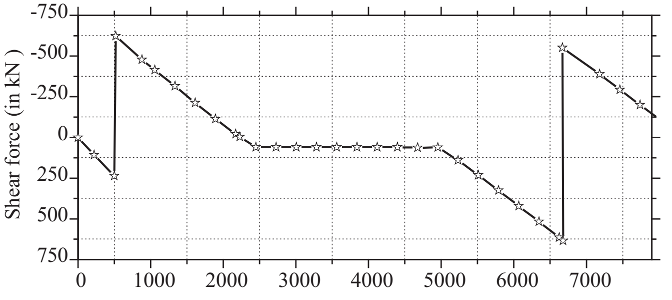
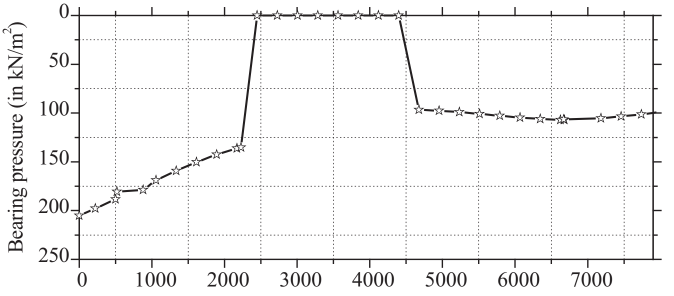


(c)



(d)

Figure 12.C.18 (*Continued*)

Example 12.7 Raft Foundation

Design a raft foundation for the layout of columns shown in Figure 12.C.19(a). All columns are of square shape of size 40 × 40 cm. ADSP = 80 kN/m^3. Use M 15 concrete and Fe 415 steel. Assume 10% as the load of raft and soil above.

A. Design of Raft Slab

Total vertical column load = (600 + 1600 + 2000 + 600 + 800 + 1800 + 2000 + 1000 + 800 + 1000 + 1200 + 600) = 14000

Eccentricity along the x direction is obtained by taking moment of column loads about the grid 1–1

$$\overline{x} = \frac{[6(1600 + 1800 + 1000) + 12(2000 + 2000 + 1200) + 18(600 + 1000 + 600)]}{14000}$$

$$= 9.1714\,\text{m}$$

$$e_x = 9.1714 - (6 + 3) = 0.1714\,\text{m}$$

Eccentricity along the y direction is obtained by taking moment of column loads about the grid C–C

Table 12.C.7 Comparative study (see comments in Section 12.C.2).

		Maximum bearing pressure (kN/m^2)	Maximum bending moment (kNm)	Maximum shear force (kN)	Maximum deflection (mm)
Conventional design	With factored load	624.323	987.323	1032.20	624.323/28 = 18.08
	With design load	624.323/1.5 = 416.22	987.323/1.5 = 658.22	1032.20/1.5 = 688.13	18.08/1.5 = 12.05
Design using BEF (with design load only)		205.050 kN/m^2 at $x = 0$ mm	440.576 kNm at $x = 6680$ mm; −299.937 kNm at $x = 2227$ mm	631.628 kN at $x = 6680$ mm; −564.406 kN at $x = 724$ mm	5.86 mm at $x = 0$ mm

