SZÉCHENYI ISTVÁN EGYETEM
SZE - GYŐR

DESIGN OF STRUCTURES 2.

3.Effects, loads and design states

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Content

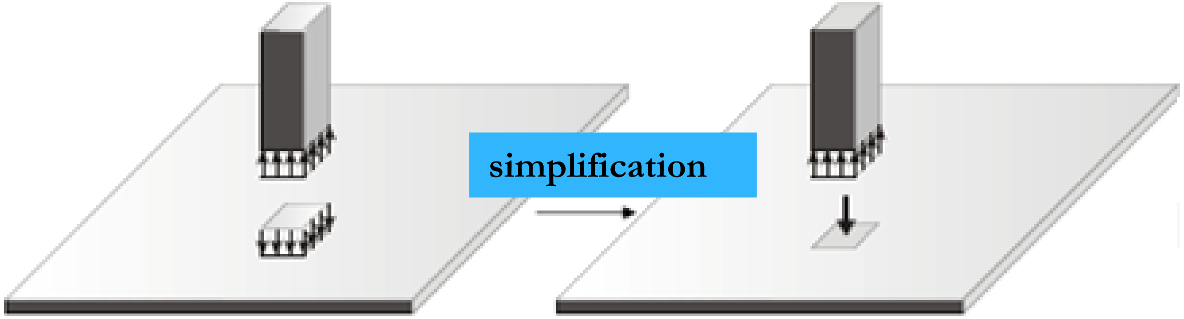
* Load arrangement
* Trasmission of loads
* Reference period
* Types of loads
  * Self-weight (Dead load)
  * Live load
  * Geotechnical action
  * Seismic action
  * Thermal climatic action
* Limit states and combinations of actions

Loads (actions)

Load arrangement:

Concentrated or point load

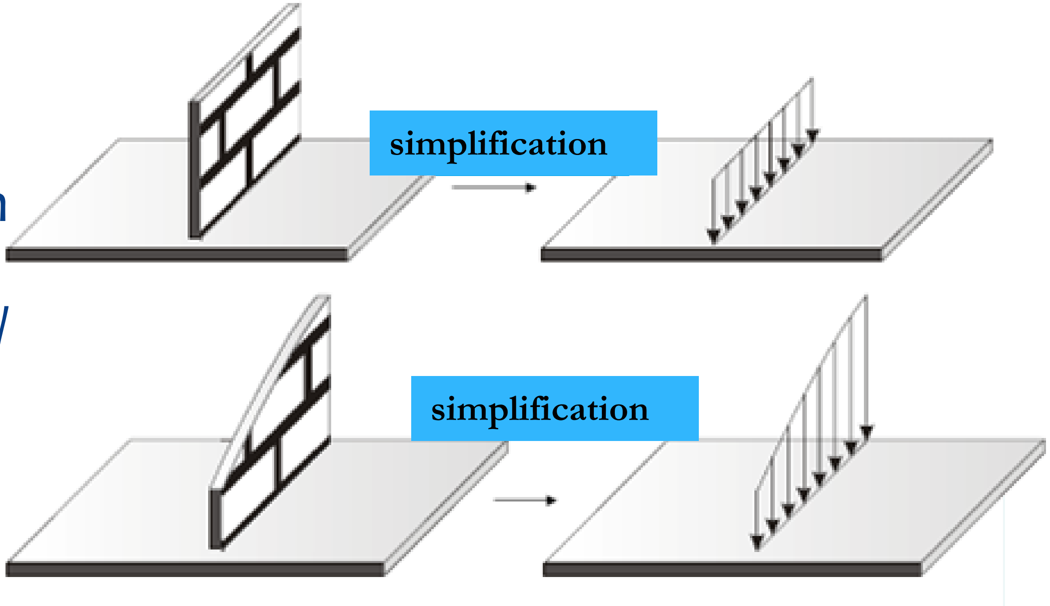
- Symbols: **F,P,G,Q,A,R**
- Unit: **N** (Newton), **kN** (kiloNewton)
- Simplifications are used in calculation



Loads (actions)

Distributed linear load

* Symbols: **p, g, q**
* Unit: **N/m, kN/m**
* Simplifications are used in calculation
* Uniformly distributed / uniformly varying load
* Calculation of resultant



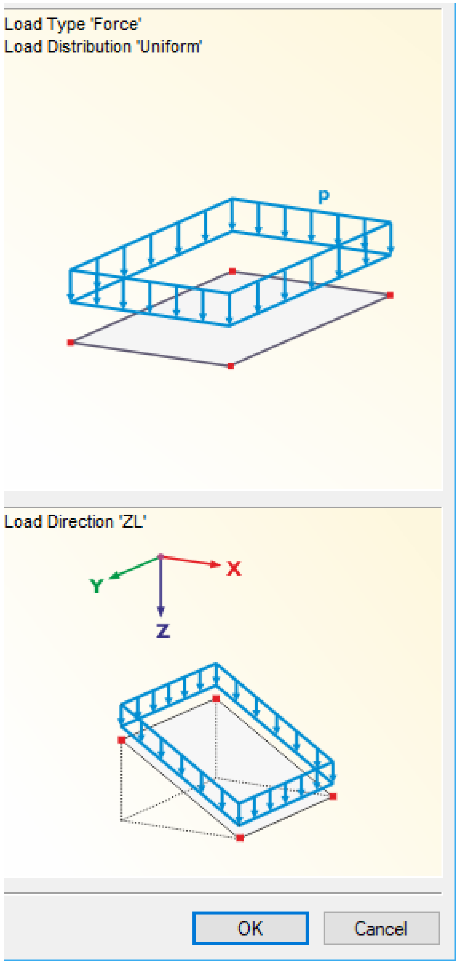
Loads (actions)

Distributed surface load

- Symbols: **p, g, q**
- Unit: **N/m^2, kN/m^2**
- For example: hydrostratic pressure

Distributed spatial load

- Dead load is usually replaced by a surface load

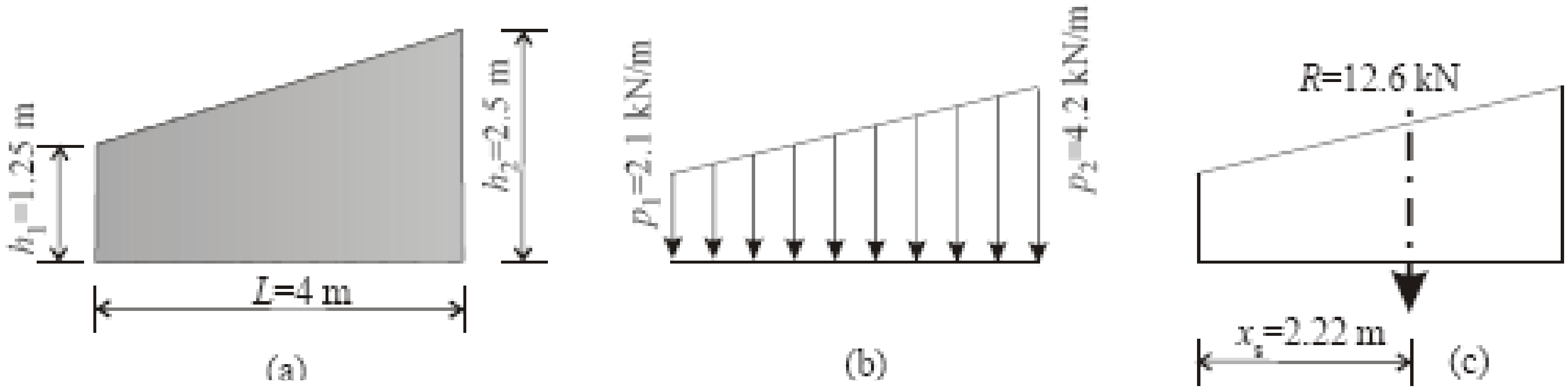


Example

Width of the wall: t=10 cm + 2x 1,5 cm plaster
Height: variable between 1.25 and 2.5 m
Length: L=4 m

Resultant?

$$\gamma_w = 12\ \mathrm{kN/m^3}$$
$$\gamma_m = 16\ \mathrm{kN/m^3}$$



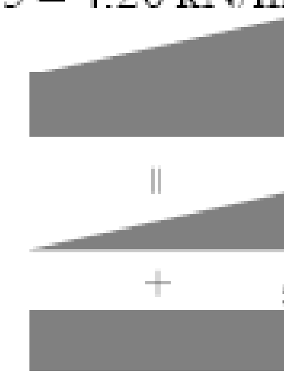
Surface load of the wall:

$$p_W = \sum t\gamma = 0.10\times 12 + 0.03\times 16 = 1.68\ \mathrm{kN/m^2}$$

$$p_1 = p_W h_1 = 1.68\times 1.25 = 2.10\ \mathrm{kN/m} \qquad p_2 = 1.68\times 2.5 = 4.20\ \mathrm{kN/m}$$

$$R = L\left(p_1 + \frac{(p_2 - p_1)}{2}\right) = 4(2.1+1.05) = 8.4\mathrm{kN} + 4.2\mathrm{kN} = 12.6\ \mathrm{kN}$$

$$x_s = \frac{8.4kN\cdot\frac{1}{2}4m + 4.2kN\cdot\frac{2}{3}4m}{12.6kN} = 2.22\ \mathrm{m}$$



