ARCHITECTURAL STRUCTURES:
FORM, BEHAVIOR, AND DESIGN

ARCH 331
DR. ANNE NICHOLS
SUMMER 2013

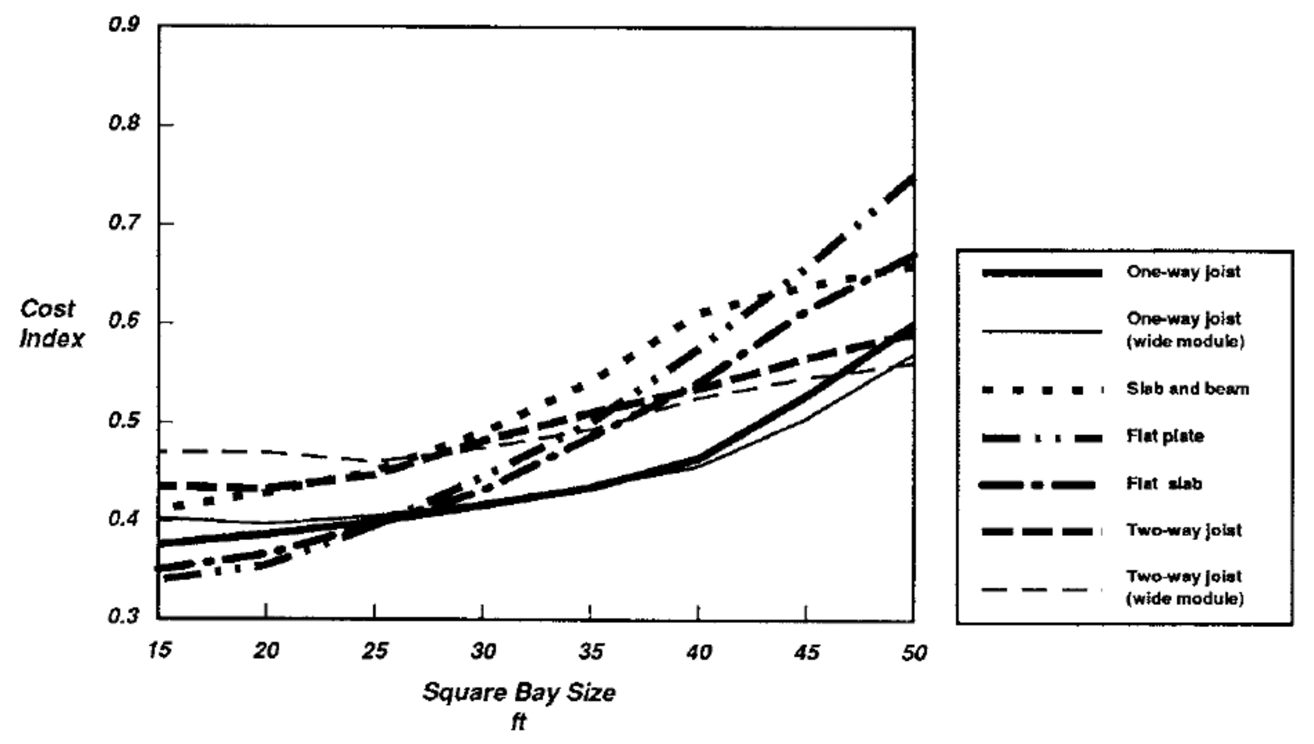
lecture
twenty two


http:// nisee.berkeley.edu/godden

concrete construction: flat spanning systems, columns & frames

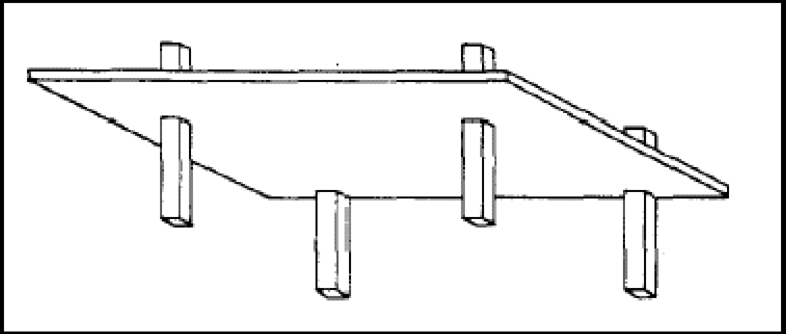
Reinforced Concrete Design

- *economical & common*
- *resist lateral loads*

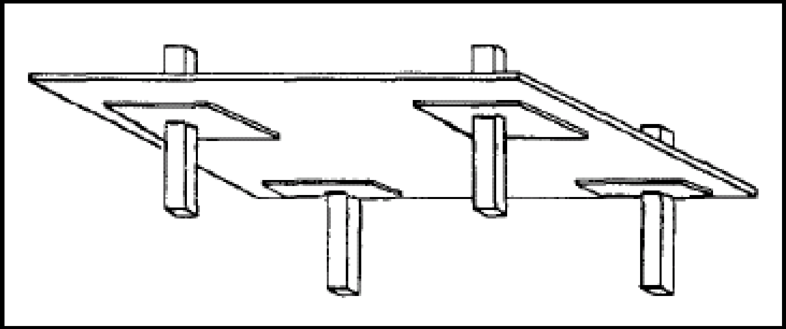


Reinforced Concrete Design

- *flat plate*
  - *– 5"-10" thick*
  - *– simple formwork*
  - *– lower story heights*



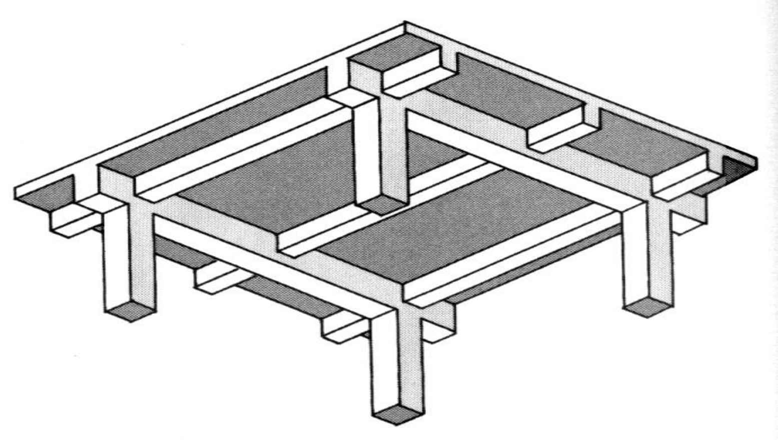
- *flat slab*
  - *– same as plate*
  - *– 2 ¼"–8" drop panels*



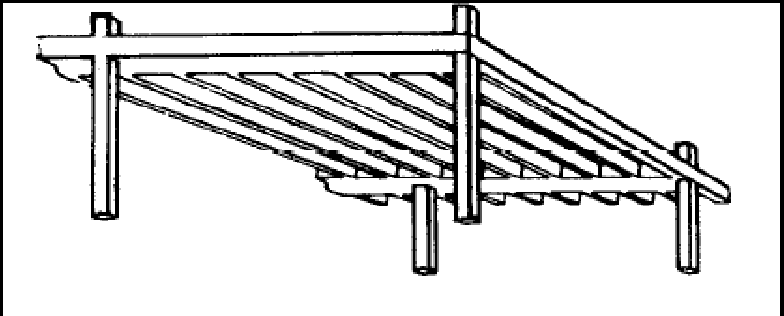
Reinforced Concrete Design

- *beam supported*
  - *slab depth ~ L/20*
  - *8"–60" deep*

- *one-way joists*
  - *3"–5" slab*
  - *8"–20" stems*
  - *5"-7" webs*

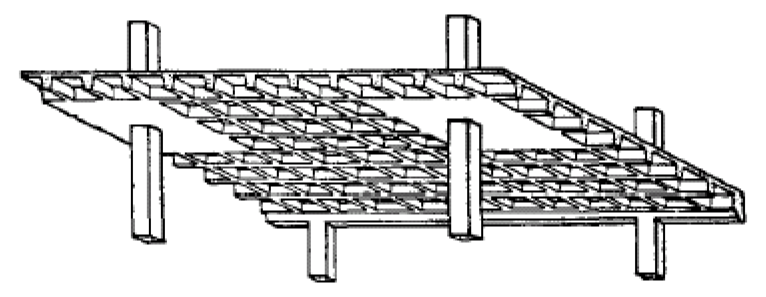


The Architect's Studio Companion

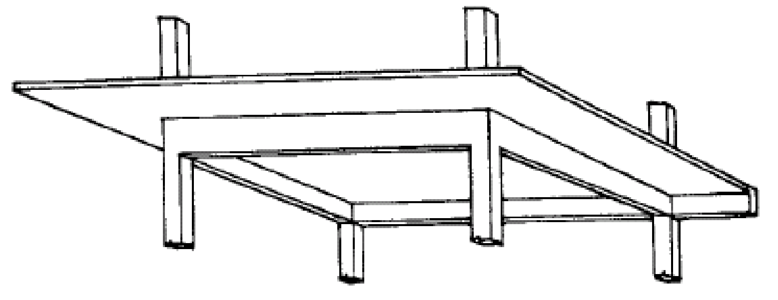


Reinforced Concrete Design

- *two-way joist*
  - *"waffle slab"*
  - *3"-5" slab*
  - *8"-24" stems*
  - *6"-8" webs*

