PROBLEM 1

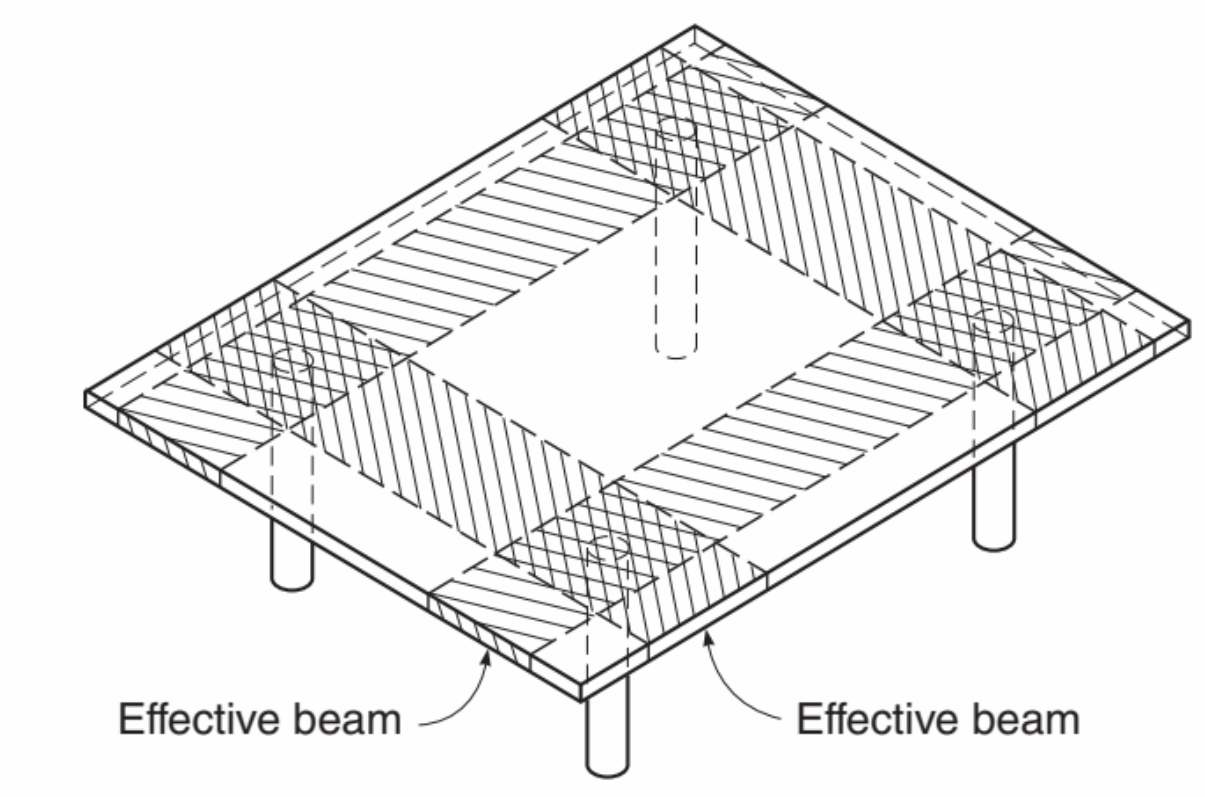
For a floor structure with typical 24 ft by 26 ft **interior** panel sizes, the superimposed dead loads are 20 psf and the superimposed live loads are 100 psf. As a preliminary design, select an appropriate flat slab thickness (without drop panels) and calculate reinforcement. Assume f'_c 4,000 psi and f_y 60,000 psi. The concrete is normal weight with a unit weight of 150 pcf. Assume that the column size is 20 inch x 20 inch.

DESIGN CONCEPT

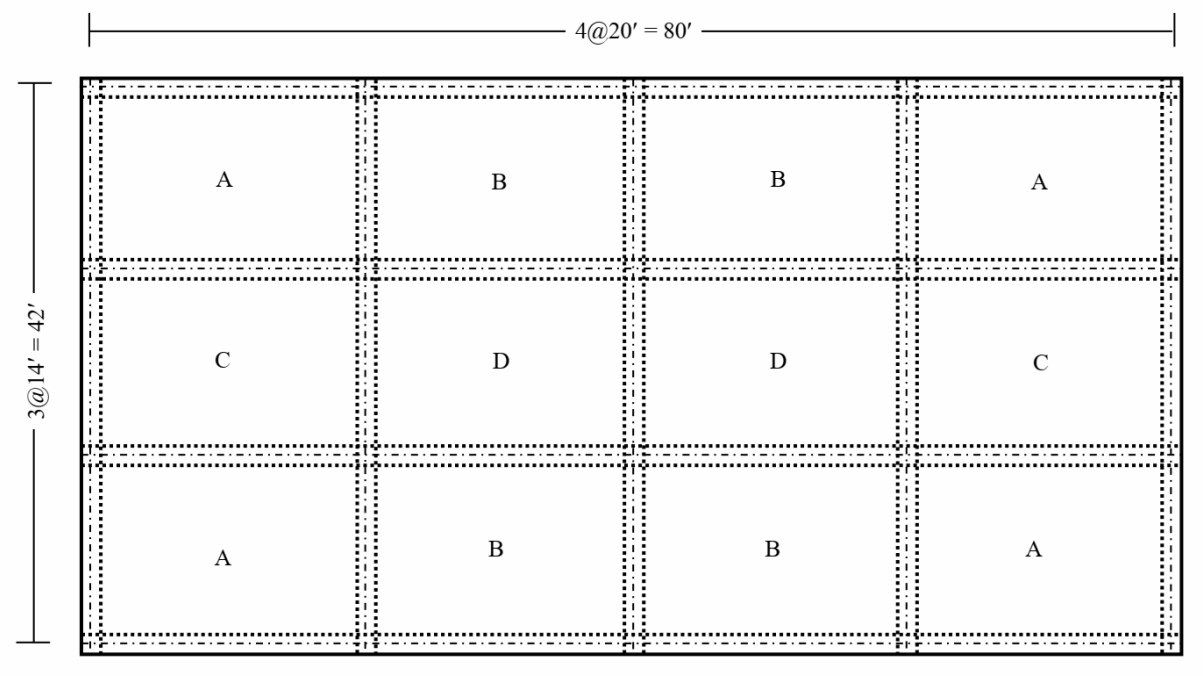
DESIGN OF TWO WAY SLAB

1. ACI Coefficient Method
2. Direct Design Method
3. Equivalent Frame Method
4. Finite Element Method

TWO WAY SLAB WITHOUT BEAM

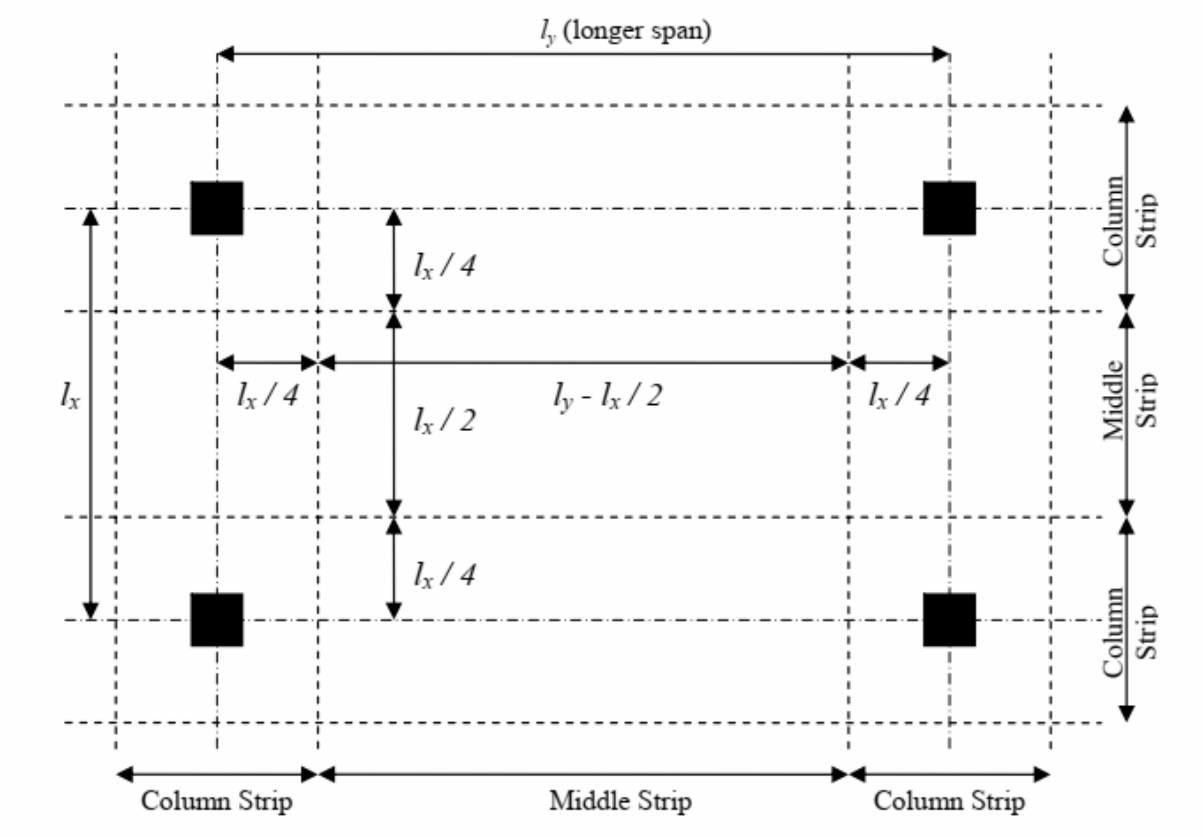


CONCEPT OF PANEL IN SLAB



CONCEPT OF COLUMN STRIP AND MIDDLE STRIP

A typical panel is divided, for purposes of design, into column strips and middle strips. A column strip is defined as a strip of slab having a width on each side of the column centerline equal to one-fourth the **smaller of the panel dimensions.** Such a strip includes column-line beams, if present. A middle strip is a design strip bounded by two column strips.



DESIGN OF FLAT PLATE

1. Determine whether the slab geometry and loading allow the use of the direct design method.

Restrictions of Direct Design Method

Moments in two-way slabs can be found using the semiempirical direct design method, subject to the following restrictions:

1. There must be a minimum of three continuous spans in each direction.

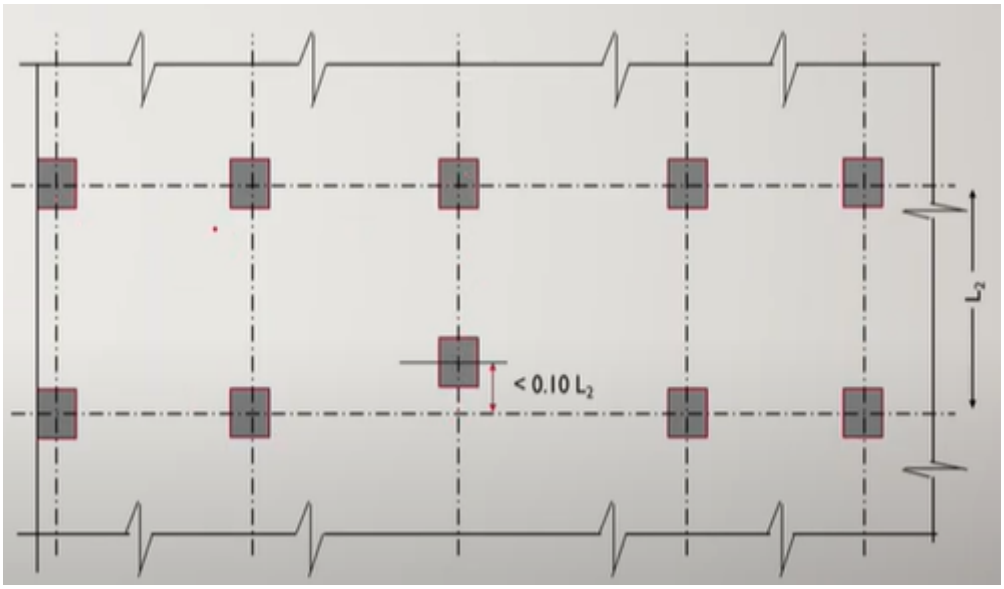
2. The panels must be rectangular, with the ratio of the longer to the shorter spans within a panel not greater than 2.

