

Details of Reinforcement

ACI 318 Chapter 25.2 Placement of Reinforcement

- Cover (ACI 20.6.1)
- Horizontal spacing in beams, s_h (ACI 25.2.1)

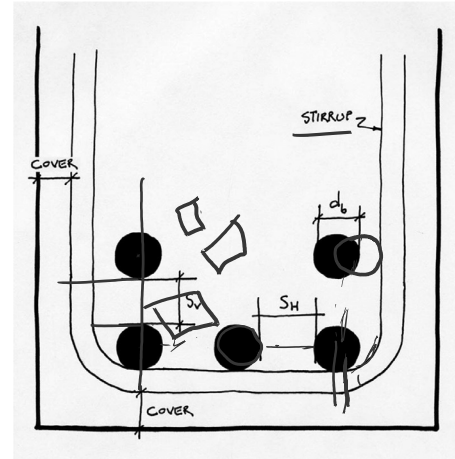
$$\frac{1 \text{ inch}}{\frac{d_b}{4/3 d_{agg,max}}}$$
- Vertical spacing in beams (ACI 25.2.2)
Min 1 inch



<https://www.constructioncost.co/honeycombing-in-concrete.html>

Table 20.6.1.3.1—Specified concrete cover for cast-in-place nonprestressed concrete members

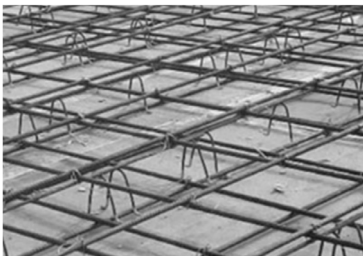
Concrete exposure	Member	Reinforcement	Specified cover, in.
Cast against and permanently in contact with ground	All	All	3
Exposed to weather or in contact with ground	All	No. 6 through No. 18 bars	2
		No. 5 bar, W31 or D31 wire, and smaller	1-1/2
Not exposed to weather or in contact with ground	Slabs, joists, and walls	No. 14 and No. 18 bars No. 11 bar and smaller	1-1/2 3/4
	Beams, columns, pedestals, and tension ties	Primary reinforcement, stirrups, ties, spirals, and hoops	1-1/2



Details of Reinforcement

ACI 318 Chapter 25 Placement of Reinforcement

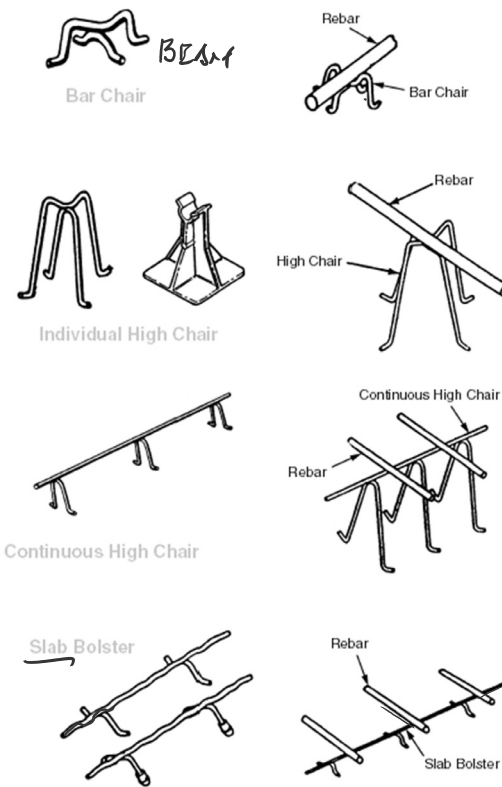
- Chairs
- Bolsters



<https://catalog.formtechinc.com>



<http://contractorsupplymagazine.com>



Details of Reinforcement

ACI 318 Chapter 25

Minimum bend diameter

- factor x d_b

Hooks for bars in tension

- ACI Table 25.3.1
- Inside diameter

Bends for stirrups

- ACI Table 25.3.2

Table 25.3.1—Standard hook geometry for development of deformed bars in tension

Type of standard hook	Bar size	Minimum inside bend diameter, in.	Straight extension ¹⁾ ℓ_{ext} , in.	Type of standard hook
90-degree hook	No. 3 through No. 8	$6d_b$	$12d_b$	
	No. 9 through No. 11	$8d_b$		
	No. 14 and No. 18	$10d_b$		
180-degree hook	No. 3 through No. 8	$6d_b$	Greater of $4d_b$ and 2.5 in.	
	No. 9 through No. 11	$8d_b$		
	No. 14 and No. 18	$10d_b$		

