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 $\text{long/short span} \leq 2$
  - successive spans can’t differ $> \frac{\text{longer span}}{3}$
  - column offset no more than 10% span
Table 4-6 Two-Way Beam-Supported Slab

<table>
<thead>
<tr>
<th>Span ratio</th>
<th>Slab Moments</th>
<th>End Span</th>
<th>Interior Span</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1 Exterior Negative</td>
<td>2 Positive</td>
</tr>
<tr>
<td>0.5</td>
<td>Column Strip Beam Slab</td>
<td>0.12 $M_0$</td>
<td>0.43 $M_0$</td>
</tr>
<tr>
<td></td>
<td>Middle Strip</td>
<td>0.02 $M_0$</td>
<td>0.08 $M_0$</td>
</tr>
<tr>
<td>1.0</td>
<td>Column Strip Beam Slab</td>
<td>0.10 $M_0$</td>
<td>0.37 $M_0$</td>
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<tr>
<td></td>
<td>Middle Strip</td>
<td>0.02 $M_0$</td>
<td>0.08 $M_0$</td>
</tr>
<tr>
<td>2.0</td>
<td>Column Strip Beam Slab</td>
<td>0.06 $M_0$</td>
<td>0.22 $M_0$</td>
</tr>
<tr>
<td></td>
<td>Middle Strip</td>
<td>0.04 $M_0$</td>
<td>0.14 $M_0$</td>
</tr>
</tbody>
</table>

Notes:
1. Beams and slab satisfy stiffness criteria: $\alpha t_2/t_1 \geq 1.0$ and $\beta t \geq 2.5$.
2. Interpolate between values shown for different $t_2/t_1$ 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

\[ b_o = 2(c_1 + d) + 2(c_2 + d) \]
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

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**