CE 320
Reinforced Concrete Design – I

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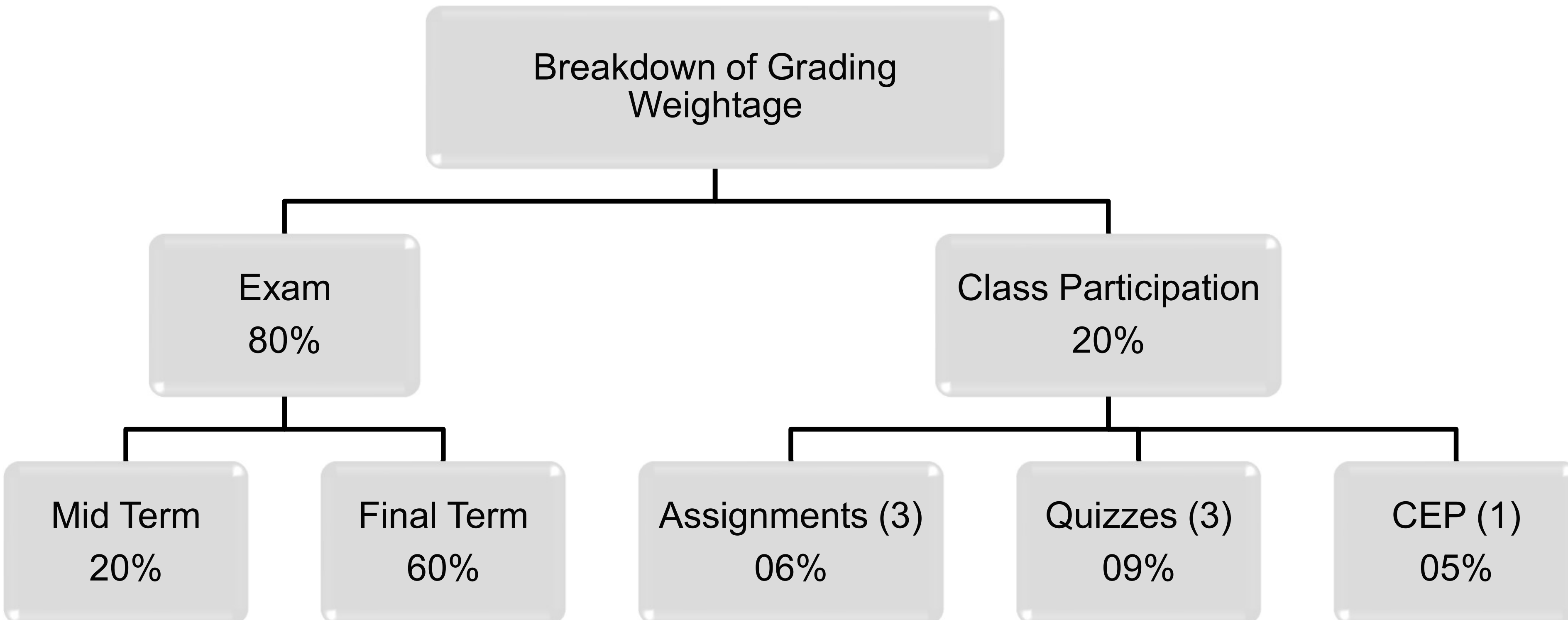
Course Contents

OBE Course Contents Spring 2023

Grading Policy

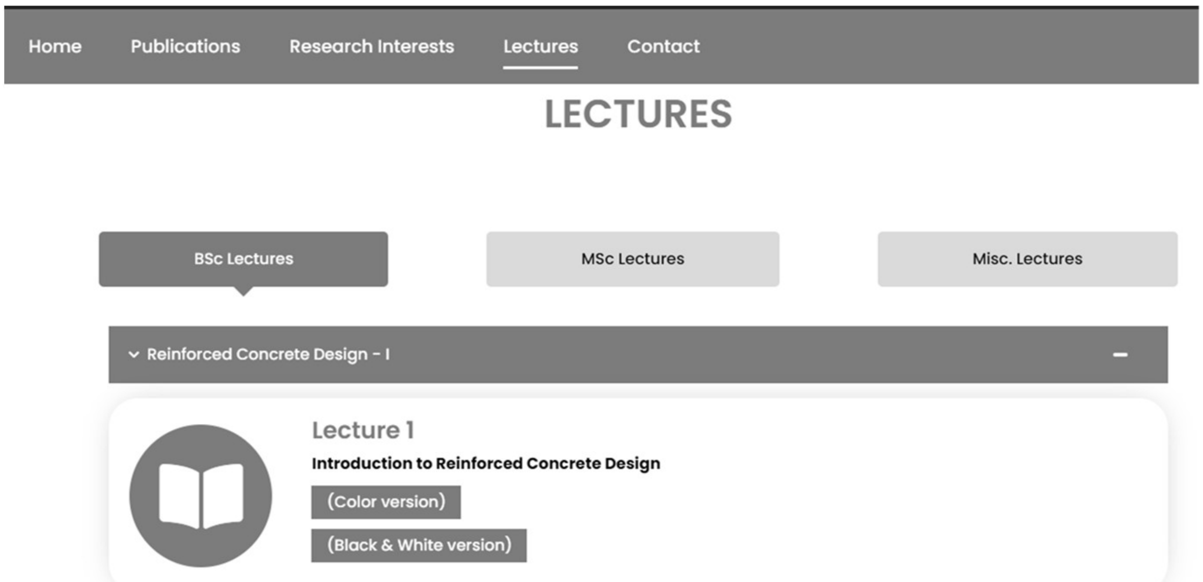


<u>Assignments & Quizzes Schedule</u>

Lectures Availability

- Previous version of lectures are available on the website.

www.drqaisarali.com



- Updated lectures upon completion will be uploaded on website as well as on Google Classroom.

Lecture 01

Introduction to Reinforced Concrete Design

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Contents of Lecture

- General
- Structural Analysis and Structural Design
- Design Codes
- Properties of Materials
- Structural Design Requirements of ACI 318
- Mechanics of Reinforced Concrete
- References

Learning Outcomes

- **At the end of this lecture, students will be able to;**
  - ***Define*** general terms related to structural engineering.
  - ***Understand*** concepts of structural design of reinforced concrete and associated topics.
  - ***Compare*** working stress method with strength design method.
  - ***Outline*** properties of concrete and reinforcing steel.

Course Objective

❑ Aim of the Course

- Humans need construction of civil structures such as buildings, bridges and dams etc. to fulfill their various needs.
- An Engineering design would ensure that these structures are built safe and economical.
- Materials such as stones, bricks, timber, steel and concrete are generally used to construct these structures.
- In this course, however, we will study some basic concepts of the design of Buildings (bridges, dams etc. will not be discussed) made of reinforced concrete.