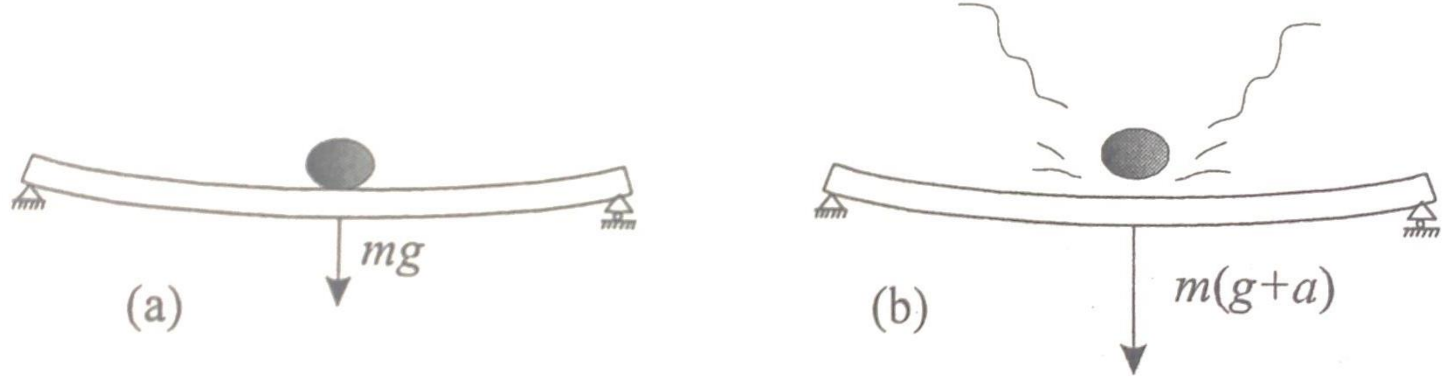
Load transmission

Static aciton

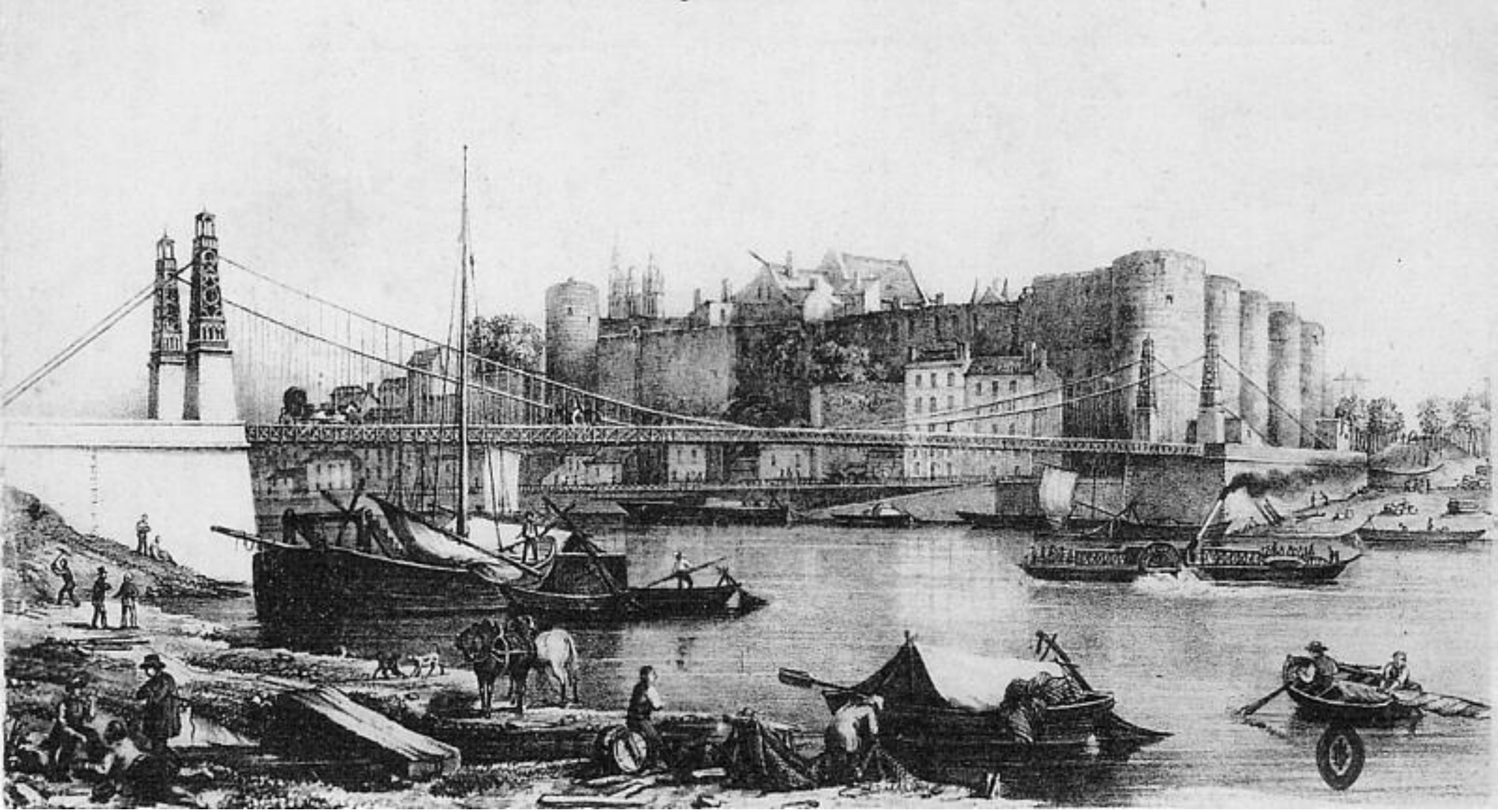
* Action that does not cause significant acceleration of the structure or structural members (Self-weight: m×g)

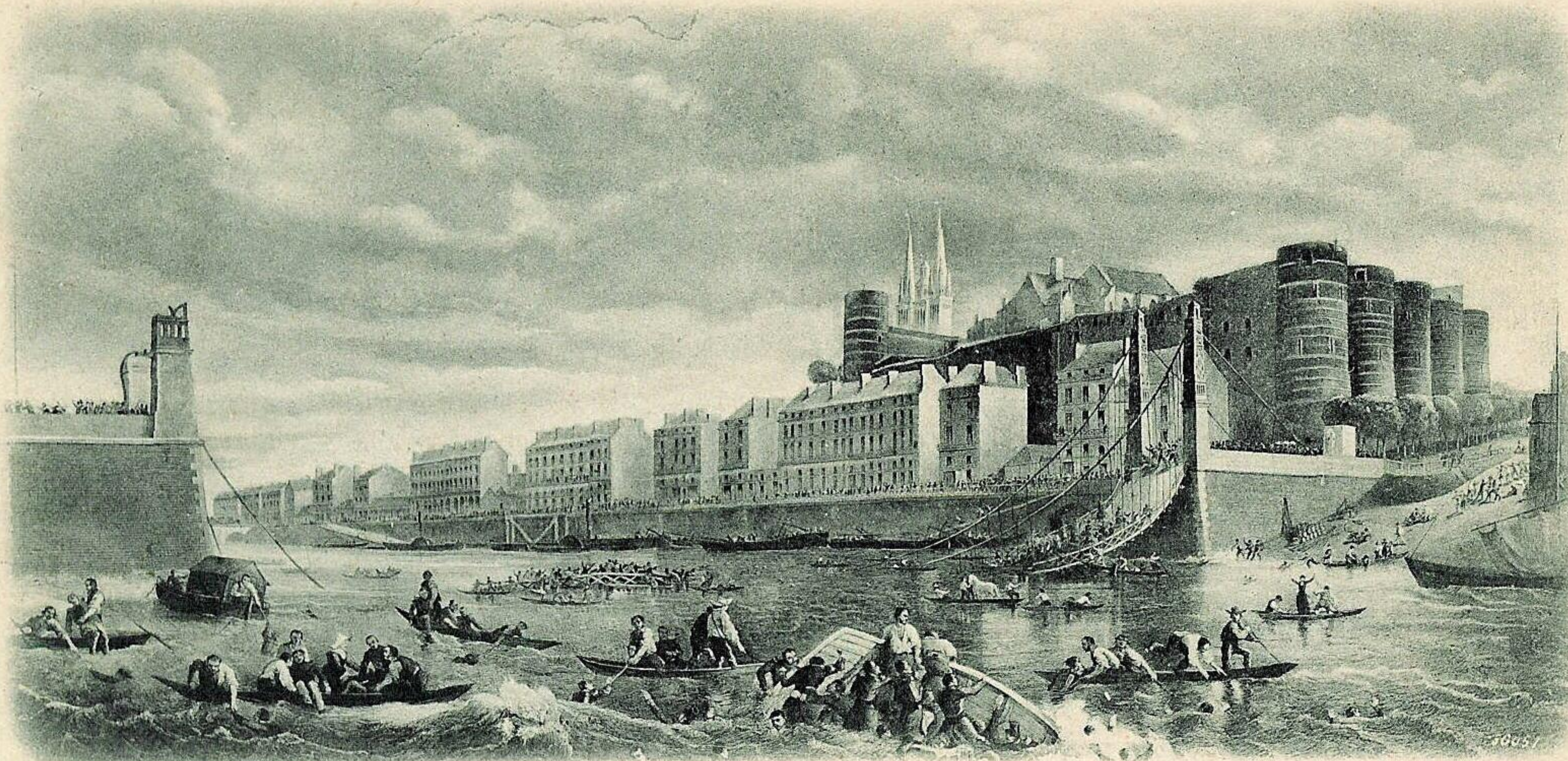
Dynamic action

* Action that causes significant acceleration of the structure or structural members
* Dropped weight on a structure: m×(a+g)
* The intensity of the load is periodically variable in time – it can cause vibration, which can be dangerous
* Suspension bridge collapse: 1850 Angers bridge, Maina



