Module 11

Foundations - Theory and Design

Lesson 29

Design of Foundations

Instructional Objectives:

At the end of this lesson, the student should be able to:

- understand and apply the design considerations to satisfy the major and other requirements of the design of foundations,

- design the plain concrete footings, isolated footings for square and rectangular columns subjected to axial loads with or without the moments, wall footings and combined footings, as per the stipulations of IS code.

11.29.1 Introduction

The two major and some other requirements of foundation structures are explained in Lesson 28. Different types of shallow and deep foundations are illustrated in that lesson. The design considerations and different codal provisions of foundation structures are also explained. However, designs of all types of foundations are beyond the scope of this course. Only shallow footings are taken up for the design in this lesson. Several numerical problems are illustrated applying the theoretical considerations discussed in Lesson 28. Problems are solved explaining the different steps of the design.

11.29.2 Numerical Problems

Problem 1:

Design a plain concrete footing for a column of 400 mm x 400 mm carrying an axial load of 400 kN under service loads. Assume safe bearing capacity of soil as 300 kN/m^2 at a depth of 1 m below the ground level. Use M 20 and Fe 415 for the design.

Solution 1:

Plain concrete footing is given in secs.11.28.2(A)1 and 11.28.5(b).

Step 1: Transfer of axial force at the base of column

It is essential that the total factored loads must be transferred at the base of column without any reinforcement. For that the bearing resistance should be greater than the total factored load P_u.

Here, the factored load P_u = 400(1.5) = 600 kN.

The bearing stress, as per cl.34.4 of IS 456 and given in Eqs.11.7 and 8 of sec.11.28.5(g) of Lesson 28, is

$$\sigma_{br} = 0.45 f_{ck} (A_1/A_2)^{1/2} \tag{11.7}$$

with a condition that

$$(A_1/A_2)^{1/2} \le 2.0 \tag{11.8}$$

Since the bearing stress σ_{br} at the column-footing interface will be governed by the column face, we have $A_1 = A_2 = 400(400) = 160000$ mm^2. Using $A_1 = A_2$, in Eq.11.7, we have

P_{br} = Bearing force = $0.45 f_{ck} A_1 = 0.45(20)(160000)(10^{-3}) = 1440$ kN > P_u (= 600 kN).

Thus, the full transfer of load P_u is possible without any reinforcement.

Step 2: Size of the footing

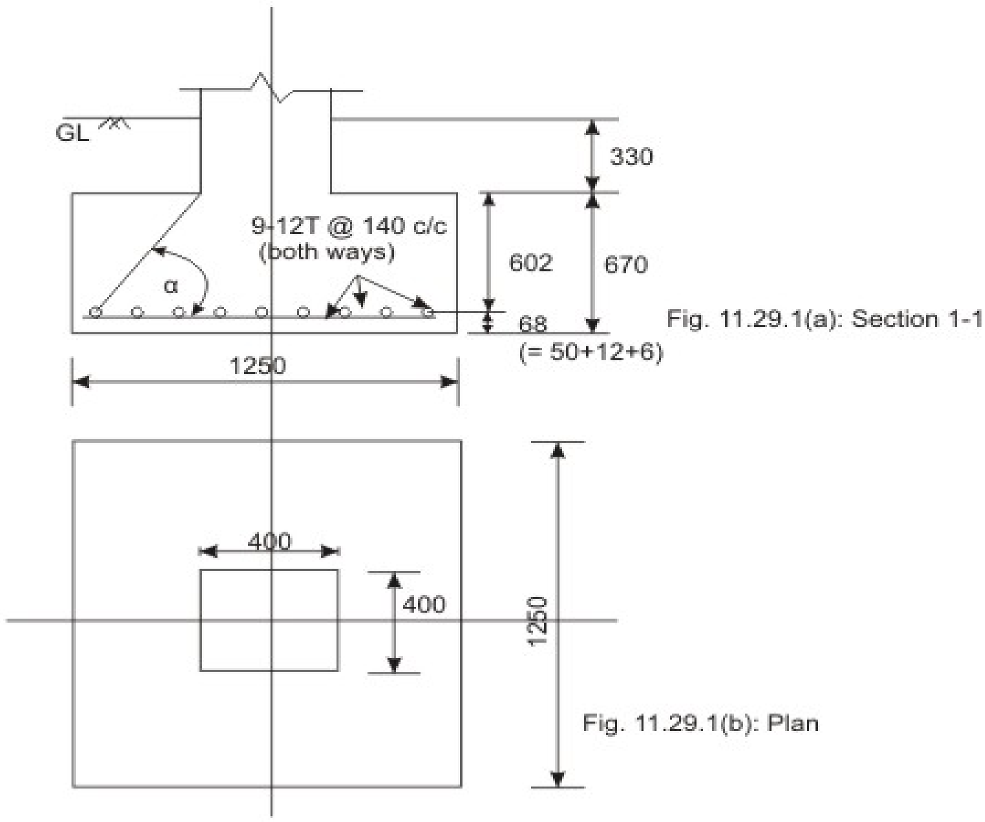

Fig. 11.29.1: Problem 1

Let us assume the weight of footing and back fill soil as 15 per cent of P_u. Then, the base area required = 400(1.15)/300 = 1.533 m^2. Provide 1250 x 1250 mm (= 1.5625 m^2) as shown in Fig.11.29.1. The bearing pressure q_a = 400(1.15)/(1.25)(1.25) = 294.4 kN/m^2.

Step 3: Thickness of footing

The thickness of the footing h is governed by Eq.11.3 of sec.11.28.5 of Lesson 28. From Eq.11.3, we have

$$\tan\alpha \le 0.9\{(100q_a/f_{ck}) + 1\}^{1/2} \quad \text{.... (11.3)}$$

$$\le 0.9[\{100(0.2944)/20\} + 1]^{1/2}$$

$$\le 1.415$$

We have from Fig.11.29.1a:

$$h = \{(1250 - 400)/2\}(\tan\alpha) = 601.375 \text{ mm}$$

Provide 1250 x 1250 x 670 mm block of plain concrete.

Step 4: Minimum reinforcement

The plain concrete block 1250 x 1250 x 670 shall be provided with the minimum reinforcement 0.12 per cent for temperature, shrinkage and tie action.

Minimum A_{st} = 0.0012(1250)(670) = 1005.0 mm^2.

Provide 9 bars of 12 mm diameter (= 1018 mm^2) both ways as shown in Fig.11.29.1b. The spacing of bars = (1250 - 50 - 12)/8 = 148.5 mm c/c. Provide the bars @ 140 mm c/c.

Step 5: Check for the gross base pressure

Assuming unit weights of concrete and soil as 24 kN/m^3 and 20 kN/m^3

Service load = 400.00 kN

Weight of footing = (0.67)(1.25)(1.25)(24) = 25.125 kN

Weight of soil = (0.33)(1.25)(1.25)(20) = 10.3125 kN

Total = 435.4375 kN

q_a = 435.4375/(1.25)(1.25) = 278.68 kN/m^2 < 300 kN/m^2

Hence, o.k.

Problem 2:

Design an isolated footing for a square column, 400 mm x 400 mm with 12-20 mm diameter longitudinal bars carrying service loads of 1500 kN with M 20 and Fe 415. The safe bearing capacity of soil is 250 kN/m^2 at a depth of 1 m below the ground level. Use M 20 and Fe 415.

Solution 2:

Step 1: Size of the footing

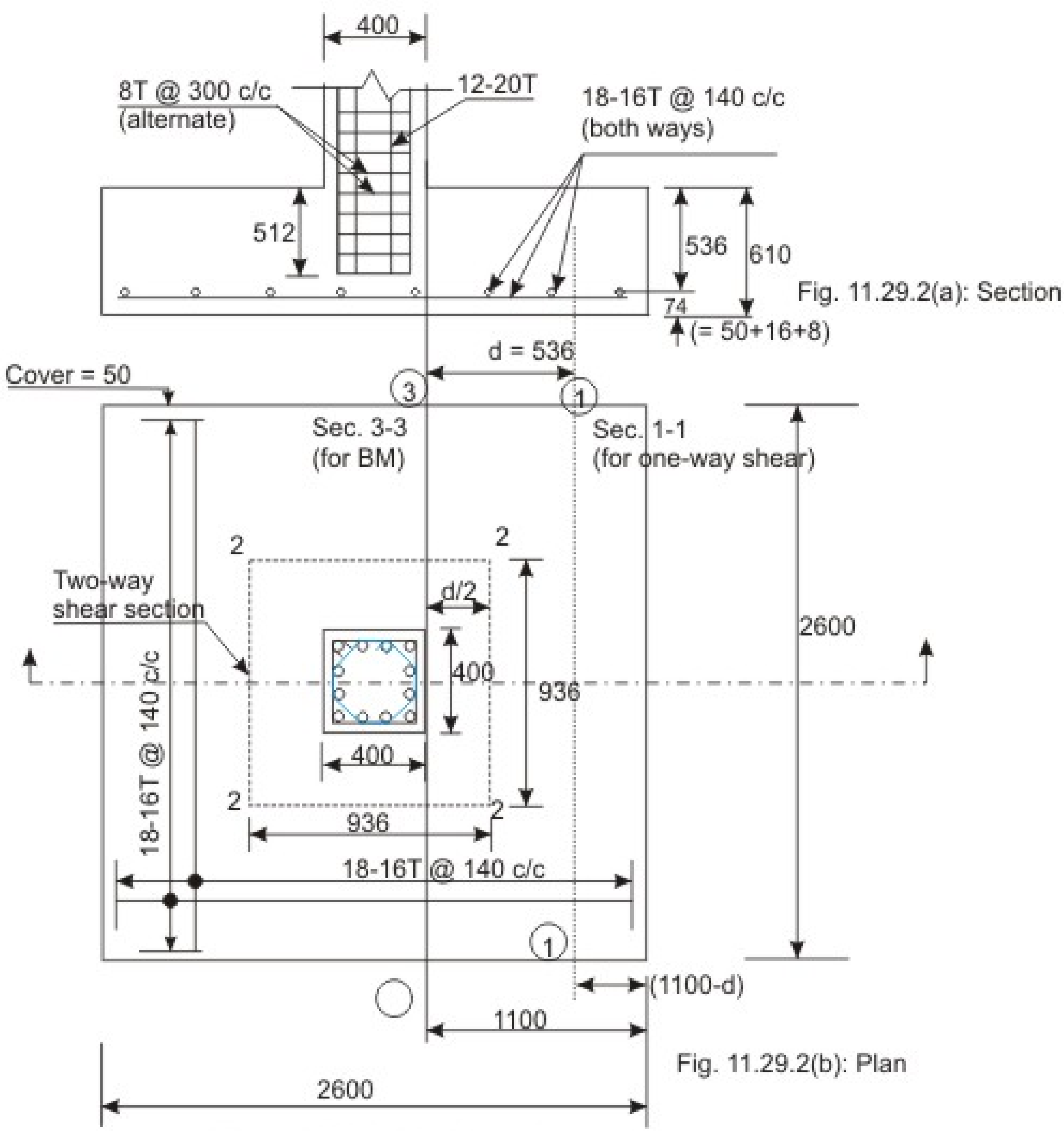

Fig. 11.29.2: Problem 2

Given P = 1500 kN, q_c = 250 kN/m^2 at a depth of 1 m below the ground level. Assuming the weight of the footing and backfill as 10 per cent of the load, the base area required = 1500(1.1)/250 = 6.6 m^2. Provide 2.6 m x 2.6 m, area = 6.76 m^2 (Fig.11.29.2b).

Step 2: Thickness of footing slab based on one-way shear

Factored soil pressure = 1500(1.5)/(2.6)(2.6) = 0.3328 N/mm^2, say, 0.333 N/mm^2.

Assuming p = 0.25% in the footing slab, for M 20 concrete τ_c = 0.36 N/mm^2 (Table 19 of IS 456). V_u = 0.36(2600)d and V_u (actual) = 0.333(2600)(1100 - d). From the condition that V_u should be more than or equal to the actual V_u, we have (see Fig.11.29.2a, sec.11):

$$0.36(2600)d \geq 0.333(2600)(1100 - d)$$

So, $d \geq$ 528.57 mm.

Provide d = 536 mm. The total depth becomes 536 + 50 + 16 + 8 (with 50 mm cover and diameter of reinforcing bars = 16 mm) = 610 mm.