3. The successive span lengths in each direction must not differ by more than one third of the longer span.

4. Columns may be offset a maximum of 10 percent of the span in the direction of the offset from either axis between centerlines of successive columns.

5. Loads must be due to gravity only, and the unfactored live load must not exceed 2 times the unfactored dead load.

6. If beams are used on the column lines, the relative stiffness of the beams in the two perpendicular directions, given by the ratio /, must be between 0.2 and 5.0


< 0.10 L2
L2

2. Determine the Slab Thickness of Flat Plate

The minimum thickness of two-way slabs without **interior beams**, according to ACI Code 8.3.1, must not be less than provided by Table 13.3. **Edge beams, often provided even for two-way slabs otherwise without beams to improve moment and shear transfer at the exterior supports, permit a reduction in minimum thickness of about 10 percent in exterior panels.** In all cases, the minimum thickness of slabs without interior beams must not be less than the following:

For slabs without drop panels 5 in.
For slabs with drop panels 4 in.

TABLE 13.3
Minimum thickness of slabs without interior beams

Yield Stress f_y, psi	Without Drop Panels			With Drop Panels		
	Exterior Panels		Interior Panels	Exterior Panels		Interior Panels
	Without Edge Beams	With Edge Beams[a]		Without Edge Beams	With Edge Beams[a]	
40,000	$\ell_n/33$	$\ell_n/36$	$\ell_n/36$	$\ell_n/36$	$\ell_n/40$	$\ell_n/40$
60,000	$\ell_n/30$	$\ell_n/33$	$\ell_n/33$	$\ell_n/33$	$\ell_n/36$	$\ell_n/36$
75,000	$\ell_n/28$	$\ell_n/31$	$\ell_n/31$	$\ell_n/31$	$\ell_n/34$	$\ell_n/34$

l_n is the clear span from the face of one column to the face of the next. Use the longer clear span when selecting a slab thickness for rectangular bays. Use h_{min} for exterior Panel.

h_{min} = for exterior panel

h_{min} = for interior panel

3. <u>Calculate the Factored Load</u>

Self weight 10 inch slab = .

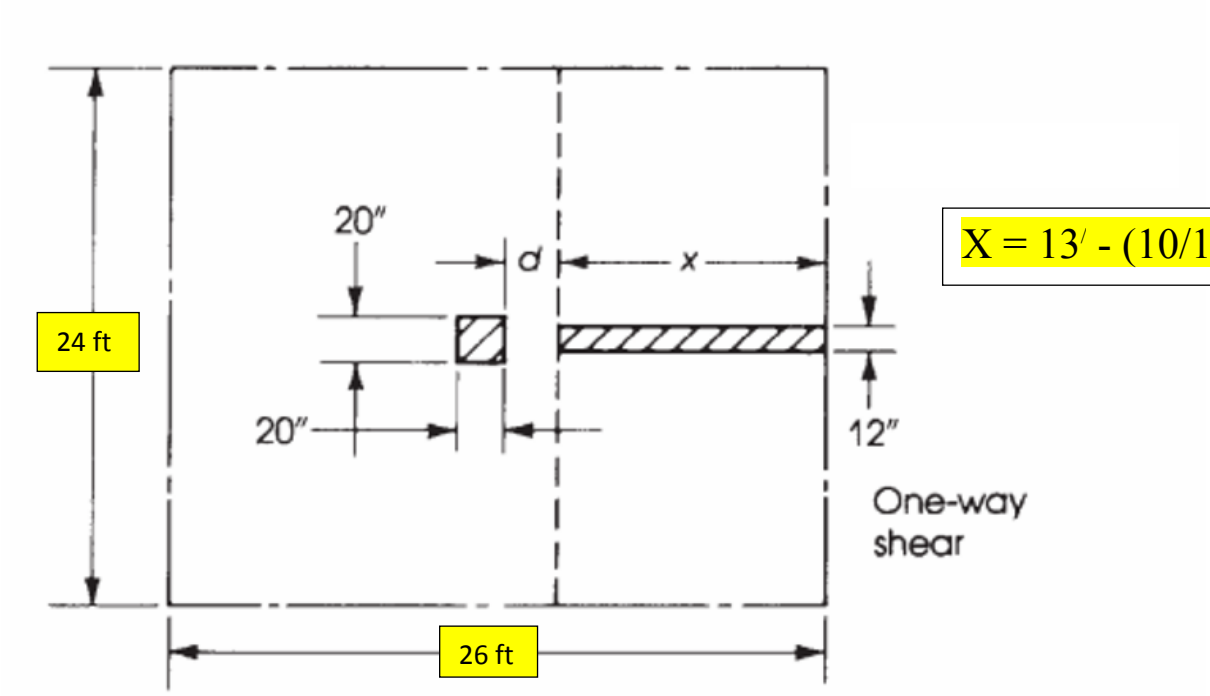
Superimposed load = 20 psf.

Live Load = 100 psf.

Factored Load, q_u = (1.2 x 145 + 1.6 x 100) = 334 psf = 0.334 ksf.

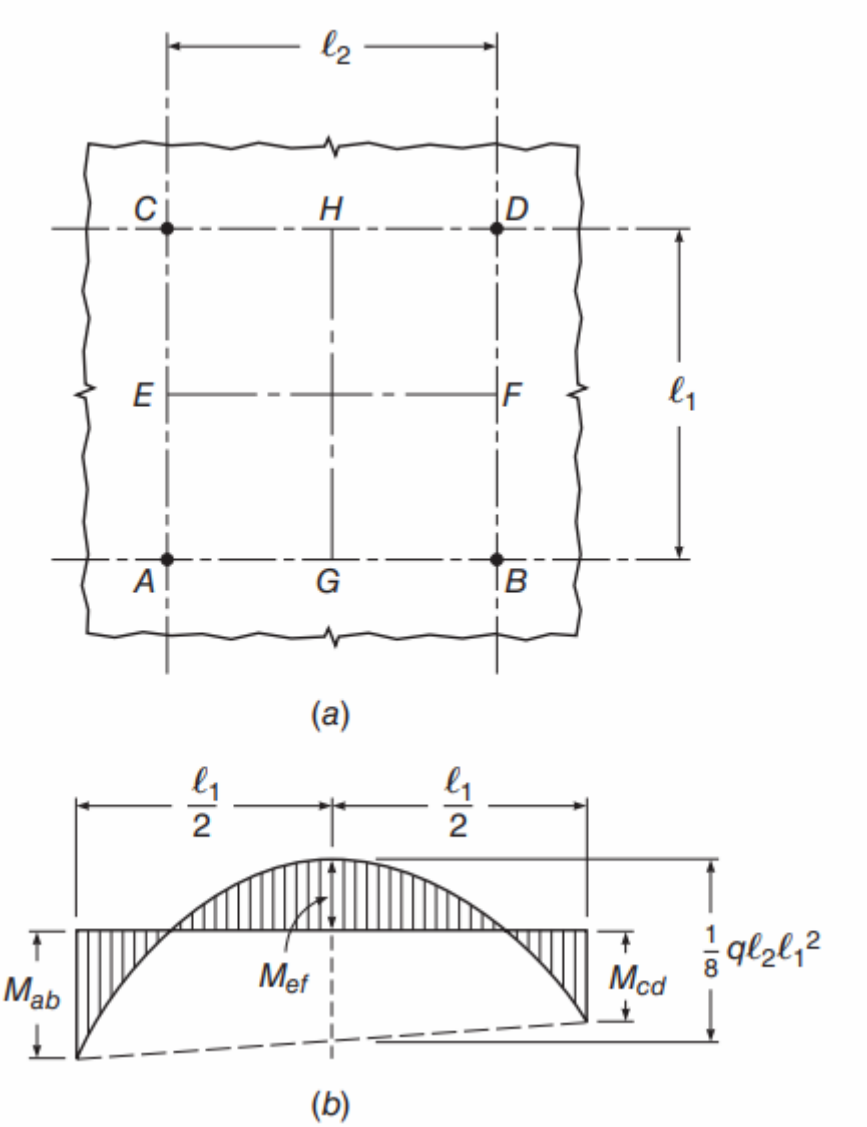
4. **Check for Shear**

Two kinds of shear may be critical in the design of flat slabs, flat plates, or footings. The first is the familiar **beam-type shear** leading to diagonal tension failure. Applicable particularly to long narrow slabs or footings, this analysis considers the slab to act as a wide beam, spanning between supports provided by the perpendicular column strips. A potential diagonal crack extends in a plane across the entire width l_2 of the slab.



X = 13′ - (10/12) - d

$V_u = q_u (1 \times x) = 0.334 \times (1 \times x) =$



The critical section is taken a distance d from the face of the column or capital. As for beams, the design shear strength must be at least equal to the required strength V_u at factored loads. The nominal shear strength V_c should be calculated by either Eq. (5.12a) or Eq. (5.12b), with b_w equal to the panel width l_2 in this case.

For members subject to shear and flexure, according to ACI Code 11.2.2, the concrete contribution to shear strength is the least of

$$V_c = \left(1.9\lambda\sqrt{f'_c} + 2500\frac{\rho_w V_u d}{M_u}\right) b_w d \qquad (5.12a)$$

$$V_c = \left(1.9\lambda\sqrt{f'_c} + 2500\,\rho_w\right) b_w d \qquad (5.12b)$$

where is the longitudinal reinforcement ratio A_s / b_w d or /bd. With the section dimension and d in inches and d and in consistent units, is expressed in pounds. In Eq. (5.12 a), the quantity d/ is not to be taken greater than 1.0.

Alternatively, failure may occur by punching shear, with the potential diagonal crack following the surface of a truncated cone or pyramid around the column, capital, or drop panel, as shown in Fig. 13.17 a. The failure surface extends from the bottom of the slab, at the support, diagonally upward to the top surface. The angle of inclination with the horizontal θ (see Fig. 13.17 b) depends upon the nature and amount of reinforcement in the slab. It may range between about 20 and 45 °. The critical section for shear is taken perpendicular to the plane of the slab and a distance d/2 from the periphery of the support, as shown. The shear force V_u to be resisted can be calculated as the total factored load on the area bounded by panel centerlines around the column less the load applied within the area defined by the critical shear perimeter, unless significant moments must be transferred from the slab to the column (see Section 13.8).

