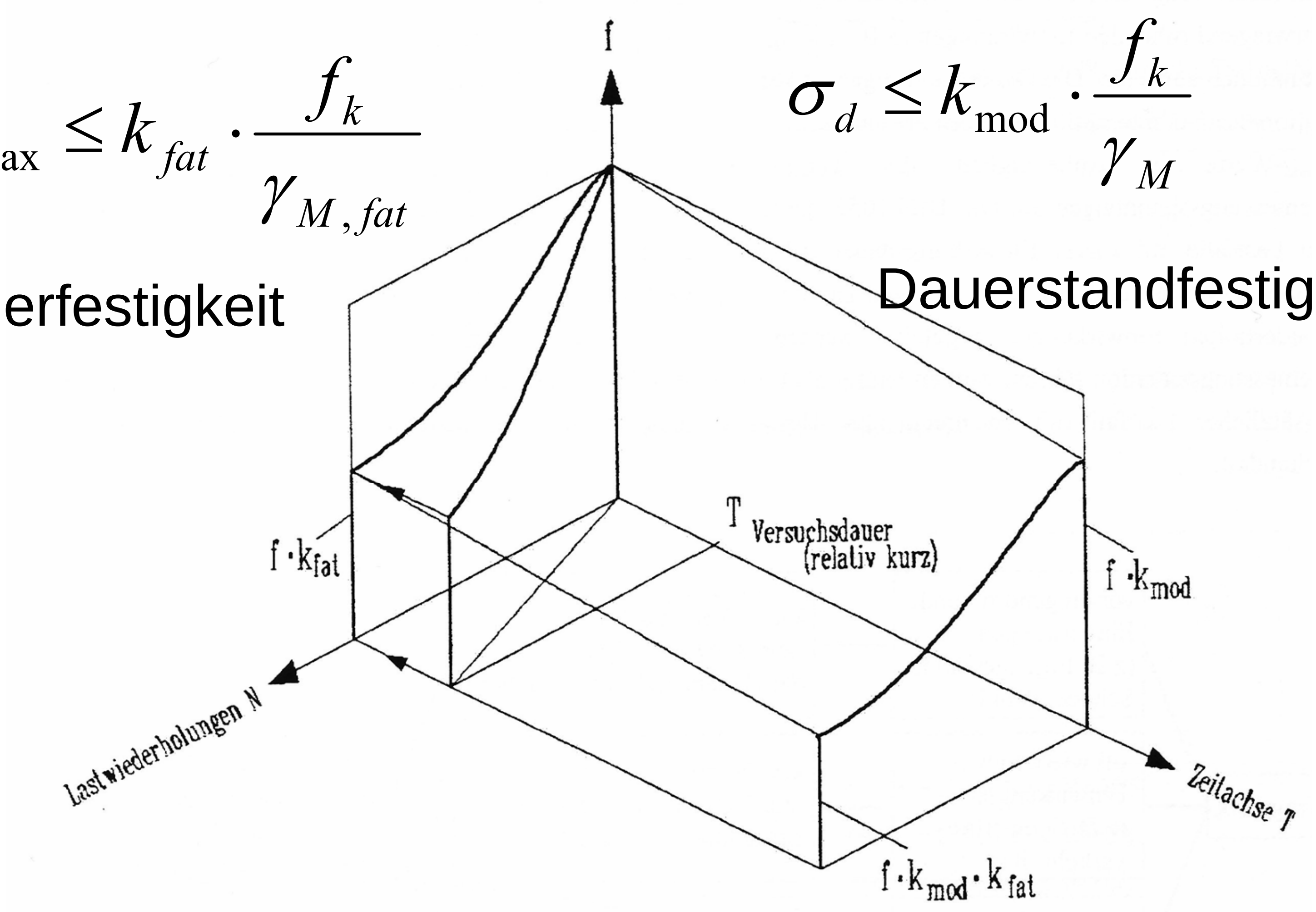


Bild 4- 2: Verknüpfung der Einflüsse aus Dauerstandfestigkeit und Dauerfestigkeit (Bild 80 aus /Kre4/)