Step 3: Checking for two-way shear

The critical section is at a distance of $d/2$ from the periphery of the column. The factored shear force (Fig.11.29.2b, sec. 2222) = 0.333{(2600)^2 – (400 + d)^2}(10)$^{-3}$ = 1959.34 kN. Shear resistance is calculated with the shear strength = $k_s\ \tau_c$ = k_s(0.25) $(f_{ck})^{1/2}$; where k_s = 0.5 + β_c (cl. 31.6.3 of IS 456). Here β_c = 1.0, k_s = 1.5 $\ngtr$ 1; so k_s = 1.0. This gives shear strength of concrete = 0.25 $(f_{ck})^{1/2}$ = 1.118 N/mm^2. So, the shear resistance = (1.118) 4 (936)(536) = 2243.58 kN > 1959.34 kN. Hence, ok.

Thus, the depth of the footing is governed by one-way shear.

Step 4: Gross bearing capacity

Assuming unit weights of concrete and soil as 24 kN/m^3 and 20 kN/m^3, respectively:

Given, the service load = 1500 kN

Weight of the footing = 2.6(2.6)(0.61)(24) = 98.967 kN

Weight of soil = 2.6(2.6)(1.0-0.61)(20) = 52.728 kN (Assuming the depth of the footing as 1.0 m).
Total = 1635.2 kN

Gross bearing pressure = 1635.2/(2.6)(2.6) = 241.893 kN/m^2 < 250 kN/m^2. Hence, ok.

Step 5: Bending moment

The critical section (Fig.11.29.2b, sec.3.3), is at the face of the column.

M_u = 0.333(2600)(1100)(550) Nmm = 523.809 kNm

Moment of resistance of the footing = Rbd^2 where R = 2.76 (Table 3.3 of Lesson 5).

Moment of resistance = 2.76(2600)(536)(536) = 2061.636 kNm > 523.809 kNm.

Area of steel shall be determined from Eq.3.23 of Lesson 5, which is:

$M_u = 0.87\, f_y\, A_{st}\, d\, \{1 - (A_{st}\, f_y/f_{ck}\, bd)\}$ …. (3.23)

Substituting M_u = 523.809 kNm, f_y = 415 N/mm^2, f_{ck} = 20 N/mm^2, d = 536 mm, b = 2600 mm, we have:

A_{st}^2 - 67161.44578 A_{st} + 181.7861758 (10^5) = 6

Solving, we get A_{st} = 2825.5805 mm^2.

Alternatively, we can use Table 2 of SP-16 to get the A_{st} as explained below:

M_u/bd^2 = 523.809(10^6)/(2600)(536)(536) = 0.7013 N/mm^2. Table 2 of SP-16 gives p = 0.2034.

A_{st} = 0.2034(2600)(536)/100 = 2834.58 mm^2.

This area is close to the other value = 2825.5805 mm^2.

However, one-way shear has been checked assuming p = 0.25%. So, use p = 0.25%. Accordingly, A_{st} = 0.0025(2600)(536) = 3484 mm^2.

Provide 18 bars of 16 mm diameter (= 3619 mm^2) both ways. The spacing of bars = {2600 – 2(50) – 16}/17 = 146.117 mm. The spacing is 140 mm c/c (Fig.11.29.2).

The bending moment in the other direction is also the same as it is a square footing. The effective depth, however, is 16 mm more than 536 mm. But, the area of steel is not needed to be determined with d = 552 mm as we are providing 0.25 per cent reinforcement based on one-way shear checking.

Step 6: Development length

$L_d = f_s\,\phi/4(\tau_{bd})$ = 0.87(415)(16)/4(1.6)(1.2) = 47(16) = 752 mm (cl.26.2.1 of IS 456).

Length available = 1100 – 50 = 1050 mm > 752 mm.

Step 7: Transfer of force at the base of the column

P_u = 1500(1.5) = 2250 kN

Compressive bearing resistance = 0.45 $f_{ck}(A_1/A_2)^{1/2}$. For the column face A_1/A_2 = 1 and for the other face A_1/A_2 > 2 but should be taken as 2. In any case, the column face governs.

Force transferred to the base through column at the interface = 0.45(20)(400)(400) = 1440 kN < 2250 kN. The balance force 2250 – 1440 = 810 kN has to be transferred by the longitudinal reinforcements, dowels or mechanical connectors. As it is convenient, we propose to continue the longitudinal bars (12-20 mm diameter) into the footing. The required development length of 12-20 mm diameter bars, assuming a stress level of 0.87f_y(810/2250) = 129.978 N/mm^2, is 129.978(20)/4(1.6)(1.2)(1.25) = 270.8 mm. Here τ_{bd} for M 20 = 1.2 N/mm^2, increased factor of 1.6 is due to deformed bars and increased factor of 1.25 is for the compression.

Length available = 610 – 50 – 16 – 16 – 16 = 512 mm > 270.8 mm (Fig.11.29.2a). Hence, o.k. The arrangement is shown in Fig.11.29.2c.

Alternatively: Design of dowels

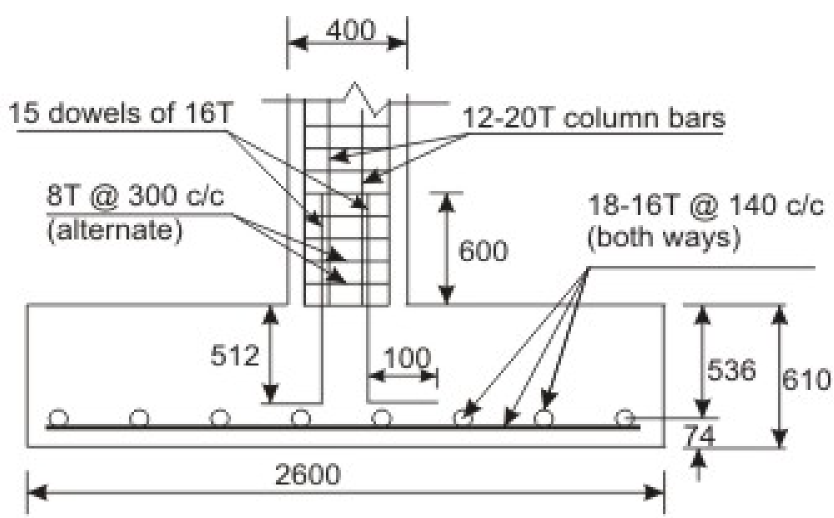

Fig. 11.29.2(c): Dowels

Fig. 11.29.2: Problem - 2

For the balance force 810 kN, the area of dowels = 810000/0.67(415) = 2913.15 mm^2. Minimum area = 0.5(400)(400)/100 = 800 mm^2 < 2913.15 mm^2 (cl.34.4.3 of IS 456). Therefore, number of 16 mm dowels = 2913.15/201 = 15. The development length of 16 mm dowels in compression = 0.87(415)(16)/4(1.6)(1.2)(1.25) = 601.76 mm. Available vertical embedment length = 610 – 50 – 16 – 16 – 16 = 512 mm. So, the dowels will be extended by another 100 mm horizontally, as shown in Fig.11.29.2c.

Problem 3:

Design a sloped footing for a square column of 400 mm x 400 mm with 16 longitudinal bars of 16 mm diameter carrying a service load of 1400 kN. Use M 20 and Fe 415 both for column and footing slab. The safe bearing capacity of soil is 150 kN/m^2.

Solution 3:

Step 1: Size of the footing

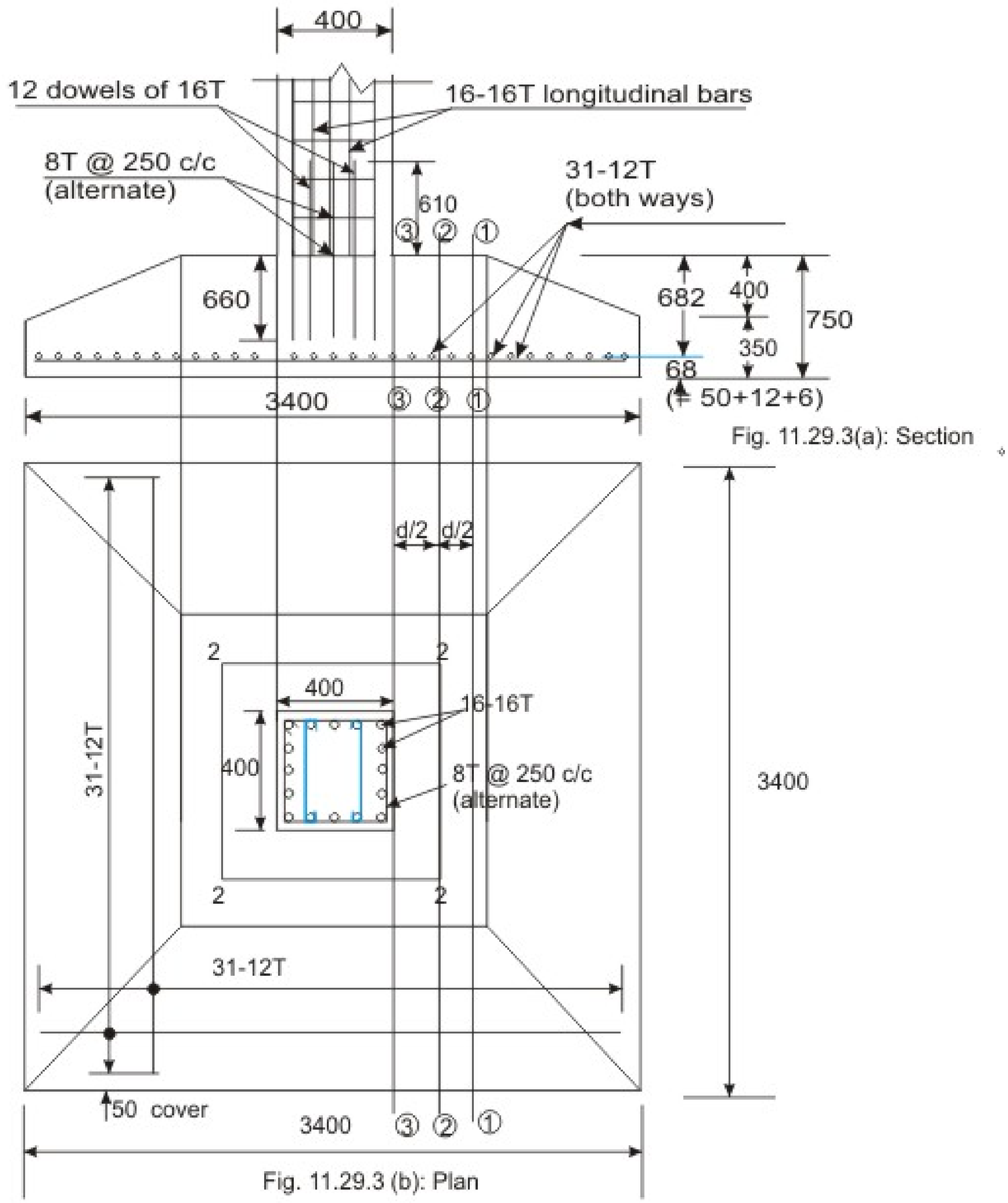

Fig. 11.29.3: Problem 3

Given P = 1400 kN and q_c = 150 kN/m^2. Assuming the weight of the footing and the back file as 10 per cent of the load, the required base area is: 1400(1.1)/150 = 10.27 m^2. Provide 3400 x 3400 mm giving 11.56 m^2 (Fig.11.29.3b).

Step 2: Thickness of footing slab based on one-way shear

Factored bearing pressure = 1400(1.5)/(3.4)(3.4) = 181.66 kN/m^2 = 0.18166 N/mm^2. Assuming 0.15 per cent reinforcement in the footing slab, Table 19 of IS 456 gives τ_c for M 20 = 0.28 N/mm^2. From the condition that the one-way shear resistance $\geq$ one-way shear force, we have at a distance d from the face of the column (sec.1-1of Figs.11.29.3a and b).

$$0.28(3400)d \geq 0.18166(1500 - d)(3400)$$

or $d \geq 590.24$ mm.

Provide total depth of footing as 670 mm, so that the effective depth = 670 – 50 – 16 – 8 = 596 mm. (The total depth is, however, increased to 750 mm in Step 7.)

