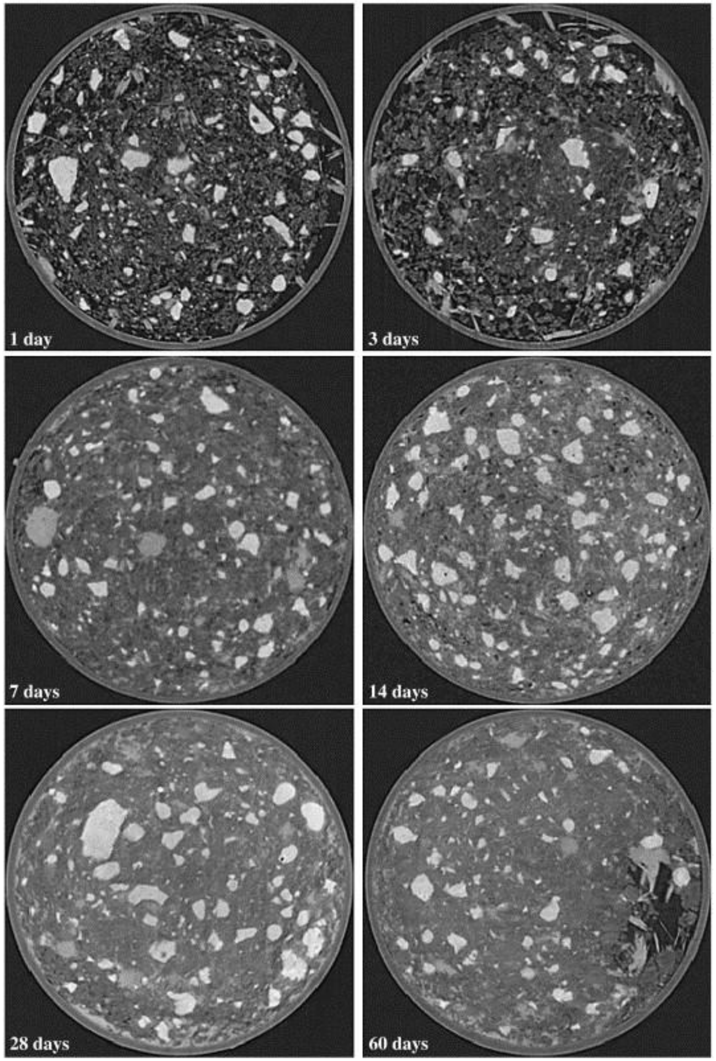

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2.1 CONCRETE STRUCTURE

2.2 TYPES OF CONCERTE

2.3 CONCRETE STRENGTH

2.4 CONCRETE DEFORMATIONS

Structure of Concrete / Structura betonului

Concrete is a composite material composed of:

- aggregates → natural → Gravel pit or quarries
→ artificial → slag / expanded clay/
→ recycled

Gravel pit (balastieră)

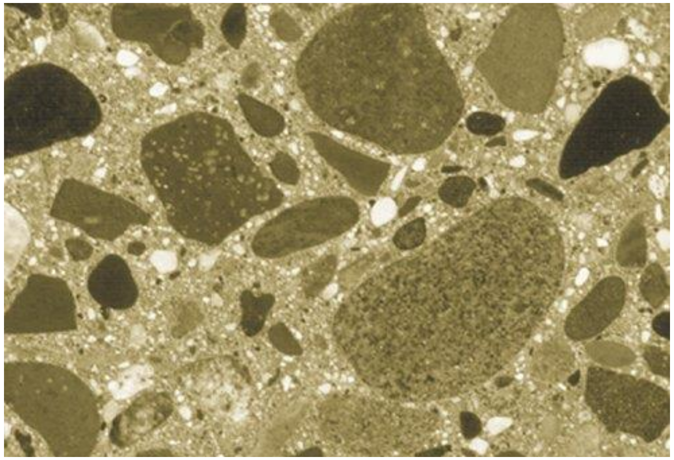
Quarry (carieră)

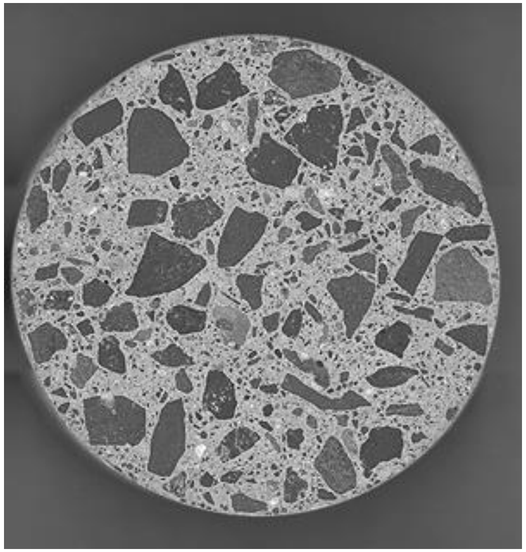
Obs:
- Higher aggregates provides density and strength
- The fine part (sand) fill the gaps between large aggregates and increase the cement binder's strength

Structure of Concrete / Structura betonului

Gravel pit aggregates

quarry aggregates



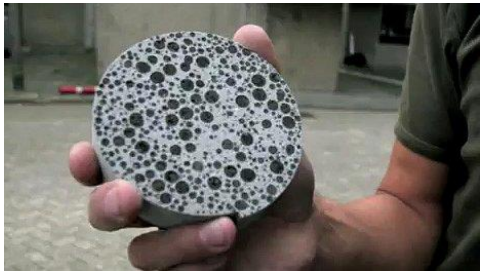


Structure of Concrete / Structura betonului

Concrete is a composite material composed of:

- aggregates → natural → Gravel pit or quarries
→ artificial → slag / expanded clay/ …
→ recycled

slag / expanded clay



aggregate from expanded glass

Structure of Concrete / Structura betonului

Concrete is a composite material composed of:

- aggregates → natural → Gravel pit or quarries
→ artificial → slag / expanded clay/ …
→ recycled

”In Japan, recycling rate of concrete debris was 96% in 2000…”

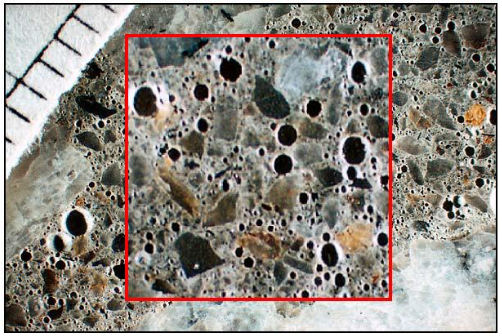
Koji SAKAI, Prof. of Kagawa University, Japan

Structure of Concrete / Structura betonului

Concrete is a composite material composed of:

- cement	→ CEM I	Portland cement (ordinary)
	→ CEM II	Portland composite cement
	→ CEM III	Blast furnace slag cement
	→ CEM IV	Pozzolanic cement
	→ CEM V	Composite cement
	→ H	hydrotechnical cement
	→ SR	sulfate resistant cement
	→ II A	white cement with additives
	→ PR/PG/PV	cement with red/yellow/green color

Structure of Concrete / Structura betonului



Concrete is a composite material composed of:

- water

- **chemical admixtures (aditivi)**
  - → Water-reducing admixtures (strength)
  - → Retarding admixtures (summer)
  - → Accelerating admixtures (winter)
  - → Superplasticizers (consistency)
  - → Corrosion-inhibiting admixtures
  - → for impermeability
  - → air-entraining (microporosity)

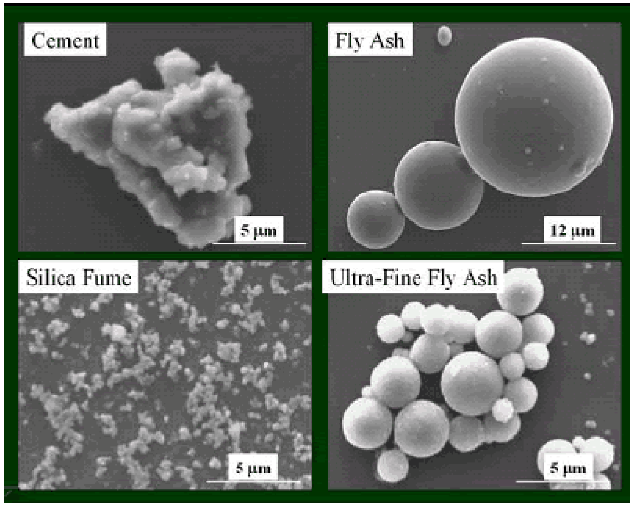
Voids ↗ absorb the pressure created by the expansion of the freezing water

Structure of Concrete / Structura betonului

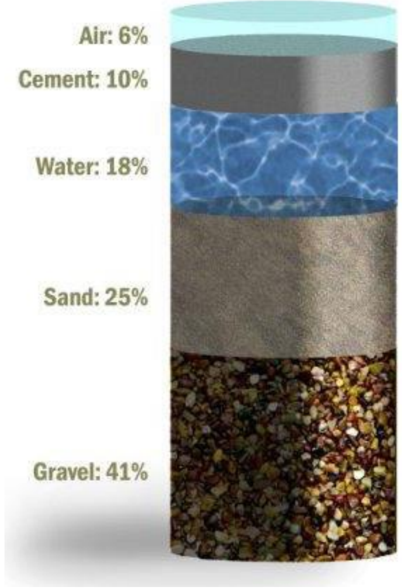
Concrete is a composite material composed of:

- **mineral admixtures (adaosuri)**

→ Granulated blast furnace slag	S
→ Natural pozzolana	P
→ Natural calcined pozzolana	Q
→ Siliceous fly ash	V
→ Calcareous fly ash	W
→ Burnt shale	T
→ Limestone	L, LL
→ Silica fume	D



Structure of Concrete / Structura betonului



Concrete is a composite material composed of:

aggregates
- → natural → Gravel pit or quarries
- → artificial → slag / expanded clay/
- → recycled

cement
- → Portland
- → Portland with admixtures
- → Hydrotehnic
- → Sulphates resistant cement

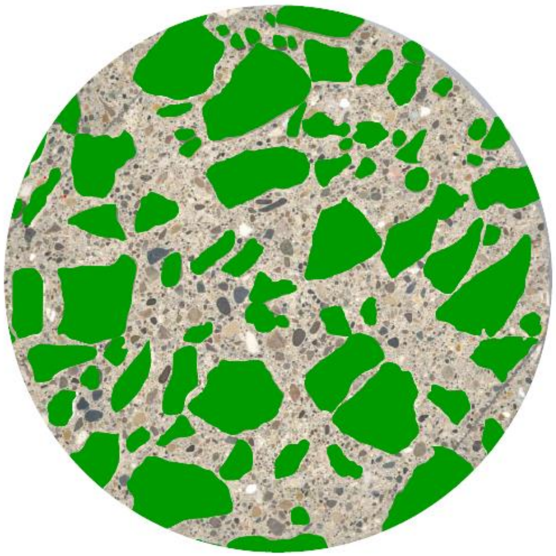
water

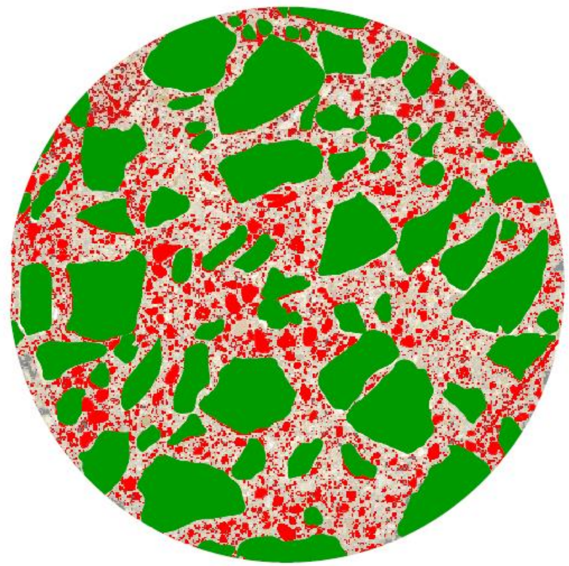
chemical admixtures (aditivi)
- → Water-reducing admixtures (strength)
- → Retarding admixtures (summer)
- → Accelerating admixtures (winter)
- → Superplasticizers (consistency)
- → Corrosion-inhibiting admixtures
- → for impermeability
- → air-entraining (microporosity)

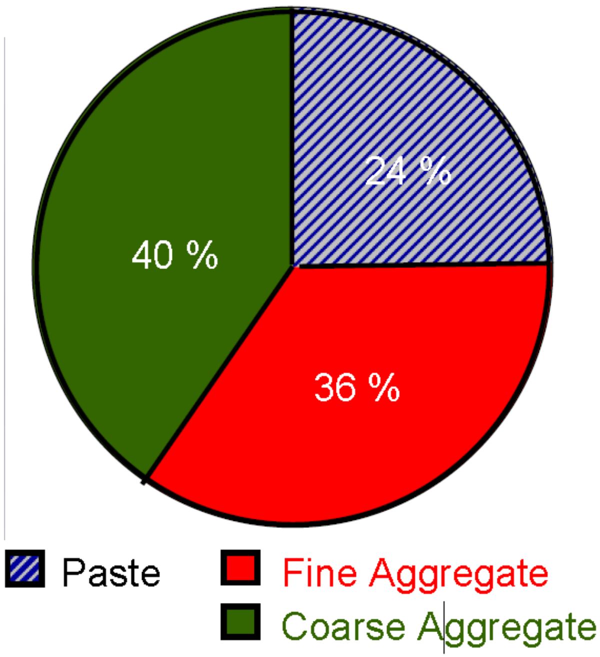
mineral admixtures (adaosuri)
- → Fly ash
- → Silica Fume
- → Ground granulated blast furnace slag
- → Rice husk ash (RHA)
- → Metakaolin

Structure of Concrete / Structura betonului

Cement paste







Coarse Aggregate   Fine Aggregate

70-80 %

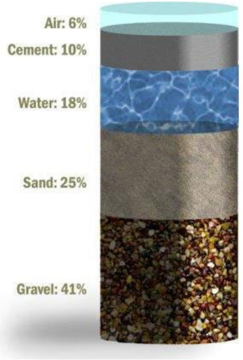
percentage by volume

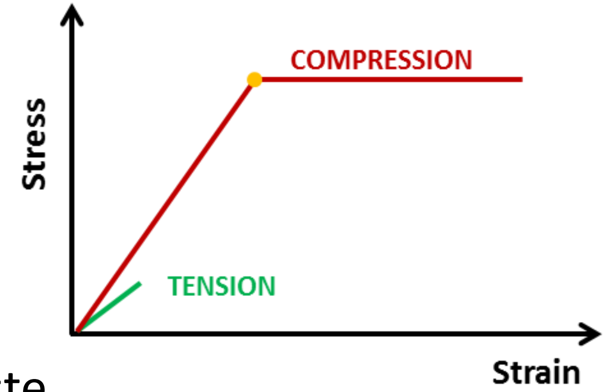
(Weiss J – Purdue University)

Structure of Concrete / Structura betonului

Concrete = biphasic material composed of aggregates embedded in the cement matrix:

- non-homogeneous
- anisotropic
- elasto-plastic material





- **Elasticity:** due to aggregates and hardened cement paste
- **Plasticity:** due to micro-cracking phenomenon
- **Viscosity:** due to uncured cement paste.

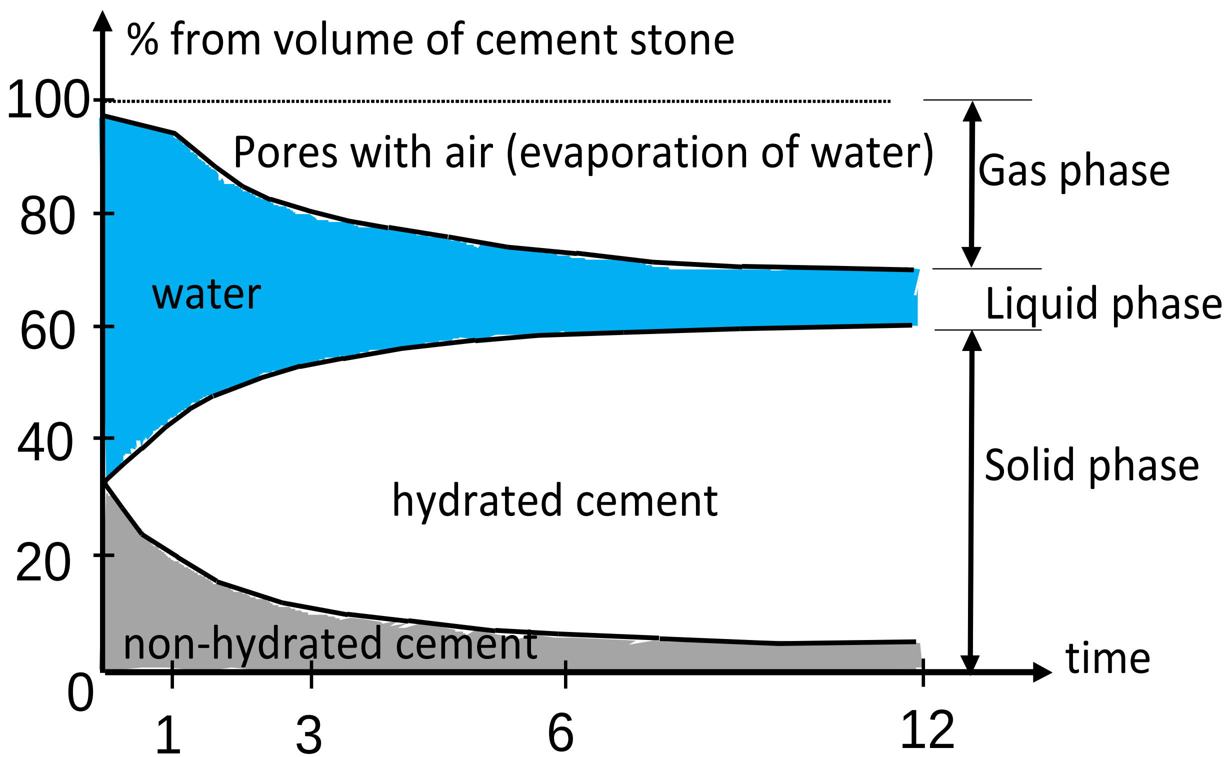
Cement paste = pseudo-solid material, composed of:

1. Hardened cement crystals → **solid phase**
2. Cement gels → **viscous phase**
3. Chemically and physically bound water, free water → **liquid phase**
4. Capillary pores and gel pores that communicate between themselves and with the outside → **gas phase**

Structure of Concrete / Structura betonului

Evolution of the concrete structure in time

Change the volume phases of cement stone



2.1 CONCRETE STRUCTURE

2.2 TYPES OF CONCERTE

2.3 CONCRETE STRENGTH

2.4 CONCRETE DEFORMATIONS

Types of Concrete / Tipuri de beton

- **FRESH CONCRETE** ρ = 2300 … 2400 kg/m^3
- **HARDENED CONCRETE** ρ = 2000 … 2600 kg/m^3
- **PLAIN CONCRETE**
- **REINFORCED CONCRETE**
- **PRESTRESSED CONCRETE**

Types of Concrete / Tipuri de beton

SPECIAL CONCRETE

- **LIGHT-WEIGHT CONCRETE (LC)** $\rho < 2000$ kg/m^3
  - CONCRETE WITH LIGHT AGGREGATES
  - CELLULAR CONCRETE (BCA)
- **HEAVYWEIGHT CONCRETE** $\rho > 2600$ kg/m^3
- **HIGH STRENGTH CONCRETE**
- **HIGH PERFORMANCE CONCRETE (HPC)**
- **POLYMER-MODIFIED CONCRETE**
- **FIBER REINFORCED CONCRETE (FRC)**
- **SELF COMPACTING CONCRETE (SCC)**
- **SHOTCRETE**

2.1 CONCRETE STRUCTURE

2.2 TYPES OF CONCERTE

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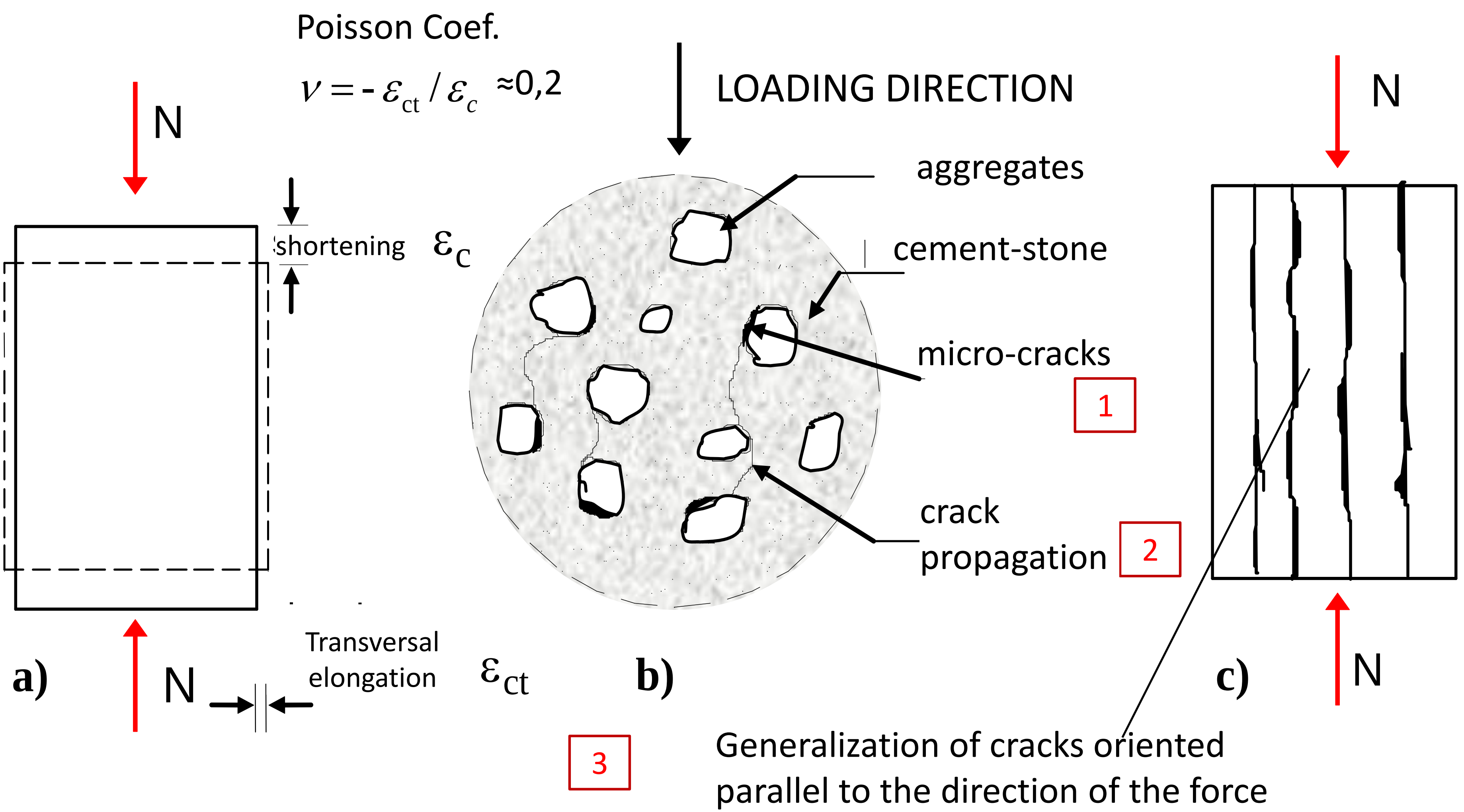
2.4 CONCRETE DEFORMATIONS

