Vemu Institute of Technology

GEOTECHNICAL ENGINEERING - II

IV B.Tech I Semester

Department of Civil Engineering

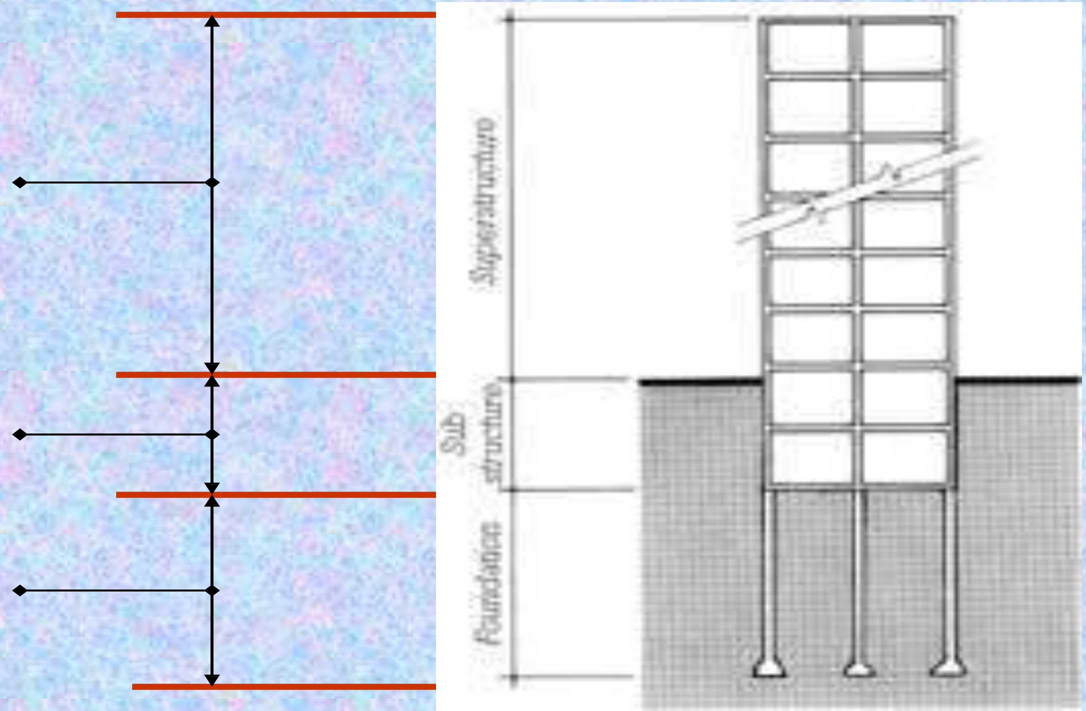
Mr. T. Murali Krishna

Major Building Parts

Superstructure

Substructure

Foundation



Syllabus

Unit 01 : Soil Exploration

Unit 02 : Shallow Foundations

Unit 03 : Pile Foundations &

Well Foundations

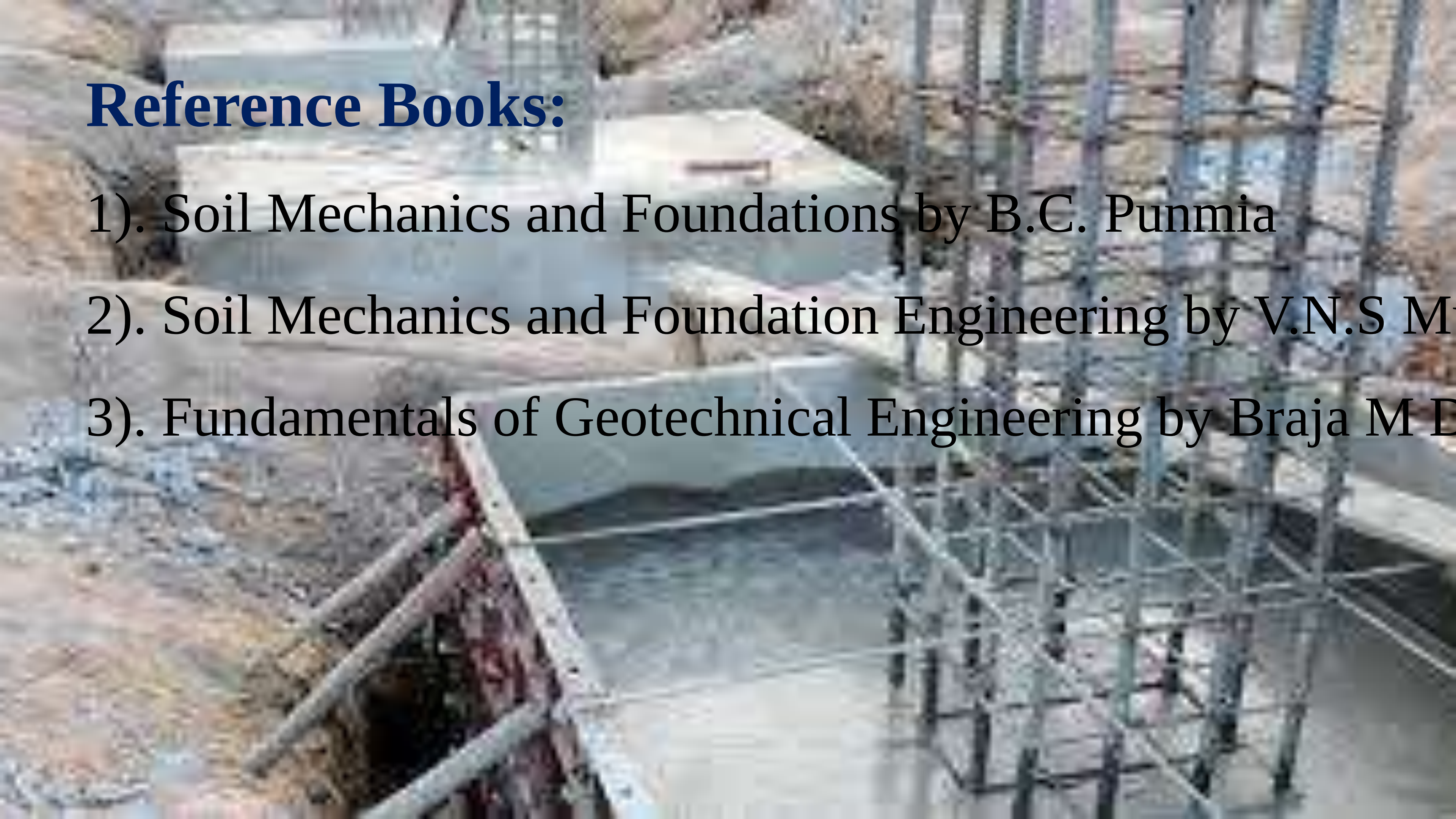

Unit 04 : Earth Slope Stability
Unit 05 : Earth Pressure Theories

Text Books

1). Geotechnical Engineering by
Dr C. Venkatramaiah

2). Soil Mechanics and Foundation Engineering by
Dr K. R. Arora

3). Soil Mechanics and Foundation Engineering by
Dr P. N. Modi



Reference Books:

1). Soil Mechanics and Foundations by B.C. Punmia

2). Soil Mechanics and Foundation Engineering by V.N.S M

3). Fundamentals of Geotechnical Engineering by Braja M D

COURSE OBJECTIVES:

The objective of this course is to enable the students

1).To know the necessity of soil exploration.

2).To design the shallow foundations.

3).To know and necessity of deep foundations

4).To perform the stability analysis of slopes.

5).To know the principles and design of earth retaining walls

Course Outcomes:

After the completion of the course the student is able to

1. **Apply the different soil exploration techniques and prepare the soil investigation report**
2. **Determine the bearing capacity of soils and estimate the settlement of structures**
3. **Design the pile foundations and well foundations**
4. **Evaluate the failure of slopes in different zones of soil**
5. **Calculate the magnitude of earth pressures and design the retaining walls**

UNIT – 01
Soil Exploration

Syllabus

Need – Methods of soil exploration – Boring and Sampling methods – Field tests – Penetration Tests – Plate load test – Pressure meter – planning of Programme and preparation of soil investigation report.

Unit 01 - Learning Objectives

1. Need of soil exploration
2. Methods of soil exploration
3. Boring and Sampling methods
4. Field tests in soil exploration
5. Penetration Tests in soil exploration
6. Pressure meter
7. planning of Programme and preparation of soil investigation report.

