SZÉCHENYI ISTVÁN EGYETEM

SZE - GYŐR

DESING OF STRUCTURES 2.

8. Special design questions (stability, expansion, stiffening)

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Content

* Fatigue of load-bearing capacity of structures
* Static equilibrium
  * Overturning safety
  * Sliding safety
  * Uplift safety
* Stability of structures
* Expansion

Fatigue of load-bearing capacity

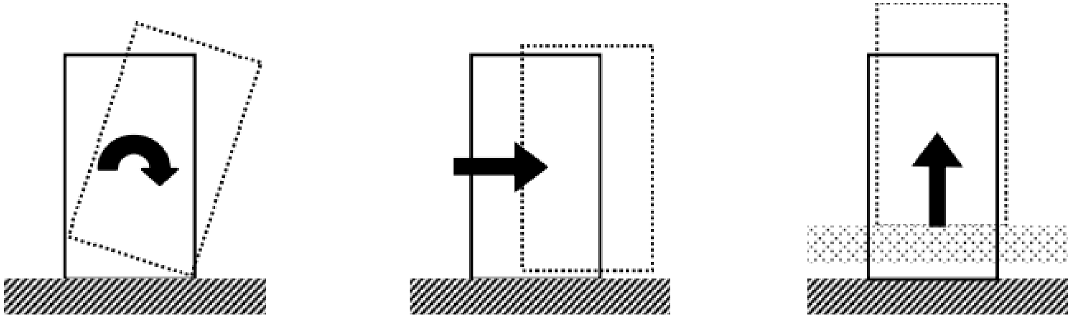
- There are three main types of fatigue of load-bearing capacity:
  - Strength
  - **Static equilibrium**
  - **Stability**

Fatigue of load-bearing capacity

* **Strength**: internal failure or excessive deformation of the structure or structural members – it depends mainly on the material of the structure
* **Static equilibrium**: Loss of static equilibrium of the structure or any part of it, there are three types of failure:
  * Overturning
  * Sliding
  * Uplift
* There are three types of **loss of stability**:
  * Buckling
  * Lateral torsional buckling
  * Denting

Static equilibrium

* Loss of static equilibrium is a sudden and sigfinicant change in structure, which does not depend on the strength of the materials or the soil.



a) overturning b) sliding c) uplift

Static equilibrium

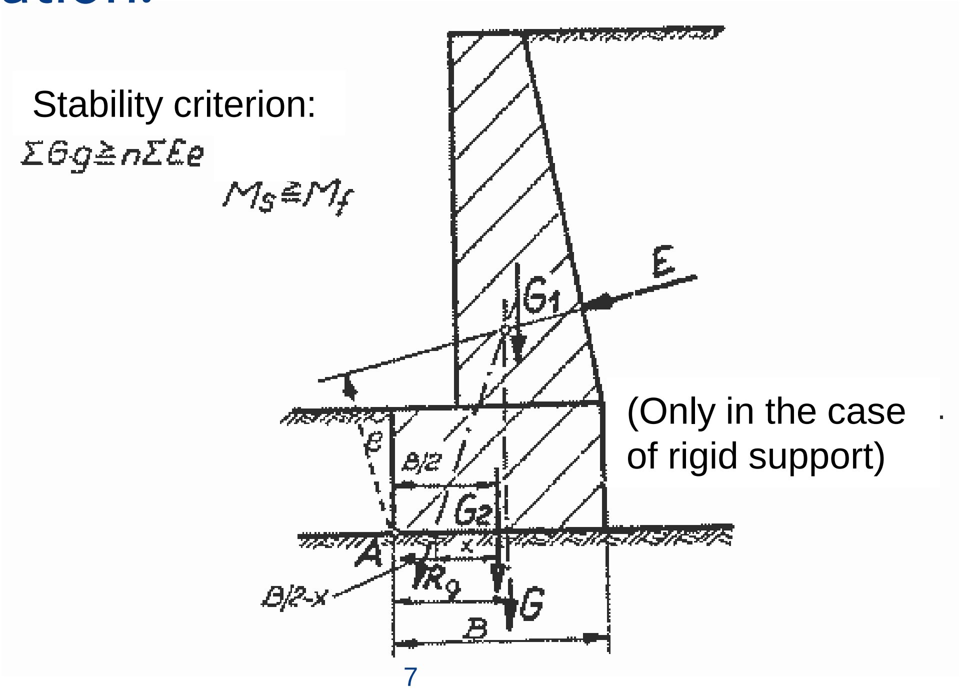
- In the ultimate limit state it should be verified the following inequality:

$$E_{d,dst} \leq E_{d,stb}$$

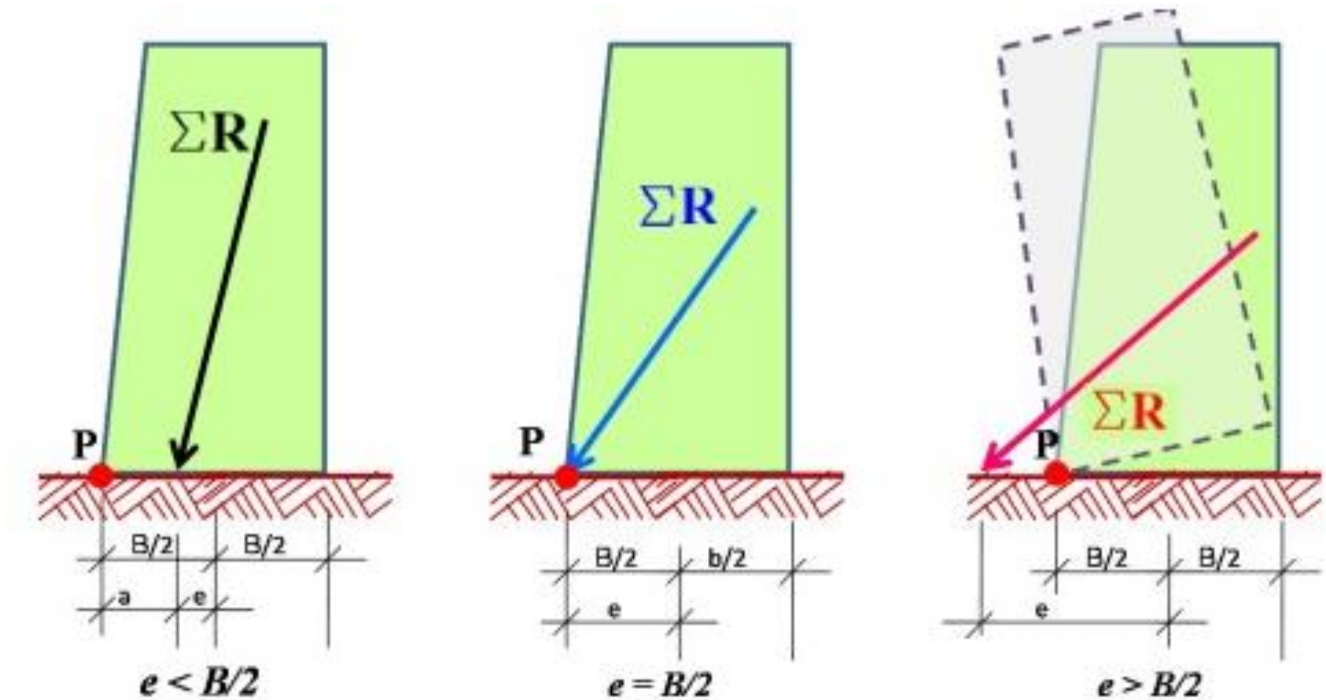
- Ahol
  - $E_{d,dst}$: is the design value of the effect of destabilising actions
  - $E_{d,stb}$: is the design value of the effect of stabilising actions

