ARCHITECTURAL STRUCTURES: FORM, BEHAVIOR, AND DESIGN
ARCH 331
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SPRING 2015

lecture twenty five

concrete construction: flat spanning systems
Reinforced Concrete Design

- economical & common
- resist lateral loads
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
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 \( L/D \leq 3 \)
  - \( l_n \) is clear span \((+M)\) or average of adjacent clear spans \((-M)\)

*Figure 2-2 Conditions for Analysis by Coefficients (ACI 8.3.3)*
Reinforced Concrete Design

**Figure 2-3** Positive Moments—All Cases

Simple Support

$\frac{w_u \ell_n^2}{11}$
End Span

$\frac{w_u \ell_n^2}{16}$
Interior Span

$\frac{w_u \ell_n^2}{14}$
End Span

Integral with Support

**Figure 2-4** Negative Moments—Beams and Slabs

Simple Support

$\frac{w_u \ell_n^2}{10}$

$\frac{w_u \ell_n^2}{11}$

$\frac{w_u \ell_n^2}{11}$

$\frac{w_u \ell_n^2}{10}$

$\frac{w_u \ell_n^2}{24}$

Spandrel Support

$\frac{*w_u \ell_n^2}{9}$ (2 spans)

Integral with Support

$\frac{w_u \ell_n^2}{16}$

Column Support
Reinforced Concrete Design

• **two-way slabs - Direct Design Method**
  – 3 or more spans each way
  – uniform loads with $L/D \leq 2$
  – rectangular panels with long/short span $\leq 2$
  – successive spans can’t differ $> longer/3$
  – column offset no more than 10% span
### Reinforced Concrete Design

#### Table 4-6 Two-Way Beam-Supported Slab

<table>
<thead>
<tr>
<th>Span ratio</th>
<th>Slab Moments</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>End Span</td>
<td>First Interior Negative</td>
<td></td>
<td>Interior Negative</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Exterior Negative</td>
<td>Positive</td>
<td></td>
<td>Negative</td>
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<tr>
<td>2/1</td>
<td>Total Moment</td>
<td>0.16 M₀</td>
<td>0.57 M₀</td>
<td>0.70 M₀</td>
<td>0.35 M₀</td>
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<tr>
<td>0.5</td>
<td>Column Strip Beam Slab</td>
<td>0.12 M₀</td>
<td>0.43 M₀</td>
<td>0.54 M₀</td>
<td>0.27 M₀</td>
<td>0.50 M₀</td>
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<tr>
<td></td>
<td></td>
<td>0.02 M₀</td>
<td>0.08 M₀</td>
<td>0.09 M₀</td>
<td>0.05 M₀</td>
<td>0.09 M₀</td>
</tr>
<tr>
<td></td>
<td>Middle Strip</td>
<td>0.02 M₀</td>
<td>0.06 M₀</td>
<td>0.07 M₀</td>
<td>0.03 M₀</td>
<td>0.06 M₀</td>
</tr>
<tr>
<td>1.0</td>
<td>Column Strip Beam Slab</td>
<td>0.10 M₀</td>
<td>0.37 M₀</td>
<td>0.45 M₀</td>
<td>0.22 M₀</td>
<td>0.42 M₀</td>
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<tr>
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<td></td>
<td>0.02 M₀</td>
<td>0.06 M₀</td>
<td>0.08 M₀</td>
<td>0.04 M₀</td>
<td>0.07 M₀</td>
</tr>
<tr>
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<td>Middle Strip</td>
<td>0.04 M₀</td>
<td>0.14 M₀</td>
<td>0.17 M₀</td>
<td>0.09 M₀</td>
<td>0.16 M₀</td>
</tr>
<tr>
<td>2.0</td>
<td>Column Strip Beam Slab</td>
<td>0.06 M₀</td>
<td>0.22 M₀</td>
<td>0.27 M₀</td>
<td>0.14 M₀</td>
<td>0.25 M₀</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.01 M₀</td>
<td>0.04 M₀</td>
<td>0.05 M₀</td>
<td>0.02 M₀</td>
<td>0.04 M₀</td>
</tr>
<tr>
<td></td>
<td>Middle Strip</td>
<td>0.09 M₀</td>
<td>0.31 M₀</td>
<td>0.38 M₀</td>
<td>0.19 M₀</td>
<td>0.36 M₀</td>
</tr>
</tbody>
</table>

**Notes:**

1. Beams and slab satisfy stiffness criteria: $\alpha_1 l_2/l_1 \geq 1.0$ and $\beta_t \geq 2.5$.
2. Interpolate between values shown for different $l_2/l_1$ 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

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

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

\[ S = \frac{bh^2}{6} \]
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
Space “Frame” Behavior

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

- increased bending stiffness with folding
- lateral buckling avoided
Folded Plates

- common for roofs
- edges need stiffening
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