General

❑ Structure

- A structure refers to a system of connected parts used to safely transfer load from one point to another.
- Important types of structure related to civil engineering include;

Buildings

Bridges

Dams

Retaining Walls

Water Tanks

General

❑ Buildings

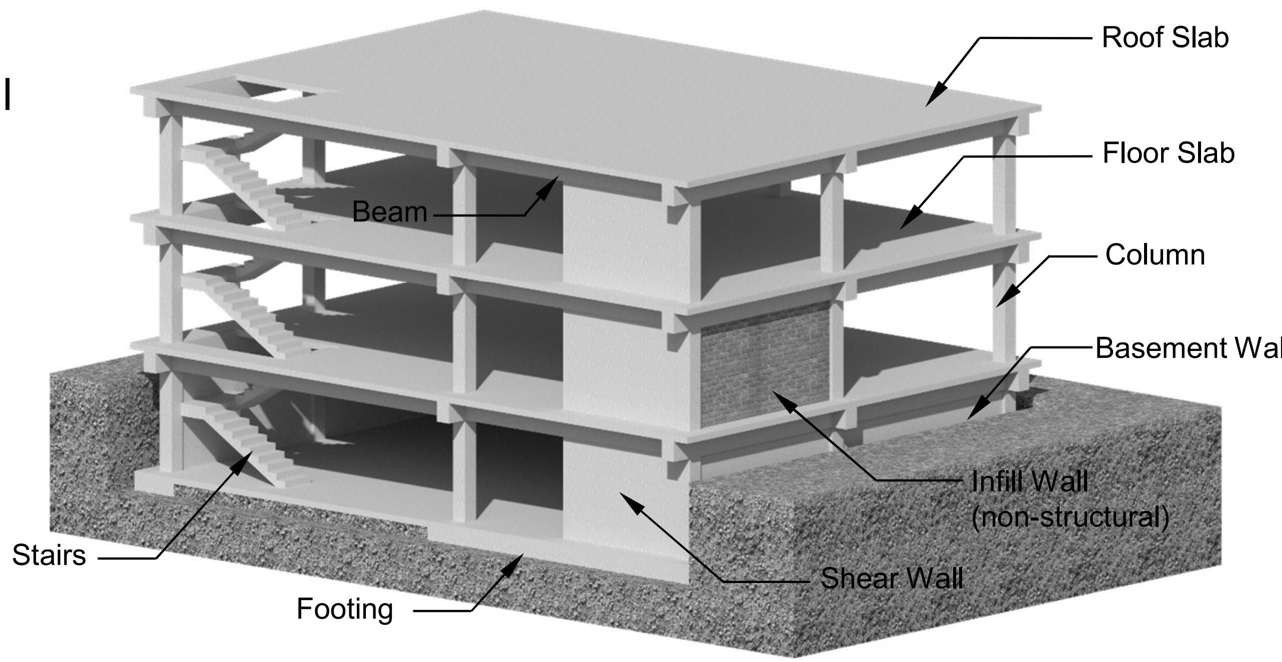
- A building is a type of structure that provides shelter, privacy and security to its occupants. The components of a building can be divided broadly into two categories;
  - Structural components
  - Non - structural components
- Structural components consists of slabs, beams, columns, footing etc., are essential for the stability of the building.
- Non-structural components include partition walls, windows, doors, furniture, MEP, and so on, are required for the building's functionality and appearance.

General

❑ Buildings

❖ Structural Components of an RC building

- General structural components of a typical reinforced concrete building are;
  - Footing
  - Basement wall
  - Shear Wall
  - Columns
  - Beams
  - Slab
  - Stairs



General

❑ Buildings

❖ Types of Structural Systems

- Based on the load transfer mechanism, structural systems are classified into different types.

- The most common types are;
  - Frame System
  - Load bearing wall system
  - Mixed System

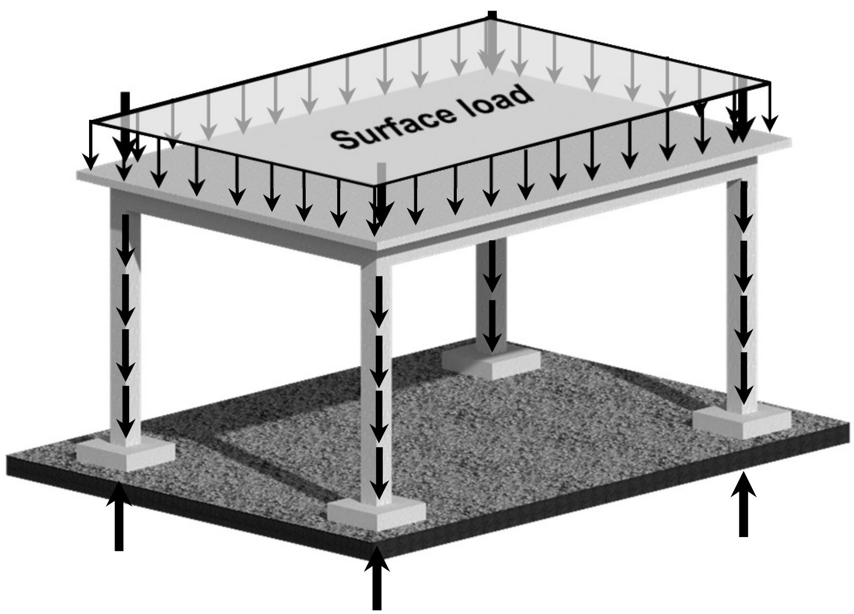
DC office_Block-B at Mansehra,KP

General

❑ Buildings

❖ Frame System

- A reinforced concrete frame building generally consist of slabs, beams columns and footings. The load transfer mechanism is shown below.



General

Buildings

Load Bearing Wall System

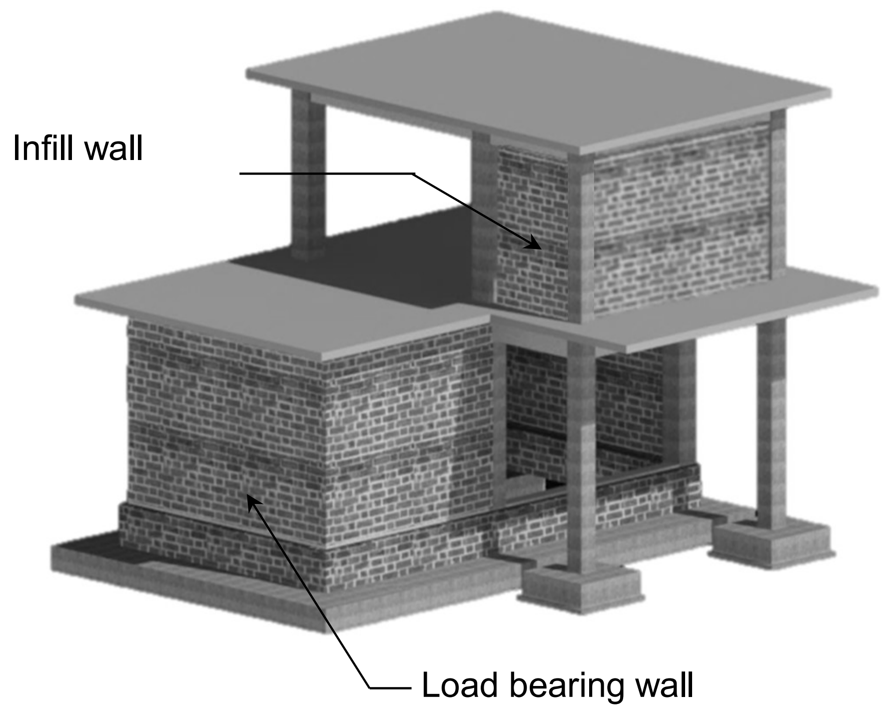
- In such buildings, load from the slab is transmitted to foundation through walls.

General

❑ Buildings

❖ Mixed System

- It is the combination of frame and load bearing wall systems.



