Metal Structures

Lecture III

Eurocodes - basic information

Contents

Standards

Many standards are marked EN (European Standard, European Norme, European Norm, Norma Europejska). Only ten groups of them: from 1990 to 1999 are named Eurocodes.

Full symbol: **X - EN - number : year of edition**

Where X - translation into national language

For example:

BS - EN 1991-1-1 : 2005 (BS = British Standard, year 2005)

PN - EN 1993-1-7 : 2007 (PN = Polska Norma, year 2007)

DIN - EN 1995-1 : 2004 (DIN = Deutsches Institut für Normung, year 2004)

NF - EN 1997-1-2 : 2006 (NF = Norme Française, year 2006)

Besides Eurocodes, there are many EN and EN ISO standards.

EN ISO = standard EN, International Organization for Standardization

Eurocodes:

- EN 1990 Basis of structural design (one sub-part)
- EN 1991 Actions on structures (ten sub-parts)
- EN 1992 Design of concrete structures (four sub-parts)
- EN 1993 Design of steel structures (twenty sub-parts)
- EN 1994 Design of composite steel and concrete structures (three sub-parts)
- EN 1995 Design of timber structures (three sub-parts)
- EN 1996 Design of masonry structures (four sub-parts)
- EN 1997 Geotechnical design (two sub-parts)
- EN 1998 Design of structures for earthquake resistance (six sub-parts)
- EN 1999 Design of aluminum structures (five sub-parts)

Σ = 58 sub-parts

Other standards, important for metal structures:

- EN 1090-2
- EN 10025-2
- EN ISO 5817
- EN ISO 6520-1
- EN 50341-1
- EN 12345
- ISO 2560

...

EN 1990 Basis of structural design

(common name: Eurocode 0)

Partial safety factors → #t / 7-10

Limit States Method → #t / 11-30

Ultimate LS, Serviceability LS → #t / 12-20

Situations and Combinations of actions → #t / 21-28

Consequences Classes → #t / 31-37, 41

Working life → #t / 38-41

Reminder of information from Introduction to Construction Design

Partial Safety Factors

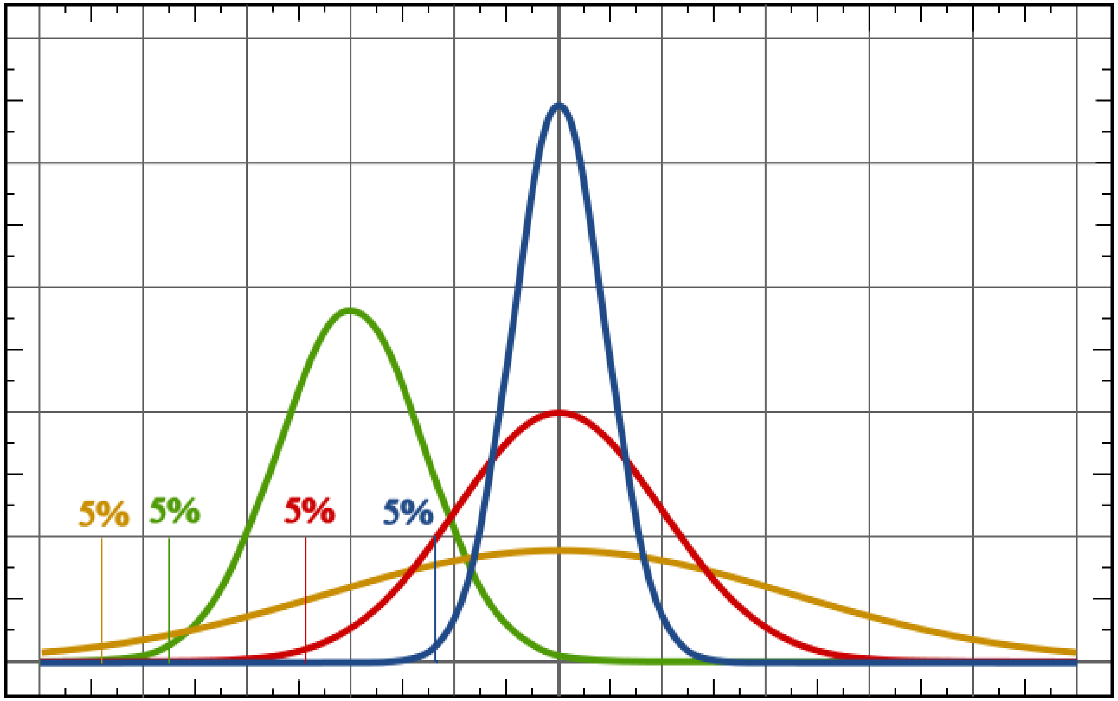


Photo: wikipedia

Generally: strength of material is equal lower 5% quantile (→ #2 / 47)

For many different calculation we often use additional safety factor for material (steel elements, steel bolts, aluminum elements) = $1/\gamma_M$

γ_M	Value	What for (examples)
γ_{M0}	1,00	Resistance of members and cross-sections
γ_{M1}	1,10	
γ_{M2}	1,25	Resistance of bolts, rivets, pins, welds, plates in bearing, members and cross-sections
γ_{M3}	1,25	Slip resistance, category C
$\gamma_{M3,\ ser}$	1,10	Slip resistance, category B
γ_{M4}	1,00	Bearing resistance of an injection bolt
γ_{M5}	1,00	Resistance for hollow section lattice girder
$\gamma_{M6,\ ser}$	1,00	Resistance of pins at SLS
γ_{M7}	1,10	Preload of high strength bolts
γ_{Mf}	Special formulas	Fatigue calculations

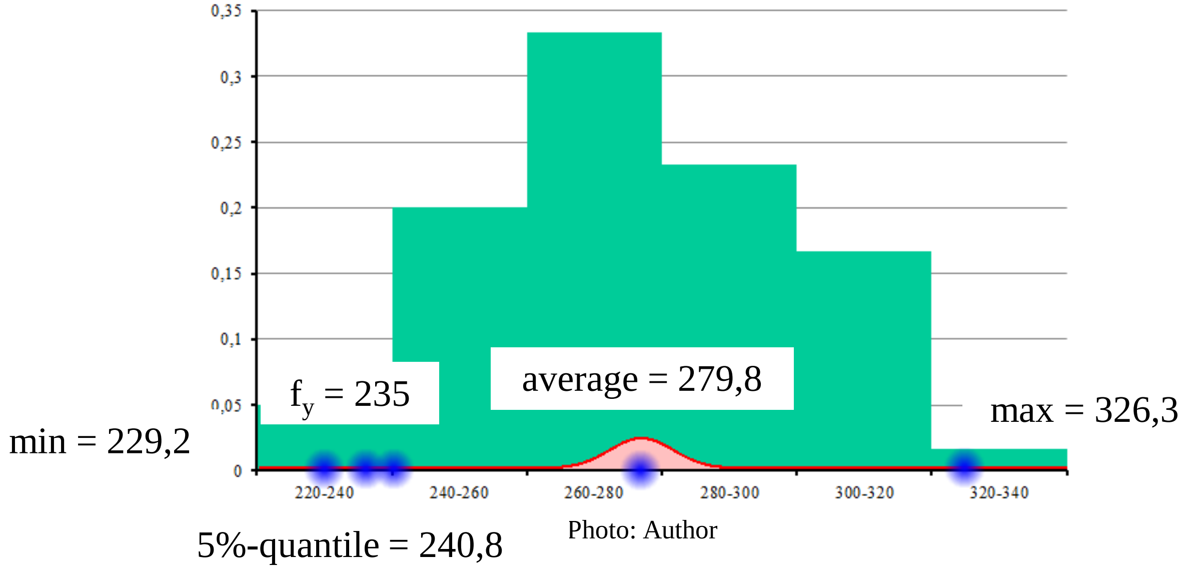


Photo: Author

As a full analogy to strength of material (lower 5% quantile), characteristic values of loads are equal any quantiles of their distributions.

For strength, we adopted **lower** quantiles for securely - in this way most of steel elements have higher strength than design value of strength.

For loads, we must take **upper** quantiles for securely - in this way in most of load cases, values of load are smaller than design value of load.

For each type of loads we use safety factors γ_F to recalculate from characteristic value to design value:

γ_{Gi} safety factor for permanent loads (for example slef-weight)

γ_{Qi} safety factor for variable actions (snow, wind, imposed load)

γ_P safety factor for accidental actions (explosions, impact from vehicles)

Generally, $\gamma_F \geq 1,0$

We have complex of various safety factors fo material and various types loads and actions. Such method is named Partial Safety Factors Method.

Loads, resistance, safety factors and combination factors define **state of structure**. State of structure is described by specific Function (→ #t / 20), which separated safe and dangerous states. Such method is named Limit States Method.

Failure

Function > 1,0

Photo: onet .pl

Limit State

Function = 1,0

Photo: viva.pl

Safe State

Function < 1,0

Ultimate Limit States, ULS (EN 1990 6.4):

EQU (equilibrium) - loss of static equilibrium of the structure or any part of it, considered as a rigid body;

STR (strength) - internal failure or excessive deformaton of the structure or structural member;

GEO (geotechnics) - failure or excessive deformaton of the ground;

FAT (fatigue) - fatigue failure.

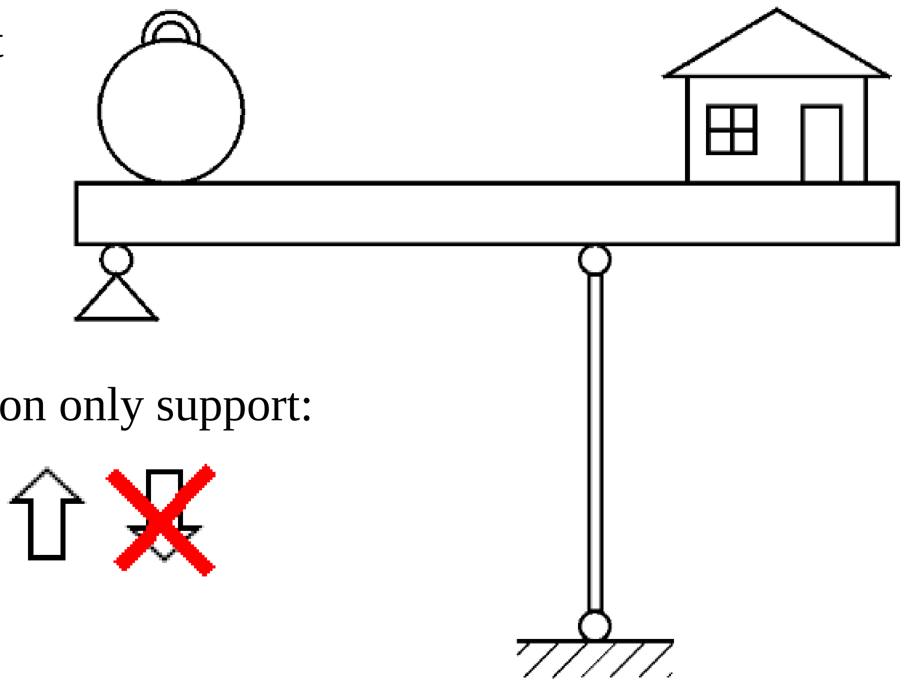
Serviceability Limit States, SLS

What is the meaning of various types of Limit States?

Structure:

Counterweight

Most important part



Compression only support:

reaction

Photo: Author

No destruction and no deformation of structure, but dangerous situation for people or structure : EQU LS

Photo: Author

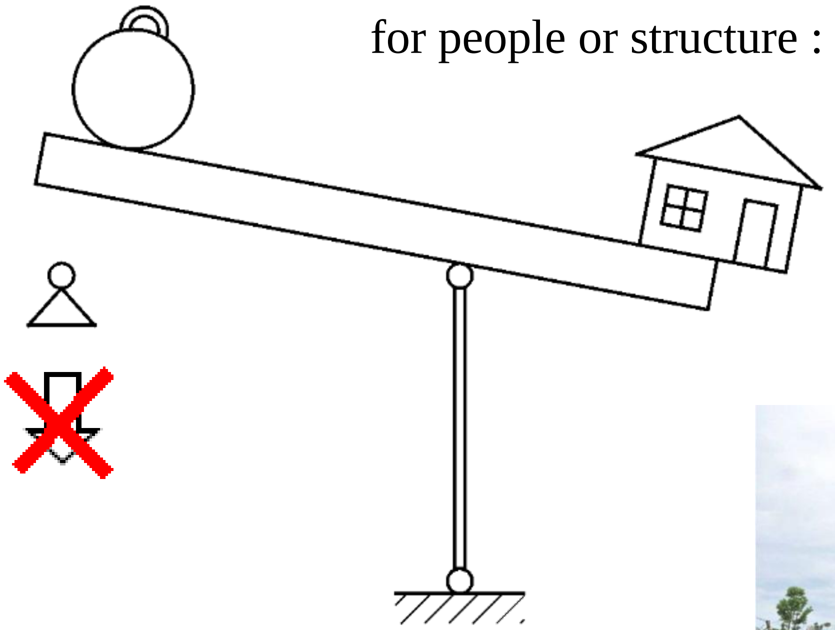


Photo: craneaccidents.com

Photo: malaysiaconstructionservices.com

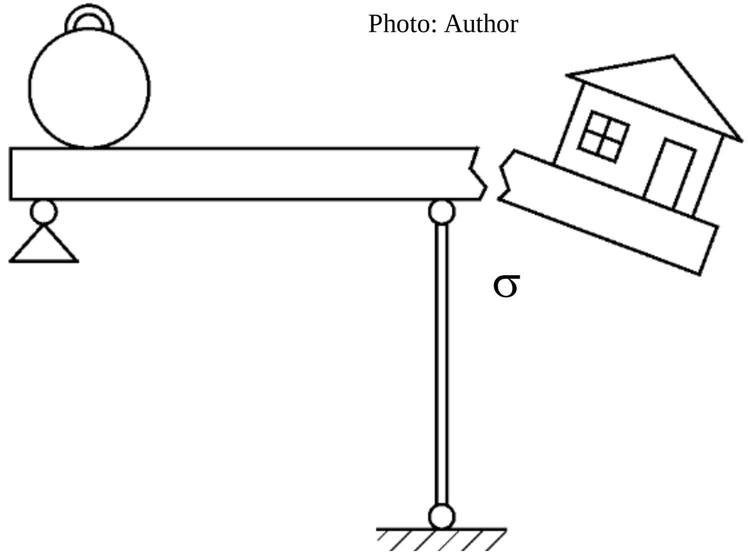
Displacement, rotation, lifting of tank by wind;

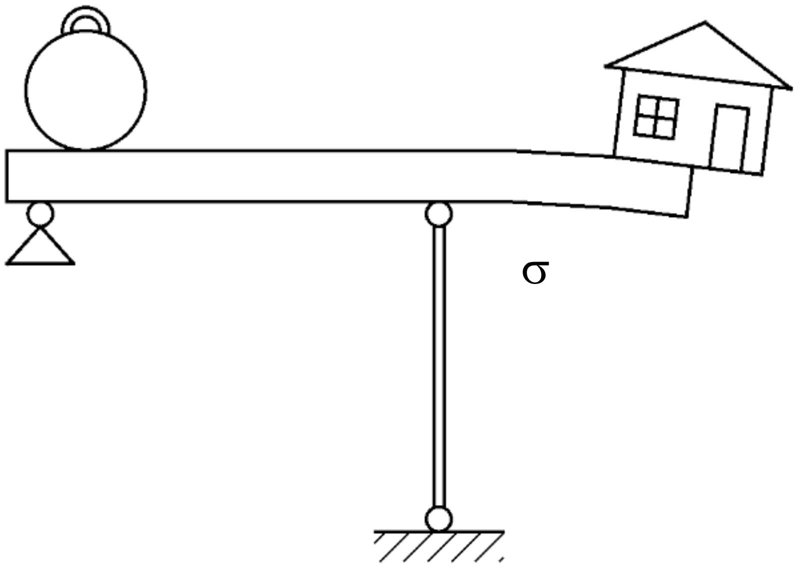
Stability of retaining wall;

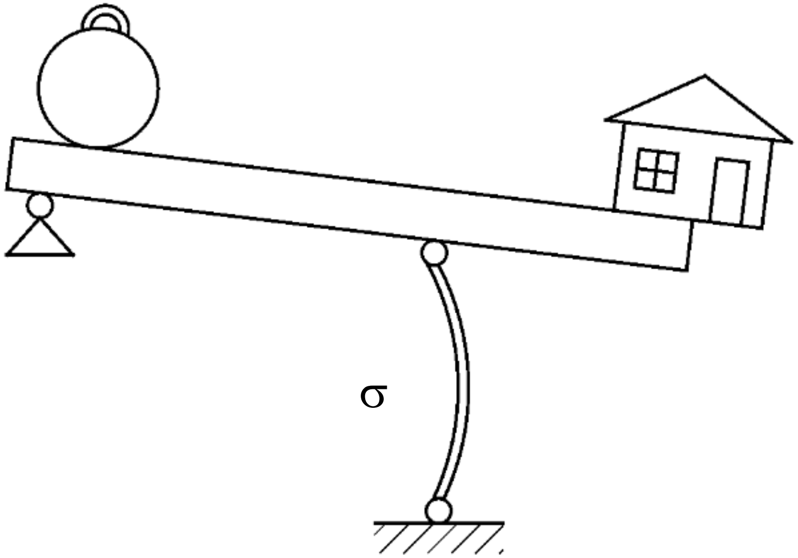
Stability of crane;

Photo: link.springer.com

Photo: Author







A dangerous situation for people or structure: STR LS

- exceeding strength ($\sigma > f_y$)
- excessive deformations ($\sigma < f_y$)
- instability ($\sigma < f_y$)

Exceeding strength (welds, bolts, members…)…

Photo: quora.com

Photo: Z. Mendera, Analiza przyczyn katastrofy hali wystawowej w Katowicach, Awarie Budowlane 2007

Photo: wikipedia

Photo: ceprofs.civil.tamu.edu

Photo: researchgate.net

Photo: civildigital.com

…lost of stability…

Photo: publish.ucc.ie

Photo: tvn24.pl

… deflection, disturbing transport gauge under the object …

Photo: dachy.info.pl

… or causing long-term water pooling on roof.