75 ANGERS (M.-et-L.). — Ancien Pont suspendu de la Basse-Chaine avant la Catastrophe du 16 avril 1850. — LL.





Catastrophe du Pont suspendu, actuellement Pont de la Basse chaine en l'année 1850 (le 11ème Leger)

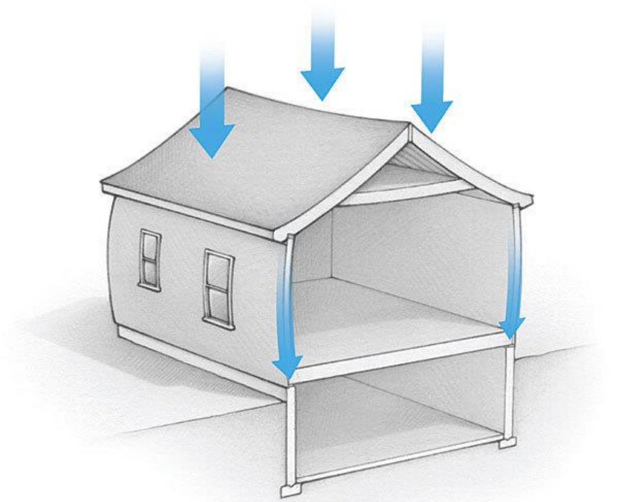
Angers

2385

Reference period

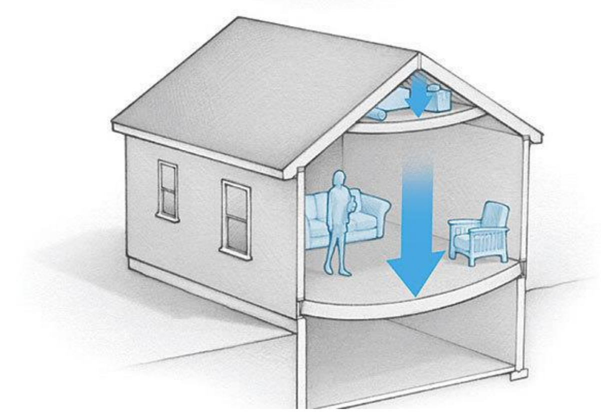
Permanent action

* Action that act throughout the whole lifetime of the structure
* The variation in magnitude is negligble
* Self-weight (g, G)



Variable action

* Action that act throughout a given reference period
* Live load, snow load, wind action (p, P)



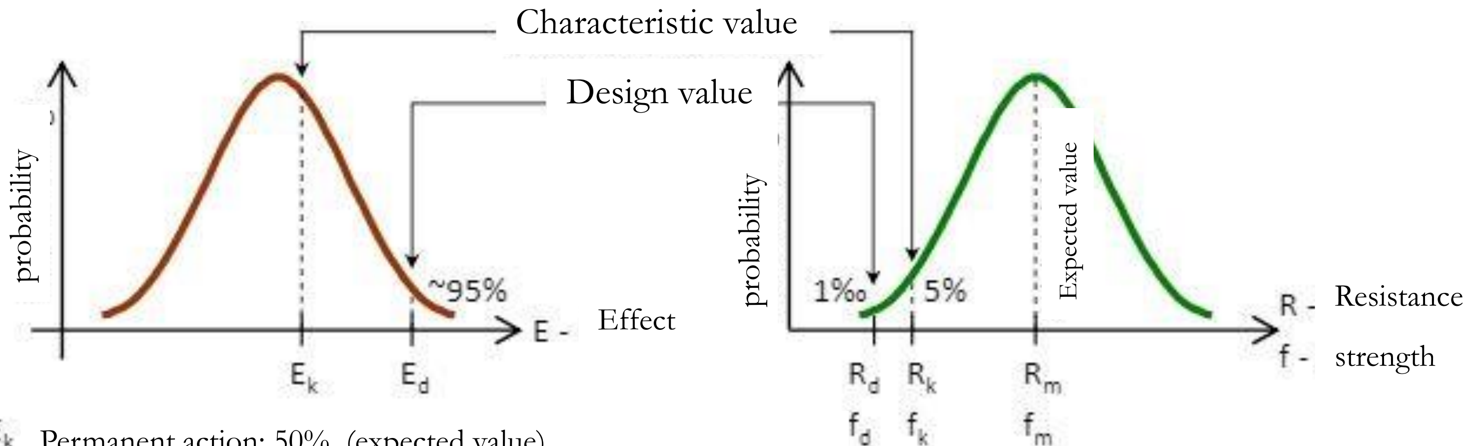
Values of actions

Standards

- Msz (Hungarian standard)
- EN-Euronorm, EC-EUROCODE

Actions

- normal value (g_a) – characteristic value (g_k)
- extremum (g_{sz}) – design value (g_d)
- $g_{sz} = \gamma_G \times g_a$; $g_d = \gamma_G \times g_k$
- Partial factor (safety or serviceability) (γ)

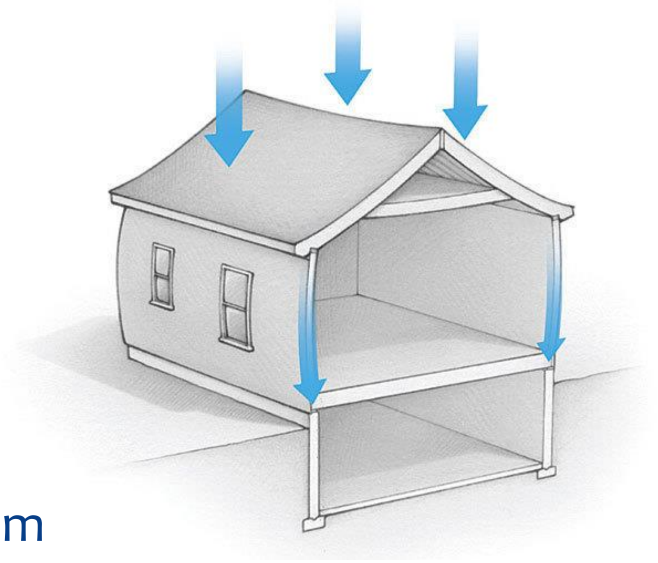


E_k Permanent action: 50% (expected value)
Variable action: percentage referred to reference period

Permanent actions: Self-weight (Dead load)

* Self-weight of structures, fixed equipment and surfacing
* Specific gravity of materials (γ):
  * Reinforced concrete: 25,0kN/m^3
  * Steel: 78,0kN/m^3
  * Wood: 6-8kN/m^3
  * Brick:8-17,0kN/m^3
  * Water: 10,0kN/m^3
* Surface loads:
  * Thickness of stucture× γ (For example: 16cm RC slab=0,16×25=4,0kN/m2
* Safety factor:
  * γ_G=1,20 (MSZ)
    γ_G=1,35 (EC)

  Dead load may be advantageous in case it reduces the loads



Self-weight (Dead load)

$\gamma_{RC} = 25\ \mathrm{kN/m^3}$ $\gamma_{rw} = 1\ \mathrm{kN/m^3}$ $\gamma_c = 23\ \mathrm{kN/m^3}$ $\gamma_m = 16\ \mathrm{kN/m^3}$ $\gamma_{st} = 23\ \mathrm{kN/m^3}$

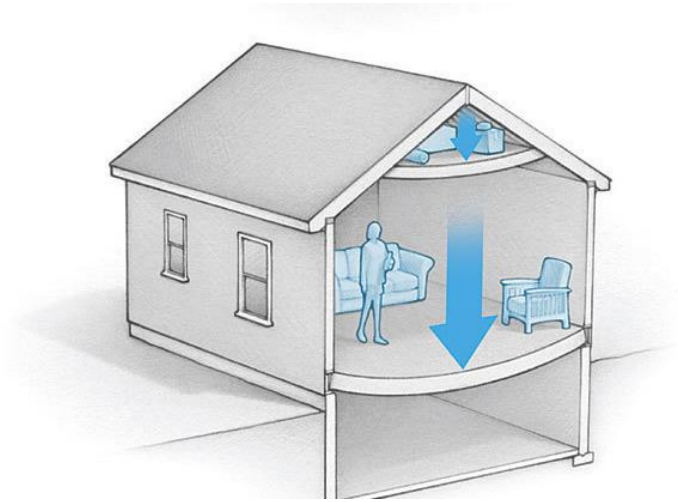
layers	Specific weight γ $[\mathrm{kN/m^3}]$	Width t [m]	Unit weight per m^2 γt $[\mathrm{kN/m^2}]$
RC	25	0.250	6.25
rockwool	1	0.080	0.08
bolster	23	0.060	1.38
morter	16	0.015	0.24
stone tile	23	0.015	0.35
Sum:		0.420	8.30