Overturning safety

- The sum of moments of forces preventing the overturning (rotation) should be higher than the sum of moments of forces causing the rotation.



Overturning safety



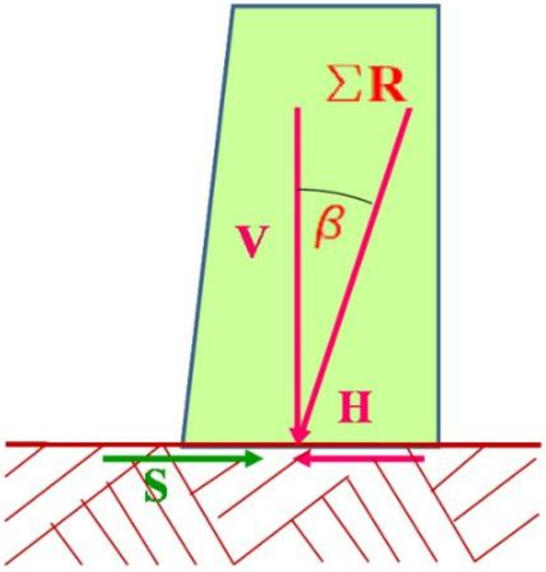
Stable position

Indifferent position

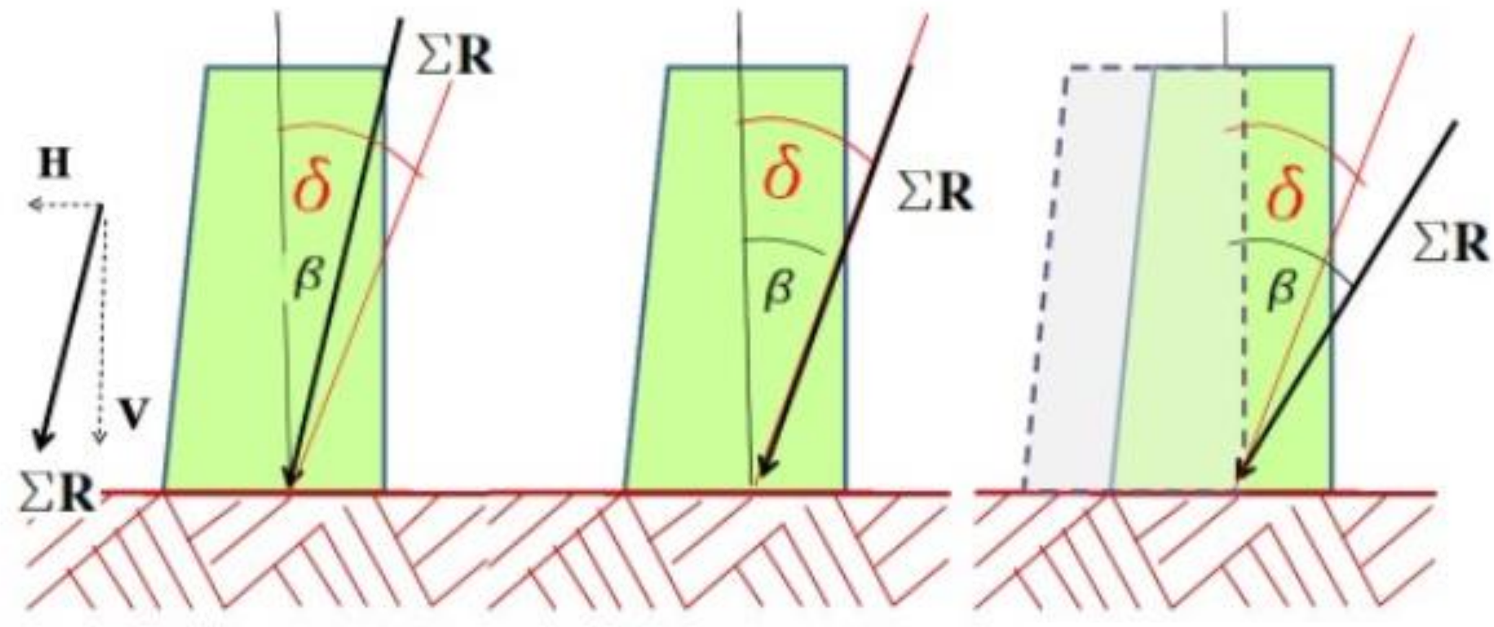
Overturning failure

Sliding safety

- It is very rare that the resultant has only vertical component
- The sliding safety should be examined on structures loaded with horizontal forces (hydrostatic and earth pressure)
- The forces preventing sliding along the bottom should be higher than the forces that will cause sliding along the bottom surface