Photo: Author

Dangerous situation for people or structure: GEO LS

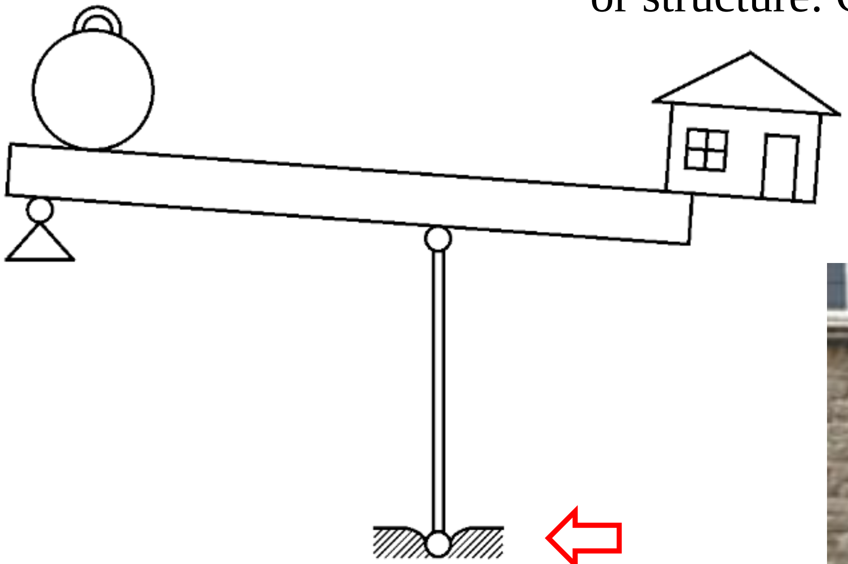


Photo: wikipedia

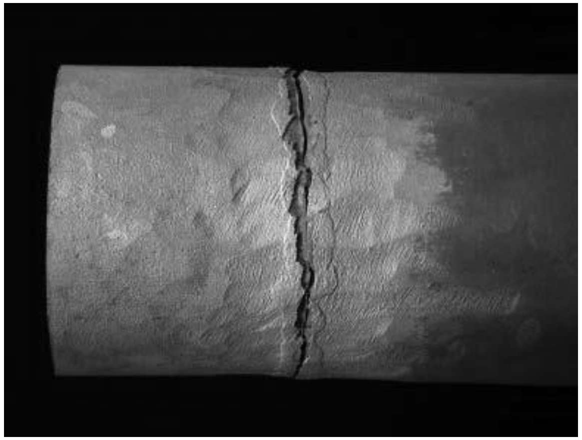
Photo: helifix.co.uk

Photo: T. Paczkowska, W. Paczkowski, T. Wróblewski, Wpływ osiadania podłoża na stan stalowej konstrukcji szkieletowej, Awarie Budowlane 2007

Foundation problems

Dynamic actions, material cracking: FAT LS

Photo: D. Kowalski, Problemy realizacji inwestycji z zakresu konstrukcji stalowych, Inżynieria Morska i Geotechnika 2013 / 5



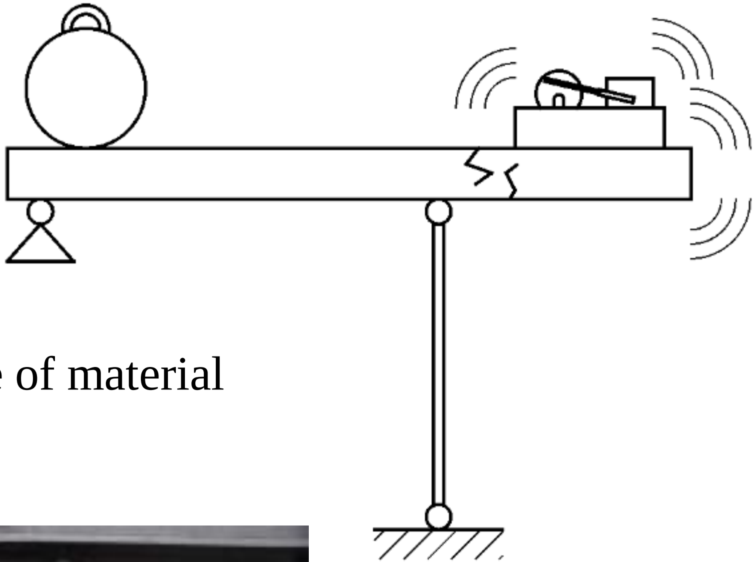


Photo: Author

Fatigue of material

Photo: incomnews.org

Photo: s3da-design.com

Serviceability Limit States SLS:

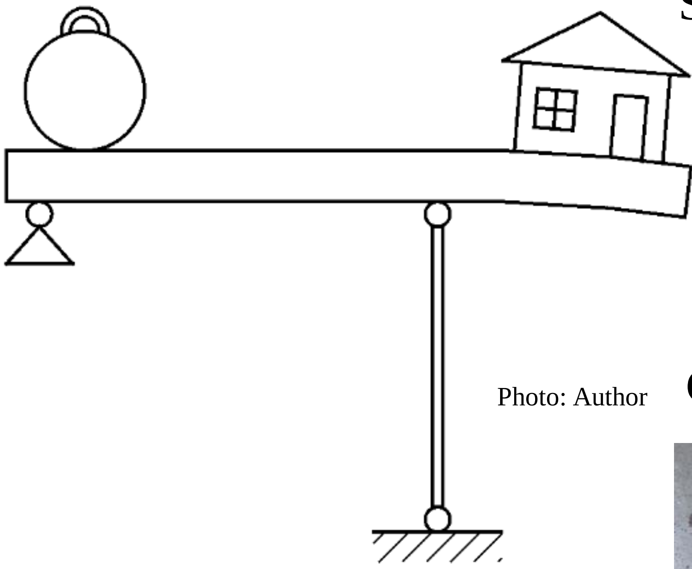


Photo: Author

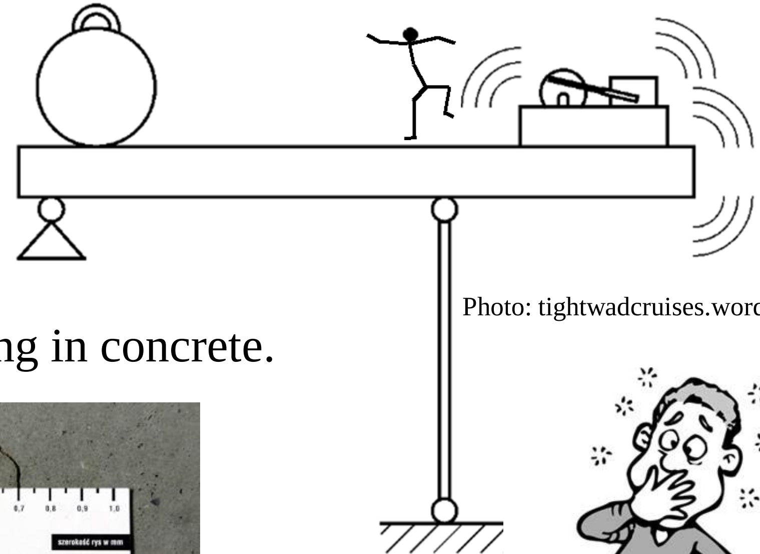


Photo: tightwadcruises.wordpress.com

Crack opening in concrete.

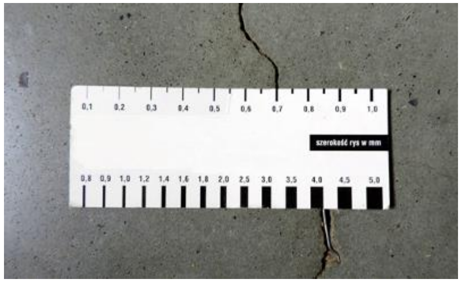


Photo: inzynierbudownictwa.pl

Deformations that pose an aesthetic, psychological problem or have a secondary effect on use.

Photo: raportsekocenbud.pl

Specific combinations of amplitude (Δ) and period (T) of vibration causing malaise.

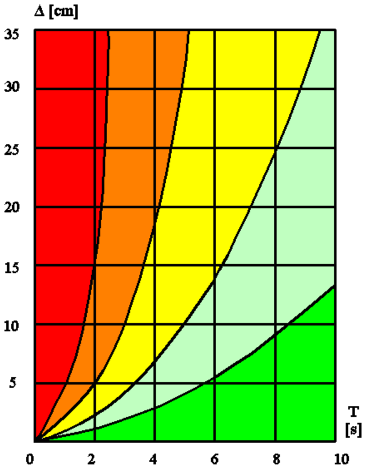


Photo: "Konstrukcje metalowe, tom II", M. Łubiński, W. Żółtowski, A. Filipowicz

Effect of loads - displacements, stresses, cross-sectional forces - we compare with **R**esistance of structure in fundamental requirement:

E / R – Limit States Function (→ #t / 11)

Specific symbols could be various:

EQU: $E_{d,\ dis} / E_{d,\ stb} \leq 1,0$

disturbing load / stabilising load

STR, **GEO**: $E_d / R_d \leq 1,0$

effect of load / resistance

FAT: specific form, which could be presented as $E_F / R_F \leq 1,0$

aplitude of loads / fatigue resistance

SLS: $E_d / C_d \leq 1,0$

deformation / accepted deformation

Various Situation / Combination of actions mus be analised for various LS.

Limit States: mechanisms and forms of destruction / failure;

Situation: duration of load;

ULS Combination: type of load;

SLS Combination: type of material;

ULS:

Situation:	Combination:
Persistent	Common for persistent and transient
Transient	
Accidental	For accidental
Seismic	For seismic

SLS:

Combination:
Characteristic
Frequent
Quasi-permanent

ULS, Persistent Situation: duration of load is similar to period of exploitation of structure:

- dead weight (gravity acts always);
- imposed load (various values, but through most part of exploitation period);
- wind (potenially on each moment through exploitation period);
- snow (potentially througt few month yearly; it could be 30%-50% of exploitation preiod)

ULS, Transient Situation: loads of short time of action, but of big occuring probaility:

- storage of materials during construction or repair;
- snow drifts

ULS, Accidental Situation: loads of small occuring probaility:

- fire
- explosion (dust in silo, gas in pipelines or tanks – **but not concern** explosive materials, terroristic acts or war);
- hitting by vehicle (car, tram, train, forklift, ship,…)

ULS, Seismic Situation: earthquakes occurs only in part of coutries in EU (for example – not in Poland), because of this such case is separated to distinct Situation.

SLS, Characteristic Combination: concerns irreversible limit states, such as cracking (cracks in **reinforced concrete**) or deformation in plastic range.

SLS, Frequent Combination: applies to reversible limit states, such as elastic deflections (**metal structures**).

SLS, Quasi-permanent Combination: deals with long-term effects and structure appearance, such as concrete rheology (**composite and prestressed structures**) and some aspects of crack calculation in **reinforced concrete and prestressed concrete**.

	ULS				SLS	
	EQU	STR	GEO	FAT		
Persistent					Characteristic	
Transient					Frequent	
Accidental					Quasi-permanent	
Seismic						

Warious values of factors Ψ_i
EN 1990 app. A

Limit States and Situation / Combinations differ in their different values of load combination factors Ψ_i

Example: there are four the <u>most important</u> types of loads, acting on structure:

- Slef-weight
- Live load
- Snow
- Wind

Eurocodes give us maximum value for each types of loads.

Photo: losyziemi.pl

Photo: 900igr.net

Probability, that **<u>at the same moment</u>** occur heavy snow and strong wind is not very big - because of this, from economical point of view, we can reduce values of loads during summation different types of loads.

$$\Psi_i \leq 1{,}0$$

Metal structures: the most often is STR LS and EQU LS - Permanent and Transient Situation (1, 2, 3, 4) and ULS - Frequent Combination (5, 6, 7):

Case E_j	G (dead weight)		Q (live load)							
			Wind		Snow		Imposed load		Temperature	
	γ_{Gi}	Ψ_i	γ_{Wi}	Ψ_i	γ_{Si}	Ψ_i	γ_{Ii}	Ψ_i	γ_{Ti}	Ψ_i
ULS										
1	1,35	**1,00**	1,50	**1,00**	1,50	$\Psi_{0,S}$	1,50	$\Psi_{0,I}$	1,50	0,60
2	1,35	**1,00**	1,50	0,60	1,50	**1,00**	1,50	$\Psi_{0,I}$	1,50	0,60
3	1,35	**1,00**	1,50	0,60	1,50	$\Psi_{0,S}$	1,50	**1,00**	1,50	0,60
4	1,35	**1,00**	1,50	0,60	1,50	$\Psi_{0,S}$	1,50	$\Psi_{0,I}$	1,50	**1,00**
5	1,00	**1,00**	1,50	**1,00**	1,50	0,00	1,50	0,00	1,50	*
SLS										
6	1,00	**1,00**	1,00	**0,2**	1,00	$\Psi_{2,S}$	1,00	$\Psi_{2,I}$	1,00	0,00
7	1,00	**1,00**	1,00	0,0	1,00	$\mathbf{\Psi_{1,S}}$	1,00	$\Psi_{2,I}$	1,00	0,00
8	1,00	**1,00**	1,00	0,0	1,00	$\Psi_{2,S}$	1,00	$\mathbf{\Psi_{1,I}}$	1,00	0,00
9	1,00	**1,00**	1,00	0,0	1,00	$\Psi_{2,S}$	1,00	$\Psi_{2,I}$	1,00	**0,50**

For Poland:

Ψ_S	$\Psi_{0,S}$	$\Psi_{1,S}$	$\Psi_{2,S}$
Locations < 1000 m. above sea level	0,5	0,2	0,2
Locations > 1000 m. above sea level	0,7	0,5	0,2

Type of using (→ #t / 43)	$\Psi_{0,I}$	$\Psi_{1,I}$	$\Psi_{2,I}$
A, B	0,7	0,5	0,3
C, D	0,7	0,7	0,6
E	1,0	0,9	0,8
F	0,7	0,7	0,7
G	0,7	0,5	0,3
H	0,0	0,0	0,0

More dangerous case with wind suction with 0.00 or 0.70

$$E_j = \Sigma (\gamma_{Gi} G_{ki}) + \Sigma (\Psi_{ij} \gamma_{Qi} Q_{ki})$$

Case 1-4, 6-9 concerns wind pressure (+dead weigth + other) and effect for STR LS;

Case 5 concenrs wind suction (-dead weight), this means EQU LS.

Summation:

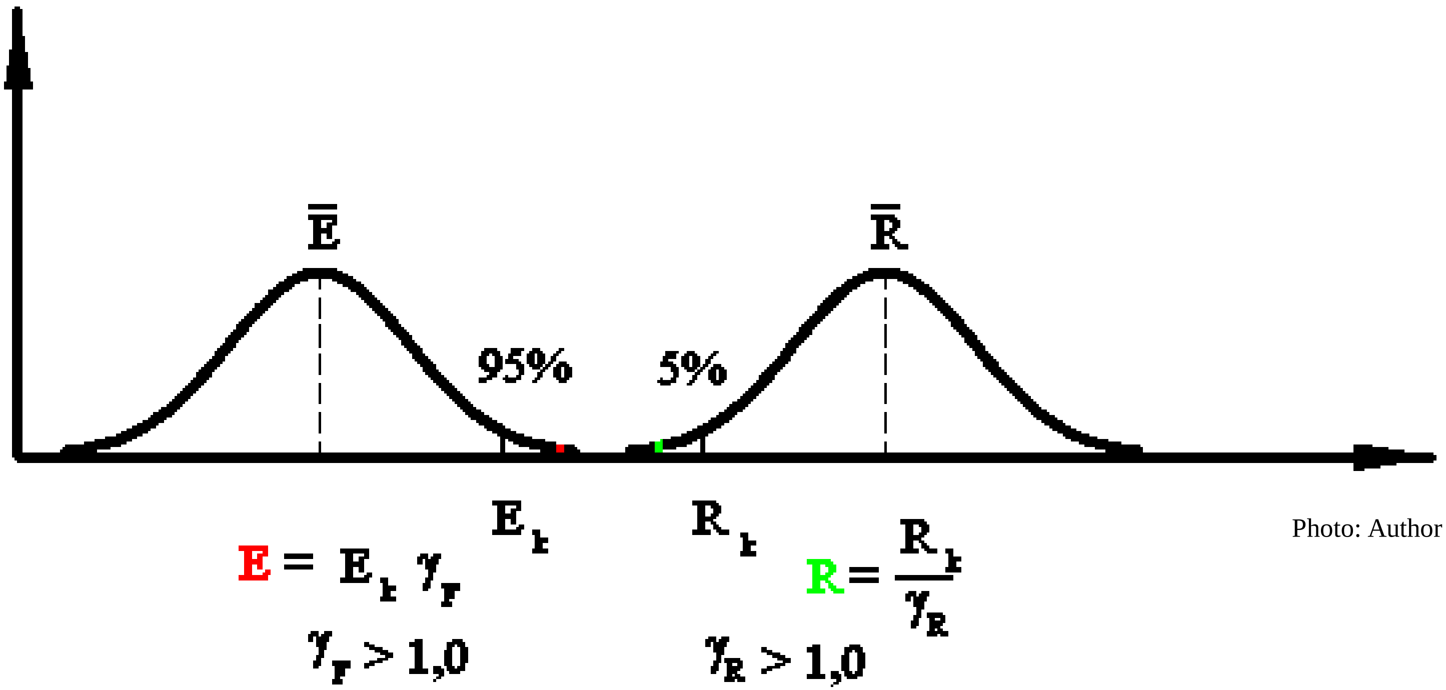


Photo: Author

$$E / R \leq 1,0$$

$$0 \leq E / R \leq 1{,}0$$

is OK for safety of structure.