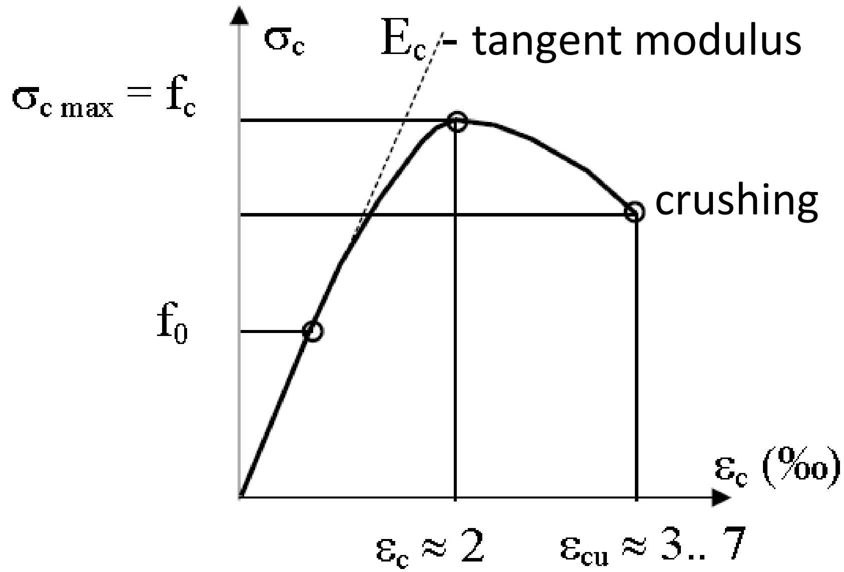
Concrete strength / Rezistențele betonului

Failure of concrete under uniaxial compression → gradualness

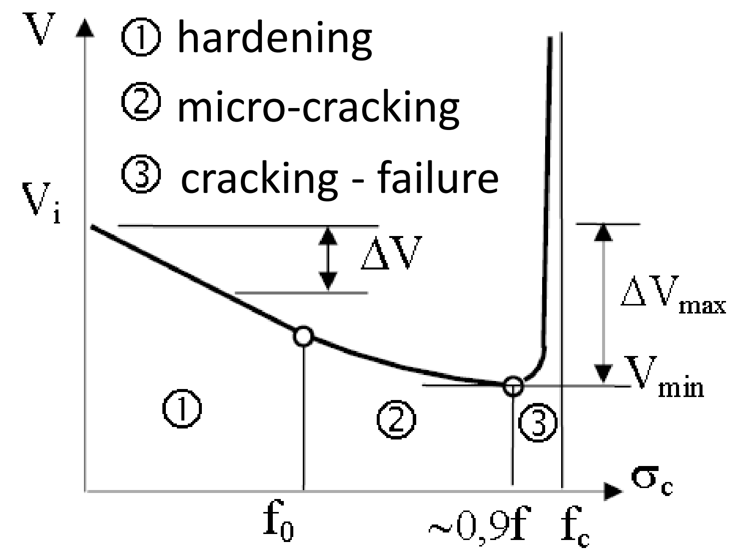


Concrete strength / Rezistențele betonului

Failure of concrete under uniaxial compression → gradualness



σ_c - ε_c CURVE OF CONCRETE SUBJECTED TO COMPRESSION



VOLUME VARIATION OF A COMPRESSED CYLINDER

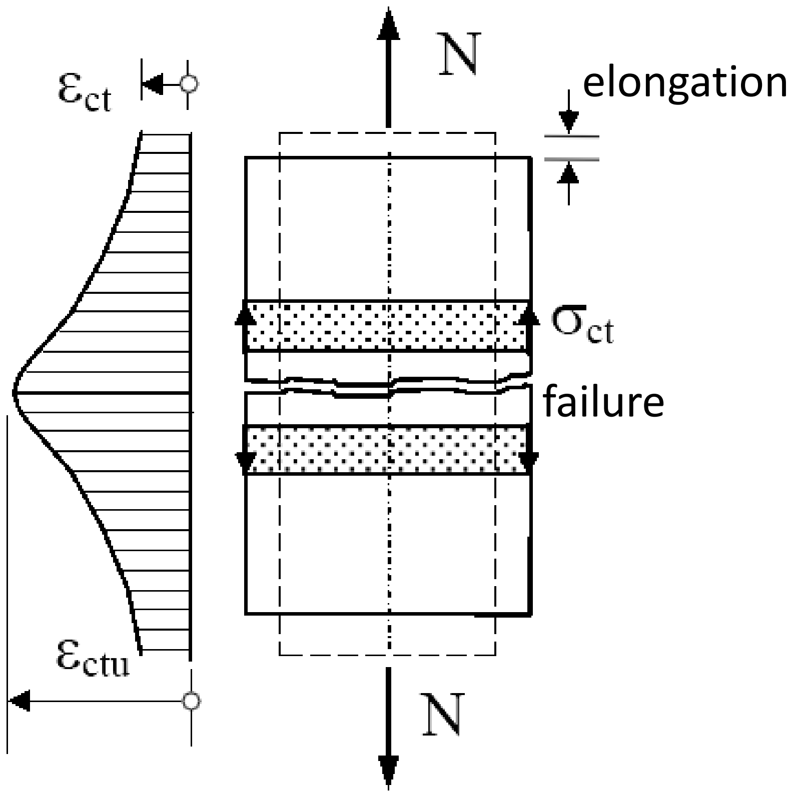
1. Elastic behavior: **hardening** → compressive stress between 0 – f_0 (f_0 = micro-cracking strength)
2. Elastic-plastic behavior : **micro-cracking** → compressive stress between f_0 - 0.9 f_c
3. Failure: **cracking-failure** → compression stress **>** 0.9 f_c

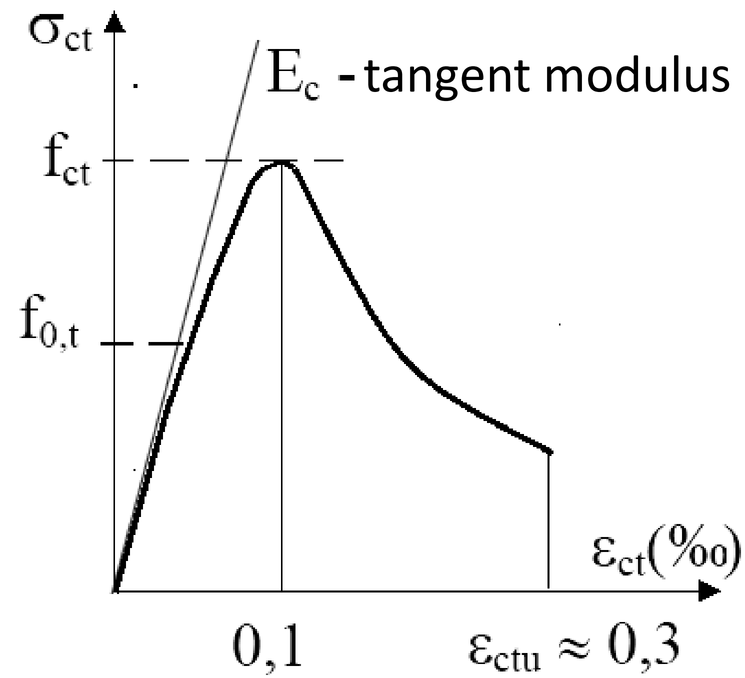
f_c = compressive strength of conceret subjected to short term static loads

Failure of plain concrete has a brittle behavior, because occurs at very small deformations.

Concrete strength / Rezistențele betonului

Failure of concrete under uniaxial tension





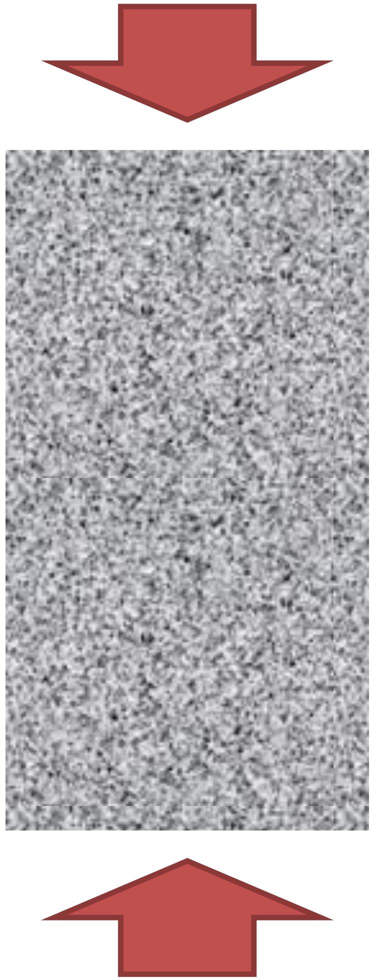
→ strongly influenced by discontinuities

Concrete strength / Rezistențele betonului

The behavior of concrete cylinder subjected to centric compression

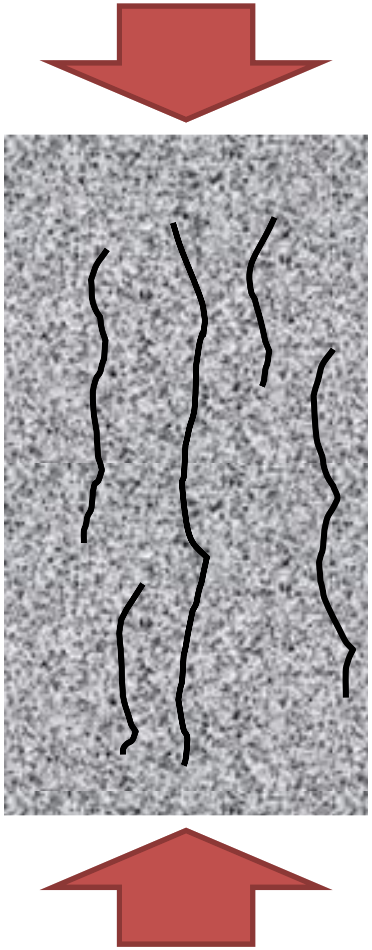
Concrete strength / Rezistențele betonului

The behavior of concrete cylinder subjected to centric compression



Concrete strength / Rezistențele betonului

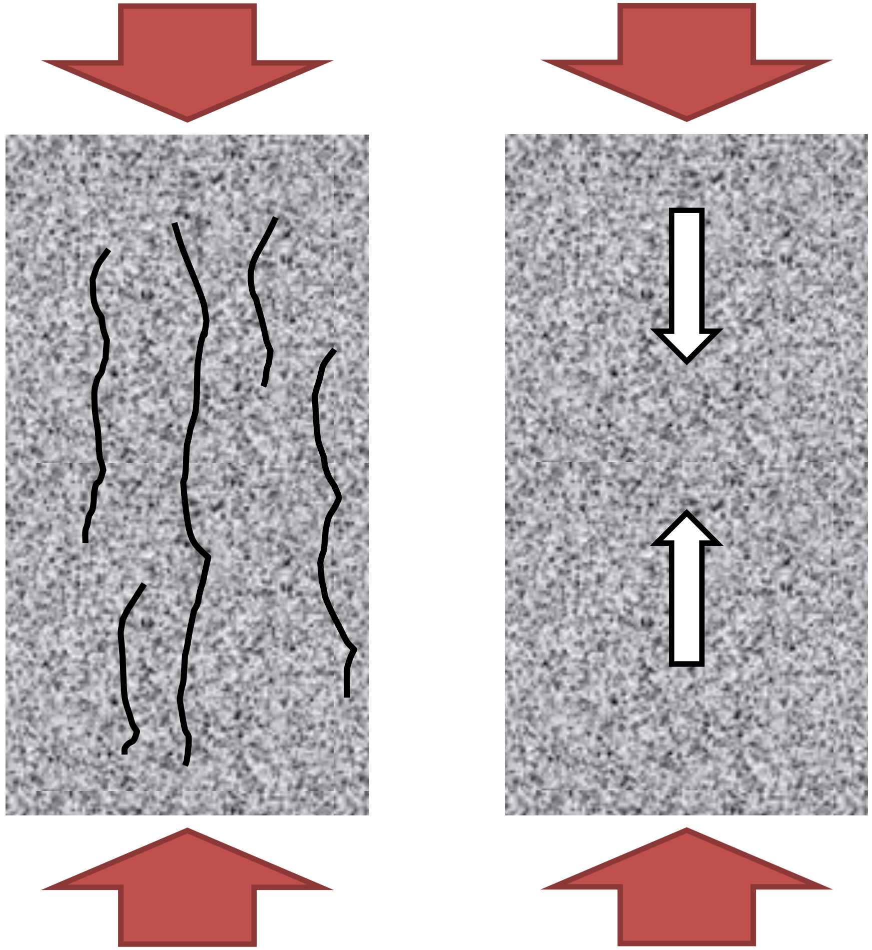
The behavior of concrete cylinder subjected to centric compression



Micro-cracks in cement paste

Concrete strength / Rezistențele betonului

The behavior of concrete cylinder subjected to centric compression

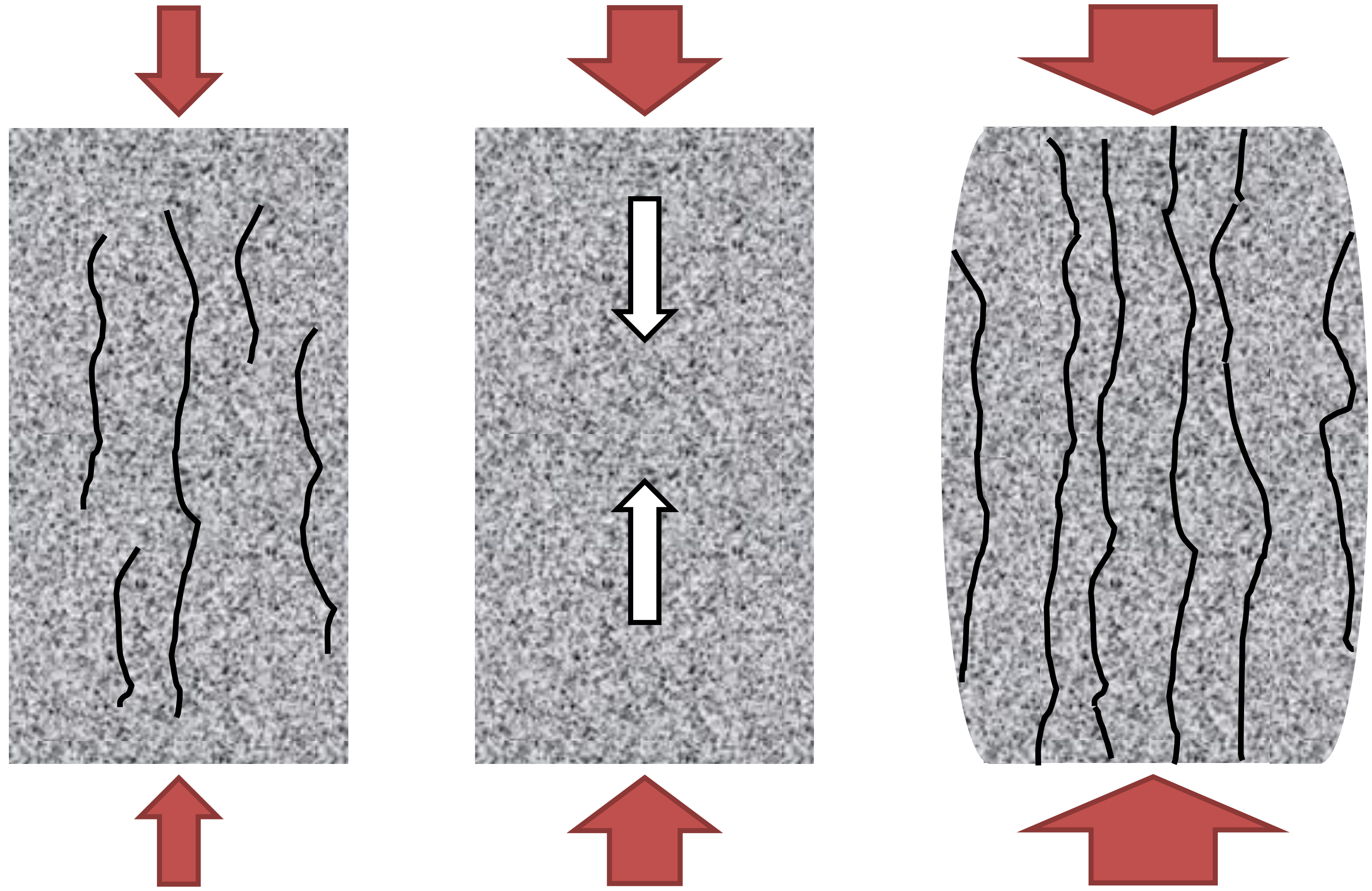


Micro-cracks in cement paste

Interior forces

Concrete strength / Rezistențele betonului

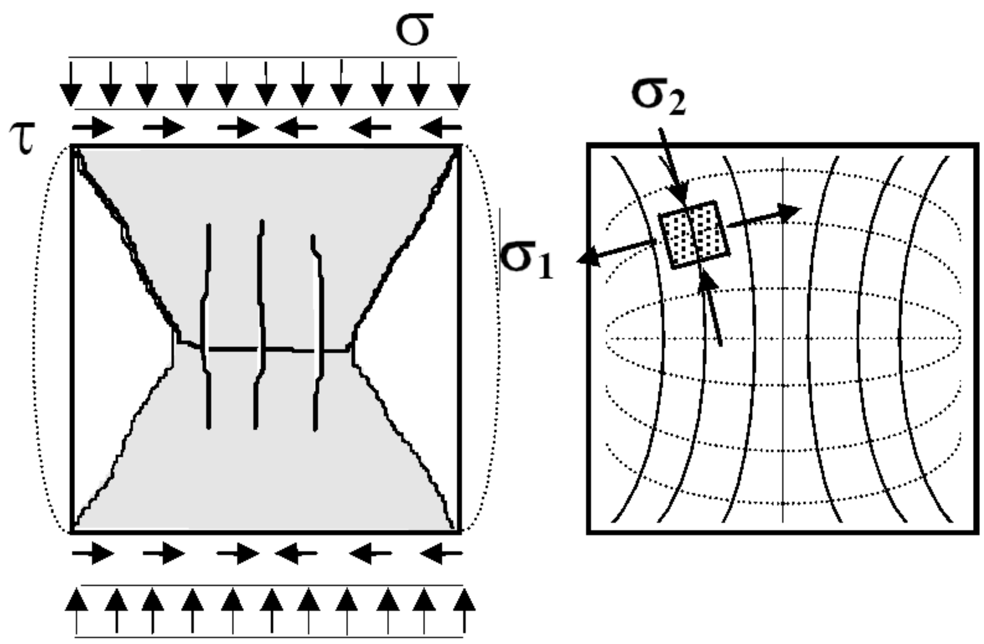
The behavior of concrete cylinder subjected to centric compression



Micro-cracks in cement paste **Interior forces** **Macro-cracks → failure**

Concrete strength / Rezistențele betonului

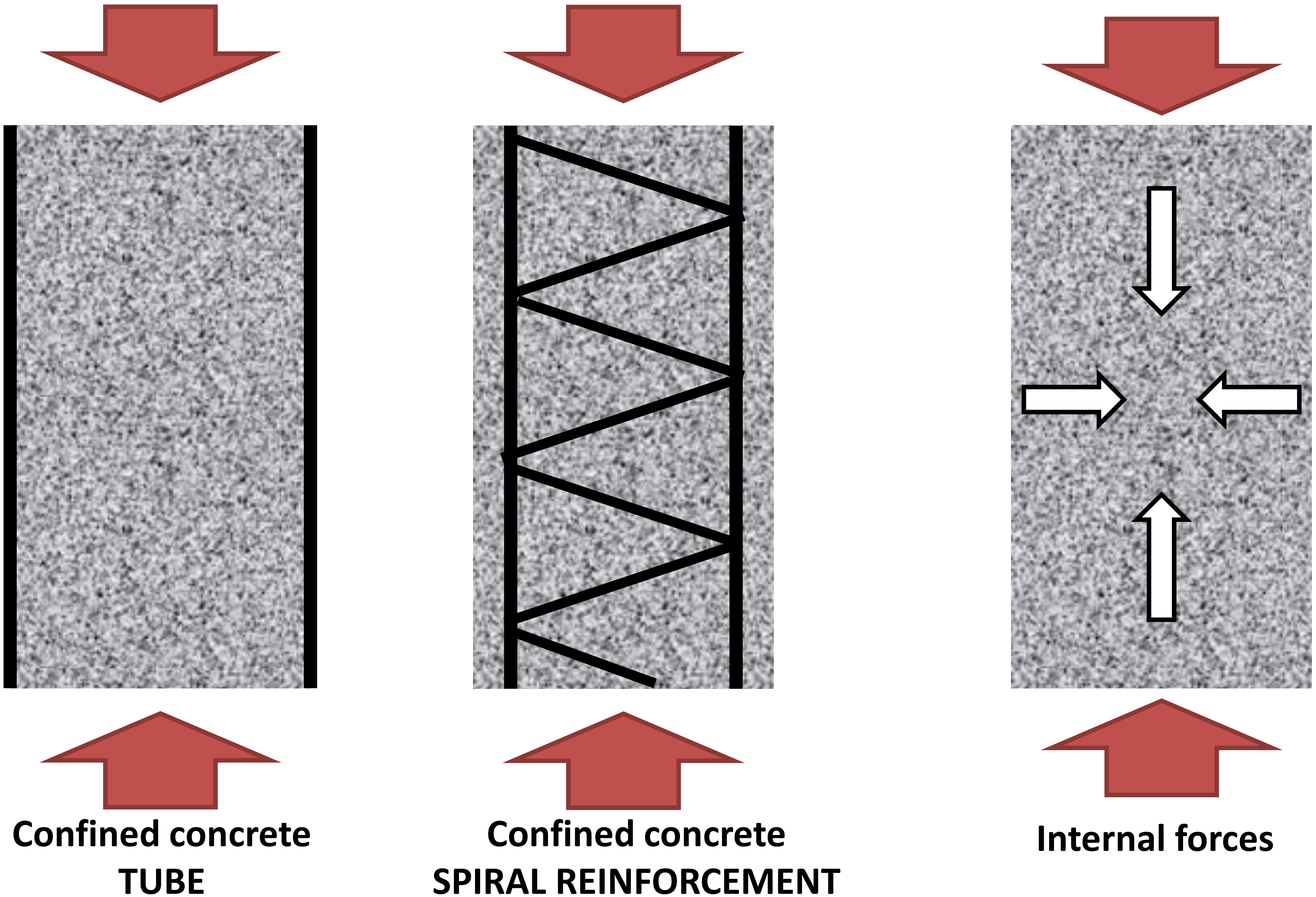
Failure of a cube specimen with friction → biaxial stresses, due to friction between the steel plates and concrete specimen



