UNIT 2 BRICK AND STONE MASONRY FOUNDATIONS

Structure

2.1 INTRODUCTION

Foundation is the bottommost component of a structure which transmits all the loads of superstructure including its own weight to the supporting soil. A foundation can be categorised as a **shallow foundation**, or a **deep foundation**. A deep foundation is one which is more than 3 m deep into the soil.

Brick and stone masonry foundation is a shallow foundation normally provided for lightly loaded structures*. Loads transmitted through walls and columns are spread over wider area by gradually increasing the base width through stepping to keep applied load intensity less than the allowable bearing capacity of the soil (Figures 2.1 and 2.2). Special provisions are made to safeguard against the adverse effects of site and soil conditions.

* Houses, flats and school buildings of not more than two storeys may be considered as lightly loaded structures.

Figure 2.1 : Section of Brick Masonry Wall Footing

Figure 2.2 : Section of Stone Masonry Wall Footing

Objectives

After studying this unit, you should be able to

- explain the design parameters of all types of foundation,
- describe the design of brick and stone masonry foundations, and
- discuss the special provisions for specific site and soil conditions.

2.2 STRUCTURAL REQUIREMENTS FOR ALL TYPES OF FOUNDATIONS

Before designing and laying foundation of any structure, site conditions, type of soils, bearing capacity of soils and loads to be transmitted through the foundation are properly assessed. Above mentioned assessments are prerequisites in order to introduce in-built protection for durability, design parameter improvement for proper layout, safety and serviceability.

2.2.1 Site Conditions

* Topographical features pertain to level of the ground, instability of slope, etc.

Reconnaissance of the site is done to assess topographical features*, ground conditions (natural or made-up ground, water drainage, etc.), plantation in the vicinity, neighbourhood of other structures, mass movement of ground in unstable areas, etc.

2.2.2 Types of Soil

Soils supporting the foundations may be put in the following five categories from bearing capacity point of view :

** Clay is an aggregate of microscopic and sub-microscopic particles derived from the chemical decomposition and disintegration of rock constituents. It is plastic within a wide range of water content. The particles are less than 0.002 mm in

Rocks

Igneous rocks and the likes without laminations are termed as hard rocks. Laminated ones such as sedimentary rocks are less strong in load bearing. Soil made of broken bed rocks, hard shells, cemented materials, etc. is another groups of rocks. The soft rocks are made of cemented materials offering high resistance to digging and excavation.

Non-cohesive Soils

Cohesionless soils are made of gravels, sand of different sizes, silt and a combination thereof.

Cohesive Soils

Clays** of different natural water contents are called cohesive soils. Black cotton soils, a variety of cohesive soils, form a major soil group in India, are characterized by high shrinkage and swelling properties.

Peat

A ditch filled with organic matters in various stages of decomposition is known as peat.

Make-up Ground

A low water-logging or marshy land area filled with refuse, excavated soil or rock for the purpose of filling a depression or raising a site above the natural ground level is called Make-up Ground.

2.2.3 Bearing Capacity

The allowable Bearing Pressure for design shall be taken as the least of the following :

(a) The *Safe Bearing Capacity* on the basis of shear strength characteristics of soil, or

(b) The *Bearing Pressure* that soil can take without exceeding permissible settlement specified by the Code*.

Safe bearing capacity of the soil is the maximum intensity of loading that the soil will safely carry without risk of shear failure irrespective of any settlement that may occur. It is obtained by dividing the ultimate bearing capacity by a factor of safety. The ultimate bearing capacity is determined by tests for shear failure and the value of factor of safety is generally taken as 2.5. For the design of lightly loaded structures the safe bearing capacity may be obtained from Table 2.1 in the absence of the test results.

Similarly, calculations are made to determine settlement of foundation from load tests**.

* IS 8009 Code of Practice for calculation of settlement of Foundations.