But, becaust of costs, no each results E/R are accepted.

For example: cross-section with E/R = 0,54 and other cross-section with E/R = 0,98;

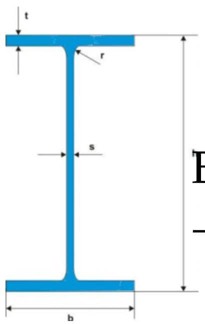


Photo: hmsteel.pl

Big cross-section
→ big resistance

$$\mathbf{0 \leq [E/ (Big\ R)] < [E / (Small\ R)] \leq 1{,}0}$$

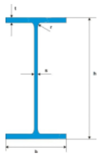


Photo: hmsteel.pl

Small cross-section
→ small resistance

Small cross-section is cheaper and lighter. E/R should be as close 1,0 as possible.

Consequences classes - effects of structure destruction

Photo: wikipedia

Consequences calsses	Description	Examples
CC3	**High consequence** for loss of human life or economic, social or environmental consequences **very heavy**	Grandstands; public buildings where consequences of failure are high
CC2	**Medium** for loss of human life or economic, social or environmental consequences **considerable**	Residential; office buildings; public buildings where consequences of failure are medium
CC1	**Low** for loss of human life and economic, social or environmental consequences **small or neglegible**	Agricultural buildings where people do not normally enter; greenhouses

EN 1990 tab B1

There are other definitions for six types of structures (IInd step of study):

Of course, it can be also decision of investor for each type of structures.

Photo: wikipedia

Because of Consequences Classes, three aspects must be taken into consideration:

- probability of destruction;
- accuracy of calculations (→ #t / 37);
- accuracy of erection process (→ #t / 37);

Structure CC2 must be safer than CC1 and CC3 safer than CC2. Probability of destruction must be smaller for CC2 than for CC1 and the smallest for CC3. According to Eurocodes (EN 1990 tab. B2):

CC	1	2	3
Reliability index β (for 50 years)…	3,3	3,8	4,3
…this means probability of destruction (for 50 years)	4 642 / 10 000 000	716 / 10 000 000	87 / 10 000 000
Proportion	53,356	8,230	1,000

This probability is achieved by change of value of partial safety factors for loads and actions during calculations.

What is the effects for calculations:

CC3 CC2 CC1

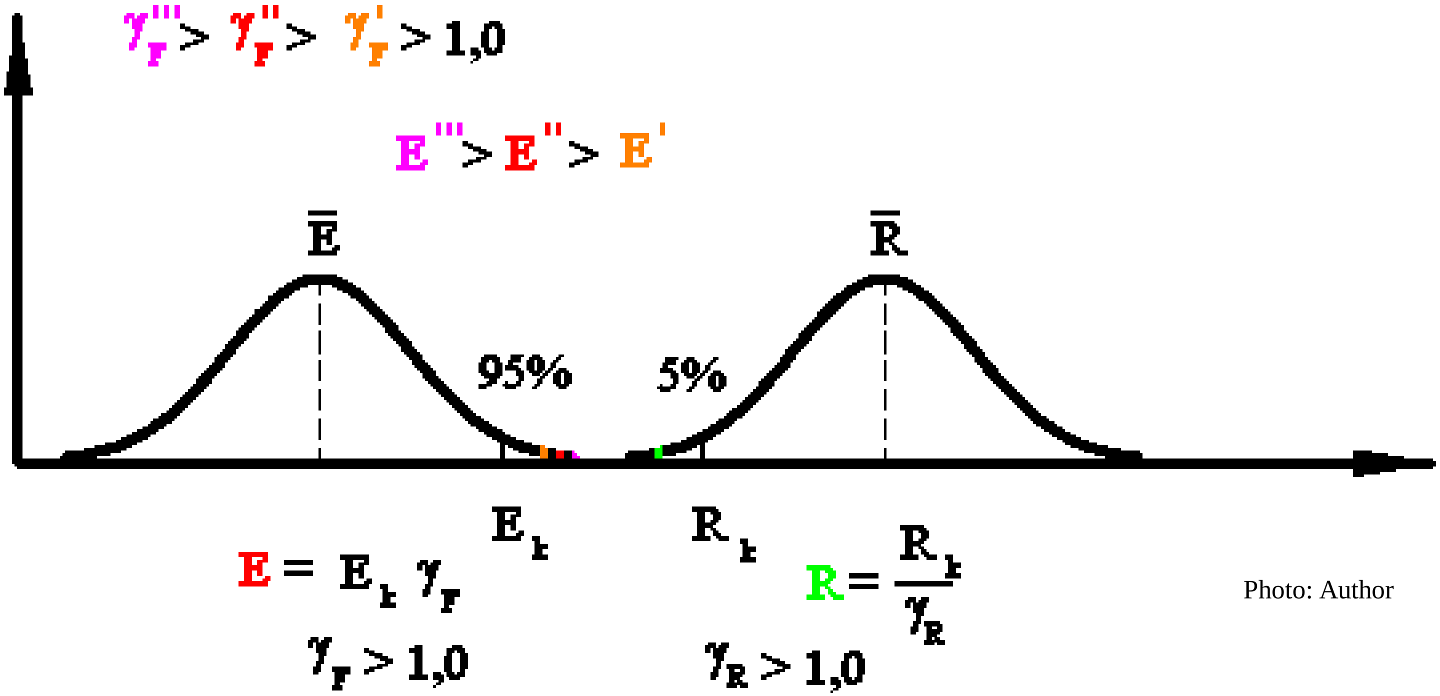


Photo: Author

$E / R \leq 1{,}0$

(sometimes another formulas for resistance)

Effects for designing; EN 1990 B3.2.(2), EN 1990, tab. B3

Effect	CC	Dead-weight		Live loads
		Timber, concrete, masonry, finishing elements	Steel, aluminum	
Unfavourable	CC1	1,20	1,35	1,35
	CC2	1,35		1,50
	CC3	1,50		1,65
Favourable	CC1, CC2, CC3	1,0	1,0	0,0
Accidental situations		1,0	1,0	1,0

T. Michałowski, M. Piekarczyk, Selected Issues of Special Steel Structures, Cracow University of Technology 2019

Effects for designing and executing; EN 1990, tab. B1 + B4 + B5

Consequences classes	Design Supervision Levels (during designing)	Characteristics	Minimum recommended requirements	Inspection Level (during execution)	Characteristics	Requirements
CC3	DSL3	Extended supervision	Third part checking (performed by an organsation different from that, which has prepared the design)	IL3	Extended inspection	Third party inspection
CC2	DSL2	Normal supervision	Checking by different person, that those originally responsible and in accordance with the procedure of the organisation	IL2	Normal inspection	Inspection in accordance with the procedures of the organisation
CC1	DSL1	Normal supervision	Self-checking (performed by the person, who has prepared the design)	IL1	Normal inspection	Self inspection

Working life - how long the structure will be operated

Photo: wikipedia

Design working life category	Indicate design working life (years)	Examples
1	10	Temoporary structure
2	10 - 25	Replaceable structural parts, e.g. gantry girders, bearings
3	15 - 30	Agricultural and similar structures
4	**50**	**Building structures and other common structures**
5	100	Monumental building structures, bridges, and other civil engineering structures

EN 1990 tab 2.1

Probability of big value of load increases with increasing length of time period; decreases with decreasing length of time period.

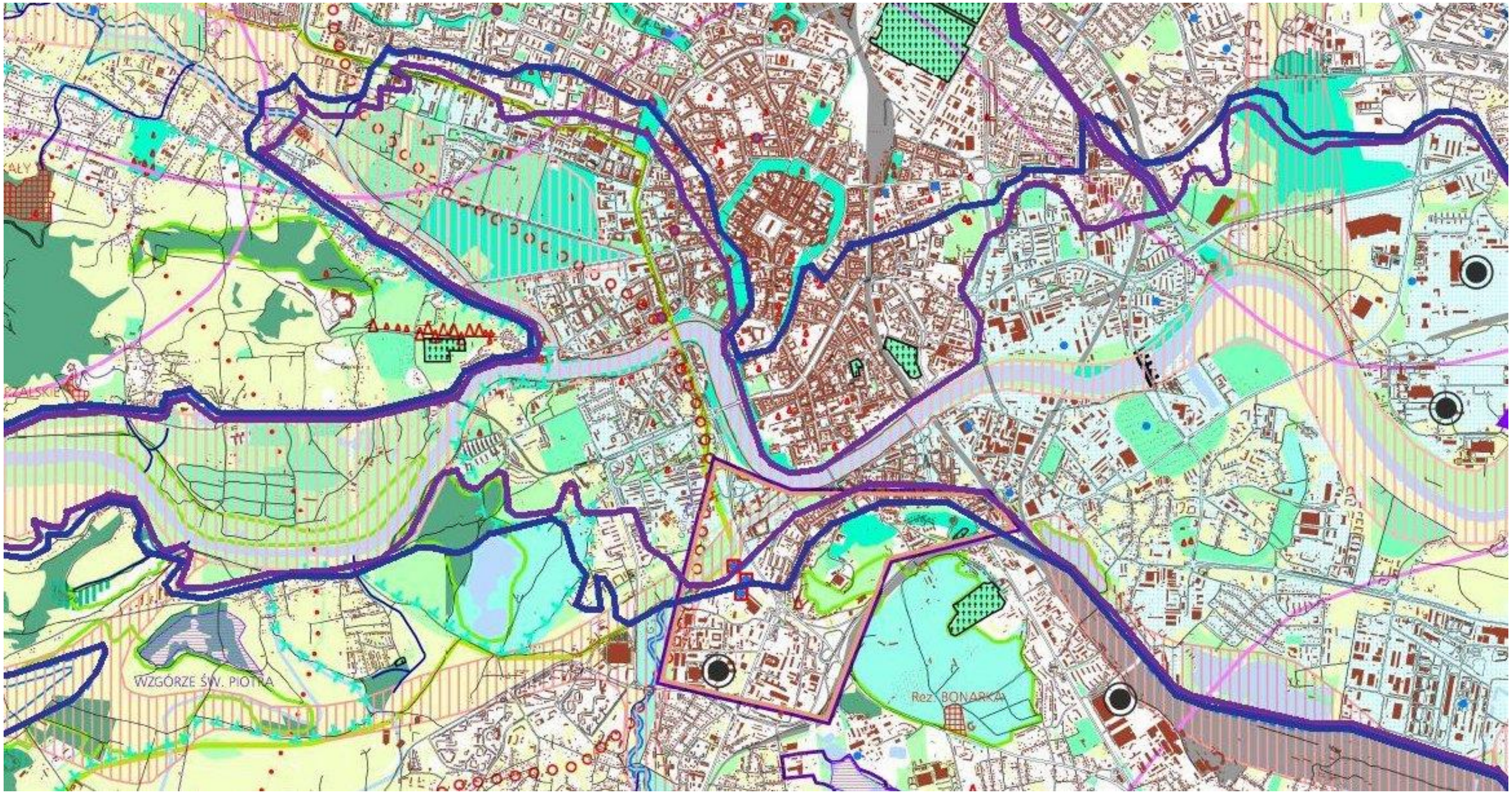


Photo: urbnews.pl

100-years flood

1000-years flood

Effects for calculations:

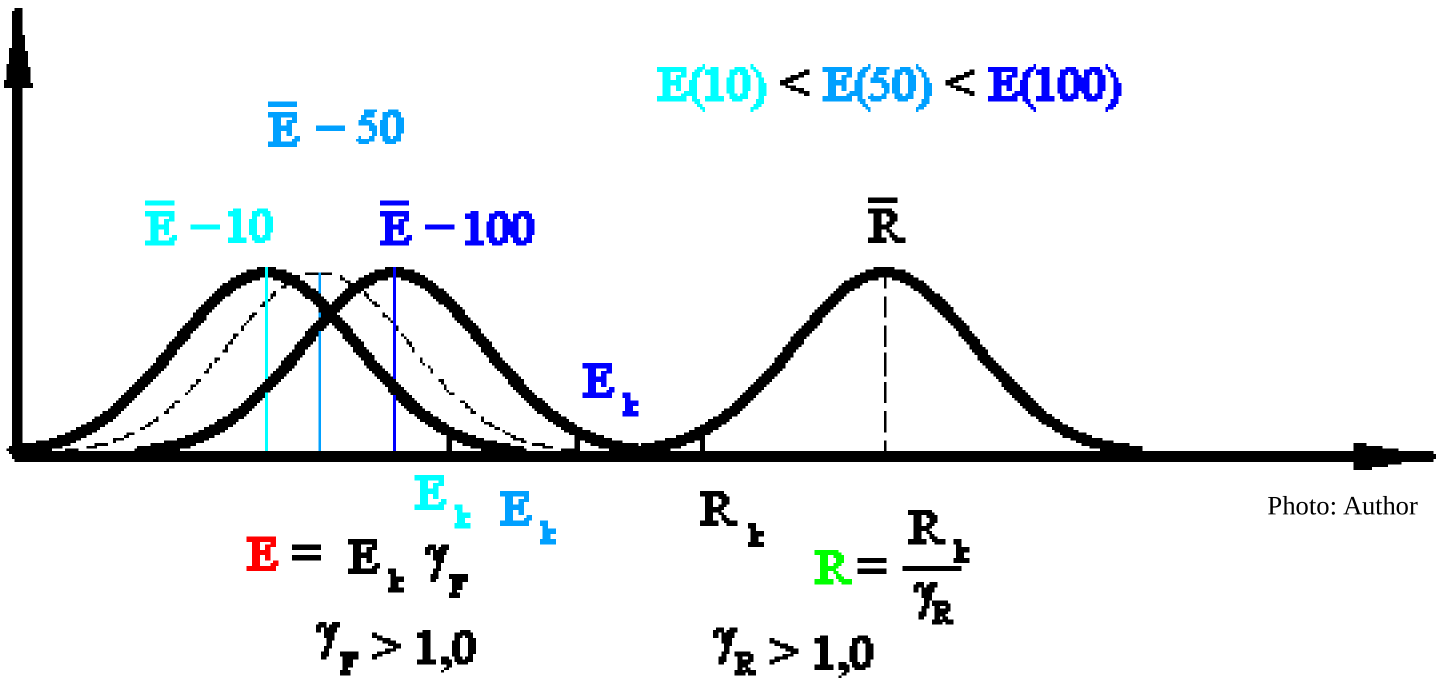


Photo: Author

$E / R \leq 1{,}0$

Consequences Classes and working life simultaneously – effects of recalculations				Working life (years)				
				10	10-25	15-30	50	100
				Recalculation of characteristic values of loads				
				Lower values			Base values	Higher values
Consequence Class	CC3	Recalculation of safety factors for loads	Higher value	L / H	L / H	L / H	Higher values	Higher values
	CC2		Base value	Lower values	Lower values	Lower values	Base values	Higher values
	CC1		Lover value	Lower values	Lower values	Lower values	Lower values	L / H

EN 1991 Actions on structures

(common name: Eurocode 1)

EN 1991-1 General actions:

- EN 1991-1-1 Densities, self-weight, imposed loads for buildings
- EN 1991-1-2 Actions on structures expose to fire
- EN 1991-1-3 Snow loads
- EN 1991-1-4 Wind actions
- EN 1991-1-5 Thermal actions
- EN 1991-1-6 Actions during execution
- EN 1991-1-7 Accidental actions
- EN 1991-1-8 Waves and coastal actions
- EN 1991-1-9 Atmosphering icing

EN 1991-2 Traffic loads on bridges

EN 1991-3 Actions induced by cranes and machinery

EN 1991-4 Silos and tanks

EN 1991-1-1 Densities, self-weight, imposed loads for buildings

Categories of use (table 6.1):

A Areas for domestic and residential activities;

B Office areas;

C Areas where people may congregate (with the exception of areas defined under category A, B, and D);

D Shopping areas;

E Areas susceptible to accumulation of goods, including access areas and industrial use;

FL Areas of actions induced by forklifts

F Traffic and parking areas for light vehicles (30 kN gross vehicle weight and 8 seats not including driver);

G Traffic and parking areas for medium vehicles (>30 kN, 160 kN gross vehicle weight, on 2 axles);

H Roofs not accessible except for normal maintenance and repair.

I Roofs accessible with occupancy according to categories A to D

K Roofs accessible for special services, such as helicopter landing areas

Examples of loads, defined in EN 1991-1-1:

Categories of loaded areas	q_k [kN/m^2]	Q_k [kN]
Category A		
- Floors	1,5 to2,0	2,0 to 3,0
- Stairs	2,0 to4,0	2,0 to 4,0
- Balconies	2,5 to 4,0	2,0 to 3,0
Category B	2,0 to 3,0	1,5 to 4,5
Category C		
- C1	2,0 to 3,0	3,0 to 4,0
- C2	3,0 to 4,0	2,5 to 7,0 (4,0)
- C3	3,0 to 5,0	4,0 to 7,0
- C4	4,5 to 5,0	3,5 to 7,0
- C5	5,0 to 7,5	3,5 to 4,5
category D		
- D1	4,0 to 5,0	3,5 to 7,0 (4,0)
- D2	4,0 to 5,0	3,5 to 7,0

EN 1991-1-1 tab. 6.2

Structure materials and storage products

Materials	Density γ [kN/m^3]
concrete (see EN 206)	
lightweight	
density class LC 1,0	9,0 to 10,0 [1)2)]
density class LC 1,2	10,0 to 12,0 [1)2)]
density class LC 1,4	12,0 to 14,0 [1)2)]
density class LC 1,6	14,0 to 16,0 [1)2)]
density class LC 1,8	16,0 to 18,0 [1)2)]
density class LC 2,0	18,0 to 20,0 [1)2)]
normal weight	24,0[1)2)]
heavy weight	> [1)2)]
mortar	
cement mortar	19,0 to 23,0
gypsum mortar	12,0 to 18,0
lime-cement mortar	18,0 to 20,0
lime mortar	12,0 to 18,0

1) Increase by 1kN/m^3 for normal percentage of reinforcing and pre-stressing steel
2) Increase by 1kN/m^3 for unhardened concrete

NOTE See Section 4

EN 1991-1-1 tab. A.1

Table A.12 - Stored products - industrial and general

Products	Density γ [kN/m^3]	Angle of repose ϕ[°]
books and documents		
books and documents,	6,0	-
densely stored	8,5	-
		-
filing racks and cabinets	6,0	-
garments and rags, bundled	11,0	-
ice, lumps	8,5	-
leather, piled	10,0	-
paper		
in rolls	15,0	-
piled	11,0	-
rubber	10,0 to 17,0	-
rock salt	22,0	45
salt	12,0	40
sawdust		
dry, bagged	3,0	-
dry, loose	2,5	45
wet, loose	5,0	45
tar, bitumen	14,0	-

NOTE See Section 4.