τ – shear stress → prevents transversal deformations
σ – normal stress
σ_1 – principal tensile stress
σ_2 – principal compression stress

Concrete strength / Rezistențele betonului

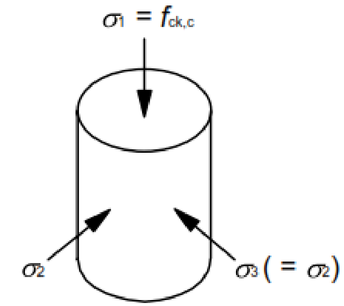
The behavior of confined concrete specimen subjected to centric compression



Concrete strength / Rezistențele betonului

Confinement of concrete = increasing compressive strength of concrete by creating **triaxial stress**

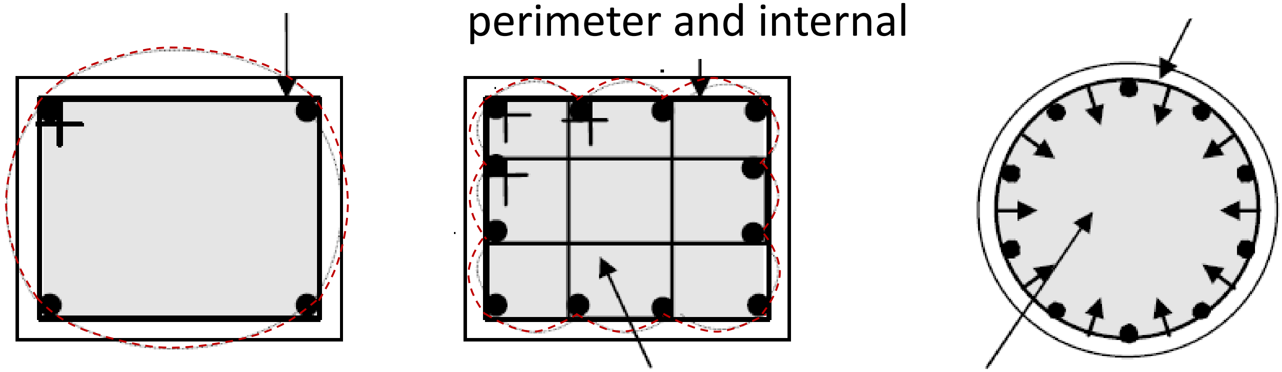
→ is achieved by preventing deformation (usually using stirrups)

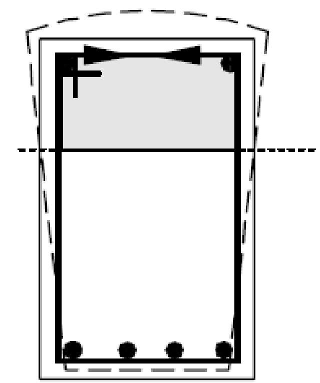


Stirrups at the perimeter

Stirrups at the perimeter and internal

spiral reinforcement





Reduced effect

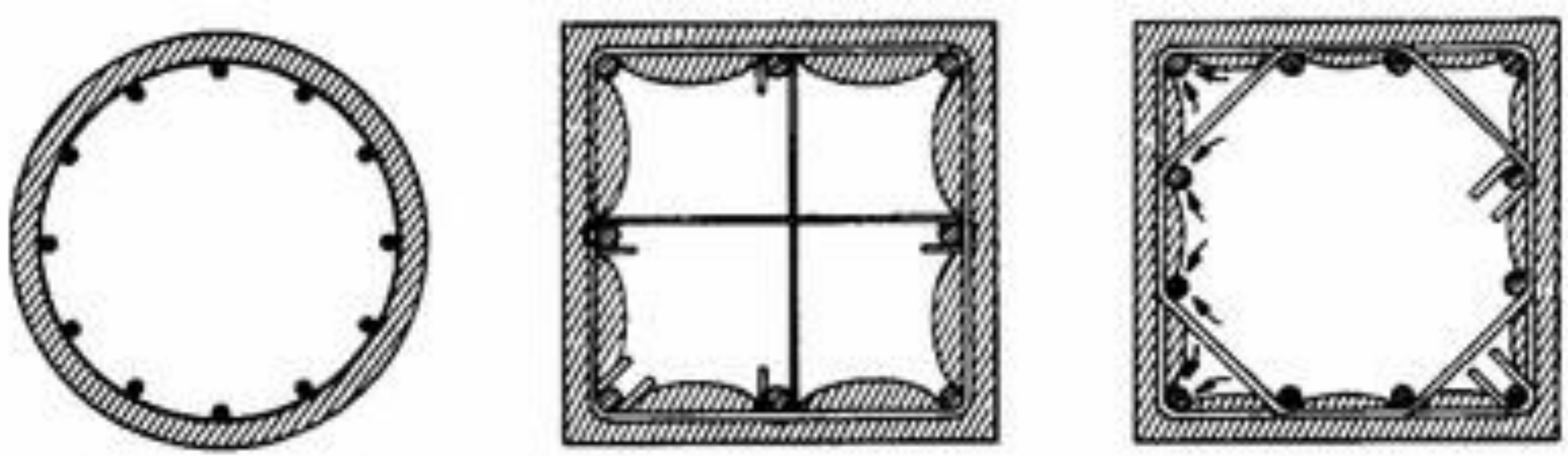
increased effects

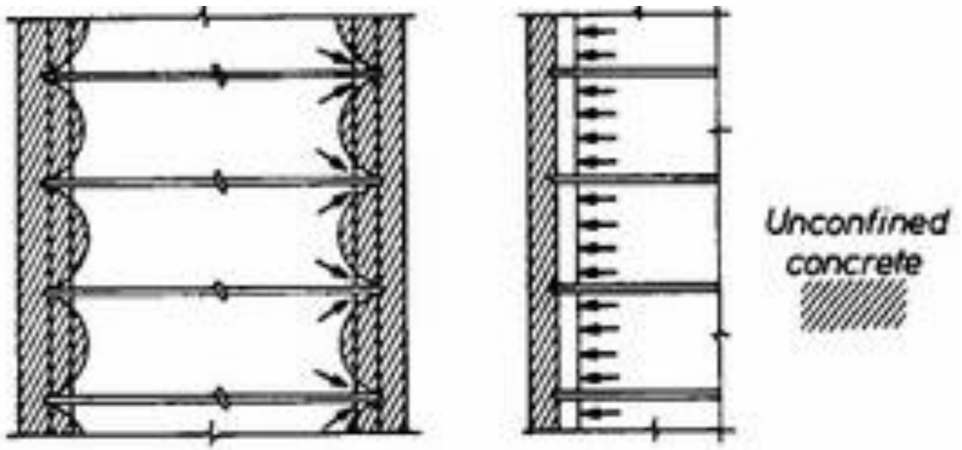
a) columns

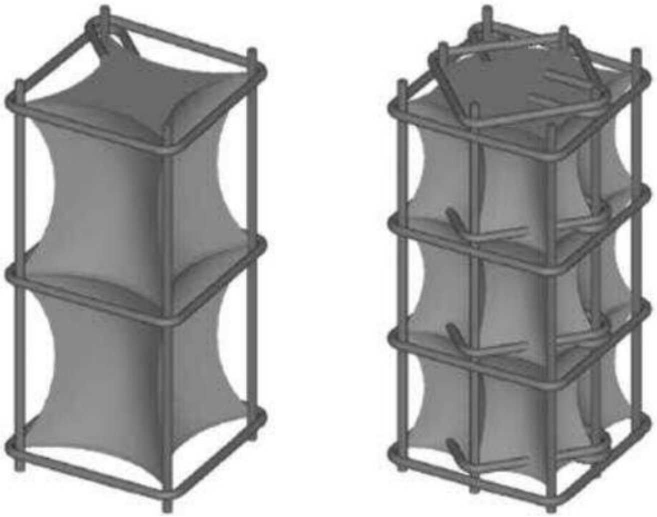
b) beam

Concrete strength / Rezistențele betonului

The behavior of confined concrete specimen subjected to centric compression

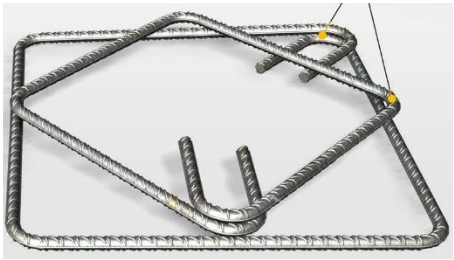


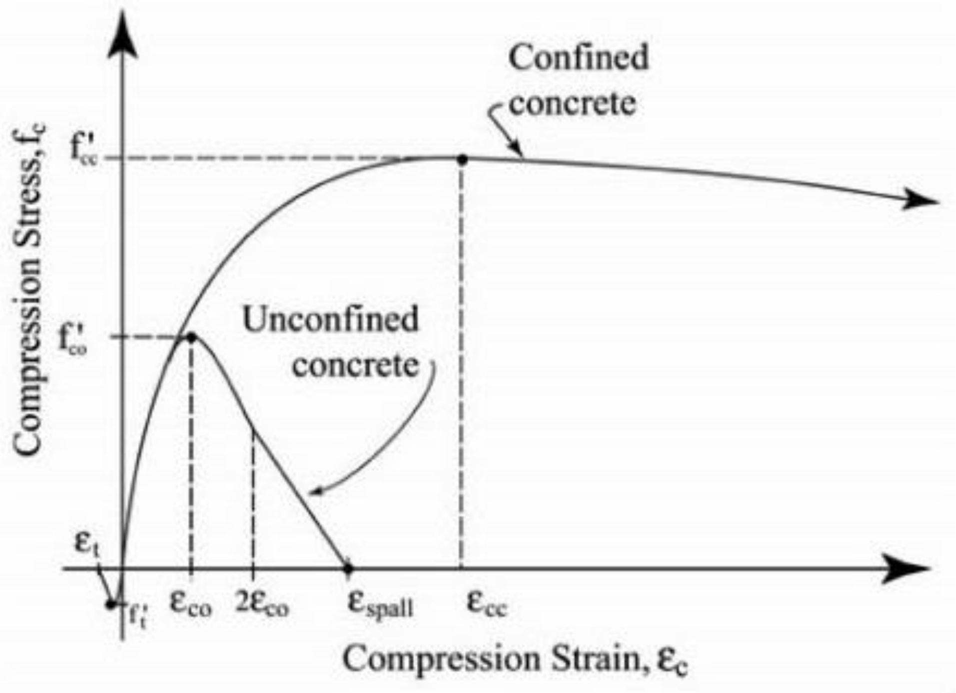


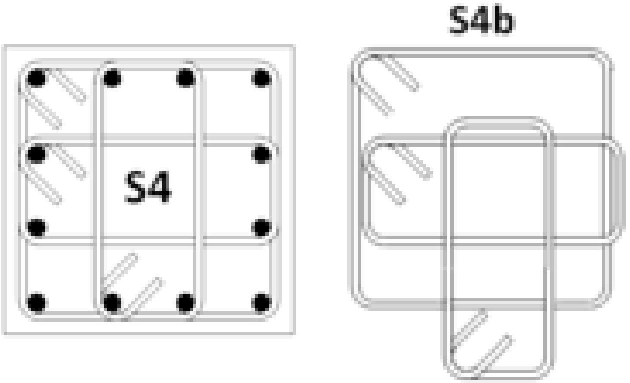


Concrete strength / Rezistențele betonului

Confinement of concrete = increasing compressive strength of concrete by creating triaxial stress







Concrete strength / Rezistențele betonului

Confinement of concrete = increasing compressive strength of concrete by creating triaxial stress

SPIRAL REINFORCEMENT

Conclusions regarding of concrete failure:

- ***concrete failure*** occurs due to ***cohesion loss***, indifferent of the stress type, when specific tensile deformations reach maximum (ultimate);

- ***concrete failure*** has a ***gradually character*** due to the accumulation of a critical amount of degradation, in the form of micro-cracks, and then cracks;

- it can be considered an ***elastic behavior*** to the value of the stress which not exceeding the ***micro-cracking strength*** (f_0);

- ***plastic behavior*** is due to appearance and development of irreversible deformation through ***micro-cracking of concrete***;

- failure of plain concrete has ***brittle character***, as occurs at very small deformations.

Concrete strength / Rezistențele betonului

Usual tests to determine concrete characteristics

Strength	Test type	Specimen	Denomination	Symbol
Compression strength	Uniaxial compression	Cylinder	Strength on cylinder *(concrete class)*	f_{cil}
		Cube	Cubic strength	f_{cub}
		Prism	Prismatic strength	f_{pr}
Tensile strength	Uniaxial tension	Prism / Cylinder	Tensile strength	f_{ct}
	Splitting tensile	Cylinder / Cube	Splitting tensile strength	$f_{ct\ sp}$
	Bending tension	Bended prism	Bending tensile strength	$f_{ct\ fl}$

Concrete strength / Rezistențele betonului

Factors affecting concrete strength

1. Quality of raw materials

Cement influencing the strength only at young ages

Aggregates
- strength
- dimension
- form
- surface texture
- mineralogical nature
- quality (density, purity, etc)

Apa "...the water should be fit for drinking..."

Concrete strength / Rezistențele betonului

Factors affecting concrete strength

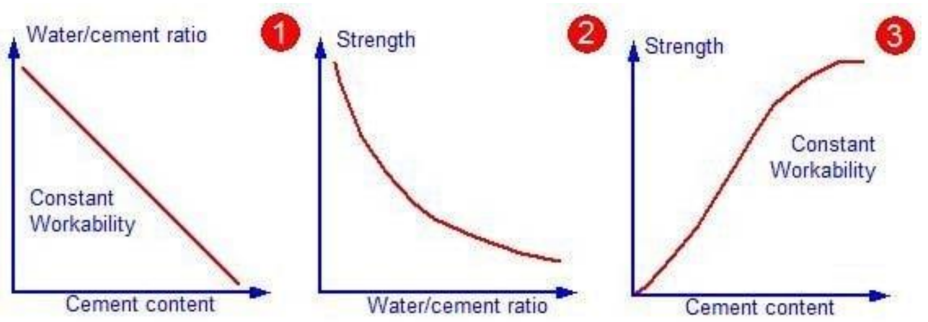
2. Proportion of constituents

W/C ratio ↘ ⇒ f_c ↗

Trained air ↗ ⇒ f_c ↘

Cement dosage ↗ ⇒ f_c ↗

Coarse / fine aggregate ratio (granulometry) ⇒ workability ⇒ strength



Factors affecting concrete strength

3. Casting conditions

Vibration $\Rightarrow$ **Compaction**

Compaction $\nearrow$ $\Rightarrow$ $f_c \nearrow$

Homogeneity $\nearrow$ $\Rightarrow$ $f_c \nearrow$

Segregation/Honeycombing $\nearrow$ $\Rightarrow$ $f_c \searrow$

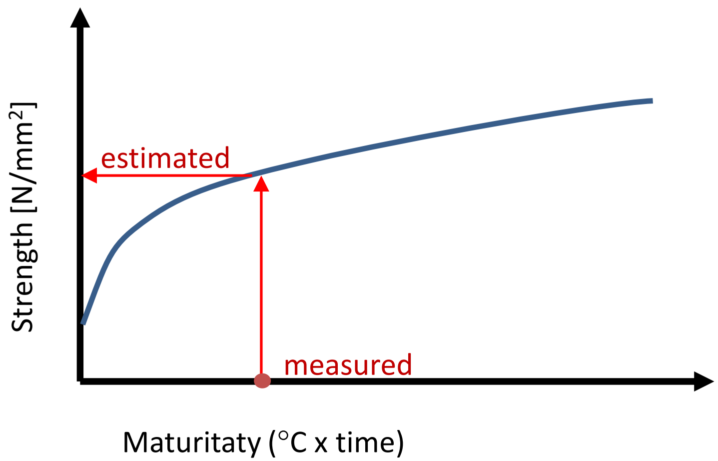
Factors affecting concrete strength

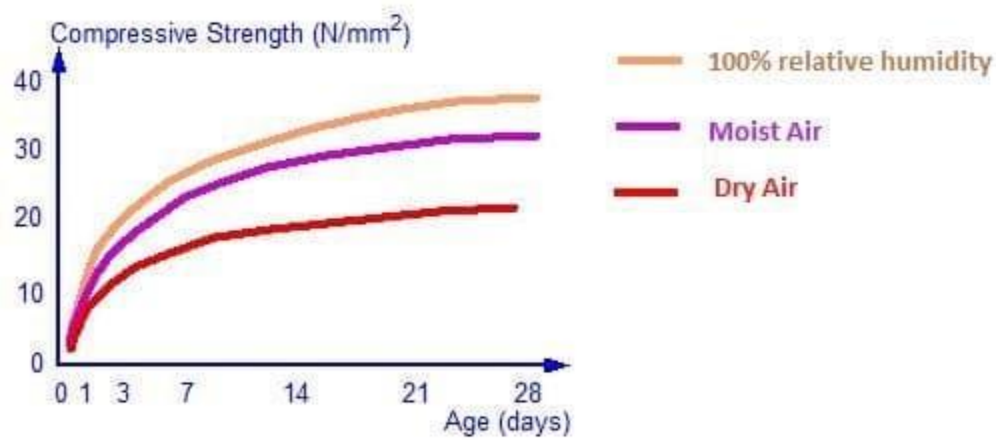
4. Working/storage conditions

Temperature ↗ ⇒ promotes hydration

Humidity ↗ ⇒ promotes hydration

Age = degree of hydration





Concrete strength / Rezistențele betonului

Factors affecting concrete strength

5. Testing conditions

Specimen dimension $\nearrow \quad \Rightarrow \quad f_c \searrow$

Specimen form
$$f_{c,cube} > f_{c,cylinder}$$
$$f_{c,cube} > f_{c,prism}$$

Specimen humidity $\nearrow \quad \Rightarrow \quad f_c \searrow$

Loading speed $\nearrow \quad \Rightarrow \quad f_c \nearrow$

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Concrete deformations / Deformațiile betonului

Causes of deformations:

- **Intrinsic** (own):
  - shrinkage
  - swelling

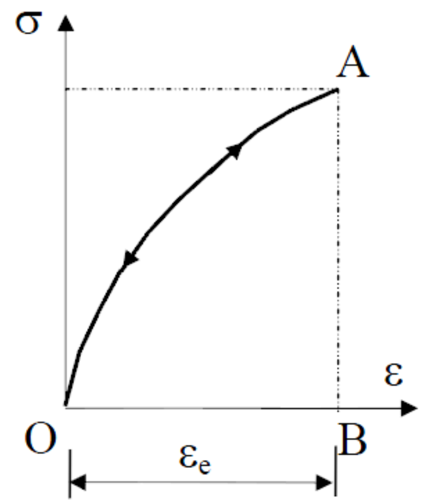
- **Exterior**:
  - direct loads
  - induced displacements
  - variation of temperatures
  - et cetera

Concrete deformations / Deformațiile betonului

Elastic deformation: due to the solid phase (aggregates, crystals formed by the cement curing)

- could be linear or non-linear

- after termination of the action, theoretically, the body returns instantaneously to its original form



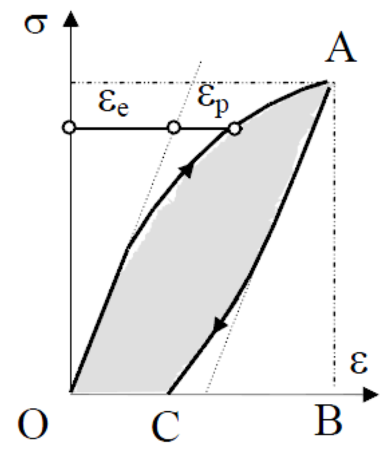
a) Elastic non-linear

Concrete deformations / Deformațiile betonului

Plastic deformation: occurs due to structural discontinuities (especially micro-cracks) which compromise the adhesion of aggregate-to-cement stone;

- appears at a certain level of stress

- increases as long as loading increases, and after the complete unloading, remaining irreversible deformation

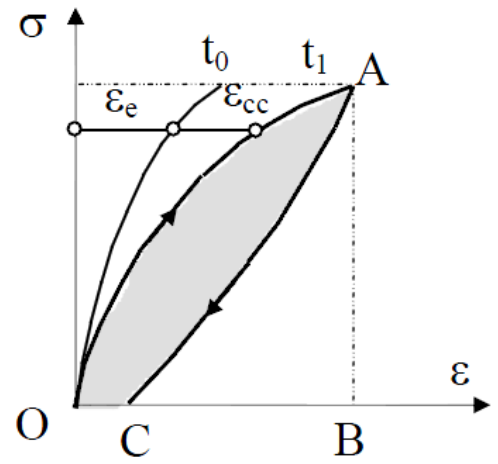


b) Elastic-plastic

Concrete deformations / Deformațiile betonului

Viscous (rheological) deformation: occurs due to the gels, called creep

- viscous deformation develops in time and is partially reversible after the termination of the action.



