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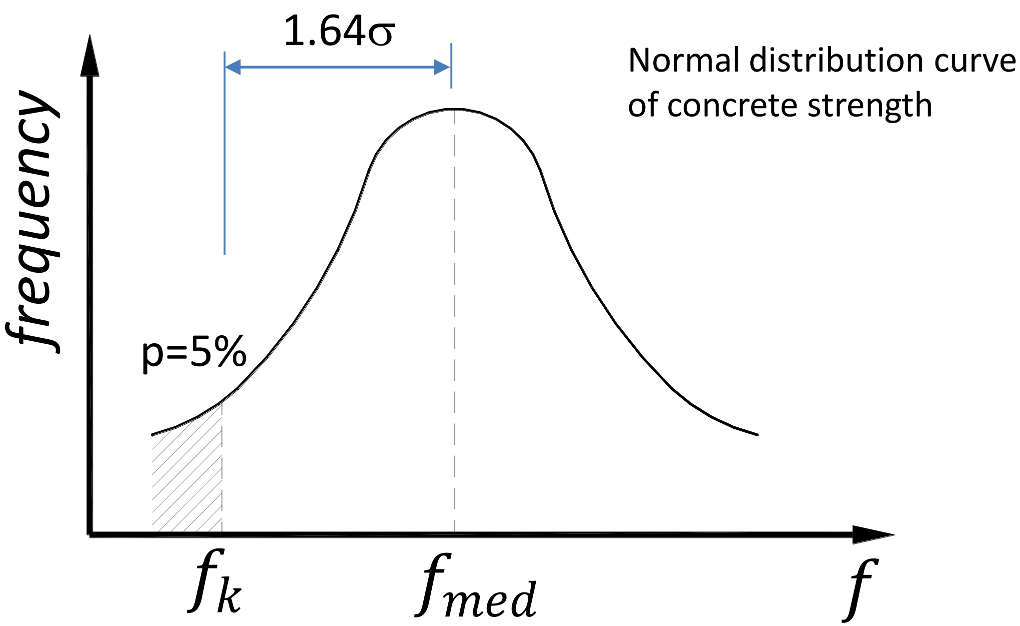
6.1 DESIGN CHARACTERISTICS OF CONCRETE

6.2 DESIGN CHARACTERISTICS OF STEEL REINFORCEMENT

Concrete / Betonul

The compressive strength of concrete is denoted by concrete strength classes which relate to the characteristic (5%) cylinder strength f_{ck}, *or the cube strength* $f_{ck,cube}$, determined at 28 days.



Strength class of concrete is a characteristic strength, because represents the value below which 5% of values are expected to fall.

C16/20

$$f_{cyl} = (0.87 - 0.002 f_{cub}) f_{cub}$$

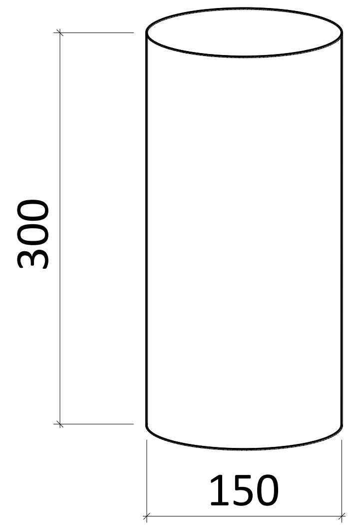
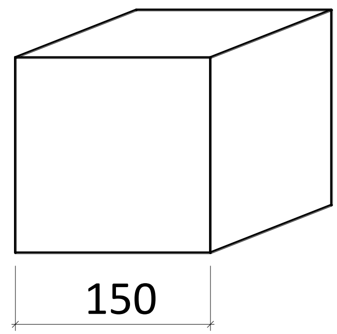
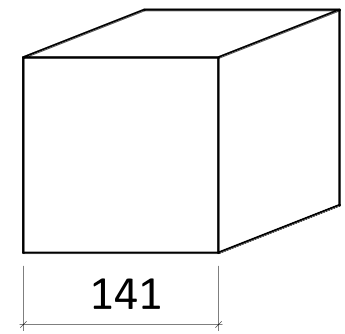
$$f_k = (1 - t c_v) f_{med}$$

$$c_v = 15\%$$

$t = 1.64$ for p=5% and n≥120

Concrete / Betonul

COMPRESSIVE STRENGTH OF CONCRETE

	SR EN 1992-1-1		STAS 10107/0-90
			
Symbol	C 16/20		Bc20
f_{ck}	f_{ck}	$f_{ck,cube}$	R_{bk}
$f_{ck} \cong 0.8 f_{ck,cube}$	**Used in calculations!**	Is not used directly in calculations!	

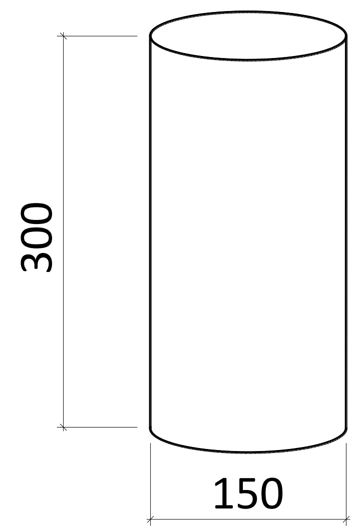
Concrete / Betonul

COMPRESSIVE STRENGTH OF CONCRETE

$$f_{ck} = f_{ck,cyl}$$

THE MEAN CONCRETE COMPRESSIVE STRENGTH

$$f_{cm} = f_{ck} + 8(MPa)$$



Concrete / Betonul

COMPRESSIVE STRENGTH OF CONCRETE AT AN **AGE t** depends on:

- type of cement
- temperature
- curing conditions

$$f_{ck}(t) = f_{cm}(t) - 8(MPa)$$ for *3 < t < 28 days*

$$f_{ck}(t) = f_{ck}$$ for *t ≥ 28 days*

$$f_{cm}(t) = \beta_{cc}(t) f_{cm}$$ with $$\beta_{cc}(t) = exp\left\{s\left[1-\left(\frac{28}{t}\right)^{1/2}\right]\right\}$$

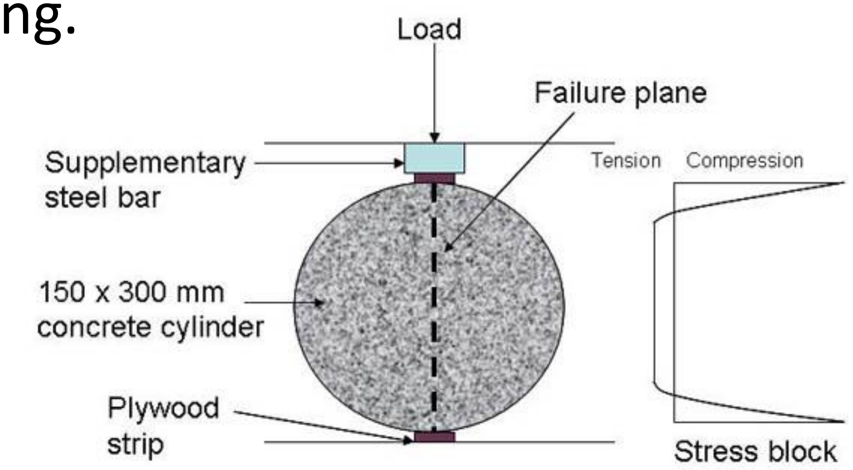
where
$f_{cm}(t)$ - mean concrete compressive strength at an age of t days
$\beta_{cc}(t)$- coefficient which depends on the age of the concrete t
s - coefficient which depends on the type of cement

Concrete / Betonul

TENSILE STRENGTH OF CONCRETE

The tensile strength of concrete f_{ct} refers to the highest stress reached under concentric tensile loading.

The usual test is splitting of a cylindrical specimen.



Where the tensile strength is determined as the splitting tensile strength ($f_{ct,sp}$) the approximate value of the axial tensile strength may be taken as:

$$f_{ct} = 0.9 f_{ct,sp}$$

TENSILE STRENGTH OF CONCRETE

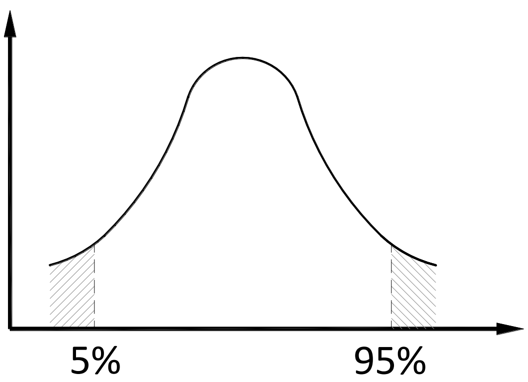
Average tensile strength is obtained from relation:

$$f_{ctm} = 0.3 f_{ck}^{2/3}$$

Other values of the characteristic tensile strength, defined by the fractal of 5% and 95%:

$$f_{ctk,0.05} = 0.7 f_{ctm}$$

$$f_{ctk,0.95} = 1.3 f_{ctm}$$



Concrete / Betonul

TENSILE STRENGTH OF CONCRETE **at an age t**

→ is strongly influenced by curing and drying conditions as well as by the dimensions of the structural members

$$f_{ctm}(t) = (\beta_{cc}(t))^{\alpha} \cdot f_{ctm}$$

where

$\alpha = 1$ *for t < 28 days*

$\alpha = 2/3$ *for t ≥ 28 days*

Concrete / Betonul

DESIGN COMPRESSIVE AND TENSILE STRENGTHS

The value of the design compressive strength is defined as

$$f_{cd} = \alpha_{cc}\frac{f_{ck}}{\gamma_c} = \frac{f_{ck}}{\gamma_c} \quad \rightarrow \quad f_{cd} = \frac{f_{ck}}{\gamma_c}$$

The value of the design tensile strength is defined as

$$f_{ctd} = \alpha_{ct}\frac{f_{ctk,0.05}}{\gamma_c} = \frac{f_{ctk,0.05}}{\gamma_c} \quad \rightarrow \quad f_{ctd} = \frac{f_{ctk,0.05}}{\gamma_c}$$

α_{cc} , α_{ct} - coefficient taking account of long term effects on the compressive/tensile strength and of unfavourable effects resulting from the way the load is applied. Recommended value is = 1.0.

Concrete / Betonul

PARTIAL SAFETY FACTORS FOR CONCRETE AND STEEL IN ULS

Table 2.1N

Design situations	γ_C for concrete	γ_S for reinforcing steel	γ_S for prestressing steel
Persistent & Transient	1,5	1,15	1,15
Accidental	1,2	1,0	1,0

Concrete / Betonul

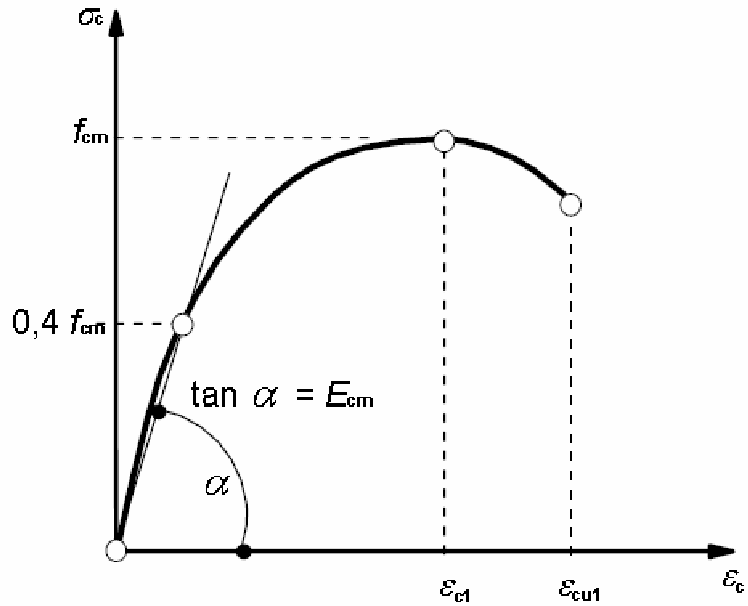
	Strength classes for concrete														Analytical relation / Explanation	
f_{ck} (MPa)	12	16	20	25	30	35	40	45	50	55	60	70	80	90		Characteristic compressive cylinder strength of concrete
$f_{ck,cube}$ (MPa)	15	20	25	30	37	45	50	55	60	67	75	85	95	105		Characteristic compressive cube strength of concrete
f_{cm} (MPa)	20	24	28	33	38	43	48	53	58	63	68	78	88	98	$f_{cm} = f_{ck}+8$(MPa)	Mean value of concrete cylinder compressive strength
f_{ctm} (MPa)	1,6	1,9	2,2	2,6	2,9	3,2	3,5	3,8	4,1	4,2	4,4	4,6	4,8	5,0	$f_{ctm}=0,30\times f_{ck}^{(2/3)} \leq$ C50/60 $f_{ctm}=2,12\cdot\ln(1+(f_{cm}/10))$ > C50/60	Mean value of axial tensile strength of concrete
$f_{ctk,0,05}$ (MPa)	1,1	1,3	1,5	1,8	2,0	2,2	2,5	2,7	2,9	3,0	3,1	3,2	3,4	3,5	$f_{ctk,0,05} = 0,7\times f_{ctm}$ 5% fractile	Characteristic tensile strength of concrete with 5% probabil.
$f_{ctk,0,95}$ (MPa)	2,0	2,5	2,9	3,3	3,8	4,2	4,6	4,9	5,3	5,5	5,7	6,0	6,3	6,6	$f_{ctk,0,95} = 1,3\times f_{ctm}$ 95% fractile	Characteristic tensile strength of concrete with 95% probabil.
E_{cm} (GPa)	27	29	30	31	33	34	35	36	37	38	39	41	42	44	$E_{cm} = 22[(f_{cm})/10]^{0,3}$ (f_{cm} in MPa)	Secant modulus of elasticity of concrete
ε_{c1} (‰)	1,8	1,9	2,0	2,1	2,2	2,25	2,3	2,4	2,45	2,5	2,6	2,7	2,8	2,8	see Figure 3.2 ε_{c1} (‰) $= 0,7\ f_{cm}^{0,31} < 2.8$	Compressive strain in the concrete at the peak stress f_c
ε_{cu1} (‰)	3,5									3,2	3,0	2,8	2,8	2,8	see Figure 3.2 for $f_{ck} \geq 50$ Mpa ε_{cu1}(‰)$=2,8+27[(98-f_{cm})/100]^4$	Ultimate compressive strain in the concrete
ε_{c2} (‰)	2,0									2,2	2,3	2,4	2, 5	2,6	see Figure 3.3 for $f_{ck} \geq 50$ Mpa ε_{c2}(‰)$=2,0+0,085(f_{ck}-50)^{0,53}$	Strain at reaching the maximum strength in concrete
ε_{cu2} (‰)	3,5									3,1	2,9	2,7	2,6	2,6	see Figure 3.3 for $f_{ck} \geq 50$ Mpa ε_{cu2}(‰)$=2,6+35[(90-f_{ck})/100]^4$	Ultimate strain in concrete
n	2,0									1,75	1,6	1,45	1,4	1,4	for $f_{ck} \geq 50$ Mpa $n=1,4+23,4[(90-f_{ck})/100]^4$	Exponent in formula 3.17
ε_{c3} (‰)	1,75									1,8	1,9	2,0	2,2	2,3	see Figure 3.4 for $f_{ck} \geq 50$ Mpa ε_{c3}(‰)$=1,75+0,55[(f_{ck}-50)/40]$	Strain at maximum strength in concrete (fig . 3.4)
ε_{cu3} (‰)	3,5									3,1	2,9	2,7	2,6	2,6	see Figure 3.4 for $f_{ck} \geq 50$ Mpa ε_{cu3}(‰)$=2,6+35[(90-f_{ck})/100]^4$	Ultimate strain in concrete (fig . 3.4)

The modulus of elasticity of a concrete (E_{cm})is controlled by the moduli of elasticity of its components.
→ secant value between $\sigma_c = 0$ and $0.4 f_{cm}$

$$E_{cm} = 22000(f_{cm}/10)^{0.3}$$

Variation of the modulus of elasticity with time:

$$E_{cm}(t) = (f_{cm}(t)/f_{cm})^{0.3} \cdot E_{cm}$$



Valid concretes with quartzite aggregates!
For limestone aggregates should be reduced by 10%
For sandstone aggregates should be reduced by 30%
For basalt aggregates should be increased by 20%.

Concrete / Betonul

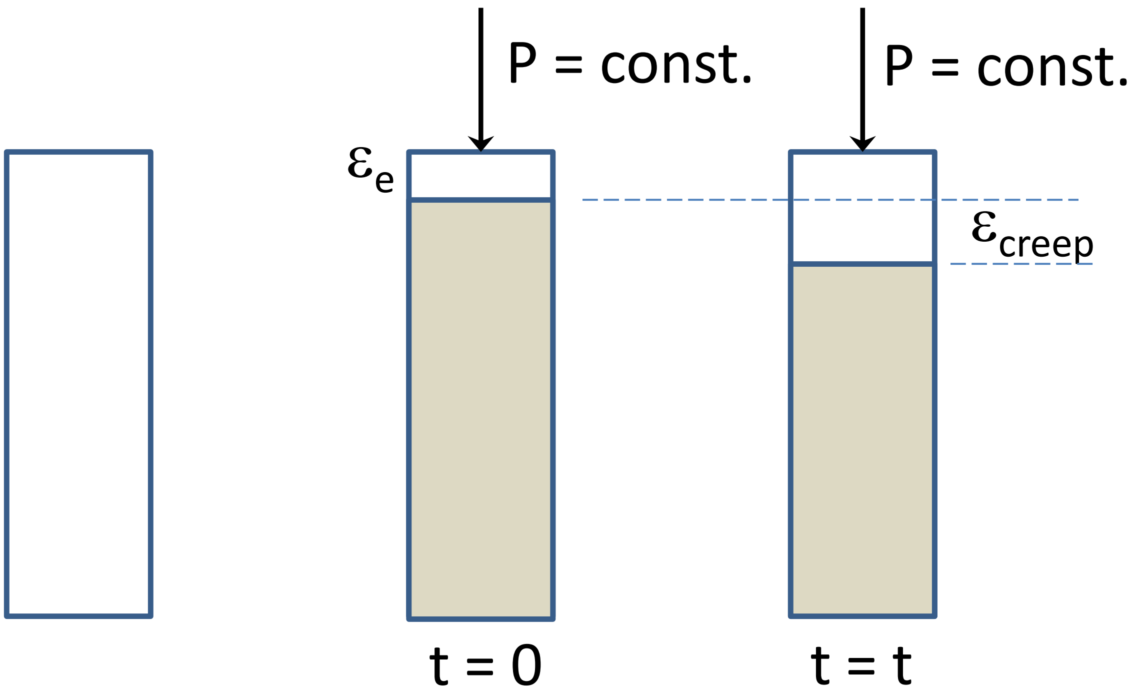
Poisson's ratio may be taken equal to

$\nu = 0,2$ for uncracked concrete
$\nu = 0$ for cracked concrete

The linear coefficient of thermal expansion may be taken equal to $10 \cdot 10^{-6}\ K^{-1}$.