The weight of the structure is: $p = 8.30\ \mathrm{kN/m^2}$

Variable actions: Live loads

* Movable, temporary and transferable loads
* The weight of the furniture, stored materials, humans, etc.
* Distributed surface loads:
  * Residence: p_a=1,5kN/m^2 q_k=2,0kN/m^2
  * Office: p_a=2,0kN/m^2 q_k=4,0kN/m^2
  * Classroom: p_a=3,0kN/m^2 q_k=4,0kN/m^2
* Safety factor:
  * γ_G=1,20-1,40 (0,00) (MSZ)

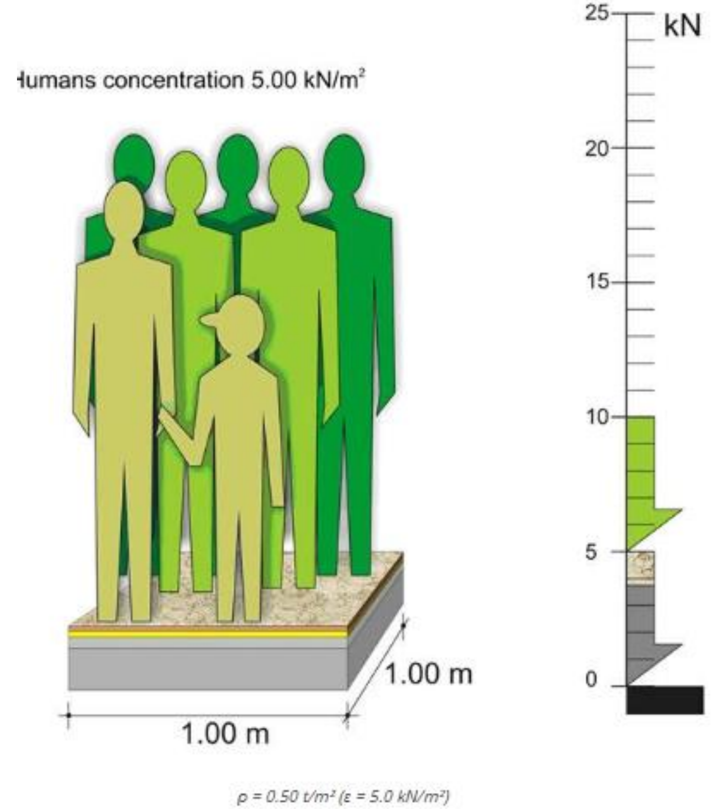
    γ_G=1,50 (0,00) (EC)



Live loads

TABLE 3.4 ***Live Loads for Residential Construction*[1]**

Application	Uniform Load	Concentrated Load
Roof[2]		
Slope ≥ 4:12	15 psf	250 lbs
Flat to 4:12 slope	20 psf	250 lbs
Attic[3]		
With limited storage	10 psf	250 lbs
With storage	20 psf	250 lbs
Floors		
Bedroom areas[3,4]	30 psf	300 lbs
Other areas	40 psf	300 lbs
Garages	50 psf	2,000 lbs (vans, light trucks)
		1,500 lbs (passenger cars)
Decks	40 psf	300 lbs
Balconies	60 psf	300 lbs
Stairs	40 psf	300 lbs
Guards and handrails	20 plf	200 lbs
Grab bars	N/A	250 lbs



Combination of actions

Loads of the slab from its weight $g_c = 8.30 \text{ kN/m}^2$ $\gamma_G = 1.35$

Service load in homes $q_c = 2.0 \text{ kN/m}^2$ $\gamma_Q = 1.5$

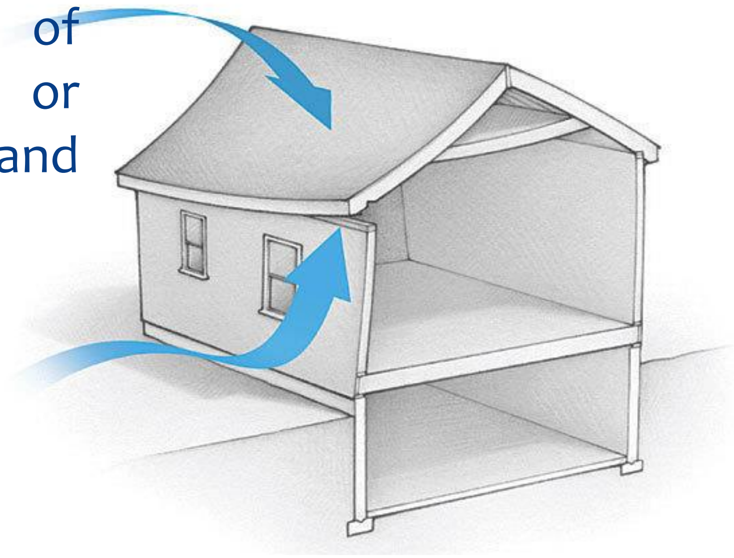
The design value of the load is:

$$p_d = \gamma_G g_c + \gamma_Q q_c = 1.35 \times 8.30 + 1.5 \times 2 = 14.20 \text{ kN/m}^2$$

Variable actions - Wind action

Wind action:

- Wind loads result from the forces exerted by the kinetic energy of the moving mass of air, which van produce a combination of direct pressure, negative pressure or suction, and drag forces on buildings and other obstacles in its path
- Wind load: $F = c \times \rho \times A \times v^2$
  - c : pressure coefficient
  - ρ : density of air
  - A : projected area
  - v : wind velocity

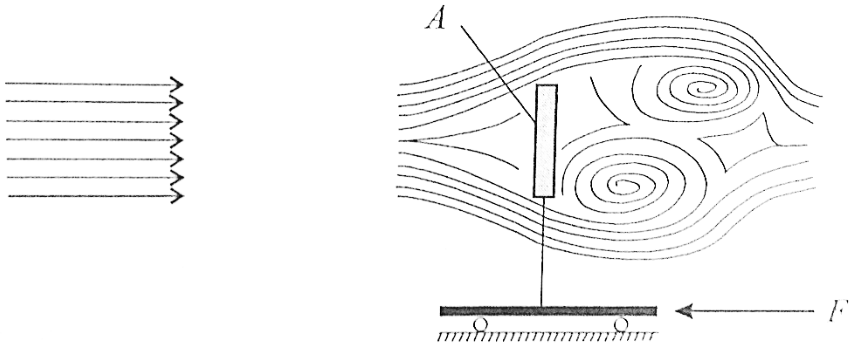


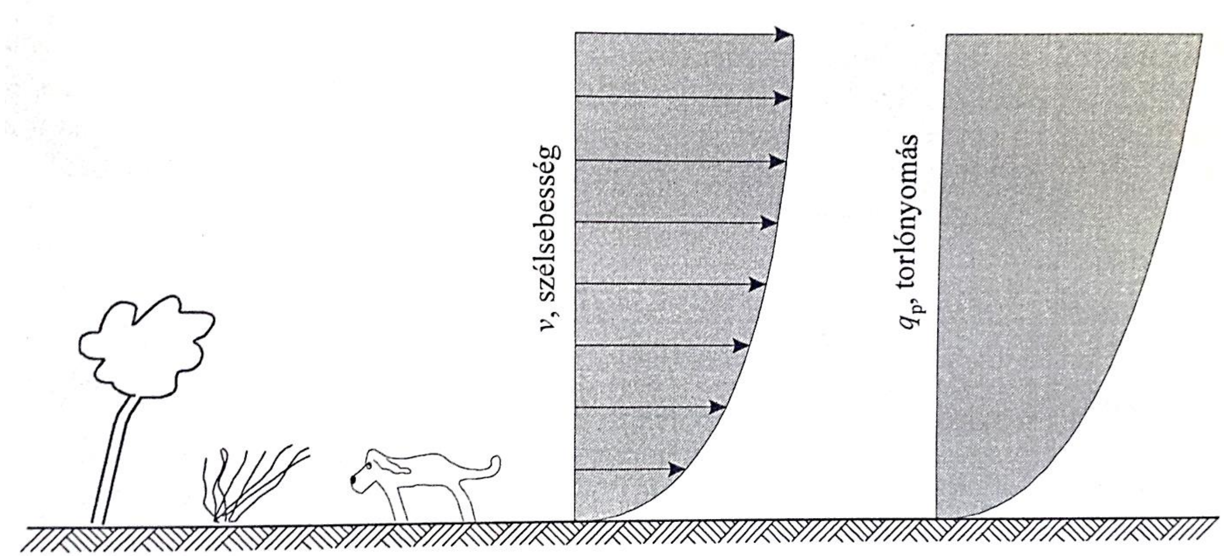
Wind load

- Usually we calculate the wind load instead of the wind force (F):
- $w_e = F/A$ and $q_p = \rho v^2$
- $w_e = c \times q_p$ (EC) ; $p_w = c \times W_o$ (MSZ)
  - w_e : characteristic value of wind load (kN/m^2);
  - p_w : normal value of wind load (kN/m^2)
  - q_p (w_o) : peak velocity pressure (kN/m2)
  - c : pressure coefficient (-)

