ARCHITECTURAL STRUCTURES:
FORM, BEHAVIOR, AND DESIGN

ARCH 331

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SUMMER 2014

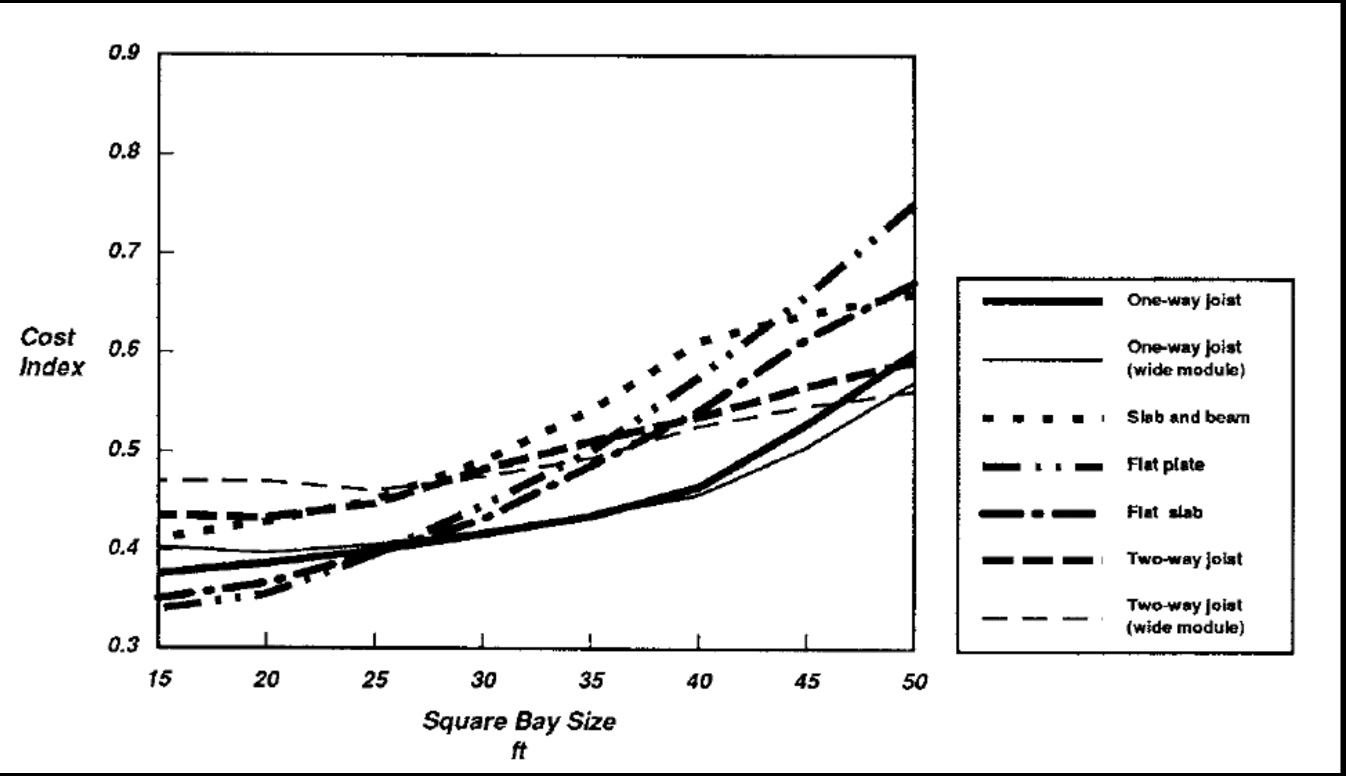
lecture
twenty two

http:// nisee.berkeley.edu/godden

concrete construction: flat spanning systems, columns & frames

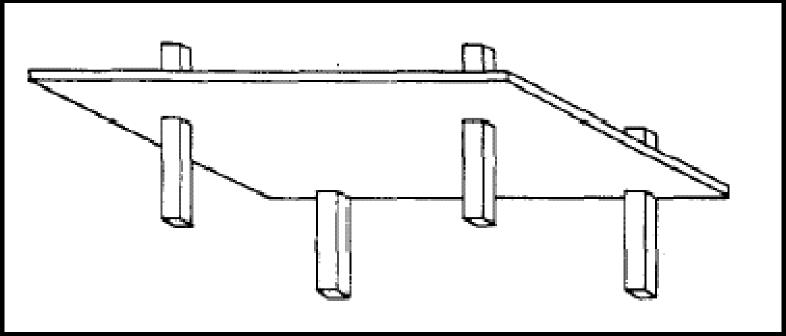
Reinforced Concrete Design

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

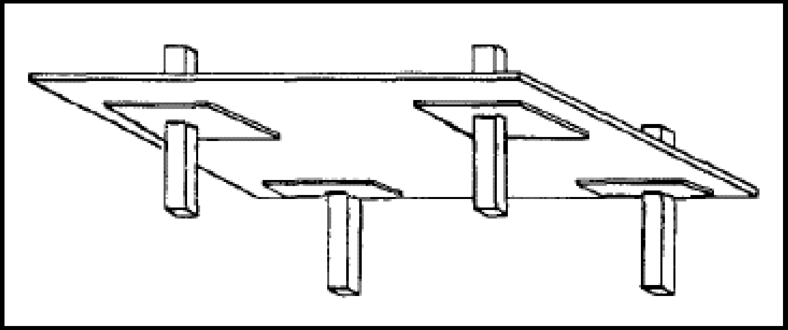


Reinforced Concrete Design

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

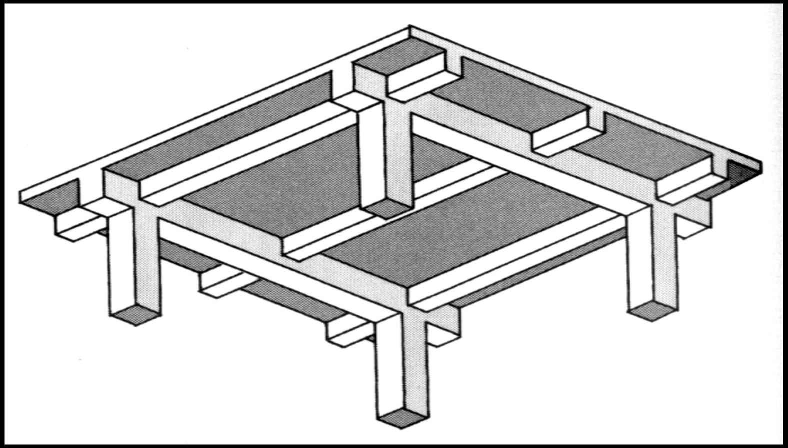


- *flat slab*
  - – *same as plate*
  - – *2 ¼"–8" drop panels*



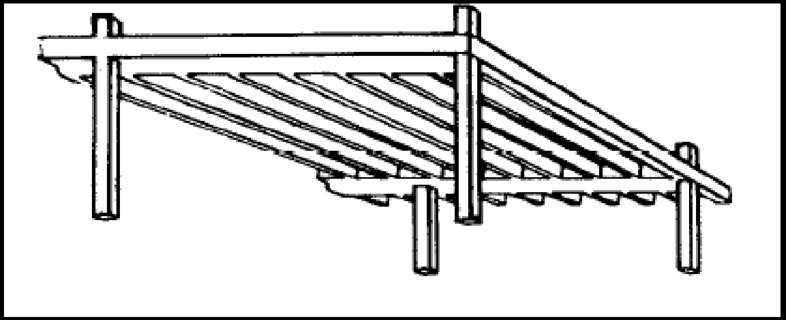
Reinforced Concrete Design

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



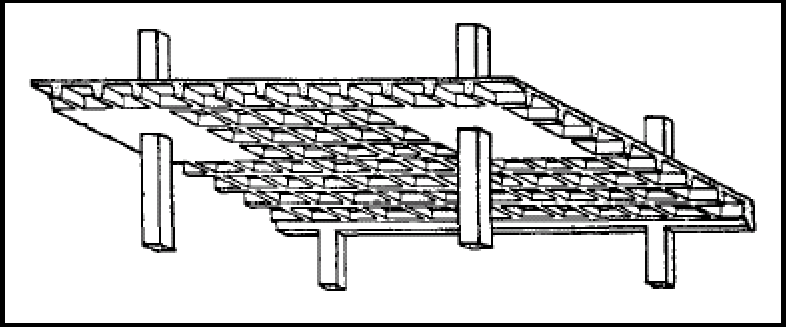
The Architect’s Studio Companion