General

❑ Buildings

❖ **Building construction animation**

Bearing wall System

Frame System

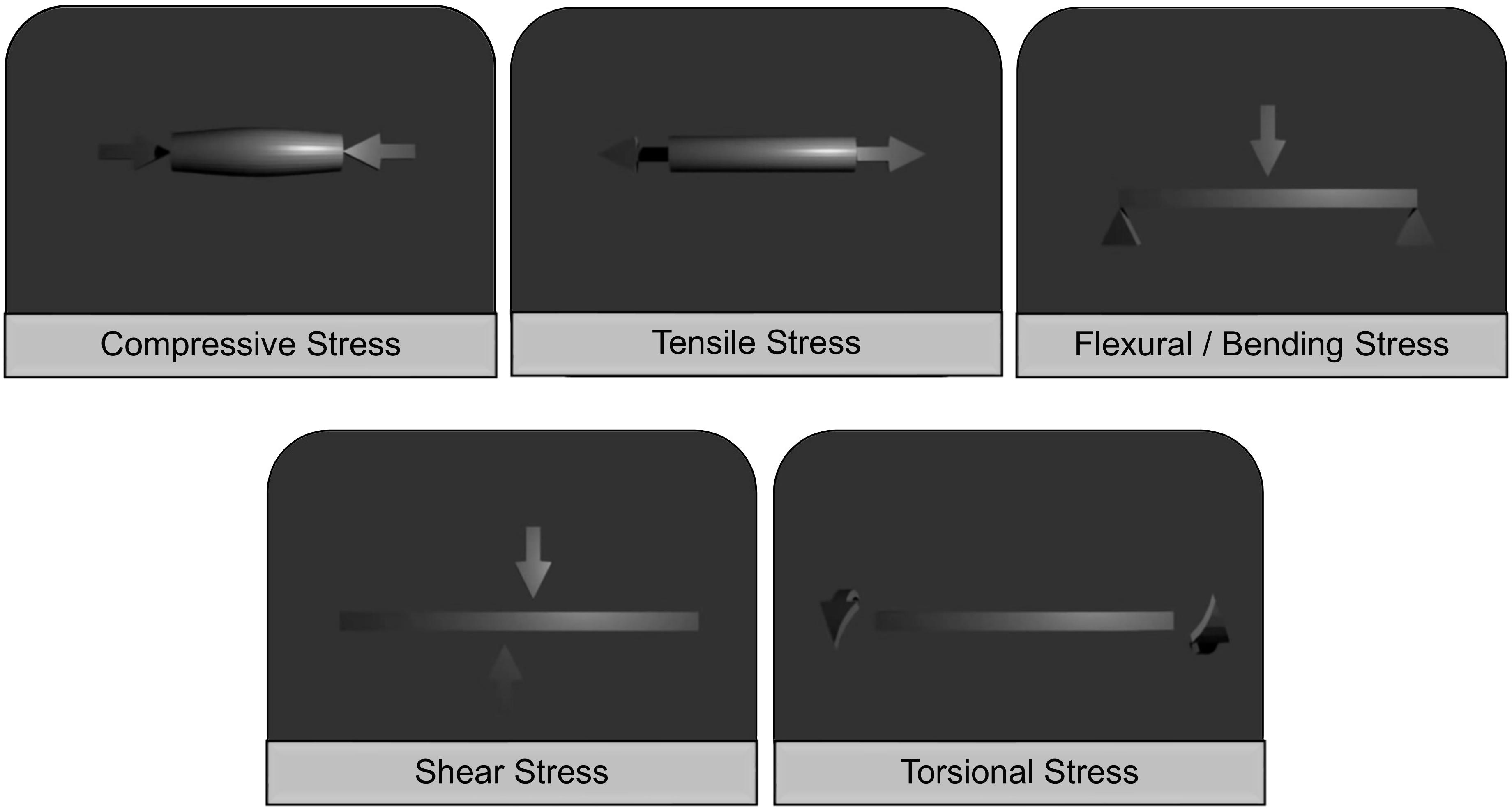
Structural Analysis and Structural Design

❑ Structural Analysis

- The prediction of performance of a structure under expected loading conditions is known as structural analysis.
- The performance of a structure is evaluated in terms of the effects of loads on its components, called “Load effects”.
- Load effects include;
  1. Stresses / Internal actions
  2. Deflections
  3. Support Reactions

Structural Analysis and Structural Design

❑ Internal actions / Stresses



Structural Analysis and Structural Design

❑ Structural Design

- Structural Design refers to the process of selecting appropriate dimensions and materials for a structure.
- The structural design of a reinforced concrete structure involves selection of size and amount of reinforcement based on the results of the analysis and the Code provisions.

Structural Analysis and Structural Design

❑ Structural Design

- A successful structural design should ensure that the structure's capacity exceeds demand with an appropriate margin of safety in order to meet the conditions of safety, serviceability, economy, and functionality.
- The following two design methods are used to obtain the required factor of safety.
  - Limit State Method
  - Working Stress Method

Structural Analysis and Structural Design

Design Methods

1. **Limit State Method**

   - A limit state is a condition (limit) of a structure beyond which it ceases to serve its intended purpose.
   - Limit state method of design is based on different limit states.

Structural Analysis and Structural Design

❑ Design Methods

1. Limit State Method

- There are two main limit states

i. Ultimate limit state

Ultimate limit consists of rupture or collapse of a part of or whole
structure.

ii. Serviceability limit state

Excessive deflections, undesirable vibrations, excessive cracking,
etc. are examples of serviceability limits.

Structural Analysis and Structural Design

❑ Design Methods

1. Limit State Method

- In the limit state method, both ultimate and serviceability limit states are considered.
- The design carried out for the ultimate state is also known as "Ultimate strength design method" or simply "Strength design method".
- The factor of safety in the strength design method is achieved by magnifying the demand and lowering the capacity based on a scientific rationale.

Structural Analysis and Structural Design

❑ Design Methods

1. Limit State Method

- Factor of Safety in Strength Design Method

We know that,

$$FS = \frac{Capacity}{Demand} > 1$$

According to Strength Design Approach;

$$\varphi Capacity = \gamma Demand \qquad where\ \varphi < 1\ and\ \gamma > 1$$

$$\frac{Capacity}{Demand} = \frac{\gamma}{\varphi}$$

$$FS = \frac{\gamma}{\varphi}$$

Structural Analysis and Structural Design

❑ Design Methods

2. Working Stress Method

- Demand is kept the same.
- Capacity is divided by 2.
- This method assumes concrete and steel act together elastically where the relationship between loads and stresses is linear .
- There is no logical way of determining margin of safety.

Structural Analysis and Structural Design

❑ Design Methods

❖ Comparison of Working Stress Method and Strength Design Method

Working Stress Method	Strength Design Method
1. Demand is kept same and capacity is divided by 2.	1. Demand is increased, and capacity is reduced based on scientific rationale.
2. Margin of safety is arbitrary.	2. Margin of safety is rational.
3. Less- economical.	3. More economical.
4. No need to check for serviceability.	4. Serviceability checks are applied.

Design Codes

❑ Code

- A code is a set of technical specifications and standards that controls the important details of design and construction.
- The purpose of code is to produce sound structures so that public will be protected from poor and inadequate design and construction.
- Building codes provide minimum requirements for the life safety and serviceability for structures.

Design Codes

General Building Codes

- Cover all aspects of building design and construction from architecture to structural to mechanical and electrical.
- UBC, IBC and Euro-code are the examples of general building codes.

Design Codes

❑ Seismic Codes

- Cover only seismic provisions of buildings such as SEAOC and NEHRP of USA, and BCP-2021 of Pakistan.

❑ Material Specific Codes

- Cover design and construction of structures using a specific material or type of structure such as ACI, AISC, AASHTO etc.

❑ Others such as ASCE

- Cover minimum design load requirements.
- Minimum Design Loads and Associated Criteria for Buildings and Other Structures (ASCE 7-16).

Design Codes

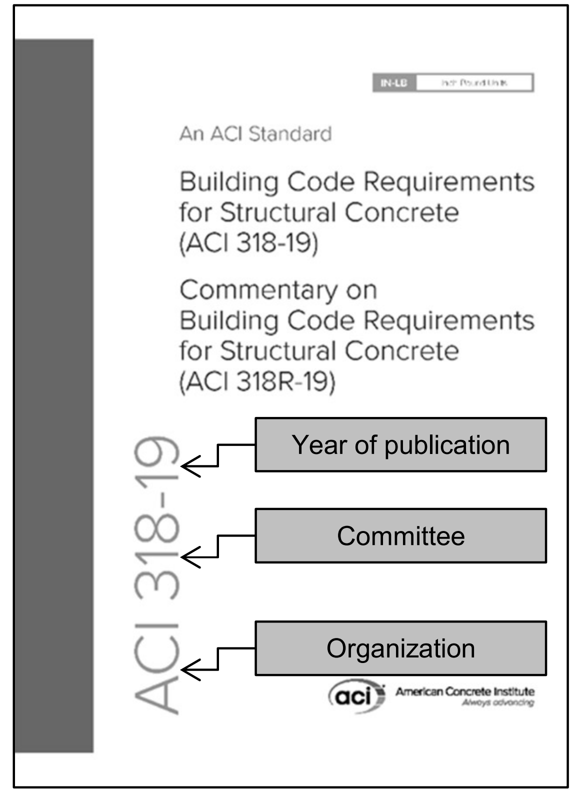
❑ The ACI MCP

- ACI MCP (American Concrete Institute Manual of Concrete Practice) contains 150 ACI committee reports; revised every three years.
- These requirements differ from one structure to another. They include;
  - ACI 318: Building Code Requirements for Structural Concrete.
  - ACI 315: The ACI Detailing Manual.
  - ACI 349: Code Requirement for Nuclear Safety Related Concrete Structures.
  - Many others.

