CHAPTER 1

Prepared by: Dr. Farouk Majeed Muhauwiss
Civil Engineering Department – College of Engineering
Tikrit University

INTRODUCTION

1.1 DEFINITIONS

All types of structures consist of two parts; the upper or *superstructure* and the lower *substructure or (foundation).*

- **FOUNDATION:** The soil beneath structures responsible for carrying the loads is the *foundation*. But, in general, it is the lowest part of a structure or building that transmits its weight safely to the underlying soil or rock.

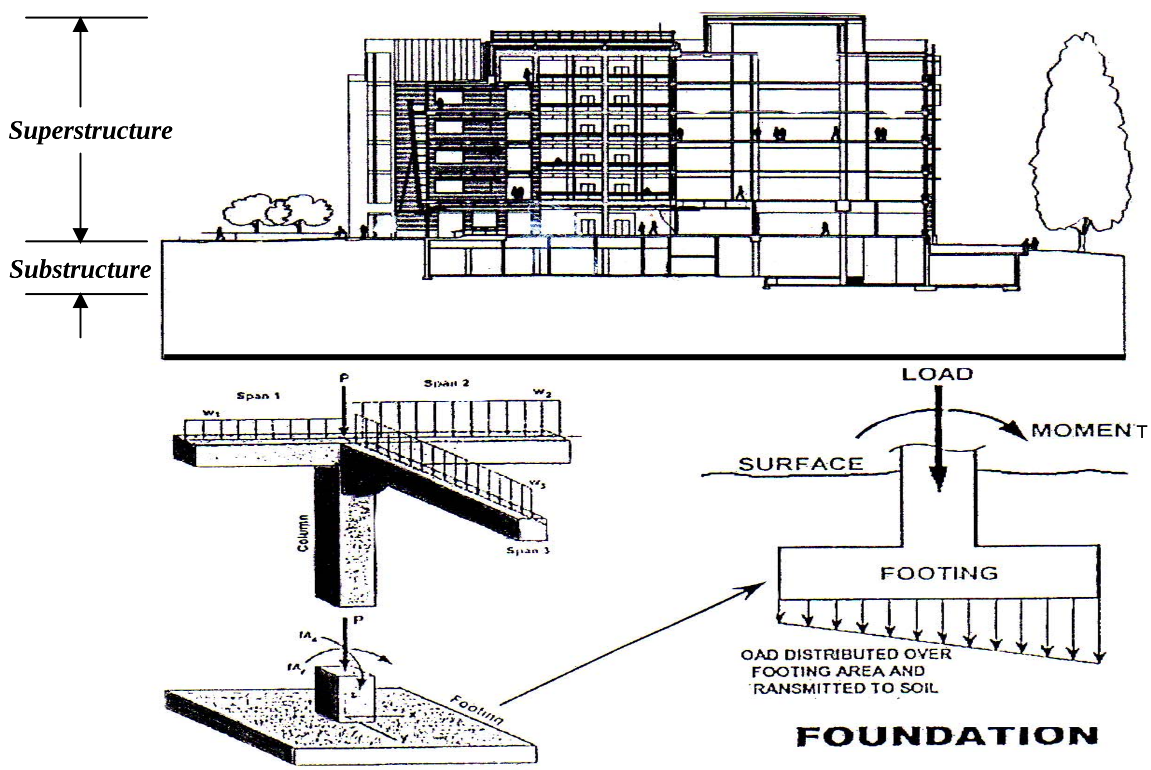


Fig. (1.1): Foundation definition.

- **FOUNDATION ENGINEERING:** is the science of applying engineering judgments and principles of soil mechanics to solve interfacing problems and retaining structures. Or it is the branch of engineering science which deals with two problems:

1. Evaluate the ability of soil to carry a load without shear failure or excessive settlement.
2. To design a proper structural member which can transmit the load from superstructure to soil taking economics into consideration.

1.2 CLASSIFICATION OF FOUNDATIONS

Foundations can be classified basically into two types: **shallow** and **deep.**

- **Shallow Foundations:**

These types of foundations are so called because they are placed at a shallow depth (relative to their dimensions) beneath the soil surface. Their depth may range from the top of soil surface to about 3 times the breadth (about 6 meters). They include ***spread footings*** as circular or square or rectangular in plan which support columns, and strip footings which support walls and other similar structures. In addition to, combined and mat foundations and soil retaining structures (retaining walls, sheet piles, excavations and reinforced earth).

- **Deep Foundations:**

The most common of these types of foundations are ***piles*** *and* ***drilled shafts***. They are called deep because they are embedded very deep (relative to their dimensions) into the soil. Their depths may run over several tens of meters. They are usually used when the top soil layers have low bearing capacities (the soil located immediately below the structure is weak, therefore the load of the structure must be transmitted to a greater depth).

The shallow foundation shown in **Fig. (1.2)** has a width B and a length L. The depth of embedment below the ground surface is equal to D_f. This depth must be adequate to avoid:

1. Lateral expulsion of soil beneath the foundation.
2. Seasonal volume changes such as freezing or the zone of active organic materials.
3. The depth be sufficient enough that the foundation should be safe against overturning, sliding, rotational failure, and overall soil shear failure and excessive settlement.

Theoretically, when B/L is equal to zero (that is, $L = \infty$), a plane strain case will exist in the soil mass supporting the foundation. For most practical cases when B/L (1/5 to 1/6), the plane strain theories will yield fairly good results.