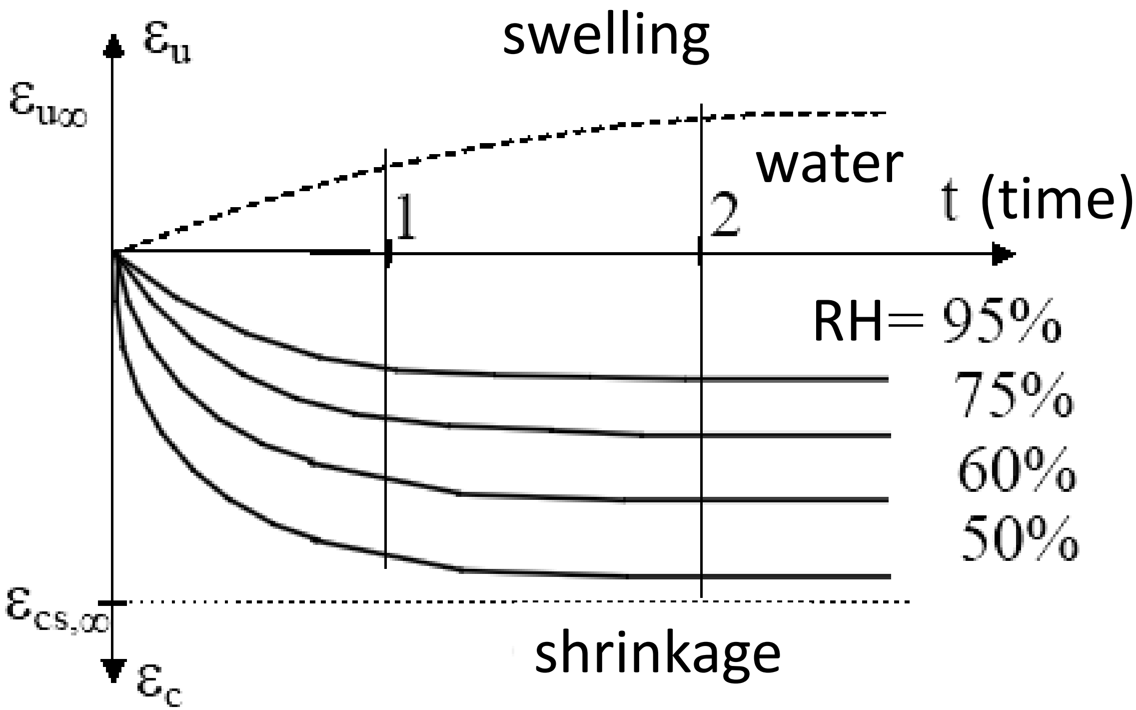
c) Non-linear - Viscous

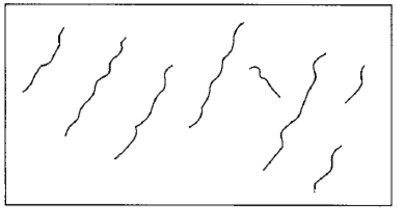
Concrete deformations / Deformațiile betonului

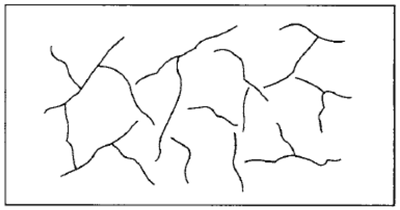
Volume of concrete stored in a dry environment decrease → **shrinkage**

ε_{cs}

Volume of concrete stored in water increase → **swelling**

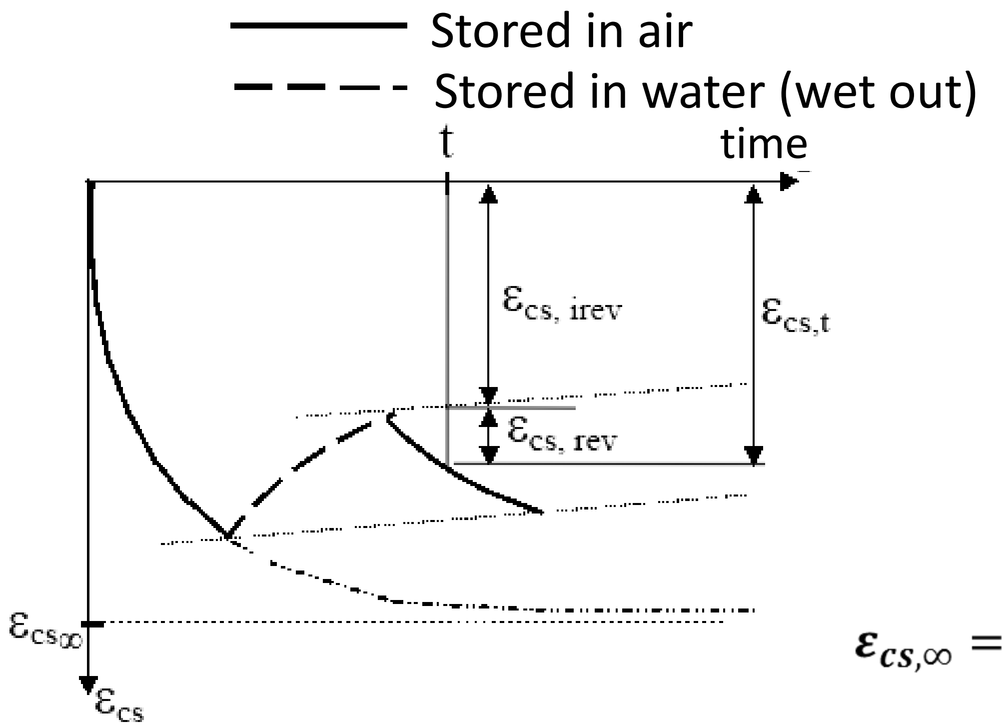






Concrete deformations / Deformațiile betonului

Volume of concrete stored in a dry environment decrease → **shrinkage**
Volume of concrete stored in water increase → **swelling**



$$\boldsymbol{\varepsilon_{cs,\infty} = 0,4 \ldots 0,8‰ > \varepsilon_{tu} = 0,1 \ldots 0,15}$$

Partial reversibility of shrinkage!!!

Concrete deformations / Deformațiile betonului

Theory → concrete deformations is due to **water migration in concrete mass**

The total shrinkage strain is composed of two components, the drying shrinkage strain and the autogenous shrinkage strain.

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

The drying shrinkage strain develops slowly, since it is a function of the migration of the water through the hardened concrete.

ε_{cd} (drying shrinkage)

The autogenous shrinkage strain 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.

ε_{ca} (autogenous shrinkage)

Concrete deformations / Deformațiile betonului

The irreversible component of shrinkage → due to aging of gels, manifested by progressive reduction of their volume and increased volume of crystals

The reversible component of shrinkage → decreases over time and is due to:

- the capillary action, independent from concrete age
- the thickness of the film of water adsorbed on the surface of gels, dependent on concrete age

Concrete deformations / Deformațiile betonului

Factors influencing concrete shrinkage and swelling

- **Humidity and temperature**

$$RH \searrow + \text{ Temp} \nearrow \quad \Rightarrow \quad \boldsymbol{\varepsilon_{cs}} \nearrow$$

- **Volume of the gels increases with cement content**

$$V_{gel} \nearrow \quad \Rightarrow \quad \boldsymbol{\varepsilon_{cs}} \nearrow$$

- **Aggregates: influencing the gravel-to-sand ratio**

gravel-to-sand ratio $\searrow$ $\Rightarrow$ Water $\nearrow$ $\Rightarrow$ Aggregate/Cement $\searrow$ $\Rightarrow$ $\boldsymbol{\varepsilon_{cs}} \nearrow$

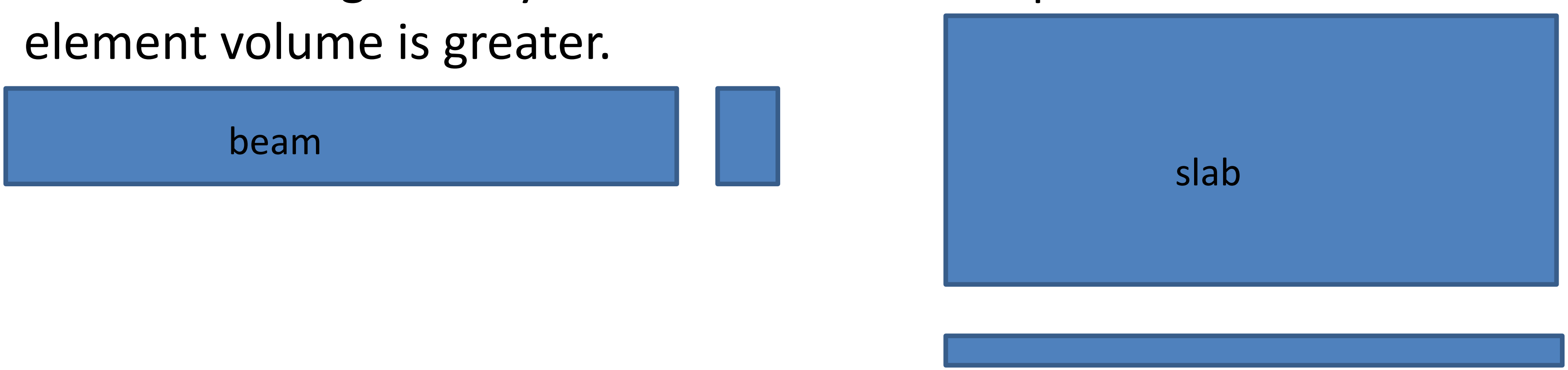
$$\varepsilon_{cs,\ cement} > \varepsilon_{cs,\ mortar} > \varepsilon_{cs,\ concrete}$$

Factors influencing concrete shrinkage and swelling

- **Concrete superplasticizer** → reduce W/C without decrease of workability

- Increased **concrete compaction** → higher concrete strength → smaller deformations from shrinkage

- Possibility of water evaporation: the contraction is greater as the surface area given by the ratio of the exposed surface and the element volume is greater.



Shrinkage of reinforced concrete

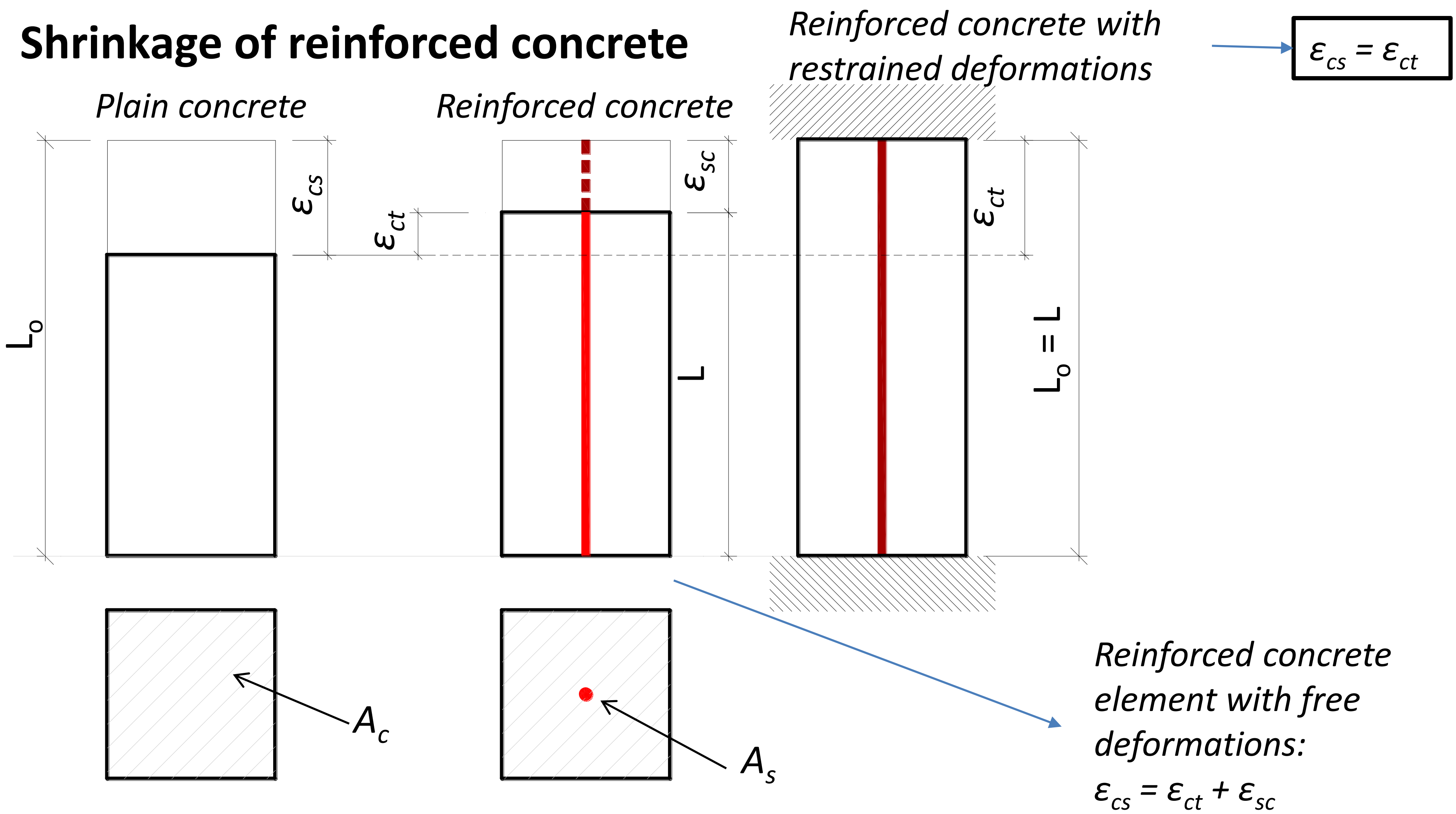
Experimentally: the value of **reinforced concrete shrinkage** it is **less than** of plain concrete, so for a higher reinforcement ratio lower shrinkage will result.

Explanation: **bond** between concrete and reinforcement **reduces the tendency of shrinkage** of the concrete, reinforcement opposing to shrinkage.

→ In **reinforcement** arise **compression** stresses, while in **concrete tensile** stresses

Concrete deformations / Deformaţiile betonului

Shrinkage of reinforced concrete



ε_{cs} = total shrinkage strain of plain concrete

ε_{sc} = compression strain in reinforcement (= shrinkage of RC)

ε_{ct} = tensile strain in concrete, caused by the presence of reinforcement

Concrete deformations / Deformațiile betonului

Shrinkage of reinforced concrete

Compression stress in reinforcement:

$$\sigma_s = \varepsilon_{sc} \cdot E_s$$

Corresponding compression force in reinforcement:

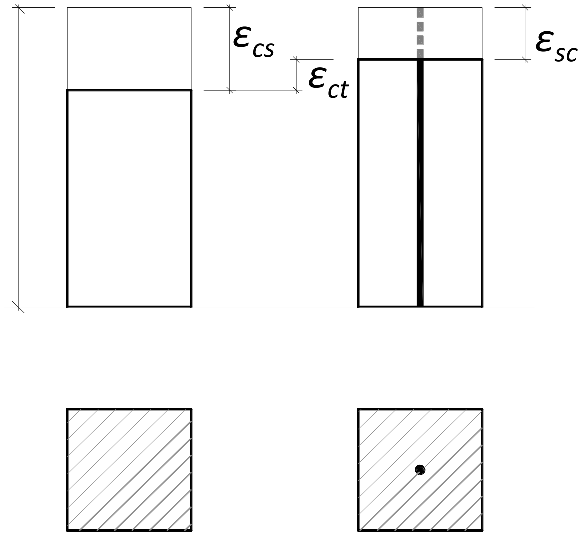
$$F_s = A_s \cdot \sigma_s$$

Tensile stress in concrete:

$$\sigma_c = \varepsilon_{ct} \cdot E_c = (\varepsilon_{cs} - \varepsilon_{sc}) \cdot E_c$$

Corresponding tensile force in concrete:

$$F_c = A_c \cdot \sigma_c$$



Shrinkage of reinforced concrete

Equilibrium condition in longitudinal direction: $F_s = F_c$

→ $A_s \cdot \varepsilon_{sc} \cdot E_s = A_c \cdot (\varepsilon_{cs} - \varepsilon_{sc}) \cdot E_c$ $\quad / A_c \cdot E_c$

→ $\rho \cdot \varepsilon_{sc} \cdot n = \varepsilon_{cs} - \varepsilon_{sc}$

Where

$\rho = \frac{A_s}{A_c}$ - reinforcement coefficient

$n = \frac{E_s}{E_c}$ - coefficient of equivalence

(= how many times is stiffer the steel then the concrete)

Concrete deformations / Deformațiile betonului

Shrinkage of reinforced concrete

→ $\rho \cdot \varepsilon_{sc} \cdot n = \varepsilon_{cs} - \varepsilon_{sc}$ → $\varepsilon_{sc} = \frac{\varepsilon_{cs}}{1+\rho \cdot n}$

Stress in reinforcement: $\sigma_s = \frac{\varepsilon_{cs}}{1+\rho \cdot n} \cdot E_s$ → compression

To determine the stress in concrete: $F_s = F_c$ →

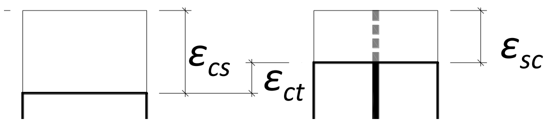
→ $A_c \cdot \sigma_s = A_c \cdot \sigma_c \quad / A_c$ →

→ $\sigma_c = \frac{A_s}{A_c} \cdot \sigma_s = \rho \cdot \sigma_s = \rho \cdot \frac{\varepsilon_{cs}}{1+\rho \cdot n} \cdot E_s = \frac{\varepsilon_{cs}}{\frac{1}{\rho}+n} \cdot E_s$

Concrete deformations / Deformaţiile betonului

Shrinkage of reinforced concrete < Shrinkage of plain concrete

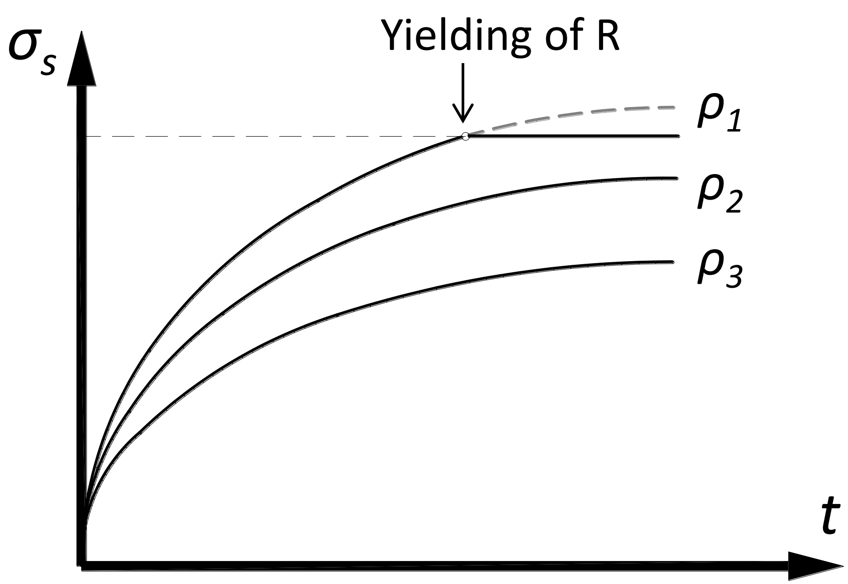
Considering $\rho(\%) \nearrow \Longrightarrow \varepsilon_{sc} \searrow$

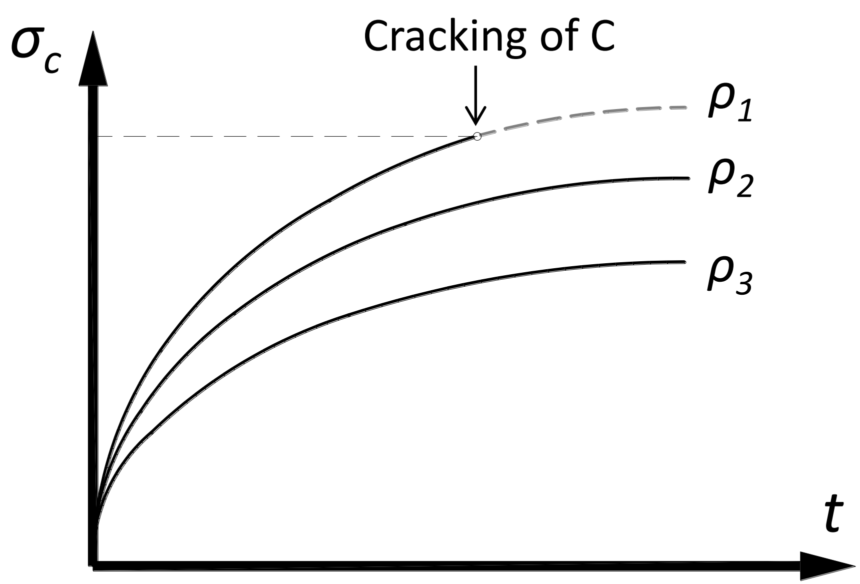


$$\varepsilon_{sc} = \frac{\varepsilon_{cs}}{1 + \rho \cdot n}$$

$$\rho_1 < \rho_2 < \rho_3$$

(for example $\rho_1 = 1\%;\ \rho_2 = 2\%;\ \rho_3 = 3\%$)

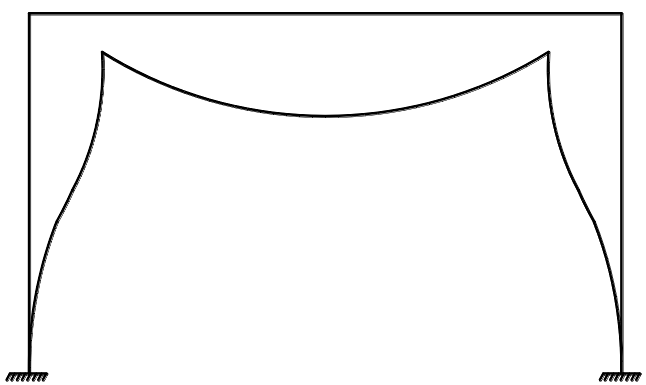


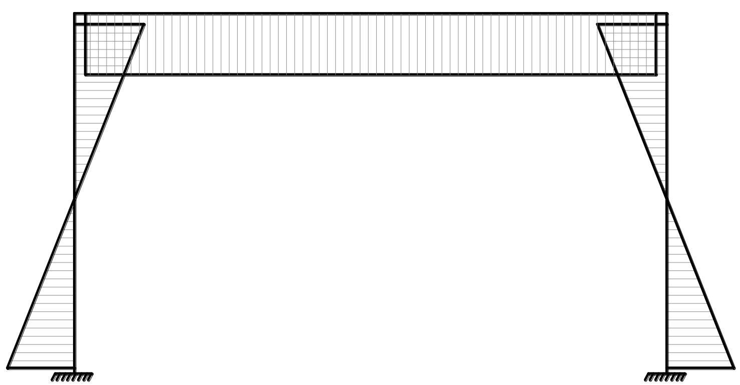


Shrinkage of reinforced concrete

In statically indeterminate structures shrinkage introduce stresses.