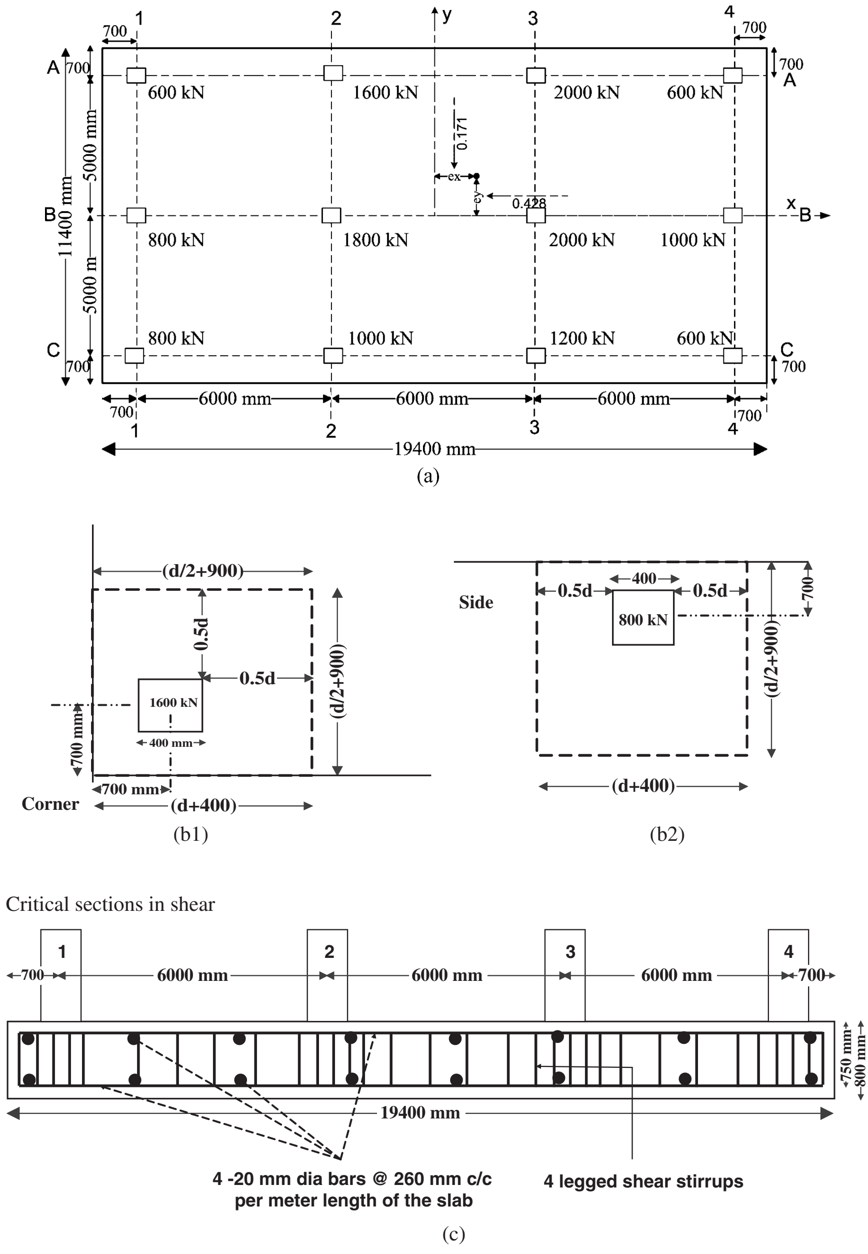


Figure 12.C.19 Raft layout and column loads; (b1) critical section in shear; (b2) critical section in shear; and (c) details of reinforcement along the longitudinal section (Example 12.7).

$$\overline{y} = \frac{[5(800 + 1800 + 2000 + 1000) + 10(600 + 1600 + 2000 + 600)]}{14000} = 5.4285\,\text{m}$$

$$e_y = 5.4285 - 5 = 0.4285\,\text{m}$$

$$I_x = \frac{19.4 \times 11.4^3}{12} = 2395.16\,\text{m}^4$$

$$I_y = \frac{11.4 \times 19.4^3}{12} = 6936.31\,\text{m}^4$$

$$A = 19.4 \times 11.4 = 221.16\,\text{m}^2$$

$$M_x = pe_y = 14000 \times 0.4285 = 6000\,\text{kNm} \quad (12.C.65)$$

$$M_y = pe_x = 14000 \times 0.1714 = 2400\,\text{kNm} \quad (12.C.66)$$

$$\frac{P}{A} = \frac{14000}{221.16} = 63.302\,\text{kN/m}^2$$

Soil pressure at different points is as follows

$$\sigma = \frac{P}{A} \pm \frac{M_y}{I_y}x \pm \frac{M_x}{I_x}y \quad (12.C.67)$$

$$\sigma = 63.302 \pm \frac{2400}{6936.31}x \pm \frac{6000}{2395.16}y = 63.158 \pm 1.5269x \pm 0.4745y$$