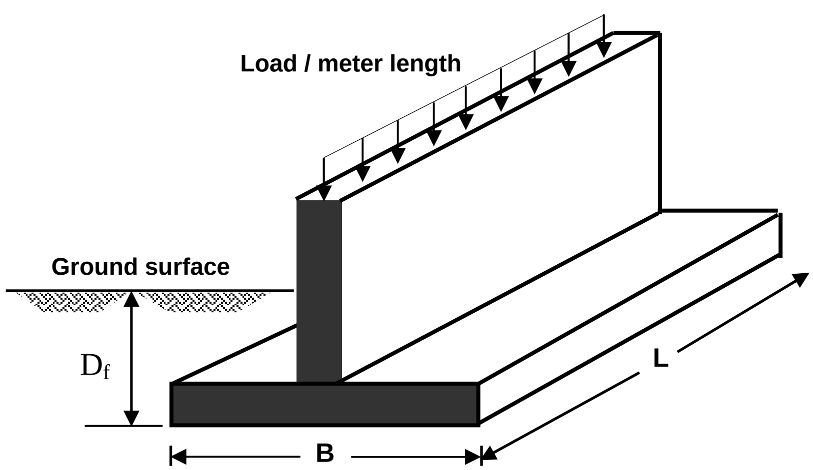


Fig. (1.2): Individual footing.

Terzaghi defined a shallow foundation as one in which the depth, D_f, is less than or equal to the width B ($D_f / B \leq 1$). Otherwise, it is considered as deep foundation.

In some cases, there is a different depth of embedment below the ground surface on both sides of a foundation as shown in **Fig. (1.3)**. For those cases, D_f should be *the depth at shallow side*, in addition to, the overburden pressure must be compared with soil cohesion to decide the type of footing required for design as follows:

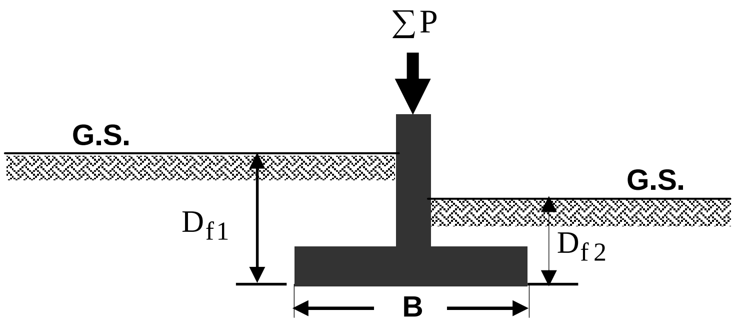


Fig. (1.3): Depth of embedment.

If $(D_{f1}.\gamma - D_{f2}.\gamma) > \frac{q_u}{2}$ ……….. **Design the member as a retaining wall.**

If $(D_{f1}.\gamma - D_{f2}.\gamma) \leq \frac{q_u}{2}$ ………..**Design the member as a footing.**

where q_u is unconfined compressive strength of soil.

From soil mechanics principles $\sigma_1 = \sigma_3.\tan^2(45+\phi/2)+2.c.\tan.(45+\phi/2)$

For Unconfined Compressive Strength Test (U.C.T.): $\sigma_1 = q_u$ **and** $\sigma_3 = 0$ **; Therefore:**

- *For Pure Cohesive Soil* **(** $\phi_u = 0$ **):** $q_u = 2.C_u$
- *For* $c-\phi$ *Soil:* $q_u = 2.C_u.\tan.(45+\phi/2)$

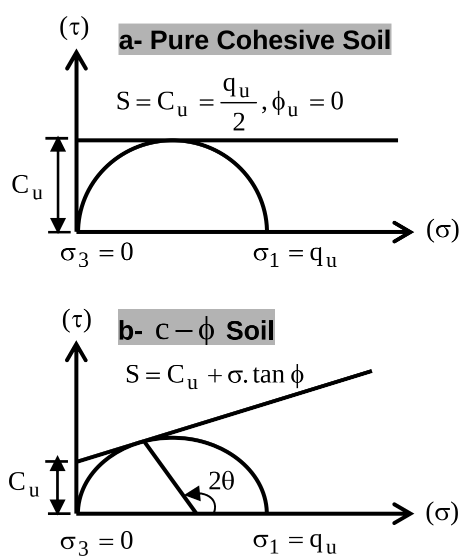


Fig. (1.4): Unconfined compressive strength test.

1.3 SETTLEMENT AT ULTIMATE LOAD

Settlement means a vertical displacement of a structure or footing or road,…etc.. The settlement of the foundation at ultimate load, S_u, is quite variable and depends on several factors. Based on laboratory and field test results, the approximate ranges for S_u values of soils are given below.

Soil	D_f / B	S_u / B (%)
Sand	0	5 to 12
Sand	Large	25 to 28
Clay	0	4 to 8
Clay	Large	15 to 20

For any foundation, one must ensure that the load per unit area of foundation does not exceed a limiting value, thereby causing shear failure in soil. This limiting value is the ***ultimate bearing capacity***, $q_{ult.}$ and generally using a factor of safety of 3 to 4 the allowable bearing capacity, $q_{all.}$ can be calculated as:

$$q_{all.} = \frac{q_{ult.}}{F.S} \quad \textbf{(1.1)}$$

However, based on limiting settlement conditions, there are other factors which must be taken into account in deriving the allowable bearing capacity. The total settlement, S_T, of a foundation will be the sum of three components:

1. Elastic or immediate settlement, S_i **; (major in sand),**
2. Primary and Secondary consolidation settlements, S_c and S_{cs} **; (major in clay).**

$$S_T = S_i + S_c + S_{cs} \quad \textbf{(1.2)}$$

Most building codes provide an allowable settlement limit for a foundation which may be well below the settlement derived corresponding to $q_{all.}$ given by **Eq.** (**1.1**). Thus, the bearing capacity corresponding to the allowable settlement must also be taken into consideration. A given structure with several shallow foundations may undergo two types of settlement:

1. Uniform or equal total settlement, and
2. Differential settlement.

Fig. (1.5a) shows a uniform settlement which occurs when a structure is built over rigid structural mat. However, depending on the load of various foundation components, a structure may experience differential settlement. A foundation may also undergo uniform tilt (**Fig. 1.5b**) or non-uniform settlement (**Fig. 1.5c**). In these cases, the angular distortion, Δ, can be defined as:

$$\Delta = \frac{S_{t(max)} - S_{t(min)}}{L'} \quad \textit{(for uniform tilt)} \quad \textbf{(1.3)}$$

$$\Delta = \frac{S_{t(max)} - S_{t(min)}}{L'_1} \quad \textit{(for non-uniform settlement)} \quad \textbf{(1.4)}$$

Limits for allowable differential settlement of various structures are available in building codes. Thus, the final design of a foundation depends on:

(a) the ultimate bearing capacity, (b) the allowable settlement, and
(c) the allowable differential settlement for the structure.

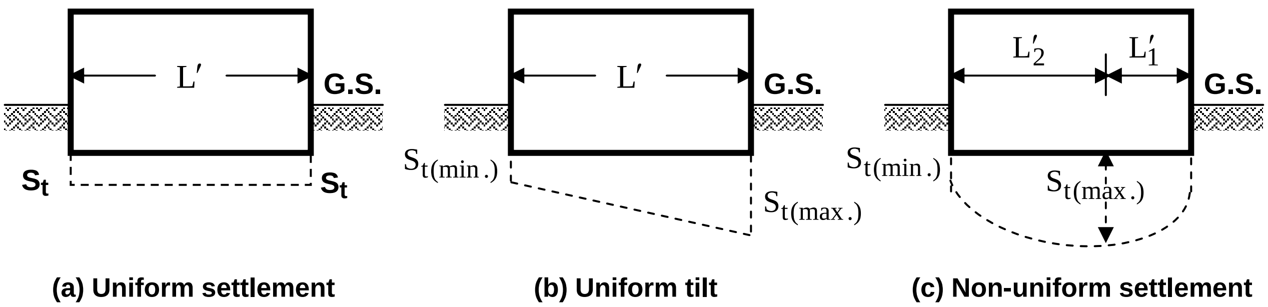


Fig. (1.5): Settlement of a structure.

Example (1.1):

A 30 cm x 30 cm column is loaded with 40 Ton. Check whether the column can be placed on soil directly or not if the allowable bearing capacity of soil is:

(a) $q_{all.} = 50$ kg/cm^2, and

(b) $q_{all.} = 1.0$ kg/cm^2.

Solution:

(a) $q_{all.} = \dfrac{Q}{A}$

or $A = \dfrac{40000}{50} = 800\ \text{cm}^2$ (minimum required area) < 900 cm^2 (area of column)……… **O.K.**

or $q_{all.} = \dfrac{40000}{30x30} = 44.4\ \text{kg/cm}^2 < 50\ \text{kg/cm}^2$ …… **O.K.**

$\therefore$ No failure may happen; and the column can be placed directly on the soil.

(b) $A = \dfrac{40000}{1.0} = 40000\ \text{cm}^2$ (minimum required area) > 900 cm^2 (area of column) **..... N.O.K.**

$\therefore$ (Not safe) and the column in this case cannot be placed directly on soil, therefore, an enlarged base is required.

$A = 40000\ \text{cm}^2 = 4\ \text{m}^2$, assuming square area: $B = \sqrt{A} = \sqrt{4} = 2\text{m}$. (see **Fig. (1.6)**).

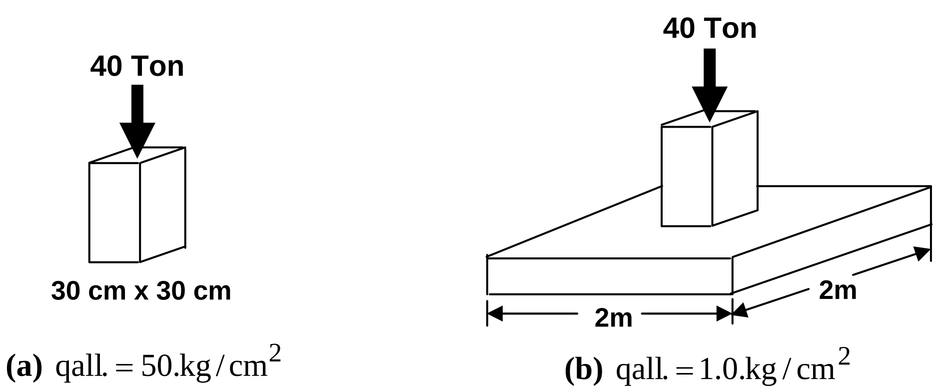


Fig. (1.6): Solution of example (1.1).

1.4 TYPES OF FAILURE IN FOOTINGS

It is possible due to load that a footing fails by one or two of the following:

(1) Shear failure: this failure must be checked against:-

(i) punching shear and **(ii)** wide beam shear. No shear failure is satisfied by providing an adequate thickness of concrete (see **Fig. 1.7**).

(2) Tension failure: this failure decides the locations and positions of steel distribution. No tension failure is satisfied by providing an adequate steel reinforcement (see **Fig. 1.7**).

