CIHAN UNIVERSITY

COLLEGE OF ENGINEERING

ARCHITECTURAL ENGINEERING DEP.

CIHAN UNIVERSITY
SULAIMANI

CONCRETE DESIGN I

CHAPTER 1

Introduction to Concrete Structures

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M.Sc. Structural Engineering

CHAPTER 1 INTRDUCTION TO CONCRETE STRUCTURES

1.1 Course Content

Course Content	
Chapter 1	Introduction to concrete structures
Chapter 2	Singly Reinforced Beams
Chapter 3	Doubly Reinforced Beams
Chapter 4	T-beams and Flanged Sections
Chapter 5	Shear and Diagonal Tension in Beams
Chapter 6	Design for Torsion
Chapter 7	One-way Slabs and Continuous Beams
Chapter 8	Design of Two-way Slabs
Chapter 9	Design of Short Columns
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Chapter 11	Bond, Development Length and Splices
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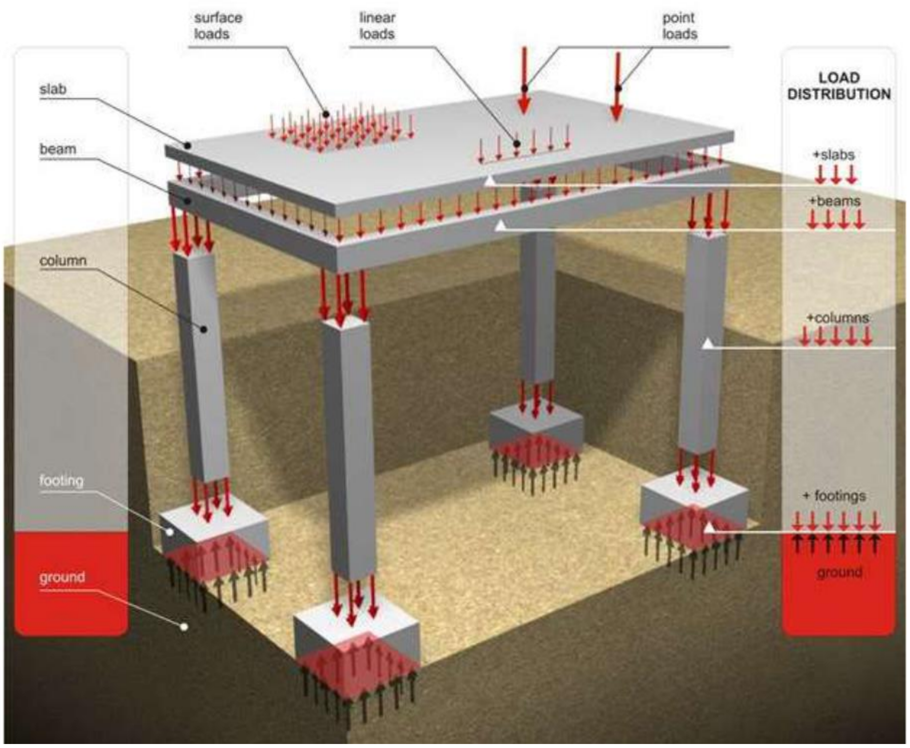
1.2 Reinforced Concrete Structures

Concrete and reinforced concrete are used as building construction materials in every country. In many countries, reinforced concrete is a dominant structural material in engineered construction.

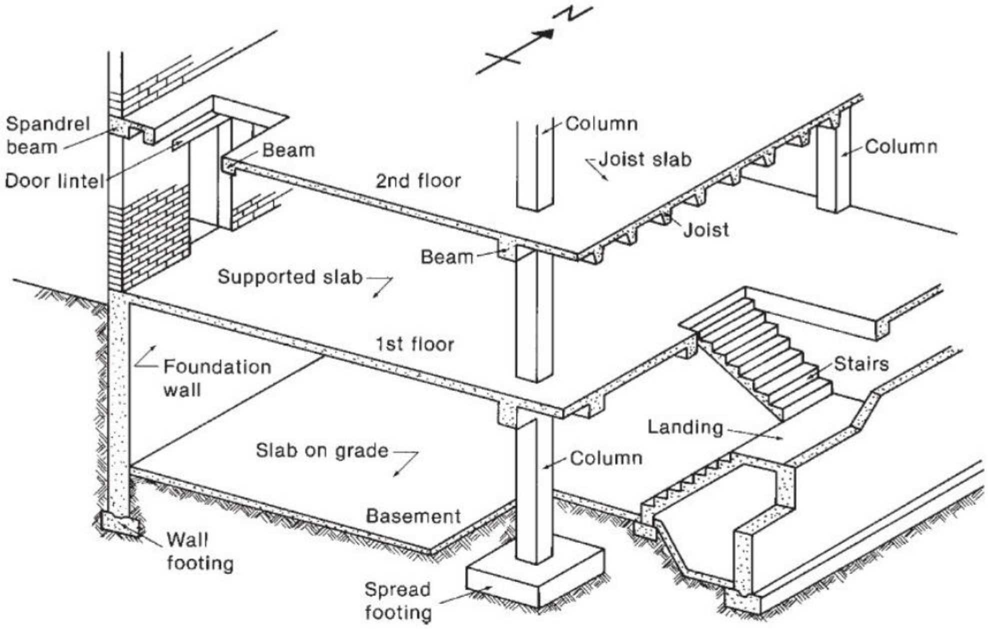
The universal nature of reinforced concrete construction stems from the wide availability of reinforcing bars and of the constituents of concrete (gravel or crushed rock, sand, water, and cement), from the relatively simple skills required in concrete construction, and from the economy of reinforced concrete compared with other forms of construction.

