UNIT 3 RCC COLUMN FOOTINGS, RAFT AND PILE FOUNDATIONS

Structure

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3.1 INTRODUCTION

As described in Unit 2, there are two types of foundations – shallow foundations and deep foundations. Isolated and combined footings as well as raft foundations are shallows foundations as their bases are less than 3m deep. These types of foundations transmit the loads through columns to the soil by spreading the loads over larger area so that allowable bearing capacity of soil is not exceeded.

Where desired allowable bearing capacity is not found at economical depth, the load of the structure is transmitted to the soil through friction and/or bearing by column – like structural components called piles.

Objectives

After studying this unit, you should be able to

- describe the types and detailing of isolated footings, combined footings, raft foundations and pile foundations.

3.2 RCC COLUMN FOOTINGS

3.2.1 General

General specifications for all types of isolated and combined footing are as follows :

(a) The minimum nominal cover to all reinforcements including link shall be not less than 50.

(b) Minimum diameter of bars for main reinforcements shall not be less than 10 mm.

(c) Minimum thickness at the edge of the footing shall not be less than 150.

(d) For beams

(i) the minimum area of tensile reinforcement, $A_s = \frac{0.85}{f_y} bd$, and

(ii) the maximum area of tensile reinforcement shall not exceed 0.04 bD.

(e) For slabs (i) the minimum area of the tensile reinforcement shall not be less than 0.12 % of total cross sectional area for deformed bars. However it is 0.15% for plain bars.

(f) All other specifications for beams and slabs will also be applicable to beams and slabs of foundations. In addition to the above, nominal reinforcements in footing slab for concrete sections of thickness greater than 1m shall be 360 mm^2/m in each direction on each face. This provision does not supersede the requirement of the minimum tensile reinforcement. All the above general specifications have been explained through illustrative typical drawings (Figures 3.1 and 3.2).

Figure 3.1 : Typical Details of an Isolated Footing

Figure 3.2 : Typical Details of a Combined Footing with Beam

3.2.2 Isolated Footings

Square Footings

Square footing is generally provided under a column whose cross section is also a square in shape. The design moment on each side is calculated at the face of the column by passing through the section a vertical plane which extends completely across the footing, and computing the moment of the forces acting over the entire area of the footing on one side of the said plane (Figure 3.3).

Figure 3.3 : Critical Section for BM for an Isolated Footing

The critical shear is calculated at a section effective depth away from the face of the column (Figure 3.4).

Figure 3.4 : Critical Section for One-way Shear for an Isolated Footing

The two-way action of the footing or punching shear is checked at the cross section shown in Figures 3.5(a) and (b).

Figure 3.5 : Critical Section for Two-way Shear for an Isolated Footing

The footing is designed as a slab without shear reinforcements. The shear strength of footing may be increased either by increasing the depth of the slab or by increasing the percentage of tensile reinforcement. The tensile reinforcement obtained in each direction is uniformly distributed in the respective direction.

In addition to above, the compressive stress beneath the column is also checked. The design and detailing based on above considerations have been illustrated through Figure 3.6.

Figure 3.6 : Reinforcement Detailing of Square Footing

Rectangular Footing

All specifications applicable for detailing of square footings are applicable for rectangular footings except for arrangement of tensile reinforcement in short direction. The long side of footing is divided in central band width, which is equal to length of short side, and outer portions. The reinforcement in the central band width = $\frac{2}{(\beta + 1)} \times$ Total reinforcement in short direction,

where $\beta = \frac{\text{Long side}}{\text{Short side}}$

The remainder of the reinforcement shall be uniformly distributed in the outer portions of the footing. Figure 3.7 illustrates the detailing of the reinforcements, etc. for a rectangular footing.

Circular Footings

The face of the circular and octagonal column for computing stresses in footing shall be taken as the sides of an inscribed square within the perimeter of the circular or octagonal columns (Figure 3.8).

Figure 3.7 : Reinforcement Detailing of Rectangular Isolated Footing

Figure 3.8 : Critical Section for BM for a Circular Footing

The detailing of reinforcement is shown in Figure 3.9.

Figure 3.9 : Reinforcement Detailing for a Circular Footing

SAQ 1

(a) Enumerate the general specifications for isolated and combined footing.

(b) Show through sketches the critical section for bending moment, shear and punching shear for isolated footings.

(c) Show through sketches the arrangement of reinforcement in case of rectangular footing.

(d) Draw both types of reinforcement arrangement of a circular footing.

