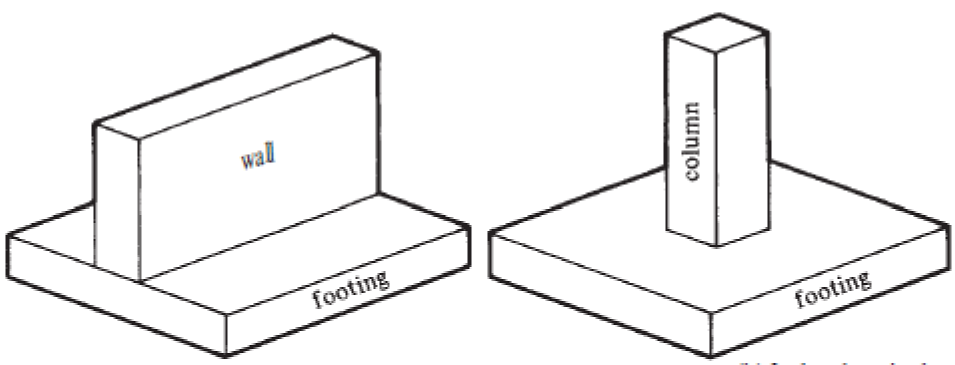
Footings are structural members used to support columns and walls and transmit their loads to the underlying soils. The closer a foundation is to the ground surface, the more economical it will be to construct.

Types of Footings

Among the several types of reinforced concrete footings in common use are the wall, isolated, combined, raft, and pile-cap types. These are briefly introduced in this section; the remainder of the chapter is used to provide more detailed information about the simpler types of this group.

1. A *wall footing*, as shown in Figure (a), is simply an enlargement of the bottom of a wall that will sufficiently distribute the load to the foundation soil. Wall footings are normally used around the perimeter of a building and perhaps for some of the interior walls.

2. An *isolated or single-column footing*, as shown in Figure (b), is used to support the load of a single column. These are the most commonly used footings, particularly where the loads are relatively light and the columns are not closely spaced.



(a) Wall footing

(b) Isolated or single-column footing

Design of Wall footing:

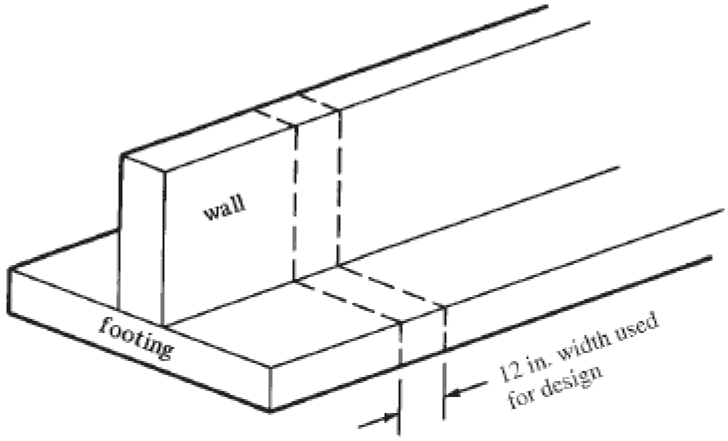


FIGURE 12.5 One-foot design strip width for wall footing.

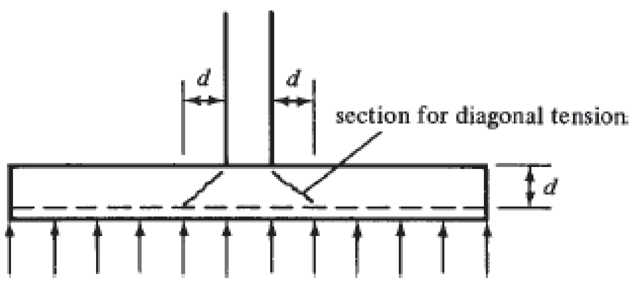
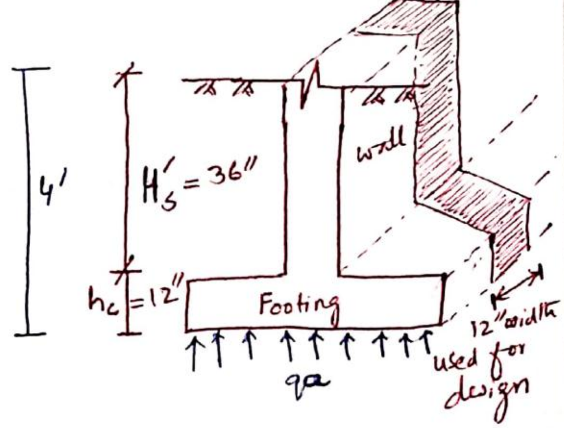


FIGURE 12.4 Critical section for shear in a wall footing.