Annex A (informative) Fatigue verification

Fatigue

Lastmodell Ermüdung, γ = 1

$$\sigma_{d,\max} \leq k_{fat} \cdot \frac{f_k}{\gamma_{M,fat}}$$

Art der Beanspruchung:
Biegung, Schub, Verbindungsmittel

Schwellen, Wechsel R

Anzahl Nobs

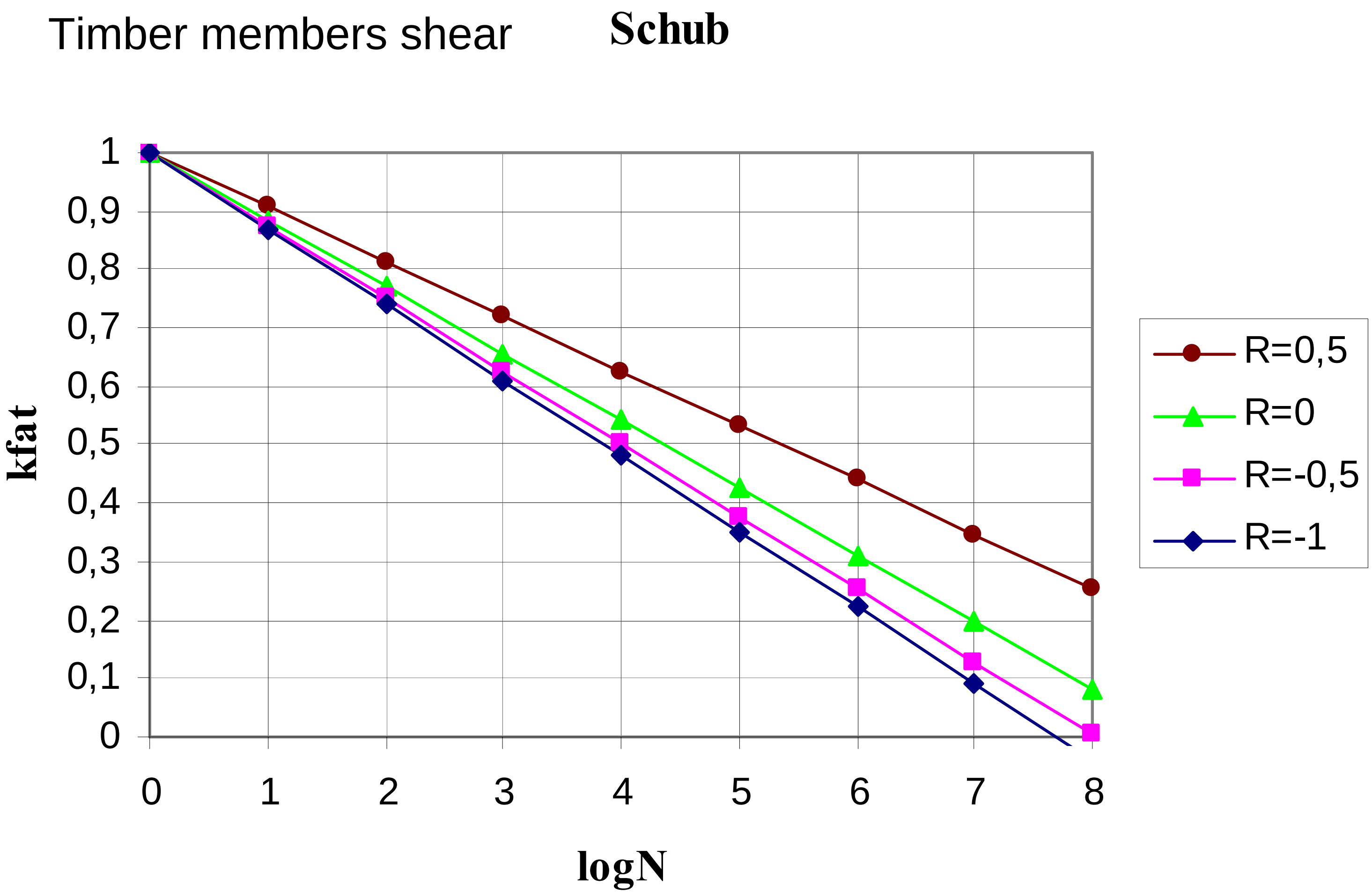
ULS

Lastmodell Tragsicherheit, γ

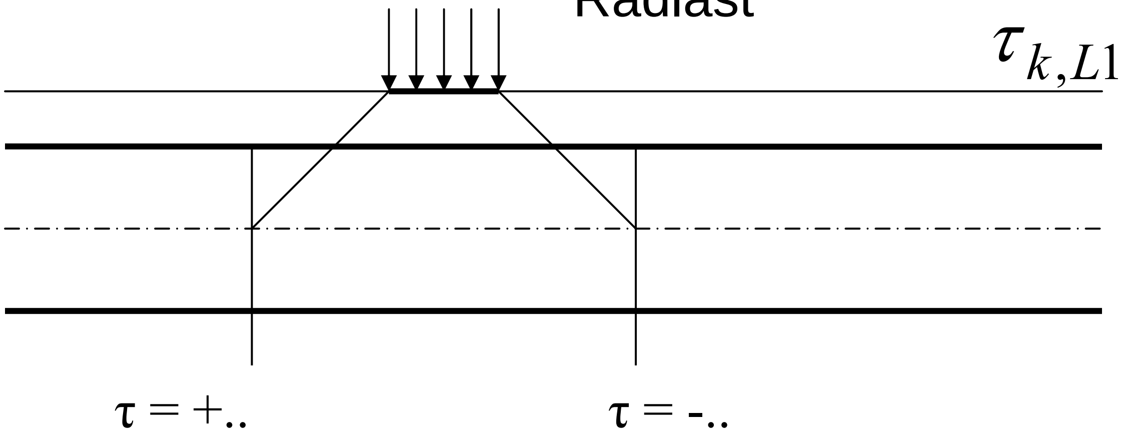
$$\sigma_d \leq k_{\mathrm{mod}} \cdot \frac{f_k}{\gamma_M}$$

Annex A (informative) Fatigue verification

Timber members shear



Annex A (informative) Fatigue verification



$$\tau_{k,L1} \cdot 1{,}5 \leq \frac{k_{\mathrm{mod}} \cdot f_{v,k}}{1{,}3}$$

$$\tau_{k,fat} = \frac{\tau_{k,L1}}{2} = \frac{f_{v,k}}{2 \cdot 2{,}17} \leq k_{fat} \cdot f_{v,k}$$

$$k_{fat} \geq \frac{1}{2 \cdot 2{,}17} = 0{,}23$$

Section 7 Serviceability limit states

Deflections

Vibrations

Section 7 Serviceability limit states

Construction part	Action	Beams, plates and trusses
Main system	Characteristic traffic load	$\ell/400$ to $\ell/500$
	Pedestrian load and Low traffic load	$\ell/200$ to $\ell/400$

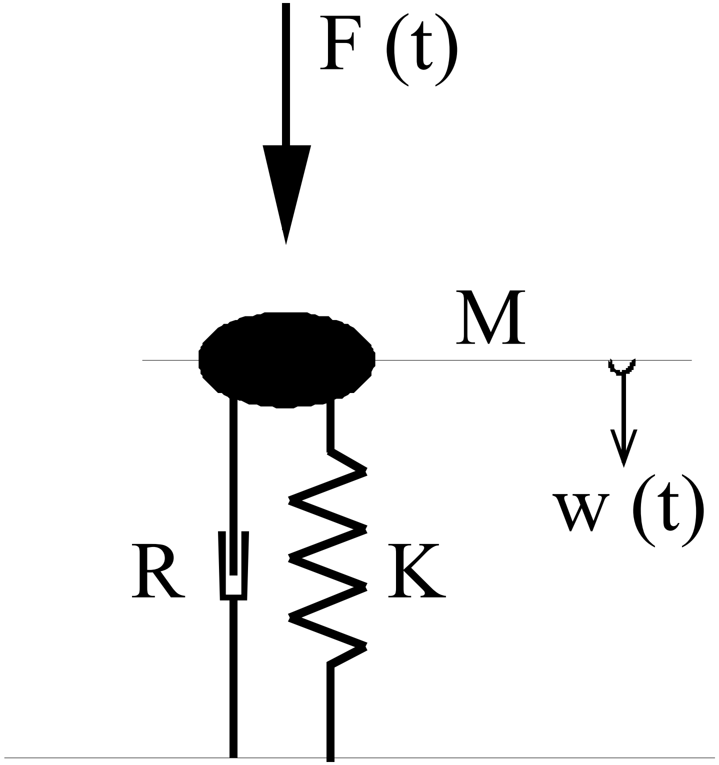
Section 7 Serviceability limit states

Conception et comportement dynamique des passerelles piétonnes

footbridge 2002

Section 7 Serviceability limit states

Deflections / Vibrations



System values
M – mass [t]
K – stiffness [kN/m]
R – attenuation [kN/(m/s)]

$$\omega = \sqrt{\frac{K}{M}} = 2\pi \cdot f$$

$$w_g = \frac{G}{K} = \frac{M \cdot g}{K} = \frac{g}{\omega^2} = \frac{g}{(2\pi \cdot f)^2}$$