3.2.3 Combined Footings

Isolated footings are the most efficient and economical form of construction of foundations. At times, when footing of two or more columns overlap or when loads of the columns on property line are to be balanced by adjacent interior columns, a combined footing for two or more columns in a line may be provided. Different forms of combined footings have been explained and illustrated in the following subsections.

Rectangular Combined Footings without Beams

Rectangular combined footing without beam shall satisfy the following specifications in addition to those applicable to isolated footings :

(a) The centroid of the footing must coincide with the centroid of the column loads to have uniform ground pressure (Figure 3.10).

Figure 3.10 : Combined Footing

(b) The slab is designed as a longitudinal inverted beam supported on columns from above. The width of support at column base along the length is taken equal to the width of column in the longitudinal direction plus 0.75 times the effective depth of slab on either side. Hence longitudinal reinforcement is provided as that for an inverted beam and transverse reinforcement in effective column base width is designed as cantilever slab on both sides. In between the effective column base width only nominal transverse reinforcement is provided. The underlying principles of design and reinforcement detailing have been explained through Figures 3.11 and 3.12.

Figure 3.11 : Assumed Load Transfer in Two-column Combined Footing without Beam

Figure 3.12 : Typical Details of a Combined Footing without Beam

Rectangular Combined Footing with Beam

When the width of foundation slab becomes too large to behave as a longitudinal beam, a beam is provided along the longitudinal axis of the slab joining centres of columns. The minimum width of such beam is the width of the widest column. The slab then cantilevers on both sides of the beam and designed as such for uniformly distributed net soil pressure. The beam behaves as an inverted beam supported on the columns and loaded with uniformly distributed load due to net soil pressure (Figure 3.12).

Trapezoidal Footing without Beam

When property line prevents the extension of combined footing as per requirement for the coincidence of CG of the footing with the CG of applied loads, and that for applied load, trapezoidal footing is provided to meet the requirement. If the width of footing is not large, the footing slab may be provided without beam. The slab is then designed as a longitudinal beam. The specifications for design and detailing remain the same as those for rectangular combined footing without beam except that the tensile reinforcements are arranged as per requirement for trapezoidal shape (Figure 3.13).

Figure 3.13 : Typical Details of a Trapezoidal Combined Footing without Beam

Trapezoidal Combined Footing with Beam

All the principles and provisions applicable for the design and detailing of a rectangular combined footing with beam are applicable in this case also except those modifications required for the shape of footing (Figure 3.14).

Figure 3.14 : Typical Details of a Trapezoidal Footing with Beam

Strap Footing

When the outer isolated footing is prevented from being cast symmetrically beyond property limit, a portion of the load of this column may be transferred to the adjacent interior column through a beam called strap beam. Hence two isolated footings connected with a strap beam is called strap footing – a form of combined footing. In this case to have equal and uniform net soil pressure, the CG of the applied loads through columns must coincide with CG of the isolated footings connected by strap beam (Figures 3.15 and 3.16).

Figure 3.15 : Typical Strap Footing with Loading Diagram

Figure 3.16 : Typical Reinforcement Detailing of Strap Footing

SAQ 2

(a) Under which circumstances a combined footing is provided?

(b) Sketch a rectangular combined footing without explaining the transverse reinforcement under the columns.

(c) Why a combined footing of trapezoidal shape is provided?

(d) Sketch the detailing of reinforcements for beam and slab separately for a rectangular combined footing with beam.

(e) Sketch a strap footing and explain its function.

3.3 RAFT FOOTINGS

A slab type foundation, with or without beams and supporting columns in two perpendicular directions, is called a Raft Foundation.

3.3.1 Mat Footings

For lightly loaded structures having columns at closer spacing but uniformly spread over the area may be provided with a foundation consisting of slab of uniform thickness *without* beams (Figure 3.17). Such foundation is called a mat foundation. For design, such slab is divided into strips by passing sections through the centre line of panels in each direction. These strips are designed as inverted beams supported on columns and loaded with soil pressure (Figure 3.18). The tensile reinforcement in each strip is uniformly distributed in that strip (Figure 3.19).

Figure 3.17 : Mat Type Raft Foundation

Figure 3.18 : Mat Type Raft Foundation with Pressure Diagram

Figure 3.19 : Reinforcement Detailing of a Mat Foundation

3.3.2 Raft Footing with Beams

In cases, where columns are heavily loaded and unevenly spaced, centreline of columns in each direction is connected with beams. Such raft foundation behaves as inverted roof and designed as such. The detailing of reinforcement, both of slabs and beams, are shown in Figures 3.20 and 3.21.