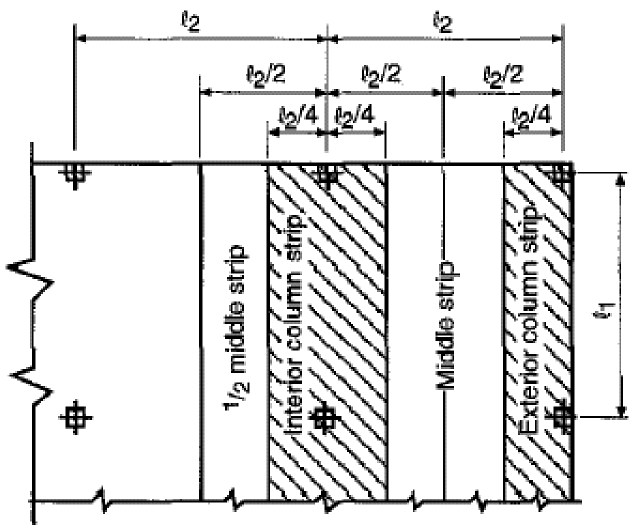


- *beam supported slab*
  - *5"-10" slabs*
  - *taller story heights*

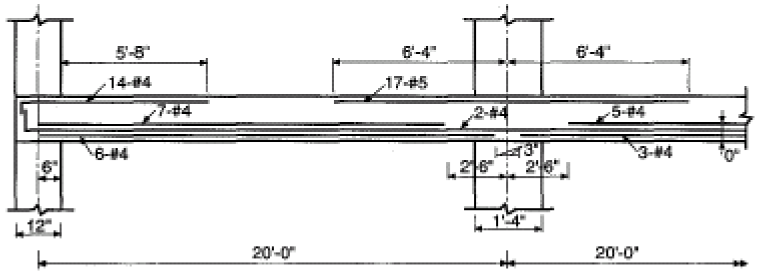


Reinforced Concrete Design

- *simplified frame analysis*
  - *strips, like continuous beams*
- *moments require flexural reinforcement*
  - *top & bottom*
  - *both directions of slab*
  - *continuous, bent or discontinuous*



(a) Column strip for $\ell_2 \leq \ell_1$



Column Strip

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)*

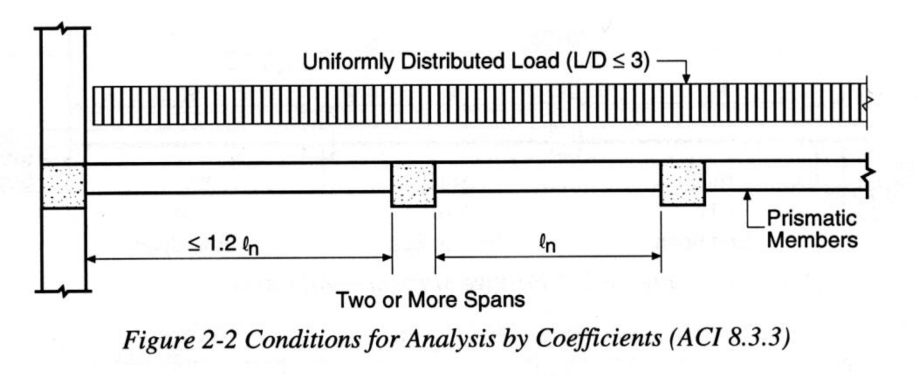


Figure 2-2 Conditions for Analysis by Coefficients (ACI 8.3.3)

Reinforced Concrete Design

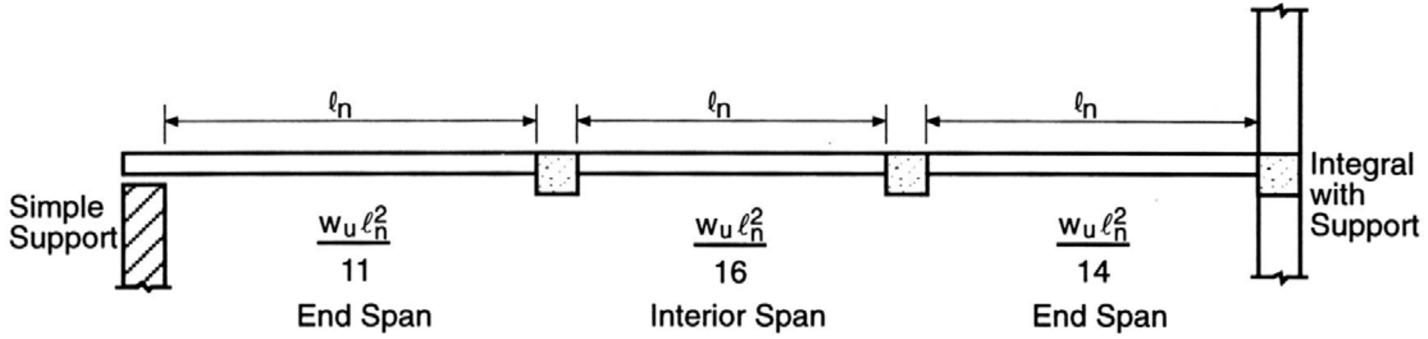


Figure 2-3 Positive Moments—All Cases

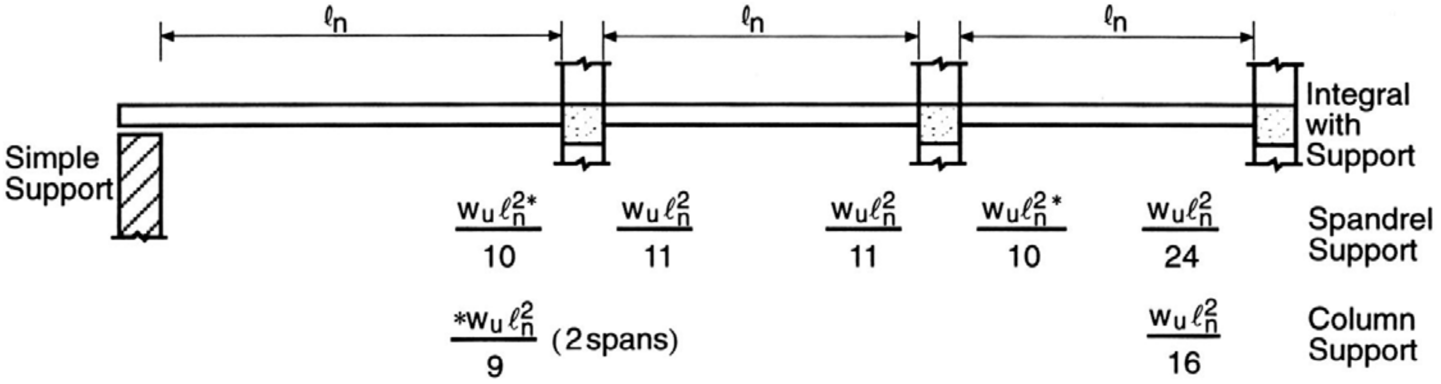
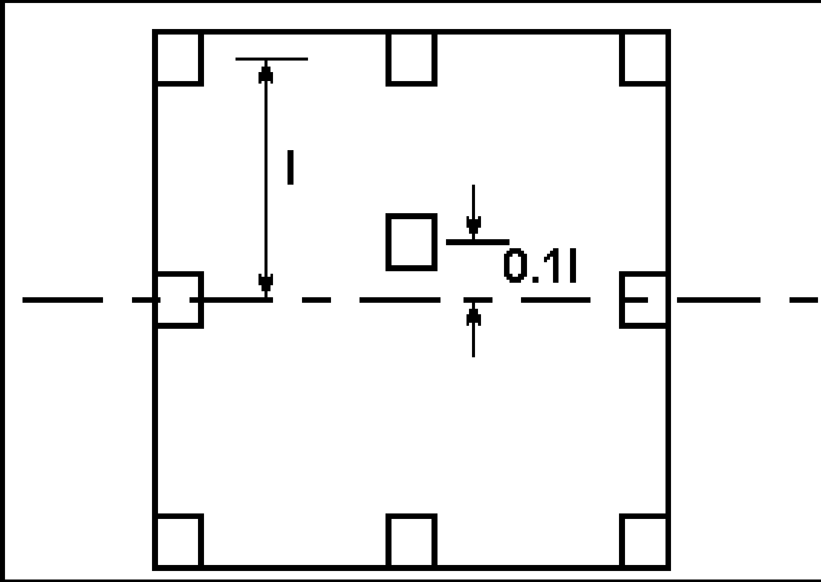


Figure 2-4 Negative Moments—Beams and Slabs

Reinforced Concrete Design

- *two-way slabs - Direct Design Method*
  - *3 or more spans each way*
  - *uniform loads with L/D ≤ 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

