where A_b is the area of one bar. (See Table A-9 in Appendix A.) In SI units, (10-5) becomes (see Table A-9M)

$$A_s/\text{m} = A_b\left(\frac{1000 \text{ mm}}{\text{bar spacing in mm}}\right) \tag{10-5M}$$

The maximum spacing of bars in one-way slabs is three times the slab thickness or 18 in., whichever is smaller (ACI Section 7.6.5). The maximum bar spacing is also governed by crack-control provisions, as was discussed in Section 9-3 (ACI Section 10.6.4).

Because a slab is thinner than the beams supporting it, the concrete in the slab shrinks more rapidly than the concrete in the beams. This may lead to shrinkage cracks in the slab. Shrinkage cracks perpendicular to the span will be crossed by flexural reinforcement, which will limit the width of these cracks. To limit the width of shrinkage cracks parallel to the span, additional *shrinkage and temperature reinforcement* is placed perpendicular to the flexural reinforcement. The amount required is specified in ACI Section 7.12, which requires the following ratios of reinforcement area to gross concrete area:

1. Slabs with Grade-40 or -50 deformed bars: 0.0020

2. Slabs with Grade-60 deformed bars or welded-wire fabric (smooth or deformed): 0.0018

3. Slabs with reinforcement with a yield strength, f_y, in excess of 60,000 psi at a yield strain of 0.35 percent: $\dfrac{0.0018 \times 60{,}000}{f_y}$, but not less than 0.0014

Shrinkage and temperature reinforcement is spaced not farther apart than the smaller of five times the slab thickness and 18 in. (ACI Section 7.12.2.2). Splices of such reinforcement must be designed to develop the full yield strength of the bars in tension (ACI Section 7.12.2.3).

It should be noted that shrinkage cracks could be wide even when this amount of shrinkage reinforcement is provided [10-2]. In buildings, this may occur when shear walls, large columns, or other stiff elements restrain the shrinkage and temperature movements. ACI Section 7.12.1.2 states that if shrinkage and temperature movements are restrained significantly, the requirements of ACI Sections 8.2.4 and 9.2.3 shall be considered. These sections ask the designer to make a realistic assessment of the shrinkage deformations and to estimate the stresses resulting from these movements. If the shrinkage movements are restrained completely, the shrinkage and temperature steel will yield at the cracks, resulting in a few wide cracks. About three times the minimum shrinkage and temperature reinforcement specified in ACI Section 7.12 is required to limit the shrinkage cracks to reasonable widths. Alternatively, unconcreted control strips may be left during construction, to be filled in with concrete after the initial shrinkage has occurred. Methods of limiting shrinkage and temperature cracking in concrete structures are reviewed in [10-3]; see also Section 9-3.

ACI Section 10.5.4 specifies that the minimum flexural reinforcement shall be the same as the amount required in ACI Section 7.12 for shrinkage and temperature, except that, as stated previously, the maximum spacing of flexural reinforcement is three times the slab thickness (ACI Section 7.6.5).

Generally, No. 4 and larger bars are used for flexural reinforcement in slabs, since smaller bars or wires tend to be bent out of position by workers walking on the reinforcement during construction. This is more critical for top reinforcement than for bottom reinforcement, because the effective depth, d, of the top steel is reduced if it is pushed down, whereas that of the bottom steel is increased.

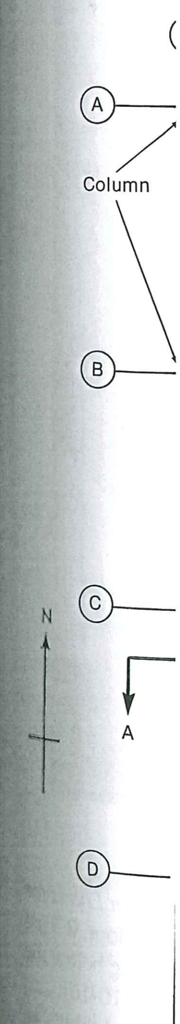


Fig. 10-14
Typical floor plan

Typical interior support:

$$V_u = \frac{277\ \text{lb/ft} \times (166/12)\text{ft}}{2} = 1916\ \text{lb/ft of width}$$

$$\phi V_c = 0.75(2\sqrt{f'_c}\, b_w d)$$

$$= 0.75(2\sqrt{3750} \times 12 \times 6.25) = 6890\ \text{lb/ft}$$

where ACI Section 9.3.2.3 gives $\phi = 0.75$ for shear and torsion.

Since $\phi V_c > V_u$, the slab chosen is adequate for shear. Therefore, **use h = 7.25 in., d = 6.25 in., and w_u = 277 lb/ft^2.** When slab thicknesses are selected on the basis of deflection control (ACI Table 9.5(a)), flexure and shear seldom govern.

7. Design of reinforcement. The calculations are done in Table 10-1 based on a 1-ft strip of slab. First, several constants used in that table must be calculated.

Table 10-1, Line 1 – The clear spans, ℓ_n, were computed as shown in Fig. 10-14.

- End bay, $\ell_n = 157$ in.
- Interior bay, $\ell_n = 166$ in.
- For interior supports, ℓ_n is the average of the two adjacent spans, so $\ell_n = 158.5$ in.

Table 10-1, Lines 2, 3, and 4 – The moments are computed as $M_u = w_n\ell_n^2 \times$ moment coefficient from line 3.