** IS 1904 – 1986 Code of Practice for Design and Construction of Foundations in Soils: General Requirements.

Table 2.1 : Safe Bearing Capacity

Sl. No.	Types of Soil	Safe Bearing Capacity (kN/m^2)
(I)	**Rocks**	
	(i) Hard Rocks without defect with lamination	3240
	(ii) Rocks with lamination	1620
	(iii) Residual deposits of shattered and broken bed rock, hard shell, cemented material, etc.	880
	(iv) Soft rock	440
(II)	**Non-cohesive Soils**	
	(i) Gravel, sand and gravel, compact and offering high Resistance to penetration when excavated	440
	(ii) Coarse sand, compact and dry	440
	(iii) Medium sand, compact and dry	245
	(iv) Fine sand, silt (dry lump easily pulverized by fingers)	150
	(v) Loose gravel or sand, gravel mixture, loose coarse to medium sand, dry	245
	(vi) Fine sand, loose and dry	100
(III)	**Cohesive Soils**	
	(i) Soft shale, hard or stiff clay in deep bed, dry	400
	(ii) Medium clay readily indented with thumb nail	245
	(iii) Moist clay and sand clay mixture which can be indented with strong thumb pressure	150
	(iv) Very soft clay indented with moderate thumb pressure	100
	(v) Very soft clay which can be penetrated several centimetres with thumb	50

2.2.4 Loads

The applied loads on foundations are of two types :

Permanent Loads

Permanent loads include dead load of the structure above foundation and imposed loads. These are also called gravity or vertical loads.

Transient Loads

Transient or temporary loads are for a short duration. Earthquake loads and wind loads are called transient loads acting horizontally.

For design purposes, generally three combinations of the above loads are considered.

(a) Dead load + Imposed load,

(b) Dead load + Earthquake or Wind load, and

(c) Dead load + Imposed loads + Earthquake or Wind loads

The loads are resolved in three mutually perpendicular directions. The vertical loads, if eccentric, are resolved into a concentric vertical load and uniaxial and/or biaxial moments (Figure 2.3).

(a) Plan Showing Eccentric Vertical Load, *P*

(b) Plan Showing Resolved Equivalent Concentric Force *P* and Moments

Figure 2.3

* (a) IS : 1893 (Part 1) 2002 Criteria for Earthquake Resistant Design of Structures.

(b) IS 456 – 2000 Plain and Reinforced Concrete – Code

Similarly, horizontal load in any direction may be resolved into one or two mutually perpendicular horizontal forces. These horizontal forces are accompanied by moments as well.

Figure 2.4 shows that the horizontal force *H* acting on a plane when resolved in *Y* and *Z* directions becomes H_y and H_z. In short, all applied forces are resolved into vertical and horizontal forces and uniaxial and/or biaxial moments for design calculations. When transient loads are taken into account, the bearing capacity of the soil is increased as per Codes*.

Figure 2.4 : Horizontal Force and Its Resolved Components

SAQ 1

(a) Define foundation. What do you mean by spread footing?

(b) What are prerequisites for proper design of shallow foundations?

(c) What do you mean by Reconnaissance of the site? Explain.

(d) In how many categories soils supporting the foundation may be put from bearing capacity point of view? Explain.

(e) Explain the terms (i) Safe Bearing Capacity, and (ii) Allowable Bearing Pressure.

(f) What are the loads transmitted through foundation to the soils. How these loads are accounted for the design of a foundation.

2.3 DESIGN OF FOUNDATION

2.3.1 Depth of Foundation

While deciding depth of foundation below finished ground level, the following main considerations may be kept in view :

(a) In normal conditions, the depth of foundation shall not be less than 0.5 m. This condition, however, does not apply to foundation on rocks.

(b) In sandy or silty soils, the depth of foundation shall be enough so that the foundation remains unaffected by scour in the rainy season as well as by frost in the winter.

(c) In case of black cotton soils, the depth of foundation shall be such that mass movement of soils due to drying and shrinkage have no effect on the foundations.

(d) Desired allowable bearing capacity must be ensured at the design depth of foundation.

(e) Rankine formula, i.e. $D = \frac{p_{Bc}}{w}\left(\frac{1 - \sin \phi}{1 + \sin \phi}\right)^2$ may be used for cohesionless soils for obtaining depth of foundation of light structures.

2.3.2 Width of Foundation

The applied load through walls or columns are spread by gradually increasing in steps the area of the footings, to such an intensity of load that the bearing capacity of the soil is not exceeded.

The angle of spread from the base of the wall or column to the outer edges of the footing in contact with the soil shall not exceed the following limits (Figure 2.5) :

(a) For brick or stone masonry $\frac{1}{2}$ horizontal to 1 vertical,

(b) For lime concrete $\frac{2}{3}$ horizontal to 1 vertical, and

Figure 2.5 : Angle of Spread

(c) For cement concrete 1 horizontal to 1 vertical column base shall always be provided with lime or cement concrete footing except when it is laid on rock. The width of the base footing (B) $\geq$ (W + 30) cm, where W = Width of wall in cm. In case the spread of the footing is only on one side due to property line, the eccentricity of the load from CG of the base of footing shall not be more than $\frac{1}{6}$ th of the width of base of footing in that direction to avoid tension. Figure 2.6 shows that if eccentricity, $e < \frac{B}{6}$, there shall be compressive stresses throughout the footing.