CREEP OF THE CONCRETE

Creep coefficient $\varphi = \dfrac{\varepsilon_{creep}}{\varepsilon_e}$



CEMENT HYDRATION → CRISTALS (elastic behavior) & GELS (viscous behavior)

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CREEP OF THE CONCRETE

→ Depends on the:

- Humidity of the environment: RH (%)
- Type of the cement: (curing rate): S - slow; N - normal; R - rapid
- Concrete strength: f_{ck}
- Age of concrete at the time of loading: t_0
- Dimensions of the element:

$h_0 = 2A_c/u$ - notional size (mm) of the cross-section
A_c – concrete cross-sectional area
u - the perimeter of that part which is exposed to drying

→ Creep is also influenced by the maturity of the concrete when the load is first applied and depends on the duration and magnitude of the loading.

Creep coefficient $\varphi(t,t_0)$ is obtained from tables if $\sigma_c \leq 0.45 f_{ck}(t_0)$

↔ linear creep is expected

Concrete / Betonul

CREEP OF THE CONCRETE

$\varphi(\infty,t_0)$ - final creep coefficient

t_0 - age of the concrete at time of loading in days

$h_0 = 2A_c/u$

A_c - concrete cross-sectional area

u - perimeter of that part which is exposed to drying

S, N, R - cement types
S - slow
N - normal
R - rapid

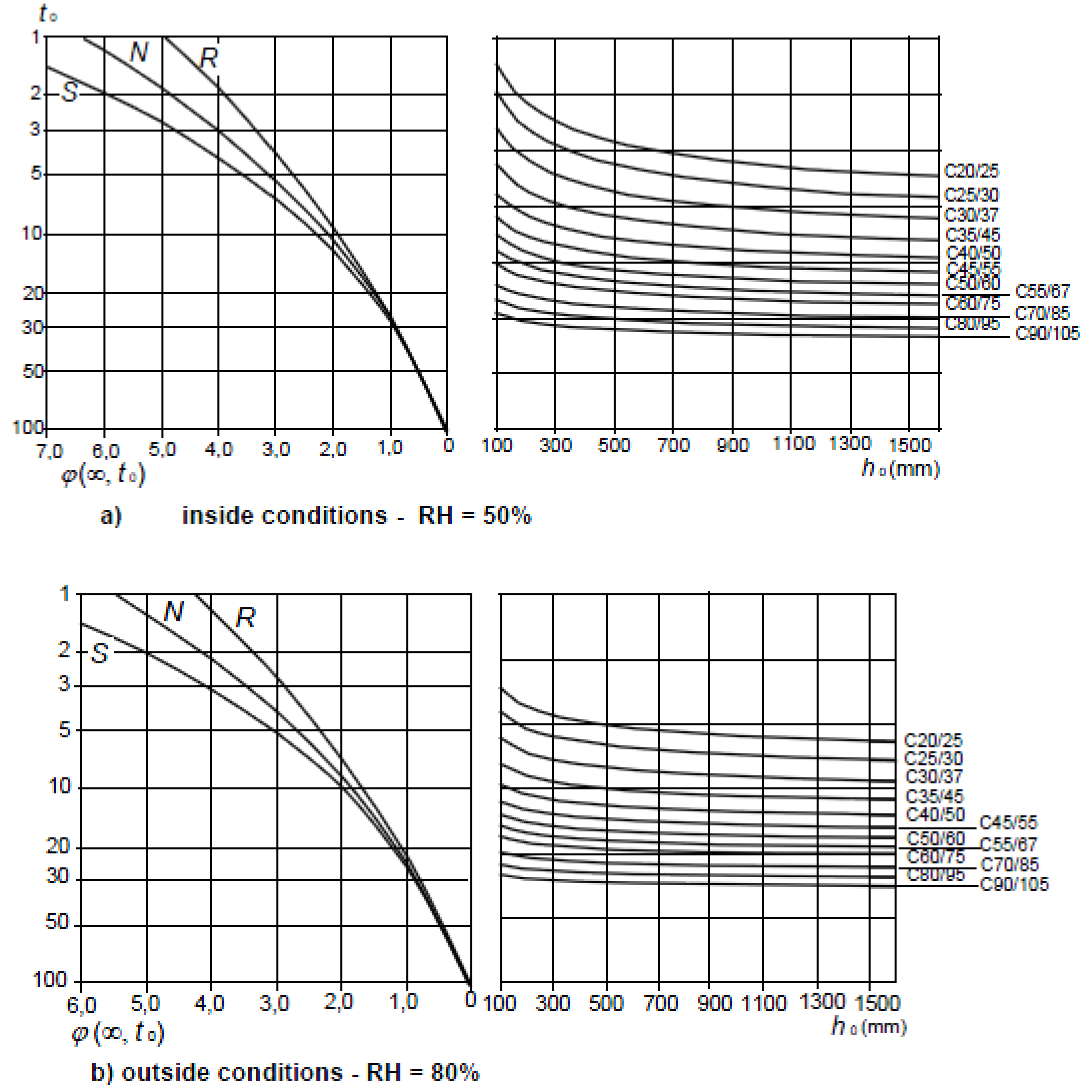
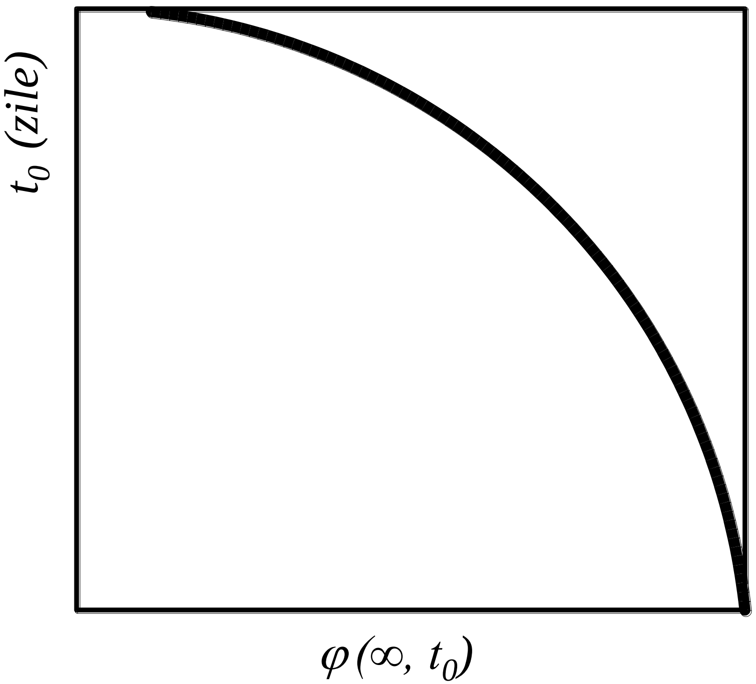
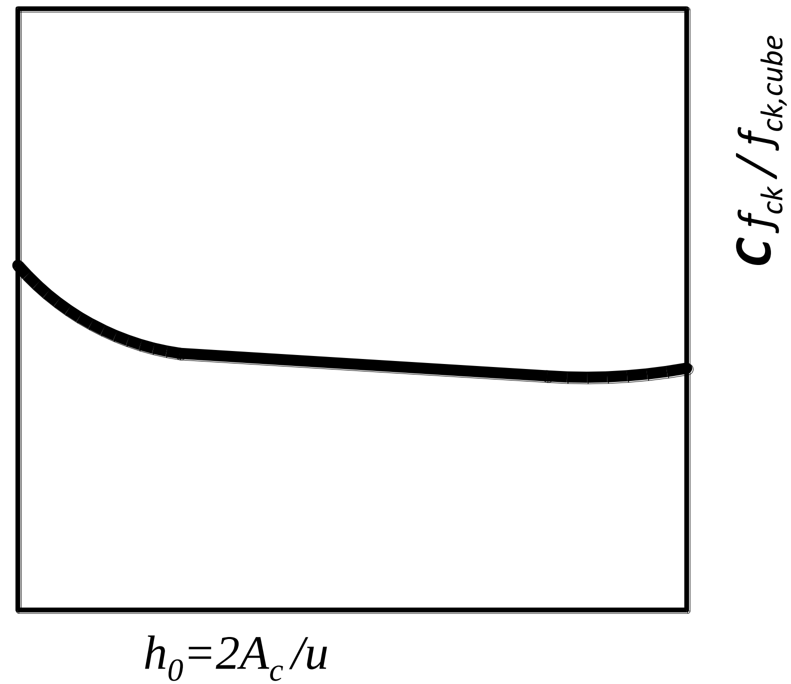


Figure 3.1: Method for determining the creep coefficient $\varphi(\infty, t_0)$ for concrete under normal environmental conditions

CREEP OF THE CONCRETE - SR EN 1991-1-1





- choose of environmental conditions (RH=50% inside; RH=80% outside)
- Choose of cement type (N, R, S)

- Choose of concrete class
- Calculus of h_0

→ *Creep of concrete depends on **humidity** of the environment, **dimensions** of the element and **composition** of concrete + **age of concrete** at the time of loading and **duration** and **magnitude** of the loading.*

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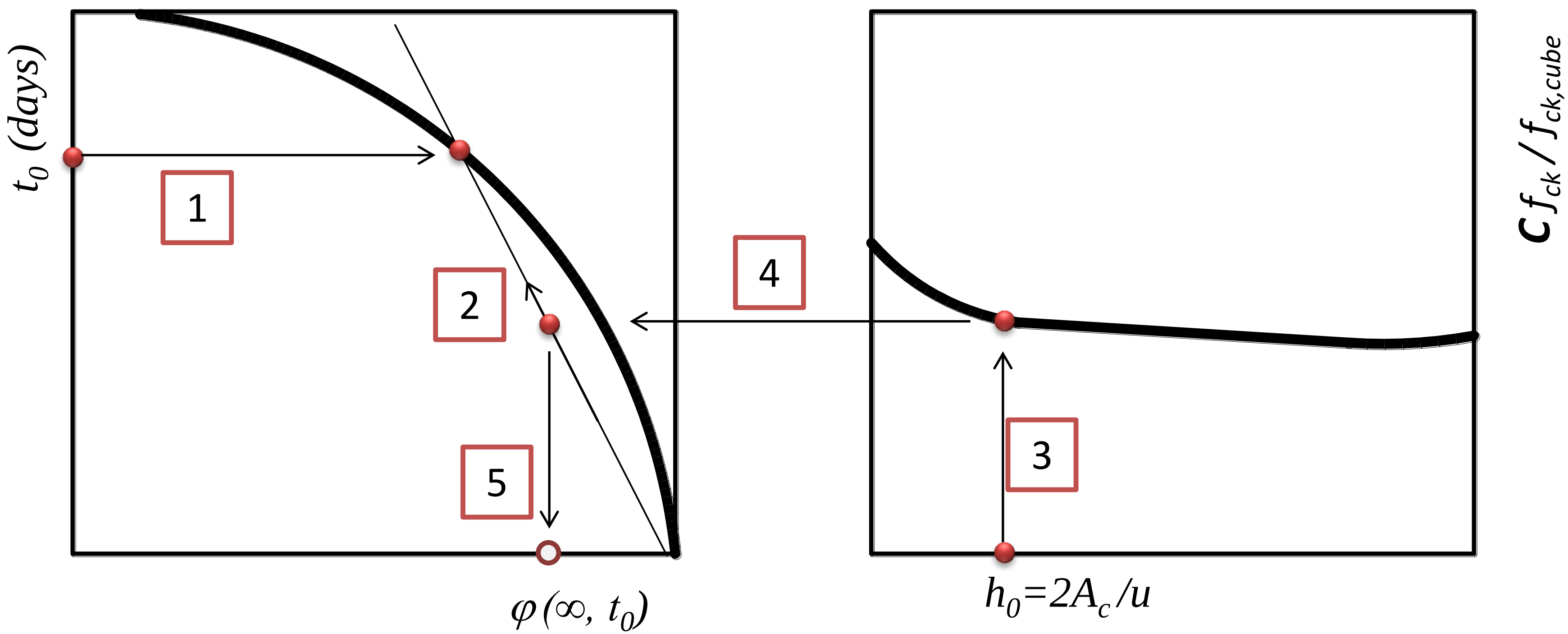
CREEP OF THE CONCRETE - SR EN 1991-1-1



1. t_0 - age of the concrete at time of loading (in days)
2. Secant

3. h_0 [mm]

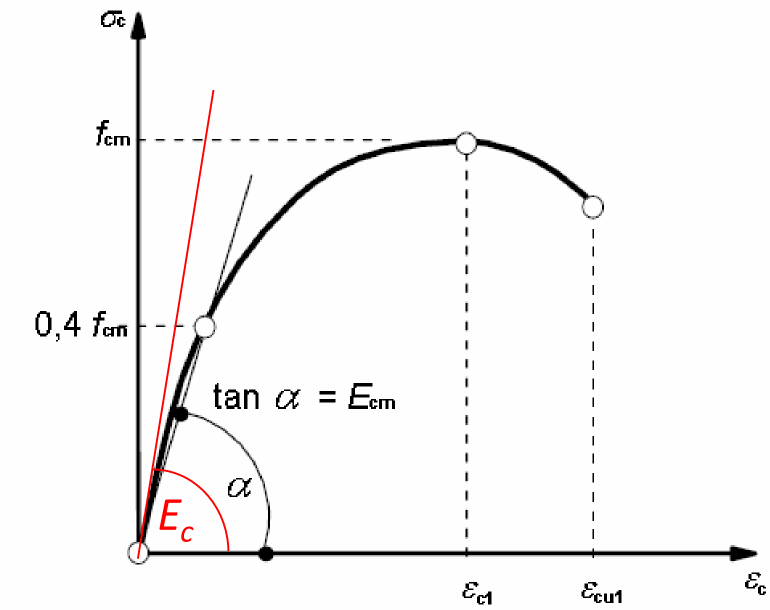
→ *Creep of concrete depends on **humidity** of the environment, **dimensions** of the element and **composition** of concrete + **age of concrete** at the time of loading and **duration** and **magnitude** of the loading.*

Concrete / Betonul

The creep deformation of concrete $\varepsilon_{cc}(\infty, t_0)$ *at time* $t = \infty$ for a constant compressive stress σ_c applied at the concrete age t_0 *is:*

$$\varepsilon_{cc}(\infty, t_0) = \varphi(\infty, t_0) \cdot (\sigma_c / E_c)$$

$$E_c = 1{,}05 E_{cm}$$



The effective modulus of elasticity of concrete under long term loads:

$$E_{c,eff} = \frac{E_{cm}}{1 + \varphi(\infty, t_0)}$$

SHRINKAGE OF THE CONCRETE

The total shrinkage strain ε_{cs} is composed of two components:

1. the drying shrinkage strain ε_{cd} - develops slowly, since it is a function of the migration of the water through the hardened concrete.

2. the autogenous shrinkage strain ε_{ca} - develops during hardening of the concrete: the major part therefore develops in the early days after casting. Autogenous shrinkage is a linear function of the concrete strength.

$$\varepsilon_{cs} = \varepsilon_{cd} + \varepsilon_{ca}$$

Concrete / Betonul

Drying shrinkage strain at an **age t**

$$\varepsilon_{cd}(t) = \beta(t,t_s) \cdot k_h \cdot \varepsilon_{cd,0}$$

$$\beta_{ds}(t,t_s) = \frac{(t-t_s)}{(t-t_s)+0{,}04\sqrt{h_0^3}}$$

Table 3.2 Nominal unrestrained drying shrinkage values $\varepsilon_{cd,0}$ (in $^0/_{00}$) for concrete with cement CEM Class N

$f_{ck}/f_{ck,cube}$ (MPa)	Relative Humidity (in $^0/_0$)					
	20	40	60	80	90	100
20/25	0.62	0.58	0.49	0.30	0.17	0.00
40/50	0.48	0.46	0.38	0.24	0.13	0.00
60/75	0.38	0.36	0.30	0.19	0.10	0.00
80/95	0.30	0.28	0.24	0.15	0.08	0.00
90/105	0.27	0.25	0.21	0.13	0.07	0.00

h_0	k_h
100	1.0
200	0.85
300	0.75
$\geq$ 500	0.70

k_h = coefficient depending on the notional size h_0

$h_0 = 2A_c/u$

t - age of the concrete at the moment considered, in days
t_s - the age of the concrete (days) at the beginning of drying shrinkage (or swelling)

Concrete / Betonul

Autogenous shrinkage ε_{ca}

$$\varepsilon_{ca}(t) = \beta_{as}(t) \cdot \varepsilon_{ca}(\infty)$$

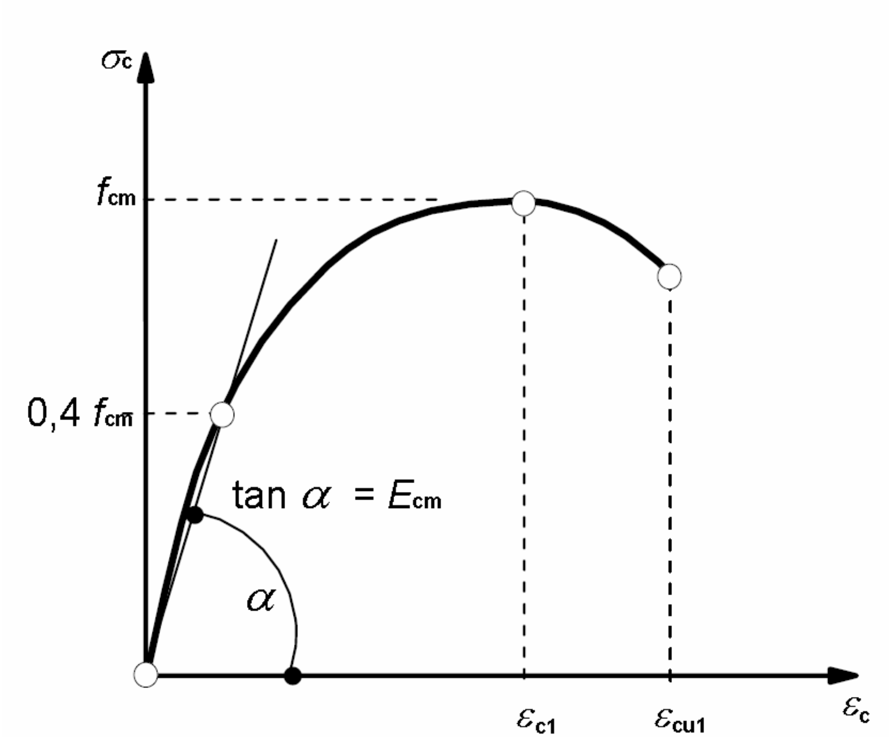
Where

$$\varepsilon_{ca}(\infty) = 2.5(f_{ck} - 10)10^{-6}$$

$$\beta_{as}(t) = 1 - exp(-0.2t^{0.5})$$

Concrete / Betonul

CONCRETE STRESS-STRAIN DIAGRAM - non-linear structural analysis



always 3,5 ‰ for concrete ≤ C50/60

$$\frac{\sigma_c}{f_{cm}} = \frac{k\eta - \eta^2}{1 + (k-2)\eta}$$

where:

