concrete construction: flat spanning systems
Reinforced Concrete Design

- economical & common
- resist lateral loads

![Graph showing cost index vs. square bay size](image)
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 $> longer/3$
  - 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>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>Total Moment</td>
<td>0.16 $M_o$</td>
<td>0.57 $M_o$</td>
</tr>
<tr>
<td></td>
<td>Column Strip Beam Slab</td>
<td>0.12 $M_o$</td>
<td>0.43 $M_o$</td>
</tr>
<tr>
<td></td>
<td>Middle Strip</td>
<td>0.02 $M_o$</td>
<td>0.08 $M_o$</td>
</tr>
<tr>
<td>1.0</td>
<td>Column Strip Beam Slab</td>
<td>0.10 $M_o$</td>
<td>0.37 $M_o$</td>
</tr>
<tr>
<td></td>
<td>Middle Strip</td>
<td>0.02 $M_o$</td>
<td>0.06 $M_o$</td>
</tr>
<tr>
<td>2.0</td>
<td>Column Strip Beam Slab</td>
<td>0.06 $M_o$</td>
<td>0.22 $M_o$</td>
</tr>
<tr>
<td></td>
<td>Middle Strip</td>
<td>0.09 $M_o$</td>
<td>0.31 $M_o$</td>
</tr>
</tbody>
</table>

**Notes:**
1. Beams and slab satisfy stiffness criteria: $\alpha_1 l_2 / l_1 \geq 1.0$ and $\beta_1 \geq 2.5$.
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

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