STRUCTURAL POCKET GUIDE

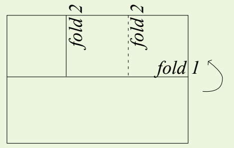
This document is intended as a concise tool for students to assess the impact of choices on the structure in their design.

Various basic cases are mentioned; for other cases, reference is made to literature.

The document is written in the **context of Belgian construction**: in particular the chapters with a red background are dependent on the national context, but it also explains why seismic loads are not addressed here.

Additional references and explanations - see **Devriese T. 2025 "Structural pocket guide for architecture students."**

Knowledge databases such as Buildwise and standards - on mynbn.be - are accessible via the Ghent University library.



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Approach to structural design

1. Conceptualize the structure and load transfers in the design. The structure ensures that all loads - both vertical (due to e.g. gravity) and horizontal (due to e.g. wind) - are transferred to the foundation. The structure is divided into elements, causing the loads to 'descend' according to the principles:
   - action = reaction
   - the whole, and each element is in equilibrium.
2. Estimate the loads. (see 3)
3. Quantify the load transfers. (see 4)
4. Determine the occurring normal forces/shear forces/moments/reactions due to the heaviest combination (see 6), making use of load combinations (see 5)
   Grosso modo:
   - strength (stress): ULS
   - deflection: SLS
5. Determine the stress/deflection occurring in the element you want to design/verify. (see 7/8)
6. Determine whether these are smaller than the allowable stress (see 11) / maximum deflection (see 9) of the structural element chosen. - see 12 for columns.

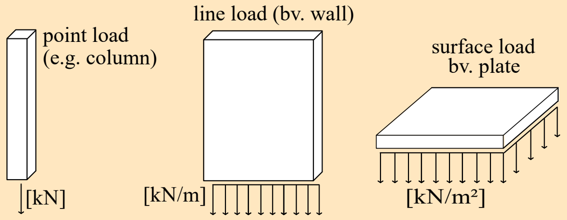
Further reading

> Basic tables

- Elaborate sets of **rules of thumb**:
  *> Table 14.1-18 pD2/281, ff. in Van Herwijnen. 2010. **Polytechnisch zakboek**. 52th ed.*
  *> 2.2.3 p77, ff. in Evans. 2014. **Structural Engineering for Architects**.*
- **Standard sizes wood products** *houtinfobois.be*
- List of **standard steel profiles** *> pC2/1, ff. Van Herwijnen. 2010. Polytechnisch zakboek. 52th ed.*
- **Buckling tables** : see section 'columns'

> Pocket guides

- van Herwijnen, e.a. 2010. **Polytechnisch zakboek**. 52th ed.
- Cobb, Fiona. 2004/2015. **Structural engineer's pocket book** (: Eurocodes). *context of United Kingdom.*
- Iano, Joseph, and Edward Allen. 2022. **The architect's studio companion : rules of thumb for preliminary design.** *Elaborate set of rules of thumb, including a chapter on structural elements.*
- McMullin, Paul, and Jonathan Price. 2016-2019. **Architect's Guidebooks to structures.**



1kN	= ~100kg	
1 N/mm	= 1 kN/m	
1 N/mm²	= 10^3 kN/m²	= 1 MPa
1 Nmm	= 10^{-6} kNm	

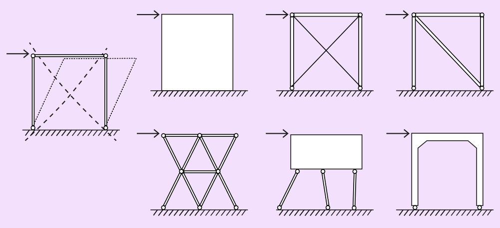
1 RULES OF THUMB

Type of member		Approximate ratio l/d
beam (overspanning (l), hoogte (d))	Lightly loaded	l/d=20
	Heavily loaded	l/d=18
slab	Simply supported	l/d=30
cantilever	Fixed at one end	l/d=7
truss	Simply supported	l/d=14
portal frame		l/d=40

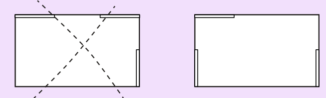
Table based on Gauld, B. 1995. Structures for architects. p.10 - see introduction ⟵ for a list of sources with more elaborate tables.