Design Codes

❑ The ACI 318 Code

- The American Concrete Institute “Building Code Requirements for Structural Concrete (ACI 318)”, referred to as the ACI code, provides minimum requirements for structural concrete design or construction.
- The term “structural concrete” is used to refer to all plain or reinforced concrete used for structural purposes.
- In this course, we will use ACI 318 -19 Code.



Properties of Materials

❑ Concrete

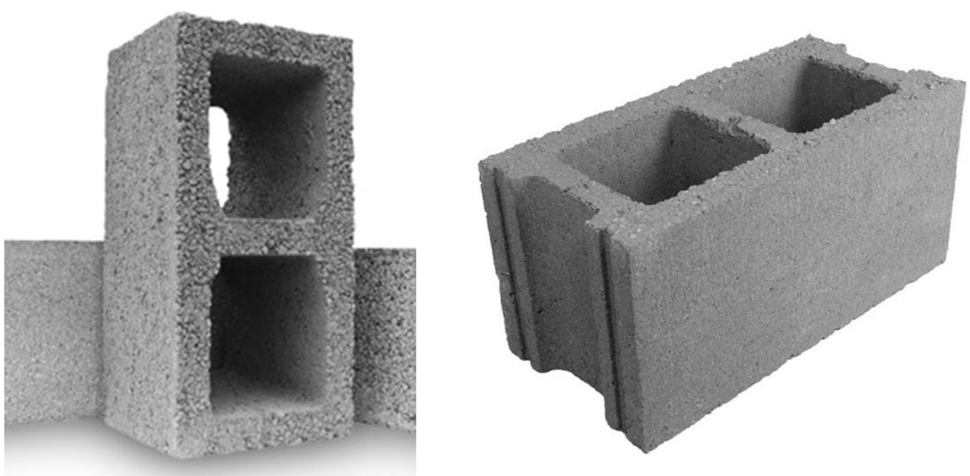
- Concrete is a mixture of hydraulic cement, aggregates, and water, with or without admixtures, fibers, or other cementitious materials.
- The properties of concrete depends on the quantity and proportions of ingredients used in the mix but can also be modified using various admixtures.
- Concrete is strong in compression but weak in tension.

Properties of Materials

❑ Types of Concrete

1. Normalweight Concrete

- Normalweight concrete is defined as “Concrete having a density of approximately 150 lb/ft^3 (2400 kg/m^3) made with normal-density aggregates”.



Properties of Materials

❑ Types of Concrete

2. Lightweight Concrete

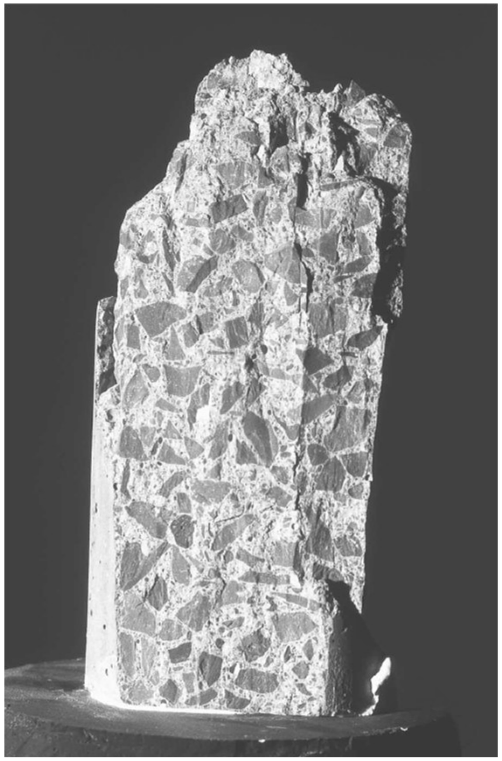
- Lightweight concrete is defined as “Concrete of substantially lower density than that made using aggregates of normal density; consists entirely of lightweight aggregate or a combination of lightweight aggregate and normal-density aggregate”.

Properties of Materials

❑ Types of Concrete

3. High performance concrete

- High performance concrete is specifically designed for unique performance and uniformity needs that regular materials and practices can't always meet.
- It is commonly used in the columns of tall building to avoid bulky sections and save floor space compared to normal concrete.

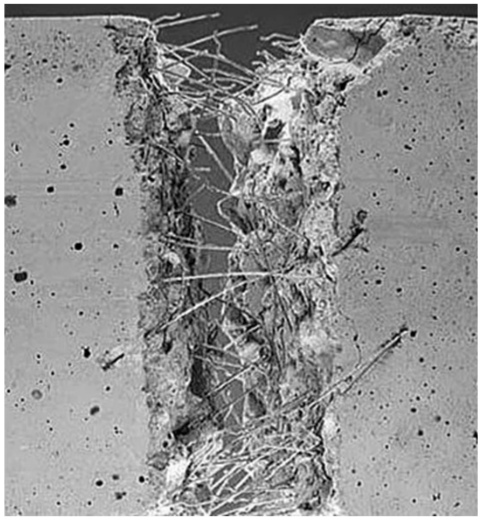


Properties of Materials

❑ Types of Concrete

4. Fibrous concrete or Fiber- reinforced concrete

- Fiber-reinforced concrete refers to concrete that contains dispersed fibers, such as steel, glass, synthetic, and natural fibers.
- These fibers enhance the concrete's tensile strength, durability, and reduce air voids.



Properties of Materials

❑ Properties of Concrete

1. Compressive Strength

- The compressive strength of concrete is a measure of the concrete's ability to resist loads which tend to compress it.
- The uniaxial compressive strength is measured by a compression test of a standard test cylinder.
- This test is used to monitor the concrete strength for quality control or acceptance purposes.
- The specified compressive strength is measured by compression tests on 6 by 12 inches cylinders, tested after 28 days of moist curing.

Properties of Materials

❑ Properties of Concrete

1. Compressive Strength

❖ **Testing methods**

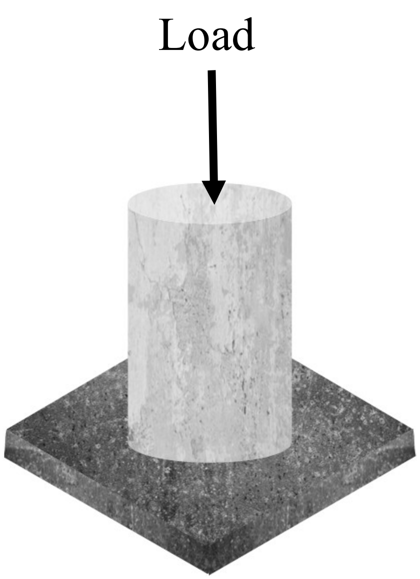
- Following are the two standard methods devised by ASTM to test the compressive strength of concrete.
  - ASTM C31/C31M−17: *Standard Practice for Making and Curing Concrete Test Specimens in the Field.*
  - ASTM C39/C39M−17b: *Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens*.