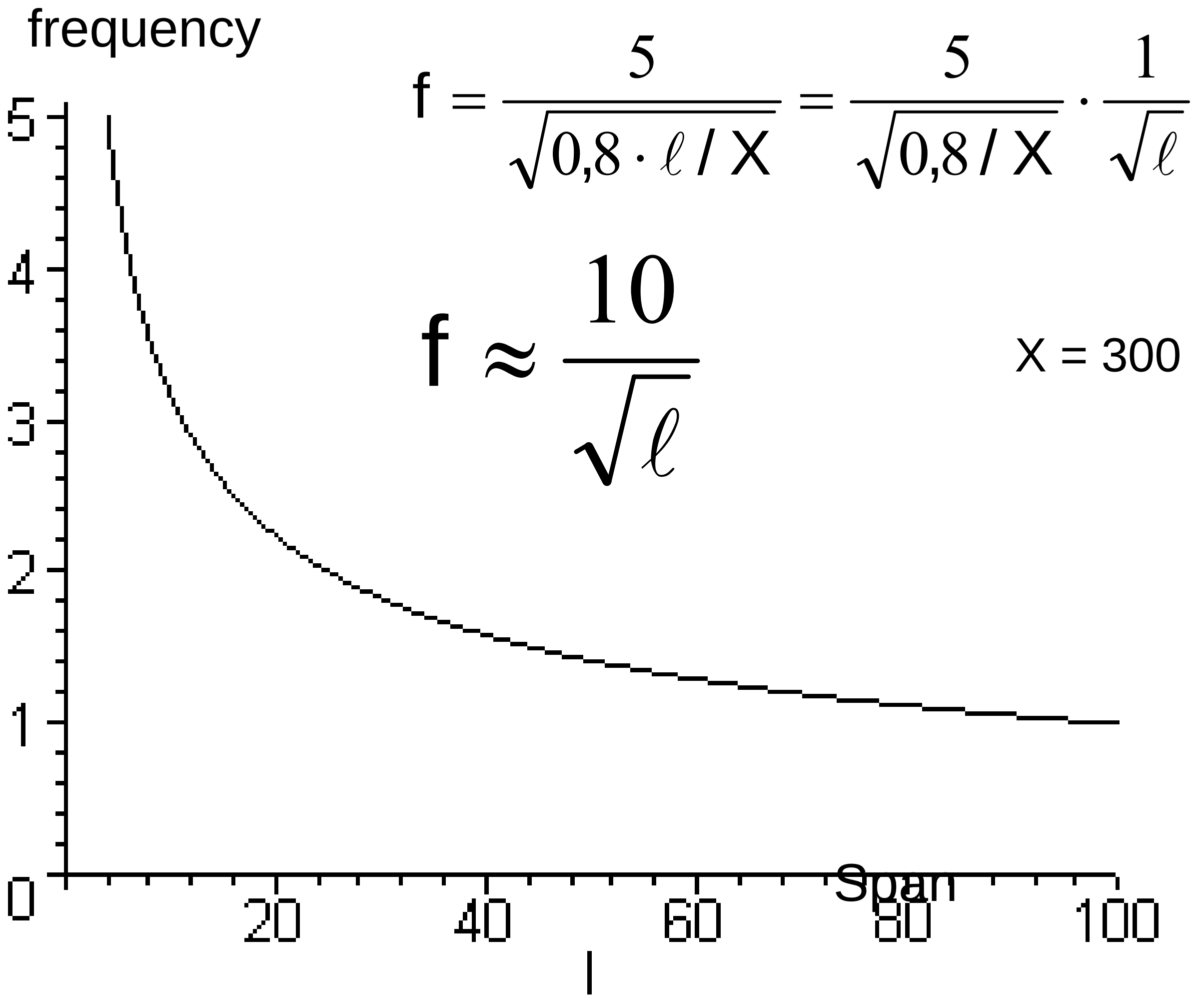
$$f = \frac{5}{\sqrt{w_g}}$$

Section 7 Serviceability limit states

$$f = \frac{5}{\sqrt{0{,}8 \cdot \ell / X}} = \frac{5}{\sqrt{0{,}8 / X}} \cdot \frac{1}{\sqrt{\ell}}$$

