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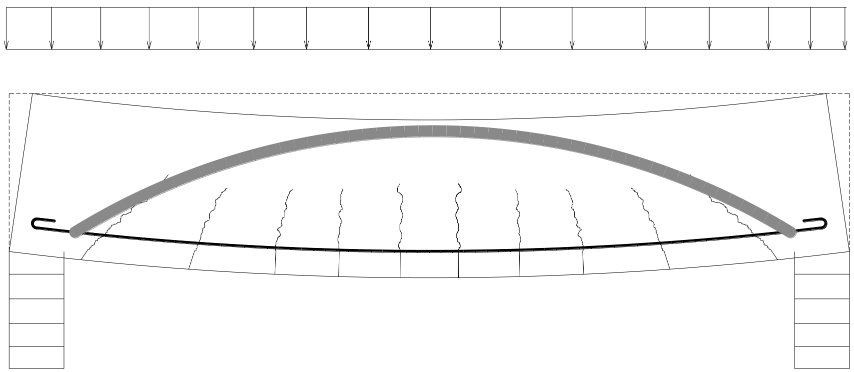
4.1 REINFORCEMENT ANCHORAGE

4.2 WORKING STAGES OF RC ELEMENTS

4.3 DURABILITY OF RC

Reinforcement anchorage in concrete

The concrete does not withstand tension, therefore associated with steel reinforcements. After concrete cracking, reinforcement is overtake tensile stresses of the elements.



⇒ Must be **ensure cooperation** between concrete and reinforcement, i.e. reinforcement slipping in conrete, by a suitable **anchorage**.

Anchorage / Ancorarea

Reinforcement anchorage in concrete is achieved trough:

- Bond
- Hooks or Heads of the bars
- Special anchorage

Anchorage / Ancorarea

Concrete and reinforcement works together due to bond.

Bond → defined by the bond strength, $\boldsymbol{f_b}$

→ is produced by

a) adhesion between concrete and steel

b) friction between reinforcement & concrete

c) clenching of concrete between bar ribs

Anchorage / Ancorarea

Concrete and reinforcement works together due to bond.

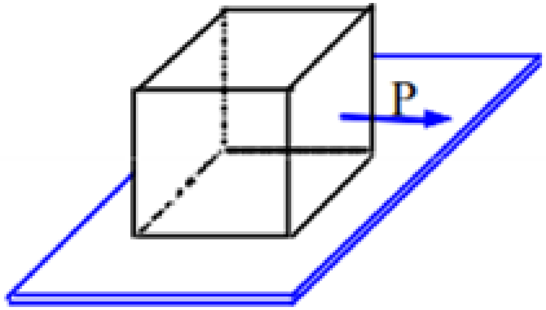
Bond → defined by the bond strength, $\boldsymbol{f_b}$

→ is produced by

a) adhesion between concrete and steel ≈10%

b) friction between reinforcement & concrete

c) clenching of concrete between bar ribs



The cube can not be moved because it is stuck on the metal plate

Anchorage / Ancorarea

Concrete and reinforcement works together due to bond.

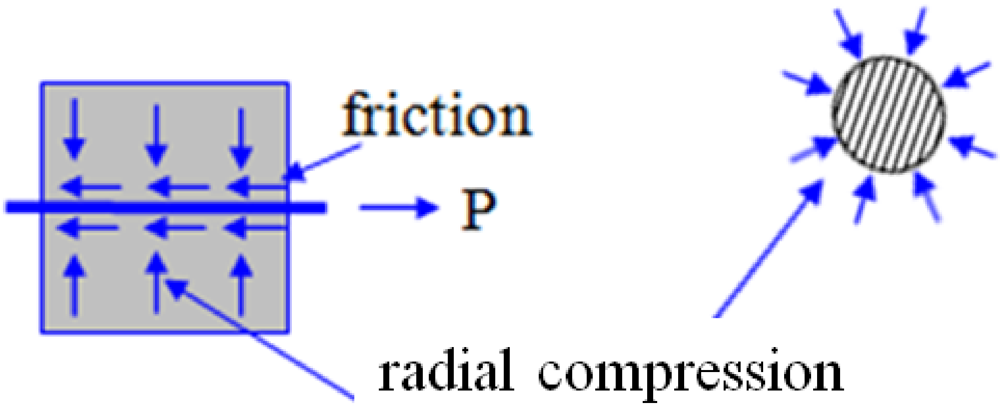
Bond → defined by the bond strength, f_b

→ is produced by

a) adhesion between concrete and steel ≈10%

b) friction between reinforcement & concrete ≈20%

c) clenching of concrete between bar ribs



- fresh concrete is shrinking
- radial compression is produced
- moving bar entail friction

Anchorage / Ancorarea

Concrete and reinforcement works together due to bond.

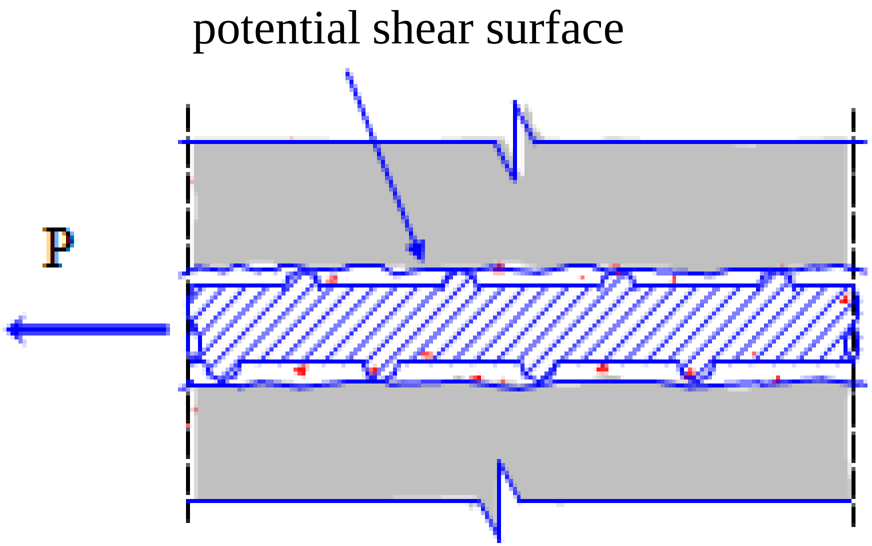
Bond → defined by the bond strength, f_b

→ is produced by

a) adhesion between concrete and steel ≈10%

b) friction between reinforcement & concrete ≈20%

c) clenching of concrete between bar ribs ≈70%



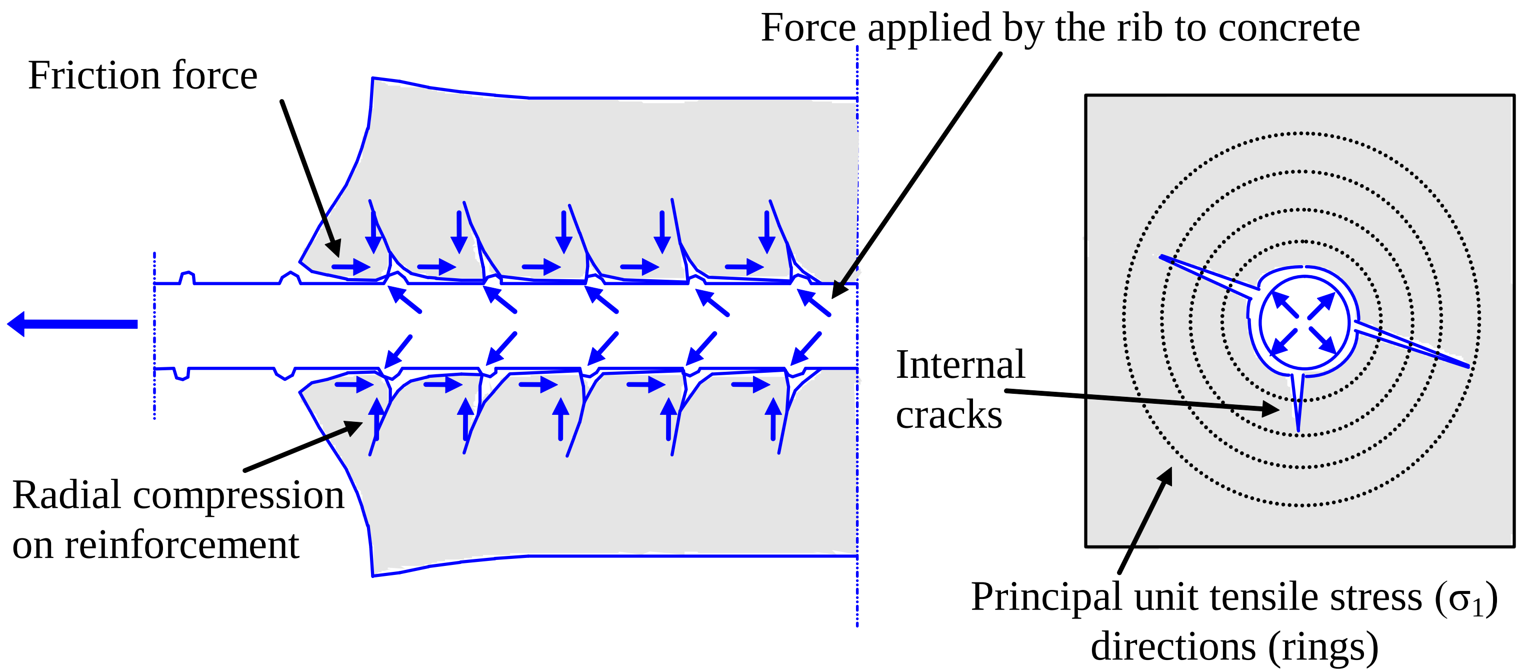
Reinforcing bars are:

- plain: OB37 (RO) → easy to pull-out the bar
- **ribbed: PC52 (RO), S500 (EU)**

- concrete must be sheared on a cylindrical surface to pull-out the bar.
- will be difficult to produce concrete shear

Anchorage / Ancorarea

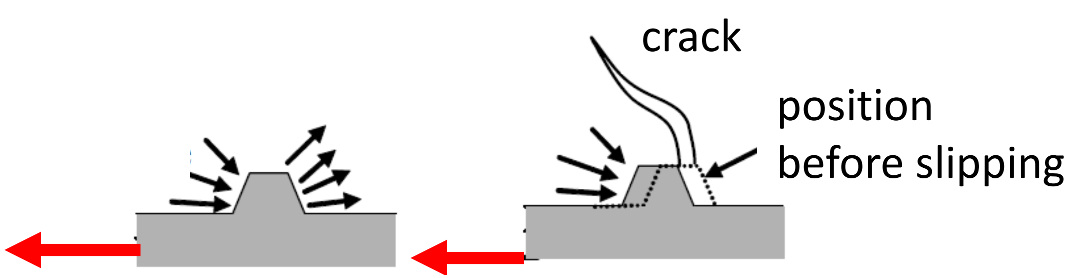
Bond model for a reinforcement with periodic profile



a) internal cracking of conrete

b) concrete splitting $\sigma_1 = f_{ct}$

(dislocation of a relative large amount of concrete)

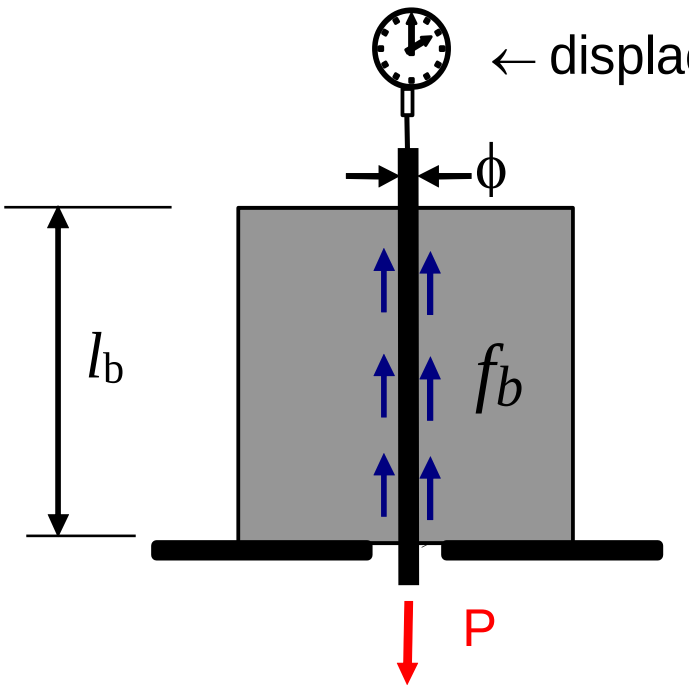


c) rib detail

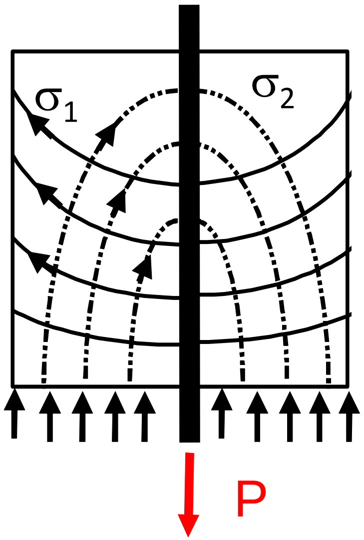
Anchorage / Ancorarea

Bond stress is obtained by pull-out test

Failure mode → Pulling out of the bar (plane bar)
→ Cracking of concrete (ribbed bar)



experimental model



trajectories of principal stresses

$\sigma_1 \rightarrow f_{ct}$

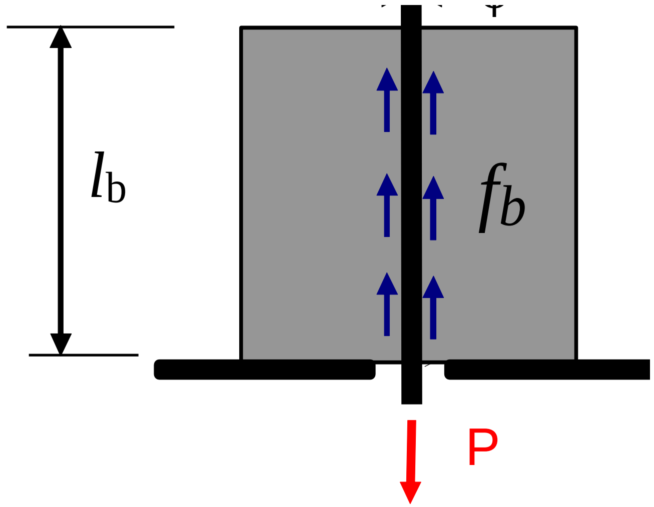
Anchorage / Ancorarea

Bond stress is obtained by pull-out test

Bond failure

→ bar sliding for plain bars

→ concrete cracking, even splitting in 2 or 3 pieces for ribbed bar



$$f_b = \frac{P}{\pi \cdot \phi \cdot l_b}$$

Anchorage / Ancorarea

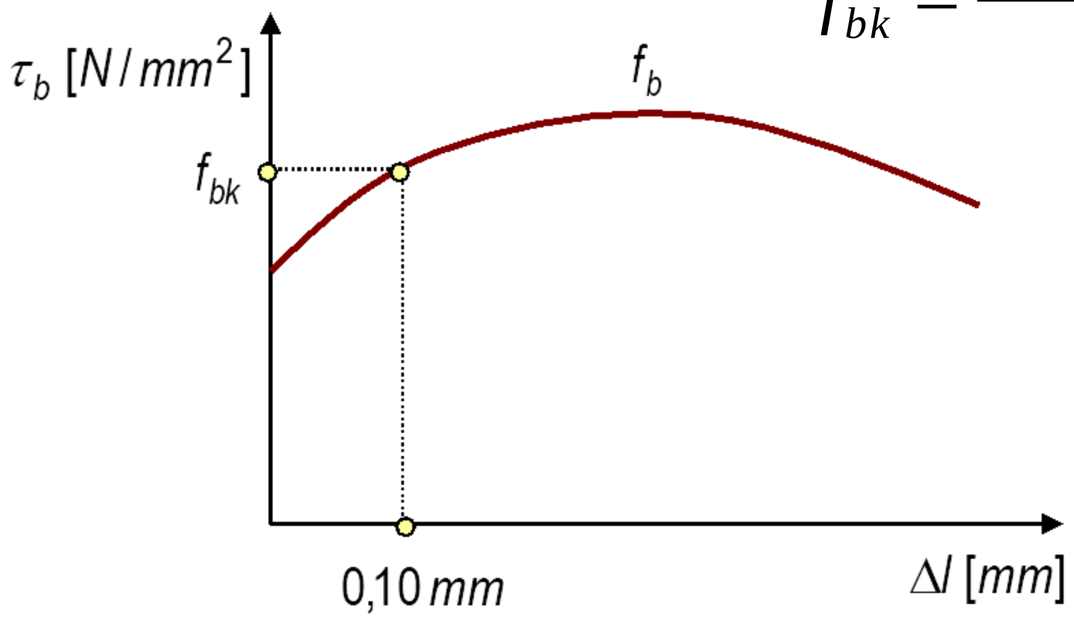
Bond stress is obtained by pull-out test

Bond failure

→ bar sliding for plain bars

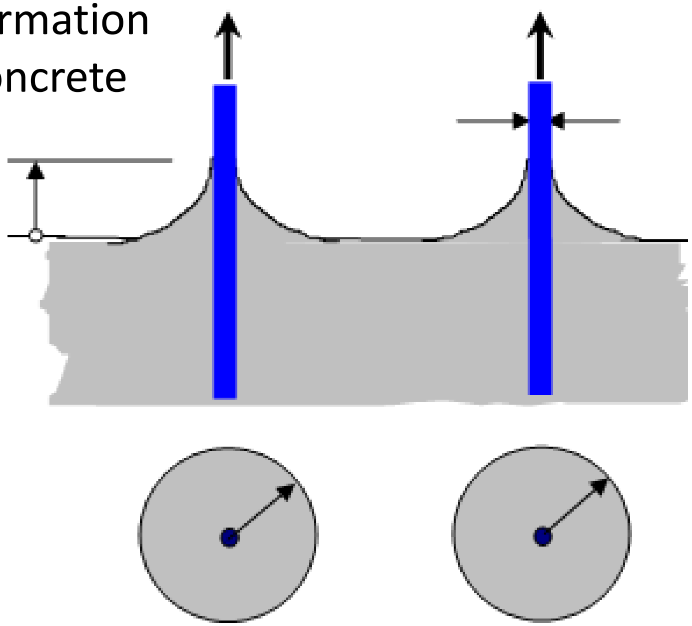
→ concrete cracking, even splitting in 2 or 3 pieces for ribbed bar

$$f_{bk} = \frac{P(\Delta l = 0.10\,mm)}{\pi \cdot \phi \cdot l_b}$$



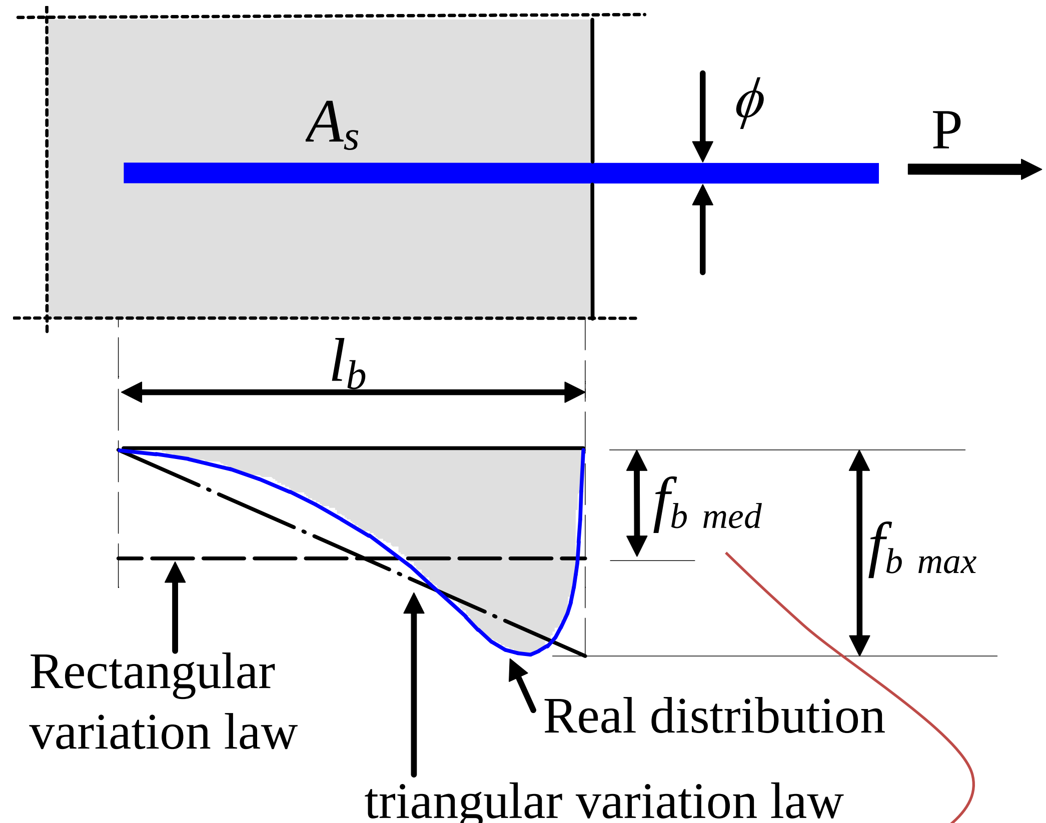
Unit bond stress distribution in transversal and longitudinal directions

local deformation of concrete



action range r = (10…15)ϕ

(influence zone)

