University Of Anbar
Engineering College
Civil Engineering Department

Reinforced Concrete I

2019 - 2020

Reinforced Concrete (1)- 3rd Year, Civil Engineering

CONTENTS

CHAPTER 1 REINFORCED CONCRETE STRUCTURES

1.1 INTRODUCTION

Many structures are built of reinforced concrete: bridges, viaducts, buildings, retaining walls, tunnels, tanks, conduits, and others.
Reinforced concrete is a logical union of two materials: plain concrete, which possesses high compressive strength but little tensile strength, and steel bars embedded in the concrete, which can provide the needed strength in tension.
First practical use of reinforced concrete was known in the mid-1800s. In the first decade of the 20th century, progress in reinforced concrete was rapid. Since the mid-1950s, reinforced concrete design practice has made the transition from that based on elastic methods to one based on strength.
Understanding of reinforced concrete behavior is still far from complete; building codes and specifications that give design procedures are continually changing to reflect latest knowledge.

1.2 REINFORCED CONCRETE MEMBERS

Every structure is proportioned as to both architecture and engineering to serve a particular function. Form and function go hand in hand, and the beat structural system is the one that fulfills most of the needs of the user while being serviceable, attractive, and economically cost efficient. Although most structures are designed for a life span of 50 years, the durability performance record indicates that properly proportioned concrete structures have generally had longer useful lives.
Reinforced concrete structures consist of a series of “members” (components) that interact to support the loads placed on the structures.
The components can be broadly classified into:

1. Floor Slabs

Floor slabs are the main horizontal elements that transmit the moving live loads as well as the stationary dead loads to the vertical framing supports of a structure. They can be:

- Slabs on beams,
- Waffle slabs,
- Slabs without beams (Flat Plates) resting directly on columns,
- Composite slabs on joists.

They can be proportioned such that they act in one direction (one-way slabs) or proportioned so that they act in two perpendicular directions (two-way slabs and flat plates).

2. Beams

Beams are the structural elements that transmit the tributary loads from floor slabs to vertical supporting columns. They are normally cast monolithically with the slabs and are structurally reinforced on one face, the lower tension side, or both the top and bottom faces. As they are cast monolithically with the slab, they form a T-beam section for interior beams or an L beam at the building exterior.

The plan dimensions of a slab panel determine whether the floor slab behaves essentially as a one-way or two-way slab.

3. Columns

The vertical elements support the structural floor system. They are compression members subjected in most cases to both bending and axial load and are of major importance in the safety considerations of any structure. If a structural system is also composed of horizontal compression members, such members would be considered as beam-columns.

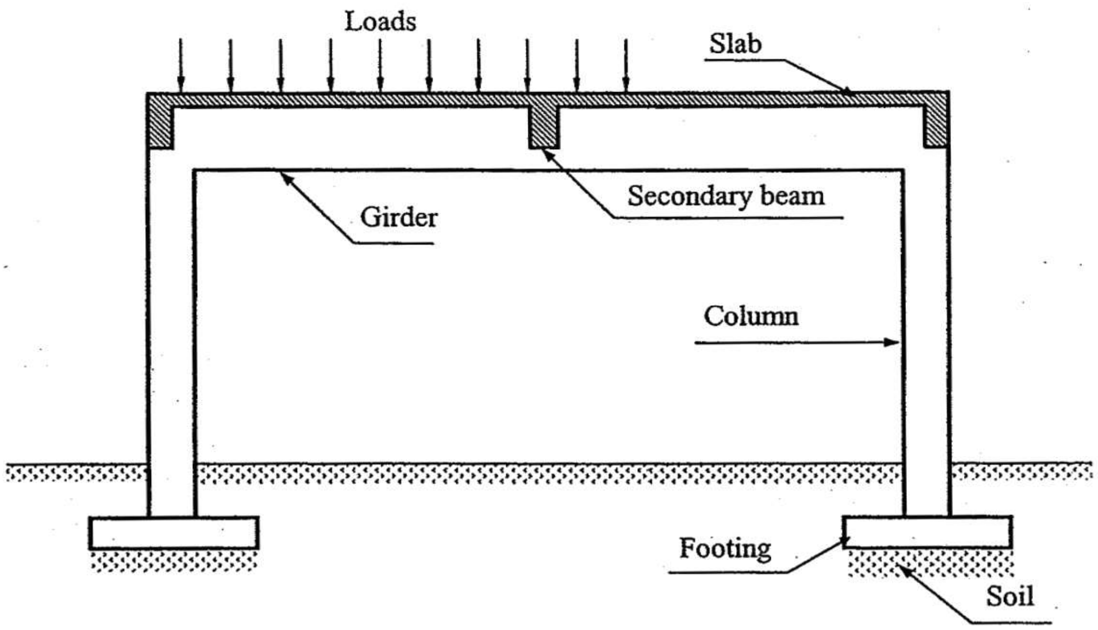
4. Walls

Walls are the vertical enclosures for building frames. They are not usually or necessarily made of concrete but of any material that esthetically fulfills the form and functional needs of the structural system. Additionally, structural concrete walls are often necessary as foundation walls, stairwell walls, and shear walls that resist horizontal wind loads and earthquake-induced loads.

