CHAPTER

1a

Prentice Hall

Reinforced Concrete Design — Fifth Edition

MATERIALS AND MECHANICS OF BENDING

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Part I – Concrete Design and Analysis

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ENCE 355 - Introduction to Structural Design

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Concrete

- Concrete is a mixture of cement, fine and coarse aggregates, and water.
- Water is the key ingredient for chemical reaction for curing.

Add Water

↓

Cement + Aggregates = Concrete

Concrete

- Concrete Ingredients

Concrete

- Cement
  – Cement is a material that has the adhesive and cohesive properties necessary to bond inert aggregates into a solid mass of adequate strength and durability.
- Aggregates
  – The bulk of the concrete mix consists of the fine and coarse aggregates.

Concrete

- Concrete Strength
  - The resulting concrete *strength* and durability are a function of the proportions of the mix as well as other factors, such as the the concrete placing, finishing, and curing history.
  - Compressive strength of concrete is relatively *high*.
  - However, its tensile strength is *small* as compared with its compressive strength.

Concrete

- Concrete Strength (cont'd)
  - Hence, steel reinforcing rods, which have high tensile strength and compressive strength, are used in combination with concrete.
  - The **steel** will resist the tension.
  - While the **concrete** will resist the compression.

Concrete

- Concrete Strength (cont'd)
  - Reinforced Concrete Beam

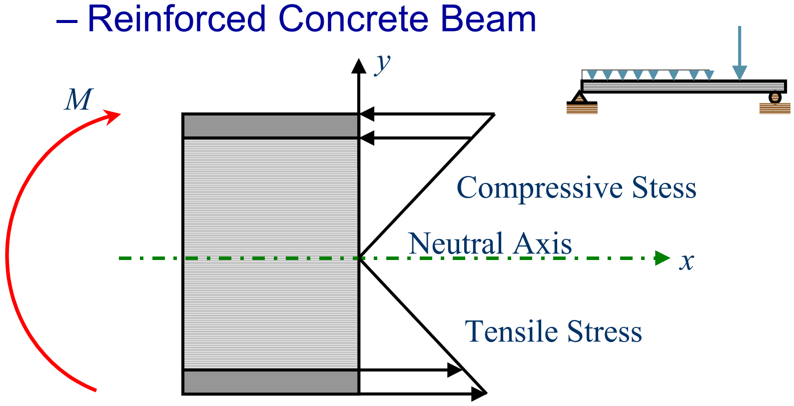
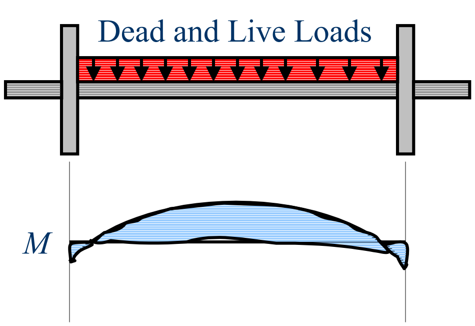