¹⁾A standard hook for deformed bars in tension includes the specific inside bend diameter and straight extension length. It shall be permitted to use a longer straight extension at the end of a hook. A longer extension shall not be considered to increase the anchorage capacity of the hook.

Table 25.3.2—Minimum inside bend diameters and standard hook geometry for stirrups, ties, and hoops

Type of standard hook	Bar size	Minimum inside bend diameter, in.	Straight extension ¹⁾ ℓ_{ext} , in.	Type of standard hook
90-degree hook	No. 3 through No. 5	$4d_b$	Greater of $6d_b$ and 3 in.	
	No. 6 through No. 8	$6d_b$	$12d_b$	
135-degree hook	No. 3 through No. 5	$4d_b$	Greater of $6d_b$ and 3 in.	
	No. 6 through No. 8	$6d_b$		
180-degree hook	No. 3 through No. 5	$4d_b$	Greater of $4d_b$ and 2.5 in.	
	No. 6 through No. 8	$6d_b$		

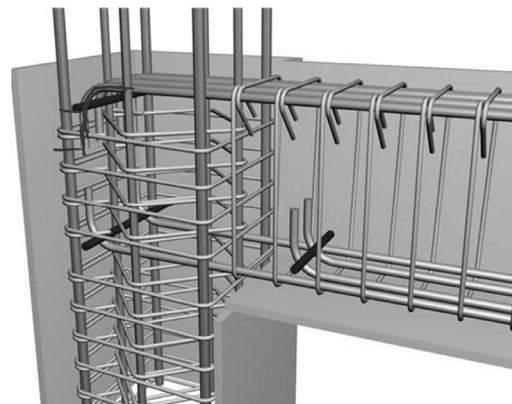
¹⁾A standard hook for stirrups, ties, and hoops includes the specific inside bend diameter and straight extension length. It shall be permitted to use a longer straight extension at the end of a hook. A longer extension shall not be considered to increase the anchorage capacity of the hook.

Details of Reinforcement

ACI 318 Chapter 25

Development length of bars

- 12" min
- Based on table 25.4.2.2



<https://www.buildinghow.com>

Table 25.4.2.4—Modification factors for development of deformed bars and deformed wires in tension

Modification factor	Condition	Value of factor
Lightweight λ	Lightweight concrete	0.75
	Lightweight concrete, where f_{cr} is specified	In accordance with 19.2.4.3
	Normalweight concrete	1.0
Epoxy ¹⁾ $\frac{\psi_e}{\psi_c}$	Epoxy-coated or zinc and epoxy dual-coated reinforcement with clear cover less than $3d_b$ or clear spacing less than $6d_b$	1.5
	Epoxy-coated or zinc and epoxy dual-coated reinforcement for all other conditions	1.2
	Uncoated or zinc-coated (galvanized) reinforcement	1.0
Size ψ_s	No. 7 and larger bars	1.0
	No. 6 and smaller bars and deformed wires	0.8
Casting position ¹⁾ ψ_t	More than 12 in. of fresh concrete placed below horizontal reinforcement	1.3
	Other	1.0

¹⁾The product $\psi_s \psi_t$ need not exceed 1.7.