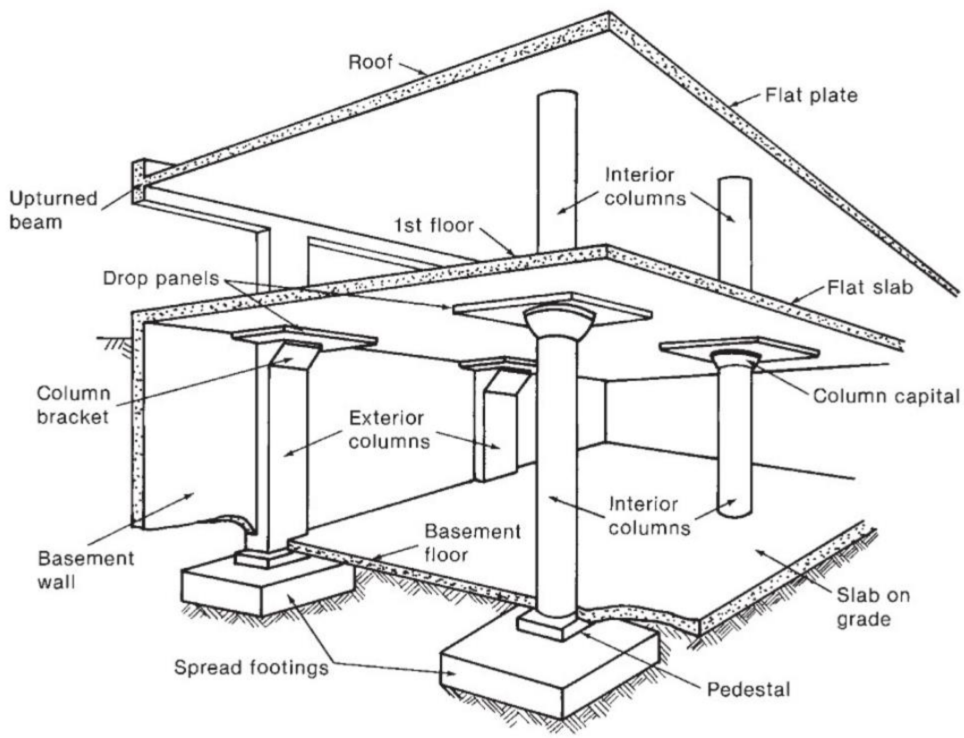
Plain concrete and reinforced concrete are used in buildings of all sorts underground structures, water tanks, wind turbine foundations and towers, offshore oil exploration and production structures, dams, bridges, and even ships.

1.3 Load Transfer and Load Path [2]



1.4 Structural Members and Components [1]





1.5 Advantages of Reinforced Concrete as a Structural Material

1. It has considerable **compressive strength** per unit cost compared with most other materials.
2. Reinforced concrete has **great resistance** to the actions of **fire** and **water**.
3. Reinforced concrete structures are **very rigid**.
4. It is a **low-maintenance** material.
5. As compared with other materials, it has a **very long service life**. Under proper conditions.
6. It is usually the only **economical material** available for footings, floor slabs, basement walls, piers, and similar applications.
7. A special feature of concrete is its **ability to be cast into an extraordinary variety of shapes** from simple slabs, beams, and columns to great arches and shells.
8. In most areas, concrete takes advantage of **inexpensive local materials** (sand, gravel, and water).
9. A **lower grade of skilled labor is required** for erection as compared with other materials such as structural steel.

1.6 Disadvantages of Reinforced Concrete as a Structural Material

1. Concrete has a **very low tensile strength**, requiring the use of tensile reinforcing.
2. **Forms are required to hold the concrete** in place until it hardens sufficiently.
3. The **low strength per unit of weight of concrete** leads to **heavy members.** This becomes an increasingly important matter for long-span structures, where **concrete's large self weight** has a **great effect** on **bending moments.**
4. **Lightweight aggregates** can be used **to reduce concrete weight**, but **the cost of the concrete is increased**.

5. Similarly, the **low strength per unit of volume of concrete** means **members** will be **relatively large**, an important consideration for tall buildings and long-span structures.
6. The **properties of concrete vary widely** because of **variations** in its **proportioning** and **mixing.**
7. Furthermore, the **placing** and **curing** of concrete is **not** as carefully **controlled** as is the production of other materials, such as structural steel and laminated wood.
8. **Two other characteristics** that can **cause problems** are concrete's **shrinkage** and **creep**.

1.7 Shear-moment diagrams and deflected shapes - Review

1.7.1 Determinate Structures

1.7.1.1 Simply-supported – Uniformly distributed loads

1.7.1.2 Simply-supported – Concentrated Load

1.7.1.3 Cantilever Members – Uniformly distributed load

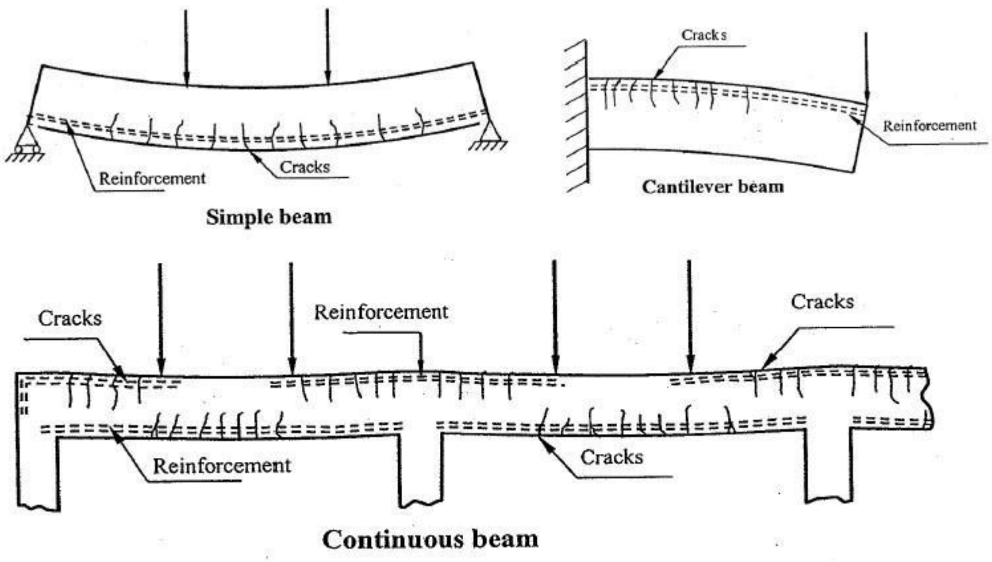
1.7.1.4 Cantilever Members – Concentrated Loads