Step 3: Checking for two-way shear (See sec.11.28.5.d-2)

At the critical section 2222 (Figs.11.29.3a and b), the shear resistance = 4(400 + 596)(596)(0.25)$(f_{ck})^{1/2}$ = 2654.73 kN.

The shear force = {(3.4)(3.4) – (0.996)(0.996)}0.18166 = 1919.78 kN < 2654.73 kN. Hence, o.k.

Step 4: Gross bearing capacity

Assuming unit weights of concrete and soil as 25 kN/m^3 and 18 kN/m^3, respectively, we have:

Load on footing = 1400.00 kN

Weight of footing = (3.4)(3.4)(0.67)(25) = 193.63 kN

Weight of soil = (3.4)(3.4)(1.25 - 0.67)(18) = 120.69 kN (Assuming the depth of the footing as 1.25 m).

Total = 1714.32 kN

Gross bearing capacity = 1714.32 / (3.4)(3.4) = 148.30 kN/m^2 < 150 kN/m^2. Hence o.k.

Step 5: Bending moment

We have to determine the area of steel in one direction as it is a square footing. So, we consider the lower effective depth which is 596 mm. The critical section is sec.33 (Figs.11.29.3a and b), where we have

$$M_u = 3400(1500)(0.18166)(1500)/2 = 694.8495 \text{ kNm}$$

$M_u/bd^2 = 694.8495(10^6)/(3400)(596)(596) = 0.575 \text{ N/mm}^2$

Table 2 of SP-16 gives, p = 0.165%. Accordingly, area of steel = 0.165(3400)(596)/100 = 3343.56 mm^2. Provide 30 bars of 12 mm diameter (= 3393 mm^2), both ways.

Step 6: Development length

Development length of 12 mm diameter bars = 0.87(415)(12)/4(1.6)(1.2) = 564.14 mm. Hence, o.k.

Step 7: Providing slope in the footing slab

Since the three critical sections (.i.e., of bending moment, two-way shear and one-way shear) are within a distance of 596 mm from the face of the column, the full depth of the footing slab is provided up to a distance of 700 mm from the face of the column. However, by providing slope the available section now is a truncated rectangle giving some less area for the one-way shear. Accordingly, the depth of the footing is increased from 670 mm to 750 mm. With a cover of 50 mm and bar diameter of 12 mm in both directions, the revised effective depth = 750 – 50 – 12 – 6 = 682 mm. Providing the minimum depth of 350 mm at the edge, as shown in Figs.11.29.3a and b, we check the one-way shear again, taking into account of the truncated rectangular cross-section at a distance of 682 mm from the face of the column.

One-way shear force = 0.18166(1500 – 682)(3400) = 505232.792 N

Area of truncated rectangle = 1800(682) + 1600(282) + 1600(682 – 282)/2

= 1998800 mm^2

The shear stress = 505232.792/1998800 = 0.2527 N/mm^2 < 0.28 N/mm^2. Hence, o.k.

Step 8: Revised area of steel

The bending moment in step 5 is 694.8495 kNm at the face of the column. With d = 682 mm now, we have

$M_u/bd^2 = 694.8495(10^6)/(3400)(682)(682) = 0.4394 \text{ N/mm}^2$

Table 2 of SP-16 gives, p is less than 0.15 per cent. Provide p = 0.15 per cent due to the one-way shear. So, A_{st} = 0.15(3400)(682)/100 = 3478.2 mm^2. Provide 31 bars of 12 mm (A_{st} = 3506 mm^2), both ways. Effectively, the number of bars has increased from 30 to 31 now.

Step 9: Transfer of force at the base of the column

P_u = 1400(1.5) = 2100 kN. Compressive bearing resistance = 0.45 $f_{ck}(A_1/A_2)^{1/2}$ = 0.45(20)(1) = 9 N/mm^2.

Force transferred at the base through the column = 9(400)(400)(10^{-3}) = 1440 kN < 2100 kN.

Provide dowels for the excess (2100 – 1440) = 660 kN. The area of dowels = 660(10^3)/(0.67)(415) = 2373.67 mm^2. Minimum area of dowels = 0.5(400)(400)/100 = 800 mm^2. Provide 12 dowels of 16 mm diameter (area = 2412 mm^2).

The development length of 16 mm dowels = 0.87(415)(16)/4(1.6)(1.2)(1.25) = 601.76 mm.

The vertical length available 750 – 50 – 12 – 12 – 16 = 660 mm > 601.76 mm. Hence, o.k. The arrangement of reinforcement and dowels is shown in Fig.11.29.3a and b.

Problem 4:

Design one isolated footing for a column 300 mm x 450 mm, having 20 bars of 20 mm diameter (A_{st} = 4021 mm^2) of Problem 1 of sec.10.25.6 of Lesson 25 carrying P_u = 1620 kN and M_u = 170 kNm using M 25 and Fe 415. Assume that the moment is reversible. The safe bearing capacity of the soil is 200 kN/m^2 at a depth of 1 metre from ground level. Use M 25 and Fe 415 for the footing.

Solution 4:

Step 1: Size of the footing

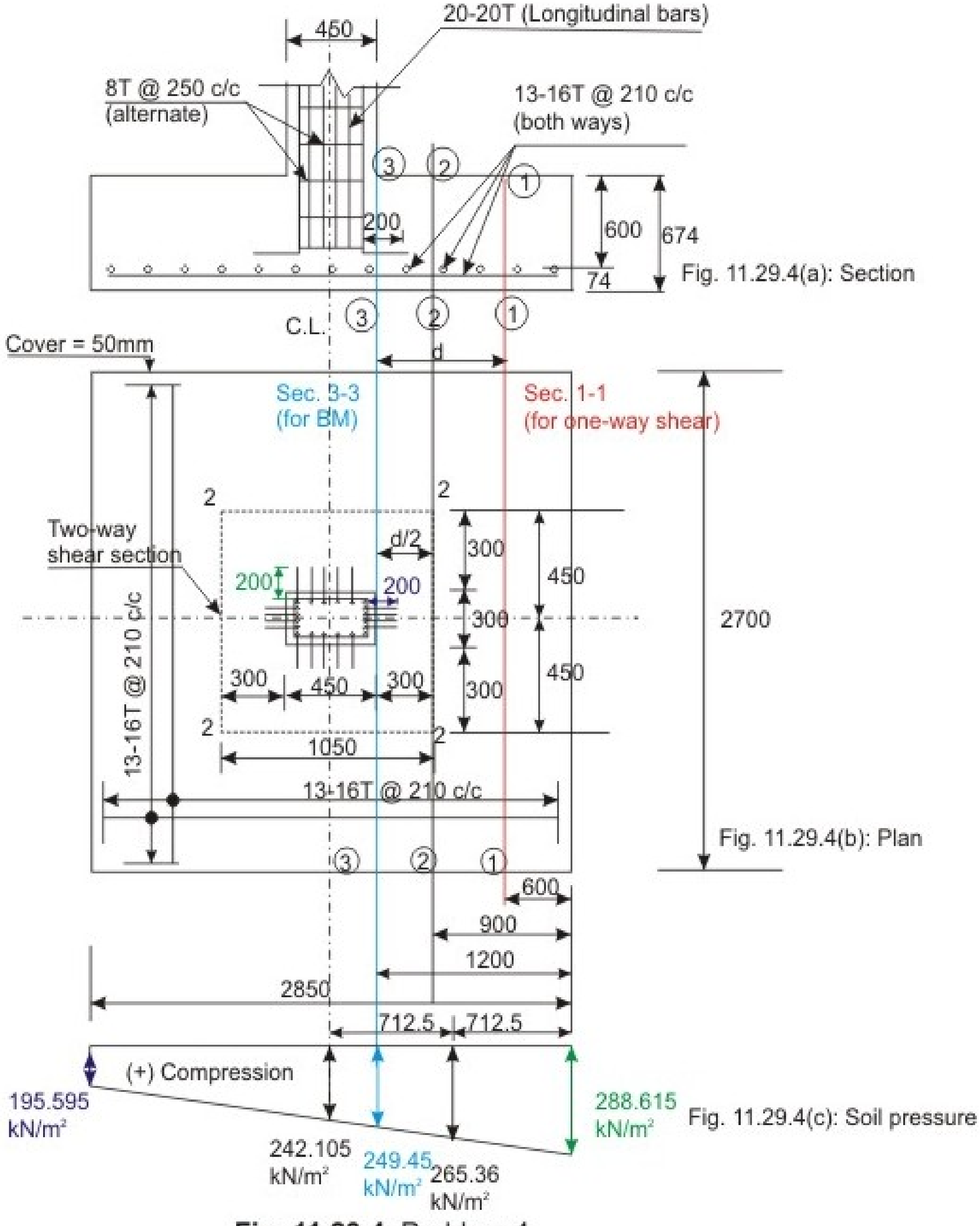

Fig. 11.29.4: Problem 4

Given P_u = 1620 kN and M_u = 170 kNm. The footing should be symmetric with respect to the column as the moment is reversible. Assuming the weights of footing and backfill as 15 per cent of P_u, the eccentricity of load P_u at the base is $e = M_u/P(1.15) = 170(10^6)/1620(1.15)(10^3)$ = 91.25 mm. This eccentricity may be taken as < L/6 of the footing.

The factored bearing pressure is 200(1.5) = 300 kN/m^2. For the footing of length L and width B, we, therefore, have:

$$P_u/BL + 6M/BL^2 \leq 300$$

or, $1620(1.15)/BL + 6(170)/BL^2 \leq 300$

or, $BL^2 - 6.21L - 3.4 \leq 0$
(1)

For the economic proportion, let us keep equal projection beyond the face of the column in the two directions. This gives

$$(L - 0.45)/2 = (B - 0.3)/2$$

or, $B = L - 0.15$
(2)

Using Eq.(2) in Eq.(1), we have

$$(L - 0.15)\, L^2 - 6.212 - 3.4 \leq 0$$

or $L^3 - 0.15\, L^2 - 6.21\, L - 3.4 \leq 0$

We have L = 2.8 m and B = 2.65 m. Let us provide L = 2.85 m and B = 2.70 m (Fig.11.29.4b). We get the maximum and minimum pressures as

1620(1.15)/(2.85)(2.70) $\pm$ 170(6)/(2.7)(2.85)(2.85) = 242.105 $\pm$ 46.51 = 288.615 kN/m^2 and 195.595 kN/m^2, respectively (Fig.11.29.4c). Both the values are less than 300 kN/m^2. Hence, o.k.

Step 2: Thickness of footing slab based on one-way shear

The critical section (sec.11 of Figs.11.29.4a and b) is at a distance d from the face of the column. The average soil pressure at sec.11 is {288.615 – (288.615 – 195.595)(1200 – d)/2850} = 249.449 + 0.0326d.

The one-way shear force at sec.11 = (2.7)(1.2 – 0.001d((249.449 + 0.0326d) kN. Assuming 0.15 per cent reinforcement in the footing slab, the shear strength of M 25 concrete = 0.29 N/mm^2. Hence, the shear strength of the section = 2700(d)(0.29)(10^3) kN. From the condition that shear strength has to be $\geq$ shear force, we have

$$2700(d)(0.29)(10^{-3}) = (2.7)(1.2 - 0.001d)(249.449 + 0.0326d)$$

This gives,

$d^2 + 15347.51534d - 9182171.779 = 0$

Solving, we get d = 576.6198. Let us assume d = 600 mm

Step 3: Checking for two-way shear

At the critical section 2222 (Figs.11.29.4a and b), the shear resistance is obtained cl.31.6.31 of IS 456, which gives τ_c = (0.5 + 450/300)(0.25)(25)$^{1/2}$ but the multiplying factor (0.5 + 450/300) $\not>$ 1.0. So, we have τ_c = 0.25(25)$^{1/2}$ = 1.25 N/mm^2. Hence, the shear resistance = (1.25)(2){(300 + 600) + (450 + 600)}(600) = 2925 kN.