Figure 1

Concrete

- Concrete Strength (cont'd)
  - Reinforced Concrete Beam

Figure 2



Concrete

- Concrete Strength (cont'd)
  - Reinforced Concrete Beam

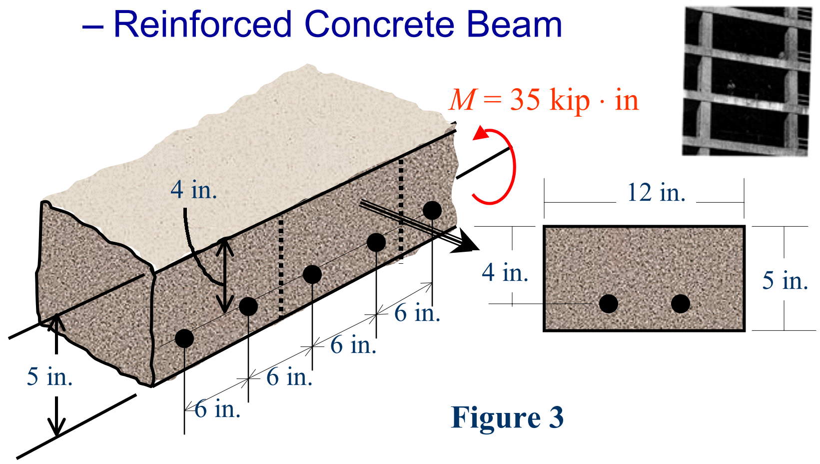
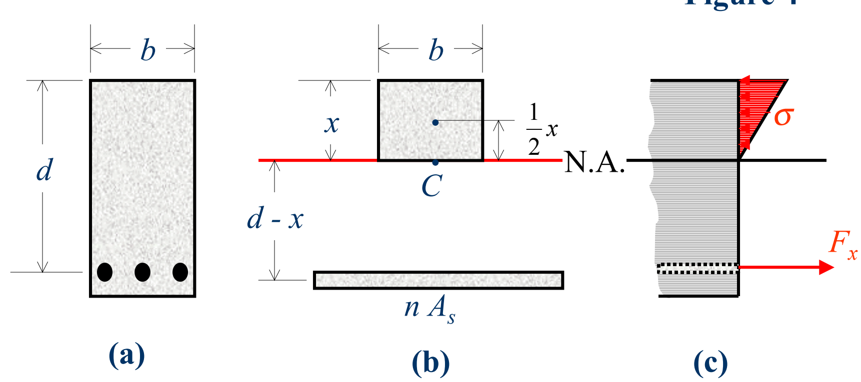


Figure 3

Concrete

- Concrete Strength (cont'd)
  - Reinforced Concrete Beam

Figure 4



Concrete

- Concrete Strength (cont'd)
  - Reinforced Concrete Beam

> – ***Concrete is very weak in tension, so it will crack below the neutral surface and the steel rods will carry the entire tensile load.***
>
> – ***The upper part of the concrete beam will carry the compressive load.***

The ACI Building Code

- ACI = American Concrete Institute
  - The design and construction of concrete buildings is controlled by

> " Building Code Requirements for Structural Concrete (ACI 318-02) and Commentary (318R-02)"

  - The code itself has no legal status, however, it has been incorporated into the building code of almost all states.
  - When incorporated, it has official sanction.

Cement and Water

- Hydraulic Cement:
  - Water is added to hydraulic cement for the chemical reaction of hydration to take place.
  - In the process of hydration, the cement sets and bonds the fresh concrete into one mass.
  - ***Portland Cement***

Calcium and Aluminum Silicates

Limestone materials provide Calcium Dioxide, CaO
Clays provides Silicon dioxide, SiO_2, and Aluminum Oxide, AL_2O_3

Cement and Water

- Cement is marketed in bulk or in 94-lb (1-ft^3) bags

- <u>Water Cement Ratio:</u>
  - The ratio of the amount of water to the amount of cement by weight

Cement and Water

- The ratio can be expressed in terms of gallons of water per bag of cement.

■ Requirements
- ***For complete hydration of cement in a mix, a water/cement ratio of***
  - ***0.35 to 0.40, or***
  - ***4 to 4.5 gal.bag***

  is required.

Aggregates

■ Aggregates occupy approximately 70% to 75% of the volume of the hardened mass.

■ The more densely the aggregate can packed, the better are the *strength* and *durability*.