These stresses could be assimilated with a variation of temperature (approximatively 15^{o}C)





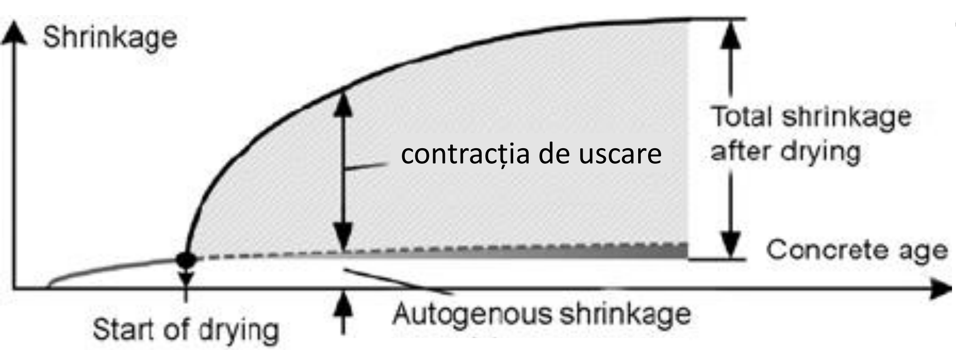
Concrete deformations / Deformațiile betonului

Concrete shrinkage in EN 1992-1-1:2004 (EC2)

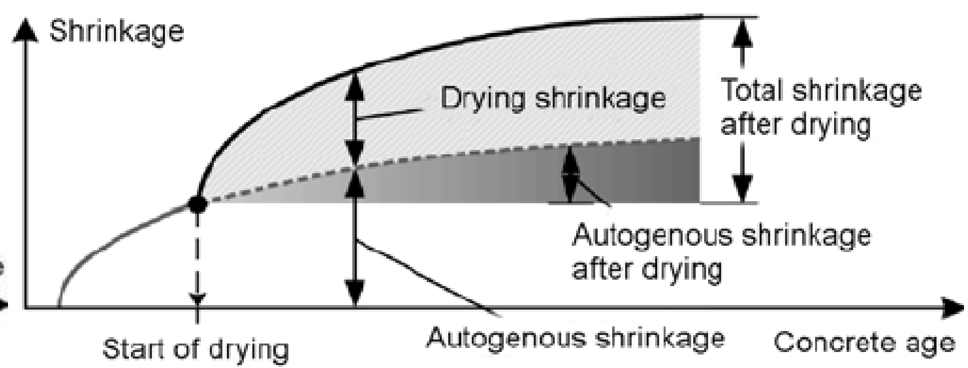
$$\varepsilon_{cs} = \varepsilon_{cd} + \varepsilon_{ca}$$

where

ε_{cs} - total shrinkage strain
ε_{cd} - drying shrinkage strain
ε_{ca} - autogenous shrinkage strain



Normal concrete



High-strength concrete

(Sakata & Shimomura 2004)

Concrete shrinkage in EN 1992-1-1:2004 (EC2)

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

$$\varepsilon_{cs,\infty} = k_h \cdot \varepsilon_{cd,0}$$

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

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

h_0	k_h
100	1.0
200	0.85
300	0.75
≥ 500	0.70

$$\varepsilon_{ca}(\infty) = 2{,}5(f_{ck} - 10) \cdot 10^{-6}$$

→ Creep of the concrete depend on the **ambient humidity**, the **dimensions** of the element and the **composition of the concrete +** the **maturity** of the concrete when the load is first applied and depends on the **duration** and **magnitude** of the loading.

Concrete shrinkage in EN 1992-1-1:2004 (EC2)

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

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

→ development of the drying shrinkage strain in time

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

→ autogenous shrinkage strain in time

→Creep of the concrete depend on the **ambient humidity**, the **dimensions** of the element and the **composition of the concrete +** the **maturity** of the concrete when the load is first applied and depends on the **duration** and **magnitude** of the loading.

Concrete deformations / Deformațiile betonului

Deformations of concrete from temperature variation

The effect of temperature variation on structures can be assimilated with imposed strains.

Temperature variations considered are from:

- environment
- climate
- technology

$$\pm\Delta l = l \cdot \varepsilon_{\Delta t} = l \cdot \Delta t \cdot \alpha$$

where

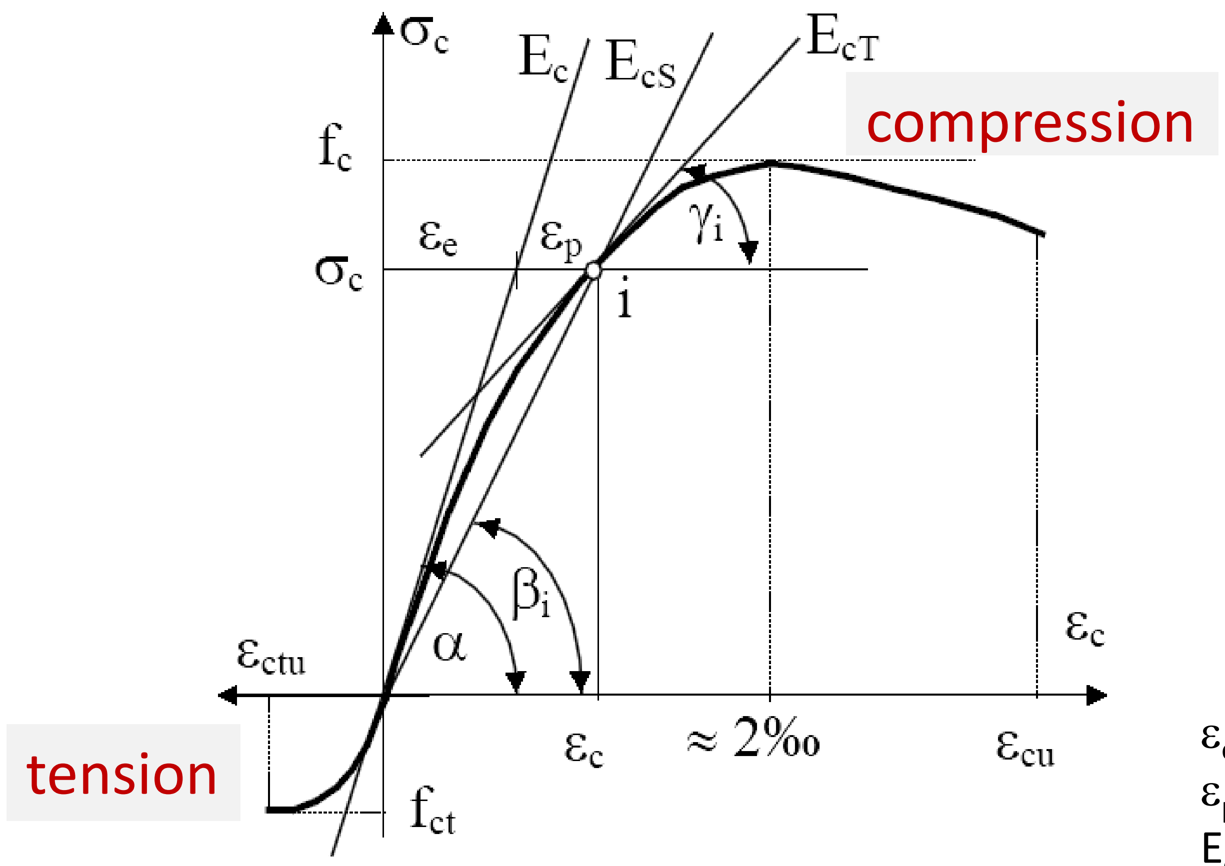
l - initial element length

Δt - temperature gradient, in °C

$\alpha = 10 \cdot 10^{-6}/°C$ - linear coefficient of thermal expansion of concrete

Deformations of concrete under short term static loads

Characteristic curve of concrete subjected to short term axial load

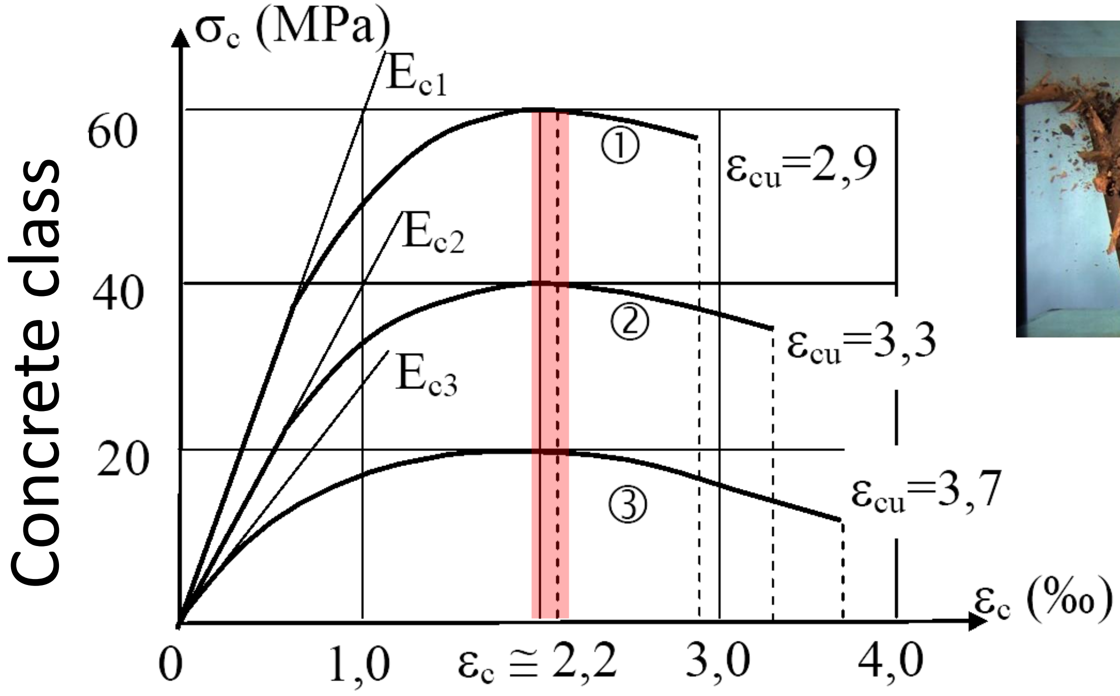


ε_e – elastic strain
ε_p – plastic strain
$E_c = \sigma_c / \varepsilon_e$ – Young modulus

Concrete deformations / Deformațiile betonului

Deformations of concrete under short term static load

Influence of the concrete quality on the characteristic curve shape

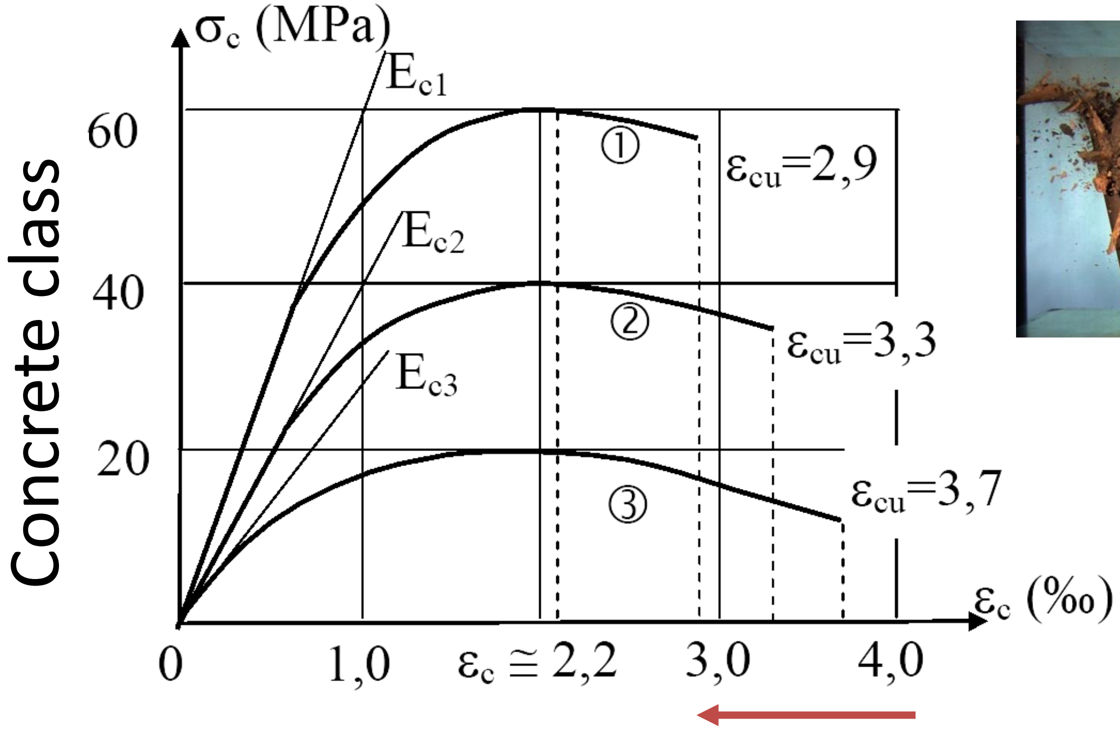


→ Deformation corresponding to compressive strength of concrete is practically the same regardless of the quality of concrete

Concrete deformations / Deformațiile betonului

Deformations of concrete under short term static load

Influence of the concrete quality on the characteristic curve shape

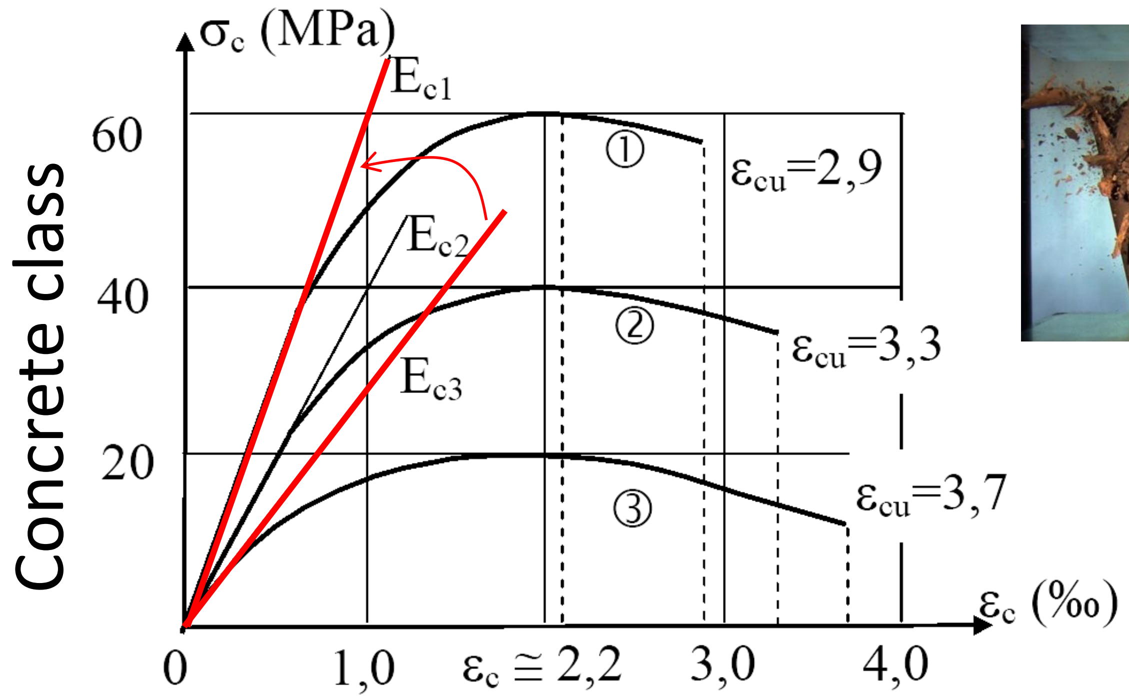


→ Ultimate strains decreases when the concrete class increase

Concrete deformations / Deformaţiile betonului

Deformations of concrete under short term static load

Influence of the concrete quality on the characteristic curve shape

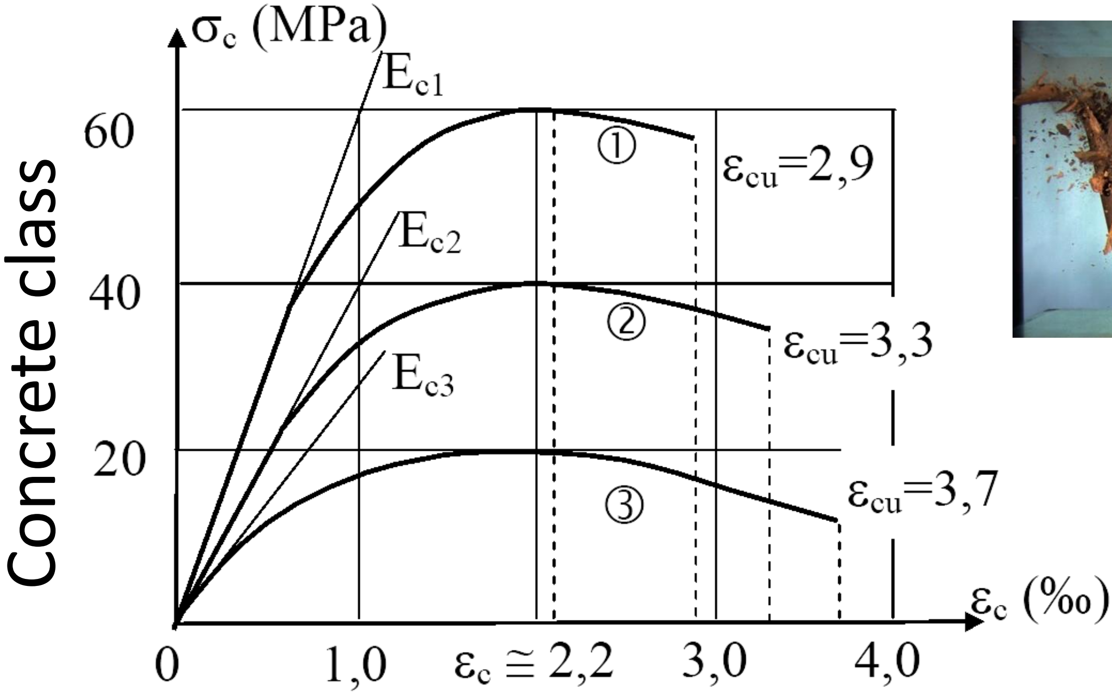


→ Modulus of elasticity increases with the concrete strength

Concrete deformations / Deformaţiile betonului

Deformations of concrete under short term static load

Influence of the concrete quality on the characteristic curve shape

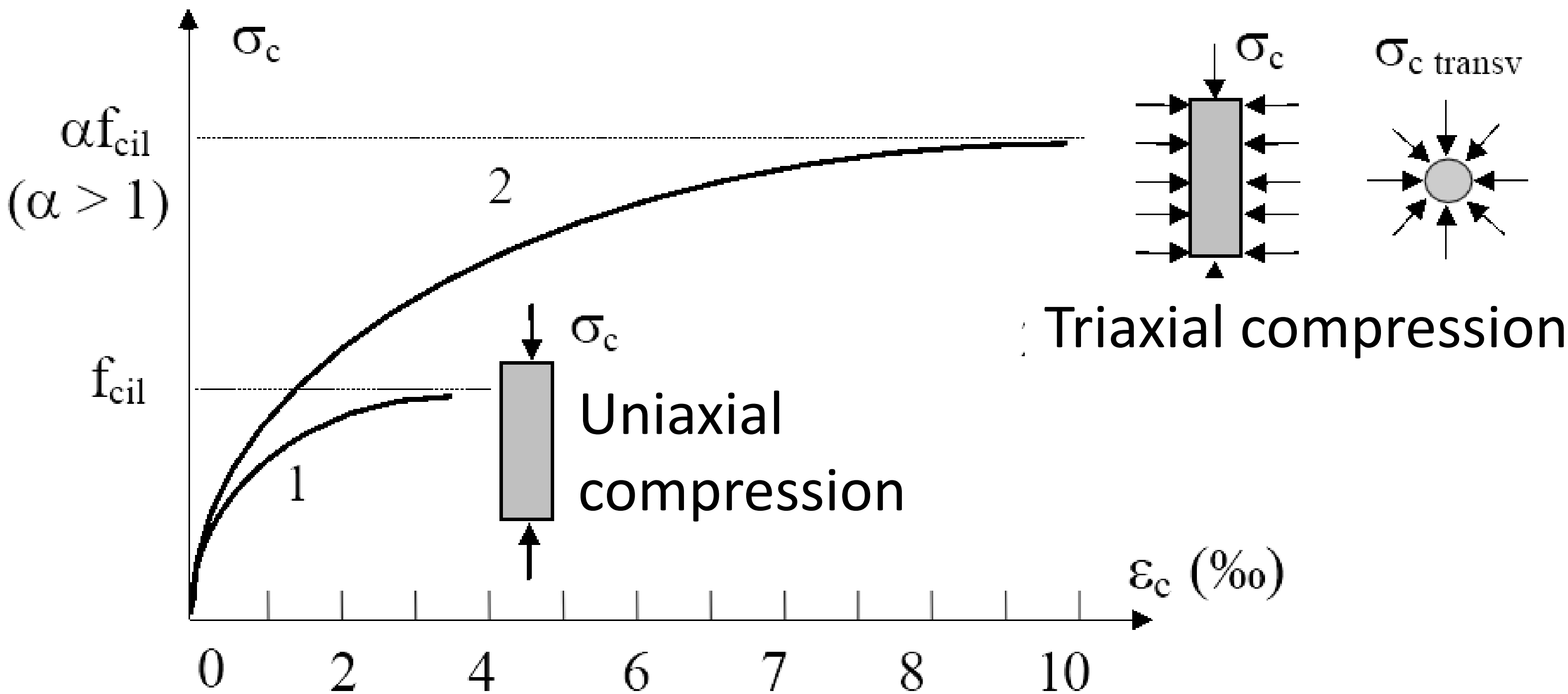


→ curve shape depends also on the loading speed →concrete strength increases and deformations decreases as the load is applied with higher speed

Concrete deformations / Deformațiile betonului

Deformations of concrete under short term static load

The influence of the confinement effect on ultimate compressive strain of concrete



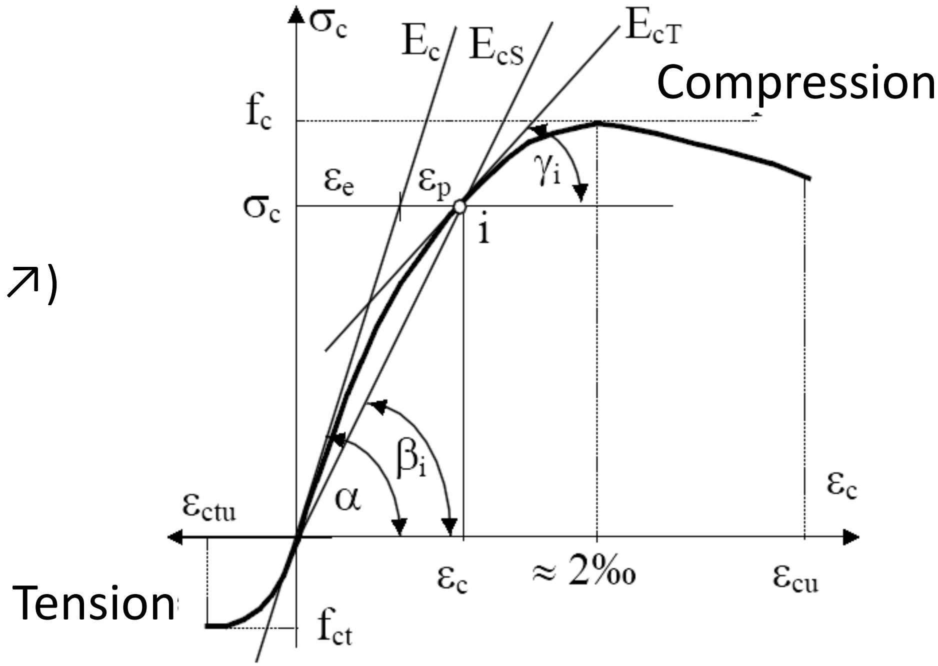
Concrete deformations / Deformațiile betonului