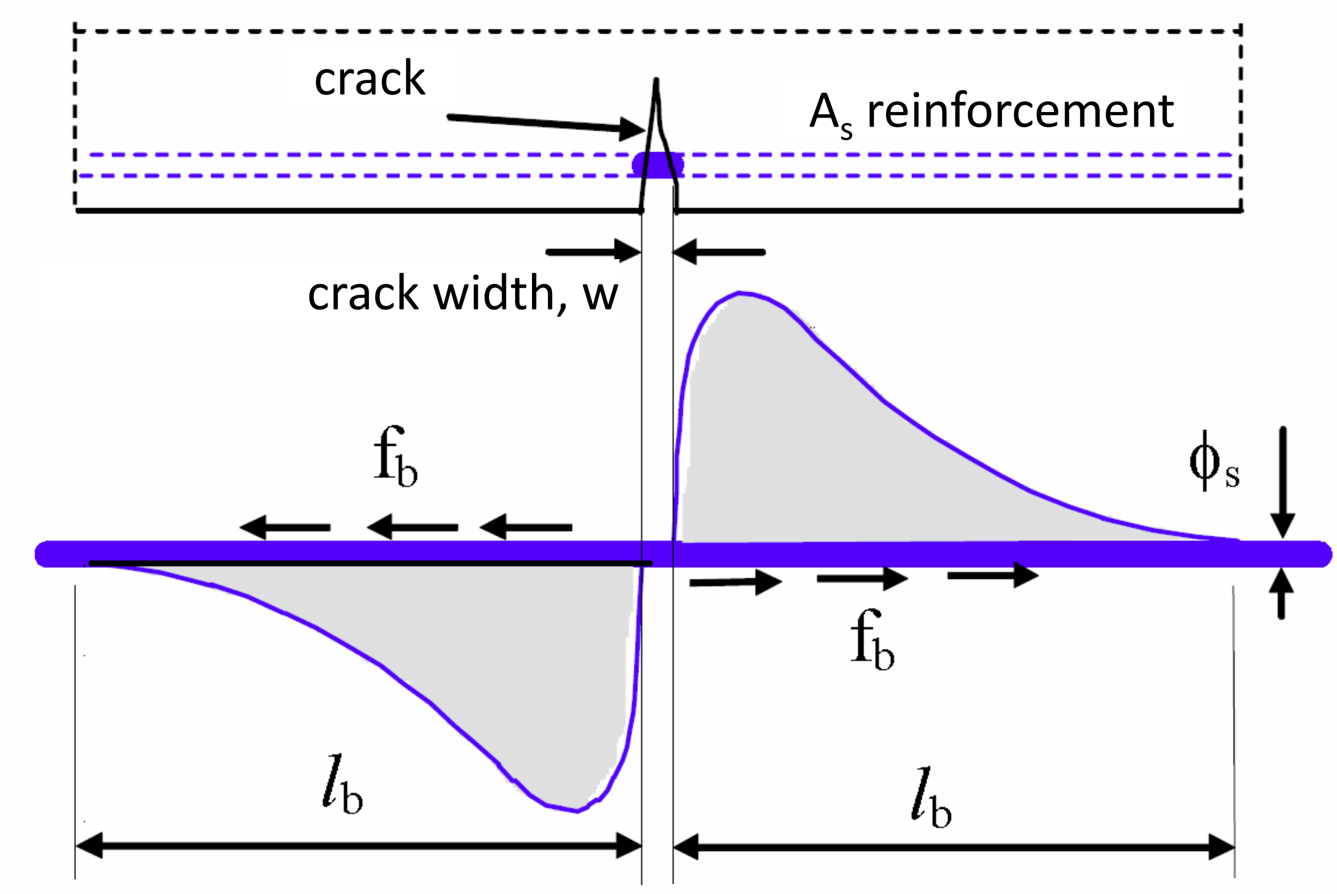


1. **It is advisable to avoid overlapping of influence zones**
2. **Usually, the overlapping of influence zones can not be avoided**

$$f_{b\ med} = \frac{P}{\pi \cdot \phi \cdot l_b}$$

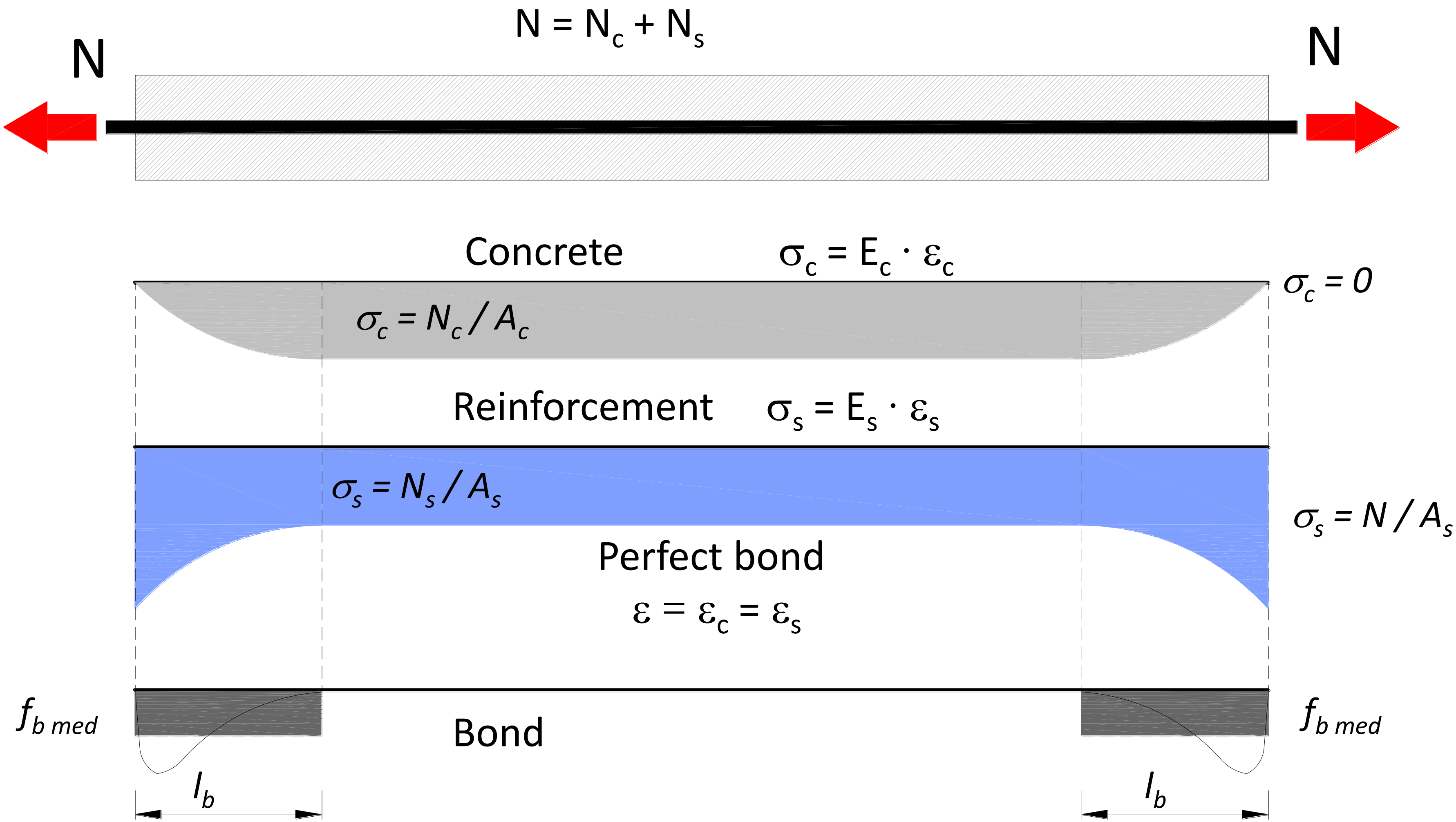
Anchorage / Ancorarea

Unit bond stress distribution in a beam, near a crack



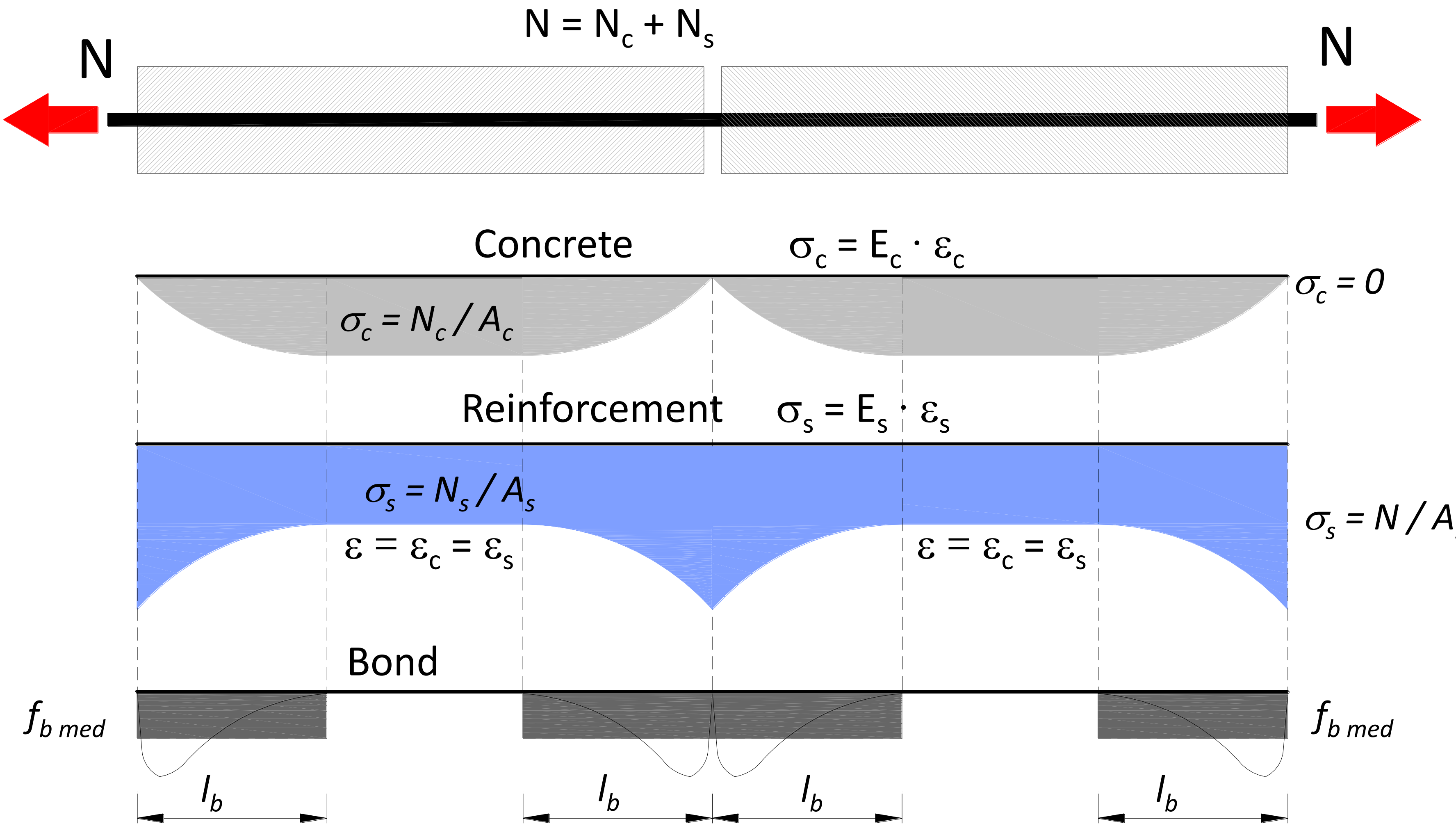
Anchorage / Ancorarea

Behavior of reinforcement embedded in concrete for centric tension



Anchorage / Ancorarea

Behavior of reinforcement embedded in concrete for centric tension



Anchorage / Ancorarea

***Necessary anchorage length** l_b → ensure stress transmission from reinforcement to concrete through bond on this length*

Rational failure condition: bond failure to be produce simultaneously with reinforcement yielding ($\sigma_{sd} = f_{yd}$)

$$N_c = N_s$$

$$\pi \cdot \phi \cdot l_b \cdot f_{bmed} = \frac{\pi \cdot \phi^2}{4} f_y \quad \rightarrow \quad l_b = \frac{\phi \cdot f_y}{4 \cdot f_{bmed}}$$

In conformity to EC2:

$$l_{b,rqd} = \frac{\phi \cdot \sigma_{sd}}{4 \cdot f_{bd}}$$

where $l_{bd} = \alpha_1 \alpha_2 \alpha_3 \alpha_4 \alpha_5 l_{b,rqd} \geq l_{b,min}$

At the limit: $l_{b,rqd} = \frac{\phi \cdot f_{yd}}{4 \cdot f_{bd}}$

Anchorage / Ancorarea

Table 8.2: Values of α_1, α_2, α_3, α_4 and α_5 coefficients

Influencing factor	Type of anchorage	Reinforcement bar	
		In tension	In compression
Shape of bars	Straight	$\alpha_1 = 1,0$	$\alpha_1 = 1,0$
	Other than straight (see Figure 8.1 (b), (c) and (d)	$\alpha_1 = 0,7$ if $c_d > 3\phi$ otherwise $\alpha_1 = 1,0$ (see Figure 8.3 for values of c_d)	$\alpha_1 = 1,0$
Concrete cover	Straight	$\alpha_2 = 1 - 0,15\,(c_d - \phi)/\phi$ $\geq 0,7$ $\leq 1,0$	$\alpha_2 = 1,0$
	Other than straight (see Figure 8.1 (b), (c) and (d))	$\alpha_2 = 1 - 0,15\,(c_d - 3\phi)/\phi$ $\geq 0,7$ $\leq 1,0$ (see Figure 8.3 for values of c_d)	$\alpha_2 = 1,0$
Confinement by transverse reinforcement not welded to main reinforcement	All types	$\alpha_3 = 1 - K\lambda$ $\geq 0,7$ $\leq 1,0$	$\alpha_3 = 1,0$
Confinement by welded transverse reinforcement*	All types, position and size as specified in Figure 8.1 (e)	$\alpha_4 = 0,7$	$\alpha_4 = 0,7$
Confinement by transverse pressure	All types	$\alpha_5 = 1 - 0,04p$ $\geq 0,7$ $\leq 1,0$	-

$$l_{bd} = \alpha_1\alpha_2\alpha_3\alpha_4\alpha_5 l_{b,rqd} \geq l_{b,min}$$

Anchorage / Ancorarea

α_1 - form of the bars assuming adequate cover

α_2 - concrete minimum cover

α_3 - confinement by transverse reinforcement

α_4 - influence of one or more welded transverse bars ($\phi_t > 0,6\phi$) along the design anchorage length

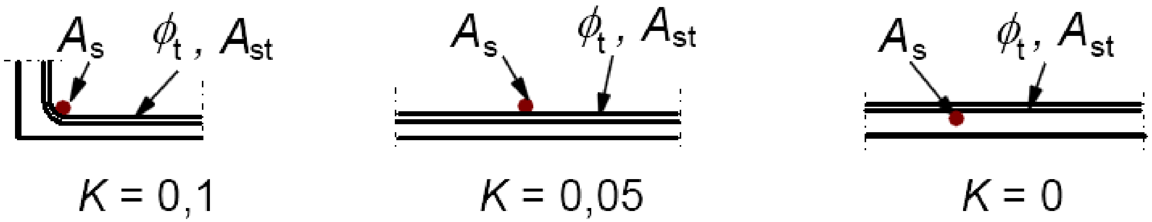
α_5 - effect of the pressure transverse to the plane of splitting along the design anchorage length

$\alpha_2\,\alpha_3\,\alpha_5 \geq 0,7$

$$l_{bd} = \alpha_1 \alpha_2 \alpha_3 \alpha_4 \alpha_5 l_{b,rqd} \geq l_{b,min}$$

Anchorage / Ancorarea

Effects of non-welded reinforcements

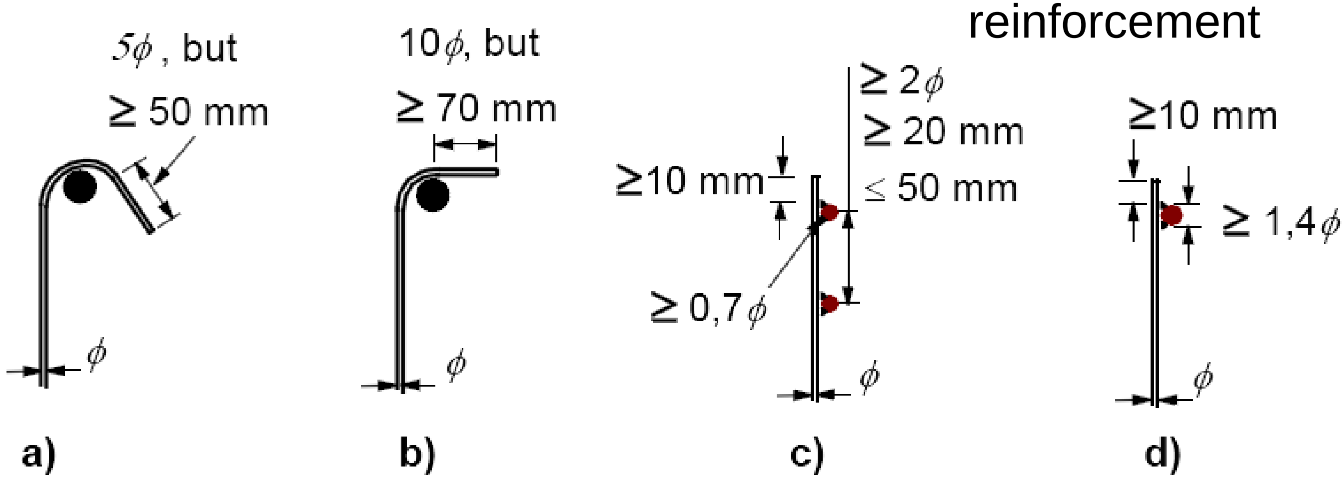


Anchorage of links and shear reinforcement

hook

bend

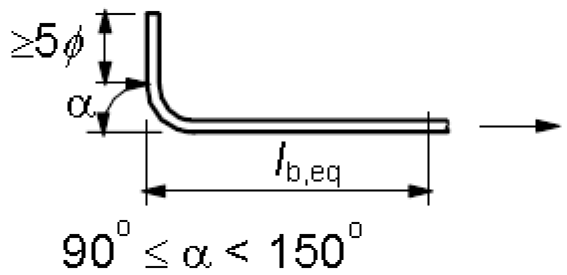
Welded transverse reinforcement



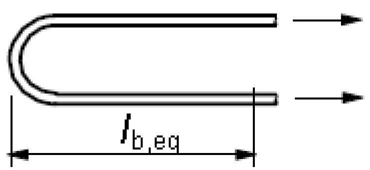
Anchorage / Ancorarea

Simplification:

$$l_{bd} = \alpha_1 l_{b,rqd}$$ - for shapes shown in Figure 8.1b to 8.1d



b) Equivalent anchorage length for standard bend



d) Equivalent anchorage length for standard loop

Table 8.2: Values of α_1, α_2, α_3, α_4 and α_5 coefficients

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		In tension	In compression
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Anchorage / Ancorarea

Simplification:

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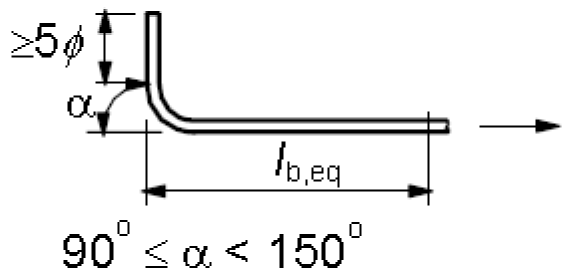
- for shapes shown in Figure 8.1b to 8.1d



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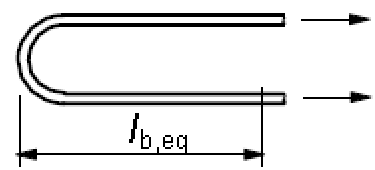

d) Equivalent anchorage length for standard loop

Table 8.2: Values of α_1, α_2, α_3, α_4 and α_5 coefficients

Influencing factor	Type of anchorage	Reinforcement bar: In tension	Reinforcement bar: In compression
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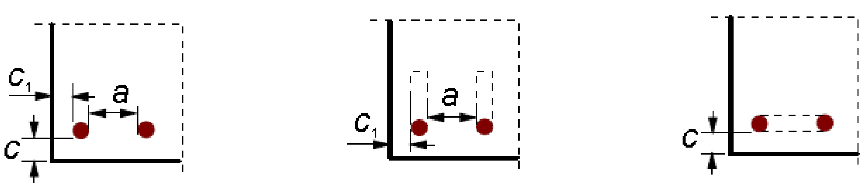
		$\alpha_1 = 0,7$ if $c_d > 3\phi$ otherwise $\alpha_1 = 1,0$ (see Figure 8.3 for values of c_d)	$\alpha_1 = 1,0$



a) Straight bars $c_d = \min(a/2, c_1, c)$

b) Bent or hooked bars $c_d = \min(a/2, c_1)$

c) Looped bars $c_d = c$

Anchorage / Ancorarea

$$f_{bd} = 2.25 \cdot \eta_1 \cdot \eta_2 \cdot f_{ctd}$$ → design value of the ultimate bond stress

where:

η_1 - is a coefficient related to the quality of the bond condition and the position of the bar during concreting

= 1.0 → when 'good' conditions are obtained

= 0.7 → for all other cases

η_2 - is related to the bar diameter

= 1.0 pt $\phi \leq 32$ mm

= (132-ϕ)/100 pt $\phi > 32$ mm

f_{ctd} – design tensile strength of concrete

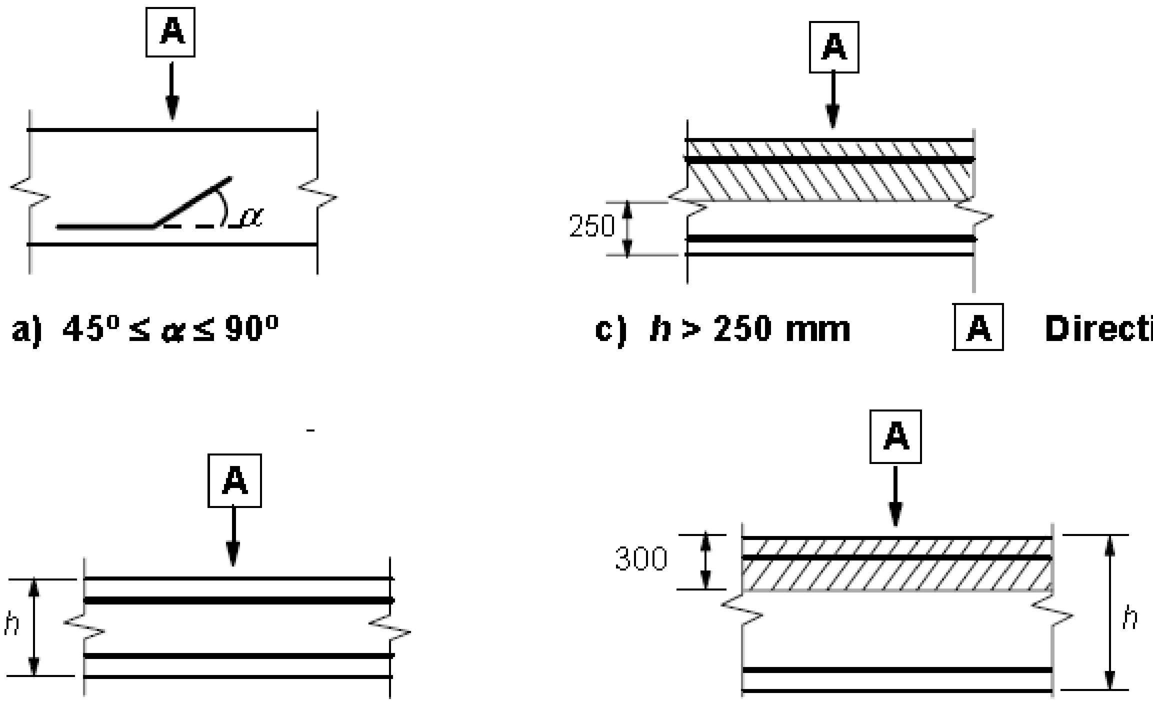
$$l_{b,rqd} = \frac{\phi \cdot f_{yd}}{4 \cdot f_{bd}}$$

$$l_{bd} = \alpha_1 \alpha_2 \alpha_3 \alpha_4 \alpha_5 l_{b,rqd} \geq l_{b,min}$$

Anchorage / Ancorarea

$$f_{bd} = 2.25 \cdot \eta_1 \cdot \eta_2 \cdot f_{ctd}$$ → design value of the ultimate bond stress

Bond conditions:



a) $45^o \leq \alpha \leq 90^o$

b) $h \leq 250$ mm

c) $h > 250$ mm

d) $h > 600$ mm

A Direction of concreting

a) & b) 'good' bond conditions for all bars

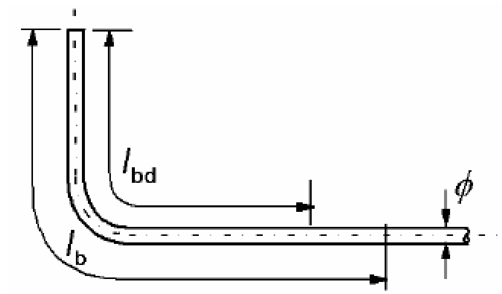
c) & d) unhatched zone – 'good' bond conditions
hatched zone – 'poor' bond conditions

Anchorage / Ancorarea

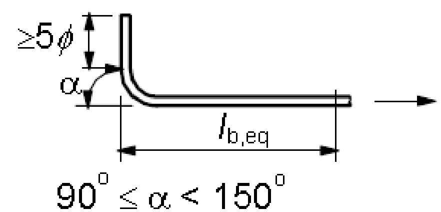
Longitudinal reinforcement bars can be anchored to through the following forms:

1. Strait ends

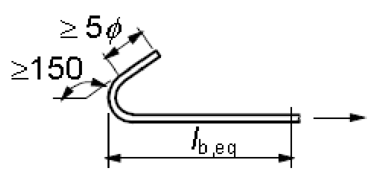
2. Bent ends



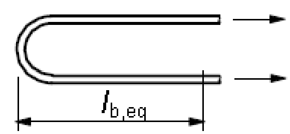
a) Basic tension anchorage length, l_b, for any shape measured along the centreline



b) Equivalent anchorage length for standard bend



c) Equivalent anchorage length for standard hook

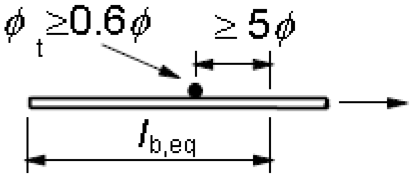


d) Equivalent anchorage length for standard loop

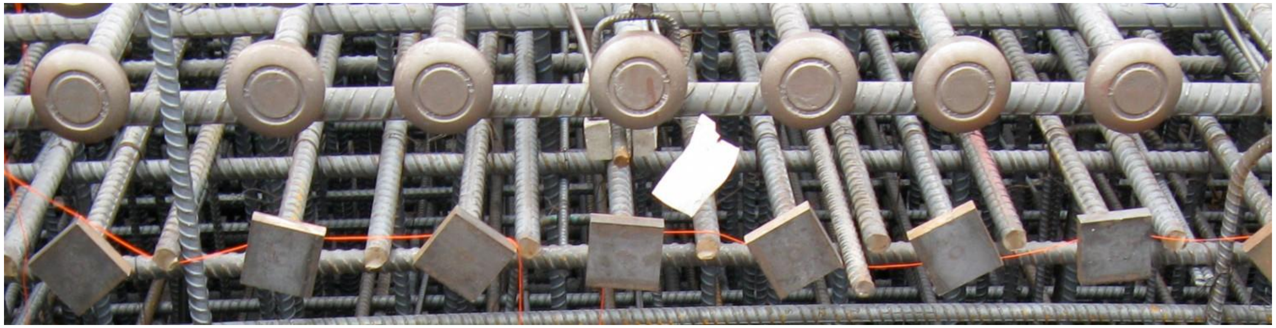
Anchorage / Ancorarea

Longitudinal reinforcement bars can be anchored to through the following forms:

3. Welded transverse bar



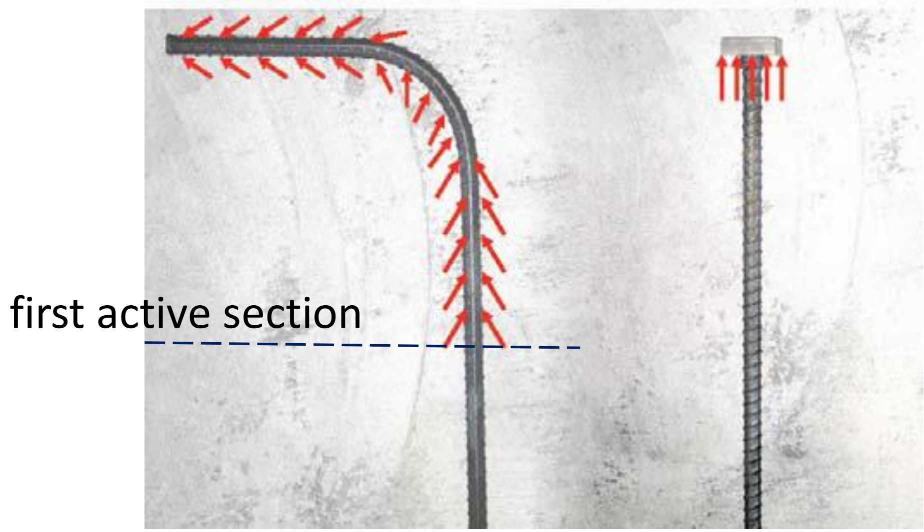
4. Special-end anchorage (headed reinforcement)



Anchorage / Ancorarea

4. Special-end anchorage (headed reinforcement)

- Transfer through concentrated stresses eliminates the need of anchorage length, without using bond
- The total length of the bar can be used
- Reducing agglomeration of reinforcements → element size reduction
- Stiff anchorage at shear reinforcement reduce shear strains, thus reducing shear crack width

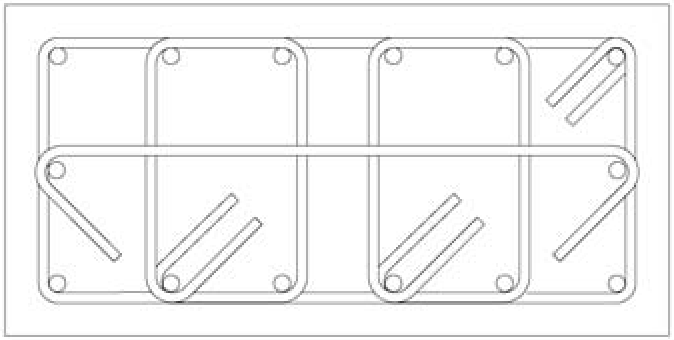


Stress distribution

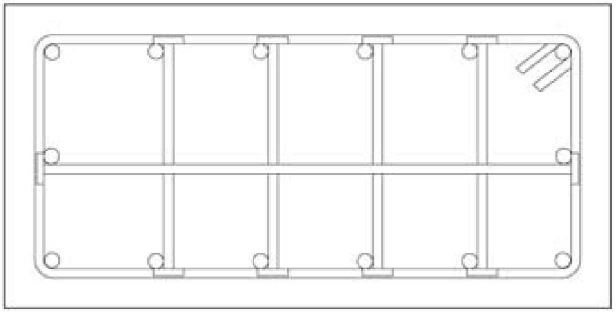
Position of the active section

Anchorage / Ancorarea

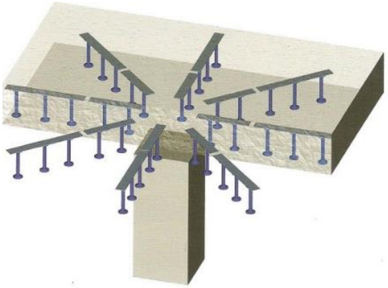
4. Special-end anchorage (headed reinforcement)

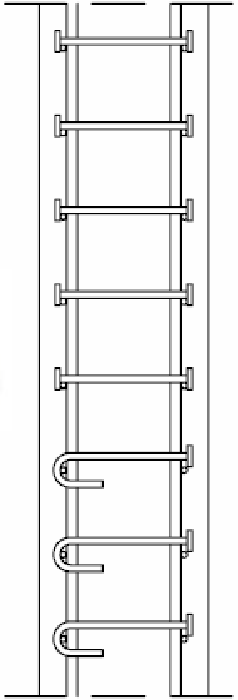


→



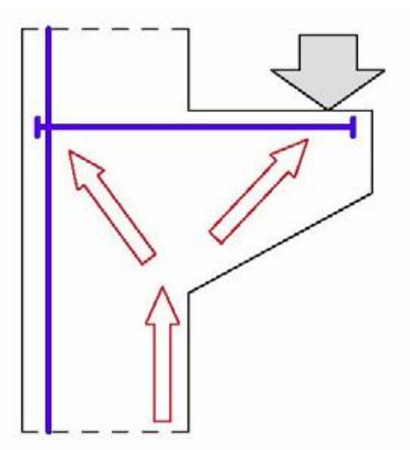
- Easy and fast to install
- No hooks of bends
- Costs ???



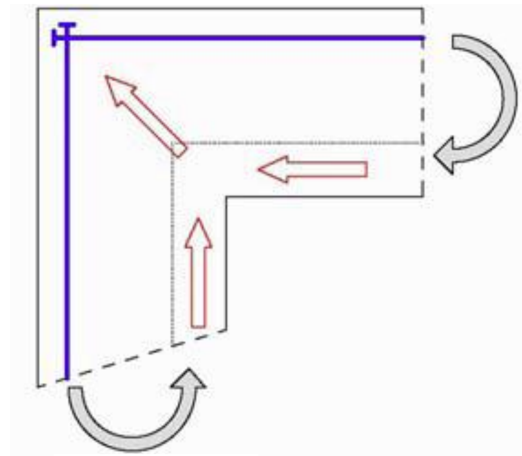


Anchorage / Ancorarea

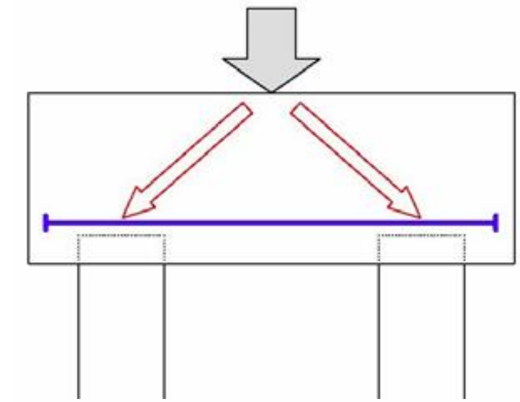
4. Special-end anchorage (headed reinforcement)

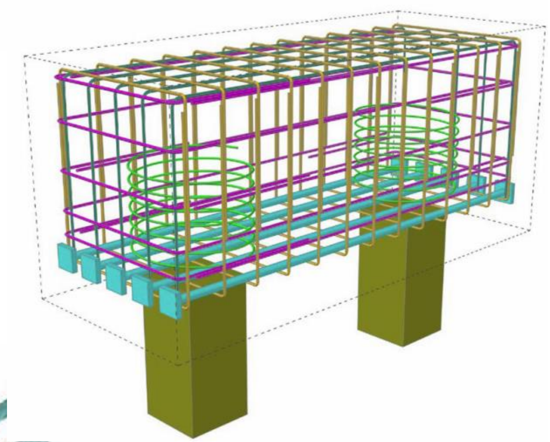


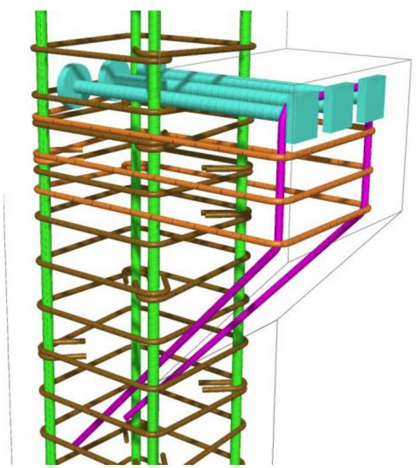
Cantilever

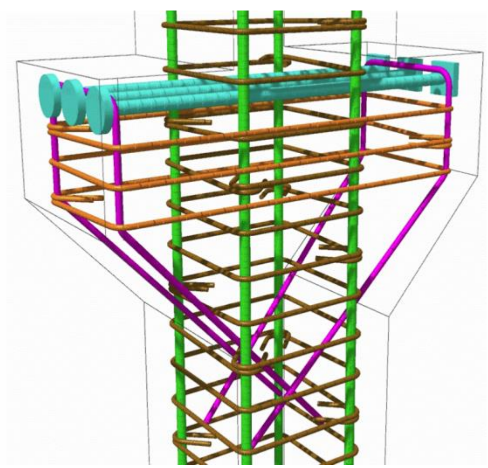


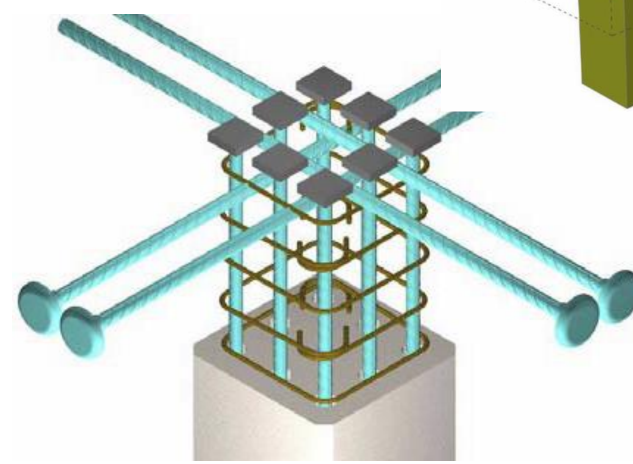
Column











(hrc.com)

Anchorage / Ancorarea

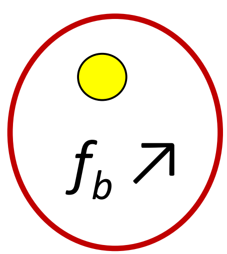
Bond strength depends on:

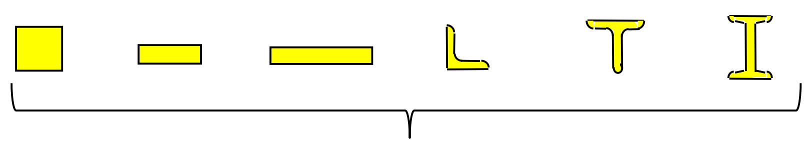
Concrete quality	C $\nearrow$	$\Rightarrow f_b \nearrow$
- Cement dosage	Cem $\nearrow$	$\Rightarrow f_b \nearrow$
- Water – cement ratio	W/Cem $\nearrow$	$\Rightarrow f_b \searrow$
- Compaction	Compaction $\nearrow$	$\Rightarrow f_b \nearrow$

- Position of the reinforcement during the casting

	for horizontal bars	$\Rightarrow f_b \searrow$ (air voids)
	for vertical bars	$\Rightarrow f_b \nearrow$

- Shape of the reinforcement cross-section





- peeks in stress distribution
- weak compaction of concrete

Bond strength depends on:

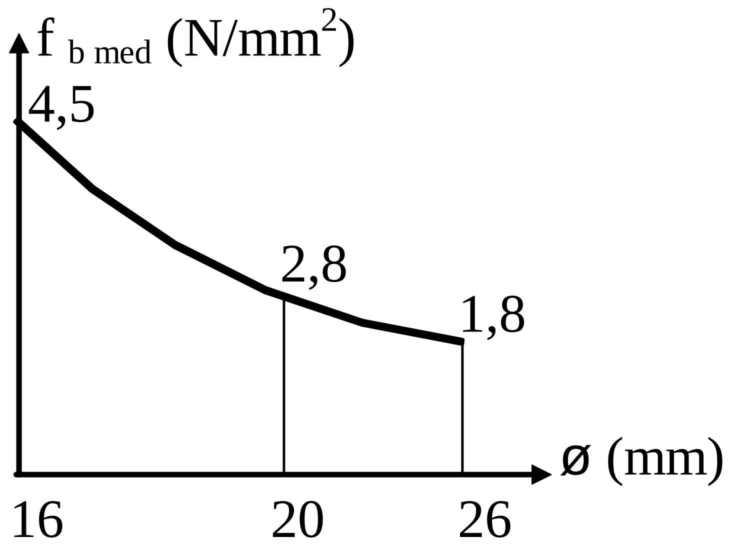
- Diameter of the bars $\phi \nearrow$ $\Rightarrow f_b \searrow$

Ex:

1ϕ16 = 4ϕ?

$f_{b,\phi 16}$ = ? MPa

$f_{b,\phi ?}$ = ? MPa



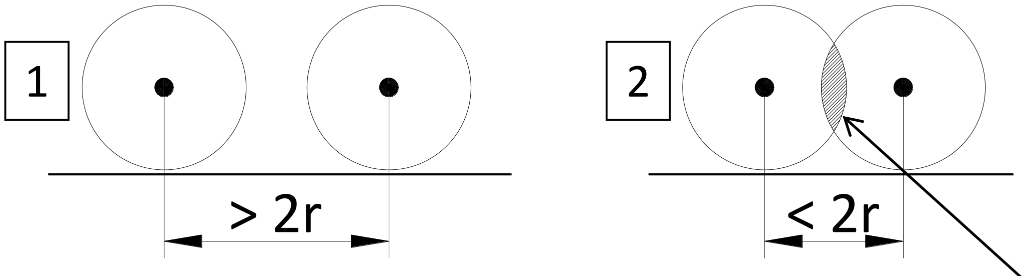
- Concrete cover C. cover $\searrow$ $\Rightarrow f_b \searrow$

radial compression $\searrow$

Anchorage / Ancorarea

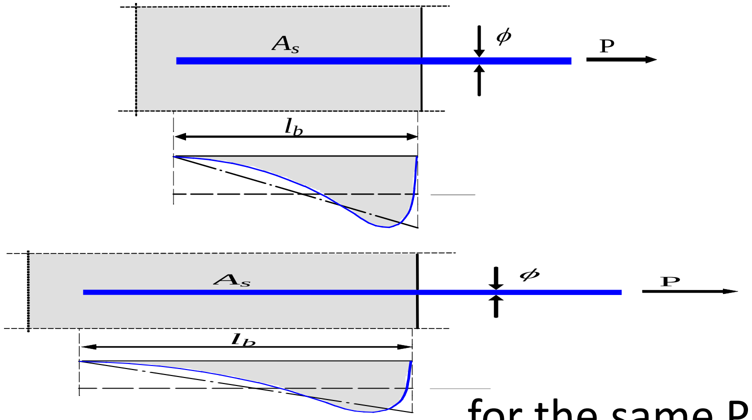
Bond strength depends on:

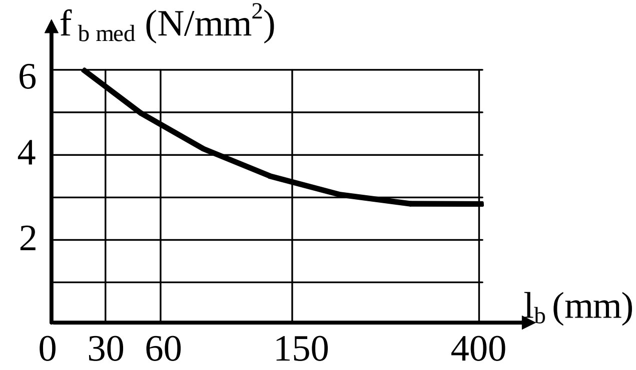
- Bar spacing $s_l \nearrow \Rightarrow f_b \nearrow$



$f_{b1} > f_{b2}$

- Embedment length $l_b \nearrow \Rightarrow f_{b\,med} \searrow$





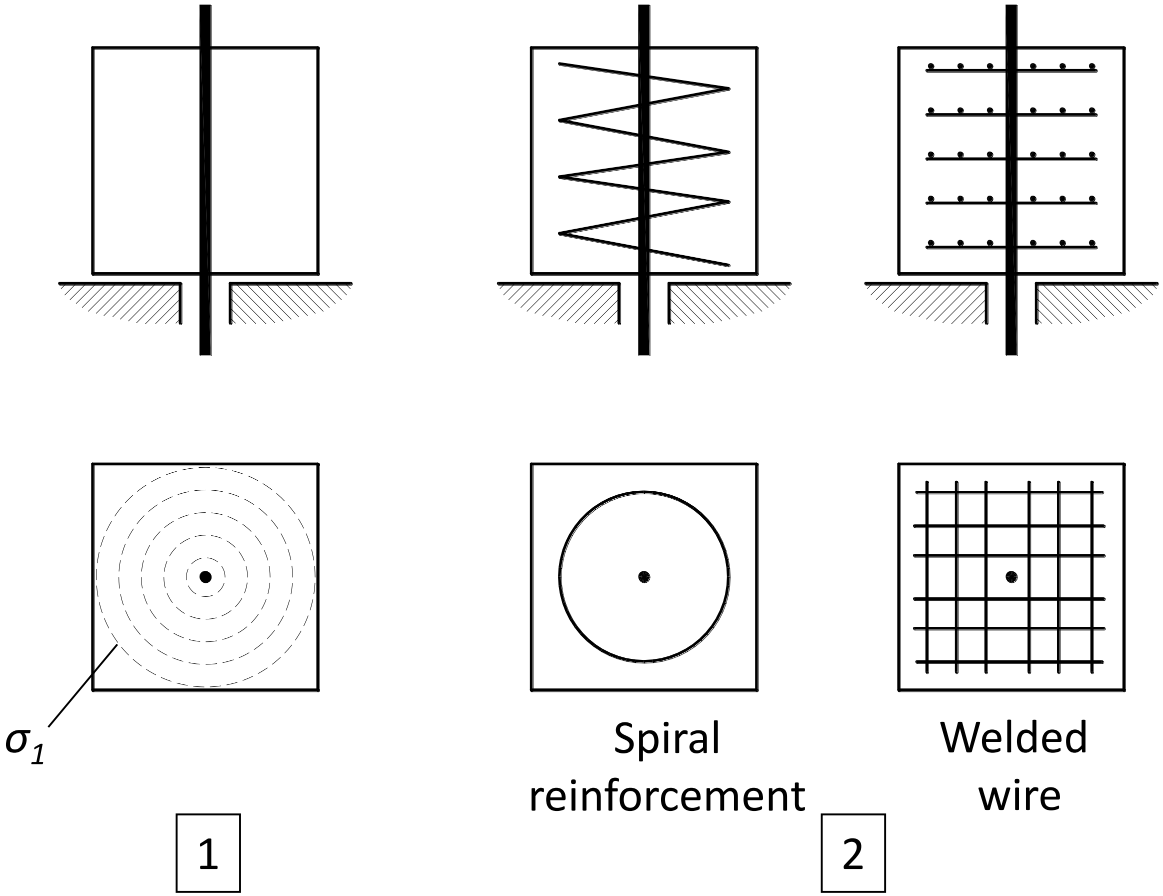
for the same P: diagram will be elongated therefore $f_{b\,med} \searrow$

Anchorage / Ancorarea

Bond strength depends on:

- Transversal reinforcement prevents (transversal) deformation

$\Rightarrow f_b \nearrow$

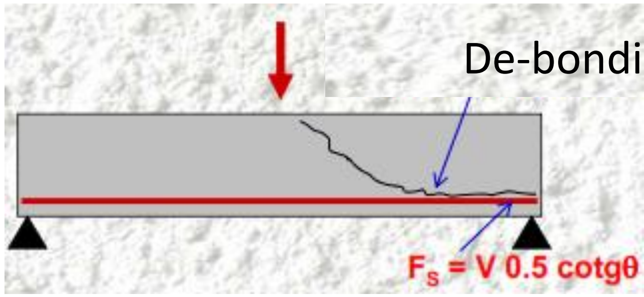


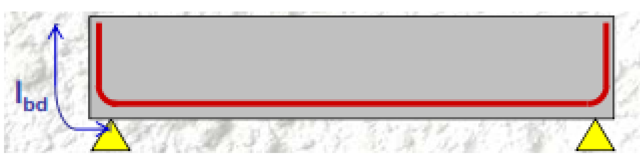
$f_{b1} < f_{b2}$

Anchorage / Ancorarea

Why bars should be anchored ?

De-bonding & failure by bond





CORRECT DETAILING

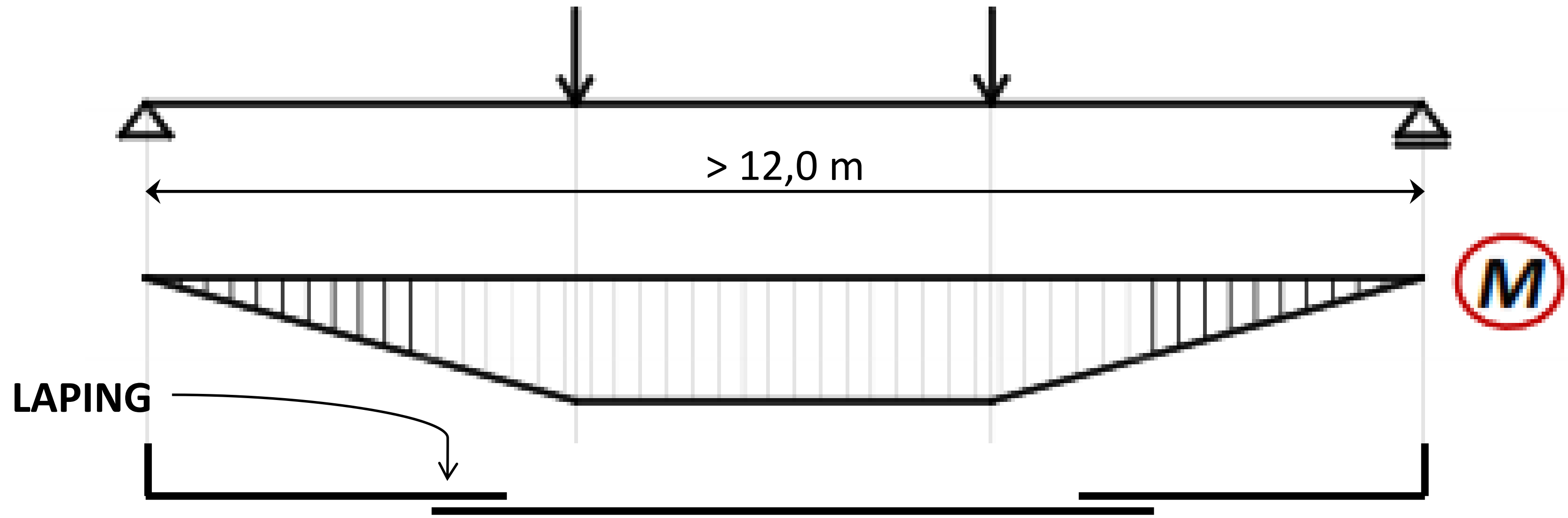
Anchorage / Ancorarea

Summary:

Anchorage of the bars must be realized to ensure:
- good transfer of reinforcement tensile force to concrete
- avoid longitudinal cracks and concrete splitting.