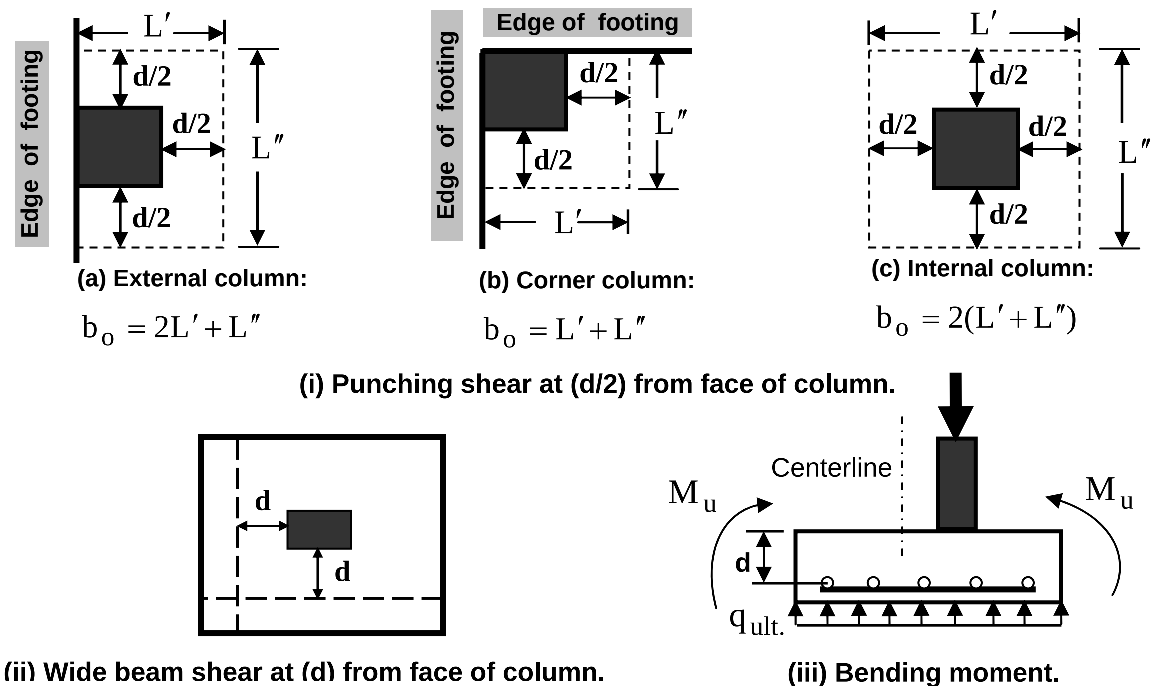


Fig. (1.7): Types of failure in footing.

1.5 TYPES OF FOOTINGS

(1) Spread or Isolated or Individual Column Footing:

It is a footing of plain or reinforced concrete that supports a single column. It may be either a square or circular or rectangular in shape or cross sectional area (see **Fig. 1.8**). However, the design of square or circular spread footings is simpler than that of rectangular one. This is evident due to the twice calculation required for rectangular footing compared with other ones. The rectangular footing is preferred in case of a moment, since the length is increased in the direction of moment to make the resultant of loads within the middle third of footing.

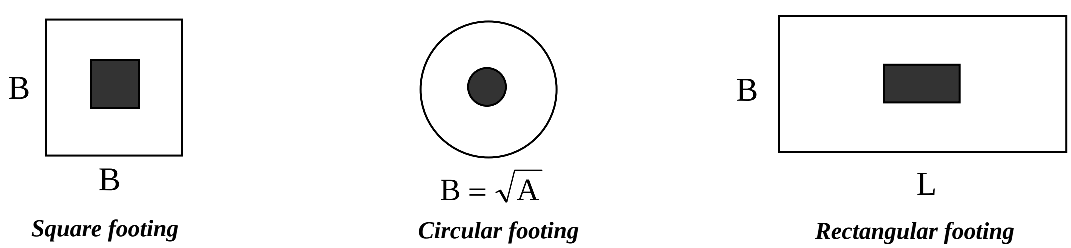


Fig. (1.8): Spread footing.

(2) Combined Footing (reinforced concrete only)**:**

It is a footing that connects several columns and can take one of the following shapes:

- **Rectangular Combined Footing** (see **Fig. 1.9**):

(a) Used along the walls of building at property lines where the footing for a wall column can not extend outside the limits of the structure.

(b) If the loads from several columns are transmitted to the same footing, the footing should be proportioned so that its centroid coincides with the center of gravity of the column loads.

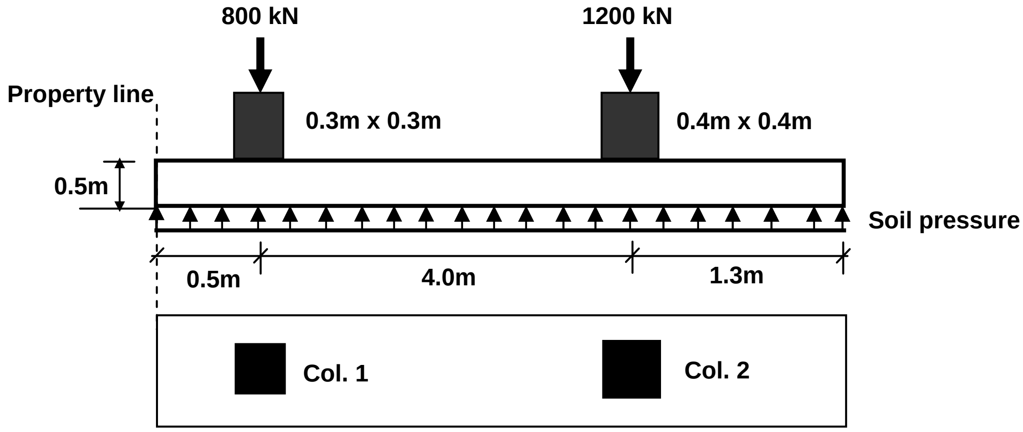


Fig. (1.9: Rectangular combined footing.