EN 1991-1-1 tab. A.12

EN 1991-1-2 Actions on structures expose to fire

Mechanical characteristics rapidly decreased for steel and aluminum structures during increasing of temperatures.

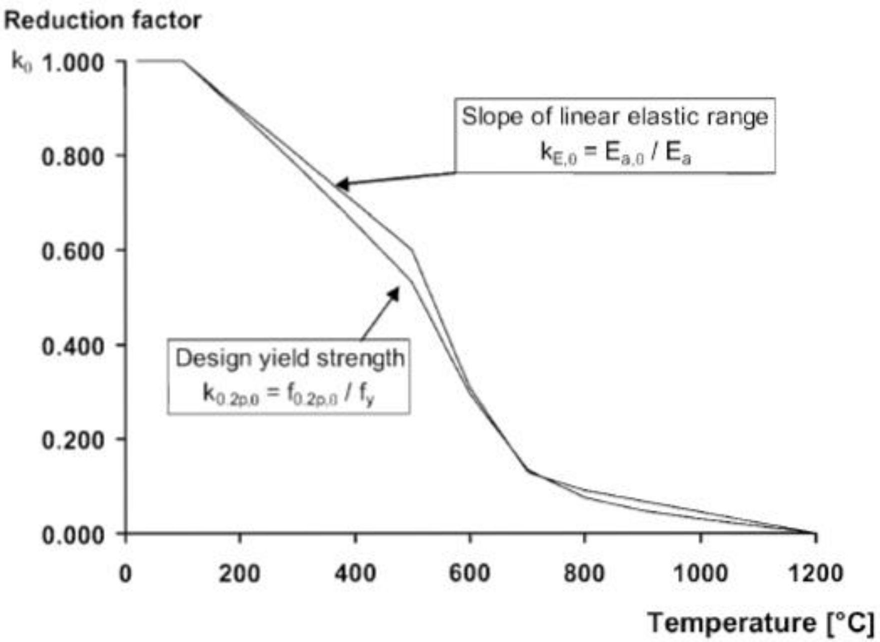


Photo: EN 1993-1-2 fig E.2

We must calculate, how much time we have to evacuation before structure collapses.

EN 1991-1-3 Snow loads   EN 1991-1-4 Wind actions

→ Des #1 / 30

For both, we have map of Poland and information about value of load at any region.

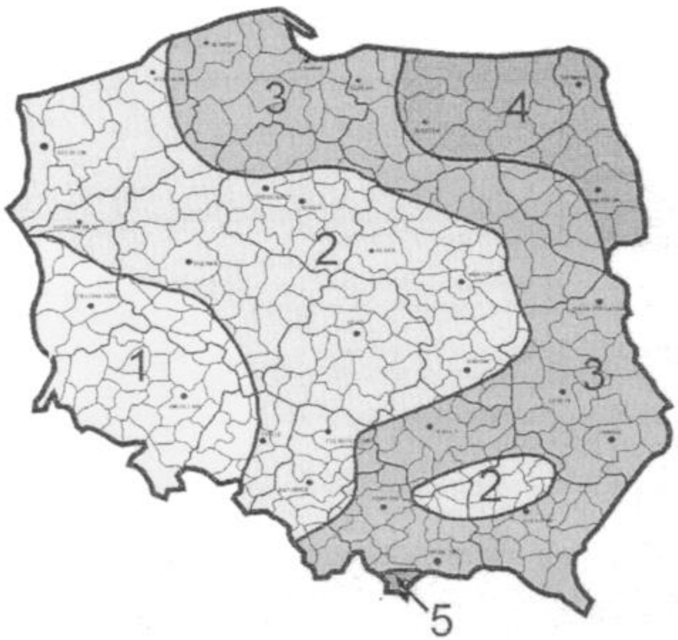


Photo: EN 1991-1-3 fig. B.1

Photo: EN 1991-1-4 fig. NB.1

This is global location - load are different for differen part of Poland

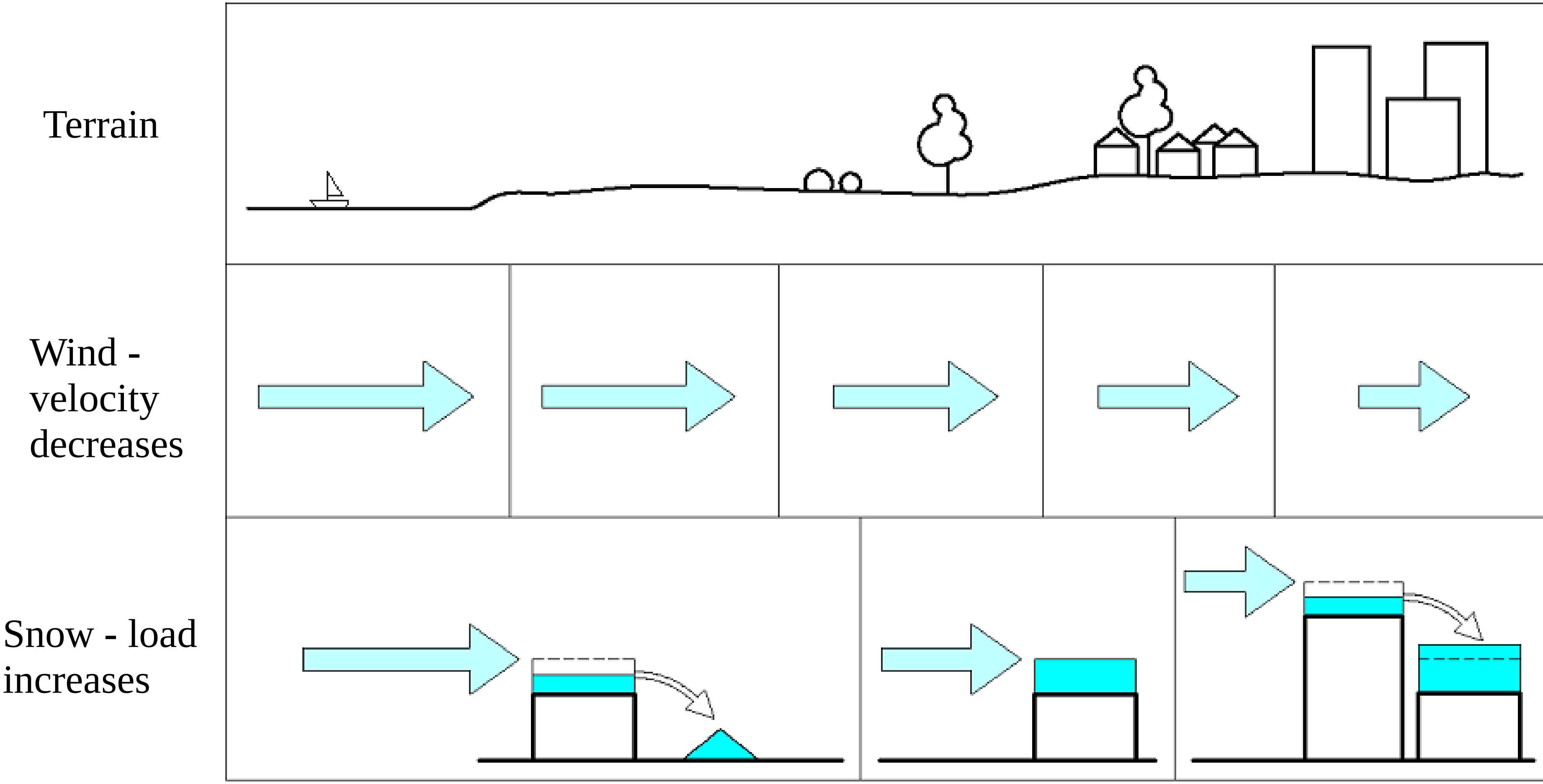
Besides, local wind velocity or snow load can be different, in dependence on surroundings - wind acts in different way in narrow streets and on the open space.

Photo: visitcracovia.com

Photo: krakjw.wordpress.com

Because of this, local location are defined for different environmental conditions.

There are five terrain categories for wind and three for snow. There are defined independently for snow (EN 1991-1-3 tab 5.1) and wind (EN 1991-1-4 tab 4.1). Rough comparison looks as follows:



→ Des #1 / 32

Photo: Author

Snow load

$$s_d = \gamma_f \ \mu_i \ C_e \ C_t \ s_k$$

$\gamma_f = 1{,}5$

C_e - terrain category → EN 1991-1-3 tab. 5.1 → #t / 49

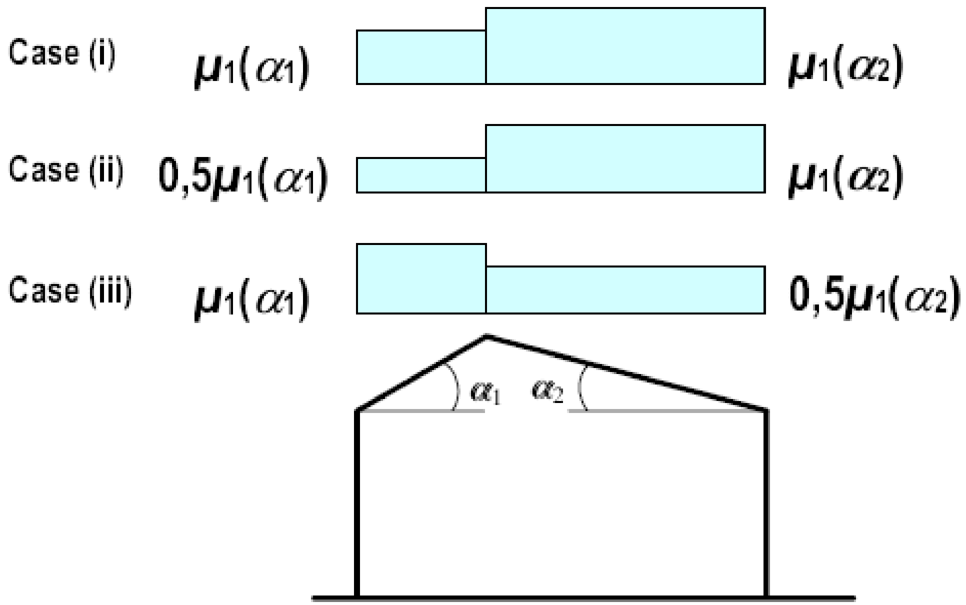
$C_t = 1{,}0$ (thermal coefficient; possibility of melting snow by heat from inside of structure)

s_k - basic value of snow load, according to region of Poland → EN 1991-1-3 fig NB1, tab NB1 → #t / 47

μ_i - shape of roof coefficient → EN 1991-1-3 p. 5.3, 6.1, 6.2, 6.3, 6.4, app B

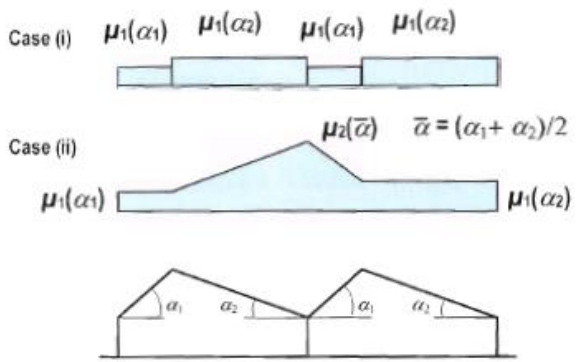
We must analyse symmetrical and antisymmetrical loads from snow.

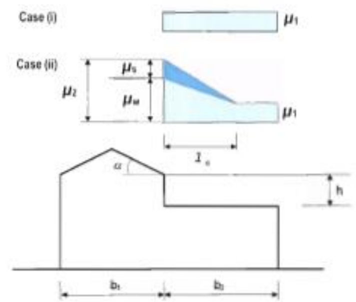
EN 1991-1-3 fig. 5.3

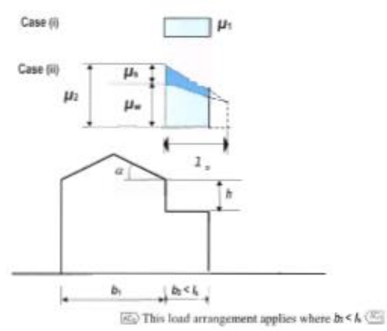


Exceptional conditions

Exceptional conditions, for Polish climate, means loads from driftings of snow ad projections and obstructions.







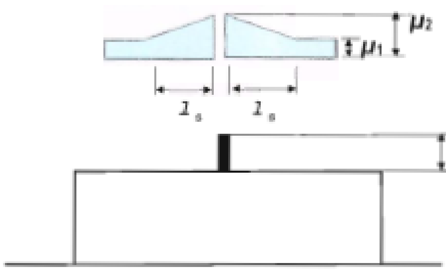


Photo: EN 1991-1-3 fig. 5.4, 5.7, 6.1

Wind action - algorithm

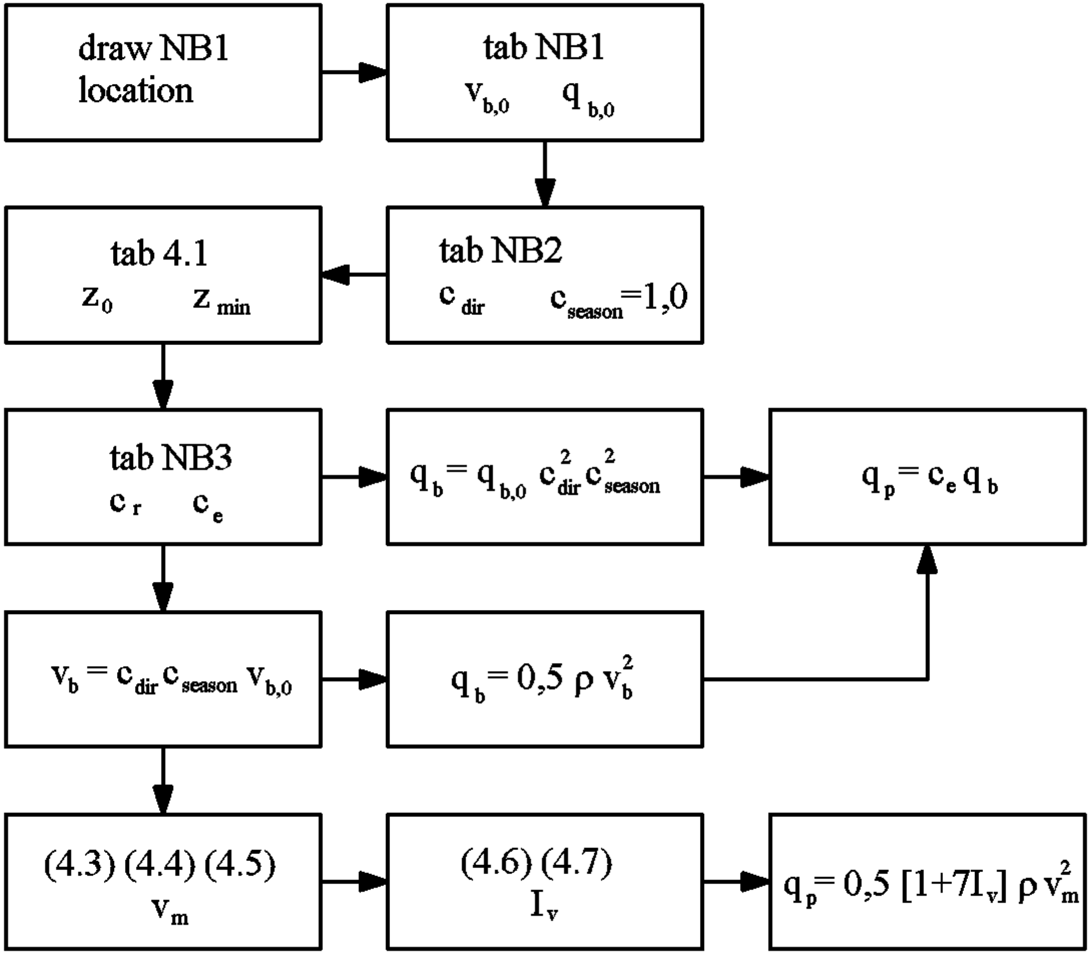


Photo: Author

Generally:

$$c_e\, q_b \approx 0,5\, [1+7I_v]\, \rho\, v_m^{\,2}$$

$v_{b,0}$, $q_{b,0}$ - basic values of wind velocity and wind pressure, according to region of Poland;

c_{dir} - different wind action according to different direction; dependent on region of Poland (for example - for Kraków the strongest wind are from south and west);

c_{season} - different wind actions in dependence of seasons; for Poland = 1,0, for other european countries can be different;

z_0, z_{min}, c_r, c_e - coefficients, which described change of wind velocity in function of altitude and terrain category.