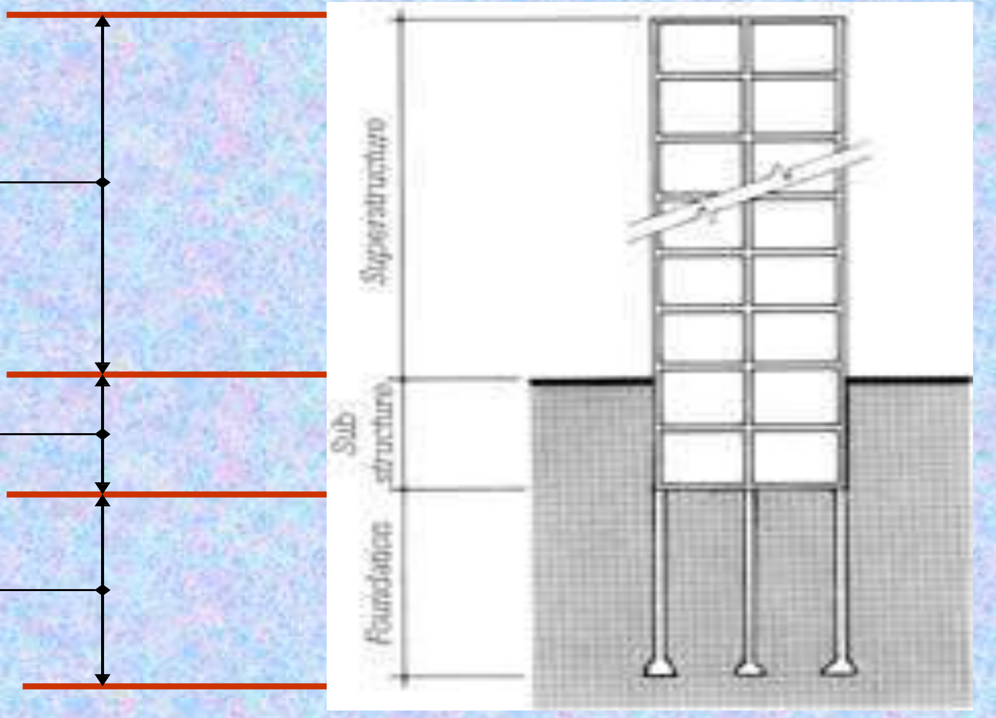
Need of soil exploration

Major Building Parts

Superstructure

Substructure

Foundation



Need of soil exploration

- Selection of the type and the depth of foundation suitable for a given structure.
- Evaluation of the load-bearing capacity of the foundation soil.
- Estimation of the probable settlement of a structure.
- Determination of potential foundation problems(for example expansive soil, collapsible soil, sanitary landfill and so on).
- Establishment of ground water table.
- Prediction of lateral earth pressure for structures like retaining walls, sheet pile bulkheads, and braced cuts.
- Establishment of construction methods for changing subsoil conditions

Soil exploration - Definition

- The process of collection soil data for the assessment soil properties at a site through series of laboratory and field investigation is collectively called Sub-soil Exploration

- Soil exploration enables the engineers to draw soil profile indicating the sequence of soil strata and the properties of soil involved

Soil exploration, in general deals with the determination of suitability of the site for the proposed construction

Importance and objective of soil exploration

- The stability of the foundation of a building, a bridge, an embankment or any other structure built on soil depends on the strength and compressibility characteristics of the subsoil.
- The field and laboratory investigations required to obtain the essential information on the subsoil is called Soil Exploration (or) Soil Investigation.

- Soil exploration may be needed not only for the design and construction of new structures, but also for deciding upon the remedial measures if an existing structure shows signs of distress after construction.
- The design and construction of highways and airport pavements will also depend upon the characteristics of the soil strata upon which they are to be aligned

Preliminary steps of site investigation

Site investigation may involve the following preliminary steps:

1). Reconnaissance

2). Study of maps and

3). Aerial photography

(1). Reconnaissance.

- Site reconnaissance is the first step in a sub-surface or sub-soil exploration programme.
- It includes a visit to the site and to study the maps and other relevant records.
- It helps in deciding future programme of site investigations, scope of work, methods of exploration to be adopted, types of samples to be taken and laboratory testing and in-situ testing.

(2). Preliminary explorations.

- The aim of preliminary explorations is to determine the depth, thickness, extent and composition of each soil stratum at the site.
- The depth of bed rock and the ground water table is also determined.
- The preliminary explorations are generally in the form of a few borings or test pits.
- Tests are conducted with cone penetrometers and sounding rods to obtain information about the strength and compressibility of soils.
- Geophysical methods are also used in preliminary explorations for locating the boundaries of different soil strata.

(3). Detailed explorations.

The purpose of detailed explorations is to determine the engineering properties of the soils in different strata.

It includes an extensive boring programme, soil sampling and testing of soil samples in the laboratory.

Field tests, such as vane shear tests, plate load tests and permeability tests are conducted to determine the properties of soils in natural state.

The tests for determination of dynamic properties are also carried out, if required.

- For complex projects involving heavy structures, such as bridges, dams, multi-storey buildings, it is essential to have detailed explorations.
- However, for small projects, especially at sites where the strata are uniform, detailed investigations may not be required.

Sub-surface exploration - Reconnaissance

The geotechnical engineer makes a visit to the site for a careful visual inspection in reconnaissance.

The information about the following features is obtained in reconnaissance.

1).The general topography of the site, the existence of drainage ditches and dumps of debris and sanitary fills.

2).Existence of settlement cracks in the structures already built near the site.

3).The evidence of landslides, creep of slopes and the shrinkage cracks.

4).The stratification of soils as observed from deep cuts near the site.

5). The location of high flood marks on the nearby buildings and bridges.

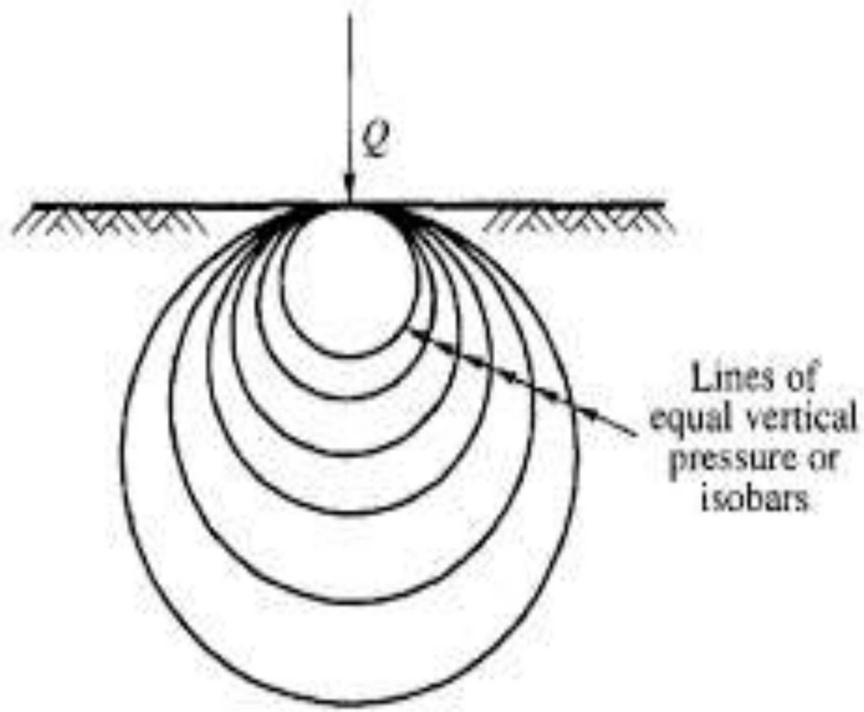
6). The depth of ground water table as observed in the wells.

7). Existence of springs, swamps, etc. at the site.

8). The drainage pattern existing at the site.

9). Types of vegetation existing at the site. The type of vegetation gives a clue about the nature of soil at the site.

10). Existence of underground water mains, power conduits, etc. at the site.


Q
Lines of
equal vertical
pressure or
isobars

According to the above criterion,

The depth of exploration should be about 1.5 times the width of the square footing and

About 3.0 times the width of the strip footing.

However, if the footings are closely spaced, the whole of the loaded area acts as a raft foundation.

In that case, the depth of boring should be at least 1.5 times the width of the entire loaded area.

In the case of multi-storeyed buildings, the depth of exploration can be taken from the following formula (Sowers and Sowers 1970),

$$D = C(S)^{0.7}$$

Here

D = The depth of exploration in mete

C = The constant which is equal to 3 for light steel buildings and narrow concrete bridges. It is equal to 6 for heavy steel buildings and wide concrete buildings.

S = The number of storeys.

S.No	**Nature of Project**	**Spacing of Bore holes in metres**
1	**Highways (Subgrade Survey)**	**300 to 600**
2	**Earth dam**	**30 to 60**
3	**Borrow pits**	**30 to 120**
4	**Multi-storeyed buildings**	**15 to 30**
5	**Single storey factories**	**30 to 90**

Direct method (or) Open excavation methods of exploration

In this method of exploration, an open excavation is made to inspect the sub-soil strata.

