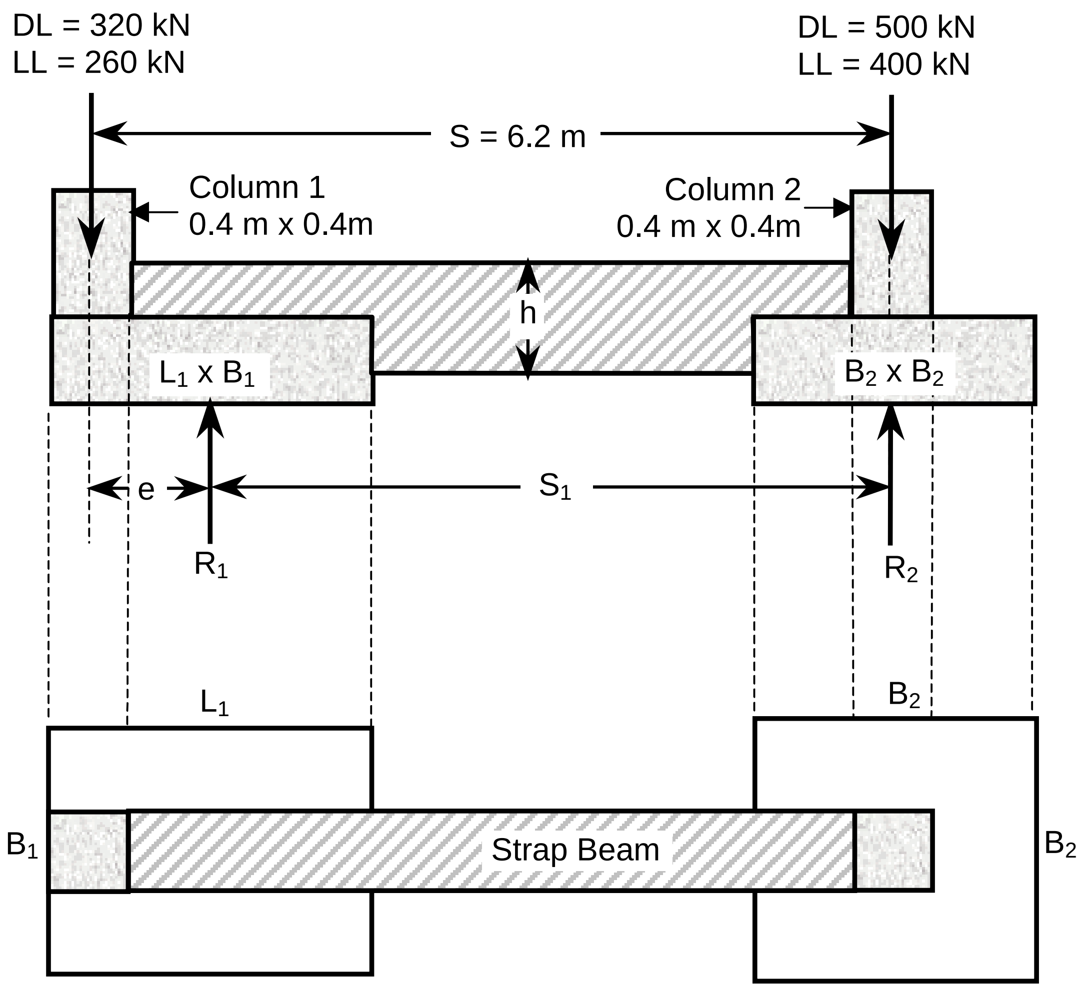
Example #1 (Design)

Example 9-3 pp. 487–489 in Textbook by J. Bowles. This example is partial in the textbook and completed here

Design the strap footing shown below. Given:

$f_c' = 24$ MPa, $f_y = 345$ MPa, and soil $q_a = 120$ kPa



SOLUTION

STEP 1 – DIMENSION FOOTINGS (Determine L_1, B_1, and B_2)

Allowable loads: $P_1 = 320 + 260 = 580$ kN
$P_2 = 500 + 400 = 900$ kN

$P = 580 + 900 = 1480$ kN

Ultimate loads : $P_{u1} = 1.4(320) + 1.7(260) = 890$ kN

$P_{u2} = 1.4(500) + 1.7(400) = 1380$ kN

$P_u = 890 + 1380 = 2270$ kN

Ultimate ratio $r_u = P_u/P = 2270/1480 = 1.53$

Ultimate applied pressure $q_u = 120 \times 1.53 = 183.6$ kPa

$\Sigma M_{col.\,2} = 0$: $R_1\,(6.2 - e) + (890 \times 6.2) = 0$ .... (1)

$\Sigma M_{R1} = 0$: $1380\,(6.2 - e) - R_2\,(6.2 - e) - 890\,e = 0$ .... (2)

$\Sigma F = 0$: $2270 - R_1 - R_2 = 0$ .... (3)

To solve these three equations assume e = 1.2 m (trial value)

a) By Eq. 1, $R_1 = 1103.6$ kN
b) By Eq. 1, $R_2 = 1166.4$ kN
c) $R_1 + R_2 = 2270$, therefore Eq. 3 is satisfied.

