

1.6 Concrete (Part II)

This section covers the following topics.

- Properties of Hardened Concrete (Part II)
- Properties of Grout
- Codal Provisions of Concrete

1.6.1 Properties of Hardened Concrete (Part II)

The properties that are discussed are as follows.

- 1) Stress-strain curves for concrete
- 2) Creep of concrete
- 3) Shrinkage of 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.

IS:1343 - 1980 recommends a parabolic characteristic stress-strain curve, proposed by Hognestad, for concrete under uniaxial compression (**Figure 3** in the Code).

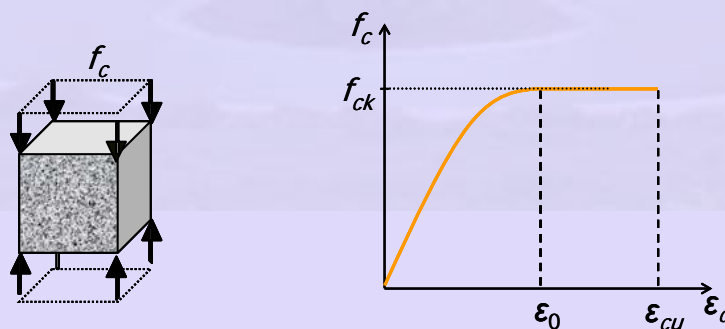


Figure 1-6.1 a) Concrete cube under compression, b) Design stress-strain curve for concrete under compression due to flexure

The equation for the design curve under compression due to flexure is as follows.

For $\varepsilon_c \leq \varepsilon_0$

$$f_{ck} = f_{ck} \left[2 \left(\frac{\varepsilon_c}{\varepsilon_0} \right) - \left(\frac{\varepsilon_c}{\varepsilon_0} \right)^2 \right] \quad (1-6.1)$$

For $\varepsilon_c > \varepsilon_0 \leq \varepsilon_{cu}$

$$f_c = f_{ck} \quad (1-6.2)$$

Here,

f_c = compressive stress

f_{ck} = characteristic compressive strength of cubes

ε_c = compressive strain

ε_0 = strain corresponding to $f_{ck} = 0.002$

ε_{cu} = ultimate compressive strain = 0.0035

For concrete under compression due to axial load, the ultimate strain is restricted to 0.002. From the characteristic curve, the design curve is defined by multiplying the stress with a size factor of 0.67 and dividing the stress by a material safety factor of $\gamma_m = 1.5$. The design curve is used in the calculation of ultimate strength. The following sketch shows the two curves.

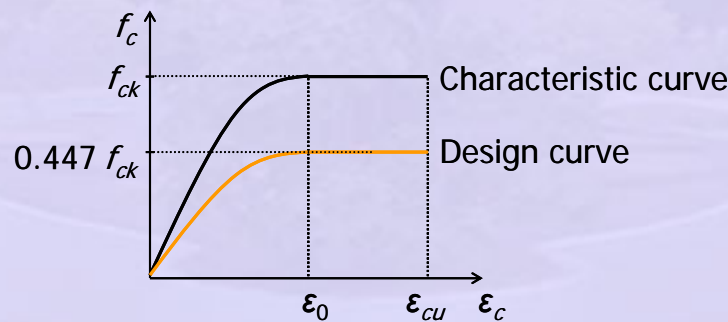


Figure 1-6.2 Stress-strain curves for concrete under compression due to flexure

In the calculation of deflection at service loads, a linear stress-strain curve is assumed up to the allowable stress. This curve is given by the following equation.

$$f_c = E_c \varepsilon_c \quad (1-6.3)$$

Note that, the size factor and the material safety factor are not used in the elastic modulus E_c .

For high strength concrete (say M100 grade of concrete and above) under uniaxial compression, the ascending and descending branches are steep.