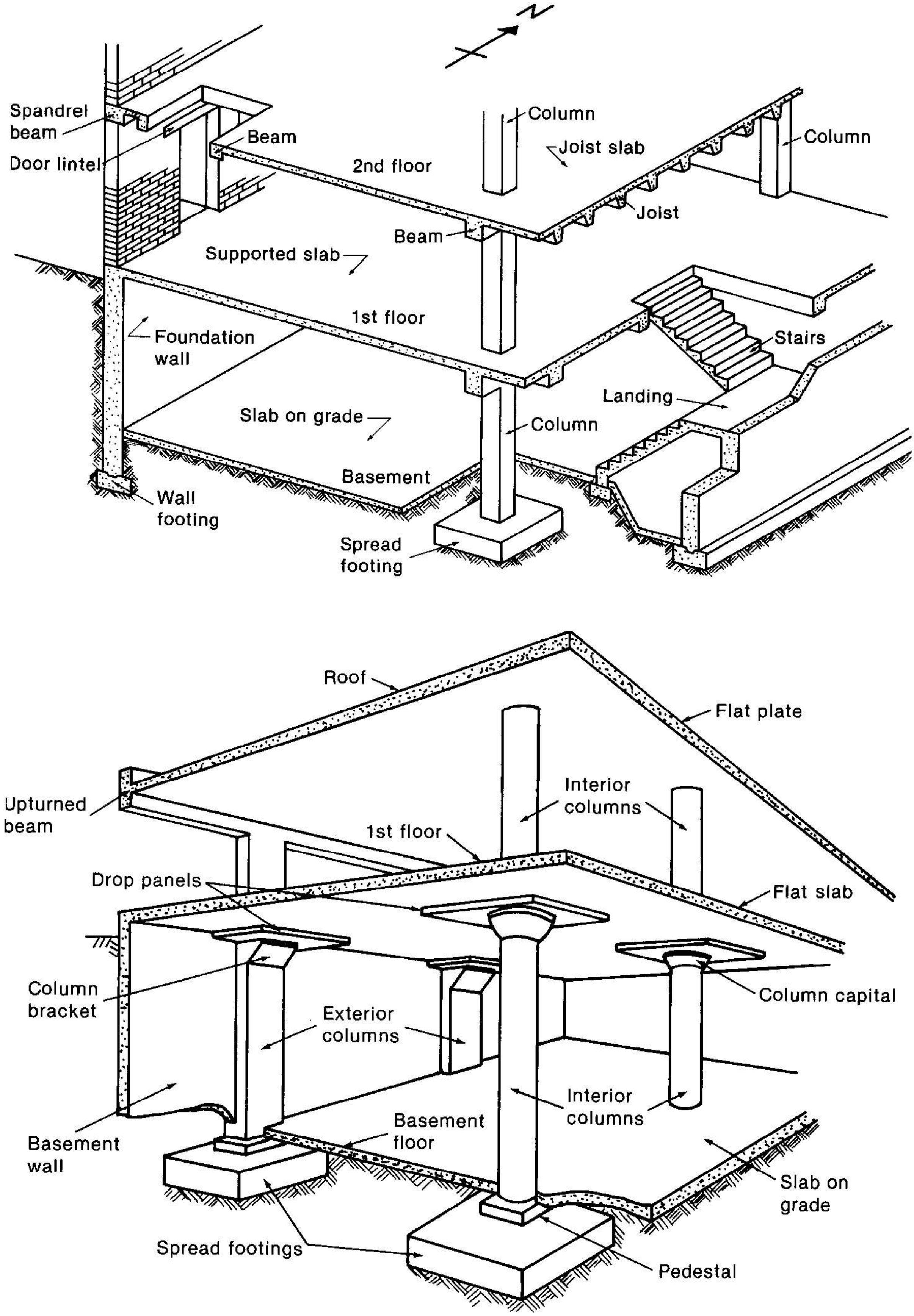
5. Foundations

Foundations are the structural concrete elements that transmit the weight of the superstructure to the supporting soil. They could be in many forms:

- Isolated footing - the simplest one. It can be viewed as an inverted slab transmitting a distributed load from the soil to the column.
- Combined footings supporting more than one column.
- Mat foundations, and rafts which are basically inverted slab and beam construction.
- Strip footing or wall footing supporting walls.
- Piles driven to rock.