1.7.2 Indeterminate Structures

1.7.2.1 Continuous Beams

1.7.2.2 Frames

1.8 Deflected Shapes and Reinforcements



Reinforcement placement for different types of beams

1.9 Unit Conversion

Overall Geometry	
Spans	1 ft = 0.3048 m
Displacements	1 in. = 25.4 mm
Surface area	1 ft^2 = 0.0929 m^2
Volume	1 ft^3 = 0.0283 m^3
	1 yd^3 = 0.765 m^3
Structural Properties	
Cross-sectional dimensions	1 in. = 25.4 mm
Area	1 in^2 = 645.2 mm^2
Section modulus	1 in^3 = 16.39 × 10^3 mm^3
Moment of inertia	1 in^4 = 0.4162 × 10^6 mm^4
Material Properties	
Density	1 lb/ft^3 = 16.03 kg/m^3
Modulus and stress	1 lb/in^2 = 0.006895 MPa
	1 kip/in^2 = 6.895 MPa
Loadings	
Concentrated loads	1 lb = 4.448 N
	1 kip = 4.448 kN
Density	1 lb/ft^3 = 0.1571 kN/m^3
Linear loads	1 kip/ft = 14.59 kN/m
Surface loads	1 lb/ft^2 = 0.0479 kN/m^2
	1 kip/ft^2 = 47.9 kN/m^2
Stress and Moments	
Stress	1 lb/in^2 = 0.006895 MPa
	1 kip/in^2 = 6.895 MPa
Moment or torque	1 ft-lb = 1.356 N-m
	1 ft-kip = 1.356 kN-m

APPENDIX B—EQUIVALENCE BETWEEN SI-METRIC, MKS-METRIC, AND U.S. CUSTOMARY UNITS OF NONHOMOGENOUS EQUATIONS IN THE CODE

Provision number	SI-metric stress in MPa	mks-metric stress in kgf/cm²	U.S. Customary units stress in pounds per square inch (psi)
	1 MPa	10 kgf/cm^2	145 psi
	f_c' = 21 MPa	f_c' = 210 kgf/cm^2	f_c' = 3000 psi
	f_c' = 28 MPa	f_c' = 280 kgf/cm^2	f_c' = 4000 psi
	f_c' = 35 MPa	f_c' = 350 kgf/cm^2	f_c' = 5000 psi
	f_c' = 40 MPa	f_c' = 420 kgf/cm^2	f_c' = 6000 psi
	f_y = 280 MPa	f_y = 2800 kgf/cm^2	f_y = 40,000 psi
	f_y = 420 MPa	f_y = 4200 kgf/cm^2	f_y = 60,000 psi

1.11 Concrete

Concrete consists primarily of a **mixture** of **cement** and **fine** and **coarse aggregates** (sand, gravel, crushed rock, and/or other materials) to which **water** has been added as a necessary ingredient for the chemical reaction of curing.

1.11.1 Concrete Constituents

Cement + water = cement paste

Cement+ water+ sand = mortar

Cement + sand + gravel = plane concrete

Concrete +reinforcement = Reinforced Concrete (RC)

1.11.2 Compressive Strength of Concrete

Compressive Strength: uniaxial compressive strength measured by a compression test of a standard cube or cylinder.

Other strength parameters, such as **tensile** or **bond strength**, are expressed relative to the compressive strength.

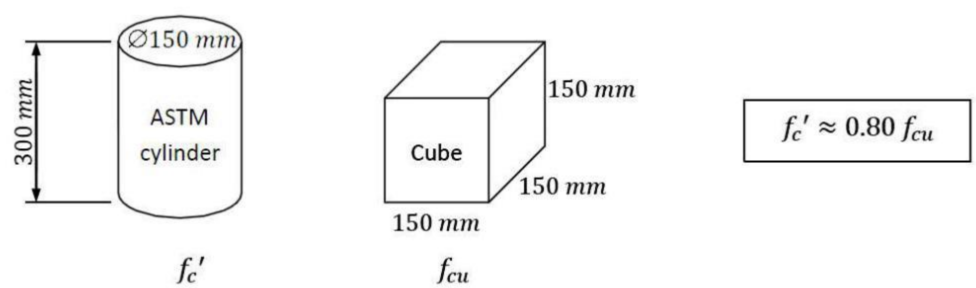


Figure 1 Cubes and Cylinders – Concrete Samples , [4]