Wall Footing:-

Design a wall footing to support a 12" wide reinforced concrete wall with a dead load D= 20k/ft and a live load L= 15 k/ft. The bottom of the footing is to be 4' below the final grade, the soil weighs 100 lb/ft³, the allowable soil pressure q_a is 4 ksf and there is no appreciable sulfur content in the soil, $f_y = 60$ ksi and $f_c' = 3$ ksi, normal weight concrete.



Given data:-

$D = 20\ k/ft$

$L = 15\ k/ft$

$\gamma_s = 100\ lb/ft^3$

$q_a = 4\ ksf = 4000\ psf$

$f_c' = 3\ ksi = 3000\ psi$

$f_y = 60\ ksi = 60{,}000\ psi$

$H_s' = 4' - h_c$

Assumed Data:-

$\gamma_c = 150\ lb/ft^3$

$h_c = 12 in$

$d = 12 - 3.5 = 8.5 in$ (The cover is referred to code 7.7.1 which says that for concrete permanently exposed to the earth soil a minimum of 3" - 4" cover is required)

Solution:-

$H_s' = 4' - h_c$

$H_s' = 4' - \frac{12}{12}$

$(H_s' = 3')$

Step 1:- Effective soil pressure "q_e"

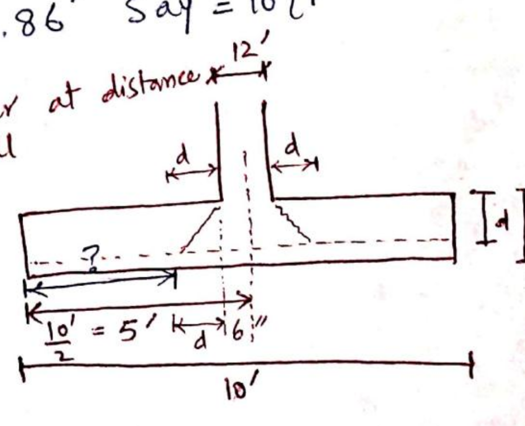
$$q_e = q_a - h_c\gamma_c - H_s'\gamma_s = 4000 - \left(\frac{12''}{12} \times 150\right) - (3 \times 100)$$

$$\boxed{q_e = 3550\ psf} = 3.55\ ksf$$

Step 2:- width of footing required

$$W = \frac{D+L}{q_e} = \quad W = \frac{20+15}{3.55} \Rightarrow W = 9.86' \text{ Say } = 10\ ft$$

Step 3:- d = Depth required for shear at distance d for the face of wall



$$d = \frac{V_u}{\phi\, 2\sqrt{f_c'}\, b_w}$$

$$V_u = \left(\frac{10}{2} - \frac{6}{12} - \frac{8.5}{12}\right) \times q_u$$

q_u = Ultimate Bearing Capacity $\quad q_u = \dfrac{1.2D + 1.6L}{\text{width of footing}}$

$q_u = \dfrac{1.2 \times 20 + 1.6 \times 15}{10}$

$\boxed{q_u = 4.80 \text{ ksf}}$

Now $V_u = \left(\dfrac{10}{2} - \dfrac{6}{12} - \dfrac{8.5}{12}\right) \times 4.80$

$\boxed{V_u = 18.20 \text{K}} = 18200 \text{ lb}$

$d = \dfrac{V_u}{\phi 2 \sqrt{f_c'} b_w} = \dfrac{18200}{0.75 \times 2 \sqrt{3000} \times 12}$

$\boxed{d = 18.46''}$

$h = d + \text{Cover} = 18.46'' + 3.5 \text{ in} = \boxed{21.96 > 12 \text{in}}$

Actual > Assumed [N-OK]