Actual shear force is determined on the basis of average soil pressure at the centre line of the cross-section which is (195.595 + 288.615)/2 = 242.105 kN/m^2 (Fig.11.29.4c). So, the actual shear force = V_u = (242.105){(2.7)(2.85) – (0.3 + 0.6)(0.45 + 0.6)} = 1634.209 kN < shear resistance (= 2925 kN). Hence, the depth of the footing is governed by one-way shear. With effective depth = 600 mm, the total depth of footing = 600 + 50 (cover) + 16 (bar dia) + 8 (half bar dia) = 674 mm.

Step 4: Gross bearing capacity

Assuming the unit weights of concrete and soil as 25 kN/m^3 and 18 kN/m^3, respectively, we have the bearing pressure for (i) P_u = 1620 kN, (ii) M_u = 170 kNm and (iii) self weight of footing and backfill soil.

(i) Due to P_u = 1620 kN: pressure = 1620/(2.7)(2.85) = 210.53 kN/m^2

(ii) Due to M_u = 170 kNm: pressure = $\pm$ 170(6)/(2.7)(2.85)(2.85) = $\pm$ 46.51 kN/m^2

(iii) Self weight of footing of depth 674 mm and soil of (1000 – 674) = 326 mm: pressure = 0.674(25) + 0.326(18) = 22.718 kN/m^2

Thus, the maximum and minimum pressures are = 210.53 + 22.718 $\pm$ 46.51 = 279.758 kN/m^2 and 186.738 kN/m^2 < 300 kN/m^2. Hence, o.k.

Step 5: Bending moment

(i) In the long direction (along the length = 2850 mm)

Bending moment at the face of column (sec.33 of Figs.11.29.4a and b) is determined where the soil pressure = 288.615 – (288.615 – 195.595)(1200)/2850 = 249.45 kN/m^2. So, the bending moment = 249.45(2.7)(1.2)(0.6) + (288.615 – 249.45)(2.7)(1.2)(2)/(2)(3) = 527.23 kNm.

M/Bd^2 = 527.23(10^6)/(2700)(616)(616) = 0.515 N/mm^2 < 3.45 N/mm^2 for M 25 concrete.

Table 3 of SP-16 gives p = 0.1462 < 0.15 per cent as required for one-way shear.

Thus, A_{st} = 0.15(2700)(616)/100 = 2494.8 mm^2. Provide 13 bars of 16 mm diameter (area = 2613 mm^2), spacing = (2700 – 100 – 16)/12 = 215.33 mm, say 210 mm c/c.

(ii) In the short direction (B = 2700 mm)

The average pressure on soil between the edge and centre of the footing = (288.615 + 242.105)/2 = 265.36 kN/m^2. The bending moment is determined with this pressure as an approximation.

Bending moment = (265.36)(1.2)(0.6)(2.85) kNm = 544.519 kNm

M/Ld^2 = 544.519(10^6)/(2850)(600)(600) = 0.531

Table 3 of SP-16 gives p = 0.15068, which gives area of steel = 0.15068(2850)(600)/100 = 2576.628 mm^2. Provide 13 bars of 16 mm diameter (area = 2613 mm^2) @ 210 mm c/c; i.e. the same arrangement in both directions.

Step 6: Development length

Development length of 16 mm diameter bars (M 25 concrete) = 0.87(415)(16)/4(1.6)(1.4) = 644.73 mm.

Length available = 1200 – 50 – 8 = 1142 mm > 644.73 mm. Hence, o.k.

Step 7: Transfer of force at the base of the column

Since the column is having moment along with the axial force, some of the bars are in tension. The transfer of tensile force is not possible through the column-footing interface. So, the longitudinal bars of columns are to be extended to the footing. The required development length of 20 mm bars = 0.87(415)/4(1.4)(1.6) = 805.92 mm. Length available = 600 mm < 805.92 mm. The bars shall be given 90^o bend and then shall be extended by 200 mm horizontally to give a total length of 600 + 8(20) (bend value) + 200 = 960 mm > 805.92 mm (Figs.11.29.4 a and b).

The arrangement of reinforcement is shown in Figs.11.29.4a and b.

Problem 5:

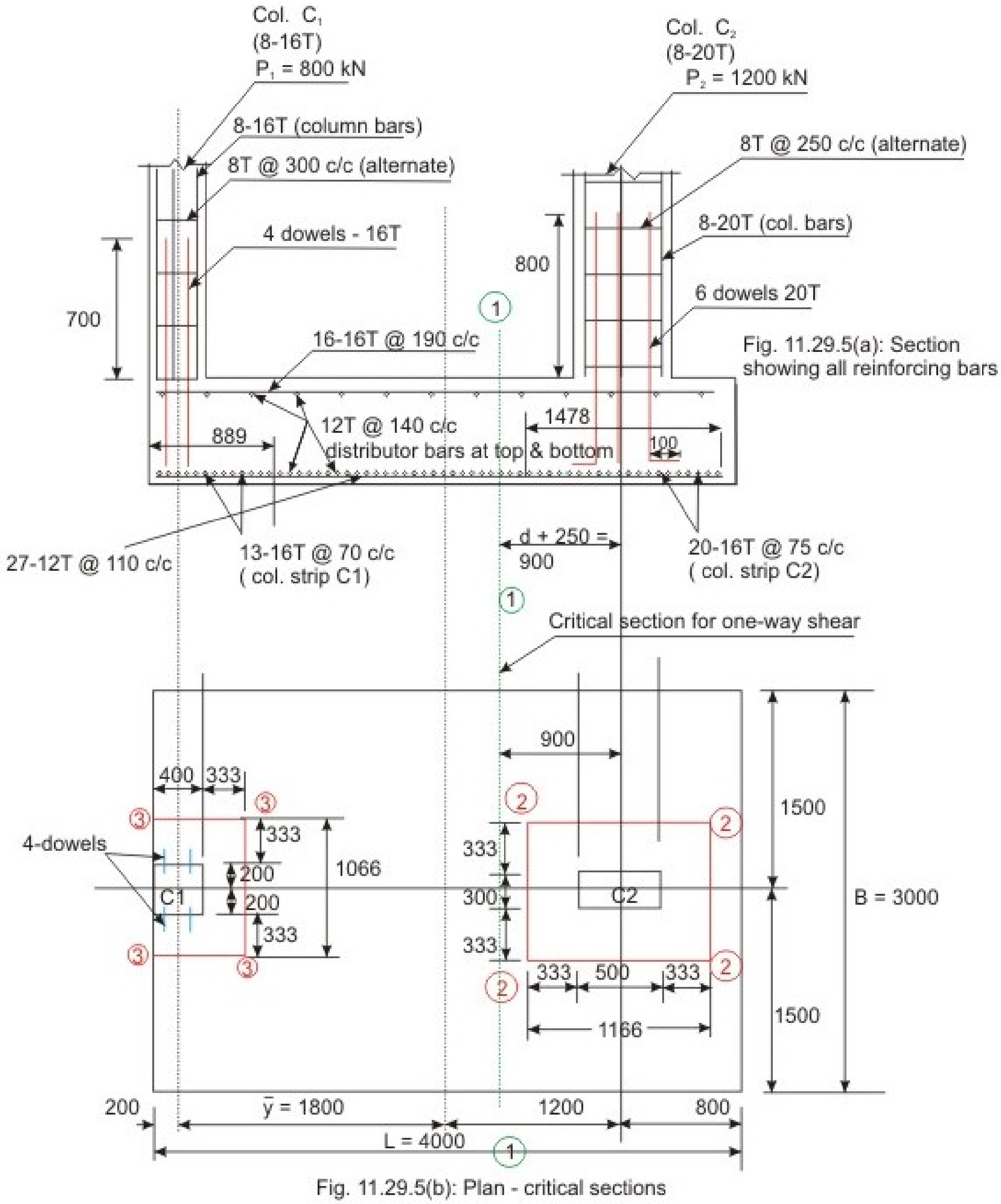

Fig. 11.29.5: Problem-5

Design a combined footing for two columns C_1, 400 mm x 400 mm with 8 bars of 16 mm diameter carrying a service load of 800 kN and C_2, 300 mm x 500 mm with 8 bars of 20 mm diameter carrying a service load of 1200 kN (Figs.11.29.5a and b). The column C_1 is flushed with the property line. The columns are at 3.0 m c/c distance. The safe bearing capacity of soil is 200 kN/m^2 at a depth of 1.5 m below the ground level. Use M 20 and Fe 415 for columns and footing.

Solution :

Step 1: Size of the footing

Assuming the weight of combined footing and backfill as 15 per cent of the total loads of the columns, we have the required base area, considering q_c = 200 kN/m^2,

Area of the base = (800 + 1200)(1.15)/200 = 11.5 m^2.

It is necessary that the resultant of the loads of two columns and the centroid of the footing coincide so that a uniform distribution of soil pressure is obtained. Thus, the distance of the centroid of the footing $\bar{y}$ from column C_1 (Fig.11.29.5b) is:

$\bar{y}$ = 800(0) + 1200(3)/2000 = 1.8 m (Fig.11.29.5b). Since $\bar{y}$ is greater than half the c/c distance of column, a rectangular footing has to be designed. Let us provide 4 m x 3 m and the dimensions are shown in Fig.11.29.5b coinciding the centroid of the footing and the resultant line of action of the two loads, i.e. at a distance of 2 m from the left edge.

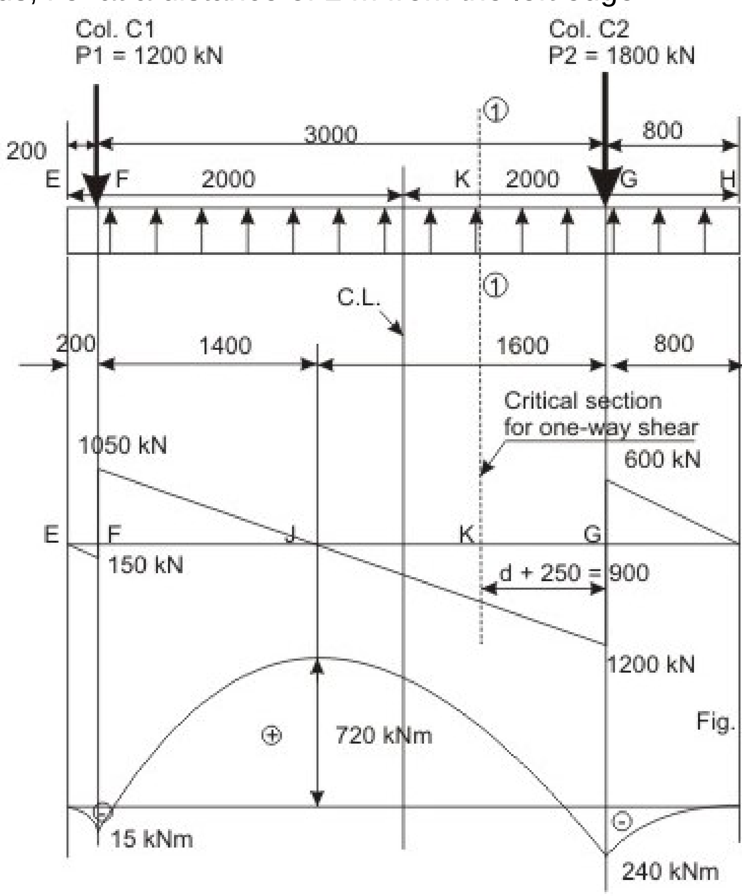

Fig. 11.29.6(a): Loads and soil pressure

Fig. 11.29.6(b): Shear force diagram

Fig. 11.29.6 (c) Bending moment diagram

Fig. 11.29.6: Loads, soil pressure, shear force and bending moment diagrams of Problem 5

Step 2: Thickness of footing slab based on one-way shear

Considering the footing as a wide beam of B = 3 m in the longitudinal direction, the uniformly distributed factored load = (800 + 1200)(1.5)/4 = 750 kN/m. Figures 11.29.6a, b and c present the column loads, soil pressure, shear force and bending moment diagrams.

The critical section of one-way shear is sec.11 (at point K) of Figs.11.29.5a and 11.29.6a, at a distance of d + 250 mm from G (the location of column C_2). The one-way shear force is

Shear force = (1600 – d – 250)1200/1600 = (1012.5 – 0.75d) kN

Assuming p = 0.15 per cent reinforcement in the footing slab, the shear strength of M 20 concrete = 0.28 N/mm^2. Hence, the shear strength of section 11 = (3000)d(0.28)(10^{-3}) kN. From the condition that shear strength $\geq$ shear force, we have

(3000)d(0.28)(10^{-3}) $\geq$ 1012.5 – 0.75d, which gives $d \geq$ 636.79 mm. Provide d = 650 mm and the total depth = 650 + 50 + 16 + 8 = 724 mm (assuming cover = 50 mm and the diameter of bars = 16 mm).