For this reason the following requirements will be fulfilled:
- the minimum spacing of the bars
- anchorage of the bars
- disposing transversal bars (welded or non-welded), if necessary
- the sufficient concrete cover

LAPPING OF BARS



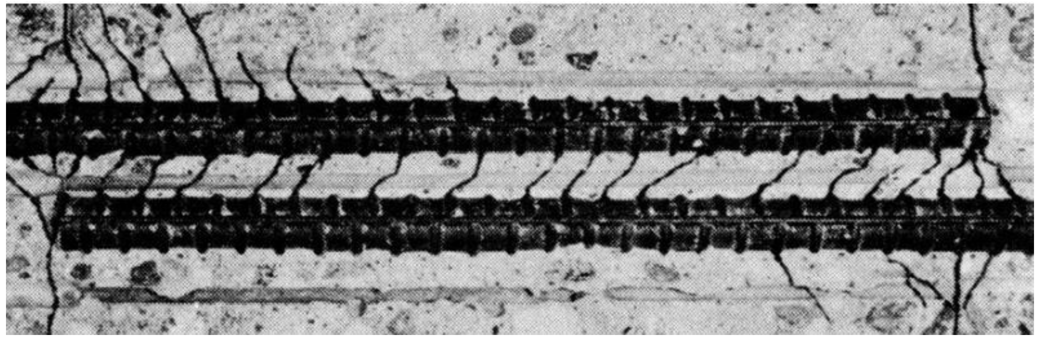
ϕ > 14 mm → maximum length =12,0 m

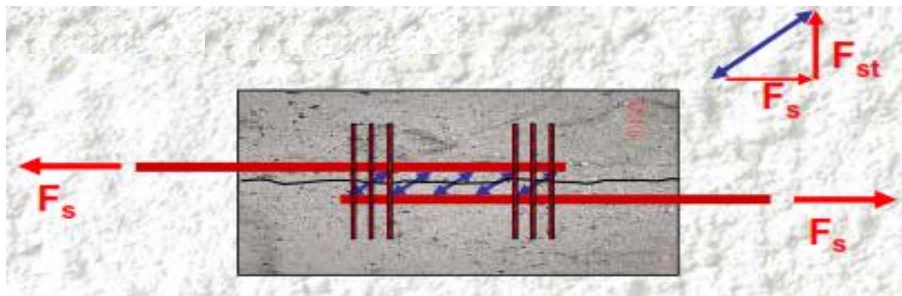
Forces are transmitted from one bar to another by:

- **lapping of bars provided with or without bends or hooks;**
- **welding;**
- **mechanical devices.**

Connection between bars should normally be staggered and not located in areas of high moments/forces (e.g. supports, plastic hinges)

LAPPING OF BARS





THE FLOW OF FORCE:
reinforcement – bond – concrete – bond – reinforcement

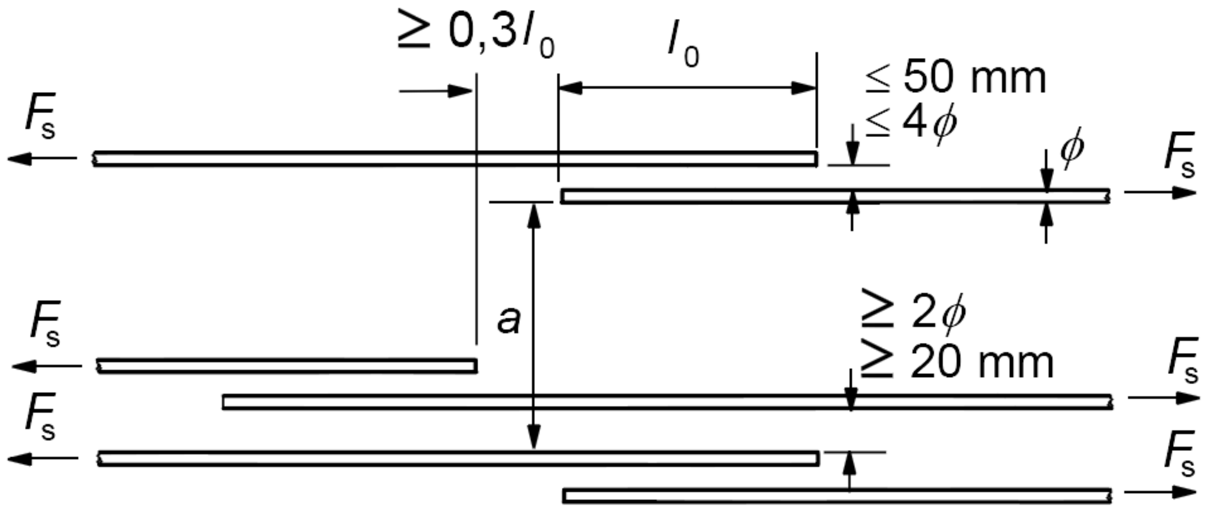
↓

Consequence of this flow is the tensile force in concrete

↓

Transverse reinforcement is required

Arrangement of lapped bars



$$l_0 = \alpha_1 \cdot \alpha_2 \cdot \alpha_3 \cdot \alpha_5 \cdot \alpha_6 \cdot l_{b,rqd} \geq l_{0,min}$$ → design lap length

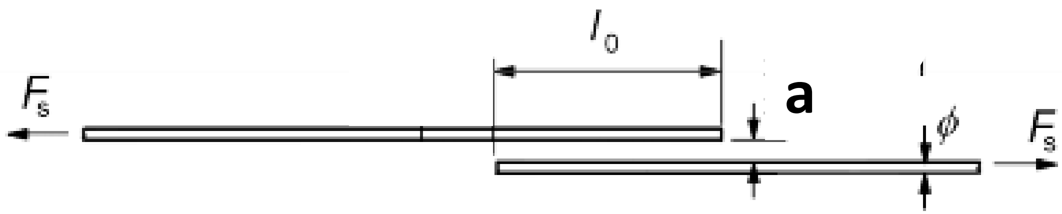
α_6 →

Percentage of lapped bars relative to the total cross-section area	< 25%	33%	50%	>50%
α_6	1	1,15	1,4	1,5
Note: Intermediate values may be determined by interpolation.				

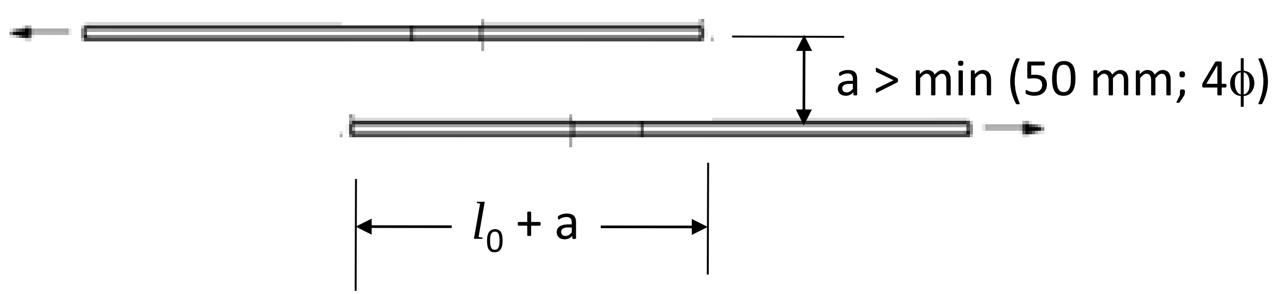
All bars in compression and secondary (distribution) reinforcement may be lapped in one section.

Arrangement of lapped bars

Clear distance between lapped bars

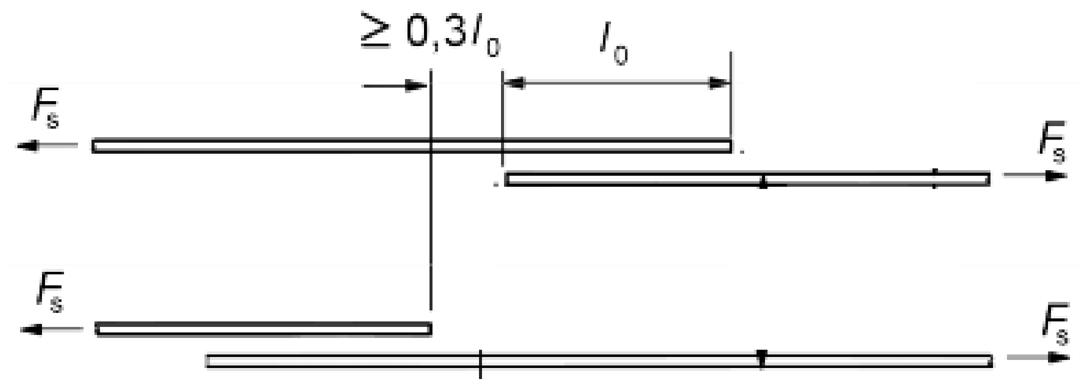


a ≤ min (50 mm; 4ϕ) otherwise l_0 should be increased by **a**

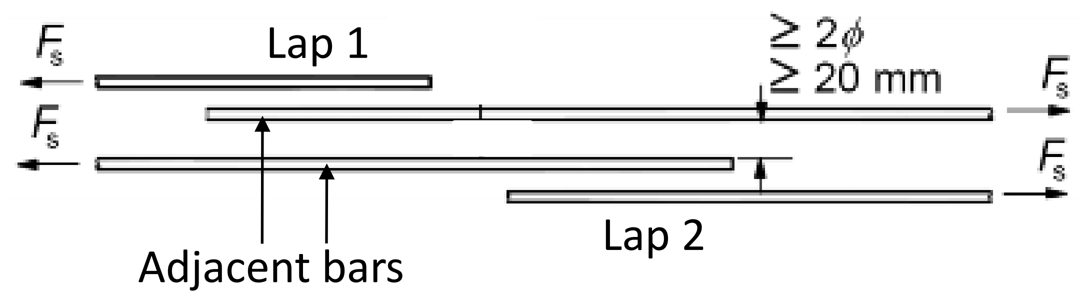


Arrangement of lapped bars

Longitudinal distance between two adjacent laps

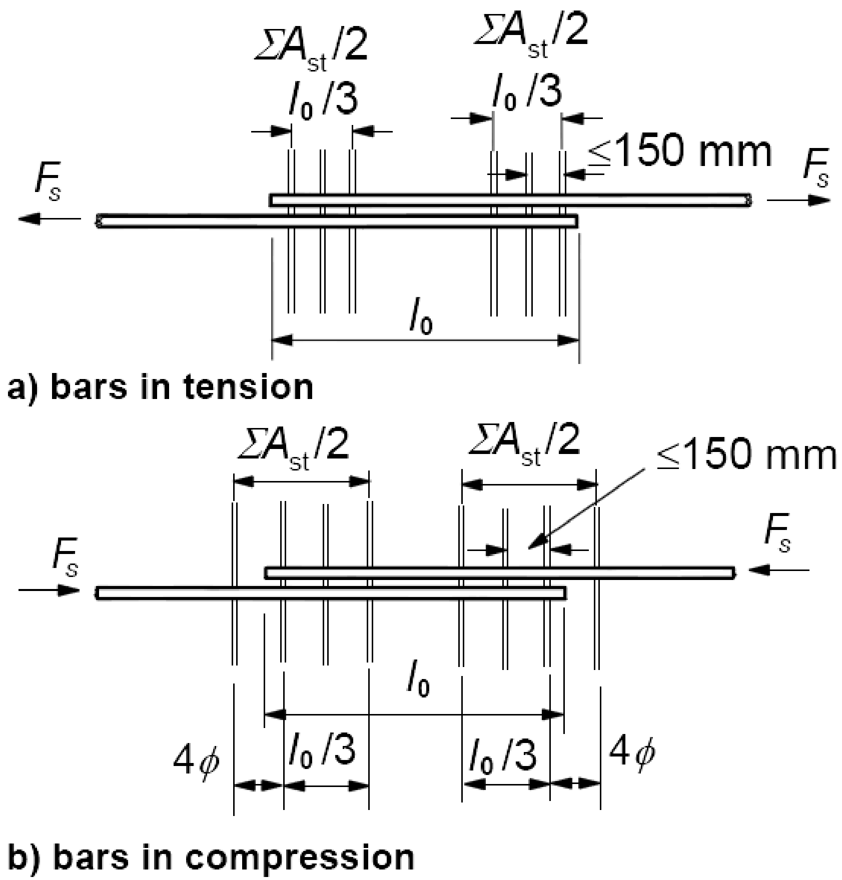


Clear distance between adjacent bars in case of adjacent laps



Transverse reinforcement in the lap zone

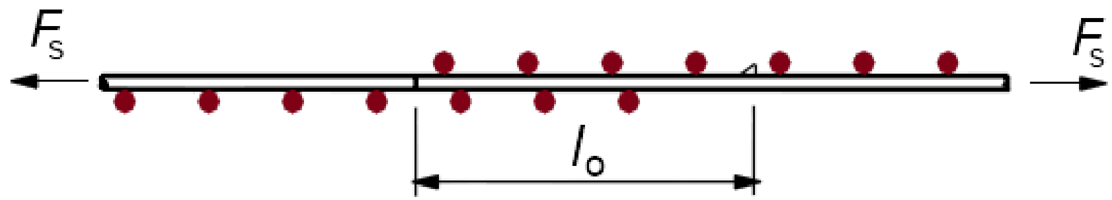
→is required in the lap zone to resist transverse tension forces



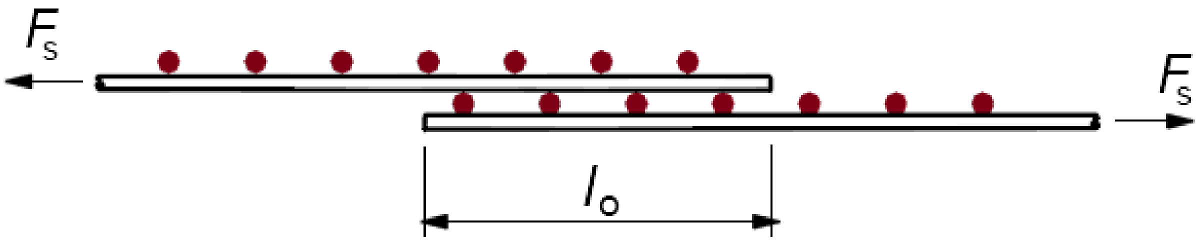
$$\Sigma A_{st} \geq 1.0 A_s$$

→ + 1 transversal bar

Laps for welded mesh fabrics made of ribbed wires reinforcement



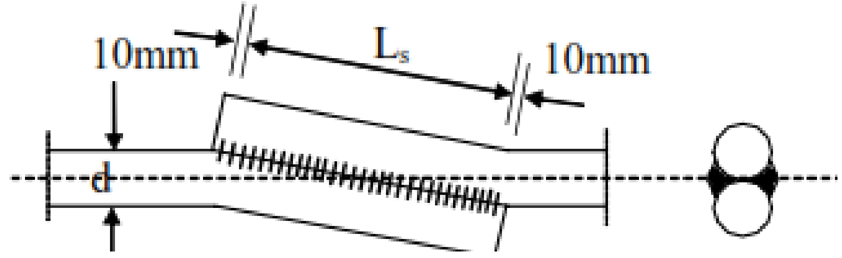
a) intermeshed fabric (longitudinal section)



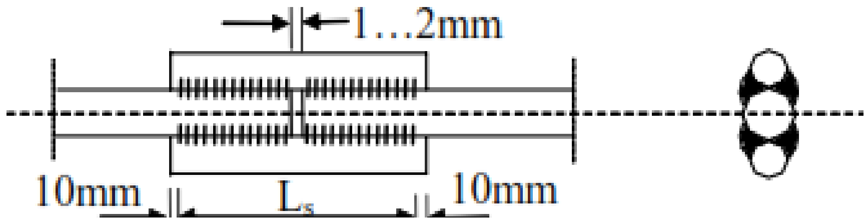
b) layered fabric (longitudinal section)

Diametrul barelor (mm)	Lungimi de suprapunere
$\phi \leq 6$	≥150 mm; cel puțin un ochi de plasă în intervalul de înnădire fig. 5.18a.
$6 < \phi \leq 8{,}5$	≥250 mm; cel puțin două ochiuri de plasă în intervalul de înnădire fig. 5.18b.
$8{,}5 < \phi \leq 12$	≥350 mm; cel puțin două ochiuri de plasă în intervalul de înnădire fig. 5.18b.

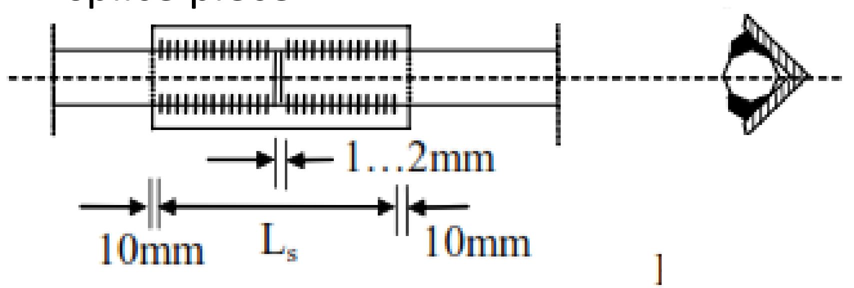
Welding



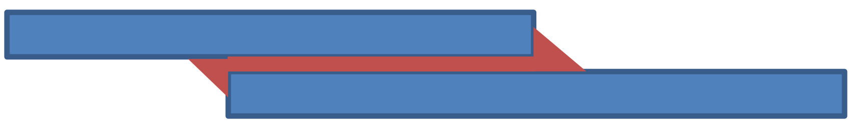
welding by overlapping



splice piece

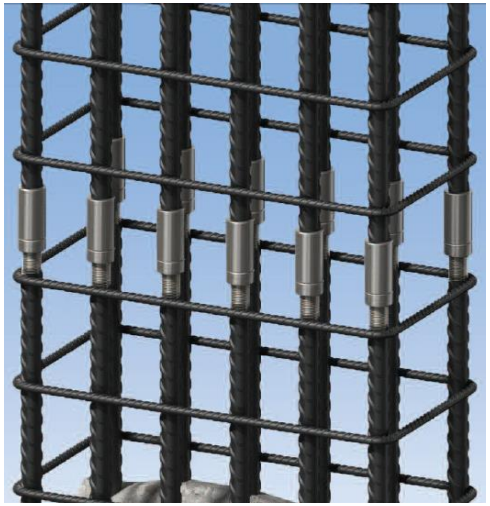


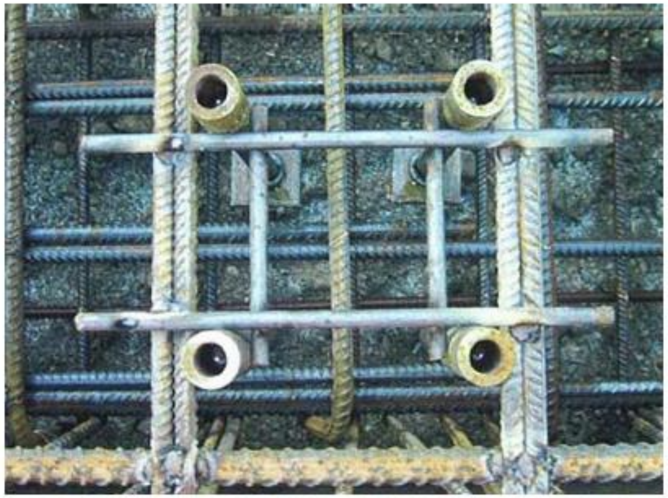
welding with angle profile



Welding details will be specified in the design project, together with specific conditions, as well as the permissible deviations.