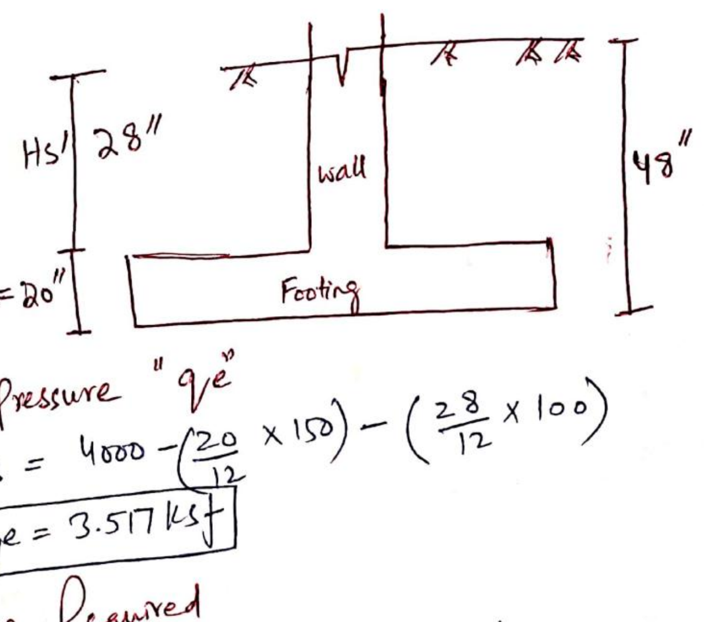
Revise Try with greater

Assume 20" Footing

$h = 20''$

$d = 20 - 3.5 = 16.5''$

Repeating step 1, 2 and 3



Step 1:- Effective Soil Pressure "qe"

$q_e = q_a - h_c \gamma_c - H_s' \gamma_s = 4000 - \left(\dfrac{20}{12} \times 150\right) - \left(\dfrac{28}{12} \times 100\right)$

$q_e = 3517 \text{ psf} = \boxed{q_e = 3.517 \text{ ksf}}$

Step 2:- Width of footing Required

$W = \dfrac{D + L}{q_e} = \dfrac{20 + 15}{3.517} = 9.95'$ Say $10'$

Step 3:- depth Required for shear

$V_u = \left(\dfrac{10}{2} - \dfrac{6}{12} - \dfrac{16.50}{12}\right) \times q_u$

$V_u = \left(\dfrac{10}{2} - \dfrac{6}{12} - \dfrac{16.5}{12}\right) \times 4.80$

$\boxed{V_u = 15 \text{K}}$

$q_u = \dfrac{1.2D + 1.6L}{\text{width}}$

$q_u = \dfrac{1.2 \times 20 + 1.6 \times 15}{10}$

$\boxed{q_u = 4.80 \text{ ksf}}$

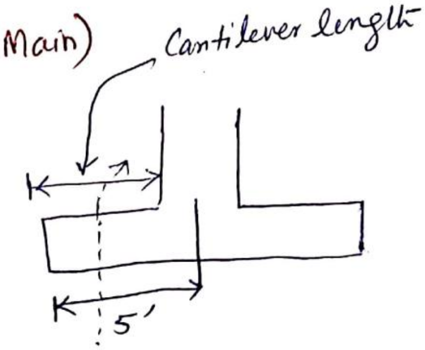
$$d = \frac{V_u}{\phi 2\sqrt{f_c'}\, b_w} = \frac{15000}{0.75 \times 2 \times \sqrt{3000} \times 12} = 15.21''$$

$$h = 15.21 + 3.5 = 18.71 \text{ in}$$

Use 20 inch total depth

$h = 20''$
$d = 16.5''$

Step 4:- Determination of Steel Area (Main)



$$\text{Cantilever length} = \frac{10}{2} - \frac{6}{12} = 4.50 \text{ ft}$$

$$M_u = (\text{Cantilever length}) \times q_u \times \tfrac{1}{2} \text{ L. Arm}$$

$$M_u = 4.50 \times 4.80 \times \frac{4.50}{2}$$

$$\boxed{M_u = 48.6 \text{ ft-K}}$$

$$\frac{M_u}{\phi b d^2} = \frac{48.6 \times 1000 \times 12}{0.9 \times 12 \times (16.5)^2} = 198.3 \text{ psi}$$