$\eta = \varepsilon_c / \varepsilon_{c1}$

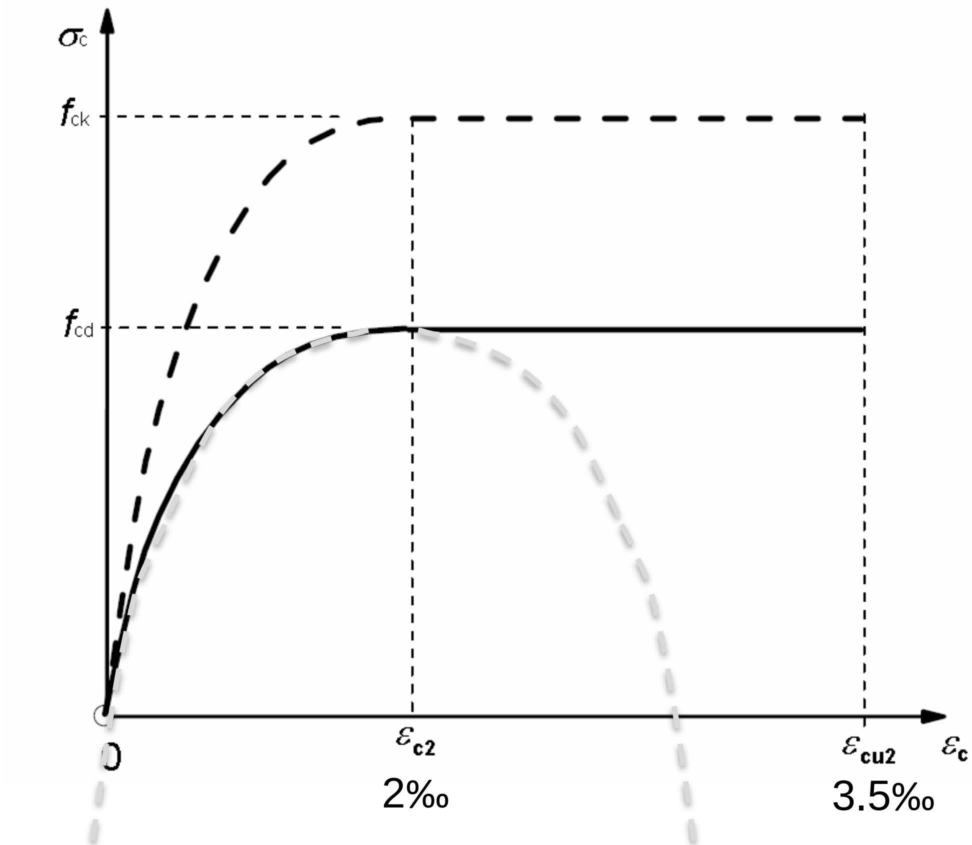
ε_{c1} is the strain at peak stress

$k = 1{,}05\, E_{cm} \times |\varepsilon_{c1}| / f_{cm}$

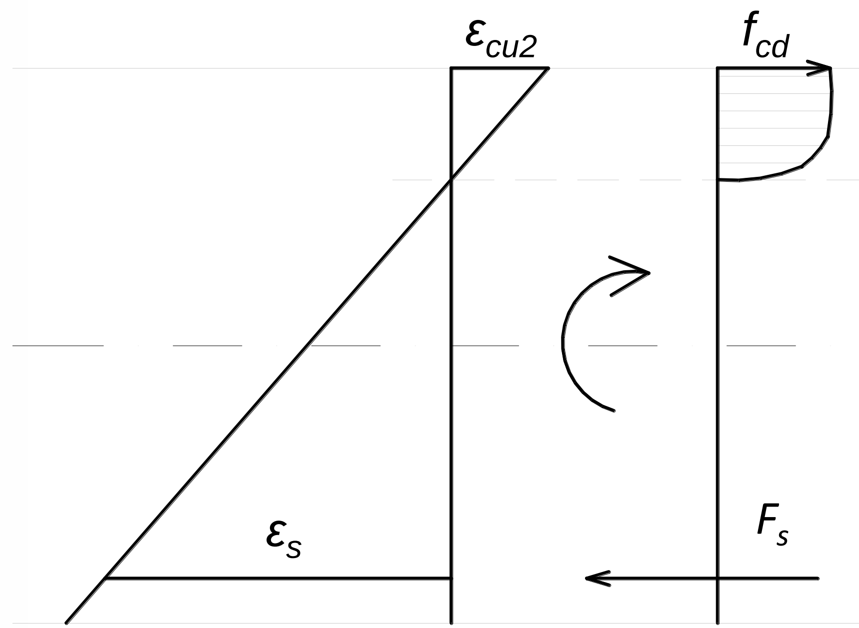
Concrete / Betonul

CONCRETE STRESS-STRAIN DIAGRAM - design of cross-sections

1. Parabola-rectangle diagram for concrete under compression



→ Valid for ≤ C50/60



$$\sigma_c = f_{cd}\left[1-\left(1-\frac{\varepsilon_c}{\varepsilon_{cd}}\right)^n\right] \quad \text{pentru} \quad 0 \le \varepsilon_c \le \varepsilon_{cd}$$

$$\sigma_c = f_{cd} \quad \text{pentru} \quad \varepsilon_{cd} \le \varepsilon_c \le \varepsilon_{cu2}$$

n = 2 for ≤ C50/60

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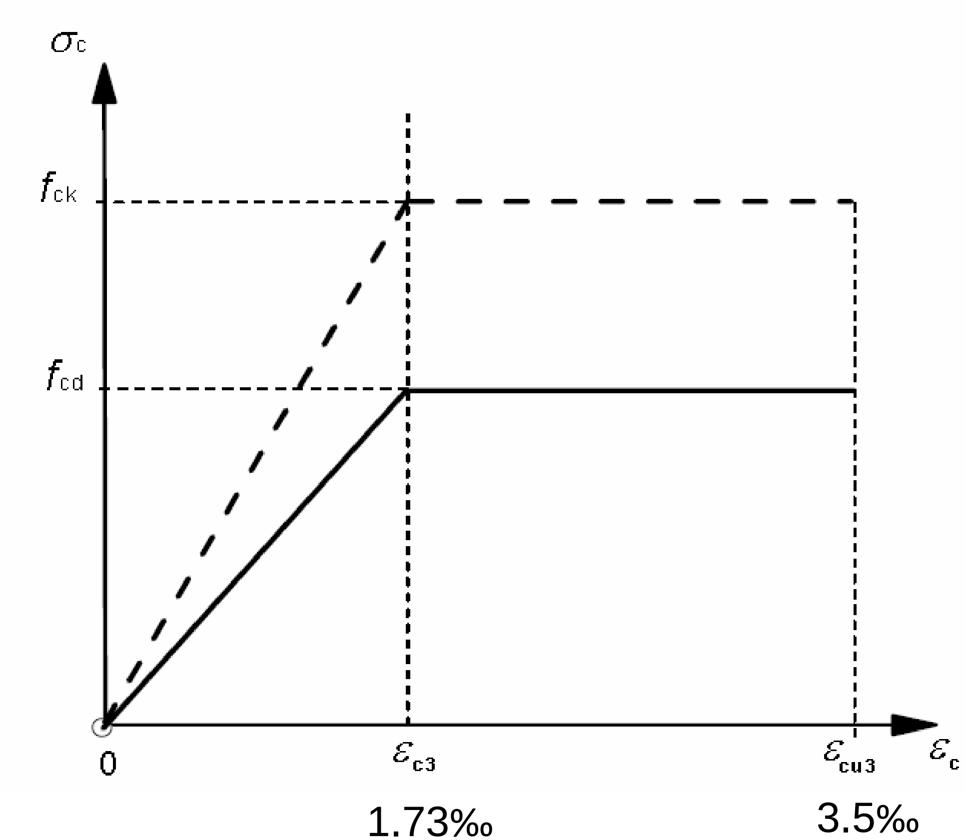
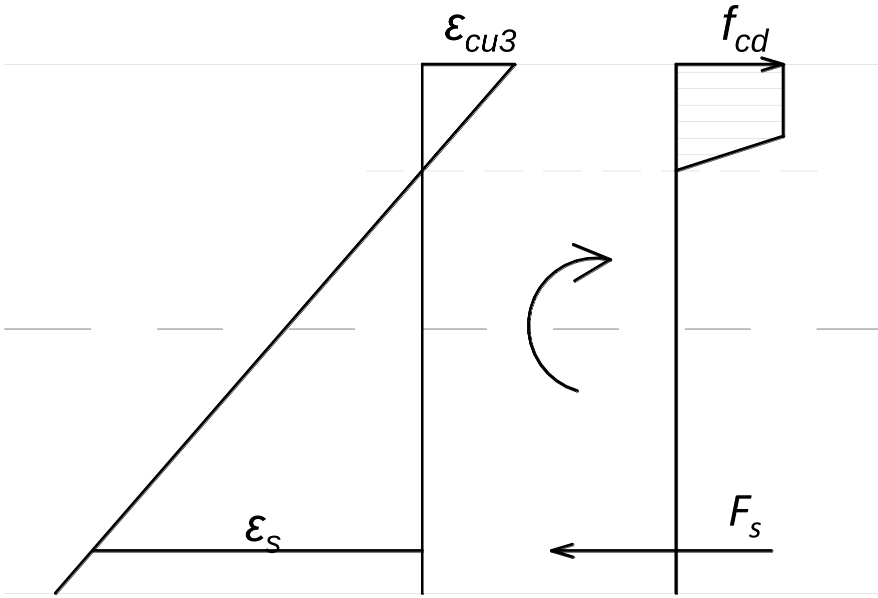
CONCRETE STRESS-STRAIN DIAGRAM - design of cross-sections

2. Bi-linear stress-strain relation



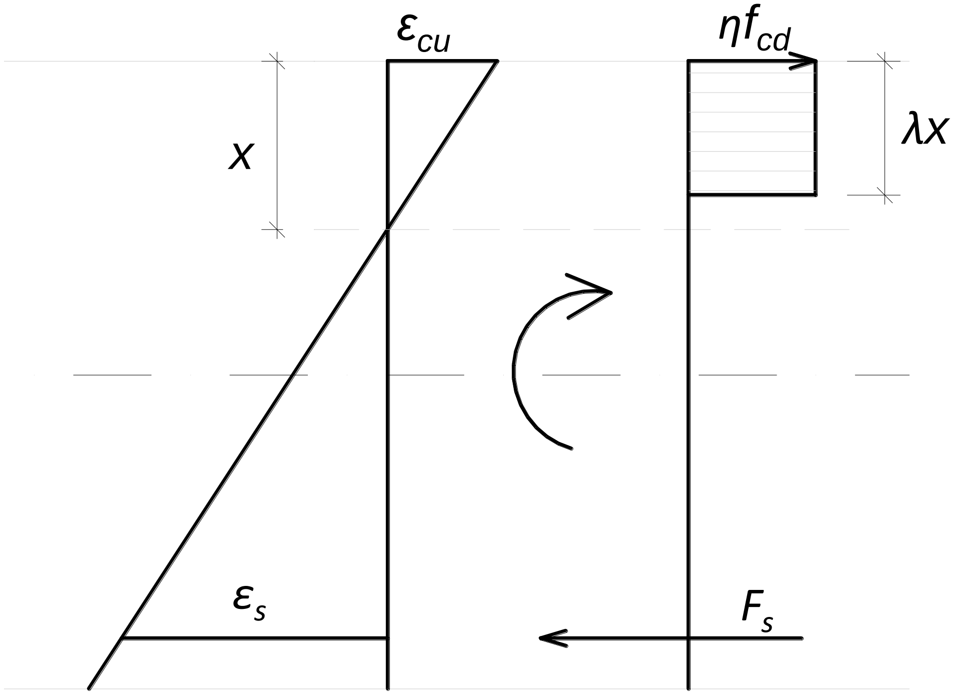


→ Valid for ≤ C50/60

Concrete / Betonul

CONCRETE STRESS-STRAIN DIAGRAM - design of cross-sections

2. Bi-linear stress-strain relation → simplified (rectangular) stress distribution



In usual cases
$\lambda = 0,8$
$\eta = 1,0$

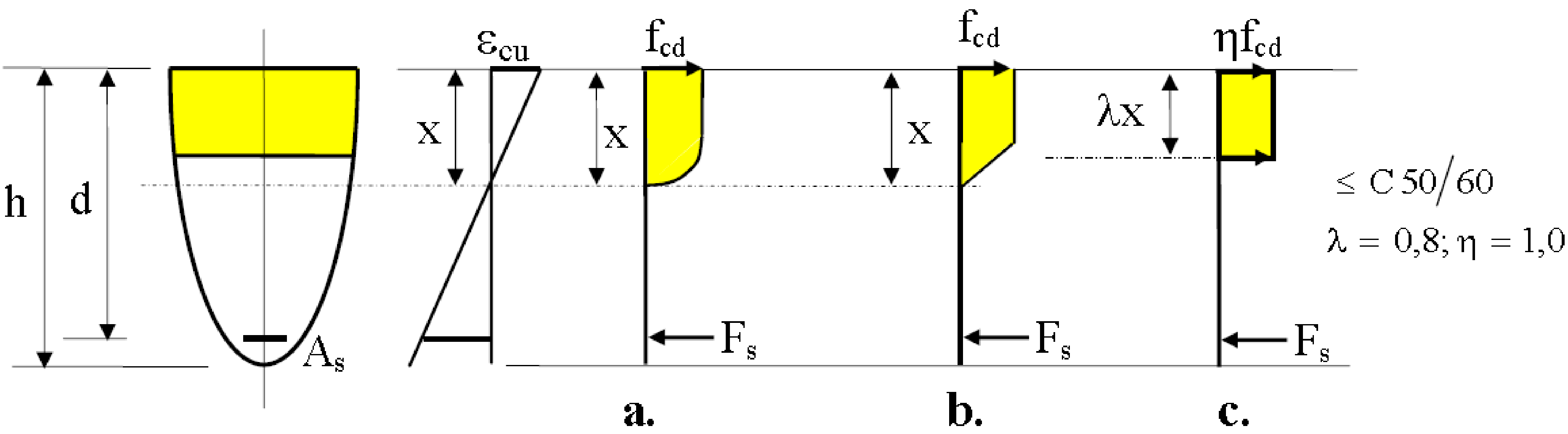
→ Valid for ≤ C50/60

$\lambda = 0,8$ for $f_{ck} \leq 50$ MPa
$\lambda = 0,8 - (f_{ck} - 50)/400$ for $50 < f_{ck} \leq 90$ MPa

and

$\eta = 1,0$ for $f_{ck} \leq 50$ MPa
$\eta = 1,0 - (f_{ck} - 50)/200$ for $50 < f_{ck} \leq 90$ MPa

CONCRETE STRESS-STRAIN DIAGRAMS



strain diagram

stress diagram

simplified stress diagram

stress block diagram

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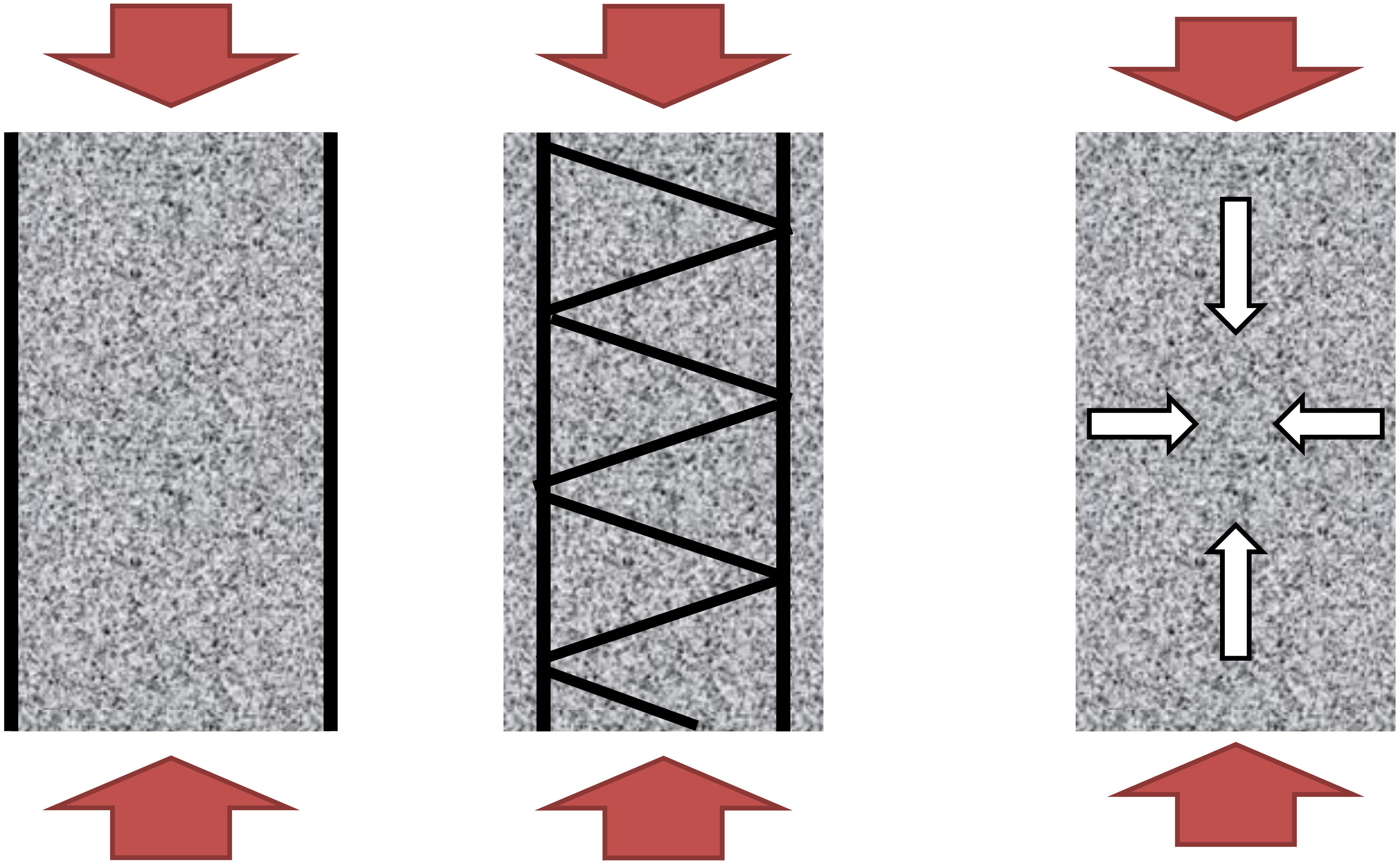
CONFINED CONCRETE