Sliding safety



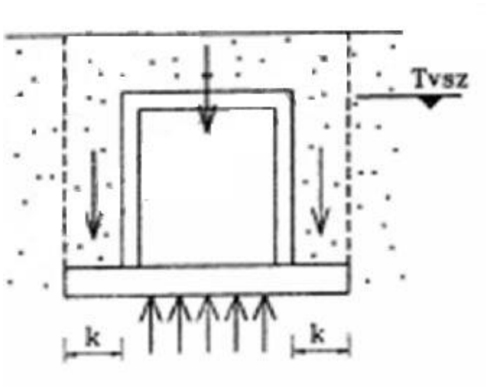
Stable position Indifferent position Sliding failure

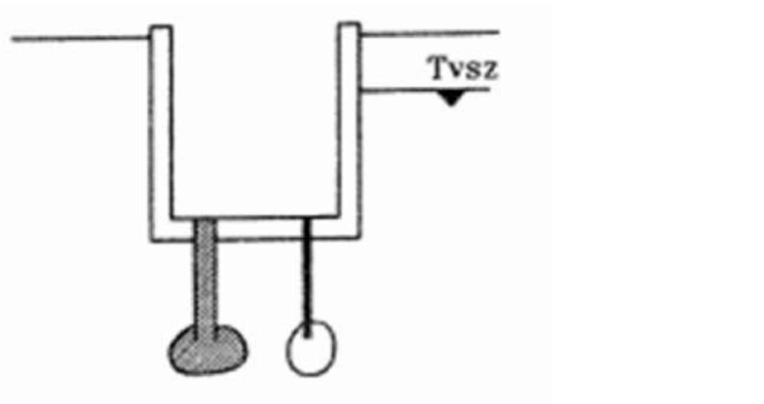
Uplift safety

* The examination of uplift safety is usually needed for lightweight and high volume structures and foundations under the water level
* For example: underground containers and garages, subways
* The sum of forces from the self-weight, the earth pressure and friction should be hihger than the buoyancy

Uplift safety

- Solutions:
  - The foundation of the structure can be streched over its walls
  - Anchoring with piles





Stability

* Loss of stability is a sudden change in the behaviour and load-bearing capacity of the structure which has no connection with the internal forces
* Loss of stability causes immediate failure in structure which can lead to collapse – to avoid this situation is one of the most important engineering task

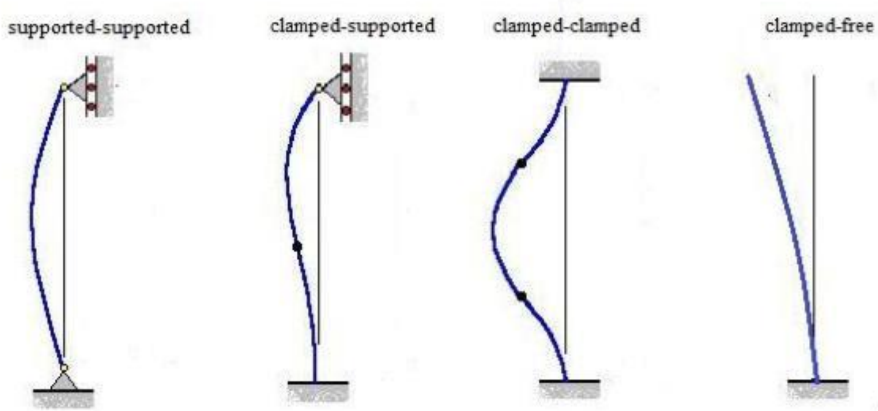
Stability

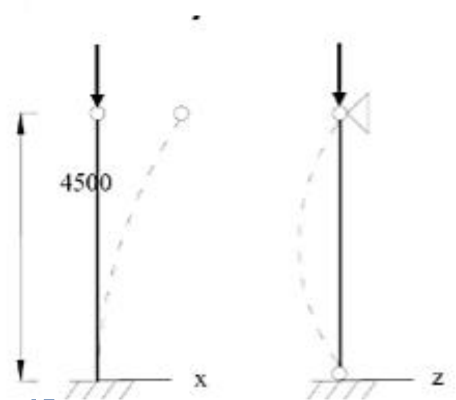
There are two tpyes of loss of stability:

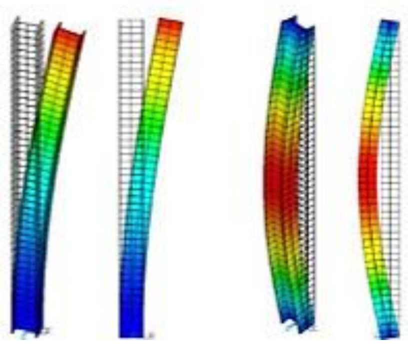
* Global
  * Buckling of compressed columns
  * Lateral buckling of beams
* Local
  * Denting of compressed and/or bending plates
  * Denting of transversely compressed plates
  * Denting of sheared plates

Buckling

The buckled shape of the column is a curve, its cross section are not distortioned

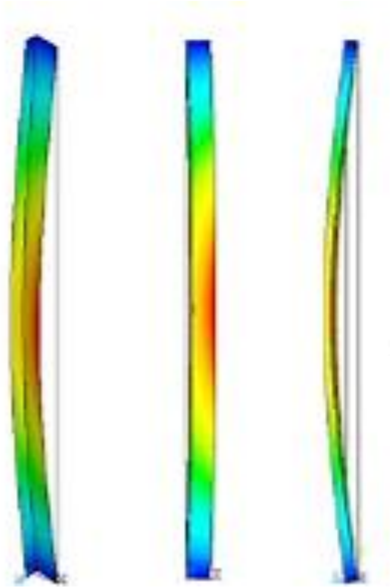


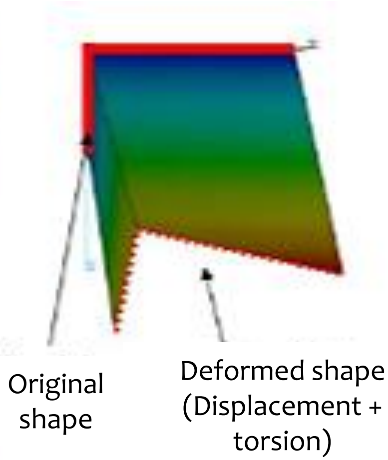


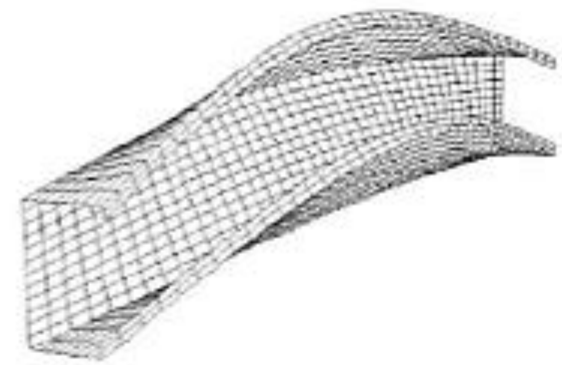


Torsional buckling

* Cross sections are not distortioned
* In the case of compression – planar or spatial torsional buckling
* In the case of bending moment – lateral torsional buckling