Figure 2.6 : $e < \frac{B}{6}$ for Footing Edge on Property Line

2.3.3 Thickness of Footings

The minimum thickness of footing of different materials may be not less than 150 mm.

Example 2.1

Design the masonry footing for a free standing 250 thick compound wall 2.5 m high above GL. The wind pressure on the wall is 300 N/m^2 (Figure 2.7). Other design parameters are as follows :

Bearing capacity of soil = 100 kN/m^2

Angle of repose of soil = 25°

Unit weight of soil = 16 kN/m^3

Unit weight of masonry = 18.85 kN/m^3.

Figure 2.7 : Compound Wall with Loading

Solution

Depth of Foundation

$$D = \frac{p_{BC}}{w}\left(\frac{1 - \sin\phi}{1 + \sin\phi}\right)^2$$

$$D = \frac{100}{16}\left(\frac{1 - \sin 25}{1 + \sin 25}\right)^2 = 1.03 \text{ m}$$

Hence, provided Depth of Foundation D = 1.1 m.

Width of Foundation

Loads/m run

Weight of wall	= 0.25 × 2.5 × 1 × 18.85	= 11.78 kN
Weight of foundation (Assuming 15% of superimposed load)	= 0.15 × 11.78	= 1.77 kN
Total gravity load		= 13.55 kN

Total wind load on wall/m run = 0.3 × 2.5 × 1 = 0.75 kN acting at $\frac{2.5}{2} + 1.1 = 2.35$ m form the base.

∴ Moment about base = 0.75 × (1.25 + 1.1) = 1.763 kNm

Maximum pressure is equated with allowable bearing capacity and the value of bearing capacity is increased by 25% for wind load

$$p_{BC} = \frac{P}{A} + \frac{M}{z}$$

or, $$125 = \frac{13.55}{1 \times B} + \frac{6 \times 1.763}{1 \times B^2}$$

or, $$125 = \frac{13.55\ B + 10.578}{B^2}$$

or, $$125\ B^2 - 13.55\ B - 10.578 = 0$$

or, $$B^2 - 0.108\ B - 0.085 = 0$$

or, $$B = \frac{0.108 \pm \sqrt{0.108^2 + 4 \times 0.085}}{2}$$

or, $B = 0.35$ m

$$B_{min} = (W + 30) \text{ cm} = (25 + 30) = 55 \text{ cm}$$
$$= 0.55 > 0.35 \text{ m.}$$

Again to have compressive pressure on the whole area of footing, eccentricity, $e \leq \frac{B}{6}$.

Here, $$e = \frac{M}{P} = \frac{1.763}{13.55} = 0.13 \text{ m} > \frac{0.55}{6} \; (= 0.092 \text{ m})$$

Hence, increased the width of footing, $W = 80$ cm

$$\therefore \quad \frac{0.80}{6} = 1.33 \text{ m} > e \; (= 0.13 \text{ m})$$

Check for Pressure

$$p_{1,2} = \frac{P}{A} \pm \frac{M}{I} y = \frac{13.55}{1 \times 0.8} \pm \frac{6 \times 1.763}{1 \times 0.8^2}$$

$$\therefore \quad p_1 = 33.41 \text{ kN/m}^2 \text{ and } p_2 = 0.41 \text{ kN/m}^2$$

The pressure diagram is given in Figure 2.8.

Figure 2.8 : Footing Plan with Loads and Pressure Diagram

Thickness of Footing (*t*)

$$t = 300 > t_{min} \; (= 150)$$

It also satisfies the condition of angle of spread of brick masonry footing.

Figure 2.9 : Designed Footing

Example 2.2

Design the lime concrete footing for a 250 wall carrying a load of 100 kN/m run (Figure 2.10).

Figure 2.10 : Wall with Loading

Safe Bearing Capacity of soil = 110 kN/m^2

Angle of repose for the soil = 28°

Unit wt. of soil = 17 kN/m^3.

Solution

Depth of Foundation

$$D = \frac{p_{BC}}{w}\left(\frac{1 - \sin\phi}{1 + \sin\phi}\right)^2 = \frac{110}{17} \times \left(\frac{1 - \sin 28}{1 + \sin 28}\right)^2$$

$= 0.84 \text{ m} > 0.5 \text{ m}.$

Hence provided Depth of Foundation, D = 0.9 m.