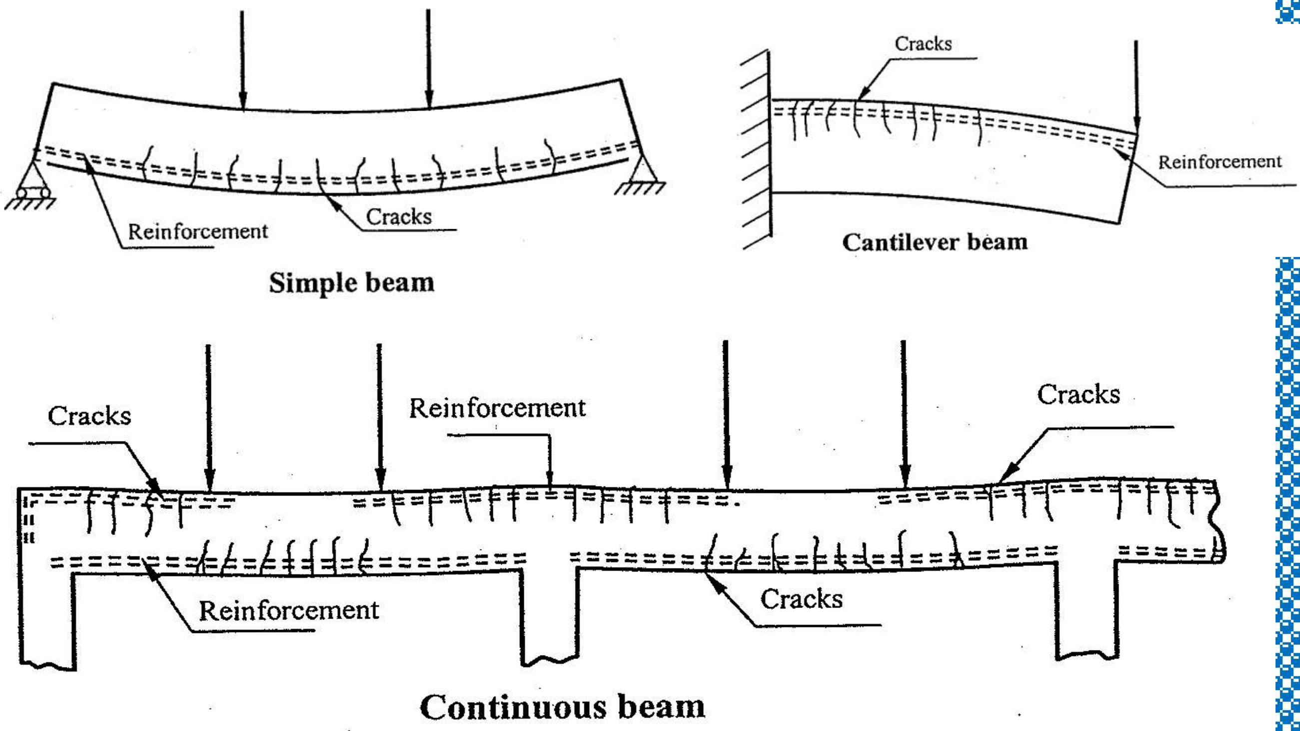
Typical reinforced concrete structural framing system



Reinforced concrete building elements

1.3 REINFORCED CONCRETE BEHAVIOR

The addition of steel reinforcement that bonds strongly to concrete produces a relatively ductile material capable of transmitting tension and suitable for any structural elements, e.g., slabs, beam, columns. Reinforcement should be placed in the locations of anticipated tensile stresses and cracking areas. For example, the main reinforcement in a simple beam is placed at the bottom fibers where the tensile stresses develop. However, for a cantilever, the main reinforcement is at the top of the beam at the location of the maximum negative moment. Finally for a continuous beam, a part of the main reinforcement should be placed near the bottom fibers where the positive moments exist and the other part is placed at the top fibers where the negative moments exist.



Reinforcement placement for different types of beams

CHAPTER 2 MATERIALS, AND PROPERTIES

2.1 CONCRETE

Plain concrete is made by mixing cement, fine aggregate, coarse aggregate, water, and frequently admixtures.
Structural concrete can be classified into:

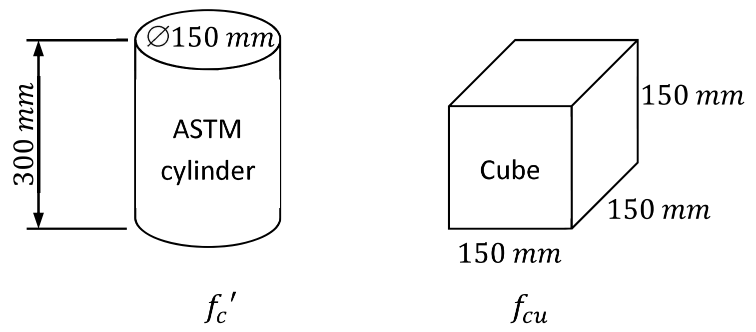
- Lightweight concrete with a unit weight from about $1350\ to\ 1850\ kg/m^3$ produced from aggregates of expanded shale, clay, slate, and slag.