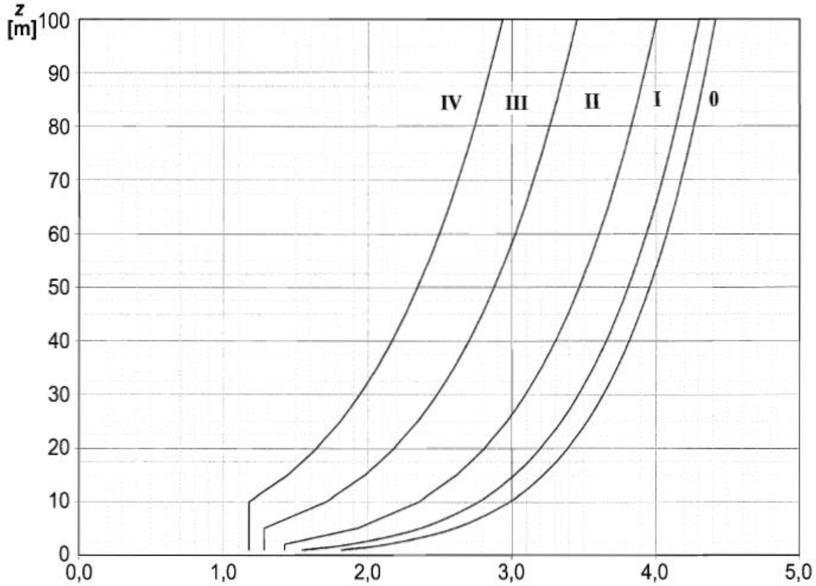


Photo: EN 1991-1-4 fig. 4.2

Wind action acts on roof and walls. For this range of project, important is only actions on blue part of building (truss), not on red part (masonry). There is important, that for roof can be nonlinear wind action (wind action depends on height).

→ Des #1 / 33

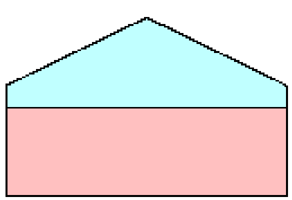
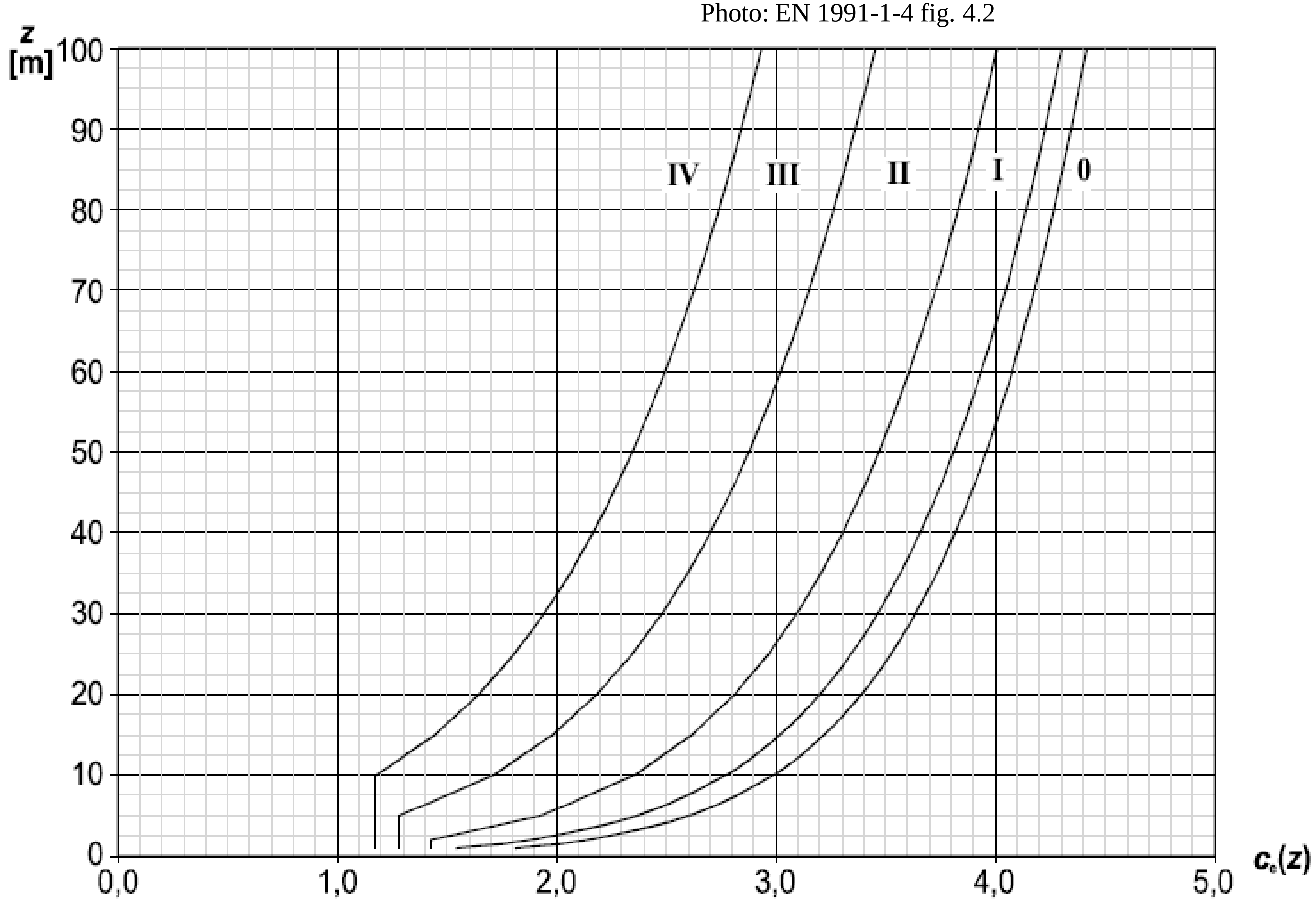


Photo: Author

Photo: EN 1991-1-4 fig. 4.2



For roofs and walls of buildings

$$w_e = \gamma_f \; c_{pi\,/\,pe} \, q_p$$

$\gamma_f = 1{,}5$

c_{pi} c_{pe} - coefficients of internal and external pressure → EN 1991-1-4 p. 7 (shape of structure)

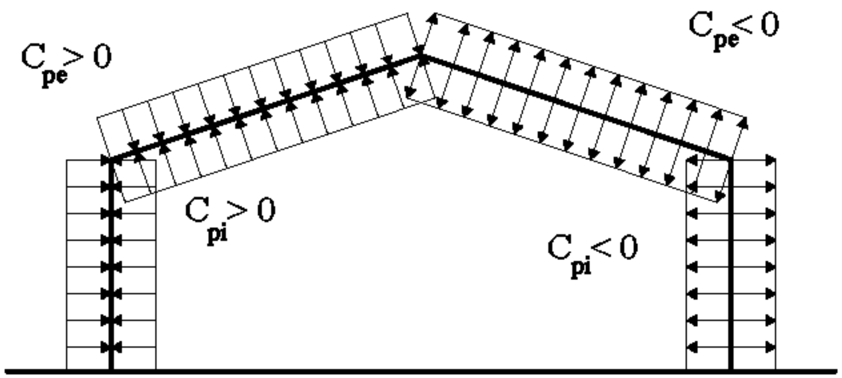


Photo: Author

For other types of structures

$$w_f\ [kN/m^2] = \gamma_f\ c_s c_d\ c_f\ q_p$$

or

$$F_w\ [kN] = \gamma_f\ c_s c_d\ c_f\ q_p\ A$$

$\gamma_f = 1,5$

c_f - aerodynamic coefficient → EN 1991-1-4 p. 7 (shape of structure)

$c_s c_d$ - dynamic coefficient → #t / 58

For structures non-susceptible to dynamic action of wind

$c_s c_d = 1,0$

For structures susceptible to dynamic action of wind

$c_s c_d \rightarrow$ EN 1991-1-4 p. 6.1, 6.2, 6.3

Susceptible or non-susceptible? → EN 1991-1-4 p. 6.2

Examples of susceptible: mast, tower, chimney, light bridge and footbridge, suspension roof, tension component

Examples of non-susceptible: bridge, office building, hall (each structure, which you will design on Ist step of study)

Rough approximation according to old Polish Standard PN B 02011

Susceptibe

Non-susceptible

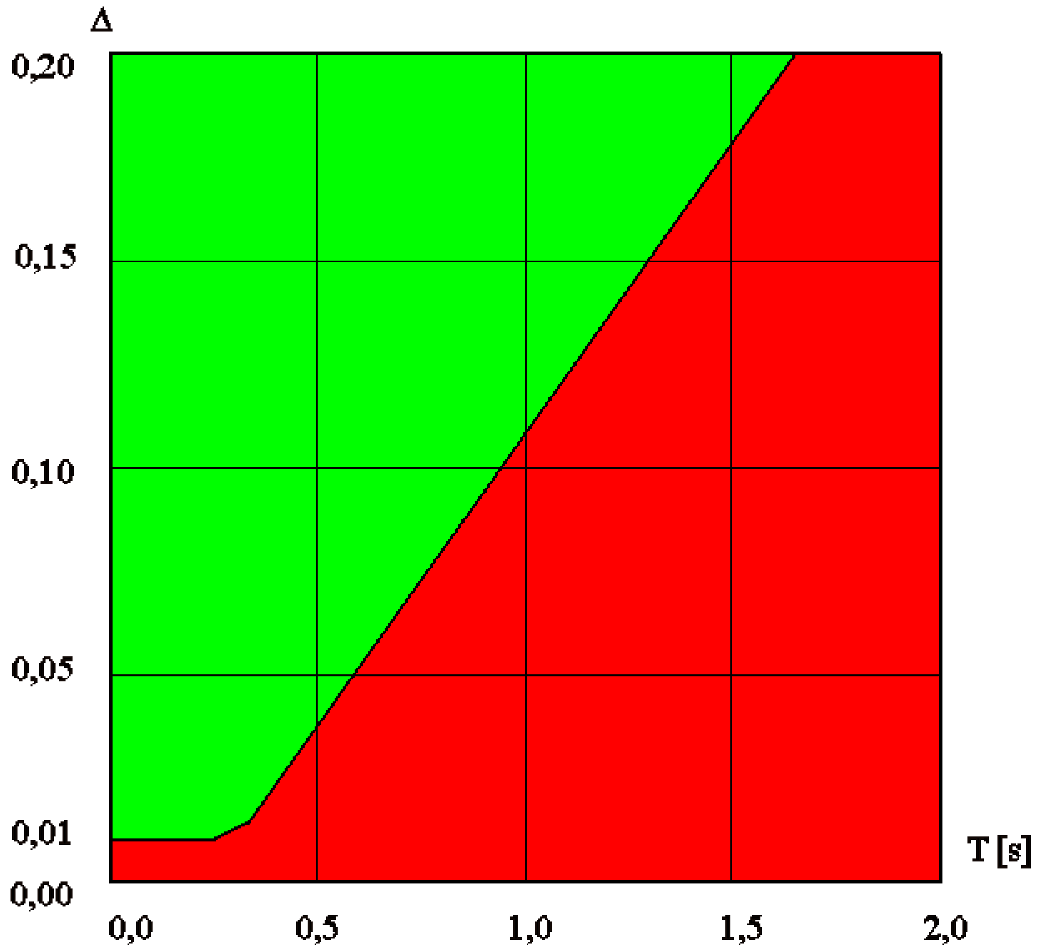
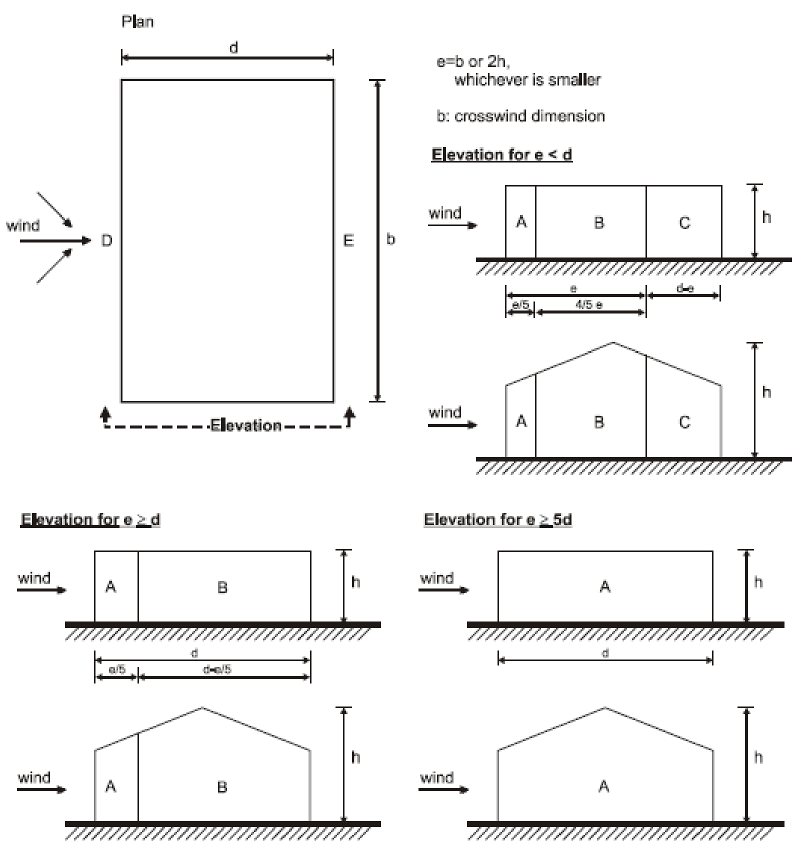


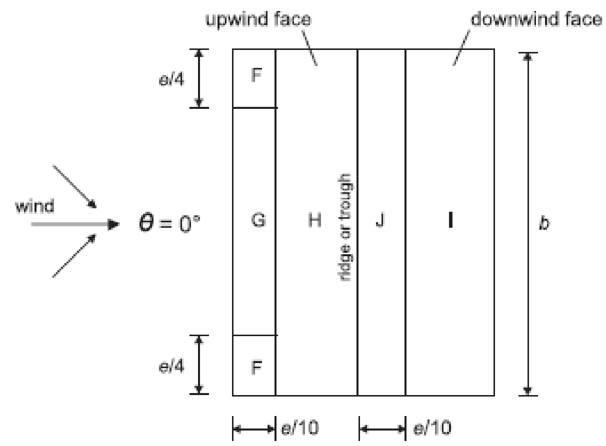
Photo: PN B 02011 fig. 1

We must analyse wind parallel and perpendicular to longitudinal axis of building.

EN 1991-1-4 fig. 7.5, 7.8

→ Des #1 / 34

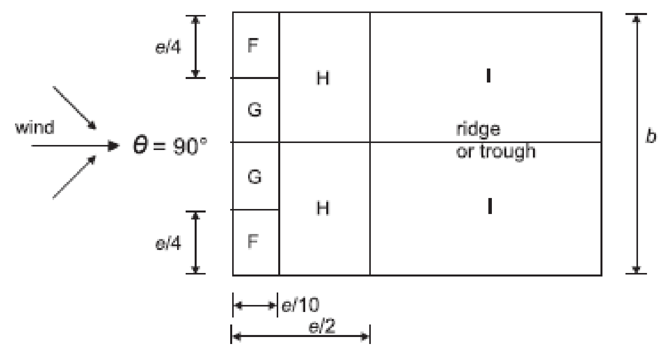




(b) wind direction $\theta = 0°$

$e = b$ or $2h$
whichever is smaller

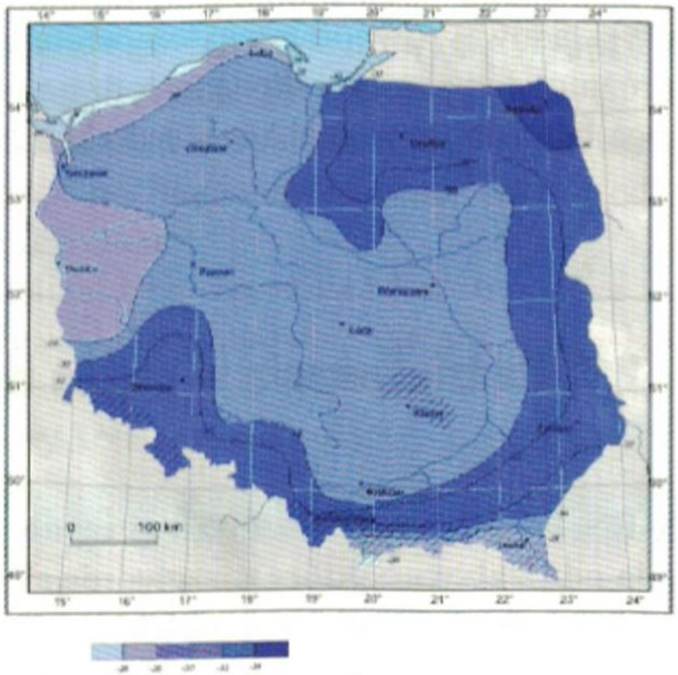
b : crosswind dimension



(c) wind direction $\theta = 90°$

EN 1991-1-5 Thermal actions

Difference between temperature of erection and temperature of exploatation



$$\Delta T = T_{min\,/\,max} - T_0$$

$$T_0 = 8\ ^oC$$

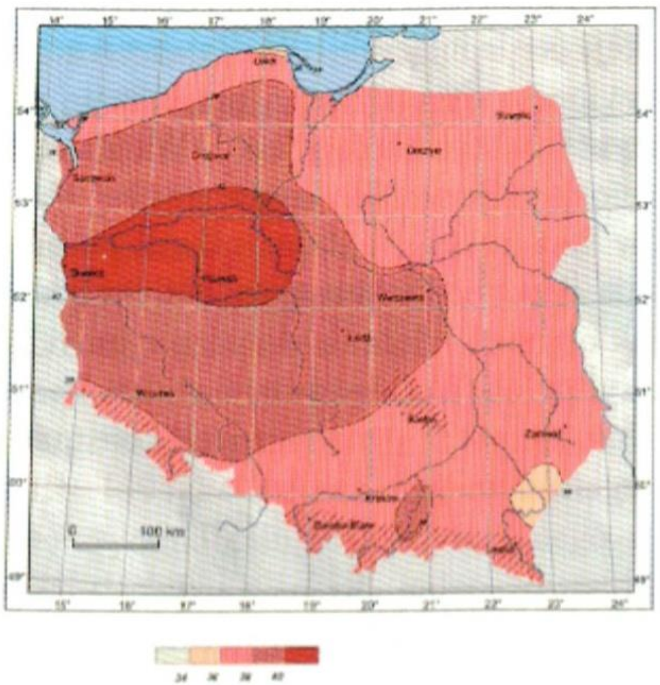


Photo: EN 1991-1-5 fig NB.3

$$T_{min}(H) = -0{,}0035\ [^oC\ /\ m]\ H + T_{min}$$

Photo: EN 1991-1-5 fig NB.2

$$T_{max}(H) = -0{,}0053\ [^oC\ /\ m]\ H + T_{max}$$

There are additional information about processes temperatures for few types of structures (for example chimneys)