Deformations of concrete under short term static load

The modulus of elasticity

$$E_c = tg\alpha = \frac{\sigma_c}{\varepsilon_e}$$

($f_c \nearrow \Rightarrow E_c \nearrow$)



Transverse modulus of elasticity

$$G_c = \frac{E_c}{2(1+\nu)} \approx 0.4E_c$$

$\nu = 0.2$ – coef. Poisson

Concrete deformations / Deformațiile betonului

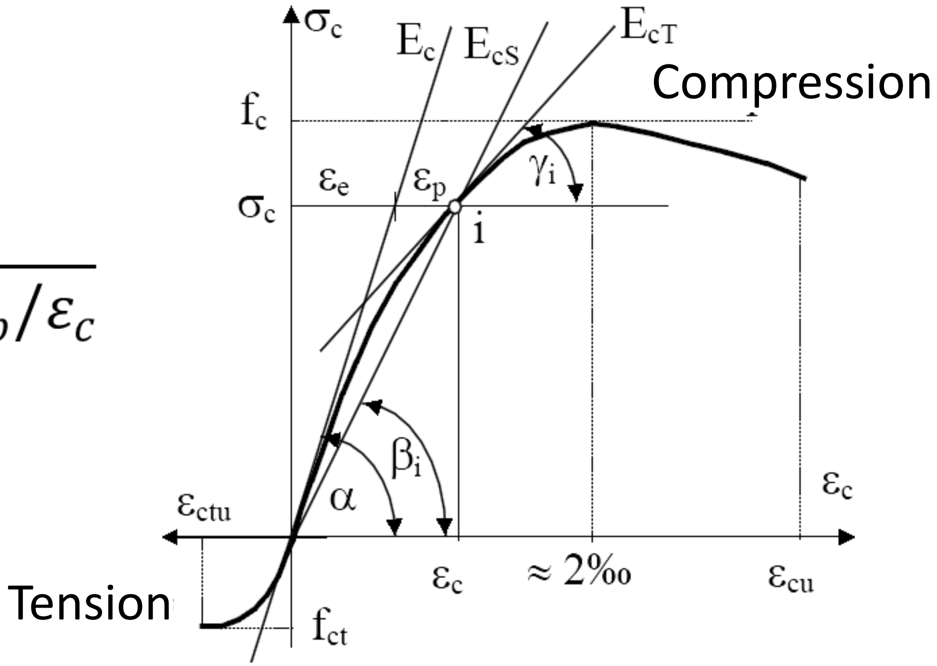
Deformations of concrete under short term static load

Secant modulus

$$E_{cS} = tg\beta = \frac{\sigma_c}{\varepsilon_c} = \frac{\sigma_c}{\varepsilon_e + \varepsilon_p} = \frac{\sigma_c}{1 + \varepsilon_p/\varepsilon_c}$$

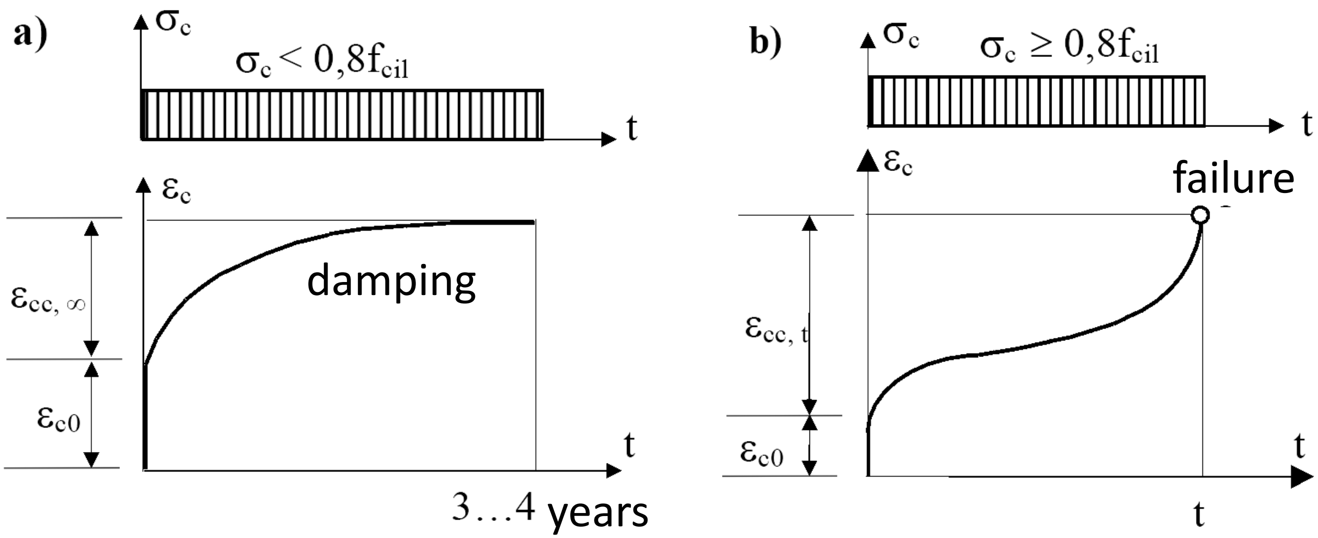
Tangent modulus

$$E_{cT} = tg\gamma = \frac{d\sigma_c}{d\varepsilon_e}$$



Concrete deformations / Deformațiile betonului

Deformations of concrete under long term static load
Creep – Time dependent deformation



$\sigma_c \leq f_0 = (0,3...0,6)f_c$ - linear creep

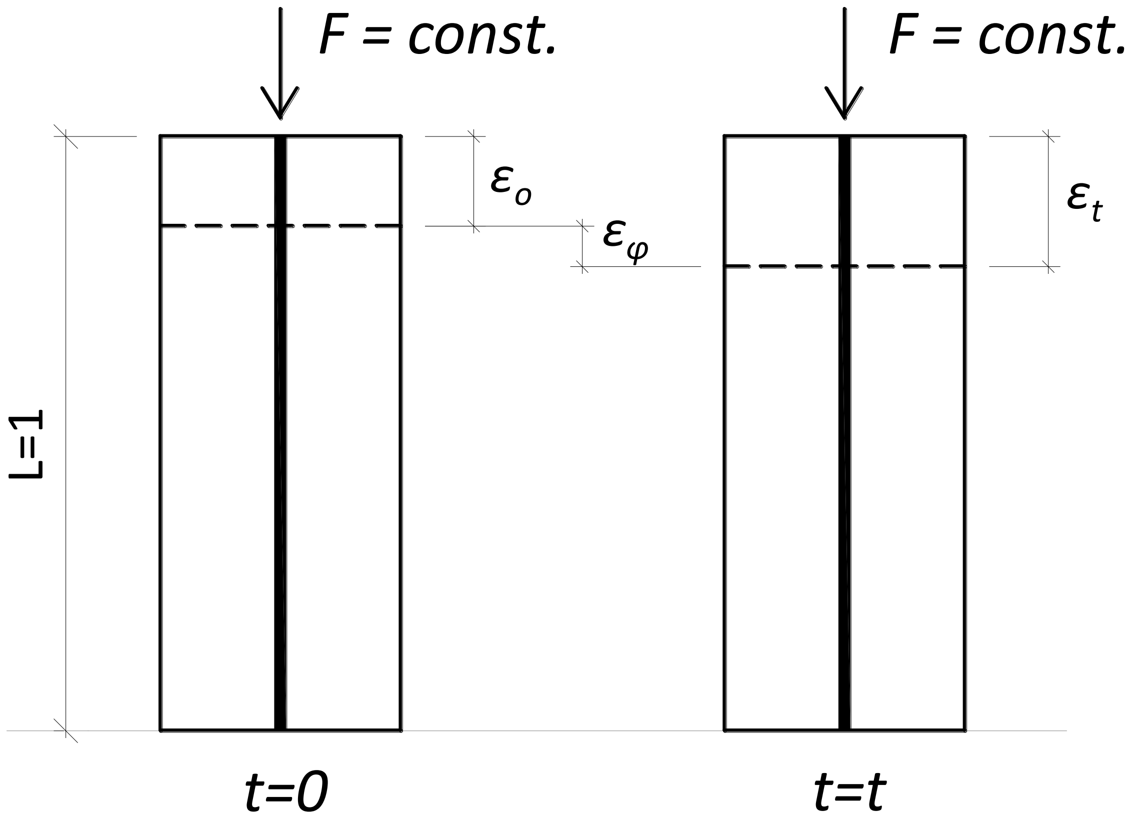
$\varepsilon_{cc,t} = \varphi(t, t_0)\ \varepsilon_e$ - creep deformation at a time *t*

$\varphi(t, t_0)$ - creep coefficient at a time *t*

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

Concrete deformations / Deformațiile betonului

Deformations of concrete under long term static load
Creep – Time dependent deformation

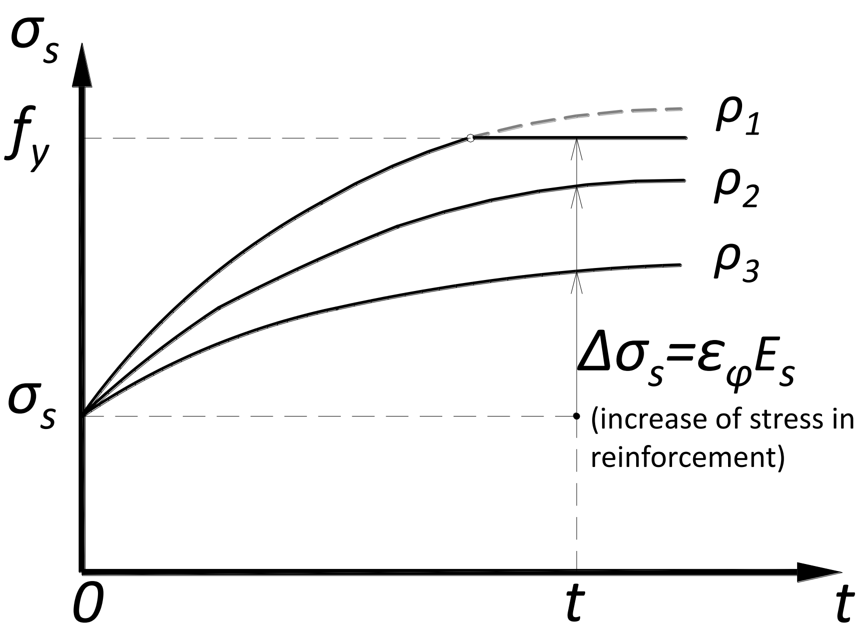


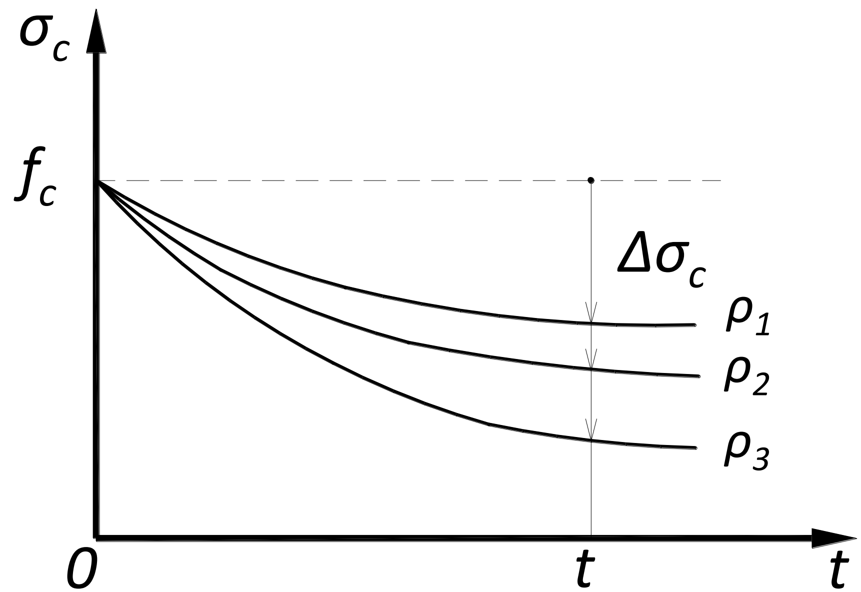
Concrete deformations / Deformațiile betonului

Deformations of concrete under long term static load

Creep – Time dependent deformation

$\rho_1 < \rho_2 < \rho_3$





σ_s ↗ → σ_c ↘

ρ ↗ → ε_φ ↘ → $\Delta\sigma_s$ ↘

ρ ↗ → force transfer ↗ → $\Delta\sigma_c$ ↗ → σ_c ↘

Concrete deformations / Deformațiile betonului

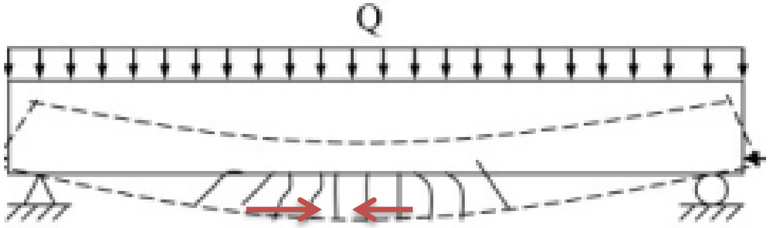
Deformations of concrete under <u>long term static load</u>
Creep – Time dependent deformation

- Creep and shrinkage in **compressed** elements acting in the same direction

$\sigma_s \nearrow \quad \rightarrow \quad \sigma_c \searrow$

- In the case of **tension** elements or with tension zone the action of creep is favorable and acțiunea curgerii lente este favorabilă and reduces the risk of cracking

$\sigma_s \nearrow \quad \rightarrow \quad \sigma_{ct} \searrow$



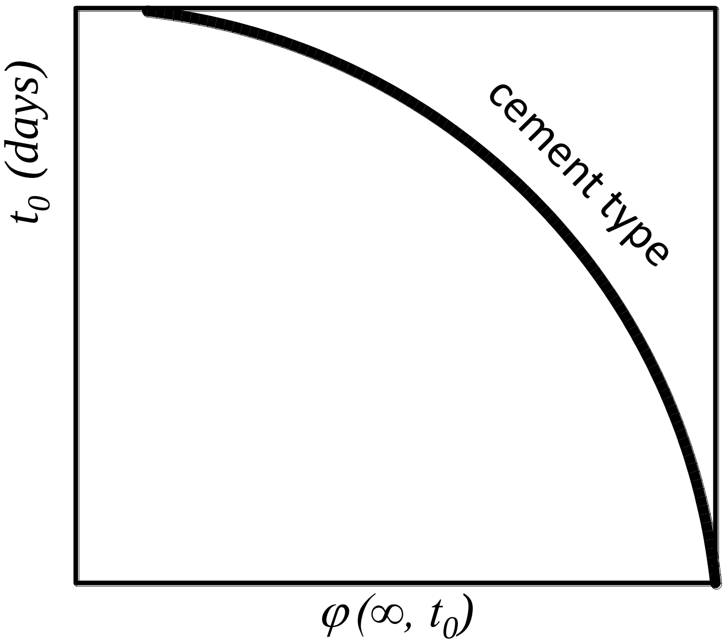
- Transversal reinforcement does not influence the creep, because it has linear character

- Creep has significant influence in case of deflection and buckling

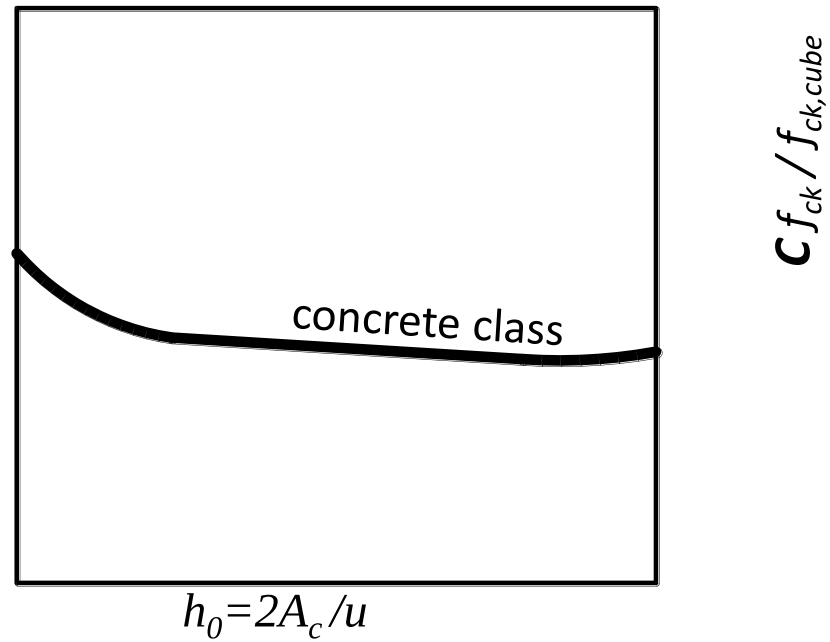
Concrete deformations/ Deformațiile betonului

Deformations of concrete under <u>long term static load</u>

Creep in SR EN 1991-1-1



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

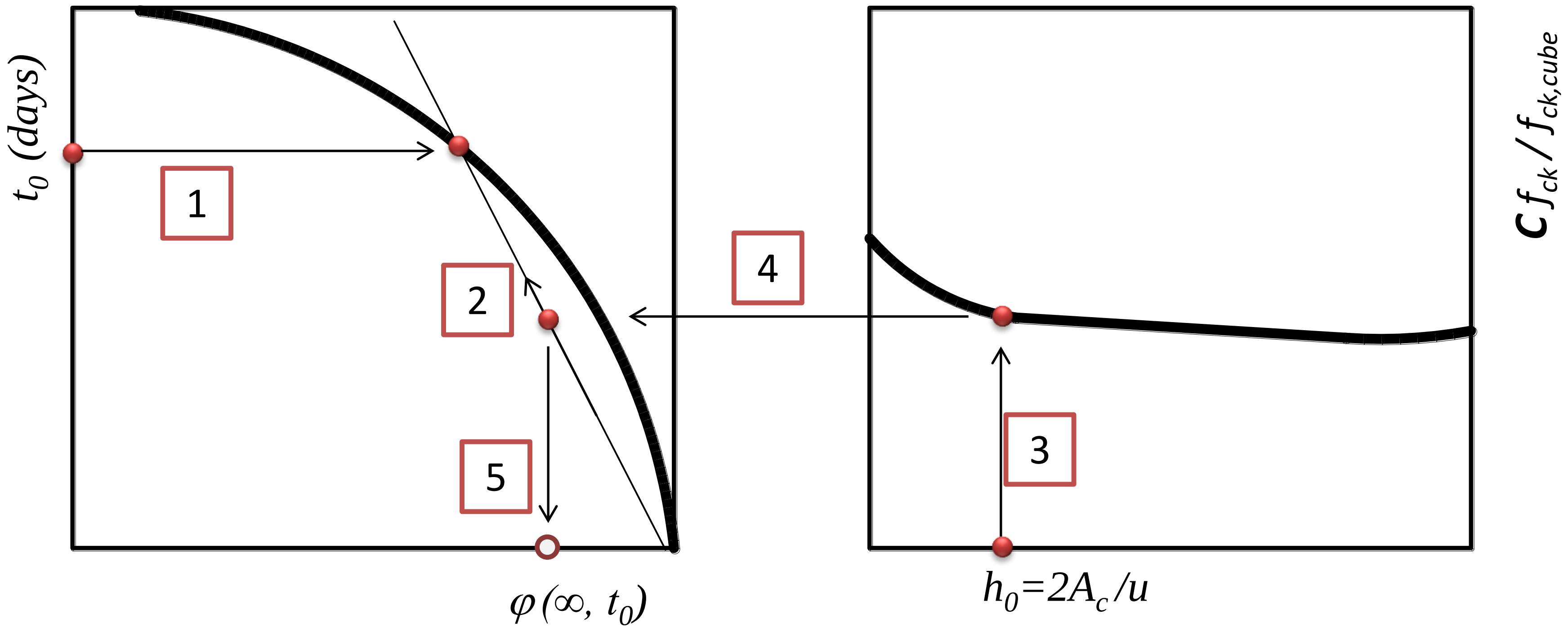


- Choose of concrete class
- compute h_0 coefficient

→Creep of the concrete depend on the **ambient humidity**, the **dimensions** of the element and the **composition of the concrete +** the **maturity** of the concrete when the load is first applied and depends on the **duration** and **magnitude** of the loading.

Concrete deformations/ Deformațiile betonului

Deformations of concrete under long term static load
Creep in SR EN 1991-1-1



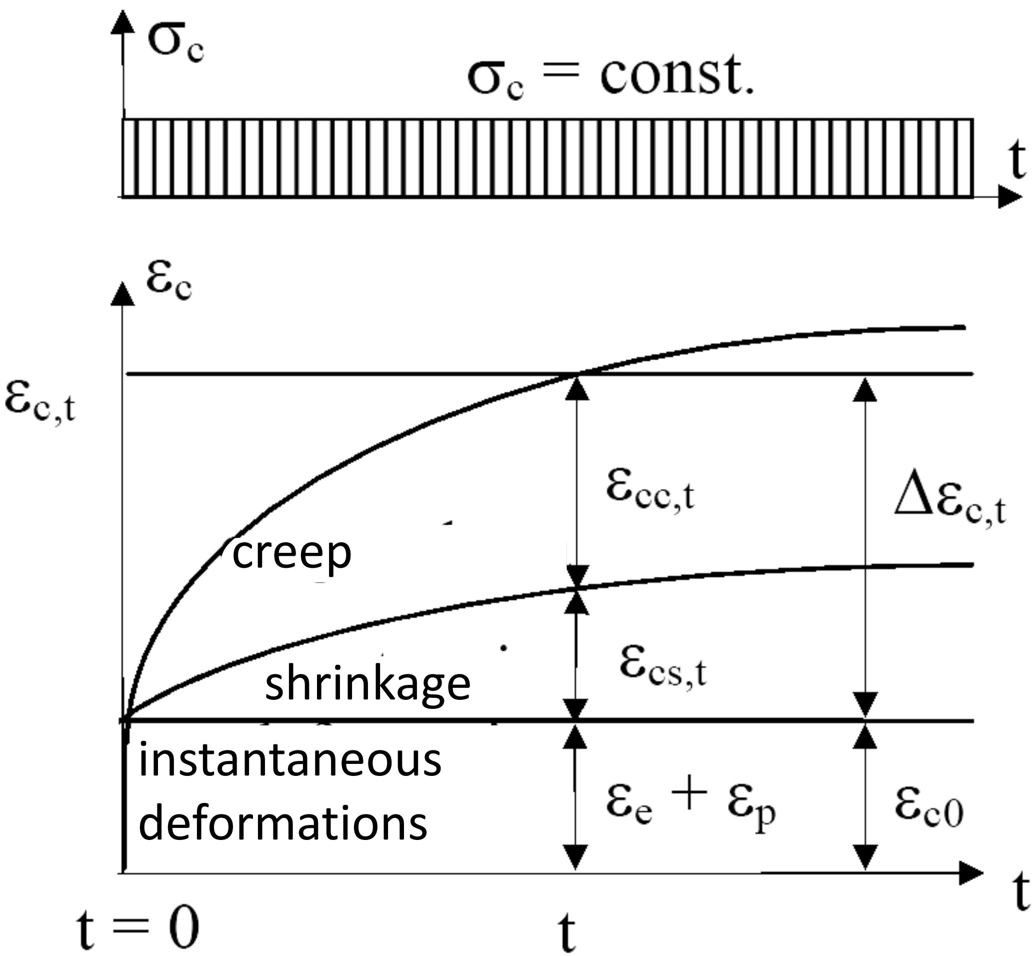
1. t_0 - age of the concrete at time of loading
2. Secant

3. h_0 [mm]

→ Creep of the concrete depend on the **ambient humidity**, the **dimensions** of the element and the **composition of the concrete +** the **maturity** of the concrete when the load is first applied and depends on the **duration** and **magnitude** of the loading.