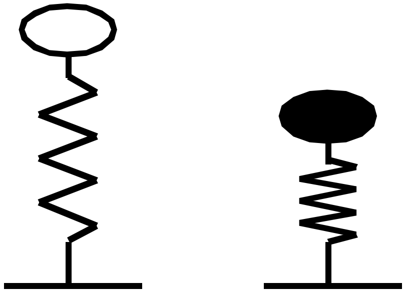
$$f \approx \frac{10}{\sqrt{\ell}}$$

X = 300



Section 7 Serviceability limit states

$$w(x,t) = w_0 \cdot \psi(x) \cdot \sin \omega t$$



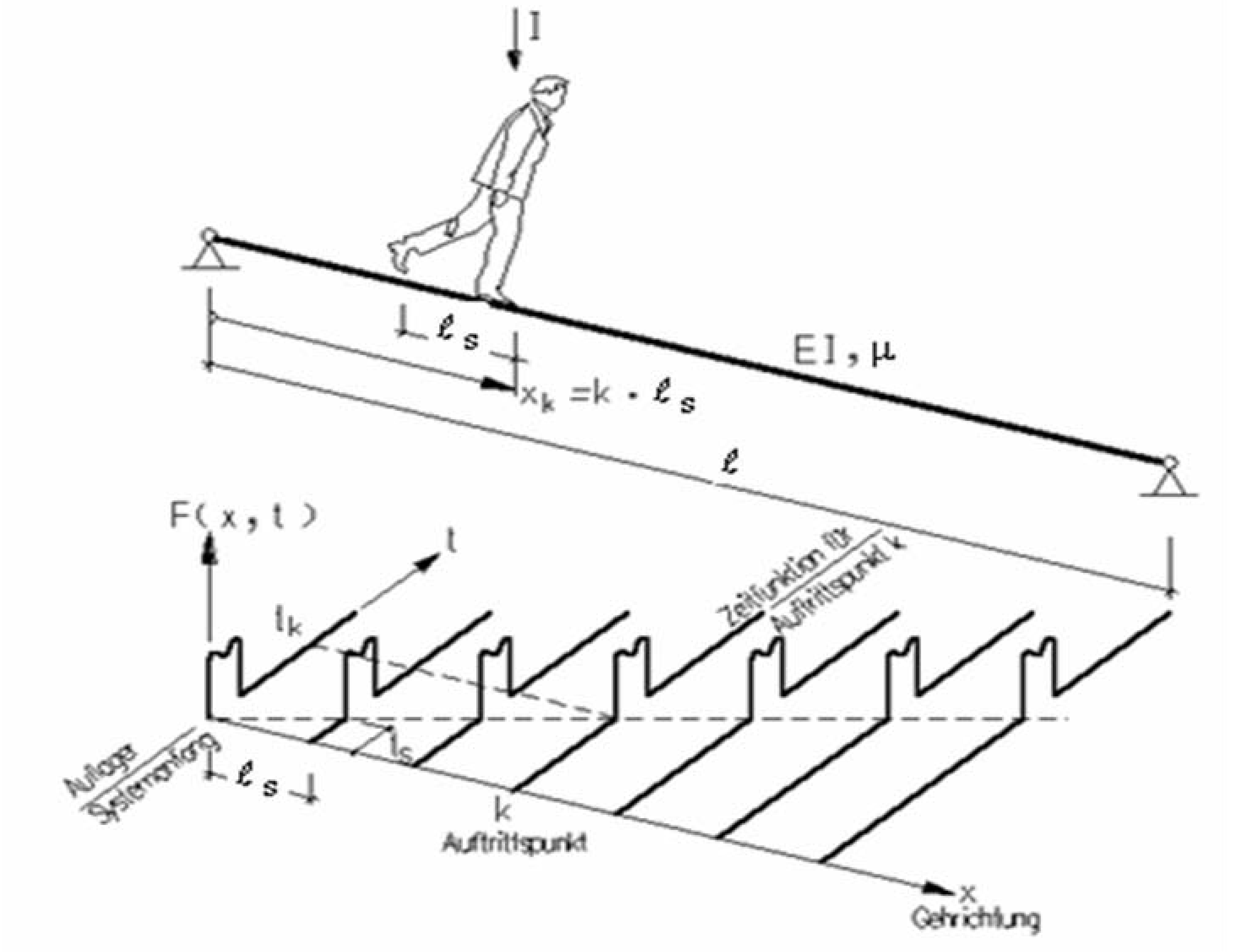
$$w(t) = w_0 \cdot \sin \omega t$$

Section 7 Serviceability limit states

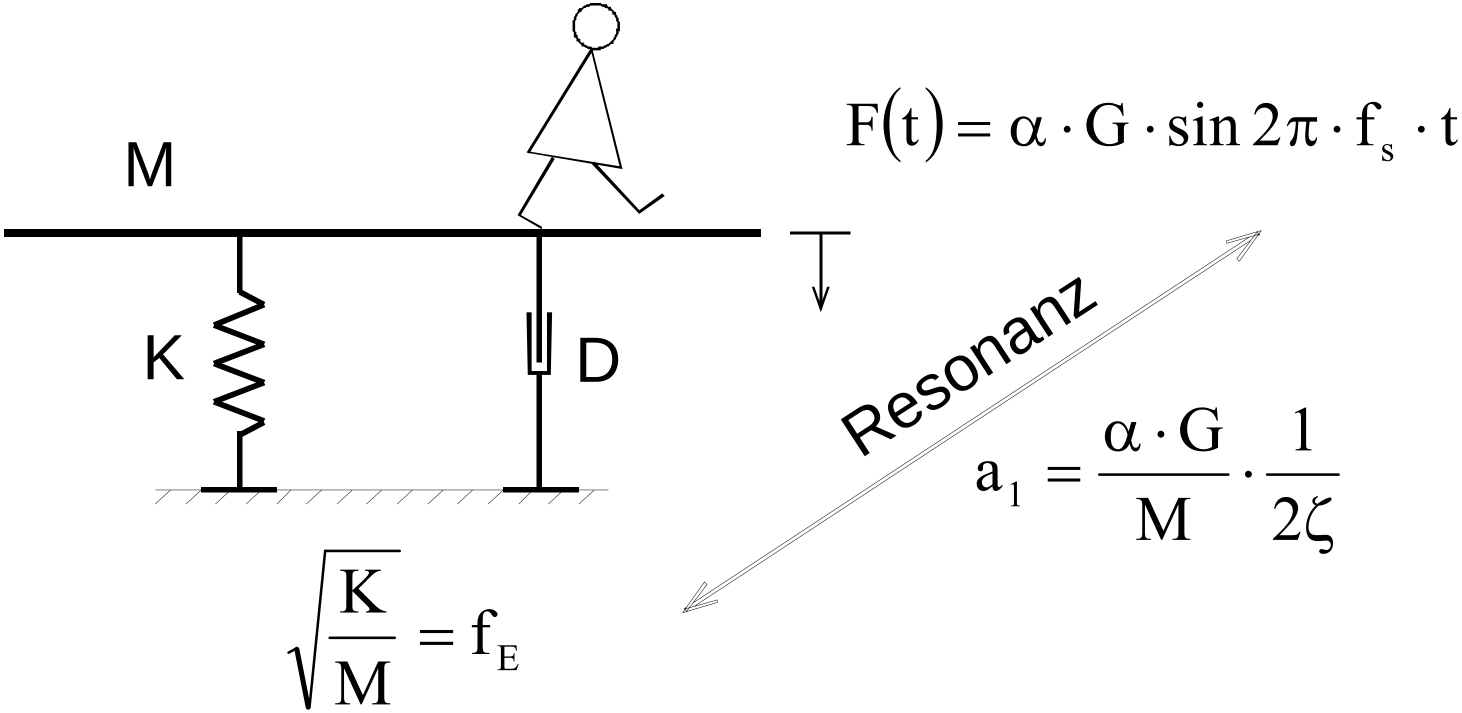
m = 1780 kg/m; l = 67,7 m; w_g = 8,8 cm

$$f = \frac{5}{\sqrt{0,8 \cdot w_g (\text{in cm})}} = \frac{5}{\sqrt{0,8 \cdot 8,8}} = 1,9\,\text{Hz}$$

Section 7 Serviceability limit states



Section 7 Serviceability limit states



$$F(t) = \alpha \cdot G \cdot \sin 2\pi \cdot f_s \cdot t$$

$$a_1 = \frac{\alpha \cdot G}{M} \cdot \frac{1}{2\zeta}$$

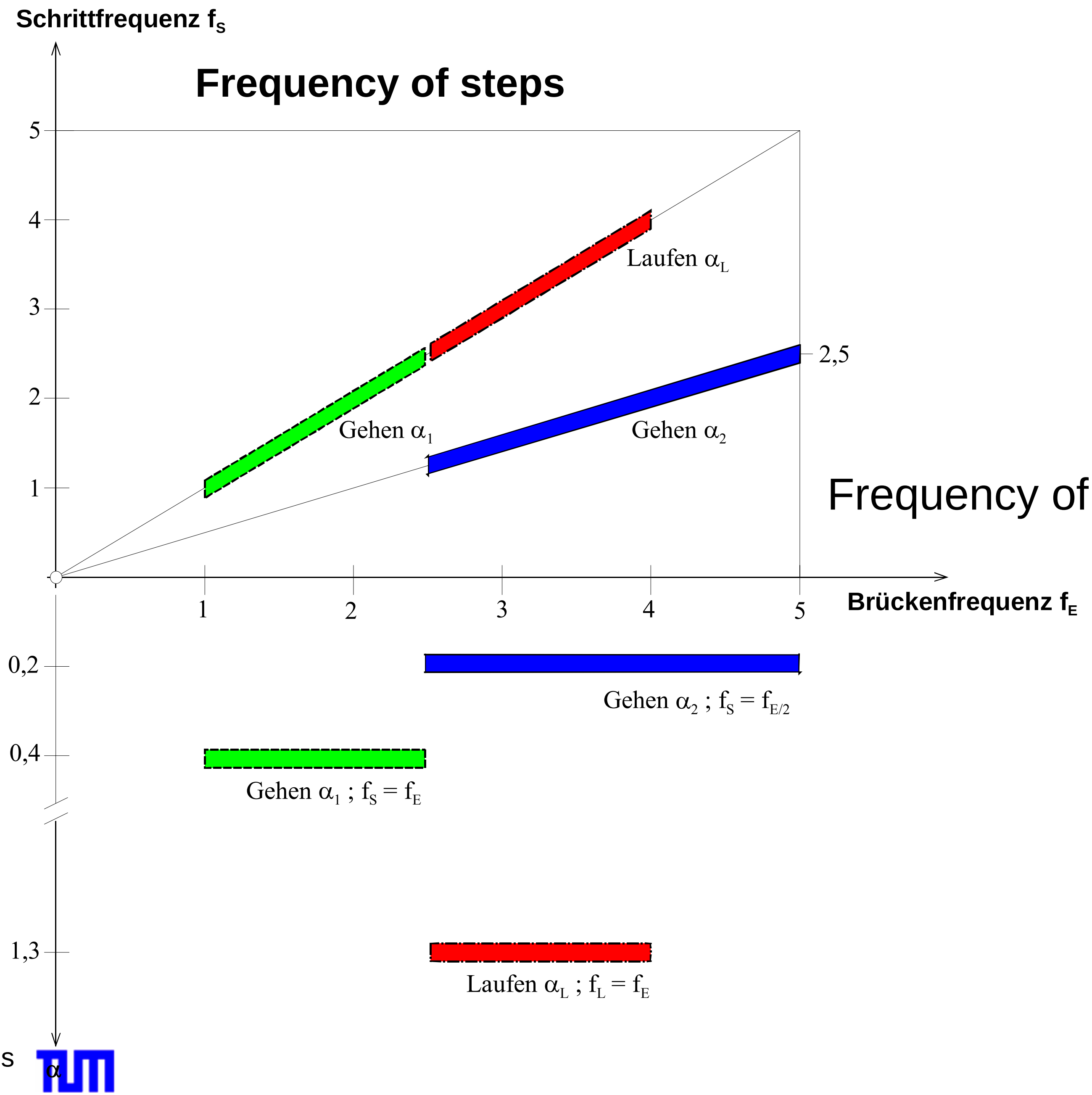
$$\sqrt{\frac{K}{M}} = f_E$$

Section 7 Serviceability limit states

1 Person

$$a_{vert,1} = \frac{\alpha \cdot G}{M} \cdot \frac{1}{2 \cdot \zeta} = \frac{200}{M_B \cdot \zeta}$$