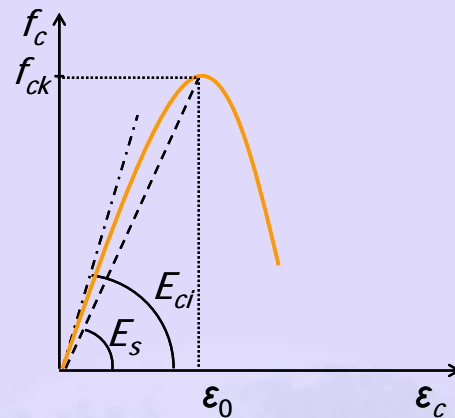


Figure 1-6.3 Stress-strain curves for high strength concrete under compression

The equation proposed by Thorenfeldt, Tomaxzewicz and Jensen is appropriate for high strength concrete.

$$f_c = f_{ck} \frac{n \left(\frac{\epsilon_c}{\epsilon_0} \right)}{n - 1 + \left(\frac{\epsilon_c}{\epsilon_0} \right)^{nk}} \quad (1-6.4)$$

The variables in the previous equation are as follows.

- f_c = compressive stress
- f_{ck} = characteristic compressive strength of cubes in N/mm^2
- ϵ_c = compressive strain
- ϵ_0 = strain corresponding to f_{ck}
- k = 1 for $\epsilon_c \leq \epsilon_0$
 = $0.67 + (f_{ck} / 77.5)$ for $\epsilon_c > \epsilon_0$. The value of k should be greater than 1.
- $n = E_{ci} / (E_{ci} - E_s)$
- E_{ci} = initial modulus
- $E_s = \text{secant modulus at } f_{ck} = f_{ck} / \epsilon_0.$

The previous equation is applicable for both the ascending and descending branches of the curve. Also, the parameter k models the slope of the descending branch, which increases with the characteristic strength f_{ck} . To be precise, the value of ϵ_0 can be considered to vary with the compressive strength of 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.

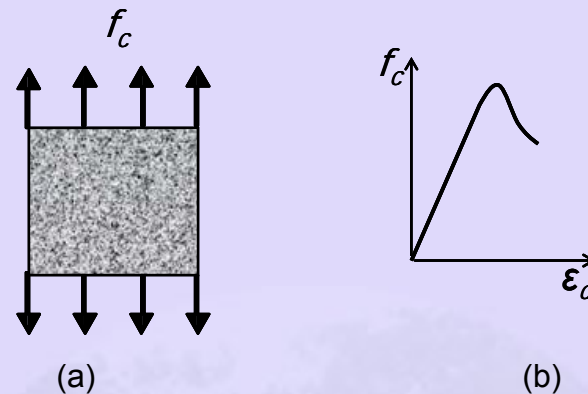


Figure 1-6.4 a) Concrete panel under tension, b) Stress-strain curve for concrete under tension

In calculation of deflections of flexural members at service loads, the nonlinearity is neglected and a linear elastic behaviour $f_c = E_c \epsilon_c$ is assumed. In the analysis of ultimate strength, the tensile strength of concrete is usually neglected.

Creep of Concrete

Creep of concrete is defined as the increase in deformation with time under constant load. Due to the creep of concrete, the prestress in the tendon is reduced with time. Hence, the study of creep is important in prestressed concrete to calculate the loss in prestress.

The creep occurs due to two causes.

1. Rearrangement of hydrated cement paste (especially the layered products)
2. Expulsion of water from voids under load

If a concrete specimen is subjected to slow compressive loading, the stress versus strain curve is elongated along the strain axis as compared to the curve for fast loading. This can be explained in terms of creep. If the load is sustained at a level, the increase in strain due to creep will lead to a shift from the fast loading curve to the slow loading curve (Figure 1-6.5).

