Introduction

Compressive Strength of Concrete, f'_c

Fig. (a)

Fig. (b)

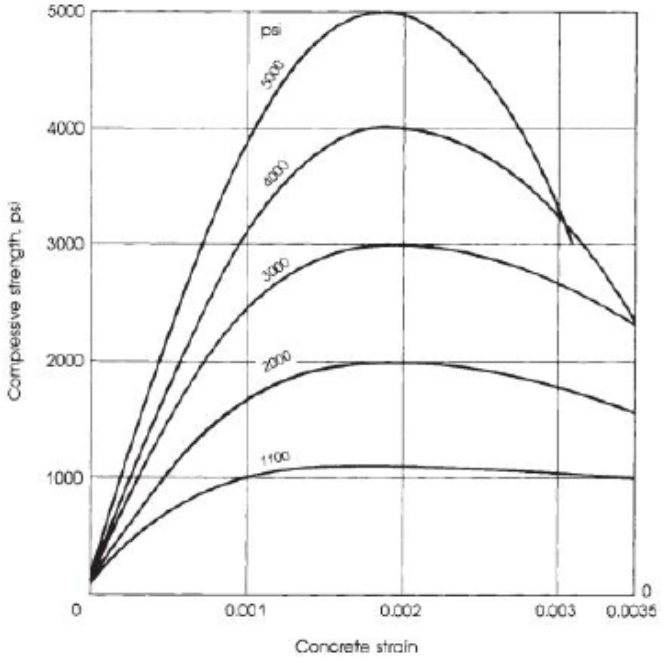
Fig. (c)

Fig. (d)

Strength of concrete is specified by the compressive strength it develops within 28 days after placement. Uniaxial compression test is used to determine compressive strength of concrete.

- **Fig. (a):** Fresh concrete is placed into a standard cylindrical mold.
- **Fig. (b):** After initial setting, the concrete cylinder that comes out of the mold has size of 6 inch in diameter and 12 inch in height. The cylinder is then placed in a water tank for curing.
- **Fig. (c):** After 28 days of initial casting, the test cylinder is then placed in a universal testing machine (UTM). Compressive force is applied from both sides (top and bottom) of the cylinder.
- **Fig. (d):** Due to high pressure exerted by the UTM, the concrete cylinder crushes.
- The compressive stress at which concrete crushes is known as *compressive strength* (ultimate strength) of concrete which is denoted by f'_c and for normal concrete it is around 4000 psi.
- Compressive strength below 3000 psi is not recommended for regular construction, and it could be as high as 20,000 psi.

Stress-Strain Curve of Concrete



Salient Features

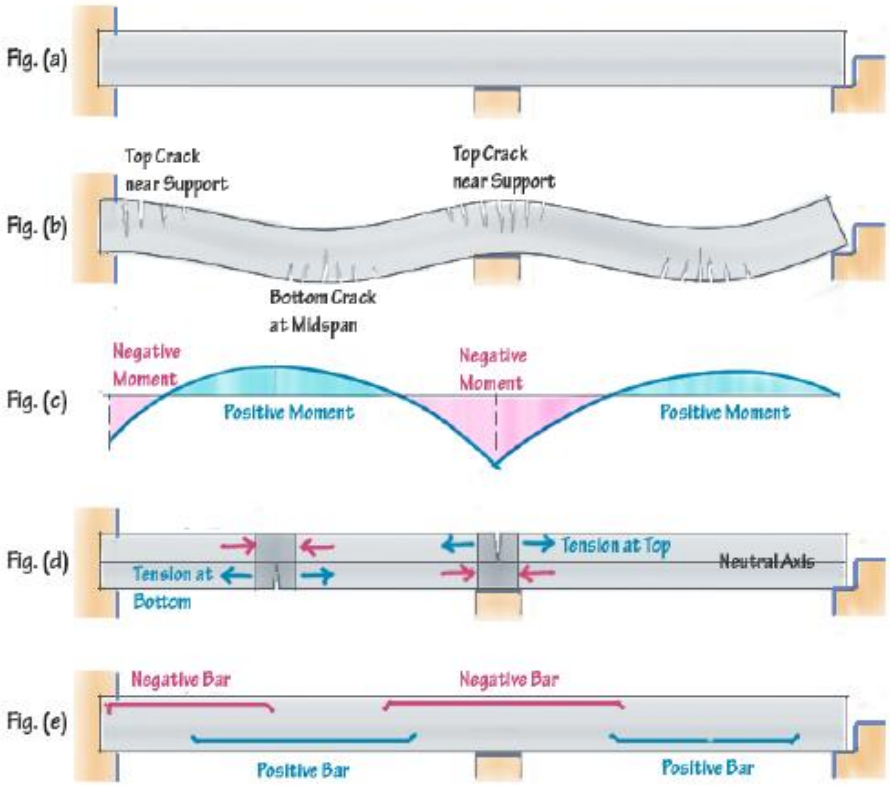
- Curves are roughly straight if the applied load is less than one-half of concrete's ultimate strength (the peak of a curve). The behavior of concrete is nonlinear at higher load.
- Regardless of strengths, all the concretes reach their ultimate strengths at strains of about 0.002.
- Concrete does not have a definite yield strength; rather, the curves run smoothly on to the point of rupture at strains of from 0.003 to 0.004.