Section 7



Frequency of steps

Frequency of bridge

Section 7 Serviceability limit states

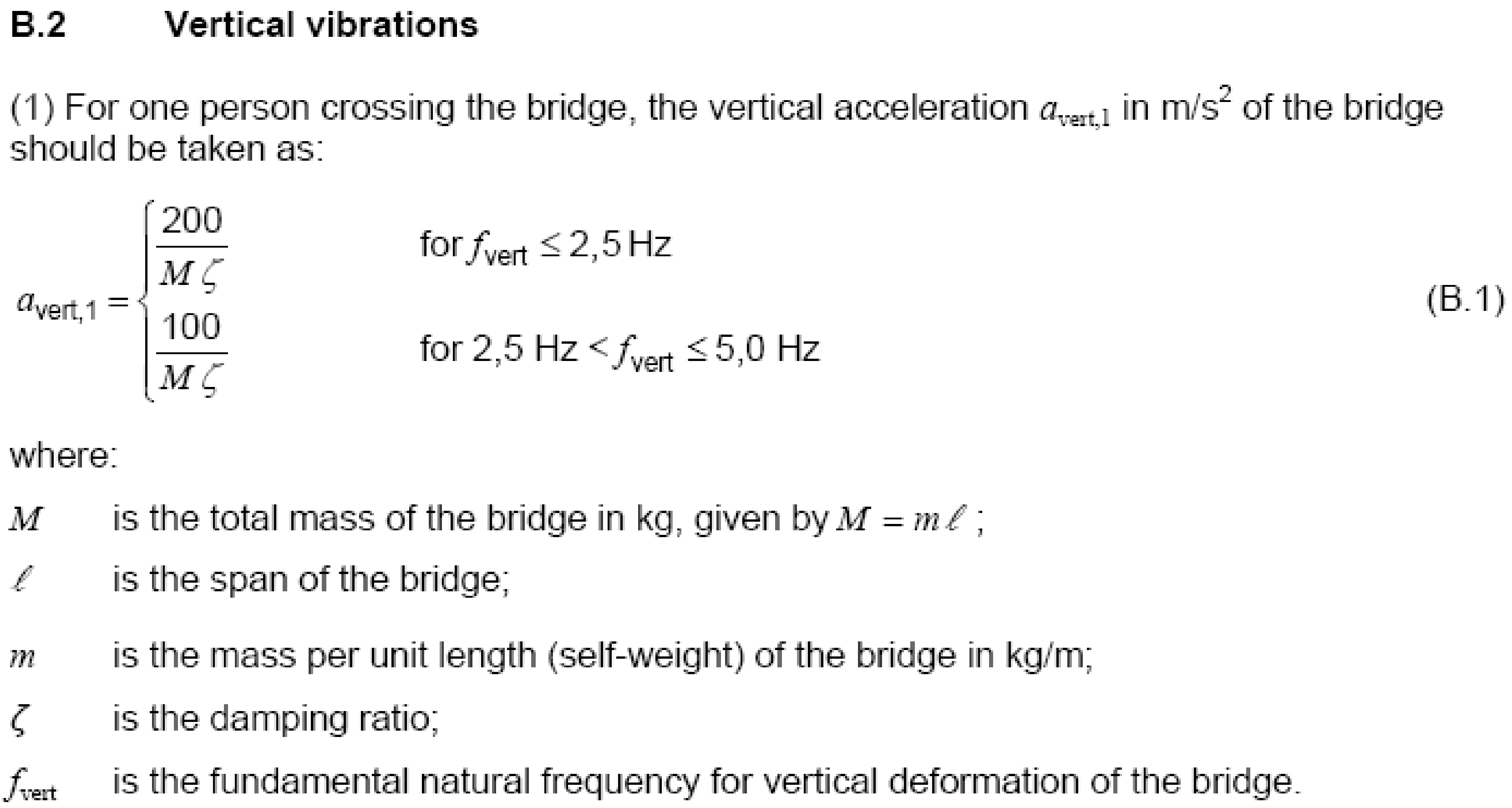
Annex B (informative) Vibrations caused by pedestrians

B.1 General

(1) The rules given in this annex apply to timber bridges with simply supported beams or truss systems excited by pedestrians.

NOTE: Corresponding rules will be found in future versions of EN 1991-2.

Section 7 Serviceability limit states



B.2 Vertical vibrations

(1) For one person crossing the bridge, the vertical acceleration $a_{\text{vert},1}$ in m/s^2 of the bridge should be taken as:

$$a_{\text{vert},1} = \begin{cases} \dfrac{200}{M\,\zeta} & \text{for } f_{\text{vert}} \le 2{,}5\ \text{Hz} \\[2ex] \dfrac{100}{M\,\zeta} & \text{for } 2{,}5\ \text{Hz} < f_{\text{vert}} \le 5{,}0\ \text{Hz} \end{cases} \tag{B.1}$$

where:

M is the total mass of the bridge in kg, given by $M = m\,\ell$;

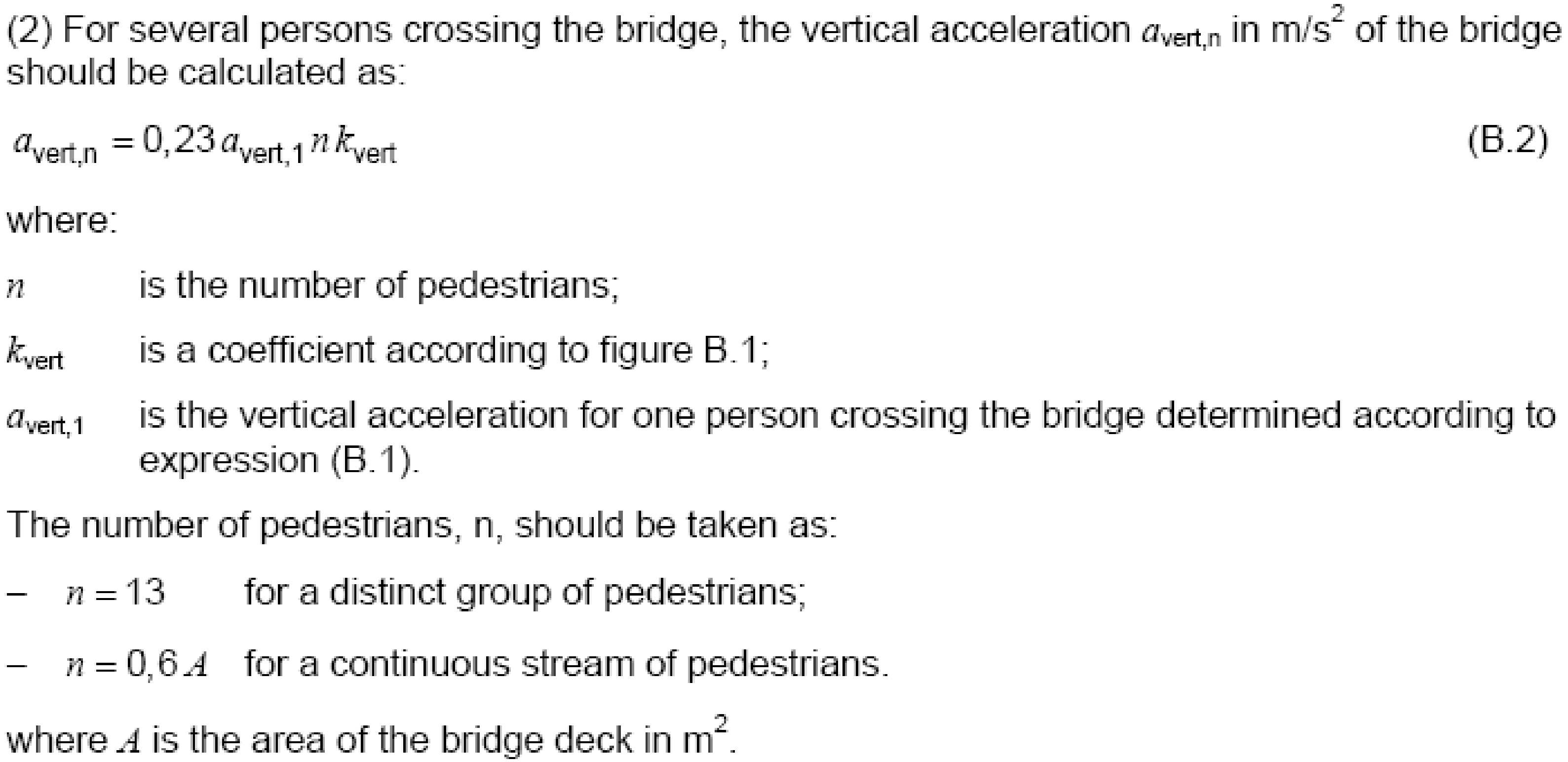
ℓ is the span of the bridge;

m is the mass per unit length (self-weight) of the bridge in kg/m;

ζ is the damping ratio;

f_{vert} is the fundamental natural frequency for vertical deformation of the bridge.

