CE 382 Reinforced Concrete Fundamentals

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Introduction

- Binding Materials
  - Clay
  - Lime
  - Gypsum
  - Cement (developed by Roman; lime & volcanic ash; hydraulic cement at 18th century)
- Concrete
  - Cement
  - Sand
  - Gravel (or other aggregate)
  - Water
  - Admixtures

Choice of Concrete

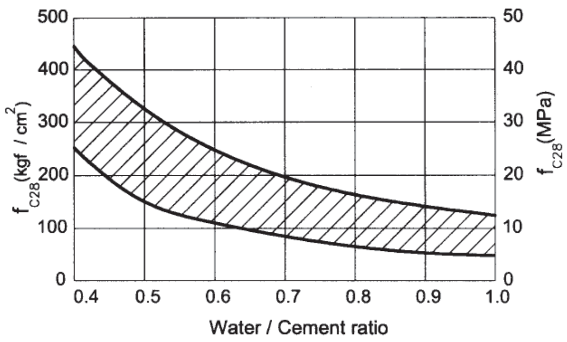
- Advantages
  - Can be mold into any shape
  - High compressive strength
  - Economy; long-term, maintenance & durability
  - Fire resistance
  - Rigidity
  - Availability
- Disadvantages
  - Low tensile strength
  - Forms and shoring
  - Relatively low strength per unit of weight or volume
  - Time-dependent volume change

Materials

- Cement
  - Particle size ⇘ strength ⇗
  - Special cements for low heat of hydration, less permeability
- Water
  - For chemical reactions
  - No acids
  - No high amount of salt
- Aggregate
  - Reduce the amount of cement paste & cost
  - Reduce the volume change of concrete
  - More durable

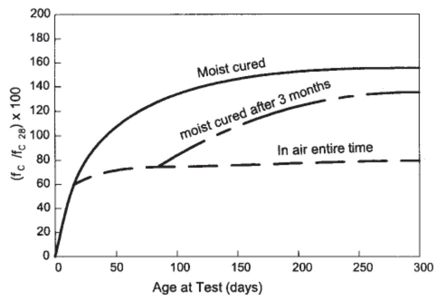
Mixing, Placing & Curing of Concrete

- Mix design for required strength & workability,
  durability & permeability
- Water/cement (w/c)↘ strength↗
  workability↘ (transportation & placing)



Mixing, Placing & Curing of Concrete

- During transportation, prevent segregation, the separation of the larger pieces from the bulk of the mass
- Avoid honeycombed spots in finished concrete
- Prefer ready-mix concrete
- Proper curing; not let water to evaporate until concrete sets



Mechanical Properties of Concrete

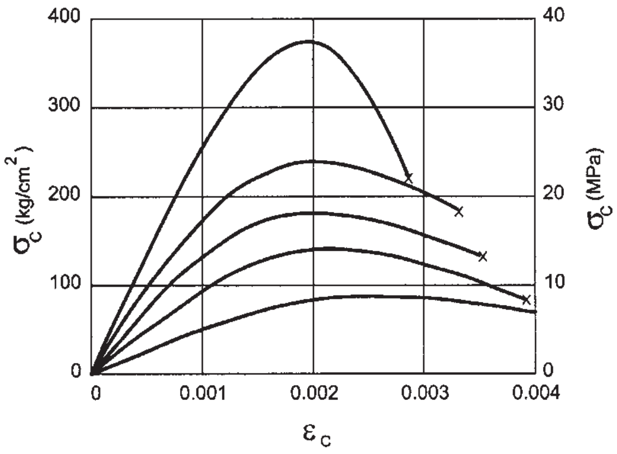
- Concrete
  - Nonlinear
  - Inelastic
  - Nonhomogeneous
  - Time dependent
- Uniaxial Compressive Strength of Concrete
  - Cube (200×200×200 mm or 150×150 ×150 mm)
  - Cylinder (150×300 mm)
  - $\frac{f_{c,cylinder}}{f_{c,cube}} = 0.7\sim1.1$ mean app. 0.80-0.85

Mechanical Properties of Concrete

- Rate of strength gain
  - 0-7 day: very fast
  - 7-28 day: slower
  - After 28 days very slow
- Size effect: size↗ strength↘
- Rate of loading↘ strength↘