Width

Loads

Load through wall		= 100 kN
Weight of foundation (Assuming 15% of superimposed load)	= 0.15 × 100	= 15 kN
Total load		= 115 kN

Width of footing;

$$B = \frac{\text{Total load}}{\text{Allowable bearing capacity}} = \frac{115}{110} = 1.045 \text{ m}$$

Minimum width of footing = (W + 30) cm = (25 + 30) cm

= 55 cm = 0.55 m < 1.045 m

Hence, the provided width of base footing, B = 1.15 m.

Provided thickness of footing t = 300 >150

It also satisfies the condition of angle of spread for lime concrete footing. The designed footing is shown in Figure 2.11.

Figure 2.11 : Designed Footing

Example 2.3

Design the foundation with cement concrete base footing for a stone column of size 500 × 500 and carrying a load of 250 kN.

Safe bearing capacity of soil = 125 kN/m^2

Angle of repose for the soil = 30°

Unit weight of soil = 20 kN/m^3

Solution

Depth of Foundation

$$D = \frac{p_{BC}}{w} \left(\frac{1 - \sin \phi}{1 + \sin \phi} \right)^2 = \frac{125}{20} \times \left(\frac{1 - \sin 30}{1 + \sin 30} \right)^2 = 0.694 \text{ m}$$

Width of Square Footing

Loads

Applied load = 250 kN

Weight of foundation = 0.15 × 250 = 37.5 kN
(Assuming self weight = 15% of superimposed load)

Total load = 287.5 kN

$$p_{BC} = \frac{\text{Total load}}{\text{Area of footing}} = \frac{287.5}{B^2}$$

or $125 = \dfrac{287.5}{B^2}$;

or $B^2 = 1.516$ m

Hence, provided B = 1.6 m (Figure 2.12).

Provided thickness of footing t = 300 > 150.

It also satisfies the condition of angle of spread of cement concrete footing.

Figure 2.12 : Designed Footing

Example 2.4

An outer 375 thick wall of lightly loaded structure of a building is falling on property line. The wall carries a load of 90 kN/m run. Design the base concrete footing for the wall.

Bearing Capacity of soil = 150 kN/m^2

Angle of Repose = 26°

Unit wt of soil = 18 kN/m^3.

Solution

Depth of foundation

$$D = \frac{p_{BC}}{w}\left(\frac{1 - \sin\phi}{1 + \sin\phi}\right)^2 = \frac{150}{18} \times \left(\frac{1 - \sin 26}{1 + \sin 26}\right)^2 = 1.27 \text{ m}$$

Hence, provided depth of foundation, D = 1.3 m.

Width of Base Footing

*Loads/*m *run*

Superimposed load		= 90 kN
Load of foundation	= 0.15 × 90	= 13.5 kN

(Assuming it to be 15% of superimposed load)

Total load = 103.5 kN

Assuming that total load is acting along centre line of the wall and taking eccentricity $e = \frac{M}{P} = \frac{B}{6}$ for no tension in footing.

$$p_{1,2} = \frac{P}{A} \pm \frac{M}{Z} = \frac{P}{1 \times B} \pm \frac{6\,Pe}{B^2} = \frac{P}{\text{B}} \pm \frac{6\,p \times B}{B^2 \times 6}$$

$$= \frac{2P}{B} \text{ and } 0$$

$$\therefore \quad p_{BC} = \frac{2P}{B} = \frac{2 \times 103.5}{B} \quad \text{or} \quad B = 1.38 \text{ m}$$

Hence, provided B = 1.4 m (Figure 2.13).

Thickness of Footing (*t*)

$$t = 150 = t_{min} \ (=150)$$

This also satisfies the condition of angle of spread for cement concrete footing.

Figure 2.13 : Footing on Property Line

SAQ 2

(a) What are the main considerations for fixing depth of footing?

(b) How the base width of the foundation is fixed? Explain.

2.4 SPECIAL PROVISIONS FOR SPECIFIC CASES

2.4.1 Foundation at Different Levels

Where footings of a structure are to be provided at different levels (a) due to sloping ground or (b) where the bottoms of the footings of a structure are at different levels or (c) at levels different from those of the footings of adjoining structures, the depths of the footings shall be such that the differences in footing elevations shall be subject to the following limitations:

(a) When ground surface slopes downward adjacent to a footing, the sloping surface shall not intersect a frustum of bearing material under the footing having sides which make an angle of 30° with the horizontal for soil. The horizontal distance from the lower edge of the footing to the sloping shall be at least 0.6 m for rock and 0.9 m for soil (Figure 2.14).