Section 7 Serviceability limit states



(2) For several persons crossing the bridge, the vertical acceleration $a_{\text{vert,n}}$ in m/s^2 of the bridge should be calculated as:

$$a_{\text{vert,n}} = 0{,}23\, a_{\text{vert,1}}\, n\, k_{\text{vert}} \tag{B.2}$$

where:

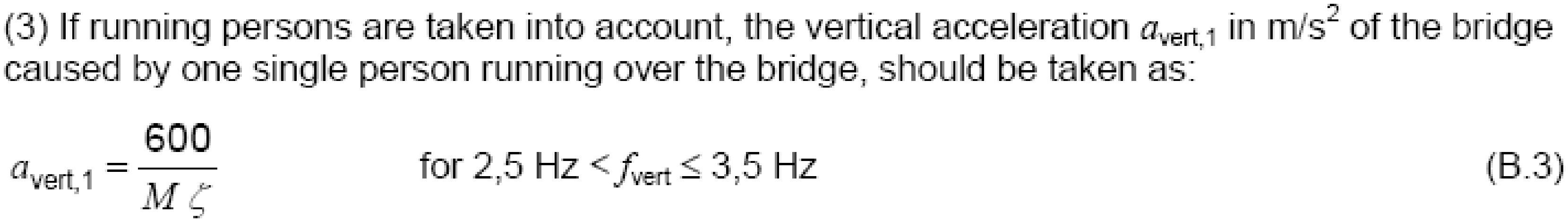
n	is the number of pedestrians;
k_{vert}	is a coefficient according to figure B.1;
$a_{\text{vert,1}}$	is the vertical acceleration for one person crossing the bridge determined according to expression (B.1).

The number of pedestrians, n, should be taken as:

- $n = 13$ for a distinct group of pedestrians;
- $n = 0{,}6\, A$ for a continuous stream of pedestrians.

where A is the area of the bridge deck in m^2.

Section 7 Serviceability limit states



(3) If running persons are taken into account, the vertical acceleration $a_{\text{vert},1}$ in m/s^2 of the bridge caused by one single person running over the bridge, should be taken as:

$$a_{\text{vert},1} = \frac{600}{M\,\zeta} \qquad \text{for } 2{,}5\ \text{Hz} < f_{\text{vert}} \leq 3{,}5\ \text{Hz} \qquad \text{(B.3)}$$

B.3 Horizontal vibrations

(1) For one person crossing the bridge the horizontal acceleration $a_{\text{hor},1}$ in m/s^2 of the bridge should be calculated as:

$$a_{\text{hor},1} = \frac{50}{M\,\zeta} \qquad \text{for } 0{,}5\ \text{Hz} \leq f_{\text{hor}} \leq 2{,}5\ \text{Hz} \qquad \text{(B.4)}$$

where f_{hor} is the fundamental natural frequency for horizontal deformation of the bridge.

(2) For several persons crossing the bridge, the horizontal acceleration $a_{\text{hor,n}}$ in m/s^2 of the bridge should be calculated as:

$$a_{\text{hor,n}} = 0{,}18\, a_{\text{hor},1}\, n\, k_{\text{hor}} \qquad \text{(B.5)}$$

where:

k_{hor} is a coefficient according to figure B.2.

The number of pedestrians, n, should be taken as:

- $n = 13$ for a distinct group of pedestrians;
- $n = 0{,}6\,A$ for a continuous stream of pedestrians,

where A is the area of the bridge deck in m^2.

M = 120.000 kg

Damping: D=0,01

$a<0{,}7\ \mathrm{m/s^2}$

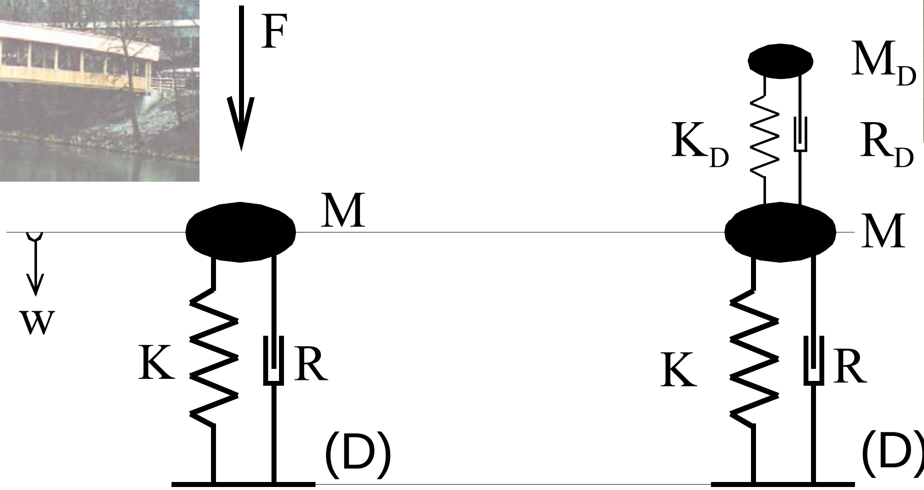
$$a_{\mathrm{vert},1}=\frac{200}{120000\cdot 0{,}01}=0{,}17\ \frac{\mathrm{m}}{\mathrm{s}^2}$$

$$a_{\mathrm{vert},13}=0{,}23\cdot 0{,}17\cdot 13=0{,}51\ \frac{\mathrm{m}}{\mathrm{s}^2}$$

$$a_{\mathrm{vert,voll}}=0{,}23\cdot 0{,}17\cdot 1\cdot b\cdot 0{,}6$$

$$=0{,}23\cdot 0{,}17\cdot 67{,}7\cdot 3{,}24\cdot 0{,}6=5{,}14\ \frac{\mathrm{m}}{\mathrm{s}^2}$$