Buckling resistance

1. Classification of cross section
2. Determination of buckling length
3. Determination of relative slenderness
4. Choice of buckling curve
5. Determination of buckling resistance

Buckling resistance

It is adequate, if $$\frac{N_{Ed}}{N_{b,Rd}} \leq 1{,}0$$

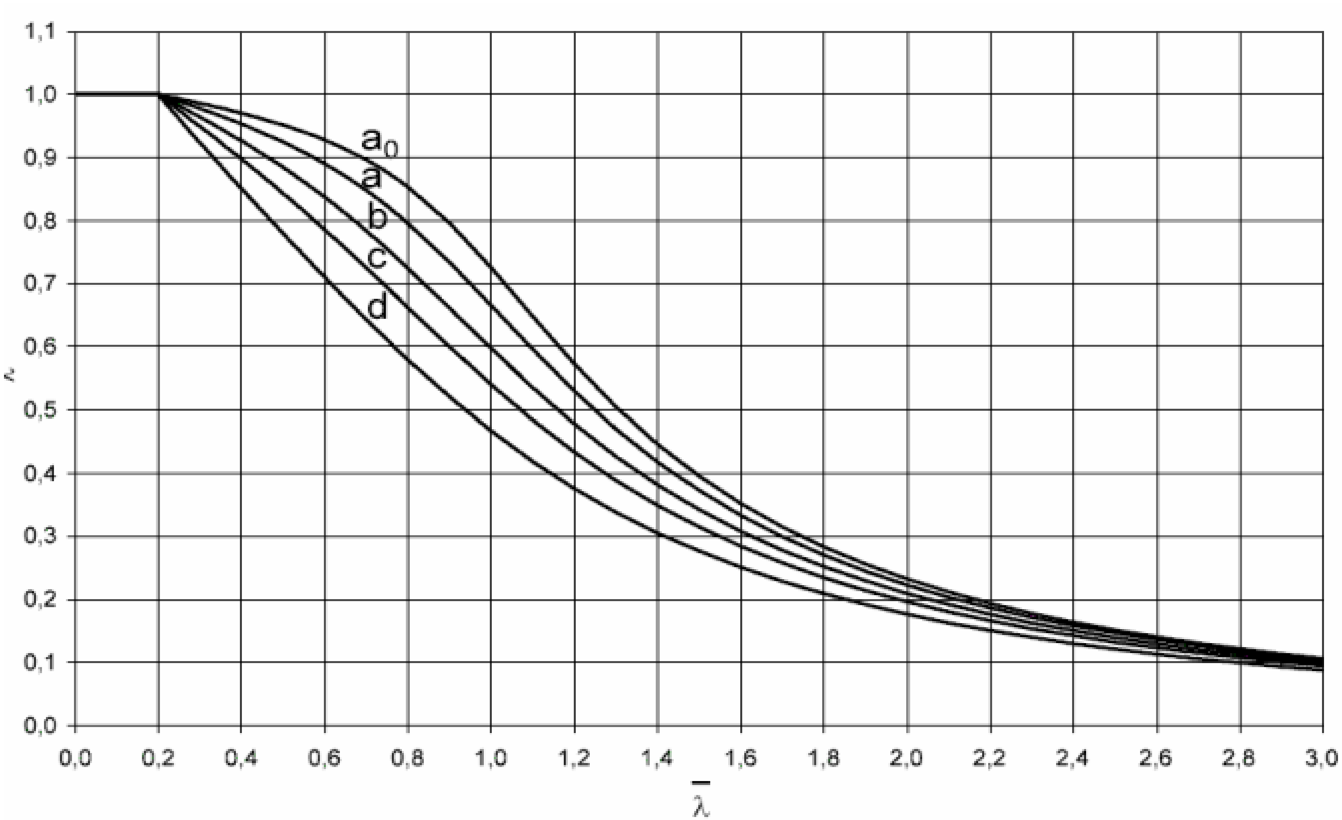
1. 2. 3. class: $$N_{b,Rd} = \frac{\chi \cdot A \cdot f_y}{\gamma_{M1}}$$

4. class: $$N_{b,Rd} = \frac{\chi \cdot A_{eff} \cdot f_y}{\gamma_{M1}}$$

χ: buckling reduction factor, which depends on the relative slenderness (λ)

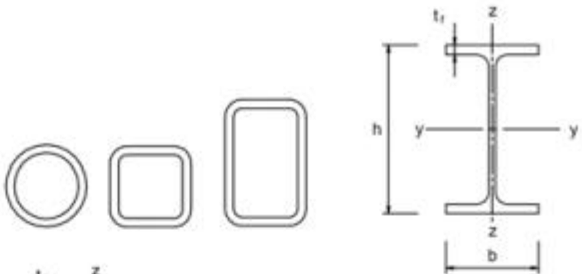
Buckling resistance

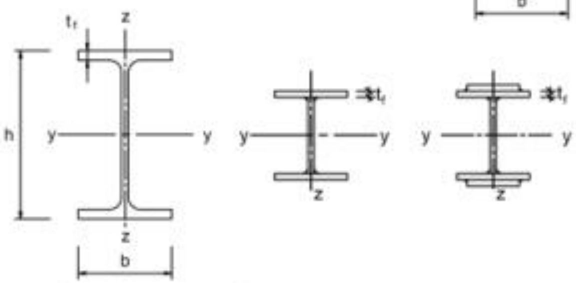
Relative slenderness:

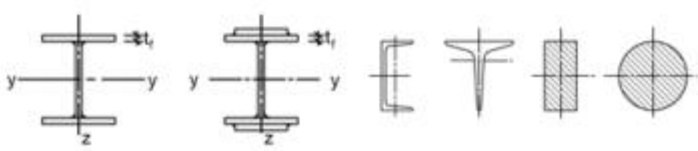


Buckling resistance

Buckling curves:

- a: 

- b: 

- c: 

- d: T is large

Buckling resistance

Relative slenderness:

1. 2. 3. class:

$$\bar{\lambda} = \sqrt{\frac{A \cdot f_y}{N_{cr}}} = \frac{L_{cr}}{i} \cdot \frac{1}{\lambda_1}$$

4. class:

$$\bar{\lambda} = \sqrt{\frac{A_{eff} \cdot f_y}{N_{cr}}} = \frac{L_{cr}}{i} \cdot \frac{\sqrt{\frac{A_{eff}}{A}}}{\lambda_1}$$

Buckling reduction factor:

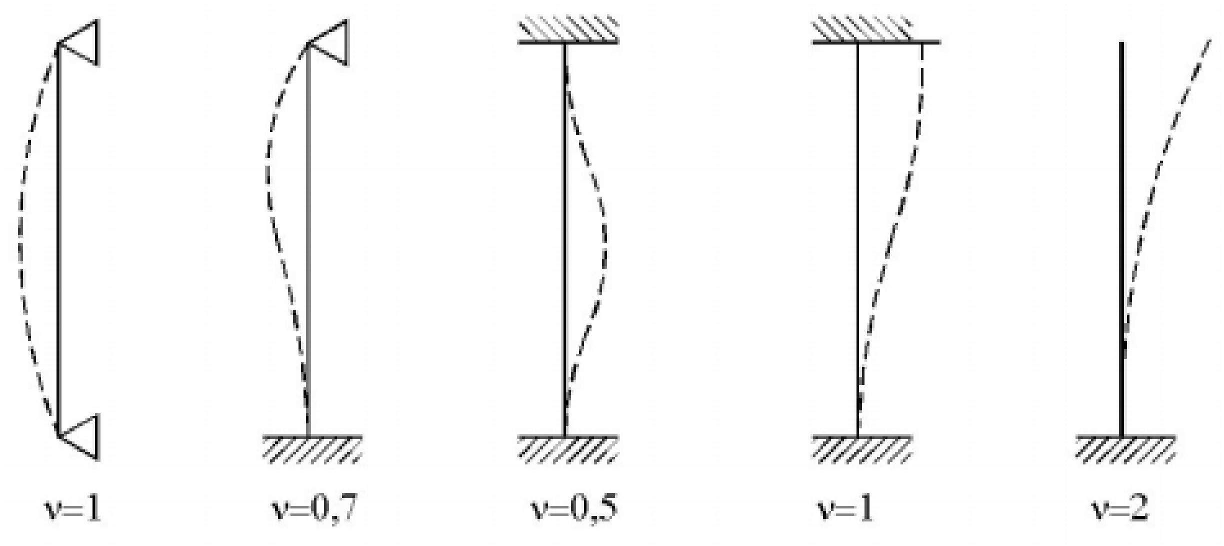
$$\chi = \frac{1}{\phi + \sqrt{\phi^2 - \bar{\lambda}^2}} \ngtr 1{,}0\,,$$

$$\phi = \frac{1 + \alpha \cdot (\bar{\lambda} - 0{,}2) + \bar{\lambda}^2}{2}\,.$$

Buckling resistance

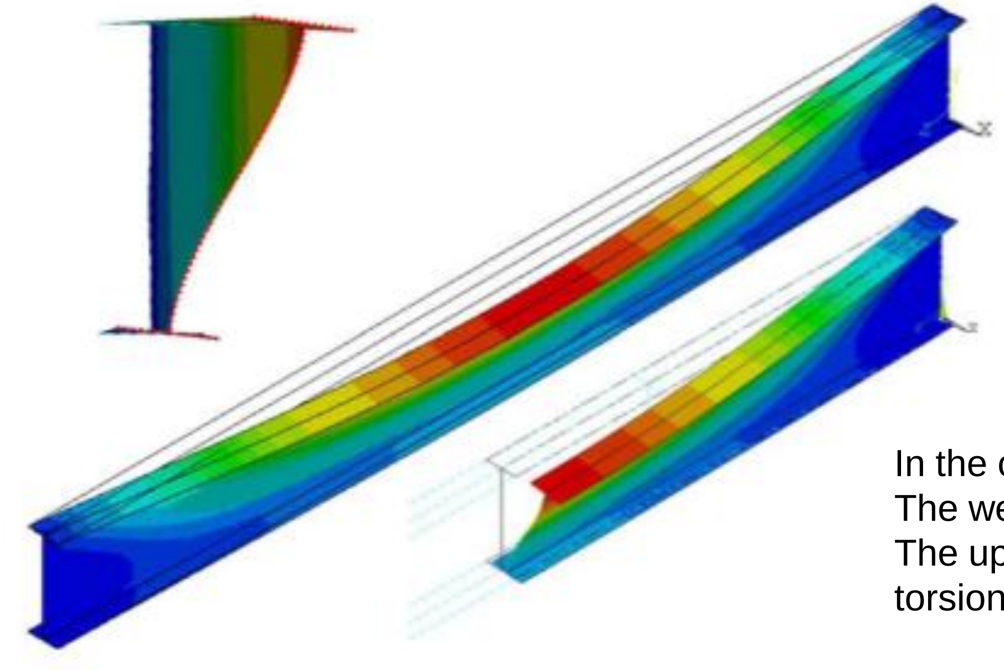
Effective length:

$$L_{cr} = \nu \cdot L$$



Lateral torsional buckling

* torsion + distortion of the cross section



In the case of high cross sections
The wenge: deformation
The upper flange: displacement + torsion