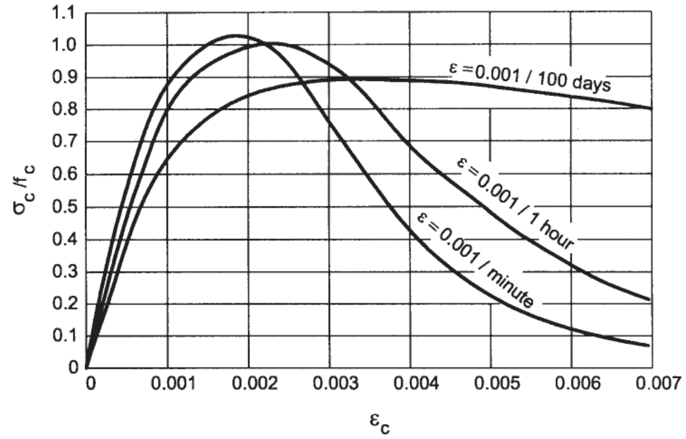
Uniaxial Compression

- ε_{co}=0.002
- Failure at ε_{cu}
- Descending portion
- Different concrete strength
- Different initial Modulus of elasticity

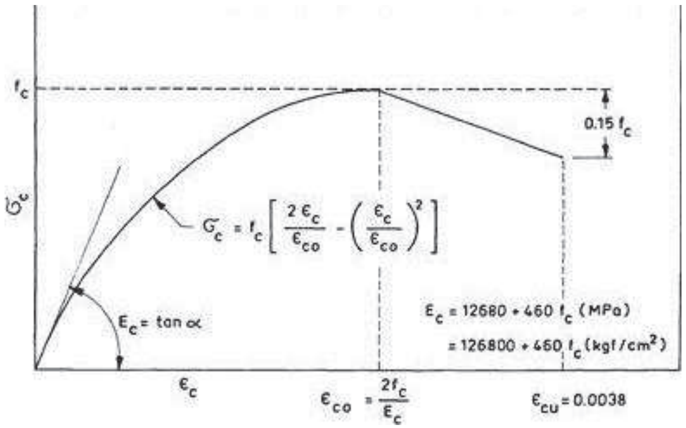


Rate of Loading

- Strain rate ↘
- Strength ↘
- Strain capacity ↗

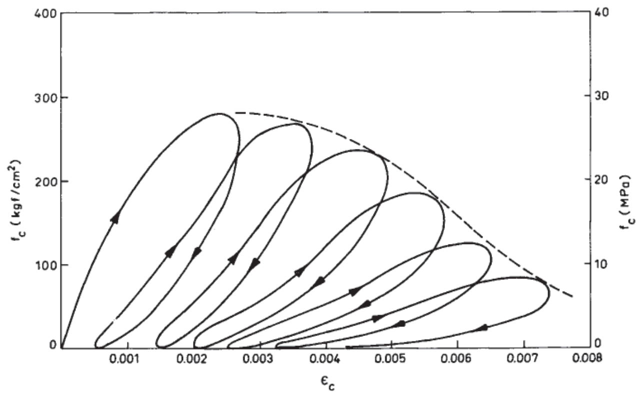


Mathematical Model



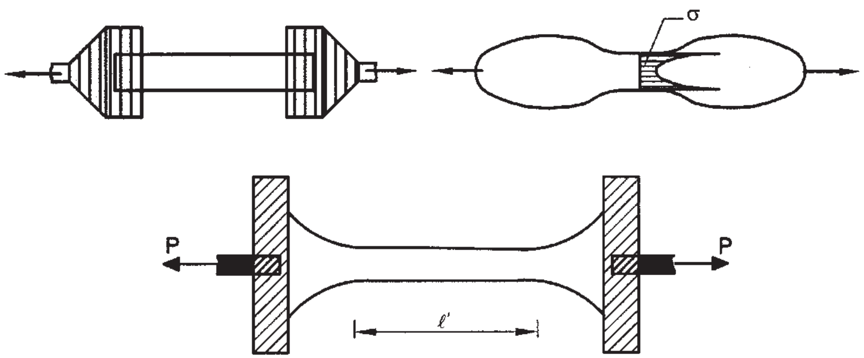
Repeated (cyclic) loading → hysteresis

- Envelope curve
- Stiffness degradation
  - # of cycles ↗
  - Stiffness ↘



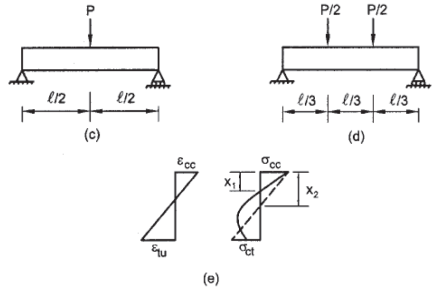
Tensile Strength of Concrete

- Direct Tensile Tests, f_{ct}



Tensile Strength of Concrete

- Indirect Tensile Tests
