Module # 4

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1. Strength porosity relationship

Strength porosity relationship

- **Strength** of the concrete is a main structural requirement that determines the capacity of the concrete to support the designed loads (weight, force, etc.) without breaking and maintain the structure stability.
- Strength is the property generally referred to concrete design and quality control.

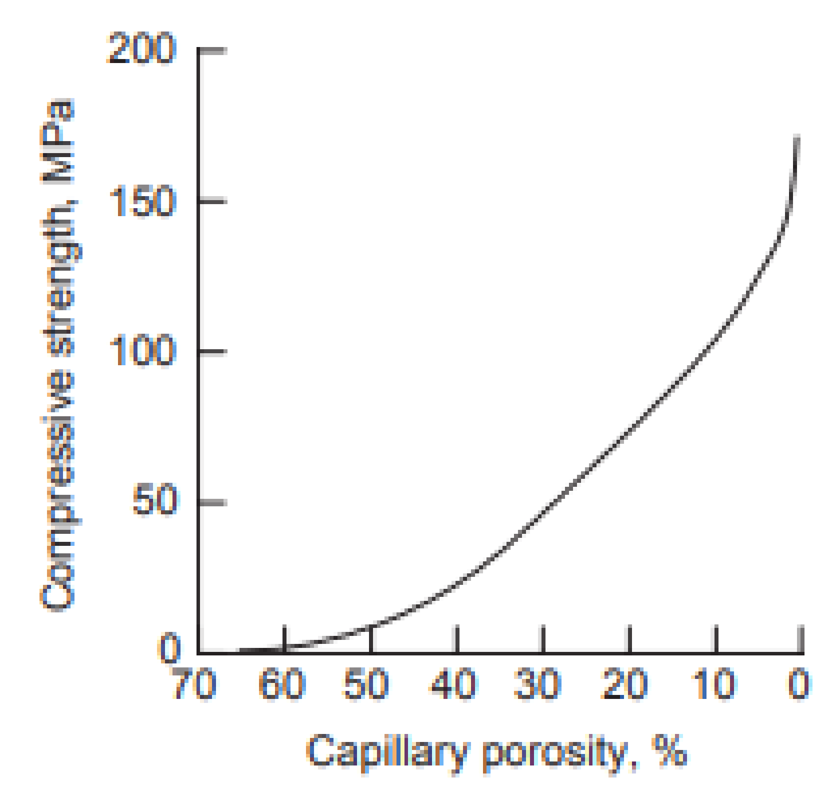
Strength Classification of Concrete

- Low-strength concrete <20 MPa compressive strength
- Moderate-strength concrete 20~40 MPa compressive strength
- High-strength concrete 40~200 MPa compressive strength
- Ultra high-strength concrete >200 MPa compressive strength

Strength porosity relationship

- **Porosity** is a measure of the void (i.e. "empty") spaces in a material, and is a fraction of the volume of voids over the total volume, between 0 and 1, or as a percentage between 0% and 100%.
- Simply we can say that Porosity is a measure of the volume of voids in concrete.
- voids in concrete can be filled with air or with water. Air voids are an obvious and easily-visible example of pores in concrete. Broadly speaking, the more porous the concrete, the weaker it will be.

Strength porosity relationship



Strength porosity relationship

Comparison of predicted and observed compressive flexure and splitting tensile strength