Table 25.4.2.2—Development length for deformed bars and deformed wires in tension

Spacing and cover	No. 6 and smaller bars and deformed wires	No. 7 and larger bars
Clear spacing of bars or wires being developed or lap spliced not less than d_b , clear cover at least d_b , and stirrups or ties throughout ℓ_d not less than the Code minimum or Clear spacing of bars or wires being developed or lap spliced at least $2d_b$ and clear cover at least d_b	$\left(\frac{f_y \psi_s \psi_e}{25 \lambda \sqrt{f'_c}} \right) d_b$	$\left(\frac{f_y \psi_s \psi_e}{20 \lambda \sqrt{f'_c}} \right) d_b$
Other cases	$\left(\frac{3 f_y \psi_s \psi_e}{50 \lambda \sqrt{f'_c}} \right) d_b$	$\left(\frac{3 f_y \psi_s \psi_e}{40 \lambda \sqrt{f'_c}} \right) d_b$

Other Useful Tables:

Table A.1 Values of Modulus of Elasticity for Normal-Weight Concrete

Customary Units		SI Units	
f'_c (psi)	E_c (psi)	f'_c (MPa)	E_c (MPa)
3,000	3,140,000	20.7	21 650
3,500	3,390,000	24.1	23 373
4,000	3,620,000	27.6	24 959
4,500	3,850,000	31.0	26 545
5,000	4,050,000	34.5	27 924

Jack C McCormac, 1978, *Design of Reinforced Concrete*.

Table A.2 Designations, Areas, Perimeters, and Weights of Standard Bars

Bar No.	Customary Units			SI Units		
	Diameter (in.)	Cross-sectional Area (in. ²)	Unit Weight (lb/ft)	Diameter (mm)	Cross-sectional Area (mm ²)	Unit Weight (kg/m)
3	0.375	0.11	0.376	9.52	71	0.560
4	0.500	0.20	0.668	12.70	129	0.994
5	0.625	0.31	1.043	15.88	200	1.552
6	0.750	0.44	1.502	19.05	284	2.235
7	0.875	0.60	2.044	22.22	387	3.042
8	1.000	0.79	2.670	25.40	510	3.973
9	1.128	1.00	3.400	28.65	645	5.060
10	1.270	1.27	4.303	32.26	819	6.404
11	1.410	1.56	5.313	35.81	1006	7.907
14	1.693	2.25	7.650	43.00	1452	11.384
18	2.257	4.00	13.600	57.33	2581	20.238

Table A.4 Areas of Groups of Standard Bars (in.²)

Bar No.	Number of Bars												
	2	3	4	5	6	7	8	9	10	11	12	13	14
4	0.39	0.58	0.78	0.98	1.18	1.37	1.57	1.77	1.96	2.16	2.36	2.55	2.75
5	0.61	0.91	1.23	1.53	1.84	2.15	2.45	2.76	3.07	3.37	3.68	3.99	4.30
6	0.88	1.32	1.77	2.21	2.65	3.09	3.53	3.98	4.42	4.86	5.30	5.74	6.19
7	1.20	1.80	2.41	3.01	3.61	4.21	4.81	5.41	6.01	6.61	7.22	7.82	8.42
8	1.57	2.35	3.14	3.93	4.71	5.50	6.28	7.07	7.85	8.64	9.43	10.21	11.00
9	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	11.00	12.00	13.00	14.00
10	2.53	3.79	5.06	6.33	7.59	8.86	10.12	11.39	12.66	13.92	15.19	16.45	17.72
11	3.12	4.68	6.25	7.81	9.37	10.94	12.50	14.06	15.62	17.19	18.75	20.31	21.87
14	4.50	6.75	9.00	11.25	13.50	15.75	18.00	20.25	22.50	24.75	27.00	29.25	31.50
18	8.00	12.00	16.00	20.00	24.00	28.00	32.00	36.00	40.00	44.00	48.00	52.00	56.00

Rectangular Beam Design

Two approaches:

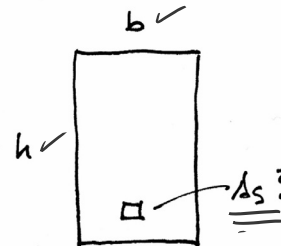
Method 1:

Data:

- Load and Span
- Material properties – f'_c , f_y
- All section dimensions: h and b

Required:

- Steel area – A_s



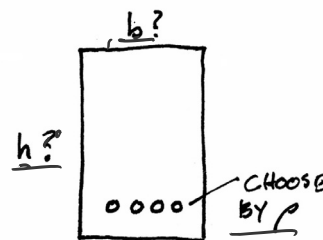
Method 2:

Data:

- Load and Span
- Some section dimensions – h or b
- Material properties – f'_c , f_y
- Choose ρ

Required:

- Steel area – A_s
- Beam dimensions – b or h



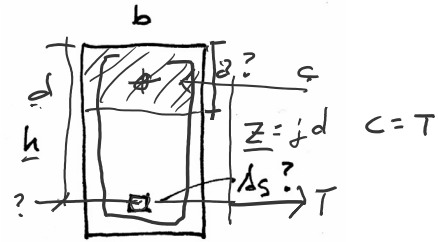
Rectangular Beam Design – Method 1

Data:

- Load and Span ✓
- Material properties – f'_c, f_y ✓
- All section dimensions – b and h ✓

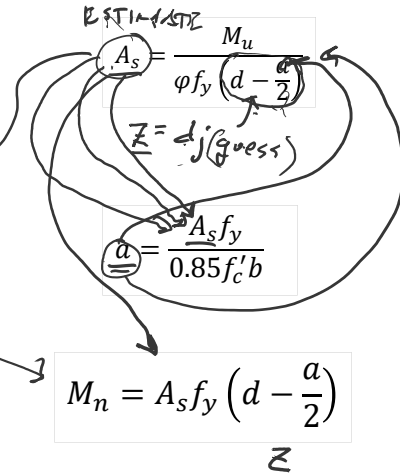
Required:

- Steel area – A_s



1. Calculate the factored load and find factored required moment, M_u REQUIRED ✓
2. Find $d = h - \text{cover} - \text{stirrup} - d_b/2$ *Bed 1-15*
3. Estimate moment arm $z = jd$, for beams $j \approx 0.9$ for slabs $j \approx 0.95$ ✓
4. Estimate A_s based on estimate of jd .
5. Use A_s to find a
6. Use a to find A_s (repeat...until **2%** accuracy)
7. Choose bars for A_s and check A_s max & min
8. Check that $\epsilon_t \geq 0.005$
9. Check $M_u \leq \phi M_n$ (final condition)
10. Design shear reinforcement (stirrups) ✓
11. Check deflection, crack control, rebar development length ✓

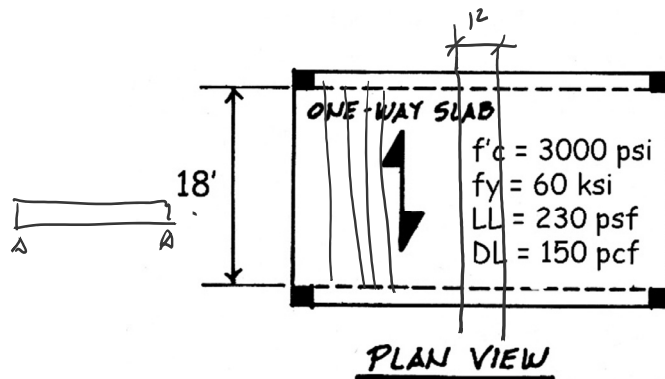
$$M_u = \frac{(Y_{DL}W_{DL} + Y_{LL}W_{LL})l^2}{8}$$



One-way Slab Design Method 1

Data:

- Load and Span
- Material properties – f'_c, f_y
- All section dimensions:
- h (based on deflection limit)
- $b = \text{typical } 12'' \text{ width}$



Required:

- Steel area – A_s

ACI

Table 7.3.1—Minimum thickness of solid nonprestressed one-way slabs

Support condition	Minimum $h^{(1)}$
Simply supported	$l/20$
One end continuous	$l/24$
Both ends continuous	$l/28$
Cantilever	$l/10$

First estimate the slab thickness, h .