3.3.3 Cellular Footings

* Reinforcement detailing are very complex, hence, avoided

Cellular footing is a type of raft footing where the foundation slab and floor slab are connected by beams in-between along the lines of columns. The space formed in-between the beams are empty shell filled with sand. Where the columns are very heavily loaded and the allowable bearing pressure of the soil is very high, such type of foundation with deeper beams is needed (Figure 3.22)*.

Figure 3.20 : Raft Foundation

Figure 3.21 : Reinforcement Details of Raft Foundation with Beam

Figure 3.22 : Cellular Type Raft Foundation

SAQ 3

(a) How a mat footing is designed? Show the reinforcement detailings of a mat footing.

(b) Sketch a cellular Footing.

3.4 PILE FOOTINGS

Where bearing capacity of soil is very low at economic depth, deep foundation (greater than 3m) is provided to transfer the column load through piles either (column like structural components) to the strata having desired allowable bearing capacity and/or to the soil on the periphery of the column through friction. RCC piles are of various types depending upon its functions and methods of casting, but only two of their types – precast piles and under-reamed piles – will be discussed here.

3.4.1 Precast Piles

Precast piles, as the name suggests, are cast in factories or at site and then driven in place by hammering. These piles transfer load mainly through friction between the soil and the pile. The reinforcement and other detailing are shown in Figure 3.23.

Figure 3.23 : Minimum Requirements of Precast Concrete Pile

3.4.2 Under-reamed Pile Foundations

This types of piles (Figure 3.24) are cast in-situ. The mould is cut to shape and size in the soil. Subsequently, the reinforcement cage is lowered in the mould and then it is filled with concrete. After the concrete is set, pile caps are made over them. The column or wall loads are, therefore, transferred to the piles through pile caps or grade beams. These piles in turn transfer the loads through bearing at the bottom as well as through under-reams. The specifications applicable to under-reamed piles are as follows :

(a) The minimum area of longitudinal reinforcement shall be 0.4% of the sectional area of pile shaft. Reinforcement is to be provided in full length.

(b) Transverse reinforcement shall not be less than 6 mm diameter at a spacing of not more than stem diameter or 300 mm, whichever is less.

(c) For piles of lengths exceeding 5m and 375 mm diameter, a minimum number of six 12 mm bars shall be provided.

(d) The circular stirrups of piles of length exceeding 5 m and diameter exceeding 375 shall be minimum 8 mm diameter bars.

(e) The nominal cover to all reinforcement shall be 40 mm in normal exposure condition. In aggressive environment of sulphate, etc., the cover may be increased to 75 mm. The pile cap, the seat of column, may be for one or more columns. The detailing of pile caps for 2 to 9 numbers of piles are given in Figure 3.25.

Figure 3.24 : Typical Details of Bored Cast in-situ Under-reamed Pile Foundation

Figure 3.25 : Configuration for Pile Caps with Typical Reinforcement Details

SAQ 4

(a) Where pile foundation is an economic proposition?

(b) Explain with sketch the principles behind reinforcement detailing in precast piles.

(c) Show the specifications of dimensioning of a double under-reamed footing.

3.5 SUMMARY

RCC shallow as well as deep foundations have been dealt with in this Unit. Shallow foundation may be isolated, combined or raft foundation. An isolated footing is a slab of square, rectangular or circular. The shape of footing depends on the shape of column and space available. In all these footing, tensile reinforcement for resisting bending as cantilever slab is provided. One-way or two-way shear is resisted by concrete section. Where adjacent isolated footings overlap either due to low allowable bearing pressure or closer spacing of column or for any other reason, a combined footing with or without beam may be provided. A strap footing is provided where a portion of the load of exterior column is to be transferred to the adjacent interior footing through a strap beam.

A raft footing is also a combined footing, but in this case, footing is two-dimensional. The slab footing, in this case, also may be with or without beams.

The pile footings are deep foundation type. The column transmits the load to pile cap from which it is transferred through a group of piles to the soil by bearing.

3.6 ANSWERS TO SAQs

SAQ 1

(a) Refer to Section 3.2.1.

(b) Refer to Section 3.2.2.

(c) Refer to Section 3.2.2.

(d) Refer to Section 3.2.2.

SAQ 2

(a) Refer to Section 3.2.3.

(b) Refer to Section 3.2.3.

(c) Refer to Section 3.2.3.

(d) Refer to Section 3.2.3.

(e) Refer to Section 3.2.3.

SAQ 3

(a) Refer to Section 1.3.1.

(b) Refer to section 3.3.3.

SAQ 4

(a) Refer to Section 3.1.4.

(b) Refer to Section 3.4.1.

(c) Refer to Section 3.4.2.