The methods can be divided into two categories

1). Pits and Trenches and

2). Drifts and shafts.

1). Pits and trenches.

Pits and Trenches are excavated at site to inspect the strata.

The size of the pit should be sufficient to provide necessary working space.

IS : 4453-1967 recommends a clear working space of 1.2 m X 1.2 m at the bottom of the pit.

The depth of pit depends on the requirement of the investigation.

- Shallow pits up to a depth of 3 m can be made without providing any lateral support.
- For deeper pits, especially below the ground water table, lateral support in the form of sheeting and bracing system is required.
- Deep pits should be properly ventilated to prevent the accumulation of dead air.
- If water is encountered in a pit, it should be suitably dewatered.

- Trenches are long shallow pits.
- The trench is continuous over a considerable length, it provides exposure along a line.
- The trenches are more suitable than pits for exploration on slopes.
- Test pits and trenches can be excavated manually or mechanically.

2). Drifts and shafts

Drifts are horizontal tunnels made in the hill-side to determine the nature and structure of the geological formation.

IS : 4453-1980 recommends that a drift should have the minimum clear dimensions of 1.5 m width and 2.0 m height in hard rock.

- Shafts are large size vertical holes made in the geological formation.
- These may be rectangular or circular in section.
- The minimum width of a rectangular shaft is 2.4 m.
- The circular shaft, the minimum diameter is 2.4 m.
- In weak ground, the sides of the shaft should be properly supported.
- Deep shafts should be properly ventilated. Shafts are used to reach a particular stratum at a depth of 4m or more.
- Shafts are also used to extend the exploration below the river bed already done by means of tunnels.

Semi direct methods – Borings for soil exploration

- When the depth of soil exploration is large, borings are used for exploration.
- A vertical bore hole is drilled in the ground to get the required information about the sub-soil strata.
- Soil samples are taken from the bore holes and tested in the laboratory.
- The bore hole may be used for conducting in-situ tests and for locating the water table.
- Extensometers or pressure meters may also be installed in the bore for the measurement of deformation in the sub-strata.

Depending upon the type of soil and the purpose of boring,

The following methods are used for drilling the bore holes.

1). Auger boring

2). Wash boring

3). Rotary boring

4). Percussion boring

5). Core boring.

1). Auger boring

- It consists of a shank with a cross-wise handle for turning and having central tapered feed screw.
- The augers can be operated either manually or mechanically.
- The hand augers used in boring are about 15 to 20 cm in diameter.
- These are suitable for advancing bore holes upto a depth of 3 to 6 m in soft soils.

- The bore hole is advanced by turning the cross arm manually and at the same time applying the thrust in the down direction.
- When the auger is filled with soil, it is taken out.
- If the bore hole is already driven, another type of auger, known as post-hole auger is used for taking soil samples

In wash boring,

- The bore hole is drilled by first driving a casing pipe, about 2 m to 3 m long
- Then inserting into it a hollow drilled rod with a chisel-shaped chopping bit at its lower end.
- Water is pumped down the hollow drilled rod, which is known as wash pipe.

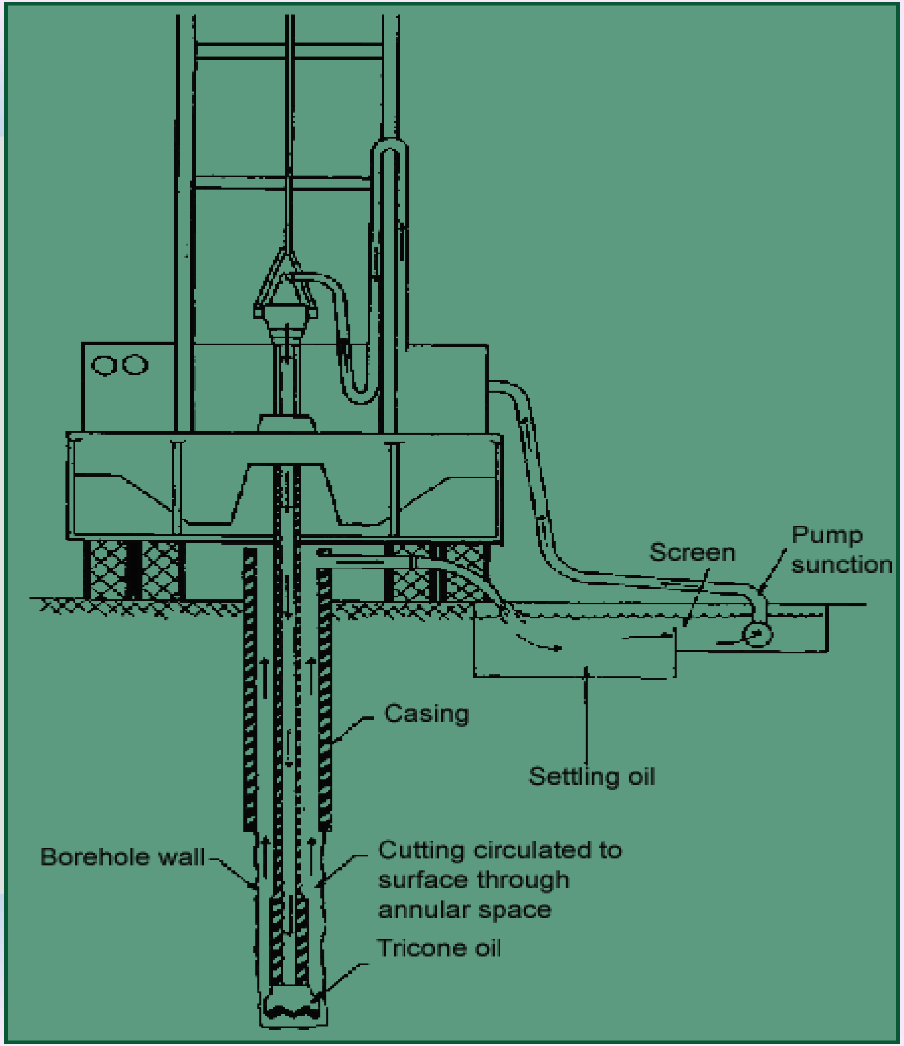
- The water emerges as a strong jet through a small opening of the chopping bit.
- The hole is advanced by a combination of chopping action and the jetting action, as the drilling bit and the accompanying water jet disintegrate the soil.
- The water and the chopping soil particles rise upward through the annular spaces between the drilled rod and the casing pipe.
- The return water, also known as wash water, is laden with soil cuttings. It is collected in a tub through a T-shaped pipe fixed at the top of the casing as shown in figure.

- The bore hole is further advanced by alternately raising and dropping the chopping bit by a winch.
- The swivel joint provided at the top of the drilled rod facilitates the turning and twisting of the rod.
- Sometimes instead of a casing pipe, specially drilling fluids made of suspension or emulsion of fat clays or bentonite combined with some chemical additives are used for supporting the walls of the bore hole.
- The wash soil samples collected in the tub do not represent the soil in its true condition.

- The wash boring may be used in all types of soils expect those mixed with gravel and boulders. The rocks also cannot be penetrated by this method.
- The wash boring is mainly used for advancing a bore hole in the ground. Once the hole has been drilled, a soil sampler is inserted to obtain the soil samples for testing in the laboratory.
- The equipment used in wash borings is relatively light and inexpensive.

- The main disadvantage of this method is that it is slow in stiff and coarse-grained soils.
- It cannot be used efficiently in hard soils, rocks and soils containing boulders.
- The method is not suitable for talking good quality undisturbed samples above ground water table, as the wash water enters the strata below the bottom of the bore hole and causes an increase in its water content.