- **Trapezoidal Combined Footing** (see **Fig. 1.10**)**:**

(a) If the maximum load exists at the exterior column,

(b) It is not possible to make the resultant of loads passes through the centroid of the footing.

(i.e., If $\frac{L}{2} > \bar{x} > \frac{L}{3}$).

- **Strap or Cantilever Combined Footing** (see **Fig. 1.11**)**:**

(a) If there is an eccentricity, and/ or

(b) If $(\bar{x} < \frac{L}{3})$.

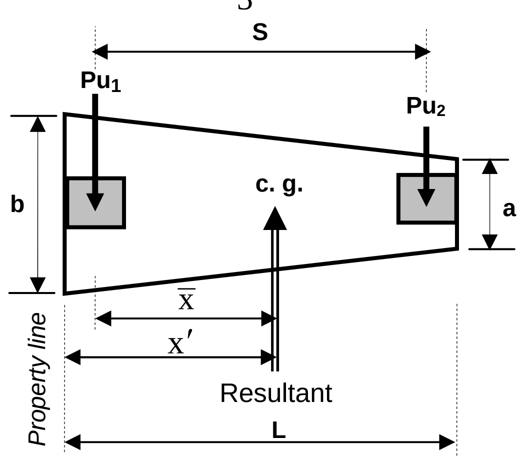


Fig. (1.10): Trapezoidal combined footing.

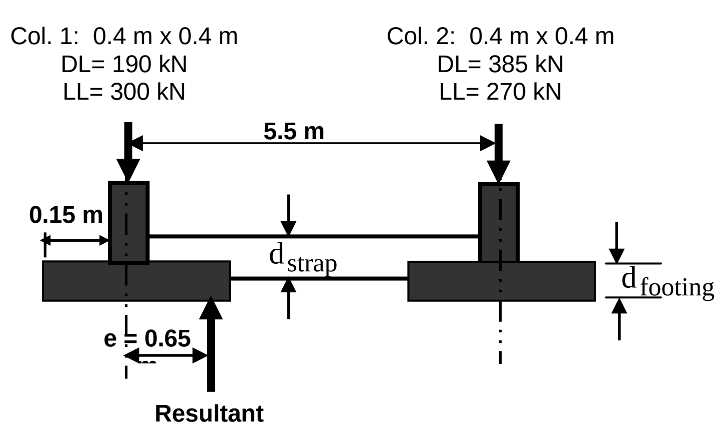


Fig. (1.11): Strap combined footing.

(3) Wall or Strip Footing *(plain or reinforced concrete only)* (see **Fig. 1.12**)**:**

This footing represents a plain strain condition, such as a footing beneath a wall. In this case, the footing area is calculated as: $\text{Area} = B.x.1 = \dfrac{\text{Total..load / unit..length}}{q_{all.}}$

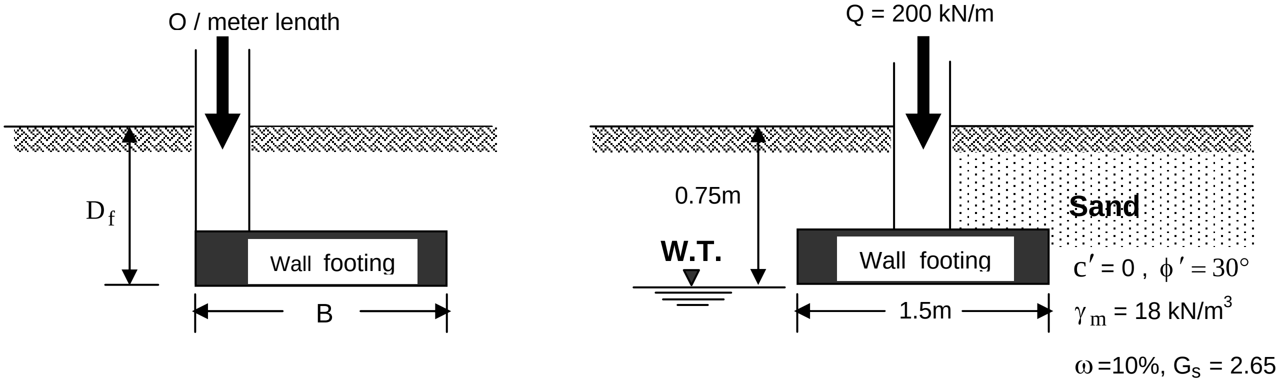


Fig. (1.12): Wall footing.

(4) Raft Foundation (see **Fig. 1.13**)**:**

Is a combined footing that covers the entire area beneath a structure and supports all the walls and columns, such that: $\dfrac{\sum Q}{A} = q_{applied} < q_{all.}$

It is used when:

- All spread footings areas represent greater than 50 % of the entire site area,
- If there is a basement and ground water table problems,
- The bearing capacity of soil is very low, and the building loads are so heavy, and
- A large differential settlement is expected to occur.