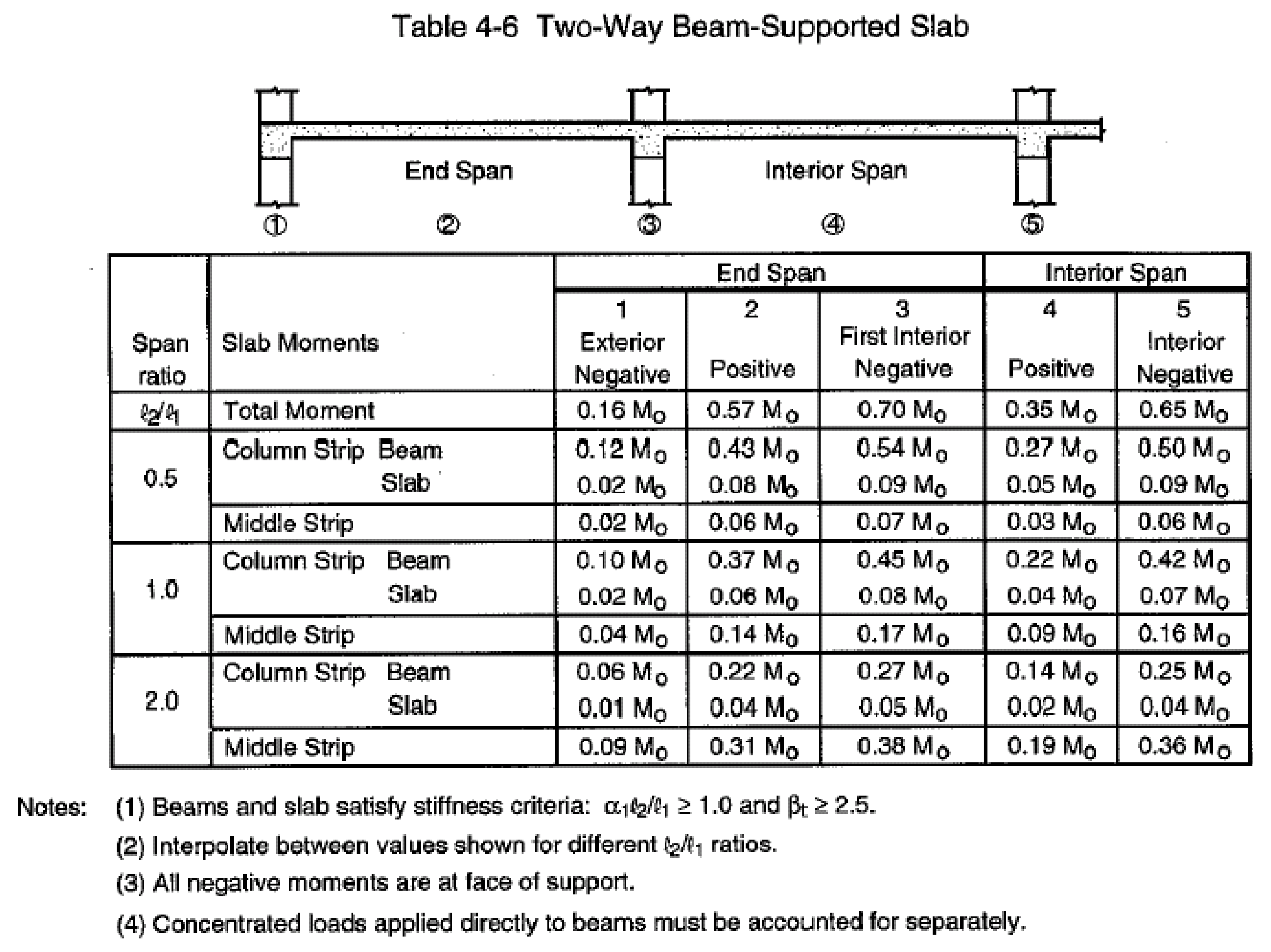


Table 4-6 Two-Way Beam-Supported Slab

End Span

Interior Span

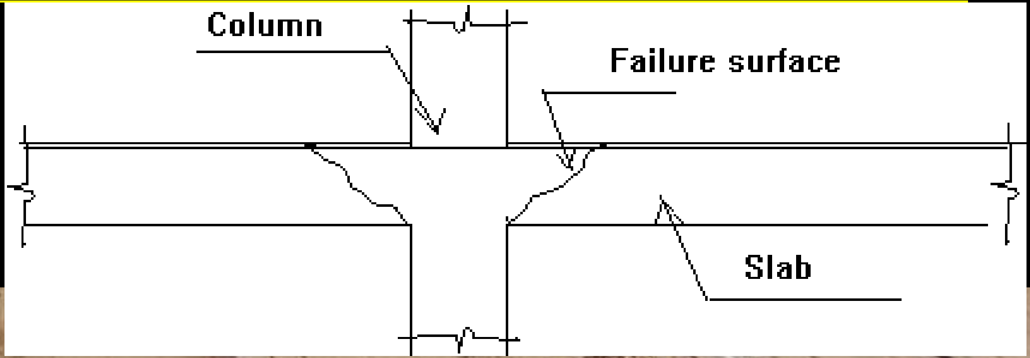
① ② ③ ④ ⑤

Span ratio ℓ_2/ℓ_1	Slab Moments		End Span 1 Exterior Negative	 2 Positive	 3 First Interior Negative	Interior Span 4 Positive	 5 Interior Negative
	Total Moment		$0.16\ M_o$	$0.57\ M_o$	$0.70\ M_o$	$0.35\ M_o$	$0.65\ M_o$
0.5	Column Strip	Beam	$0.12\ M_o$	$0.43\ M_o$	$0.54\ M_o$	$0.27\ M_o$	$0.50\ M_o$
		Slab	$0.02\ M_o$	$0.08\ M_o$	$0.09\ M_o$	$0.05\ M_o$	$0.09\ M_o$
	Middle Strip		$0.02\ M_o$	$0.06\ M_o$	$0.07\ M_o$	$0.03\ M_o$	$0.06\ M_o$
1.0	Column Strip	Beam	$0.10\ M_o$	$0.37\ M_o$	$0.45\ M_o$	$0.22\ M_o$	$0.42\ M_o$
		Slab	$0.02\ M_o$	$0.06\ M_o$	$0.08\ M_o$	$0.04\ M_o$	$0.07\ M_o$
	Middle Strip		$0.04\ M_o$	$0.14\ M_o$	$0.17\ M_o$	$0.09\ M_o$	$0.16\ M_o$
2.0	Column Strip	Beam	$0.06\ M_o$	$0.22\ M_o$	$0.27\ M_o$	$0.14\ M_o$	$0.25\ M_o$
		Slab	$0.01\ M_o$	$0.04\ M_o$	$0.05\ M_o$	$0.02\ M_o$	$0.04\ M_o$
	Middle Strip		$0.09\ M_o$	$0.31\ M_o$	$0.38\ M_o$	$0.19\ M_o$	$0.36\ M_o$

Notes:
(1) Beams and slab satisfy stiffness criteria: $\alpha_1\ell_2/\ell_1 \geq 1.0$ and $\beta_t \geq 2.5$.
(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.