Step 3: Checking for two-way shear

(i) Around column C_2

The effective depth along 4.0 m is 650 + 16 = 666 mm. The critical section for the two-way shear around column C_2 is at a distance of 666/2 = 333 mm from the face of the column and marked by 2222 line in Fig.11.29.5b. The two-way punching shear force, considering the soil pressure = 750/3 = 250 kN/m^2, is

V_u = 1800 – (1.166)(0.966)(250) = 1518.411 kN

As per cl.31.6.3.1 of IS 456, here k_s = 0.5 + (500/300) but $\ngtr$ 1.0; so, k_s = 1.0. Therefore, shear strength of concrete = 0.25$(20)^{1/2}$ (2){(300 + 666) + (500 + 666)}(666) = 3174.92 kN > 1518.411 kN. Hence, o.k.

(ii) Around column C_1

The effective depth of footing is 666 mm. The critical section is marked by 3333 in Fig.11.29.5b. The two-way punching shear = 1200 – (1.066)(0.733)(250) = 1004.65 kN. The resistance to two-way shear = 0.25$(20)^{1/2}$ (2){(1066 + 733)}(666) = 2679.1 kN > 1004.65 kN. Hence, o.k.

Thus, the depth of the footing is governed by one-way shear.

Step 4: Gross bearing capacity

Assuming unit weights of concrete and soil as 25 kN/m^3 and 18 kN/m^3, respectively, the gross bearing capacity under service load is determined below.

(i) Due to two loads: (800 + 1200)/(3)(4) = 166.67 kN/m^2

(ii) Due to weight of the footing: With a total depth of the footing = 724 mm, the pressure = 0.724(25) = 18.1 kN/m^2.

(iii) Due to backfill of 1500 – 724 = 776 mm, the pressure = 0.776(18) = 13.968 kN/m^2.

The total pressure = 166.67 + 18.1 + 13.968 = 198.738 kN/m^2 < 200 kN/m^2. Hence, o.k.

Step 5: Bending moments (longitudinal direction)

(i) Maximum positive moment

Figure 11.29.6c shows the maximum positive bending moment = 720 kNm at a distance of 1.4 m from the column C_1 (at point J). With effective depth d = 666 mm, we have

$$M/Bd^2 = 720(10^6)/(3000)(666)(666) = 0.541 \text{ N/mm}^2$$

Table 2 of SP-16 gives p = 0.1553 per cent.

$$A_{st} = 0.1553(3000)(666)/100 = 3102.894 \text{ mm}^2$$

Provide 16 bars of 16 mm diameter (area = 3217 mm^2), spacing = (3000 – 50 – 16)/15 = 195.6 mm c/c, say 190 mm c/c.

Development length of 16 mm bars = 47.01(16) = 752.16 mm

Length available = 1600 – 50 – 16 = 1534 mm > 752.16 mm

Hence, o.k.

(ii) Maximum negative moment

Figure 11.29.6c shows the maximum negative moment = 240 kNm at a distance of 800 mm from the right edge. With the effective depth = 666 mm, we have

$$M/Bd^2 = 240(10^6)/(3000)(666)(666) = 0.018 \text{ N/mm}^2$$

It is very nominal. So, provide 0.15 per cent steel, which gives A_{st} = 0.15(3000)(666)/100 = 2997 mm^2. Provide 27 bars of 12 mm (area = 3053 mm^2) at spacing = (3000 – 50 – 12)/26 = 113 mm c/c; say 110 mm c/c.

Development length = 47.01(12) = 564 mm

Length available = 800 – 50 – 12 = 738 mm > 564 mm

Hence, o.k.

Step 6: Design of column strip as transverse beam

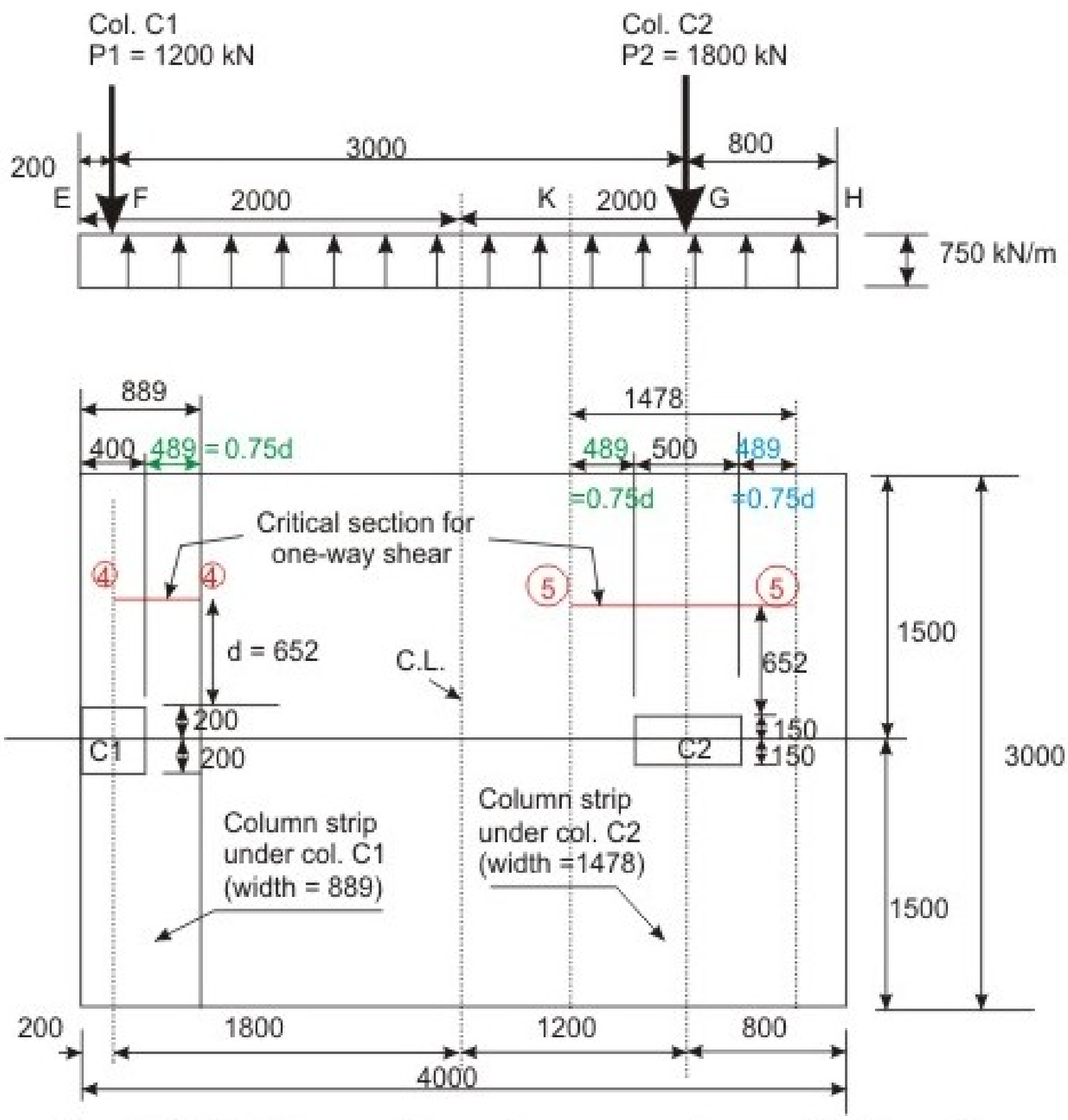

Fig. 11.29.7: Column strips as transverse beams (Problem 5)

Figure 11.29.7 shows the two column strips under columns C_1 and C_2.

(i) Transverse beam under column C_1

The width of the transverse beam is 0.75d from the face of column C_1. The effective depth is 666 – 6 – 8 = 652 mm, as the effective depth in the longitudinal direction = 666 mm, bottom bar diameter in longitudinal direction = 12 mm and assuming the bar diameter in the transverse direction as 16 mm. We have to check the depth and reinforcement in the transverse direction considering one-way shear and bending moment.

(A) One-way shear

The factored load for this transverse strip = 1200/3 = 400 kN/m. The section of the one-way shear in sec.44 (Fig.11.29.7) at a distance of d = 652 mm from the face of column C_1. The width of the transverse strip = 400 + 0.75(652) = 889 mm.

One-way shear force in sec.44 = (1500 – 652 – 200)(400)(10^{-3}) = 259.2 kN

Shear stress developed = 259.2(10^3)/(889)(652) = 0.447 N/mm^2

To have the shear strength of concrete $\geq$ 0.447 N/mm^2, the percentage of reinforcement is determined by linear interpolation from Table 19 of IS 456, so that the depth of footing may remain unchanged. Table 19 of IS 456 gives p = 0.43125. Accordingly, A_{st} = 0.43125(889)(652)/100 = 2499.65 mm^2. Provide 13 bars of 16 mm (area = 2613 mm^2), spacing = 889/12 = 74.08 mm c/c, say 70 mm c/c. However, this area of steel shall be checked for bending moment consideration also.

(B) Bending moment at the face of column C_1 in the transverse strip under column

Bending moment = (1.3)(1.3)(400)/2 = 338 kNm. We, therefore, have

M/(width of strip)d^2 = 338(10^6)/(889)(652)(652) = 0.89 N/mm^2

Table 2 of SP-16 gives p = 0.2608 < 0.43125. Hence, the area of steel as determine for one-way shear consideration is to be provided. Provide 13 bars of 16 mm @ 70 mm c/c in the column strip of width 889 mm under the column C_1.

Development length of 16 mm bars = 47.01(16) = 752.16 mm

Length available = 1300 – 50 – 16 = 1234 mm > 752.16 mm

Hence, o.k.

(ii) Transverse beam under column C_2

Figure 11.29.7 shows the strip of width = 500 + 0.75d + 0.75 d = 500 + 1.5(652) = 1478 mm, considering the effective depth of footing = 652 mm.

(A) One-way shear

The factored load for this transverse strip = 1800/3 = 600 kN/m. The one-way shear section is marked by sec.5.5 in Fig.11.29.7 at a distance of d = 652 mm from the face of the column C_2.

One-way shear in sec.55 (of width = 1478 mm) = (1500 – 652 – 150)(600)(10^{-3})

= 418.8 kN

The shear stress developed = 418.8(10^3)/(1478)(652) = 0.434 N/mm^2

The corresponding percentage of area of steel, as obtained from Table 19 of IS 456 is, p = 0.404 per cent. Accordingly, A_{st} = 0.404(1478)(652)/100 = 3893.17 mm^2. Provide 20 bars of 16 mm (area = 4021 mm^2), spacing = 1478/19 = 77.78 mm c/c, say 75 mm c/c. However, this area of steel shall be checked for bending moment consideration also.

(B) Bending moment at the face of column C_2 in the transverse strip under column C_2

The bending moment = (1.35)(1.35)(600)/2 = 546.75 kNm. We, therefore, have

M/(width of strip)d^2 = 546.75(10^6)/(1478)(652)(652) = 0.87 N/mm^2

Table 2 of SP-16 gives: p = 0.2544 < 0.404 per cent as required for one-way shear. So, provide 20 bars of 16 mm diameter @ 75 mm c/c in the column strip of width 1478 under column C_2.

Development length as calculated in Step (B) of col strip C_1 = 752.16 mm

The length available = 1350 – 50 – 16 = 1284 mm > 752.16 mm

Hence, o.k.

Step 7: Transfer of forces at the base of the columns

(A) For column C_1

The limiting bearing stress at the column face governs where the bearing stress = 0.45f_{ck} = 9 N/mm^2, since the column C_1 is at the edge of the footing.

The force that can be transferred = 9(400)(400)(10^{-3}) = 1440 kN > 1200 kN, load of column C_1. Hence full transfer of force is possible without the need of any dowels. However, four 16 mm nominal dowels are provided as shown in Figs.11.29.5a and b.

