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 (\(-M\))
Reinforced Concrete Design

Figure 2-3 Positive Moments—All Cases

Figure 2-4 Negative Moments—Beams and Slabs
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 $>\frac{\text{longer}}{3}$
  - 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>
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<tbody>
<tr>
<td></td>
<td></td>
<td>End Span</td>
<td>Interior Span</td>
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<td></td>
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<tr>
<td></td>
<td></td>
<td>1 Exterior</td>
<td>2 Positive</td>
<td>3 First Interior</td>
<td>4 Positive</td>
<td>5 Interior</td>
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<tr>
<td></td>
<td></td>
<td>Negative</td>
<td>Positive</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>
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<td>0.54 M₀</td>
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<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>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>
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<tr>
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<td>0.01 M₀</td>
<td>0.04 M₀</td>
<td>0.05 M₀</td>
<td>0.02 M₀</td>
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<tr>
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<td>Middle Strip</td>
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<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: \( \alpha_1 \beta_1 \geq 1.0 \) and \( \beta_1 \geq 2.5 \).
2. Interpolate between values shown for different \( \frac{h_2}{h_1} \) 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
  - $b_w$ & $b_t$ 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

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