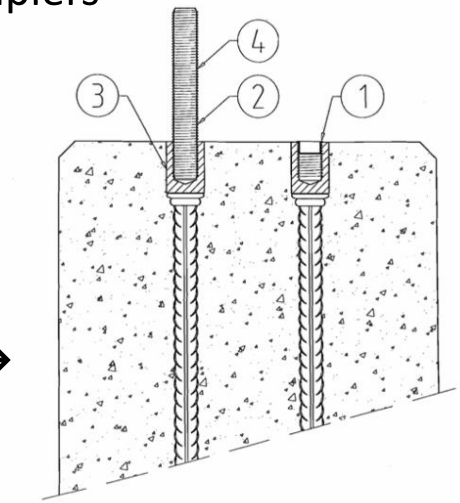
Mechanical couplers



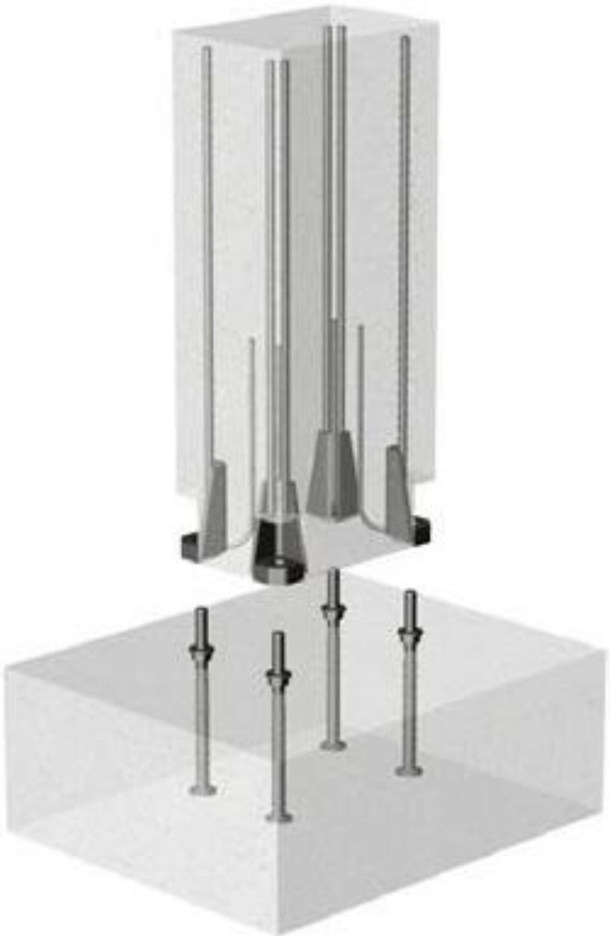


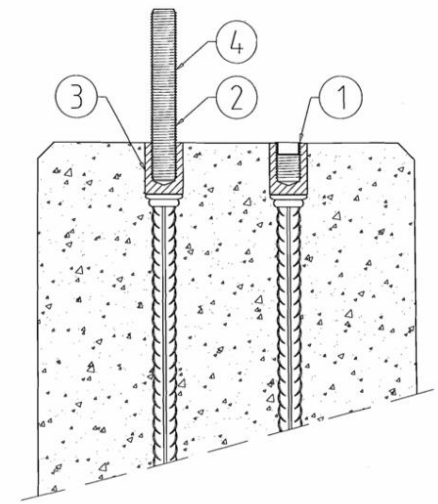
Standard and position couplers

Foundations →

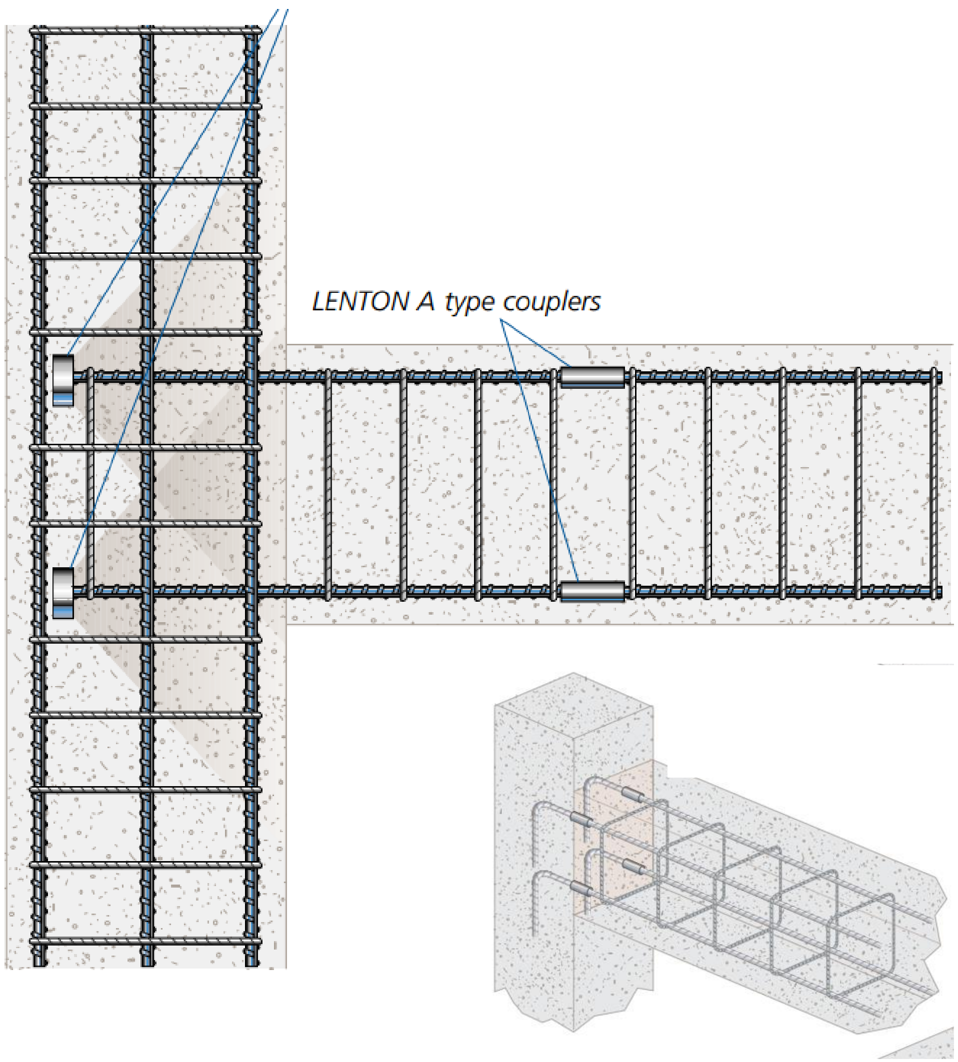


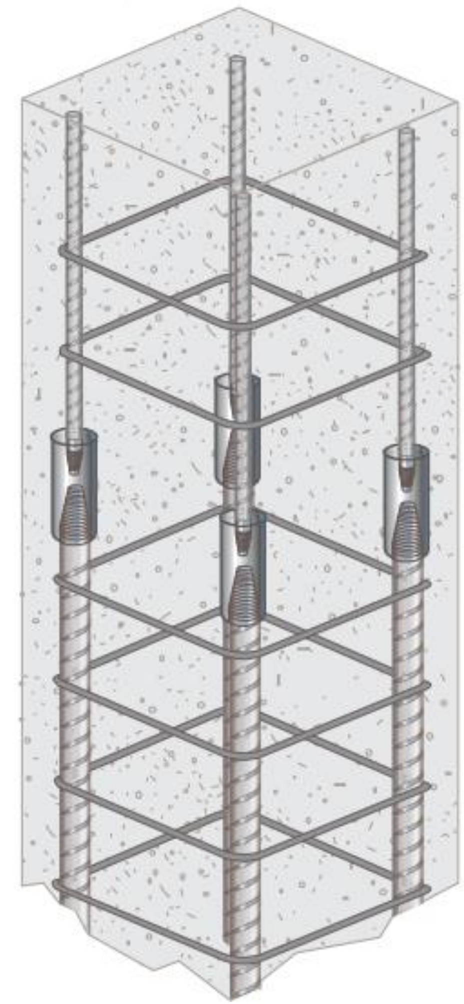
Mechanical couplers



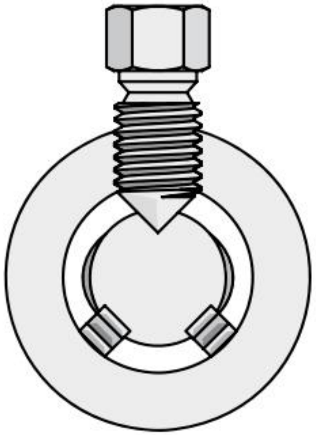


Mechanical couplers

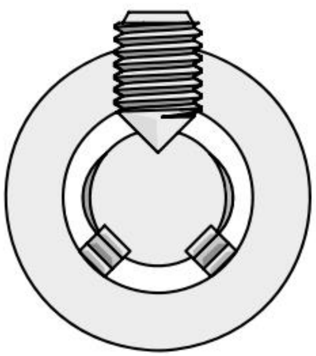




Mechanical couplers

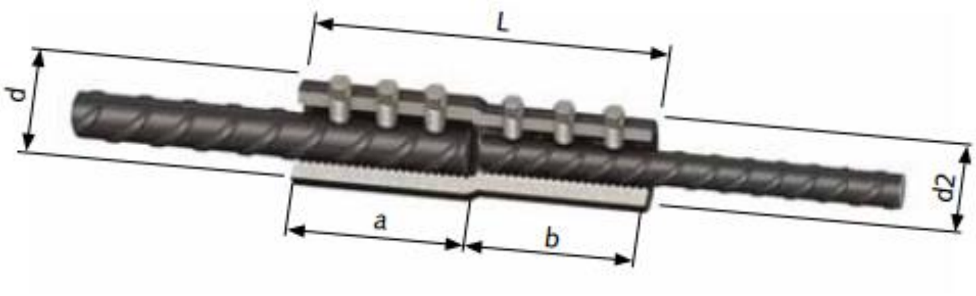


Coupler with screwed-in shear-off screw



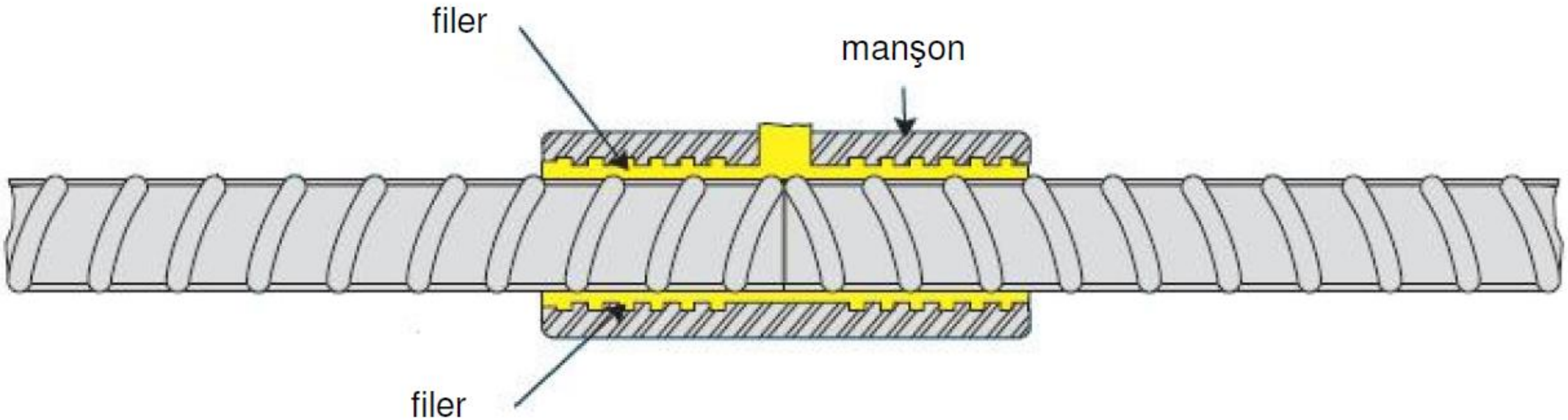
Coupler with sheared-off screw head

Mechanical couplers



halfen.com

Mechanical couplers



4.1 REINFORCEMENT ANCHORAGE

4.2 WORKING STAGES OF RC ELEMENTS

4.3 DURABILITY OF RC

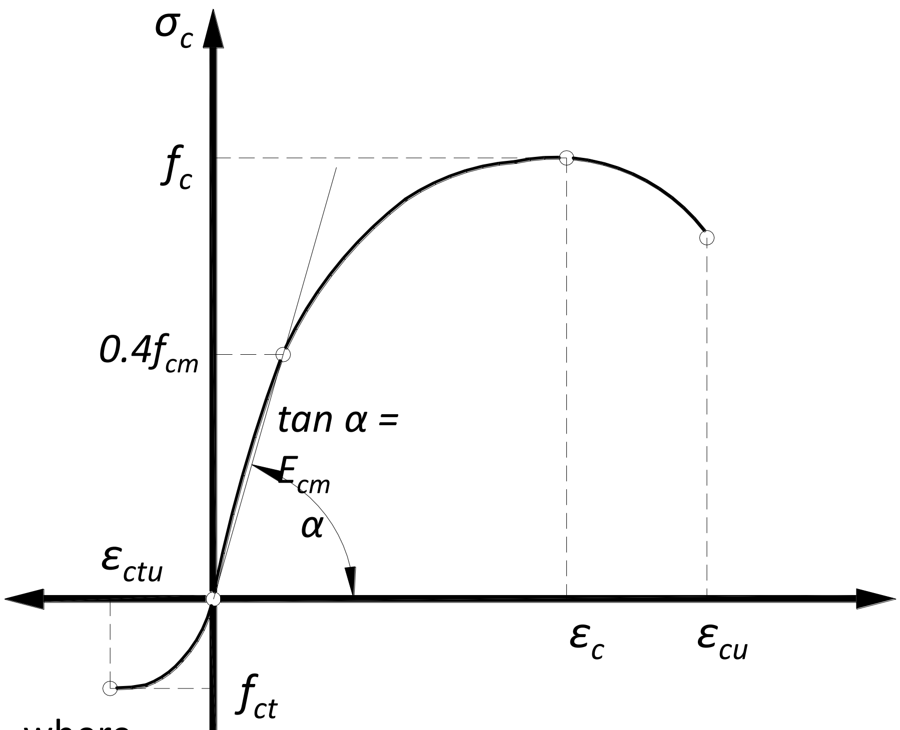
Working stages / Stadiile de lucru

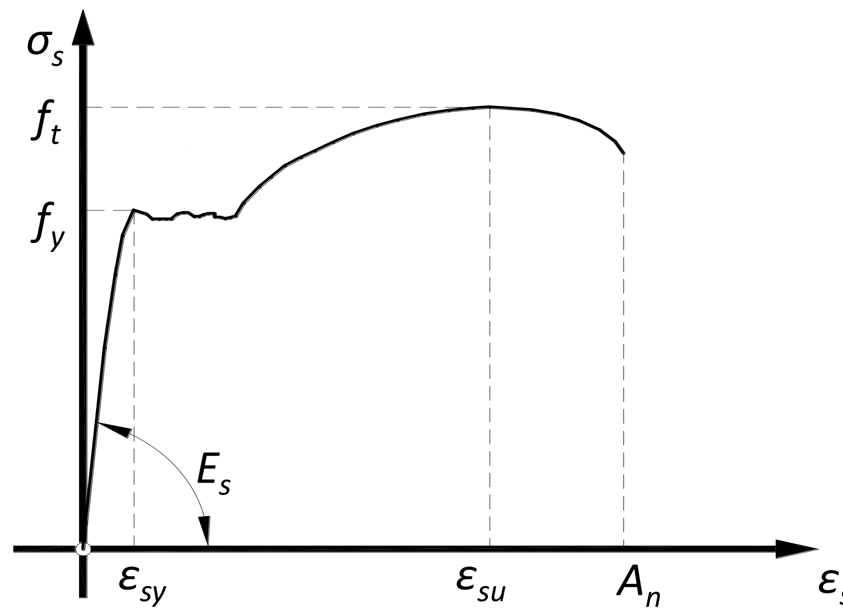
The behaviour of RC elements depends on the value of internal forces induced by loads.

In time, intensity of internal forces increasing, that leads to changes in stress distributions.

Working stages / Stadiile de lucru

Concrete and steel has different characteristics, emphasized by the ***σ – ε*** diagrams.





where
f_c – compressive strength of concrete
f_{ct} – tensile strength of concrete
ε_{cu} – ultimate compressive strain of concrete
ε_{ctu} – ultimate tensile strain of concrete
E_{cm} – secant modulus of elasticity

where
f_y – yielding limit
f_t – tensile strength of steel
ε_{su} – ultimate tensile strain
ε_{sy} – strain at yielding
E_s – Young's modulus of steel

Working stages / Stadiile de lucru

During the life of the element there are the following stages:

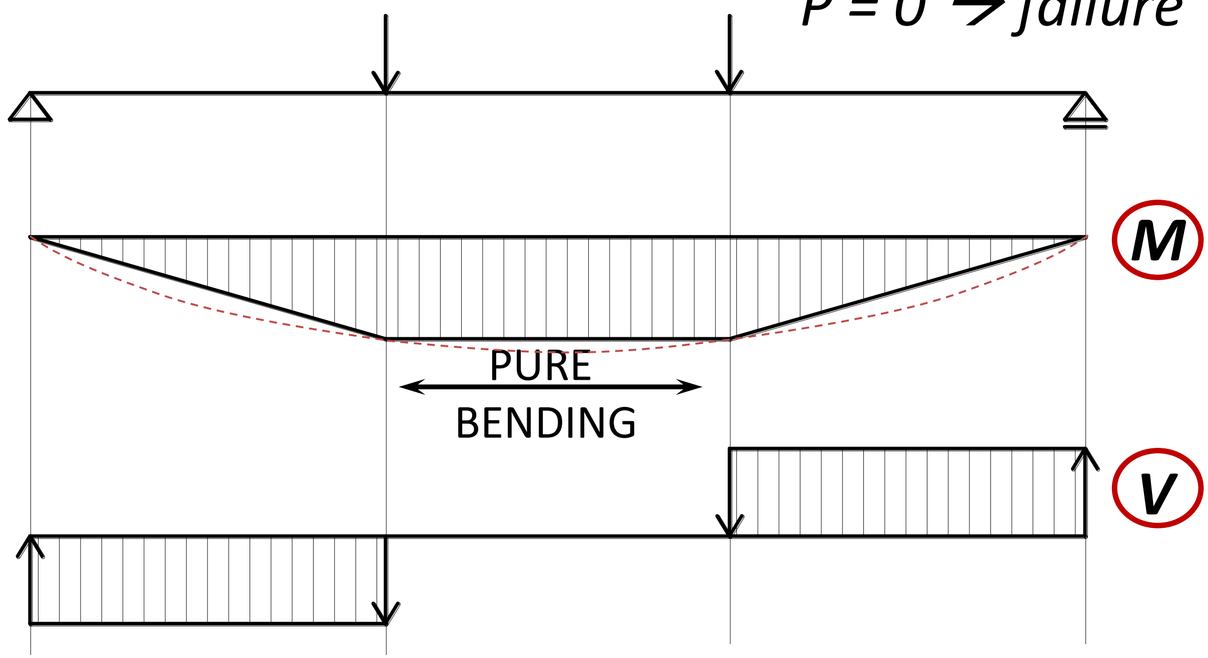
I. Elastic

II. Elasto-plasic (service)

III. Plastic stage (failure)

To discuss these stages → consider a simply supported beam

P = 0 → failure



Working stages / Stadiile de lucru

STAGE I.

- Low value of loads
- Concrete is uncracked → entire cross section is active
- Bending stiffness is maximum (EI)
- Mainly elastic behavior

Limit of Stage I. ⇔ $\varepsilon_{ct} = \varepsilon_{ctu}$ → $\sigma_{ct} = f_{ct}$

- plastic deformations are produced in the tensioned concrete at the limit of the stage

- at the limit of the stage, for a very small increasing of loads, tensioned concrete will crack; M_{cr} = cracking bending moment.

Working stages / Stadiile de lucru

STAGE I.

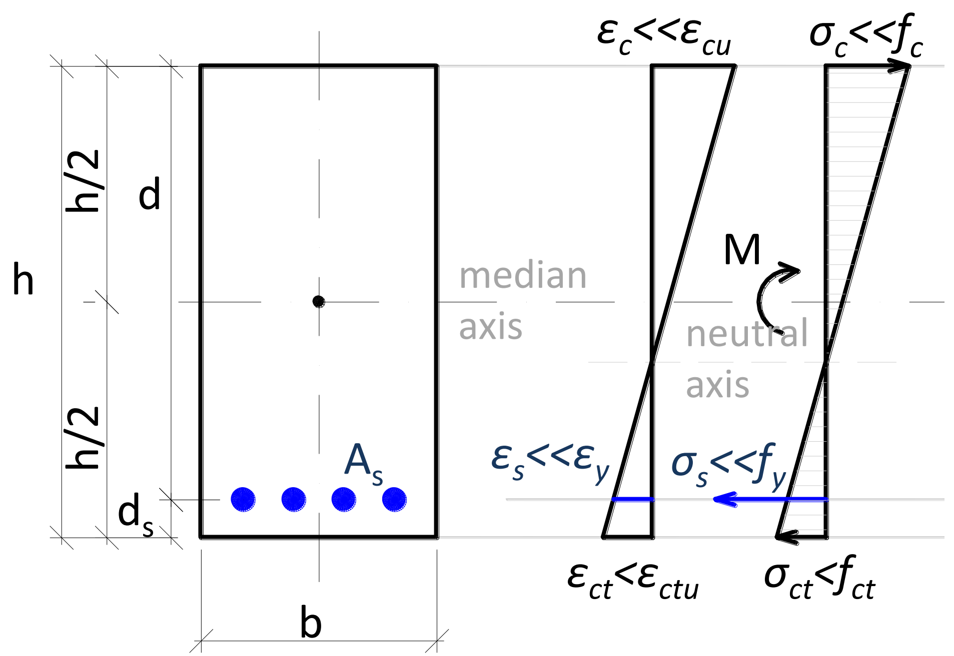
→ *Design in stage I is generally used for hydro-technical structures.*

Design in stage I is not economical because the stress in reinforcement is very small

→ Reinforcement is not used to at its capacity.

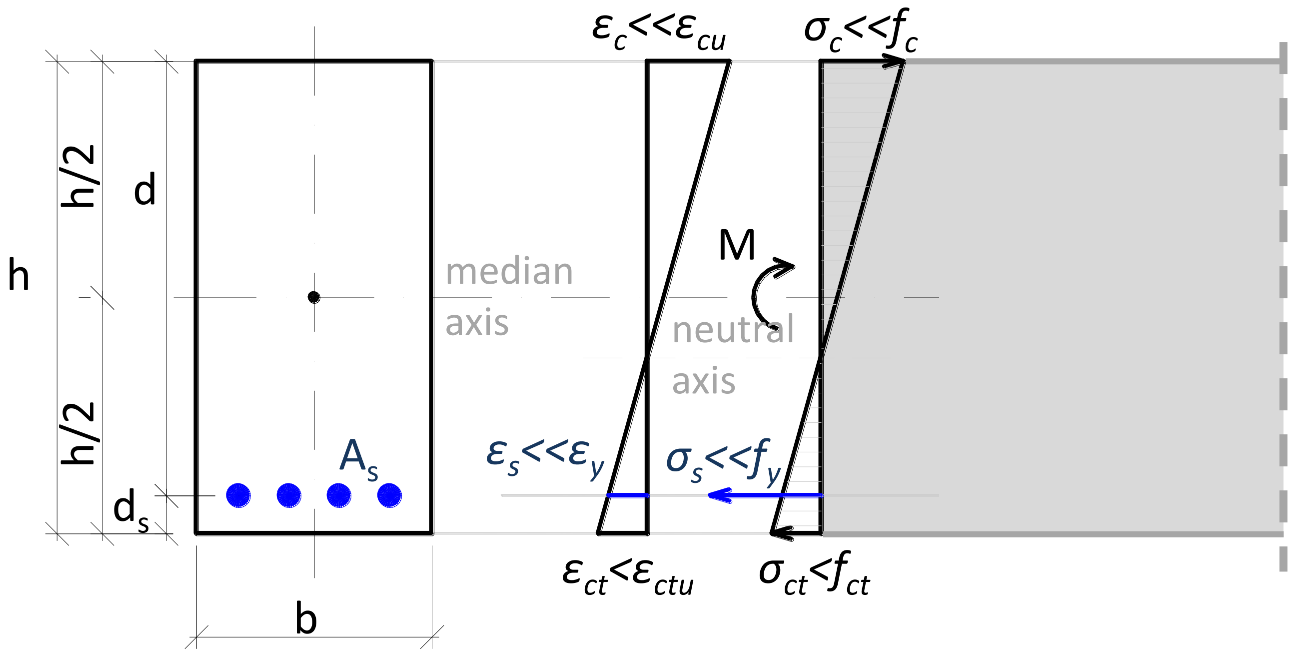
$$\sigma_s = \varepsilon_s \cdot E_s \approx \varepsilon_{tu} \cdot E_s = \frac{0.10 \ldots 0.15}{1000} \cdot 210000 = 21 \ldots 30\, N/mm^2 \ll f_y = 210 \ldots 500\ N/mm^2$$

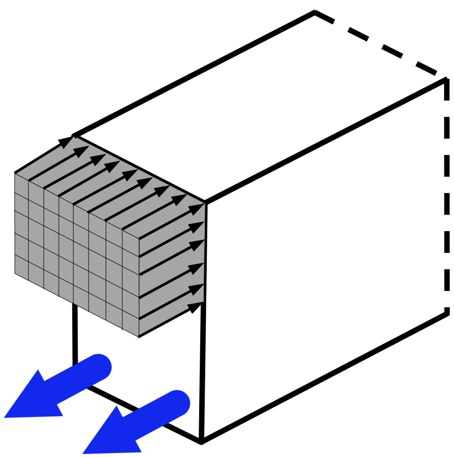
≈ 0.1…0.15‰

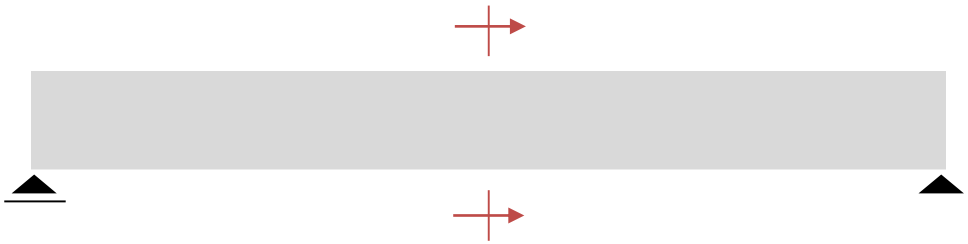


Working stages / Stadiile de lucru

STAGE I.

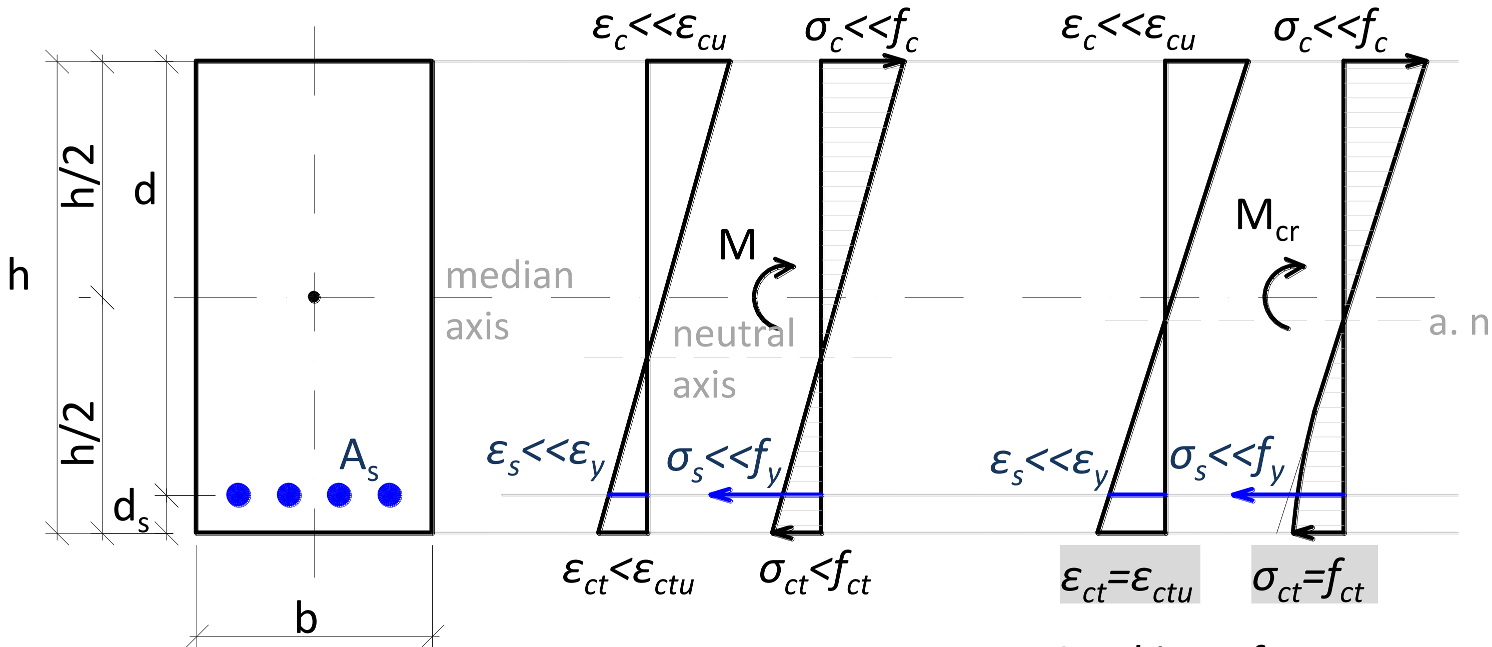






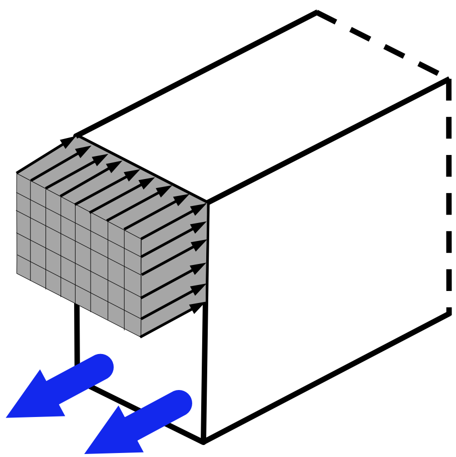
Working stages / Stadiile de lucru

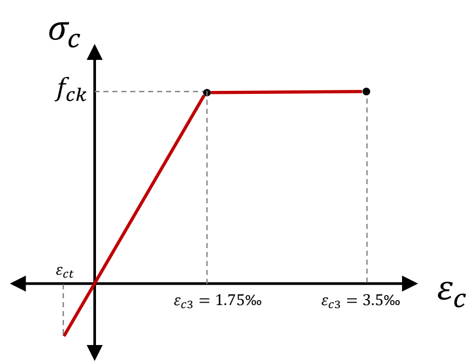
STAGE I.

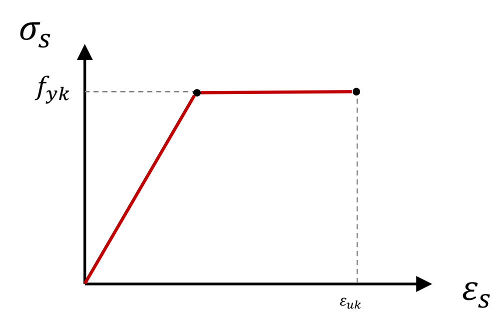


Cracking of concrete

Limit of Stage I.