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

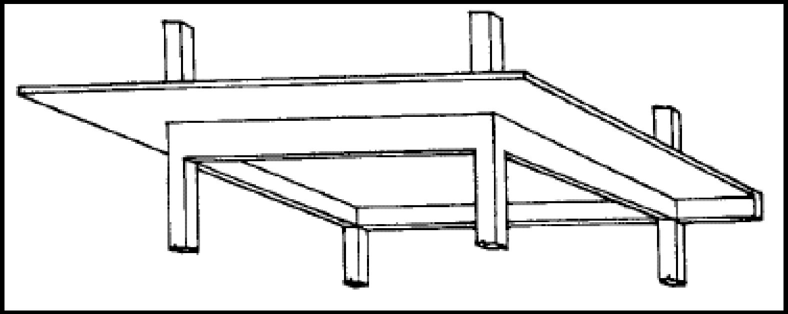


Reinforced Concrete Design

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

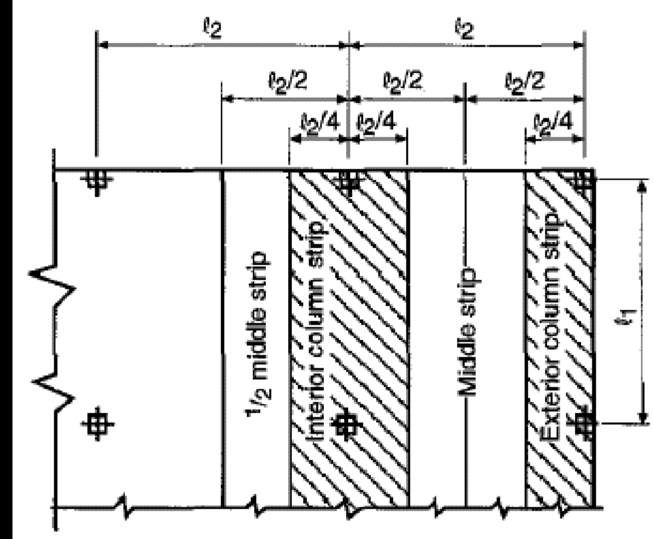


- beam supported slab
  - 5"-10" slabs
  - taller story heights

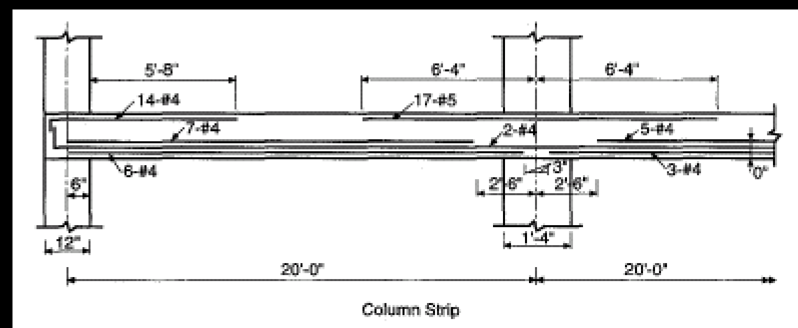


Reinforced Concrete Design

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



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



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)

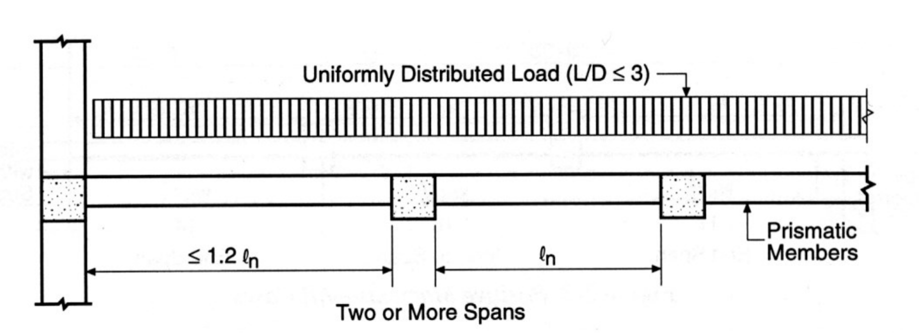


Figure 2-2 Conditions for Analysis by Coefficients (ACI 8.3.3)

Reinforced Concrete Design

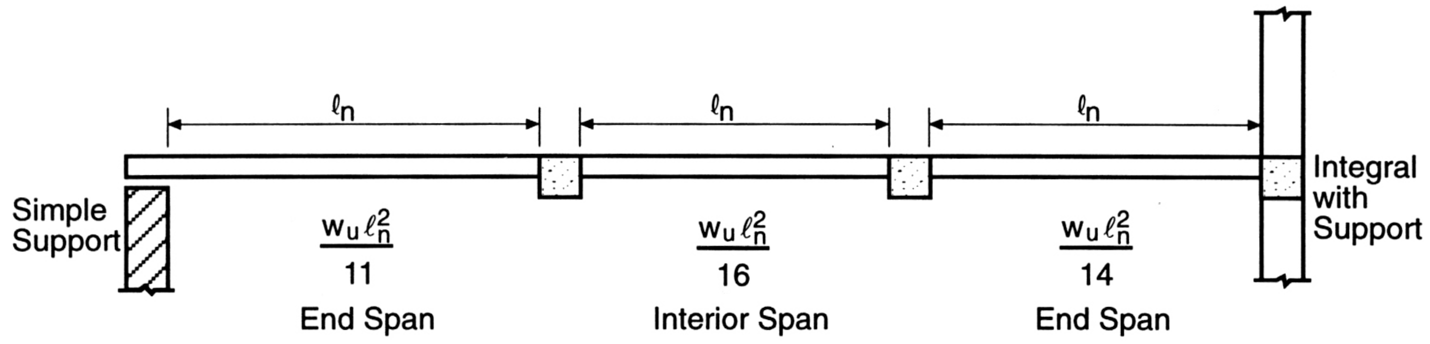


Figure 2-3 Positive Moments—All Cases

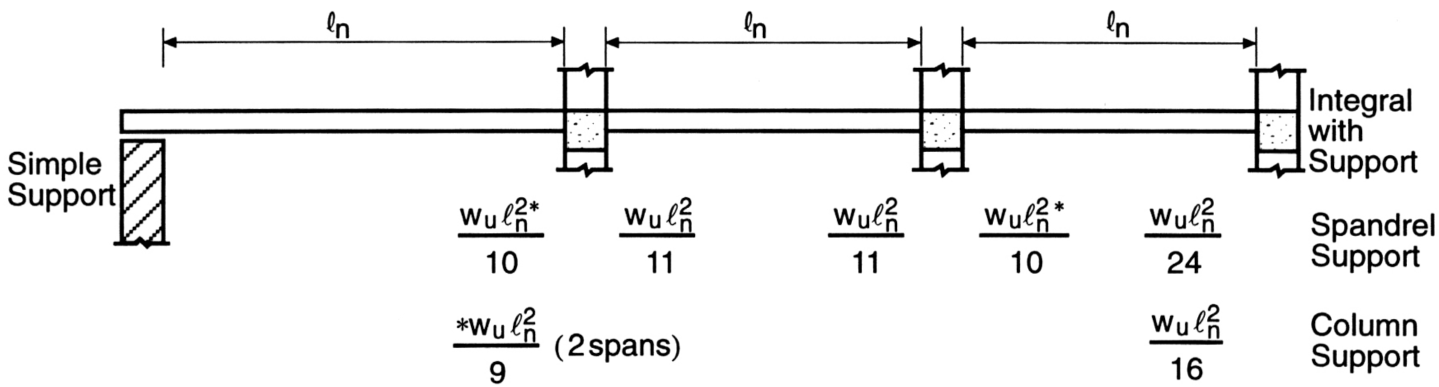
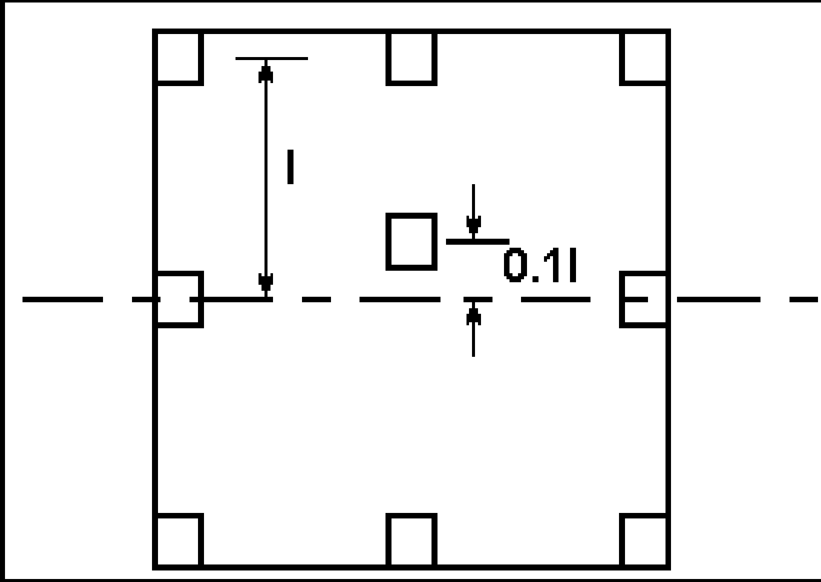