→ increasing compressive strength of concrete by creating **triaxial stress**



Confined concrete TUBE

Confined concrete SPIRAL REINFORCEMENT

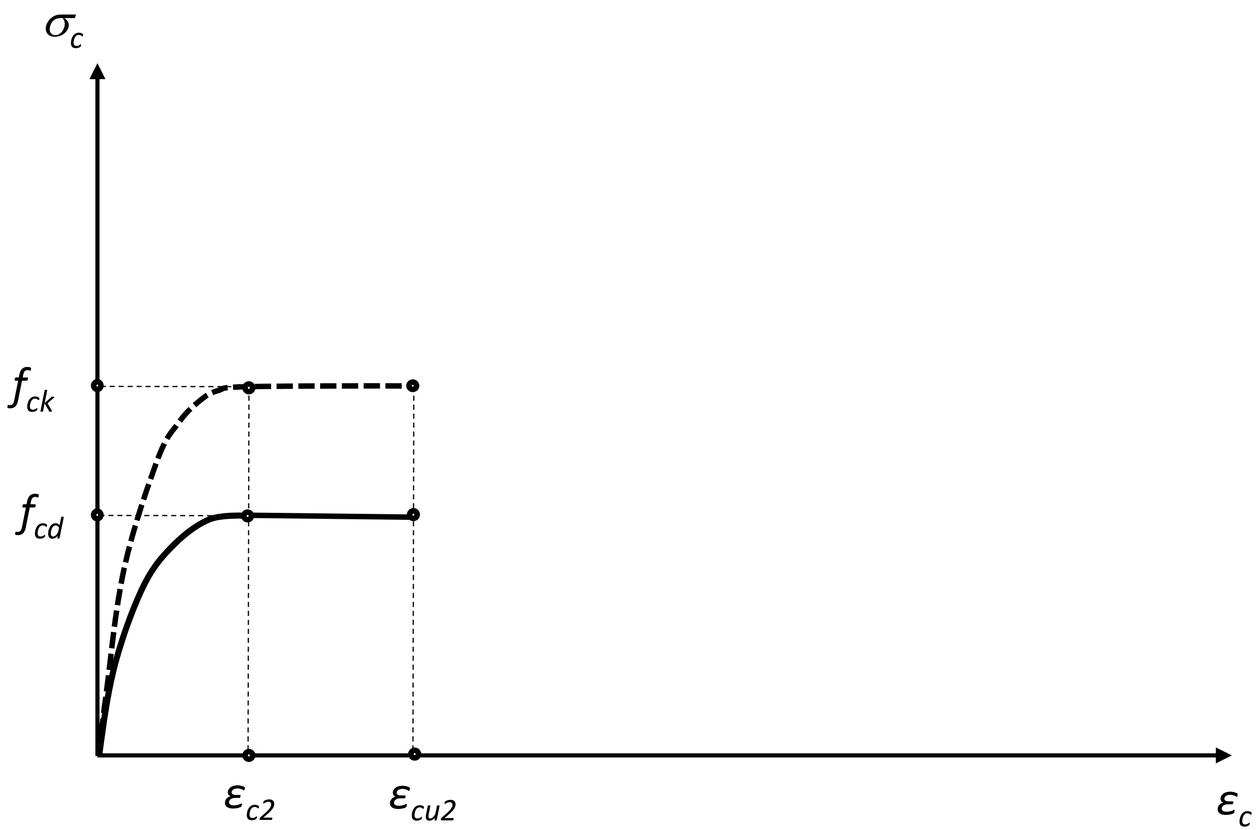
Internal forces

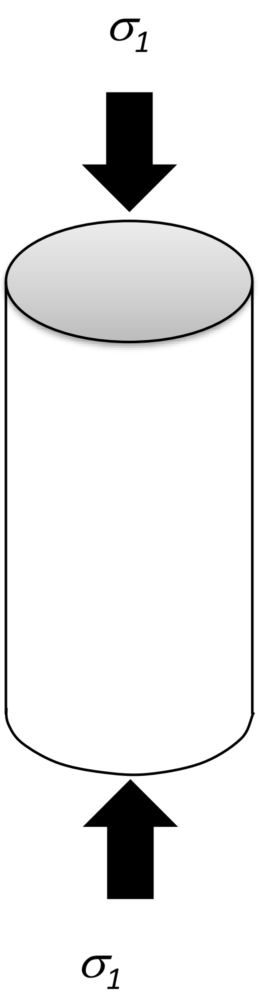
Concrete / Betonul

CONFINED CONCRETE

→ increasing compressive strength of concrete by creating **triaxial stress**

→ Increasing the characteristic compressive stresses to $f_{ck,c}$ and the deformations to $\varepsilon_{cu2,c}$



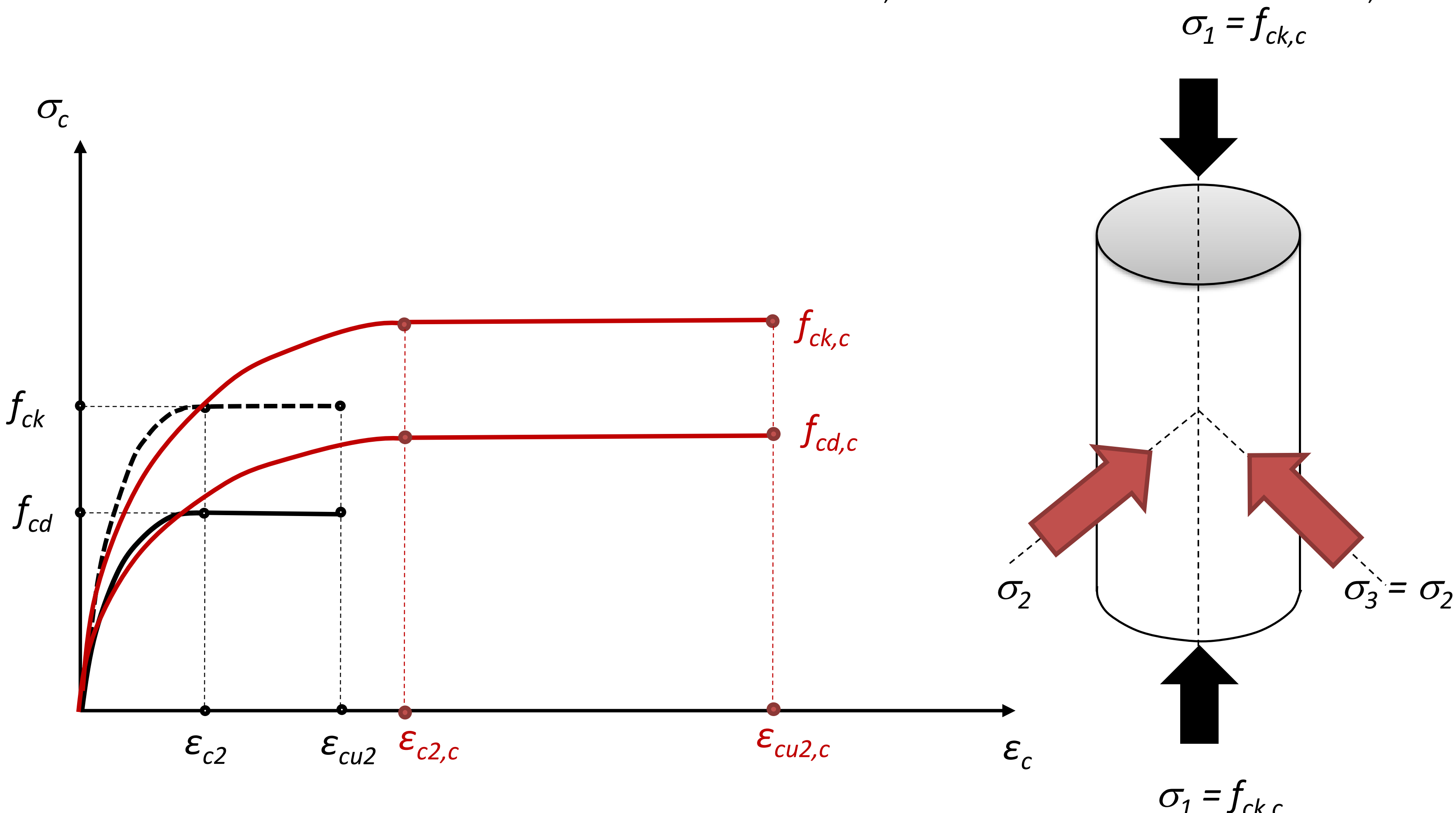


Concrete / Betonul

CONFINED CONCRETE

→ increasing compressive strength of concrete by creating **triaxial stress**

→ Increasing the characteristic compressive stresses to $f_{ck,c}$ and the deformations to $\varepsilon_{cu2,c}$



$\sigma_2 = \sigma_3$ – compressive stresses, perpendicular to element axis

Concrete / Betonul

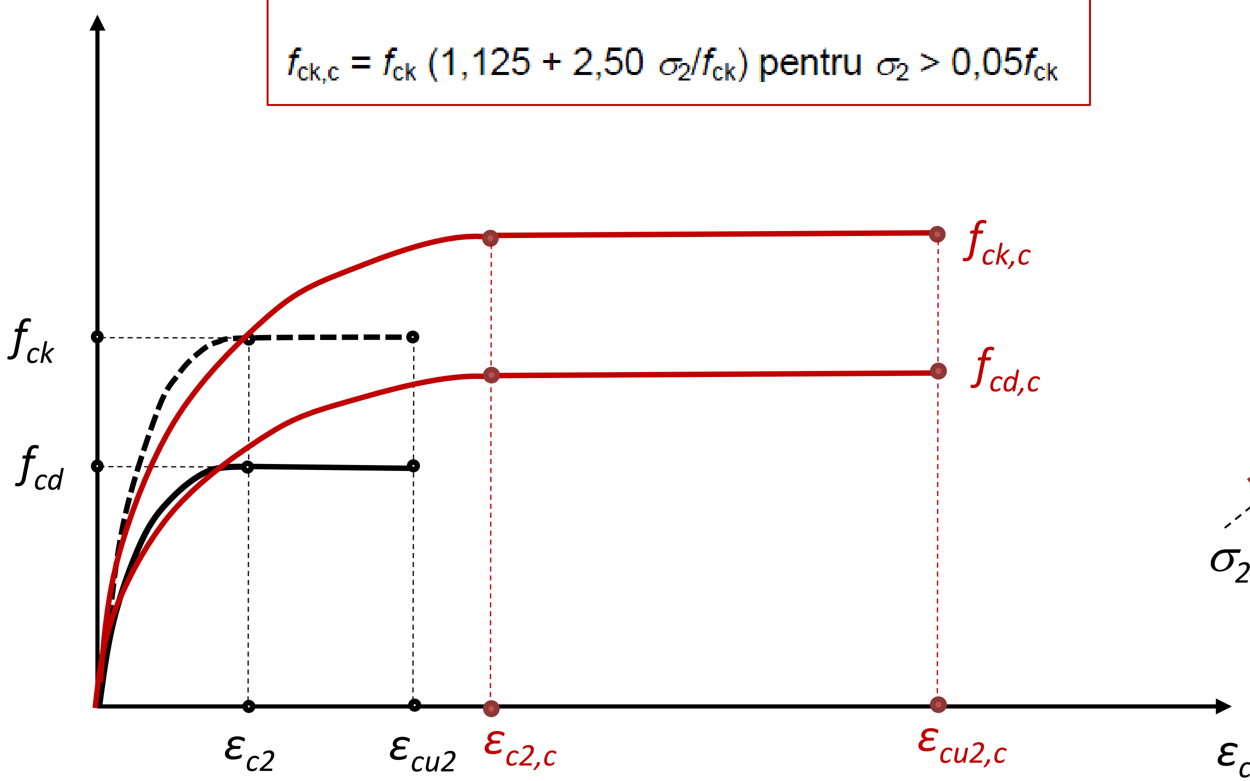
CONFINED CONCRETE

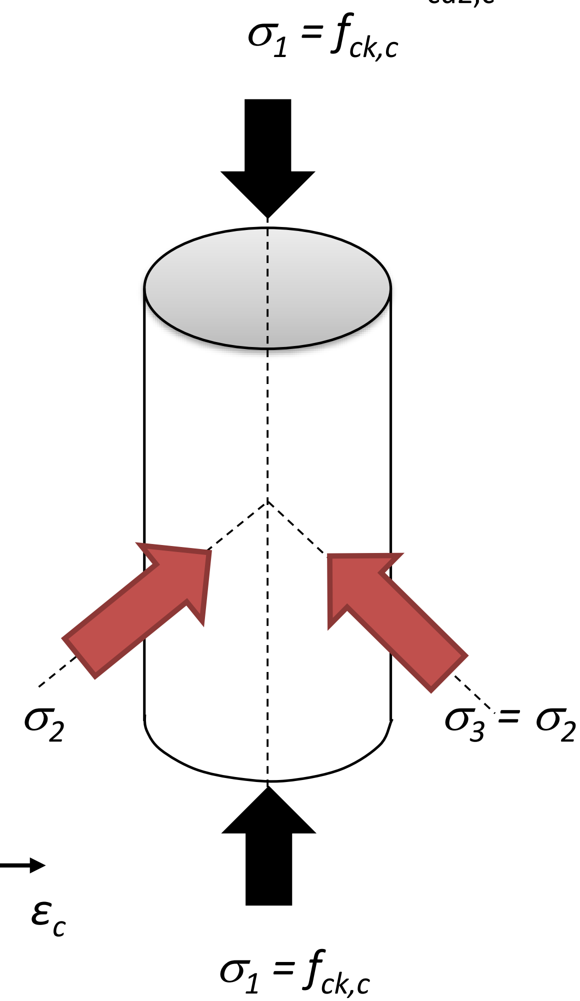
→ increasing compressive strength of concrete by creating **triaxial stress**

→ Increasing the characteristic compressive stresses to $f_{ck,c}$ and the deformations to $\varepsilon_{cu2,c}$

$f_{ck,c} = f_{ck}\,(1{,}000 + 5{,}0\ \sigma_2/f_{ck})$ pentru $\sigma_2 \leq 0{,}05 f_{ck}$

$f_{ck,c} = f_{ck}\,(1{,}125 + 2{,}50\ \sigma_2/f_{ck})$ pentru $\sigma_2 > 0{,}05 f_{ck}$





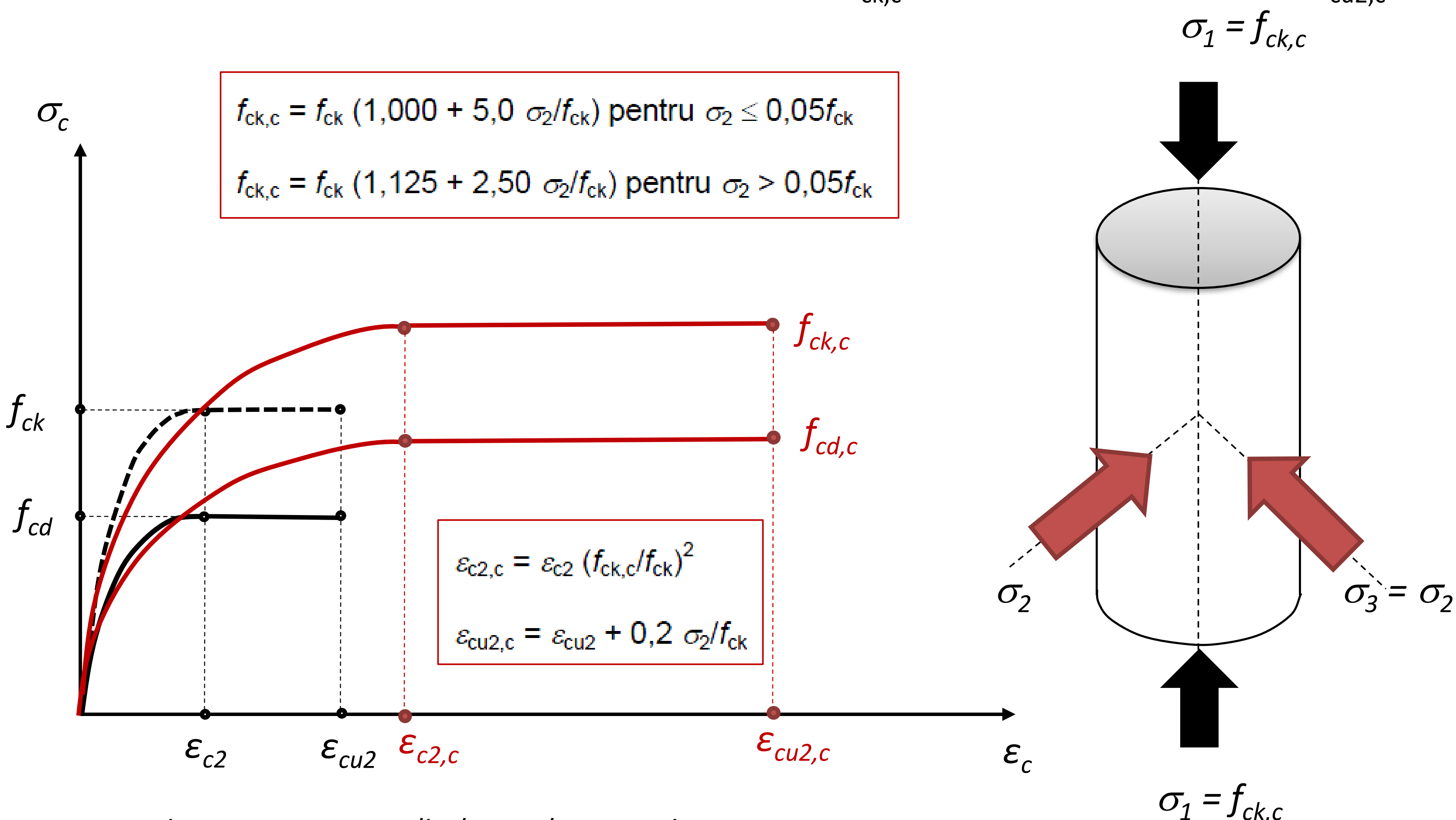
$\sigma_2 = \sigma_3$ – compressive stresses, perpendicular to element axis

Concrete / Betonul

CONFINED CONCRETE

→ increasing compressive strength of concrete by creating **triaxial stress**

→ Increasing the characteristic compressive stresses to $f_{ck,c}$ and the deformations to $\varepsilon_{cu2,c}$



$f_{ck,c} = f_{ck}\,(1{,}000 + 5{,}0\ \sigma_2/f_{ck})$ pentru $\sigma_2 \le 0{,}05 f_{ck}$

$f_{ck,c} = f_{ck}\,(1{,}125 + 2{,}50\ \sigma_2/f_{ck})$ pentru $\sigma_2 > 0{,}05 f_{ck}$