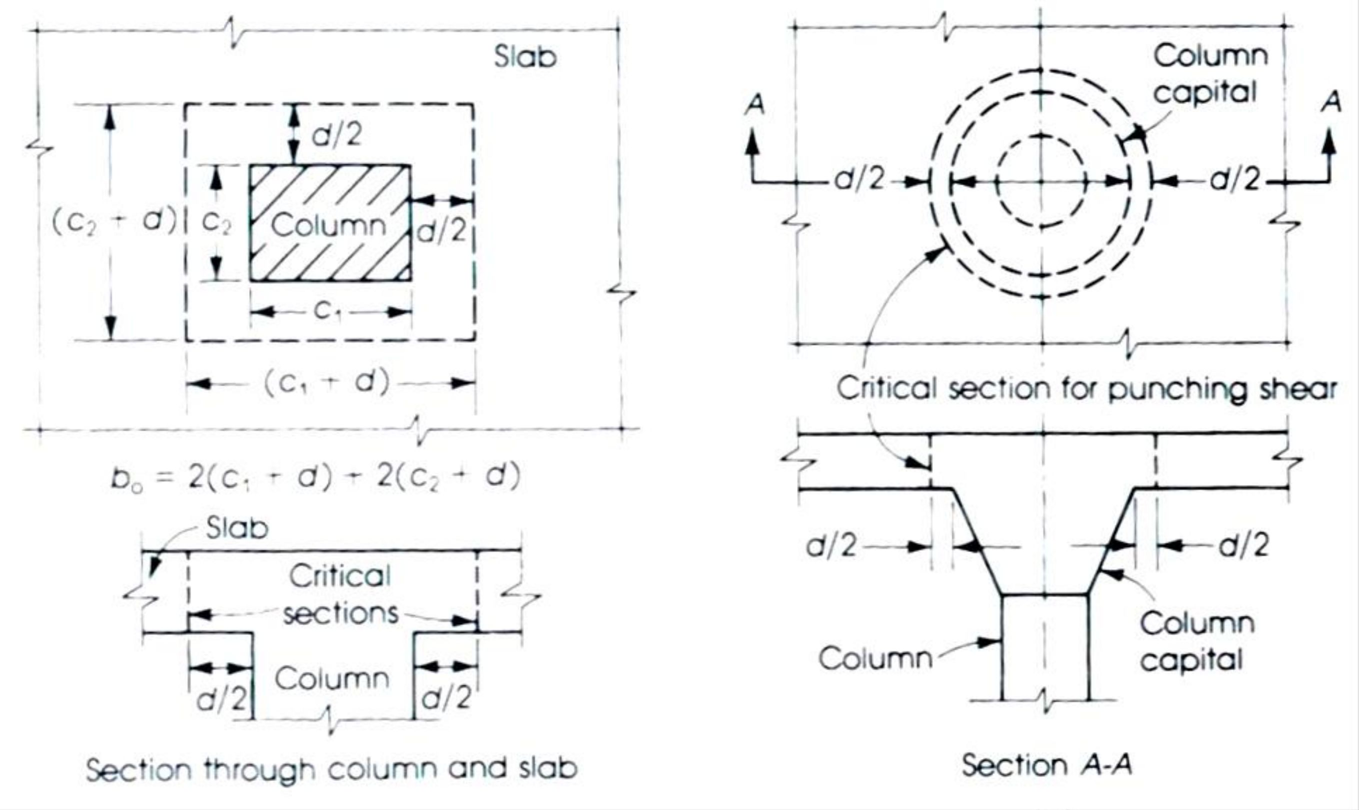
Shear in Concrete

- *at columns*
- *want to avoid stirrups*
- *can use shear studs or heads*



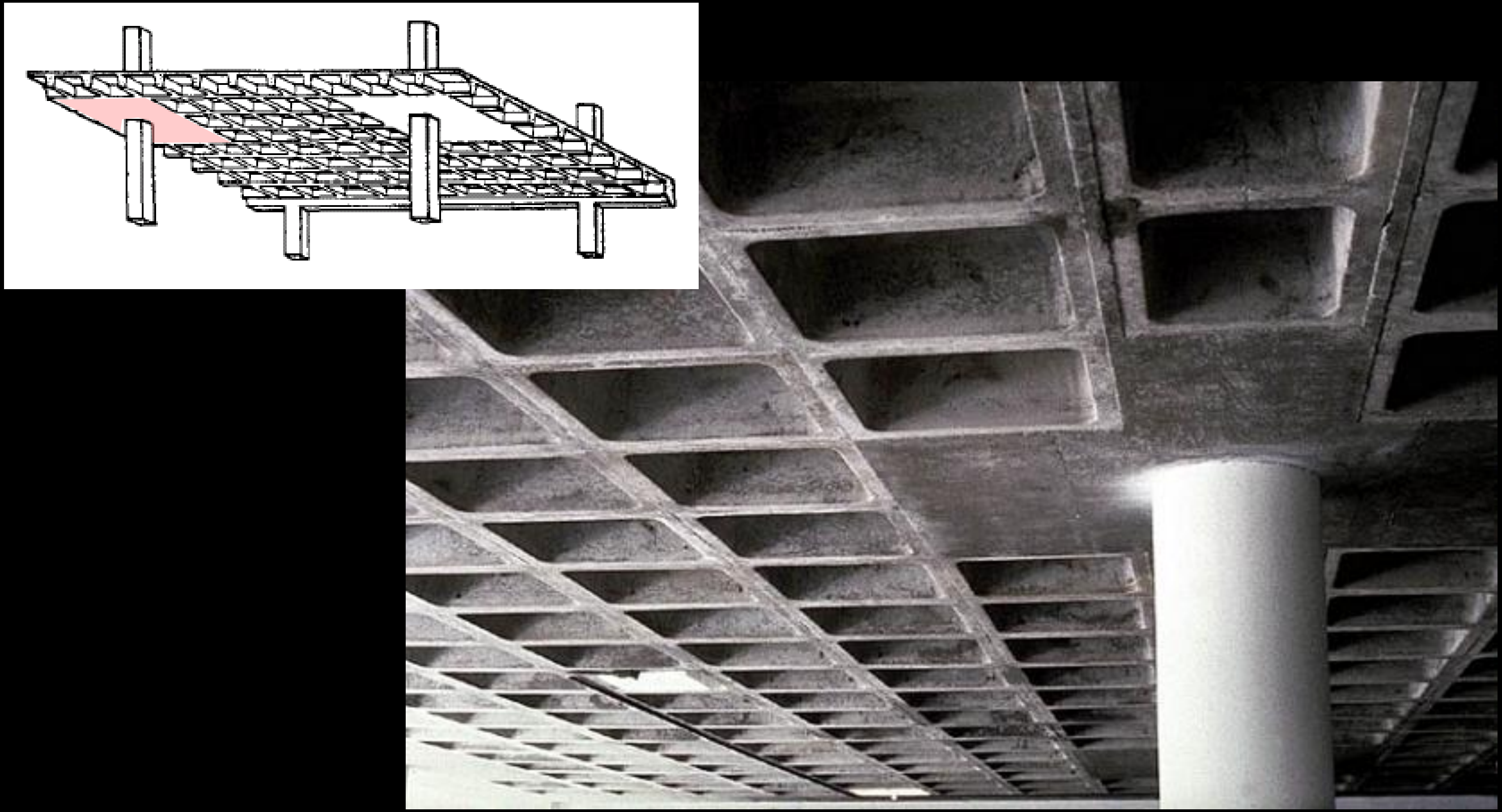
Shear in Concrete

- *critical section at d/2 from*
  - *column face, column capital or drop panel*



Shear in Concrete

- *at columns with waffle slabs*



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Openings in Slabs

- careful placement of holes
- shear strength reduced
- bending & deflection can increase

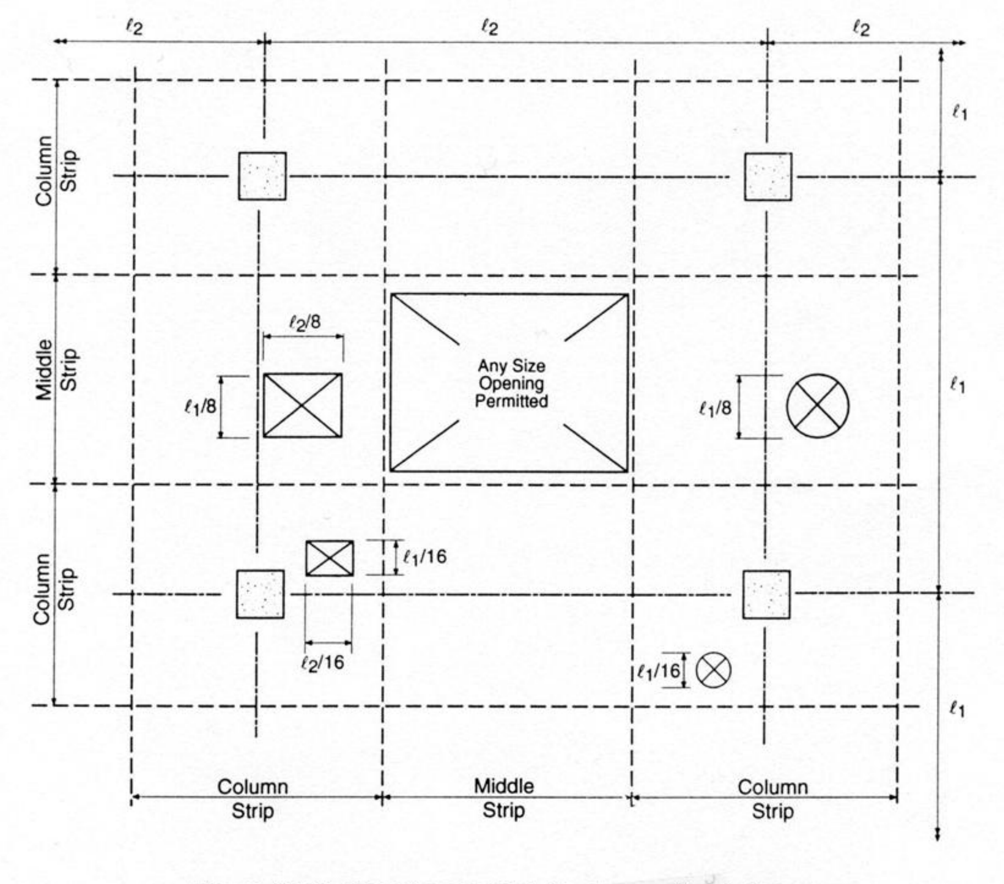


Figure 18-11 Openings in Slab Systems without Beams

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*

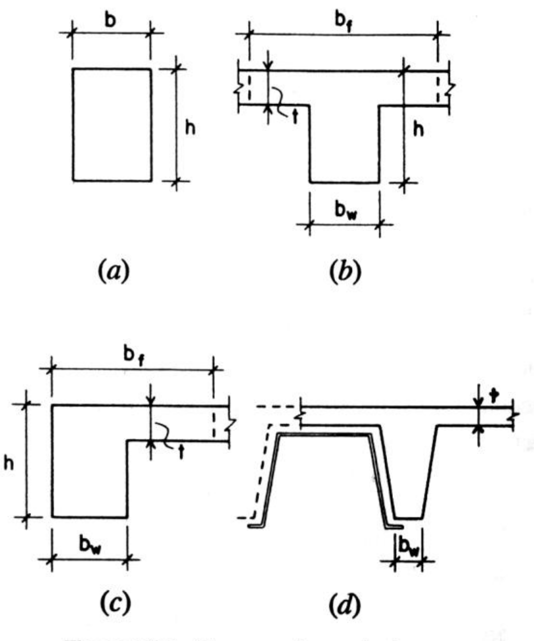
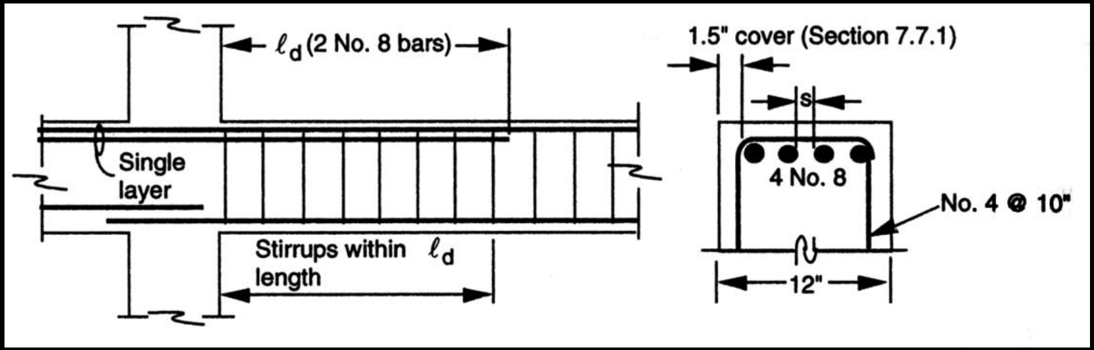