2 GLOBAL STABILITY

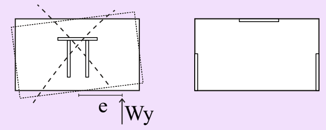
Horizontal stability is secured by bracing it, with the help of walls / vertical elements.



Minimal three, axes do not go through one point .



By preference, the elements are positioned symmetrically,with the largest possible distance.



3 LOADS

These values are 'characteristic' values

Rule of thumb **total weight of building** per floor incl. mobile loads, façades,... (estimations for columns/ foundations)
heavy 12 kN/m²
light 10 kN/m²

density (volumetric weight) (density.thickness = surface load)		[kN/m³]
steel		78,5
concrete	reinforced	25
tiles	ceramic	25
glass		25
sand	dry / wet	16 / 20
masonry	brick	18
chape		19
water		10
wood	softwood (pine)	5,5
	OSB, multiplex	7
	CLT	4,4

Permanent loads P

Permanent loads P		[kN/m²]
green roof	extensive	2,0
	intensive	5,5
solar panels incl. ballast		0,3
tiled roof (beams 8x23 cm, c.t.c.1,4 m, insulation 300 mm, roof boarding 18 mm & ceramic roof tiles)		0,8
light walls < 2kN/m per length of wall		0,8
< 3kN/m per length of wall		1,2

Mobile loads Q

Mobile loads Q	[kN/m²]
Areas for domestic and residential activities : floors	2
stairs	3
Balconies	4 (min.)
Offices areas (public areas not susceptible to crowding)	3
Public areas where people can congregate	
• Areas with tables (eetzalen, cafés, leeszalen,...)	3
• Areas with fixed seats (theaters, lecture halls, waiting rooms,...)	4
• Areas without obstacles for moving people (areas in museums, corridors in public buildings sports halls, concert halls, ...)	5
Areas for archive, storage and industrial usage	
• Areas susceptible to accumulation of goods , including access areas (such as archives)	7,5
• Industrial usage	5
Garages and vehicle traffic areas	
• Traffic and parking areas for light vehicles (≤ 30kN) such as garages, parking halls	2,5
• Traffic and parking areas for medium vehicles (30kN ≤ 160kN) such as access routes, delivery zones, zones accessible to fire engines.	5
Roofs: not accessible except for normal maintenance and repair. *This value is a rule of thumb and includes snow and wind pressures*	1
Wind (*Rule of thumb!*) *Online tool for precise wind loads: eurocodeapplied.com or 'WInt' via Buildwise*	1

Based on Eurocode NBN EN 1991-1-1 & ANB - chapter 6.3

> reference works

- Sandaker, Bjørn Normann, e.a. 2019. **The structural basis of architecture.** Third edition.
- Muttoni, Aurelio. 2011. **The art of structures.**
- Arends, Jan, e.a. 2022. **Vademecum voor draagconstructies van gebouwen**. Chair of Structural Design and Mechanics, TUDelft
- Kdodadadi, Anahita. 2022. **Basic Concepts of Structural Design for Architecture Students.** Portland State University.
- Evans, Peter, et.al. 2014. **Structural Engineering for Architects.**
- Möller, Eberhard, e.a. 2022. **Manual of structural design.**
- Hunt, Tony. 2003. **Tony Hunt's Structures Notebook.**
- Lin, T. Y., and Sidney D. Stotesbury. 1981. **Structural concepts and systems for architects and engineers.**