$\varepsilon_{c2,c} = \varepsilon_{c2}\,(f_{ck,c}/f_{ck})^2$

$\varepsilon_{cu2,c} = \varepsilon_{cu2} + 0{,}2\ \sigma_2/f_{ck}$

$\sigma_2 = \sigma_3$ – compressive stresses, perpendicular to element axis

Concrete / Betonul

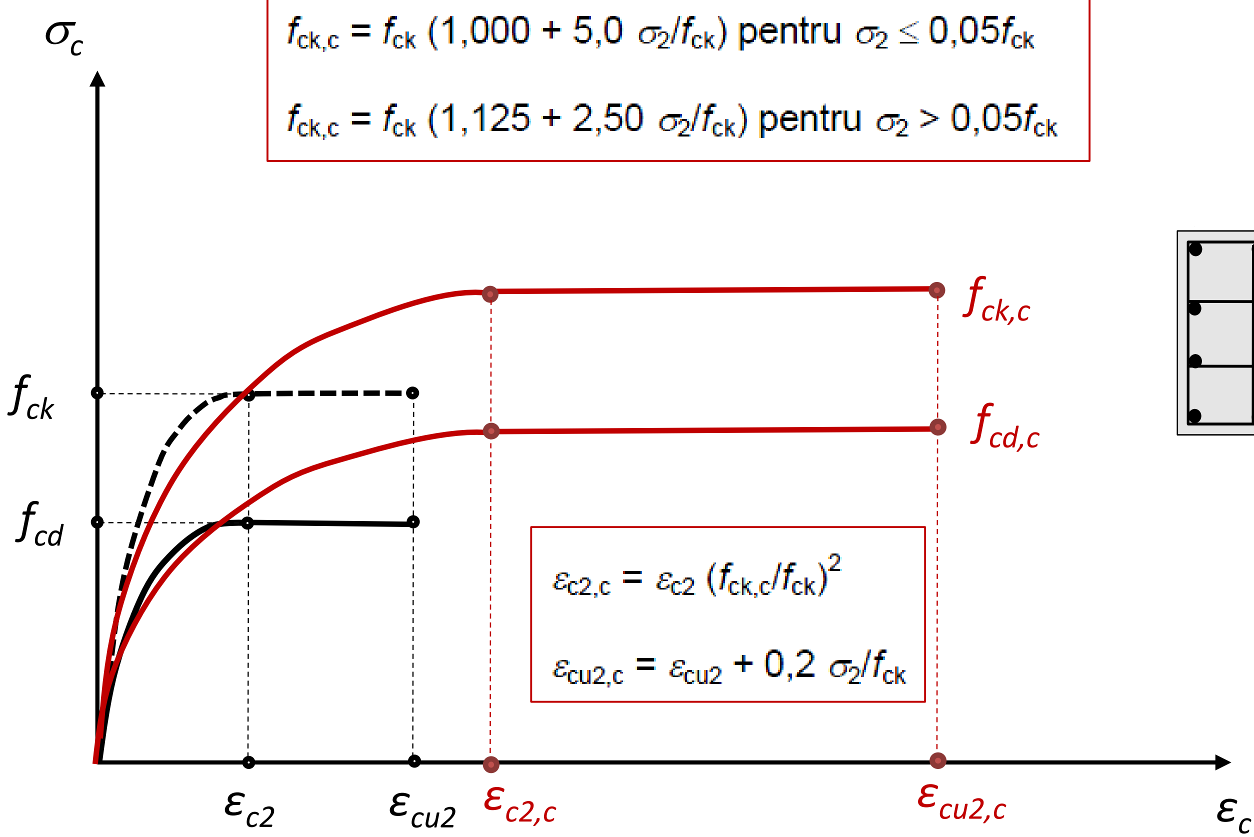
CONFINED CONCRETE

→ increasing compressive strength of concrete by creating **triaxial stress**

→ Increasing the characteristic compressive stresses to $f_{ck,c}$ and the deformations to $\varepsilon_{cu2,c}$

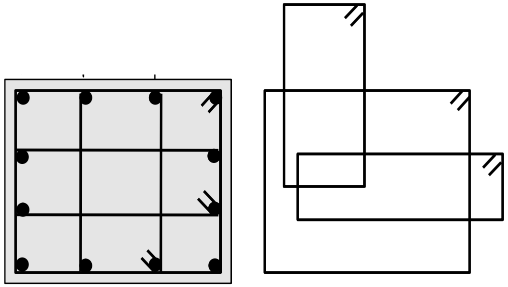
$$f_{ck,c} = f_{ck}\,(1{,}000 + 5{,}0\,\sigma_2/f_{ck}) \text{ pentru } \sigma_2 \leq 0{,}05 f_{ck}$$

$$f_{ck,c} = f_{ck}\,(1{,}125 + 2{,}50\,\sigma_2/f_{ck}) \text{ pentru } \sigma_2 > 0{,}05 f_{ck}$$



$$\varepsilon_{c2,c} = \varepsilon_{c2}\,(f_{ck,c}/f_{ck})^2$$

$$\varepsilon_{cu2,c} = \varepsilon_{cu2} + 0{,}2\,\sigma_2/f_{ck}$$



$\sigma_2 = \sigma_3$ – compressive stresses, perpendicular to element axis

6.1 DESIGN CHARACTERISTICS OF CONCRETE

6.2 DESIGN CHARACTERISTICS OF STEEL REINFORCEMENT

PERFORMANCE CRITERIA FOR STEEL REINFORCEMENTS

Strength criteria:

- Characteristic yield strength f_{yk} or $f_{0,2k}$

- Upper limit of the strength $\boldsymbol{f_{y,max} \leq 1,3\, f_{yk}}$

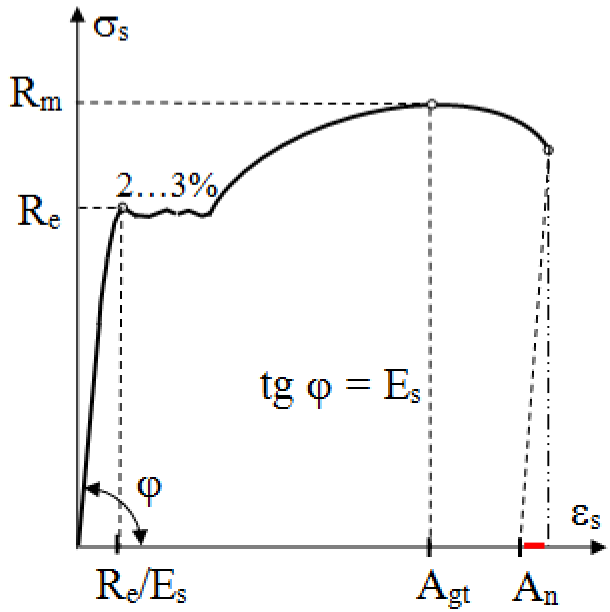
- Characteristic tensile strength (f_{tk})

- Fatigue

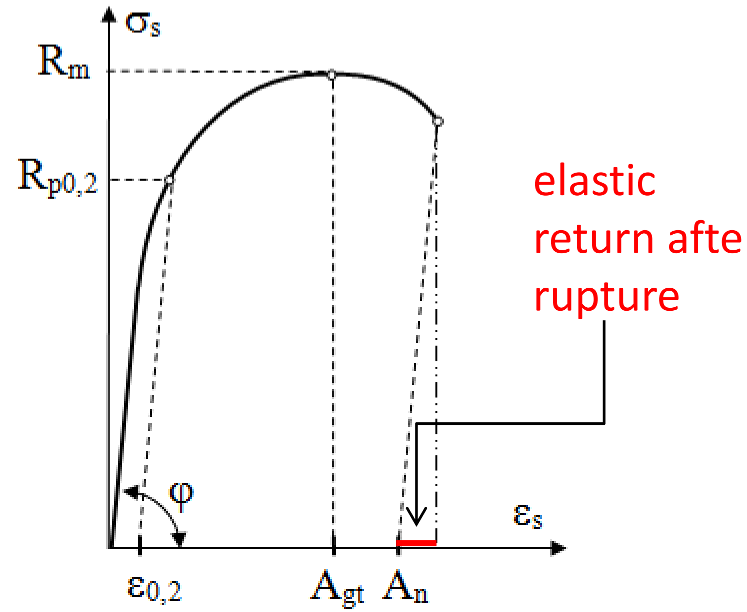
Steel / Oțelul

PERFORMANCE CRITERIA FOR STEEL REINFORCEMENTS

Symbols according to the technical specification ST009-2011 & steel producers



Hot rolled steel



Cold worked steel

Re – natural yield strength → $\mathbf{f_{yk}}$ ← $R_{p0,2}$ – conventional yield strength

R_m – tensile strength → $\mathbf{f_t}$

A_{gt} – total elongation corresponding to maximum force

A_n – elongation after rupture (plastic deformation)

Note: is not acceptable to have $A_n < A_{gt}$ (ductility problem)

PERFORMANCE CRITERIA FOR STEEL REINFORCEMENTS

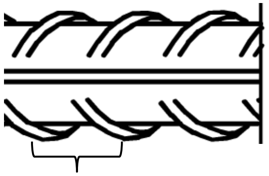
Ductility criteria:

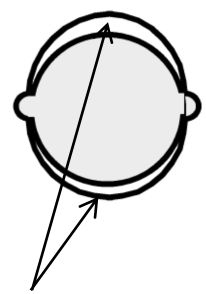
- characteristic value of $k = (f_t/f_y)_k$

- characteristic value of ε_{uk}

- resistance to bending-unbending and weldability

- rib factor (bond) $f_R = A_R/(\pi d_{nom} s)$





Φ	f_{Rmin}
5…6	0.035
6.5…12	0.040
>12	0.056

where s = rib distance

A_R = relative rib area

$f_R \geq f_{Rmin}$ → for high bond strength steel

$f_R < f_{Rmin}$ → for plain bars

Steel / Oțelul

PERFORMANCE CRITERIA FOR STEEL REINFORCEMENTS

Fatigue

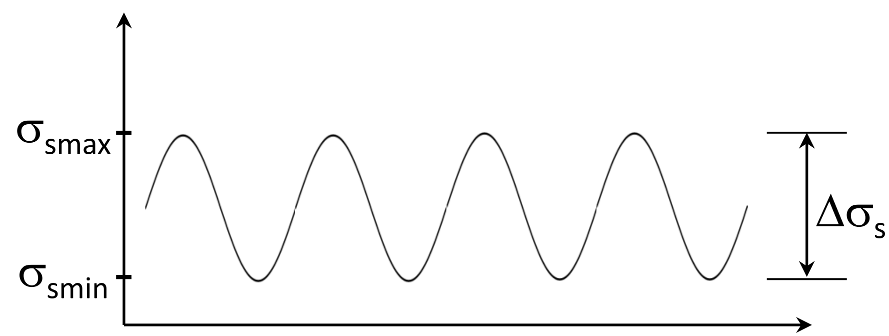
→Dynamic cycles leads to decreasing of strength

→Dynamic cycles may be characterized by:

- Coefficient of asymmetry $\rho = \frac{\sigma_{smin}}{\sigma_{smax}}$

- Amplitude (range of stress) $\Delta\sigma_s = \sigma_{smax} - \sigma_{smin}$

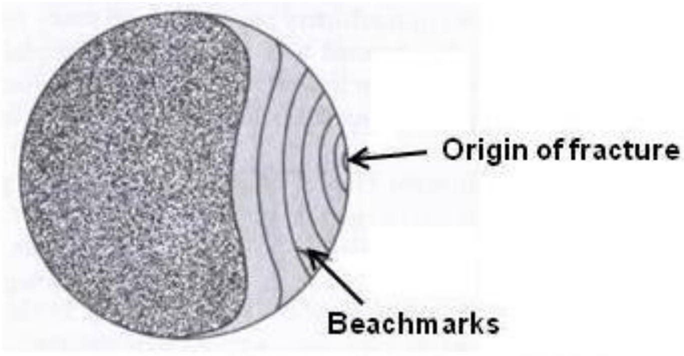
Product form		Bars and de-coiled rods			Wire Fabrics		
Class		A	B	C	A	B	C
Fatigue stress range (MPa) (for $N \geq 2 \times 10^6$ cycles) with an upper limit of βf_{yk}		≥150			≥100		
Bond: Minimum relative rib area, $f_{R,min}$	Nominal bar size (mm)						
	5 - 6	0,035					
	6,5 to 12	0,040					
	> 12	0,056					



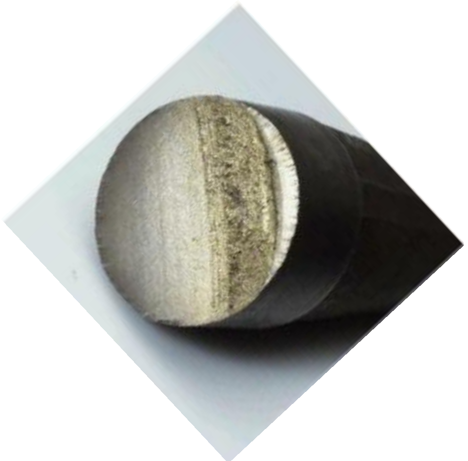
PERFORMANCE CRITERIA FOR STEEL REINFORCEMENTS

Fatigue strength depends on:

- range of stress, whatever are σ_{smin} & σ_{smax}
- welds
- steel quality:
  - grade
  - manner of storage (fatigue strength of reinforcement in real elements is smaller with 40 … 70% than in laboratory testings due to local damages, e.g. corrosion, scratches, etc.)



Fatigue Fracture with Beachmarks

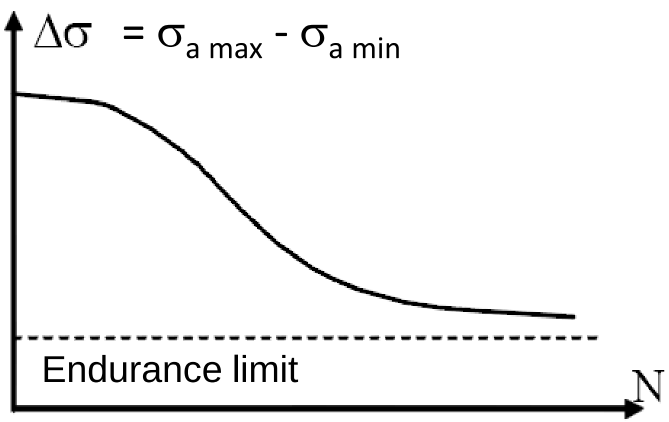


Steel / Oțelul

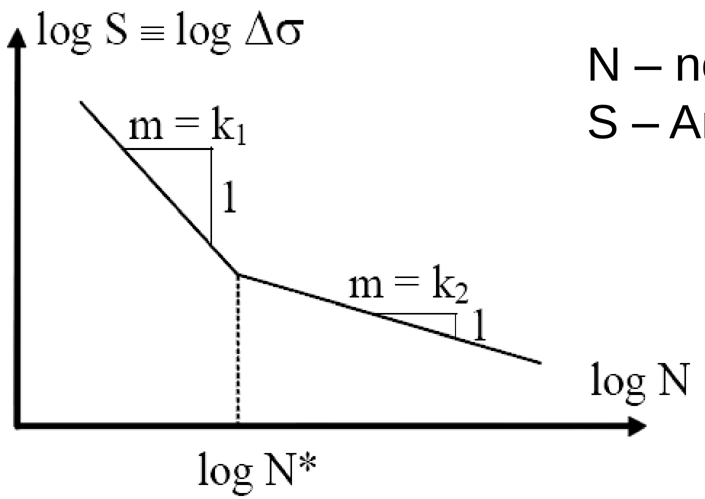
PERFORMANCE CRITERIA FOR STEEL REINFORCEMENTS

Fatigue

Behaviour of steel under fatigue load:



Wöhler diagram
→ real behaviour



N – no. of cycles
S – Amplitude

S-N curve
→ in codes

When $\Delta\sigma$ does not exceed a certain value, called limit amplitude or endurance limit, the material will resist unlimited in time during the N loading / unloading cycles.

PERFORMANCE CRITERIA FOR STEEL REINFORCEMENTS

Fatigue

Condition for bars & de-coiled rods:

$$\Delta\sigma_{s,max} \leq 70\ MPa$$

PERFORMANCE CRITERIA FOR STEEL REINFORCEMENTS

Other criteria:

- Ability to be bent
- Bond characteristics (f_R)
- Sectional dimensions and tolerances
- Fatigue strength with upper limit of βf_{yk} *for* N ≥ 2x10^6 cycles
- Weldability
- Shear strength (at least 0.3 A f_{yk})
- Weld resistance for welded fabrics and cages

Steel / Oțelul

Table C.1: Properties of reinforcement

Product form	Bars and de-coiled rods			Wire Fabrics			Requirement or quantile value (%)
Class	A	B	C	A	B	C	-
Characteristic yield strength f_{yk} or $f_{0,2k}$ (MPa)	400 to 600						5,0
Minimum value of $k = (f_t/f_y)_k$	≥1,05	≥1,08	≥1,15 <1,35	≥1,05	≥1,08	≥1,15 <1,35	10,0
Characteristic strain at maximum force, ε_{uk} (%)	≥2,5	≥5,0	≥7,5	≥2,5	≥5,0	≥7,5	10,0
Bendability	Bend/Rebend test			-			
Shear strength	-			0,3 A f_{yk} (A is area of wire)			Minimum
Maximum deviation from nominal mass (individual bar or wire) (%) — Nominal bar size (mm): ≤ 8 > 8	± 6,0 ± 4,5						5,0

Steel / Oțelul

Products used as reinforcement in Romania

Commercial denomination	Equivalent denomination	Nominal diameter (mm)	Minimal characteristic values		
			Yielding limit f_{yk} [Mpa]	Tensile strength f_{tk} [Mpa]	Elongation at failure A_5 [%]
OB37	S255	6…12	255	360	25
	S235	14…40	235		
PC52	S355	6…14	355	510	20
	S345	16…28	345		
	S335	32…40	335		
PC60	S420	6…12	420	590	16
	S405	14…28	405		
	S395	32…40	395		

low quality steel

Steel / Oțelul

Modulus of elasticity

E_s = 200000 MPa

Density = 7850 kg/m^3

The reference value is characteristic strength steel for strength

$\boldsymbol{f_{yk} = f_y}$ - apparent value of the yield limit

$\boldsymbol{f_{yk} = f_{0,2}}$ - conventional yield strength limit

Design strength of the steel

$$f_{yd} = \frac{f_{yk}}{\gamma_s}$$

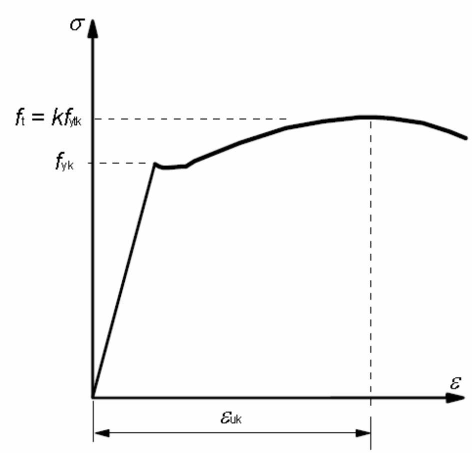
Steel / Oțelul

The reinforcement shall have adequate ductility as defined by the ratio of tensile strength to the yield stress, $(f_t/f_y)_k$ and the elongation at maximum force, ε_{uk}

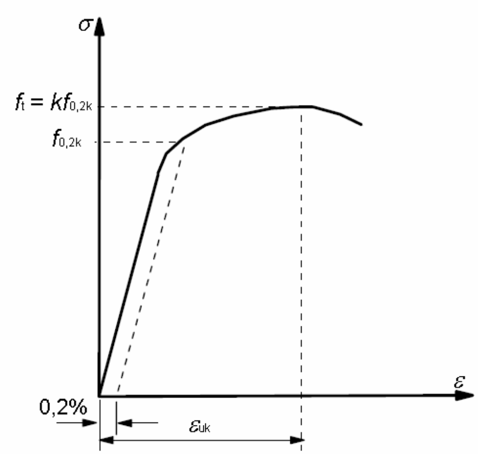
Class A – generally low diameters (< 12mm), used in welded fabrics : *low ductility*