  - Modulus of Rupture Test, f_{ctf}

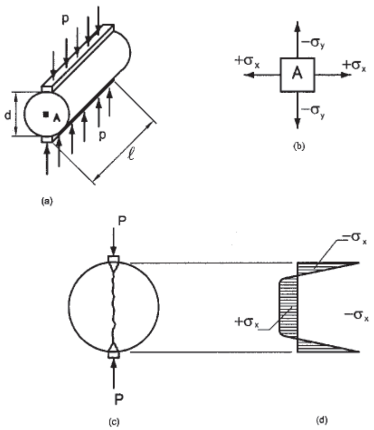


$$f_{ctf} = \frac{M \cdot y}{I}$$

$$f_{ctf} > f_{ct}$$

Tensile Strength of Concrete

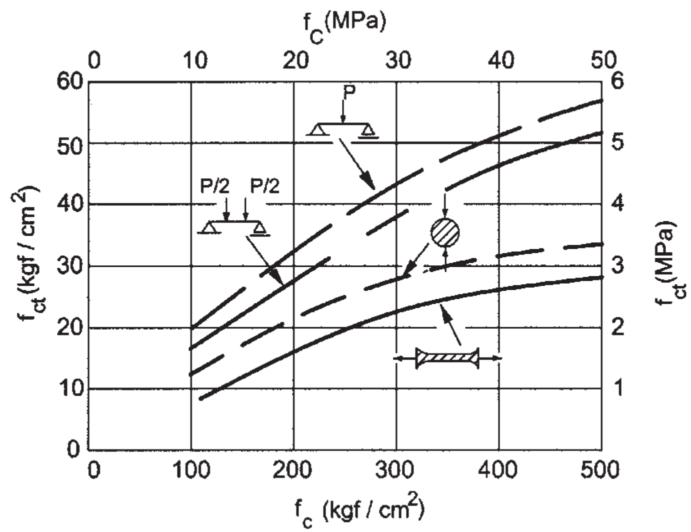
- Indirect Tensile Tests
  - Split Cylinder Test, f_{cts}



$$f_{cts} = \frac{2 \cdot P}{\pi \cdot \ell \cdot d}$$

$$f_{cts} > f_{ct}$$

Tensile Strength of Concrete

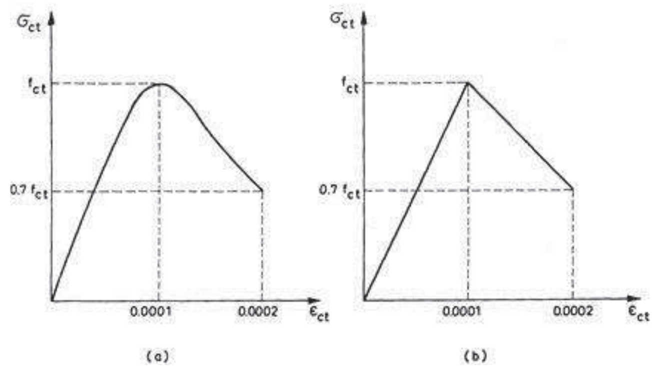


Tensile Strength of Concrete

TS 500-2000

- Direct tensile strength $f_{ct} = 0.35\sqrt{f_c}$
- Split tensile strength $f_{cts} = 0.50\sqrt{f_c}$
- Flexural tensile strength $f_{ctf} = 0.64\sqrt{f_c}$ (two point)
- Flexural tensile strength $f_{ctf} = 0.70\sqrt{f_c}$ (single point)