Figure 14.5 Common shapes for beams.

$$S = \frac{bh^2}{6}$$

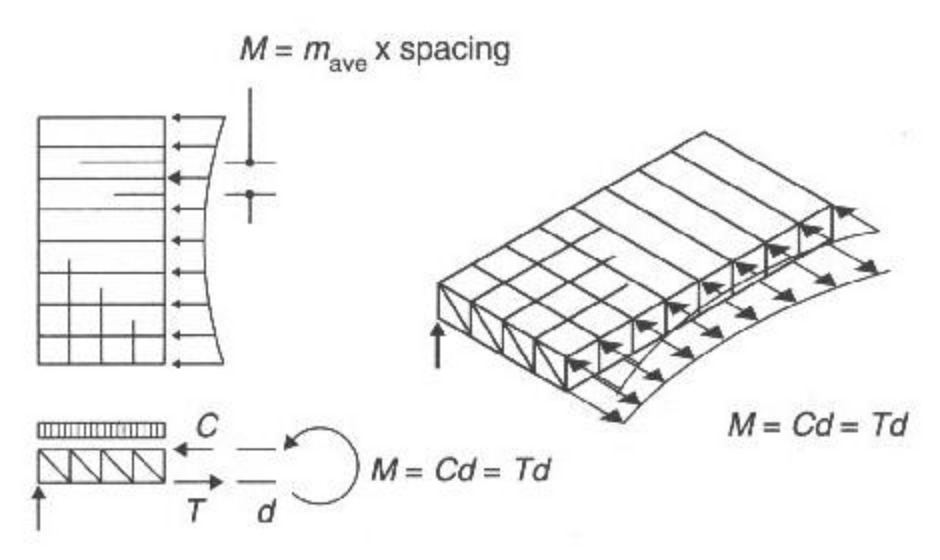
General Beam Design (cont'd)

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



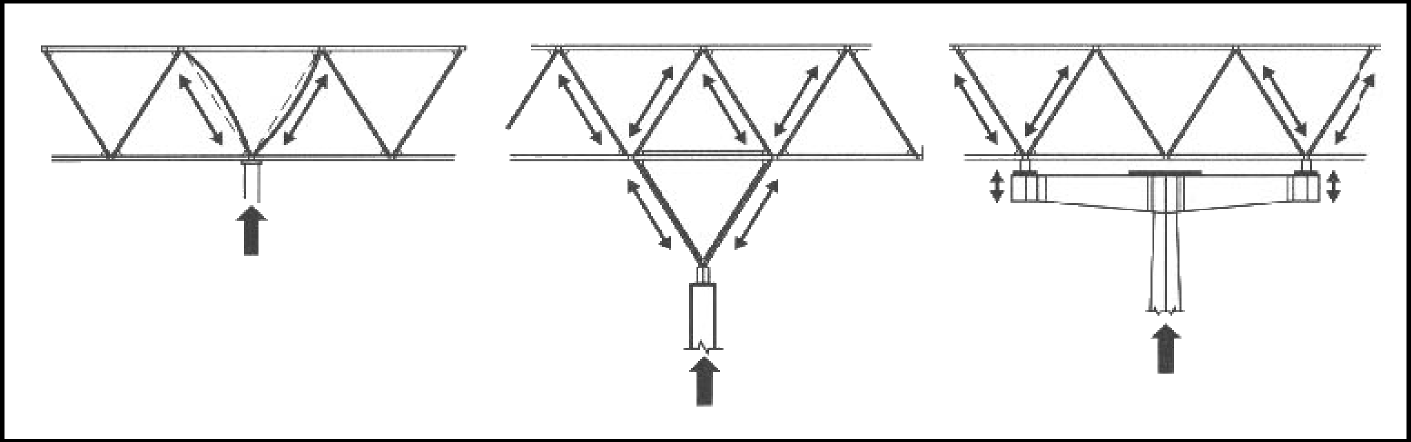
Space "Frame" Behavior

- *handle uniformly distributed loads well*
- *bending moment*
  - *tension & compression "couple" with depth*
  - *member sizes can vary, but difficult*



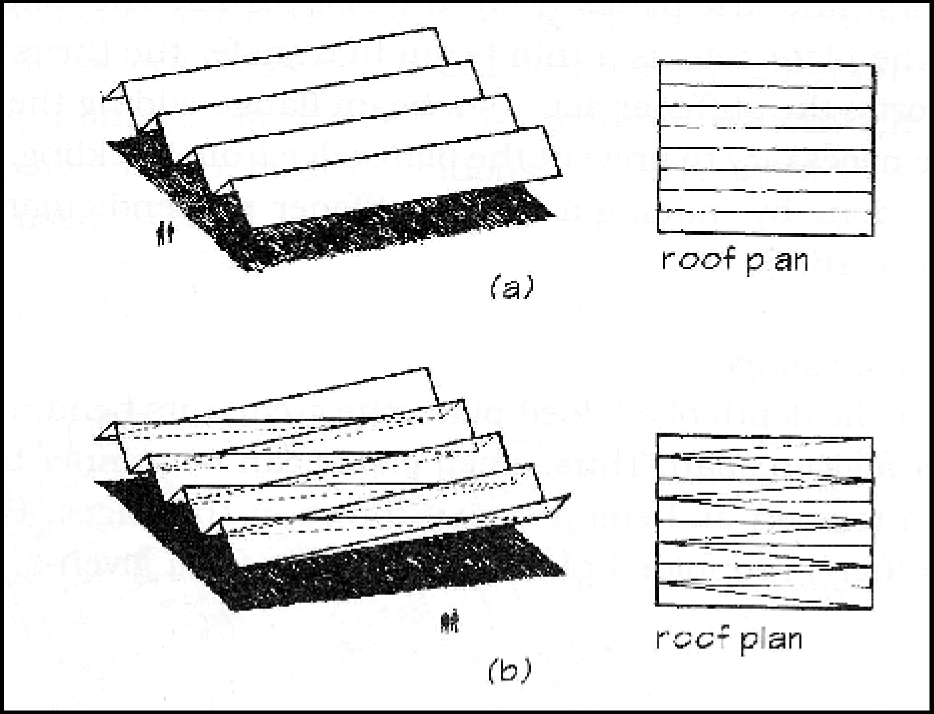
Space “Frame” Behavior

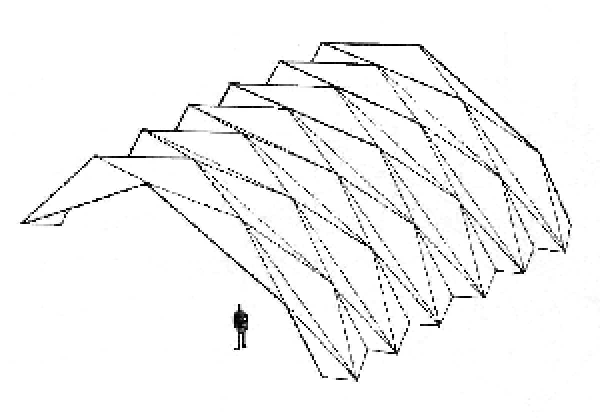
- *shear at columns*
- *support conditions still important*
  - *point supports not optimal*
- *fabrication/construction can dominate design*