Concrete deformations / Deformațiile betonului

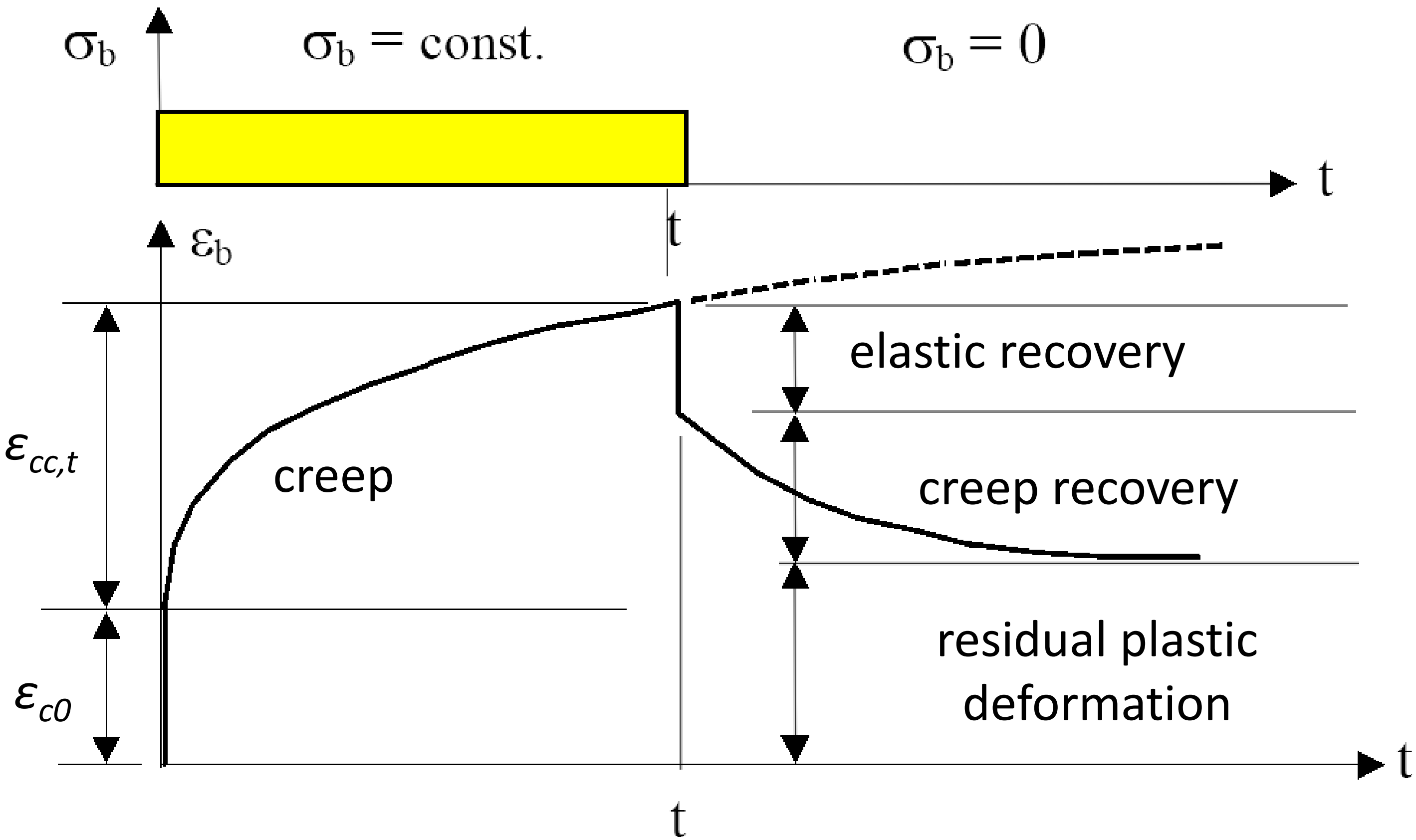
Time dependent deformations – The total deformation of concrete



$$\varepsilon_{c,total} = \underbrace{\varepsilon_{c0}}_{\varepsilon_e + \varepsilon_p} + \underbrace{\Delta\varepsilon_{c,t}}_{\varepsilon_{cs,t} + \varepsilon_{cc,t}}$$

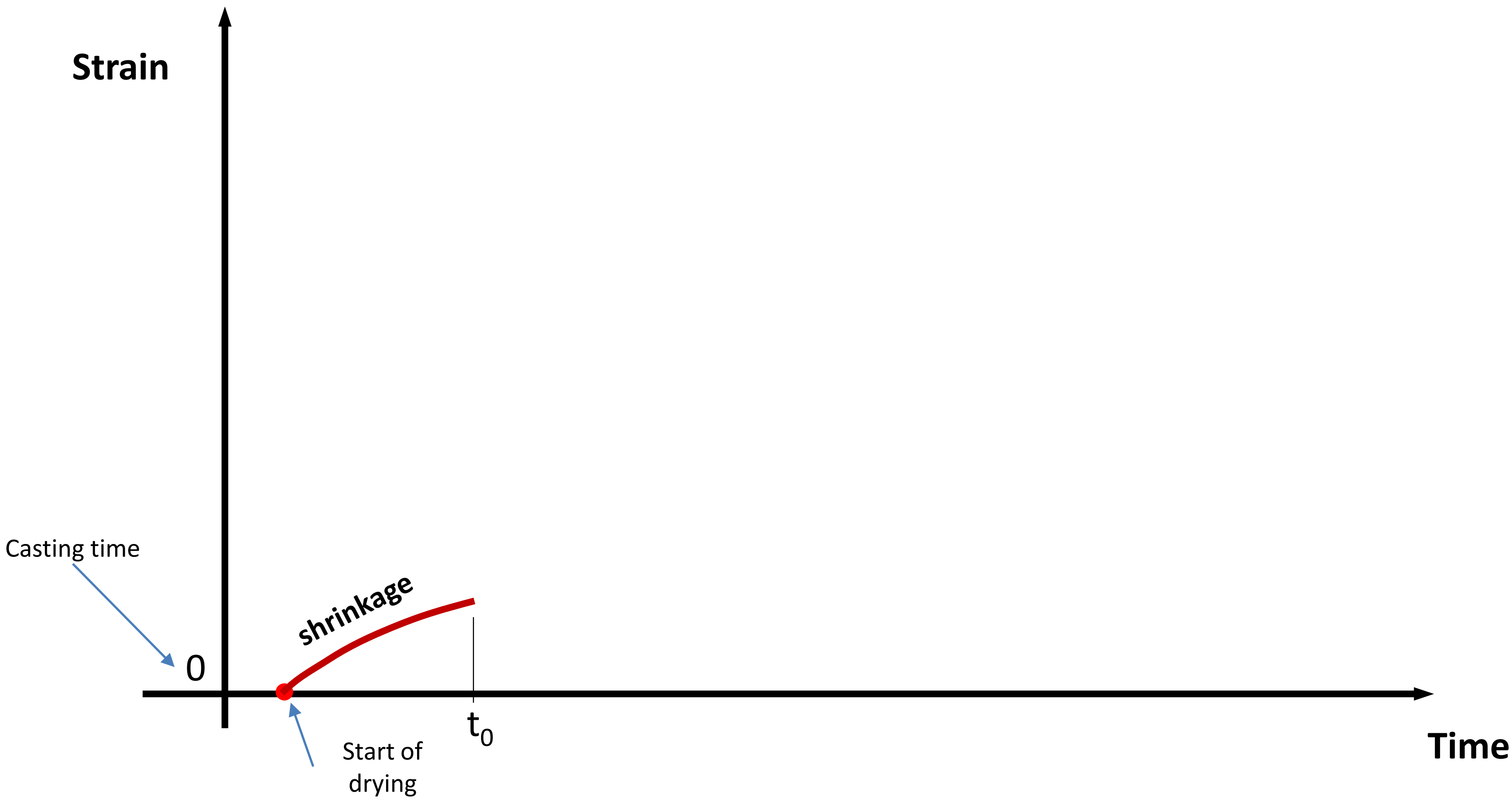
Concrete deformations / Deformaţiile betonului

Time dependent deformations – Effect of unloading on creep



Concrete deformations/ Deformațiile betonului

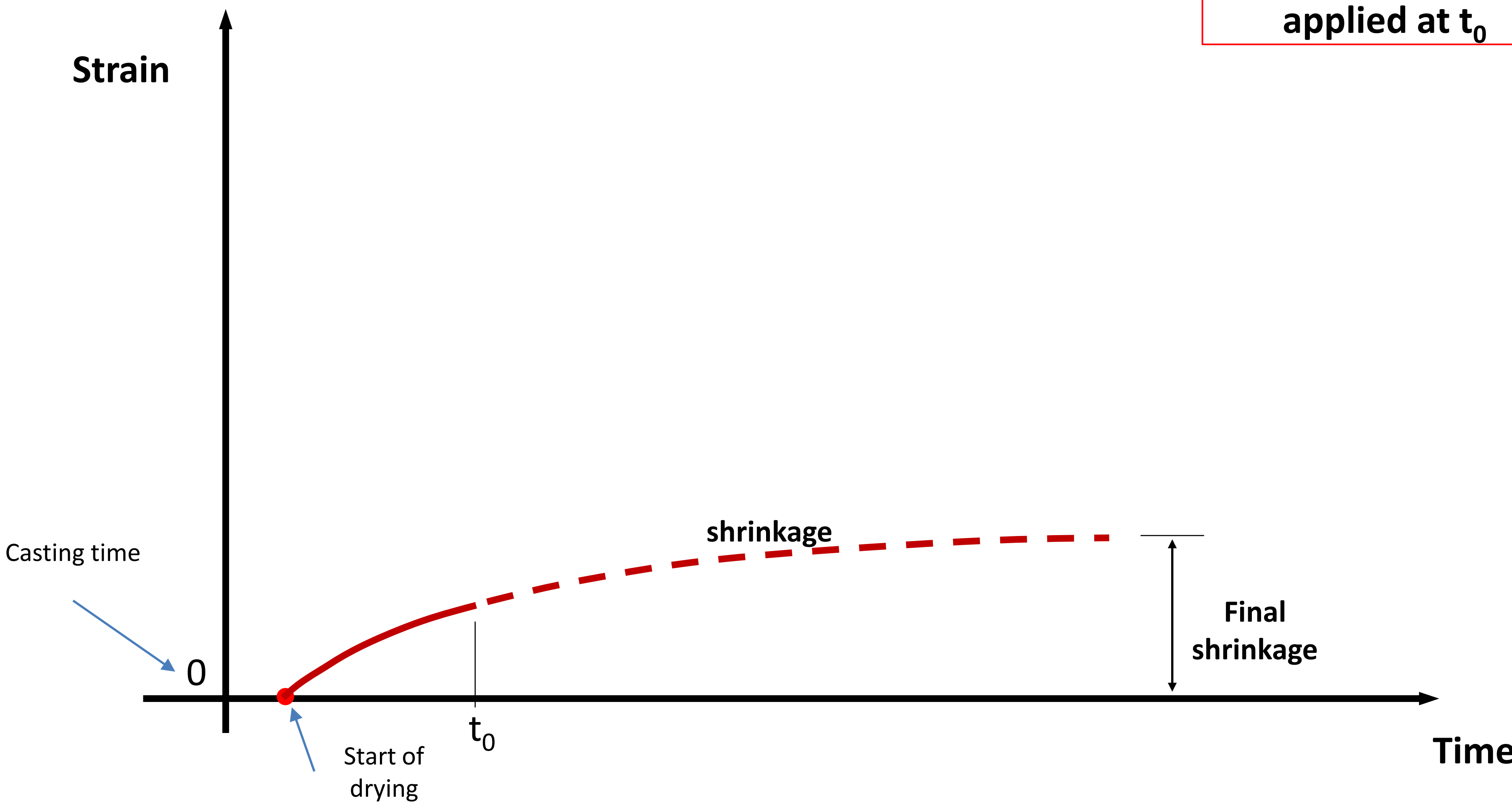
Time dependent deformations – Effect of unloading on creep



