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 \( L/D \leq 3 \)
  - \( \ell_n \) 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 \( L/D \leq 3 \)
  - rectangular panels with long/short span \( \leq 2 \)
  - 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

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
  - $b_w$ & $b_l$ for $T$
  - to fit reinforcement + stirrups
- slab design, $t$
  - deflection control & shear

General Beam Design (cont’d)

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

General Beam Design

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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

**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 (4 bars minimum)

**Slenderness**

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

- relative rotation

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

Column Behavior

Column Design

- \( \phi_c = 0.65 \) for ties, \( \phi_c = 0.75 \) for spirals
- \( P_o \) – no bending
- \( P_u \leq \phi_c P_n \)
  - 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
  \( (P-\Delta) \)
Columns with Bending

• for ultimate strength behavior, ultimate strains can’t be exceeded
  – concrete $0.003$
  – steel $\frac{f_y}{E}$

• $P$ reduces with $M$

Design Methods

• calculation intensive
  – handbook charts
  – computer programs

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