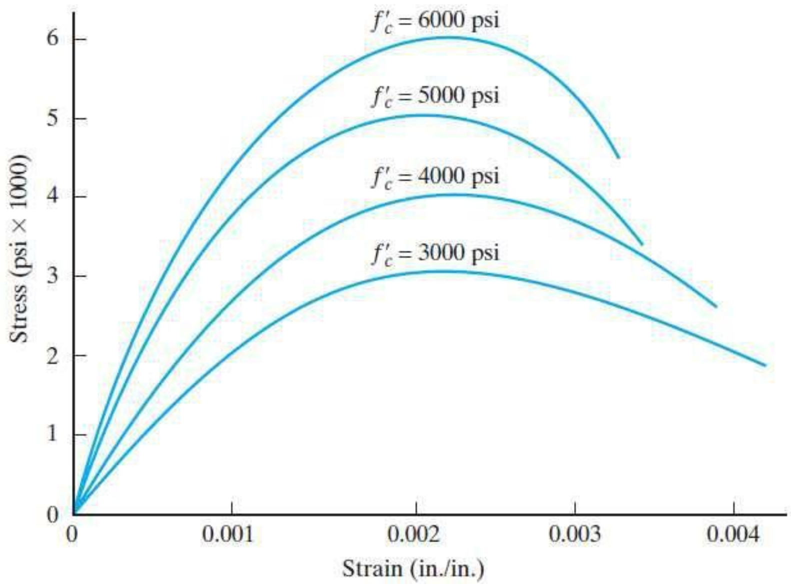


Figure 2 Typical stress-strain of Concrete in Compression [3]

1.11.3 Factors affecting Strength of Concrete (Homework)

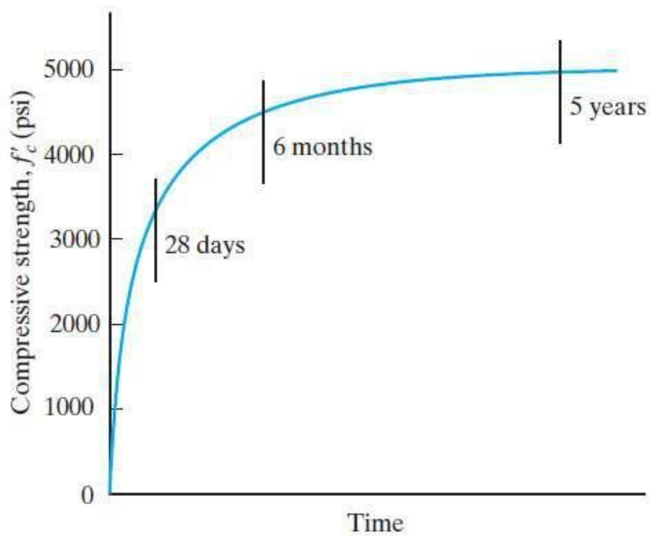


FIGURE 1-2 Strength–time relationship for concrete.

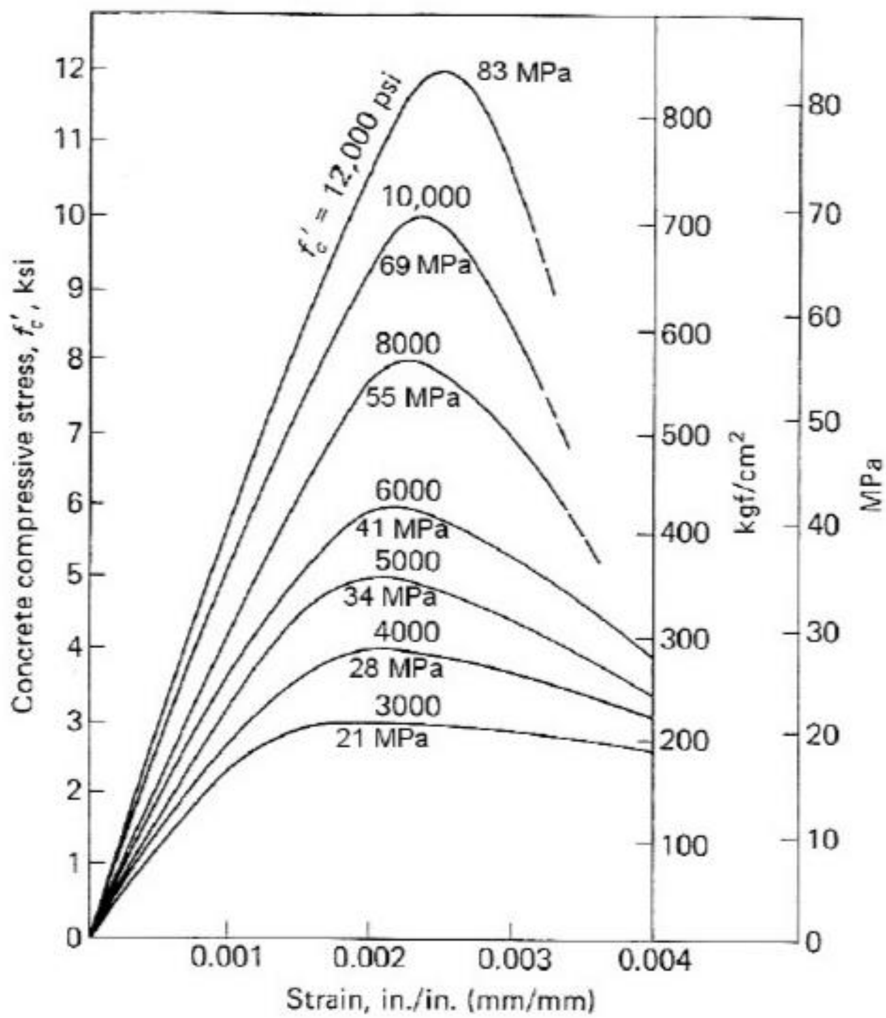


Figure 3 Stress-strain curves [5]

1.11.4 Modulus of Elasticity

Its **value varies** with different **concrete strengths**, **concrete age**, **type of loading**, and **the characteristics** and **proportions of the cement and aggregates**.