Calculation of dimensions L_1, B_1 and B_2

Footing 1: $L_1 = 2 \times \left(e + \frac{l_1}{2}\right) = 2 \times \left(1.2 + \frac{0.4}{2}\right) = 2.8$ m

$$B_1 = \frac{R_1}{q_u\ L_1} = \frac{1103.6}{183.6 \times 2.8} = 2.15 \text{ m}$$

Area of footing 1, $A_1 = 2.8 \times 2.15 = 6.01\ m^2$

Footing 2: $B_2 = \sqrt{\frac{R_2}{q_u}} = \sqrt{\frac{1166.4}{183.6}} = 2.52$ m

Area of footing 2, $A_2 = (2.52)^2 = 6.35\ m^2$

Total Area of strap footing $A = A_1 + A_2 = 6.01 + 6.35 = 12.36\ m^2$

The following table shows alternative solutions for the various e-values.

e	R_1, kN	R_2, kN	Footing 1			Footing 2		Total A, m^2
			L_1, m	B_1, m	A_1, m^2	B_2, m	A_2, m^2	
0.8	1021.9	1248.1	2.00	2.78	5.57	2.61	6.80	12.36
0.9	1041.1	1228.9	2.20	2.58	5.67	2.59	6.69	12.36
1.0	1061.2	1208.8	2.40	2.41	5.78	2.57	6.58	12.36
1.1	1082.0	1188.0	2.60	2.27	5.89	2.54	6.47	12.36
1.2	1103.6	1166.4	2.80	2.15	6.01	2.52	6.35	12.36
1.3	1126.1	1143.9	3.00	2.04	6.13	2.50	6.23	12.36
1.4	1149.6	1120.4	3.20	1.96	6.26	2.47	6.10	12.36
1.5	1174.0	1096.0	3.40	1.88	6.39	2.44	5.97	12.36
1.6	1199.6	1070.4	3.60	1.81	6.53	2.41	5.83	12.36
1.7	1226.2	1043.8	3.80	1.76	6.68	2.38	5.69	12.36

From this table the following can be observed:

1. All values of e will check Eq. 3, i.e. $R_1 + R_2 = 2270$
2. Regardless of the value of e, the total area A = 12.36 m^2. This makes sense since the total area A = $\frac{R_1 + R_2}{q_u} = \frac{2270}{183.6} = 12.36\ m^2$ and is independent of e.
3. For e = 0.9 m, $B_1 = B_2$. This would seem to be the best choice. However, the value of e gives $L_1 < B_1$
4. For e= 1.0 m the resulting Footing 1 is square with $L_1 \approx B_1 = 2.41$ m. This would seem to the most ideal solution