Section 7 Serviceability limit states



$$F = F_0 \cdot \sin\ \Omega t$$

$$M = 60\ t$$

$$R = 16{,}7\ \frac{kN}{m/s}$$

$$D = 0{,}01$$

$$K = 12530\ kN/m$$

M_D = 3,4 t

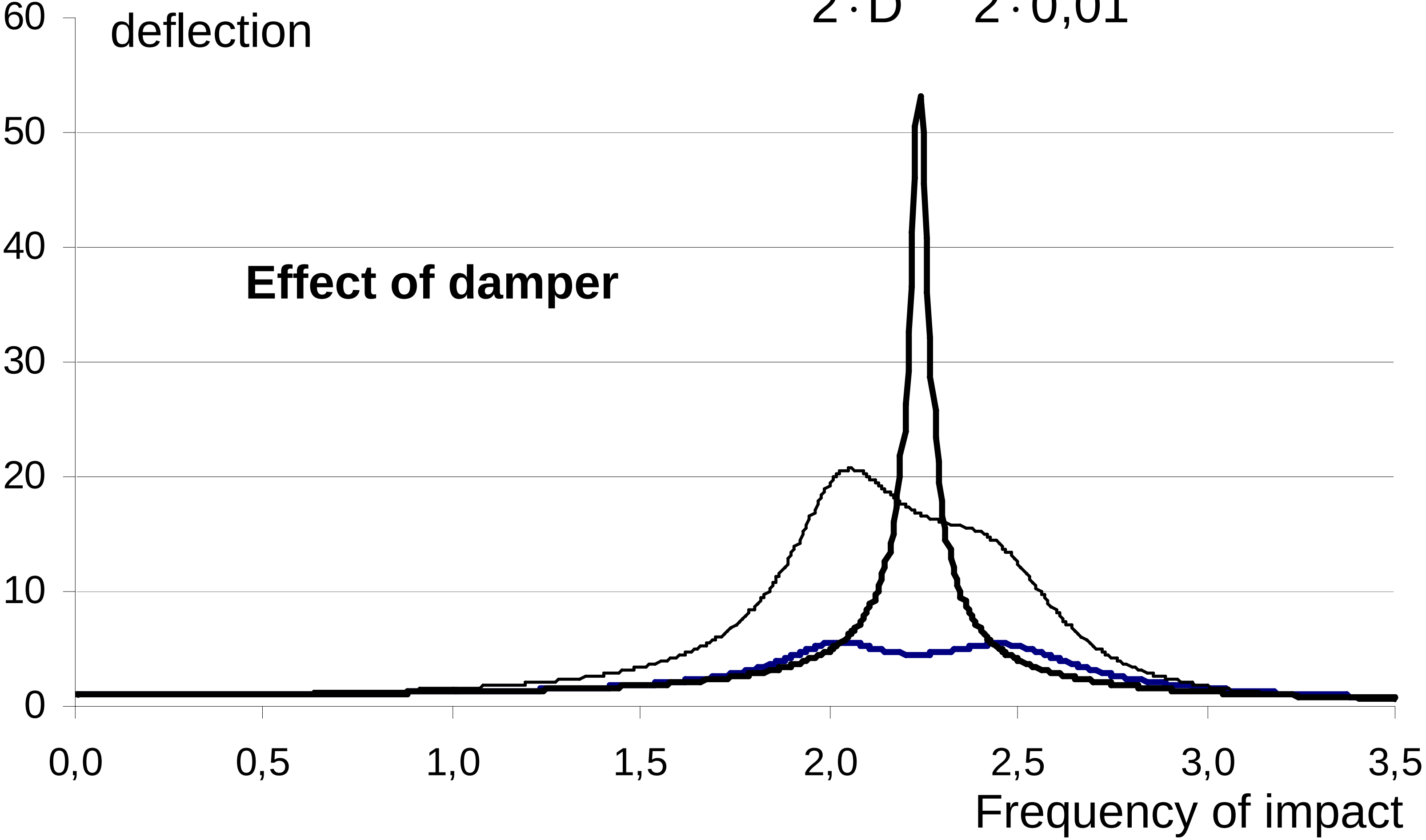
R = 12,5

D = 0,13

K = 636

Section 7 Serviceability limit states

$$\frac{1}{2 \cdot D} = \frac{1}{2 \cdot 0{,}01} = 50$$



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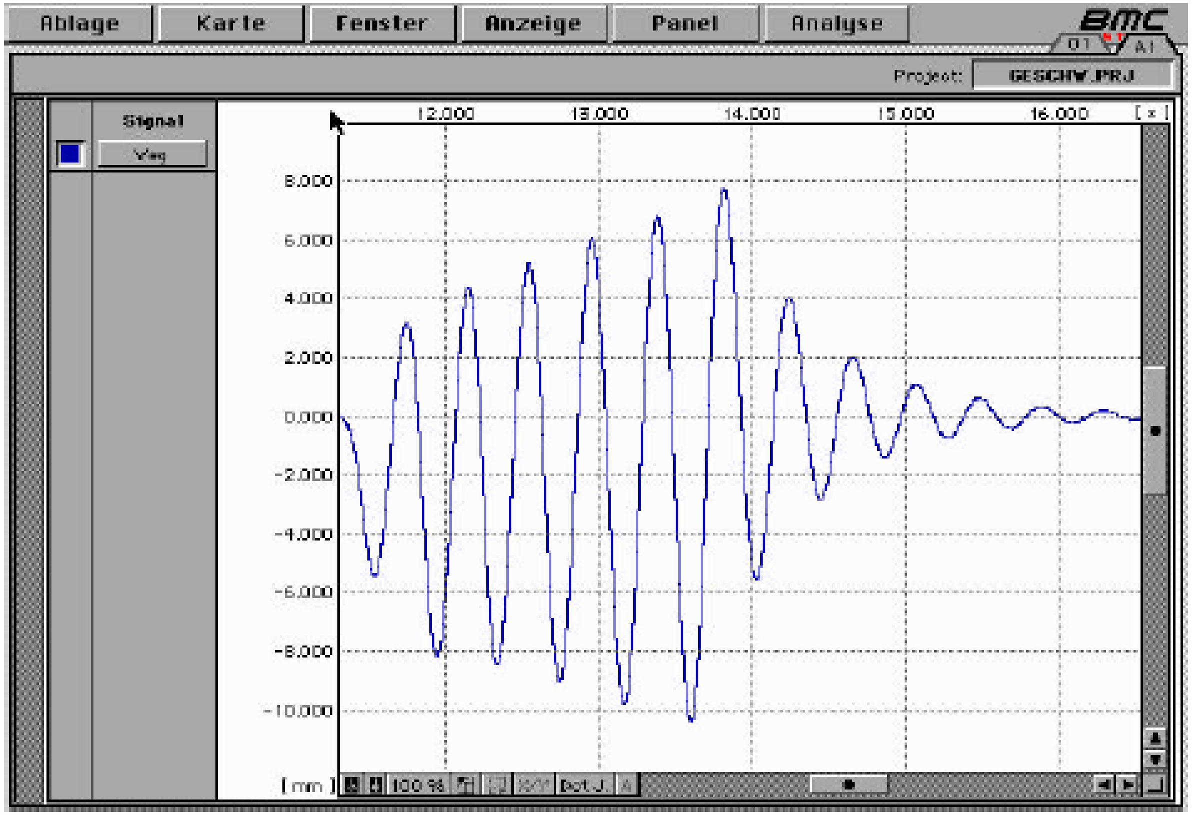
Dämpferprotokoll, Gerb



Section 7 Serviceability limit states

Connection:

$$F_D = G_D \cdot \left(1 \pm \frac{a}{g} \cdot \frac{1}{2D_D} \sqrt{1 + (2D_D)^2} \right)$$

The calculation:

$G_D = M_D \times g = 3{,}2$ t x 9,81 m/s² = 32 kN
$a = 0{,}7$ m/s² limit of acceleration of the bridge movement
$D_D = 0{,}1$ value of damping

$$F_D = 34 \cdot \left(1 \pm \frac{0{,}7}{9{,}81} \cdot \frac{1}{2 \cdot 0{,}1} \sqrt{1 + (2 \cdot 0{,}1)^2} \right) = 34 \cdot (1 \pm 0{,}07 \cdot 4{,}81) = 34 \cdot (1 \pm 0{,}34)\,\text{kN}$$