Types of Modulus of Elasticity

Initial Modulus

Tangent Modulus

Secant Modulus

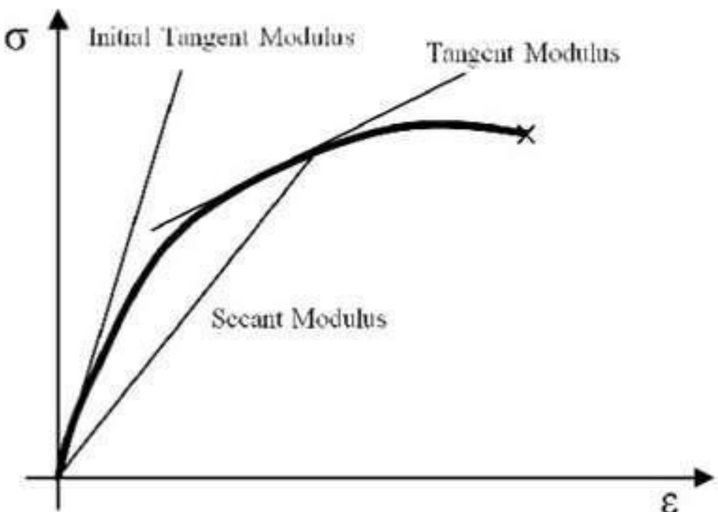


Figure 4 Various types of Modulus of Elasticity

According to ACI318M-14 (19.2.2)

Ec is defined as the **slope** of a line drawn from **zero stress to 0.45 fc'** compressive stress (secant modulus)

A. For values of density from 1440 and 2560 kg/m^3

$$E_c = W_c^{1.5}\, 0.043 \sqrt{fc'}$$ **ACI 318M− 14(19.2.2)**

B. For normal weight concrete

$$E_c = 4700 \sqrt{fc'}$$ **ACI 318M−14(19.2.2)**

For **high-strength concrete**, **ACI**-equation **overestimates**. Based on studies, the following expression is recommended for strength classes between **42 MPa** and **83 Mpa** (Normal weight Concrete) (McMacormac, 2014)

$$E_c(MPa) = \left(3.32\sqrt{fc'} + 6895\right)\left(\frac{W_c}{2320}\right)^{1.5}$$

1.11.5 Poisson Ratio

As a concrete cylinder is **subjected** to **compressive loads**, it **not only shortens** in **length** but also **expands laterally**. The **ratio** of this **lateral expansion** to the **longitudinal shortening** is referred to as **Poisson's ratio**. Its **value varies** from **about 0.11** for the **higher-strength concretes** to as high as **0.21** for the **weaker-grade concretes**, with **average values of about 0.16**.

1.11.6 Tensile Strength of Concrete

The **tensile strength** of concrete **varies** from about **8% to 15%** of its **compressive strength**. **A major reason** for **this small strength** is the fact that **concrete** is **filled with fine cracks.** The cracks have **little effect** when concrete is **subjected to compression loads** because the **loads cause the cracks to close** and permit compression transfer. Obviously, **this is not the case for tensile loads**.

Tests to measure the tensile strength of concrete

Direct Tensile Test

Modulus of Rupture

Split-cylinder Test

$$f_r = 0.62\,\lambda\sqrt{fc'}$$

ACI 318M − 14(19.2.3.1)

λ **: light-weight modification factor;**

λ **= 1.0 for normal-weight concrete, for light-weight concrete refer to ACI318M-14 (table 19.2.4.2).**

1.12 Durability of Concrete

The **compressive strength** of concrete may be dictated by **exposure to freeze-thaw** conditions or **chemicals** such as **deicers** or **sulfates.** These conditions may **require** a **greater compressive strength or lower water–cement ratio** than those required to carry the calculated loads.

1.12.1 Clear Concrete Cover (ACI318M-14: 20.6.1.3)

Concrete exposure	Member	Reinforcement	Specified cover, mm
Cast against and permanently in contact with ground	All	All	75
Exposed to weather or in contact with ground	All	No. 19 through No. 57 bars	50
		No. 16 bar, MW200 or MD200 wire, and smaller	40
Not exposed to weather or in contact with ground	Slabs, joists, and walls	No. 43 and No. 57 bars	40
		No. 36 bar and smaller	20
	Beams, columns, pedestals, and tension ties	Primary reinforcement, stirrups, ties, spirals, and hoops	40

For <u>bundled bars</u>, concrete cover is the maximum of

Equivalent diameter

50 mm

75 mm (contact with ground)

1.13 Reinforcement

The **reinforcing used for concrete** structures may be in the form of **bars or welded** wire fabric. Reinforcing bars are referred to as **plain** or **deformed**. The **deformed bars**, which have **ribbed projections** rolled onto their surfaces (patterns differing with different manufacturers) to **provide better bonding between the concrete and the steel**, are used for almost all applications. [6]

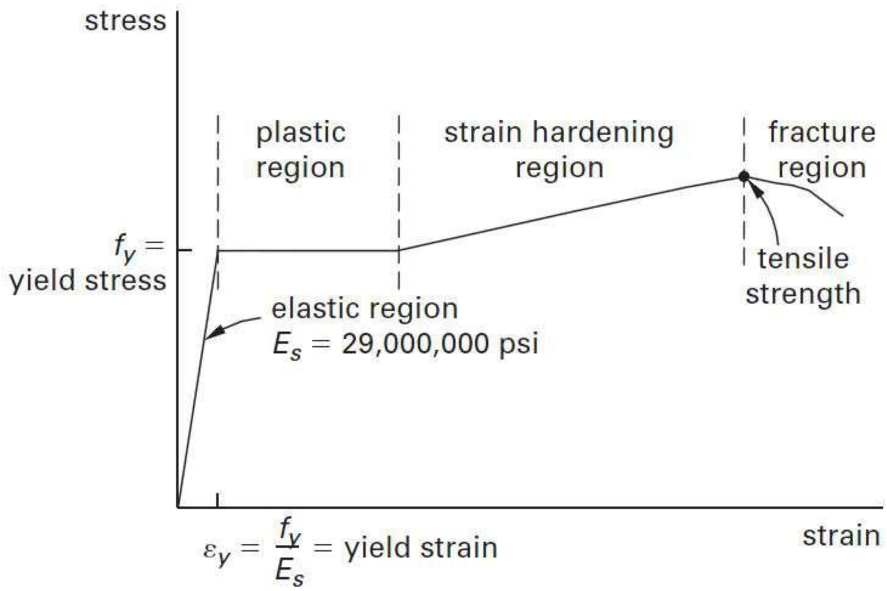


Figure 5 Idealized stress-strain curve for grade 60 (420MPa) reinforcing steel [4]