Figure 2-4 Negative Moments—Beams and Slabs

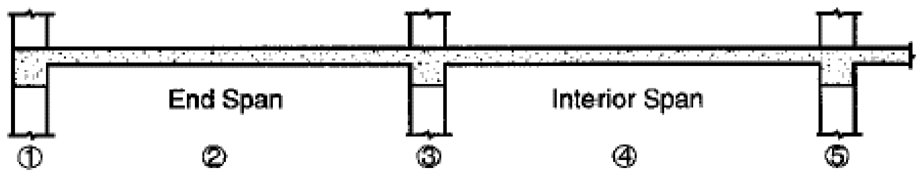
Reinforced Concrete Design

- two-way slabs - Direct Design Method
  - 3 or more spans each way
  - uniform loads with L/D $\leq$ 3
  - 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

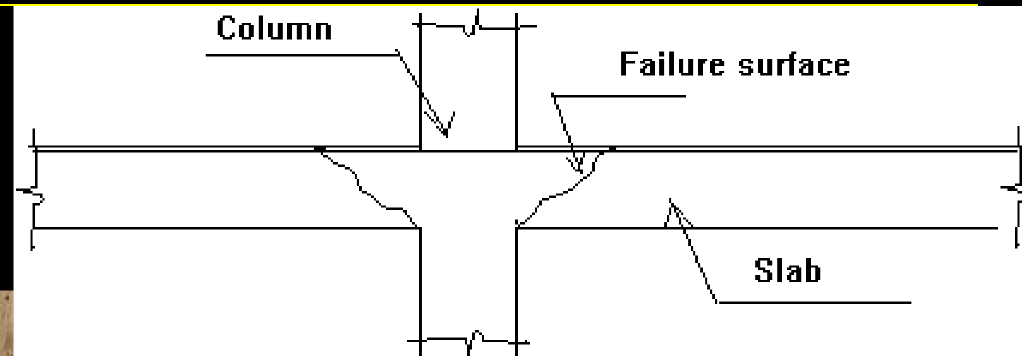


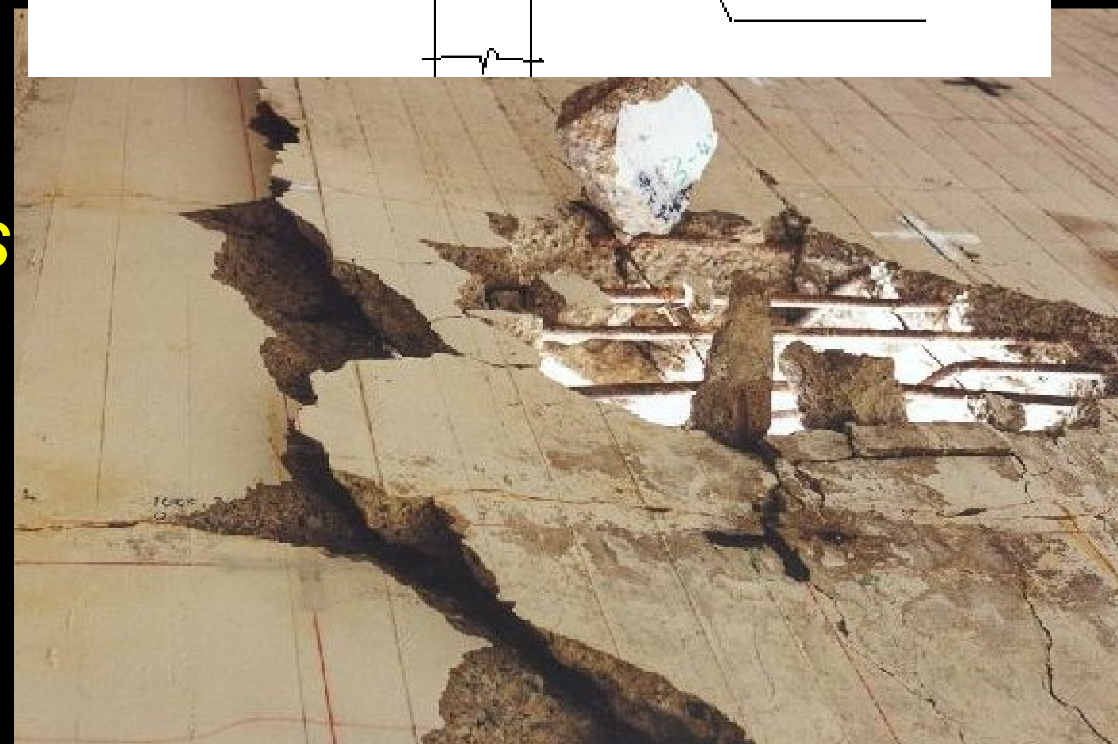
Span ratio ℓ_2/ℓ_1	Slab Moments		End Span 1 Exterior Negative	End Span 2 Positive	End Span 3 First Interior Negative	Interior Span 4 Positive	Interior Span 5 Interior Negative
	Total Moment		$0.16\ M_o$	$0.57\ M_o$	$0.70\ M_o$	$0.35\ M_o$	$0.65\ M_o$
0.5	Column Strip	Beam	$0.12\ M_o$	$0.43\ M_o$	$0.54\ M_o$	$0.27\ M_o$	$0.50\ M_o$
		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

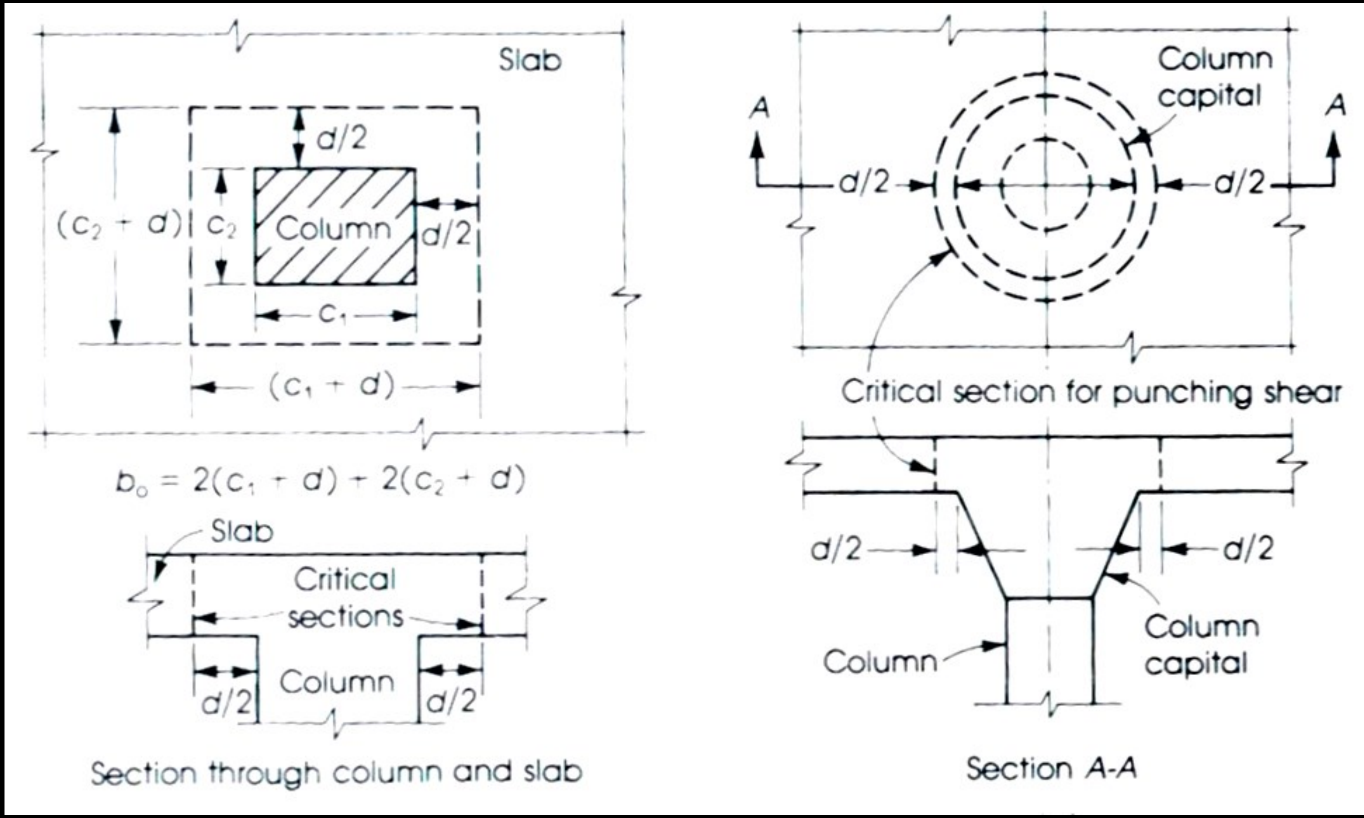
- at columns
- want to avoid stirrups
- can use shear studs or heads