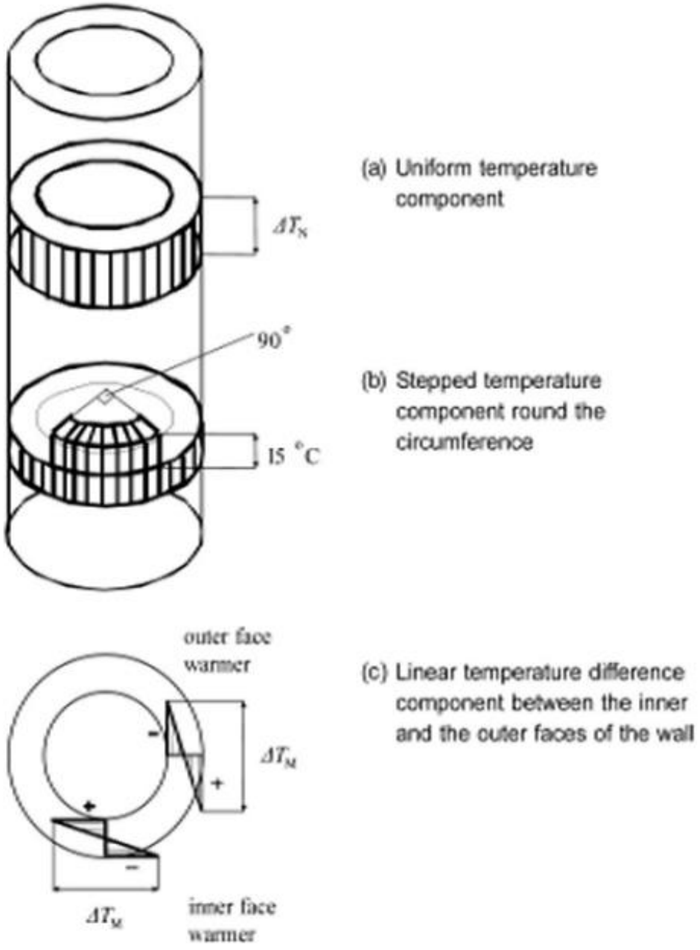


Photo: EN 1991-1-5 fig. 7.1

EN 1991-1-6 Actions during execution - workers, machines action, timbering...

Photo: money.pl

Photo: wikipedia

Photo: zbm.home.pl

EN 1991-1-7 Accidental actions

Photo: radiomerkury.pl

Photo: article.wn.com

Photo: acehotel.com

Photo: nczas.com

Photo: tvn24.pl

Photo: dailymail.co.uk

Photo: dailymail.co.uk

Actions generated by vehicles (cars, trams, trains, forklifts, ships)

Photo: ruwac.com

But EN 1991-1-7 **not includes** effects of :

Photo: telecombloger.ru

Special actions:

Dust explosions (in silos)

Gas explosions (pipelines, tanks)

Photo: pakistantoday.com.pk

Photo: cnbc.com

terrorist attack
war
explosive materials

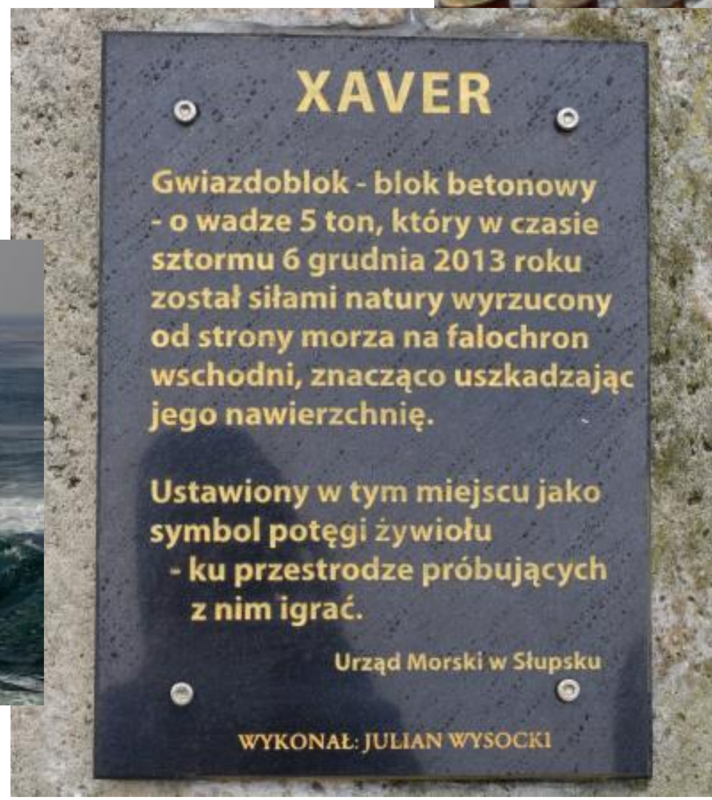
Photo: mysafetysign.com

EN 1991-1-8 Actions from waves and currents on coastal structures

Eurocode in preparation

Photo: Author

Photo: wikipedia


XAVER

Gwiazdoblok - blok betonowy - o wadze 5 ton, który w czasie sztormu 6 grudnia 2013 roku został siłami natury wyrzucony od strony morza na falochron wschodni, znacząco uszkadzając jego nawierzchnię.

Ustawiony w tym miejscu jako symbol potęgi żywiołu - ku przestrodze próbujących z nim igrać.

Urząd Morski w Słupsku

WYKONAŁ: JULIAN WYSOCKI

Photo: morska-przystan.pl

EN 1991-1-9 Atmospheric icing is one of the most important types of actions for many steel structures: masts, towers, electro-energetic towers, rope structures. Eurocode in preparation.

Photo: iwas.org

Photo: ise.pl

Photo: imgur.com

Photo: hin.no

EN 1991-2 Traffic loads on bridges

Photo: EN 1991-2 fig. 4

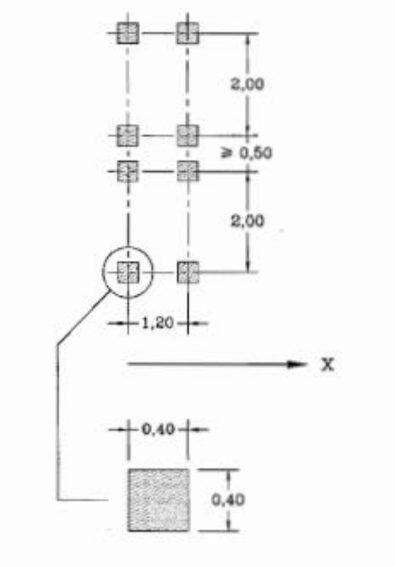


Photo: obiezyswiatka.eu

Photo: newsweek.pl

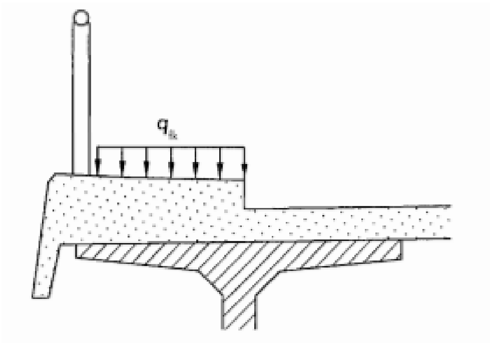


Photo: EN 1991-2 fig. 5.1

Photo: kurier-kolejowy.pl

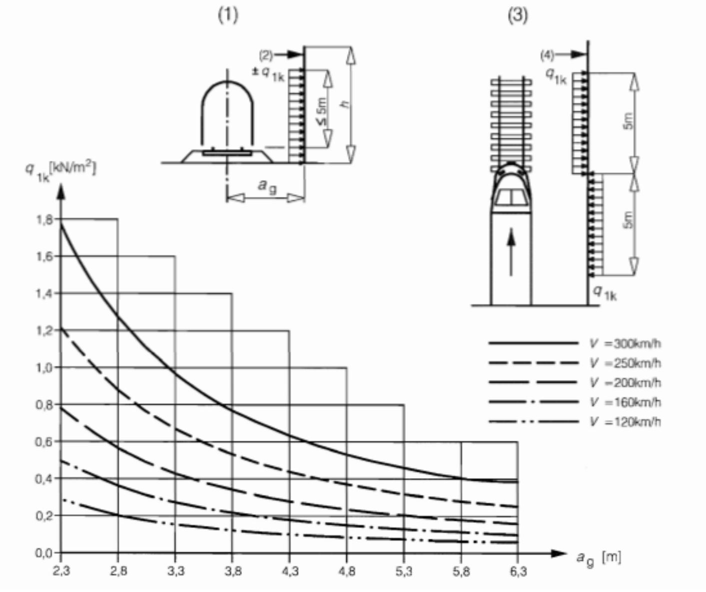


Photo: EN 1991-2 tab. 6.22

EN 1991-3 Actions induced by cranes and machinery

Photo: sztaplarek.pl

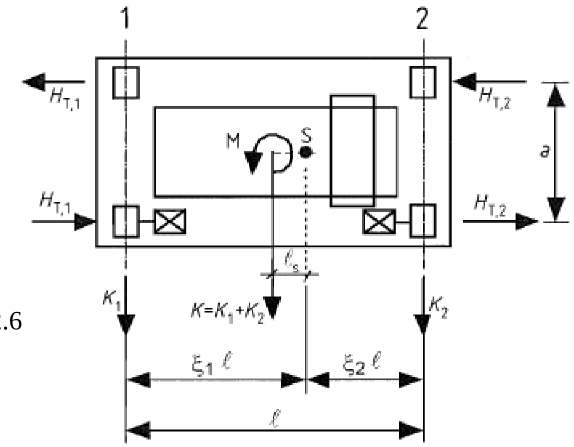


Photo: EN 1991-3 fig. 2.6

EN 1991-4 Silos and tanks

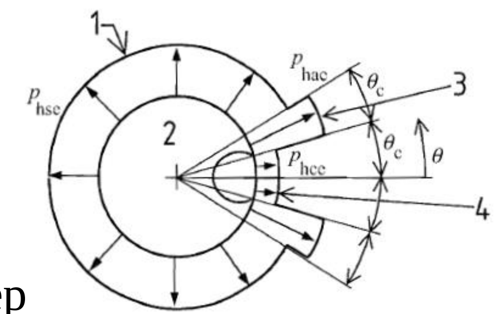


Photo: EN 1991-4 fig. 5.5

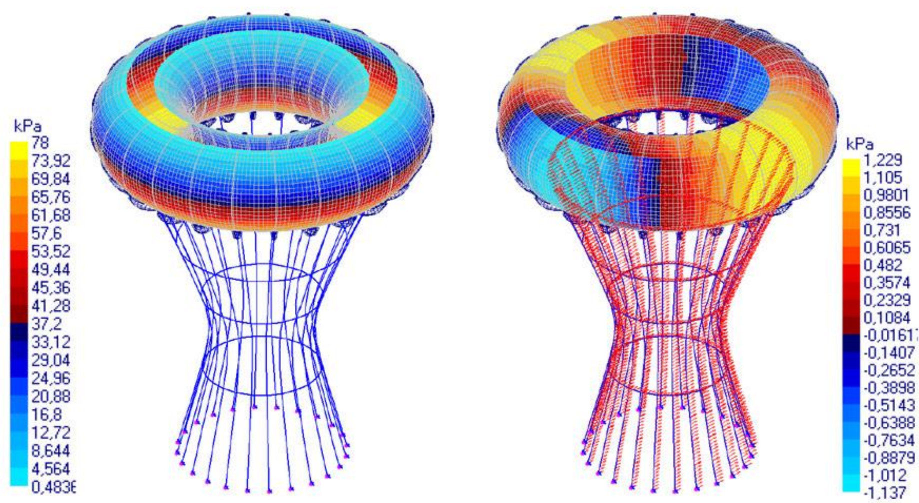


Photo: tarnow.net.pl

Both will be detaily presented on IInd step of studies

EN 1993 Design of steel structures

(common name: Eurocode 3)

EN 1993-1 General rules:

- EN 1993-1-1 General rules and rules for buildings
- EN 1993-1-2 Structural fire design
- EN 1993-1-3 Supplementary rules for cold-formed members and sheeting
- EN 1993-1-4 Supplementary rules for stainless steels
- EN 1993-1-5 Plated structural elements
- EN 1993-1-6 Strength and stability of shell structures
- EN 1993-1-7 Plated structures subject to out of plane loading
- EN 1993-1-8 Design of joints
- EN 1993-1-9 Fatigue
- EN 1993-1-10 Material toughness and through-thickness properties
- EN 1993-1-11 Design of structures with tension components
- EN 1993-1-12 Additional rules for the extension of EN 1993 up to steel grades S 700

EN 1993 Design of steel structures (part II)

EN 1993-2 Steel bridges

EN 1993-3 Towers, masts and chimneys :

EN 1993-3-1 Towers and masts

EN 1993-3-2 Chimneys

EN 1993-4 Silos, tanks and pipelines:

EN 1993-4-1 Silos

EN 1993-4-2 Tanks

EN 1993-4-3 Pipelines

EN 1993-5 Pilling

EN 1993-6 Crane supporting structures

EN 1999 Design of aluminiuml structures

(common name: Eurocode 9)

EN 1999-1-1 General structural rules

EN 1999-1-2 Structural fire design

EN 1999-1-3 Structures susceptible to fatigue

EN 1999-1-4 Cold-formed structural sheeting

EN 1999-1-5 Shell structures

Philosophy of metal Eurocodes

Level of calculation → #t / 74-76

Parts of structure → #t / 77-82

Imperfections → #t / 83-84

Classes of cross-sections → #t / 85

First- and second-order analysis → #t / 86

Elastic and plastic analysis → #t / 87

Level of calculation - different for different level of structure

Level of point:

$$T_\sigma = \begin{matrix} \sigma_{11} & \tau_{12} & \tau_{13} \\ \tau_{21} & \sigma_{22} & \tau_{23} \\ \tau_{31} & \tau_{32} & \sigma_{33} \end{matrix}$$

$$\sigma_{HMH} = \sqrt{[\sigma_{11}^2 + \sigma_{22}^2 + \sigma_{33}^2 - \sigma_{11}\sigma_{22} - \sigma_{11}\sigma_{33} - \sigma_{22}\sigma_{33} + 3(\tau_{12}^2 + \tau_{23}^2 + \tau_{13}^2)]}$$

$$\sigma_{HMH} / f_y \leq 1{,}0$$

$$\sigma_{HMH} = \sqrt{[\sigma^2 + 3(\tau_1^2 + \tau_2^2)]}$$

Welds (I[st] step of study)
Shells, fatigue calculations, crane supporting structures (II[nd] step of study)

(~ 10% of calculation's conditions)

Level of cross-sections:

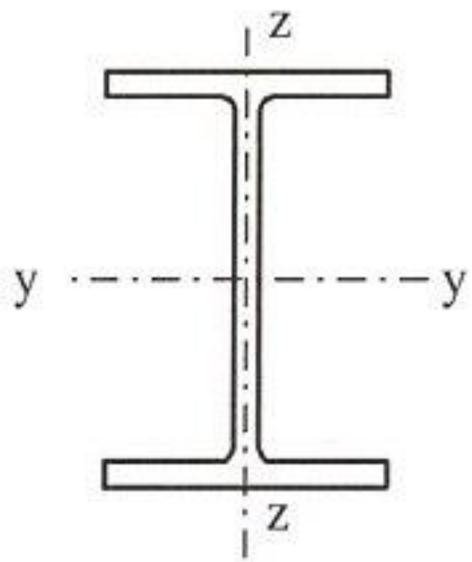


Photo: Author

F – geometrical characteristic of cross-section

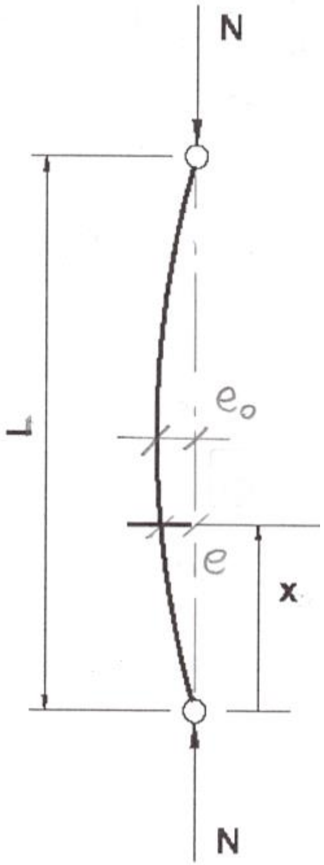
$$R = F\ f_y$$

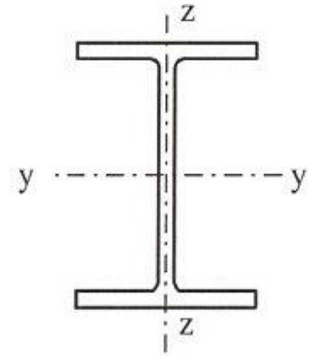
$$E / R \leq 1{,}0$$

Elements, nodes - when instability is not important; bolts, rivets, pins

(~ 40% of calculation's conditions)

Level of elements:





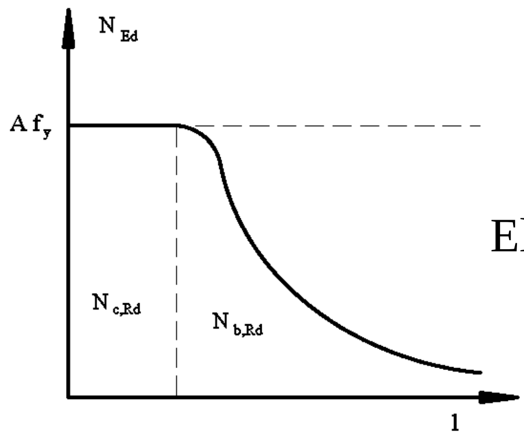


Photo: Author

F – geometrical characteristic of cross-section
χ - instability coefficient (depends on element geometry)

$$R = \chi F f_y$$

$$E / R \leq 1{,}0$$

Elements, nodes - when instability is important

(~ 60% of calculation's conditions)

Parts of structure

Photo: Author

Each steel structure can be divided into three parts:

- members
- connections
- joints

Members

Bars, beams, purlins, rafters, girders, columns, bracings - calculations according to level of cross-section or level of element.