Section 7 Serviceability limit states

Bridge: 120 t   Damper: 3,2 t

Section 7 Serviceability limit states

Pedestrian bridge: $f < 5$ Hz

Design of damper! **$M_D = 0{,}05\ M_{bridge,\ vibrating}$**

Design the place for the damper!
Fixing: $\approx 2 \times G_D$

Use Bridge

Measure

Observe

Decide

Section 7 Serviceability limit states

Bridge in Karlsfeld near Munich

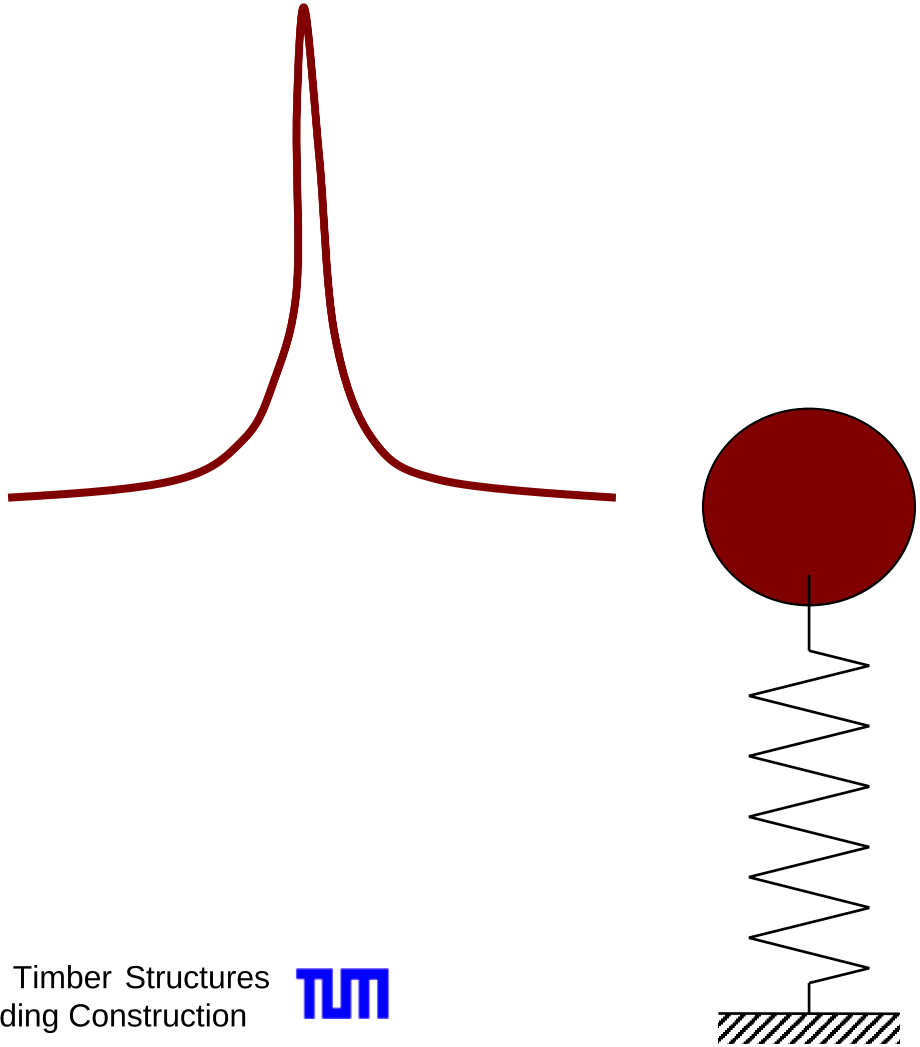
Damper was designed

Horizontal vibrations!

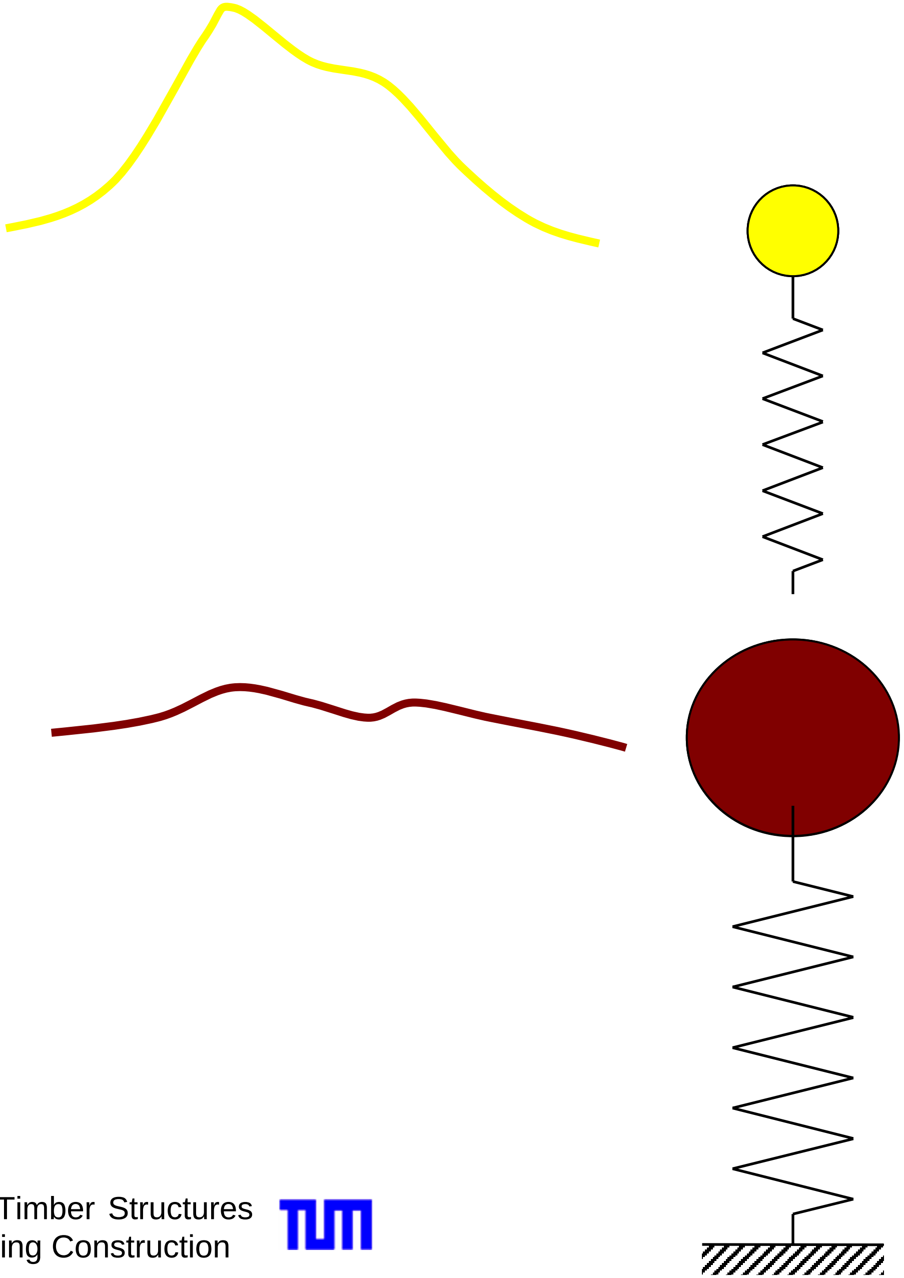
6 M-1 PANORAMA Samstag/Sonntag, 23./24. Febr

91 Stoßdämpfer für Londons Wackelbrücke

Milleniums bridge - London



Einmassenschwinger



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Section 7 Serviceability limit states

Thank you very much
for your attention!

Vielen Dank für‘s Zuhören !