Other lightweight materials such as pumice, scoria, perlite, vermiculite, and diatomite are used to produce insulating lightweight concretes ranging in density from about $250\ to\ 1450\ kg/m^3$.

- Normal-weight concrete with a unit weight from about $1800\ to\ 2400\ kg/m^3$ produced from the most commonly used aggregates— sand, gravel, crushed stone.
- Heavyweight concrete with a unit weight from about $3200\ to\ 5600\ kg/m^3$ produced from such materials such as barite, limonite, magnetite, ilmenite, hematite, iron, and steel punching or shot. It is used for shielding against radiations in nuclear reactor containers and other structures.

2.2 COMPRESSIVE STRENGTH

The strength of concrete is controlled by the proportioning of cement, coarse and fine aggregates, water, and various admixtures. The most important variable is (w/c) ratio.
Concrete strength (f_c') – uniaxial compressive strength measured by a compression test of a standard test cylinder ($150\ mm$ diameter by $300\ mm$ high) on the 28th day–ASTM C31, C39.
In many countries, the standard test unit is the cube ($200 \times 200 \times 200\ mm$).
The concrete strength depends on the size and shape of the test specimen and the manner of testing. For this reason the cylinder ($\varnothing 150\ mm$ by $300\ mm$ high) strength is 80% of the $150 - mm$ cube strength and 83% of the $200 - mm$ cube strength.



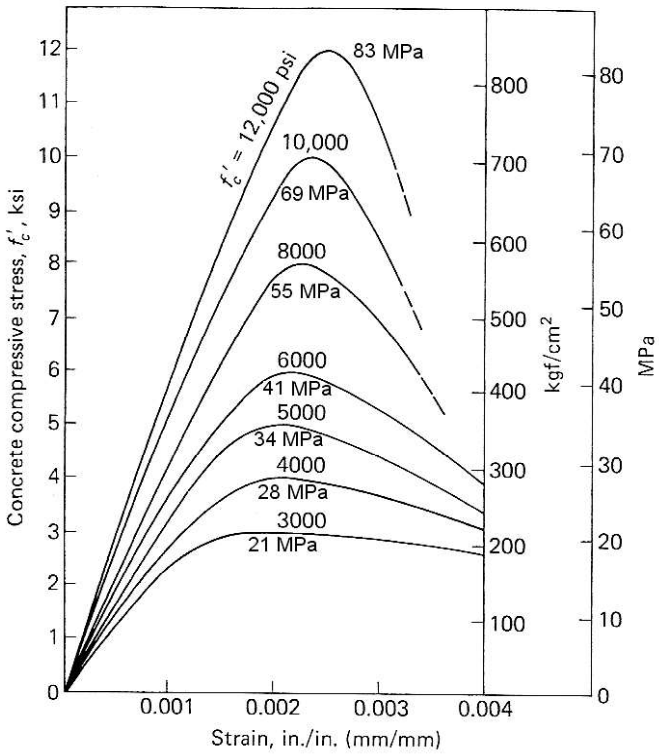
$$f_c' \approx 0.80\ f_{cu}$$

Stress-strain relationship: Typical curves for specimens ($150 \times 300\ mm$ cylinders) loaded in compression at 28 days.

Lower-strength concrete has greater deformability (ductility) than higher-strength concrete (length of the portion of the curve after the maximum stress is reached at a strain between 0.002 and 0.0025).

Ultimate strain at crushing of concrete varies from 0.003 to as high as 0.008.

- In usual reinforced concrete design $f_c{}'$ of $(24\ to\ 35\ MPa)$ are used for nonprestressed structures.
- $f_c{}'$ of $(35$ to $42\ MPa)$ are used for prestressed concrete.
- $f_c{}'$ of $(42$ to $97\ MPa)$ are used particularly in columns of tall buildings.



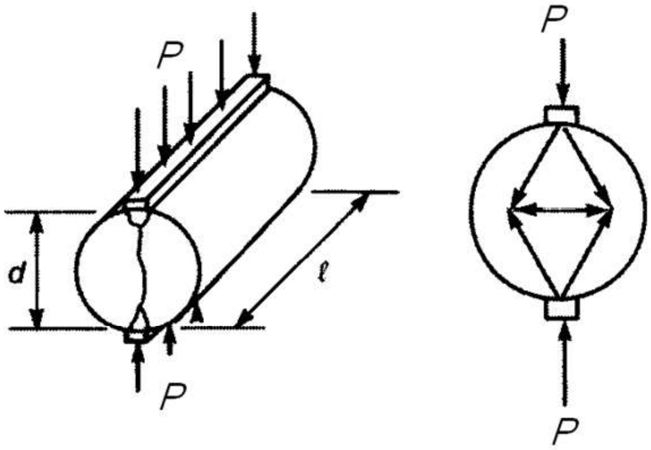
2.3 TENSILE STRENGTH

Concrete tensile strength is about $10\ to\ 15\%$ of its compressive strength.