Tensile Strength of Concrete

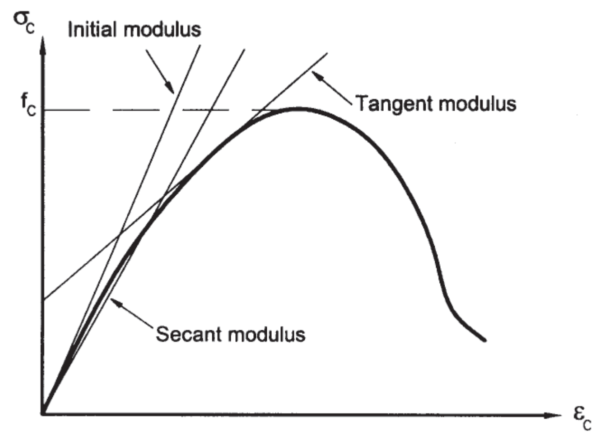


Shear Strength of Concrete

- Shear strength > tensile strength
- 35% - 80% of compressive strength
- Not of primary importance
- Principal tensile stresses

Modulus of Elasticity

- Slope of the σ–ε curve
- Changes with the stress level
- Initial modulus
- Secant modulus
  - 0-0.5f_c
- Tangent modulus
  - @0.4-0.5f_c



Modulus of Elasticity

$$E_c = w_c^{1.5} \cdot 0.043 \cdot \sqrt{f_c'}$$

$$E_c = 4700 \cdot \sqrt{f_c'}$$

ACI 318-08
w_c between 1440-2560 kg/m^3

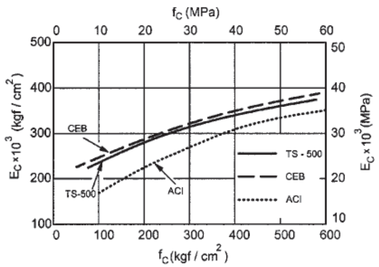
(in MPa)

$$E_{cm} = 22000\left(\frac{f_{cm}}{10}\right)^{0.3}$$

EuroCode 2

$$E_{cj} = 3250 \cdot \sqrt{f_{ckj}} + 14000$$

TS 500-2000

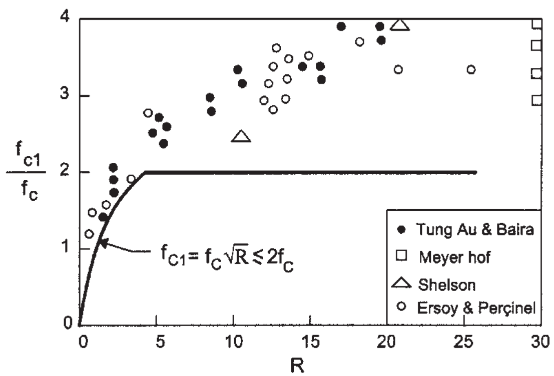


Modulus of Elasticity

- **Under sustained load → time dependent deformations →** $E_c \searrow$ to $^1/_2$ or even $^1/_3$ of its initial value
  - Level of loading
  - Age of concrete
  - Humidity
  - Temperature
  - time

Bearing strength

- $f_{cl} = f_c\sqrt{R} \;\; \leq \;\; 2f_c$
- $R = \dfrac{total\ area}{loaded\ area}$
- f_{cl}: bearing strength
- R $\nearrow$ $\quad f_{cl} \nearrow$

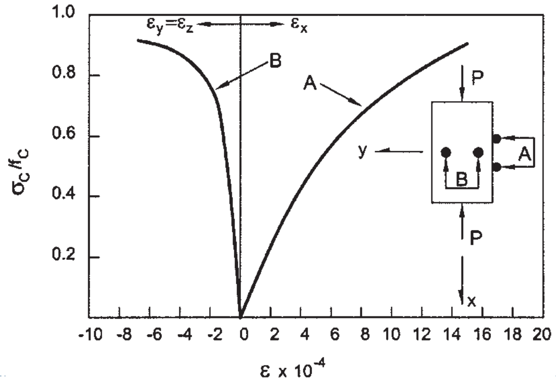


Coefficient of thermal expansion

- of concrete 1×10^{-5} mm/mm/°C
- the same for steel

Poisson's Ratio

- $\mu = \frac{transverse\ strain}{longitudinal\ strain}$
- in the design μ is neglected
- ${}^{\sigma_c}/_{f_c} = 0.3 - 0.7 \rightarrow \mu_c = 0.15 - 0.25$
- TS 500 μ_c = 0.20