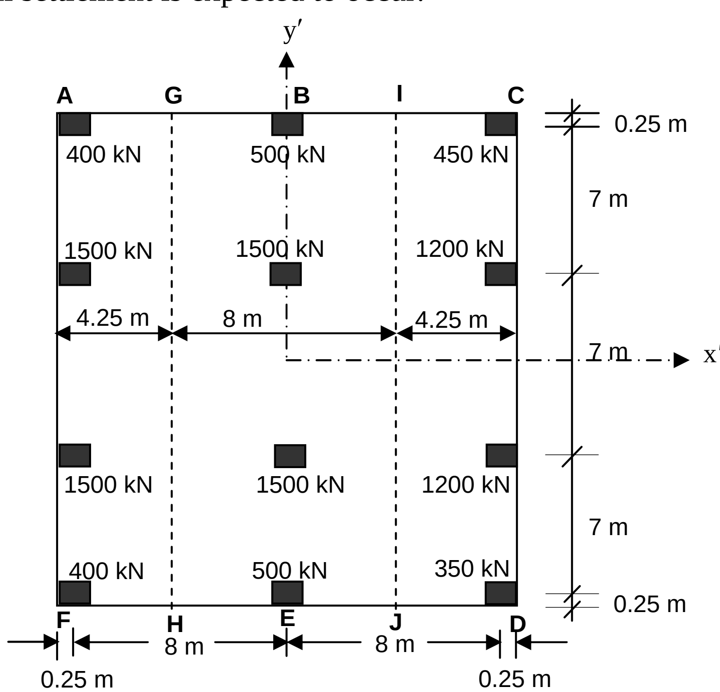


Fig. (1.13): Raft foundation.

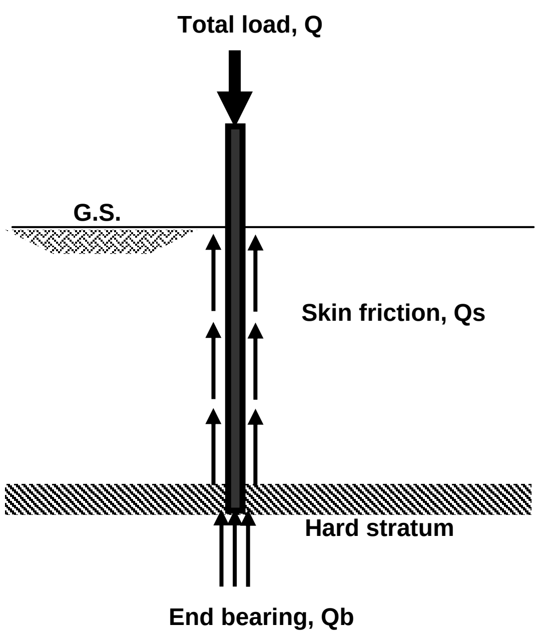
(5) Pile Foundation (see **Fig. 1.14**)**:**

Pile is a structural member made of wood, steel or concrete used to transmit the load from superstructure to underlying soil stratum in the following cases:

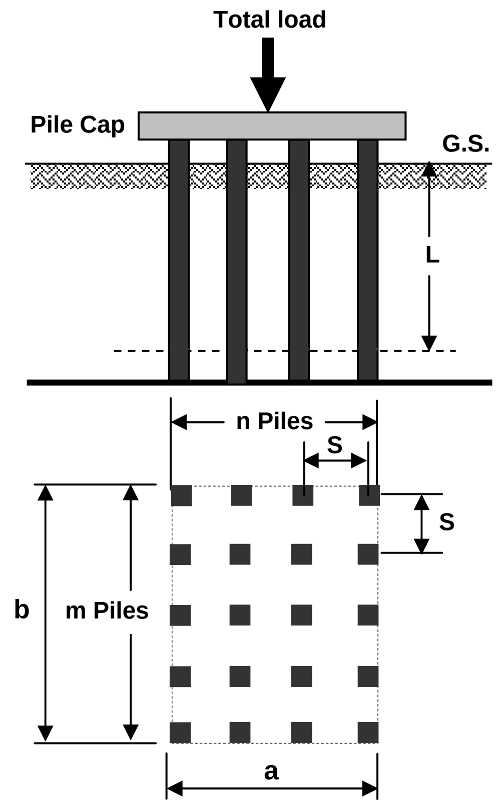
- When the soil profile consists of weak compressible soils,
- If $q_{applied} .. > .. q_{all.}$,
- To resist tension or uplift forces induced by horizontal forces acting on superstructure due to wind or earthquakes loads.

Piles usually are of two types:

(a) Driven piles, suitable for granular soils,
(b) Bored piles, suitable for clayey soils,
Each type of these piles can be made of precast concrete or cast in place.



(a) Single Pile



(b) Layout of Piles in groups.

Fig. (1.14): Single and group piles.

(6) Pier Foundation (see **Fig. 1.15)**:

It is an underground structural member that serves the same purpose as a footing. However, the ratio of the depth of foundation to the base width of piers is usually greater than 4 *($D_f /B >4$)*, *w*hereas, for footings this ratio is commonly less than unity *($D_f /B \leq 1$)*. A drilled pier is a cylindrical column that has essentially the same function as piles. The drilled pier foundation is used to transfer the structural load from the upper unstable soils to the lower firm stratum.

A part of the pier above the foundation is known as **a pier shaft**. The base of a pier shaft may rest directly on a firm stratum or it may be supported on piles. A pier shaft located at the end of a bridge and subjected to lateral earth pressure is known as an **abutment.**

Essentially, piers and piles serve the same purpose. The distinction is based on the method of installation. A pile is installed by driving and a pier by auger drilling. In general, a single pier is used to support the same heavy column load resisted by group of piles.

Fig. (1.15): Pier foundations.

(7) Floating Foundation:

If the weight of the constructed structure or building equal to the weight of the replaced excavated soil a foundation is known as fully compensated foundation. But if this condition is not satisfied, it is considered as semi-compensated foundation.