At corner *A*–4

$$\sigma_{A-4} = 63.158 + 0.346 \times 9.7 + 2.505 \times 5.7 = 80.93 \cong \text{BC of soil}\,(80\,\text{kN/m}^2)$$

At corner *C*–4

$$\sigma_{C-4} = 63.158 + 0.346 \times 9.7 - 2.505 \times 5.7 = 74.225\ \text{kN/m}^2$$

At corner *A*–1

$$\sigma_{A-1} = 63.158 - 0.346 \times 9.7 + 2.505 \times 5.7 = 52.38\,\text{kN/m}^2$$

At corner *C*–1

$$\sigma_{C-1} = 63.158 - 0.346 \times 9.7 - 2.505 \times 5.7 = 45.67\,\text{kN/m}^2$$

At corner *B*–4

$$\sigma_{B-4} = 63.158 + 0.346 \times 9.7 = 66.658\,\text{kN/m}^2$$

At corner *B*–1

$$\sigma_{B-1} = 63.158 - 0.346 \times 9.7 = 59.943\,\text{kN/m}^2$$

In the x direction, the raft is divided in three strips, that is three equivalent beams:

1. Beam *A*–*A* with 3.2 m width and soil pressure of 80 kN/m^2
2. Beam *B*–*B* with 5.0 m width and soil pressure of $\frac{(80 + 66.65)}{2} = 73.32\,\text{kN/m}^2$
3. Beam *C*–*C* with 5.0 m width and soil pressure of $\frac{(66.65 + 52.38)}{2} = 59.52\,\text{kN/m}^2$.

The bending moment is obtained by using a coefficient 1/10 and L as the center to center of column distance

$$+M = -M = \frac{wL^2}{10} \tag{12.C.68}$$

For strip *A*–*A*

$$\text{Maximum moment} = \frac{80 \times 6^2}{10} = 288\,\text{kNm/m}$$

For strip *B*–*B*

$$\text{Maximum moment} = \frac{73.32 \times 6^2}{10} = 263.95\,\text{kNm/m}$$

For strip *C*–*C*

$$\text{Maximum moment} = \frac{59.52 \times 6^2}{10} = 214.272\,\text{kNm/m}$$

For any strip in the y direction, take $M = \frac{wL^2}{8}$ since there is only a two-span equivalent beam.
For strip 4–4

$$\text{Maximum moment} = \frac{80 \times 5^2}{8} = 250\,\text{kNm/m}$$

The depth of the raft is governed by two-way shear at one of the exterior columns. If the location of critical shear is not obvious, it may be necessary to check all possible locations.

Shear strength of concrete, $\tau_c = 0.25\sqrt{f_{ck}} = 0.25\sqrt{15} = 0.97\text{N/mm}^2$

For a corner column (say *C*–1)

Perimeter $b_o = 2\left(\frac{d}{2} + 900\right) = d + 1800\,\text{mm}$ (Figure 12.C.19(b))

$$\tau_v = \frac{V_u}{b_o d} = \frac{1.5 \times 800 \times 1000}{(d + 1800)d} = 0.97$$

$$= \frac{1200000}{(d + 1800)d} = 0.97$$

$$\Rightarrow d^2 + 1800d - 1237113.40 = 0$$

$$d = \frac{-1800 \pm \sqrt{(1800^2 + 4 \times 1 \times 1237113.40)}}{2 \times 1} = 530.773\ \text{mm}$$