The strength of concrete in tension is an important property that greatly affects that extent and size of cracking in structures.

Tensile strength is usually determined by using:

- Split-cylinder test (ASTM C496). A standard $150 \times 300\ mm$ compression test cylinder is placed on its side and loaded in compression along a diameter. The splitting tensile strength f_{ct} is computed as



$$f_{ct} = \frac{2P}{\pi l d}$$

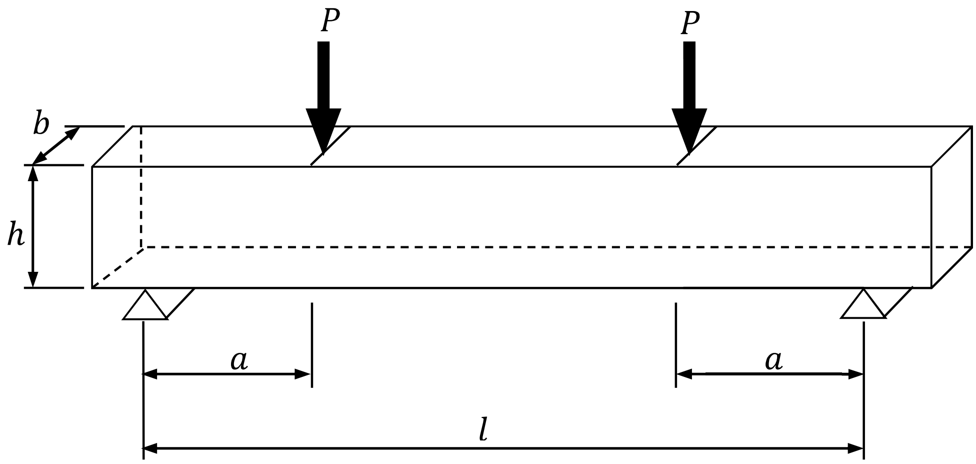
- Tensile strength in flexure (modulus of rupture) (ASTM C78 or C293). A plain concrete beam $150 \times 150\ mm\ \times 750\ mm\ long,$ is loaded in flexure at the third points of 600-mm span until it fails due to cracking on the tension face. Modulus of rupture f_r is computed as

$$f_r = \frac{M}{I}c = \frac{6M}{bh^2} = \frac{6Pa}{bh^2}$$

It is accepted (ACI 9.5.2.3) that an average value for f_r may be taken as

$$f_r = 0.62\ \lambda\sqrt{f_c{}'}\ , \qquad f_c' \quad in\ MPa$$

$$where \qquad \lambda = 1 \quad for\ normalweight\ concrete.$$

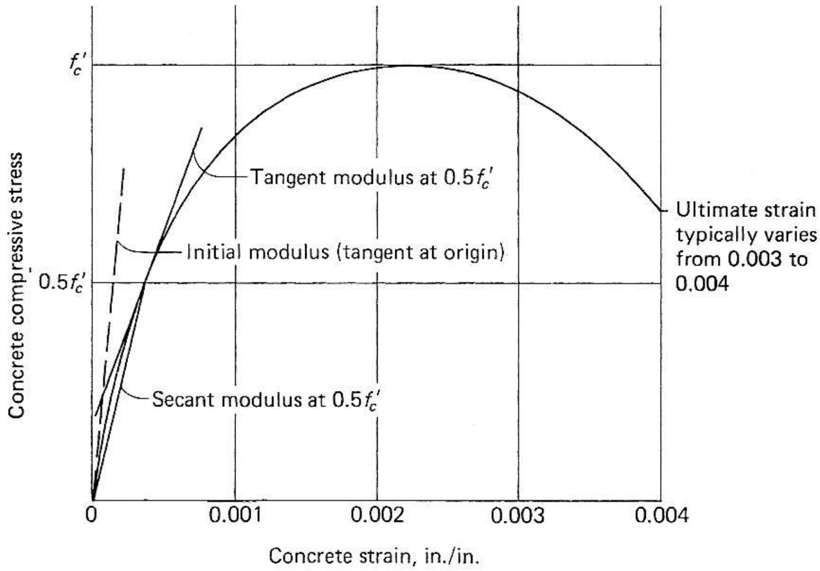


- Direct axial tension test. It is difficult to measure accurately and not in use today.