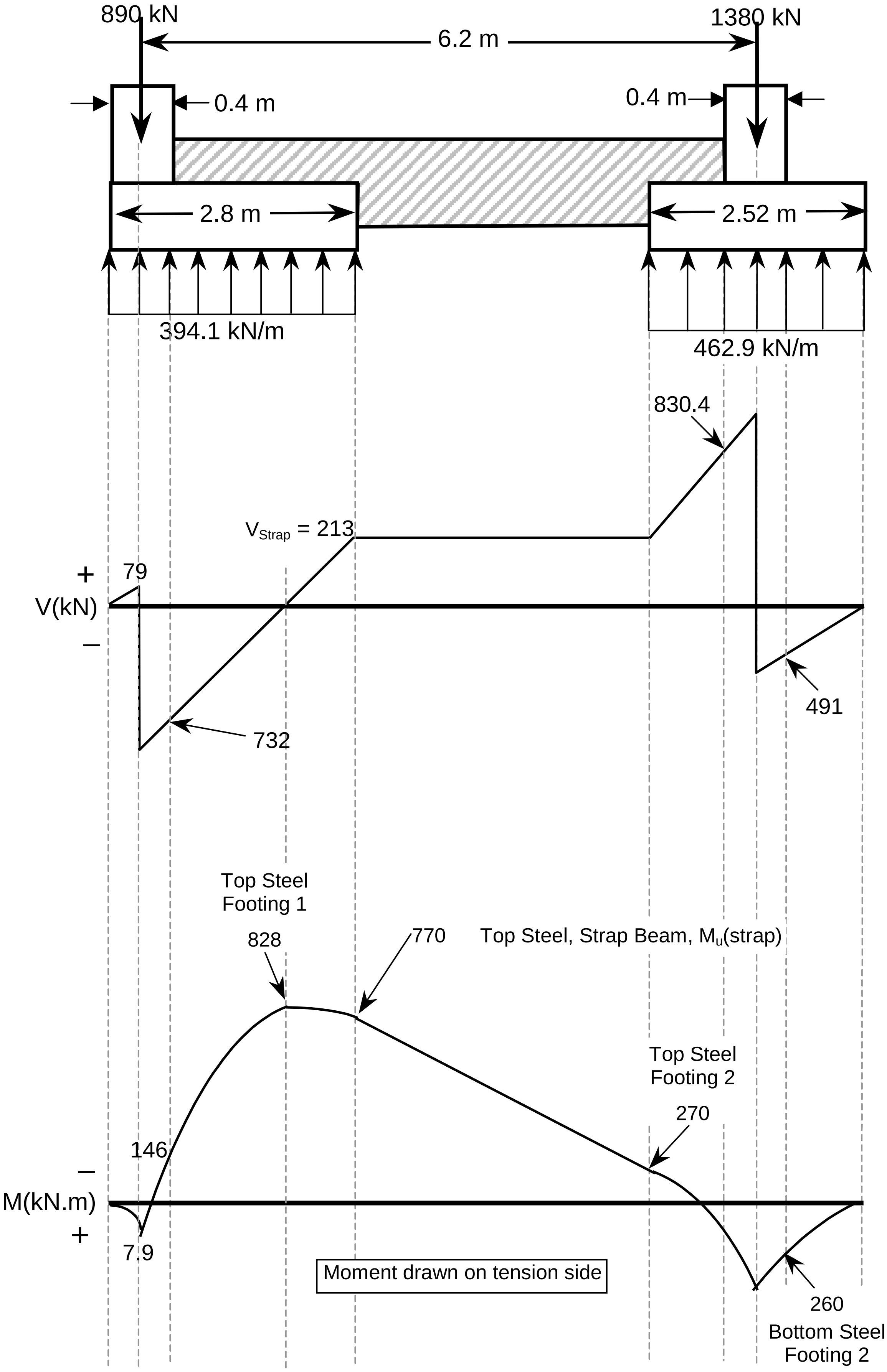
To continue with the solution of the textbook, we shall assume e = 1.2 m and use **L_1 = 2.8 m, B_1 = 2.15 m and B_2 = 2.52 m.**

STEP 2 – DRAW SHEAR AND MOMENT DIAGRAMS (L - DIRECTION)

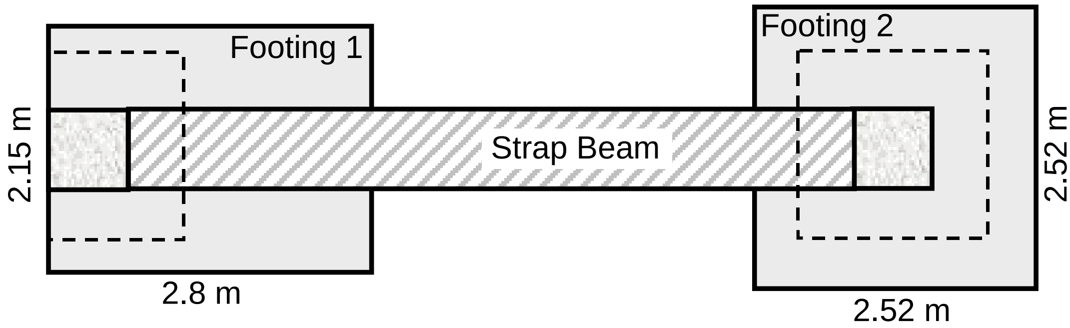
$q_{u1,\ L}$ = 183.6 x 2.15 = 394.1 kN/m

$q_{u2,\ L}$ = 183.6 x 2.52 = 462.9 kN/m

The shear and bending moment diagrams are shown on the next page.