The maximum factored moment has been calculated in line 4, as 5.02 ft-kip/ft. We will calculate the reinforcement required at this location, i.e., at the exterior face of the first interior column, and at the corresponding lever arm, jd, and then use that value of jd at all other critical sections. Since the moment is smaller at all other sections, this value of jd will be on the safe (too small) side and will lead to values of A_s that are slightly too large, again on the safe side. We thus have

Table 10-1, line 5 Use (4-34) and $M_u = 5.02$ ft-kips/ft from line 4.

$$A_s = \frac{M_u}{\phi f_y jd} \qquad (4\text{-}34)$$

For a first trial, assume that $jd = 0.925d$ for a slab. Also assume $\phi = 0.90$ for a tension-controlled section. Therefore,

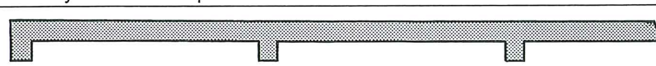
$$A_s = \frac{5.02 \times 12{,}000}{0.9 \times 60{,}000\,(0.925 \times 6.25)}$$

$$= 0.193\ \text{in.}^2/\text{ft}$$

If this is provided exactly,

$$a = \frac{0.193 \times 60{,}000}{0.85 \times 3750 \times 12} = 0.303\ \text{in.}$$

TABLE 10-1 Calculations for One-Way Slab—Example 10-1



Line					
1. ℓ_n, ft	13.08	13.08	13.46	13.83	13.83
2. $(w_u\ell_n^2)$	47.40	47.40	50.18	53.0	53.0
3. M coefficients	1/24	1/14	1/10 1/11	1/16	1/11
4. M_u, ft-kip/ft	1.97	3.39	5.02 ~~4.56~~	3.31	4.82
5. $A_{s(\text{req'd})}$, in.^{2}/ft	~~0.072~~	~~0.123~~	0.183	~~0.120~~	0.175
6. $A_{s(\text{min})}$, in.^{2}/ft	0.157	0.157	~~0.157~~	0.157	~~0.157~~
7. Choose steel	No. 4 @ 12″	No. 4 @ 12″	No. 4 @ 12	No. 4 @ 12″	No. 4 @ 12
8. A_s provided	0.20	0.20	0.20	0.20	0.20

NOTE: 7,12 steel is for either top or bott bar locations

TENSILE!

and

$$jd = d - \frac{a}{2}$$

$$= 6.25 - \frac{0.303}{2} = 6.10 \text{ in.}$$

(Note that $j = \dfrac{6.10}{6.25} = 0.976$ in this case compared with the assumed value of 0.925.)

Becuase the first estimate of A_s was based on a guess of jd, we will recompute the required A_s:

$$A_s(\text{in.}^2/\text{ft}) = \frac{M_u \times 12{,}000}{0.9 \times 60{,}000 \times 6.10}$$

$$= 0.0364 \times M_u \text{ (ft-kips/ft)}$$

The area of steel required at any section will be computed as $A_s(\text{in.}^2/\text{ft}) = 0.0364 \times M_u$ (ft-kips/ft). At the first interior support, this gives $A_s = 0.183$ in.^{2}/ft.

Table 10-1, Line 6 Compute the minimum flexural reinforcement, using ACI Section. 10.5.4, which refers to ACI Section 7.12 for amount and spacing:

$$A_{s(\min)} = 0.0018bh$$

$$= 0.0018 \times 12 \text{ in.} \times 7.25 \text{ in.}$$

$$= 0.157 \text{ in.}^2/\text{ft}$$

For maximum spacing, ACI Section 7.6.5 gives $3h = 21.75$ in., but not more than 18 in. Therefore, maximum spacing $= 18$ in.

8. Check reinforcement spacing for crack control. To control the width of cracks on the tension face of the slab, ACI Section 10.6.4 limits the maximum spacing of the flexural reinforcement closest to the tension face of the slab to

$$s = \frac{540}{f_s} - 2.5\,c_c, \quad \text{but not more than } 12\left(\frac{36}{f_s}\right) \text{ in.} \tag{10-7}$$

(ACI Eq. 10-5)

where f_s is the stress in the tension steel in ksi, which can be taken as $0.6f_y = 36$ ksi, and c_c is the clear cover from the tension face of the slab to the surface of the reinforcement nearest to it, taken as 0.75 in. from ACI Section 7.7.1(c), together giving

$$s = \frac{540}{0.6 \times 60} - 2.5 \times 0.75 \text{ in.} = 13.1 \text{ in., but not more than } 12\left(\frac{36}{36}\right) \text{ in.} = 12 \text{ in.}$$

This overrides the 18-in. maximum spacing selected in the previous step in the design.

9. Select the top and bottom flexural steel. The remaining flexural calculations are given in Table 10-1. The choice of the reinforcement in line 7 of this table is made by using (10-5) or Table A-9. The resulting steel arrangement is shown in Fig. 10-17. The cutoff points have been computed by using Fig. A-5c, since the slab geometry allowed the use of the ACI moment coefficients.

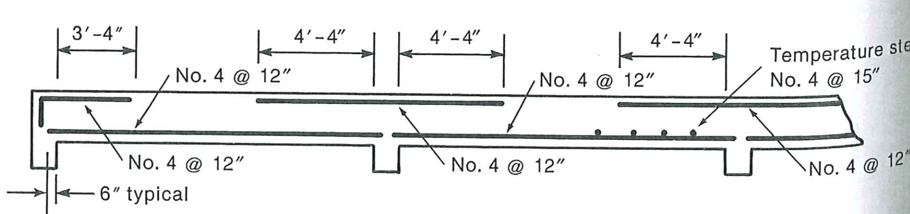


Fig. 10-17 Reinforcement—Example 10-1.