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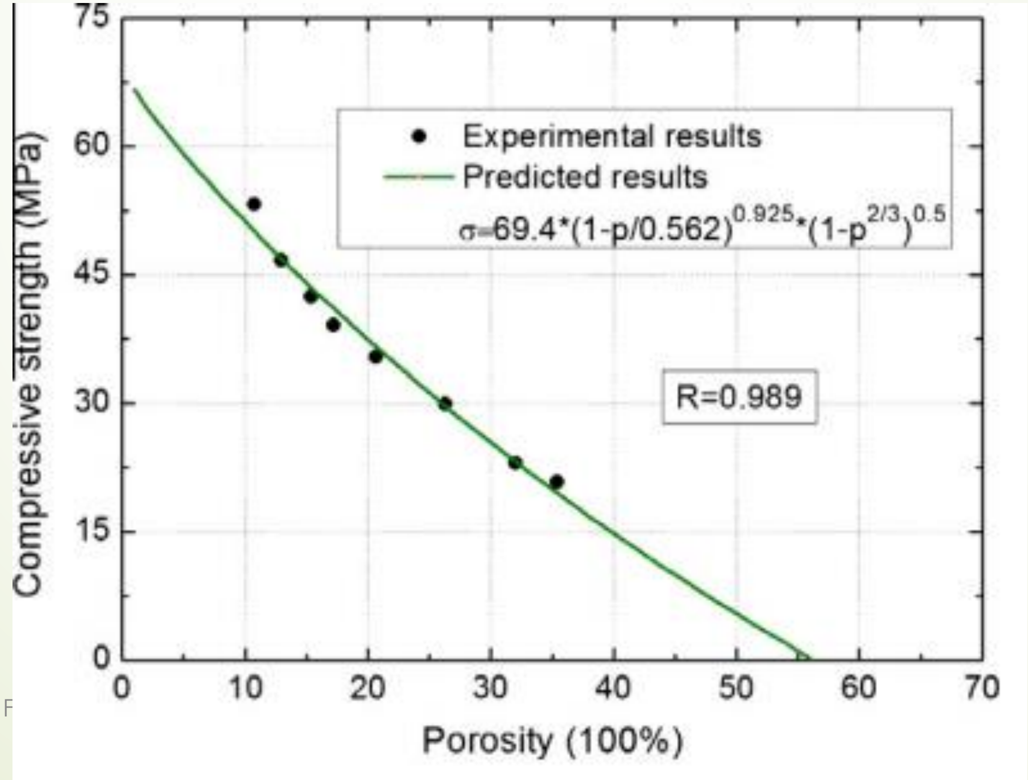