2.4 MODULUS OF ELASTICITY

The modulus of elasticity of concrete varies, unlike that of steel, with strength.

A typical stress-strain curve for concrete in compression is shown. The initial modulus (tangent at origin), the tangent modulus (at $0.5\,f_c{}'$), and the secant modulus are noted. Usually the secant modulus at from $25\ to\ 50\%$ of the compressive strength $f_c{}'$ is considered to be the modulus of elasticity. The empirical formula given by ACI-8.5.1



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

For normalweight concrete, E_c shall be permitted to be taken as $E_c = 4700\sqrt{f_c{}'}$,

where, $1440 \le w_c \le 2560\ \ kg/m^3 \quad and \quad f_c'\ in\ MPa$.

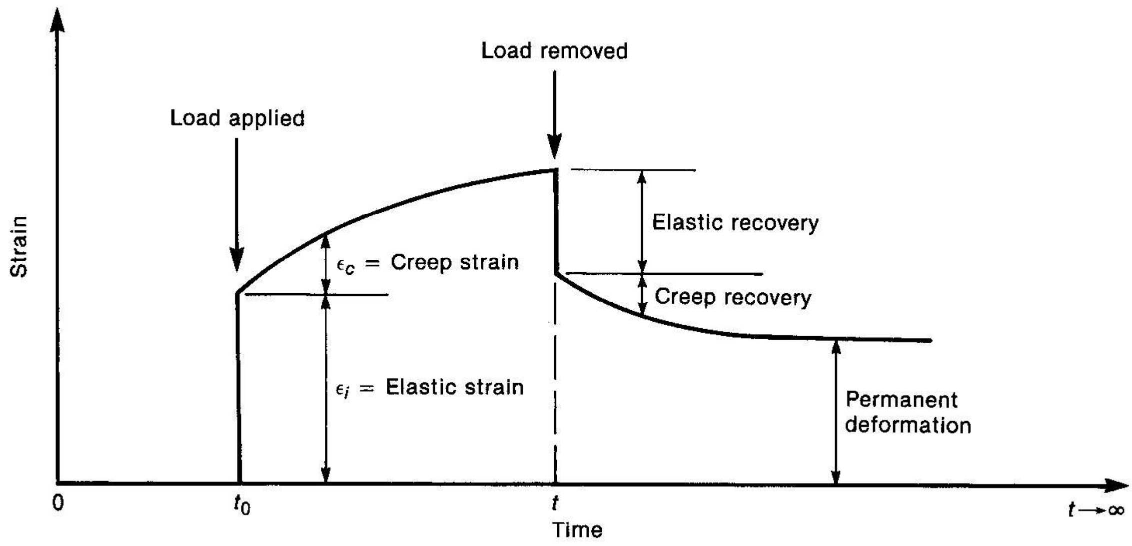
2.5 CREEP AND SHRINKAGE

Creep and shrinkage are time-dependent deformations that, along with cracking, provide the greatest concern for the designer because of the inaccuracies and unknowns that surround them. Concrete is elastic only under loads of short duration; and, because of additional deformation with time, the effective behavior is that of an inelastic material. Deflection after a long period of time is therefore difficult to predict, but its control is needed to assure serviceability during the life of the structure.

Creep (or plastic flow) is the property of concrete (and other materials) by which it continues to deform with time under sustained loads at unit stresses within the accepted elastic range (say, below $0.5\ f_c'$). This inelastic deformation increases at a decreasing rate during the time of loading, and its total magnitude may be several times as large as the short-time elastic deformation. Frequently creep is associated with shrinkage, since both are occurring simultaneously and often provide the same net effect: increased deformation with time.

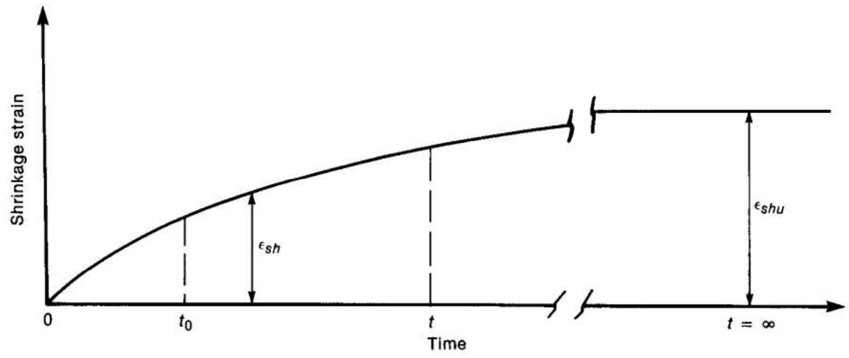
The internal mechanism of creep, or "plastic flow" as it is sometimes called, may be due to any one or a combination of the following: (1) crystalline flow in the aggregate and hardened cement paste; (2) plastic flow of the cement paste surrounding the aggregate; (3) closing of internal voids; and (4) the flow of water out of the cement gel due to external load and drying.