Class B – most commonly used in RC elements: *medium ductility (DCL & DCM)*

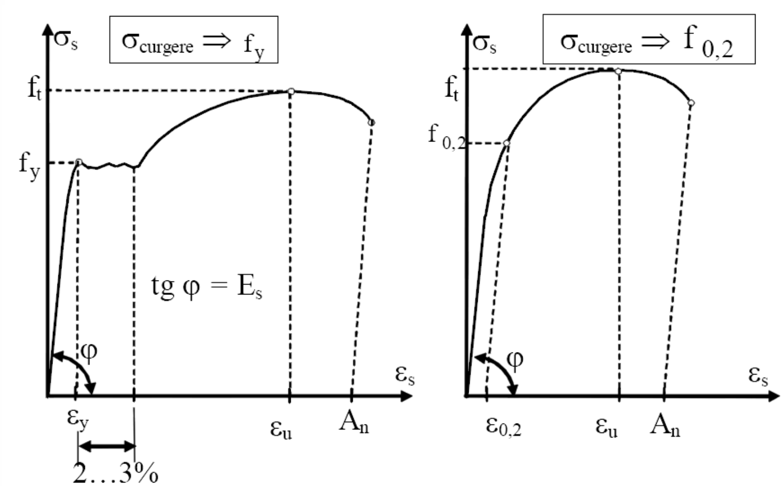
Class C – *high ductility*, used in earthquake resistance structures *(DCH)*



a) Hot rolled steel

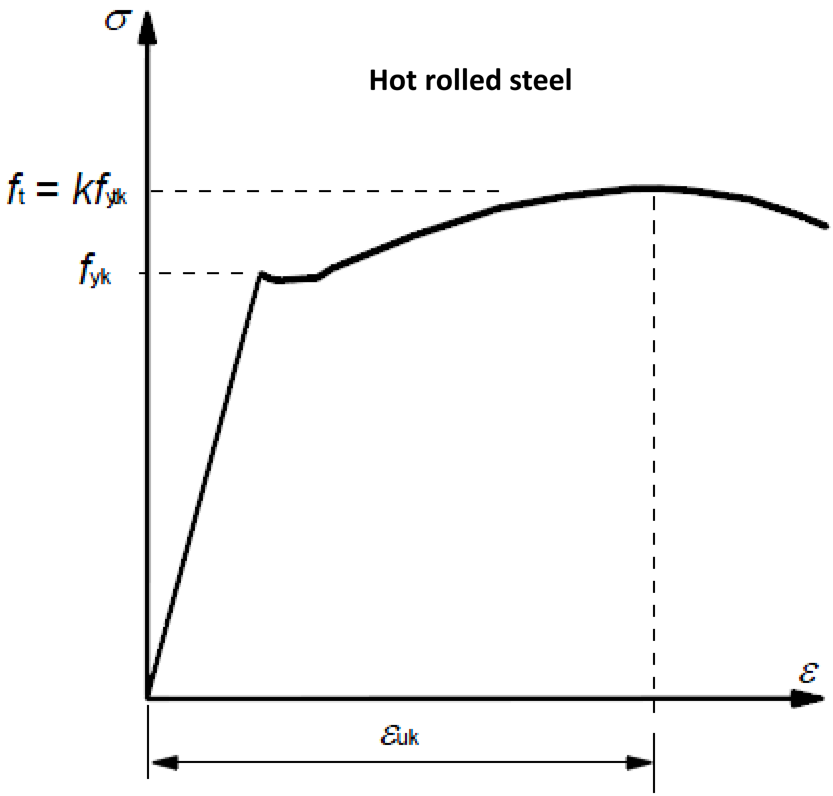


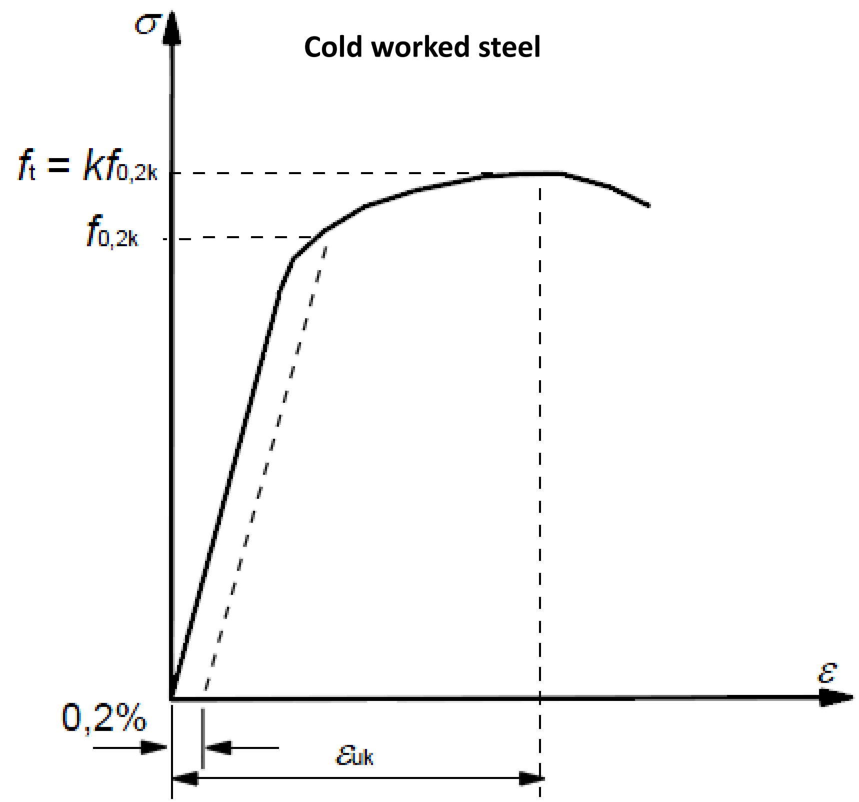
b) Cold worked steel



Steel / Oțelul

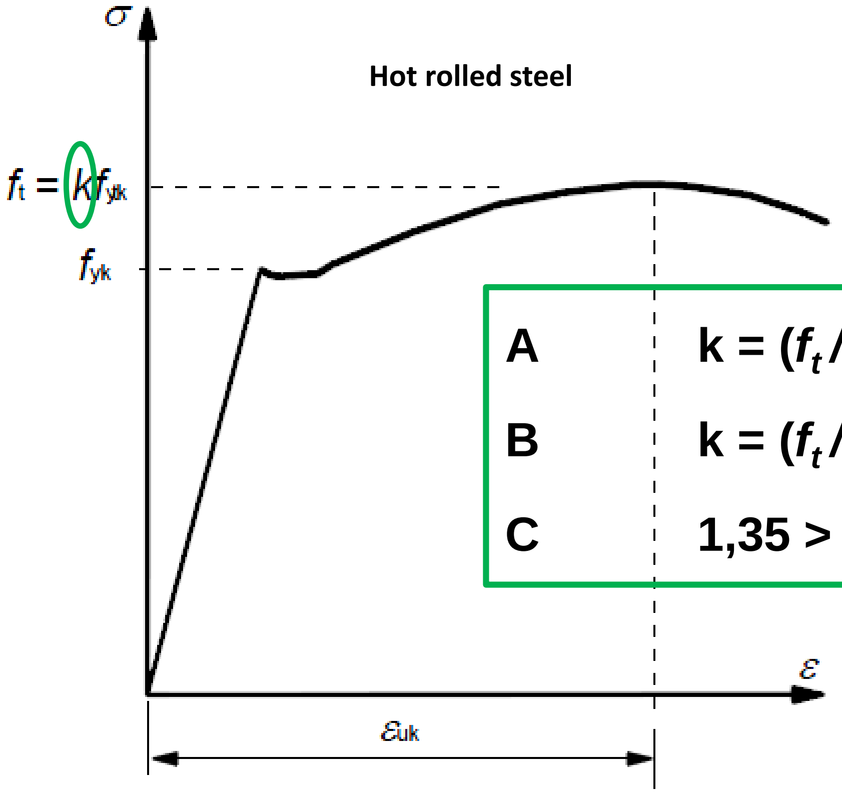
Ductility



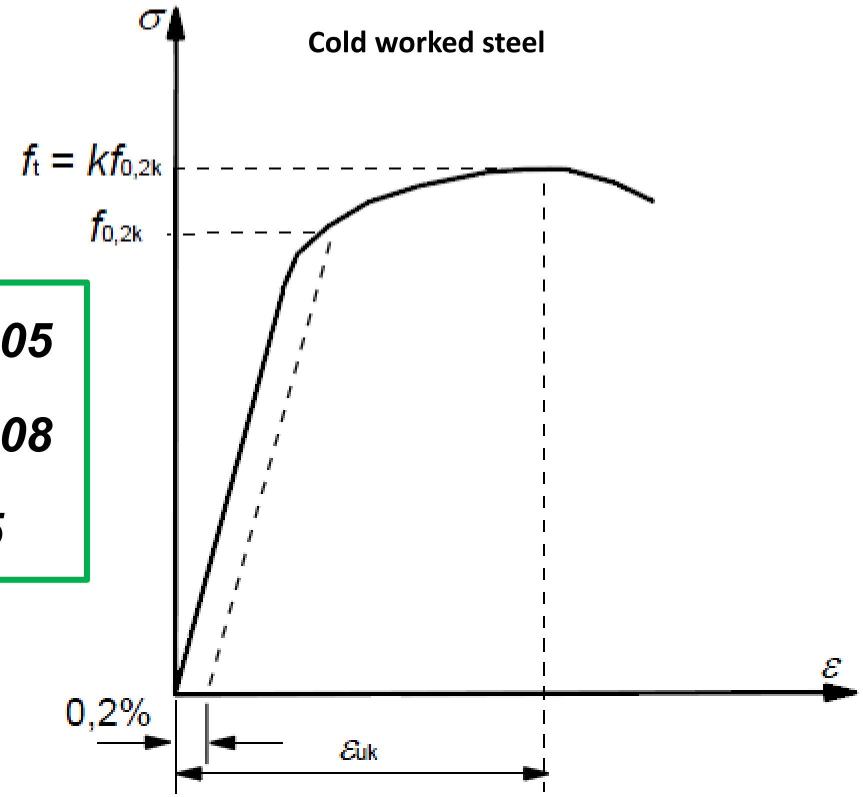


Steel / Oțelul

Ductility

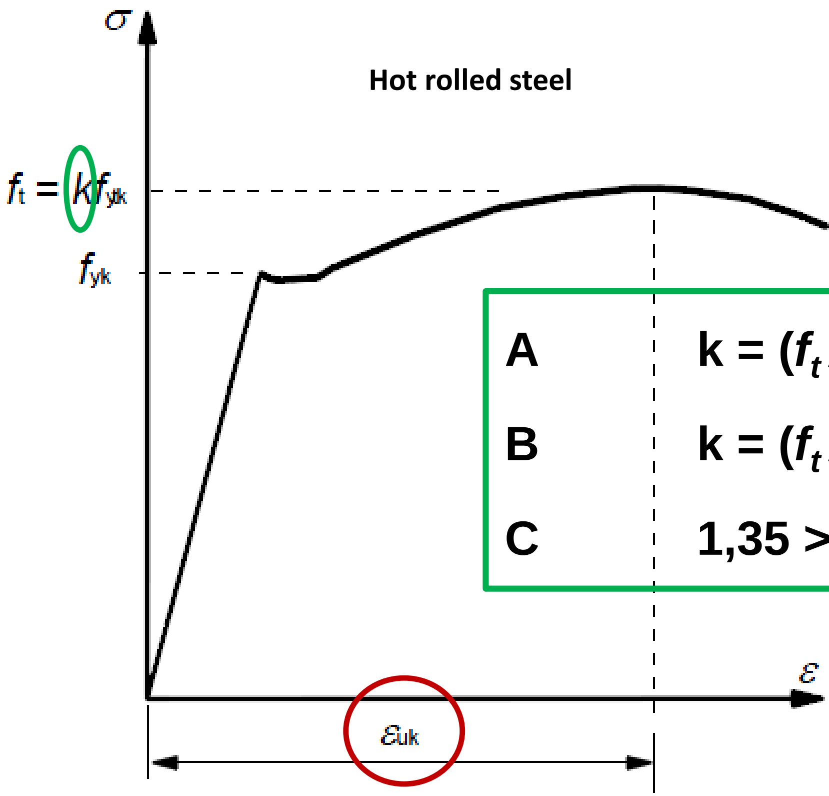


A	$k = (f_t / f_y)_k \geq 1{,}05$
B	$k = (f_t / f_y)_k \geq 1{,}08$
C	$1{,}35 > k \geq 1{,}15$

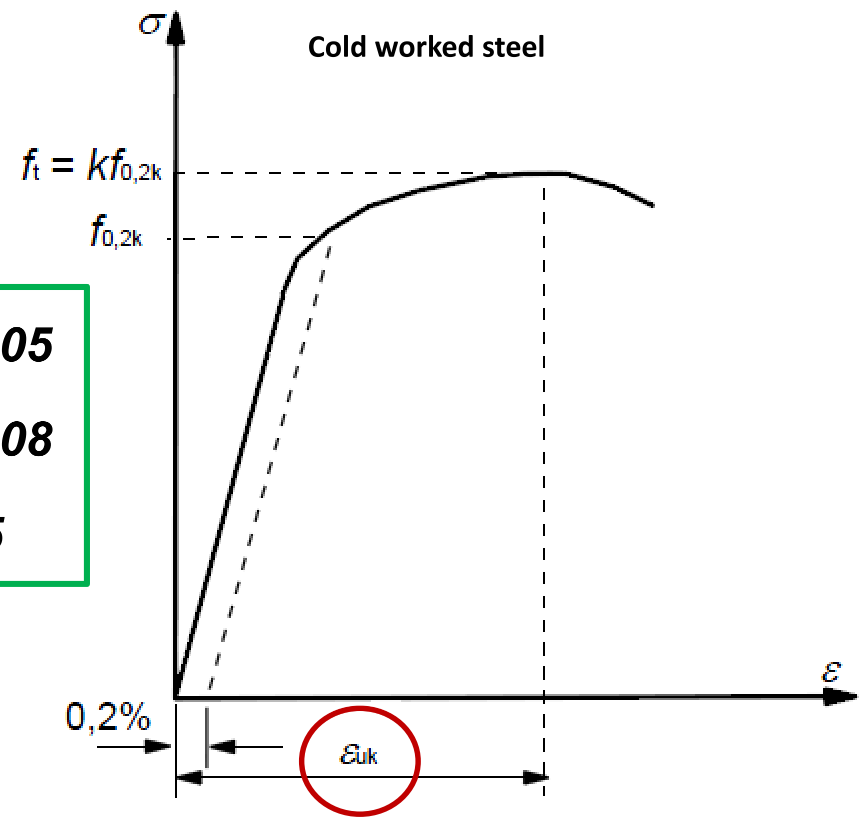


Steel / Oțelul

Ductility



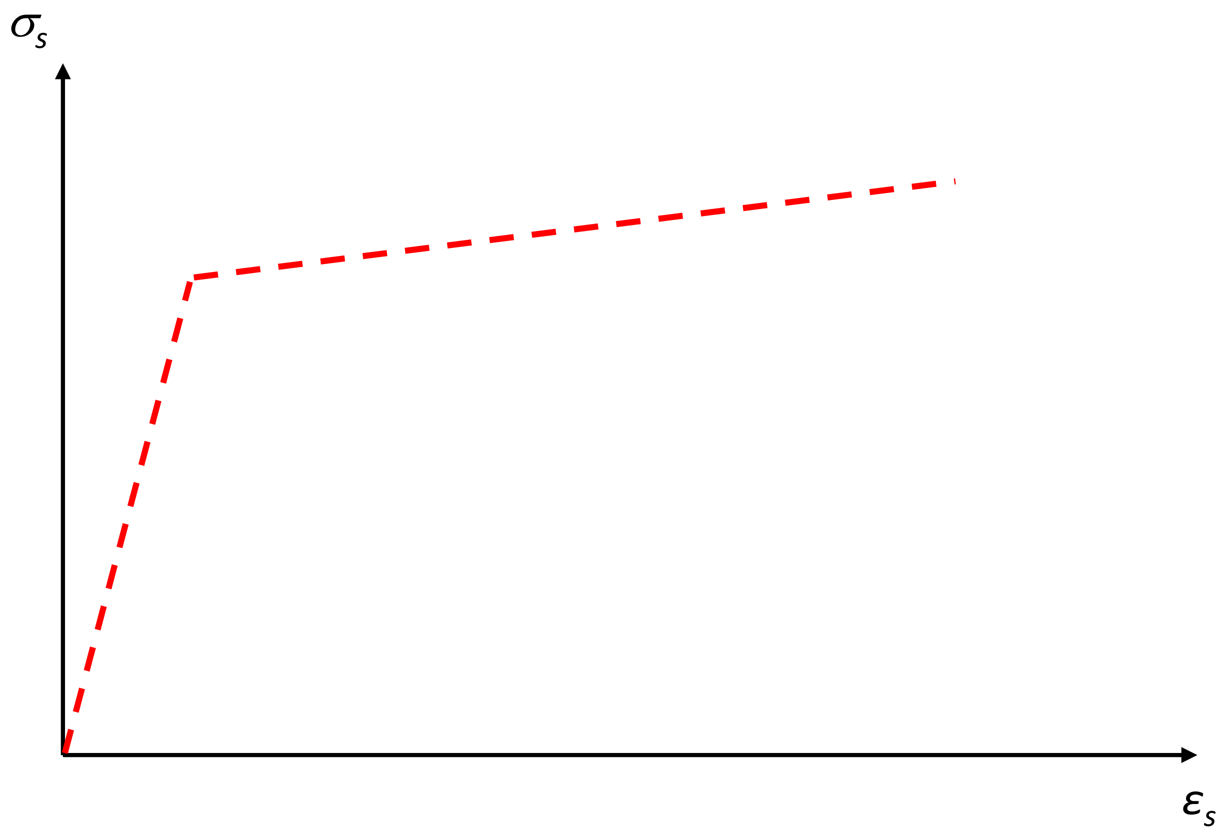
A	$k = (f_t / f_y)_k \geq 1,05$
B	$k = (f_t / f_y)_k \geq 1,08$
C	$1,35 > k \geq 1,15$



A	B	C
$\varepsilon_{ck} \geq 25‰$	$\varepsilon_{ck} \geq 50‰$	$\varepsilon_{ck} \geq 75‰$

