Basics of Reinforced Concrete Design

Presented by: Ronald Thornton, P.E.

Reinforced Concrete Design

• Define several terms related to reinforced concrete design
• Learn the basic theory behind structural analysis and reinforced concrete design
• What is “Area-of-Steel”?  
• Design codes
• Non-destructive testing of concrete
Reinforced Concrete Design

• Member
  – Wall, Slab, Beam, or Column

Reinforced Concrete Design

• Boundary Conditions
  – Simply supported
  – Fixed Ends
  – Cantilever
  – Propped Cantilever
  – Continuous Support
Reinforced Concrete Design

• Applied Loads
  – Dead Loads
  – Live Loads
  – Earth Loads
  – Seismic
  – Hydrostatic
  – Wind, Snow, ice,…..

Reinforced Concrete Design

• Loads

  Concentrated Load

  Uniform or Superimposed load
Reinforced Concrete Design

• Load Factor – A multiplier that magnifies the load for design purposes.
• Load Combinations – ACI 318, Article 9.2
  – $U = 1.4D$
  – $U = 1.2D + 1.6L + 0.5(L_r \text{ or } S \text{ or } R)$
  – $U = 1.2D + 1.0E + 1.0L + 0.2S$

Reinforced Concrete Design

• Basic Requirement for Strength.
  – Design Strength $\geq$ Required Strength
    – $f_N$ (Nominal Strength) $\geq$ $U$ (Ultimate Strength)
      • Ultimate = Factored
  – Capacity $\geq$ Demand
Reinforced Concrete Design

• Strength Reduction Factor, $F$ – A multiplier that reduces the capacity of the member for design purposes.
• ACI 318, Article 9.3
  – Moment = 0.90
  – Shear = 0.75
  – Axial = 0.70

Reinforced Concrete Design

• Strength Reduction Factor, $F$ – A multiplier that reduces the capacity of the member for design purposes.
• AASHTO Standard
  – Moment = 0.90
  – Shear = 0.85
  – Axial = 0.70
Reinforced Concrete Design

- **Force**
  - Shear – Is greatest near the support
  - Flexure – Bending Moment
  - Axial – Typically related to columns

\[
\text{Shear Diagram} \\
(+) \text{ Positive}
\]

Reinforced Concrete Design

- **Shear – Moment Diagram (Uniform Load)**

\[
\text{Moment Diagram} \\
\text{Simple Support}
\]
Reinforced Concrete Design

• Shear – Moment Diagram (Uniform Load)

Shear Diagram

(+) Positive

Moment Diagram
Fixed Support

(-) Negative

"STRESS"
Reinforced Concrete Design

• Basic Stress Formula

\[ \sigma = \frac{P}{A} \pm \frac{M \times c}{I} \]

– \( P \) = Applied Load
– \( A \) = Area resisting the load
– \( M \) = Applied Moment
– \( c \) = Distance from Centroid to Extreme Fiber
– \( I \) = Moment-of-Inertia

Reinforced Concrete Design

• Concrete Properties

– \( f_c \) = Compressive Strength, psi
– \( v_c \) = Allowable Shear Stress, psi \( v_c = \beta \sqrt{f_c} \)
– \( f_r \) = Modulus-of-Rupture, psi \( f_r = 7.5 \sqrt{f_c} \)
– \( c \) = Distance from Centroid to Extreme Fiber
– \( I \) = Moment-of-Inertia: A member’s tendency to resist bending or rotation, \( in^4 \) \( I = b \times h^3 / 12 \)
Reinforced Concrete Design

- IF $fr < Mc/l$
  - Brittle Failure

Reinforced Concrete Design

- Reinforcing Steel Properties
  - Yield Strength, $F_y = 60,000$psi
  - Modulus-of-Elasticity, $E_c = 29,000,000$psi
  - “Ductility” – Ability to stretch without breaking
## Reinforced Concrete Design

### Equations

\[
\varepsilon = 0.003 \\
\varepsilon_s = \frac{F_y}{E_s} \\
F_y A_s \\
M = 0.85 f'_c (d - \frac{a}{2})
\]

### Bar Size and Diameter Table

<table>
<thead>
<tr>
<th>Bar Size</th>
<th>Diameter (in)</th>
<th>A_b (in²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>.375</td>
<td>.11</td>
</tr>
<tr>
<td>4</td>
<td>.500</td>
<td>.20</td>
</tr>
<tr>
<td>5</td>
<td>.625</td>
<td>.31</td>
</tr>
<tr>
<td>6</td>
<td>.750</td>
<td>.44</td>
</tr>
<tr>
<td>7</td>
<td>.875</td>
<td>.60</td>
</tr>
<tr>
<td>8</td>
<td>1.00</td>
<td>.79</td>
</tr>
<tr>
<td>9</td>
<td>1.128</td>
<td>1.00</td>
</tr>
<tr>
<td>10</td>
<td>1.270</td>
<td>1.27</td>
</tr>
<tr>
<td>11</td>
<td>1.410</td>
<td>1.56</td>
</tr>
</tbody>
</table>

Source: Concrete Reinforcing Steel Institute - CRSI
Reinforced Concrete Design

Beam

\[ A_s = A_b \times \text{Number of Bars} \]

(3) # 6 Bars

\[ A_s = 0.44 \times 3 = 1.32 \text{in}^2 \]

Reinforced Concrete Design

Slab

\[ A_s = \frac{A_b \times 12}{\text{Spacing}} \]

#5 @ 9"oc

\[ A_s = \frac{0.41 \text{in}^2 \times 12"}{9"} = 0.41 \text{in}^2/ft \]
Reinforced Concrete Design