Figure 2.14 : Footing in Sloping Ground

(b) In case of footing in granular soil, a line drawn between the lower adjacent edges of adjacent footings shall not have a steeper slope than 1 vertical to 2 horizontal (Figure 2.15).

Figure 2.15 : Footing in Granular Soil or Clayey Soil

(c) In case of clayey soil, a line drawn between the lower adjacent edge of the upper footing and the upper adjacent edge of the lower footing shall not have a steeper slope than 1 vertical to 2 horizontal (Figure 2.15).

The above requirements may be assumed to have been complied with if

(a) the materials on the higher levels is supported by a retaining wall (Figure 2.16), or

(b) the factor of safety against shear failure of soil is taken as 4.

Figure 2.16 : Earth Retained by a Retaining Wall

2.4.2 Mass Movement of Ground in Unstable Areas

Mass movement of ground may be due to mining subsidence, landslips on unstable slopes and creep on clayey slopes.

The foundations in all the above cases must be very strong to sustain the effect of such movements.

On sloping ground the spread foundation shall be laid on horizontal bearing and stepped. The height of steps shall not be greater than thickness of foundation. The steps shall be overlapped for a distance equal to the thickness of the footing or twice the height of the steps whichever is greater (Figure 2.17).

Figure 2.17 : Stepped Footing on Slopping Ground

2.4.3 Footing at Higher Level in Black Cotton Soils

If the depth of the footing in black cotton soil is too deep to become economical, the footing may be put at higher level provided the difference between the base of footing and the depth at which the allowable bearing capacity occurs may be filled either with (a) concrete of strength not less than the allowable bearing capacity of soil or with (b) the sand, gravel, etc. in which case width of fill should be more than the width of foundation by an extent of dispersion of load from the base of the foundation on either side at the rate of 2 vertical to 1 horizontal (Figure 2.18).

(a) Filled with Concrete **(b) Filled with Sand**

Figure 2.18

2.4.4 Groundwater Containing Soluble Salts

These salts are mostly sulphates and/or chlorides. They are harmful to cement as well as to reinforcements. To guard against the ill effects of such salts the following steps may be taken :

(a) Richer mix of concrete may be used to prevent ingress of water.

(b) Sulphate resisting cements such as Portland Pozzolana cement, Portland slag cement, supersulphated cement, etc. may be used for different concentration of sulphates.

The chloride content of all materials used for concrete and that of ground water shall be controlled to ward off its ill effect on durability of reinforcement.

For detail informations IS 456:2000 Plain and Reinforced Concrete – Code of Practice may be consulted.

SAQ 3

(a) Explain through diagrams the special provision made to lay foundations at different levels for different soil conditions.

(b) What are the precautions taken when there is apprehension of mass movement of ground in unstable areas?

(c) What are the methods of protection reinforced cement concrete structure against the sulphate and chloride attack?

2.5 SUMMARY

Brick and stone masonry foundations are suitable generally for lightly loaded structures. For proper design and layout of all types of foundations, informations regarding

(a) site conditions,

(b) types of soils,

(c) bearing capacity of soils, and

(d) loads transmitted through wall and columns to the foundations

are essential.

Design of foundation in this case is very simple. The depth of foundation is calculated by Rankine Formula for cohesionless soil. Other parameters for deciding the depth of foundation have also been discussed in this Unit. The load on wall or column is gradually spread in steps by increasing the area downward to such an intensity of load that bearing capacity of soil is not exceeded. The minimum thickness and thickness to offset ratio for footings of masonry, lime concrete and cement concrete have been put in standard format for fixing width and thickness of footing. The design of masonry foundation has been illustrated with examples.

Special provisions made to meet the specific requirements for different site conditions have also been discussed.

2.6 ANSWERS TO SAQs

SAQ 1

(a) Refer Section 2.1.

(b) Refer Section 2.2.

(c) Refer Section 2.2.1.

(d) Refer Section 2.2.2.

(e) Refer Section 2.2.3.

(f) Refer Section 2.2.4.

SAQ 2

(a) Refer Section 2.3.1.

(b) Refer Section 2.3.2.

SAQ 3

(a) Refer Section 2.4.1.

(b) Refer Section 2.4.2.

(c) Refer Section 2.4.3.