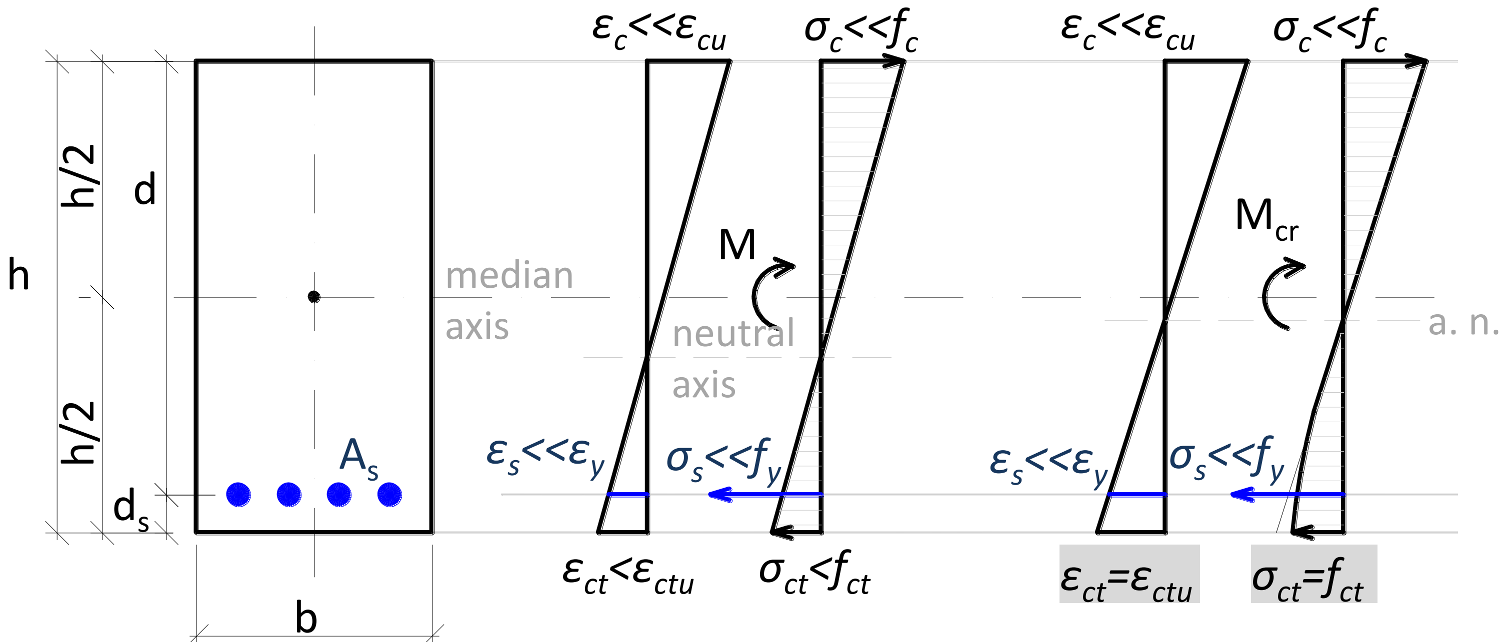


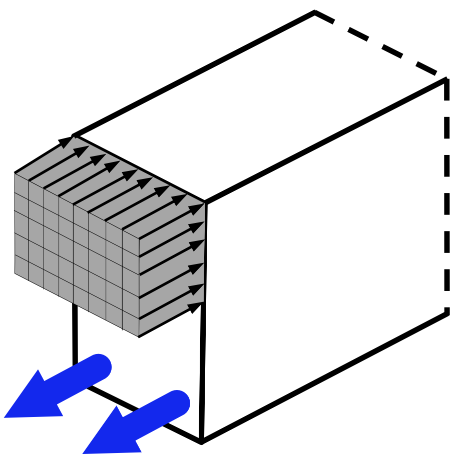




Working stages / Stadiile de lucru

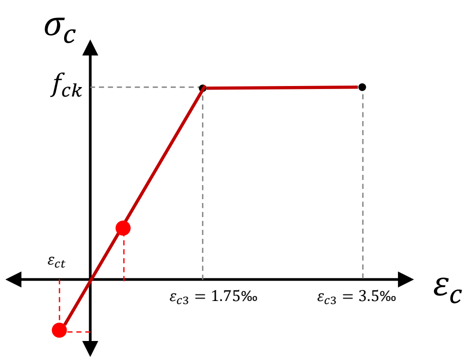
STAGE I.

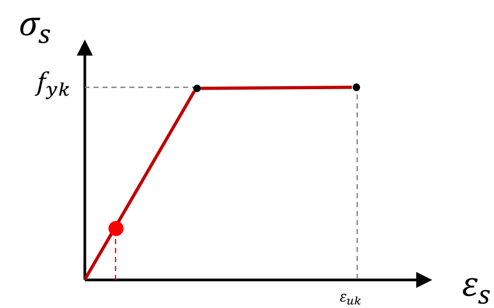




Cracking of concrete

Limit of Stage I.

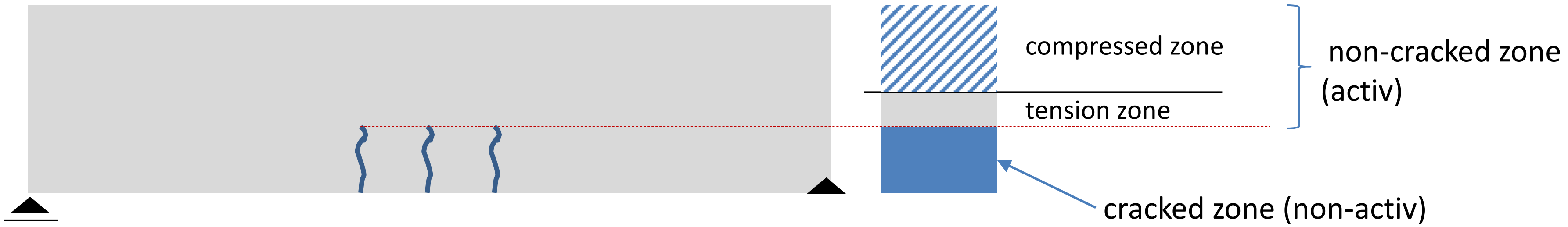




Working stages / Stadiile de lucru

STAGE II. – service stage

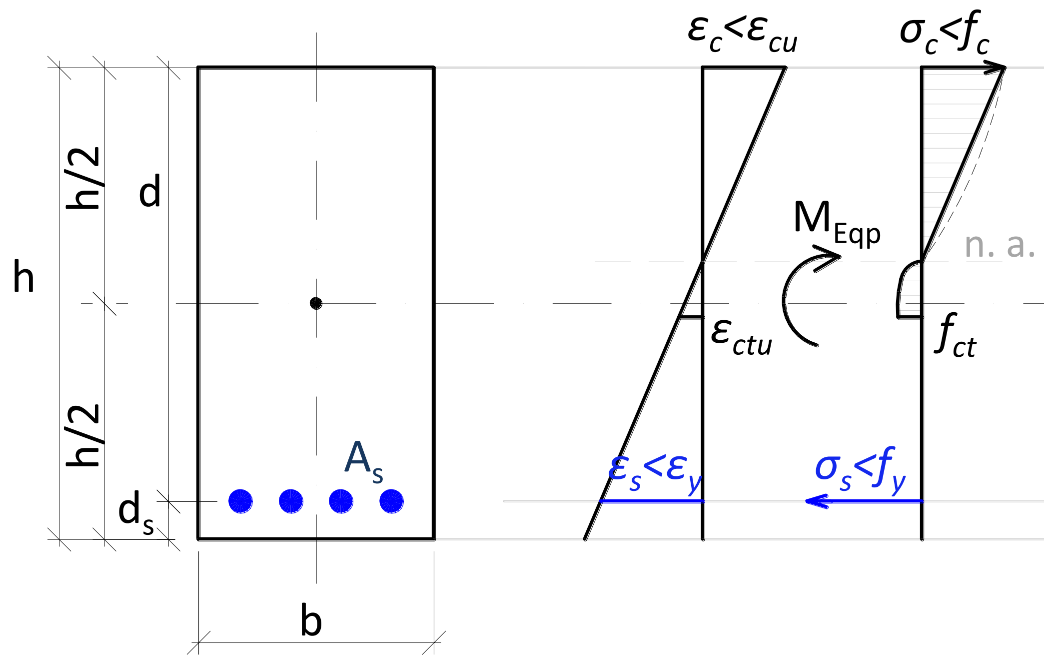
- under service loads, tension zone of the element is cracked
- concrete in tension is neglected
- active section consists of compressed concrete and tension reinforcement
- bending stiffness (EI) of the section decreases as a result of cracking
- generally, elastic behaviour, characterized by:
    - in compressed concrete: $\sigma_c \approx 0,5\ f_c$
    - in tensioned reinforcement: $\sigma_s \approx 0,7...0.8\ f_y$

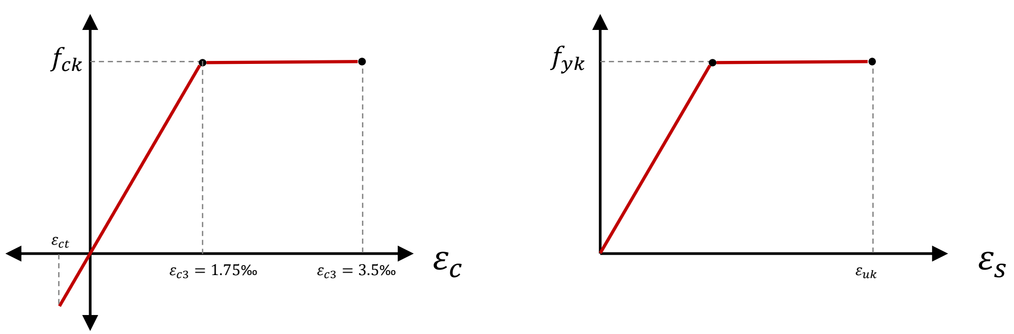


Working stages / Stadiile de lucru

STAGE II. – service stage

→ Is the basis of design for SLS and fatigue

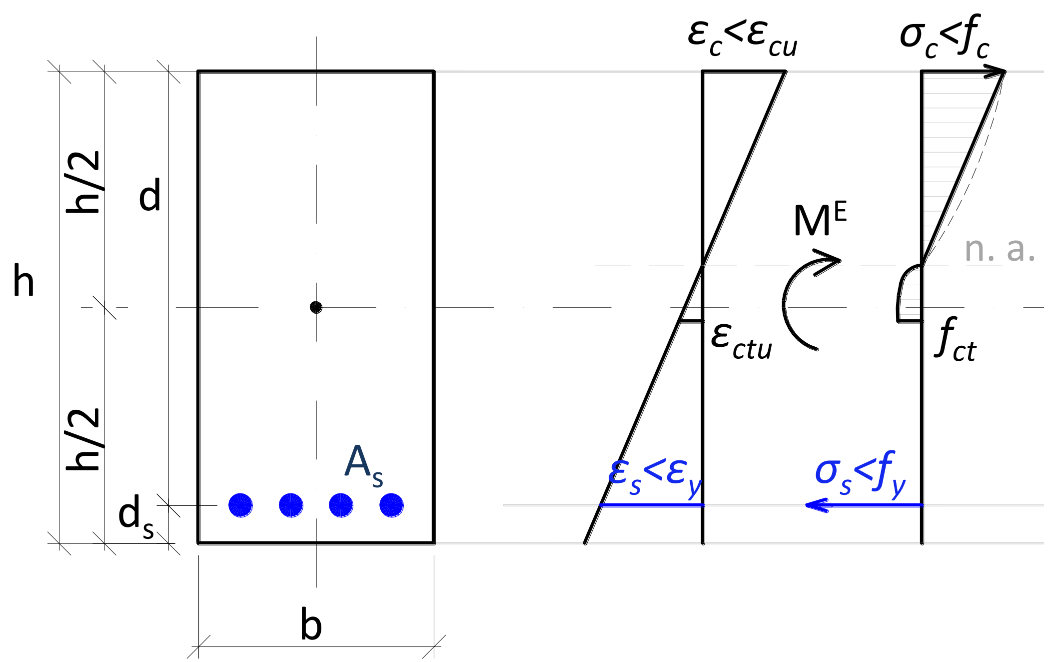


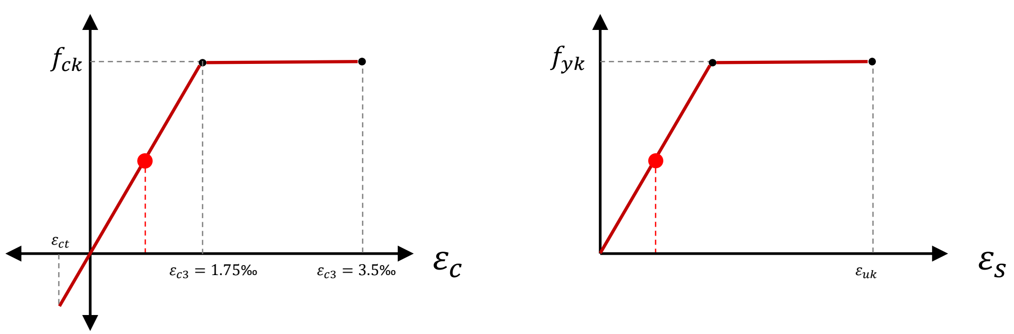


Working stages / Stadiile de lucru

STAGE II. – service stage

→ Is the basis of design for SLS and fatigue





STAGE II. – service stage

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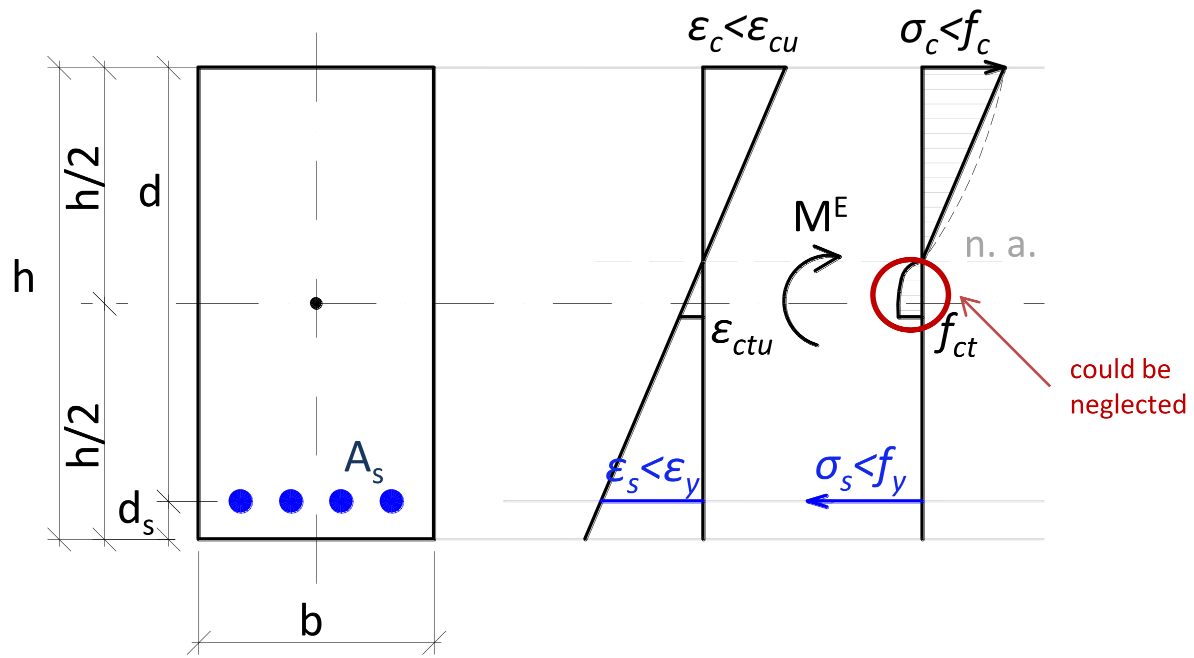
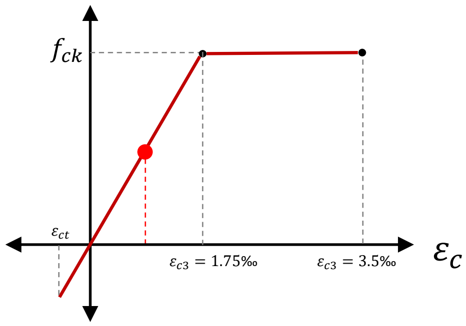
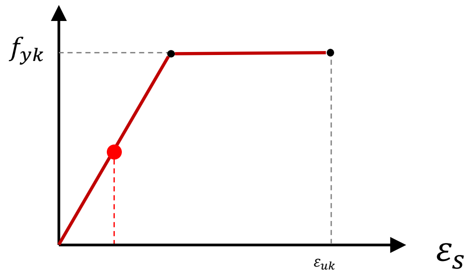






STAGE III. – Failure stage

- Increasing of loads leads to further increase of strains and stresses
- Reinforcement starts to yield in case of usual reinforcement percentages (p = 0,3…2,5%)

- Under constant loads there is a progressive rotation of the section induced by reinforcement yielding. This situation is defined as plastic hinge involving the curved diagram in compressed concrete → corresponding the bending moment $M_p = A_s f_y z \approx 0,9 A_s f_y d$ (p = plastic)

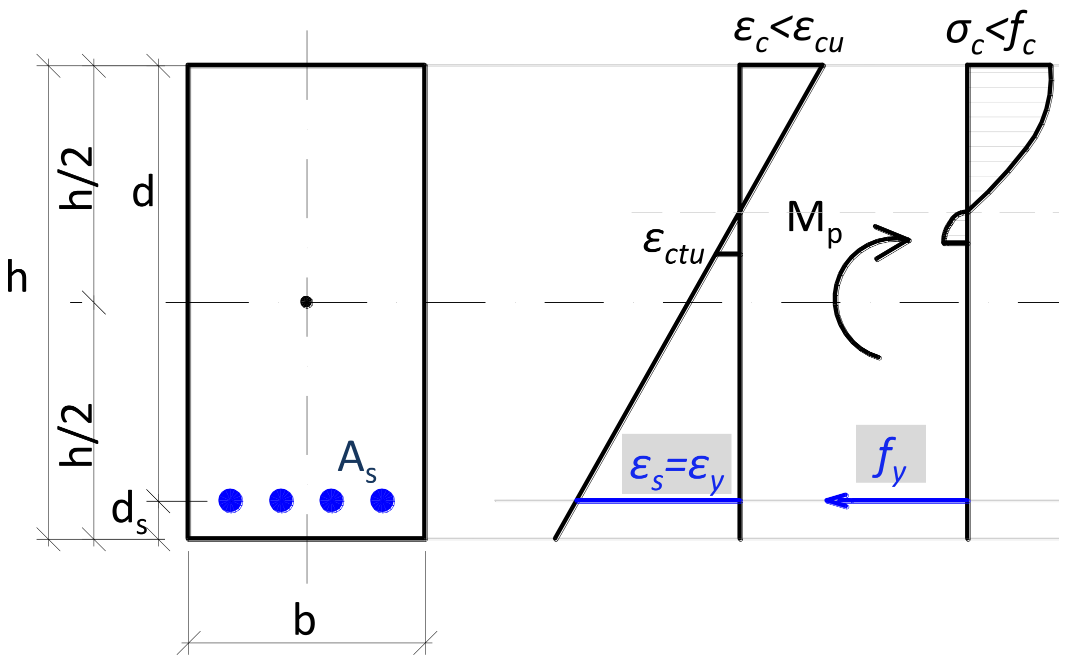
- stiffness decreasing, deformations increasing, neutral axis rising toward the maximum point → Minimum bending stiffness & very high deflection

- further increasing of loads leads finally to crushing of compressed concrete → corresponding to M_R (failure or resisting moment).

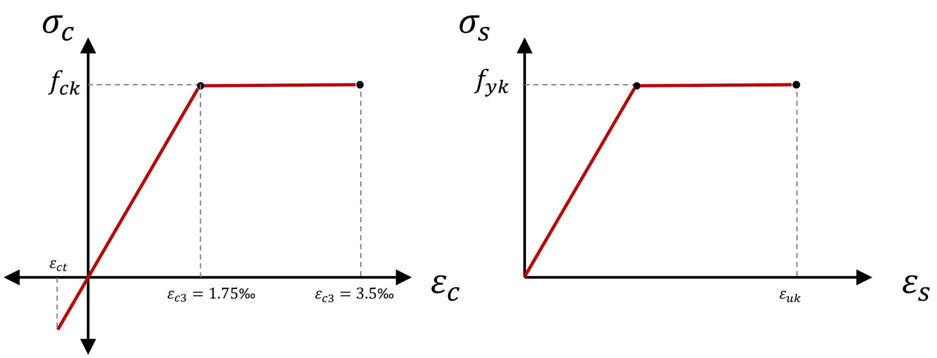
- the failure is ductile, because of the large deformations before the collapse.