Lateral buckling resistance

* It is adequate, if $\frac{M_{Ed}}{M_{b,Rd}} \leq 1{,}0$

$$M_{b,Rd} = \chi_{LT} \cdot W_y \frac{f_y}{\gamma_{M1}}$$

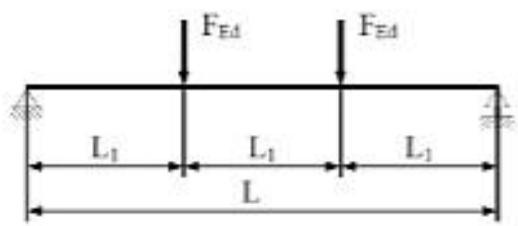
$W_y = W_{pl,y}$	1. and 2. class
$W_y = W_{el,y}$	3. class
$W_y = W_{eff,y}$	4. class
χ_{LT}	Reduction factor based on the relative slenderness

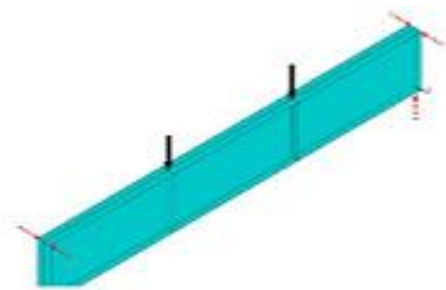
Relative slenderness:

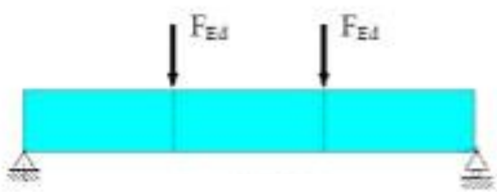
$$\bar{\lambda}_{LT} = \sqrt{\frac{W_y \cdot f_y}{M_{cr}}}$$

Local denting

Effect of longitudinal stresses:

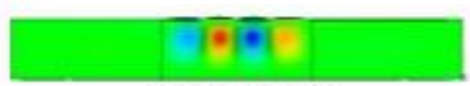




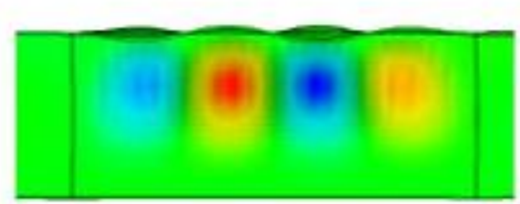


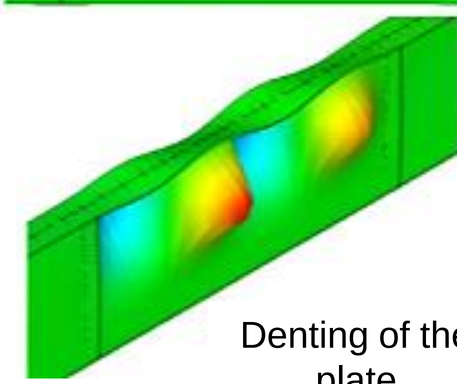
model

moment diagram



denting

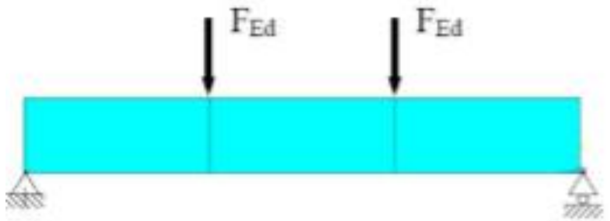




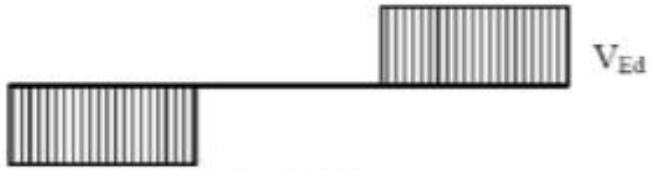
Denting of the plate

Local denting

Shear denting

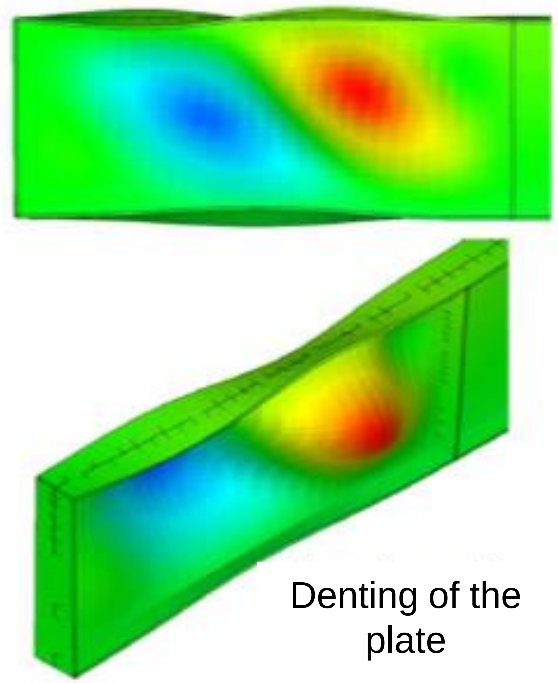


model



shear diagram

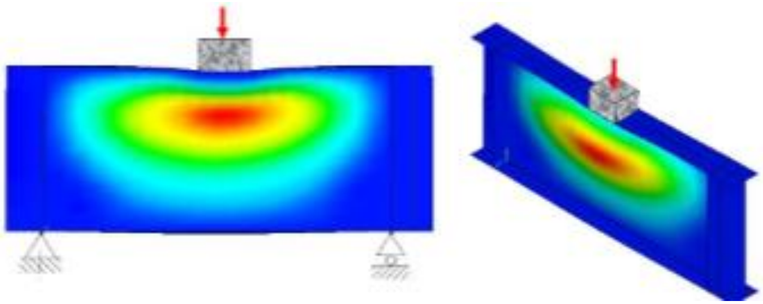
denting



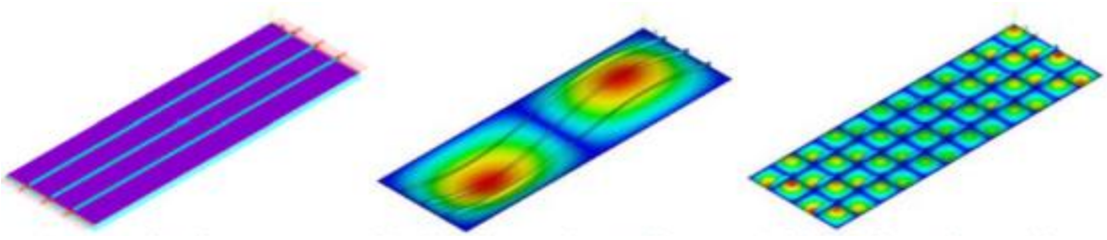
Denting of the plate

Local denting

- In the case of point loads: (reaction forces)