Ultimate Strain of Concrete, ϵ_u

ACI-318 code recommends to use the value of 0.003 as the ultimate strain of concrete. Concrete is assumed to be failed by crushing if it is compressed beyond this strain.

Note: ACI-318, published by American Concrete Institute, is the gold standard among building codes for concrete structures. It is practiced by many countries that do not have their own building code and Bangladesh is no exception. The guidelines for concrete structures in the Bangladesh National Building Code (BNBC) highly resembles to ACI-318.

Why Reinforcement is Required in Concrete Structure



- Concrete is strong in resisting compression but very weak in resisting *tension*. In reinforced concrete analysis, it is assumed that concrete cannot resist any tension at all.
- **Fig. (a), (b):** A continuous beam, shown in Fig. (a), deflects like the shape shown in Fig. (b) due to its self weight. Crack appears at bottom at midspan as well as at top near supports.
- **Fig. (c):** This happens because positive moment occurs at midspan of beam and negative moment occurs near support. The moment diagram of the beam is shown in Fig. (c).
- **Fig. (d):** The positive moment causes tension *below* the neutral axis and the negative moment causes tension *above* the neutral axis. Since concrete is very weak in resisting tension, cracks appear at these tensile zones.
- **Fig. (e):** To help concrete to resist tension, steel reinforcements are provided at the crack prone zones (tensile zones). The reinforcement placed at bottom of a section at midspan is known as *positive bar*. The reinforcement placed at top near support is known as *negative bar*.

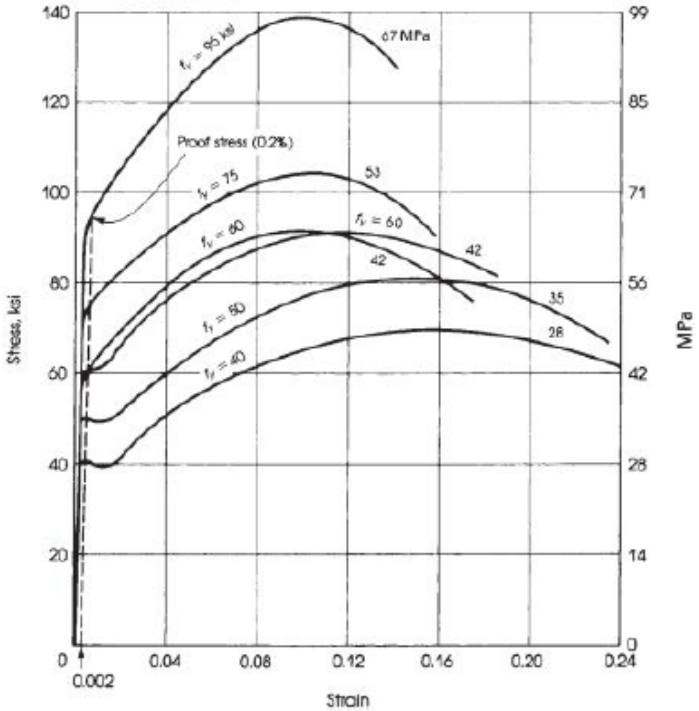
Reinforcing Steel

Reinforcing Bar Size Table

No.	Dia. (in)	Area (in^2)	Remarks
3	3/8	0.11	Slab
4	0.5	0.20	
5	5/8	0.31	Beam
6	6/8	0.44	
7	7/8	0.60	
8	1.0	0.79	
9	1.128	1.00	Column
10	1.27	1.27	
11	1.41	1.56	
14	1.693	2.25	
18	2.257	4.00	

- The primary contribution of steel in reinforced concrete beam is to provide tension.
- Bars usually have ribbed projections rolled onto their surfaces. It provides better bonding between the concrete and the steel.
- Steel bar is designated by its strength and size. For example, a Grade 60 No. 9 bar indicates that its tensile strength is 60 ksi, diameter is 1.128 inch and cross sectional area is 1.00 in^2.
- Only few designated sizes of bars are available. Grade 40 and Grade 60 are the most common types of construction steel.
- Smaller bars are used in slabs, medium sized bars are used in beams and larger bars are usually used in columns.
- Bridges, dams, wastewater treatment plants, and various coastal structures often exposed to corrosive chemicals. To protect steel from corrosion, epoxy coated reinforced bars are used.

Stress-Strain Curve of Steel



Salient Features

- Stress strain curve of steel has definitive yield point unlike concrete.
- All steels start to yield approximately at 0.002 strain which is known as *yield strain* (ϵ_y).
- Behavior of steel is linear before yield strain, but beyond that, it becomes nonlinear.
- Steel can undergo very large deformation prior to failure unlike concrete.
- ACI-318 code recommends that the tensile strain (ϵ_t) of steel in a concrete beam should have strain of 0.005 or more before failure.

Tensile strength (yield strength) of steel is denoted by f_y and Grade 60 steel ($f_y = 60$ ksi) is very common in construction. Tensile strength is detemined by tension test of steel.