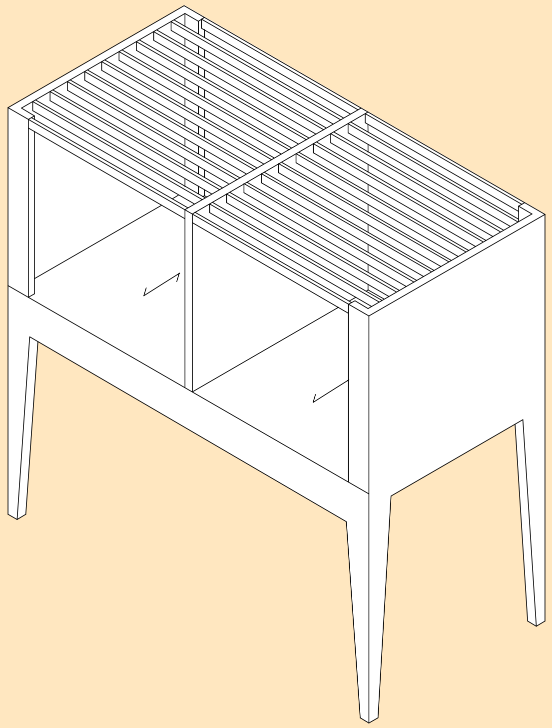
> basic principles

- Hunt, Tony. 2003. **Tony Hunt's Structures Notebook.**
- Lin, T. Y., en Sidney D. Stotesbury. 1981. **Structural concepts and systems for architects and engineers.**
- Provost, Michel, Philippe De Kemmeter, en David Attas. 2011. **Comment tout ça tient?** Voyage au pays des structures.
- Salvadori, Mario, Robert Heller, en Deborah Oakley. 2016. **Salvadori's Structure in Architecture.**

4 LOAD PATHS

- All loads (vertical & horizontal) are deviated to the foundations.
- Through load paths, you determine the loads on each element.

Example: Vertical load path



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*Digital version & updates **bit.ly/structuralpocketguide** or QR-code*
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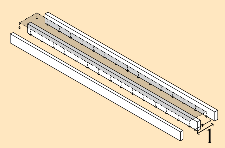
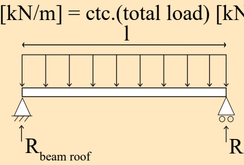
Loads and scheme of beam in roof

Permanent loads on roof are for example finishing, solar panels and self-weight.
Variable loads on roof are for example snow, wind pressure, maintenance.



width of load on beam=2.½ ctc
ctc = center to center distance of beams

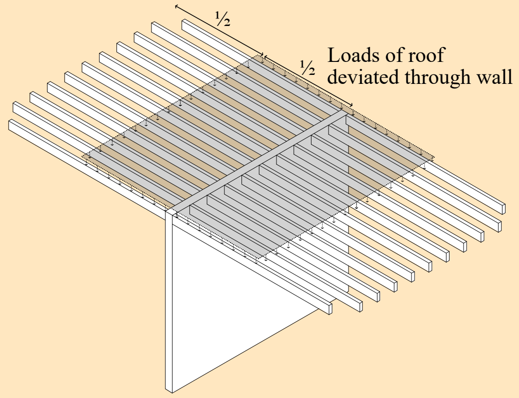
load [kN/m] = ctc.(total load) [kN/m²]

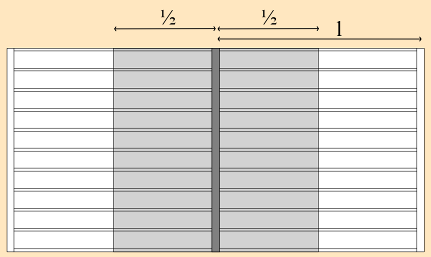


= ½ (loads on beam from roof)

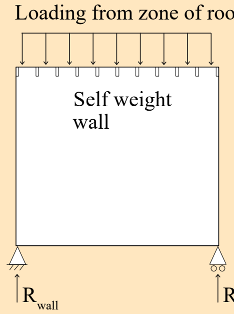
(total load) is the design value of the sum of the self weight, the permanent loading and the variable loading.

