CONCRETE AND REINFORCED CONCRETE

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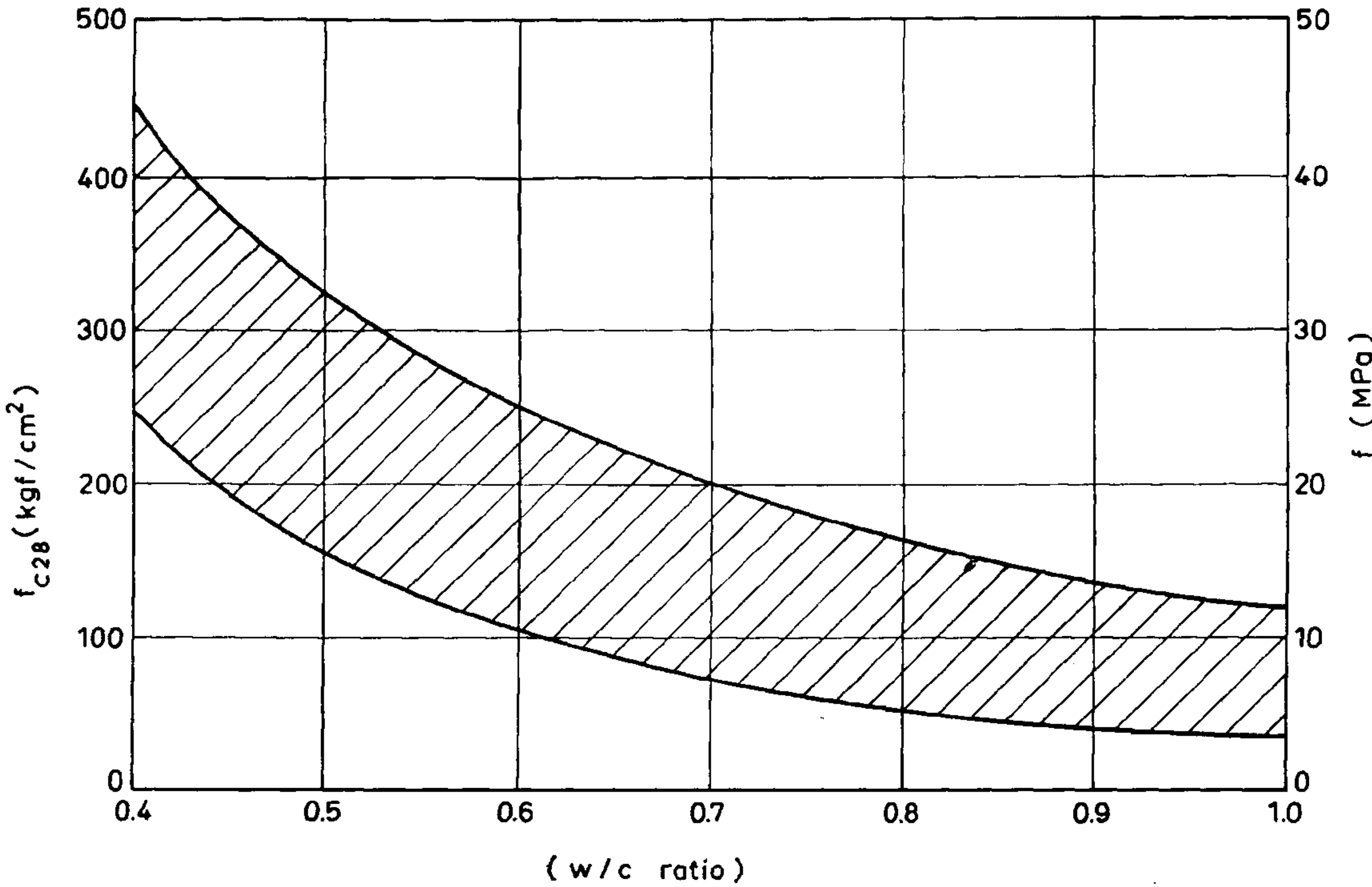
CONCRETE

Concrete is composed of sand and gravel (crushed rock or other aggregates) held together by a hardened paste of cement and water.

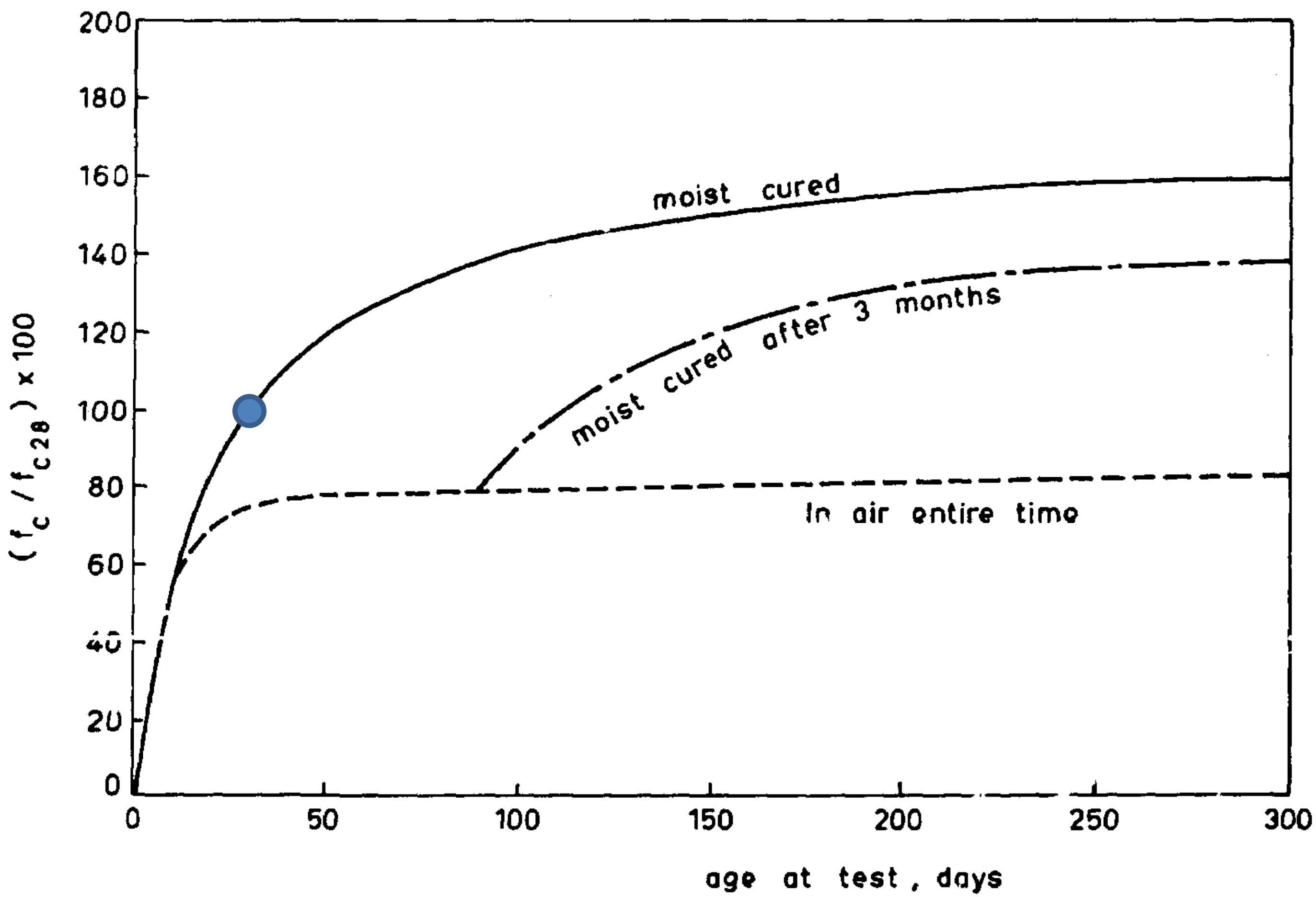
The mixed ingredients, when properly proportioned, make a plastic mass, which can be cast or molded into a predetermined size and shape.

Water is necessary for the chemical reaction of cement. However, the amount of water used for concrete is usually greater than the amount needed for the chemical reaction. The extra water is necessary for workability of the mix.