■ Types of Aggregates:
- **Fine**: sand (pass No. 4 sieve)
- **Coarse**: particles (retained in No. 4 Sieve)

Concrete in Compression

- As was mentioned earlier, compressive strength of concrete is relatively *high*.
- The compressive strength of concrete is denoted by $f_c^{'}$.
- Units commonly used for $f_c^{'}$:
  - Pounds per square inch (psi)
  - Kips per square inch (ksi)

Concrete in Compression

- Compression Tests and Stress-Strain Diagram

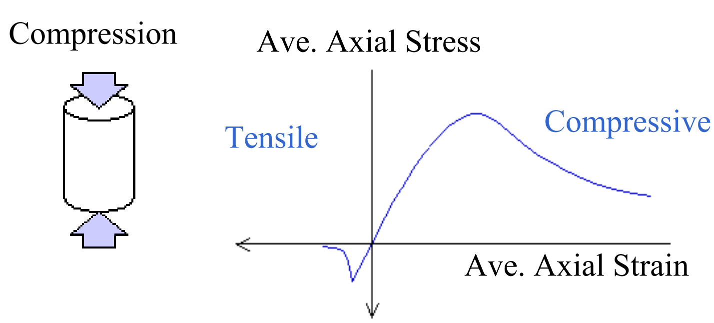


Figure 5

Concrete in Compression

■ Concrete Compressive Strength

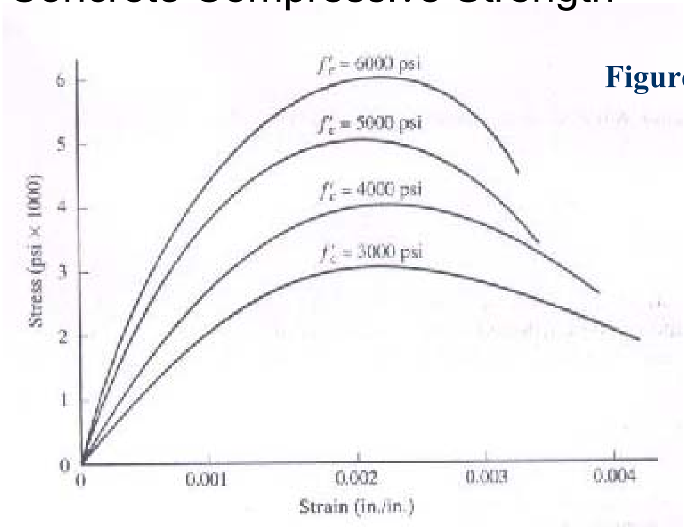


Figure 6

Concrete in Compression

■ Concrete Compressive Strength

- The curves of Fig. 6 represent the result of compression tests on 28-day standard cylinders for varying design mix.
- f_c' is not the stress that exists in the specimen at failure but rather which occurs at a strain of 0.002 in/in.
- 28-day concrete strength f_c' range from 2500 to 9000 psi, with 3000 to 4000 psi being common for reinforced structures, and 5000 to 6000 psi for pre-stressed concrete members.

Concrete in Compression

- Concrete Compressive Strength
  - Concrete strength varies with time, and the specified concrete strength is usually that strength that occurs ***28 days after the placing of concrete***.
  - A typical strength-time curve for normal stone concrete is shown in Fig. 7.
  - Generally, concrete attains approximately 70% of its 28-day strength in 7 days, and approximately 85% to 90% in 14 days.