Concrete deformations/ Deformațiile betonului

Time dependent deformations – Effect of unloading on creep

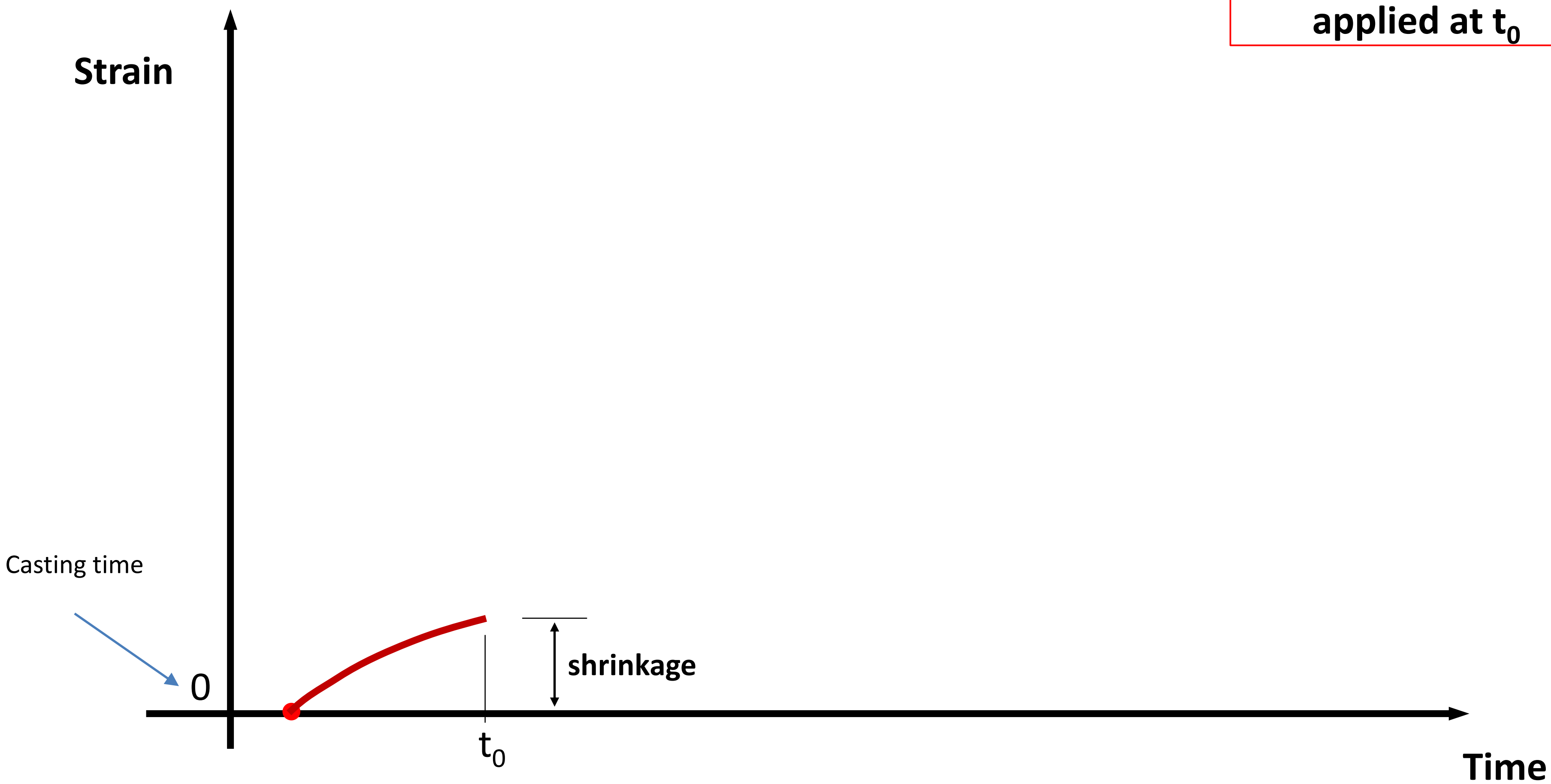
If no external force applied at t_0



Concrete deformations/ Deformațiile betonului

Time dependent deformations – Effect of unloading on creep

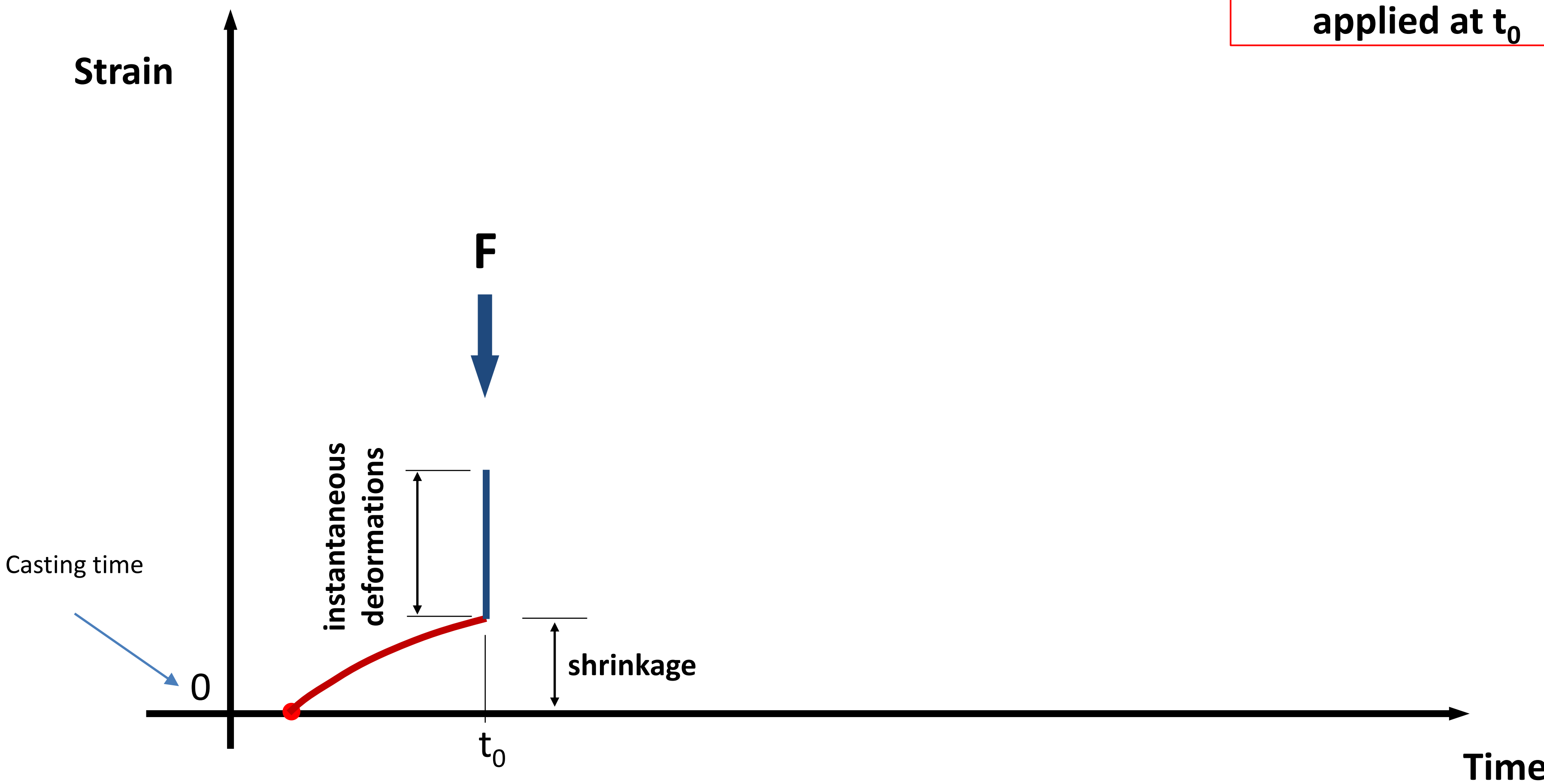
If external force is applied at t_0



Concrete deformations/ Deformațiile betonului

Time dependent deformations – Effect of unloading on creep

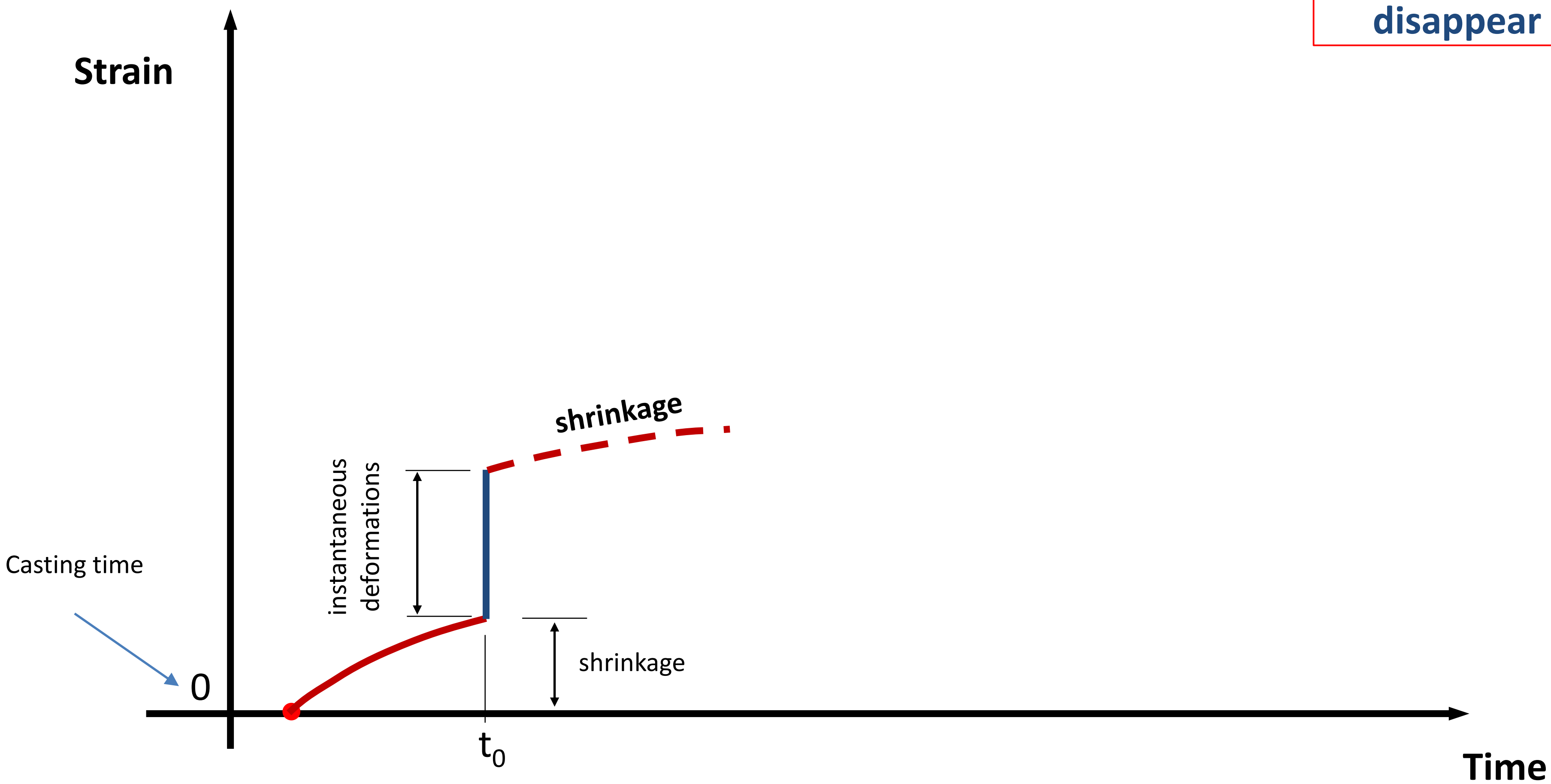
If **external force** is applied at t_0



Concrete deformations/ Deformațiile betonului

Time dependent deformations – Effect of unloading on creep

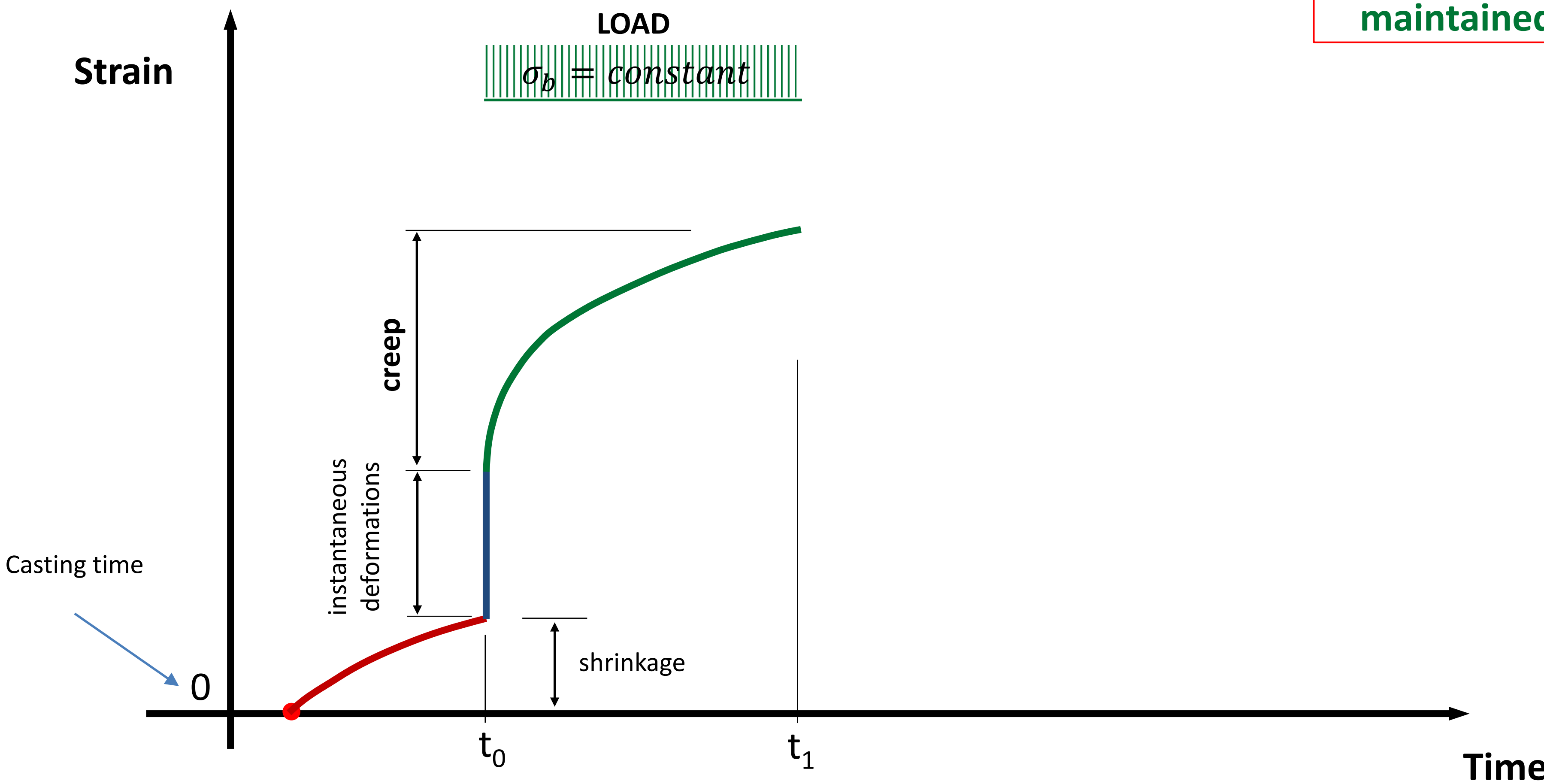
If the **force disappear**



Concrete deformations/ Deformațiile betonului

Time dependent deformations – Effect of unloading on creep

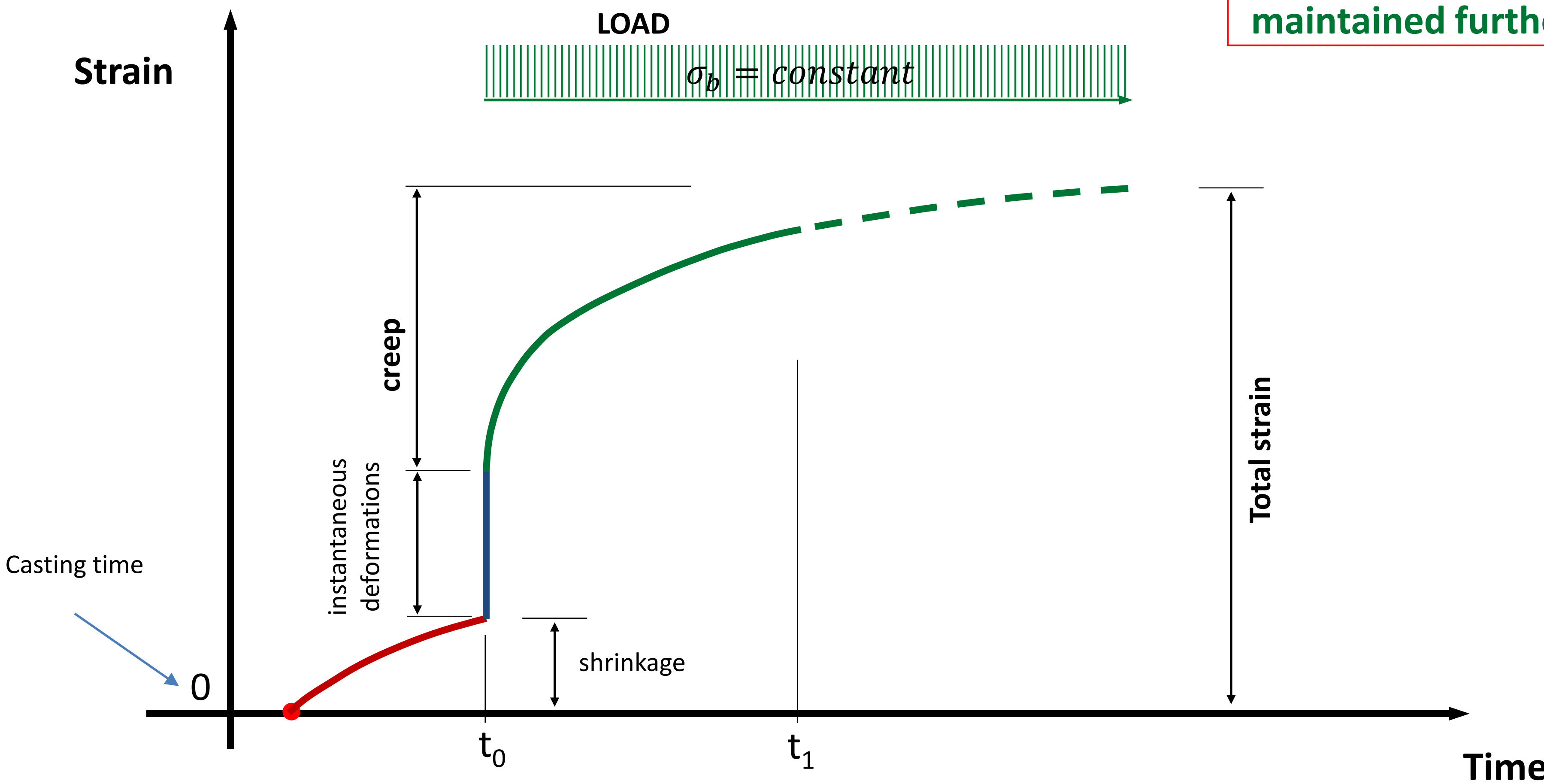
If the load is maintained



Concrete deformations/ Deformațiile betonului

Time dependent deformations – Effect of unloading on creep

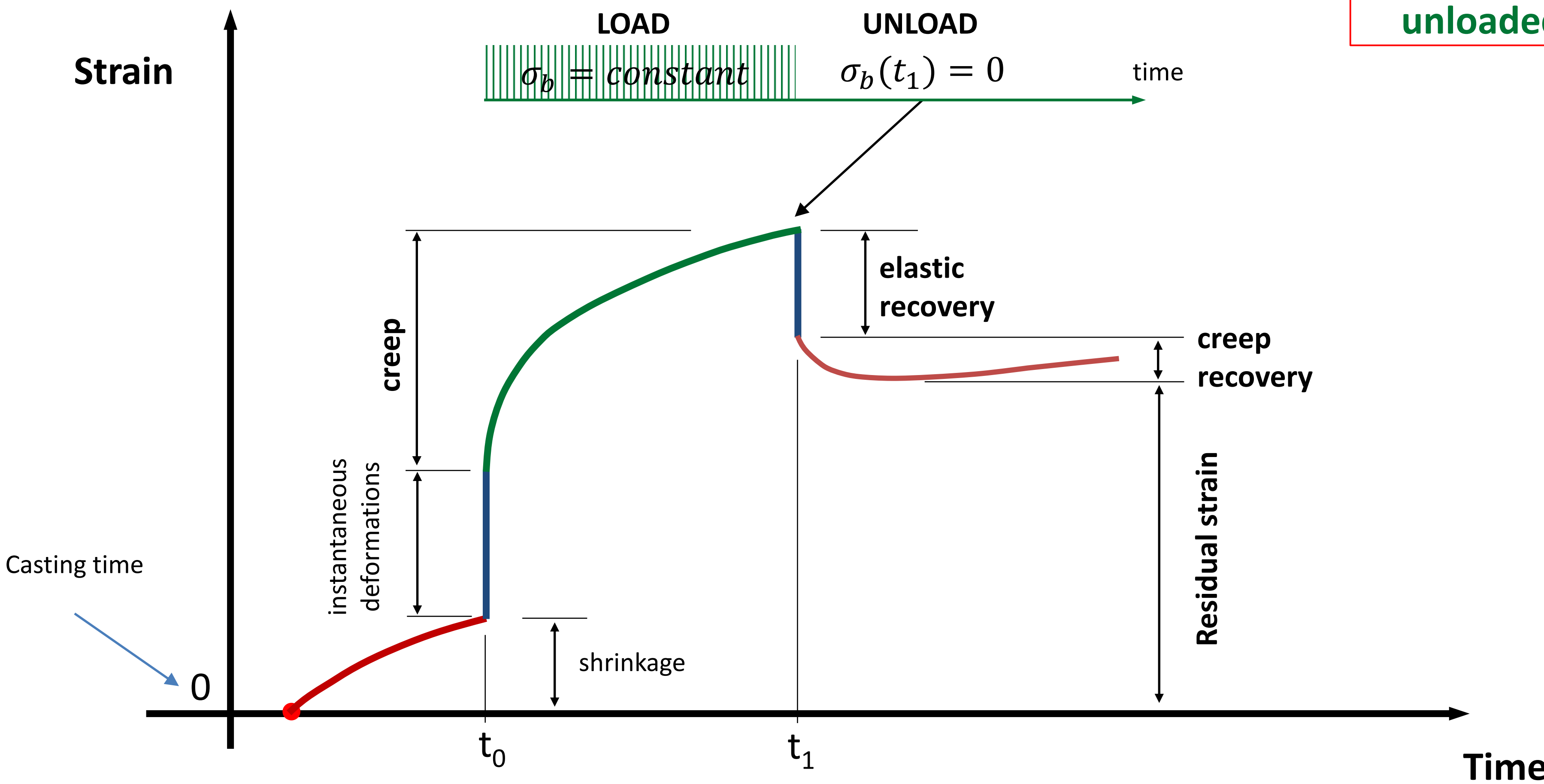
If the load is maintained further



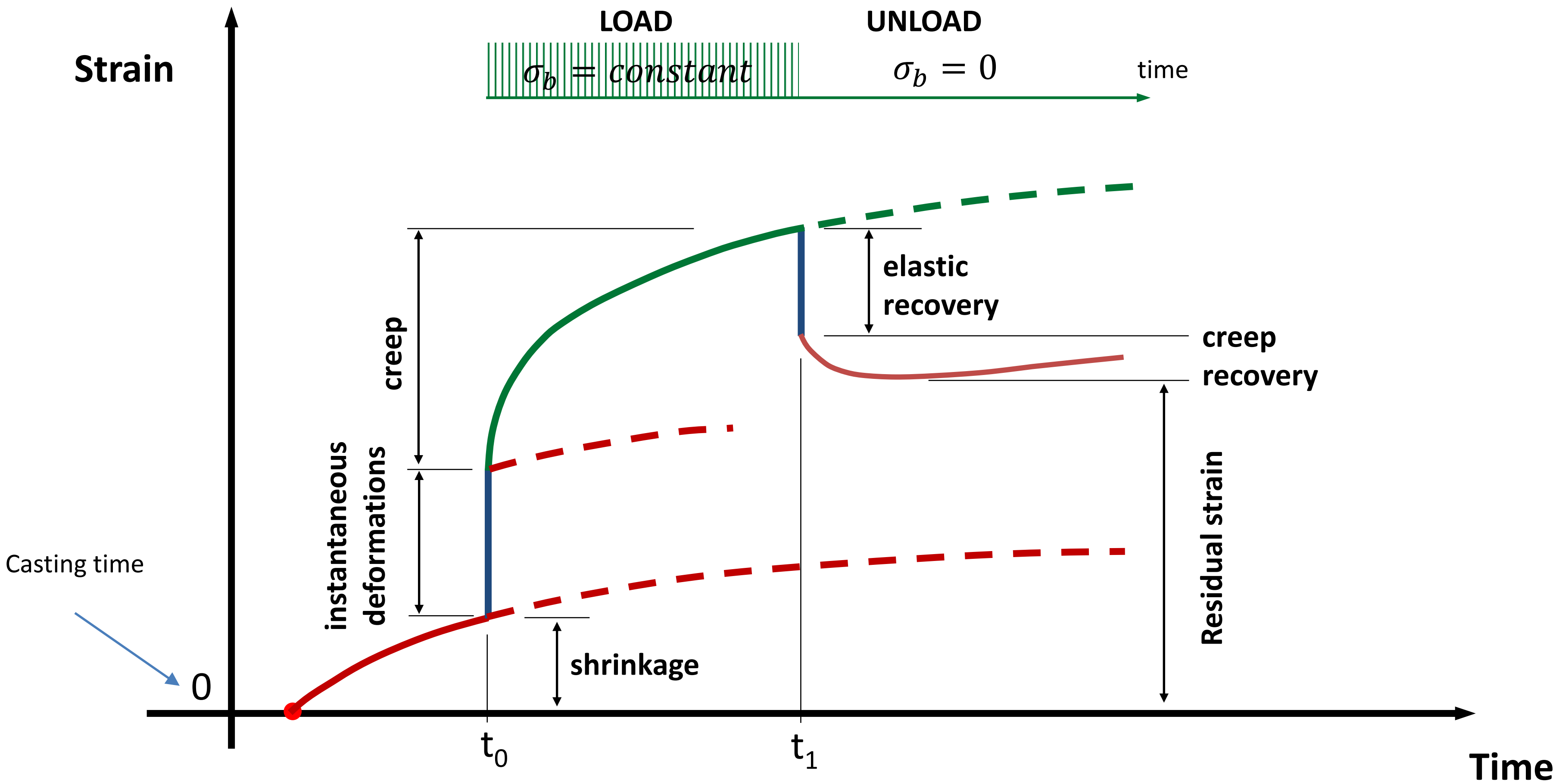
Concrete deformations/ Deformațiile betonului

Time dependent deformations – Effect of unloading on creep

If is **unloaded**

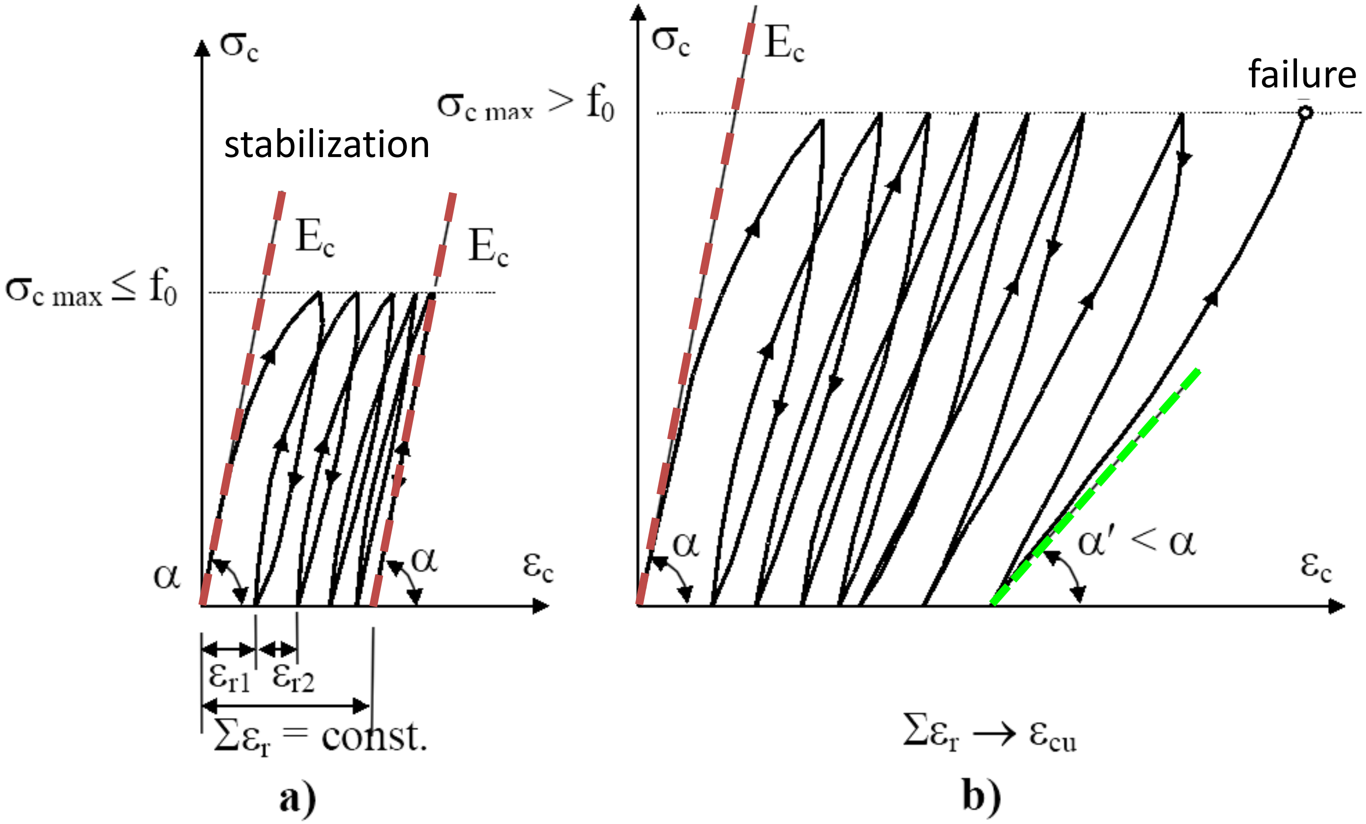


Time dependent deformations – Effect of unloading on creep



Concrete deformations / Deformațiile betonului

Deformations of concrete under repeated dynamic loads



ε_r = remanent strain (irreversible)

Reinforced Concrete / Betonul armat

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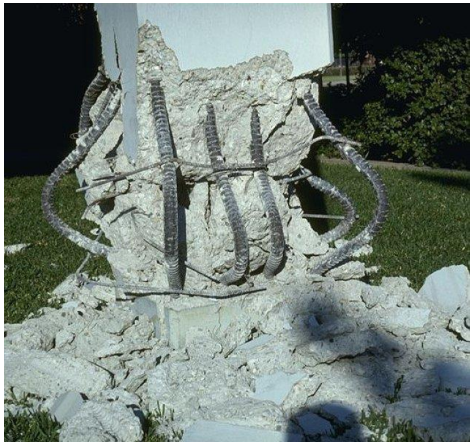

Thank you for your attention!