For a corner column (say A–2)

$$\text{Perimeter } b_o = 2\left(\frac{d}{2} + 900\right) + (d + 400) = 2d + 2200\ \text{mm}$$

$$\tau_v = \frac{V_u}{b_o d} = \frac{1.5 \times 1600 \times 1000}{(2d + 2200)d} = 0.97$$

$$d^2 + 1100d - 1237113.40 = 0 \qquad (12.C.69)$$

$$\Rightarrow d = \frac{-1100 \pm \sqrt{(1100^2 + 4 \times 1 \times 1237113.40)}}{2 \times 1} = 690.811\ \text{mm}$$

However, adopt an effective depth of 750 mm and overall depth of 800 mm

Reinforcement in the longitudinal direction is given by (considering a 1 m wide strip)

$$A_t = 0.5\frac{15}{415}\left[1 - \sqrt{1 - \frac{4.6 \times 288 \times 10^6}{15 \times 1000 \times 750^2}}\right]1000 \times 750 = 1109.51\ \text{mm}^2$$

Use 20 mm bars, $A_\phi = 314.151\ \text{mm}^2$

$$\text{Number of bars} = \frac{1109.51}{\frac{\pi}{4}20^2} = 3.531 \cong 4\ \text{bars}$$

$$\text{Spacing of long bars} = \frac{1000 \times \frac{\pi}{4}20^2}{1109.51} = 283.152\ \text{mm}$$

Provide 4–20 mm Φ bars for reinforcement @ 260 mm c/c at top and bottom in both directions.

$$\text{Minimum reinforcement in the slabs} = 0.12\%$$
$$= \frac{0.12}{100} \times 800 \times 1000$$
$$= 960\ \text{mm}^2/\text{m} < 1109.51\ \text{mm}^2/\text{m}$$

Minimum steel governs in the remaining raft. Critical sections in shear.

WINBEF Solution:

WINBEF Input

Young's modulus of soil, $E_s = 10^5\ \text{kN/m}^2$, unit weight of soil, $\gamma_{soil} = 20\ \text{kN/m}^3$.

Poisson's ratio of soil, $v_s = 0.3$.
Young's modulus of concrete

$$E_f = 5000\sqrt{\sigma_{ck}} = 5000\sqrt{15} = 19364.92\ \mathrm{N/mm^2} = 1.9364 \times 10^7\ \mathrm{kN/m^2}$$

B = breadth of foundation = 1.0 m (considering a 1 m wide strip for design).
Moment of inertia of the concrete beam $I_f = \frac{Bd^3}{12} = \frac{1.0\times0.8^3}{12} = 0.04267\ \mathrm{m^4}$.
Modulus of subgrade reaction, $k_s = \frac{1}{B(\mathrm{mm})}\left[0.65\ \sqrt[12]{\frac{E_sB^4}{E_fI_f}}\right]\frac{E_s}{1-v_s^2}$.

$$k_s = \frac{0.65}{1000}\frac{10^5}{(1-0.3^2)}\sqrt[12]{\frac{10^5 \times 1.0^4}{1.9364 \times 10^7 \times 0.04267}} = \frac{59902}{1000} = 59.902\ \mathrm{kN/m^2/mm}.$$

Loading Data for WINBEF and Results

The loading data is shown in Figure 12.C.20.

Note: In the loading diagram, the load coming on to the beam is taken as maximum of A, B and C strip loads as explained below (see Figure 12.C.19(a)).

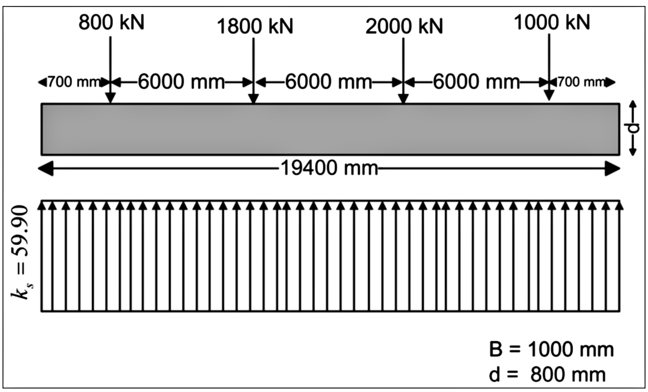


Figure 12.C.20 Loading data for WINBEF solution (Example 12.7).