Wind load

$$F = c\rho A v^2,$$





Wind load

- The value of the wind pressure (q_p) depends on:
  - The geographical situation
  - The built-up density
  - The altitude
- The safety factor of the wind load:
  - EC: γ=1,5
  - MSZ: γ=1,2

Wind load

Values of factors S_2

Structure		Topo-graphical factor	5	10	15	20	30	40	50	60	80	100	120	140	160	180	200
			Height of structure h (m)														
Cladding etc.		1	0.88	1.00	1.03	1.06	1.09	1.12	1.14	1.15	1.18	1.20	1.22	1.24	1.25	1.26	1.27
		2	0.79	0.93	1.00	1.03	1.07	1.10	1.12	1.14	1.17	1.19	1.21	1.22	1.24	1.25	1.26
		3	0.70	0.78	0.88	0.95	1.01	1.05	1.08	1.10	1.13	1.16	1.18	1.20	1.21	1.23	1.24
		4	0.60	0.67	0.74	0.79	0.90	0.97	1.02	1.05	1.10	1.13	1.15	1.17	1.19	1.20	1.22
Maximum vertical or maximum horizontal dimension	$\ngtr$ 50 m	1	0.83	0.95	0.99	1.01	1.05	1.08	1.10	1.12	1.15	1.17	1.19	1.20	1.22	1.23	1.24
		2	0.74	0.88	0.95	0.98	1.03	1.06	1.08	1.10	1.13	1.16	1.18	1.19	1.21	1.22	1.24
		3	0.65	0.74	0.83	0.90	0.97	1.01	1.04	1.06	1.10	1.12	1.15	1.17	1.18	1.20	1.21
		4	0.55	0.62	0.69	0.75	0.85	0.93	0.98	1.02	1.07	1.10	1.13	1.15	1.17	1.19	1.21
	> 50 m	1	0.78	0.90	0.94	0.96	1.00	1.03	1.06	1.08	1.11	1.13	1.15	1.17	1.19	1.20	1.21
		2	0.70	0.83	0.91	0.94	0.98	1.01	1.04	1.06	1.09	1.12	1.14	1.16	1.18	1.19	1.21
		3	0.60	0.69	0.78	0.85	0.92	0.96	1.00	1.02	1.06	1.09	1.11	1.13	1.15	1.17	1.18
		4	0.50	0.58	0.64	0.70	0.79	0.89	0.94	0.98	1.03	1.07	1.10	1.12	1.14	1.16	1.18

Notes

h is height (in metres) above general level of terrain to top of structure or part of structure. Increase to be made for structures on edge of cliff or steep hill.

Topographical factors

1. open country with no obstructions
2. open country with scattered wind-breaks
3. country with many wind-breaks; small towns; suburbs of large cities
4. city centres and other environments with large anc frequent obstructions.

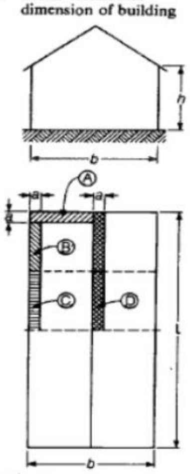
Wind pressures on structures—1

EXTERNAL PRESSURE COEFFICIENT C_{pe} FOR ROOFS OF CLAD BUILDINGS

Pitched roofs

h Height to eaves or parapet

b Lesser horizontal dimension of building



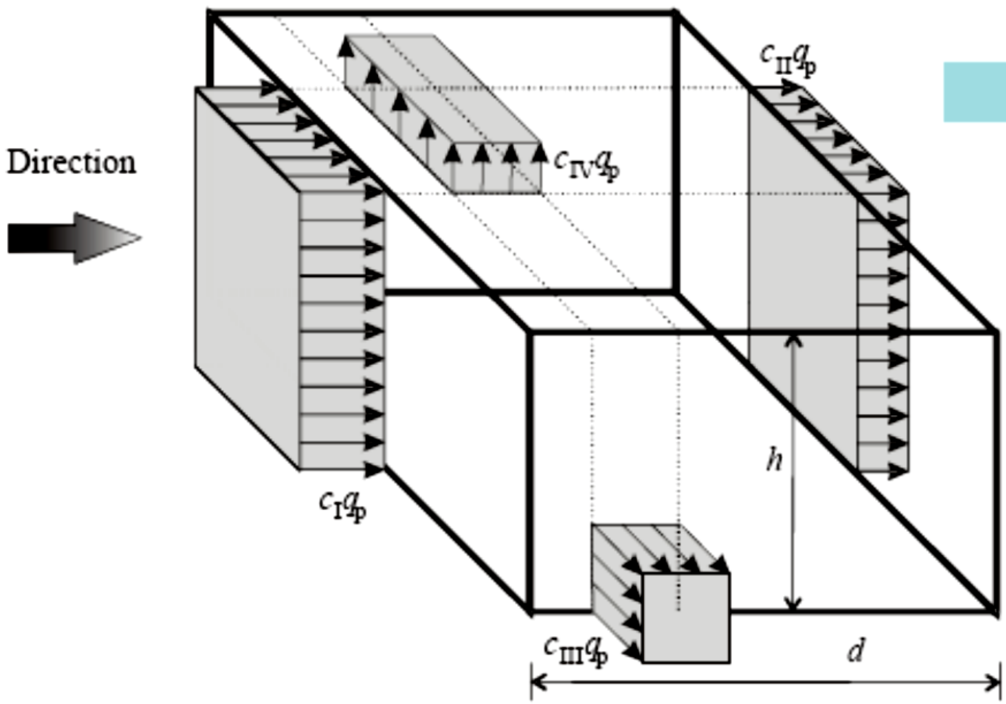
Building height ratio		$h \ngtr b/2$				$b/2 < h \ngtr 3b/2$				$3b/2 < h \ngtr 6b$			
		Wind at right angles to building		Wind parallel to building		Wind at right angles to building		Wind parallel to building		Wind at right angles to building		Wind parallel to building	
	Slope of roof (deg.)	Wind-ward slope	Lee-ward slope	Wind-ward half	Lee-ward half	Wind-ward slope	Lee-ward slope	Wind-ward half	Lee-ward half	Wind-ward slope	Lee-ward slope	Wind-ward half	Lee-ward half
Overall coefficients	0	−0.8	−0.4	−0.8	−0.4	−0.8	−0.6	−1.0	−0.6	−0.7	−0.6	−0.9	−0.7
	5	−0.9	−0.4	−0.8	−0.4	−0.9	−0.6	−0.9	−0.6	−0.7	−0.6	−0.8	−0.8
	10	−1.2	−0.4	−0.8	−0.6	−1.1	−0.6	−0.8	−0.6	−0.7	−0.6	−0.8	−0.8
	20	−0.4	−0.4	−0.7	−0.6	−0.7	−0.5	−0.8	−0.6	−0.8	−0.6	−0.8	−0.8
	30	0	−0.4	−0.7	−0.6	−0.2	−0.5	−0.8	−0.8	−1.0	−0.5	−0.8	−0.7
	40	—	—	—	—	—	—	—	—	−0.2	−0.5	−0.8	−0.7
	45	+0.3	−0.5	−0.7	−0.6	+0.2	−0.5	−0.8	−0.8	—	—	—	—
	50	—	—	—	—	—	—	—	—	+0.2	−0.5	−0.8	−0.7
	60	+0.7	−0.6	−0.7	−0.6	+0.6	−0.5	−0.8	−0.8	+0.5	−0.5	−0.8	−0.7
		Area				Area				Area			
		A	B	C	D	A	B	C	D	A	B	C	D
l coefficients	0	−2.0	−2.0	−2.0	—	−2.0	−2.0	−2.0	—	−2.0	−2.0	−2.0	—
	5	−1.4	−1.2	−1.2	−1.0	−2.0	−2.0	−1.5	−1.0	−2.0	−2.0	−1.5	−1.0
	10	−1.4	−1.4	—	−1.2	−2.0	−2.0	−1.5	−1.2	−2.0	−2.0	−1.5	−1.2
	20	−1.0	—	—	−1.2	−1.5	−1.5	−1.5	−1.0	−1.5	−1.5	−1.5	−1.2
	30	−0.8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Wind load