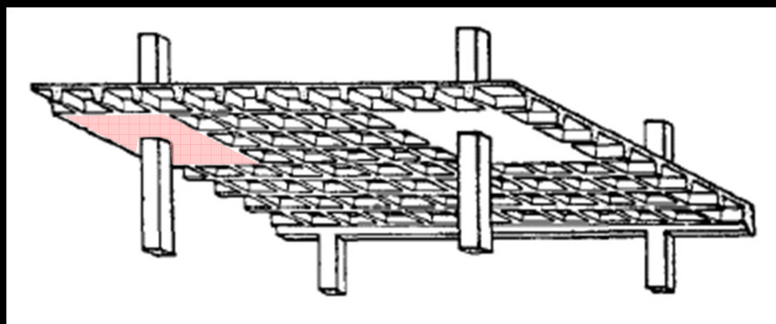
Shear in Concrete

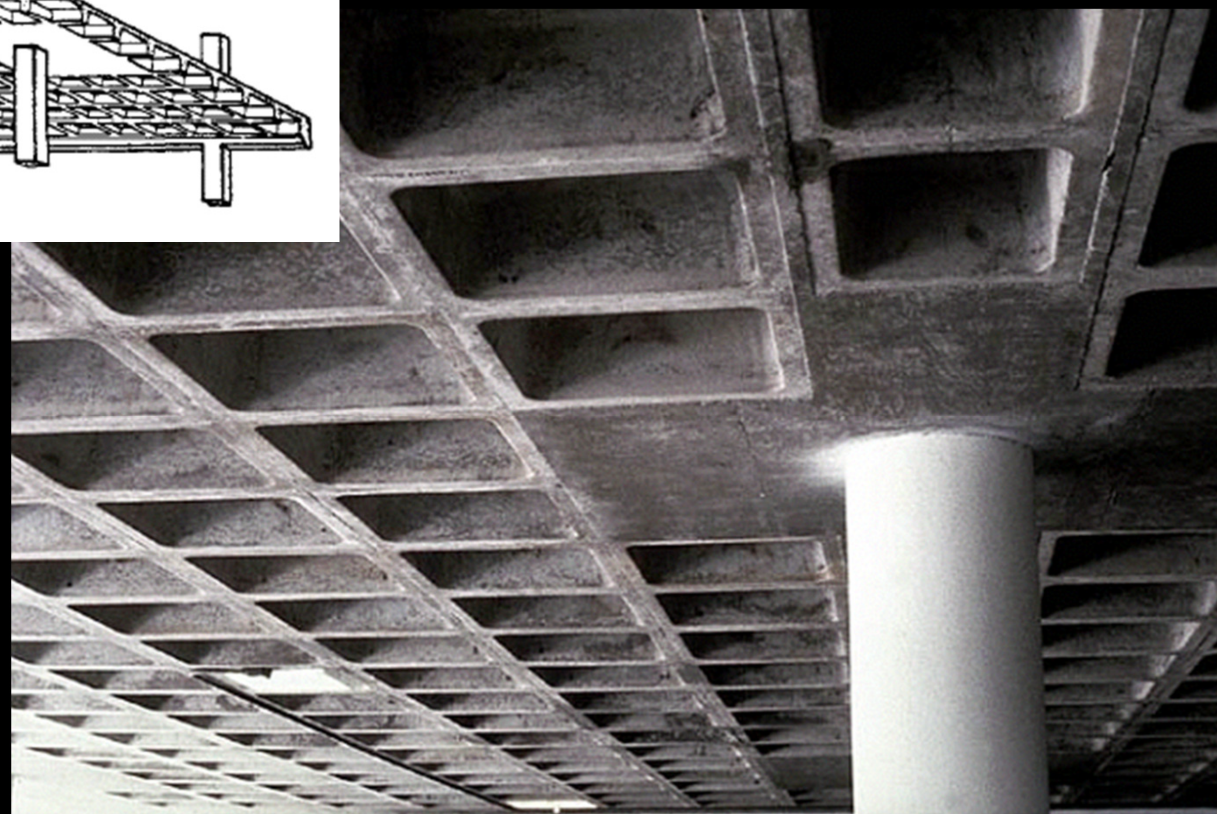
- critical section at d/2 from
  - column face, column capital or drop panel



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

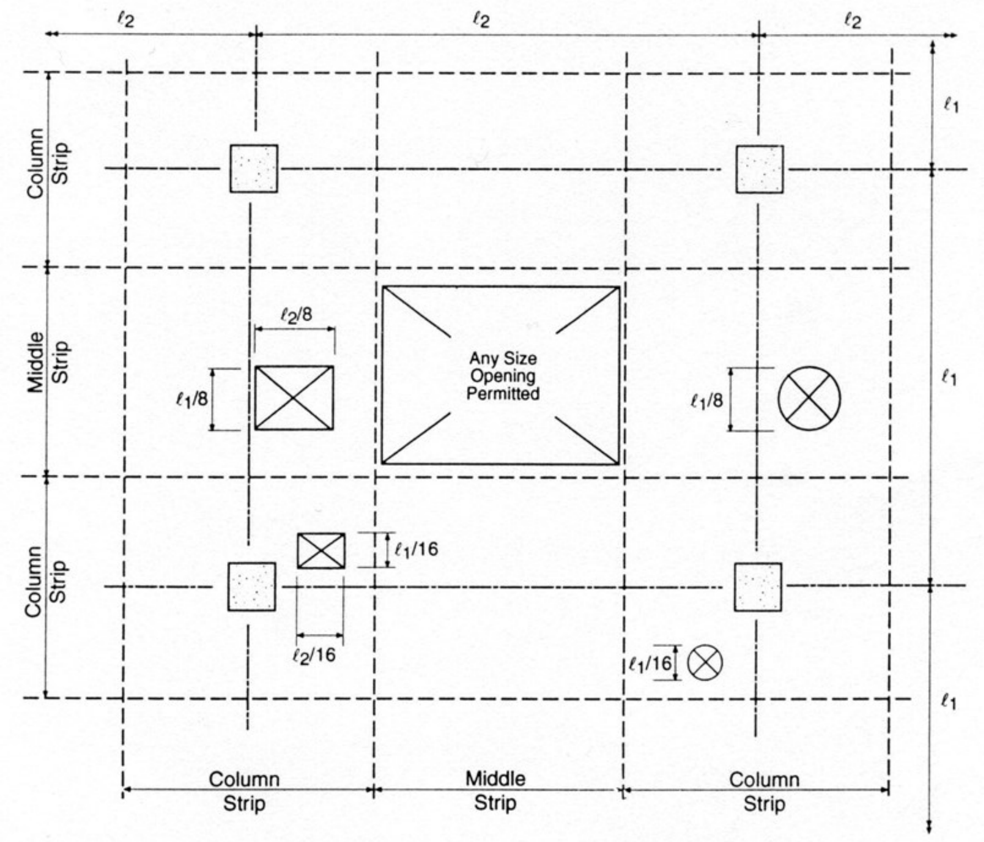


Figure 18-11 Openings in Slab Systems without Beams

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

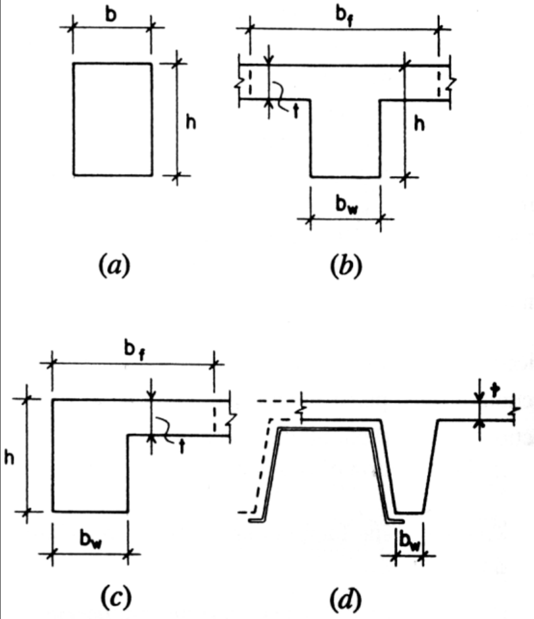
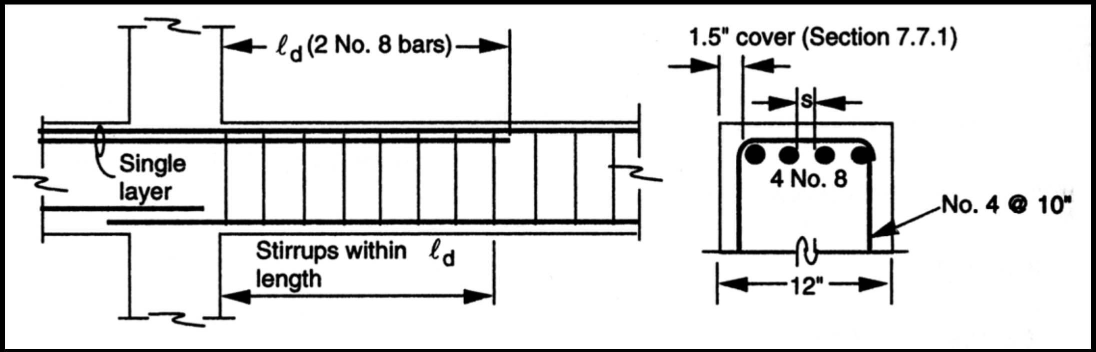


Figure 14.5 Common shapes for beams.