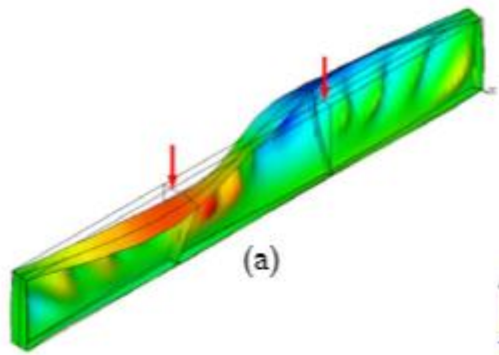
- Solution: stiffening: stability resistance can be increased without increasing the thickness of the plate



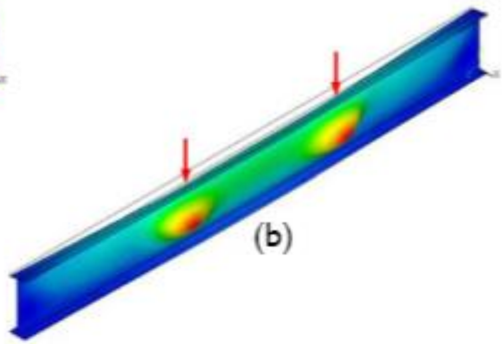
Use of stiffening Global denting Local denting

Local denting

It is important to analyse the interaction of these phenomenons

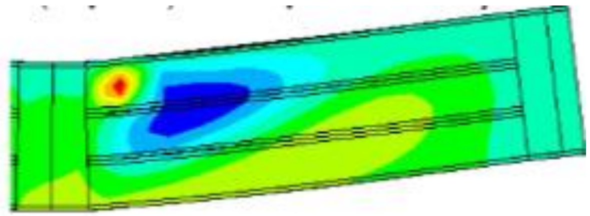


(a) Interaction of lateral torsional buckling and denting



(b) Interaction of buckling and denting

Interaction of bending and shear denting

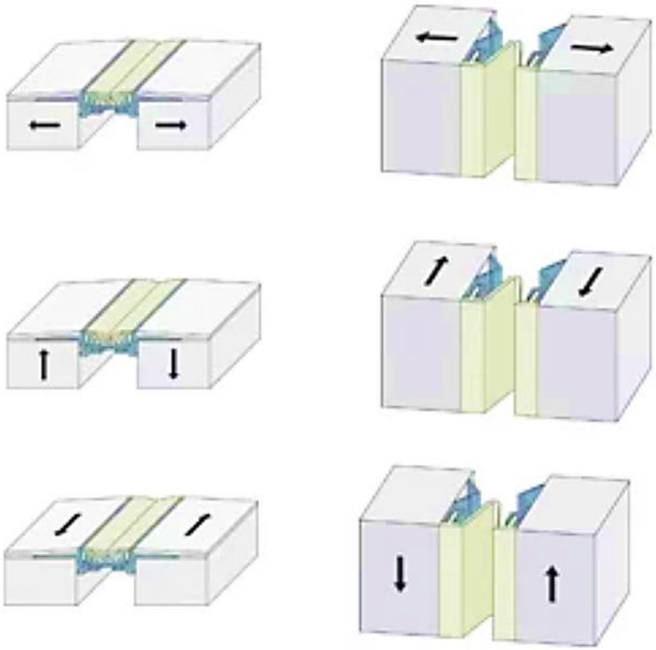


Expansion

- **Expansion joint** = an interruption of the continuity of the building in order to allow the expansion and conraction of the structural parts
- Structural expansion joints are used for limitation of these movements and preventing the damages
- The expansion joints are used both in vertical and horizontal direction, usually its width increases with the height of the building

Expansion

* The expansion joints should be able to deal with the following movements:
  * Thermal expansion and contraction
  * Sinkage
  * Wind action
  * Seismic action



Allowable building length without expansion

* The maximum allowable building length without the use of expansion joints mainly depends on the material and the temperature variation to which the structure is subjected through the year

Material	Building length [m] - Protected from external thermal effects	Building length [m] - Subjected to external thermal effects
Wood	Unlimited	Unlimited
Steel	120…150	100
Prefabricated RC frames	50…60	40
Cast in place RC frames	40…50	30
Other RC structures	30…40	25
Brick and stone	25…30	-

Allowable building length without expansion

- The maximum allowable building length without the use of expansion joints depends also on the structural joints

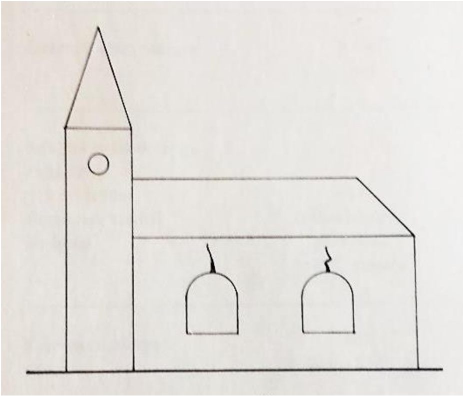
↓

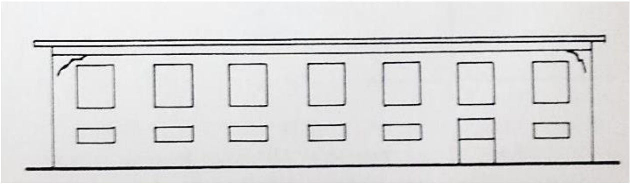
- In the case of cast in place concrete structures the allowable building length is less
- The joints of the prefabricated RC frames or steel structures allows greater movements
- The building length without expansion can be increased

→ in this case the additional loading from the thermal expansion have to be taken into account in the design process