Punching Shear in Flat Slabs

PUNCHING SHEAR FAILURE

A typical flat plate punching shear failure is characterized by the slab failing at the intersection point of the column. This results in the column breaking through the portion of the surrounding slab. This type of failure is one of the most critical problems to consider when determining the thickness of flat plates at the column-slab intersection. Accurate prediction of punching shear strength is a major concern and absolutely necessary for engineers so they can design a safe structure.

DEFINITION OF CRITICAL SHEAR PERIPHERY

Figure 7 shows a plan view of a typical interior column. The ACI Code approach is based on a simple analytical model. It assumes that the critical shear surface lies at a d/2 distance from the face of the column, where d is the effective depth of the slab. The shear surface area then is the length of the critical periphery (or perimeter of the critical section) multiplied by d.

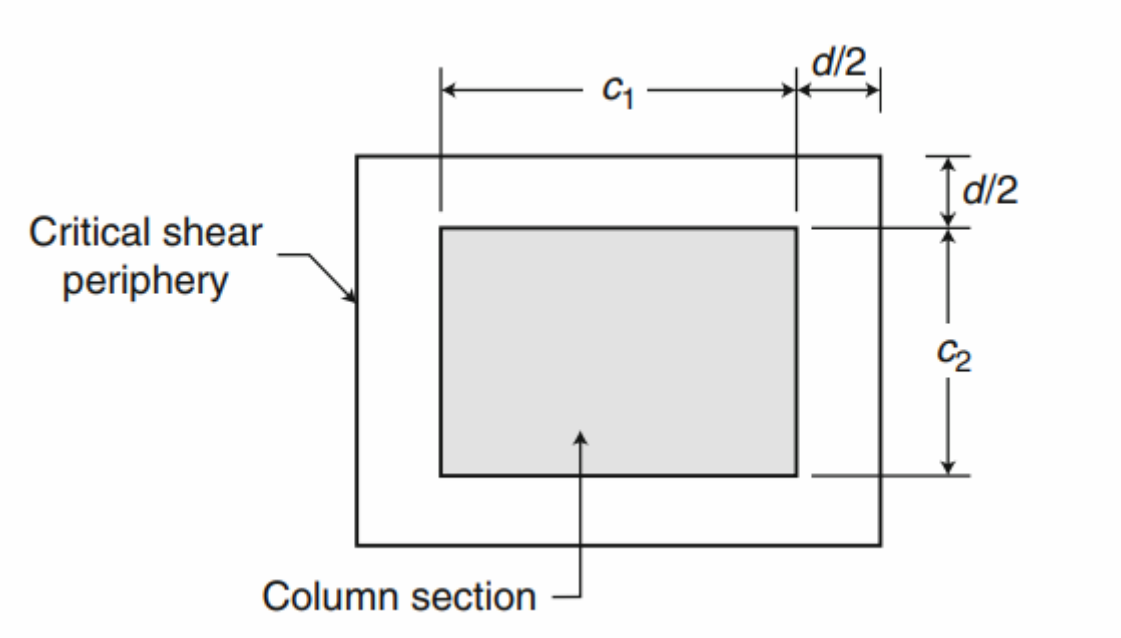


Figure 7: Definition of the Critical Shear Periphery at an Interior Column, b_0 = Column Periphery + 8 x

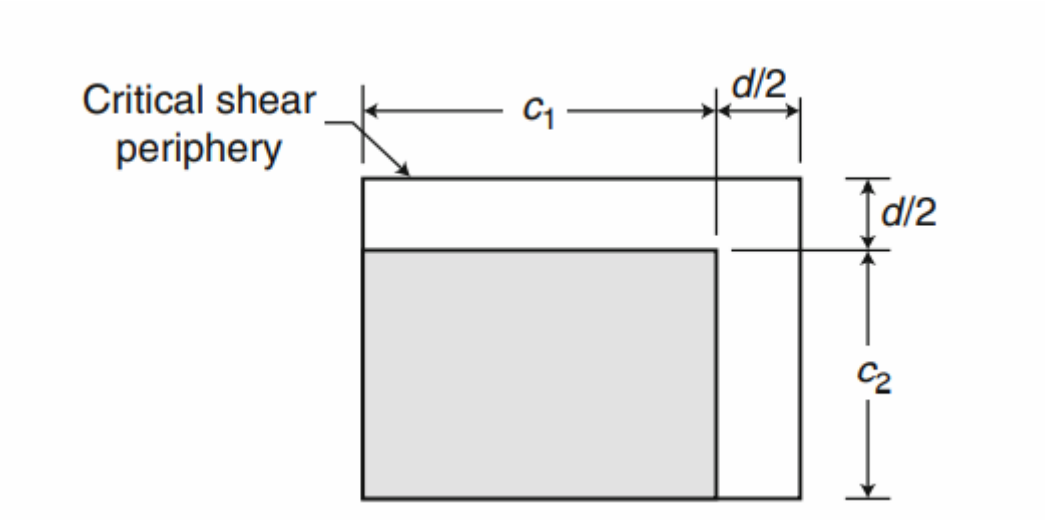


Figure 8: Definition of the Shear Periphery at a Corner Column, $b_0 = c_1 + c_2 + 2$

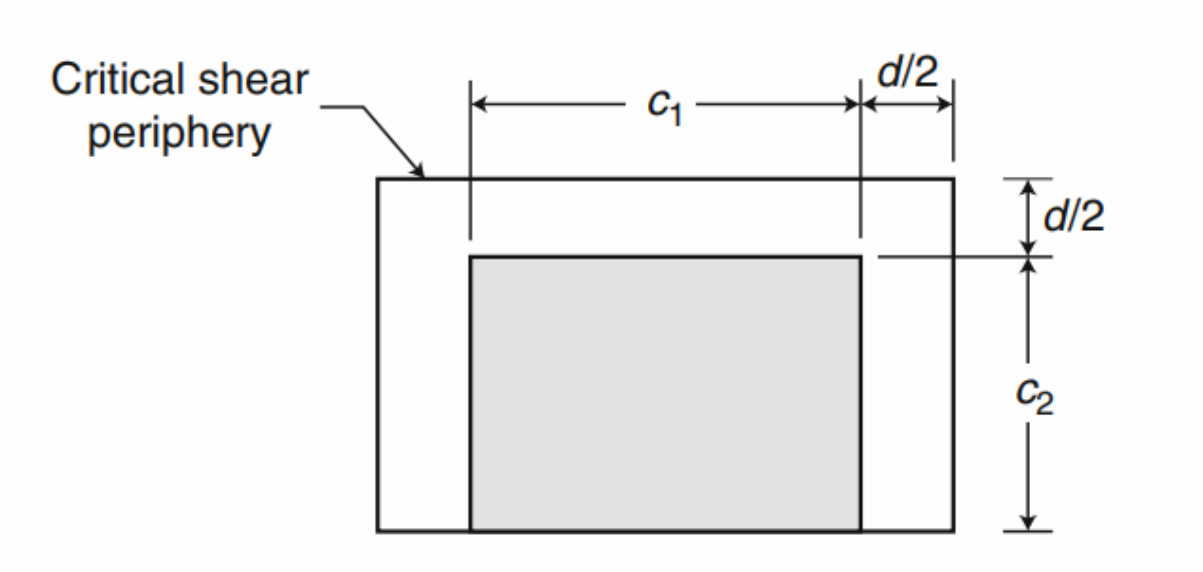


Figure 12: Definition of the Shear Periphery at an Edge Column, $b_0 = c_1 + 2c_2 + 4$

Experience has shown that vertical chases, ducts, pipes, and so on are somehow "attracted" to columns. Although structures can tolerate openings near columns, openings reduce the available shear periphery. Figure 10 shows some examples of openings near a column and the resulting reduction in the effectiveness of the shear transfer.

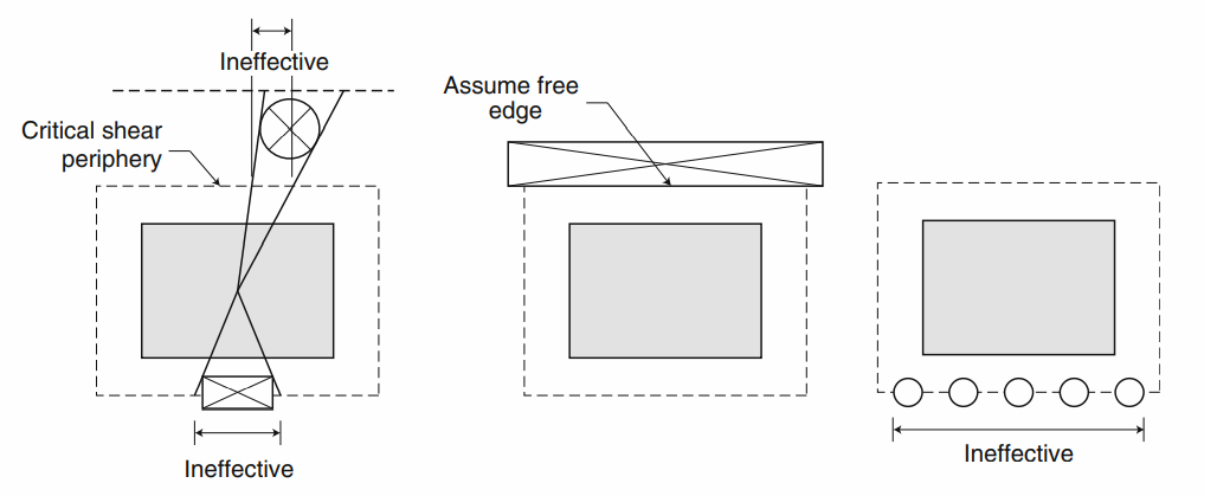


Figure 10: Lost Effective Periphery due to Openings near Columns

4. Check for Punching Shear

The factored load/shear on interior Panel

$$V_u = q_u \text{ x } A = \ - = 206.482 \text{ k} = 206482 \text{ lb}$$

The ACI Code gives the maximum factored shear to be transferred by stresses on the concrete from the slab to the column as the smallest of Equations (6.1), (6.2), and (6.3) (ACI Code Table 22.6.5.2).

$$\phi V_c = \phi\left(2 + \frac{4}{\beta}\right)\lambda\sqrt{f_c'}\, b_o d \qquad (6.1)$$

d = 10 – 0.75 – = 8.875

b_0 = (20 +8.875) x 4 = 115.50 in

= 0.75 (2 +) 1 x 115.50 x 8.875 = 291738 lb

where β is the ratio of the long side to the short side of the column's cross section, and b_o is the shear periphery (perimeter of the critical section for shear). λ is the lightweight concrete factor (λ = 0.75 for 'all-lightweight', λ = 0.85 for 'sand-light-weight', and λ = 1.0 for 'normal weight' concrete). As in Chapter 4, ϕ = 0.75 for shear. Equation (6.1) is the governing formula when the column's cross section is an elongated rectangle, with the ratio of longer side to shorter side greater than 2.

$$\phi V_c = \phi\left(\frac{\alpha_s d}{b_o} + 2\right)\lambda\sqrt{f_c'}\,b_o d \qquad (6.2)$$