(B) For column C_2

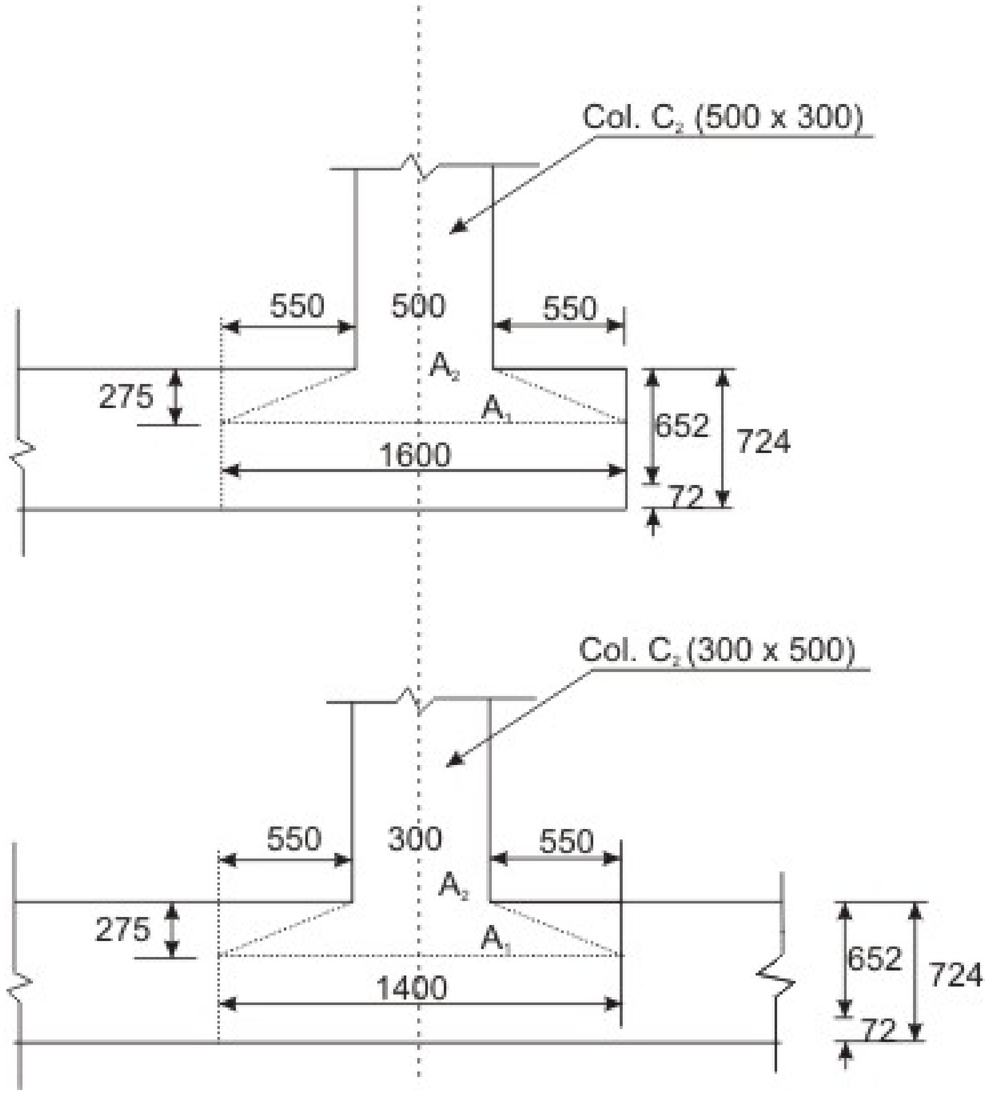

Fig. 11.29.8: Dimensions of A_1 and A_2 of Problem 5

Figure 11.29.8 shows the dimensions to determine A_1 and A_2 for the column C_2 and the footing. Accordingly,

A_1 = (1600)(1400) mm^2, and

A_2 = (300)(500) mm^2

$(A_1/A_2)^{1/2}$ = {(16)(14)/(3)(5)}$^{1/2}$ = 3.86 but limited to 2

The bearing stress at the column face = $0.45f_{ck}$ = 9 N/mm^2, and the bearing stress at the footing face = $0.45f_{ck}(2)$ = 18 N/mm^2. However, the bearing stress of 9 N/mm^2 governs.

The force that can be transferred through the column C_2 = 9(300)(500) = 1350 kN < 1800 kN. For the excess force (1800 – 1350) = 450 kN, dowels shall be provided. The area of dowels = 450(10^3)/0.67(415) = 1618.414 mm^2. The minimum area of dowels = 0.5(300)(500)/100 = 750 mm^2. Provide 6 dowels of 20 mm diameter (area = 1885 mm^2).

The development length required in compression

= 0.97(415)(20)/4(1.6)(1.2)(1.25) = 752.2 mm.

The length available = 652 – 20 = 632 mm

Therefore, the dowels shall be given a 90^o bend and shall be extended horizontally by 100 mm to have a total length of 632 + 8(20) + 100 = 892 mm > 752.2 mm (Figs.11.29.5a and b).

Step 8: Distribution reinforcement

Nominal distribution reinforcement shall be provided at top and bottom where the main reinforcement bars are not provided. The amount @ 0.12 per cent comes to 0.12(1000)(652)/100 = 782.4 mm^2/metre. Provide 12 mm diameter bars @ 140 mm c/c (area = 808 mm^2/m).

All the reinforcing bars and dowels are shown in Figs.11.29.5a and b.

11.29.3 Practice Questions and Problems with Answers

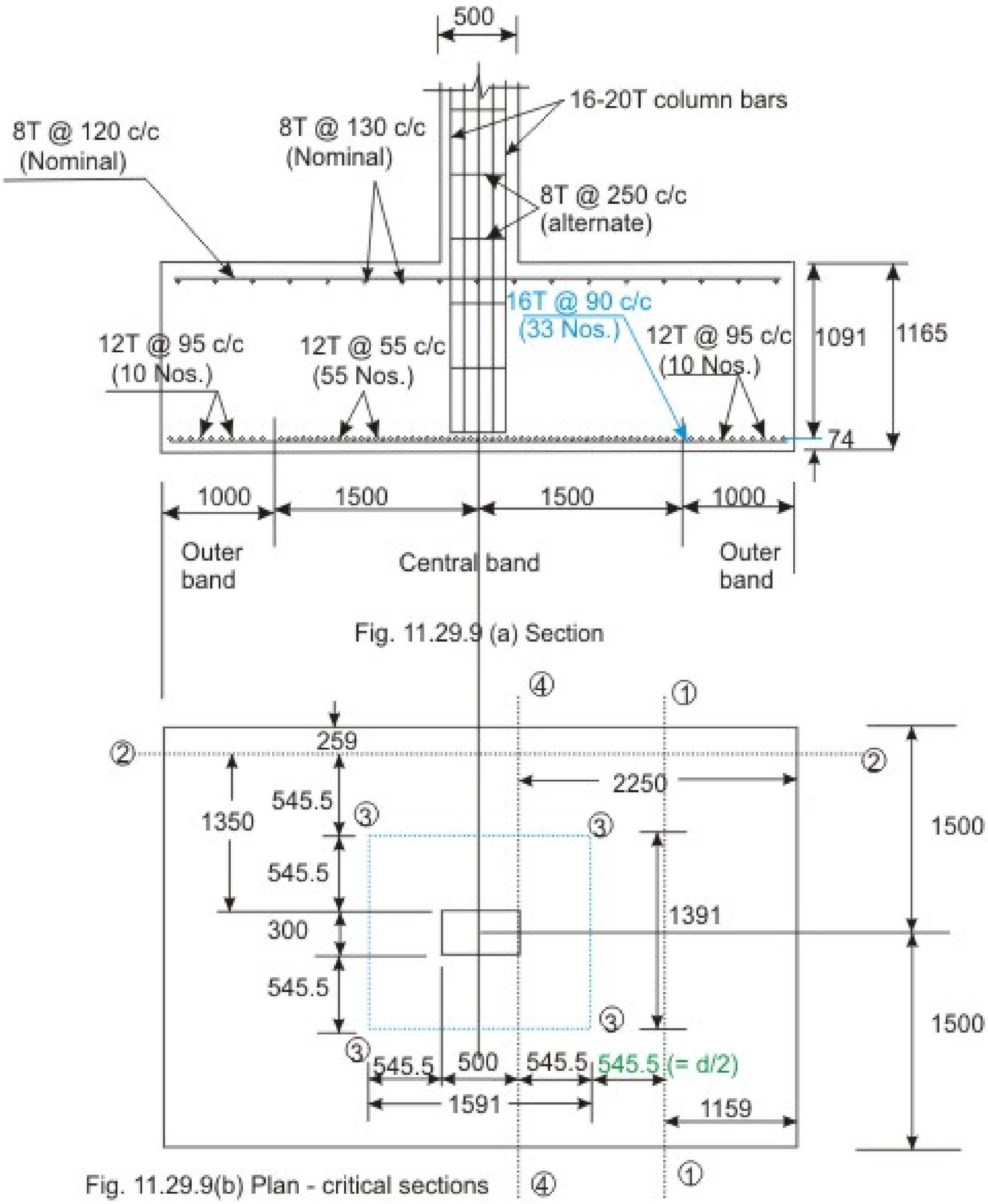

Fig. 11.29.9 (a) Section

Fig. 11.29.9(b) Plan - critical sections

Fig. 11.29.9: Problem Q.1

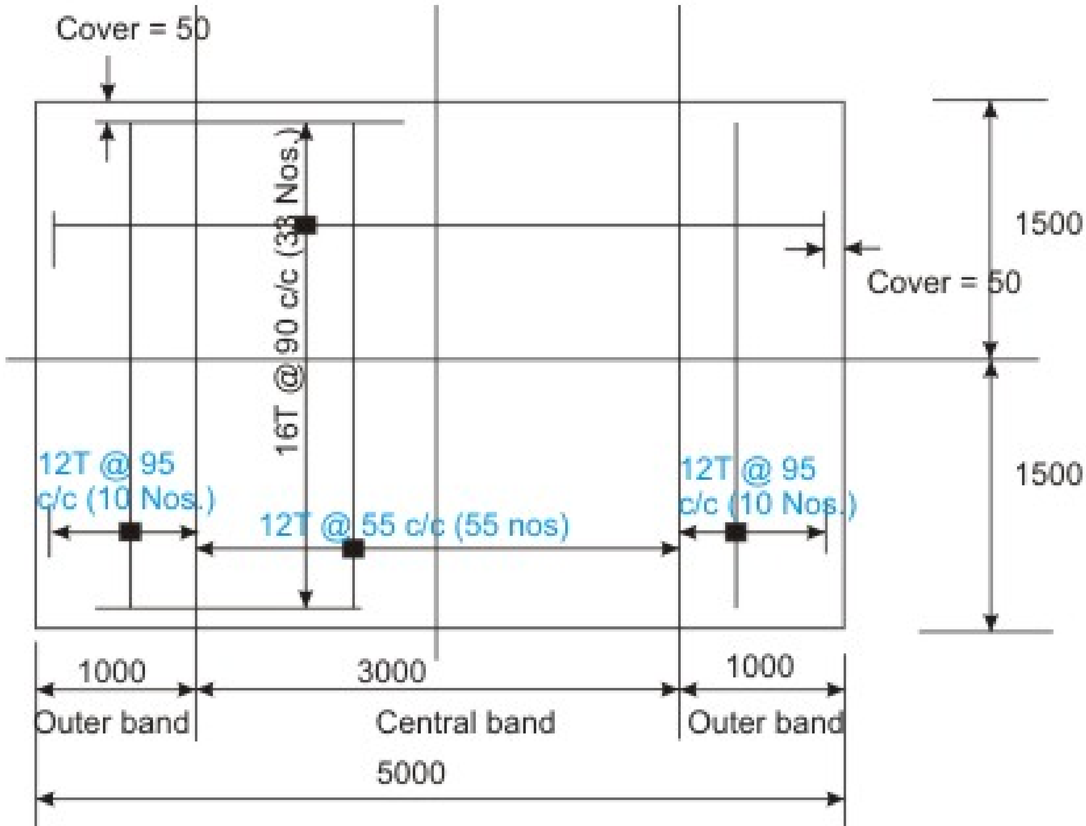

Fig. 11.29.9(c): Plan -Reinforcing bars (band wise)

Fig. 11.29.9: Problem - Q.1

Q.1: Design an isolated footing for a rectangular column, 300 mm x 500 mm with 16-20 mm diameter longitudinal bars carrying a service load of 3000 kN (Figs.11.29.9a and b). Assume safe bearing capacity of soil as 260 kN/m^2 at a depth of 1 m below ground level. Use M 20 and Fe 415.