characteristic value of wind load → $w_c = q_p c$

peak velocity pressure → q_p

pressure coefficient → c



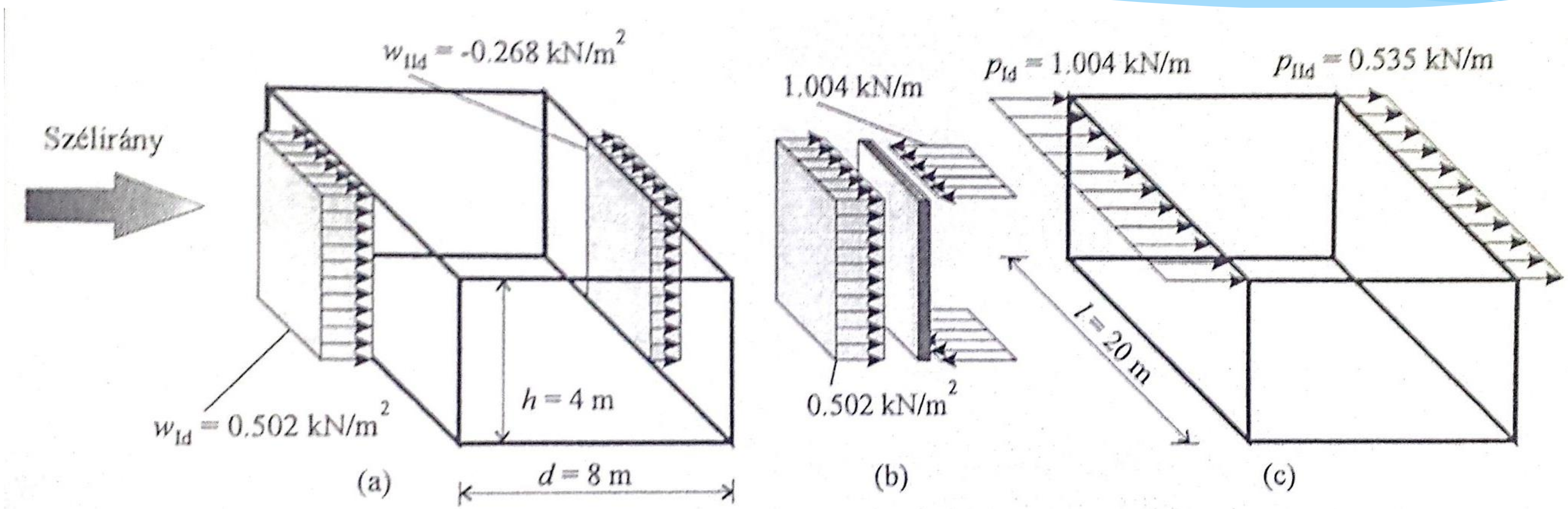
$c_I = 0.733$

$c_{II} = -0.367$

$c_{III} = -0.96$

$c_{IV} = -0.8$

Wind load



Peak velocity pressure according to Eurocode standard: $q_p = 0.446\,\mathrm{kN/m^2}$

Pressure coefficients: $c_I = 0.733 \quad c_{II} = -0.367$

Safety factor: $\gamma_Q = 1.5$

$$w_{I,d} = \gamma_Q c_I q_p = 1.5 \times 0.733 \times 0.446 = 0.490\,\mathrm{kN/m^2} \quad \text{(pressure)}$$

$$w_{II,d} = \gamma_Q c_{II} q_p = 1.5 \times (-)0.367 \times 0.446 = -0.246\,\mathrm{kN/m^2} \quad \text{(„suction”)}$$

On top slab:

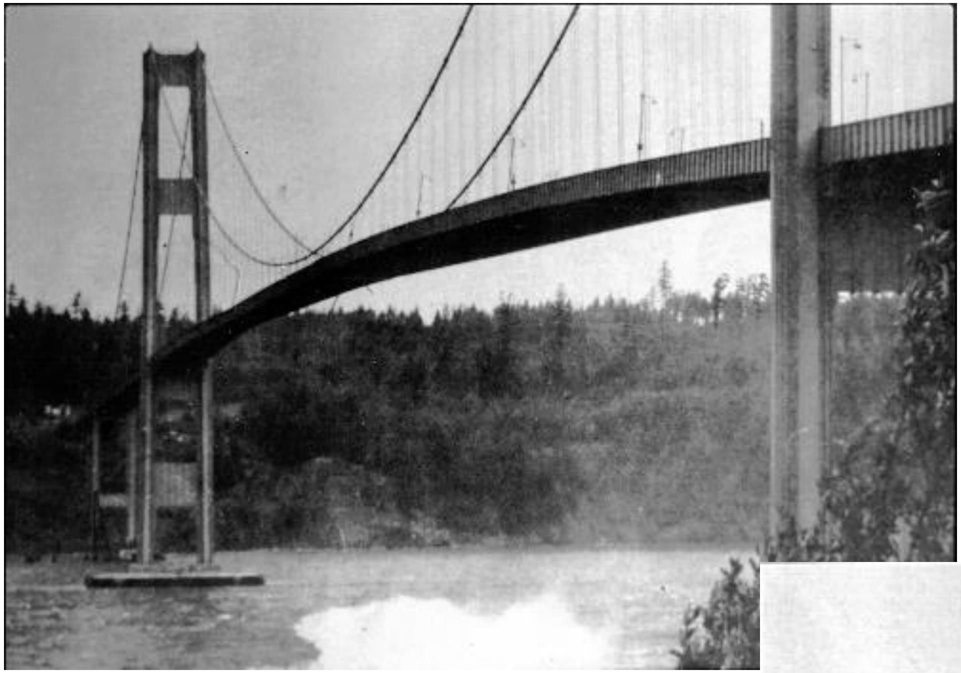
$$p_{I,d} = w_{I,d} h/2 = 0.490 \times 4/2 = 0.98\,\mathrm{kN/m}$$

$$p_{II,d} = |w_{II,d}| h/2 = 0.246 \times 4/2 = 0.492\,\mathrm{kN/m}$$

Dynamic effect of wind action

* Dangerous at tall, slender buildings
* Collapse of Tacoma Narrow bridge
* Wind velocity: 67km/h
* Vertical movement with an amplitude of 0,9 m
* Horizontal movement with an amplitude of 0,6 m
* Cause of the collapse:
  * Too weak stiffening trusses, high torsional forces

https://www.youtube.com/watch?v=HzHibQFxjY4



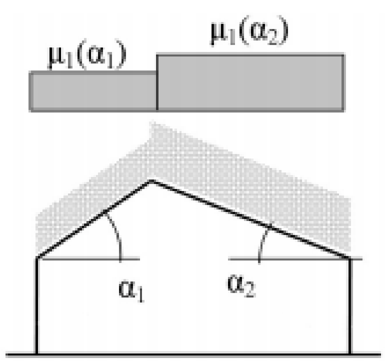

Variable actions – Snow load

* The value of the snow load depends on the snowfall and the realingnment of the snow
* Realingment can be caused
  * By comedown from the roof
  * by the wind (snow accumulation)

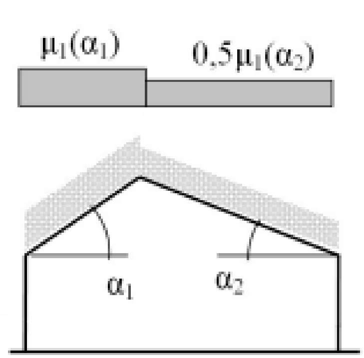
Snow load

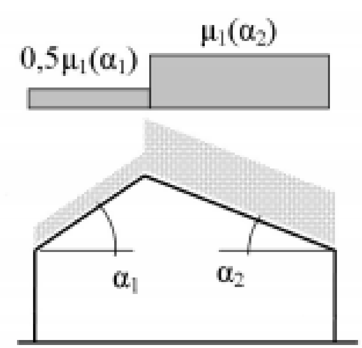
- Characteristic value of snow load:
  - $s=\mu_i \times s_k$ (EC)
  - μ_i : snow load shape coefficient
  - s_k characteristic snow load on ground (until altitude of 400 m : $s_k=1{,}25\ kN/m^2$)

Without snow accumulation:



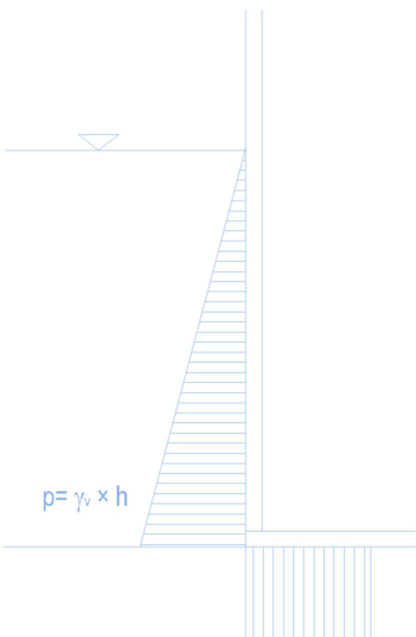
In case of snow accumulation:

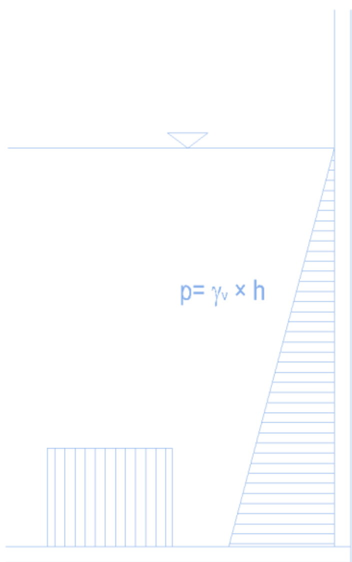


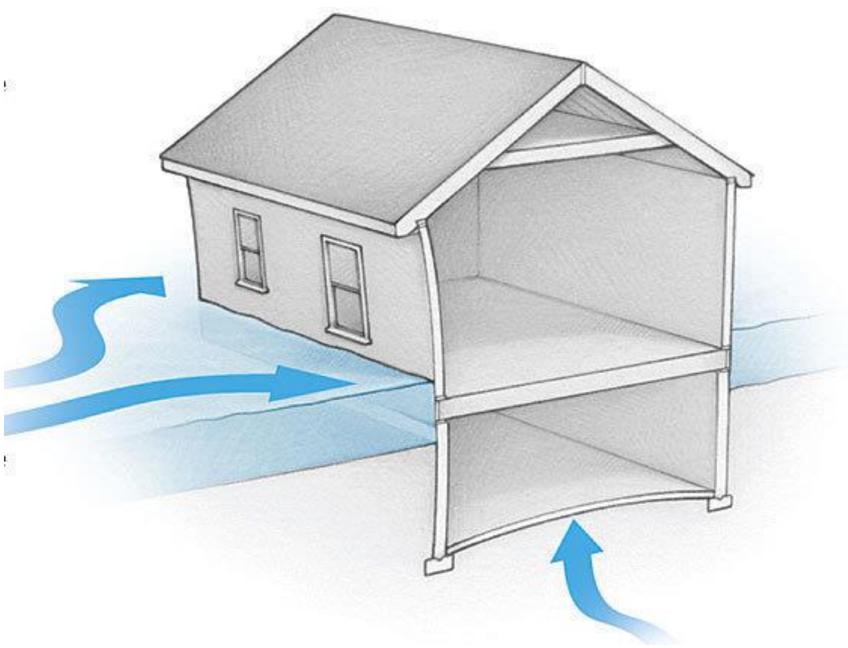


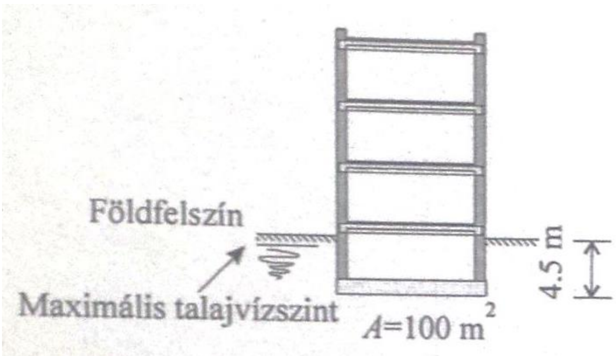
Hydrostatic pressure in soil

- $p = \gamma_v \times h$
  - γ_v : specific gravity of water
  - h : distance from water level









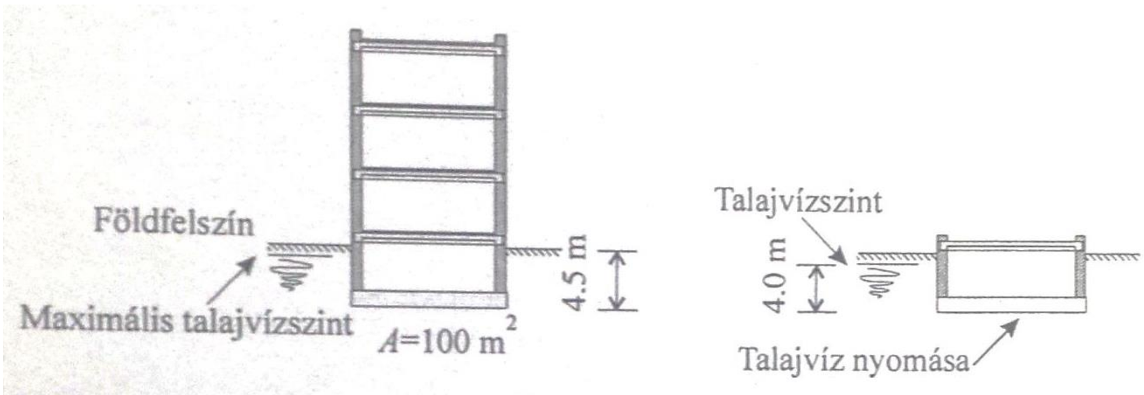
$G_c = 10\,000 \text{ kN}$ $\gamma_G = 1.35$ or $\gamma_G = 0.9$

$Q_c = 2\,000 \text{ kN}$ $\gamma_Q = 1.5$

Is the foundation safe is the strength of the ground is 300 kN/m^2 ?

$$\sigma = \frac{\gamma_G G_c + \gamma_Q Q_c}{A} = \frac{1.35 \times 10\,000 + 1.5 \times 2000}{10 \times 10} = 165 \frac{\text{kN}}{\text{m}^2} < 300 \frac{\text{kN}}{\text{m}^2}$$

SAFE!



Stabilizing dead loads on building: $G_{c1} = 3\,500\ \text{kN}$ $\gamma_G = 1.35$ or $\gamma_G = 0.9$

Stabilizing live loads on building: $Q_{c1} = 700\ \text{kN}$ $\gamma_Q = 1.5$

Buoyancy force: $\gamma_b = 1$

Will the cellar float up? The specific weight of water is $\gamma_w = 10\text{kN/m}^3$

$p = \gamma_w x = 10\text{kN/m}^3 \times 4\text{m} = 40\ \text{kN/m}^2$ pressure at depth x below the water surface

Destabilizing force:
(buoyancy force)

$$B = \gamma_b \gamma_w V = 1 \times 10 \times 100 \cdot 4 = 4000\ \text{kN}$$

Stabilizing force
(weight of struc

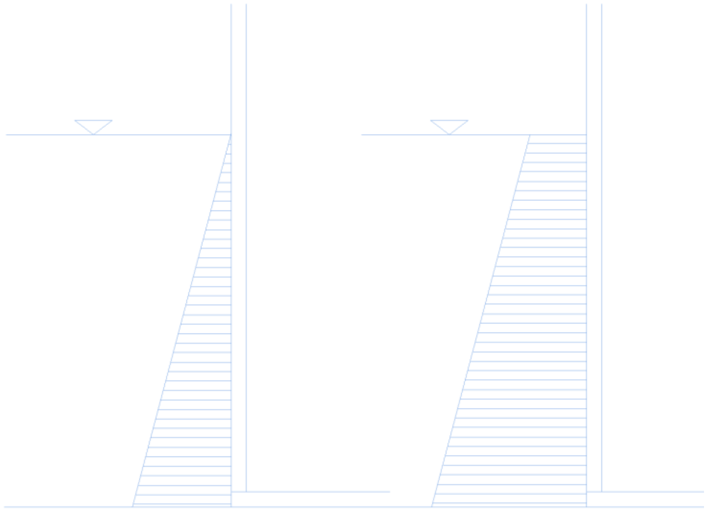
$$E_{d\ stb} = \gamma_G G_{c1} = 0.9 \times 3500 = 3150\ \text{kN} < 4000\ \text{kN}$$

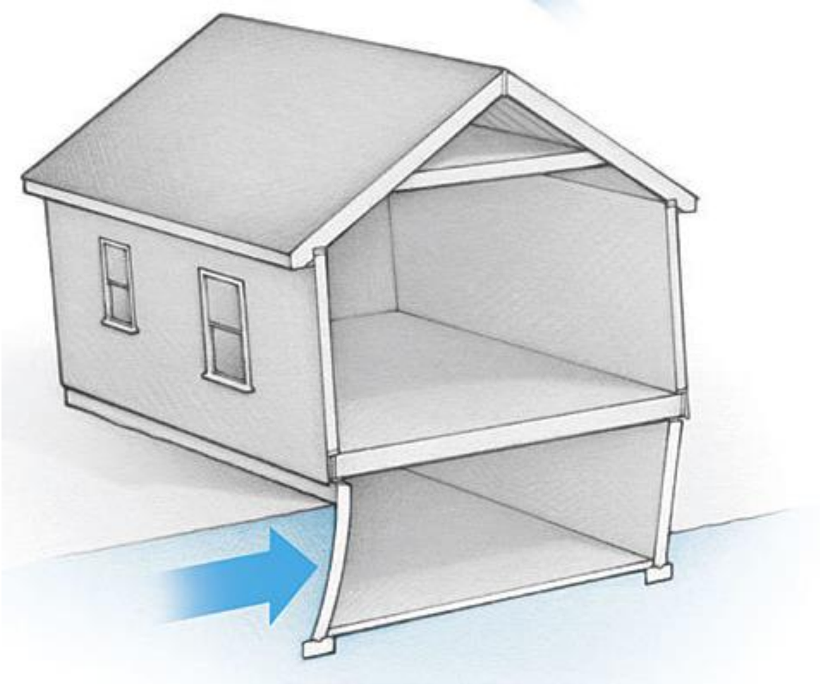
NOT SAFE!