3. Rotary drilling



UNIT – II
SHALLOW
FOUNDATIONS

UNIT – II

SHALLOW FOUNDATIONS:

Types – choice of foundation – Location of depth – Safe Bearing Capacity – Terzaghi`s, Meyerhoff‟s and Skempton`s Methods ALLOWABLE BEARING PRESSURE : Safe bearing pressure based on N- value – allowable bearing pressure; safe bearing capacity and settlement from plate load test – allowable settlements of structures – Settlement Analysis

Major Building Parts

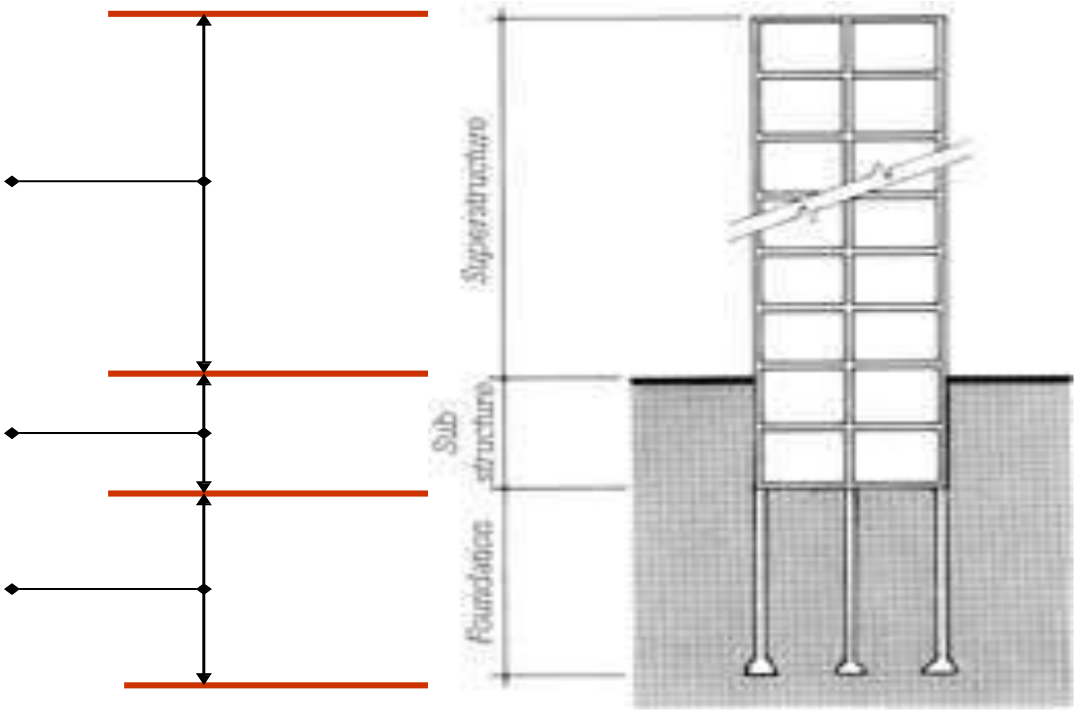
Major Building Parts

Superstructure

Substructure

Foundation

Foundation

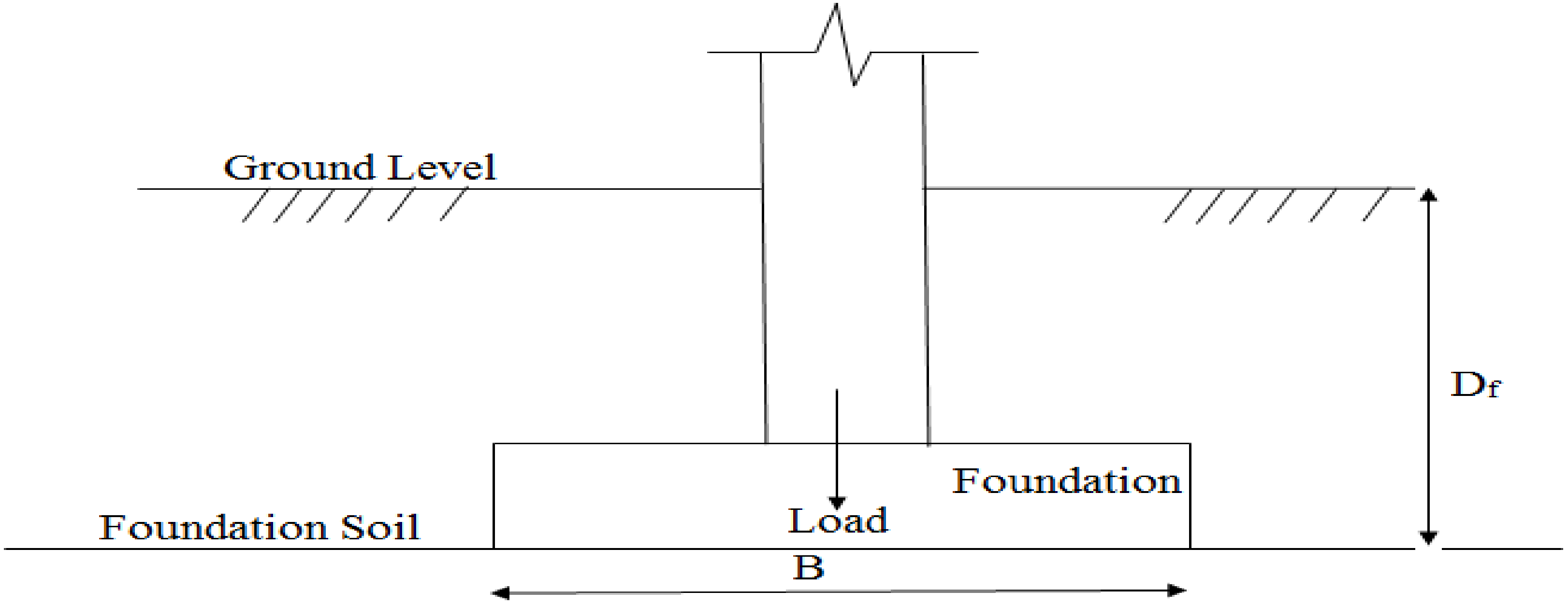


INTRODUCTION TO FOUNDATIONS

The foundation is the lowest part of the structure which is in contact with the soil or rock lying below and transmits the loads of the structure to it.

The soil which lies below the foundation to which the structural loads are transmitted from the foundation is known as the foundation soil.

The foundations are required for distributing the loads of the structure on a larger area.

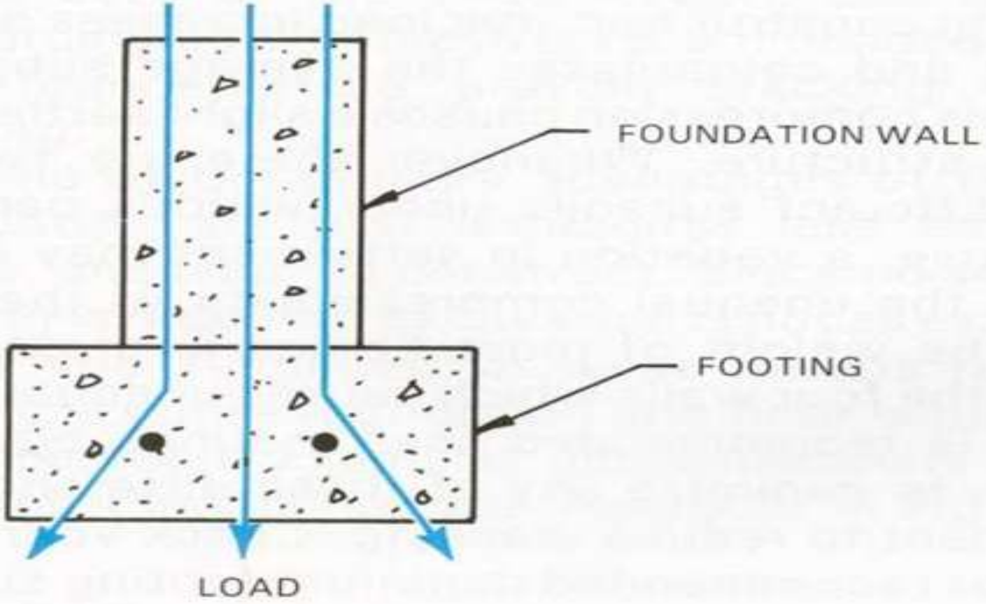


Here

D_f = The depth of foundation and

B = The width of foundation

Weight Distribution in Fo



The footing distributes the building weight over a broad area.

The foundation should be designed such that

1). The soil below the foundation does not fail in shear and

2). The settlement of the foundation is within the safe limits

General requirements of foundations

Foundations should be constructed to satisfy the following requirements

1). The foundations shall be constructed to sustain the dead and imposed loads and to transmit these loads to the foundation soil in such a way that the pressure on foundation soil will not cause excessive settlement which would impair the stability of the structure.

2). Foundation base should be rigid so that differential settlements are minimized, specially for the case when super-imposed loads are not evenly distributed.

3). Foundation should be taken sufficiently deep to guard the structure against the damage or distress caused by swelling or shrinkage of the foundation soil or sub-soil.

4). Foundation should be so located that its performance may not be affected due to any unexpected future influence.

Foundation Loads

- Dead Load
- Live Load
- Wind Load
- Earthquake Load

Foundation Loads
Dead Load
Live Load
Wind Load
Earthquake

The wind loads may be neglected in the design of foundation unless the wind load on the foundation exceeds one-third of the load due to dead load and live load combined.