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

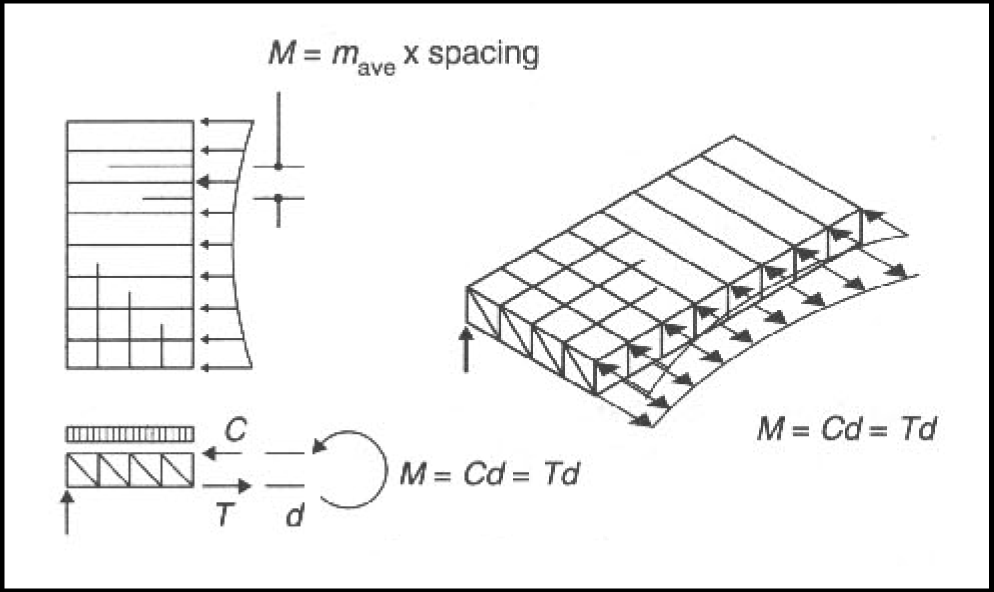
General Beam Design (cont'd)

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



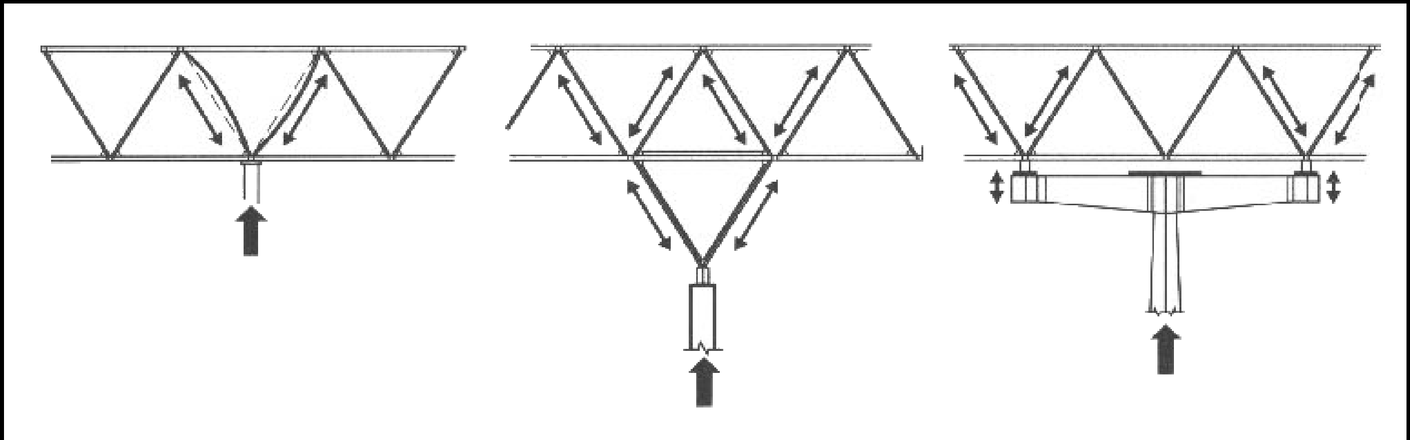
Space "Frame" Behavior

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



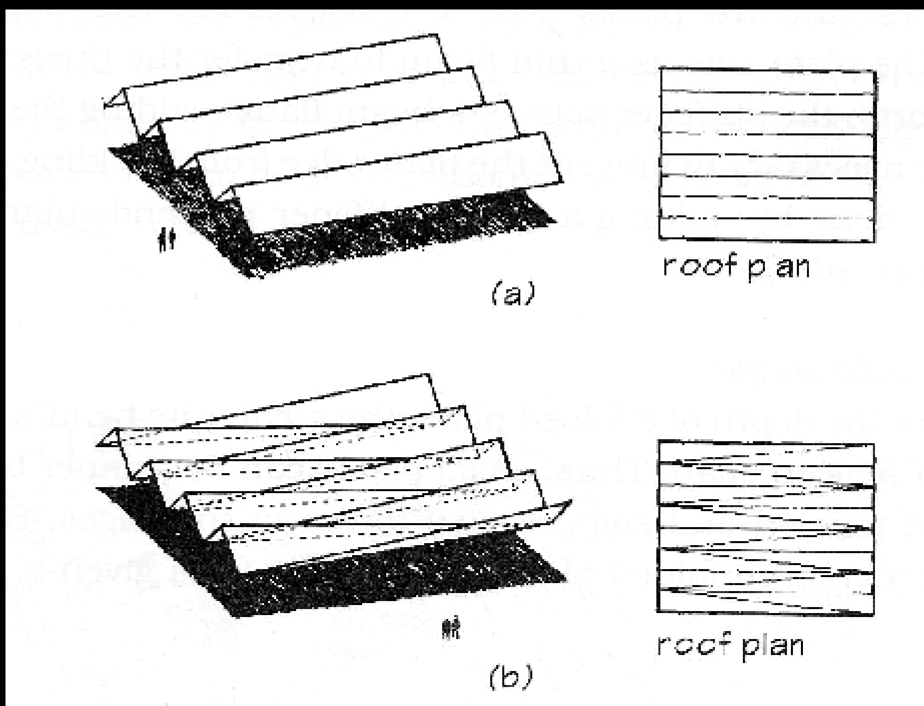
Space “Frame” Behavior

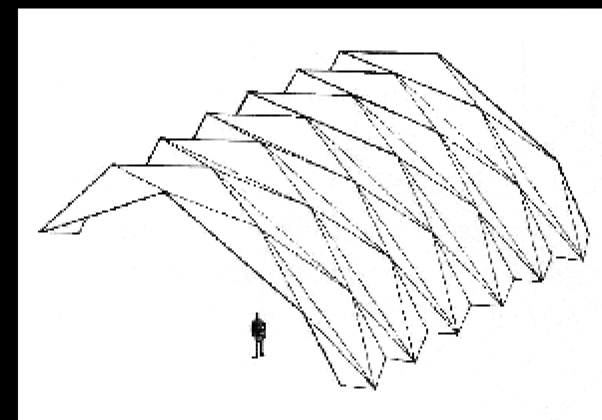
- shear at columns
- support conditions still important
  - point supports not optimal
- fabrication/construction can dominate design

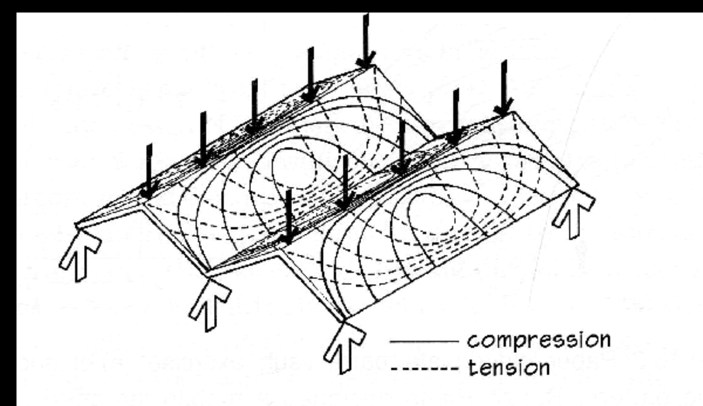


Folded Plates

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







Folded Plates

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

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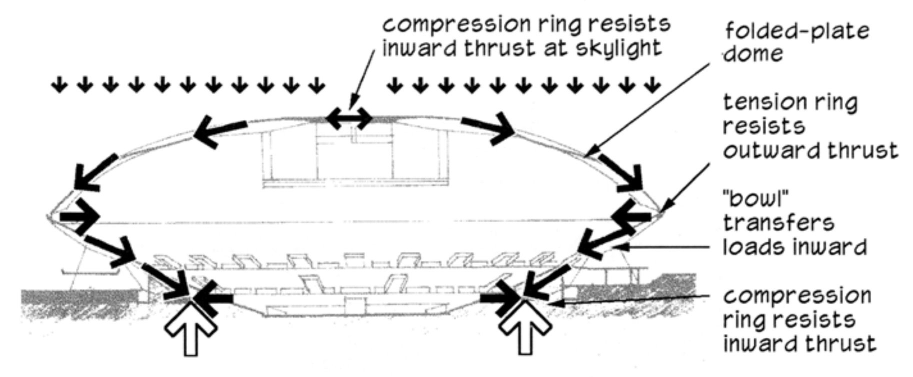
Folded Plates