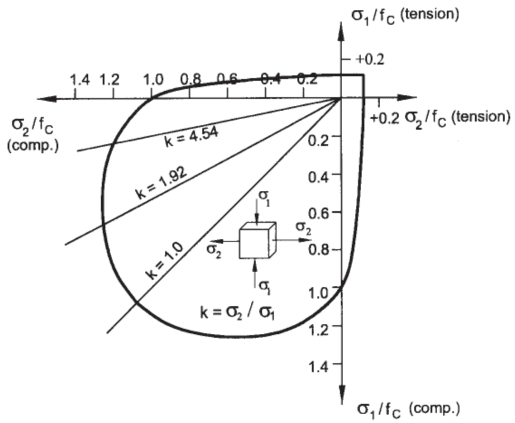


Shear modulus

- $G_c = \frac{E_c}{2(1+\mu_c)}$ elasticity equation
- TS 500 $G_c = 0.4E_c$

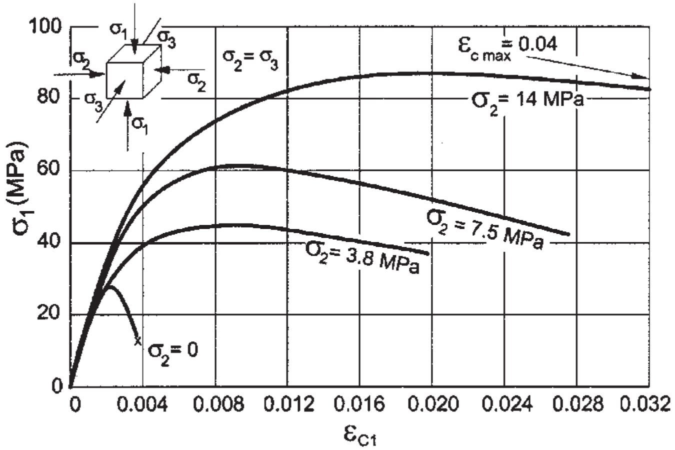
Behavior under multi-axial stresses

- Biaxial
  - Tensile stresses in both direction
    - The strength is not different than that of uniaxial tension
  - One in tension, orthogonal in compression
    - Strength is less as compared to uniaxial tension
  - Compression in both directions
    - Strength is greater than uniaxial compression



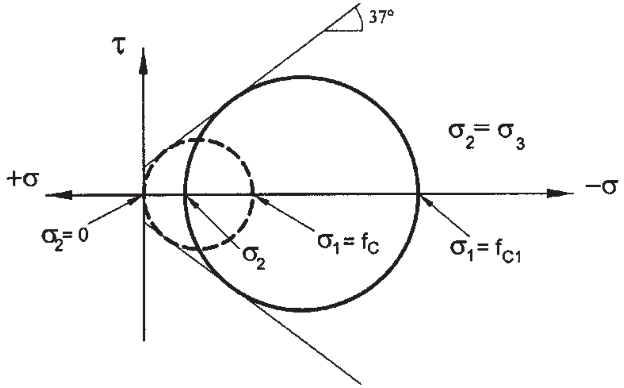
Behavior under multi-axial stresses

- Triaxial
  - $\sigma_2 = \sigma_3$ ⇗ → strength and strain capacity of concrete ⇗



Behavior under multi-axial stresses

- If $\sigma_2=\sigma_3$ and all stresses are compressive
- $f_{cl} = f_c + 4.0\sigma_2$

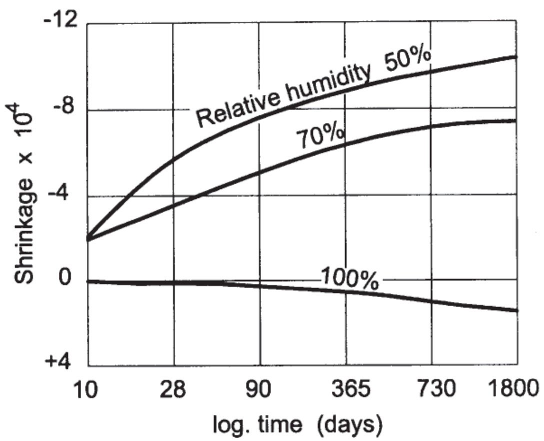


Time dependent deformations of concrete

- Shrinkage
  - Water necessary for hydration → appr. 25% of the cement by weight
  - For workability more water is used
  - Excess water evaporates → volume ⇘ (shrink)
  - Shrinkage causes significant deformations & stresses in concrete structures
  - Shrinkage can affect both strength and serviceability of the structure