Expansion

* There are significant differences between the structures made from many smaller or a few bigger elements – typical cracks on brick structures
* „sensible” joints:
  * Connection between brick and reinforced concrete structures (mainly on flat roofs, where fluctuation in temperature is high)
  * Timber ceiling (alternation of dry and wet condition)

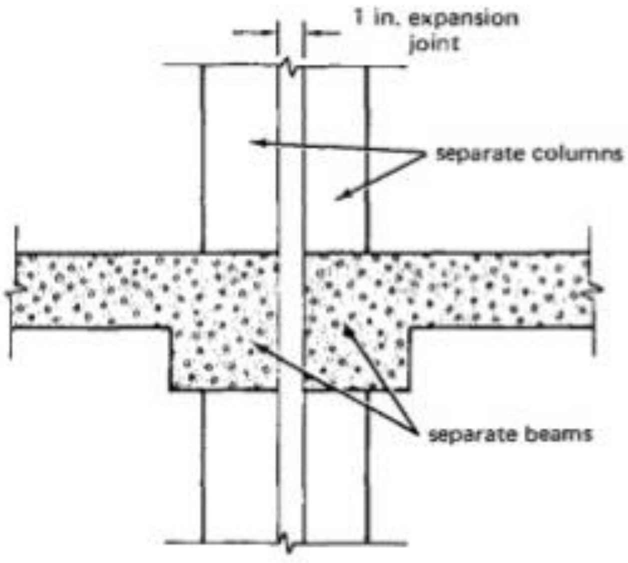




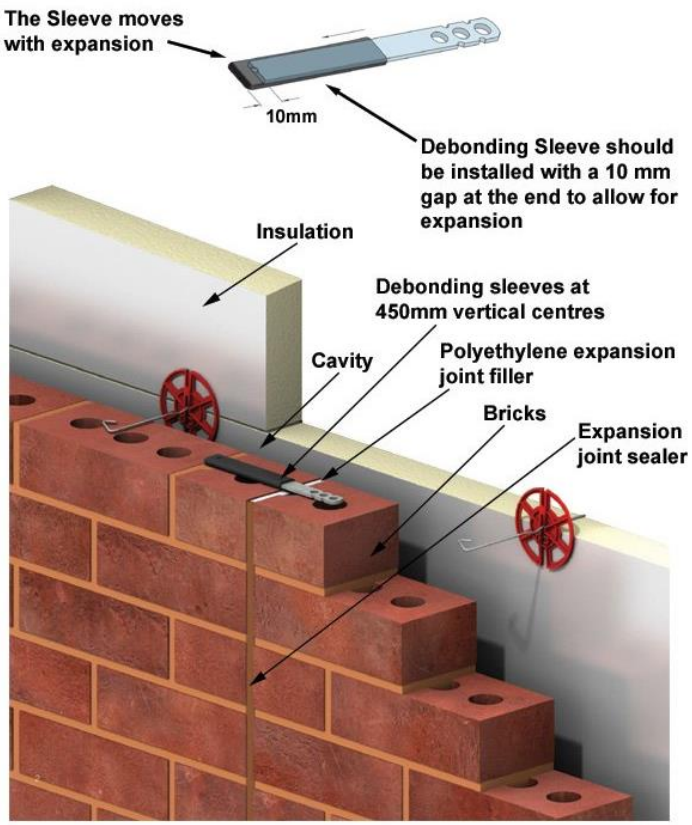
Expansion joints

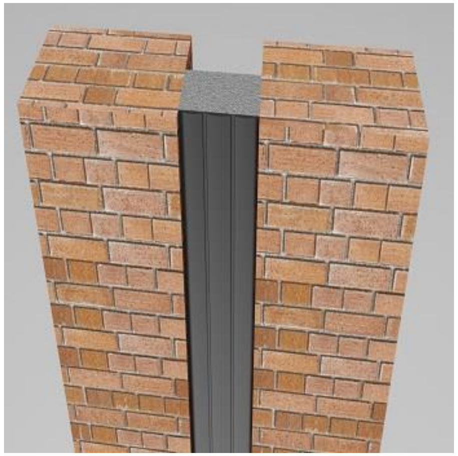
Structural solutions:

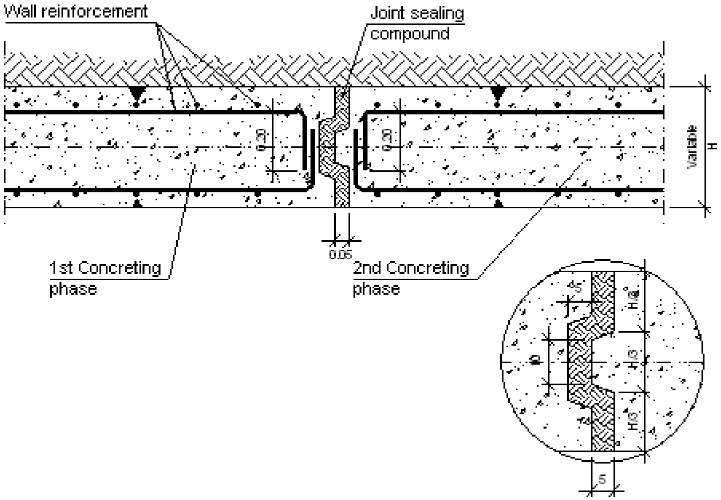
* Double column (wall)
* With secondary structural elements (In the case of small spans)

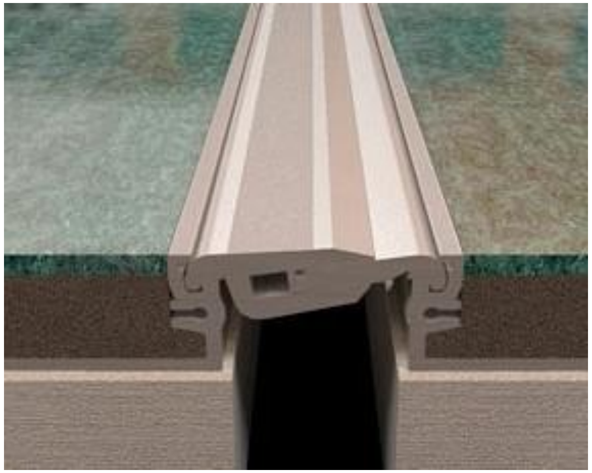


Expansion joints









Thank you for your attention!