= 0.75 (1 x x 115.5 x 8.875 = 171970 lb (Controls)

where α_s is 40 for interior columns, 30 for edge columns, and 20 for corner columns.

$$\phi V_c = \phi\left(4\lambda\sqrt{f_c'}\,b_o d\right) \qquad (6.3)$$

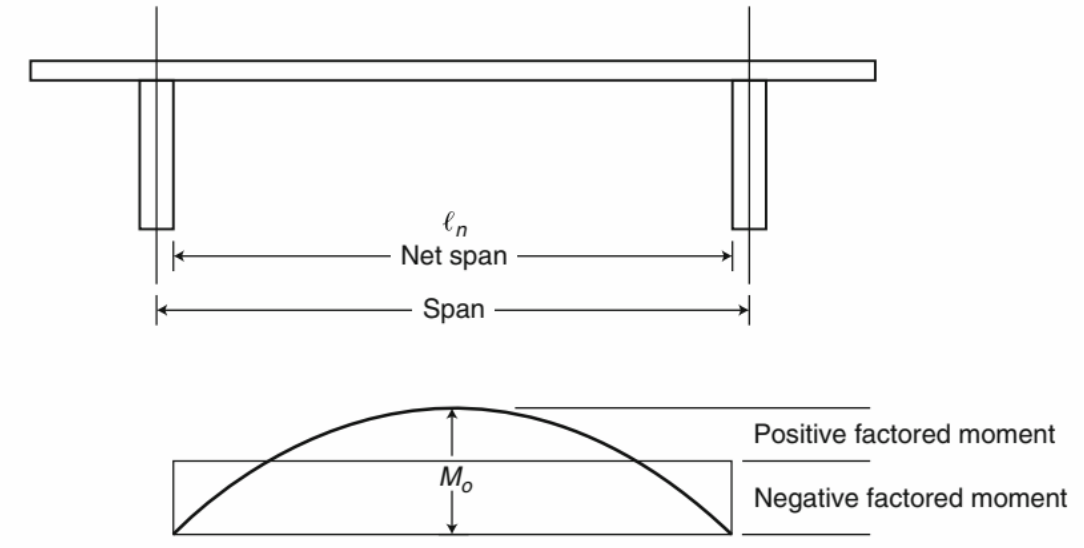
4. Determination of Total Moment in Longitudinal and Transverse Direction

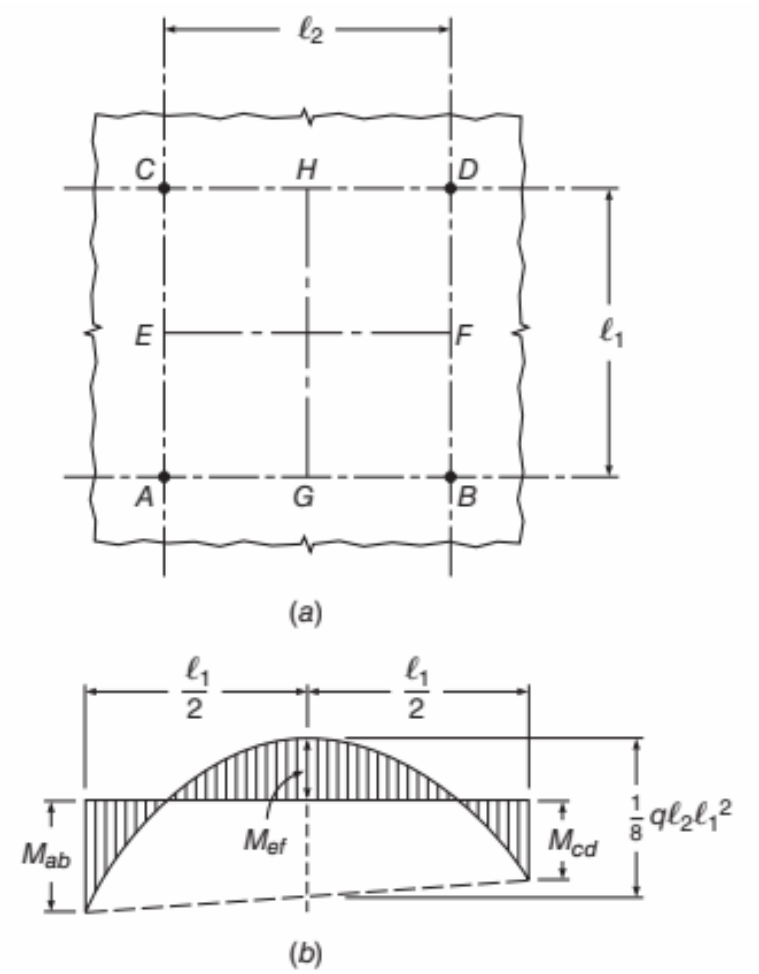
a. Calculate the absolute sum of the average positive and negative moments in both long and short direction on a panel (ACI Code 8.10.3.2)

$$M_o = \frac{q_u \ell_2 \ell_n^2}{8}$$

where

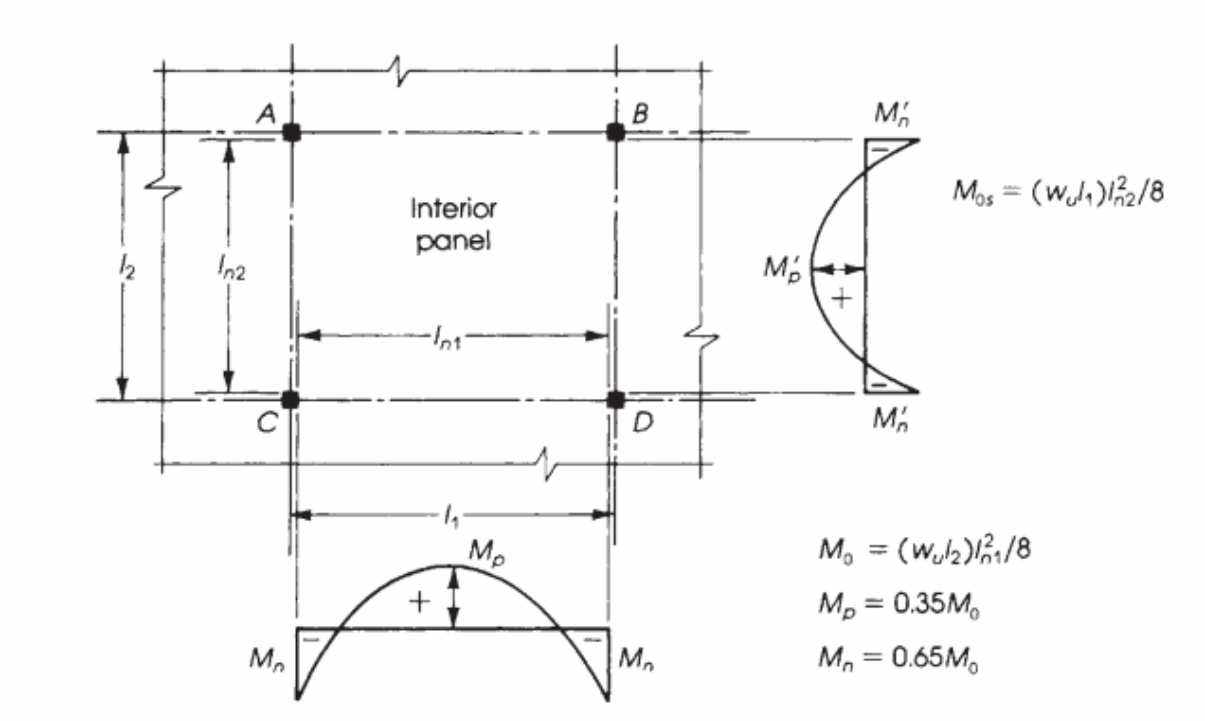
q_u = the factored load on a unit area (psf);
ℓ_n = the clear (net) span length in the direction for which moments are being determined;
ℓ_2 = the length of span (center to center) transverse to ℓ_n;





b. Divide M_0 into Positive and Negative Moments in both direction

a. In an interior span, the negative factored moment is 0.65 M_0 and the positive factored moment is 0.35 M_0.



c. In an exterior span, the ratios of the total negative moments and the positive moments are strongly dependent on the presence of beams between columns. Edge beams on the exterior perimeter help support the exterior wall system and better control deflections around the periphery, where deflections may be harmful to the wall system.

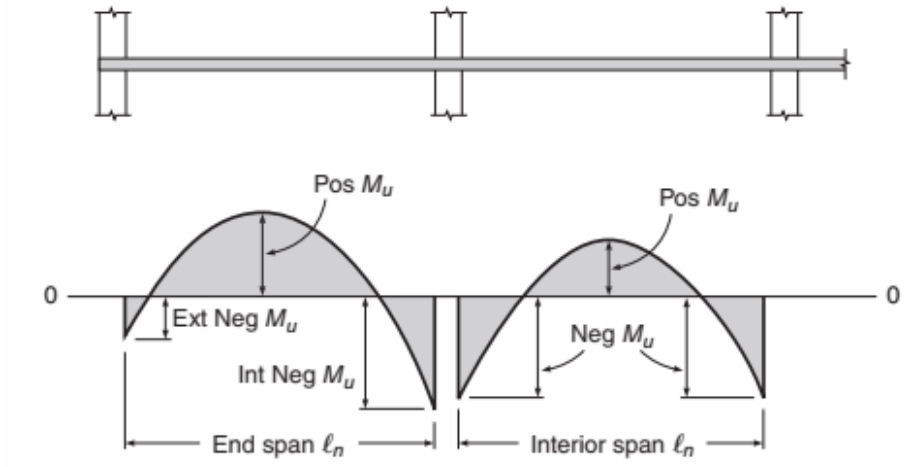


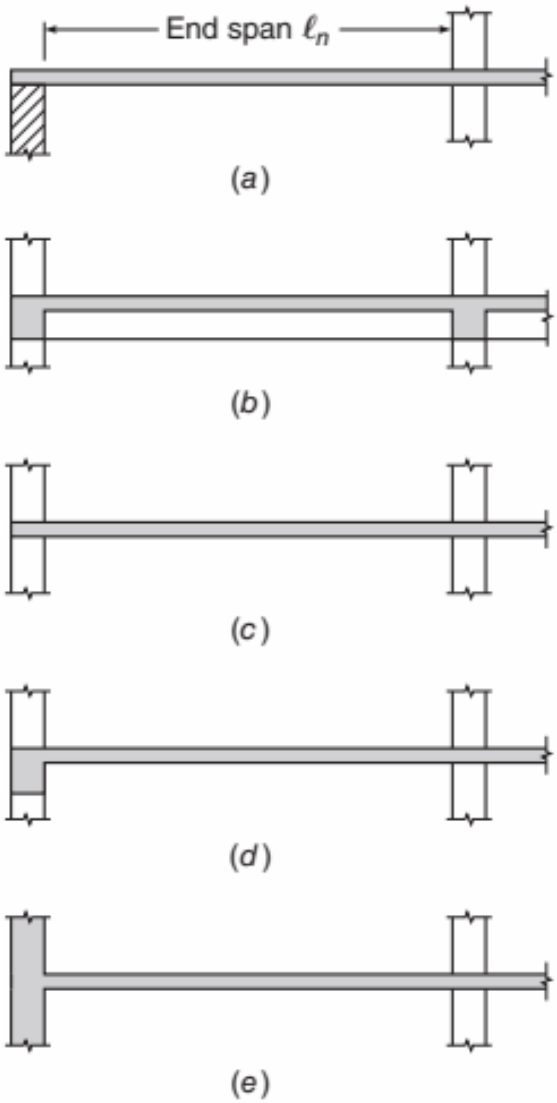
Figure 13.7: Distribution of total static moment M_o to critical sections for positive and negative bending.