– *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*

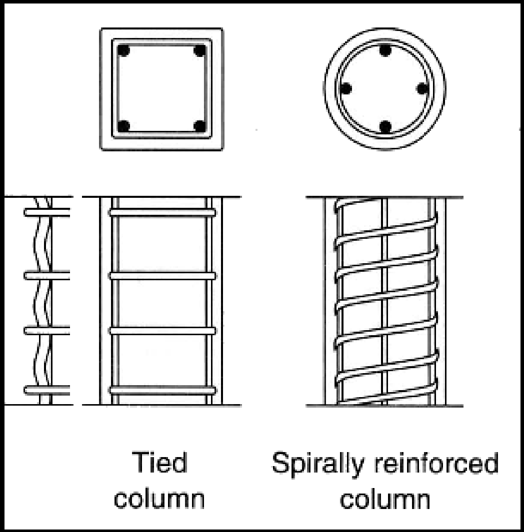
Concrete in Compression

- 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)

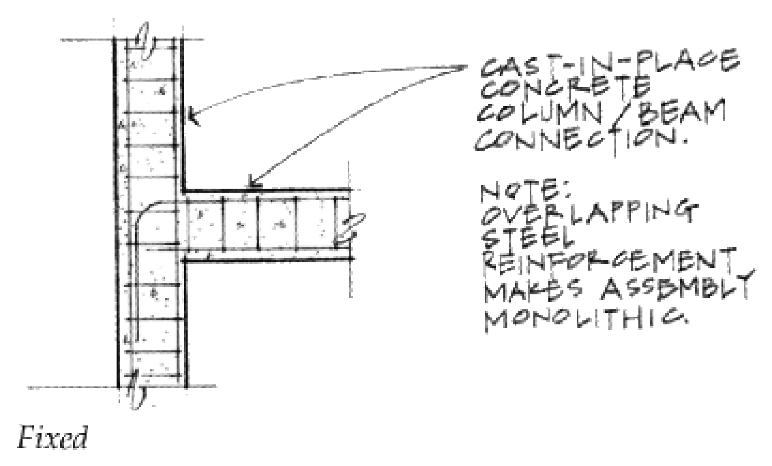


  - minimum amount of longitudinal steel (#5 bars minimum: 4 with ties, 5 with spiral)

Slenderness

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

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



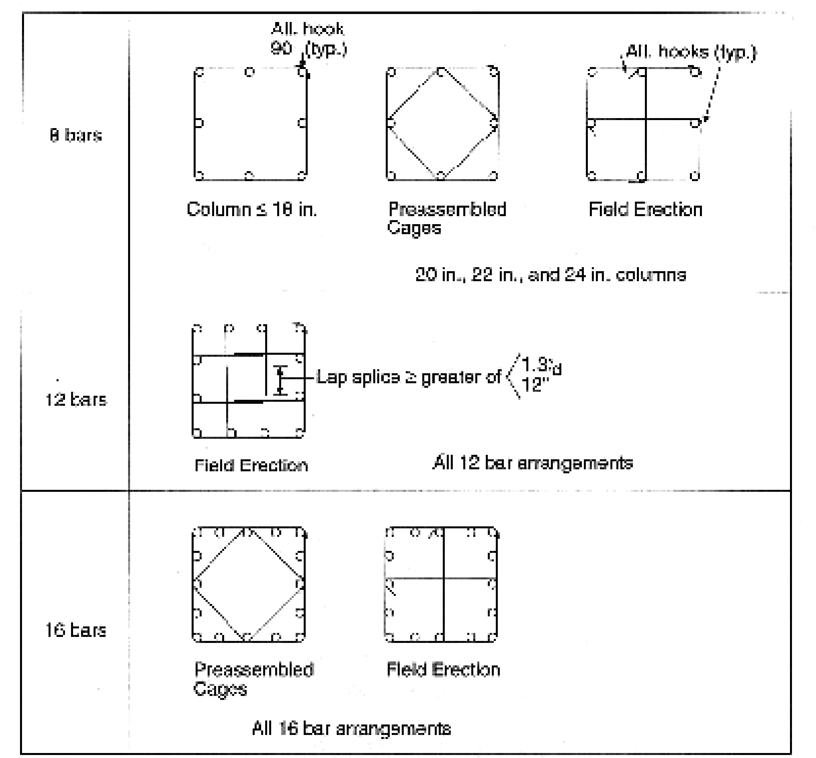
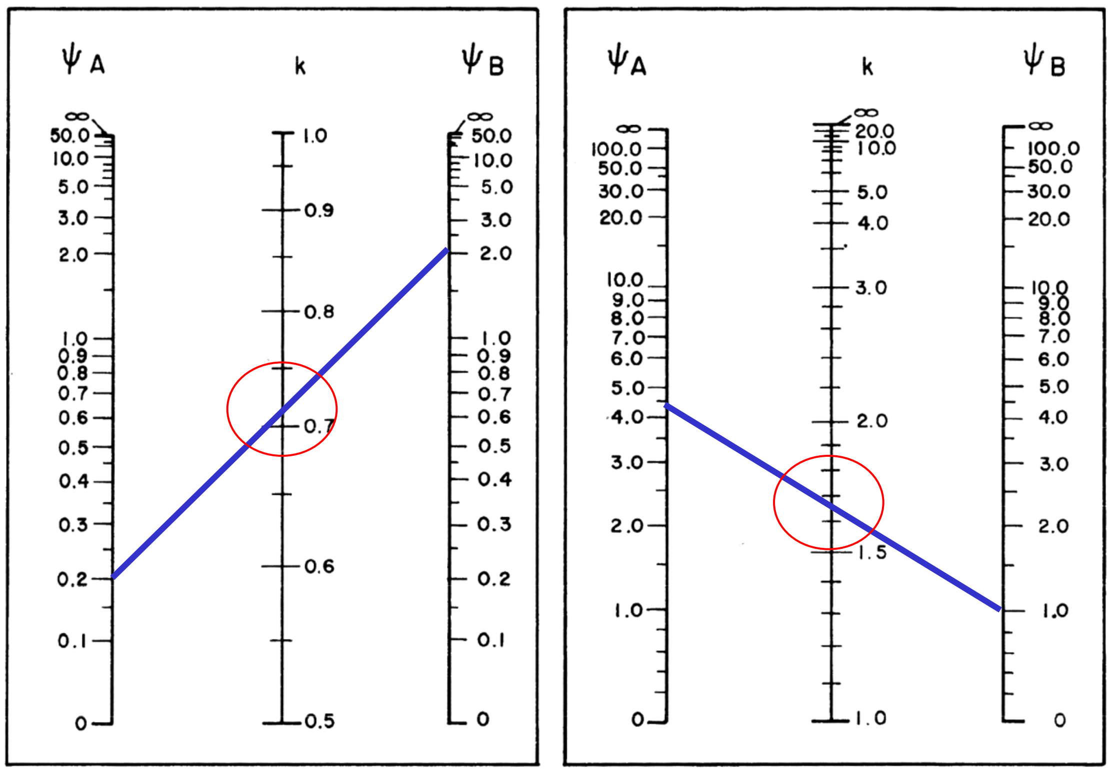


Figure 5-7 Column Tie Details

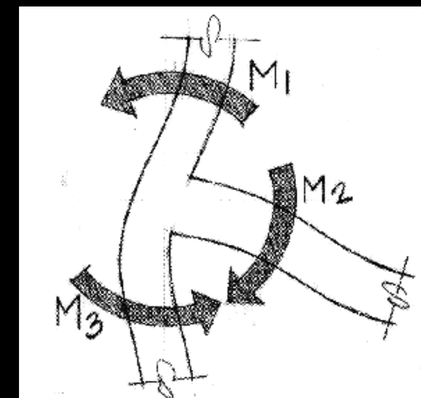
Effective Length (revisited)

- *relative rotation*



(a) Nonsway Frames

(b) Sway Frames



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

Column Behavior

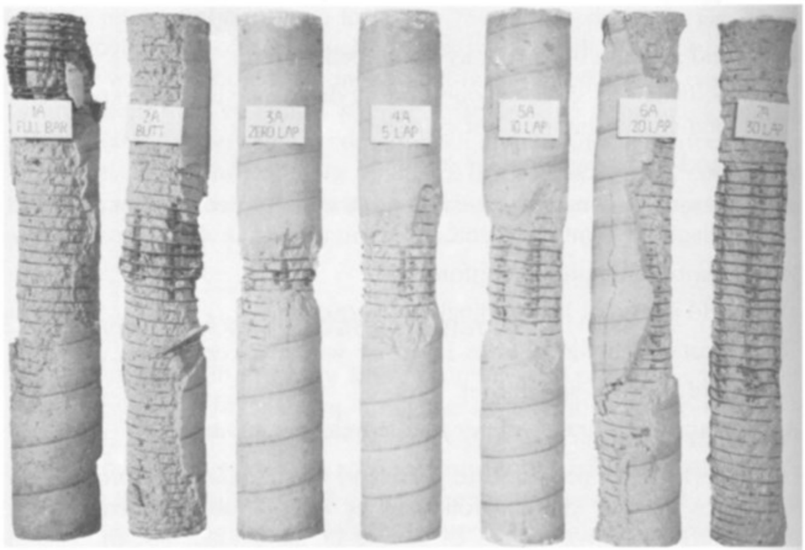


Figure 13.3.2 Spirally reinforced column behavior. (Courtesy of Portland Cement Association.)