1.13.1 Designation and area (Table)

diameter	Area, mm^2
10	78
12	113
16	201
20	314
25	491
32	804
36	1018

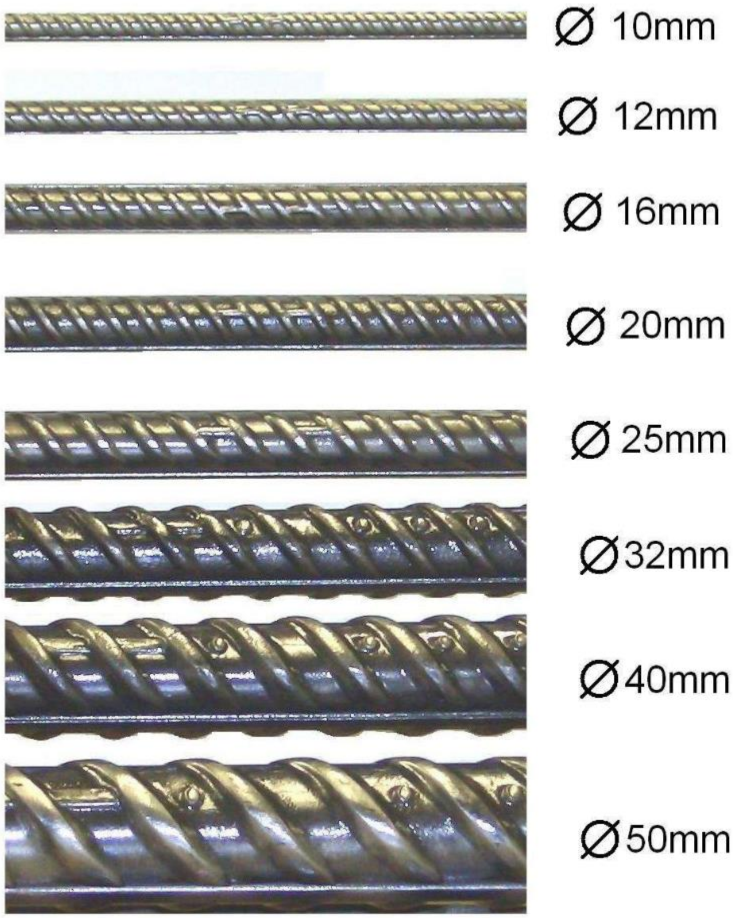
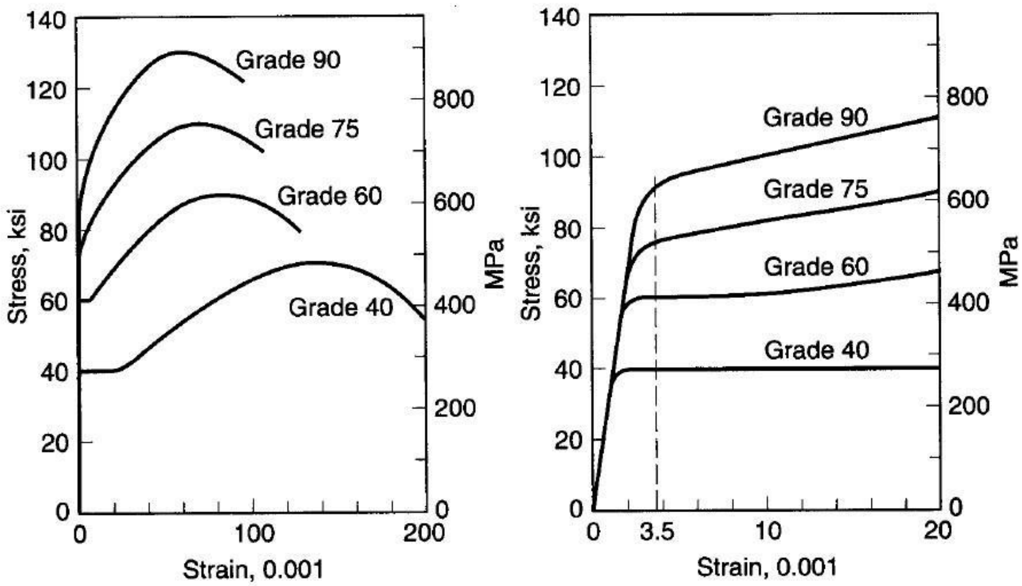