Refeering to Appendix A Table A.12

when $\dfrac{M_u}{\phi b d^2} = 198.3$

then by interpolation $\rho = 0.00345$

	$\frac{M_u}{\phi b d^2}$	ρ
x_1	195.8	0.0034 y_1
x_2	198.3	? y_2
x_3	201.3	0.0035 y_3

$$y_2 = \frac{(x_2 - x_1)(y_3 - y_1)}{(x_3 - x_1)} + y_1$$

$$y_2 = \frac{(198.3 - 195.8)(0.0035 - 0.0034)}{201.3 - 195.8} + 0.0034$$

$$\boxed{y_2 = 0.00345}$$

$$A_s = \rho b d = 0.00345 \times 12 \times 16.5$$

$\boxed{A_s = 0.68 \text{ in}^2}$ Refer to table A.6

using #7 bar @ 10" c/c spacing

$$\boxed{A_{s\,selected} = 0.72 \text{ in}^2}$$

TABLE A.12 $f_y = 60{,}000$ psi; $f'_c = 3000$ psi—U.S. Customary Units

	ρ	$\frac{M_u}{\phi bd^2}$	ρ	$\frac{M_u}{\phi bd^2}$	ρ	$\frac{M_u}{\phi bd^2}$	ρ	$\frac{M_u}{\phi bd^2}$
ρ_{min} for	0.0018	105.7	0.0048	271.7	0.0078	424.9	0.0108	565.4
temp. and	0.0019	111.5	0.0049	277.0	0.0079	429.8	0.0109	569.9
shrinkage	0.0020	117.2	0.0050	282.3	0.0080	434.7	0.0110	574.3
	0.0021	122.9	0.0051	287.6	0.0081	439.5	0.0111	578.8
	0.0022	128.6	0.0052	292.9	0.0082	444.4	0.0112	582.3
	0.0023	134.3	0.0053	298.1	0.0083	449.2	0.0113	587.6
	0.0024	139.9	0.0054	303.4	0.0084	454.0	0.0114	592.0
	0.0025	145.6	0.0055	308.6	0.0085	458.8	0.0115	596.4
	0.0026	151.2	0.0056	313.8	0.0086	463.6	0.0116	600.7
	0.0027	156.9	0.0057	319.0	0.0087	468.4	0.0117	605.1
	0.0028	162.5	0.0058	324.2	0.0088	473.2	0.0118	609.4
	0.0029	168.1	0.0059	329.4	0.0089	477.9	0.0119	613.7
	0.0030	173.7	0.0060	334.5	0.0090	482.6	0.0120	618.0
	0.0031	179.2	0.0061	339.7	0.0091	487.4	0.0121	622.3
	0.0032	184.8	0.0062	344.8	0.0092	492.1	0.0122	626.6
ρ_{min} for	0.0033	190.3	0.0063	349.9	0.0093	496.8	0.0123	630.9
flexure	0.0034	195.8	0.0064	355.0	0.0094	501.4	0.0124	635.1
	0.0035	201.3	0.0065	360.1	0.0095	506.1	0.0125	639.4
	0.0036	206.8	0.0066	365.2	0.0096	510.7	0.0126	643.6
	0.0037	212.3	0.0067	370.2	0.0097	515.4	0.0127	647.8
	0.0038	217.8	0.0068	375.3	0.0098	520.0	0.0128	652.0
	0.0039	223.2	0.0069	380.3	0.0099	524.6	0.0129	656.2
	0.0040	228.7	0.0070	385.3	0.0100	529.2	0.0130	660.9
	0.0041	234.1	0.0071	390.3	0.0101	533.8	0.0131	664.5
	0.0042	239.5	0.0072	395.3	0.0102	538.3	0.0132	668.6
	0.0043	244.9	0.0073	400.3	0.0103	542.9	0.0133	672.8
	0.0044	250.3	0.0074	405.2	0.0104	547.4	0.0134	676.9
	0.0045	255.7	0.0075	410.2	0.0105	551.9	0.0135	681.0
	0.0046	261.0	0.0076	415.1	0.0106	556.4	0.0136	685.0
	0.0047	266.4	0.0077	420.0	0.0107	560.9		