Time dependent deformations of concrete

- Shrinkage depends on evaporation → function of
  - Temperature
  - Humidity
  - Area of exposed surface
  - Water content of mix
  - Time



Time dependent deformations of concrete

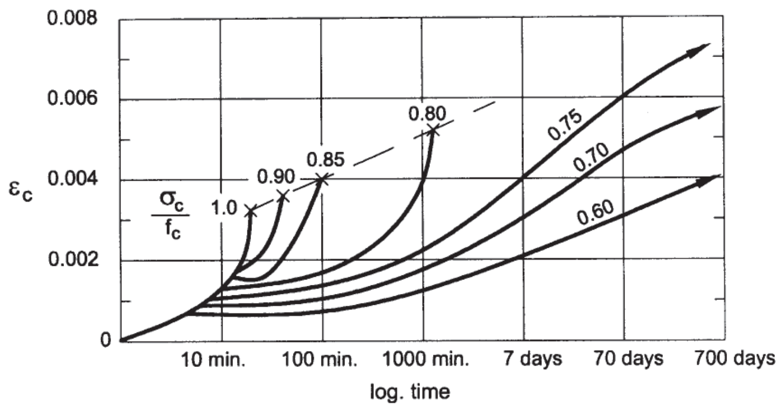
- Plain concrete → not strained → shrinkage causes no stresses
- RC members → not restrained → compression in steel & tension in concrete
- RC member restrained → internal forces due to shrinkage
- For long walls and buildings → expansion joints

Time dependent deformations of concrete

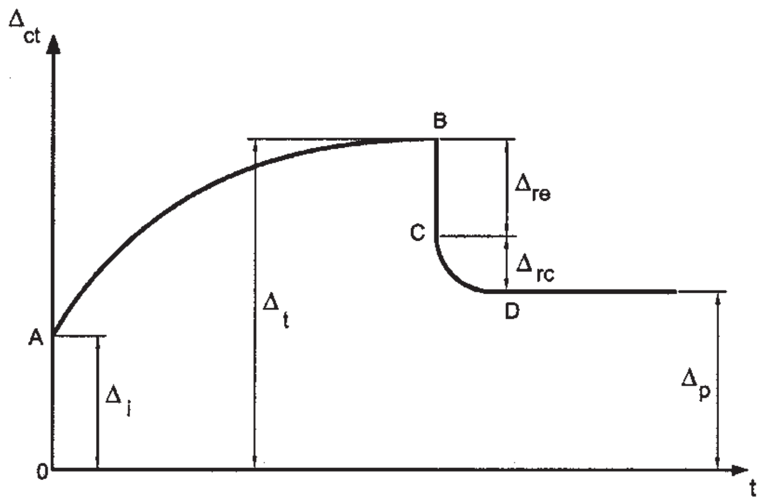
- Creep
  - Time dependent deformations under sustained load
  - Depends on
    - The age of concrete ↗ → creep ↘
    - w/c ratio ↗ → creep ↗
    - Humidity ↗ → creep ↘
    - Level of sustained load
    - Time
  - Significant amount of redistribution due to creep in RC structures