In the case of end spans, the apportionment of the total static moment among the three critical moment sections (interior negative, positive, and exterior negative, as illustrated by Figure 13.7) depends upon the flexural restraint provided for the slab by the exterior column or the exterior wall, as the case may be, and depends also upon the presence or absence of beams on the column lines. ACI Code 8.10.4 specifies five alternative sets of moment distribution coefficients for end spans, as shown in
Table 13.1 and illustrated in Figure 13.8.

TABLE 13.1
Distribution factors applied to static moment M_o for positive and negative moments in end span

	(a)	(b)	(c)	(d)	(e)
			Slab without Beams between Interior Supports		
	Exterior Edge Unrestrained	Slab with Beams between All Supports	Without Edge Beam	With Edge Beam	Exterior Edge Fully Restrained
Interior negative moment	0.75	0.70	0.70	0.70	0.65
Positive moment	0.63	0.57	0.52	0.50	0.35
Exterior negative moment	0	0.16	0.26	0.30	0.65

FIGURE 13.8
Conditions of edge restraint considered in distributing total static moment M_o to critical sections in an end span: (*a*) exterior edge unrestrained, for example, supported by a masonry wall; (*b*) slab with beams between all supports; (*c*) slab without beams, that is, flat plate; (*d*) slab without beams between interior supports but with edge beam; and (*e*) exterior edge fully restrained, for example, by monolithic concrete wall.



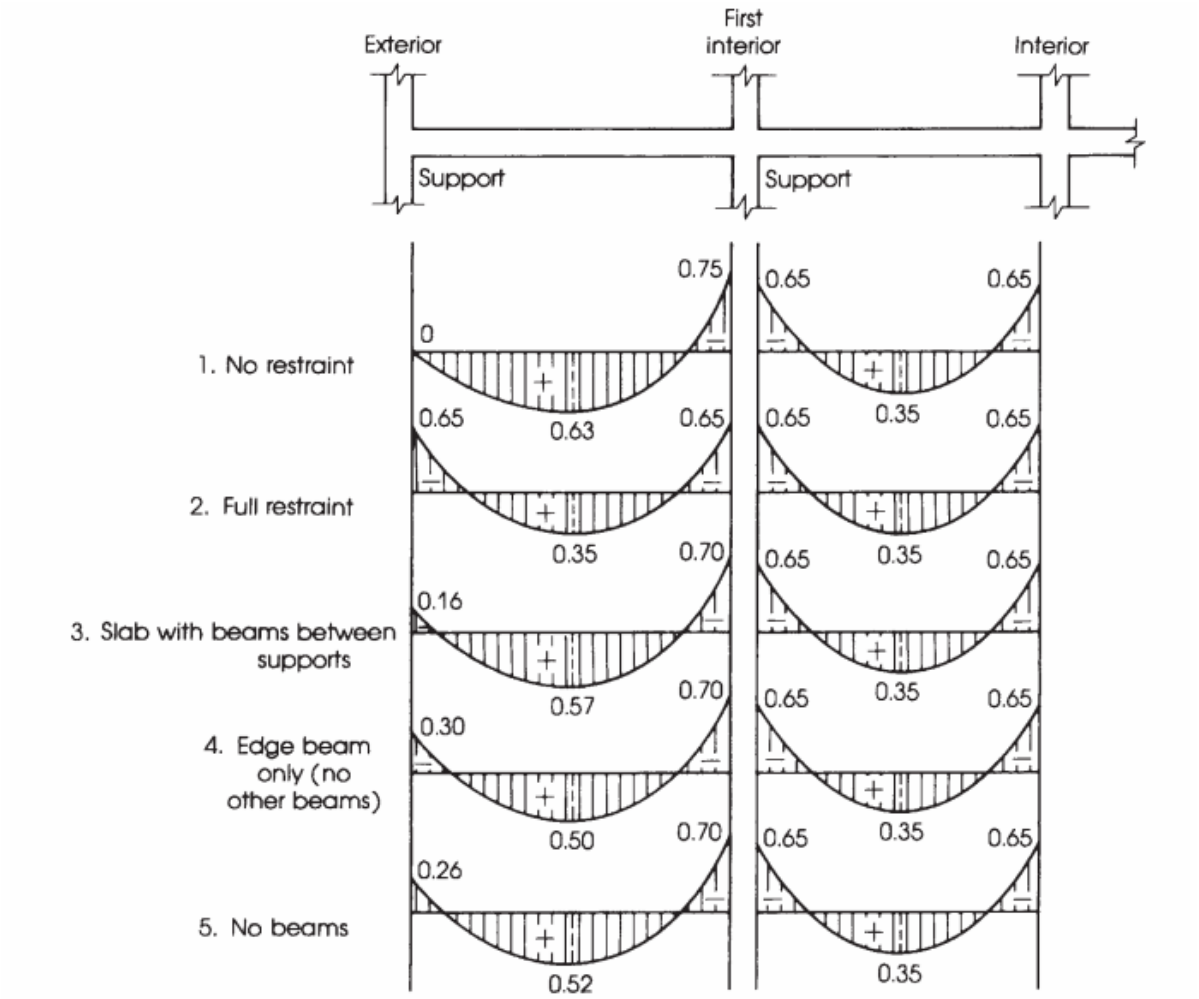


Figure 12: Distribution of Total Static Moment into Negative and Positive Moments

TABLE 13.1
Distribution factors applied to static moment M_o for positive and negative moments in end span

	(a)	(b)	(c)	(d)	(e)
			Slab without Beams between Interior Supports		
	Exterior Edge Unrestrained	Slab with Beams between All Supports	Without Edge Beam	With Edge Beam	Exterior Edge Fully Restrained
Interior negative moment	0.75	0.70	0.70	0.70	0.65
Positive moment	0.63	0.57	0.52	0.50	0.35
Exterior negative moment	0	0.16	0.26	0.30	0.65

c. Distribute M_{neg} and M_{pos} between Column Strip and the Middle Strip

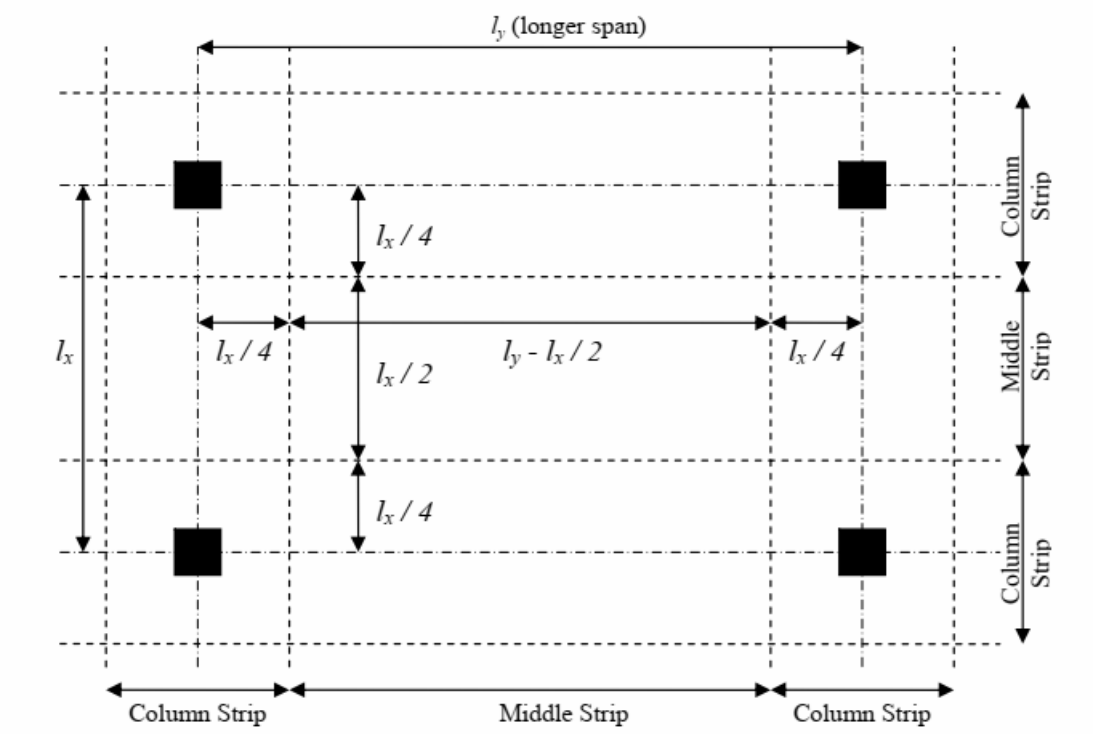
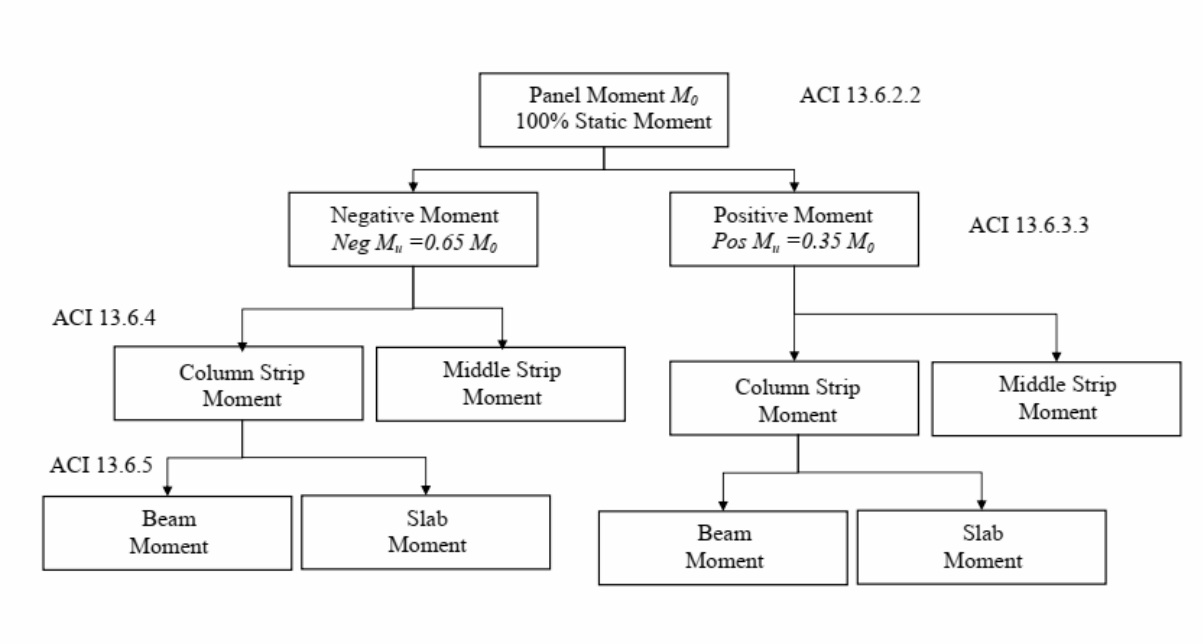