(8) Retaining Walls:

Retaining walls are structures used to provide stability for earth or other materials at their natural slopes. In general, they are used to support soil banks and water or also to maintain difference in the elevation of the ground surface on each of wall sides. Retaining walls are commonly supported by soil (or rock) underlying the base slab, or supported on piles; as in case of bridge abutments and where water may undercut the base soil as in water front structures. There are many types of retaining walls, each type serves different purposes and fit different requirements. They're mainly classified according to its behavior against the soil as:

(a) Gravity Retaining Walls are constructed of plain concrete or stone masonry. They depend mostly on their own weight and any soil resting on the wall for stability. This type of construction is not economical for walls higher than 3m (see **Fig. 1.16a**).

(b) Semi-Gravity Retaining Walls are modification of gravity wall in which small amounts of reinforcing steel are introduced. This helps minimizing the wall section (see **Fig. 1.16b**).

(c) Cantilever Retaining Walls are the most common type of retaining walls that used for wall height up to 8m. It derives its name from the fact that its individual parts behave as, and are designed as, cantilever beams. The stability of this type is a function of the strength of its individual parts (see **Fig. 1.16c**).

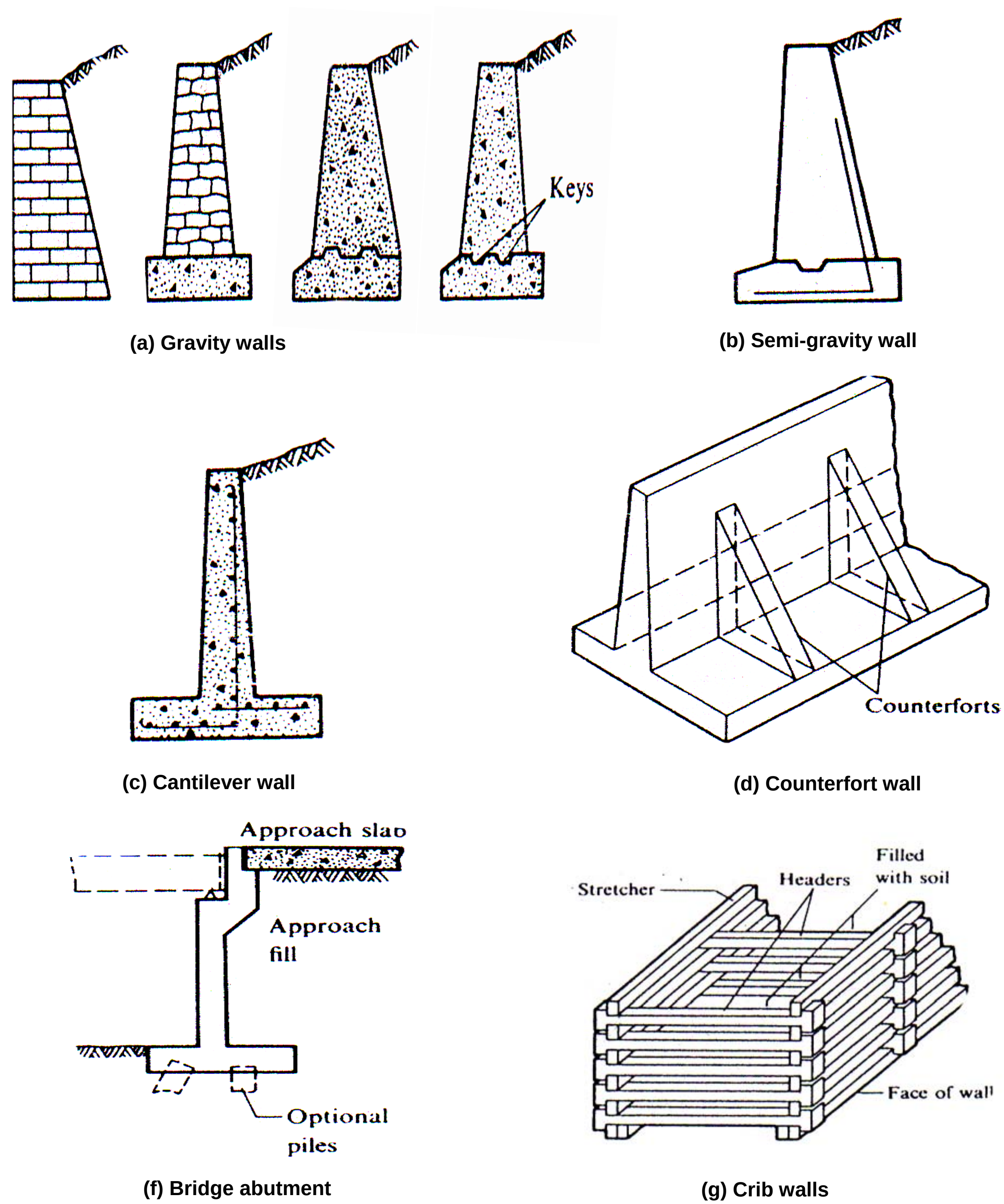
(d) Counterfort Retaining Walls are similar to cantilever retaining walls, at regular intervals, however, they have thin vertical concrete slabs behind the wall known as counterforts that tie the wall and base slab together and reduce the shear and bending moment. They're economical when the wall height exceeds 8m (see **Fig. 1.16d**).

(e) Buttress Retaining Walls this type is similar to counterfort retaining wall, except the bracing is in front of the wall and is in compression instead of tension.

(f) Bridge Abutments are special type of retaining walls, not only containing the approach fill, but serving as a support for the bridge superstructure (see **Fig. 1.16f**).