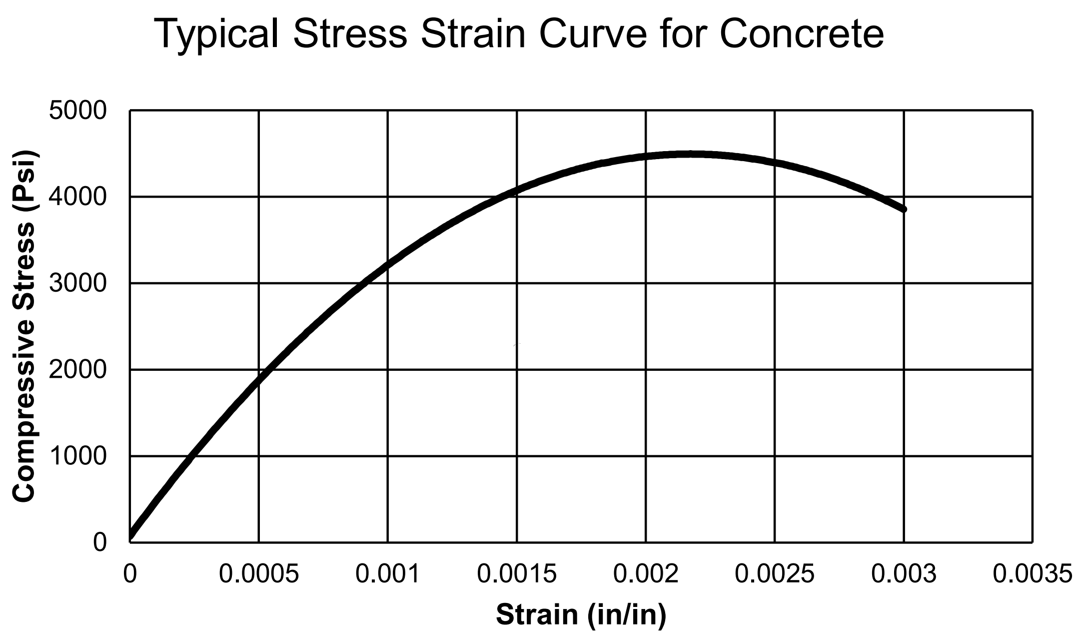
Properties of Materials

❑ Properties of Concrete

1. Compressive Strength

- ❖ **Stress-strain Curve**



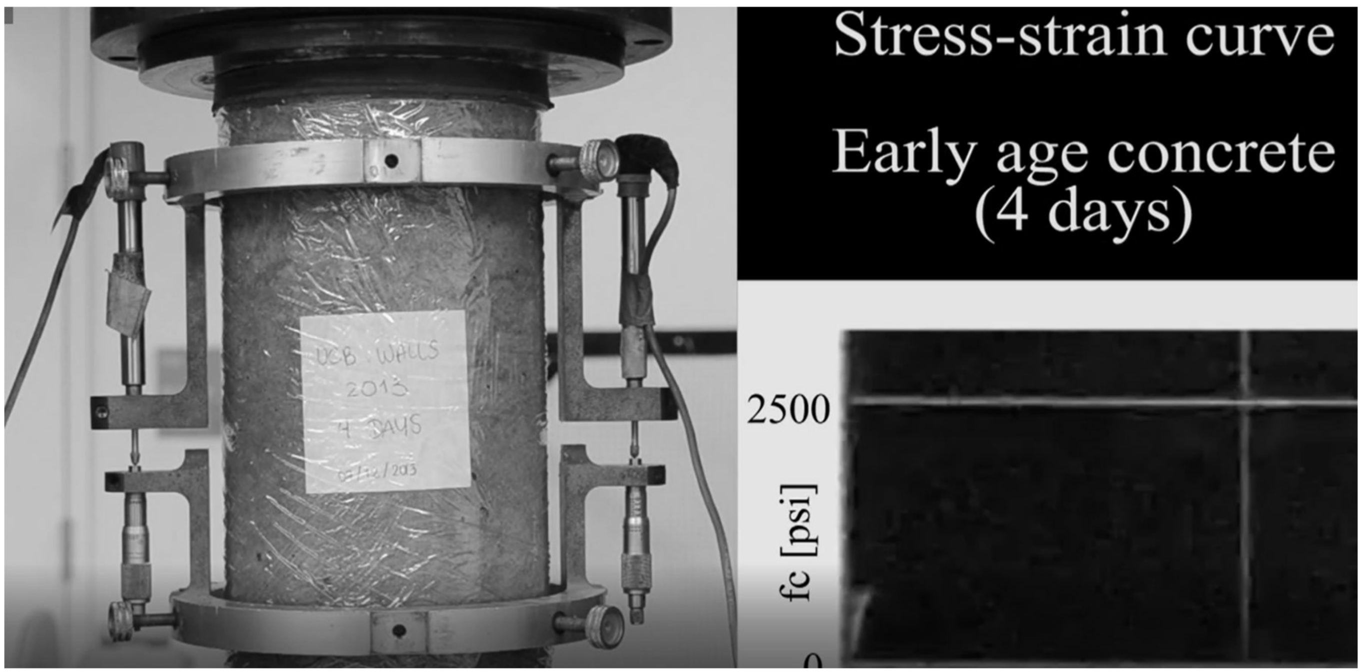


Properties of Materials

❑ Properties of Concrete

1. Compressive Strength

❖ **Test for Compressive Strength of Cylindrical Concrete Specimen**

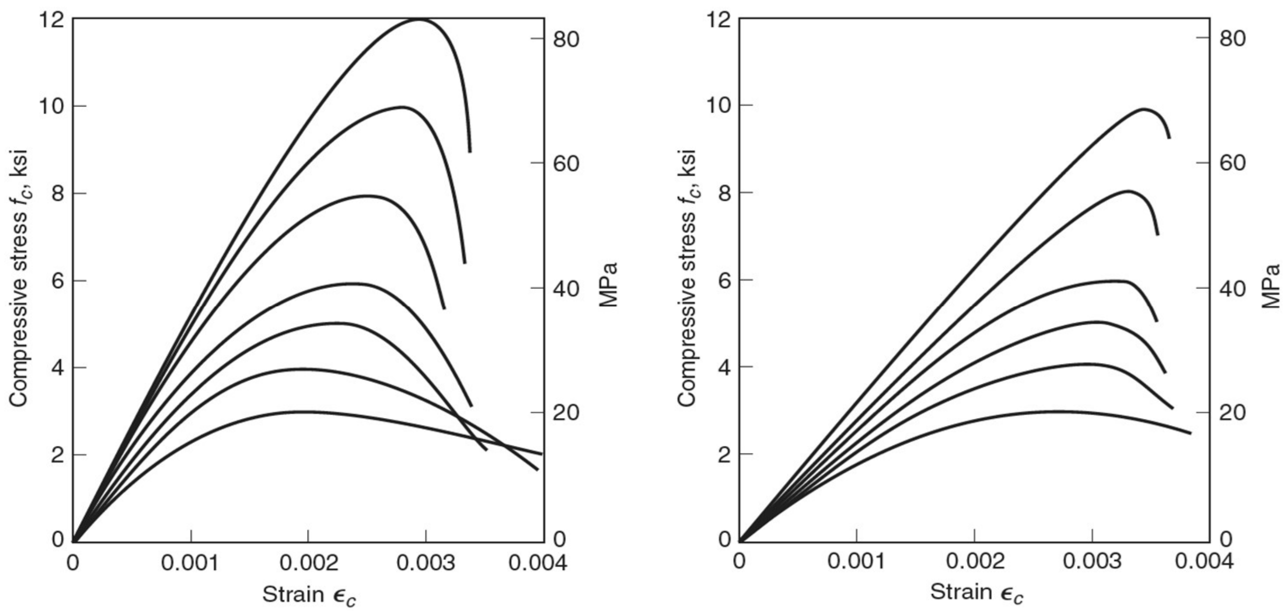


Properties of Materials

❑ Properties of Concrete

1. Compressive Strength

❖ **Typical Stress - strain Curves**



For normalweight concrete	*For lightweight concrete*

(Ref: Design of concrete structures, 15th edition, chapter 2, page 37)

Properties of Materials

Properties of Concrete

2. Tensile Strength

- It is a measure of the maximum stress on the tension face of an unreinforced concrete beam or slab at the point of failure in bending.
- There are three methods to determine the tensile strength of concrete;
  i. Direct tensile strength (f_t')
  ii. Split cylinder strength (f_{ct})
  iii. Modulus of rupture (f_r)
- The modulus of rupture approach is discussed next.