Factors affecting the magnitude of creep are (1) the constituents—such as the composition and fineness of the cement, the admixtures, and the size, grading, and mineral content of the aggregates: (2) proportions such as water content and water-cement ratio; (3) curing temperature and humidity; (4) relative humidity during period of use; (5) age at loading; (6) duration of loading; (7) magnitude of stress; (8) surface-volume ratio of the member; and (9) slump.



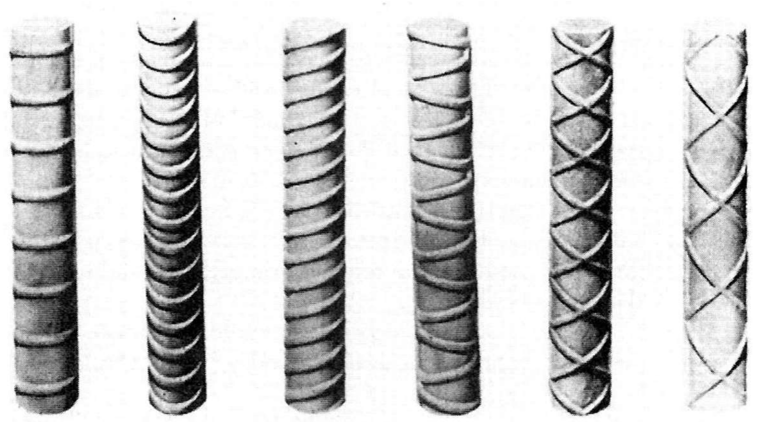
Creep of concrete will often cause an increase in the long-term deflection of members. Unlike concrete, steel is not susceptible to creep. For this reason, steel reinforcement is often provided in the compression zone of beams to reduce their long-term deflection.

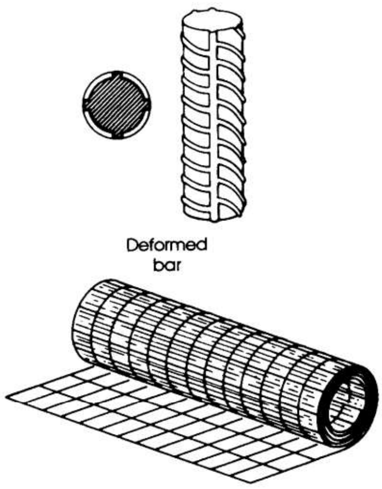
Shrinkage, broadly defined, is the volume change during hardening and curing of the concrete. It is unrelated to load application. The main cause of shrinkage is the loss of water as the concrete dries and hardens. It is possible for concrete cured continuously under water to increase in volume; however, the usual concern is with a decrease in volume. In general, the same factors have been found to influence shrinkage strain as those that influence creep—primarily those factors related to moisture loss.



2.6 STEEL REINFORCEMENT

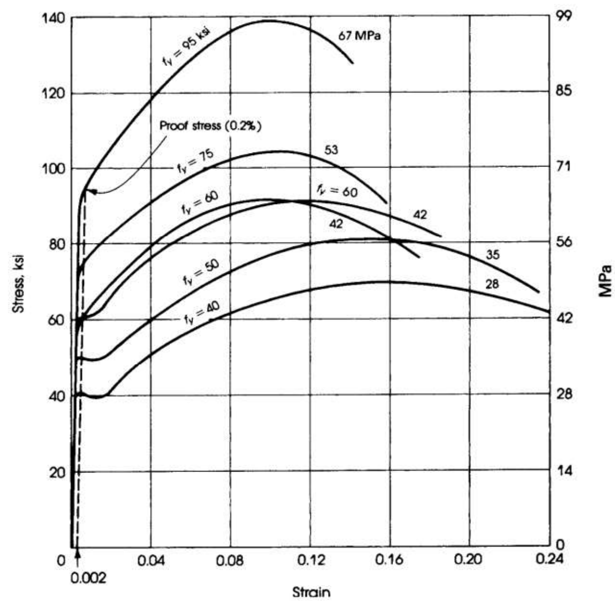
The useful strength of ordinary reinforcing steels in tension as well as compression, the yield strength is about 15 times the compressive strength of common structural concrete and well over 100 times its tensile strength.





Steel reinforcement may consist of :

- Bars (deformed bars, as in picture below) – for usual construction.
- Welded wire fabric – is used in thins slabs, thin shells.
- Wires – are used for prestressed concrete.