890 kN
1380 kN
6.2 m
0.4 m
0.4 m
2.8 m
2.52 m
394.1 kN/m
462.9 kN/m
830.4
V_Strap = 213
79
+
V(kN)
–
732
491
Top Steel
Footing 1
828
770
Top Steel, Strap Beam, M_u(strap)
Top Steel
Footing 2
270
146
–
M(kN.m)
+
7.9
Moment drawn on tension side
260
Bottom Steel
Footing 2

STEP 3 – DEPTH OF CONCRETE, d'



Estimate d' for footing 1 by 3-way punching shear under column 1

Using Structural Depth of Concrete table for punching shear failure, with P_{u1} = 890 kN, f_c' = 24 MPa and $p' = 2\ell + w = 2(0.4) + 0.4 = 1.2$ m, the value of **d' ≈ 0.35 m**

Estimate d' for footing 2 by 4-way punching shear under column 2

Using Structural Depth of Concrete table for punching shear failure, with P_{u2} = 1380 kN, f_c' = 24 MPa and $p' = 2\ell + 2w = 2(0.4) + 2(0.4) = 1.6$ m, the value of **d' ≈ 0.42 m**

Therefore use d' = 0.45 m for both footings

STEP 4 – REINFORCEMENT IN L-DIRECTION

Calculation of moments per meter (values from moment diagram)

Footing 1 (top steel), M_u / m = 828/2.15 = 383.1 kN.m/m

Footing 2 (top steel), M_u / m = 270/2.15 = 125.6 kN.m/m

Footing 2 (bottom steel), M_u / m = 260/2.15 = 120.9 kN.m/m

Strap beam, M_u = 770 kN/m

STEP 5 – <u>REINFORCEMENT IN B-DIRECTION</u>

<u>For Footing 1</u>

$$L_1' = \frac{B_1 - b_1}{2} = \frac{2.1 - 0.3}{2} = 0.925 \text{ m}$$

$$M_{u1} = \frac{q_u}{2}(L_1')^2 = \frac{186.6}{2}(0.925)^2 = 78.5 \text{ kN.m/m}$$

<u>For Footing 2</u>

$$L_2' = \frac{B_2 - b_2}{2} = \frac{2.52 - 0.3}{2} = 1.11 \text{ m}$$

$$M_{u2} = \frac{q_u}{2}(L_2')^2 = \frac{186.6}{2}(1.11)^2 = 113.1 \text{ kN.m/m}$$

STEP 6 – <u>DEPTH OF STRAP BEAM</u>

Assume that the width of the trap = b = 0.3 m

V_{Strap} = 213 kN (from shear diagram)

Shear strength of concrete $\nu_c = 8.87\sqrt{f'_c} = 8.87\sqrt{24000} = 1374.1$ kPa

The shear stress, $\nu_u = \frac{V_{strap}}{b\ h} = \frac{213}{0.3\ h} = 1374.1$

Solving for h, we get h = 0.52 m. Use h = 0.55 m

<u>Reinforcements:</u>

Using the footing depth in step 3 and the moments in steps 4 and 5, the reinforcement of Footing 1 and 2 are obtained from Percent Steel Tables. In a similar fashion, using h of the strap in step 6 and the moment in step 4, the reinforcement of the strap is obtained from Percent Steel Tables. It should be noted that the reinforcement in the footings is per meter while for the strap it is total. For these reinforcements, the following table is prepared.

Reinforcement for the footings and strap: f_c' = 24 MPa and f_y = 345 MPa

Direction	Steel Location	M_u, kN.m/m	p, % per m	P_{min}, %	Required, A_s, cm^2/m	Bar size @ spacing in cm c-c	Provided A_s, cm^2/m
L - Direction	Footing 1 (top)	383.1	0.62	0.41	27.9	ϕ20 @ 12.5 cm	28.27
	Strap Beam (top)	770	0.90		14.9*	2 ϕ20 @ 25 cm**	15.71
	Footing 2 (top)	125.6	0.21		18.5	ϕ20 @ 20 cm	18.85
	Footing 2 (bottom)	120.9	0.20		18.5	ϕ20 @ 20 cm	18.85
B-Direction	Footing 1 (bottom)	78.5	0.13		18.5	ϕ20 @ 20 cm	18.85
	Footing 2 (bottom)	113.1	0.18		18.5	ϕ20 @ 20 cm	18.85

* Since the strap beam used is 0.3 x 0.55 m, then A_s = 0.90 x 0.3 x 0.55

** Total number of bars in strap bean

The problem is completed by drawing the final design sketch, which shows all dimensions and reinforcements. This is left to the student.