Properties of Materials

❑ Properties of Concrete

2. Tensile Strength (Modulus of Rupture)

- The Flexural strength or Modulus of rupture is calculated using the following formula

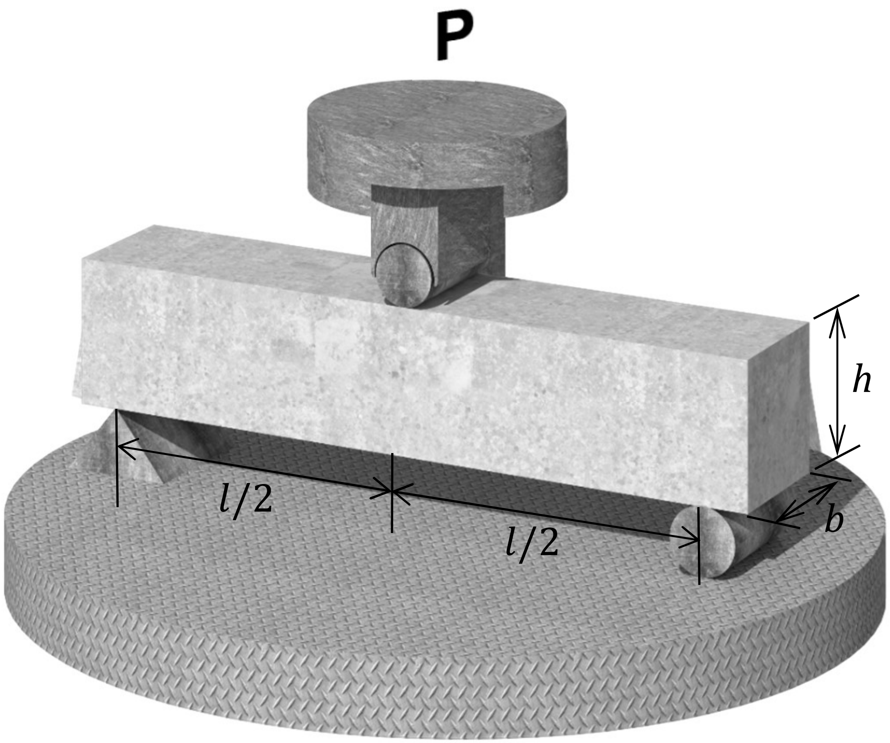
$$f_r = \frac{6M}{bh^2}$$

Where;

$M = Pl/4$, $b = h = 6''$ and $l = 30''$

Putting values, we get;

$$f_r = \frac{5}{24}P \qquad (psi)$$



Properties of Materials

Properties of Concrete

2. Tensile Strength (Modulus of Rupture)

- **Relation between compressive and tensile strength**

TABLE 2.3
Approximate range of tensile strengths of concrete

	Normalweight Concrete, psi	Lightweight Concrete, psi
Direct tensile strength f_t'	3 to 5 $\sqrt{f_c'}$	2 to 3 $\sqrt{f_c'}$
Split-cylinder strength f_{ct}	6 to 8 $\sqrt{f_c'}$	4 to 6 $\sqrt{f_c'}$
Modulus of rupture f_r	8 to 12 $\sqrt{f_c'}$	6 to 8 $\sqrt{f_c'}$

(Source: Design of concrete structures, 15th edition, chapter 2, page 43)

Properties of Materials

❑ Properties of Concrete

2. Tensile Strength (Modulus of Rupture)

- As per ACI 318-19, section 19.2.3.1, Modulus of rupture, f_r for concrete shall be calculated by:

$$f_r = 7.5\lambda\sqrt{f_c'} \quad (psi)$$

- The value of $\boldsymbol{\lambda}$ shall be permitted to take as;
  - 0.75 for lightweight concrete (19.2.4.2)
  - 1.0 for normal weight concrete (19.2.4.3)

Properties of Materials

❑ Properties of Concrete

3. Modulus of Elasticity

- Modulus of elasticity also known as Young’s modulus is the ratio of axial stress to the axial strain.
- It is basically the slope of Stress-strain curve within the elastic limits.
- Concrete's modulus of elasticity is not constant, but changes based on the type and compressive strength of the concrete.

Properties of Materials

❑ Properties of Concrete

3. Modulus of Elasticity

- As per ACI section 19.2.2.1, Modulus of elasticity E_c for concrete shall be accordance with (a) or (b):

a) For values of w_c between 90 and 160 lb/ft^3

$$E_c = w_c^{1.5} 33\sqrt{f_c'} \quad (psi)$$

b) For Normal weight concrete

$$E_c = 57000\sqrt{f_c'} \quad (psi)$$

Where, w_c is the equilibrium density of concrete mixture.

Properties of Materials

❑ Properties of Concrete

4. Modulus of Rigidity

- Modulus of rigidity also known as Shear modulus “G” is the ratio of shear stress to the shear strain.
- Mathematically, we have

$$G = \frac{Shear\ Stress}{Shear\ strain} = \frac{\tau}{\gamma}$$

- This property depends on the elasticity of the material, the more elastic the material, the higher the modulus of rigidity and vice versa.

Properties of Materials

Properties of Concrete

5. Modulus of Rigidity

- The ratio of modulus of elasticity of steel E_s to that of concrete E_c is known as modular ratio.
- Mathematically, modular ratio is expressed as;

$$n = \frac{E_s}{E_c} = \frac{29000{,}000}{57000 \times \sqrt{f_c'}} = \frac{508.8}{\sqrt{f_c'}}$$

- Since the modulus of elasticity of concrete changes with time, age at loading, modular ratio also changes accordingly.
- The modular ratio for a normalweight concrete having compressive strength of 3000psi is 9.3.

Properties of Materials

❑ Properties of Concrete

6. Poison′s Ratio

- The ratio of transverse strain to longitudinal strain in the direction of the stretching force is known as poison's ratio.
- Mathematically, Poisson's ratio is expressed as;

$$\upsilon = \frac{Transeverse\ strain}{Longitudinal\ strain}$$

- Poisson's ratio is positive for tensile while negative for compressive deformation.
- The Poisson's ratio of concrete ranges from 0.1 – 0.2.

Properties of Materials

❑ Properties of Concrete

7. Unit Weight

- Weight of a material per unit volume is called unit weight or weight density.
- The unit weight of concrete depends on percentage of reinforcement, type of aggregate, number of voids.
- Unit weight for plain cement concrete varies from 140 to 145 lb/ft^3 , while that for reinforced concrete is 150 lb/ft^3.

Properties of Materials

❑ Properties of Concrete

8. Creep and Shrinkage

- Creep is “time-dependent deformation of concrete due to sustained load”.
- Shrinkage is defined as “Decrease in either length or volume of a material resulting from changes in moisture content or chemical changes”.
- Both creep and shrinkage result in cracking of concrete leading to reduction in stiffness.
- Excessive creep and shrinkage strains can cause structural issues, stress redistribution, prestress loss, and potential failure.

