Concrete construction: flat spanning systems

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

- economical & common
- resist lateral loads

- 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 $L/D \leq 3$
  - $\ell_n$ 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 ≤ 2
  - 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

Table 4-6 Two-Way Beam-Supported Slab

<table>
<thead>
<tr>
<th>Span</th>
<th>Slab Moments</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total Moment</td>
<td>1 Exterior Negative</td>
<td>2 Positive</td>
<td>3 First Interior Negative</td>
<td>4 Positive</td>
</tr>
<tr>
<td>0.0</td>
<td>Column Strip Beam Slab</td>
<td>5.13 M&lt;sub&gt;B&lt;/sub&gt;</td>
<td>-0.57 M&lt;sub&gt;B&lt;/sub&gt;</td>
<td>0.67 M&lt;sub&gt;B&lt;/sub&gt;</td>
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<tr>
<td></td>
<td>Beam Strip</td>
<td>0.00 M&lt;sub&gt;B&lt;/sub&gt;</td>
<td>0.00 M&lt;sub&gt;B&lt;/sub&gt;</td>
<td>0.00 M&lt;sub&gt;B&lt;/sub&gt;</td>
<td>0.00 M&lt;sub&gt;B&lt;/sub&gt;</td>
</tr>
<tr>
<td>1.0</td>
<td>Column Strip Beam Slab</td>
<td>5.36 M&lt;sub&gt;B&lt;/sub&gt;</td>
<td>-0.37 M&lt;sub&gt;B&lt;/sub&gt;</td>
<td>0.48 M&lt;sub&gt;B&lt;/sub&gt;</td>
<td>-0.25 M&lt;sub&gt;B&lt;/sub&gt;</td>
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<tr>
<td></td>
<td>Beam Strip</td>
<td>0.00 M&lt;sub&gt;B&lt;/sub&gt;</td>
<td>0.00 M&lt;sub&gt;B&lt;/sub&gt;</td>
<td>0.00 M&lt;sub&gt;B&lt;/sub&gt;</td>
<td>0.00 M&lt;sub&gt;B&lt;/sub&gt;</td>
</tr>
<tr>
<td>2.0</td>
<td>Column Strip Beam Slab</td>
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<td>-0.30 M&lt;sub&gt;B&lt;/sub&gt;</td>
<td>0.51 M&lt;sub&gt;B&lt;/sub&gt;</td>
<td>-0.25 M&lt;sub&gt;B&lt;/sub&gt;</td>
</tr>
<tr>
<td></td>
<td>Beam Strip</td>
<td>0.00 M&lt;sub&gt;B&lt;/sub&gt;</td>
<td>0.00 M&lt;sub&gt;B&lt;/sub&gt;</td>
<td>0.00 M&lt;sub&gt;B&lt;/sub&gt;</td>
<td>0.00 M&lt;sub&gt;B&lt;/sub&gt;</td>
</tr>
</tbody>
</table>

Notes:
1. Beams and slab satisfy stiffness criteria: α<sub>B</sub>G ≥ 1.0 and β<sub>B</sub> ≥ 2.0.
2. Interpolate between values shown for different γ<sub>B</sub>; reduce.
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
**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
  - $b_w$ & $b_r$ for $T$
  - to fit reinforcement + stirrups
- slab design, $t$
  - deflection control & shear

**General Beam Design (cont’d)**

- custom design:
  - longitudinal steel
  - shear reinforcement
  - detailing

\[ S = \frac{bh^2}{6} \]
**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

www.library.illinois.edu