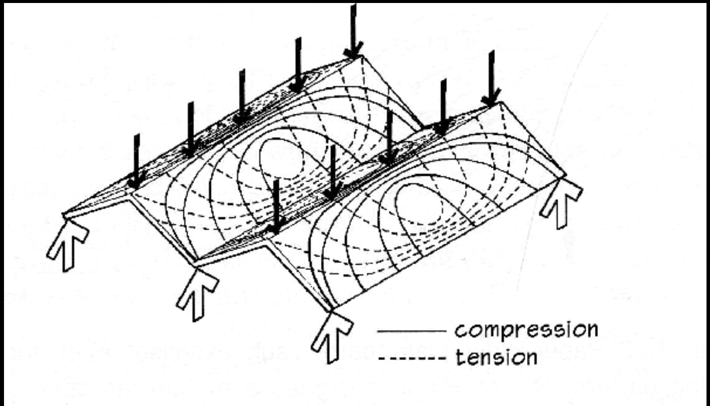


Folded Plates

- *increased bending stiffness with folding*
- *lateral buckling avoided*







Folded Plates

- *common for roofs*
- *edges need stiffening*

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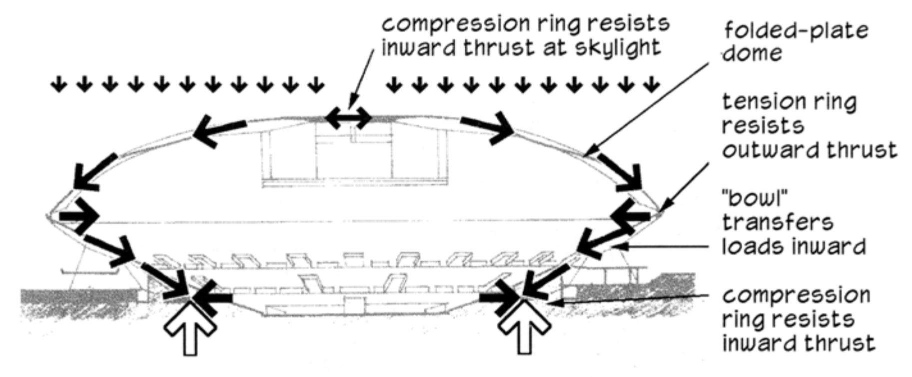
Folded Plates

www.library.illinois.edu



- 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

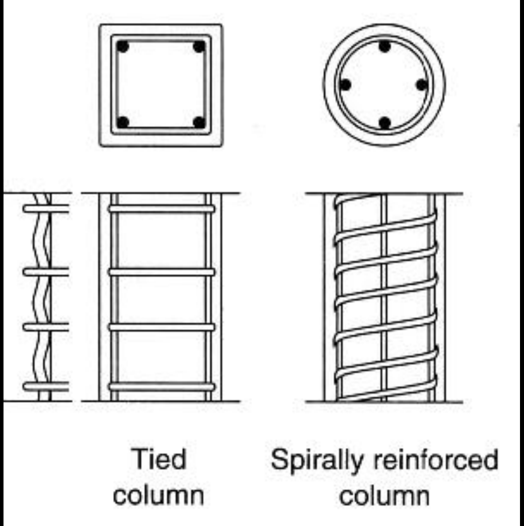
Concrete in Compression

- *crushing*
- *vertical cracking*
  - *tension*
- *diagonal cracking*
  - *shear*
- f'_c

http://www.bam.de

Columns Reinforcement

- *columns require*
  - *ties or spiral reinforcement to “confine” concrete (#3 bars minimum)*

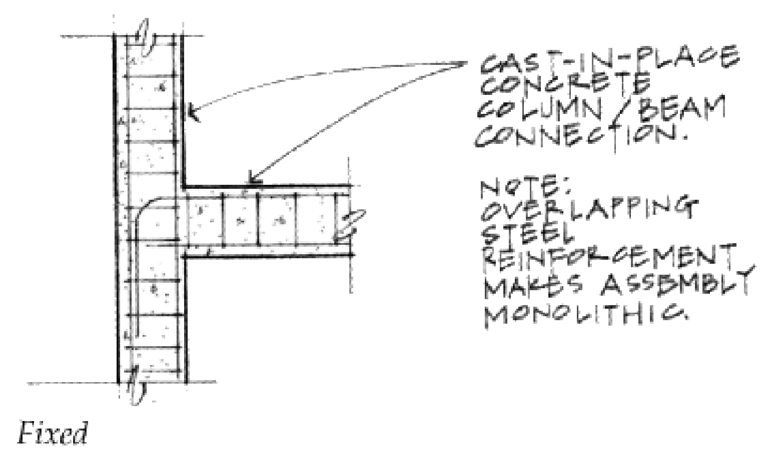


  - *minimum amount of longitudinal steel (#5 bars minimum: 4 with ties, 5 with spiral)*

Slenderness

- *effective length in monolithic with respect to stiffness of joint: Ψ & k*
- *not slender when*

$$\frac{kL_u}{r} < 22$$



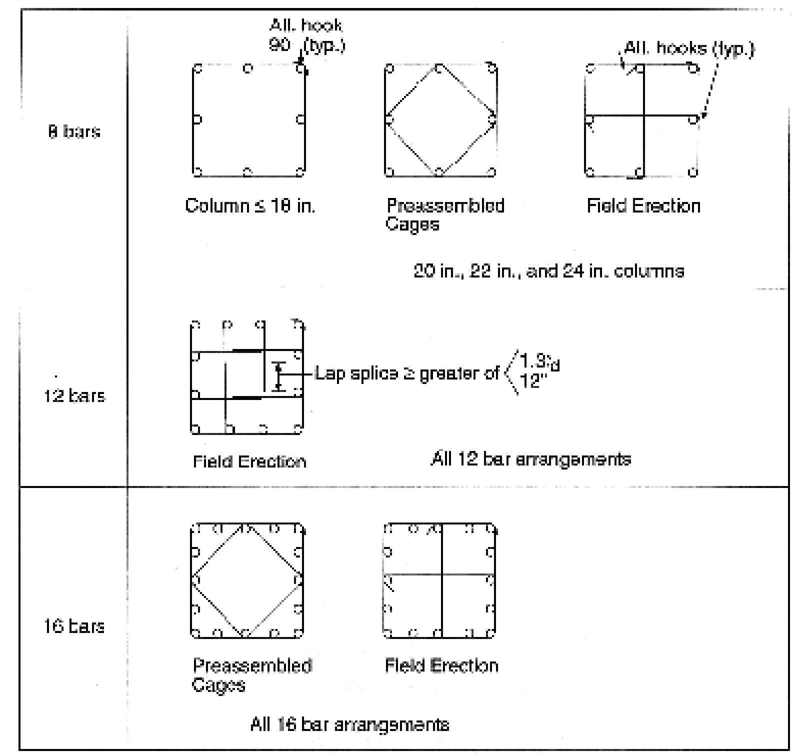
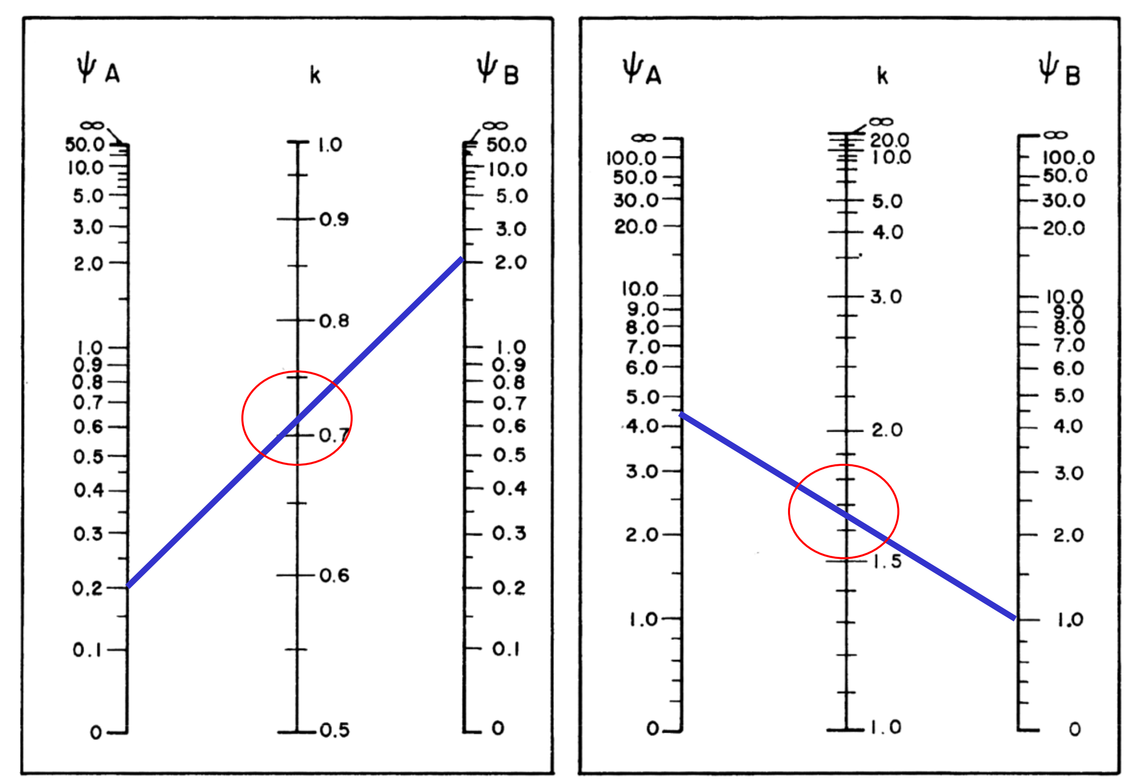


Figure 5-7 Column Tie Details

Effective Length (revisited)

- *relative rotation*

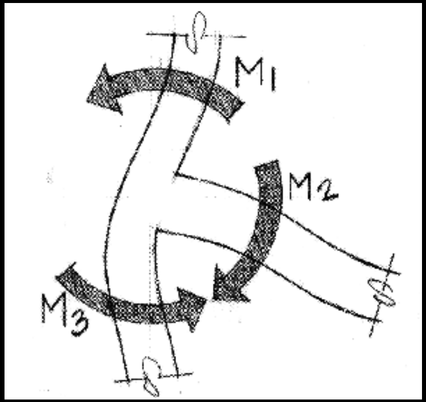


(a)

Nonsway Frames

(b)

