





Ch. 11 Slab Design (One Way)

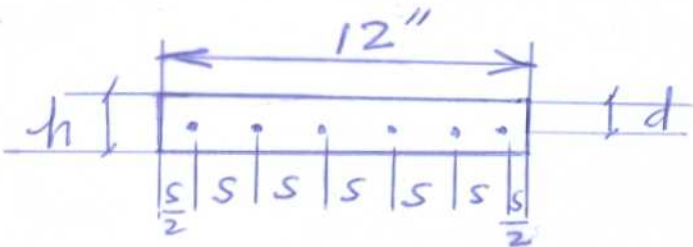
(1) Minimum Slab Thickness

To control excessive deflection, the following slab thicknesses are recommended:

				
h =	L/20	L/24	L/28	L/10

(2) Steel Spacing Formula

The design of a slab will be based on a strip of 12 in. width with a depth h. If S is denote spacing of the reinforcement and N is the Number of bars used in 12" width the one may write the following:



$A_s = a_s N$, a_s is the area of one bar.

$$\rho = \frac{A_s}{bd} = \frac{A_s}{(12)(d)} = \frac{Na_s}{Nsd} = \frac{a_s}{sd}$$

$$\rho = \frac{a_s}{sd}$$

or

$$S = \frac{a_s}{\rho d}$$

(3) Temperature/Shrinkage Steel

To handle stress which may induce due to temperature and shrinkage, steel provided in two directions one is the main steel carrying the load and the other in a direction perpendicular and according to ACI., the reinforcement rates for temperature and shrinkage ρ_t .

$$\rho_t = 0.00020 \text{ for Grade 40 steel}$$

$$\rho_t = 0.0018 \text{ for Grade 60 steel.}$$

and the spacing of the steel should be calculated as $s = \frac{a_s}{\rho_t d}$ but should not be larger than the smaller of (5 h or 18 in.).

(4) Procedure for Slab Design (One Way)

- 1) Compute slab thickness according to the table provided by ACI.
- 2) Compute the total factored load (dead load, self weight, and live load).
- 3) Compute the ultimate moment (M_u) at the ends (negative moment) and the middle (positive moment) using the ACI coefficients.
- 4) Compute the reinforcement ratio:

a) Using table B-2 (from M_u and d), or

b) Get $R = \frac{M_u}{bd^2} = \frac{M_u}{(12)d^2}$ and find $\rho = \frac{1}{m} \left[1 - \sqrt{1 - \frac{2mR}{f_y}} \right]$,

$$m = \frac{f_y}{0.85 f_c'}$$

- 5) Calculate the required spacing $S = \frac{a_s}{\rho d}$.

critical moment values within 10 or 15% of the actual values, more than close enough for preliminary design purposes. Once an approximate moment value is determined, the required cross-sectional dimensions to accommodate that moment safely and economically are found. Other chapters in this book are devoted to procedures and design aids that help achieve this next step in a straightforward manner.

4.5 ACI COEFFICIENTS

The American Concrete Institute (ACI) Code provides some coefficients which can be used in lieu of an indeterminate analysis for buildings of usual construction and commonly encountered load and span conditions. These are provided in Figure 4.18. In most instances they tend to be conservative, and therefore are more appropriate for preliminary design than for use in the final design process. They can be used for continuous slabs or beams, but the Code restricts their use to situations where:

1. Two or more spans exist.
2. Only uniform loads are present.
3. The live load does not exceed three times the dead load.
4. The longer of any two adjacent spans does not exceed the shorter by more than 20%.

In Figure 4.18 the span length L is to be taken as the *clear span* for the positive moment and the *average of two adjacent clear spans* for negative moments. When there are two different coefficients for negative moments on opposite sides of a supporting element, the larger moment should be used for both because only one pattern of negative mo-