Loads and scheme of intermediate wall





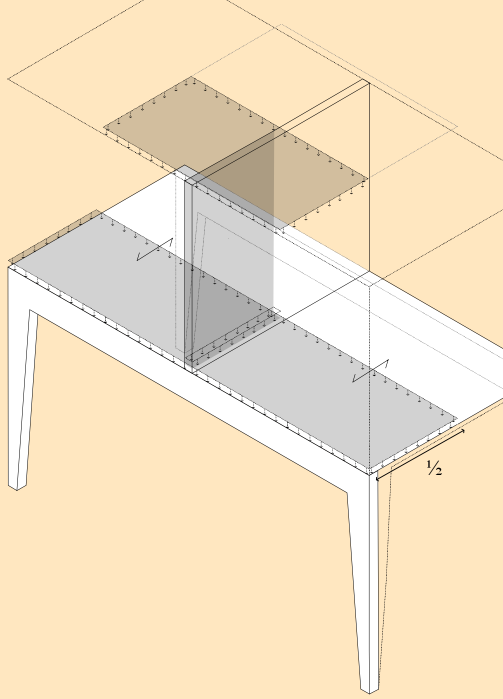
Loading from zone of roof on wall

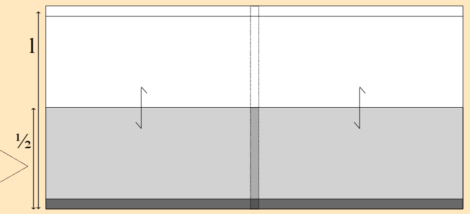


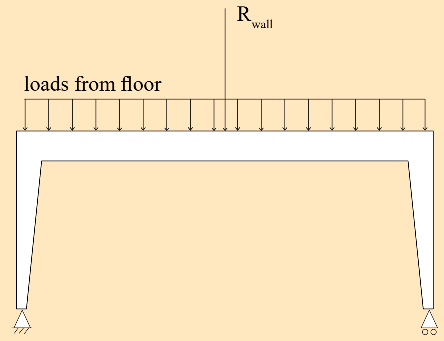
R_{wall}= ½ (loading from zone of roof + self weight wall)

Loads and scheme of portico

Permanent loads on floor are for example finishing and self-weight.
Variable loads on floor are for example imposed mobile loads.







5 COMBINATIONS

Design values loading

(general, unfavourable effect)

$G_d = \gamma_G . G_k$
$Q_d = \gamma_Q . Q_k$

	G	Q
ULS*	γG=1,35	γQ=1,50
SLS	γG=1	γQ=1

*rule of thumb:
ULS =characteristic load*1,4

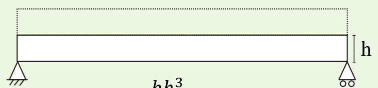
ULS Ultimate **L**imit **S**tate (for stress,...)
SLS Serviceability **L**imit **S**tate (for deformations,..)

γ safety factor
d design value
k characteristic value
G permanent loading
Q mobile loading

6 INFLUENCE

GEOMETRY

(section) influences material tensions and deflections through the moment of Inertia I



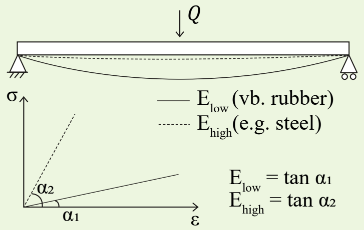
h $\quad I_y = \dfrac{bh^3}{12}$

2h $\quad I_y = \dfrac{b(2h)^3}{12} = 8\dfrac{bh^3}{12}$

An element with a higher I is more stiff,
- the tension will be lower
- the deformation will be lower
than for an element with a lower I.

MATERIAL

influences the deflection through modulus of elasticity E



E_{low} (vb. rubber)
E_{high} (e.g. steel)

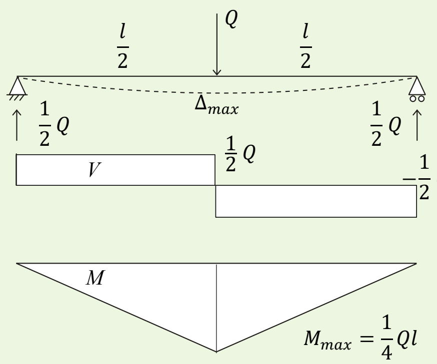
$E_{low} = \tan \alpha_1$
$E_{high} = \tan \alpha_2$