Sway Frames



$$\Psi = \frac{\sum EI/l_c}{\sum EI/l_b}$$

Column Behavior

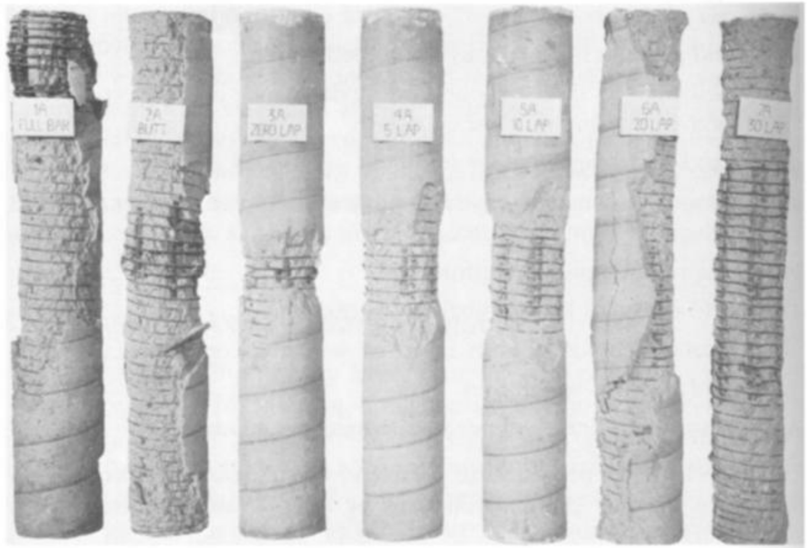


Figure 13.3.2 Spirally reinforced column behavior. (Courtesy of Portland Cement Association.)

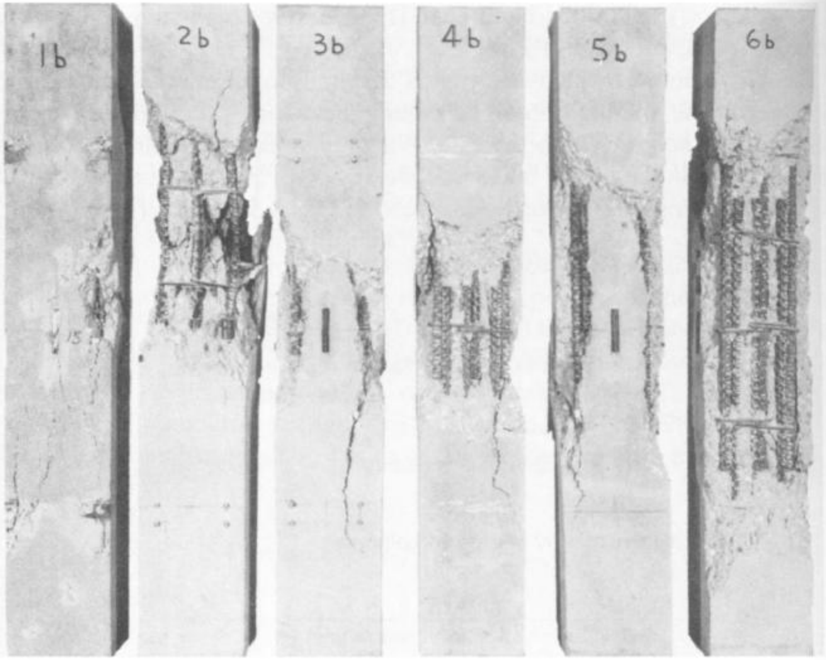


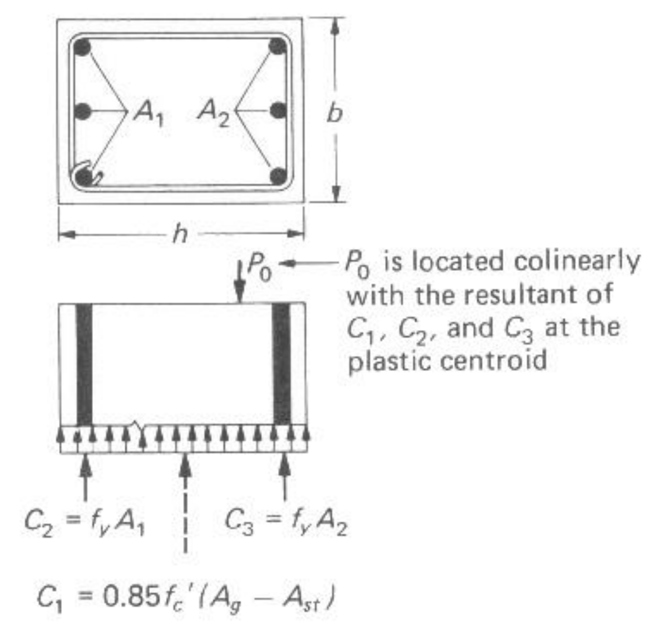
Figure 13.3.3 Tied column behavior. (Courtesy of Portland Cement Association.)

Column Design

- ϕ_c = 0.65 for ties, ϕ_c = 0.75 for spirals
- P_o – no bending

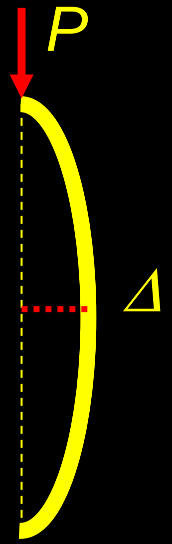
$$P_o = 0.85 f_c'(A_g - A_{st}) + f_y A_{st}$$

- $P_u \leq \phi_c P_n$
  - – 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-Δ)*



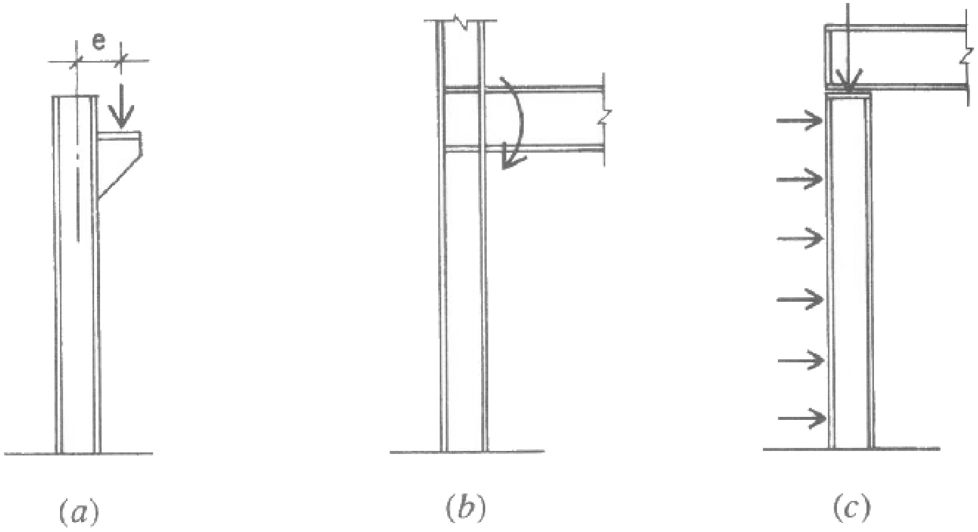


Figure 10.6 Considerations for development of bending in steel columns; (*a*) bending induced by eccentric load, (*b*) bending transferred to column in a rigid frame, and (*c*) combined loading condition, separately producing axial compression and bending.

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*

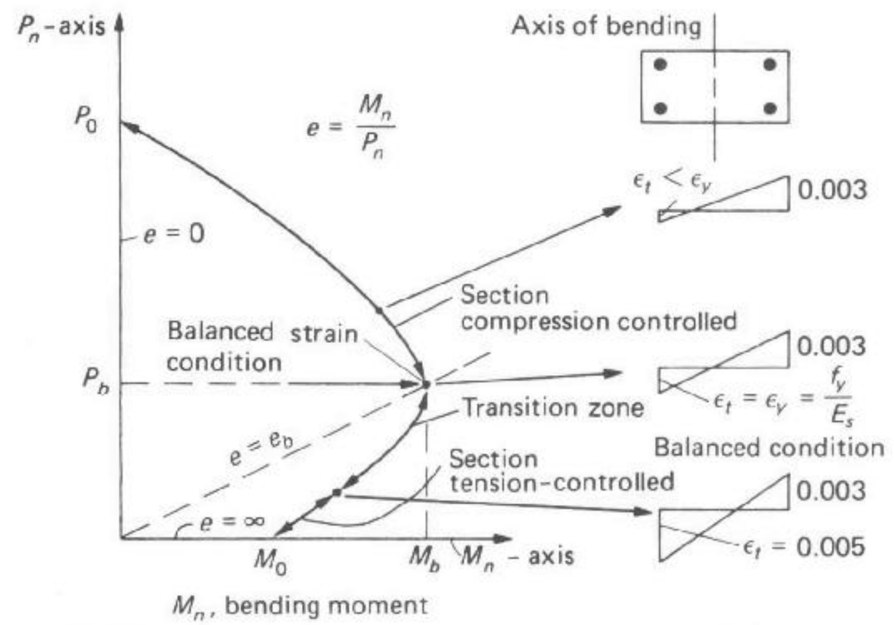


Figure 13.6.1 Typical strength interaction diagram for axial compression and bending moment about one axis. Transition zone is where $\epsilon_y \le \epsilon_t \le 0.005$.