A.1:

Step 1: Size of the footing

Given P = 3000 kN and q_c = 260 kN/m^2. Assuming the weight of the footing and backfill as 25 per cent of the load, the base area required = 3000(1.25)/260 = 14.42 m^2. Provide 3 m x 5 m giving 15 m^2 area.

Step 2: Thickness of footing slab based on one-way shear

(i) Along 5 m direction

The critical section of one-way shear is marked by sec.11 in Fig.11.29.9b.

Factored soil pressure = 3000(1.5)/15 = 300 kN/m^2 = 0.3 N/mm^2

Assuming 0.2 per cent reinforcement in the footing slab, Table 19 of IS 456 gives τ_c for M 20 = 0.32 N/mm^2. From the condition that the shear resistance $\geq$ shear force, we have:

$$0.32(3000)d \geq 0.3(2250 - d)(3000)$$

or $d \geq 1088.71$ mm

Using 16 mm diameter bars with 50 mm cover the total depth = 1088.71 + 50 + 16 + 8 = 1162.71 mm. Provide total depth of 1165 mm, so that d = 1091 mm.

(ii) Along 3 m direction

The critical section of one-way shear is marked by sec.2-2 in Fig.11.29.9b.

Resistance shear force = 0.32(5000)(1091) = 1745.6 kN

Actual shear force = 0.3(259)(5000) = 388.5 kN < 1745.6 kN

Hence, o.k.

Step 3: Checking for two-way shear

The critical section is marked by 3-3-3-3 in Fig. 11.29.9b.

The permissible shear strength of concrete M 20

$$= (0.5 + \beta)\, 0.25(f_{ck})^{1/2} = 0.25(20)^{1/2} = 1.118 \text{ N/mm}^2$$

Total perimeter of section 3-3-3-3 = 2(500 + 1091 + 300 + 1091) = 5964 mm giving area = 5964(1091) = 6506724 mm^2.

Actual shear force = {15 – (1.591)(1.391)}(300) = 3836.0757 kN

Shear stress = 3836.0757(10^3)/6506724 = 0.5896 N/mm^2 < 1.118 N/mm^2

Hence, o.k.

The depth of the footing slab is governed by one-way shear here.

Step 4: Gross bearing capacity

Assuming unit weights of concrete and soil as 25 kN/m^3 and 20 kN/m^3, respectively, we have

Service load = 3000 kN

Weight of footing slab = 3(5)(1.165)(25) = 436.875 kN

Weight of backfill = 3(5)(1.165)(20) = 349.5

Total loads = 3786.375 kN

Gross bearing capacity = 3786.375/15 = 252.425 kN/m^2 < 260 kN/m^2

Hence, o.k.

Step 5: Bending moments

(i) In the long direction

The critical section of the bending moment in the long direction is marked by sec.4-4, (at the face of column) in Fig.11.29.9b. With factored soil pressure q = 0.3 N/mm^2, the bending moment is 0.3(3000)(2250)(2250)/2 = 2278.125 kNm.

Moment of resistance of the section = RBd^2 = 2.76(3000)(1091)(1091)(10^{-6}) = 9855.53 kNm > 2278.125 kNm. Hence, o.k.

The area of steel is determined from Eq.3.23 of Lesson 5, which is,

$$M_u = 0.87\, f_y\, A_{st}\, d\, \{1 - A_{st}\, f_y/f_{ck}\, b\, d\}$$

or $\quad 2278.125(10^6) = 0.87(415)(A_{st})(1091) - 0.87(A_{st}^2)(415)^2/(20)(3000)$

or $\quad A_{st}^2 - 157734.9398\, A_{st} + 912.249313(10^6) = 0,$

which gives A_{st} = 6012.6245, i.e., p = 0.1837 per cent. However, we have to provide 0.2 per cent, as required for the one-way shear. So, A_{st} = 0.2(3000)(1091)/100 = 6546 mm^2. Provide 33 bars of 16 mm diameter (area = 6634 mm^2, shown in Fig. 11.29.9c). The uniform spacing = (3000 – 50 – 16)/32 = 91.69 mm c/c, say @ 90 mm c/c. Alternatively,

$$M_u/Bd^2 = 2278.125(10^6)/(3000)(1091)(1091) = 0.638$$

Table 2 of SP-16 gives p = 0.1834 per cent, which is very close to the computed p = 0.1837 per cent. So, provide 33 bars of 16 mm diameter @ 90 mm c/c in the long direction.

The development length of 16 mm bar is 47.01(16) = 752.16 mm

Length available = 2250 – 50 – 16 = 2184 mm > 752.16 mm

Hence, o.k.

(ii) In the short direction

The critical section is marked by sec.5-5 in Fig.11.29.9b, (at the face of column) where the bending moment is:

0.3(5000)(1350)(1350)/2 = 1366.875 kNm

We get

M_u/Ld^2 = 1366.875(10^6)/(5000)(1091)(1091) = 0.2296

This is a low value, which is not included in SP-16. So, provide 0.15 per cent to have

A_{st} = 0.15(5000)(1091)/100 = 8182.5 mm^2

However, we have to check for one-way shear as the p provided 0.15 per cent is less than 0.2 per cent, required for the one-way shear and for which τ_c = 0.28 N/mm^2 (Table 19 of IS 456). The one-way shear force, as calculated in step 2(ii) is 388.5 kN. The resistance force of shear at this section = 0.28(5000)(1091) = 1527.4 kN > 388.5 kN. Hence, o.k.

Further, the total area of steel 8182.5 mm^2 has to be distributed in the central band of width 3 m and two outer bands of width 0.75 m each as stipulated in cl.34.3.1c of IS 456. The reinforcement in the central band is obtained as given below:

A_{st} for central band = (2/β + 1) (total area of steel)

where β = 5/3 = 1.67. Thus,

Area of steel in the central band = (2/2.67)(8182.5) = 6129.21 mm^2

Provide 55 bars of 12 mm (area = 6220 mm^2) at the spacing of 3000/54 = 55.55 mm c/c, say, @ 55 mm c/c. Each of two outer band needs (8182.5 – 6129.21)/2 = 1026.65 mm^2. Provide 10 bars of 12 mm diameter (area = 1131 mm^2). The spacing = (1000 – 50)/10 = 95 mm c/c, say @ 90 mm c/c. Thus, the total area of steel provided = 6220 + 1131 + 1131 = 8482 mm^2 > 8182 mm^2 (Fig. 11.29.9c).

The development length required for 12 mm bars = (47.01)(12) = 564.12 mm

Length available = 1350 – 50 – 16 = 1284 mm > 564.12 mm

Hence, o.k.

Step 6: Transfer of force at the base of the column

Factored load = 3000(1.5) = 4500 kN. From the limiting bearing stress at the column-footing interface 0.45 $f_{ck}(A_1/A_2)^{1/2}$, we have

(i) At the column face, where $A_1 = A_2$; bearing stress = 0.45 f_{ck} = 9.0 N/mm^2

(ii) At the footing face, $A_{1\,=\,15\ \mathrm{m}}{}^2$ and A_2 = (0.3)(0.5) = 0.15 m^2. But, $(A_1/A_2)^{1/2} \ngtr 2$. So, the bearing stress = 2(9) = 18 N/mm^2.

Therefore, the column face governs. The force that can be transferred through bearing = 9(500)(300) = 1350 kN. The excess force to be transferred by dowels = 4500 – 1350 = 3150 kN.

Area of dowels = 3150(10^3)/0.67(415) = 11328.9 mm^2. Minimum area of dowels = 0.5(300)(500)/100 = 750 mm^2. So, the number of 20 mm dowels = 36. Instead of providing 36 dowels, it is convenient to extend the sixteen column bars of 20 mm diameter to the footing.

The development length required = 0.87(415)(20)/4(1.6)(1.25)(1.2) = 752.2 mm

Length available = 1091 – 74 = 1017 mm > 752.2 mm

Step 7: Nominal reinforcement

Clause 34.5.2 stipulates to provide @ 360 mm^2 per metre length in each direction on each force, when the thickness of footing slab is greater than one metre. So, the minimum reinforcement is 8 mm bars @ 130 mm c/c (area = 387 mm^2/m), wherever there is no other reinforcement.

The reinforcement bars are shown in Figs.11.29.9a and c.

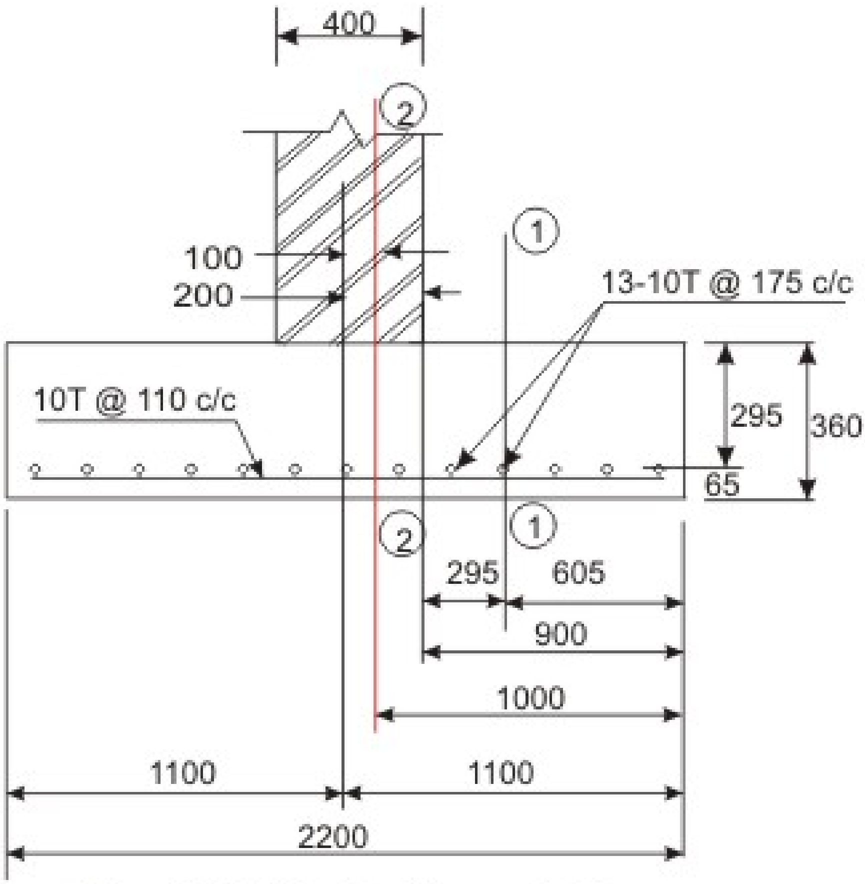

Fig. 11.29.10: Problem - Q. 2

Q.2: Design a reinforced concrete footing for a wall of 400 mm thickness transmitting a load of 200 kN/m (Fig.11.29.10) under service condition. Assume the safe bearing capacity of soil as 100 kN/m^2 at a depth of 1 m below the ground level. Use M 20 and Fe 415.

A.2:

Step 1: Size of the footing

Given axial load = 200 kN/m and safe bearing capacity of soil q_c = 100 kN/m^2 at a depth of 1 m below the ground level. Assuming the self weight of footing and backfill as 10 per cent, the area of the base required = 200(1.1)/100 = 2.2 m^2. Provide width of 2.2 m for every one metre to get the required area of 2.2 m^2.

Step 2: Thickness of footing slab based on shear

The critical section of shear is marked as sec.1-1 in Fig.11.29.10, at a distance of effective depth d of the footing.

Factored soil pressure = 200(1.5)/2.2 = 136.36 kN/m^2 = 0.13636 N/mm^2.

Assuming 0.15 per cent reinforcement in the footing slab, the shear strength of M 20 τ_c = 0.28 N/mm^2. From the condition that the shear strength of the section $\geq$ actual shear force in sec.11, we have:

$0.28(1000)d \geq (0.13636)(1000)(900 - d)$

This gives $d \geq 294.755$ mm. Using cover of 50 mm and diameter of reinforcing bar as 10 mm, the total depth of footing = 295 + 50 + 10 + 5 = 360 mm. This gives effective depth = 295 mm.