Working stages / Stadiile de lucru

STAGE III. – Failure stage

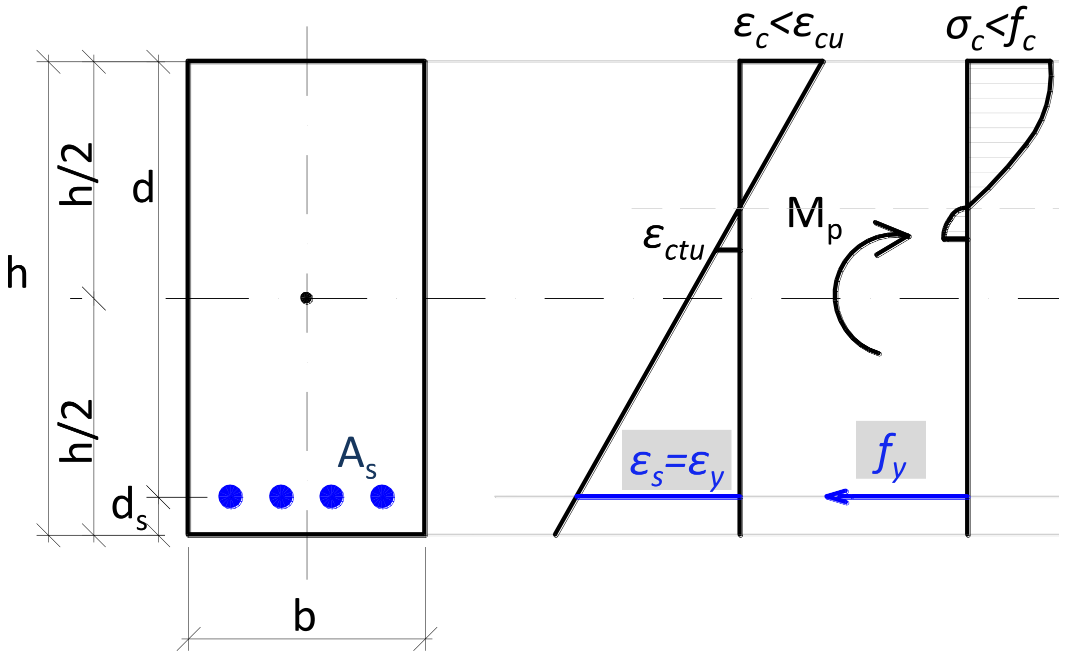


Reinforcement yielding

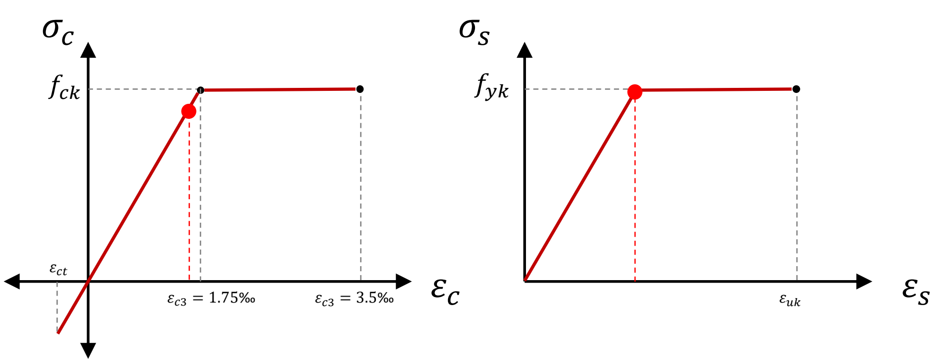


Working stages / Stadiile de lucru

STAGE III. – Failure stage

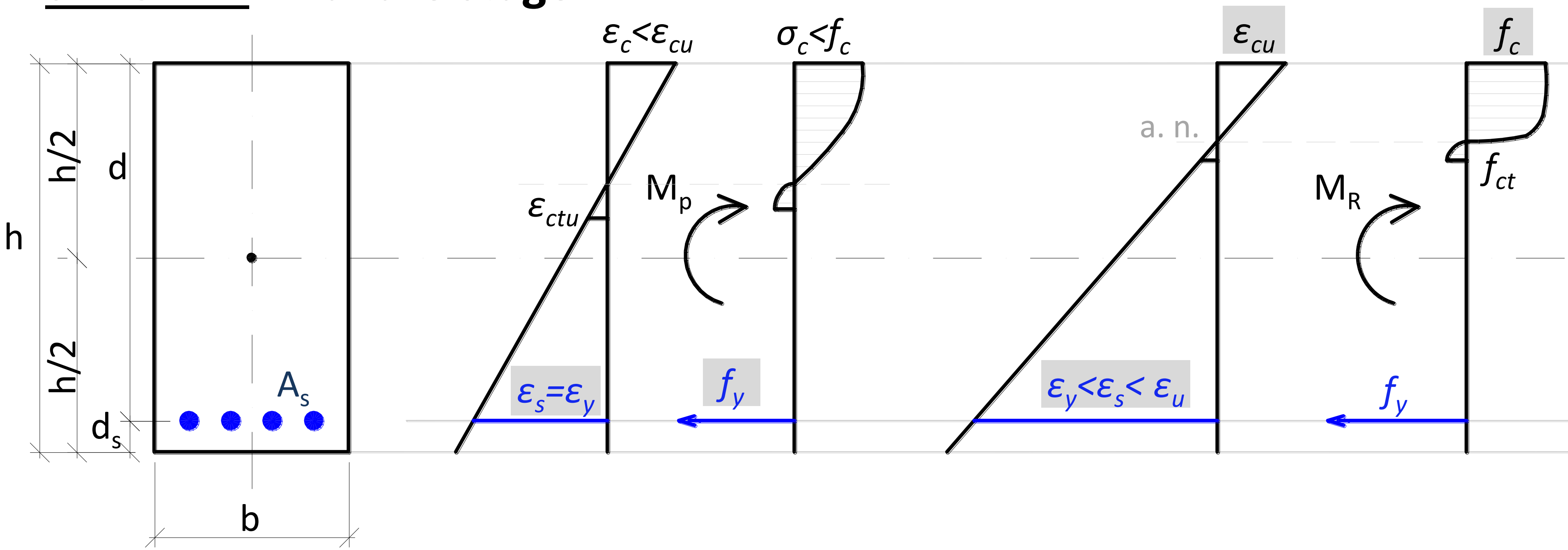


Reinforcement yielding



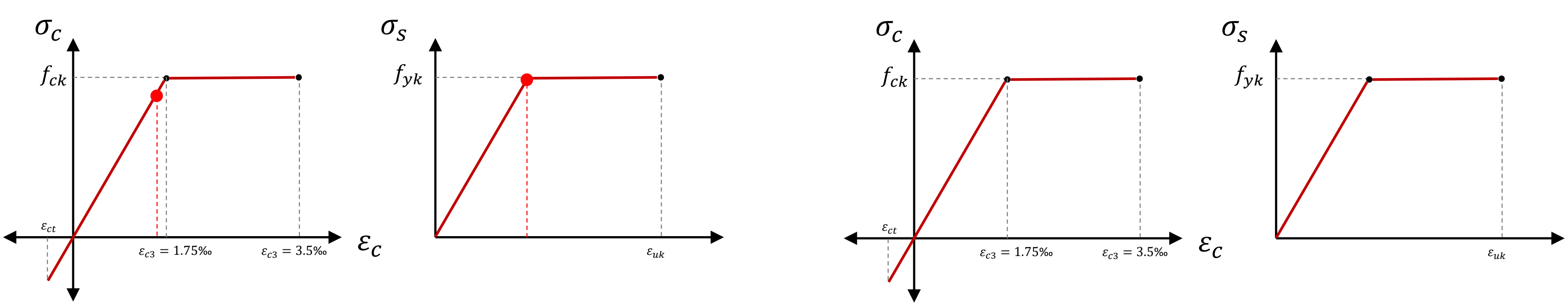
Working stages / Stadiile de lucru

STAGE III. – Failure stage



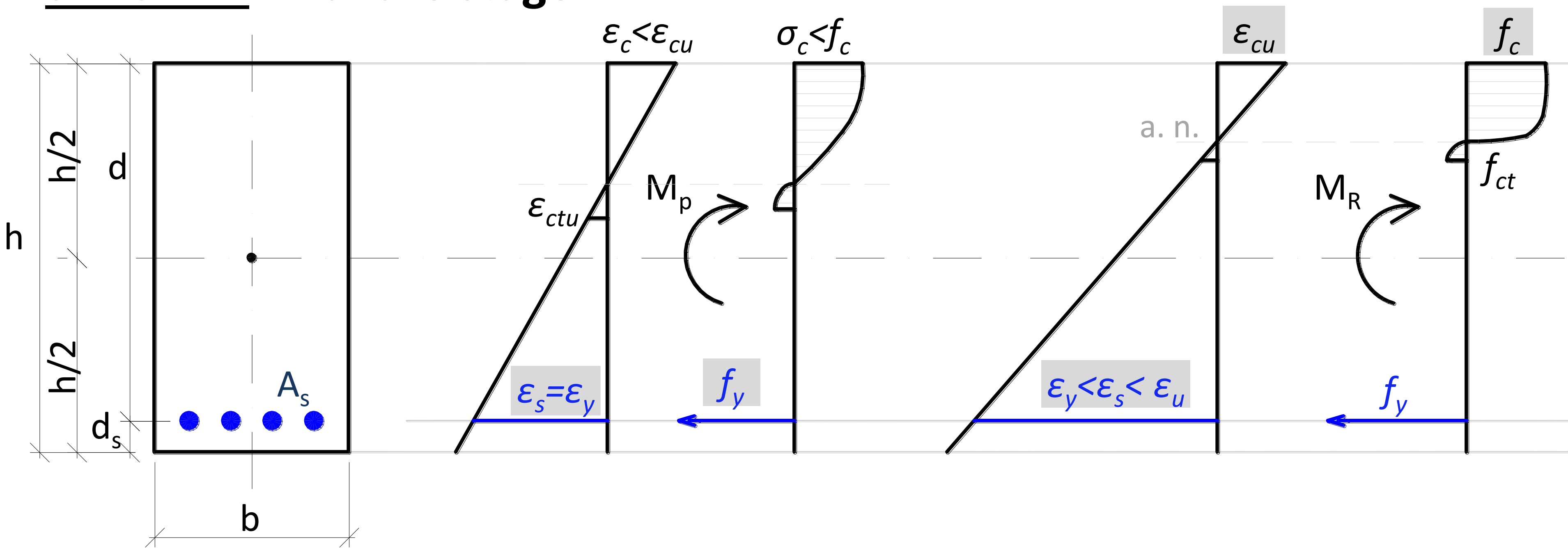
Reinforcement yielding

Concrete crushing



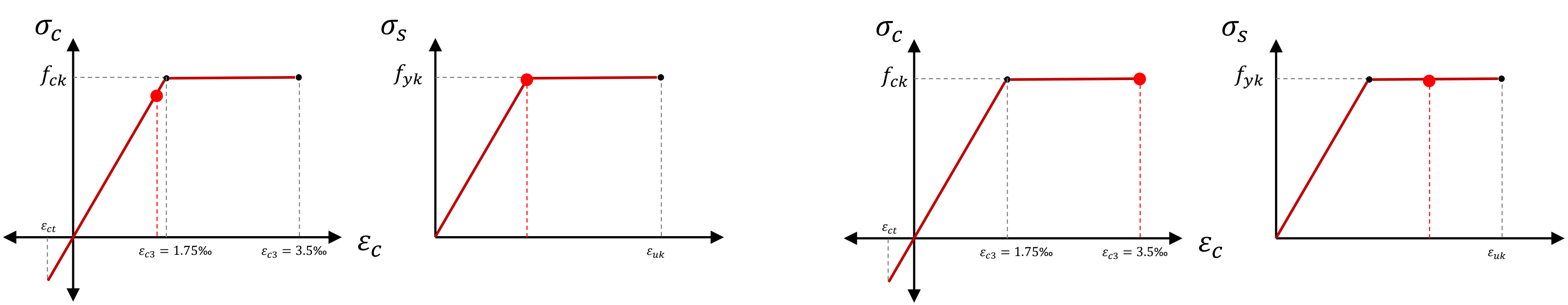
Working stages / Stadiile de lucru

STAGE III. – Failure stage

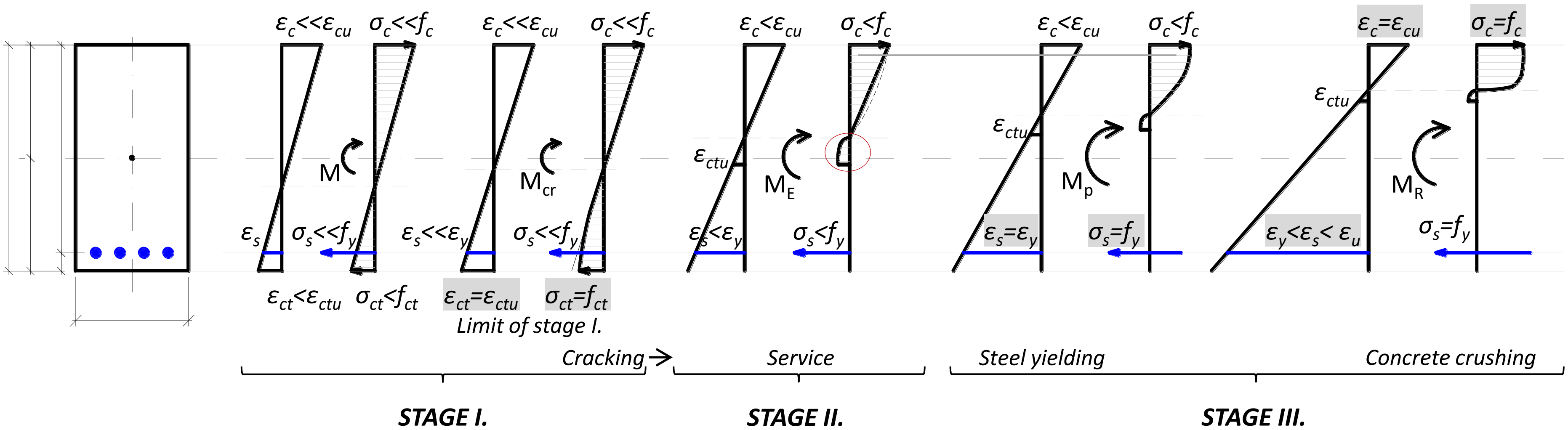


Reinforcement yielding

Concrete crushing



Working stages / Stadiile de lucru



STAGE I.

a)
- entire section is active
- elastic deformations
- n.a. is under the element axis
- element stiffness is maximum
- instable stage

b)
- plasticization of tensioned concrete
- M_{cr} – cracking moment

STAGE II.

- reducing the stiffness
- active zones: compressed concrete and tensioned rebar
- n.a. rising above the element axis

$$\sigma_c \cong 0.5 f_c$$

$$\sigma_s \cong (0.7 \div 0.8) f_y$$

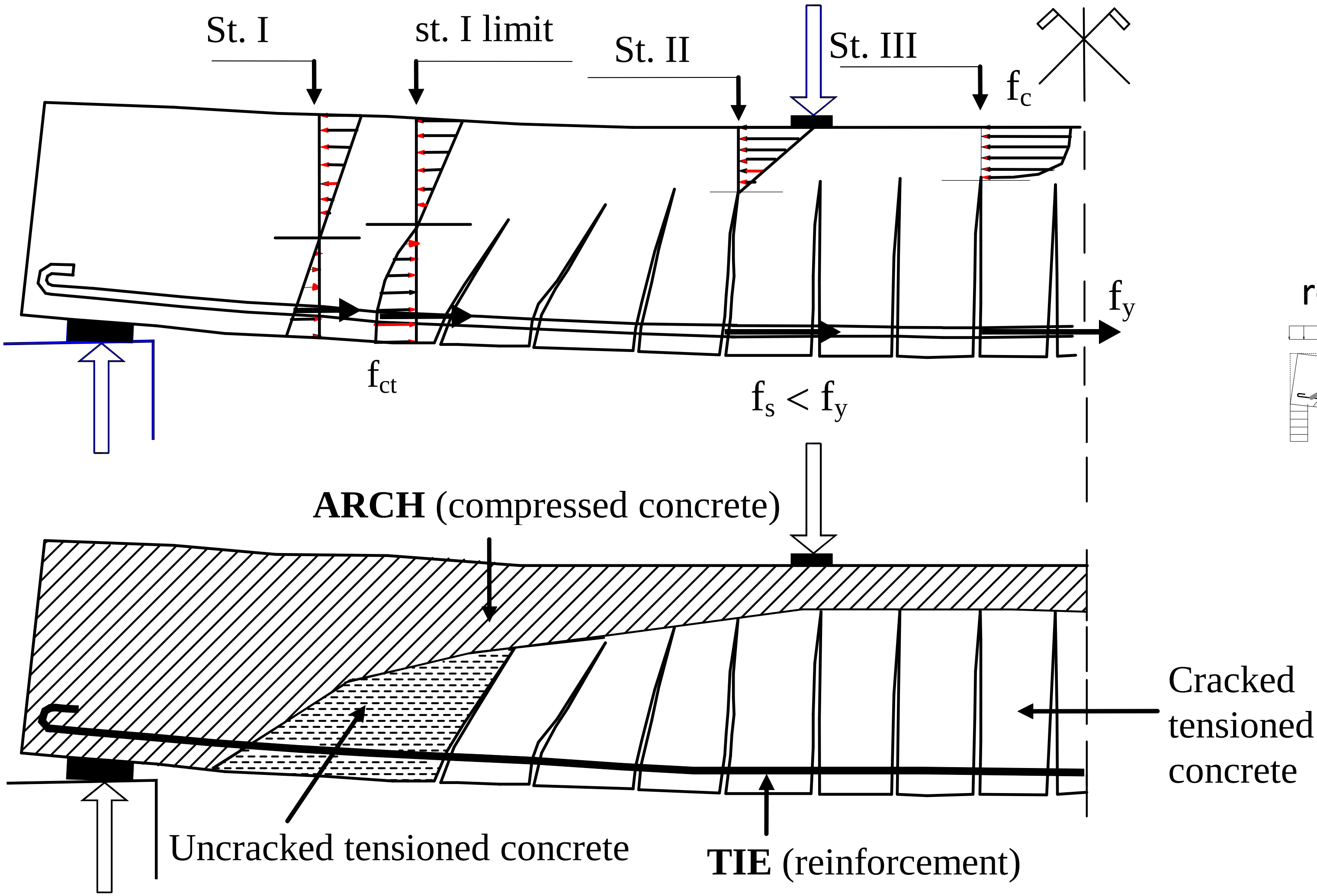
STAGE III.

a)
- increasing of deformations
- yielding of reinforcement
- plastic deformation of concrete
- forming of plastic hinges
- $M_p \approx 0.9 A_s f_y d$

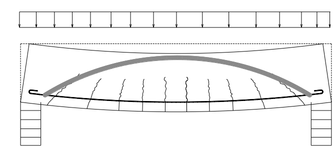
b)
- n.a. in the maximum position
- stiffness of the section is minimum
- very large deformations
- failure by crushing of compressed concrete
- ductile behaviour

Working stages / Stadiile de lucru

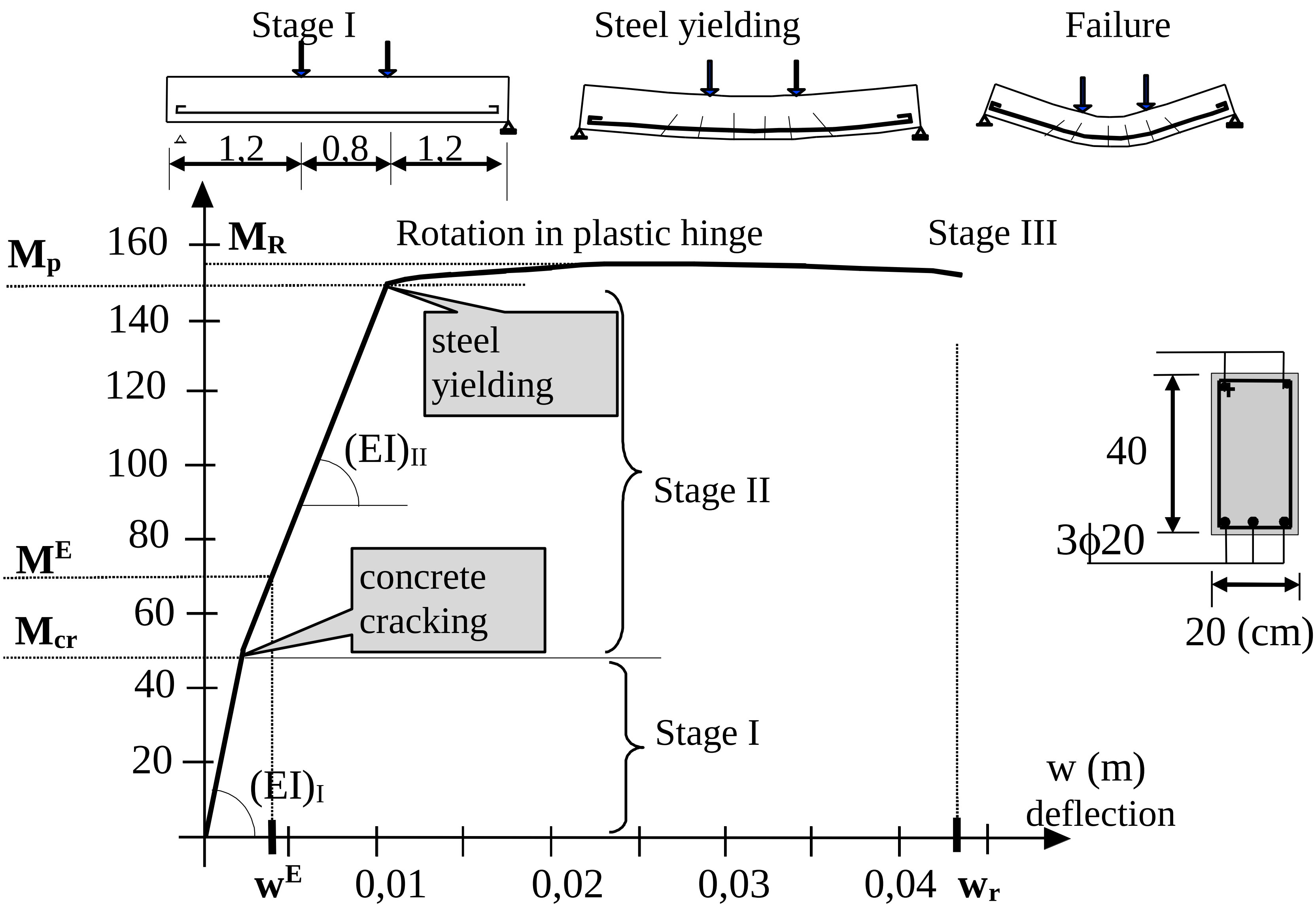
- Along the element could be find all the working stages.
- The element works as a concrete arch with a steel tie



remember ?!



Working stages / Stadiile de lucru



FINAL REMARKS

- Failure of RC elements having **usual reinforcement percentage** between **0.4 ÷ 2.0 (2.5)%** begins with yielding of reinforcement and finishing by crushing of compressed concrete.

- Elements with great value of reinforcement percentage = **over-reinforced concrete** → no more yielding of reinforcement, failure is produced by crushing of compressed concrete

Is not advisable to use such case:

- reinforcement is not yield → not economical
- failure is a brittle-one

- Element with low reinforcement percentage = **under-reinforced concrete** → failure is produced by tensile failure of reinforcement, without crushing of compressed concrete → used in massive constructions.

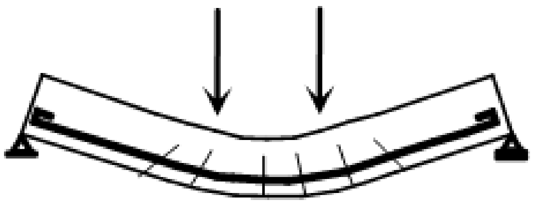
$\rho\% = A_s / A_c \times 100$ → reinforcement percentage

Working stages / Stadiile de lucru

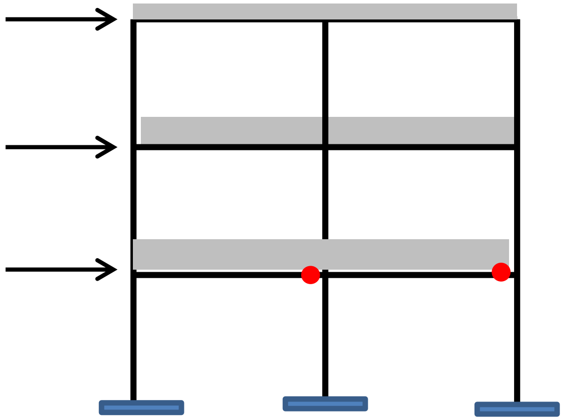
FINAL REMARKS

STATICALLY DETERMINATED STRUCTURES

Plastic hinge shows immediate failure



STATICALLY INDETERMINATE STRUCTURES



Plastic hinge:
- structure still stands
- reduction of the static indeterminacy
- redistribution of efforts to other areas
- **ensure dissipation of the seismic energy**

BASIC PRINCIPLE OF SEISMIC DESIGN

4.1 REINFORCEMENT ANCHORAGE

4.2 WORKING STAGES OF RC ELEMENTS

4.3 DURABILITY OF RC

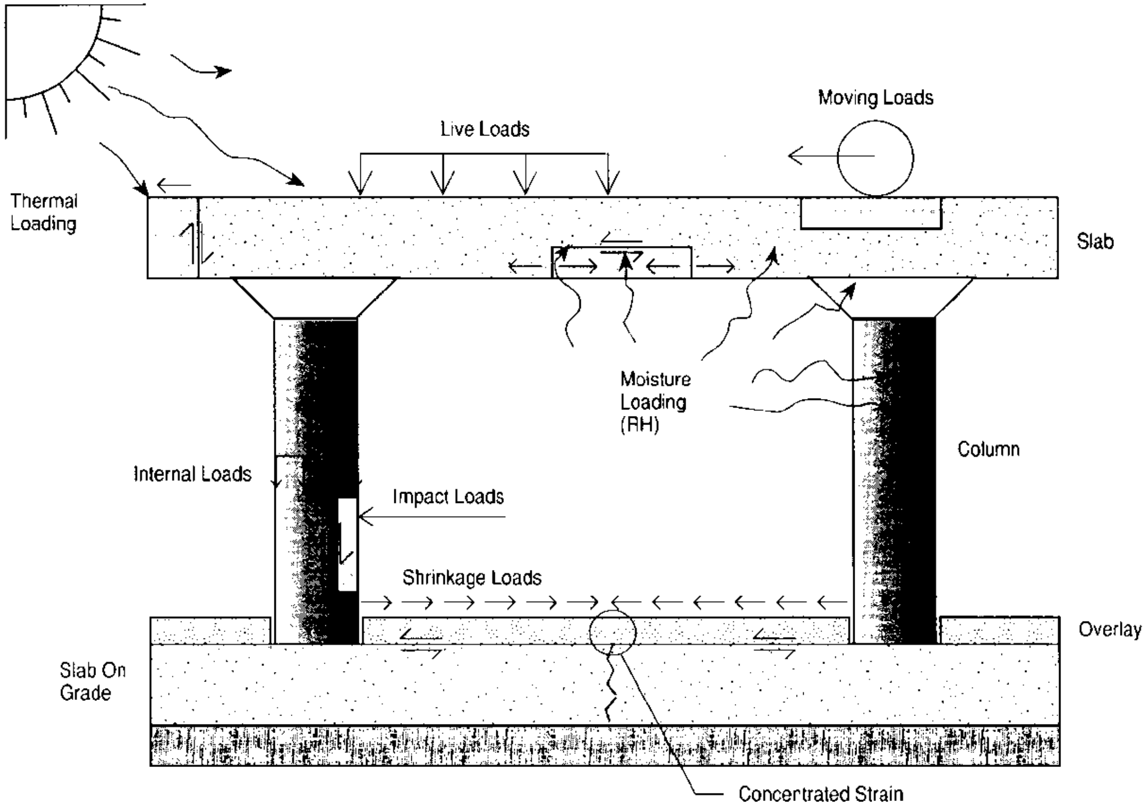
Durability / Durabilitatea

Definition

A durable structure shall meet the requirements of serviceability, strength and stability throughout its design working life, without significant loss of utility or excessive unforeseen maintenance.

→Corrosion: carbonation or chlorides
→Freeze-Thaw
→Alkali-silica reactions

Factors affecting structures →

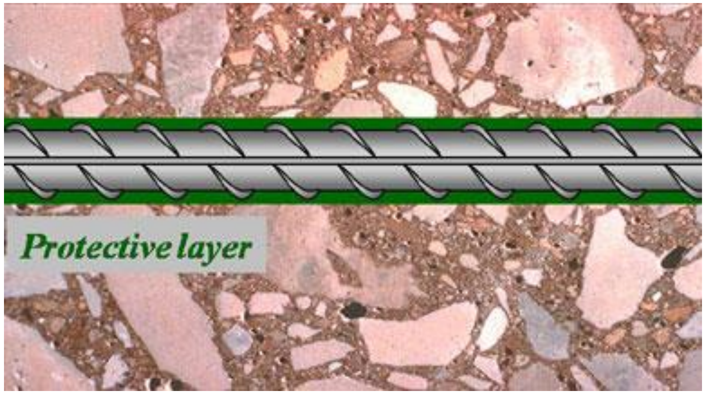


Durability / Durabilitatea

Reinforcement corrosion – initiated by chlorides

Durability / Durabilitatea

Reinforcement corrosion – initiated by carbonation



In time →

$Ca(OH)_2$ + CO_2 → $CaCO_3$ + H_2O

concrete — environment — it is not alkaline → no further protection

pH 13-14 reduced to **pH 7-8**

CO_2 → nothing happens!