Steel / Oțelul

DESIGN DATA FOR REINFORCING STEEL



Steel / Oțelul

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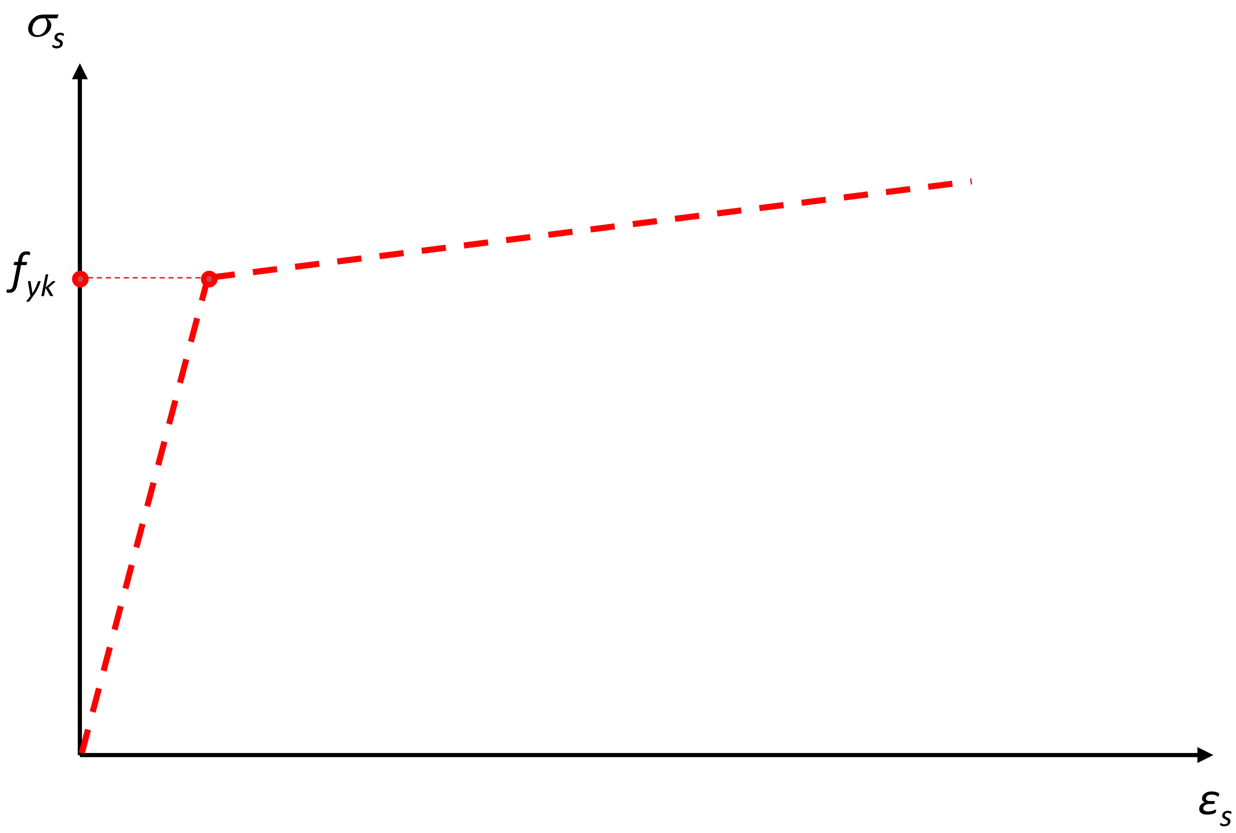
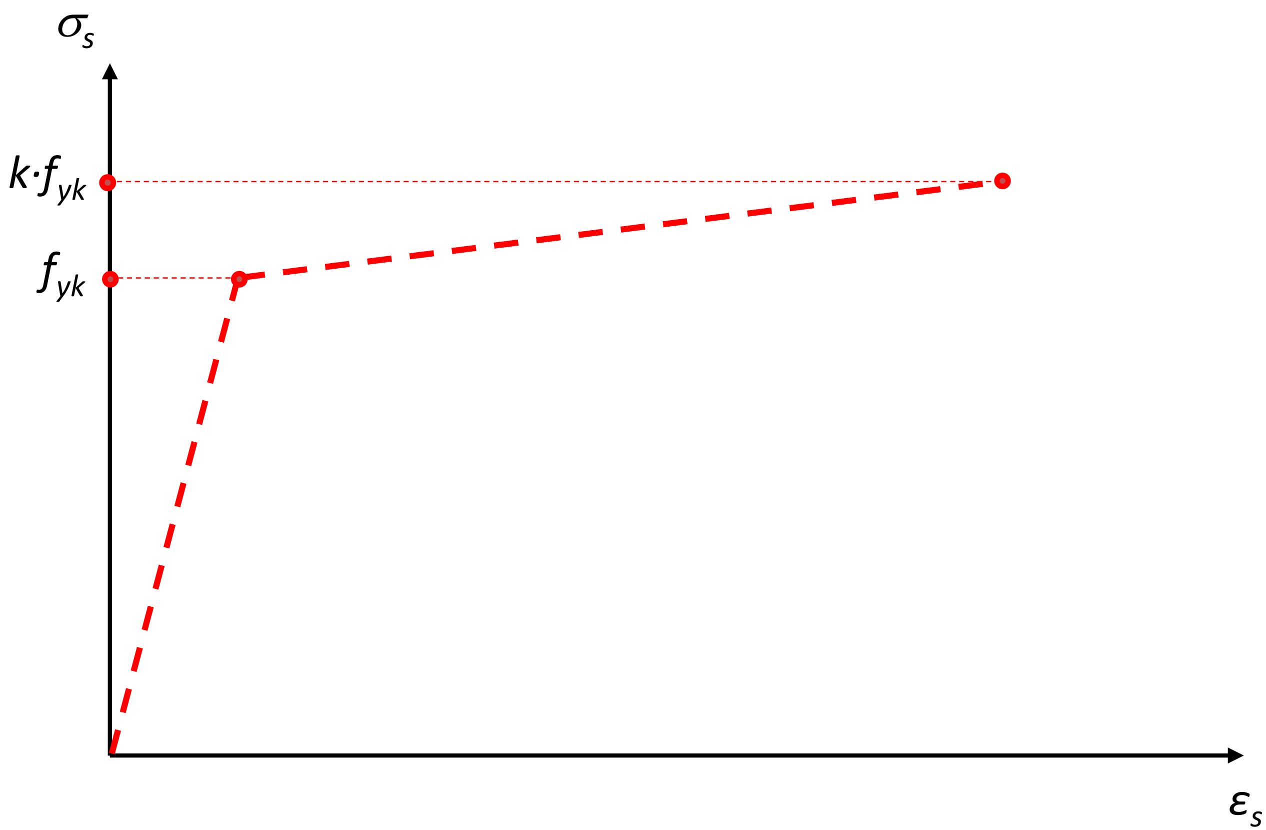


Steel / Oțelul

DESIGN DATA FOR REINFORCING STEEL



Steel / Oțelul

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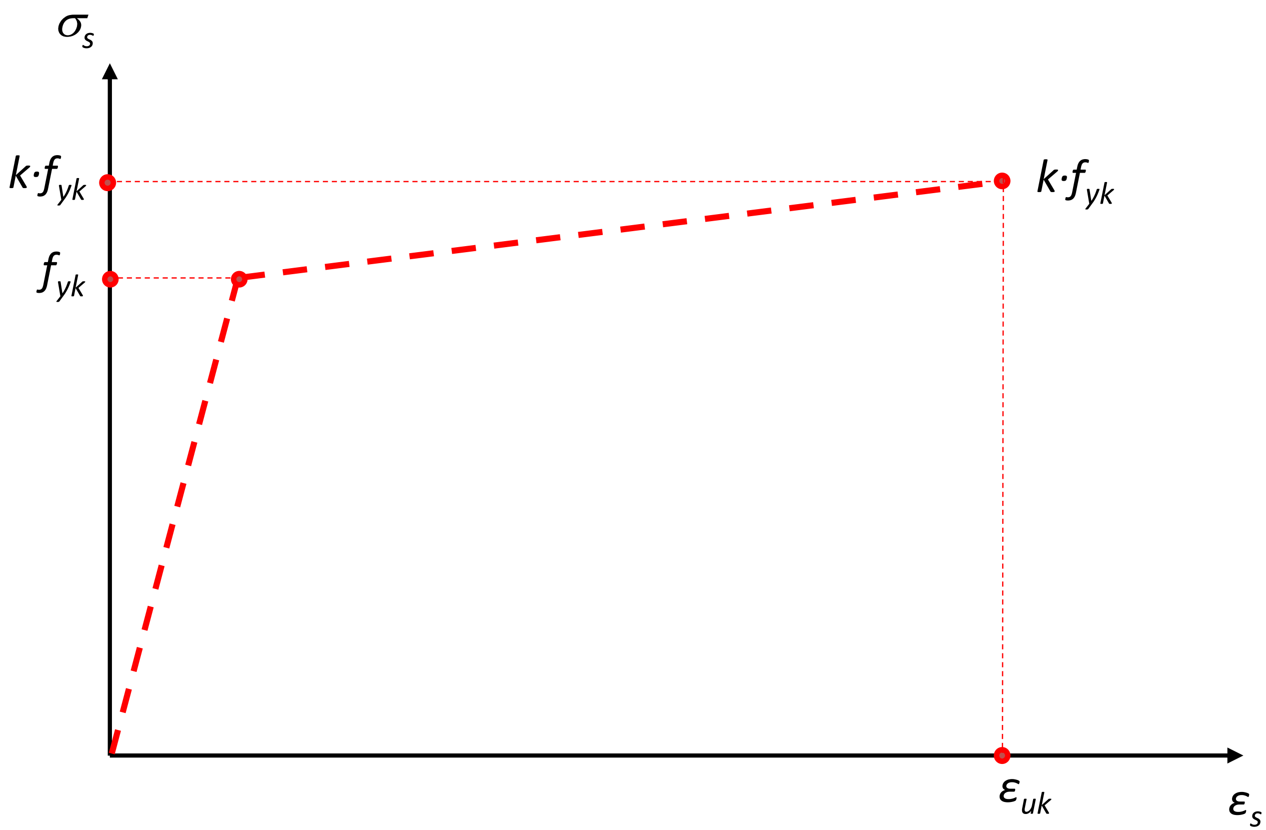

Steel / Oțelul

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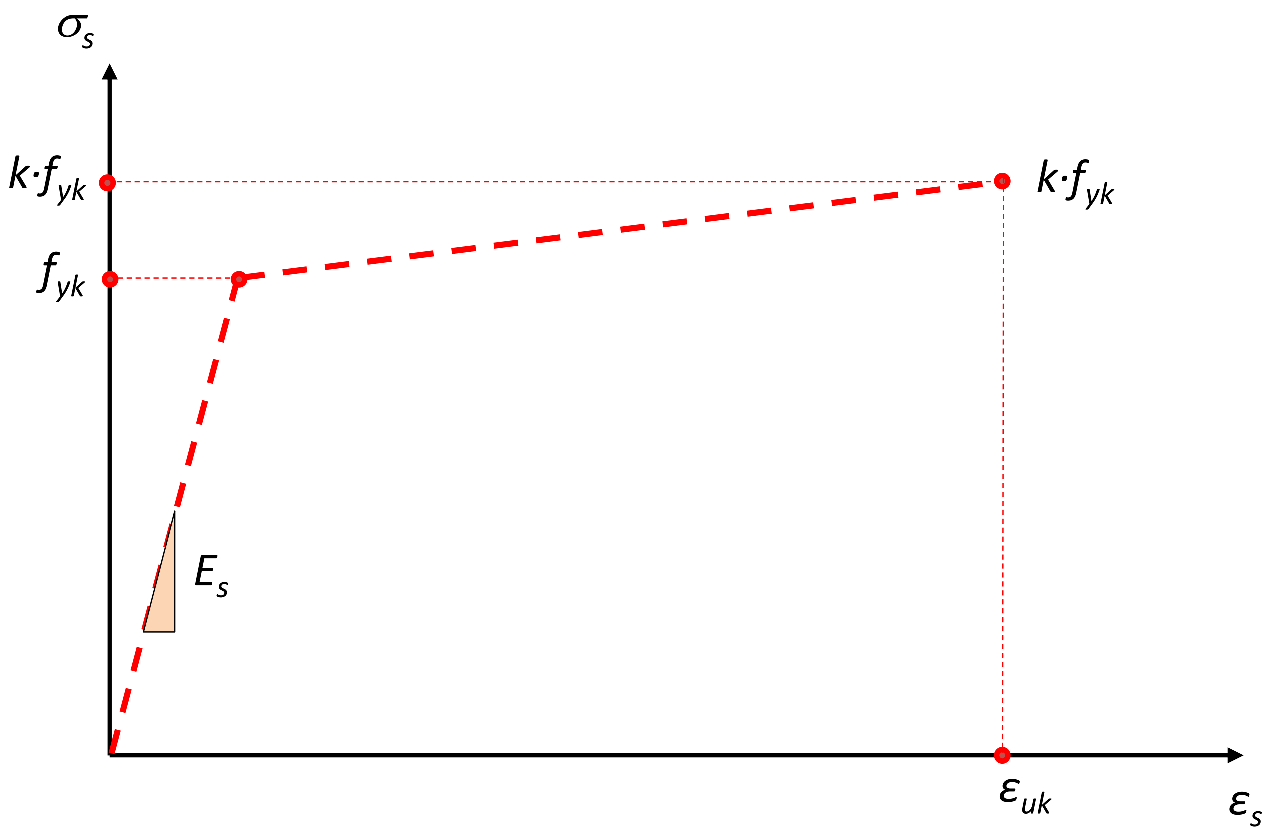

Steel / Oțelul

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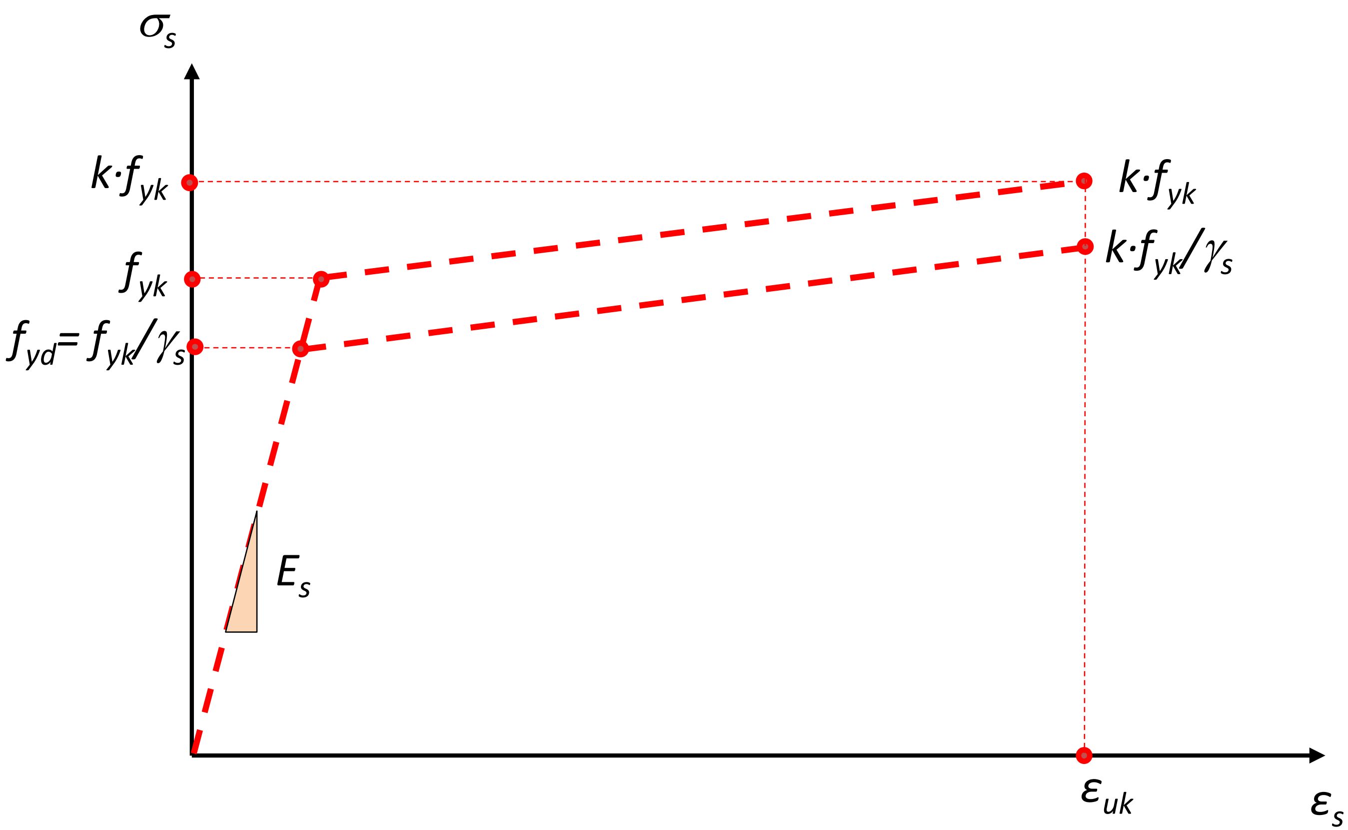

Steel / Oțelul

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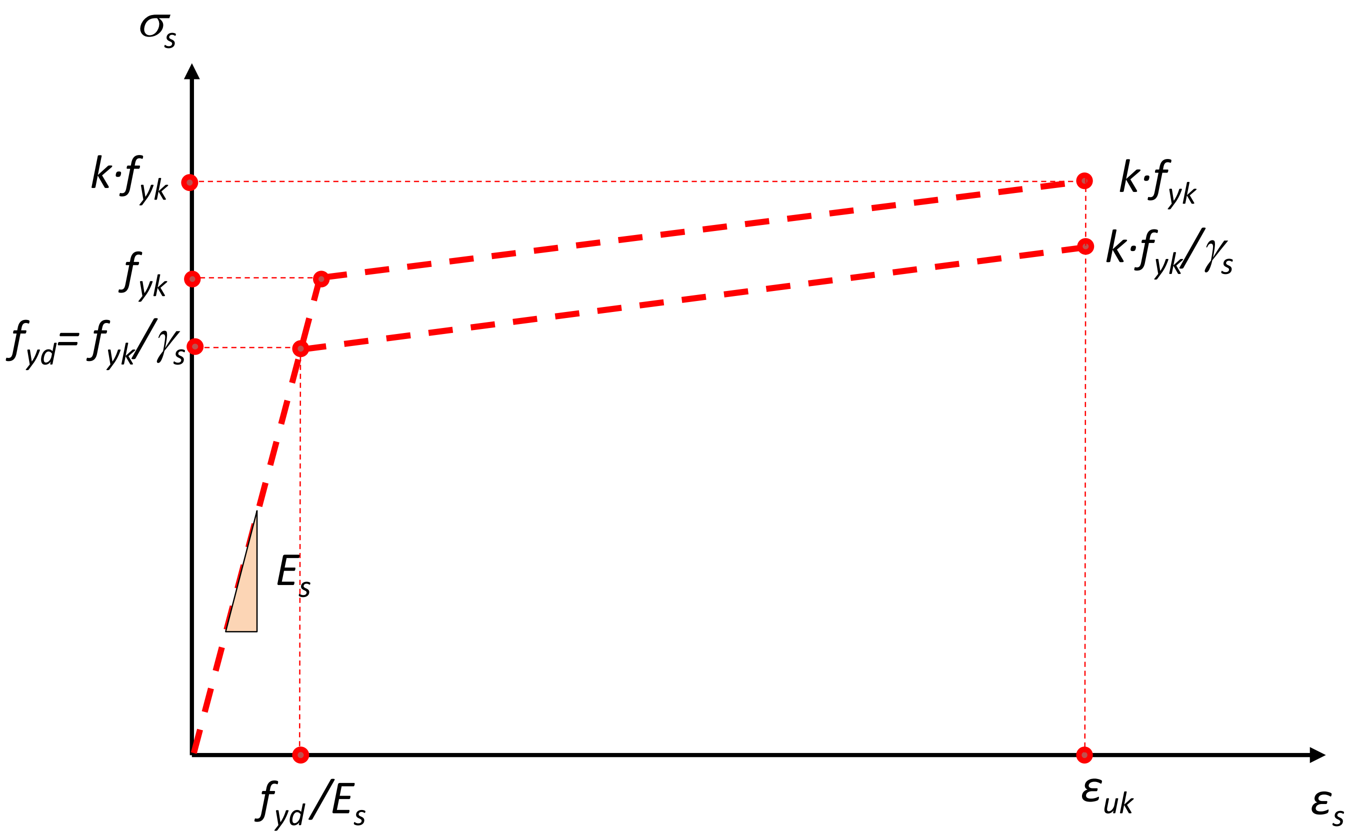