Types of Foundations

Foundations may be broadly classified into two categories

1). Shallow Foundations and 2). Deep Foundations

According to Terzaghi criterion,

1). The foundation is termed as shallow foundation if its depth (D_f) is equal to (or) less than the width (B) of foundation.

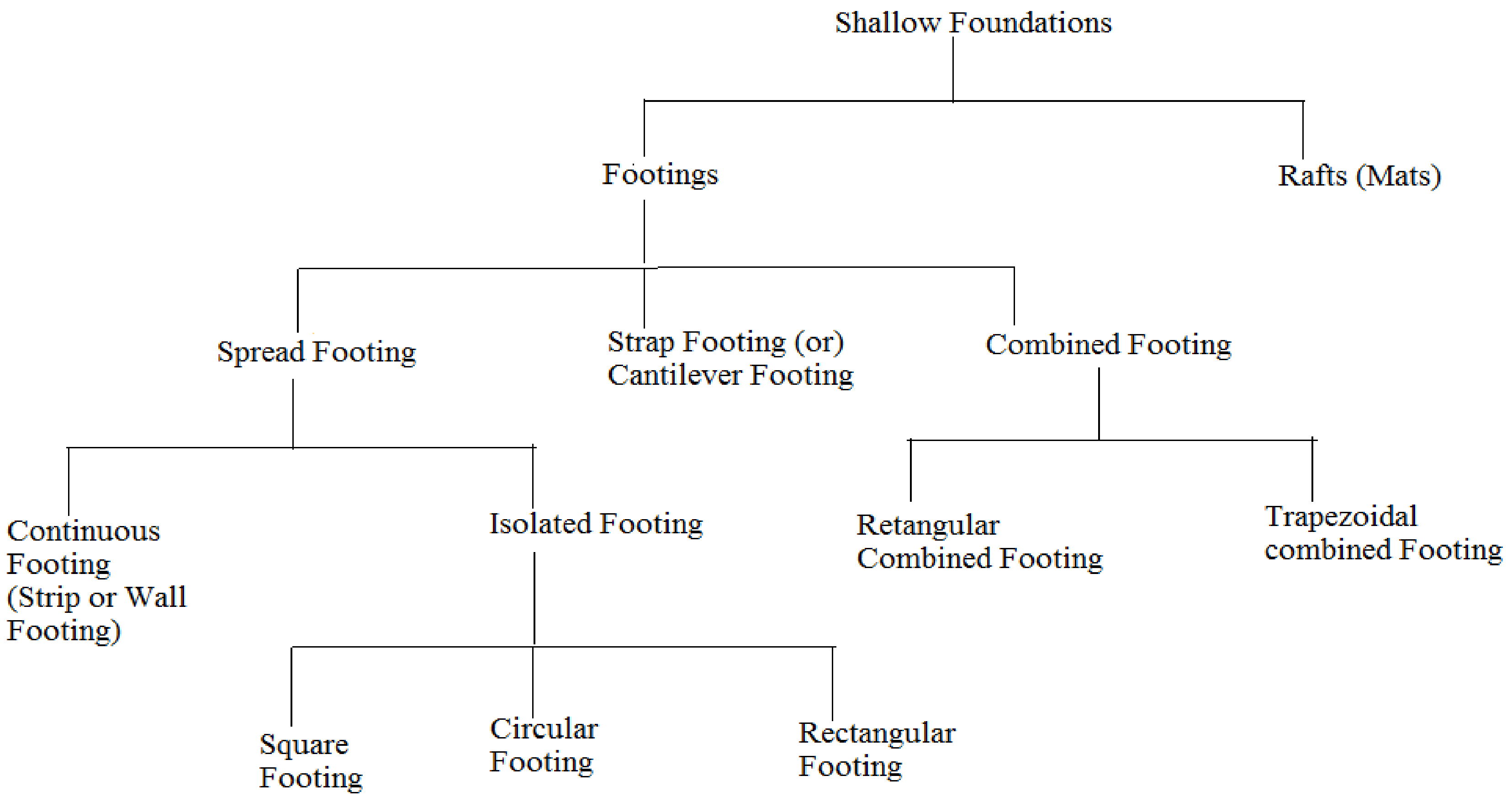
2). The foundation is termed as deep foundation if its depth (D_f) is more than the width (B) of foundation

Thus

1). $\frac{D_f}{B} \leq 1$ for Shallow foundation and

1). $\frac{D_f}{B} > 1$ for Deep foundation

Classification of Shallow Foundations


Shallow Foundations
Footings
Rafts (Mats)
Spread Footing
Strap Footing (or) Cantilever Footing
Combined Footing
Continuous Footing (Strip or Wall Footing)
Isolated Footing
Retangular Combined Footing
Trapezoidal combined Footing
Square Footing
Circular Footing
Rectangular Footing

Classification of Deep Foundations

Deep Foundatins

- Deep Footing
- Pile Foundation
- Pier Foundation
- Well Foundation (or) Caissons

Factors governing the selection of a type of shallow Foundation

The following are the different types of shallow foundations

1). Spread footing 2). Strip footing 3). Strap Footing 4). Combined footing
5). Raft or Mat foundation

The selection of a type of shallow foundation is based on the following factors

1). Soil strength or Bearing capacity of soil 2). Ground conditions 3). Foundation loads
4). Construction methods 5). Impact on adjacent property

SPREAD FOOTING

- Spread footing is a shallow foundation.

- The spread footing is selected where the well compacted and stable foundation soil is available near the ground level.

- Spread footing also called as isolated footing or pad footing or individual footing is provided to support an individual column.

- Spread footing is circular, square or rectangular slab of uniform thickness.

STRIP FOOTING

- Strip footing is a shallow foundation.

- The strip footing is used to support a line of loads such as a load bearing wall

- Strip footing is also used where the line of column positions are so close that individual spread footings would be pointless

STRAP FOOTING

- A strap footing usually supports two columns, so it’s a special type of combined footing.

- If the property line exists at or near the edge of an exterior column, a normal isolated footing would be placed eccentrically under this column and it would tend to tilt.

- This problem may be prevented by connecting this footing with the adjacent interior footing with a strap concrete beam.

COMBINED FOOTING

- The footing used for two columns or more than two columns is called combined footing.

- The combined footing is mainly two types

1). Rectangular footing and 2). Trapezoidal footing.

- The combined footing is provided under the following situations

1). When the columns are located extremely close to each other and their individual footings are overlaying.

RAFT or MAT FOUNDATION

- Raft or mat foundation is shallow foundation.

- Raft foundation is used to spread the load from a structure over a large area.

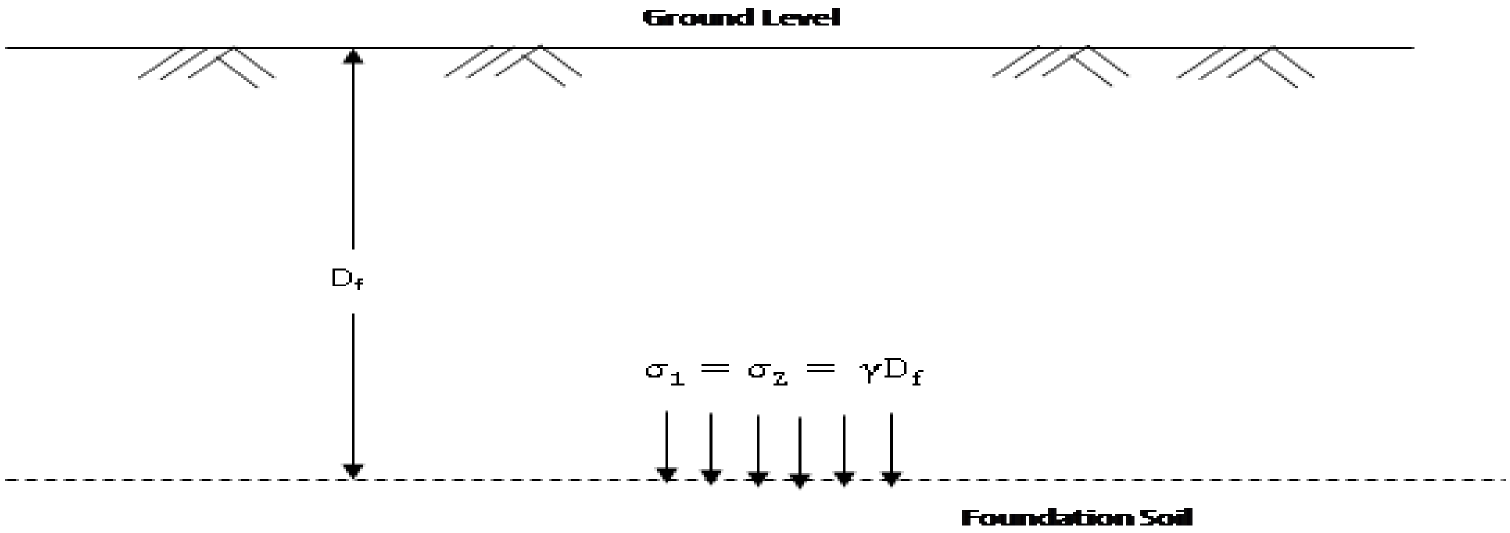
- Raft foundation covers the entire area of te structure.