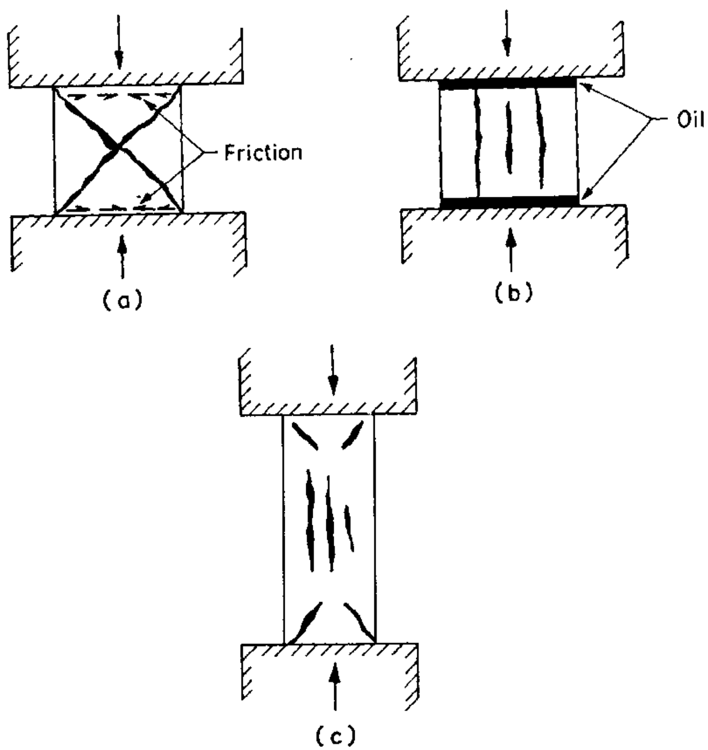
Effect of w/c Ratio



Effect of Curing



Mechanical Properties of Concrete Uniaxial Compressive Strength, f_c



Problems with cube specimens:

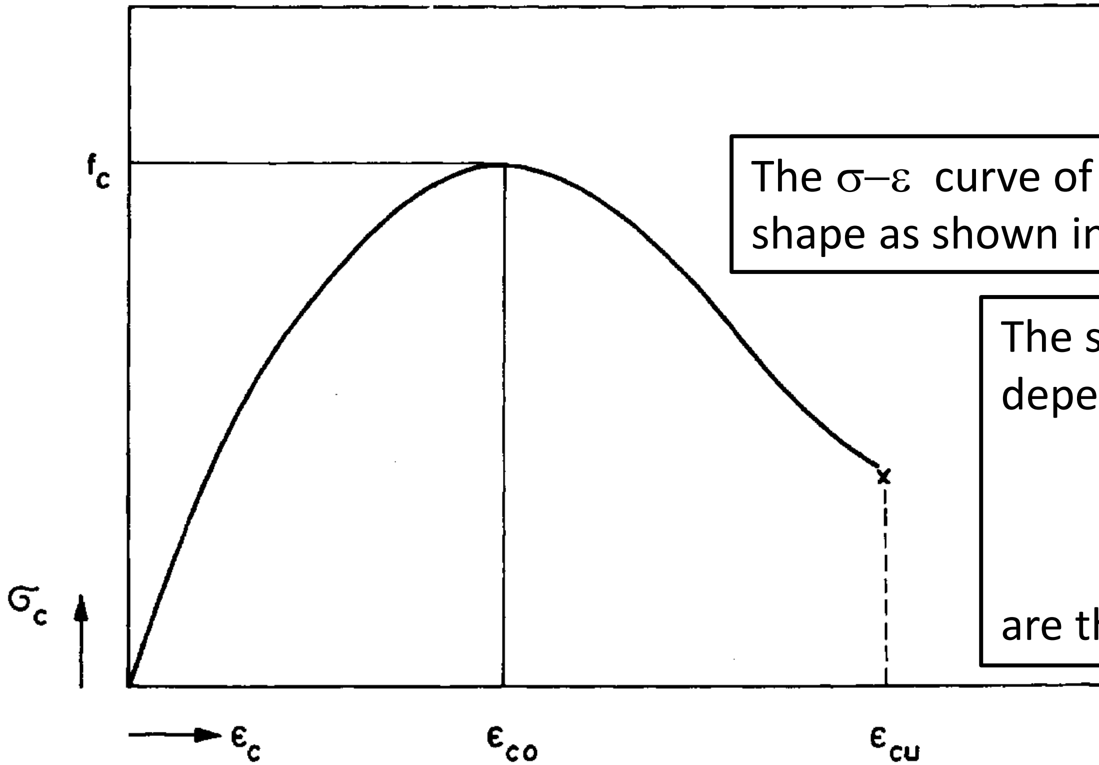
- As the cross-sectional area is large they generally require high capacity press
- Sharp corners are potential stress concentration locations
- If no proper action is taken state of stress is bi-directional due to friction.

In cylinder specimens most of these problems are not encountered. Therefore they are widely used.

Size Effecet as size ↓ f_c ↑

Standard Cube: 200×200 ×200 mm or 150×150 ×150 mm
Standard cylinder: 150×300 mm
f_c from standard cylinder ~ 0.7 – 1.1 f_c from standard cube => Another geometric effect

Uniaxial Compressive σ–ε Characteristics



The σ–ε curve of concrete is nonlinear and it has a shape as shown in the figure.

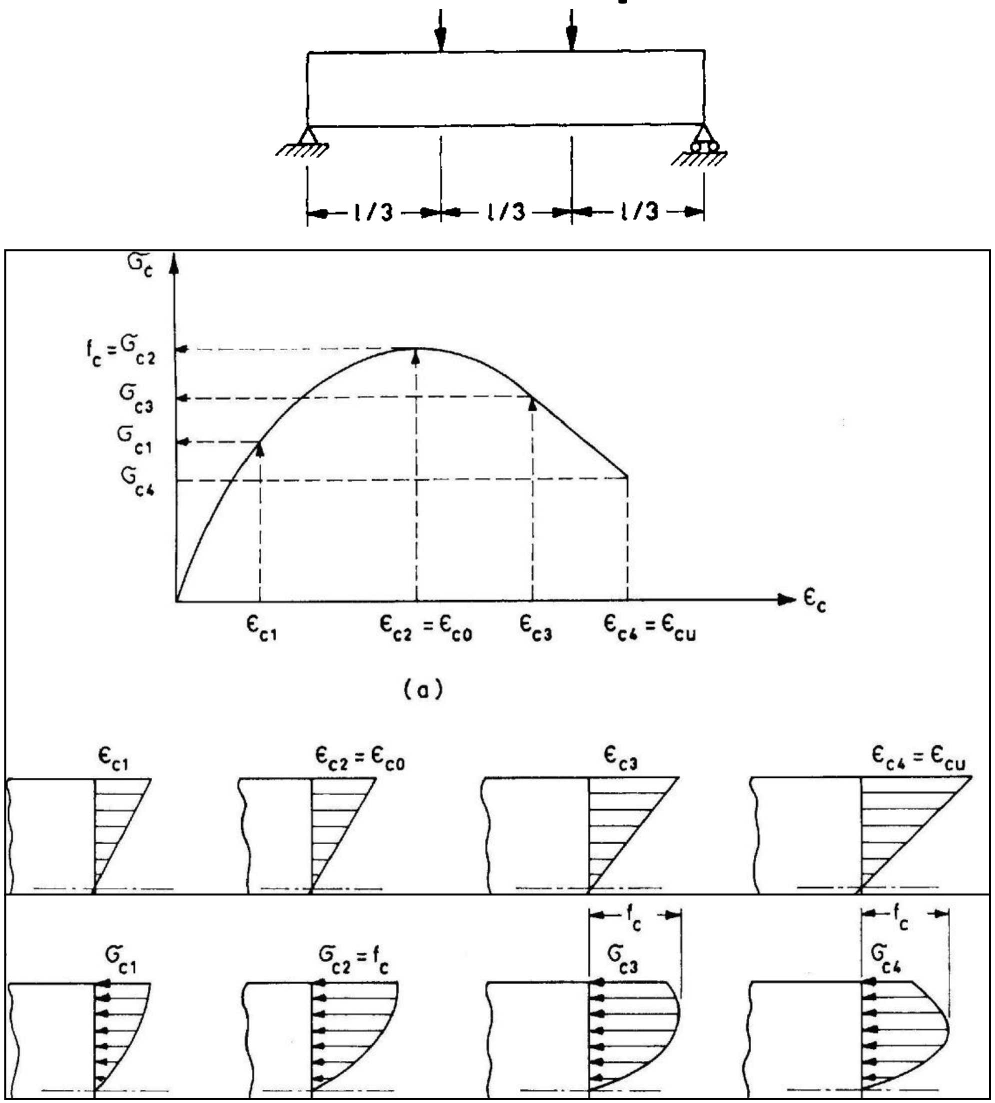
The stress-strain properties of concrete depend on many variables among which,

(a) strength of concrete
(b) Confinement
(c) rate of loading

are the most important ones.