TABLE 13.2
Column-strip moment, portion of total moment at critical section

		ℓ_2/ℓ_1		
		0.5	**1.0**	**2.0**
Interior negative moment				
$\alpha_{f1}\ell_2/\ell_1 = 0$		0.75	0.75	0.75
$\alpha_{f1}\ell_2/\ell_1 \geq 1.0$		0.90	0.75	0.45
Exterior negative moment				
$\alpha_{f1}\ell_2/\ell_1 = 0$	$\beta_t = 0$	1.00	1.00	1.00
	$\beta_t \geq 2.5$	0.75	0.75	0.75
$\alpha_{f1}\ell_2/\ell_1 \geq 1.0$	$\beta_t = 0$	1.00	1.00	1.00
	$\beta_t \geq 2.5$	0.90	0.75	0.45
Positive moment				
$\alpha_{f1}\ell_2/\ell_1 = 0$		0.60	0.60	0.60
$\alpha_{f1}\ell_2/\ell_1 \geq 1.0$		0.90	0.75	0.45



d. **Determination of Reinforcement Ratio (ρ)**

The maximum practical reinforcement ratio is

$$\rho_{0.005} = 0.85\beta_1 \frac{f'_c}{f_y} \frac{\epsilon_u}{\epsilon_u + 0.005}$$

8. Check Minimum Required Effective Depth controlled by Maximum Negative Moment at the Interior Support by formula

$$d^2 = \frac{M_u}{\phi\rho f_y\, b(1 - 0.59\rho f_y/f'_c)}$$

If it is o.k. only then proceed. Otherwise increase the thickness of slab (h).

9. Assume Stress Block for Maximum Moment and find out A_s for all Section in both direction. This is a trial and counter check Method.

$$A_s = \frac{M_u}{\phi f_y (d - a/2)}$$

$$a = \frac{A_s f_y}{0.85 f_c' b}$$

or

psi

Flexural Resistance Factor, R

=

R =

DESIGN OF INTERIOR FLAT PLATE PANEL (LONG DIRECTION)

=

= 593.3 k-ft

0.65 x 593.3 = 385.645 k-ft

0.35 x 593.3 = 207.685 k-ft

Description	Column Strip		Middle Strip	
	Negative	Positive	Negative	Positive
Moment Distribution (%)	75 %	60 %	25 %	40 %
(k-ft)	289.24	124.61	96.41	83.1
Width of Strip, b (inch)	144		144	
Effective Depth, d (inch)	8.875		8.875	
	340/306		102	
Steel Ratio, (%)	0.006		0.0019	
	7.66		2.43	
	2.59		2.59	
Bars Selected (Straight)	18 # 6		13 # 4	
Spacing	8.5		12	

DESIGN OF INTERIOR FLAT PLATE PANEL (SHORT DIRECTION)

= = 541.22 k-ft

0.65 x 541.22 = 351.80 k-ft

0.35 x 541.22 = 189.427 k-ft

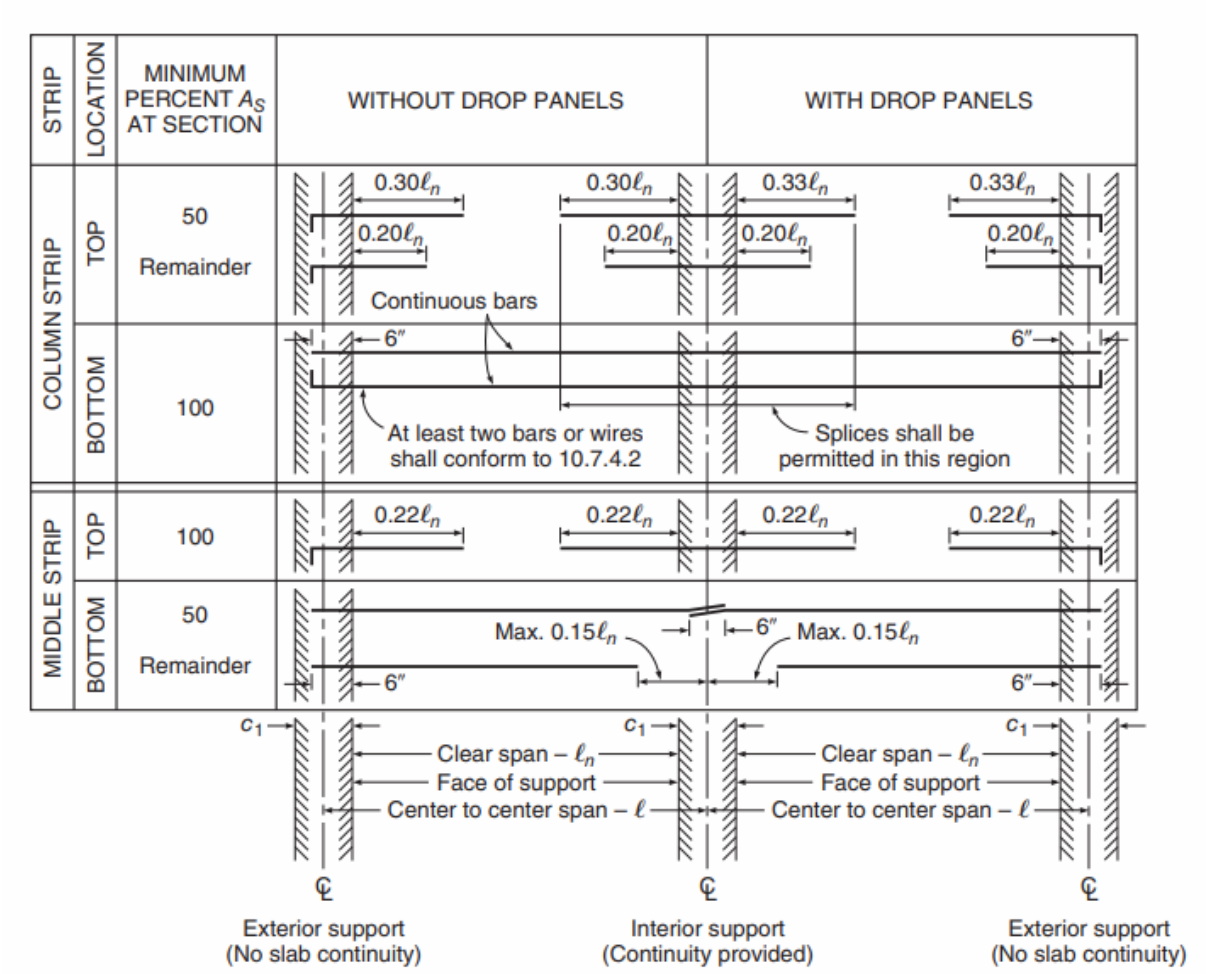
Description	Column Strip		Middle Strip	
	Negative	Positive	Negative	Positive
Moment Distribution (%)				
(k-ft)				
Width of Strip, b (inch)				
Effective Depth, d (inch)				
Steel Ratio, (%)				
Bars Selected (Straight)				
Spacing				

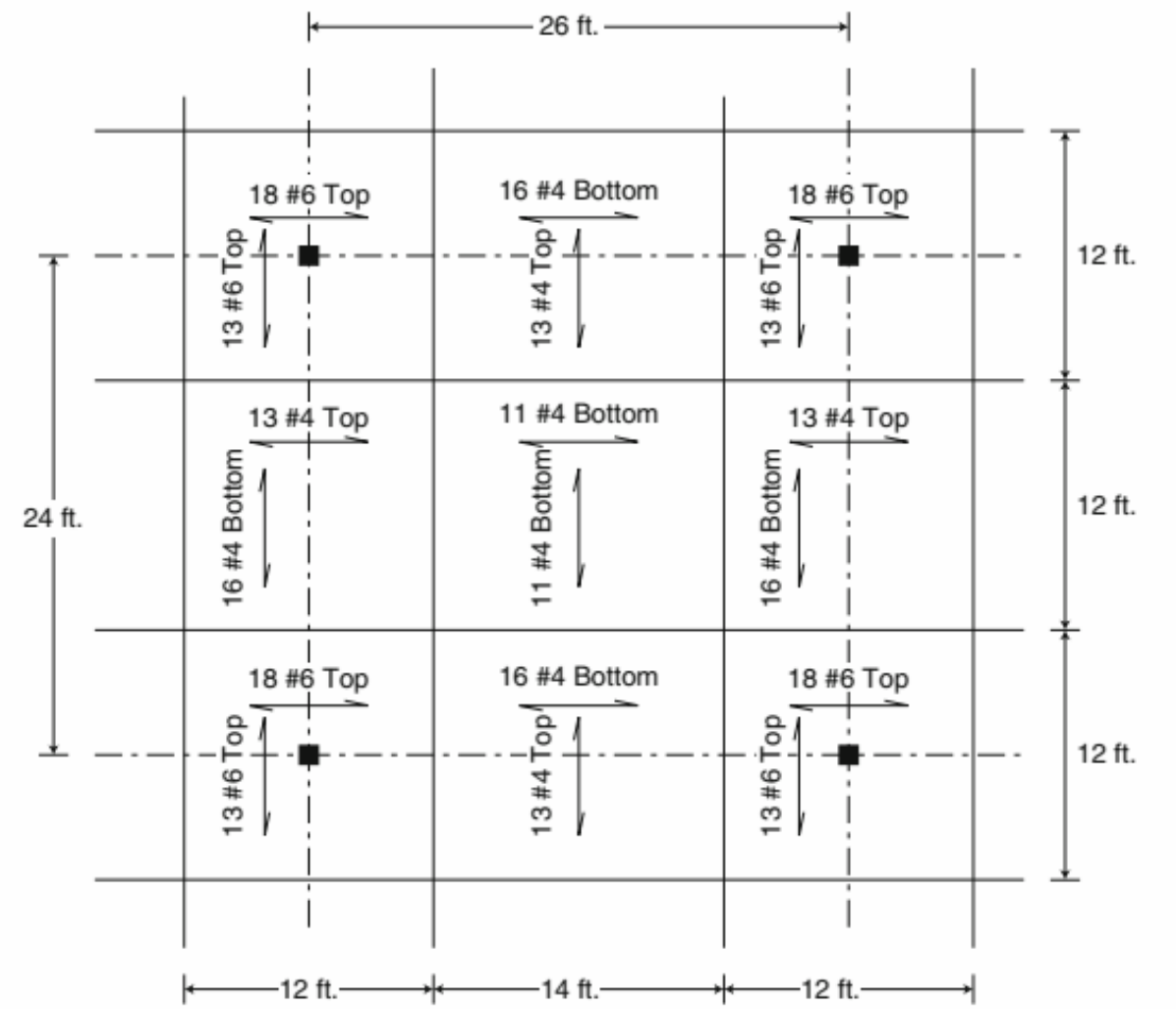
10. Check Factored Shear force for Beam Type Shear (One Way Shear) at a distance d from the face of the interior support and Punching Shear (Two Way Shear) at a distance d/2 from the face of interior support and nominal shear strength of concrete slab

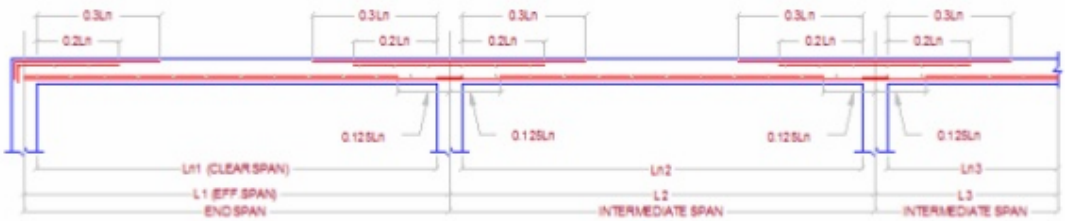
11. **Detailing of Reinforcement**

Consistent with the assumptions made in analysis, flexural reinforcement in two-way slab systems is placed in an orthogonal grid, with bars parallel to the sides of the panels. Bar diameters and spacings may be found as described in Section 12.2. Straight bars are generally used throughout, although in some cases positive-moment steel is bent up where no longer needed, to provide for part or all of the negative requirement. To provide for local concentrated loads, as well as to ensure that tensile cracks are narrow and well distributed, **a maximum bar spacing at critical sections of 2 times the total slab thickness or 18 in.** is specified by ACI Code 8.7.2.2 for two-way slabs. At least the minimum steel required for temperature and shrinkage crack control (see Section 12.3) must be provided. For protection of the steel against damage from fire or corrosion, at least 3/4 inch concrete cover must be maintained.