TABLE A.6 Areas of Bars in Slabs (in^2/ft) — U.S. Customary Units

Spacing (in.)	Bar No.								
	3	4	5	6	7	8	9	10	11
3	0.44	0.78	1.23	1.77	2.40	3.14	4.00	5.06	6.25
$3\frac{1}{2}$	0.38	0.67	1.05	1.51	2.06	2.69	3.43	4.34	5.36
4	0.33	0.59	0.92	1.32	1.80	2.36	3.00	3.80	4.68
$4\frac{1}{2}$	0.29	0.52	0.82	1.18	1.60	2.09	2.67	3.37	4.17
5	0.26	0.47	0.74	1.06	1.44	1.88	2.40	3.04	3.75
$5\frac{1}{2}$	0.24	0.43	0.67	0.96	1.31	1.71	2.18	2.76	3.41
6	0.22	0.39	0.61	0.88	1.20	1.57	2.00	2.53	3.12
$6\frac{1}{2}$	0.20	0.36	0.57	0.82	1.11	1.45	1.85	2.34	2.89
7	0.19	0.34	0.53	0.76	1.03	1.35	1.71	2.17	2.68
$7\frac{1}{2}$	0.18	0.31	0.49	0.71	0.96	1.26	1.60	2.02	2.50
8	0.17	0.29	0.46	0.66	0.90	1.18	1.50	1.89	2.34
9	0.15	0.26	0.41	0.59	0.80	1.05	1.33	1.69	2.08
10	0.13	0.24	0.37	0.53	0.72	0.94	1.20	1.52	1.87
12	0.11	0.20	0.31	0.44	0.60	0.78	1.00	1.27	1.56

TABLE A.4 Areas of Groups of Standard Bars (in.^{2}) — U.S. Customary Units

	Number of Bars								
Bar No.	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
4	0.39	0.58	0.78	0.98	1.18	1.37	1.57	1.77	1.96
5	0.61	0.91	1.23	1.53	1.84	2.15	2.45	2.76	3.07
6	0.88	1.32	1.77	2.21	2.65	3.09	3.53	3.98	4.42
7	1.20	1.80	2.41	3.01	3.61	4.21	4.81	5.41	6.01
8	1.57	2.35	3.14	3.93	4.71	5.50	6.28	7.07	7.85
9	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00
10	2.53	3.79	5.06	6.33	7.59	8.86	10.12	11.39	12.66
11	3.12	4.68	6.25	7.81	9.37	10.94	12.50	14.06	15.62
14	4.50	6.75	9.00	11.25	13.50	15.75	18.00	20.25	22.50
18	8.00	12.00	16.00	20.00	24.00	28.00	32.00	36.00	40.00

	Number of Bars									
Bar No.	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
4	2.16	2.36	2.55	2.75	2.95	3.14	3.34	3.53	3.73	3.93
5	3.37	3.68	3.99	4.30	4.60	4.91	5.22	5.52	5.83	6.14
6	4.86	5.30	5.74	6.19	6.63	7.07	7.51	7.95	8.39	8.84
7	6.61	7.22	7.82	8.42	9.02	9.62	10.22	10.82	11.43	12.03
8	8.64	9.43	10.21	11.00	11.78	12.57	13.35	14.14	14.92	15.71
9	11.00	12.00	13.00	14.00	15.00	16.00	17.00	18.00	19.00	20.00
10	13.92	15.19	16.45	17.72	18.98	20.25	21.52	22.78	24.05	25.31
11	17.19	18.75	20.31	21.87	23.44	25.00	26.56	28.12	29.69	31.25
14	24.75	27.00	29.25	31.50	33.75	36.00	38.25	40.50	42.75	45.00
18	44.00	48.00	52.00	56.00	60.00	64.00	68.00	72.00	76.00	80.00

Step 5:- Longitudinal Temperature and Shrinkage Steel

$A_s = \rho bd = 0.0018 \times 12 \times 20$

$A_s = 0.432 in^2$ Using Table A-6

#5 @ 8" c/c $\boxed{A_{s\,selected} = 0.46 in^2}$

Step 6:- Development length

$\psi_t = \psi_e = \psi_s = \lambda = 1$

$\frac{l_d}{d_b} = \frac{3}{40} \frac{f_y}{\lambda\sqrt{f_c'}} \frac{\psi_t \psi_e \psi_s}{\frac{C_b}{d_b}} \rightarrow (1)$