- Raft foundation is often needed on soft or loose soils which have low value of bearing capacity.

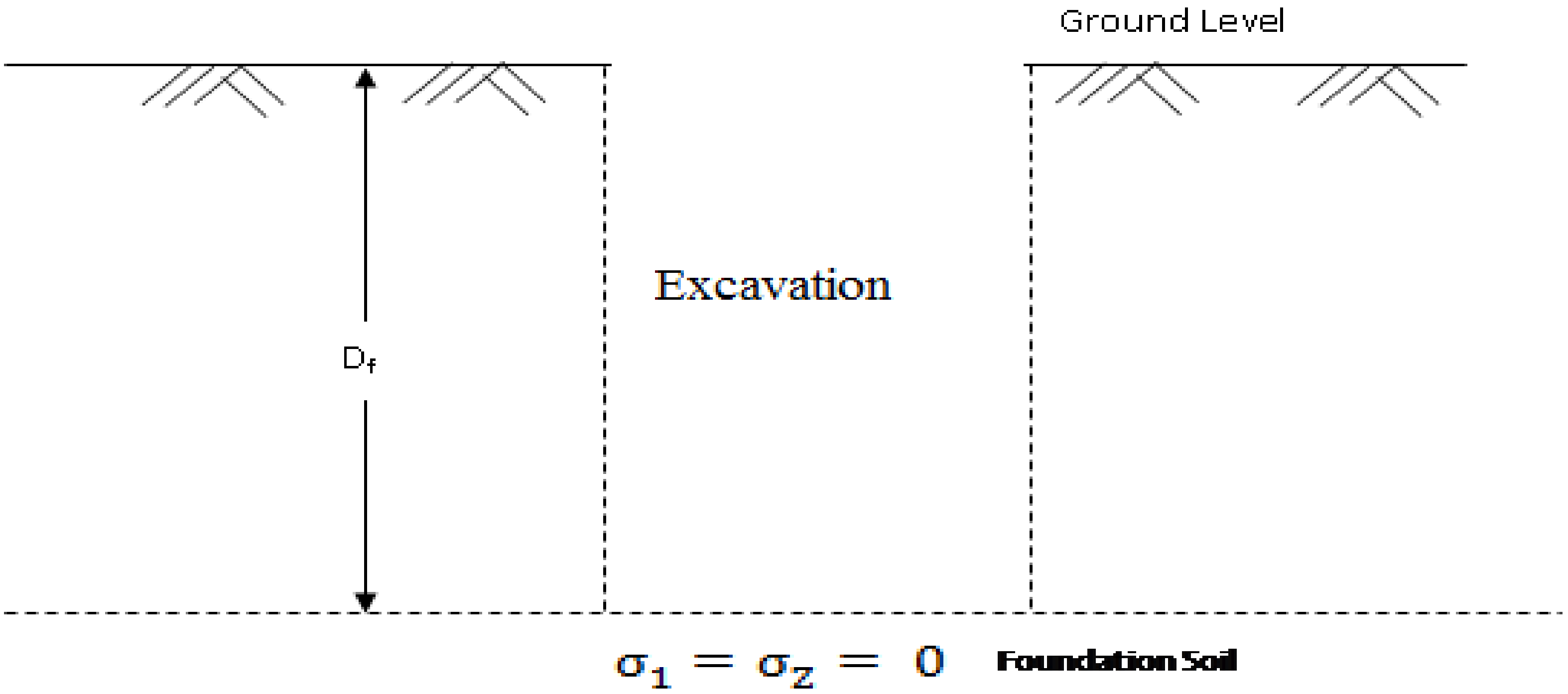
ADVANTAGES OF RAFT FOUNDATION

- It spread the structural load over a large area
- It provides more structural stability
- It reduces the settlements of the structure
- It offers more resistance to uplift forces
- It distributes the structural loads more evenly onto the foundation soil.

BEARING CAPACITY OF SOIL



$\sigma_1 = \sigma_z = \gamma D_f$ = Geostatic stress (or)Over burden pressure(or) Surcharge pressure


Ground Level
Excavation
D_f
$\sigma_1 = \sigma_z = 0$
Foundation Soil

Basic Definitions

The basic definitions relevant to the bearing capacity of soil are as given below.

1). Bearing Capacity

Bearing capacity is defined as the load carrying capacity of the foundation soil which enables it to bear the loads transmitted to it from the structure.

The bearing capacity is usually expressed as the load per unit area.

6). Net Ultimate Bearing Capacity

The net ultimate bearing capacity is defined as the maximum load per unit area in excess of the surcharge pressure which the foundation soil can withstand without the causing the shear failure of the foundation soil.

The net ultimate bearing capacity is denoted by " q_{nu} "

Thus

The net ultimate bearing capacity is equal to the gross ultimate bearing capacity minus the surcharge pressure.

∴ The net ultimate Bearing Capacity = The gross ultimate Bearing Capacity - The surcharge pressure

$$\therefore q_{nu} = q_u - \gamma D_f$$

Here

γ = The unit weight of the foundation soil and

D_f = The depth of foundation

7). Safe Bearing Capacity

The safe bearing capacity is defined as the maximum load per unit area which the foundation soil can carry safely without the risk of shear failure.

The safe bearing capacity is obtained by dividing the ultimate bearing capacity with a suitable factor of safety.

$$\text{The safe bearing capacity} = \frac{\text{The ultimate bearing capacity}}{\text{The factor of safety}}$$

The factor of safety for foundations may range from 2 to 5.

8). Net safe Bearing Capacity (q_{ns})

The net safe bearing capacity is defined as the maximum load per unit area in excess of the surcharge pressure which the foundation soil can carry safely without the risk of shear failure.

The net safe bearing capacity is obtained by dividing the net ultimate bearing capcity with a suitable factor of safety.

$$\text{The net safe bearing capacity} = q_{ns} = \frac{\text{The net ultimate bearing capacity}}{\text{The factor of safety}}$$

$$\therefore q_{ns} = \frac{q_{nu}}{F}$$

Factors affecting the Bearing capacity of Foundation Soil

The following factors will affect the bearing capacity of the foundation soil.

1). Nature of the soil and its physical and engineering properties.

2). Nature of foundation such as the size, shape, depth below the ground level etc.

3). Total and differential settlements that the structure can withstand without the failure.

4). Location of the ground water table relative to the level of the foundation

5). Initial stresses in the soil below the ground level

Criteria for the Determination of Bearing Capacity

The determination of bearing capacity of foundation soil is based on the following two criterion

1). The shear failure of the foundation soil shall not occur – shear strength criteria

2). The settlement of the foundation soil must be limited to safe and acceptable magnitude – settlement criteria

The shear strength criteria and the settlement criteria are independent.

The design value of safe bearing capacity would be the smaller of the two values obtained from these two criteria.

Methods to Determine the Bearing Capacity

The following methods are adopted to determine the bearing capacity of the foundation soil