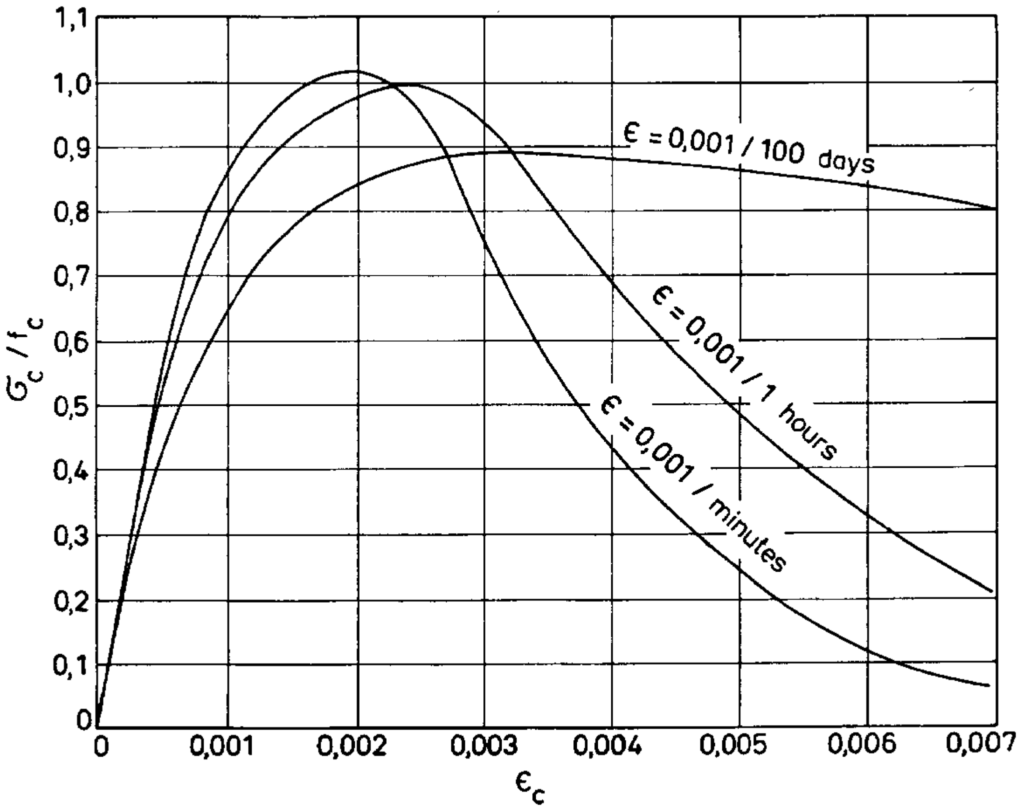
The maximum stress is reached at a strain of ε_{co}, which is approximately 0.002 for unconfined normal strength concrete.

Uniaxial Compressive σ–ε Characteristics



Beyond ε_{co} , strain increase is accomplished with decreasing stress (descending portion). The descending portion enables concrete to unload under increasing strains. Due to this property of the σ–ε diagrams, a section subjected to bending does not fail when the extreme fiber reaches the maximum stress, because at this stage the strain is ε_{co}, whereas the failure strain is ε_{cu}. As the strain increases beyond ε_{co} at the extreme fiber, the stress drops following the σ–ε diagram.

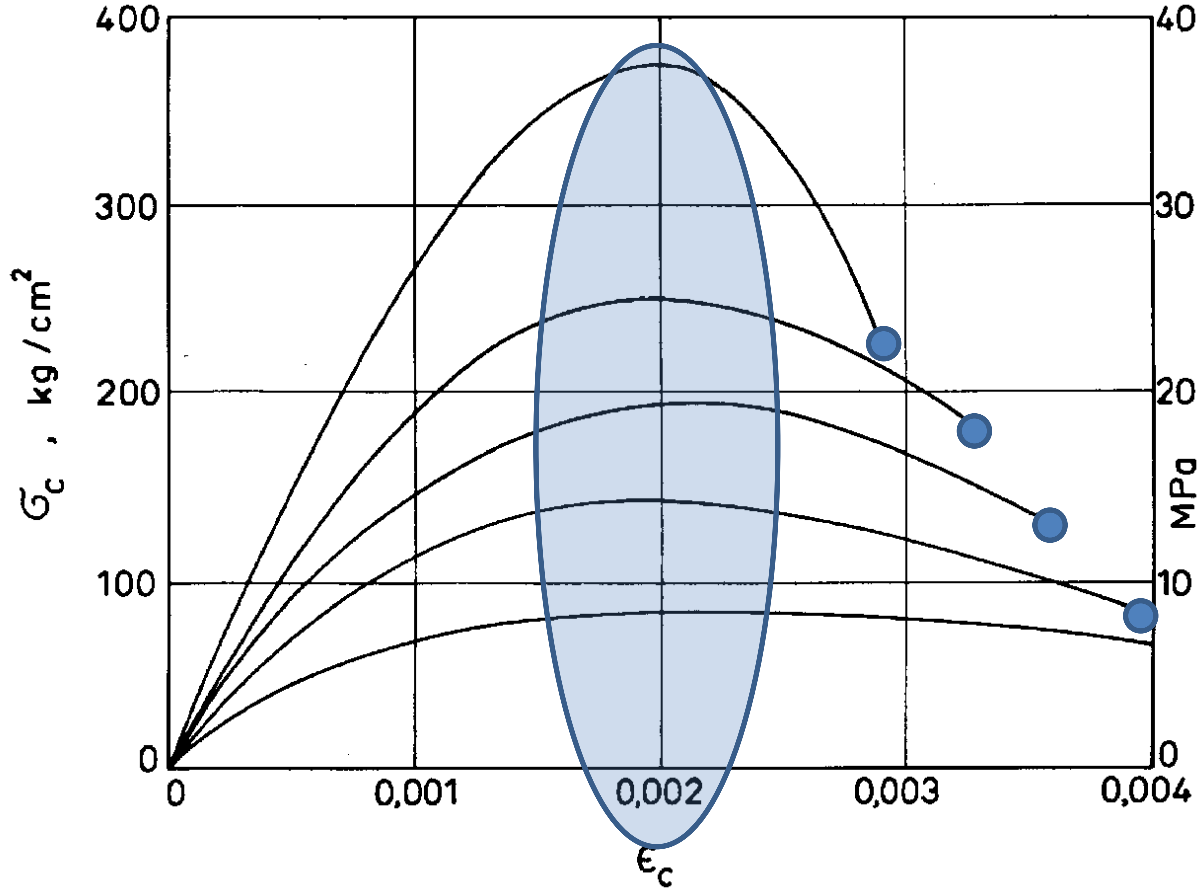
Uniaxial Compressive σ–ε Characteristics



Concrete is a time dependent material. Therefore, the rate of loading affects the compressive strength. The strength of a specimen, which is loaded slowly, is lower as compared to an identical specimen, which is tested under fast loading.

Due to this, a certain rate is specified for the standard tests.