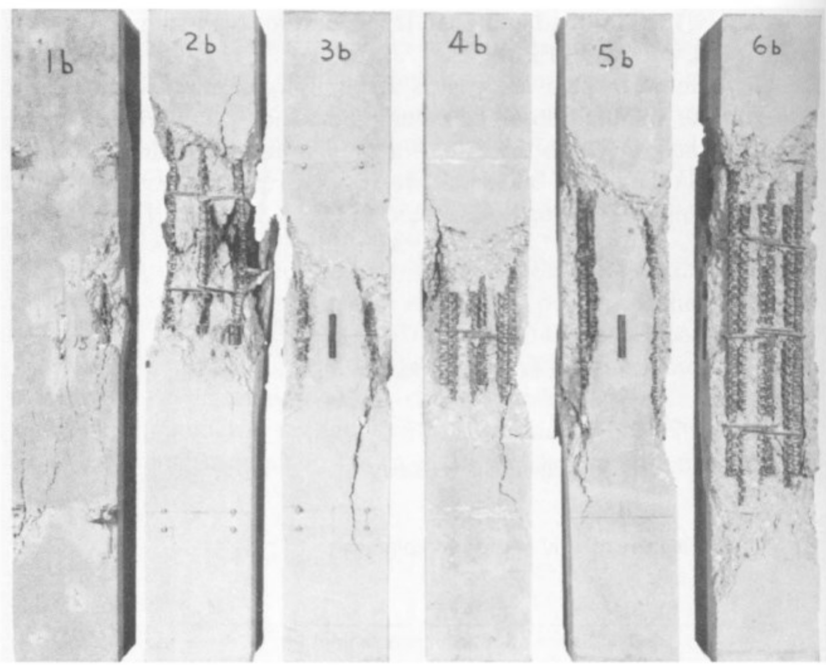


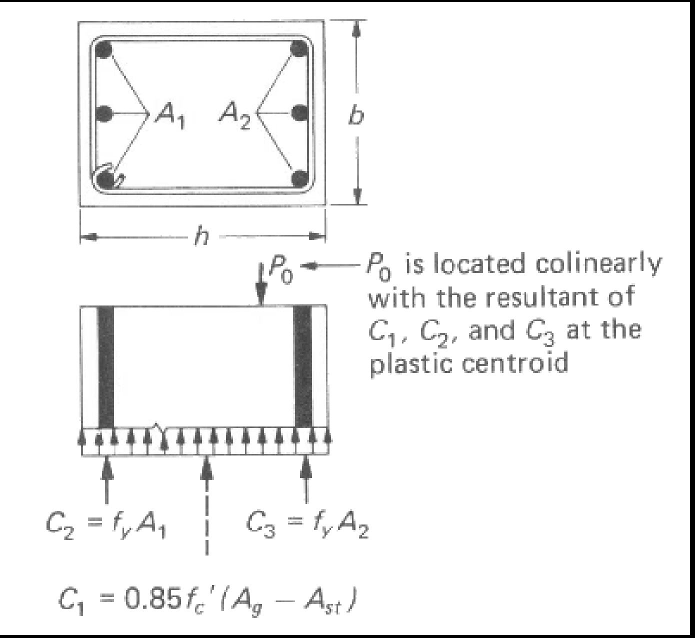
Figure 13.3.3 Tied column behavior. (Courtesy of Portland Cement Association.)

Column Design

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

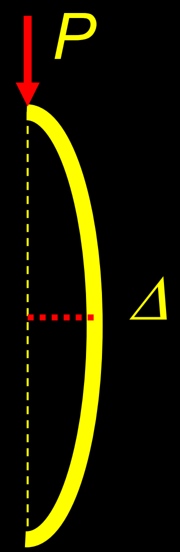
$$P_o = 0.85 f_c'(A_g - A_{st}) + f_y A_{st}$$

- $P_u \le \phi_c P_n$
  - 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)*



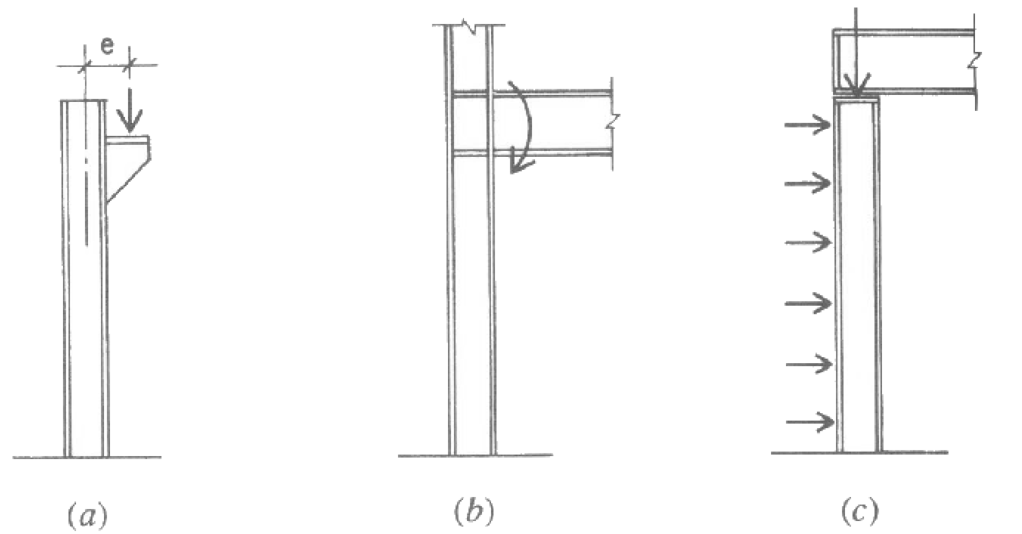


Figure 10.6 Considerations for development of bending in steel columns; (*a*) bending induced by eccentric load, (*b*) bending transferred to column in a rigid frame, and (*c*) combined loading condition, separately producing axial compression and bending.

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*

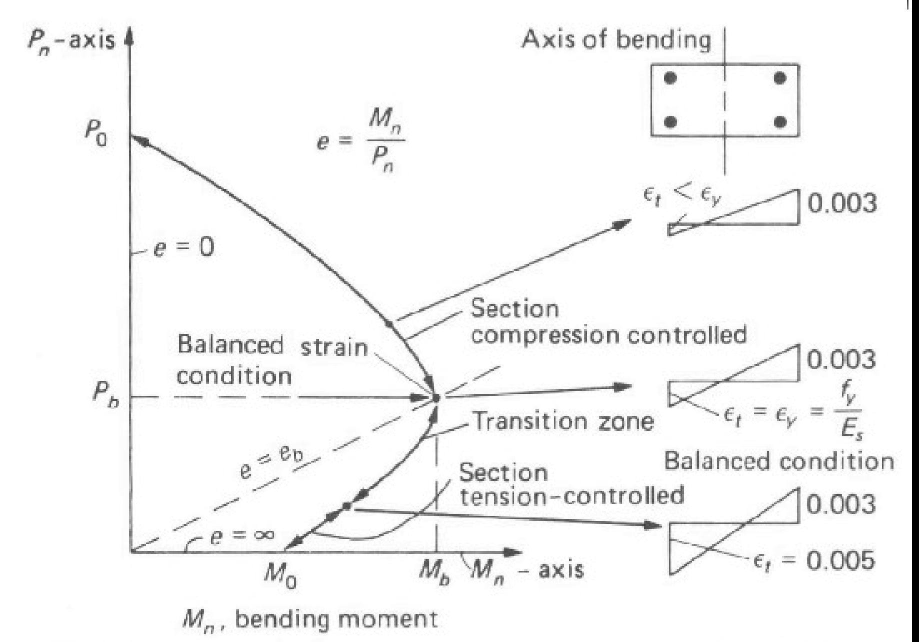


Figure 13.6.1 Typical strength interaction diagram for axial compression and bending moment about one axis. Transition zone is where $\epsilon_y \le \epsilon_t \le 0.005$.