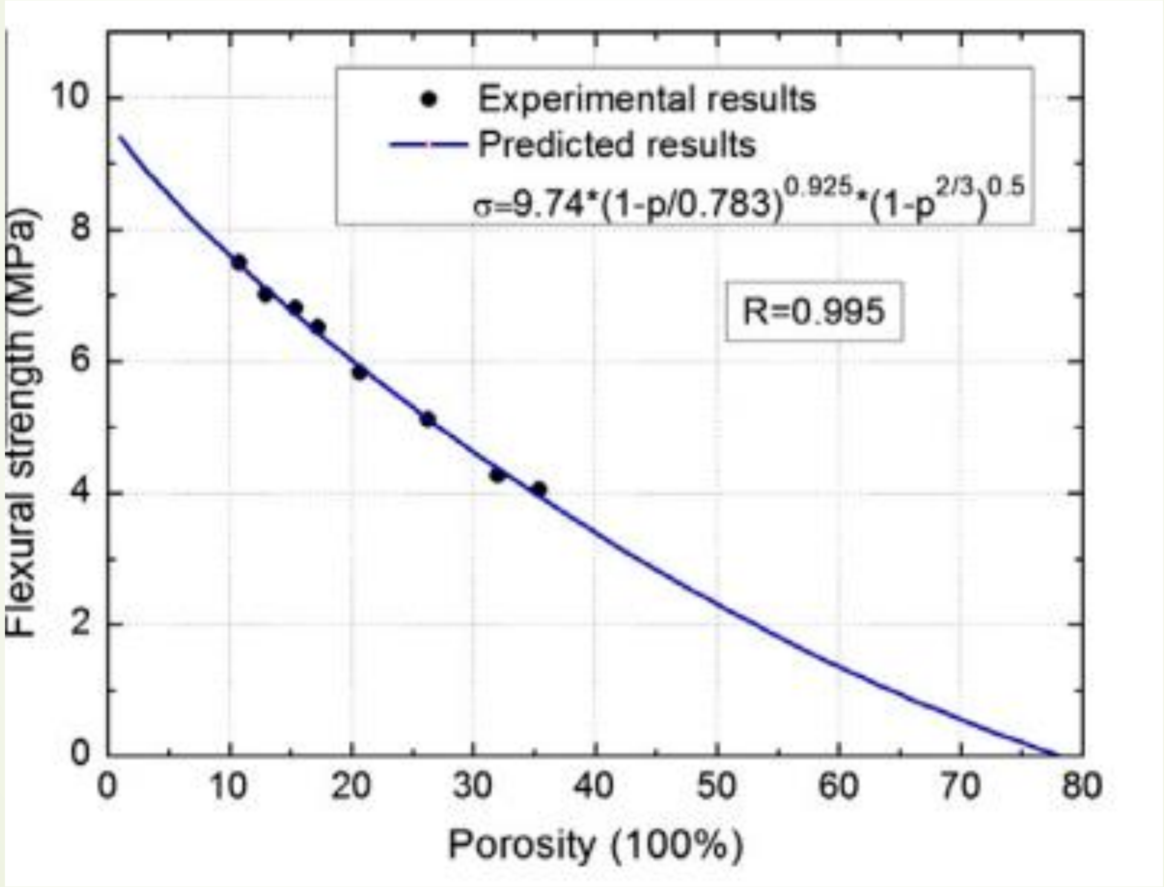
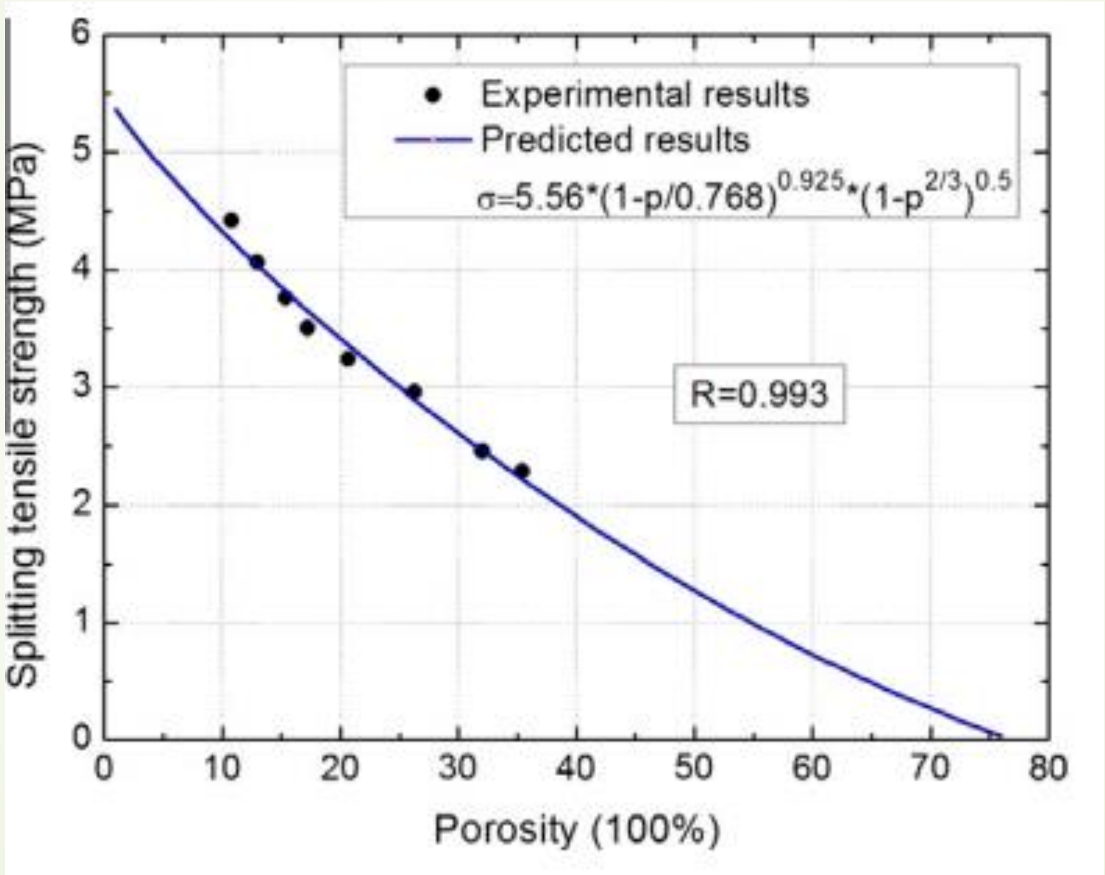