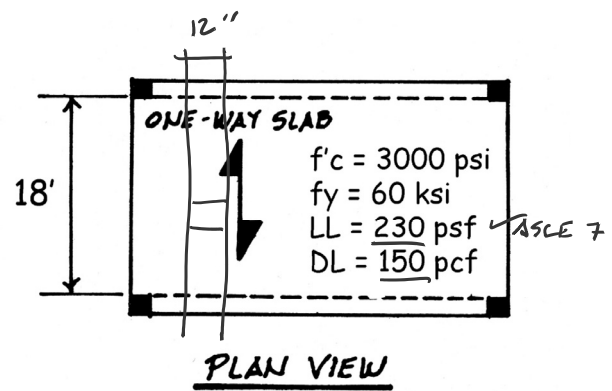
Try first the recommended minimum.

Deeper sections require less steel, but of course more concrete.

THICKNESS, h , BASED ON DEFLECTION

$$h = \frac{l}{20} = \frac{18' \times 12}{20} = 10.8'' \text{ USE } 11''$$

One-way Slab Slab Design



1. Calculate the dead load and find required M_u

FACTOR LOADS

$$DL = \frac{11''}{12} (150) = 137.5 \text{ PSF}$$

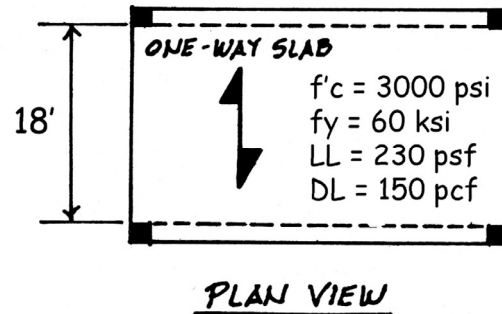
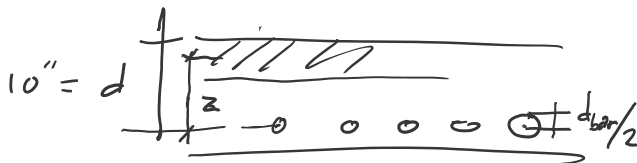
$$LL \text{ (GIVEN)} = 230 \text{ PSF}$$

$$w_u = 1.2(137.5) + 1.6(230) = 533 \text{ PSF} = \text{PLF}$$

$$M_u = \frac{w_u l^2}{8} = \frac{533 \text{ PLF} (18')^2}{8} = 21,587 \text{ ft-lb}$$

$$\phi M_n = 259 \text{ ft-k}$$

One-way Slab Slab Design



2. Find d based on the estimated h and rebar size (guessing #4)

For $j \approx 0.95$, $d = h - \overset{\text{INSIDE}}{\text{COVER}} - \frac{1}{2} \text{ BAR}$

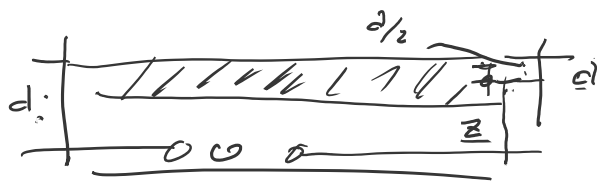
$$d = 11'' - \frac{3}{4}'' - \frac{1}{2} \left(\frac{1}{2} \right)''$$

$$d = 11'' - 1'' = 10''$$

3. Estimate moment arm $z \approx 0.95 d$

$$z \approx j d \approx 0.95 (10'') = 9.5'' \text{ ESTIMATE}$$

One-way Slab Slab Design



4. Estimate A_s based on estimate of z

5. Use A_s to find a

6. Use a to find A_s (repeat...)

TRIAL 1

$$A_s = \frac{M_u}{\phi f_y (z)} = \frac{259 \text{ in}^2\text{-k}}{0.9 (60 \text{ KSI}) (9.5 \text{ in})} = 0.505 \text{ in}^2$$

REQ.

$$a = \frac{A_s f_y}{.85 f_c' b} = \frac{0.505 (60)}{.85 (3) (12)} = 0.99 \text{ in}$$

Guess

TRIAL 2

$$A_s = \frac{M_u}{\phi f_y (z)} = \frac{259}{0.9 (60) (10 - \frac{.99}{2})}$$

$$A_s = 0.5046 \text{ in}^2 \quad \text{WITHIN 2\%}$$

$$0.505$$

One-way Slab Slab Design

7. Choose bars for A_s required:

either

choose bars and calculate spacing
or

choose spacing and find bar size
If the bar size changes, re-calculate to find new d . Then, re-calculate A_s ...