Figure 6 Reinforcing Bar Sizes

Extra Notes

1.13.2 Steel Grades [7]



1.13.3 Idealized Stress-strain curves for reinforcing steel

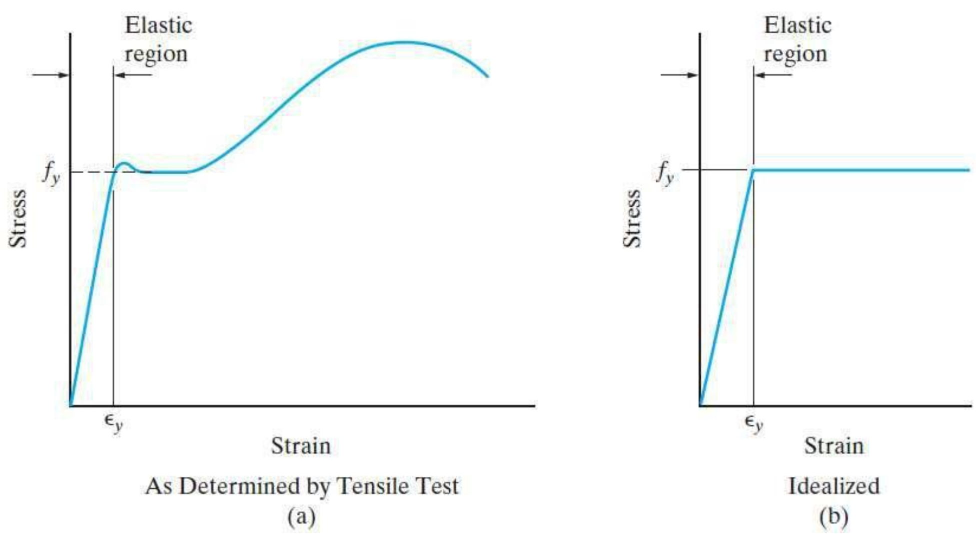


Figure 7 Stress-strain diagram for reinforcing steel, [4]

1.13.4 Compatibility of Concrete and Steel [6]

Concrete and **steel reinforcing** work together beautifully in reinforced concrete structures. The advantages of each material seem to compensate for the disadvantages of the other. For instance, the great shortcoming of concrete is its lack of tensile strength, but tensile strength is one of the great advantages of steel.

Reinforcing bars have tensile strengths equal to approximately **100 times** that of the usual concretes used. The two materials **bond together very well** so there is little chance of slippage between the two; thus, they will act together as a unit in resisting forces.

The excellent bond obtained is the result of the **chemical adhesion** between the two materials, the natural roughness of the bars, and the closely spaced rib-shaped deformations rolled onto the bars' surfaces.

Reinforcing bars are subject to **corrosion**, but the **concrete** surrounding them provides them with **excellent protection**. The strength of exposed steel subjected to the temperatures reached in fires of ordinary intensity is nil, but **enclosing the reinforcing steel in concrete produces very satisfactory fire ratings**.

Finally, **concrete and steel** work well together in relation to **temperature changes** because their **coefficients of thermal expansion are quite close**. **For steel**, the coefficient is **0.0000065** per unit length per degree Fahrenheit, while it varies for **concrete** from about **0.000004 to 0.000007** (average value: **0.0000055**).

1.14 Other Reinforcing Material (Homework)

1.15 Objectives of Design

Appropriateness

Economy

Structural Adequacy

Maintainability

1.16 Building Codes and the ACI code

The primary design criteria for structural concrete in ACI 318 ensure

adequate strength

adequate ductility

serviceability

practical and economical constructability

a. **Strength:** A structural member will **support the loads safely** if, at every section, **the resistance (strength)** of the member **exceeds the effects of the loads:**

Resistance ≥ load effects

ΦRn ≥ Ru

$$\text{Design strength} \geq \text{Factored load (i.e., required strength)}$$
$$\phi P_n \geq P_u$$
$$\phi M_n \geq M_u$$
$$\phi V_n \geq V_u$$

b. **Ductility:** is the ability of a material or member to deform visibly without fracture. Plain concrete is a brittle material, but if reinforcement is properly placed inside, concrete members can behave in a ductile manner.

A **ductile member** can generally redistribute loads to less highly stressed regions. This can **protect** the member in the event of an **accidental overload**, and in the case of an extraordinary overload can warm of impending collapse.

In the **ACI code**, **adequate ductility is assured by placing minimum limits on the amount of steel** that must be provided in particular members and by imposing upper limits on the amount of reinforcement that can be considered effective in a member. [4]

c. **Serviceability:** is the characteristic of a structure **to serve** its intended function **under the service loads** (**that is, unfactored loads**). Important serviceability issues for structural concrete **include defections, crack widths, and durability.**

d. **Constructability Issues:** Many of the design rules **in ACI 318** exist to alleviate the **difficulties of placing and consolidating fresh concrete.** These take the form of **minimum bar spacing**, **maximum steel percentages**, or **minimum member size for various types of members.**

1.17 Loadings

1.17.1 Dead Load

Dead loads are loads of **constant magnitude** that **remain in one position.** They **include** the **weight of the structure** under consideration **as well as any fixtures that are permanently attached to it**. For a reinforced concrete building, some dead loads are the **frames**, **walls**, **floors**, **ceilings**, **stairways**, **roofs**, and **plumbing**. The approximate weights of some common materials used for floors, walls, roofs, and the like are given in **Table 1.2.** [6]

1.17.2 Live Load

Live loads are **loads** that can **change in magnitude and position**. They include occupancy loads, warehouse materials, construction loads, overhead service cranes, equipment operating loads, and many others. These loads are taken from Table 4-1 in ASCE 7-10

Roof live loads are 20 psf (pounds per square feet) maximum distributed uniformly over the entire roof.