Strength porosity relationship



Strength porosity relationship



Strength porosity relationship

Degree of consolidation/ Porosity: Neville states that the volume of pores in concrete influences the strength of concrete by the following power function type: $f_c = f_{c,0} \cdot (1 - p)^n$, where p is the volume of voids, f_c the strength of concrete with porosity p, $f_{c,0}$ strength at zero porosity, and n a coefficient obtained by regression analysis. If the previous formula was plotted on a log scale, a general linear relationship can be established – as porosity increases, the compressive strength decreases. Specimens that have low degrees of compaction will have, as a result, high volume of voids and, therefore, will yield lower strength results.

Strength porosity relationship

In general, there exists a fundamental relationship between porosity and strength of solids which, for simple homogeneous materials, can be described by the expression

S = So exp (-kp)

Where:

So is the strength at zero porosity,

p is the porosity and

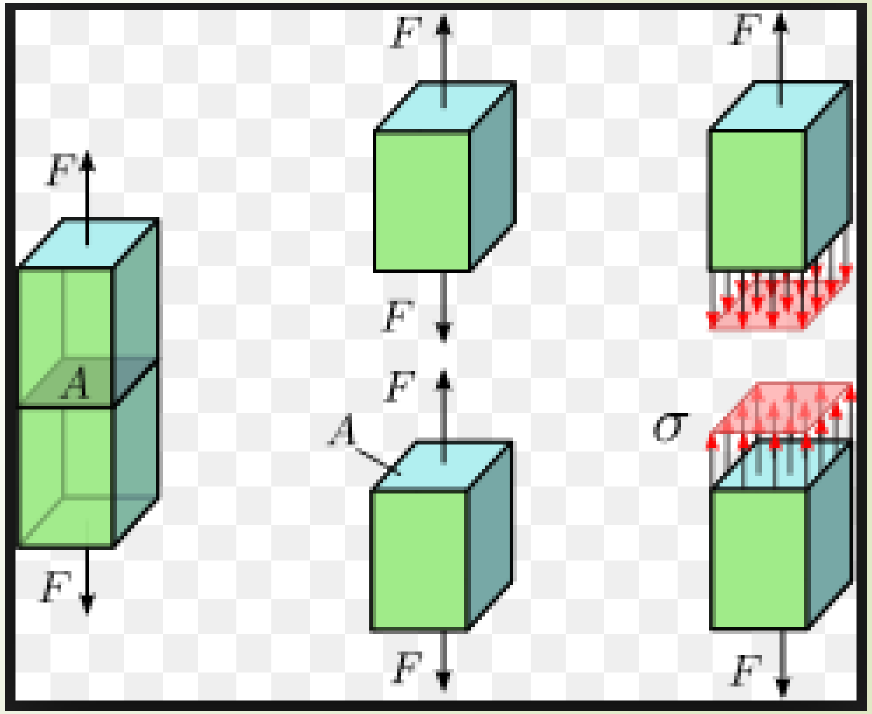
k is a constant.

S = strength of the material which has a given porosity

2. Failure Mode In Concrete

Failure Mode In Concrete

- With a material such as concrete, which contains void spaces of various size and shape in the matrix and micro-cracks at the interfacial transition zone, the failure modes under stress are very complex and vary with the type of stress.
- Under uniaxial tension, relatively less energy is needed for the initiation and growth of cracks in the matrix.