Uniaxial Compressive σ–ε Characteristics

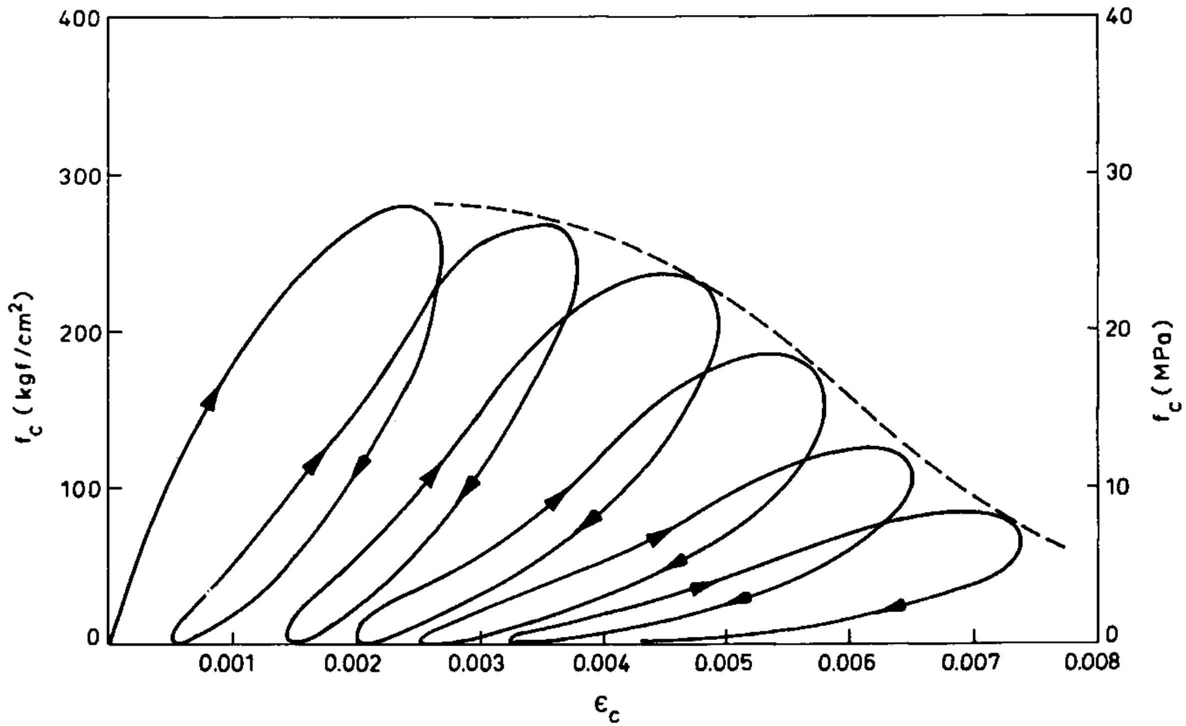


As the strength increases, the curve becomes steeper, with a smaller strain capacity at failure. It should also be noticed that the strain corresponding to maximum stress is almost same for each curve ($\varepsilon_{co} \cong 0.002$). The initial tangent to each curve, which might be called the initial modulus of elasticity, increases with increasing strength.

Uniaxial Compressive $\sigma-\varepsilon$ Characteristics

Other than the concrete strength and the rate of loading, confinement , the dimensions of the specimen and the stiffness of the testing machine also influence the $\sigma-\varepsilon$ curves obtained from cylinder tests.

Uniaxial Compressive σ–ε Characteristics



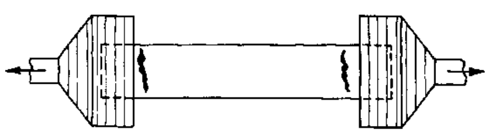
Repeated compressive loading produces a pronounced hysteresis effect in the σ–ε curve. Tests made in 1960s revealed that the envelope curve obtained by joining the peaks of each cycle is almost identical with the curve obtained from monotonically increasing load application. It should be noticed that the stiffness decreases significantly as the number of cycles increase. This is called "stiffness degradation".

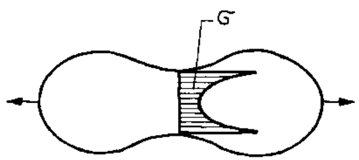
Uniaxial Tensile σ–ε Characteristics

Concrete, being a brittle material has a very low tensile strength (approximately 10 to 15 percent of the compressive strength).

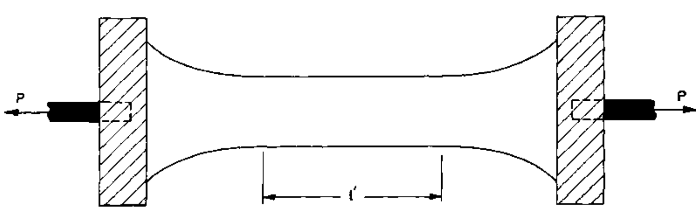
The ideal test specimen to obtain the tensile strength and the σ–ε diagram in tension would be a specimen subjected to uniaxial tension.

Direct Tension Tests:





These tests were not successful.

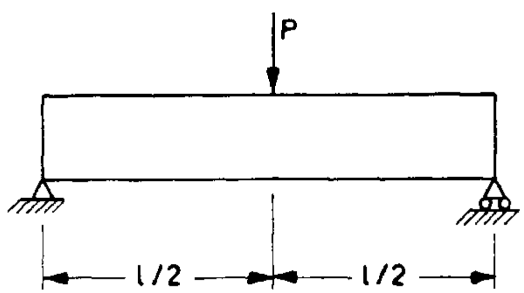


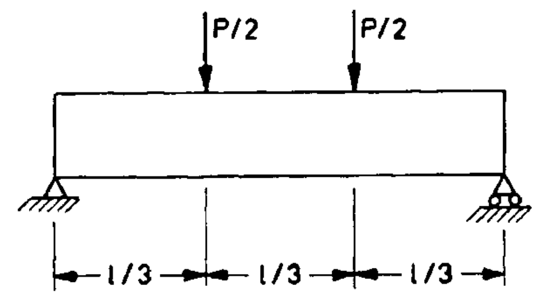
Early in sixties Prof. H. Rüsch developed a direct tensile test specimen, which proved to be very successful. The stress distribution is well defined at the test section, no stress concentration occurs and the introduction of load offers no difficulties or local failures. The tensile strength thus obtained is called the direct tensile strength of concrete, f_{ctd}.

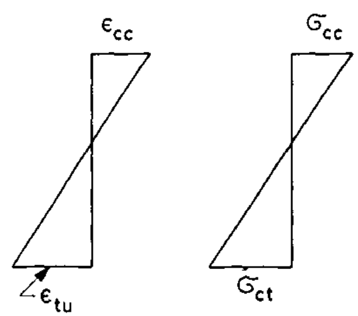
Uniaxial Tensile σ–ε Characteristics

Indirect Tension Tests:

The oldest indirect test is the flexure test or better known as "Modulus of Rupture Test"specimen to obtain the tensile strength and the σ–ε diagram in tension would be a specimen subjected to uniaxial tension.

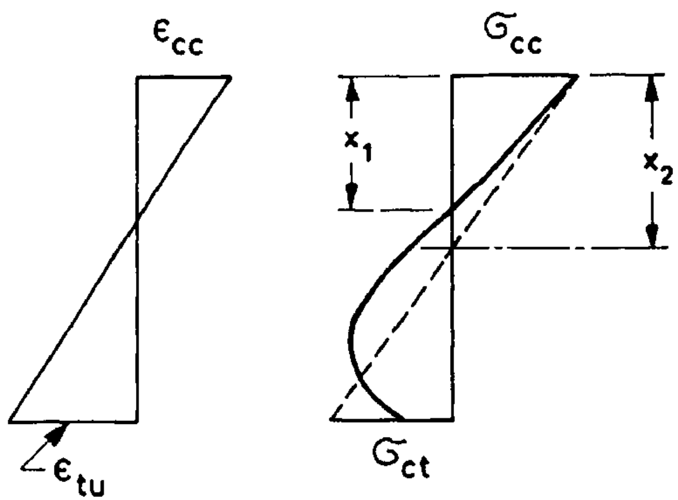






$$f_{ctf} = \frac{M \cdot y}{I} \quad \text{where } y = h/2$$

Uniaxial Tensile σ–ε Characteristics



The tensile strength obtained from flexural tests is higher than the true tensile strength.

In the derivation of f_{ctf} the stress distribution shown with dotted lines in the figure is assumed to be true.