Photo: Author

Photo: civildigital.com

Example from Ist design project: resistance and stability of truss bars.

(~ 40% of calculation's conditions)

Connections

Welds and shank of bolts - calculation according to level of point (for welds) or cross-section (shearing resistance or tension resistance of shank of bolts)

Example from Ist design project: resistance for welds.

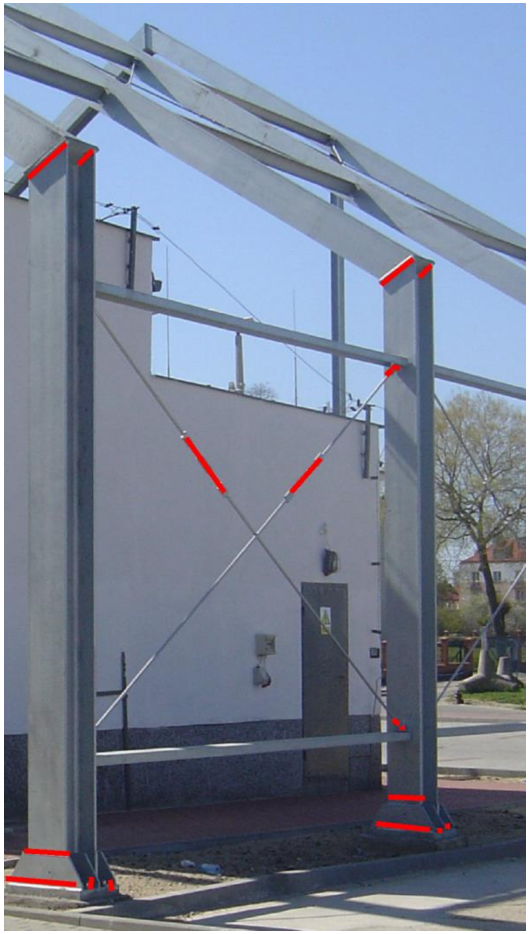


Photo: Author

Photo: ceprofs.civil.tamu.edu

Photo: researchgate.net

(~ 10% of calculation's conditions)

Joints

Small parts of members, where are contact between two or more members. There are many specific phenomenons on these short part of beams, columns, etc. Calculation according to level of cross-section and level of element.

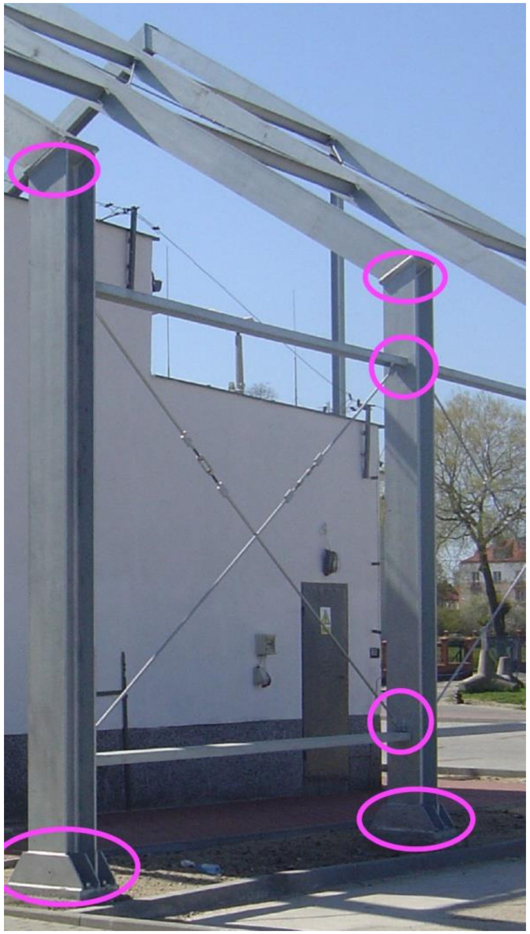


Photo: Author

Example from Ist design project: resistance of truss joints.

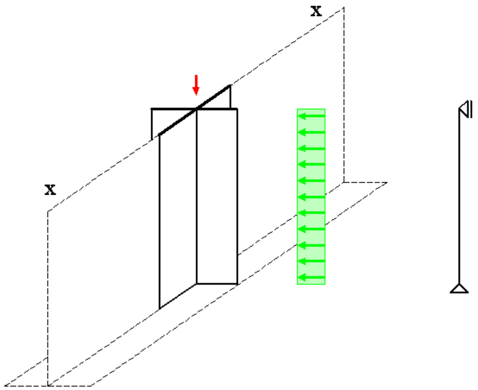
Photo: scielo.br

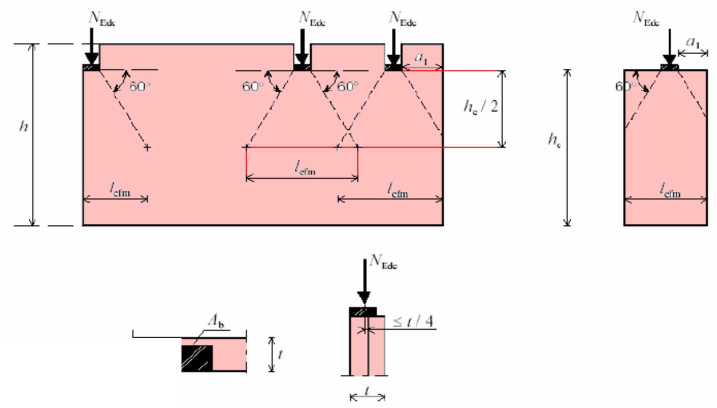
Photo: ascelibrary.org

Photo: osha.gov

(~ 60% of calculation's conditions)

Joints - more examples:





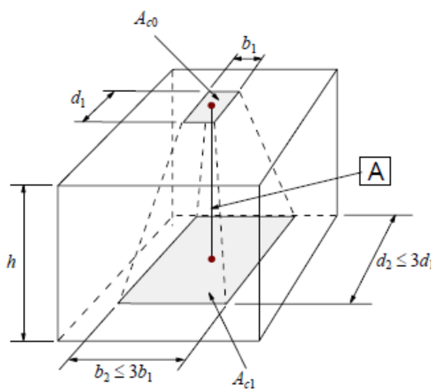
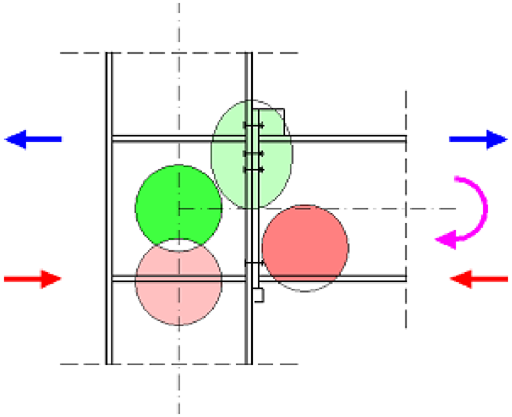


Photo: Author



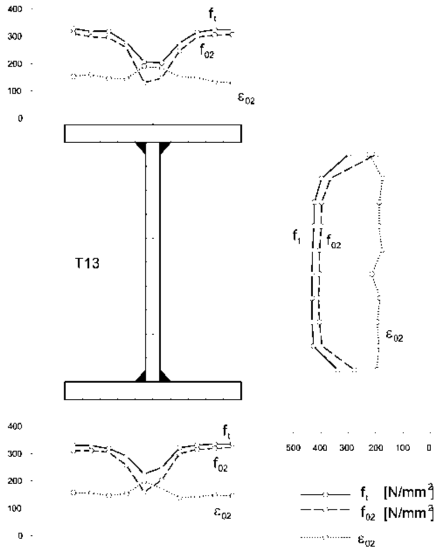
- vertical stiffeners;
- support on masonry structures;
- contact with concrete base;
- rigid join beam-column;
- and many many others;

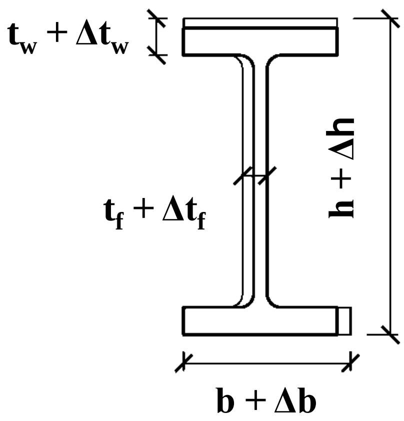
Distinction between "connection" and "joint" is not completely clear and precise in Eurocode.

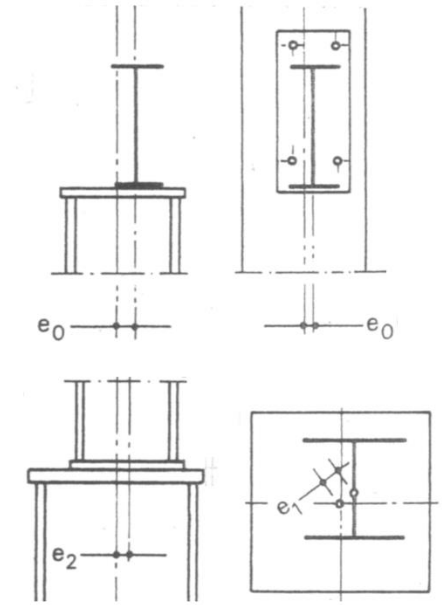
The simplest situation is for welded structures: it's opposition between resistance of welds (calculated at level of point, #t / 74) and resistance and stability of short parts of members at zone of interactions of loads and stresses (calculated by many specific ways, depend on type of joint).

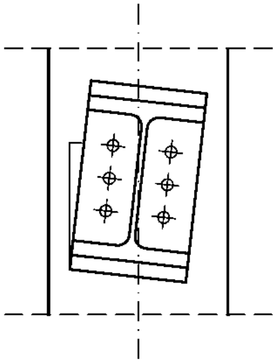
In case ofbolted structures, distinction "connection" - "joint" is problematic. The same, resistance and stability of short parts of members at zone of interactions of loads and stresses must be calculated. Shanks of bolts can be analysed as "connections", but additionally occurs many specific phenomenons concern interaction between shanks and adjacent parts of members.

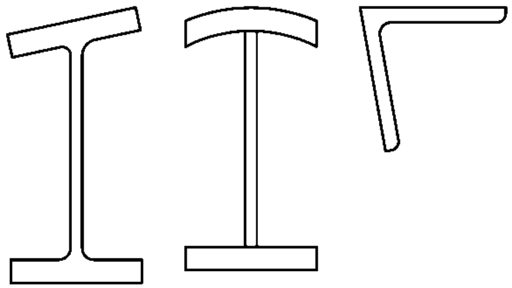
Imperfections - there are no ideal structures in real world











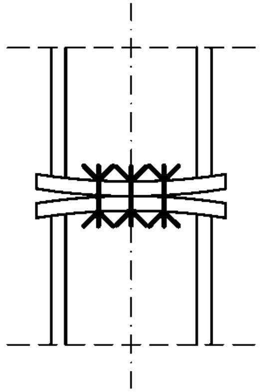
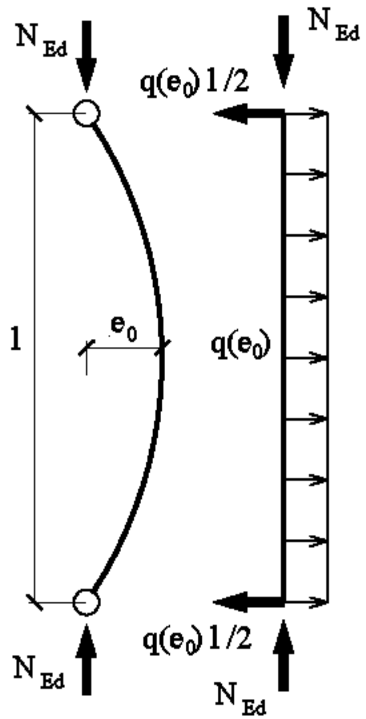


Photo: Author

This phenomenon is mainly presented as bow imperfections and sway imperfections - both causes additional cross-sectional forces



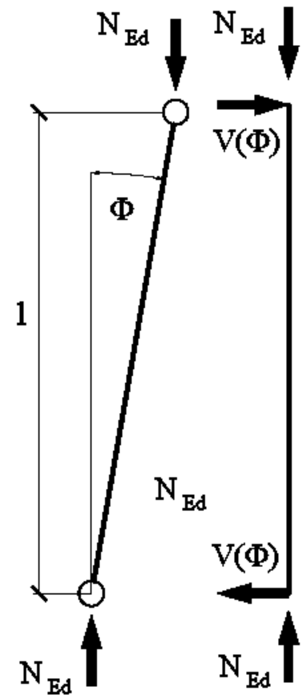
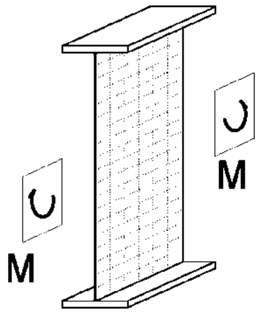
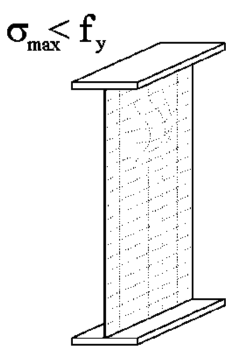


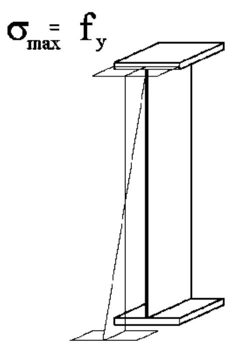
Photo: Author

Many other ways of analysis of imperfections will be presented on Lecture #6

Classes of cross-section - different resistance for local instabilities







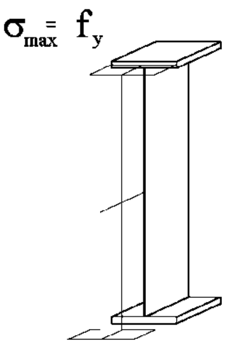


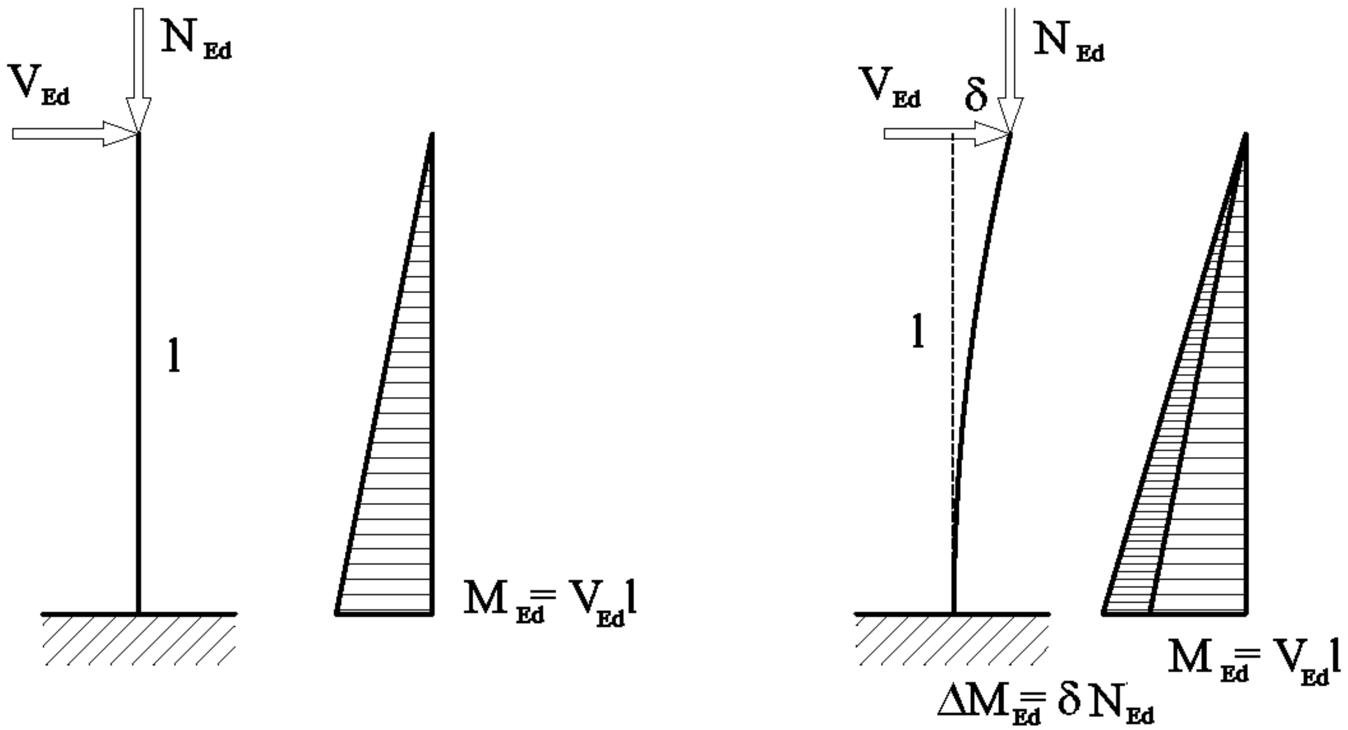
Photo: Author

Different formulas of R

First- and second-order analysis

There is additional bending moment from axial force for very flexible structures

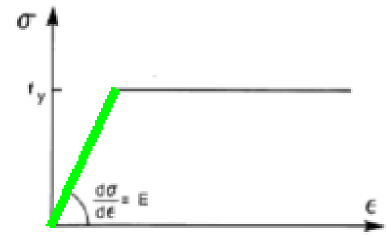
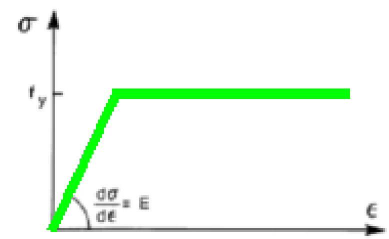
Photo: Author