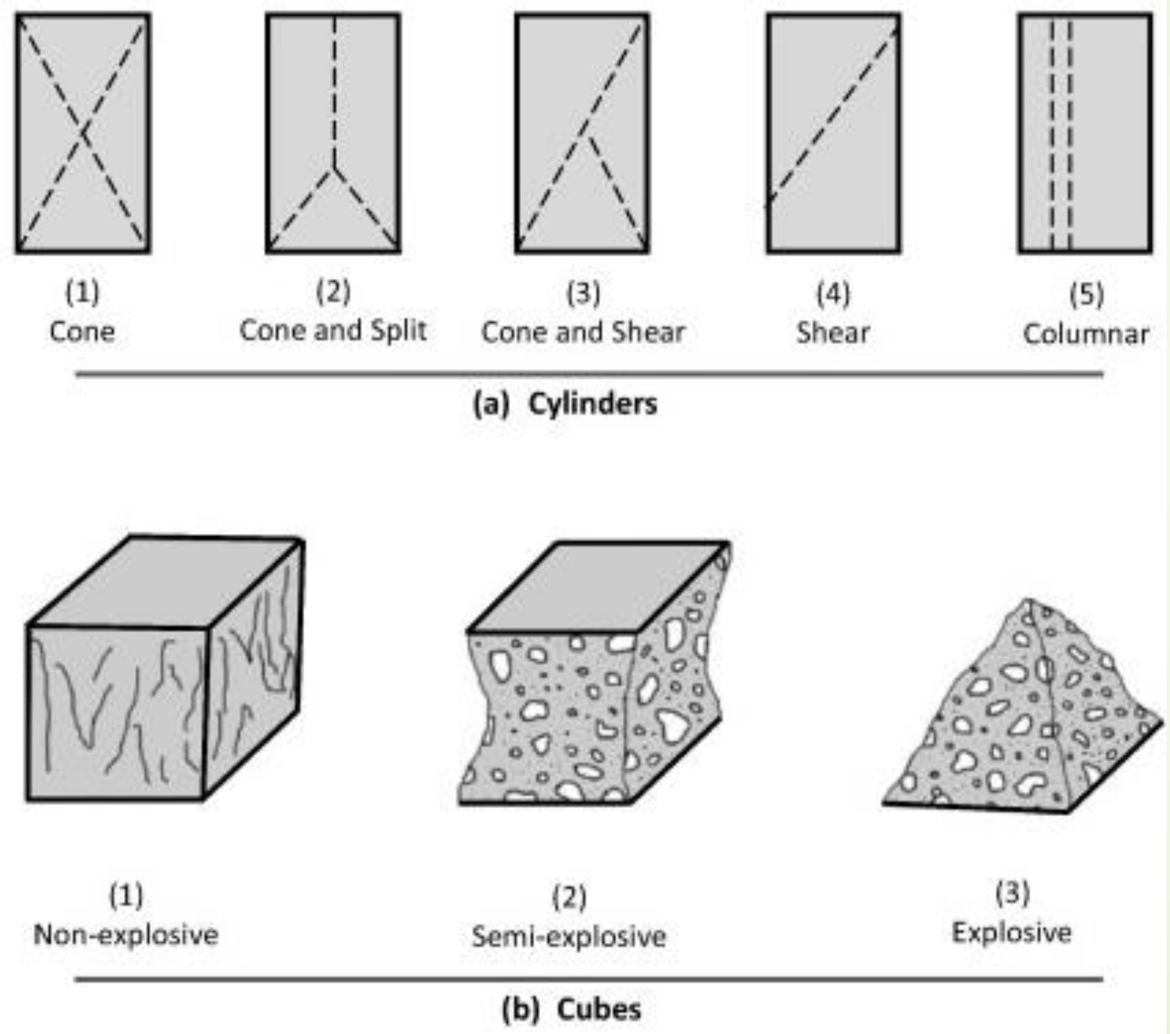


Failure Mode In Concrete

- Pre-existing cracks at the interfacial transition zone and newly formed cracks in the matrix, account for the brittle failure.
- In compression, the failure mode is less brittle because considerably more energy is needed to form and to extend cracks in the matrix.
- It is generally agreed that, in a uniaxial compression test on medium- or low-strength concrete, no cracks are initiated in the matrix up to about 50 percent of the failure stress; at this stage a stable system of cracks, called shear-bond cracks.
- At higher stress levels, cracks are initiated within the matrix; their number and size increases progressively with increasing stress levels. The cracks in the matrix at the interfacial transition zone and shear-bond cracks eventually join up, and generally a failure surface develops at about 20° to 30° from the direction of the load, as shown in Figure in next slide

