Concrete construction: flat spanning systems, columns & frames

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

- 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 ≤ 3
  - rectangular panels with long/short span ≤ 2
  - successive spans can't differ > longer/3
  - column offset no more than 10% span

Reinforced Concrete Design

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 ratio</th>
<th>Slab Moments</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1 Exterior Positive</td>
<td>2 Positive</td>
<td>3 First Interior Negative</td>
<td>4 Positive</td>
<td>5 Interior Negative</td>
</tr>
<tr>
<td>2.0</td>
<td>Column Strip Beam Slab</td>
<td>0.06 M₀</td>
<td>0.24 M₀</td>
<td>0.58 M₀</td>
<td>0.58 M₀</td>
<td>0.40 M₀</td>
</tr>
<tr>
<td>2.0</td>
<td>Middle Strip Slab</td>
<td>0.01 M₀</td>
<td>0.09 M₀</td>
<td>0.17 M₀</td>
<td>0.17 M₀</td>
<td>0.16 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>0.20 M₀</td>
<td>0.42 M₀</td>
</tr>
<tr>
<td>1.0</td>
<td>Middle Strip Slab</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>
<td>0.5</td>
<td>Column Strip Beam Slab</td>
<td>0.12 M₀</td>
<td>0.40 M₀</td>
<td>0.54 M₀</td>
<td>0.27 M₀</td>
<td>0.56 M₀</td>
</tr>
<tr>
<td>0.5</td>
<td>Middle Strip Slab</td>
<td>0.02 M₀</td>
<td>0.06 M₀</td>
<td>0.07 M₀</td>
<td>0.06 M₀</td>
<td>0.06 M₀</td>
</tr>
</tbody>
</table>

Notes:
1. Beams and slabs satisfy deflection criteria: δсрδ ≤ 1.0 and δсрδ ≥ 0.6.
2. Interpolate between values shown for different L/D, ratio.
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
  - $b_w$ & $b_f$ 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

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

**Concrete in Compression**

- crushing
- vertical cracking
  - tension
- diagonal cracking
  - shear
- $f_c'$

**Columns Reinforcement**

- columns require
  - ties or spiral reinforcement to "confine" concrete (#3 bars minimum)
  - minimum amount of longitudinal steel (#5 bars minimum: 4 with ties, 5 with spiral)

**Slenderness**

- effective length in monolithic with respect to stiffness of joint: $\Psi \& k$
- not slender when
  $$\frac{kL_u}{r} < 22$$
**Effective Length (revisited)**

- relative rotation

![Graph showing Effective Length](image)

\[ \Psi = \frac{\sum EI}{l_c} \]

**Column Design**

- \( \phi_c = 0.65 \) for ties, \( \phi_c = 0.75 \) for spirals
- \( P_o \) – no bending
  \[ P_o = 0.85 f'_c (A_g - A_{st}) + f_y A_{st} \]
- \( P_u \leq \phi_c P_n \)
  - ties: \( P_n = 0.8P_o \)
  - spiral: \( P_n = 0.85P_o \)
- nominal axial capacity:
  - presumes steel yields
  - concrete at ultimate stress

**Columns with Bending**

- eccentric loads can cause moments
- moments can change shape and induce more deflection (P-\( \Delta \))

![Diagram of Column Bending](image)
**Columns with Bending**

- For ultimate strength behavior, ultimate strains can't be exceeded
  - Concrete $0.003$
  - Steel $\frac{f_y}{E_s}$
- $P$ reduces with $M$

**Design Methods**

- Calculation intensive
  - Handbook charts
  - Computer programs

**Columns with Bending**

- Need to consider combined stresses
- Linear strain
- Steel stress at or below $f_y$
- Plot interaction diagram

**Design Considerations**

- Bending at both ends
  - $P-\Delta$ maximum
- Biaxial bending
- Walls
  - Unit wide columns
  - "Deep" beam shear
- Detailing
  - Shorter development lengths
  - Dowels to footings