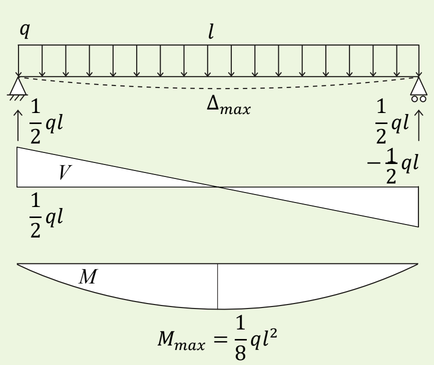
A material with a higher E is more stiff, and thus deflects less under the same loading than a material with a lower E.

LOADING & BOUNDARY CONDITIONS > BASIC CASES OF BEAM FORMULAS

Point load Q [kN] $\quad$ **Q = ql** $\quad$ **Distributed load q [kN/m]**

simply supported beam

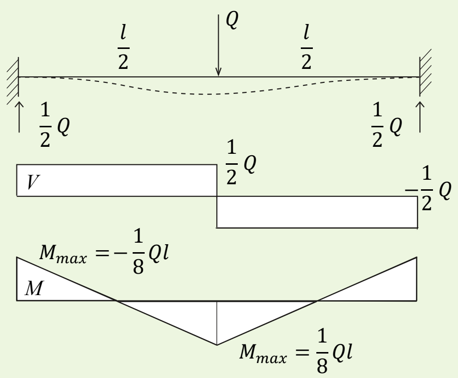


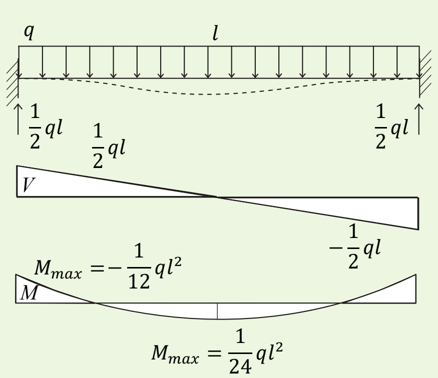


Deflection $\Delta_{max} = \dfrac{1}{48}\dfrac{Ql^3}{EI}$ $\quad$ Deflection $\Delta_{max} = \dfrac{5}{384}\dfrac{ql^4}{EI}$

Set Q and l equal for all cases
If deflection for this case = **1** $\quad$ Then the deflection for this case thus Δ relative (same Q and l) **5/8**

2 fixed end

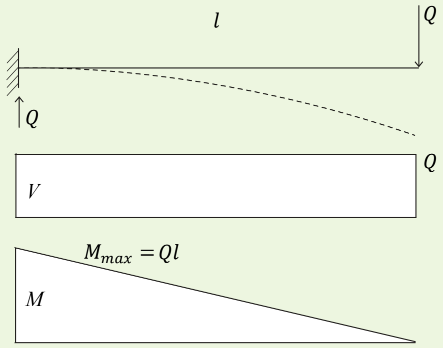


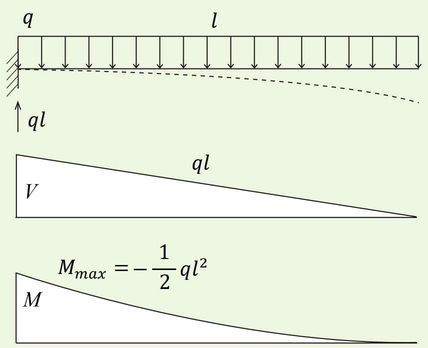


Deflection $\Delta_{max} = \dfrac{1}{192}\dfrac{Ql^3}{EI}$ $\quad$ Deflection $\Delta_{max} = \dfrac{1}{384}\dfrac{ql^4}{EI}$

Δrelative (same Q and l) **1/4** $\quad$ Δrelative (same Q and l) **1/8**

Cantilevers





Deflection $\Delta_{max} = \dfrac{1}{3}\dfrac{Ql^3}{EI}$ $\quad$ Deflection $\Delta_{max} = \dfrac{1}{8}\dfrac{ql^4}{EI}$