Time dependent deformations of concrete

- Creep
  - Level of sustained load

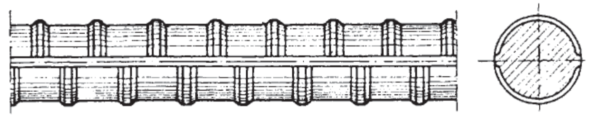


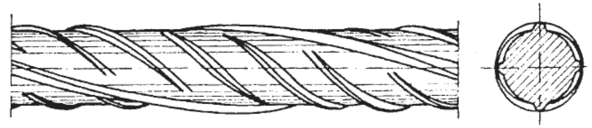
Time dependent deformations of concrete



Steel reinforcement

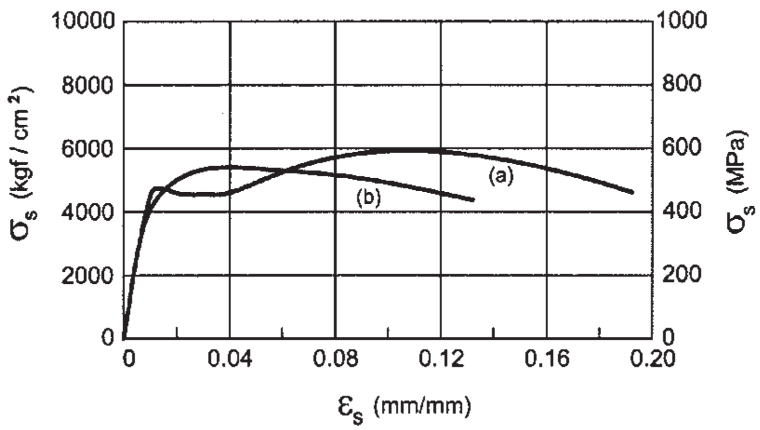
- Plain bars, S220
- Deformed bars, S420





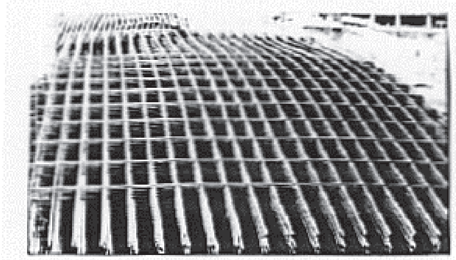
Steel reinforcement

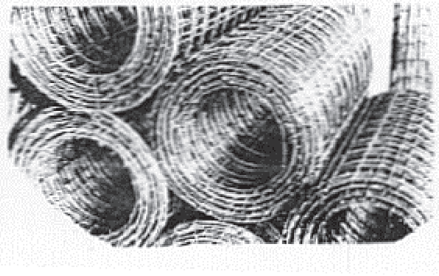
- Hot rolled
- Cold worked



Steel reinforcement

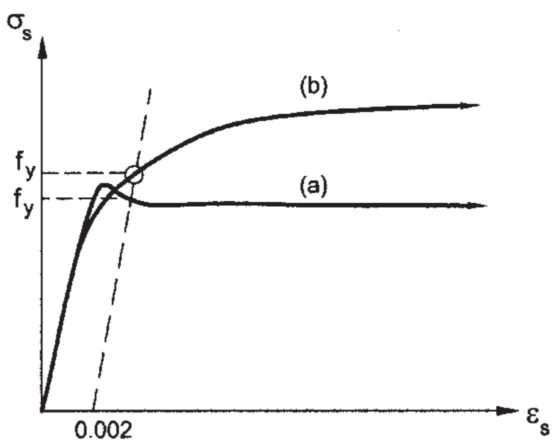
- Welded wire fabric





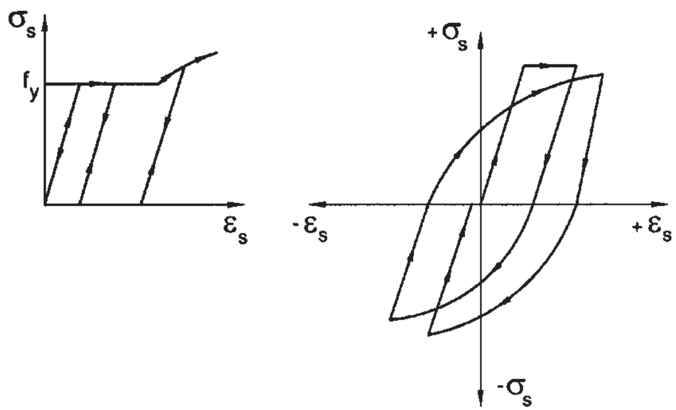
Steel reinforcement

- $\phi 8$, $\phi 10$, $\phi 12$, $\phi 22$
- #5, #8
- E_s = 200 000 MPa



Steel reinforcement

- Behavior under repeated and reversed loading
  - Bauschinger effect



(a) (b)

Concrete grades

- C16: characteristic cylinder compressive strength of 28 days in MPa
- C16, C18, C20, C25, C30,…, C50, → high strength concrete