ψ_t = Reinforcement location factor

ψ_e = Coating Factor

ψ_s = Reinforcement Size factor

λ = Concrete modification factor

if $\frac{C_b}{d_b} > 2.5$ then use 2.5

C_b = side cover = 3.5"

d_b = dia of Main bar = $\frac{7}{8} = 0.875"$

$\frac{C_b}{d_b} = \frac{3.5}{0.875} = 4 > 2.5$ so $\frac{C_b}{d_b} = 2.5$

using eq (1)

$\frac{l_b}{d_b} = \frac{3}{40} \times \frac{60{,}000}{1\sqrt{3000}} \times \frac{1 \times 1 \times 1}{2.5}$

$\frac{l_b}{d_b} = 32.86$

$\frac{l_b}{d_b} \frac{A_{s\,req}}{A_{s\,selected}} = 32.86 \times \frac{0.68}{0.72} = 31.03$

$l_d = 31.03 \times 0.875 = 27.15"$

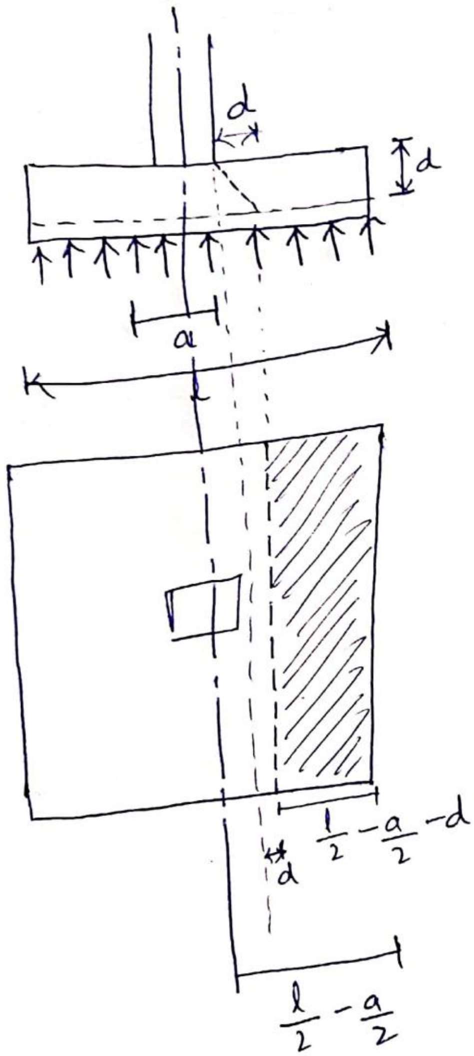
Say = $\boxed{l_d = 28"}$

Design of Square Isolated Footings

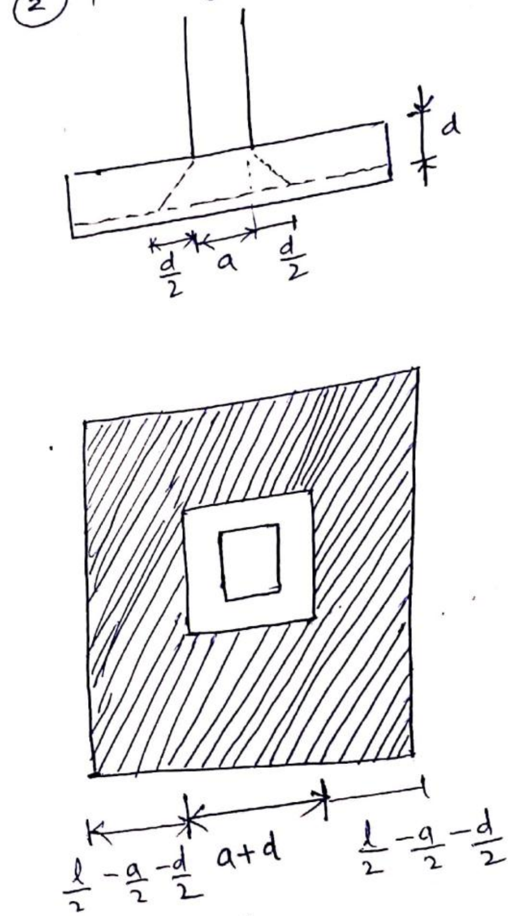
Shears

Two shear conditions must be considered in column footing regardless of their shapes.

① One Way Shear.