Δrelative (same Q and l) **16** $\quad$ Δrelative (same Q and l) **6**

More cases: van Herwijnen, et al. 2010. Polytechnisch zakboek. 52e druk. p.B2/29 e.v., online by looking for 'Beam formulas'. Online tools (for more complex situations and/or more load cases): Skyciv.com and Clearcalcs.com

7 BASIC FORMULAS

$M = F\,e$

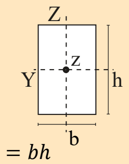
$\sigma = \dfrac{F}{A} = \dfrac{M}{W} = \dfrac{Mz}{I}$ $\qquad \Delta l = \dfrac{F\,l}{EA}$

$\sigma = E\varepsilon$

$\varepsilon = \dfrac{\Delta l}{l}$

M	moment	[Nm]
F	force	[N]
e	excentricity	[mm]
z	lever arm	[mm]
σ	stress	[N/mm²]
A	surface	[mm²]
E	elasticity	[N/mm²]
l	length	[mm]
Δl	elongation	[mm]
ε	strain	[-]

CROSS SECTION: RECTANGLE



cross section

$A = \int dA \qquad A = bh$

moment of inertia

$I_y = \int z^2 dA \qquad I_y = \dfrac{bh^3}{12}$

$I_z = \int y^2 dA \qquad I_z = \dfrac{hb^3}{12}$

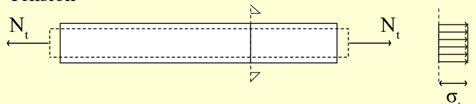
section modulus (bending)

$W_y = \dfrac{I_y}{z} \qquad W_y = \dfrac{bh^2}{6}$

$W_z = \dfrac{I_z}{y} \qquad W_z = \dfrac{hb^2}{6}$

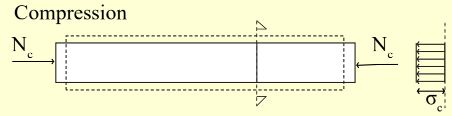
8 INTERNAL FORCES

Tension



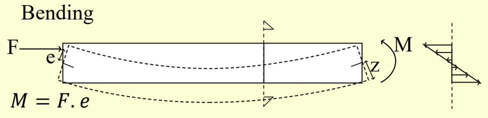
$\sigma_\tau = \frac{N_{td}}{A} \le f_{td}$

Compression



$\sigma_c = \frac{N_{cd}}{A} \le \omega_{buc} f_{cd}$

Bending

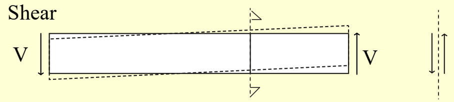


$M = F.e$

$\frac{M}{W} \le f_{md}$

$\sigma_m = \frac{M_d z}{I}$

Shear

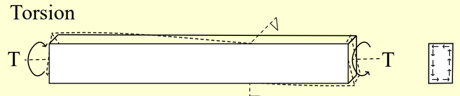


$\tau_{max} = \frac{3}{2}\frac{V}{A}$

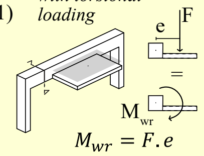
$\tau_{adm} = \frac{\sigma_{adm}}{\sqrt{3}}$

Von Mises

Torsion



example of beam with torsional loading



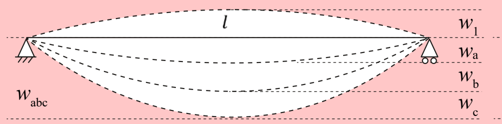
$M_{wr} = F.e$

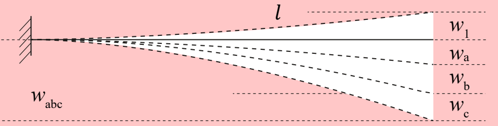
d	'design value' (incl. safety factors - see 11)
t	tension
c	compression
m	moment
adm	admissible