For calculations, new value of horizontal force is applied: $V_{Ed}^{*} = V_{Ed}\ \alpha^{*}$

Elastic and plastic analysis

Photo: Author

Analysis	Class of corss-section → #t / 85	Stress-strain relationship EN 1993-1-1 fig. 5.3
Elastic	I, II, III, IV	
Plastic	I	

Different formulas for resistance for elastic and plastic analysis

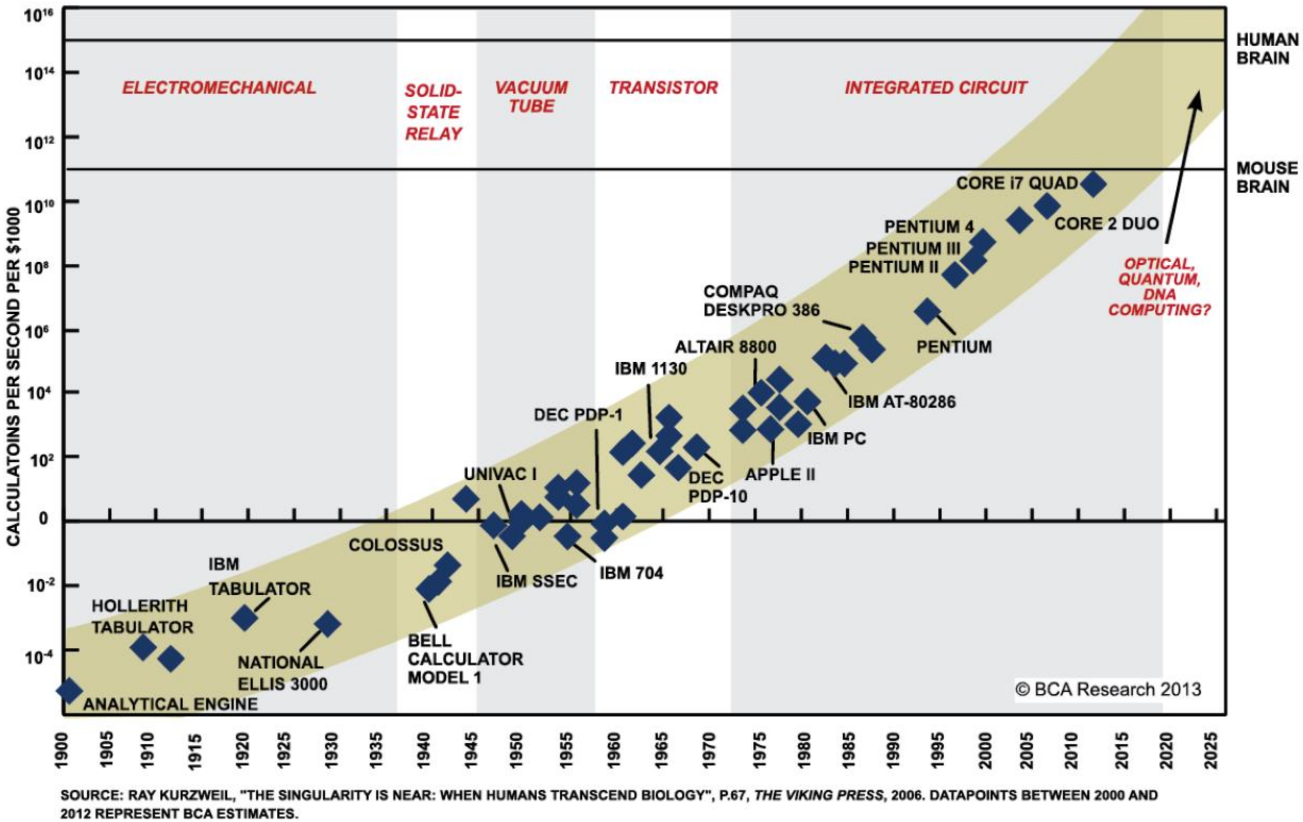
Additional important information

1975 – Beginning of work on the Eurocodes;

1980 – 2000 – Work in progress;

About 2004 – Final versions of Eurocodes;

Photo: dobreprogramy.pl



Conclusion: work on the Eurocodes starts,when computing power of computers was

~10 800 000 000 times less (!)

than today; was finished, when computing power of computers was

~10 000 times less (!)

than today.

Fundamental assumption of Eurocodes: all calculations can be performed without a computer (handmade = Forces Method, Displacements Method). The Eurocodes incorporated a number of procedures to simplify calculations (3D → 2D; nonlinear relationship → linear relationship + additional effects; etc). Today some of these simplifications are not really needed, because of the increase in computing power of computers.

Today, not quite in the spirit of the Eurocodes, we should try to take full advantage of computers.

Calculations:	Handmade	By computer
2 D	**Acceptable**	Acceptable
3 D	Acceptable	**Recommended**

Calculations:	Handmade	By computer
Elastic analysis: linear dependence **σ–ε**	**Conditionally acceptable (II – IV class c-s)**	Acceptable (linear model of material)
Plastic analysis: nonlinear dependence **σ–ε** (material nonlinerality)	**Conditionally acceptable (I class c-s)**	**Recommended (nonlinear model of material)**

Calculations:	Handmade	By computer
I[st] order effects	**Conditionally acceptable (→ #/86)**	Acceptable (smal deformations)
II[nd] order effects (geometrical nonlinerality)	**Conditionally acceptable (→ #/86)**	**Recommended (large deformations)**

Photo: genius.com

ATTENTION

Computer is never more clever than user

Photo: wikipedia

Photo: thesaltfactory.org

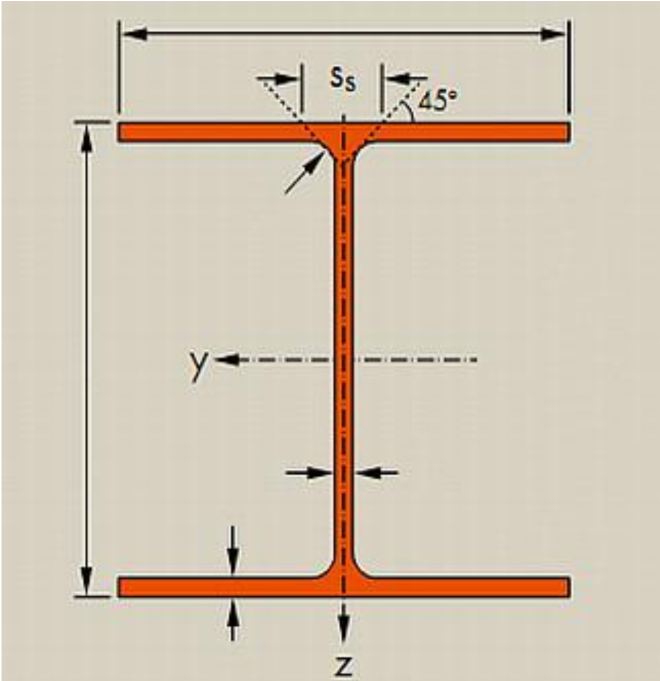


Photo: optimax.pl

Axes

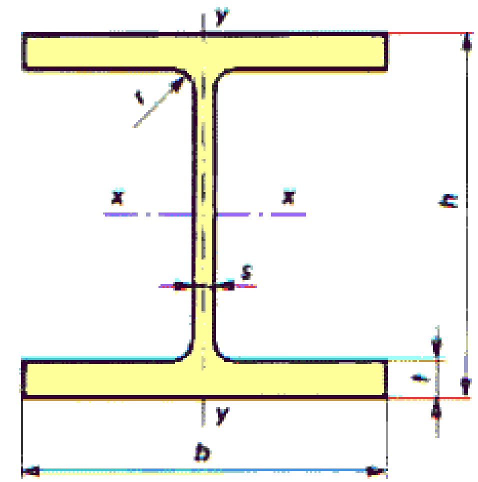


Photo: stalesia.com

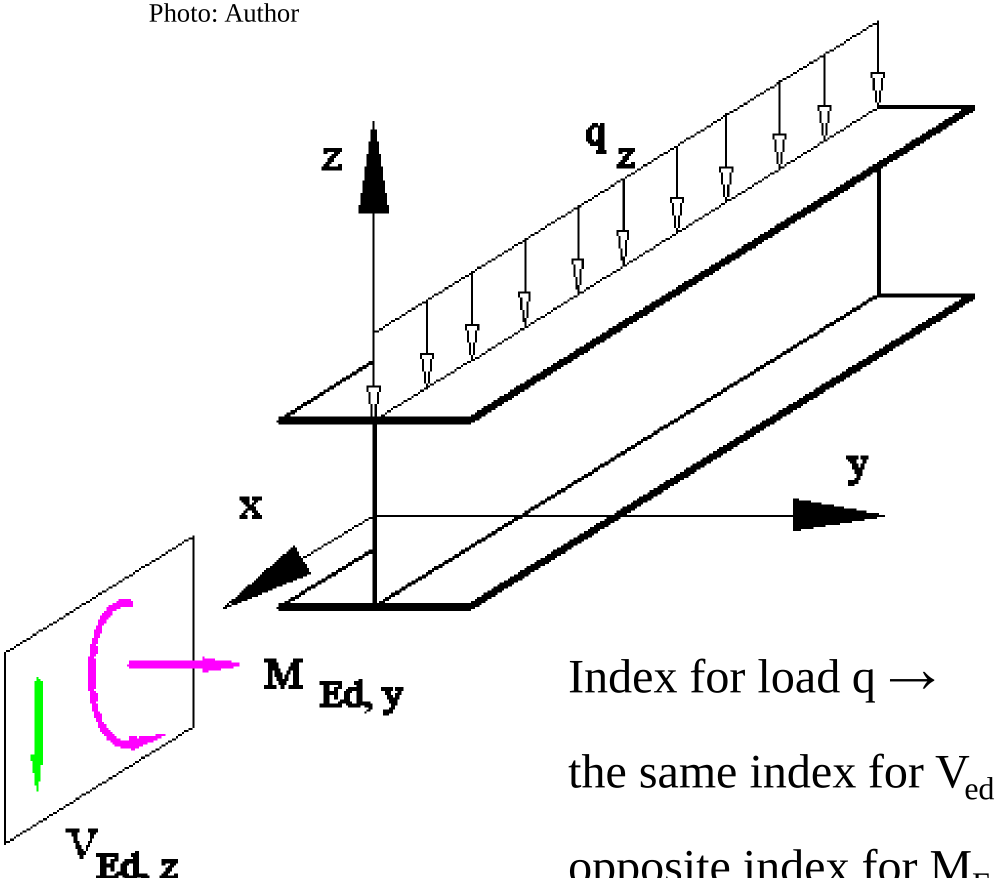
According to Eurocodes, for I-beam horizontal axis of cross-section is named Y, vertical - Z

There are many old-editions tables, where horizontal axis of cross-section is named X, vertical - Y

There is danger to confuse the geometrical characteristics for the old and the new Y

Names of axes, cross-sectional forces, displacements and loads

Photo: Author



$q_z \rightarrow V_{Ed,\,z}$, $M_{Ed,\,y}$

$\Delta_z = a\, q_z\, l^4 / (E\, J_y)$

$M_{Rd,\,y} \approx W_y$

Index for load q →

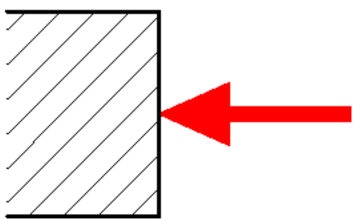
the same index for V_{ed} and Δ (y → y, z → z);

opposite index for $M_{Ed,}$, $M_{Rd,}$, J and W (y → z, z → y);

Positive and negative stress

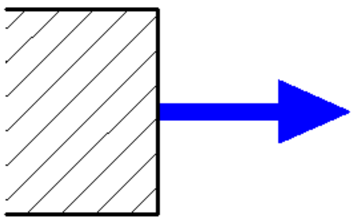
→ Des #1 / 48

According to Eurocodes:



$N_{Ed} > 0$
$\sigma > 0$

Photo: Author



$N_{Ed} < 0$
$\sigma < 0$

There is possible, that for diferent computer programmes these signs can be adopted by the opposite way. It's very important especially for buckling under axial force (buckling ↔ compressive force).

Unfortunately, in Eurocode can be found many inconsequences. The most often case is:

General situation is divided into sub-cases

A – full information about way of calculation

B – no information about way of calculation

The most part of such situation concern various phenomenon in rigid bolted joints (for example: resistance for netto area around hols for bolts, stiffness of shear joints, impact of axial force for bending moment resistance).

Rare case is contradictions between different points in Eurocode. An examples are calculation of concrete base resistance under hinged support of columns or calculation of built-up columns.

All these problems will be mentioned in future lectures.

Algorithm

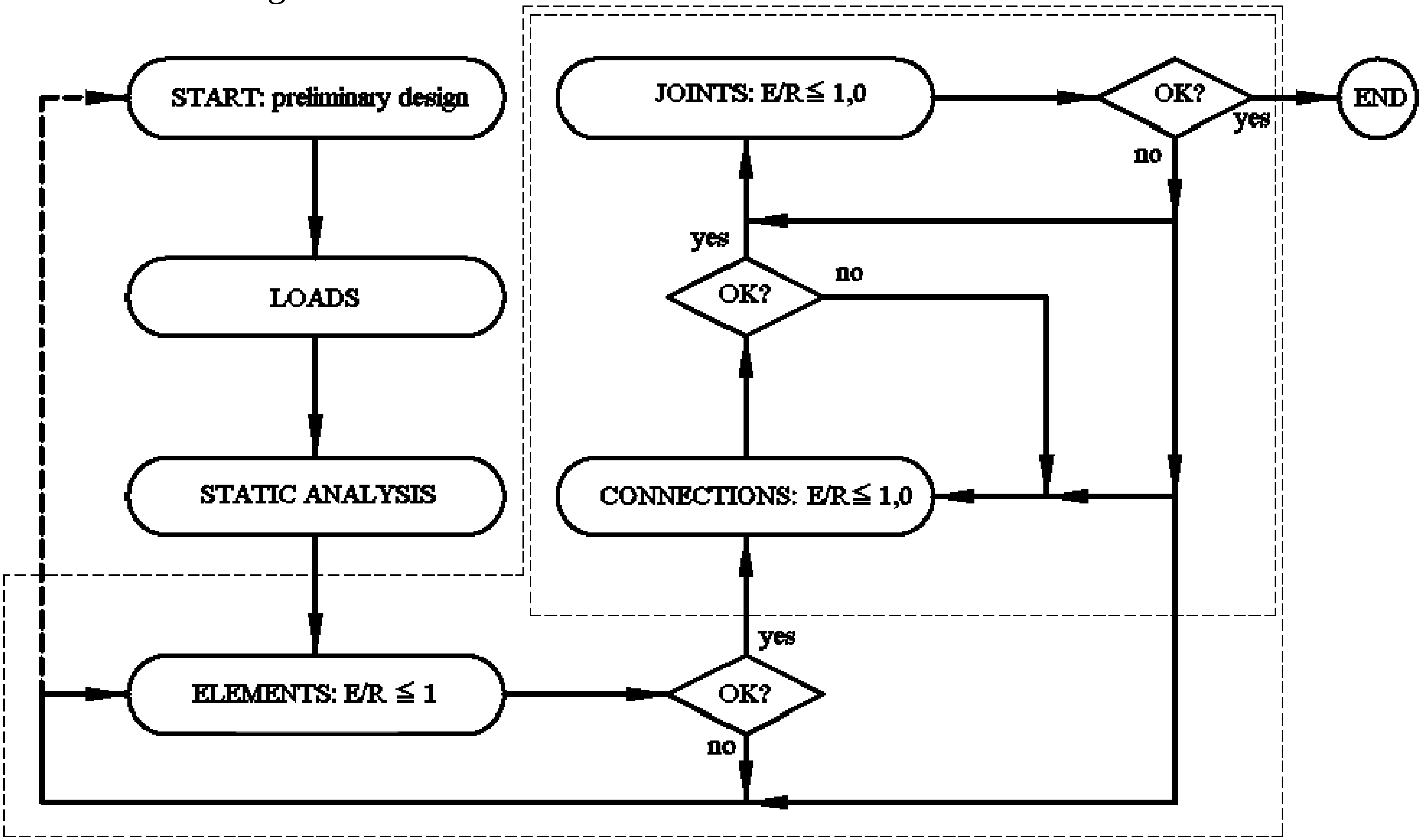


Photo: Author

Examination issues

Dependences between average value, characteristic value, safety factor and design value for loads and materials

Explanation of Limit States Method

Explanation of various Limit States

The importance of consequences classes

The importance of working life

Forklift - wózek widłowy

Crane - suwnica

Stainless steel - stal nierdzewna

Toughness - kruche pękanie

Pilings - palowanie, grodze

Bolt - śruba

Rivet - nit

Pin - sworzeń

Sway stiffenes - przesuwność

Local buckling - wyboczenie lokalne, lokalna utrata stateczności

Thank you for attention

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