1). Analytical methods 2). Plate bearing tests 3). Penetration tests

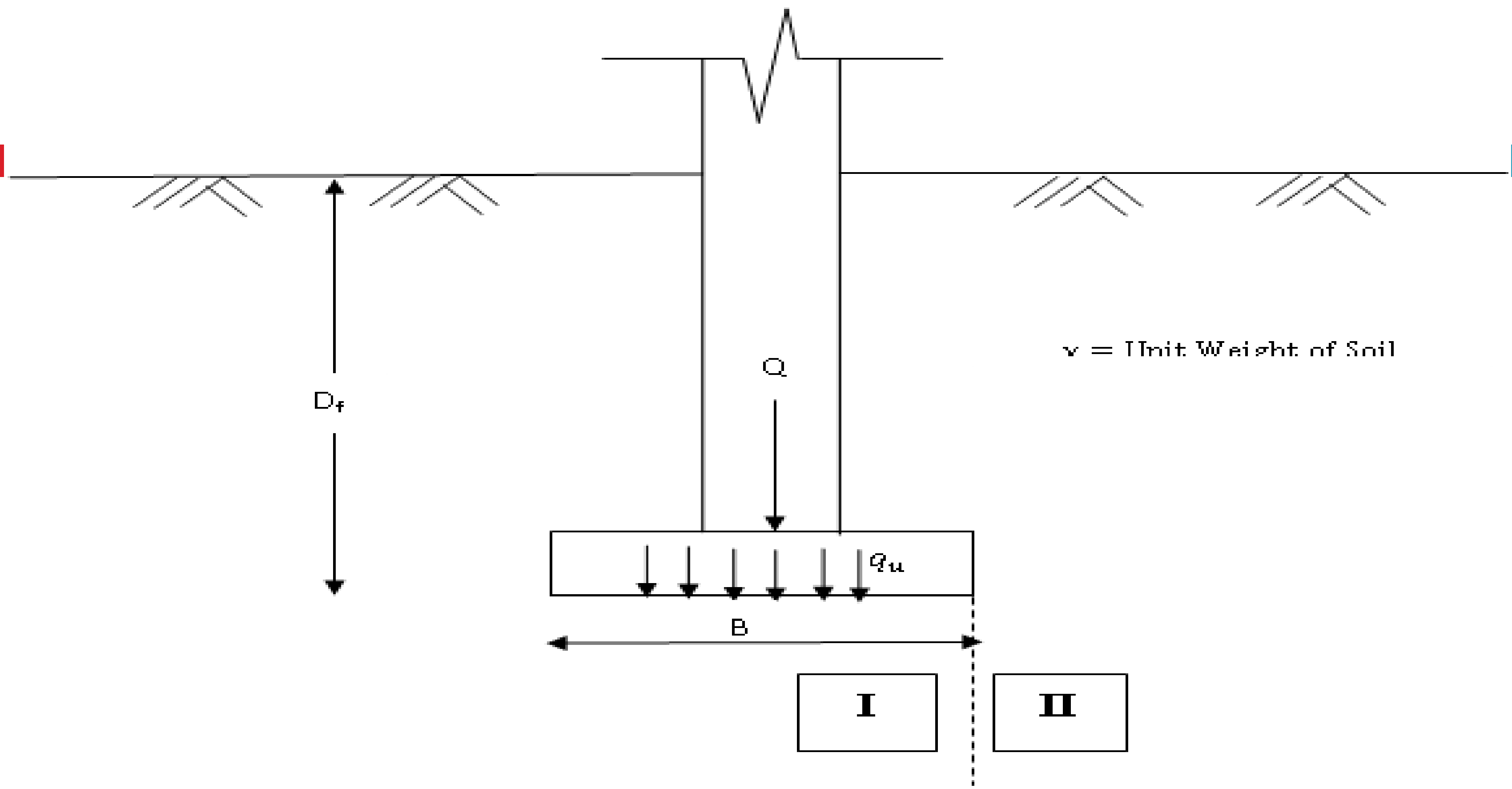
4). Laboratory tests and 5). Bearing capacity tables in various codes

The number of analytical method given by Rankine, Prandtl, Terzaghi, Meyerhof, Hansen, Vesic, Skempton etc are used to determine the bearing capacity of the foundation soil.

The plate bearing tests like the plate load test are conducted in the field to determine the bearing capacity of foundation soil.

Penetration tests are conducted in the field by using the penetrometers to measure the resistance of the soil to penetration. This resistance can be correlated to the bearing capacity of the soil.

Simple laboratory tests may be useful to determine the bearing capacity of pure clays.


γ = Unit Weight of Soil
Q
D_f
q_u
B
I
II

The first soil element, the vertical stress (σ_1) is the major principal stress and the horizontal stress (σ_3) is the minor principal stress.

The major principal stress (σ_1) acting on the first soil element is equal to the ultimate bearing capacity (q_u) and the first soil element is in active state condition.

$$\therefore \ \sigma_1 = q_u$$

Now, the minor horizontal principal stress (σ_3) acting on the first element is given by

$\sigma_3 = K_a \sigma_1$ But K_a = The coefficient of active lateral earth pressure = $\left(\frac{1-\sin \emptyset}{1+\sin \emptyset}\right)$

$$\therefore \ \sigma_3 = \left(\frac{1-\sin \emptyset}{1+\sin \emptyset}\right) q_u \ \text{-------------} \ (1)$$

The second soil element, the vertical stress (σ_3) is the minor principal stress and the horizontal stress (σ_1) is the major principal stress.

The vertical minor principal stress (σ_3) acting on the second soil element due to the weight of the over burden soil is given by

$$\sigma_3 = \gamma D_f$$

The second soil element is in passive state condition.

Now, the passive major horizontal principal stress (σ_1) acting on the second element is given by

$\sigma_1 = K_p \, \sigma_3$ But K_p = The coefficient of passive lateral earth pressure = $\left(\frac{1 + \sin \emptyset}{1 - \sin \emptyset}\right)$

$$\therefore \; \sigma_1 = \left(\frac{1+\sin \emptyset}{1-\sin \emptyset}\right) \gamma D_f \text{ ------------- (2)}$$

Since both elements are at the same depth from the ground level

The horizontal minor principal stress (σ_3) acting on the first element = The horizontal major principal stress (σ_1) acting on the second element.

Now, from equations (1) and (2) we get

$$\left(\frac{1-\sin\phi}{1+\sin\phi}\right) q_u = \left(\frac{1+\sin\phi}{1-\sin\phi}\right) \gamma D_f$$

$$\therefore q_u = \left(\frac{1+\sin\phi}{1-\sin\phi}\right)^2 \gamma D_f \quad \text{------------} \ (3)$$

The above equation gives the approximate value of the ultimate bearing capacity of the foundation soil.

Rankine did not consider the cohesion (C) of the soil.

Unit - III

Analysis and Structural Design of R.C.C. Footings

Analysis and Structural Design of R.C.C Isolated, Combined and Strap Footings.

Deep Foundations - I

Pile foundations, Types of pile foundations, Estimation of bearing capacity of pile foundation by dynamic and static formulae, Bearing capacity and Settlement analysis of pile groups, Negative skin friction, Pile load tests.

1). Introduction to pile foundations

2). Types of pile foundations

3). Estimation of bearing capacity of pile foundation by static and dynamic formulae

4). Pile load test

5). Negative skin friction

6). Bearing capacity and Settlement analysis of pile groups

Introduction to Deep Foundations

When the soil near the ground surface is not capable of supporting a structure, deep foundation is required to transfer the loads to deeper hard strata.

The most common types of deep foundations are Pile foundations, Pier foundations and Well foundations.

The pile is made of steel, concrete or wood.

The pile is either driven into the soil or formed in-situ by excavating a bore hole into the soil and filling it with concrete.

The **Pile** greater than 0.6m diameter is generally termed as **Pier**.

Necessity of Pile Foundation

Pile foundations are used in the following conditions

1). When the soil strata just below the ground surface is highly compressible and very weak to support the load transmitted by the structure.

2). Pile foundation is required for the transmission of structural loads through deep water to a firm stratum.

3). Pile foundation is required when the soil conditions are such that erosion or scour of soil may occur from underneath a shallow foundation.

4). In case of expansive soils such as black cotton soil, which swell or shrink as water content changes, the pile foundation is required to transfer the loads below the active zone.

5). Pile foundation is required for some structures such as transmission towers and off-shore platforms which are subjected to uplift effect.

Classification of Piles

The piles are classified

1). Based on the material used

2). Based on the mode of transfer of load

3). Based on the method of construction or installation

4). Based on the usage   and

5). Based on the displacement of soil

1). Classification based on material used

According to the materials used the piles are classified as

a). Steel piles

b). Concrete piles

c). Timber piles and

d). Composite piles

2). Classification based on mode of transfer of loads

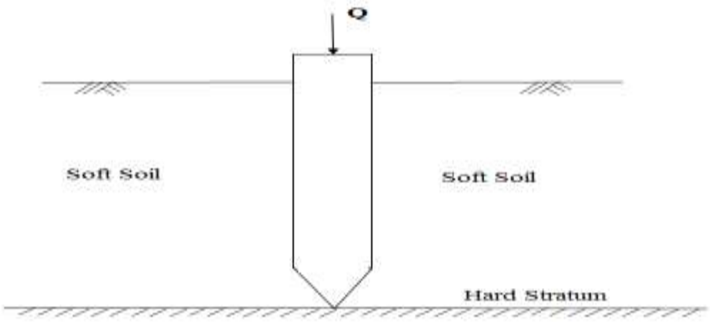
According to the mode of transfer of loads, the piles are classified as

a). End-bearing piles   b). Friction piles and c). Combined end-bearing and friction piles

The end-bearing piles transmit the loads through the pile tip to a suitable hard stratum, passing the soft soil stratum.

The ultimate load carrying capacity (Q_u) of the end bearing pile depends upon the bearing capacity of the hard stratum.