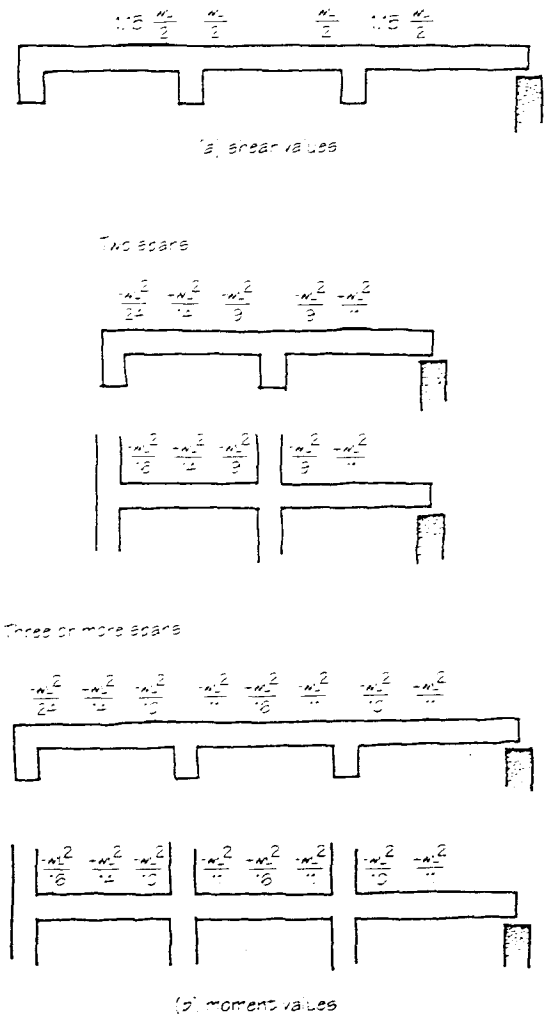


FIGURE 4.18 ACI moment coefficients.

ment steel will be placed across that support when the design is finally executed.

For interior spans the maximum shearing force may be taken as half the span load, i.e., $wL/2$. For an exterior span, however, the

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SLAB DESIGN

11.1 THICKNESS OF ONE-WAY SLABS

The overall thickness of most one-way slabs is established by the American Concrete Institute (ACI) Code provisions for minimum thickness. In lieu of providing accurate deflection computations, the Code indicates that the minimum "thickness of construction" values of Table 11.1 may be used. For many beams the proportions dictated by good design practice and economical construction will result in thicknesses greater than these. However, for slabs this is usually not the case.

A one-way continuous slab spanning 12 ft will have the following thickness if dictated by Table 11.1:

$$h = \frac{12(12)}{28} = 5.14 \approx 5.5 \text{ in}$$





The same span if simply supported rather than continuous will have

$$h = \frac{12(12)}{20} = 7.2 \approx 7.5 \text{ in}$$

11.2 TEMPERATURE/SHRINKAGE STEEL

Concrete elements require reinforcing to be placed for the control of cracks due to temperature and shrinkage stresses wherever reinforcing has not been placed for structural

TABLE 11.1 *Minimum thicknesses*

	<i>Minimum Thickness, h</i>			
				
Solid one-way slabs	L/20	L/24	L/28	L/10
Beams	L/16	L/18.5	L/21	L/8

reasons. In beams and columns plenty of steel exists to handle the temperature and shrinkage stresses as well as stresses from live and dead loads. However, in a one-way slab temperature steel is normally required in the direction perpendicular to the moment steel. It is usually placed between the negative and positive moment steel. The Code requires that ρ_t for temperature/shrinkage be at least as large as

0.0020 for Grade 40 steel

0.0018 for Grade 60 steel

where ρ_t is based upon the full slab thickness

$$\rho_t = \frac{A_s}{bh} \quad (11-1)$$

The Code also requires that bars placed for temperature or shrinkage be no farther apart than the smaller of five times the slab thickness, or 18 in.

11.3 STEEL REQUIREMENTS FOR MOMENT

Knowing that the primary reinforcing steel for slabs is often #4 or #5 bars and the cover requirement for slabs is $\frac{3}{4}$ in clear, it is easy to get an effective depth value. If we assume the use of #4 bars, e.g., in a slab which is 5 in thick, the d value will be 5 in less $\frac{3}{4}$ -in cover less $\frac{1}{4}$ -in bar radius, or 4 in net.

For continuous slabs the ACI coefficients discussed in Chapter 4 are particularly useful. For example, if we can ascertain that the slab in question fits one of the cases in Figure 4.18b, and the design moments can thus be determined, then finding out the amount of steel needed at each crucial moment location is not difficult.

Tables B.2 of the Appendix provide M_r values for a one-foot width of slab for various ρ and d combinations. Three concrete

strengths for each of the two commonly used steel strengths are included. The tables have ρ values below ρ_{\min} for beams because for slabs the minimum amount of flexural steel required is governed by temperature and shrinkage rather than bending, except that moment bars shall be placed no farther apart than the lesser of three times the slab thickness, or 18 in.

Once the ρ needed has been established, it is easy to determine the spacing required to provide the corresponding amount of steel.

Example 11.1 Assume that by using the minimum thickness requirements a certain slab must be at least 6 in thick. If $f'_c = 3000$ psi and $f_y = 40$ ksi, determine the required spacing of #4 bars in order to carry a factored load moment of 4.5 kip-ft.