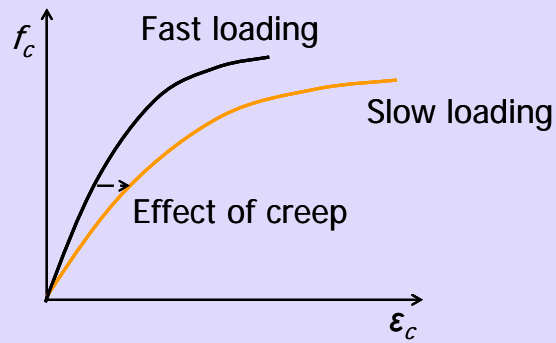


Figure 1-6.5 Stress-strain curves for concrete under compression

Creep is quantified in terms of the strain that occurs in addition to the elastic strain due to the applied loads. If the applied loads are close to the service loads, the creep strain increases at a decreasing rate with time. The ultimate creep strain is found to be proportional to the elastic strain. The ratio of the ultimate creep strain to the elastic strain is called the **creep coefficient θ** .

For stress in concrete less than about one-third of the characteristic strength, the ultimate creep strain is given as follows.

$$\epsilon_{cr,ult} = \theta \epsilon_{el} \quad (1-6.5)$$

The variation of strain with time, under constant axial compressive stress, is represented in the following figure.

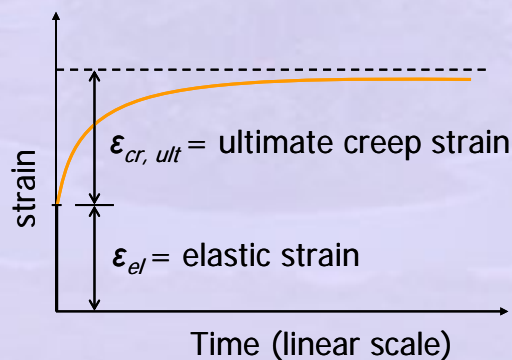


Figure 1-6.6 Variation of strain with time for concrete under compression

If the load is removed, the elastic strain is immediately recovered. However the recovered elastic strain is less than the initial elastic strain, as the elastic modulus increases with age.

There is reduction of strain due to creep recovery which is less than the creep strain. There is some residual strain which cannot be recovered (Figure 1-6.7).

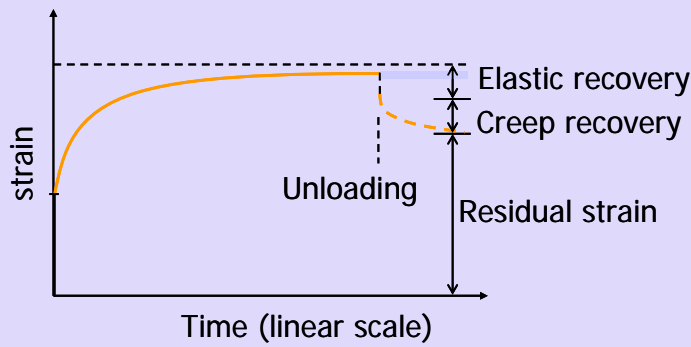


Figure 1-6.7 Variation of strain with time showing the effect of unloading

The creep strain depends on several factors. It increases with the increase in the following variables.

- 1) Cement content (cement paste to aggregate ratio)
- 2) Water-to-cement ratio
- 3) Air entrainment
- 4) Ambient temperature.

The creep strain decreases with the increase in the following variables.

- 1) Age of concrete at the time of loading.
- 2) Relative humidity
- 3) Volume to surface area ratio.

The creep strain also depends on the type of aggregate.

IS:1343 - 1980 gives guidelines to estimate the ultimate creep strain in **Section 5.2.5**. It is a simplified estimate where only one factor has been considered. The factor is age of loading of the prestressed concrete structure. The creep coefficient θ is provided for three values of age of loading.

Table 1-6.1 Creep coefficient θ for three values of age of loading

Age of Loading	Creep Coefficient
7 days	2.2
28 days	1.6
1 year	1.1

It can be observed that if the structure is loaded at 7 days, the creep coefficient is 2.2. This means that the creep strain is 2.2 times the elastic strain. Thus, the total strain is more than thrice the elastic strain. Hence, it is necessary to study the effect of creep in the loss of prestress and deflection of prestressed flexural members. Even if the structure is loaded at 28 days, the creep strain is substantial. This implies higher loss of prestress and higher deflection.