σ	stress (acting)	[N/mm²]
τ	optredende schuifspanning	[N/mm²]
f	admissible stress	[N/mm²]
N	normal force	[N]
M	moment	[Nmm]
V	shear	[N]
T	torsional moment	[Nm]
z	distance to neutral axis	[mm]
I	moment of inertia	[mm⁴]
W	section modulus	[mm³]
ω_{buc}	reduction factor for buckling (< 1)	

9 DEFORMATION

LOADS IN SLS





w_1	*camber*
w_a	*Initial, immediate deformation, under permanent loading*
w_b	*Increase of deformation under (additional) permanent loading*
	e.g. due to creep in concrete or wood, or by adding a finishing layer at a later stage
w_c	*Increase of deformation due to variable loading*
w_{abc}	*Total deformation of the construction element*

Maximal vertical deformation		2 simple supports	cantilever
Appearance: Total deflection due to all loads and time-dependent effects (creep, etc.)	w_{abc}	l/300	l/150
Finishing of floors	w_{bc}		
Larges sizes or firmly attached		l/500	l/500
Small sizes or attached with tolerance		l/350	l/350
Flexible covering		l/250	l/250
Finishing of ceilings	w_{bc}		
Plastered		l/350	l/175
Not plastered, suspended		l/250	l/125
Roofing			
stiff		l/250	l/125
flexible		l/125	l/125
Vertical walls (Cracking in partition walls and facades)	w_{bc}		
Reinforced walls		l/350	l/175
Not reinforced, with large openings		l/1000	l/500
Moveable walls		l/250	l/125
Windows with glazing	w_{bc}		
No tolerance in relation to structure (e.g. sliding doors)		l/1000	l/500
Tolerance in relation to structure		l/350	l/175
Slope and drainage (towards the drain)		> 2%	
Vibration	w_a		
General (if natural frequency < 3,5Hz)		20 mm	
Sports-, dance-, and concerthalls (if natural frequency < 7Hz)		5 mm	

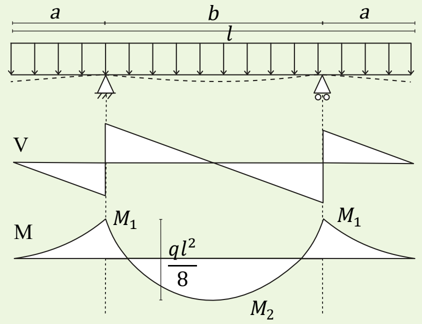
Maximal horizontal deformation	
Balustrade: horizontal displacement of handrail	h/100
Facade glazing: horizontal displacement due to wind	y/225 (max 13mm)

Based on NBN B03-003 (based on reference in NBN EN 1990 ANB. The eurocode does not give limitations for deformations.) Horizontal displacement balustrades: NBN B03-004, on facade due to wind: Buildwise 'Dimensioneringsmethode rapport 11'

CONTINUOUS BEAMS

Cantilevers and/or continuous beams are beneficial for moment distribution and deflection.

See below how the zone between the supports behaves like a beam with two fixed ends, and how the outer zones behave like cantilevers over the support.



special case
if a=0,353.b then M1=M2 and M1+M2= $\dfrac{ql^2}{8}$
(= Mmax distributed load & 2 simple supports)

10 MATERIAL

Material-properties (characteristic)	Wood (C24)	Concrete (C30/37)	Steel (S235)	Masonry
Easticity E [N/mm²]	11000	33000	210000	5000
Mass density ρ [kg/m³]	350	2500	7850	1800
tensile strength f_t [N/mm²]	14,5	2,9	235	0,05
compression strength f_c [N/mm²]	21	30	235	5-25
bending strength f_m [N/mm²]	24	3	235	0,05

11 VERIFICATION

LOAD < RESISTANCE

Basic beam verification - **manual**:
- Stress check: OK if the occurring stress (based on 'beam formulas' and 'internal forces') < permissible material stress - loads in ULS
- Deformation check: OK if the occurring deflection (based on 'beam formulas') < maximum deflection - loads in SLS

Online **calculation tools** for 'manual' verification: eurocodeapplied.com
For complex calculations: FEM software. e.g. 'Diamonds' (Buildsoft), 'RFEM' (Dlubal), 'Scia Engineer'.