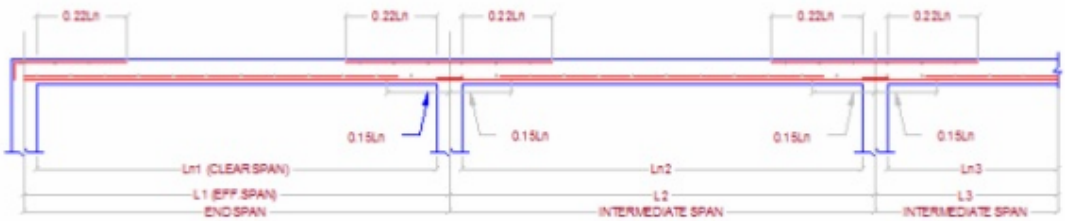
For the entire panel, including both middle strips and column strips in each direction, the moments in the long direction will be larger than those in the short direction, as is easily confirmed by calculating the static moment M_0 in each direction for a rectangular panel. Noting that the apportioning of M_0 first to negative and positive-moment sections, and then laterally to column and middle strips, is done by applying exactly the same ratios in each direction to the corresponding section, it is clear that the middle-strip positive moments (for example) are larger in the long direction than the short direction, exactly the opposite of the situation for the slab with stiff edge beams. In the column strips, positive and negative moments are larger in the long than in the short direction. On this basis, the designer is led to place the long-direction negative and positive bars, in both middle and column strips, closer to the top or bottom surface of the slab, respectively, with the larger effective depth.


STRIP
LOCATION
MINIMUM PERCENT A_S AT SECTION
WITHOUT DROP PANELS
WITH DROP PANELS
COLUMN STRIP
TOP
50
Remainder
$0.30\ell_n$
$0.20\ell_n$
$0.33\ell_n$
Continuous bars
BOTTOM
100
6″
At least two bars or wires shall conform to 10.7.4.2
Splices shall be permitted in this region
MIDDLE STRIP
TOP
100
$0.22\ell_n$
BOTTOM
50
Remainder
Max. $0.15\ell_n$
c_1
Clear span – ℓ_n
Face of support
Center to center span – ℓ
Exterior support (No slab continuity)
Interior support (Continuity provided)
Exterior support (No slab continuity)





TYPICAL SECTION THROUGH COLUMN STRIP



TYPICAL SECTION THROUGH MIDDLE STRIP

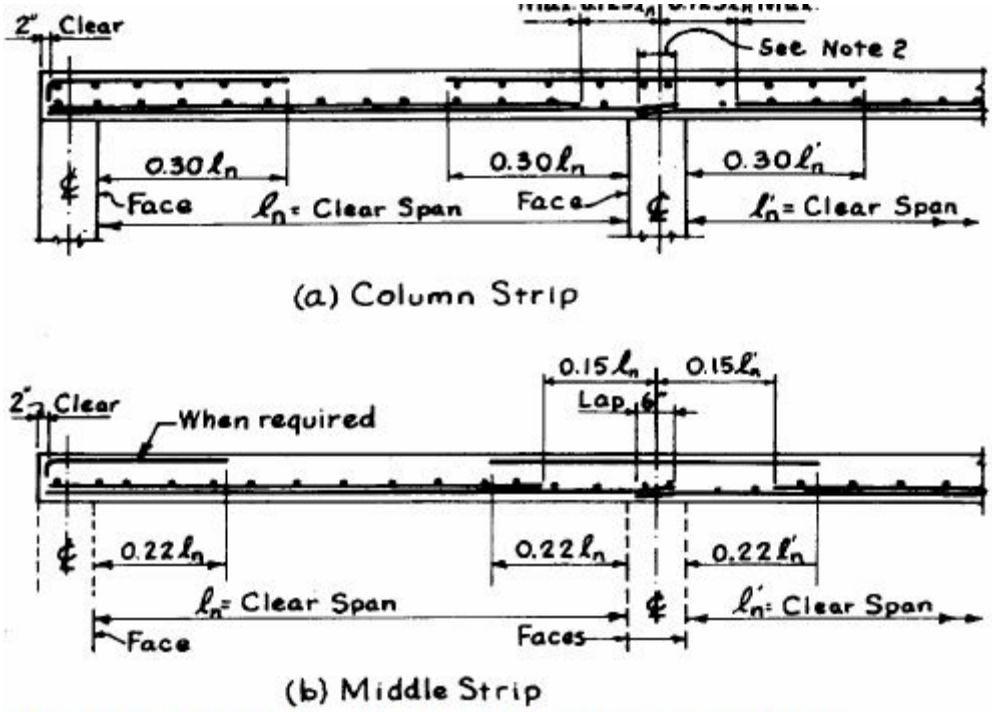
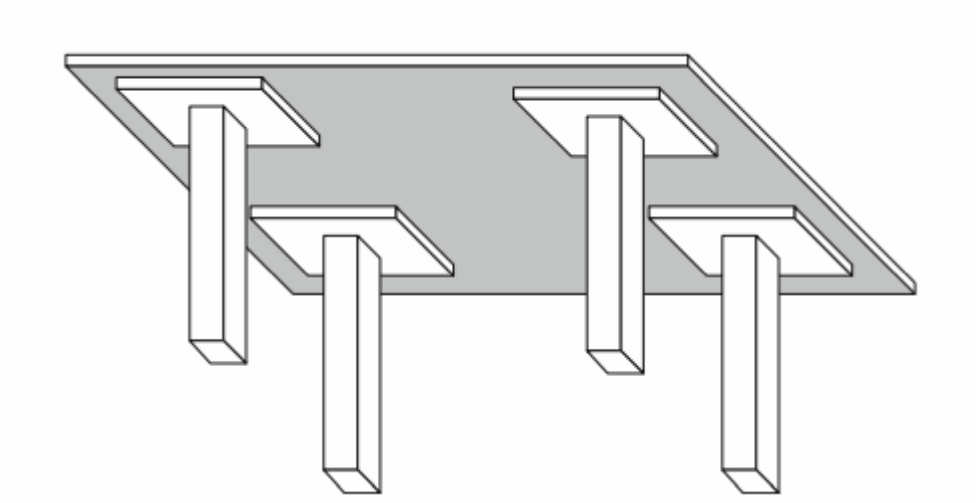


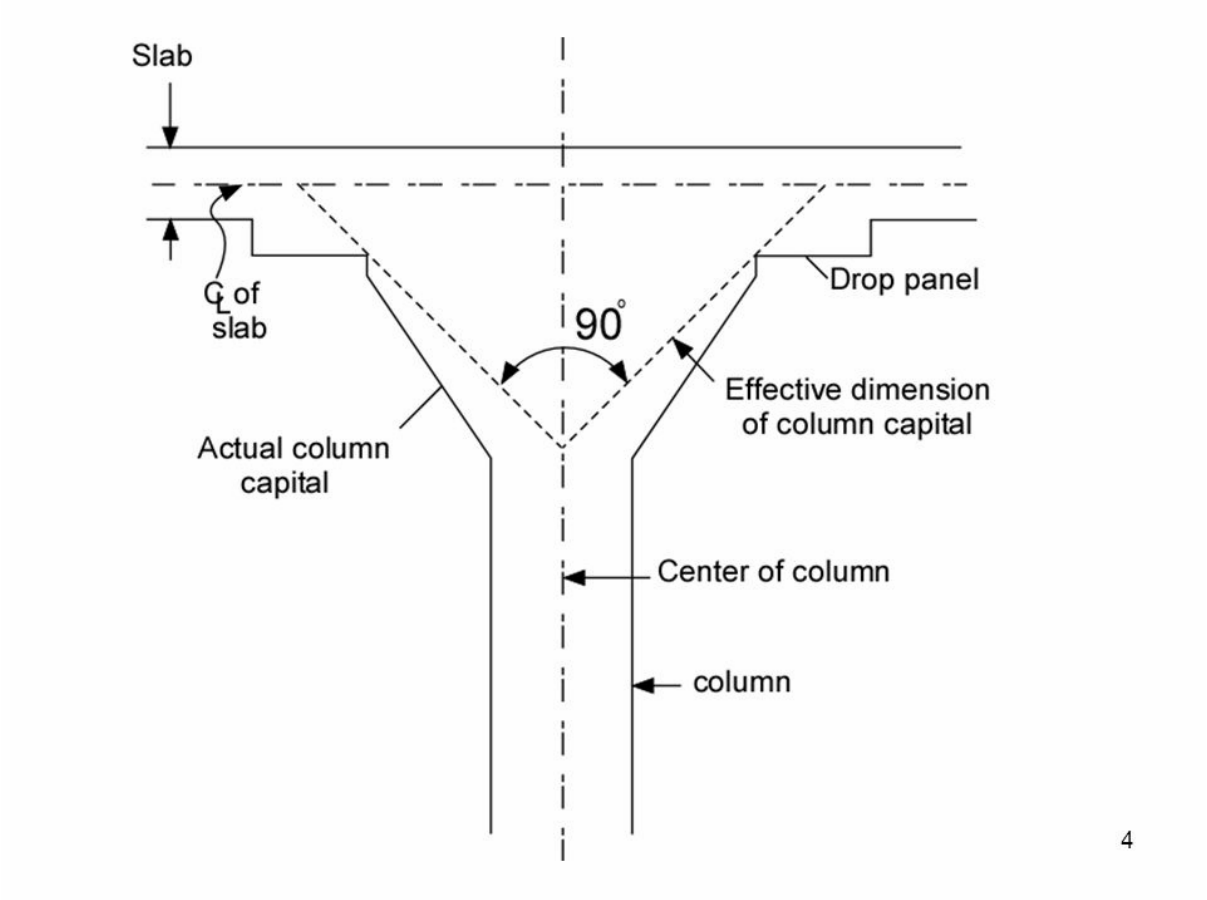
FIGURE 9.30 Reinforcing bar details for column and middle strips of flat plates.