Solution: The effective depth will be 6 in less $\frac{3}{4}$ in less $\frac{1}{4}$ in, or 5 in. From Table B.2(40/3), for Grade 40 steel and 3000 psi concrete we find that a ρ value of 0.0055 is needed for an M_r of 4.5 kip-ft.

Since for a 12-in width

$$A_s = \rho(12)(d)$$

and knowing that the number of bars in a 12-in width is $12 \div s$, then

$$A_s = \frac{12}{s}(a_s)$$

where $a_s =$ area of one bar.

Setting these two expressions equal to one another gives us

$$s = \frac{a_s}{\rho d} \quad (11-2)$$

Since the area of one #4 bar is 0.20 in², we get

$$\begin{aligned} s &= \frac{0.20}{0.0055(5)} \\ &= 7.3 \text{ (rounding down)} \approx 7 \text{ in} \end{aligned}$$

This is within the Code controls of $3h$, or 18 in, for maximum spacing of moment bars.

Finally, we need to check this result against the requirement for temperature/shrinkage. This is based upon the full thickness, and for Grade 40 steel we must provide a ρ_t of at least 0.0020:

$$s = \frac{a_s}{\rho_t h} \quad (11-3)$$

$$= \frac{0.20}{0.0020(6)}$$

$$= 16.6 \approx 16.5 \text{ in}$$

Since 7 in is less than 16.5 in, the temperature/shrinkage requirement will not govern.

Temperature/shrinkage steel will be required at right angles to the moment steel, of course, and if #4 bars are used, they should be spaced no farther apart than 16.5 in as computed previously. This will also meet the Code maximum of $5h$, or 18 in.

Example 11.2 Determine the required depth and specify the required steel for the three-bay, one-way slab of Figure 11.1. Use $f_y = 40$ ksi steel and 3000 psi concrete. Use #4 bars for all steel parallel to the span and #3 bars for temperature steel in the other direction. The live load is 100 psf and the only dead load is the slab itself.

Solution: The required thickness from Table 11.1 will be

$$h = \frac{12.5(12)}{28} = 5.36 \approx 5.5 \text{ in}$$

Knowing that the required cover is $\frac{3}{4}$ in and using #4 bars, we find that the effective depth will be 4.5 in. The self-weight can be determined as

$$\frac{5.5}{12}(150) = 69 \text{ psf}$$

Therefore, the factored uniform load is

$$w_u = 1.4(69) + 1.7(100)$$

$$= 267 \text{ plf} = 0.267 \text{ klf}$$

Using the ACI coefficients of Figure 4.18b, we see that the tabular format in Table 11.2 is convenient to find the required moment steel. Note that only the larger of the two moments c and d' will be used since the two locations are reinforced by the same steel bars running across the beam. Also, notice that in compliance with the proper use of the coefficients the average of the two span lengths was used in determining that moment.

The Code stipulates a maximum spacing of $3h$, or 18 in for moment steel. The value of $3h$ in this case is 16.5 in. Thus, the spacing at location a should be 16.5 in unless temperature and shrinkage requirements govern.

Checking the temperature/shrinkage requirement in the direction of the span, and using #4 bars and Grade 40 steel, we get

$$s = \frac{a_s}{\rho_t h} \quad (11-3)$$

$$= \frac{0.20}{0.0020(5.5)}$$

$$= 18.2 \approx 18 \text{ in}$$

FIGURE 11.1 Three-bay, one-way slab.