Step 3: Checking for the moment

The critical section for the bending moment is marked marked as sec.2-2 in Fig.11.29.10, where the bending moment (factored) is,

M_u = (1)(0.13636)(1000)(1000)/2 = 68.18 kNm/m

The capacity of the section = (2.76)(1000)(295)(295) = 240.189 kNm/m > 68.18 kNm/m. Hence, o.k.

M/bd^2 = 68.18(10^6)/1000(295)(295) = 0.784 N/mm^2

Table 2 of SP-16 gives p = 0.2282 per cent. Accordingly, A_{st} = 0.2282(1000)(295)/100 = 673.19 mm^2/m. Provide 10 mm diameter bars @ 110 mm c/c which gives 714 mm^2/m > 673.19 mm^2/m.

Step 4: Development length

The development length of 10 mm bars = 47.01(10) = 470.1 mm

Length available = 900 – 50 = 850 > 542.88

Step 5: Distribution reinforcement

Minimum reinforcement @ 0.12 per cent should be provided longitudinally.

A_{st} = 0.12(2200)(360)/100 950.4 mm^2

Provide 13 bars of 10 mm diameter (area = 1021 mm^2). The spacing = (2200 – 50 – 10)/12 = 178.33 mm c/c, say @ 175 mm c/c.

Step 6: Transfer of loads at wall-footing base

Bearing stress = $0.45\, f_{ck}\, (A_1/A_2)^{1/2}$ = 0.45(20)(1) = 9 N/mm^2

The forces that can be transferred = 9(1000)(2200)(10^{-3}) kN = 19800 kN >> factored load of 200(1.5) = 300 kN. Hence, o.k.

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11.29.5 Test 29 with Solutions

Maximum Marks = 50, Maximum Time = 30 minutes

Answer all questions.

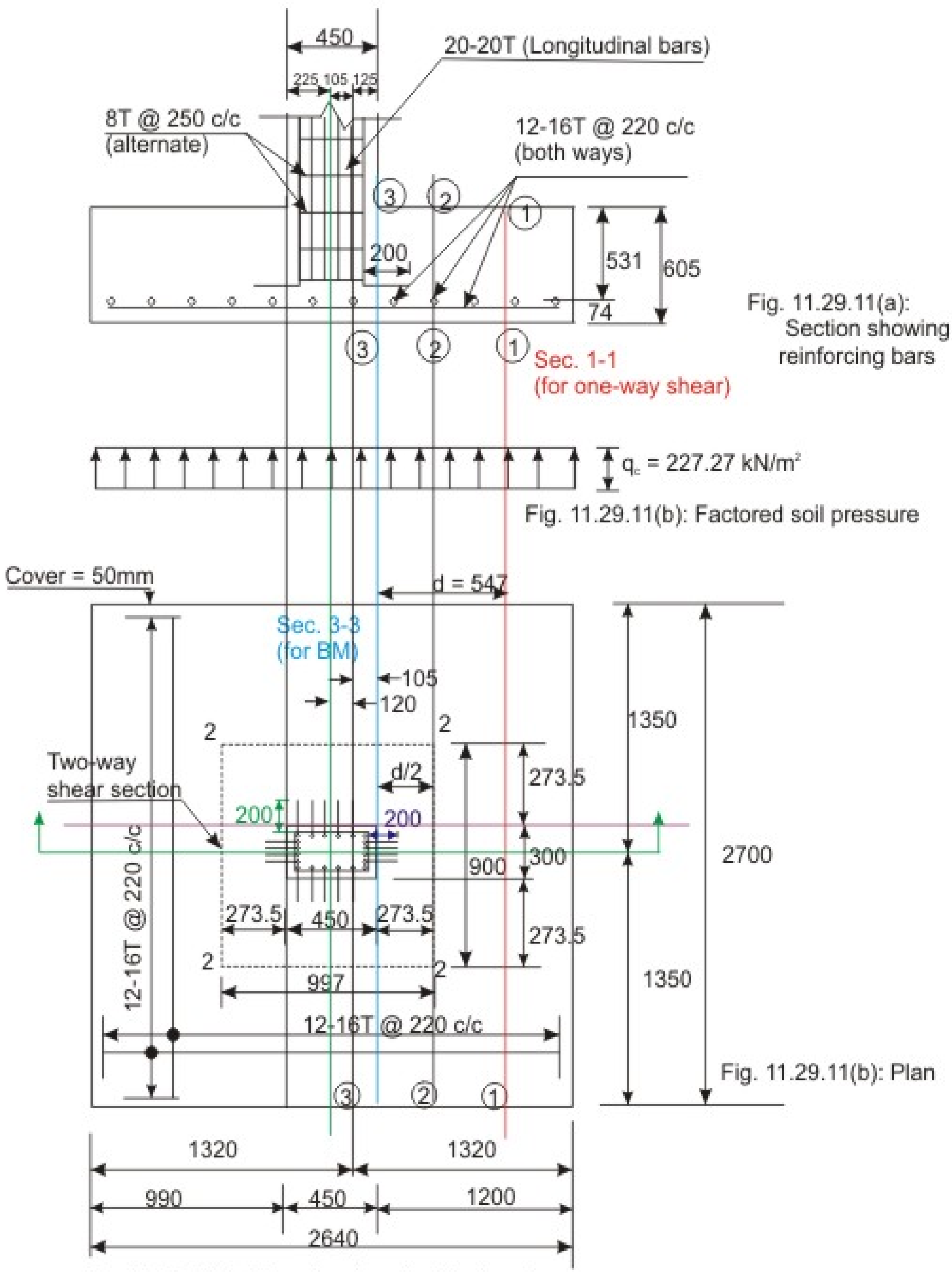

Fig. 11.29.11(c): Plan showing all critical sections

Fig. 11.29.11: TQ.1

TQ.1: Redesign the footing of Problem 4 of section 11.29.2 (Fig.11.29.4) to have uniform base pressure considering that moments are due to dead load and hence irreversible (Fig.11.29.11). Other data of Prolem 4 are: column size = 300 mm x 450 mm, longitudinal bars of column = 20 bars of 20 mm (A_{st} = 4021 mm^2), P_u = 1620 kN, M_u = 170 kNm, safe bearing capacity of soil = 200 kN/m^2 at a depth of 1 metre below the ground level, grade of concrete = M 25 and grade of steel = Fe 415.

(50 marks)

A.TQ.1:

Step 1: Size of the footing

The required eccentricity between the centroids of column and footing = M_u/P_u = 170(10^6)/1620(10^3) = 104.938 mm, say 105 mm.

Assuming the weight of the footing and backfill as 15 per cent, the required base area = 1620(1.15)/200(1.5) = 6.21 m^2.

It is desirable that the cantilever projections in the two direction from the respective column face should be equal. Accordingly, the footing is selected as 2.7 m x 2.64 m where the centre line of column is located at a distance of 105 mm left from the centre line of footing, as shown in Fig.11.29.11c. The arrangement shows that the cantilever projections are equal (1200 mm).

Step 2: Thickness of footing based on one-way shear

Factored soil pressure = 1620/(2.7)(2.64) = 227.27 kN/m^2 (Fig.11.29.11b). The critical section of one-way shear is marked by sec.1-1 in Figs.11.29.11a and c, at a distance of d from the face of the column, where the factored shear V_u is,

V_u = 0.22727(2700)(1200 – d) = (736354.8 – 613.629 d) N

Assuming 0.15 per cent reinforcement in the footing slab, Table 19 of IS 456 gives τ_c = 0.29 for M 25 concrete. Accordingly, the resistance shear of the section is 0.29(2700)d = 783d. From the condition that the resistance shear $\geq$ actual shear, we have

783 d $\geq$ 736354.8 – 613.629 d, which gives $d \geq$ 527.237. Let us use full depth = 527.237 + 50 + 16 + 8 = 601.237 mm, say 605 mm, so that d = 605 – 50 – 8 = 547 mm in the long direction and 605 – 50 – 16 – 8 = 531 mm in the short direction.

Step 3: Checking for two-way shear

The shear strength of concrete for two-way shear = $0.25(f_{ck})^{1/2}$ (cl.31.6.3 of IS 456) = 1.25 N/mm^2. The resistance shear of the section is (sec.2222 of Fig.11.29.11c):

(1.25)(2){(450 + 547) + (300 + 547)}(547) = 2521.67 kN

The actual shear force in sec.2222 (Fig. 11.29.11c) is

{(2.7)(2.64) – (0.997)(0.847)}(227.27) = 1428.06 kN < 2521.67 kN

Hence, o.k.

Step 4: Gross bearing capacity

Assuming unit weights of concrete and soil as 25 kN/m^3 and 18 kN/m^3, we have the factored gross bearing capacity as

q = (1620)/(2.7)(2.64) + {0.605(25) + 0.395(18)}

= 249.509 kN/m^2 < 300 kN/m^2

Step 5: Bending moment

(i) In the short direction

The critical section is marked by sec.33 in Fig.11.29.11c, at the face of column, where the bending moment is:

M_u = (2.7){(1.2)(1.2)/2}227.27 = 441.82 kNm

M_u/Ld^2 = 441.82(10^6)/(2.7)(10^3)(547)(547) = 0.546 N/mm^2 < 3.45 N/mm^2 for M 25 and Fe 415.

Hence, the section has the capacity to resist M_u = 441.82 kNm.

Table 3 of SP-16 gives p = 0.15488 per cent. Accordingly,

A_{st} = 0.15488(2700)(547)/100 = 2287.42 mm^2

Provide 12 bars of 16 mm diameter (area = 2412 mm^2). The spacing = (2700 – 50 – 16)/11 = 239.45 mm c/c, say 220 mm c/c. Provide 12 bars of 16 mm diameter @ 220 mm c/c.

Development length of 16 mm diameter bars

= 0.87(415)(16)/4(1.4)(1.6) = 644.73 mm

Length available = 1200 – 50 – 16 = 1134 mm > 644.73 mm

Hence, o.k.

(ii) In the long direction

The critical section is marked by sec.4-4 in Fig.11.29.11c, at the face of column, where the moment M_u is,

M_u = (2.64){(1.2)(1.2)/2}(227.27) = 431.994 kNm

M_u/Bd^2 = 431.994(10^6)/(2640)(531)(531) = 0.5803 N/mm^2 < 3.45 N/mm^2

Hence, the section can carry this moment. Table 3 of SP-16 gives p = 0.16509 per cent. Accordingly,

A_{st} = 0.16509(2640)(531)/100 = 2314.2976 mm^2

Provide 12 bars of 16 mm diameter (area = 2412 mm^2). The spacing = (2640 – 50 – 16)/11 = 234 mm c/c, say 220 mm c/c. Provide 12 bars of 16 mm diameter @ 220 mm c/c.

Development length as calculated in (i) for 16 mm diameter = 644.73 mm

Length available = 1200 – 50 – 16 = 1134 mm > 644.73 mm

Hence, o.k.

Step 6: Transfer of force at the base of column

Since the column is having moment along with the axial force, some of the bars are in tension. The transfer of tensile force is not possible through the column-footing interface. So, the longitudinal bars of column are to extended to the footing. The required development length of 20 mm bars = 0.87(415)/4(1.4)(1.6) = 805.92 mm. Length available = 531 mm < 805.92 mm. The bars shall be given 90^o bend and then shall be extended by 200 mm horizontally to give a total length of 531 + 8(20) (bend value) + 200 = 891 mm > 805.92 mm.

The arrangement of reinforcing bars is shown in Fig.11.29.11a.

11.29.6 Summary of this Lesson

This lesson illustrates the applications of the requirements for the design of foundations, explained in Lesson 28. Five illustrative examples, two practice problems and one test problem include plain concrete footings, isolated footings of square and rectangular columns transferring axial loads with or without moments to the footings, wall footings and combined footings. The solutions of illustrative problems and practice of the practice and test problems will give a clear understanding of the design of footings under different circumstances and soil conditions. All the designs are done following the stipulations of IS codes. It is, however, worth mentioning that all the footings explained in this lesson are shallow foundations. The design of deep foundations is beyond the scope of this course.