Reinforced Concrete Design

- economical & common
- resist lateral loads

Concrete Spans

Lecture 22
Architectural Structures
ARCH 331
DR. ANNE NICHOLS
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concrete construction:
flat spanning systems, columns & frames

Reinforced Concrete Design

- flat plate
  - 5”-10” thick
  - simple formwork
  - lower story heights

- flat slab
  - same as plate
  - 2 ¼”-8” drop panels

Reinforced Concrete Design

- beam supported
  - slab depth ~ L/20
  - 8”-60” deep

- one-way joists
  - 3”-5” slab
  - 8”-20” stems
  - 5”-7” webs

http://nisee.berkeley.edu/godden
Reinforced Concrete Design

- two-way joist
  - “waffle slab”
  - 3”-5” slab
  - 8”-24” stems
  - 6”-8” webs
- beam supported slab
  - 5”-10” slabs
  - taller story heights

Reinforced Concrete Design

- simplified frame analysis
  - strips, like continuous beams
- moments require flexural reinforcement
  - top & bottom
  - both directions of slab
  - continuous, bent or discontinuous

Reinforced Concrete Design

- one-way slabs (wide beam design)
  - approximate analysis for moment & shear coefficients
  - two or more spans
  - ~ same lengths
  - \( w_u \) from combos
  - uniform loads with \( L/D \leq 3 \)
  - \( \ell_n \) is clear span (+M) or average of adjacent clear spans (-M)
Reinforced Concrete Design

- two-way slabs - Direct Design Method
  - 3 or more spans each way
  - uniform loads with L/D ≤ 3
  - rectangular panels with long/short span ≤ 2
  - successive spans can’t differ > longer/3
  - column offset no more than 10% span

Shear in Concrete

- at columns
- want to avoid stirrups
- can use shear studs or heads

Reinforced Concrete Design

<table>
<thead>
<tr>
<th>Span ratio</th>
<th>Slab Moments</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
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</thead>
<tbody>
<tr>
<td>0.5</td>
<td>Column Side Beam: Slab</td>
<td>$0.10 M_p$</td>
<td>$0.37 M_p$</td>
<td>$0.70 M_p$</td>
<td>$0.27 M_p$</td>
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<td>$0.02 M_p$</td>
<td>$0.06 M_p$</td>
<td>$0.07 M_p$</td>
<td>$0.03 M_p$</td>
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<td>$0.31 M_p$</td>
<td>$0.38 M_p$</td>
<td>$0.19 M_p$</td>
</tr>
</tbody>
</table>

Notes:
1. Beams and slab safety stiffness criteria: $\alpha_{ust} \geq 1.0$ and $h_s \geq 2.5$.
2. Interpolate between values shown for different $h_s/t_i$ ratios.
3. All negative moments are at face of support.
4. Concentrated loads applied directly to beams must be accounted for separately.

Shear in Concrete

- critical section at d/2 from
  - column face, column capital or drop panel

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Shear in Concrete

• at columns with waffle slabs

Openings in Slabs

• careful placement of holes
• shear strength reduced
• bending & deflection can increase

General Beam Design

• $f'_c$ & $f_y$ needed
• usually size just $b$ & $h$
  – even inches typical (forms)
  – similar joist to beam depth
  – $b:h$ of 1:1.5-1:2.5
  – $b_w$ & $b_f$ for $T$
  – to fit reinforcement + stirrups
• slab design, $t$
  – deflection control & shear

General Beam Design (cont’d)

• custom design:
  – longitudinal steel
  – shear reinforcement
  – detailing
Space “Frame” Behavior

- handle uniformly distributed loads well
- bending moment
  - tension & compression “couple” with depth
  - member sizes can vary, but difficult

Folded Plates

- increased bending stiffness with folding
- lateral buckling avoided

Space “Frame” Behavior

- shear at columns
- support conditions still important
  - point supports not optimal
- fabrication/construction can dominate design

Folded Plates

- common for roofs
- edges need stiffening

http://nisee.berkeley.edu/godden
Folded Plates

- State Farm Center (Assembly Hall), University of Illinois
- Harrison & Abramovitz 1963
- Edge-supported dome spanning 400 feet wound with 614 miles of one-fifth inch steel wire

Concrete in Compression

- crushing
- vertical cracking
  - tension
- diagonal cracking
  - shear
- $f'_c$

Columns Reinforcement

- columns require
  - ties or spiral reinforcement to “confine” concrete (#3 bars minimum)
  - minimum amount of longitudinal steel (4 bars minimum)

Slenderness

- effective length in monolithic with respect to stiffness of joint: $\Psi$ & $k$
- not slender when

$$\frac{kL_u}{r} \leq 22$$

*not braced*
Effective Length (revisited)

- relative rotation

\[ \Psi = \frac{\sum EI}{l_c} \]

Column Behavior

Columns with Bending

- eccentric loads can cause moments
- moments can change shape and induce more deflection

(P-\(\Delta\))

Column Design

- \(\phi_c = 0.65\) for ties, \(\phi_c = 0.75\) for spirals
- \(P_o\) – no bending
- \(P_u \leq \phi_c P_n\)
  - ties: \(P_n = 0.8P_o\)
  - spiral: \(P_n = 0.85P_o\)
- nominal axial capacity:
  - presumes steel yields
  - concrete at ultimate stress

\[ P = 0.85 f'_c (A_g - A_{st}) + f_y A_{st} \]
Columns with Bending

- for ultimate strength behavior, ultimate strains can’t be exceeded
  - concrete 0.003
  - steel \( \frac{f_y}{E_s} \)
- \( P \) reduces with \( M \)

Design Methods

- calculation intensive
  - handbook charts
  - computer programs

Columns with Bending

- need to consider combined stresses
- linear strain
- steel stress at or below \( f_y \)
- plot interaction diagram

Design Considerations

- bending at both ends
  - \( P-\Delta \) maximum
- biaxial bending
- walls
  - unit wide columns
  - “deep” beam shear
- detailing
  - shorter development lengths
  - dowels to footings