Failure Mode In Concrete

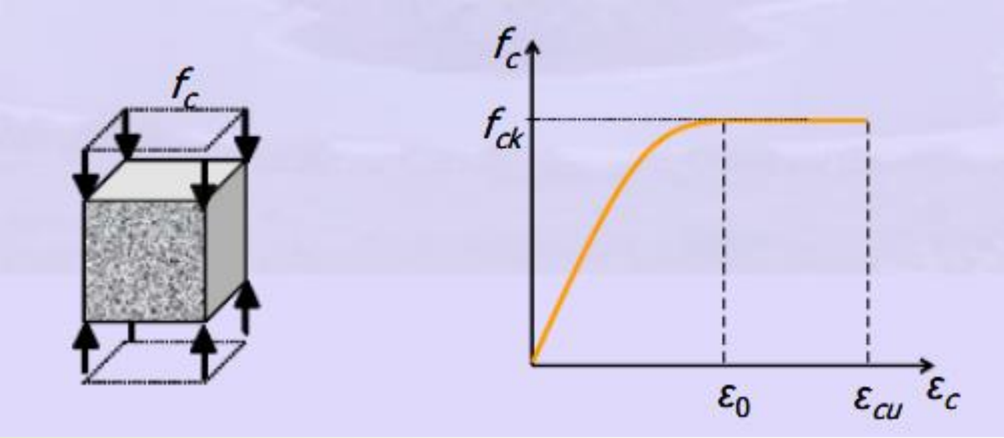
Failure Mode In Concrete



Failure Mode In Concrete

Stress-strain Curves for Concrete

Curve under **uniaxial compression** the stress versus strain behaviour of concrete under uniaxial compression is initially linear (stress is proportional to strain) and elastic (strain is recovered at unloading). With the generation of micro-cracks, the behaviour becomes nonlinear and inelastic. After the specimen reaches the peak stress, the resisting stress decreases with increase in strain.



fc = compressive stress

fck = actual compressive strength of cubes or cylindrical concrete specimen

εc = compressive strain

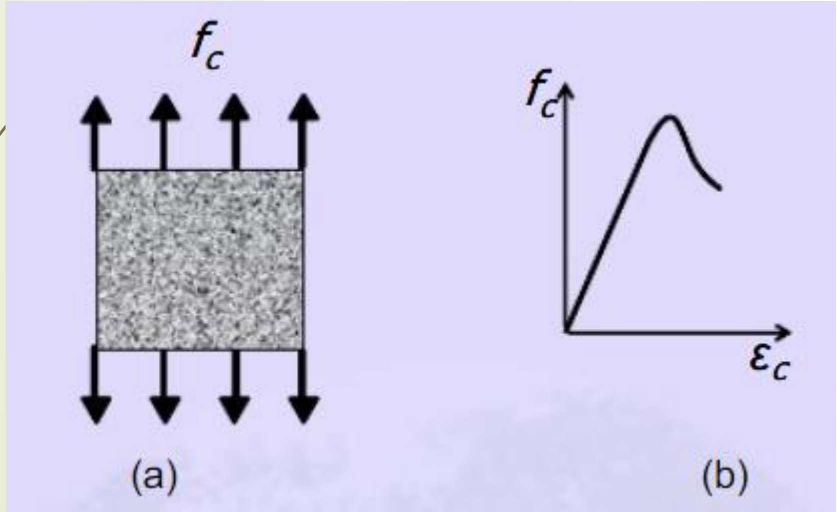
εo= strain corresponding to fck

εcu = ultimate compressive strain

Failure Mode In Concrete

Curve under uniaxial tension

The stress versus strain behaviour of concrete under uniaxial tension is linear elastic initially. Close to cracking nonlinear behaviour is observed. Curve directly falls due to direct brittle failure due to uniaxial tensile force.



fc = Tensile stress
εc = Tensile strain

3. Elastic Behavior of Concrete

Elastic Behavior of Concrete

Modulus of elasticity (also known as elastic modulus, coefficient of elasticity) of a material is a number which is defined by the ratio of the applied stress to the corresponding strain within the elastic limit.

- Physically it indicates a material's resistance to being deformed when a stress is applied to it.
- Modulus of elasticity also indicates the stiffness of a material. Value of elastic modulus is higher for the stiffer materials.