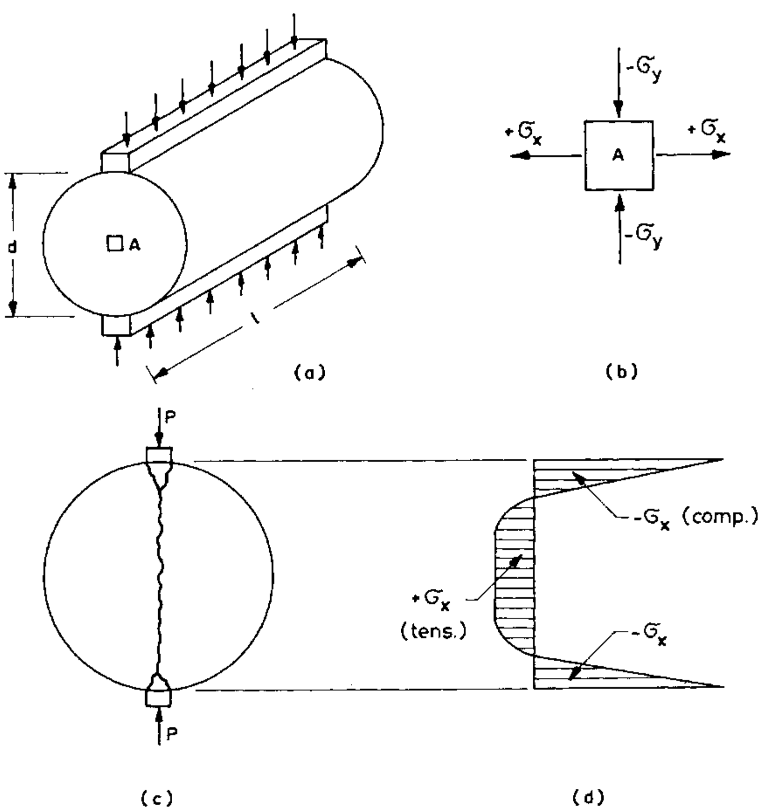
Due to inelastic behavior of concrete, however, redistribution takes place and the stress distribution becomes like the one shown by the solid line in the same figure.

The computations based on an idealized linear stress distribution will, therefore, overestimate the tensile strength.

Uniaxial Tensile σ–ε Characteristics

Indirect Tension Tests:

The other indirect method for determining the tensile strength is the "Split Cylinder Test".

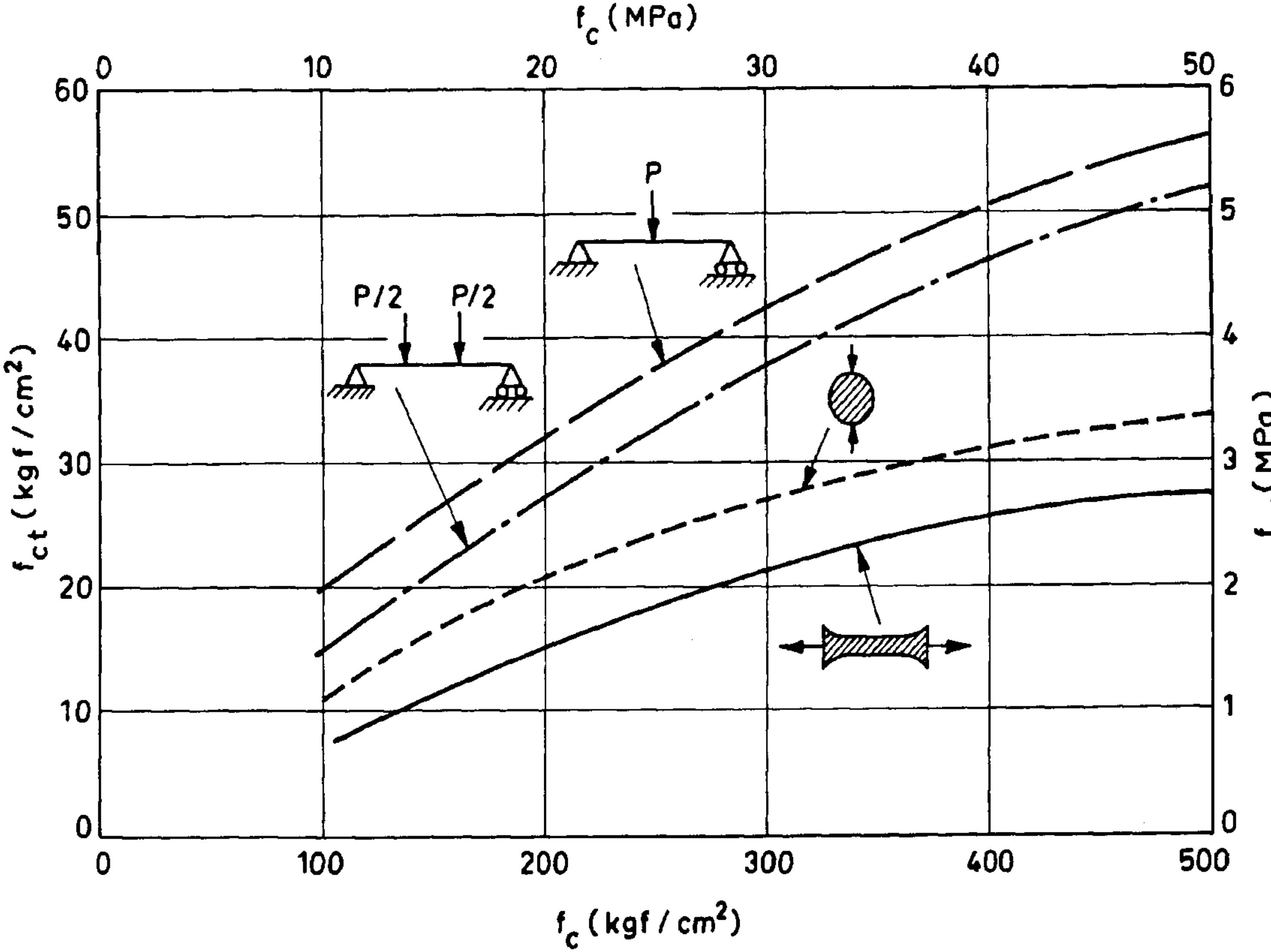


$$f_{cts} = \frac{2P}{\pi \ell d}$$

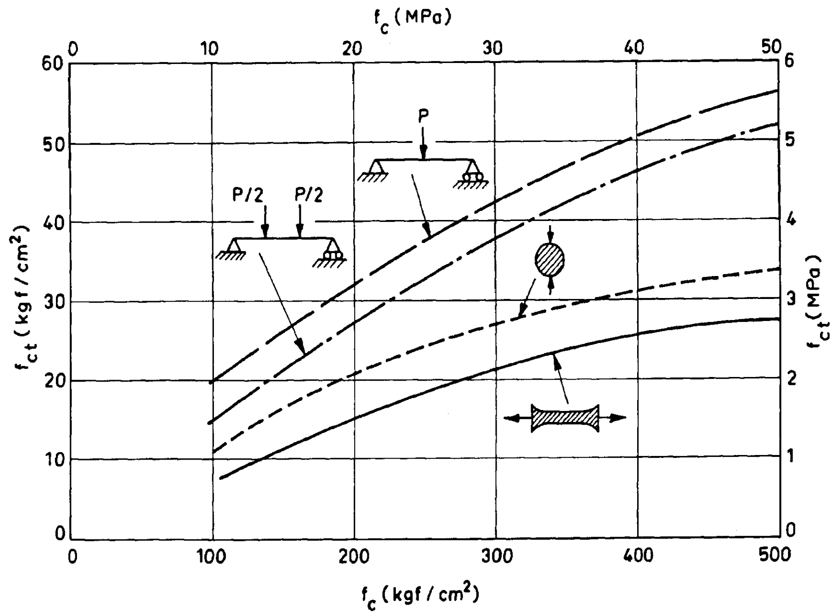
The tensile strength obtained this way is not the true tensile strength. This is why it is called “split tensile strength.”

“f_{cts}” is lower than the direct tensile strength.