STEEL

Steel can be easily verified following the steps described above.

Design value admissible material stress

$f_d = \dfrac{f_k}{\gamma_m}$ $\qquad \gamma_m$ (partial safety factor for material rule of thumb: γ_m=1

REINFORCED CONCRETE

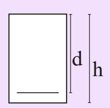
Design value admissible material stress

$f_{cd} = \alpha_{cc}\dfrac{f_{ck}}{\gamma_c}$ $\qquad \gamma_c = 1{,}5$, $\alpha_{cc} = 0{,}85$

Concrete cracks and creeps, therefore it cannot as simply be verified through material stress.
Formula to estimate efficient beam height d_{ec} based on moment (ULS)

d = lever arm between reinforcement and the opposite extreme (in compression)
[zie courses on concrete: μ=0,1591 > ε_c=2,76 & ε_s=10,0]

$d_{ec} = 2{,}507\sqrt{\dfrac{M_d}{b\,.\,f_{cd}}}$



d = 0,9h

MASONRY

Design value admissible material stress

$\sigma_{max,d}$ =1 N/mm²

WOOD

Wood is an anisotropic material; the grain direction is very important for the material properties.
Product type, load duration and humidity have a significant influence.
online tool for verifications: calculatis.storaenso.com

Design value admissible material stress

$f_d = k_{mod}\dfrac{f_k}{\gamma_m}$

kmod (effect load duration and humidity)
rules of thumb for normal humidity, floor in house:
- timber, GL, LVL, multiplex: 0,5
- CLT 0,8
- other 0,2

elaborate table: NBN EN 1995-1-1 table 3.1

γ_m (partial safety factor for material)
- LVL, multiplex, OSB 1,2
- other 1,3

elaborate tabel: NBN EN 1995-1-1 table 2.3

Final deformation E_{fin}

In the case of wood, the final deformation depends on the humidity

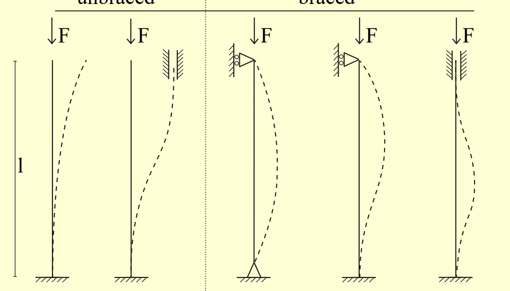
$E_{fin} = \dfrac{E}{1 + k_{def}}$

kdef
rule of thumb for inner spaces ('normal humidity'):
- timber, GL, LVL 0,6
- multiplex, CLT 0,8
- other 2,25

elaborate table: NBN EN 1995-1-1 table 3.2

12 COLUMNS

In an imperfect world, elements in compression can **buckle** and zones in compression in beams are prone to 'lateral torsional buckling'.



l_k= 2 l $\quad l_k$= l $\quad l_k$= l $\quad l_k$= 0,7 l $\quad l_k$= 0,5 l

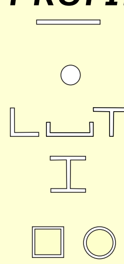
'braced' means that other elements secure global stability, which makes sure that ends cannot displace horizontally (see 2.)

$F_{buc} = \dfrac{\pi^2 EI}{l_k^2}$

Carefull! The elastic buckling load F_{buc} does not consider relative slenderness. Verification happens through tools.

Buckling tables give maximal loading for standard **steel profiles** as a function of the buckling length l_k, they thus allow to select a fit tubular profile from the tables when the load is known. See Herwijnen, et al. 2010. Polytechnisch zakboek. 52e druk. p.D2/177 ff.

PROFILE SELECTION



- least structurally efficient
- suitable for columns that are not slender and only lightly loaded
- suitable for lightly loaded columns
- efficient choice, easy connections
- structurally the most efficient choice, complex connections