Modulus of elasticity E= f/s

Here,

f= applied stress on a body
s= strain corresponding to the applied stress

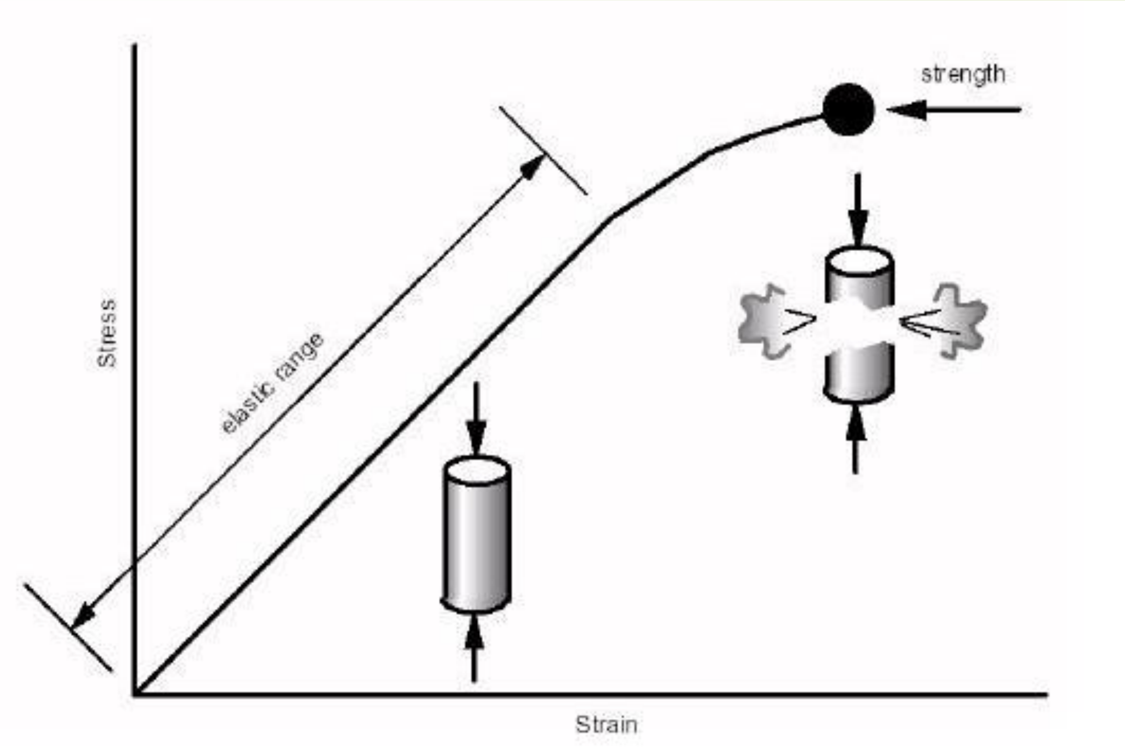
Elastic Behavior of Concrete

Elastic Behavior of Concrete

- **Units of Elastic Modulus**

Units of elastic modulus are followings:

- In SI unit MPa or N/mm2 or KN/m2.
- In FPS unit psi or ksi or psf or ksf.



4. Drying shrinkage and creep

Drying shrinkage and creep

- When concrete is subjected to compressive loading it deforms instantaneously. This immediate deformation is called **instantaneous strain**.
- Now, if the load is maintained for a considerable period of time, concrete undergoes additional deformations even without any increase in the load. This time-dependent strain is termed as **creep**.

  Drying shrinkage (often, simply **shrinkage**) is the reduction in volume of hardened concrete due to loss of moisture by evaporation.

  There are several similarities and dissimilarities between creep and shrinkage. First, the source for both the effects are the same, which is loss of adsorbed moisture from the hydrated cement paste. In shrinkage, the loss is due to difference in the relative humidity of concrete and the environment, in creep it is due to sustained applied stress.

Drying shrinkage and creep

- The factors that effect creep also effects shrinkage.
- They both affect with: cement content, water content, aggregate content, relative humidity, temperature, thickness of the member, etc.
- However, unlike creep, shrinkage is not dependent on the loading conditions.

5. Thermal shrinkage

Thermal shrinkage

- A more professional term to thermal shrinkage is thermal contraction. It's not just concrete that has this characteristic. Many materials will expand when their temperature is raised beyond a certain point, and they will contract when the temperature goes down, and the material starts cooling down.
- If the surroundings and the concrete process is not properly controlled by professionals, you will observe thermal cracking. Concrete will crack if there is a massive difference between its own temperature and that of the surroundings. If certain parts of concrete are hotter than the others, this may also result in cracks.