Uniaxial Tensile $\sigma-\varepsilon$ Characteristics



Uniaxial Tensile σ–ε Characteristics

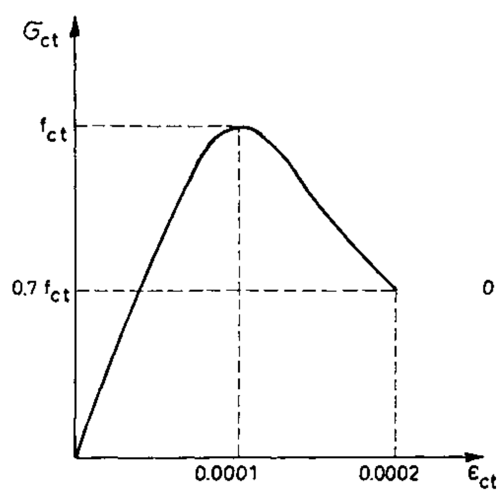


Direct tensile strength (if f_{ct} is in MPa)	$0.35\sqrt{f_c}$
Split tensile strength (if f_{cts} is in MPa)	$0.50\sqrt{f_c}$
Flexural tensile strength (if f_{ctf} is in MPa) (Single load at midspan)	$0.7\sqrt{f_c}$
Flexural tensile strength (if f_{ctf} is in MPa) (Two point loads)	$0.64\sqrt{f_c}$

Uniaxial Tensile $\sigma-\varepsilon$ Characteristics

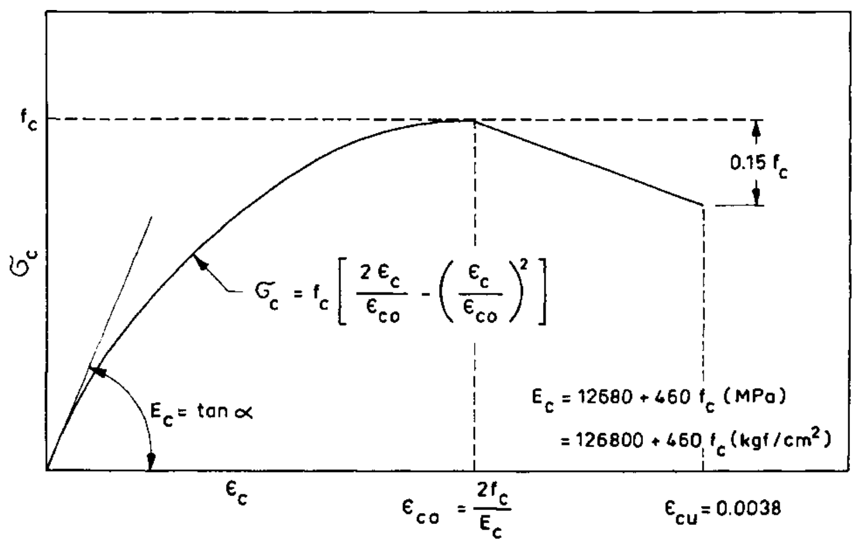
The most realistic stress-strain curves for concrete in tension were obtained by Rüsch. Rüsch found out that the shape of the curve changed significantly with the rate of loading (rate of strain) and the strength of concrete.

The initial portion of the stress-strain curve for concrete under uniaxial tension is almost linear up the peak stress as shown in the figure. The shape and length of the descending portion depend mainly on the rate of strain and the strength of the concrete.

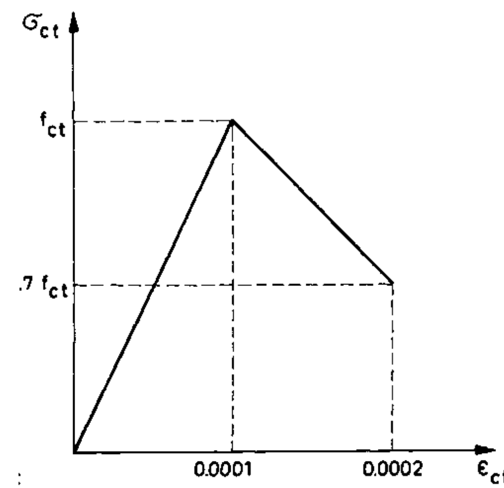


Uniaxial σ–ε Models for Concrete

Compression: (Hognestad Model)



Tension: Bilinear Model



Shear Strength of Concrete

Shear strength of concrete is 35-80 percent greater than its tensile strength, therefore in RC members there is no direct shear problem.

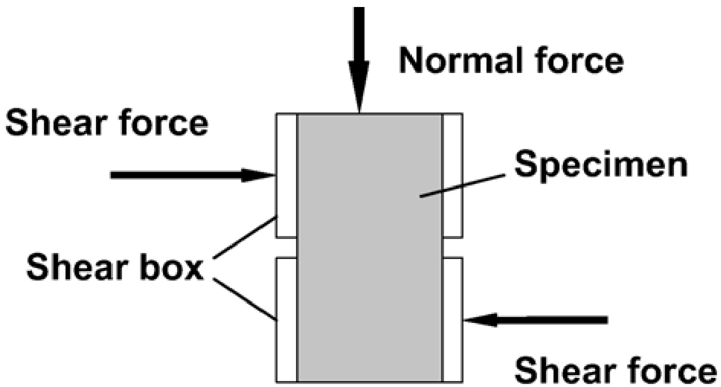


Fig. 3. Basic configuration of direct shear test.

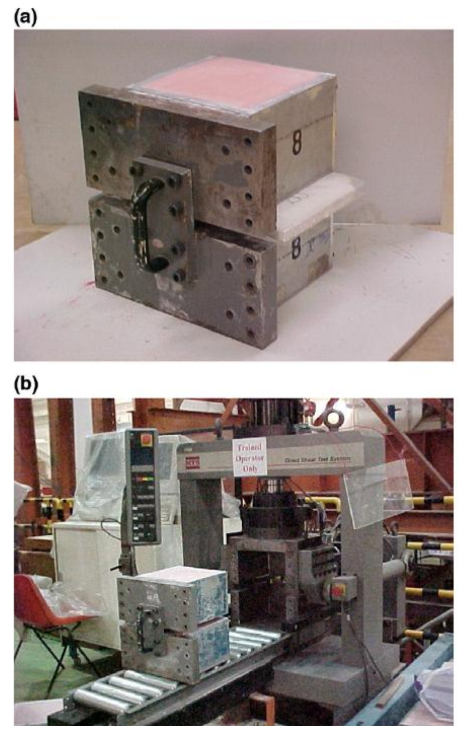


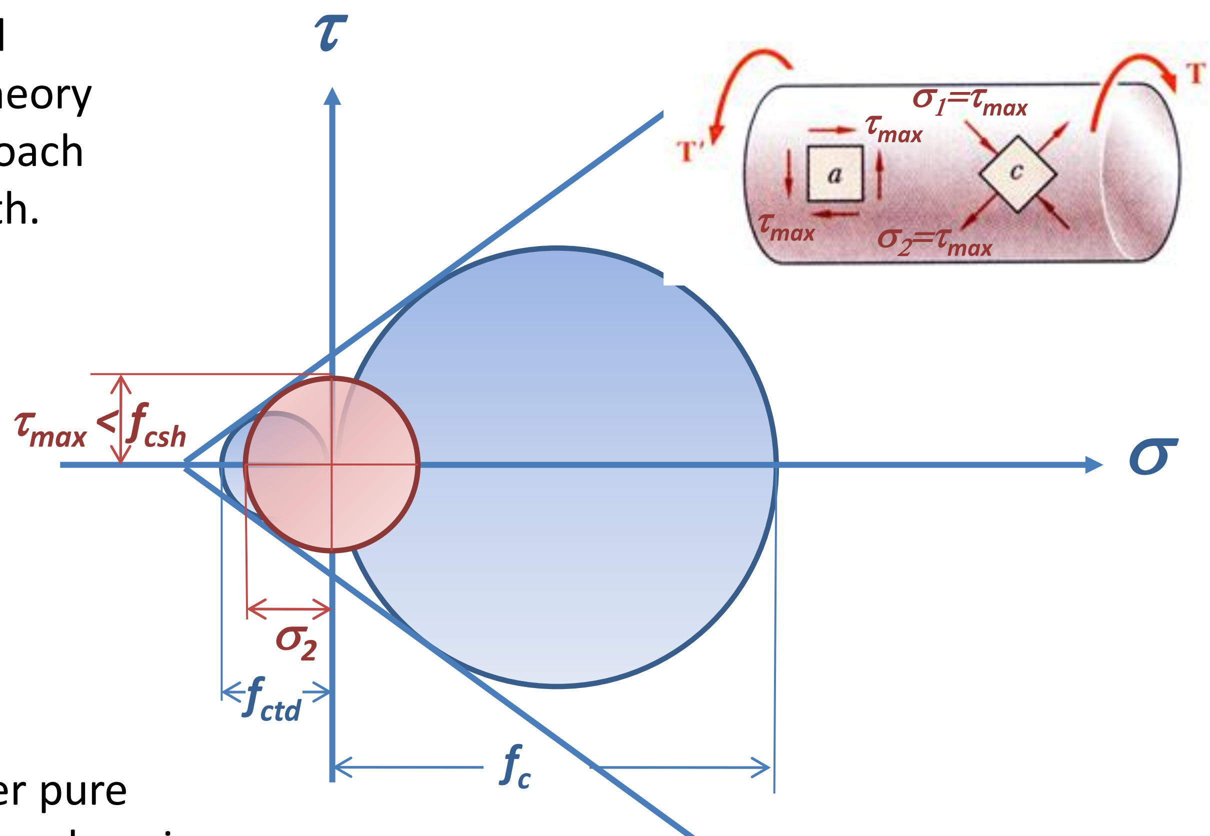
Fig. 4. (a) Specimen preparation for direct shear test (b) setup detail of direct shear test.