The maximum load on strip 1–1: maximum of A1 (600 kN), B1 (800 kN) and C1 (800 kN), which is 800 kN.

The maximum load on strip 2–2: maximum of A2 (1600 kN), B2 (1800 kN) and C2 (1000 kN), which is 1800 kN.

The maximum load on strip 3–3: maximum of A3 (2000 kN), B3 (2000 kN) and C3 (1200 kN), which is 2000 kN.

The maximum load on strip 4–4: maximum of A4 (600 kN), B4 (1000 kN) and C4 (1000 kN), which is 1000 kN.

The details of deflection, bending moment, shear force and bearing pressure are shown in Figure 12.C.21. Please see also comments given in Section 12.C.2.

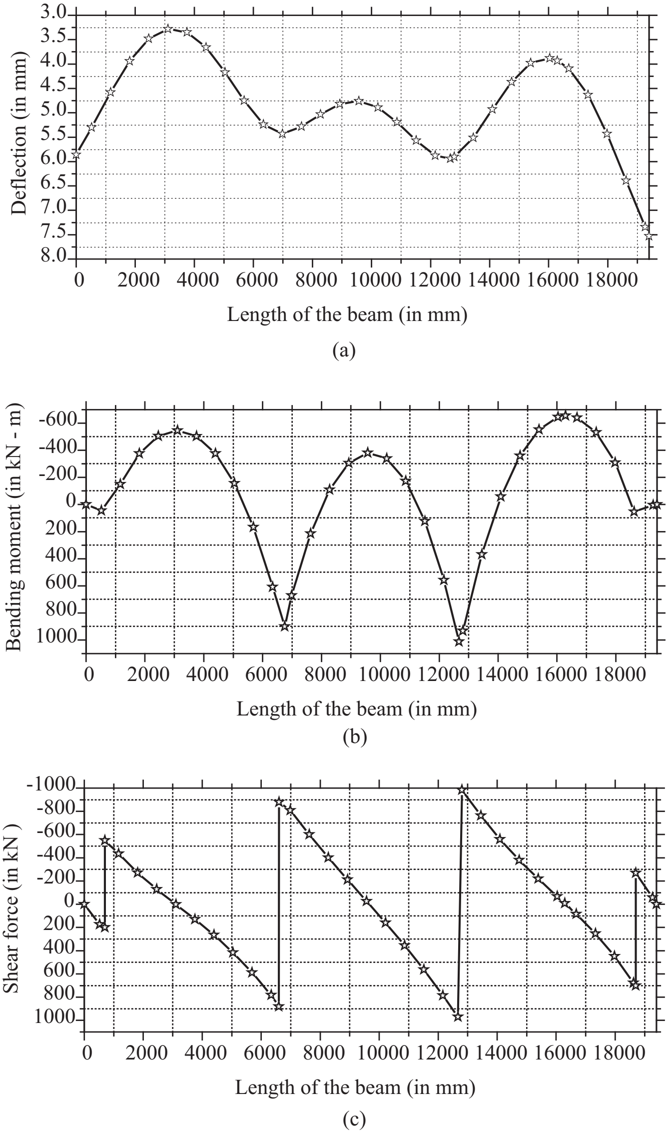


Figure 12.C.21 (a) BEF deflection diagram; (b) BEF bending moment diagram; (c) BEF shear force diagram; and (d) BEF bearing pressure diagram (Example 12.7).

Example 12.8 Annular Raft Foundation

Design an annular (circular) raft for a circular tank whose outer diameter is 12 m and is supported by a ring beam of 9 m diameter. The inner diameter of the annulus is 8 m. The factored soil pressure under the raft is 80 kN/m^2 and a linearly varying soil pressure due to