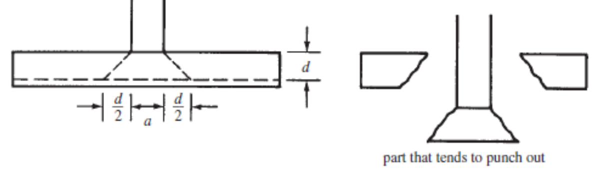
② Two way or Punching shear



$$d = \frac{V_{u1}}{\phi\, 2\sqrt{f_c'}\, b_w}$$

$$d = \frac{V_{u2}}{\phi\, 4\sqrt{f_c'}\, b_o}$$

$$d = \frac{V_{u2}}{\phi\left(\frac{\alpha_s d}{b_o} + 2\right)\sqrt{f_c'}\, b_o}$$



Design a Square column footing for a 16inch square tied interior column that Supports a dead load $P_D = 200K$ and live load $P_L = 160K$. The column is reinforced with #8 bars, the base of the footing is 5' below grade, the soil weight is 100 lb/ft³, $f_y = 60{,}000$ psi and $f_c' = 3000$ psi and $q_a = 5000$ psf.

Given data:-

$P_D = 200K$

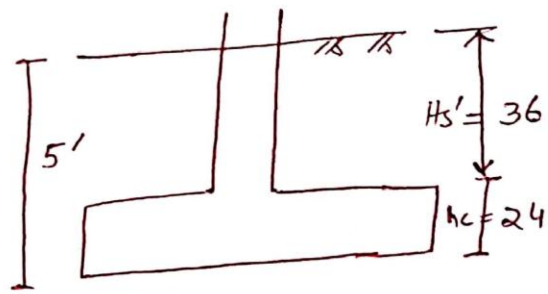
$P_L = 160K$

$\gamma_s = 100\ lb/ft^3$

$f_y = 60{,}000\ psi$

$f_c' = 3000\ psi$

$q_a = 5000\ psf$



Assumed Data:-

$\gamma_c = 150\ lb/ft^3$

$h_c = 24"$, $d = 19.5"$

$H_s' = 36"$

Solution:- Step 1:- Effective Soil Pressure "qe"

$q_e = q_a - h_c \times \gamma_c - H_s' \times \gamma_s = 5000 - \left(\frac{24}{12} \times 150\right) - \left(\frac{36}{12}\right) \times 100$

$q_e = 4400\ psf = 4.40\ ksf$

$\boxed{q_e = 4.40\ ksf}$

Step 2:- Area of footing

Area of footing $= \frac{P_D + P_L}{q_e} = \frac{200 + 160}{4.40} = 81.82\ ft^2$

Area $= 81\ ft^2$

Use 9' x 9" Footing

Step 3:- Ultimate Bearing Capacity

$$q_u = \frac{1.2P_D + 1.6P_L}{\text{Area of footing}} = \frac{(1.2\times 200)+(1.6\times 160)}{81}$$

$$\boxed{q_u = 6.12\ ksf}$$

Step 4:- Depth required for two way or Punching shear

The "d" required for two-way shear is the largest Value obtained from the following expression.

(i) $d = \dfrac{V_{u2}}{\phi 4\sqrt{f_c'}\, b_o}$

$\alpha_s = 40$ for Column where Perimeter is four sided — Square Column.

(ii) $d = \dfrac{V_{u2}}{\phi\left(\dfrac{\alpha_s d}{b_o}+2\right)\sqrt{f_c'}\, b_o}$

b_o = Perimeter around the punching area $= 4(a+d)$

$b_o = 4(a+d) = 4(16+19.5)$

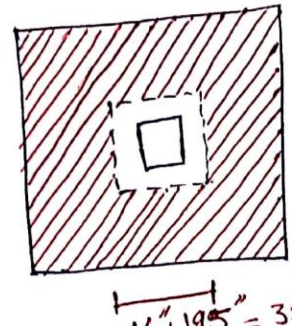
$\boxed{b_o = 142\ in}$

$V_{u2} = \{A - (a+d)\} \times q_u$

$V_{u2} = \left\{81 - \left(\dfrac{16+19.5}{12}\right)\right\} \times 6.12$

$V_{u2} = 442.09K = 442090\ lb$

$\boxed{V_{u2} = 442090\ lb}$



① $d = \dfrac{V_{u2}}{\phi 4\sqrt{f_c'}\, b_o} = \dfrac{442090}{0.75\times 4\sqrt{3000}\times 142} = 18.95'' < 19.5''$ (OK)