Check $A_{s,min}$

(for slabs $A_{s,min}$ from ACI Table 7.6.1.1)

CHOOSE BARS

USING #4

$$A_s = 0.505 \text{ in}^2$$

$$\frac{0.505}{12 \text{ in}} \cdot 12 \text{ in} = 0.2 \text{ bars/ft}$$

$$s = 4.75 \text{ in} \rightarrow 4 \text{ in o.c.}$$

\therefore USE 4" o.c. (always round down)

$$A_s = 0.60 \text{ in}^2/\text{FT} > 0.505 \checkmark$$

ALTERNATE FOR MAX. S = 18" MAX

$$\frac{0.505}{12 \text{ in}} ; \frac{A_b}{18 \text{ in}} ; A_b = 0.75 \text{ in}^2$$

$$\#8 = 0.79 \checkmark$$

\therefore USE #8 @ 18" o.c.

$$A_s = 0.526 \text{ in}^2/\text{FT} > 0.505 \checkmark$$

Table 7.6.1.1— $A_{s,min}$ for nonprestressed one-way slabs

Reinforcement type	f_y , psi	$A_{s,min}$
Deformed bars	< 60,000	$0.0020A_g$
Deformed bars or welded wire reinforcement	$\geq 60,000$	Greater of: $\frac{0.0018 \times 60,000}{f_y} A_g$ $0.0014A_g$

Check $A_{s,min}$

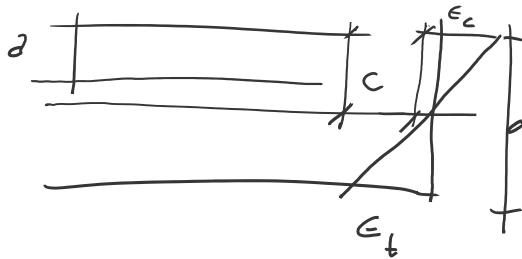
$$A_{s,min} = 0.0018 \frac{A_g}{b \times h} = 0.0018 (12) (11 \text{ in})$$

$$= 0.24 \text{ in}^2 < 0.526 \text{ in}^2 \checkmark \text{ OK}$$

0.60 \checkmark

One-way Slab Slab Design

8. Check that $\epsilon_t \geq 0.005$



RE-CALC 2 FOR $A_s = 0.6 \text{ m}^2/\text{ft}$

$$a = \frac{A_s f_y}{0.85 F'_c b} = \frac{0.6(60)}{0.85(3)(12)} = 1.176''$$

$$c = \frac{a}{\beta_1} = \frac{1.176}{0.85} = 1.384''$$

$$\epsilon_t = \frac{d - c}{c} 0.003 = \frac{9.5'' - 1.384''}{1.384''} 0.003 = 0.01759$$

$$0.01759 > 0.005$$

\therefore TENSION CONTROLLED \checkmark

One-way Slab Slab Design

9. Check $M_u \leq \phi M_n$
(final condition)

$$A_s = A_{s, \text{used}}$$

$$M_n = Tz$$

$$M_n = A_s F_y \left(d - \frac{a}{2} \right)$$

$$M_n = 0.6(60) \left(9.5'' - \frac{1.176}{2} \right)$$

$$M_n = 36(8.911'') = 320.8 \text{ K-''}$$

$$\phi M_n = 0.9(320.8) = 288.7 \text{ K-''}$$

10. Add stirrups (no stirrups in slab)

$$M_u = 259 \text{ K-''} < 288.7 \text{ K-''}$$

$$M_u < \phi M_n \checkmark \text{ OK}$$

11. Check deflection, crack control,
and rebar development length