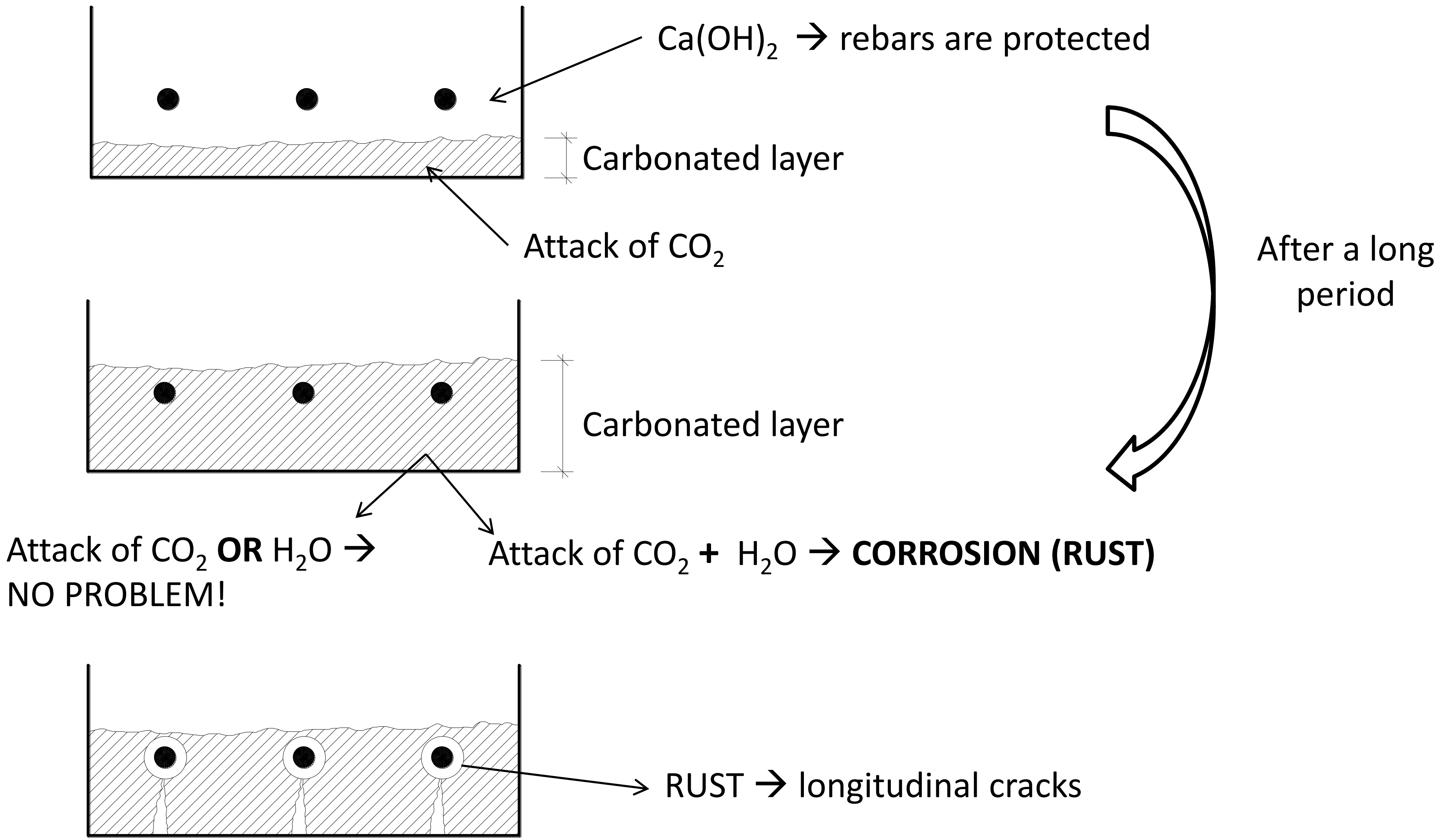
H_2O → nothing happens!

But CO_2 + H_2O → H_2CO_3 (carbonic acid)

After depassivation H_2CO_3 attack reinforcement → corrosion (rust)

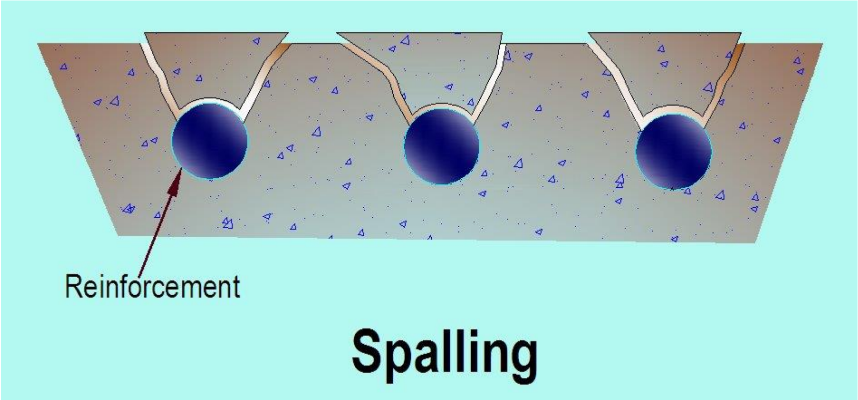
Durability / Durabilitatea

Reinforcement corrosion – initiated by carbonation



Durability / Durabilitatea

Reinforcement corrosion – initiated by carbonation



Durability / Durabilitatea

Freeze-Thaw attack

Durability / Durabilitatea

Reinforcement corrosion - superposed effects




Durability / Durabilitatea

Construction design lifetime (for guidance)

Category	Construction design lifetime (in years)	Type of construction (Examples)
5	=100	Important constructions, monumental buildings
4	50 – 100	Structures for buildings and current constructions
3	15 – 30	Structures for farm buildings or similar
2	10 – 25	Construction parts which could be replaced
1	10	Temporary structures

Durability / Durabilitatea

Durability of concrete depends on:

- **Exposure conditions:** atmosphere, soil, seawater, salt, mechanical abrasion, storage or contact with chemicals → **exposure class X**

- **Cement type** → in some cases may require special cements resistant to chemicals

- **Concrete quality** → chosen usually from strength condition, but may be required superior classes in certain environmental conditions (density & strength)

- **Thickness of concrete cover** → is calculated according to the exposure class, to protect the reinforcement from penetration of aggressive substances, but also in case of fire

- **Crack width** → if is not exceed the permissible openings (generally 0.3 mm), are generally not dangerous

If the factors are favorable, concrete durability could be very high.

Durability / Durabilitatea

0 → no risk of corrosion or attack

C → **Carbonation** = corrosion induced by Carbonation

D → **Deicing salt** = corrosion induced by chlorides

S → **Seawater** = corrosion induced by chlorides

F →**Frost** = **F**reeze/thaw attack

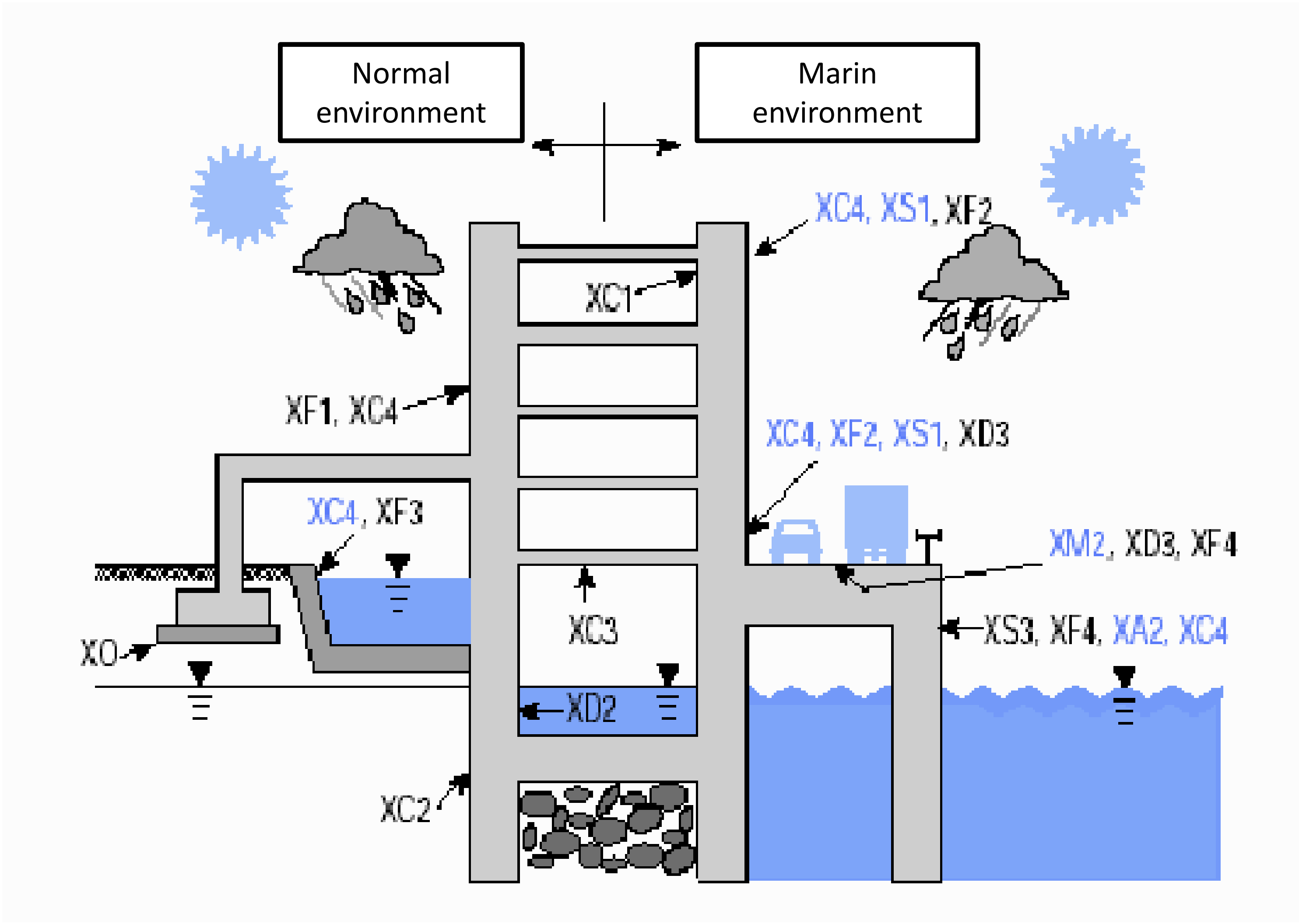
A → **Agressive environmet** = chemical attack

+ M → **Mechanical abrasion**

Class designation	Description of the environment	Informative examples where exposure classes may occur
1 No risk of corrosion or attack		
X0	For concrete without reinforcement or embedded metal: all exposures except where there is freeze/thaw, abrasion or chemical attack For concrete with reinforcement or embedded metal: very dry	Concrete inside buildings with very low air humidity
2 Corrosion induced by carbonation		
XC1	Dry or permanently wet	Concrete inside buildings with low air humidity Concrete permanently submerged in water
XC2	Wet, rarely dry	Concrete surfaces subject to long-term water contact Many foundations
XC3	Moderate humidity	Concrete inside buildings with moderate or high air humidity External concrete sheltered from rain
XC4	Cyclic wet and dry	Concrete surfaces subject to water contact, not within exposure class XC2
3 Corrosion induced by chlorides		
XD1	Moderate humidity	Concrete surfaces exposed to airborne chlorides
XD2	Wet, rarely dry	Swimming pools Concrete components exposed to industrial waters containing chlorides
XD3	Cyclic wet and dry	Parts of bridges exposed to spray containing chlorides Pavements Car park slabs
4 Corrosion induced by chlorides from sea water		
XS1	Exposed to airborne salt but not in direct contact with sea water	Structures near to or on the coast
XS2	Permanently submerged	Parts of marine structures
XS3	Tidal, splash and spray zones	Parts of marine structures
5. Freeze/Thaw Attack		
XF1	Moderate water saturation, without de-icing agent	Vertical concrete surfaces exposed to rain and freezing
XF2	Moderate water saturation, with de-icing agent	Vertical concrete surfaces of road structures exposed to freezing and airborne de-icing agents
XF3	High water saturation, without de-icing agents	Horizontal concrete surfaces exposed to rain and freezing
XF4	High water saturation with de-icing agents or sea water	Road and bridge decks exposed to de-icing agents Concrete surfaces exposed to direct spray containing de-icing agents and freezing Splash zone of marine structures exposed to freezing
6. Chemical attack		
XA1	Slightly aggressive chemical environment according to EN 206-1, Table 2	Natural soils and ground water
XA2	Moderately aggressive chemical environment according to EN 206-1, Table 2	Natural soils and ground water
XA3	Highly aggressive chemical environment according to EN 206-1, Table 2	Natural soils and ground water

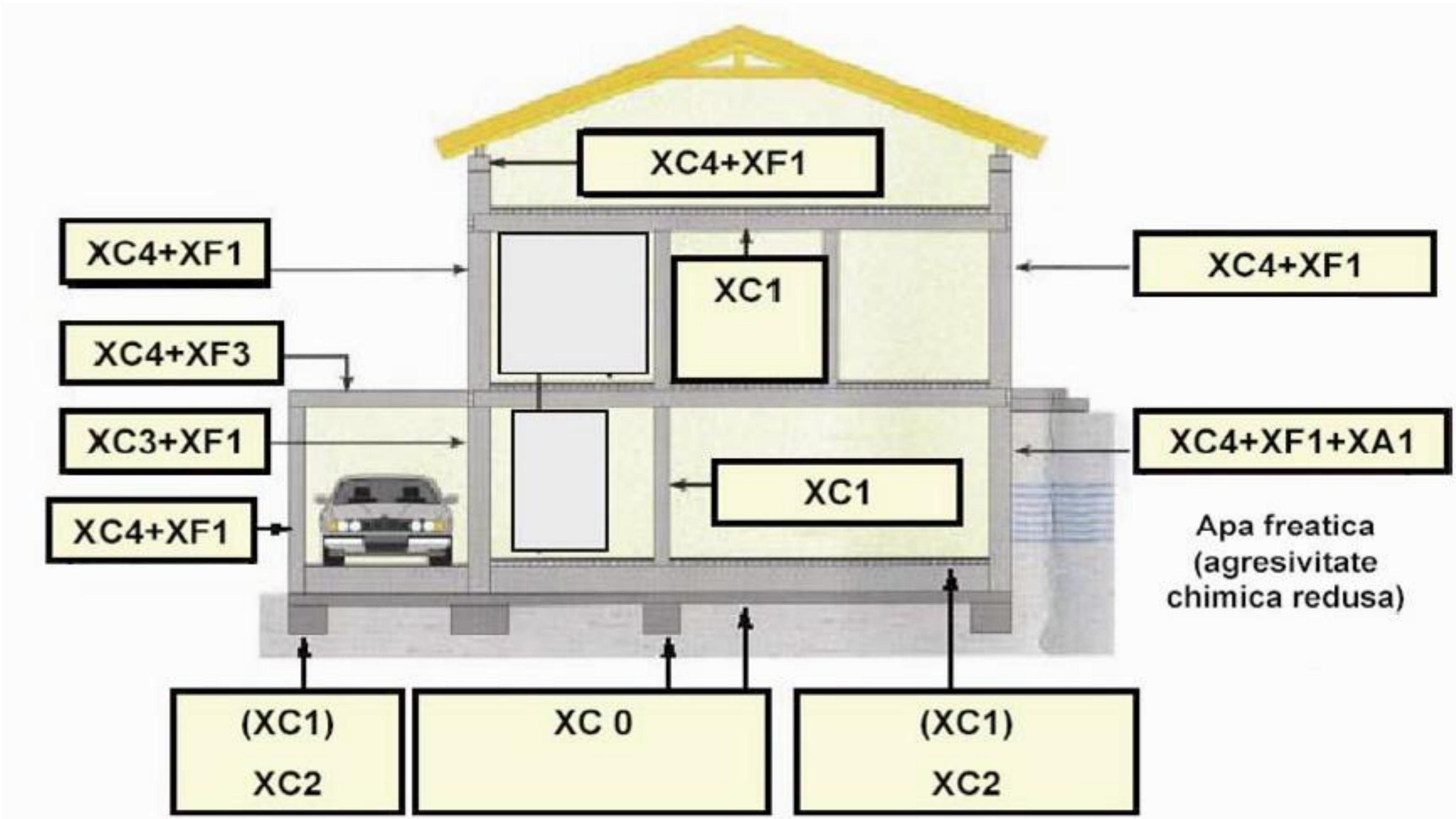
Durability / Durabilitatea

Reinforcement corrosion - superposed effects



Durability / Durabilitatea

Reinforcement corrosion - superposed effects



Durability / Durabilitatea

Strategies considered for increasing sustainability:

A. **Avoidance of degradation reactions** - is obtained by:

→ "environmental change" application of membrane elements, protective films, etc .;

→ chose of non-reactive materials: stainless steel, coated reinforcement, non-reactive aggregates, sulfates resistant cements ;

→ reactions inhibition by cathodic protection, use of air entraining admixtures to to increase freeze-thaw resistance.

B. **The selection of the optimum materials and compositions**, suitable to resist to the expected degradation reactions

→ suitable concrete composition;

→ concrete cover thickness related to the environmental conditions;

→ applying appropriate technologies for compacting concrete;

→ increase the cross section of the elements resulted from the calculation, if is necessary

Concrete cover

→is the distance between the surface of the reinforcement closest to the nearest concrete surface (including links and stirrups and surface reinforcement where relevant) and the nearest concrete surface.

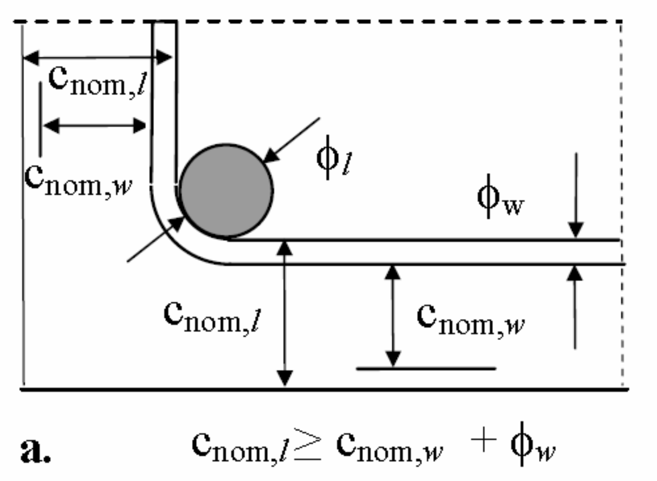
The concrete cover ensures:
- Force transfer by bond from reinforcement to concrete
- Protection of steel rebars against corrosion (durability)
- An adequate fire resistance (not treated here)

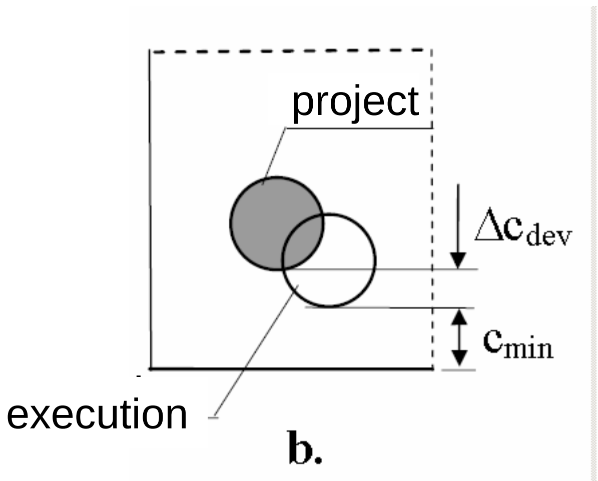
The nominal cover shall be specified on the drawings !!! :

Durability / Durabilitatea

$$c_{nom} = c_{min} + \Delta c_{dev}$$

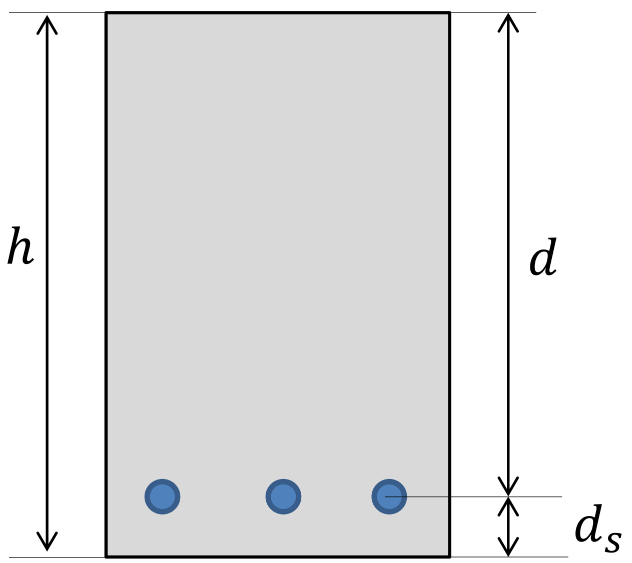
Δc_{dev} = *5 mm* for cast-in-place slab (N. Annex)
= 10 mm for the rest of the element (A.N.)

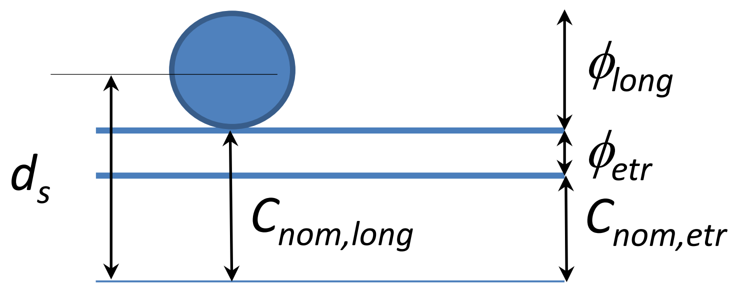




Durability / Durabilitatea

$$c_{nom} = c_{min} + \Delta c_{dev}$$





Durability / Durabilitatea

Minimum concrete cover

$$c_{min} = max\,\{c_{min,b}; c_{min,dur} + \Delta c_{dur,\gamma} - \Delta c_{dur,st} - \Delta c_{dur,add};\ 10\,mm\}$$

$$c_{min} = max\,\{\underbrace{c_{min,b}}_{\text{bond}}; \underbrace{c_{min,dur}}_{\text{durability}};\ 10\,mm\}$$

- $c_{min,b}$ - minimum cover due to bond requirement
- $c_{min,dur}$ - minimum cover due to environmental conditions (N. Annex)
- $\Delta c_{dur,\gamma}$ - additive safety element (generally =0) (N. Annex)
- $\Delta c_{dur,st}$ - reduction of minimum cover for use of stainless steel (N. Annex)
- $\Delta c_{dur,add}$ - reduction of minimum cover for use of additional protection (N. Annex)

Durability / Durabilitatea

Minimum concrete cover

$$c_{min} = max\,\{\underbrace{c_{min,b}}_{\text{bond}};\ \underbrace{c_{min,dur}}_{\text{durability}};\ 10\,mm\}$$

$c_{min,b} \geq\ \phi$

$c_{min,dur}$ = function of structural class (recommended S4 for a design working life of 50 years) and exposure class

Environmental Requirement for $c_{min,dur}$ (mm)							
Structural Class	Exposure Class according to Table 4.1						
	X0	XC1	XC2 / XC3	XC4	XD1 / XS1	XD2 / XS2	XD3 / XS3
S1	10	10	10	15	20	25	30
S2	10	10	15	20	25	30	35
S3	10	10	20	25	30	35	40
S4	10	15	25	30	35	40	45
S5	15	20	30	35	40	45	50
S6	20	25	35	40	45	50	55

Durability / Durabilitatea

Recommended structural classification

Structural Class							
Criterion	Exposure Class according to Table 4.1						
	X0	XC1	XC2 / XC3	XC4	XD1	XD2 / XS1	XD3 / XS2 / XS3
Design Working Life of 100 years	increase class by 2	increase class by 2	increase class by 2	increase class by 2	increase class by 2	increase class by 2	increase class by 2
Strength Class [1)2)]	≥ C30/37 reduce class by 1	≥ C30/37 reduce class by 1	≥ C35/45 reduce class by 1	≥ C40/50 reduce class by 1	≥ C40/50 reduce class by 1	≥ C40/50 reduce class by 1	≥ C45/55 reduce class by 1
Member with slab geometry (position of reinforcement not affected by construction process)	reduce class by 1	reduce class by 1	reduce class by 1	reduce class by 1	reduce class by 1	reduce class by 1	reduce class by 1
Special Quality Control of the concrete production ensured	reduce class by 1	reduce class by 1	reduce class by 1	reduce class by 1	reduce class by 1	reduce class by 1	reduce class by 1

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