Curing the concrete adequately and delaying the application of load provide long term benefits with regards to durability, loss of prestress and deflection.

In special situations detailed calculations may be necessary to monitor creep strain with time. Specialised literature or international codes can provide guidelines for such calculations.

Shrinkage of Concrete

Shrinkage of concrete is defined as the contraction due to loss of moisture. The study of shrinkage is also important in prestressed concrete to calculate the loss in prestress.

The shrinkage occurs due to two causes.

1. Loss of water from voids
2. Reduction of volume during carbonation

The following figure shows the variation of shrinkage strain with time. Here, t_0 is the time at commencement of drying. The shrinkage strain increases at a decreasing rate with time. The ultimate shrinkage strain (ϵ_{sh}) is estimated to calculate the loss in prestress.

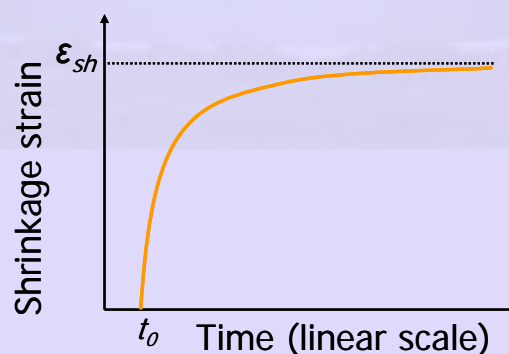


Figure 1-6.8 Variation of shrinkage strain with time

Like creep, shrinkage also depends on several factors. The shrinkage strain increases with the increase in the following variables.

- 1) Ambient temperature
- 2) Temperature gradient in the members
- 3) Water-to-cement ratio
- 4) Cement content.

The shrinkage strain decreases with the increase in the following variables.

- 1) Age of concrete at commencement of drying
- 2) Relative humidity
- 3) Volume to surface area ratio.

The shrinkage strain also depends on the type of aggregate.

IS:1343 - 1980 gives guidelines to estimate the shrinkage strain in **Section 5.2.4**. It is a simplified estimate of the ultimate shrinkage strain (ϵ_{sh}).

For pre-tension

$$\epsilon_{sh} = 0.0003 \quad (1-6.6)$$

For post-tension

$$\epsilon_{sh} = \frac{0.0002}{\log_{10}(t+2)} \quad (1-6.7)$$

Here, t is the age at transfer in days. Note that for post-tension, t is the age at transfer in days which approximates the curing time.

It can be observed that with increasing age at transfer, the shrinkage strain reduces. As mentioned before, curing the concrete adequately and delaying the application of load provide long term benefits with regards to durability and loss of prestress.

In special situations detailed calculations may be necessary to monitor shrinkage strain with time. Specialised literature or international codes can provide guidelines for such calculations.

1.6.2 Properties of Grout

Grout is a mixture of water, cement and optional materials like sand, water-reducing admixtures, expansion agent and pozzolans. The water-to-cement ratio is around 0.5. Fine sand is used to avoid segregation.

The desirable properties of grout are as follows.

- 1) Fluidity
- 2) Minimum bleeding and segregation
- 3) Low shrinkage
- 4) Adequate strength after hardening
- 5) No detrimental compounds
- 6) Durable.

IS:1343 - 1980 specifies the properties of grout in **Sections 12.3.1** and **Section 12.3.2**.

The following specifications are important.

- 1) The sand should pass 150 μm Indian Standard sieve.
- 2) The compressive strength of 100 mm cubes of the grout shall not be less than 17 N/mm^2 at 7 days.



1.6.5 Codal Provisions of Concrete

The following topics are covered in **IS:1343 - 1980** under the respective sections. These provisions are not duplicated here.

Table 1-6.2 Topics and sections

Workability of concrete	Section 6
Concrete mix proportioning	Section 8
Production and control of concrete	Section 9
Formwork	Section 10
Transporting, placing, compacting	Section 13
Concrete under special conditions	Section 14
Sampling and strength test of concrete	Section 15
Acceptance criteria	Section 16
Inspection and testing of structures	Section 17