Shear Strength of Concrete

Rankine Theory: A simplified version of Mohr-Coulomb Theory based on shear friction approach for the estimation of strength.

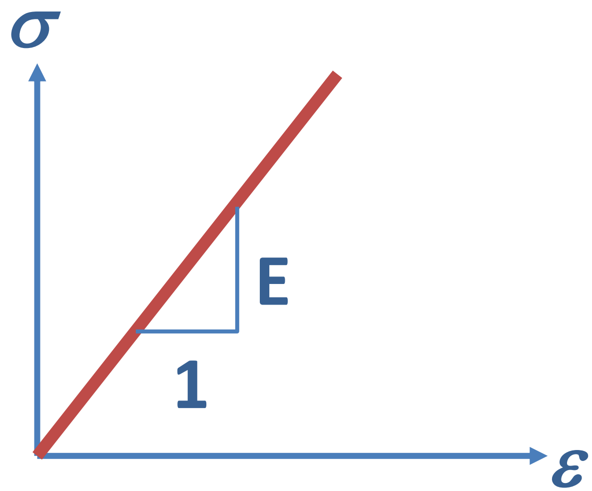
Theory indicates that even when the concrete is under pure torsion the maximum tensile strength that can be mobilized shall be less than the direct tensile srength of concrete.

$\sigma_2 < f_{ctd}$

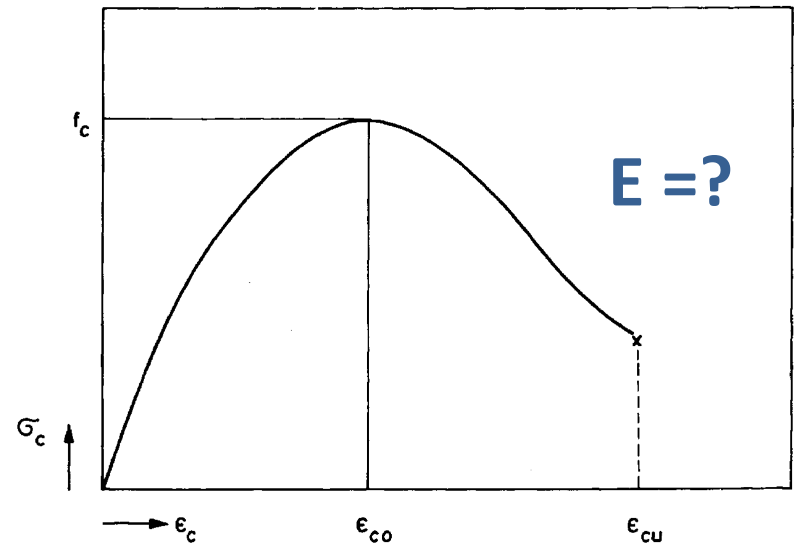


This means that, even under pure shear, failure of concrete members is due to exhaustion of its tensile strength.

Modulus of Elasticity



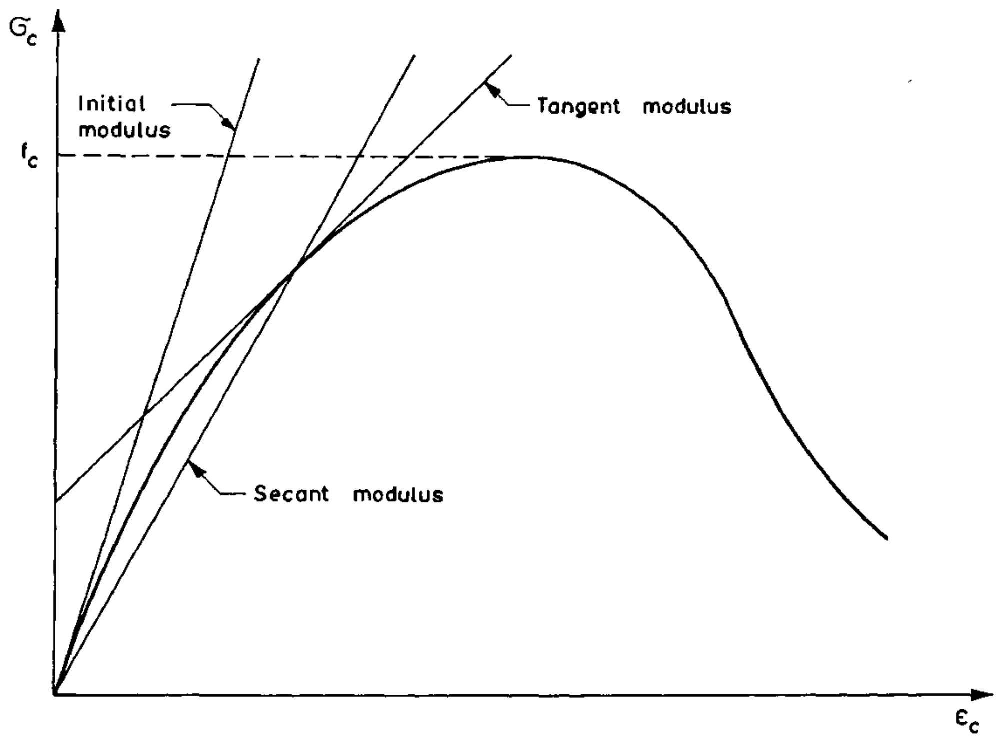
Linear Elastic



Nonlinear Ineastic

Concrete is not a linearly elastic material. Therefore, it is difficult to justify any definition the modulus of elasticity for concrete. Modulus of elasticity is defined as the slope of the stress-strain curve. The slope of the stress-strain diagram of concrete is affected by the stress level and many other variables. Hence, the modulus of elasticity of concrete has to be defined in several different ways.

Modulus of Elasticity



Initial Modulus: Slope of the tangent line drawn to the σ–ε curve at the origin

Secant Modulus: Slope of the secant line drawn between the point corresponding to a stress level of $0.5f_c$ and the origin of the s-e curve.

Tangent Modulus: Slope of the tangent line drawn to the σ–ε curve at curve at a stress level, which corresponds to 40 to 50 percent of the compressive strength.

<u>In design and research, any of these three can be used, depending on the problem.</u>

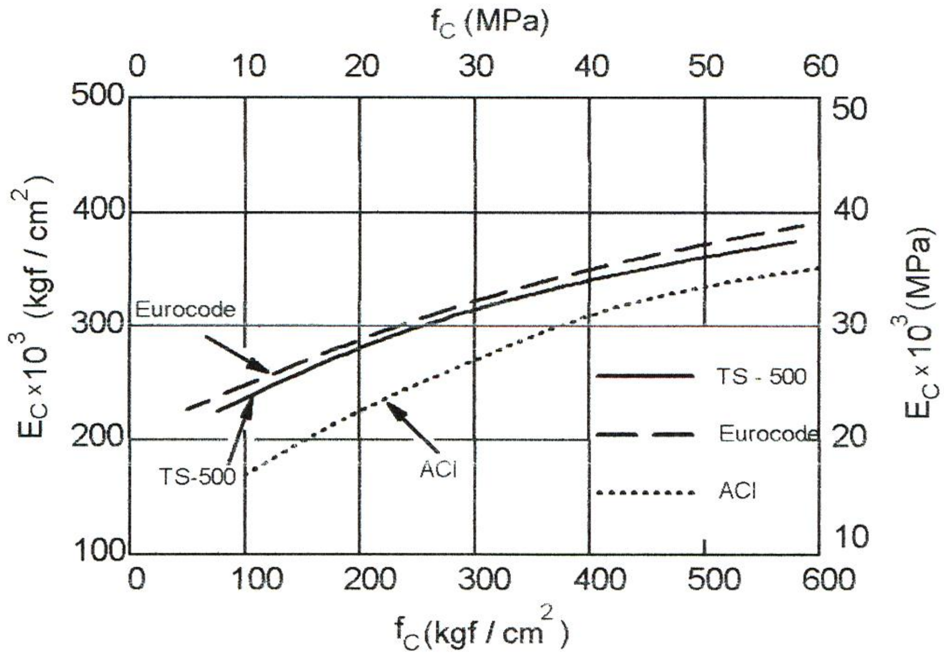
Modulus of Elasticity

ACI318 $E_{cj} = 4750\sqrt{f_{cj}}$ (in MPa) (1.7)

Eurocode 2 $E_{cj} = 9500(f_{cj} + 8)^{1/3}$ (in MPa) (1.8)

TS500 $E_{cj} = 3250\sqrt{f_{cj}} + 14000$ (in MPa) (1.9)

Here, *'j'* is an age indicator. *'j'* is normally taken as 28 days.