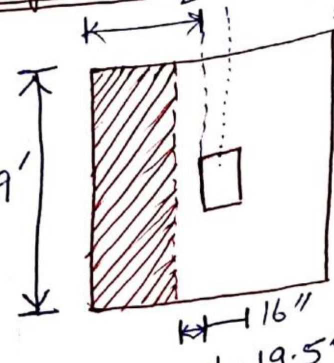
② $d = \dfrac{V_{u2}}{\phi\left(\dfrac{\alpha_s d}{b_o}+2\right)\sqrt{f_c'}\, b_o} = \dfrac{442090}{0.75\left(\dfrac{40\times 19.5}{142}+2\right)\sqrt{3000}\times 142} = 10.12'' < 19.5''$ (OK)

Since both values of d are less than the assumed value of 19.5" so Punching shear is OK

Step 5:- Depth Required for One way shear

$\frac{L}{2} - \frac{a}{2} = \frac{9}{2} - \frac{16}{2}/12$

$= 3.83'$



$V_{u1} = (9 \times 2.208) \times q_u$

$V_{u1} = (9 \times 2.208) \times 6.12$

$\boxed{V_{u1} = 121.62\,k}$

$V_{u1} = 121620\,lb$

$d = \frac{V_u}{\phi 2\sqrt{f_c'}\, b_w} = \frac{121620}{0.75 \times 2 \times \sqrt{3000} \times (9 \times 12)}$

$d = 13.71'' < 19.5$ $\boxed{OK}$

Use $\boxed{h = 24''}$ in total depth

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

$= \frac{9}{2} - \frac{16}{2} - 19.5$

$= 4.5 - \frac{8}{12} - \frac{19.5}{12}$

$= 4.5' - 0.667' - 1.625'$

$= 2.208'$ (feet)

Moment :-

$M_u = 3.83 \times 9 \times 6.12 \times \frac{3.83}{2}$

$\boxed{M_u = 404\,ft\text{-}k}$

$\frac{M_u}{\phi b d^2} = \frac{404 \times 1000 \times 12}{0.9 \times (9 \times 12) \times (19.5)^2} = 131.2\,psi$

Use Appendix A Table A.12

$\frac{M_u}{\phi b d^2} = 134.3$ $\rho = 0.0023$ $< \rho_{min}$ for flexure

then use Greater of

① $\frac{200}{60,000} = 0.0033$

② $\frac{3\sqrt{3000}}{60000} = 0.00274$

So $\rho = 0.0033$

Area of Steel :-

$A_s = \rho b d$

$A_s = 0.0033 \times (9 \times 12) \times 19.5$

$\boxed{A_s = 6.95 \, in^2}$

use Table A.4 9 #8 bar in both direction ($A_{s_{selected}} = 7.07 in^2$)

Development length :-

$\psi_t = \psi_e = \psi_s = \lambda = 1$

ψ_t = Reinforcement location factor

ψ_e = Coating factor

ψ_s = Reinforcement Size factor

λ = Concrete Modification factor.

$$\frac{l_d}{d_b} = \frac{3}{40} \frac{f_y}{\lambda \sqrt{f_c'}} \frac{\psi_t \psi_e \psi_s}{\frac{C_b}{d_b}} \rightarrow (1)$$

if $\frac{C_b}{d_b} > 2.5$ then use 2.5

C_b = Side cover $= 3.5''$

d_b = dia of bar $= \frac{8}{8} = 1''$

$\frac{C_b}{d_b} = \frac{3.5}{1} = 3.5 > 2.5$ so use 2.5

Using eq (1)

$$\frac{l_b}{d_b} = \frac{3}{40} \times \frac{60000}{1\sqrt{3000}} \times \frac{1 \times 1 \times 1}{2.5} = 32.86 .$$

$$\frac{l_b}{d_b} \frac{A_{s\,req}}{A_{s\,selected}} = 32.86 \times \frac{6.95}{7.07} = 32.30$$

$l_d = 32.30 \times d_b = 32.30 \times 1$

$\boxed{l_d = 32''}$ OK