Properties of Materials

❑ Properties of Concrete

9. Fire Resistance

- Fire resistance is defined as "*The property of a material or assembly to withstand fire or give protection from it*".
- Fire resistance is controlled by both the physical and thermal properties of the structural element.
- Due to the inert nature of its components, concrete is proven to have a high degree of fire resistance.
- ASTM E119-20: *Standard Test Methods for Fire Tests of Building Construction and Materials.*

Properties of Materials

❑ Factors Affecting Properties of Concrete

Factors	Effects
Water-cement ratio	Water/Cement ratio is inversely proportional to the strength of concrete. Higher the w/c ratio, lower will be the strength.
Degree of Compaction	Concrete compaction improves density by eliminating air gaps, increasing impermeability and strength.
Curing	Curing of concrete is the most essential to prevent plastic shrinkage, temperature control, strength gain and durability.
Weather conditions	Change in temperature causes shrinkage, freezing and thawing which results in loss of concrete strength.
Age of concrete	The strength of concrete increases with its age.

Properties of Materials

❑ Steel

- Steel is a hard, strong grey or bluish-grey alloy of iron with carbon and some other elements, used as a structural and fabricating material.

❑ Classification of Steel (Based on composition)

1. **Plain Carbon Steel**
   - Low carbon steel /Mild steel (0.16% - 0.30 % of carbon)
   - Medium carbon steel (0.30% to 0.60% of carbon)
   - High carbon steel (0.60% to 1% of carbon)
2. **Low Alloy Steel** (≤ 8% alloying element)
3. **High Alloy Steel** (> 8% alloying element)

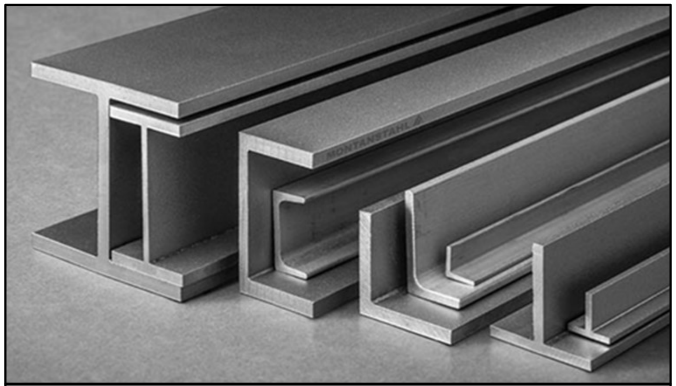
Properties of Materials

- **Classification of Steel (Based on use)**

Deformed Bar Reinforcement

Plain Reinforcement

Prestressing Steel



Structural Steel

Properties of Materials

Properties of Reinforcing Steel

Deformed Bar Reinforcement

- As per ACI 318-19,20.2.1.1, deformed bar reinforcement shall be used in reinforced concrete.
- Deformed bars shall conform to one of the following ASTM specifications;

  (a) ASTM A615

  (b) ASTM A706

Properties of Materials

❑ Properties of Reinforcing Steel

❖ Deformed Bar Reinforcement

1. **ASTM A615**

- It covers deformed carbon-steel reinforcing bars that are currently the most widely used type of steel bar in reinforced concrete construction.
- Bars of this type are marked with the letter "S" per the specification requirements.

Properties of Materials

❑ Properties of Reinforcing Steel

❖ Deformed Bar Reinforcement

2. **ASTM A706**

- It covers low-alloy steel deformed bars intended for applications where controlled tensile properties, restrictions on chemical composition to enhance weldability, or both, are required.
- Bars of this type are marked with the letter “W” per the specification requirements.

Properties of Materials

❑ Properties of Reinforcing Steel

❖ Deformed Bar Reinforcement

- **Physical Properties**

Bar Designation	Diameter (in)	Area (in^2)	Weight (lb/ft)
#3	0.375	0.11	0.38
#4	0.500	0.20	0.67
#5	0.625	0.31	1.04
#6	0.750	0.44	1.50
#7	0.875	0.60	2.04
#8	1.000	0.79	2.67
#9	1.128	1.00	3.40
#10	1.270	1.27	4.30
#11	1.410	1.56	5.313
#14	1.693	2.25	7.65
#18	2.257	4.00	13.60

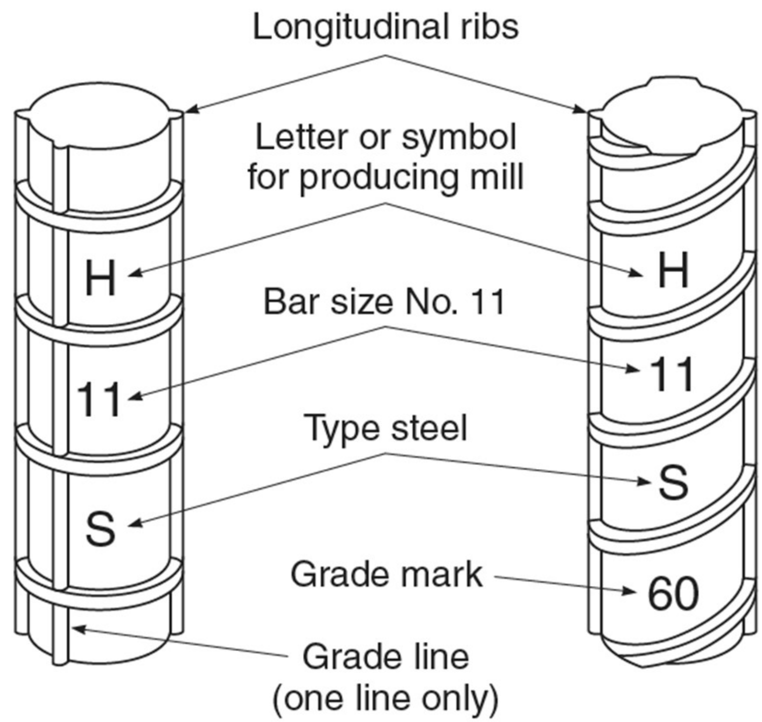
Source: ACI 318-19 Appendix B ─ ASTM Standard Reinforcing Bars

Properties of Materials

❑ Properties of Reinforcing Steel

❖ Deformed Bar Reinforcement

- **Bar Markings**



Grade 60

Properties of Materials

❑ Properties of Reinforcing Steel

❖ Deformed Bar Reinforcement

- **Strength**

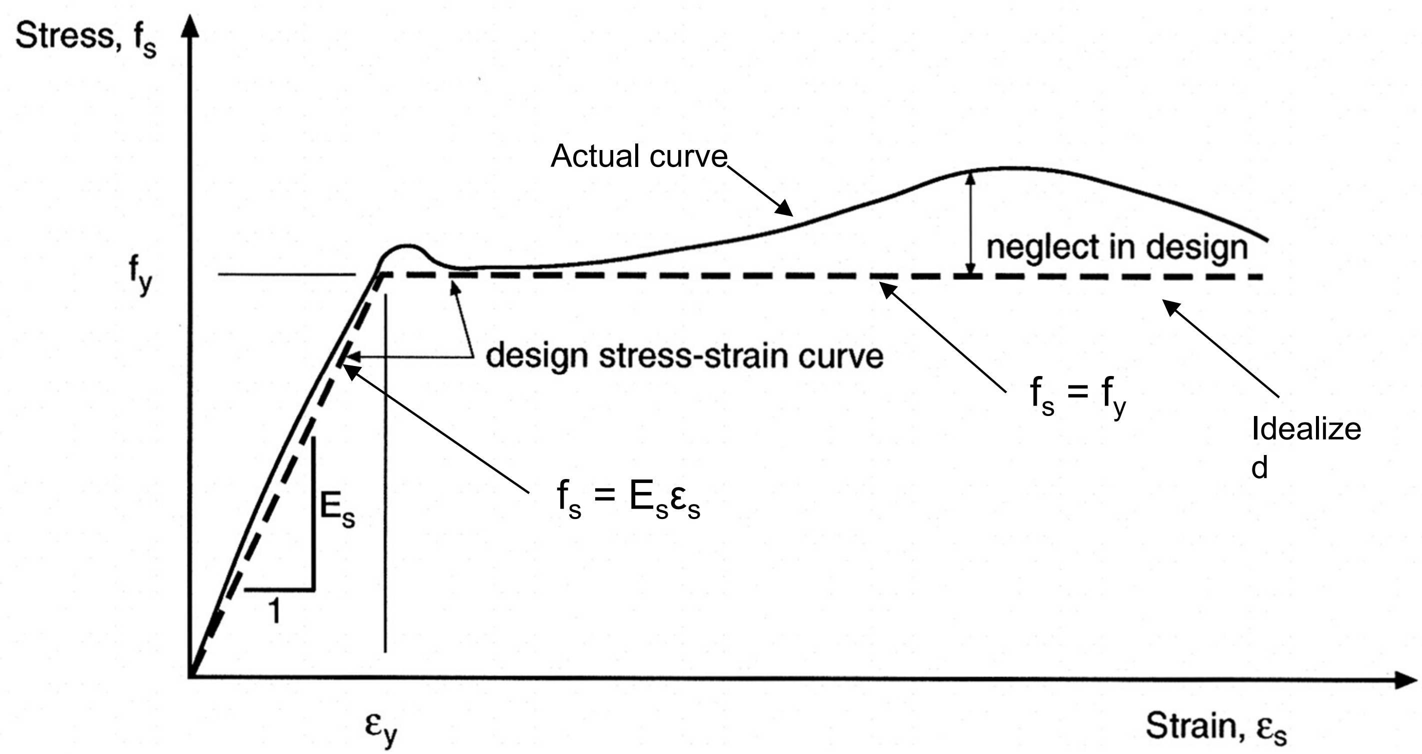
Steel Grade	Minimum Yield Strength, f_y (ksi)	Tensile Strength (ksi)
40	40	60
60	60	80
80	80	100
100	100	115