Thermal shrinkage

- Concrete, as with all materials changes dimensions when the temperature changes. That is quantified by the coefficient of thermal expansion.
- When concrete is poured into large elements, the heat of hydration of the cementitious materials causes the concrete to get warm to very hot. That causes the concrete to expand (and more rapidly harden).
- When the concrete cools, it tends to shrink. The outer concrete will cool before the inner concrete, will inducing stresses in the concrete. And, possibly crack it.

Thermal Cracking of Concrete and Prevention

- Temperature difference within a concrete structure may be caused by portions of the structure losing heat of hydration at different rates or by the weather conditions cooling or heating one portion of the structure to a different degree or at a different rate than another portion of the structure.
- These temperature differences result in differential volume change, leading to cracks.
- This is normally associated with mass concrete including large and thicker sections (500mm) of column, piers, beams, footings and slabs.

Thermal Cracking of Concrete and Prevention

Thermal Cracking of Concrete and Prevention

- Temperature differential due to changes in the ambient temperature can affect any structure.
- The temperature gradient may be caused by either the centre of the concrete heating up more than the outside due to the liberation of heat during cement hydration or more rapid cooling of the exterior relative to the interior.
- Both cases result in tensile stresses on the exterior and, if the stresses exceed the tensile strength, cracking will occur.
- The tensile stresses are proportional to the temperature differential called **coefficient of thermal expansion**.

Thermal Cracking of Concrete and Prevention

Thermal Coefficient Of Portland Cement Concrete

- All materials expand and contract to some extent as their temperatures rise or fall. The coefficient of thermal expansion is a measure of a material's expansion or contraction with temperature.
- Because the length changes associated with thermal expansion are very small, the coefficient of thermal expansion is usually expressed in micro-strains per unit temperature change.
- The coefficient of thermal expansion of Portland cement concrete (PCC) ranges from about 8 to 12 micro-strains/°C.

Thermal Cracking of Concrete and Prevention

Thermal Coefficient Of Portland Cement Concrete

- The range of coefficient of thermal expansion values for different concretes reflects the variation in coefficient of thermal expansion of concrete's component materials.
- For example, concrete containing limestone aggregate has a lower coefficient of thermal expansion than concrete containing siliceous aggregate. Because aggregate comprises about 70% of the concrete, aggregate type has the greatest effect on the coefficient of thermal expansion of concrete.

Typical α ranges for common PCC components.

	Coefficient of Thermal Expansion	
	10^{-6}/°C	10^{-6}/°F
Aggregate		
Granite	7-9	4-5
Basalt	6-8	3.3-4.4
Limestone	6	3.3
Dolomite	7-10	4-5.5
Sandstone	11-12	6.1-6.7
Quartzite	11-13	6.1-7.2
Marble	4-7	2.2-4
Cement Paste (saturated)		
w/c = 0.4	18-20	10-11
w/c = 0.5	18-20	10-11
w/c = 0.6	18-20	10-11
Concrete	7.4-13	4.1-7.3
Steel	11-12	6.1-6.7

Thermal Cracking of Concrete and Prevention

Thermal Coefficient Of Portland Cement Concrete

- The coefficient of thermal expansion is calculated according to the following formula:
- coefficient of thermal expansion = $(\Delta L/L_0) / \Delta T$

where

- ΔL = length change of specimen,
- L_0 = initial measured length of specimen, and
- ΔT = temperature change.

Thermal Cracking of Concrete and Prevention

Preventive Measures:

- Reducing maximum internal temperature.
- Controlling the rate at which the concrete cools by insulating the exposed concrete surface during first 5 days. This could be done by 50mm thick thermopol sheets. (Use of thermally insulating material as formwork) Keeping insulating formwork for longer duration.
- Increasing the tensile strength of concrete.
- Reducing the concrete temperature at placement up to say 32 degree centigrade.
- Using low heat of hydration cement or using fly ash replacement of part of cement.
- Keeping steel formwork warm by air heating during winter.
- Low grade of cement.


The End