Concrete in Compression

- Concrete Compressive Strength

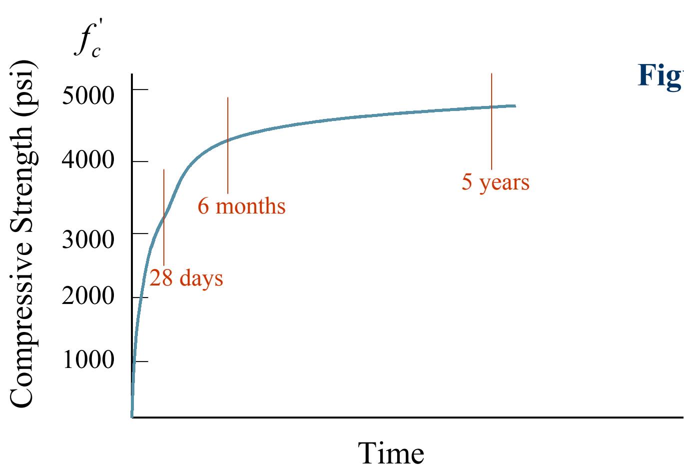


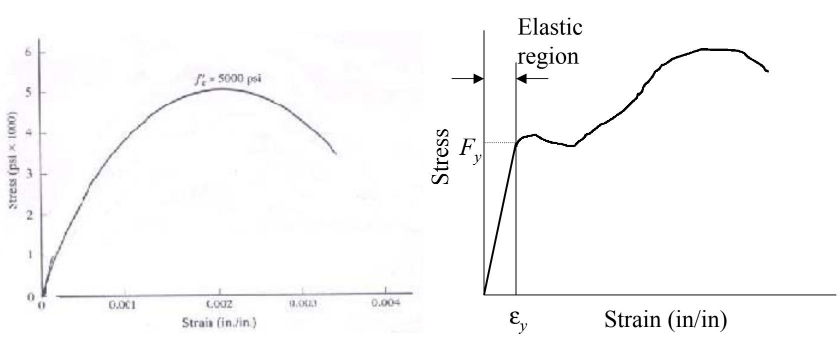
Figure 7

Concrete in Compression

- Modulus of Elasticity
  - In review of Fig. 8a, the initial slope of the curve varies, unlike that of steel (Fig 8b), and only approximates a straight line.
  - For steel, where stresses are below the yield point and the material behaves elastically, the stress-strain plot will be a straight line.
  - The slope of the straight line for steel is the modulus of elasticity.

Concrete in Compression

- Modulus of Elasticity



(a) Concrete **(b) Steel**

Figure 8

Concrete in Compression

- Modulus of Elasticity
  - For concrete, however, the straight-line portion of the curve is very short, if it exists at all.
  - Therefore, there exists no constant value of the modulus of elasticity for a given concrete since the stress-strain ratio is not constant.
  - Even, if a straight line is assumed, the modulus of elasticity would be different for concrete of different strengths.

Concrete in Compression

- Modulus of Elasticity

At low and moderate stresses, up to about $0.5f'_c$, concrete is commonly assumed to behave elastically.

Concrete in Compression

- Empirical Expressions for the Modulus of Elasticity (by ACI Code)

For a unit weight w_c of concrete between 90 and 155 lb/ft^3:

$$E_c = w_c^{1.5} 33 \sqrt{f'_c} \qquad (1)$$

where
E_c = modulus of elasticity of concrete in compression (psi)
w_c = unit weight of concrete (lb/ft^3)
f'_c = compressive strength of concrete (psi)

CHAPTER 1a. MATERIALS AND MECHANICS OF BENDING

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Concrete in Compression

- Empirical Expressions for the Modulus of Elasticity (by ACI Code)

For a unit weight w_c taken as 144 lb/ft^3:

$$E_c = 57{,}000 \sqrt{f'_c} \qquad (2)$$

where
E_c = modulus of elasticity of concrete in compression (psi)
w_c = unit weight of concrete (lb/ft^3)
f'_c = compressive strength of concrete (psi)

Concrete in Compression

- Example 1

  What the modulus of elasticity E_c for concrete having a unit weight of 150 pcf and a compressive strength of 5 ksi?

Using Eq. 1,

$$E_c = w_c^{1.5} 33\sqrt{f_c'}$$
$$= (150)^{1.5}(33)\sqrt{5000} = \underline{\underline{4{,}286{,}826 \text{ psi}}}$$

Concrete in Compression

- Creep
  - Concrete under load, exhibits a phenomenon called *creep*.
  - This a property by which concrete continues to deform over long periods of time while under a constant load.
  - Creep occurs at a decreasing rate over a period of time and may cease after several years.
  - Higher strength concrete exhibits less creep.