The “Grade” of steel is the minimum specified yield stress (point) expressed in:

- MPa for SI reinforcing bar Grades 300, 350, 420, and 520.
- ksi for Inch-Pound reinforcing bar Grades 40, 50, 60, and 75.

The introduction of carbon and alloying additives in steel increases its strength but reduces its ductility. The proportion of carbon used in structural steels varies between 0.2% and 0.3%.

The steel modulus of elasticity (E_s) is constant for all types of steel. The ACI Code has adopted a value of $E_s = 2 \times 10^5\ MPa\ (29 \times 10^6\ psi\ )$.

Summary of minimum ASTM strength requirements

Product	ASTM Specification	Designation	Minimum Yield Strength, psi (MPa)	Minimum Tensile Strength, psi (MPa)
Reinforcing bars	A615	Grade 40 Grade 60 Grade 75	40,000 (280) 60,000 (420) 75,000 (520)	60,000 (420) 90,000 (620) 100,000 (690)
	A706	Grade 60	60,000 (420) [78,000 (540) maximum]	80,000 (550)[a]
	A996	Grade 40 Grade 50 Grade 60	40,000 (280) 50,000 (350) 60,000 (420)	60,000 (420) 80,000 (550) 90,000 (620)
	A1035	Grade 100	100,000 (690)	150,000 (1030)
Deformed bar mats	A184	Same as reinforcing bars		
Zinc-coated bars	A767	Same as reinforcing bars		
Epoxy-coated bars	A775, A934	Same as reinforcing bars		
Stainless-steel bars[b]	A955	Same as reinforcing bars		
Wire Plain	A82		70,000 (480)	80,000 (550)
Deformed	A496		75,000 (515)	85,000 (585)
Welded wire reinforcement Plain W1.2 and larger Smaller than W1.2	A185		 65,000 (450) 56,000 (385)	 75,000 (515) 70,000 (485)
Deformed	A497		70,000 (480)	80,000 (550)
Prestressing tendons Seven-wire strand	A416	Grade 250 (stress-relieved)	212,500 (1465)	250,000 (1725)
		Grade 250 (low-relaxation)	225,000 (1555)	250,000 (1725)
		Grade 270 (stress-relieved)	229,500 (1580)	270,000 (1860)
		Grade 270 (low-relaxation)	243,000 (1675)	270,000 (1860)
Wire	A421	Stress-relieved	199,750 (1375) to 212,500 (1465)[c]	235,000 (1620) to 250,000 (1725)[c]
		Low-relaxation	211,500 (1455) to 225,000 (1550)[c]	235,000 (1620) to 250,000 (1725)[c]
Bars	A722	Type I (plain) Type II (deformed)	127,500 (800) 120,000 (825)	150,000 (1035) 150,000 (1035)
Compacted strand[b]	A779	Type 245 Type 260 Type 270	241,900 (1480) 228,800 (1575) 234,900 (1620)	247,000 (1700) 263,000 (1810) 270,000 (1860)

[a] But not less than 1.25 times the actual yield strength.
[b] Not listed in ACI 318.
[c] Minimum strength depends on wire size.

Cross sectional Areas of standard steel bars for reinforced concrete structures

Diameter, mm	Area of bars for Number of bars , cm^2									Mass, Kg/ m
	1	2	3	4	5	6	7	8	9	
6	0.283	0.565	0.848	1.131	1.414	1.696	1.979	2.262	2.545	0.222
8	0.503	1.005	1.508	2.011	2.513	3.016	3.519	4.021	4.524	0.395
10	0.785	1.571	2.356	3.142	3.927	4.712	5.498	6.283	7.069	0.617
12	1.131	2.262	3.393	4.524	5.655	6.786	7.917	9.048	10.179	0.888
14	1.539	3.079	4.618	6.158	7.697	9.236	10.776	12.315	13.854	1.208
16	2.011	4.021	6.032	8.042	10.053	12.064	14.074	16.085	18.096	1.578
18	2.545	5.089	7.634	10.179	12.723	15.268	17.813	20.358	22.902	1.998
20	3.142	6.283	9.425	12.566	15.708	18.850	21.991	25.133	28.274	2.466
22	3.801	7.603	11.404	15.205	19.007	22.808	26.609	30.411	34.212	2.984
25	4.909	9.817	14.726	19.635	24.544	29.452	34.361	39.270	44.179	3.854
28	6.158	12.315	18.473	24.630	30.788	36.945	43.103	49.260	55.418	4.834
32	8.042	16.085	24.127	32.170	40.212	48.255	56.297	64.340	72.382	6.314
36	10.179	20.358	30.536	40.715	50.894	61.073	71.251	81.430	91.609	7.991
40	12.566	25.133	37.699	50.265	62.832	75.398	87.965	100.531	113.097	9.865
45	15.904	31.809	47.713	63.617	79.522	95.426	111.330	127.235	143.139	12.486