TABLE 1.1
Minimum uniformly distributed live loads

Occupancy or Use	Live Load, kN/m²
Apartments (see residential)	
Access floor systems	
Office use	2.4
Computer use	4.8
Armories and drill rooms	7.2
Assembly areas and theaters	
Fixed seats (fastened to floor)	2.9
Lobbies	4.8
Movable seats	4.8
Platforms (assembly)	4.8
Stage floors	7.2
Balconies (exterior)	4.8
On one and two-family residences only, and not exceeding 9.3 m²	2.9
Bowling alleys, poolrooms, and similar recreational areas	3.6
Catwalks for maintenance access	1.9
Corridors	
First floor	4.8
Other floors, same as occupancy served except as indicated	
Dance halls and ballrooms	4.8
Decks (patio and roof)	
Same as area served, or for the type of occupancy accommodated	
Dining rooms and restaurants	4.8
Dwellings (see residential)	
Fire escapes	4.8
On single-family dwellings only	1.9
Garages (passenger cars only)	1.9
Trucks and buses[a]	
Grandstands (see stadium and arena bleachers)	
Gymnasiums, main floors and balconies[b]	4.8
Hospitals	
Operating rooms, laboratories	2.9
Patient rooms	1.9
Corridors above first floor	3.8
Hotels (see residential)	
Libraries	
Reading rooms	2.9
Stack rooms[c]	7.2
Corridors above first floor	3.8
Manufacturing	
Light	6.0
Heavy	12.0
Marquees and canopies	3.6
Office buildings	
File and computer rooms shall be designed for heavier loads based on anticipated occupancy	
Lobbies and first-floor corridors	4.8

TABLE 1.1
(Continued)

Occupancy or Use	Live Load, kN/m²
Offices	2.4
Corridors above first floor	3.8
Penal institutions	
Cell blocks	1.9
Corridors	4.8
Residential	
Dwellings (one and two-family)	
Uninhabitable attics without storage	0.5
Uninhabitable attics with storage	1.0
Habitable attics and sleeping areas	1.4
All other areas except stairs and balconies	1.9
Hotels and multifamily houses	
Private rooms and corridors serving them	1.9
Public rooms and corridors serving them	4.8
Reviewing stands, grandstands, and bleachers[b]	
Roofs	
Ordinary flat, pitched, and curved roofs	1.0
Roofs used for promenade purposes	2.9
Roofs used for roof gardens or assembly purpose	4.8
Roofs used for other special purposes[e]	
Awnings and canopies	
Fabric construction supported by a lightweight rigid skeleton structure[f]	0.25
All other construction	1.0
Schools	
Classrooms	1.9
Corridors above first floor	3.8
First-floor corridors	4.8
Sidewalks, vehicular driveways, and yards subject to trucking[d]	12.0
Stadiums and arenas	
Bleachers[b]	4.8
Fixed seats (fastened to floor)[b]	2.9
Stairs and exit ways	4.8
One and two-family residences only	1.9
Storage areas above ceilings	1.0
Storage warehouses (shall be designed for heavier loads if required for anticipated storage)	
Light	6.0
Heavy	12.0
Stores	
Retail	
First floor	4.8
Upper floors	3.6
Wholesale, all floors	6.0
Walkways and elevated platforms (other than exitways)	2.9
Yards and terraces, pedestrians	4.8

Figure 8 Minimum Live Load, [7]

1.19 Safety Factors

There are three main reasons why safety factors, such as load and resistance factors, are necessary in structural design:

1. **Variability in strength:** The actual strengths (resistances) of beams, columns, or other structural members will almost always differ from the values calculated by the designer. The main reasons for this are as follows
   - o variability of the strengths of concrete and reinforcement,
   - o differences between the as-built dimensions and those shown on the structural drawings, and
   - o effects of simplifying assumptions made in deriving the equations for member strength.
2. **Variability in loadings:** All loadings are variable, especially live loads and environmental loads due to snow, wind, or earthquakes.
3. **Consequences of failure:** A number of subjective factors must be considered in determining an acceptable level of safety for a particular class of structure.

1.19.1 Load Factors and Combinations [8]

The **required strength U** is expressed in terms of **factored loads**, or related internal moments and forces. Factored loads are the loads specified in the general building code **multiplied** by appropriate **load factors**.

Load combination	Equation	Primary load
$U = 1.4D$	(5.3.1a)	D
$U = 1.2D + 1.6L + 0.5(L_r \text{ or } S \text{ or } R)$	(5.3.1b)	L
$U = 1.2D + 1.6(L_r \text{ or } S \text{ or } R) + (1.0L \text{ or } 0.5W)$	(5.3.1c)	L_r or S or R
$U = 1.2D + 1.0W + 1.0L + 0.5(L_r \text{ or } S \text{ or } R)$	(5.3.1d)	W
$U = 1.2D + 1.0E + 1.0L + 0.2S$	(5.3.1e)	E
$U = 0.9D + 1.0W$	(5.3.1f)	W
$U = 0.9D + 1.0E$	(5.3.1g)	E

1.19.2 Strength Reduction Factors (ACI318M-14: Table 21.2.1)

	Action or structural element	ϕ	Exceptions
(a)	Moment, axial force, or combined moment and axial force	0.65 to 0.90 in accordance with 21.2.2	Near ends of pretensioned members where strands are not fully developed, ϕ shall be in accordance with 21.2.3.
(b)	Shear	0.75	Additional requirements are given in 21.2.4 for structures designed to resist earthquake effects.
(c)	Torsion	0.75	—
(d)	Bearing	0.65	—

1.21 Design for Economy [1]

A major aim of structural design is economy. The **overall cost of a building project** is strongly **affected by** both the **cost of the structure** and **the financing charges**, which are a **function of the rate of construction**.

Formwork costs can be **reduced** by **reusing the forms** from area to area and floor to floor. Beam, slab, and column sizes should be chosen to allow the maximum reuse of the forms. It is generally **uneconomical** to try to save concrete and steel by meticulously calculating the size of every beam and column to fit the loads exactly, because, although this could save cents in materials, it will cost dollars in forming costs.

Furthermore, **changing section sizes** often leads to **increased design complexity**, which in turn leads to a **greater chance of design error** and a **greater chance of construction error**. A simple design that achieves all the critical requirements saves design and construction time and generally gives an economical structure.

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