• Welded Wire Reinforcing
  – 4 x 8 W6/W3
    • Longitudinal Wire Spacing (4”) x
    • Transverse Wire Spacing (8”)
    • W = Smooth Wire (D = Deformed Wire)
    • Longitudinal Wire Size ($A_w = .06in^2$)
    • Transverse Wire Size ($A_w = .03in^2$)

Source: Wire Reinforcing Institute - WRI

Reinforced Concrete Design

• Welded Wire Reinforcing
  – $A_s = \frac{A_w \times 12}{Spacing}$
  – $A_s = \frac{0.06in^2 \times 12"}{6"} = 0.18in^2/ft$  Longitudinal
  – $A_s = \frac{0.03in^2 \times 12"}{R"} = 0.045in^2/ft$  Transverse
Reinforced Concrete Design

• $A_s$ Required – 0.40in$^2$/ft
  – #4 @ 6"oc = 0.40in$^2$/ft
  – #5 @ 9"oc = 0.41in$^2$/ft
  – #6 @ 13"oc = 0.41in$^2$/ft
  – D10 @ 3"oc = 0.40in$^2$/ft (Grade 70 Wire)

Reinforced Concrete Design

• “Serviceability”
  – Satisfactory Performance under normal service conditions
  – Code Related
  – Ensures durability and service life
  – Use unfactored loads
Reinforced Concrete Design

- “Serviceability”
  - Crack Control
  - Limitation of Service Load Stress
  - Deflection
  - Fatigue
  - Minimum Reinforcing Limits
  - Bar Development
  - Splices

Reinforced Concrete Design

- “Serviceability”
  - Code Related
    - ACI 318 – Structural Concrete Building Code
    - ACI 350 – Environmental Engineering Structures
    - AASHTO Standard Specification
    - AASHTO LRFD Specification
    - AREMA – American Railway Engineering Manual
    - CSA Canadian Standards Association
Reinforced Concrete Design

• “Serviceability”
  – Crack Control
    • Steel Stress
    • Bar Cover
    • Bar Spacing

\[ z = f_s \sqrt[3]{d_c A} \]
\[ A = 2d_c \times \text{Spacing} \]
\[ f_s = 0.6F_y \]

Reinforced Concrete Design

• \(A_s\) Required – 0.40in\(^2\)/ft; \(Z_{\text{max}}\) = 130kips/in
  – #4 @ 6”oc = 0.40in\(^2\)/ft
    • \(Z = 120\)kips/in \ OK
  – #5 @ 9”oc = 0.41in\(^2\)/ft
    • \(Z = 140\)kips/in \ NG
  – #6 @ 13”oc = 0.41in\(^2\)/ft
    • \(Z = 162\)kips/in \ NG
  – D10 @ 3”oc = 0.40in\(^2\)/ft (Grade 70 Wire)
    • \(Z = 92\)kips/in \ OK
Reinforced Concrete Design

- $A_s$ Required – 0.40in$^2$/ft; $Z_{\text{max}} = 130$ kips/in
  - Yield Adjustment \[ A_{s, \text{adj}} = A_{s, \text{req'd}} \times \frac{F_y \text{ bar}}{F_y \text{ wire}} \]
    \[ A_{s, \text{adj}} = 0.40 \text{ in}^2/\text{ft} \times \frac{60}{70} = 0.34\text{in}^2/\text{ft} \]
  - Try D17 Wire @ 6”oc, $A_s = 0.34\text{in}^2/\text{ft}$
    - $Z = 138$ kips/in NG
  - Try D8.5 Wire @ 3”oc, $A_s = 0.34\text{in}^2/\text{ft}$
    - $Z = 107$ kips/in OK

Reinforced Concrete Design

- “Minimum Flexural Reinforcing”
  - Established by Code
    - ACI 318 \[ A_{s, \text{min}} = \frac{3 \sqrt{f'_c}}{f_y} b_w d \]
    - But not less than \[ 200b_w d / f_y \]
    - AASHTO Standard \[ \phi M_n \geq 1.2M_{cr} \]
      - Same as LRFD
    - Minimum waived if \[ A_{s, \text{prov}} \geq 4/3A_{s, \text{req'd}} \]
      - Ex: 0.40in$^2$/ft $\times$ 1.333 = 0.53in$^2$/ft
Reinforced Concrete Design

• “Minimum Temperature Reinforcing”
  – Established by Code
    • ACI 318
      – Slabs $As_{min} = 0.0018Ag$ Where, $Ag = b \times h$
      – Walls Horiz = 0.0020Ag
      – Walls Vertical = 0.0012Ag
      – Chapter 16, Precast Walls = 0.0010Ag
    • AASHTO Standard = .125in$²$/ft

Non-Destructive Testing

• Two types of rebar locaters
  – Cover Meter (R-Meter)
    • Emits an electromagnetic pulse to detect the magnetic field induced by rebar.
  – Ground Penetrating Radar (GPR)
    • Transmits polarized pulses of electromagnetic energy into the surface then records the energy that is reflected back to the surface.
Non-Destructive Testing

- Cover Meter (R-Meter)
  - Can be used in wet or dry conditions
  - Can detect the presence and approximate bar cover
  - Not very accurate at determining bar diameter
    - $\pm 1$ bar size at best
  - Results can be affected by the presence of other metals, i.e. form ties
Non-Destructive Testing

- Ground Penetrating Radar (GPR)
  - Sensitive to moisture conditions
  - Cannot be used on wet surfaces
  - Requires well trained users
  - Reasonably accurate if properly calibrated
    - Bar cover reportedly within 3mm (FHWA)
Non-Destructive Testing

- Primary purpose is to locate rebar prior to coring or drilling
- Not intended for QC purposes

??QUESTIONS??
Basics of Reinforced Concrete Design
Presented by: Ronald Thornton, P.E.