12. **Design of Drop Panels**

According to ACI Code 8.2.4, a drop panel must project below the soffit of the slab at least one-quarter of the adjacent panel thickness and extends outward at least one-sixth of the center to center of supports.



13. **Design of Column Capital**



4

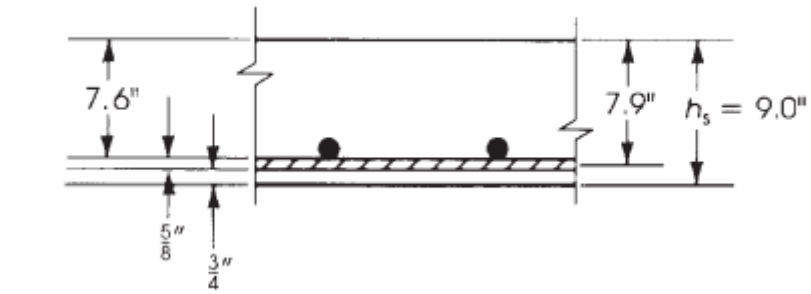


Figure 20: Calculation of Effective Depth, d

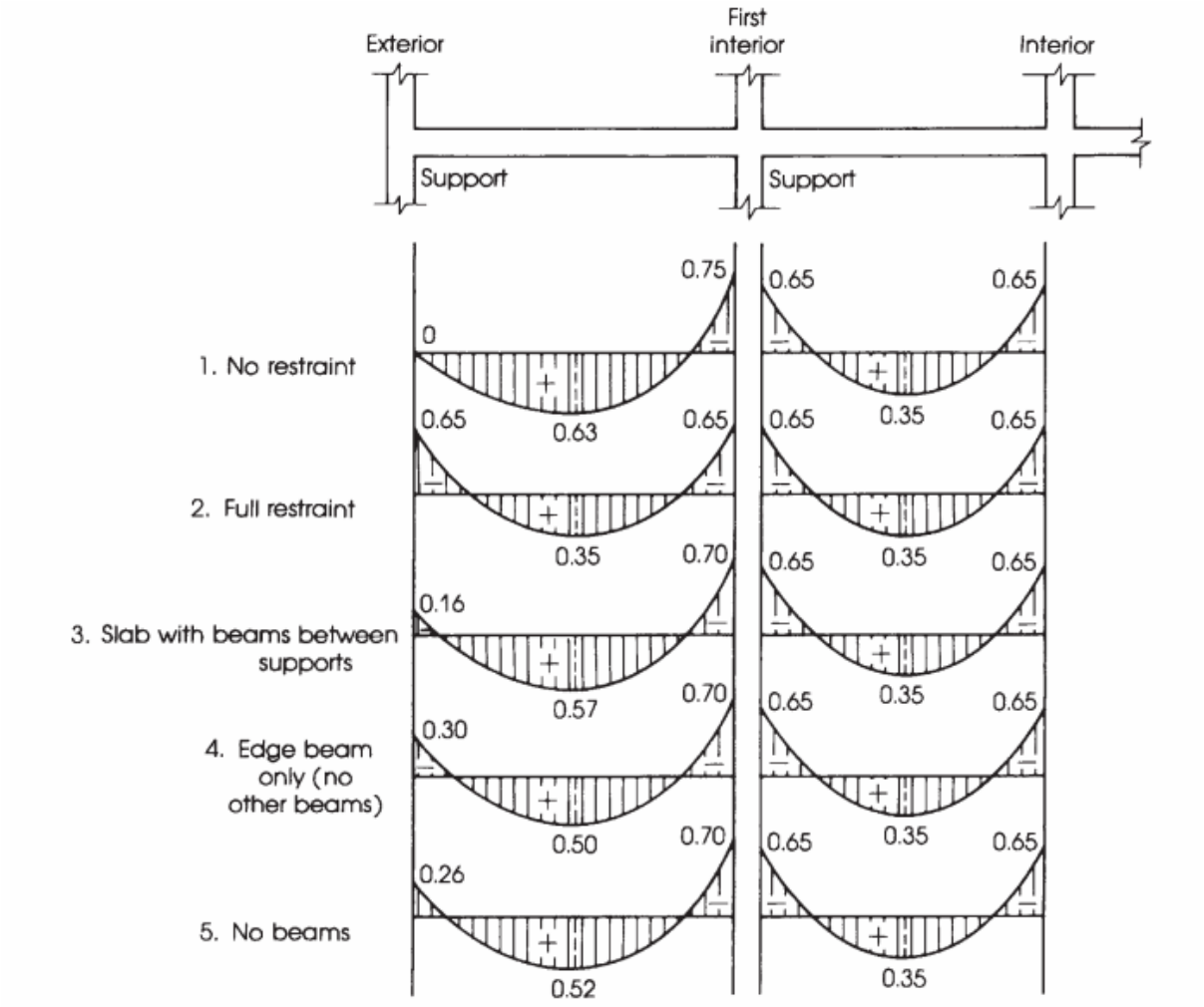

Exterior
First interior
Interior
Support
Support
1. No restraint
2. Full restraint
3. Slab with beams between supports
4. Edge beam only (no other beams)
5. No beams
0.75
0.65
0.65
0
0.65
0.63
0.65
0.65
0.35
0.65
0.35
0.70
0.65
0.35
0.65
0.16
0.57
0.70
0.65
0.35
0.65
0.30
0.50
0.70
0.65
0.35
0.65
0.26
0.52
0.35

Table 6.2 Percent distribution of moments into positive moments and negative moments in an end bay (ACI Code Table 8.10.4.2)

	(1)	(2)	(3)	(4)	(5)
			Slabs without beams between interior supports		
	Exterior edge unrestrained	Slab with beams between all supports	Without edge beam	With edge beam	Exterior edge fully restrained
Interior negative factored moment	0.75	0.70	0.70	0.70	0.65
Positive factored moment	0.63	0.57	0.52	0.50	0.35
Exterior negative factored moment	0	0.16	0.26	0.30	0.65

Table 6.3 Percent of interior negative moments assigned to column strips (ACI Code Table 8.10.5.1)

ℓ_2/ℓ_1	0.5	1.0	2.0
$(\alpha_{f1}\ell_2/\ell_1) = 0$	75	75	75
$(\alpha_{f1}\ell_2/\ell_1) \geq 1.0$	90	75	45

Table 6.4 Percent of positive moments assigned to column strips (ACI Code Table 8.10.5.5)

ℓ_2/ℓ_1	0.5	1.0	2.0
$(\alpha_{f1}\ell_2/\ell_1) = 0$	60	60	60
$(\alpha_{f1}\ell_2/\ell_1) \geq 1.0$	90	75	45

Table 6.5 Percent distribution of negative moment at an exterior column into the column strip (ACI Code Table 8.10.5.2)

ℓ_2/ℓ_1		0.5	1.0	2.0
$(\alpha_{f1}\ell_2/\ell_1) = 0$	$\beta_t = 0$	100	100	100
	$\beta_t \geq 2.5$	75	75	75
$(\alpha_{f1}\ell_2/\ell_1) \geq 1.0$	$\beta_t = 0$	100	100	100
	$\beta_t \geq 2.5$	90	75	45

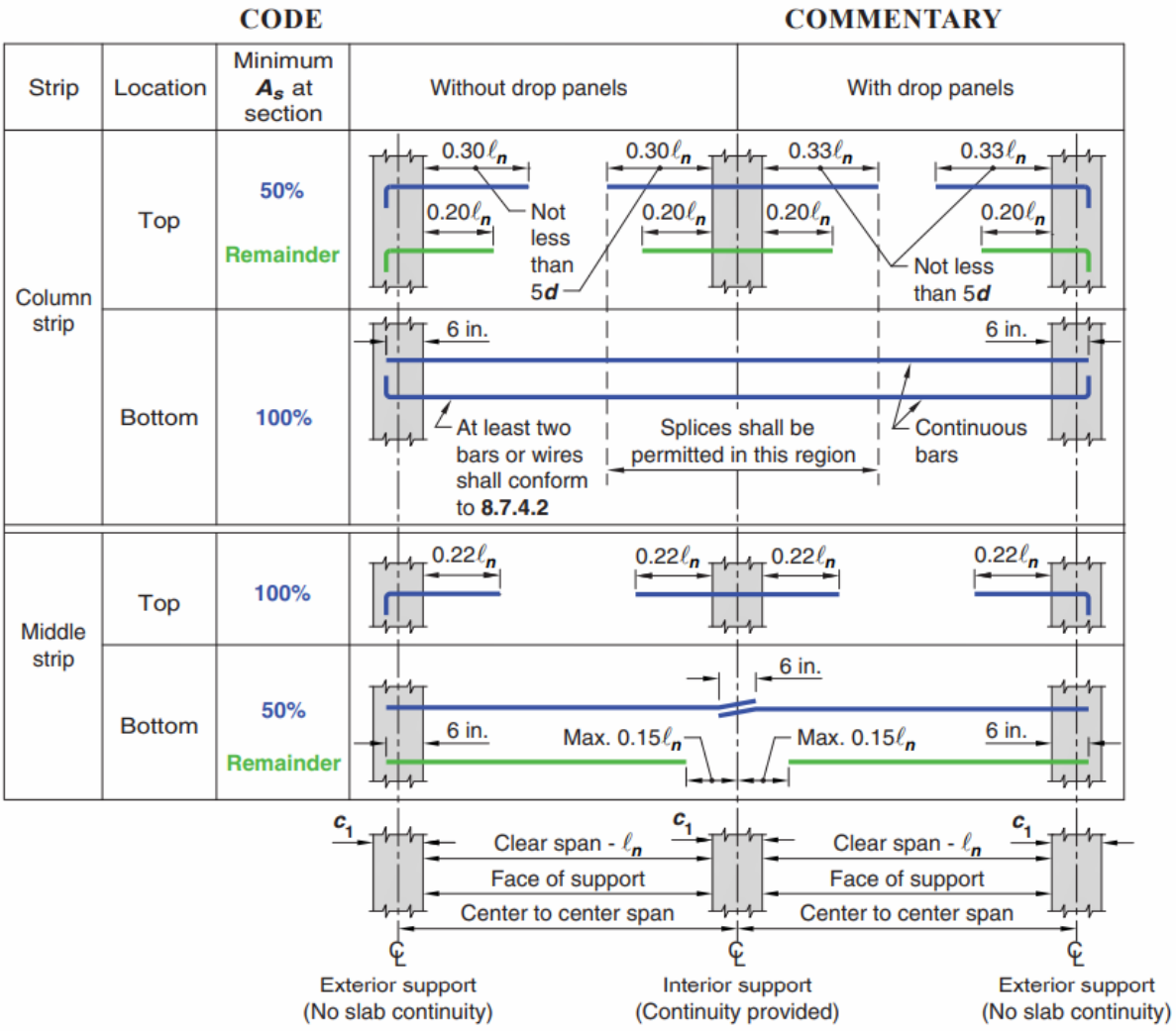


Fig. 8.7.4.1.3—Minimum extensions for deformed reinforcement in two-way slabs without beams.