1.054/1.541 Mechanics and Design of Concrete Structures (3-0-9)

Outline 1

Introduction / Design Criteria for Reinforced Concrete Structures

- Structural design
  - Definition of design:

    Determination of the general shape and all specific dimensions of a particular structure so that it will perform the function for which it is created and will safely withstand the influences which will act on it throughout its useful life.

    → Principles of mechanics, structural analysis, behavioral knowledge in structures and materials.

    → Engineering experience and intuition.

    → (a) Function, (b) strength with safety requirements will vary for structures.

    → Influences and structural response:

    Influences → Structure → Structural response

Influences	Structural response
Loads	Failure (strength)
Temperature fluctuations	Failure mode
Foundation settlements	Deformations
Time effects	Cracking
Corrosion	Stresses
Earthquakes	Motion
Other environmental effects	

  - Structural mechanics:

    A tool that permits one to predict the response (with a required level of accuracy, and a good degree of certainty) of a structure to defined influences.

- Role of the designer (engineer) of a structure

Design criteria for concrete

- Two schools of thoughts
  1. Base strength predictions on nonlinear theory using actual σ-ε relation
     - 1897 – M.R. von Thullie (flexural theory)
     - 1899 – W. Ritter (parabolic stress distribution theory]
  2. Straight-line theory (elastic)
     - 1900 – E. Coignet and N. de Tedesco (the straight-line (elastic) theory of concrete behavior)

- Working Stress Design (WSD) – Elastic theory
  1. Assess loads (service loads) (Building Code Requirements)
  2. Use linear elastic analysis techniques to obtain the resulting internal forces (load effects): bending, axial force, shear, torsion

  At service loads: $\sigma_{\max} \leq \sigma_{\text{all}}$

  e.g. $\sigma_{\text{all}}^{c} = 0.45 f_c^{'}$ compression in bending

  $\sigma_{\text{all}}^{s} = 0.50 f_y$ flexure

- Ultimate Strength Design (USD)
  - The members are designed taking inelastic strain into account to reach ultimate strength when an ultimate load is applied to the structure.
  - The load effects at the ultimate load may be found by

    (a) assuming a linear-elastic behavior

    (b) taking into account the nonlinear redistribution of actions.
  - Sectional design is based on ultimate load conditions.
  - Some reasons for the trend towards USD are

    (a) Efficient distribution of stresses

(b) Allows a more rational selection of the load factors

(c) Allows designer to assess the ductility of the structure in the post-elastic range

- Limit State Design
  - Serviceability limit state:
    Deformation, fatigue, ductility.
  - Ultimate limit state:
    Strength, plastic collapse, brittle fracture, instability, etc.
  - It has been recognized that the design approach for reinforced concrete (RC) ideally should combine the best features of ultimate strength and working stress designs:
    (a) strength at ultimate load
    (b) deflections at service load
    (c) crack widths at service load

- ACI (American Concrete Institute) Code emphasizes:
  (a) strength provisions
  (b) serviceability provisions (deflections, crack widths)
  (c) ductility provisions (stress redistribution, ductile failure)

Design factors

- 1956 – A.L.L. Baker (simplified method of safety factor determination)
- 1971 – ACI Code (*load factors* and *capacity (strength, resistance) reduction factors*)
- 2002 – ACI 318 Building Code
- Design loads (U) are factored to ensure the safety and reliability of structural performance.
- Structural capacities (ϕ) of concrete material are reduced to account for inaccuracies in construction and variations in properties.

- Safety
  - Semi-probabilistic design is achieved by introducing the use of load factors, γ_l, and capacity reduction factors, ϕ.
  - Load factors – ACI 318 Building Code
    - Load combinations

      U = 1.4(D + F)

      U = 1.2(D + F + T) + 1.6(L + H) + 0.5(L_r or S or R)

      U = 1.2D + 1.6(L_r or S or R) + (1.0L or 0.8W)

      U = 1.2D + 1.6W + 0.5L + 1.0(L_r or S or R)

      U = 1.2D + 1.0E + 1.0L + 0.2S

      U = 0.9D + 1.6W + 1.6H

      U = 0.9D + 1.0E + 1.6H

      where D = dead load; F = lateral fluid pressure; T = self-straining force (creep, shrinkage, and temperature effects); L = live load; H = load due to the weight and lateral pressure of soil and water in soil; L_r = roof load; S = snow load; R = rain load; W = wind load; E = earthquake load.
    - ACI 318-02 also provides exceptions to the values in above expressions.

  - Capacity reduction factors – ACI 318 Building Code
    - Members subject to structural actions and their associated reduction factor (ϕ)

      Beam or slab in bending or flexure: 0.9

      Columns with ties: 0.65

      Columns with spirals: 0.70

      Columns carrying very small axial loads: 0.65~0.9 for tie stirrups and 0.7~0.9 for spiral stirrups.

      Beam in shear and torsion: 0.75

- Relation between resistance capacity and load effects

  $\phi R_n \geq \sum_{i=1}^{m} \gamma_i l_i$ → resistance ≥ sum of load effects

  For a structure loaded by dead and live loads the overall safety factor is

  $$s = \frac{1.2D + 1.6L}{D + L} \cdot \frac{1}{\phi}$$

Making of concrete

- Cements
  - Portland cements
  - Non-portland cements
- Aggregates – Coarse and fine
- Water
- Chemical admixtures
  - Accelerating admixtures
  - Air-entraining admixtures
  - Water-reducing and set-controlling admixtures
  - Finely divided admixtures
  - Polymers (for polymer-modified concrete)
  - Superplasticizers
  - Silica-fume admixture (for high-strength concrete)
  - Corrosion inhibitors

Raw material components of cement

- Lime (CaO)
- Silica (SiO_2)
- Alumina (Al_2O_3)

Properties of portland cement components

Component	Rate of reaction	Heat liberated	Ultimate cementing value
Tricalcium silicate, C_3S	Medium	Medium	Good
Dicalcium silicate, C_2S	Slow	Small	Good
Tricalcium aluminate, C_3A	Fast	Large	Poor
Tetracalium aluminoferrate, C_4AF	Slow	Small	Poor

- Types of portland cements
  - Type I: All-purpose cement
  - Type II: Comparatively low heat liberation; used in large structures
  - Type III: High strength in 3 days
  - Type IV: Used in mass concrete dams
  - Type V: Used in sewers and structure exposed to sulfates

- Mixture design methods of concrete
  - ACI method of mixture design for normal strength concrete
  - Portland Cement Association (PCA) method of mixture design

- Quality tests on concrete
  - Workability
  - Air content
  - Compressive strength of hardened concrete
  - Flexural strength of plain concrete beams
  - Tensile strength from splitting tests

- Advantages and disadvantages of concrete
  - Advantages
    - Ability to be cast
    - Economical

- Durable
- Fire resistant
- Energy efficient
- On-site fabrication
- Aesthetic properties

- Disadvantages
    - Low tensile strength
    - Low ductility
    - Volume instability
    - Low strength-to-weight ratio

Properties of steel reinforcement

- Young's modulus, E_s
- Yield strength, f_y
- Ultimate strength, f_u
- Steel grade
- Geometrical properties (diameter, surface treatment)

Types of reinforced concrete structural systems

- Beam-column systems
- Slab and shell systems
- Wall systems
- Foundation systems