Columns with Bending

- *need to consider combined stresses*
- *linear strain*
- *steel stress at or below f_y*
- *plot interaction diagram*

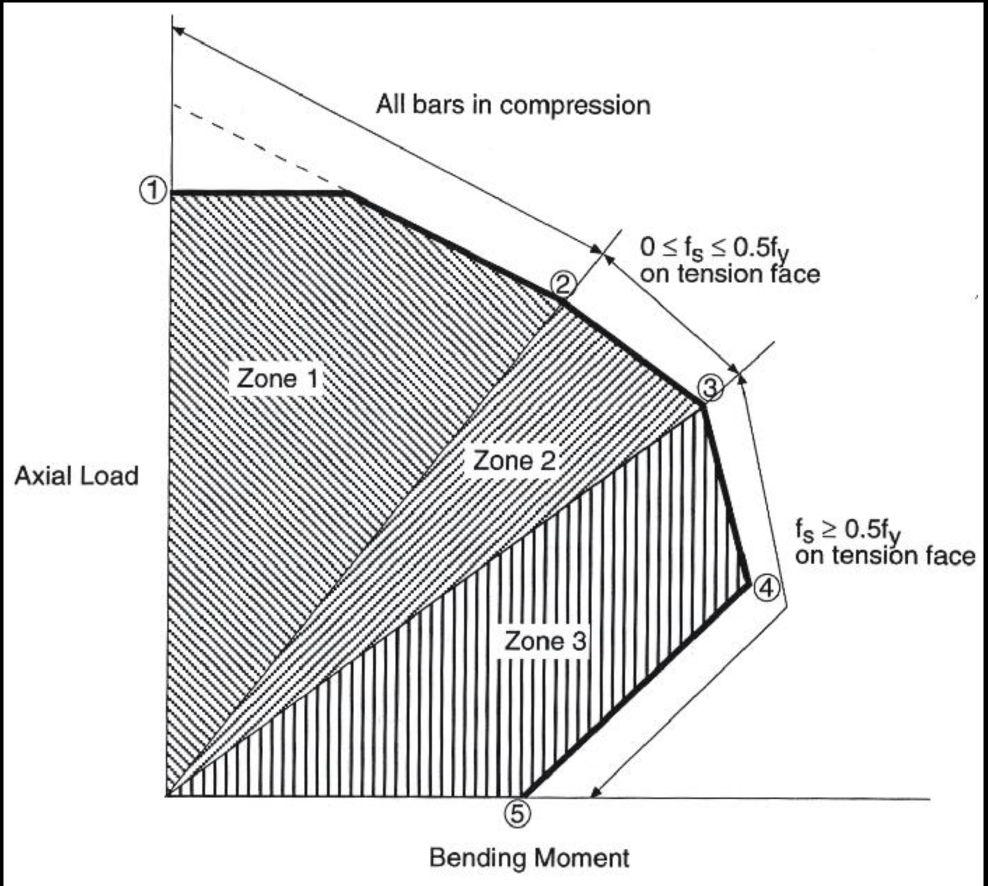


Figure 5-3 Transition Stages on Interaction Diagram

Design Methods

- *calculation intensive*
  - *handbook charts*
  - *computer programs*

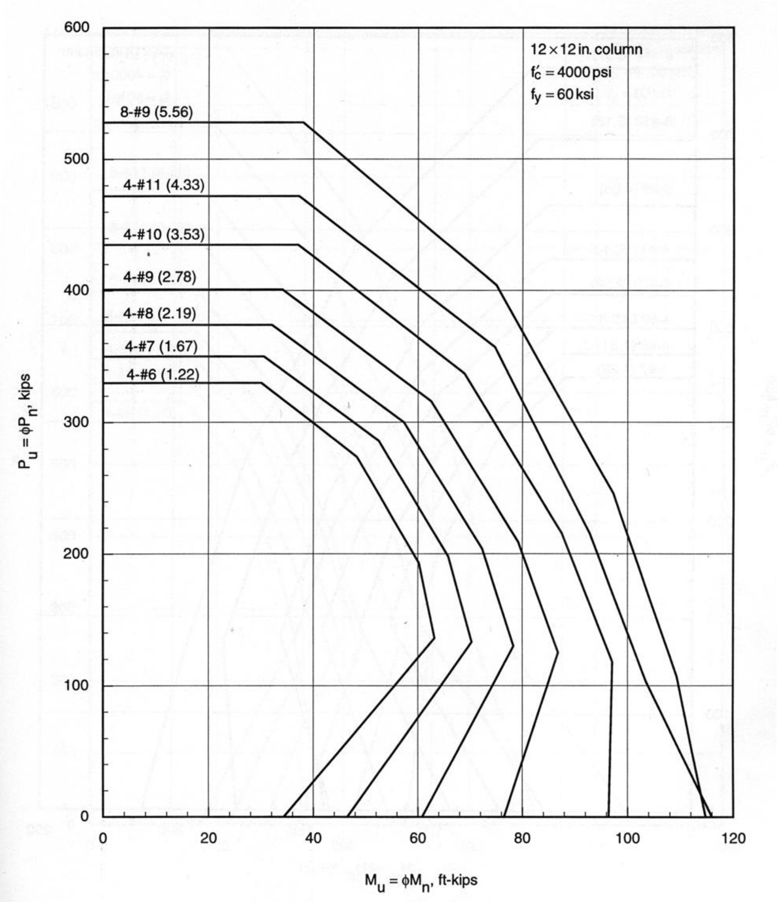
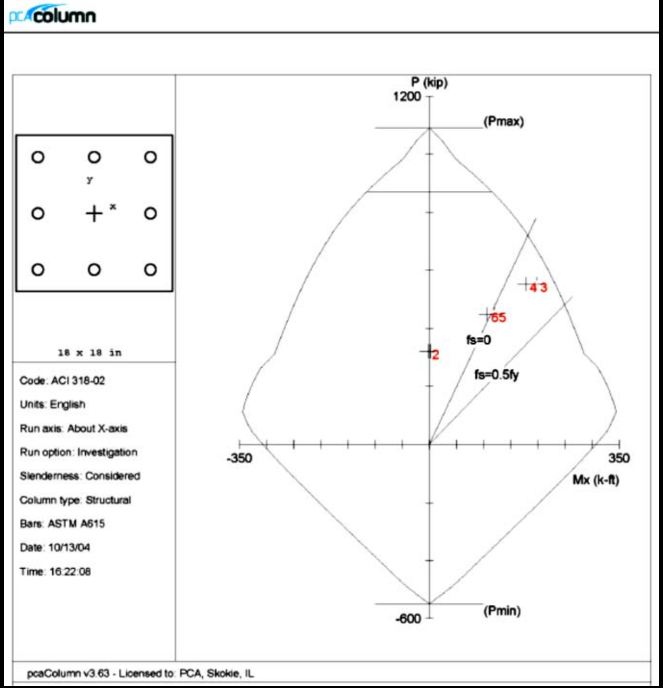


Figure 5-17 12 × 12 in. Column Design Chart



18 x 18 in

Code: ACI 318-02

Units: English

Run axis: About X-axis

Run option: Investigation

Slenderness: Considered

Column type: Structural

Bars: ASTM A615

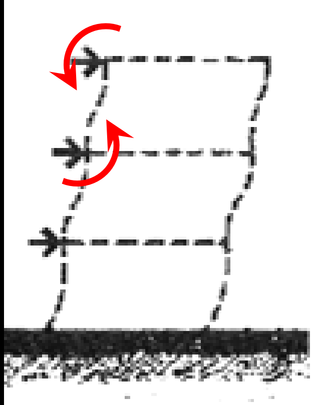
Date: 10/13/04

Time: 16:22:08

pcaColumn v3.63 - Licensed to: PCA, Skokie, IL

Design Considerations

- bending at both ends
  - P- Δ maximum
- biaxial bending
- walls
  - unit wide columns
  - “deep” beam shear
- detailing
  - shorter development lengths
  - dowels to footings



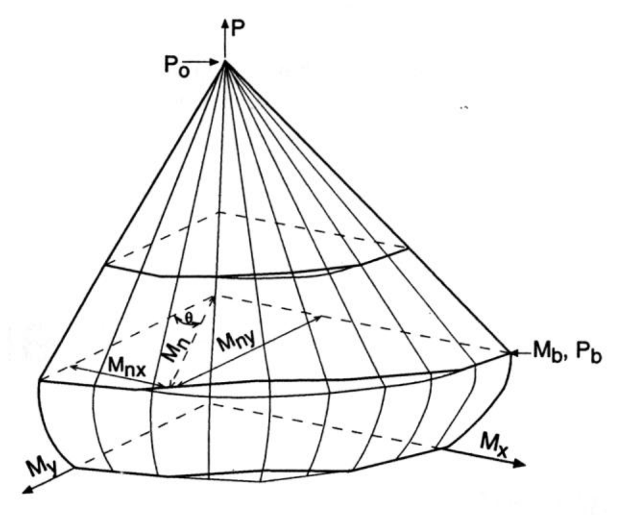
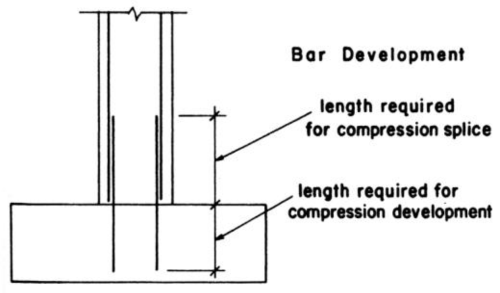


Figure 12-1 Biaxial Interaction Surface



(c) Footing without Pedestal