Steel / Oțelul

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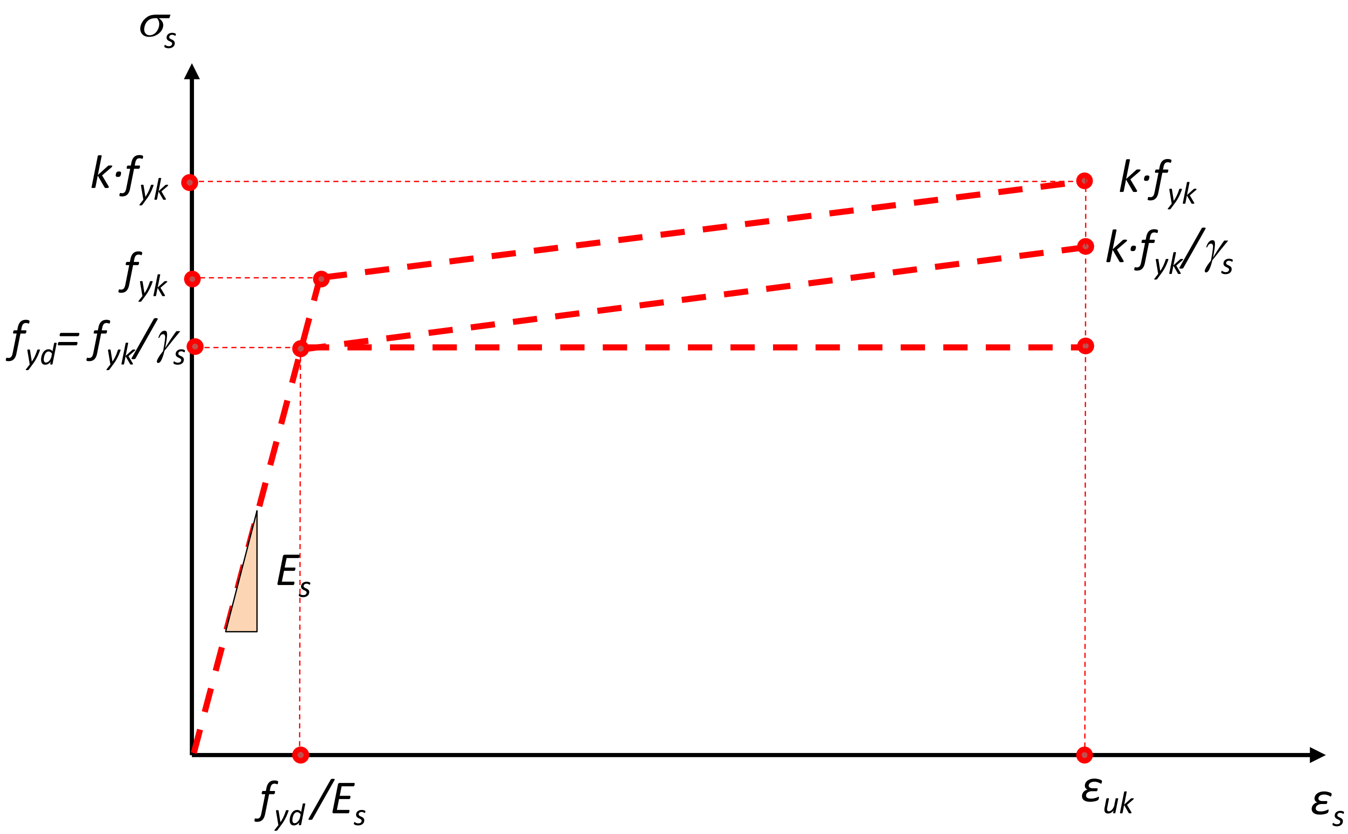

Steel / Oțelul

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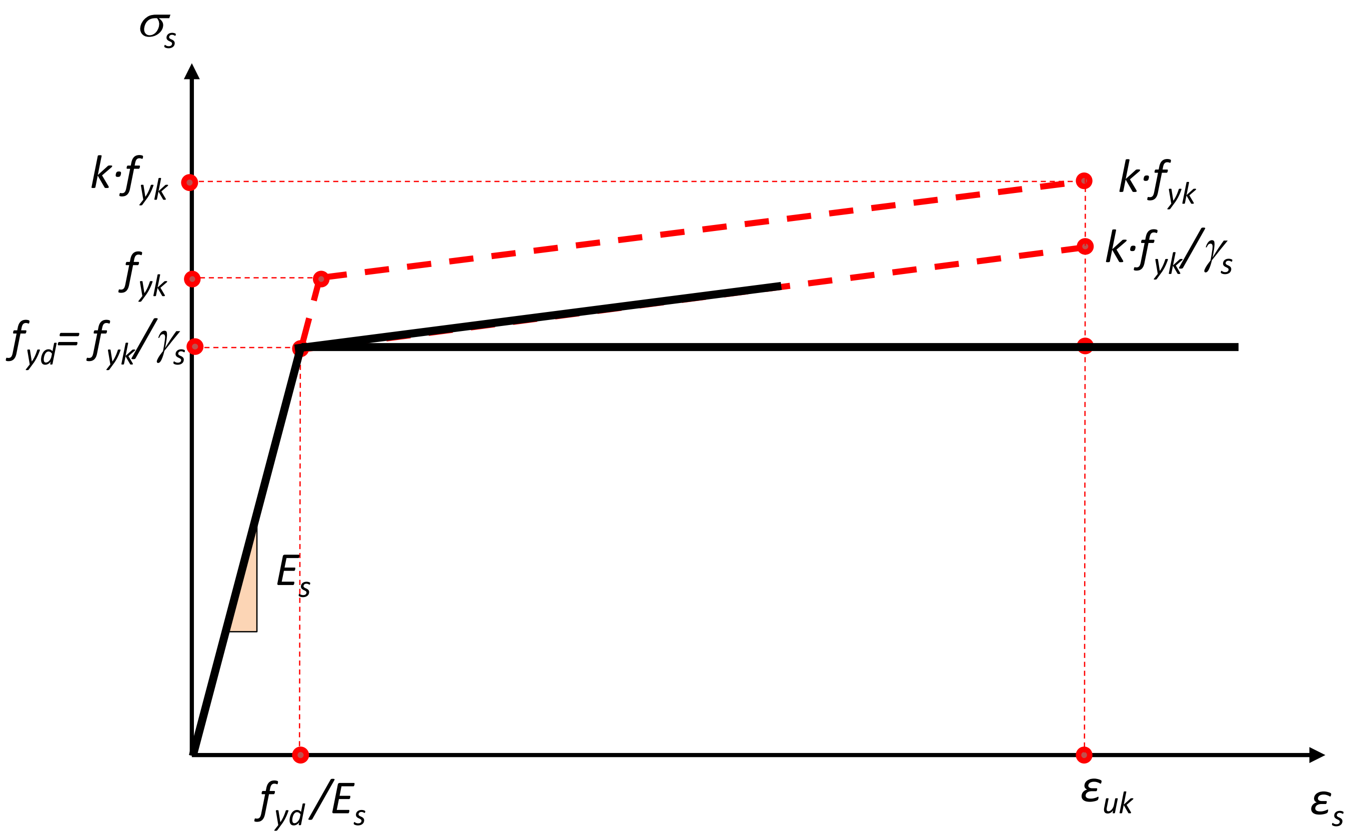
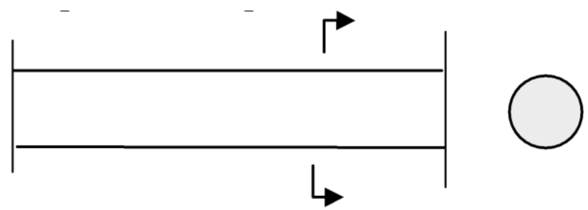


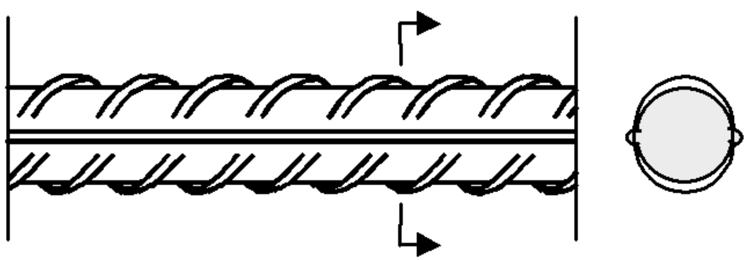
Steel / Oțelul

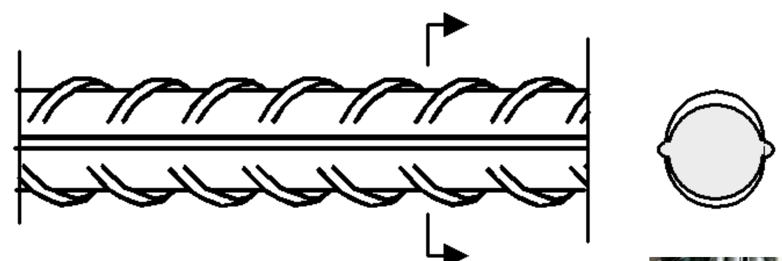
ROMANIAN PRODUCTS

OB37 → - plain bar used for stirrups and helix or as secondary reinforcement



PC52 and **PC60** → ribbed bars, used as principal reinforcement (structural)





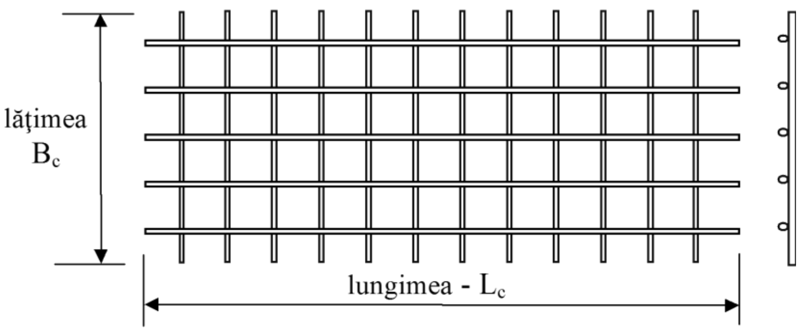
Delivery:

- Coiled for ϕ = 6…12 mm
- Strait bars $\phi \geq$ 14 mm; L = 8(10)…18 m

Steel / Oțelul

ROMANIAN PRODUCTS

STNB cold drawn wire
ϕ = 3…10mm
plain wire used for welded fabrics (STAS 438/3-89)
characteristics - table



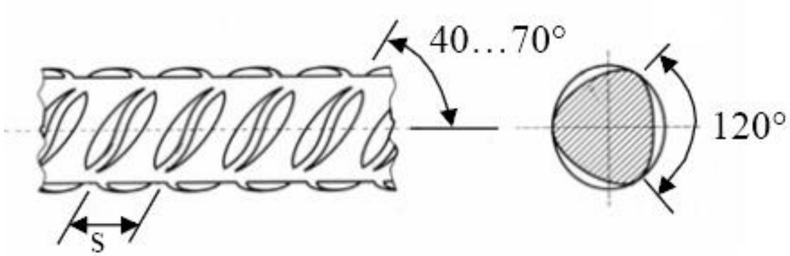
ϕ (mm)	Minimal characteristic values		
	f_{yk} (MPa)	f_{tk} (MPa)	Elongation at failure A_{10} (%)
3,0; 3,5; 4,0	510	610	6
4,5; 5,0; 5,6	460	560	7
6,0; 6,5; 7,1			8
8,0; 9,0; 10,0	400	510	8

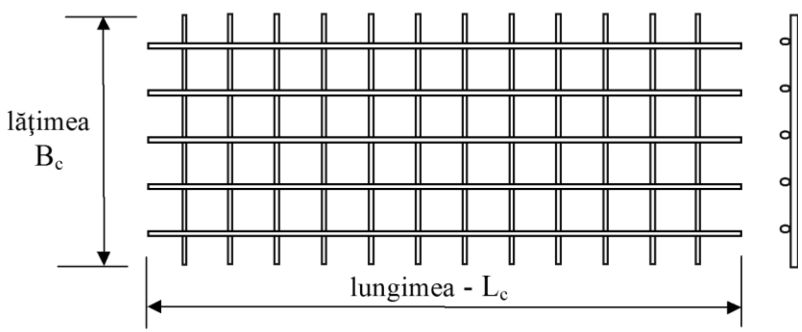
- frequency of use: G-high; L-medium; S-low
- style: Q – squared grid; R – rectangular grid
- dimension: 6,0 x 2,45 m

Steel / Oțelul

ROMANIAN PRODUCTS

SPPB indented wire by plastic deformation
ϕ= 4…8 mm
$f_{0,2k}$ = 460 MPa
f_{tk} = 510 MPa
used for welded fabrics; dimensions by the producer





CLASSIFICATION OF THE ROMANIAN PRODUCTS

- Steel **PC60** satisfies both criteria of strength and ductility

- Steel **OB37** and **PC52** **don't satisfy** requirements of yielding limit strength

$$f_{y,max} < 400\ MPa$$

- **Ductility** is satisfied for all the laminated rebars, the ratio $k = f_t / f_{yk}$ = 1,4…1,5

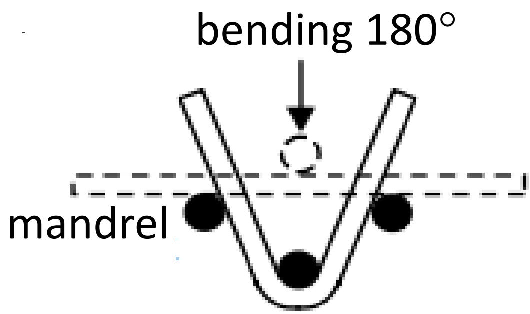
- Elongation at maximum force has higher values than those prescribed

- Delivery:
    - Coiled for ϕ = 6…12 mm
    - Strait bars $\phi \geq$ 14 mm; L = 8(10)…18 m

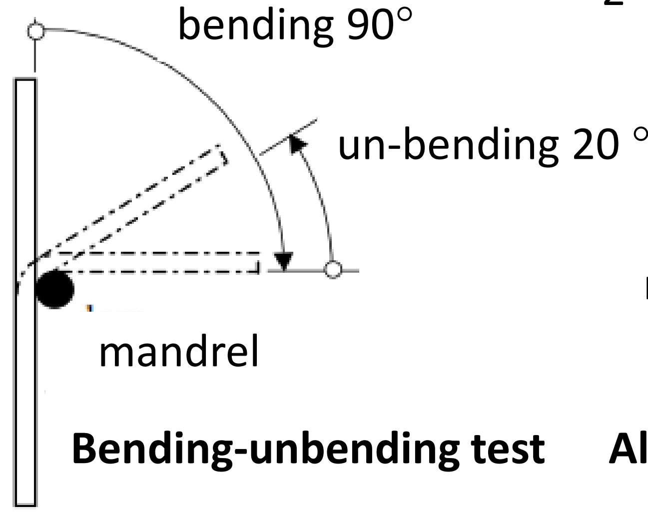
Steel / Oțelul

TESTS FOR BARS

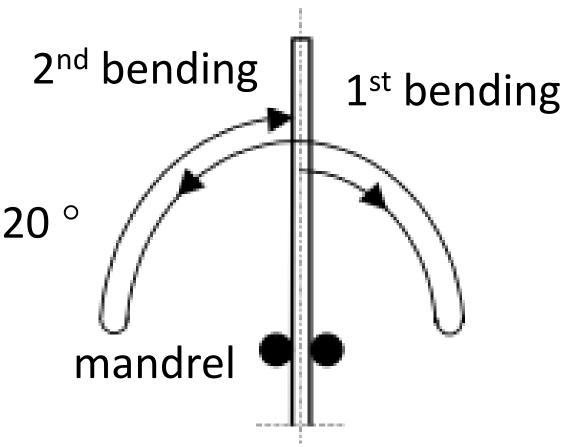
Tension test



Bending test

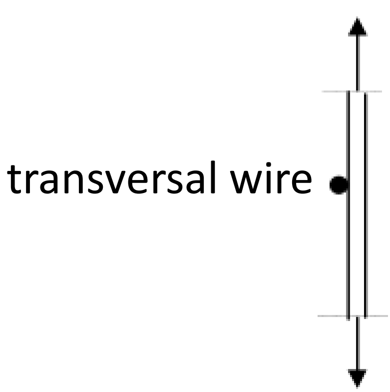


Bending-unbending test

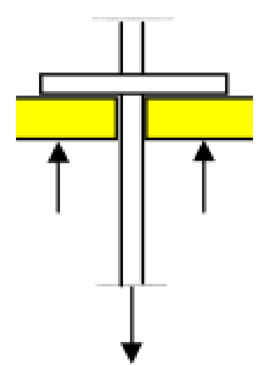


Alternated bending test

TESTS FOR FABRICS

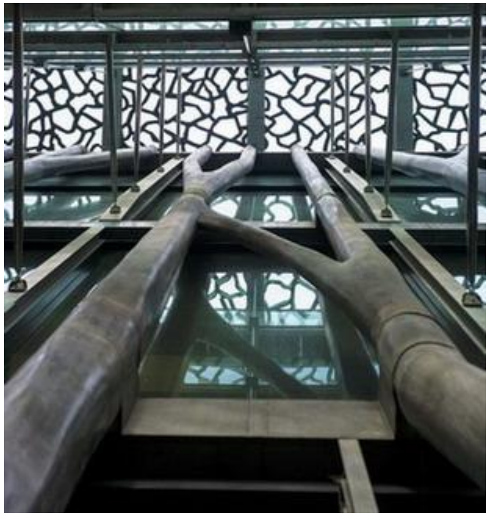


Testing the wire



Testing the weld

THANK YOU FOR YOUR ATTENTION!



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