(g) Crib Walls are built-up members of pieces of precast concrete, metal, or timber and are supported by anchor pieces embedded in the soil for stability (see **Fig. 1.16g**).

*Among these walls, only the **cantilever retaining walls** and **bridge abutments** are much used.*



(a) Gravity walls

(b) Semi-gravity wall

(c) Cantilever wall

(d) Counterfort wall

(f) Bridge abutment

(g) Crib walls

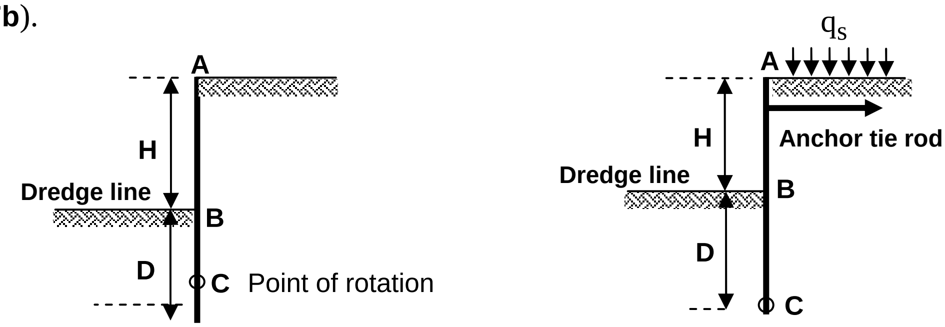
Fig. (1.16): Common types of retaining walls.

(9) Sheet Piles Walls:

These are classified as; anchored and cantilevered sheet pile walls; each kind of them may be used in single or double sheets walls.

(a) Cantilever or Free Sheet-Pile Walls are constructed by driving a sheet pile to a depth sufficient to develop a cantilever beam type reaction to resist the active pressures on the wall. That is, the embedment length which must be adequate to resist both lateral forces as well as a bending moment (see **Fig. 1.17a**).

(b) Anchored or Fixed Sheet-Pile Walls are types of retaining walls found in waterfront construction, which are used to form wharves or piers for loading and unloading ships (see **Fig. 1.17b**).

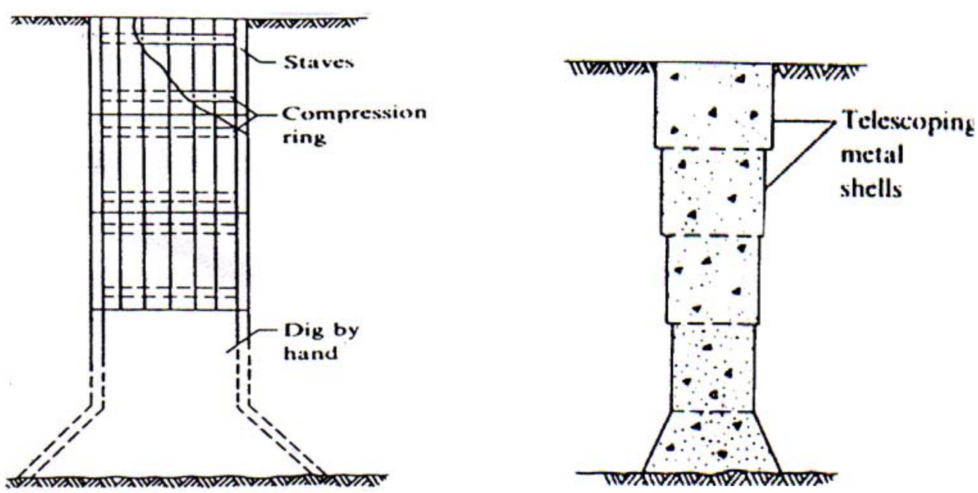


(a) Cantilever sheet pile wall. (b) Anchored sheet pile wall.

Fig. (1.17): Types of sheet piling walls.

(10) Caissons:

A hollow shaft or box with sharp ends or cutting edges for ease penetrating into soil used to isolate the site of project from the surrounding area. The material inside the caisson is removed by dredged through openings in the top or by hand excavation. Whereas, the lower part of it may be sealed from atmosphere and filled with air under pressure to exclude water from work space (see **Fig. 1.18**).



(a) The Chicago method. (b) The Gow method.

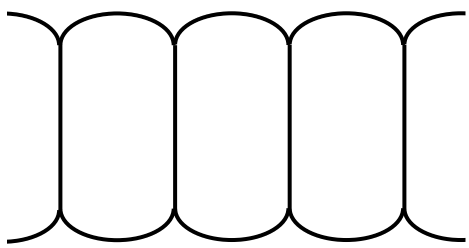
Fig. (1.18): Methods of caisson construction.

(11) Cofferdams:

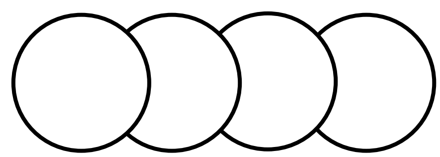
(a) Single and Double Sheet Pile Cofferdams: used for depth of water not exceeds 3.0 m.
(b) Cellular Cofferdams: used for higher depths of water, i.e., greater than 3.0 m.

These are relatively watertight enclosures of wood or steel sheet piles. Before the cofferdam is pumped out, one set of bracing is installed just above the water line. The water level is then lowered to the elevation at which another set of bracing must be installed. Successive lowering of water level and installation of bracing continue until the cofferdam is pumped out (see **Fig. 1.19**).

(a) Circular, economical for deep cells.



(b) Diaphragm, economical in quiet water.



(c) Modified circular.

Fig. (1.19: Cellular cofferdams.