Properties of Materials

❑ Properties of Reinforcing Steel

❖ Deformed Bar Reinforcement

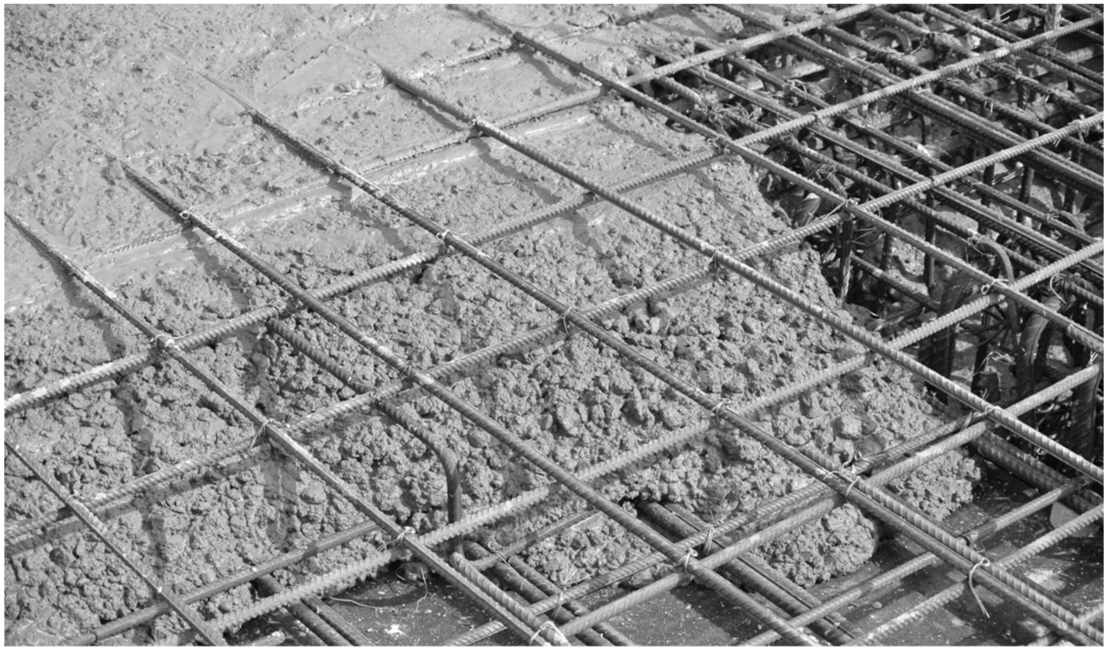
- **Typical Stress-strain curve**



Properties of Materials

❑ Reinforced Concrete

- Reinforced Concrete is a type of concrete in which steel is utilized as reinforcement to improve the tensile strength of concrete components.



Properties of Materials

❑ Advantages of Reinforced Concrete

Properties	Description
Strong and durable	Reinforced concrete has a good compressive strength and durable compared to other building materials.
Economical	RCC is less expensive than other building materials such as steel.
Readily Available	The raw ingredients needed to prepare RCC are widely available and reasonably priced.
Mould-able	RCC can be moulded at any shape and size as per architectural requirements.
Fire Resistant	RCC are more fire resistant comparatively to other construction materials like wood, Steel, etc.

Properties of Materials

❑ Disadvantages of Reinforced Concrete

Properties	Description
Uncertainty in strength	The main steps of using reinforced concrete are mixing, casting, and curing. All of this affects the final strength.
High early maintenance	RCC needs too much maintenance during its construction, like proper curing, checking of cracks, prevention from direct sunlight etc.
Slow strength gain	RCC takes time to gain its full strength. Thus, R.C.C. structures can't be used immediately after construction unlike steel structures.
More site space	R.C.C. needs lot of form-work, centering and shuttering to be fixed, thus require more site space and skilled labor.
Heavier sections	R.C.C. structures are heavier than structures of other materials like steel, wood and glass etc.

Design Requirements of ACI 318

❑ Design Loads

❖ Load (ACI, 2.3)

- Forces or other actions that result from the weight of all building materials, occupants, and their possessions, environmental effects, differential movement, and restrained dimensional changes; permanent loads are those loads in which variations over time are rare or of small magnitude; all other loads are variable loads.

Design Requirements of ACI 318

❑ Design Loads

❖ Dead Load (ACI, 2.3)

a) The weights of the members, supported structure, and permanent attachments or accessories that are likely to be present on a structure in service; OR

b) Loads meeting specific criteria found in the general building code; without load factors.

Design Requirements of ACI 318

❑ Design Loads

❖ Live Load (ACI, 2.3)

a) Load that is not permanently applied to a structure, but is likely to occur during the service life of the structure (excluding environmental loads); OR

b) Loads meeting specific criteria found in the general building code; without load factors.

- ACI 318 has adopted ASCE/SEI 7 for selecting minimum design live load for buildings and other structures.

❖ Other Loads

- Include earthquake loads, wind loads, snow loads etc.

Design Requirements of ACI 318

Design Loads

- **Service Loads (ACI, 2.3)**

  All loads, static or transitory, imposed on a structure or element thereof, during the operation of a facility, without load factors are known as service loads.

- **Factored Loads (ACI 2.3)**

  All loads, static or transitory, imposed on a structure or element thereof, during the operation of a facility, with load factors are known as factored loads.

Design Requirements of ACI 318

❑ Selection of Design Procedure

- According to the ACI 318-19, Section 4.6, the Reinforced Concrete members shall be designed using the Strength Design Method.
- The basic requirement for strength design may be expressed as follows;

Capacity ≥ Demand

$$\emptyset C = \gamma D$$

Mechanics of Reinforced Concrete

❑ Mechanics of Reinforced Concrete

- The formulation of equations used for the design of reinforced concrete is based on the mechanics of reinforced concrete.
- The ACI 318 Code specifies the behavior and mechanics of reinforced concrete under axial, flexure, shear, and torsional loads.
- The mechanics of reinforced concrete for flexure will be thoroughly covered in the next week's presentation.

References

- Design of Concrete Structures 14th / 15th edition by Nilson, Darwin and Dolan.
- Building Code Requirements for Structural Concrete (ACI 318-19)