Columns with Bending

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

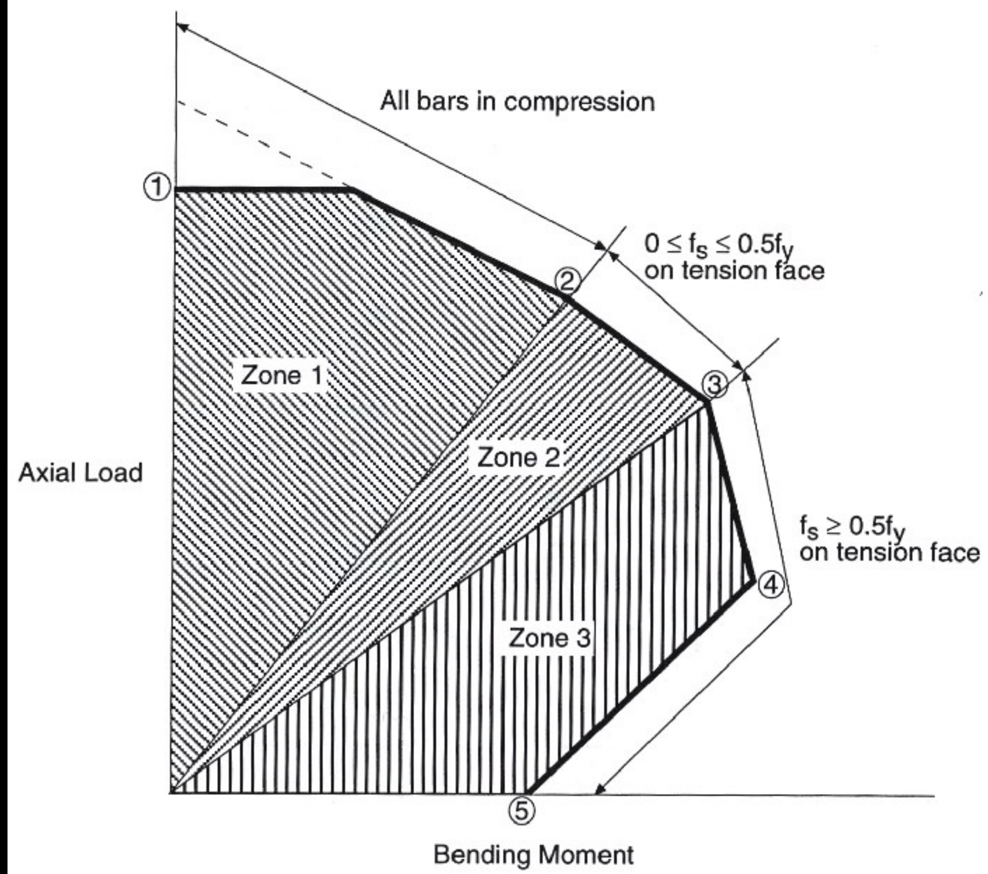
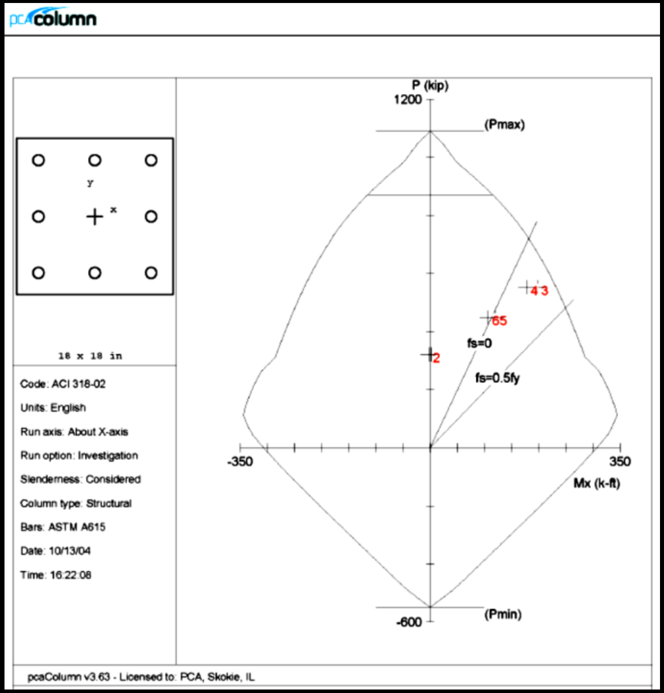


Figure 5-3 Transition Stages on Interaction Diagram

Design Methods

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



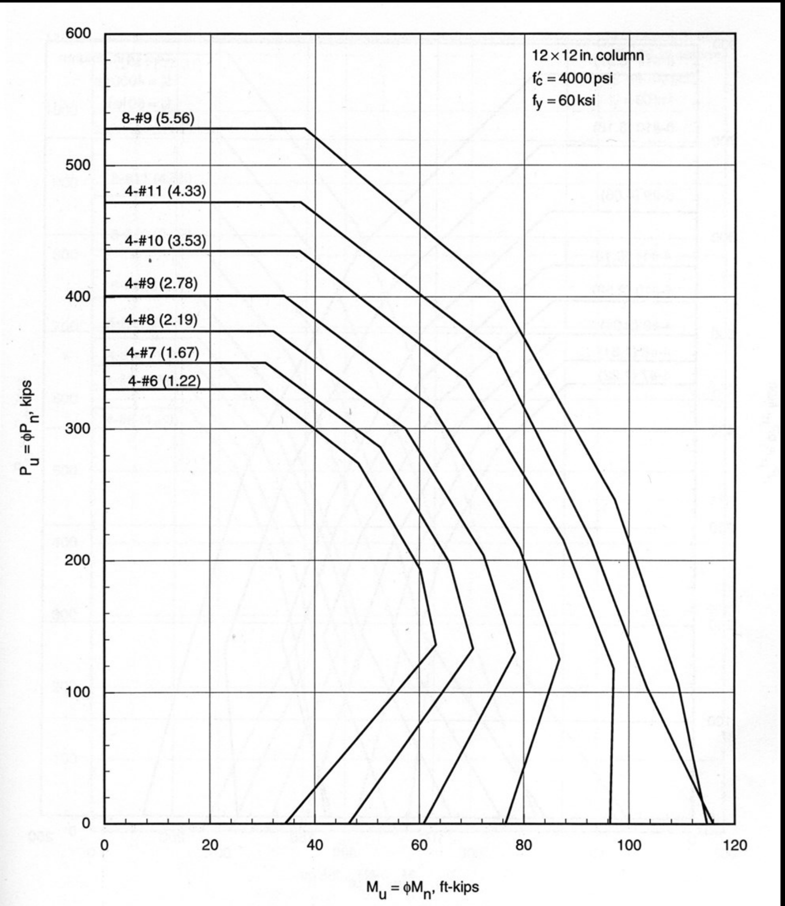
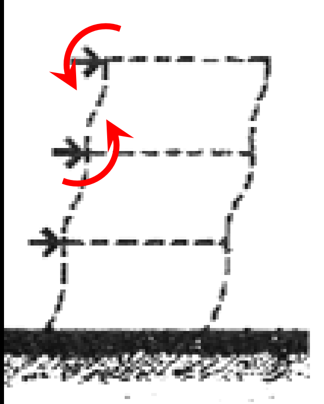


Figure 5-17 12 × 12 in. Column Design Chart

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*



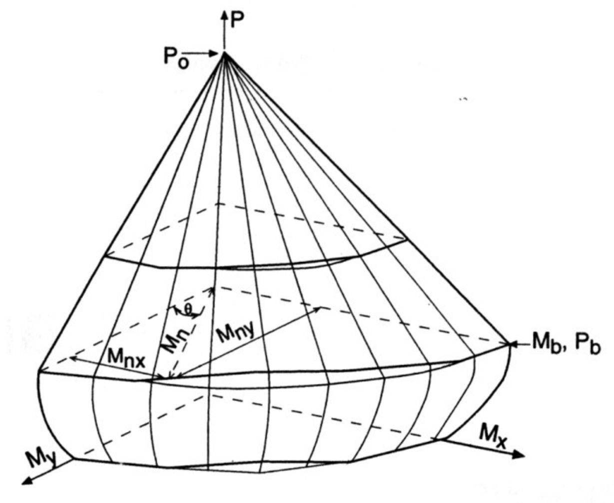
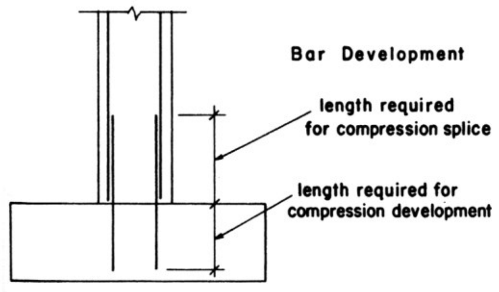


Figure 12-1 Biaxial Interaction Surface



(c) Footing without Pedestal