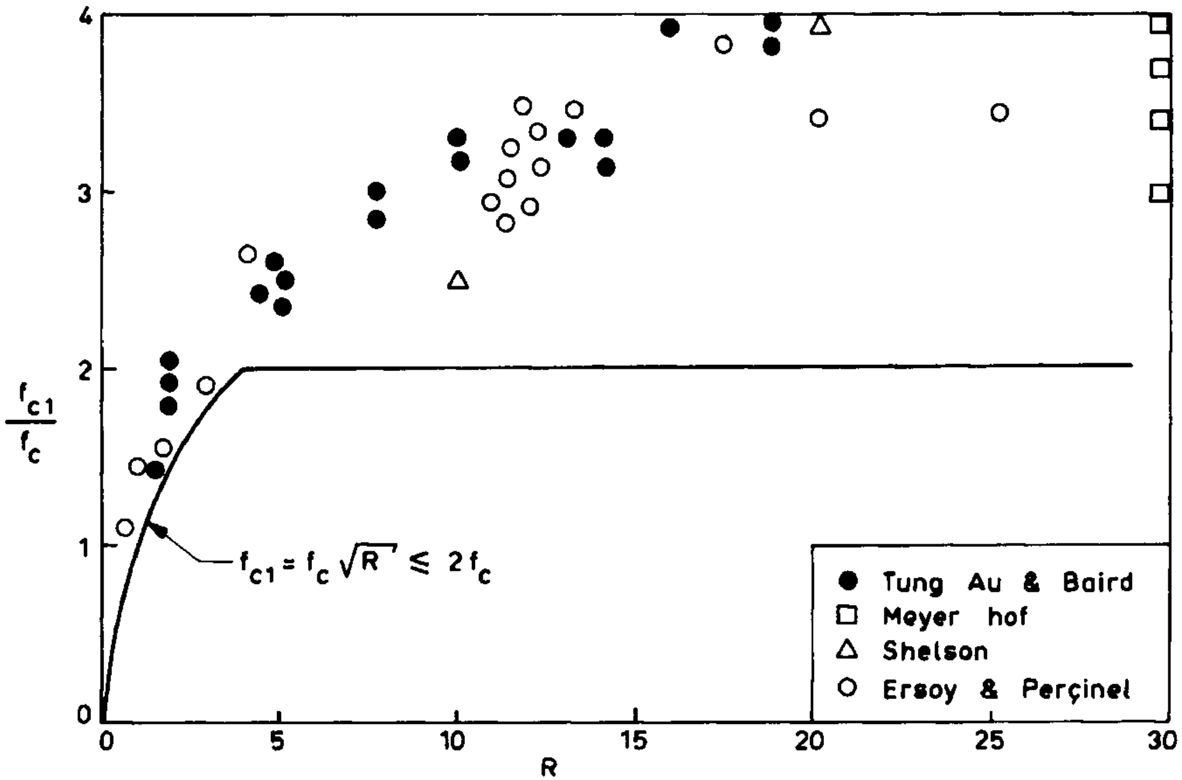


Creep vs. Modulus of Elasticity

- When concrete is kept under compression, deformations increase as a function of time. This phenomenon is known as "CREEP."
- CREEP reduces the modulus of elasticity considerably.
- The reduced value is a function of the level of loading, age of concrete, humidity, temperature and time.
- As a result of creep, for a specimen kept under load for two years, Modulus of Elasticity can be decreased to 1/2 or even 1/3 of its initial value.
- Therefore, to compute the time dependent deformations in concrete, a reduced value for the Modulus of Elasticity should be used.

Bearing Strength

Experiments have revealed that the compressive strength of concrete increases when the loaded area is smaller than the total area of the member.



In case of point loads

$$f_{cl} = f_c\sqrt{R} \quad \leq \quad 2f_c$$

In case of strip loads

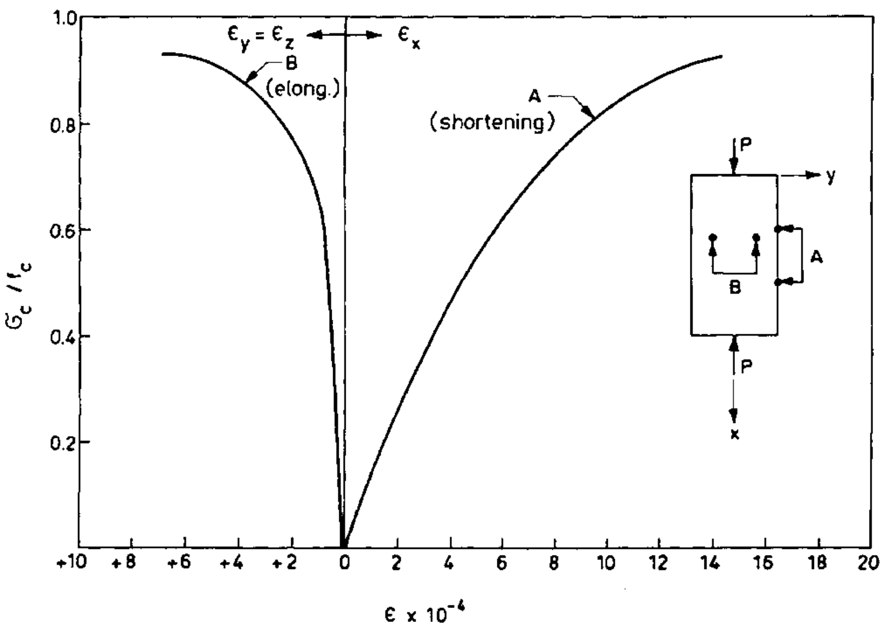
$$f_{cl} = \frac{f_c}{1.5}\sqrt{\frac{b}{b'}} \quad \leq \quad 1.5f_c$$

The ratio of total area to the loaded area is R.

b and b' are the widths of the member and the loaded area, respectively

Shear Modulus, Poisson's Ratio and Coefficient of Thermal Expansion

- Coefficient of thermal expansion for concrete can be taken as 1□10-5 mm/mm/C° which happens to be same with that of steel.
- Tests made at METU have revealed that the Poisson's ratio changes significantly with the load level.



Poisson's ratio = the ratio of the transverse strain to the longitudinal strain.

At very high stress levels Poisson's ratio increases considerably. For σ_c/f_c=0.3-0.7, the Poisson's ratio = 0.15-0.25.

In and TS-500, it is specified as 0.20.

Shear Modulus, Poisson's Ratio and Coefficient of Thermal Expansion

Shear modulus also varies as a function of the load level. Various values have been recommended based on E_c and μ_c values found experimentally using the following Elasticity equation.

$$G_c = \frac{E_c}{2(1+\mu_c)}$$

In late 1960s, an extensive research program was carried at METU to study the relationship between G_c and E_c. As a result of these tests, it was concluded that $G_c = 0.4\ E_c$.

This result is also consistent with μ_c =0.2. In above expression, setting , one gets $G_c \cong 0.4\ E_c$.

INGALLS Building (1902), Cincinnati

The first RC high-rise building in the world. The 16-story, 64 m tall building proved, for the first time, the safety and economy of RC frames for this type of construction.