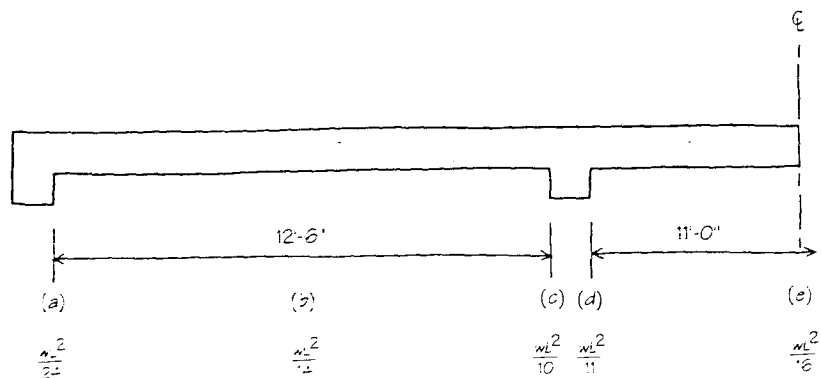


TABLE 11.2

	(a)	(b)	(c)	(e)
	$\frac{wL^2}{24}$	$\frac{wL^2}{14}$	$\frac{wL^2}{10}$	$\frac{wL^2}{16}$
	$\frac{0.267(12.5)^2}{24}$	$\frac{0.267(12.5)^2}{14}$	$\frac{0.267(11.75)^2}{10}$	$\frac{0.267(11)^2}{16}$
M_u (kip-ft)	1.74	2.98	3.68	2.02
ρ [Table B.2(40/3)]	0.0025	0.0045	0.0055	0.0030
$s = \frac{a_s}{\rho d}$	$\frac{0.20}{0.0025(4.5)}$	$\frac{0.20}{0.0045(4.5)}$	$\frac{0.20}{0.0055(4.5)}$	$\frac{0.20}{0.0030(4.5)}$
s (in)	17.8	9.9	8.1	14.8
	≈ 17.5	≈ 9.5	≈ 8.0	≈ 14.5

For temperature steel the maximums are 5h. or 18 in, but in this case moment controls throughout. Using #3 temperature steel in the other direction as specified in the problem statement, we obtain

$$s = \frac{0.11}{0.0020(5.5)} = 10 \text{ in}$$

Figure 11.2 shows how the reinforcing pattern might be established. The Code requires that at least one-fourth the positive moment steel be carried into the support at continuous ends. Since the bars cannot be spaced farther apart than 18 in, it is logical to change the 9.5-in spacing to 9 in for the positive moment steel in the outer spans so that alternate bars could be continued into the support. All of the positive moment steel in the middle span should be continued to the beam.

The reader is referred to the Code directly for the precise details of steel placement.

11.4 BEHAVIOR OF TWO-WAY SLABS

The proper analysis of the forces in two-way slabs is not treated in this basic text and only a brief discussion involving behavior and procedures is included here.

One-way slabs are used when the spacing of beams is relatively small, say, 6 to 16 ft, and the slab panels themselves are almost always rectangular. The slab action carries the loads to the beams, which in turn deposit their reactions as concentrated loads on girders (Figure 3.6).

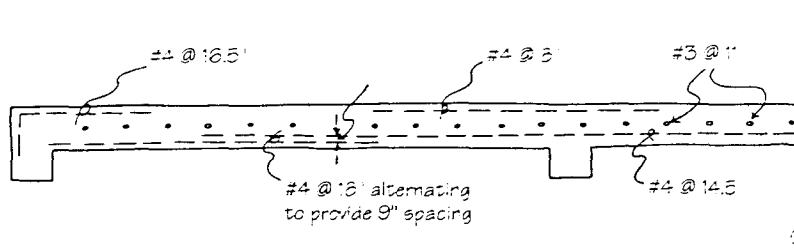
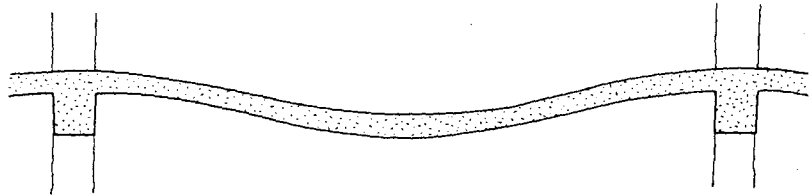


FIGURE 11.2 Steel requirements for Example 11.2.

FIGURE 11.3 Section through the middle of a two-way slab system; columns shown are in the background.



Two-way action develops in slabs that are more square where the beams frame directly into columns at the four corners of the slab (Figure 3.4). For smaller spans the beams can be omitted and the system is then more properly called a flat plate (Figure 3.2). Flat plates and two-way flat slabs behave in much the same manner, except that plate systems have a problem with shear around the base of the columns (punching shear). For this reason flat plates often have a thickened portion in the immediate vicinity of the columns in the form of a *drop panel* or *conical shear head* (Figure 3.3).

Deflection often controls the thickness of two-way slabs, just as with one-way slabs, but the rules for minimum thickness are not nearly so simple. A two-way slab dishes

downward in the middle such that a mid-span section cut through in either direction would appear as in Figure 11.3. (The beam deflections would be relatively small and for clarity are not shown.)

The reinforcement, of course, runs in both primary directions and is located near the bottom of the slab in areas of positive moment (the "dish") and near the top of the slab in areas of negative moment, where the slab passes over beams. This is true whether or not beams actually exist because in their absence the portions of the plate that connect the columns tend to behave like wide shallow beams (see Figure 11.4). These form what are called *column strips*.

For analysis purposes the slab is divided into an orthogonal grid of *column strips* and

FIGURE 11.4 Two-way flat plate.