Earth pressure

- $p = k \times \gamma_s \times h$
  - γ_s : specific gravity of soil
  - h : height
  - k: soil coefficient

    (1/3-1/2)

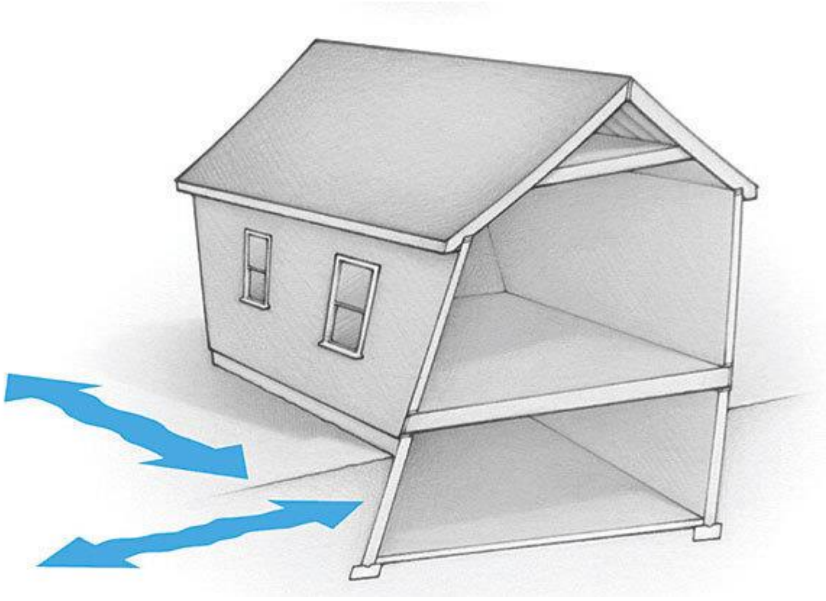




Seismic action

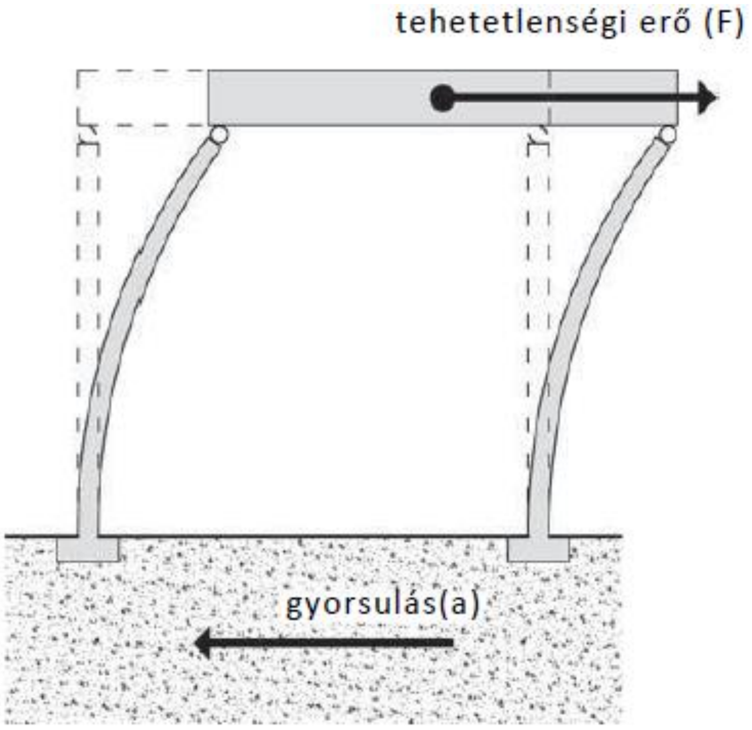
Earthquake causes shaking and ground rupture, which causes vibration in buildings.

* The earthquake can be:
  * vertical vibration – vertical intertial forces
  * Horizontal vibration – horizontal inertial forces



Seismic action

* The horizontal movements cause significant horizontal forces
* Earthquake is a process in time, its characteristics are
  * The acceleration of the soil
  * The intensity and
  * The frequency range of the earthquake
  * The horizontal force

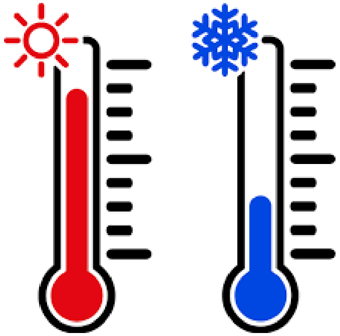


Seismic action

- If the building is not stiff enough, it may get into resonance with the earthquake, and the acceleration of the slabs may exceed the acceleration of the earth
- Seismic load:
  - $F_E = m \times S_d$
  - S_d the value of „response spectrum”, which is the acceleration of the building caused by the eartquake at a given place – it depends on the stiffness of the building and the period of vibration

Thermal actions

* Changes of temperature causes deformations in the structures
* In the case of restrained deformation stresses occur in the structure
* Design aspects:
  * Dilatation/Expansion is used – deformations are allowed
  * Designing the structures capable for forces caused by changes of temperature
  * $\Delta L = L \times \alpha \times \Delta t$ – length change



Additional actions

- Forces caused by construction (storage, movement of structural elements and materials, concrete pressure on formwork)
- Icing
- Load from accumulated dust
- Unequal sinkage of foundations

Design situations

- Set of physical conditions representing the real conditions occuring a certain time interval for which the design will demonstrate that relevant limit states are not exceeded
  - **Persistent design situation**
    - Design situation that is relevant during a period of the same order as the design working life of the structure
  - **Transient design situation**
    - Design situation that is relevant during a period of much shorter time than the design working life of the structure and which has a high probability of occurence (loads during the construction, maintainance)
  - **Accidental design situation**
    - Design situation involving expectional conditions of the structure or its exposure, including fire, explosion, impact or local failure
  - **Seismic design situation**

Limit states

Limit states = States beyond which the structure no longer fulfils the relevant design criteria

Ultimate limit states

* states associated with collapse or with other similar forms of structural failure:
  * Loss of equilibrium of the structure or any part of it
  * Failure by excessive deformation, transformation of the structure or any part of it into a mechanism, rupture, loss of stability of the structure or any part of it, including supports and foundations
  * Failure caused by fatigue or other time-dependent effects

Serviceability limit states

* The limit states that concern
  * Deformations that affect the appearance, the comfort of users or the funcitioning or durability of the structure
  * Vibrations that cause discomfort to people or that limit the functional effectiveness of the structure

Combination of actions

- **Ultimate limit states:**
  - Persistent or transient design situations
  - Accidental design situations
  - Seismic design situations
- **Serviceability limit states:**
  - Characteristic combination $\rightarrow \psi_0$
    for irreversible serviceability limit states
    (uncracked concrete)
  - Frequent combination $\rightarrow \psi_1$
    for reversible serviceability limit states
    (vibration)
  - Quasi-permanent combination $\rightarrow \psi_2$
    for long-term effects
    (deformations, crack width)

Combination of actions

For persistent and transient design situations:

Usually:

$$\sum_{j\geq 1}\gamma_{Gj}\cdot G_{kj}"+"\gamma_{Q1}\cdot Q_{k1}"+"\sum_{i\neq 1}\gamma_{Qi}\cdot\psi_{0i}\cdot Q_{ki}$$

* Alternative:
  * a)

$$\sum_{j\geq 1}\gamma_{Gj}\cdot G_{kj}"+"\gamma_{Q1}\cdot\psi_{01}\cdot Q_{k1}"+"\sum_{i\neq 1}\gamma_{Qi}\cdot\psi_{0i}\cdot Q_{ki}$$

  * b)

$$\sum_{j\geq 1}\xi\cdot\gamma_{Gj}\cdot G_{kj}"+"\gamma_{Q1}\cdot Q_{k1}"+"\sum_{i\neq 1}\gamma_{Qi}\cdot\psi_{0i}\cdot Q_{ki}$$

$$\xi = 0{,}85$$

Combination of actions

Serviceability limit states:

- Characteristic combination: (for uncracked state of RC)

$$\sum_{j\geq 1} G_{kj} "+" Q_{k1} "+" \sum_{i>1} \psi_{0i} \cdot Q_{ki}$$

- Frequent combination (for crack control of prestressed RC structures ; deformation and stiffness control of buildings):

$$\sum_{j\geq 1} G_{kj} "+" \psi_{11} \cdot Q_{k1} "+" \sum_{i>1} \psi_{2i} \cdot Q_{ki}$$

- Quasi-static combination (for examination of the effects of long-term effects, deformation sof structural elements and crack width of RC structures)

$$\sum_{j\geq 1} G_{kj} "+" \sum_{i\geq 1} \psi_{2i} \cdot Q_{ki}$$

Combination of actions

Accidental design situations:

- The combinations are needed:
  - One includes an accidental action (***A_d***) (for example: vehicle collision, which is a direct action)
  - The another is related to the additional effects, where ***A_d=0*** ,but the indirect effects have to be taken into account (for example: changed geometry or material properties)

$$\sum_j G_{kj} "+" A_d "+" \psi_{11} \cdot Q_{k1} "+" \sum_{i \neq 1} \psi_{2i} \cdot Q_{ki}$$

Thank you for your attention!