The ultimate load (Q_u) carries by the end bearing pile is equal to the load carried by the pile point (Q_p)



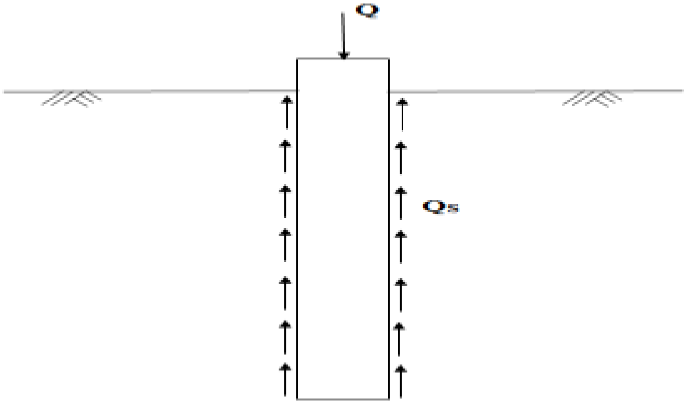
The friction piles are used when the hard stratum does not exist at a reasonable depth from the ground surface.

The friction piles do not reach the hard stratum.

The friction piles transfer the load through skin friction between the embedded surface of the pile and the surrounding soil.

The ultimate load (Q_u) carried by the friction pile is equal to the load transferred by skin friction (Q_s).

The friction piles are also known as the floating piles.



The combined end bearing and friction piles transfer the loads by a combination of end bearing at the bottom of the pile and friction along the surface of the pile shaft.

The ultimate load carried by the pile (Q_u) is equal to the sum of the load carried by the pile point (Q_p) and the load carried by the skin friction (Q_s).

$$\therefore \; Q_U = Q_P + Q_S$$

3). Classification based on method of installation

According to the method of installation (or) construction, the piles are classified as

a). Driven piles :

These piles are driven into the soil by applying blows of heavy hammer on their top

b). Driven and Cast-insitu piles

These piles are formed by driving a casing pipe into the soil. The casing pipe is later filled with concrete.

c). Bored and Cast-insitu piles

These piles are formed by excavating a hole into the ground and then filling it with concrete

d). Jacked piles

These piles are jacked into the soil by applying a downward force with the help of a hydraulic jack.

4). Classification based on usage

According to the usage the piles are classified as

a). Load bearing piles

These piles are used to transfer the loads of the structure to a suitable hard stratum either by end bearing or by skin friction or by both

b). Compaction piles

These piles are driven into the loose granular soils to increase the relative density. The bearing capacity of the soil is increased due to densification caused by vibration.

c). Tension piles

These piles are in tension. These piles are used to anchor down the structures subjected to hydrostatic uplift forces or overturning forces.

5). Classification based on displacement of soil

According to the volume of soil displaced during installation, the piles are classified as

a). Displacement piles

All driven piles are displacement piles. The soil is displaced laterally when the pile is driven into it. Precast concrete piles and closed end pipe piles are highly displacement piles. Steel H-piles are low displacement piles.

b). Non – displacement piles

The bored piles are non-displacement piles. The soil is not subjected to displacement during the drilling of bore hole.

2). Dynamic formulae

The ultimate load carrying capacity of a driven pile can be estimated from the Dynamic formulae. The ultimate carrying capacity of a driven pile in certain types of soils is related to the resistance against the penetration developed during the driving operation.

The dynamic formulae are based on the assumption that the kinetic energy delivered by the hammer during driving operation is equal to the work done on the pile.

3). In-situ penetration tests

The ultimate load capacity of a pile can be determined from the results of in-situ standard penetration test.

Empirical formulae are used to determine the point resistance (Q_P) and the shaft resistance (Q_P) from the standard penetration number (N). Cone penetration test is also used to estimate the pile capacity.

4). Pile load test

The pile load test is most reliable method to determine the ultimate load capacity of a pile. Tn pile load test, the test pile is driven and loaded up to failure.

The pile capacity is related to either the load at failure or the load at which the settlement do not exceed the permissible limits.

Static Methods for Driven Pile in Sand

According to the static methods

The ultimate load carrying capacity (Q_U) of a single pile driven into sand is given by

$Q_U = Q_P + Q_S$

Here

Q_U = The ultimate failure load of pile foundation

Q_P = The tip resistance of pile = $q_P A_P$

Q_S = The shaft resistance developed due to friction between the soil and the pile = $f_S A_S$

In the above equation

q_P = The ultimate bearing capacity of the soil at the pile tip

A_P = The area of the pile tip

f_S = The average unit skin friction between the sand and the pile surface and

A_S = The effective surface area of the pile in contact with the sand

Here

$\bar{q}$ = The effective vertical pressure at the pile tip.

B = Pile tip width or diameter

γ = The unit weight of soil in the zone of the pile tip

N_q and N_γ = The bearing capacity factors for deep foundation

In driven piles the second term "$0.4\,\gamma\,B\,N_\gamma$" is small and hence it is neglected.

Thus for driven piles

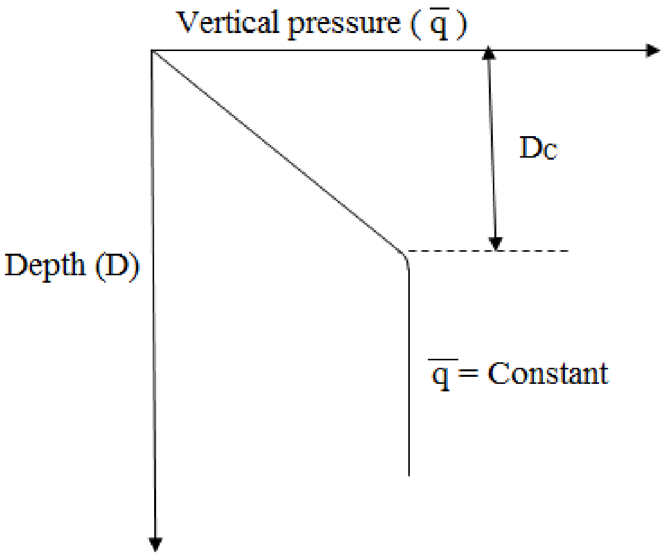
$$q_P = \bar{q}\,N_q$$

In case of driven piles, the effective vertical pressure ($\bar{q}$) at the tip of the pile will increase with the depth (D) only up to certain depth known as the critical depth (D_C). After the critical depth the effective vertical pressure remains constant.

The critical depth (D_C) depends on the angle of shearing resistance of the soil (ϕ') and the width of the pile tip (B).

The critical depth (D_C) is taken as “10 B” in loose sand and “20 B” in dense sand.

N_q is the bearing capacity factor



$\therefore$The tip resistance of pile = $Q_P = \bar{q}\, N_q\, A_P$

b). Method of determination of “Q_S”

The shaft resistance due to friction (Q_S) on pile foundation is given by

$Q_S = f_S \, A_S$

Here

f_S = The unit skin friction between the sand and the pile surface

A_S = The surface area of the pile = P x D

P = The perimeter of the pile and

D = The depth of pile

The unit skin friction (f_S) for a straight – sided pile depends upon the soil pressure acting normal to the pile surface and the coefficient of friction between the sand and the pile material.

The soil pressure acting normal to the vertical straight – sided pile surface is the horizontal pressure (σ_h)

The values of ‘K’ and ‘δ’ are as given in the table

Pile Material	δ	K (Loose Sand)	K (Dense Sand)
Steel	20^0	0.5	1.0
Concrete	$0.75\ \phi$	1.0	2.0
Timber	$0.67\ \phi$	1.5	4.0

Here

K_i = The earth pressure co-efficient of i^{th} layer

$(\overline{\sigma_V})_i$ = The effective vertical pressure in the i^{th} layer

$\text{Tan}\,\delta_i$ = The coefficient of friction in the i^{th} layer

$(A_S)_i$ = The surface area of the pile in the i^{th} layer

Now, the ultimate bearing capacity (Q_U) of the pile foundation

a). In uniform soil is given by

$$Q_U = \bar{q}\, N_q\, A_P + K\, \frac{1}{2}\, \gamma\, D\, \tan\delta\, P\, D$$

b), In layered soil deposit

$$Q_U = \bar{q}\, N_q\, A_P + \sum_{i=1}^{n} K_i\, (\overline{\sigma_V})_i\, \text{Tan}\,\delta_i\, (A_S)_i$$

Static Methods for Driven Pile in clay

According to the static methods

The ultimate load carrying capacity (Q_U) of a single pile driven into clay is given by

$Q_U = Q_P + Q_S$

Here

Q_U = The ultimate failure load of pile foundation

Q_P = The tip resistance of pile $= q_P A_P$

q_P = The gross ultimate bearing capacity of the soil at the pile tip

A_P = The area of the pile tip

In saturated clay

$$q_p = c\,N_c + \bar{q}\,N_q$$

Here

c = The cohesion of soil at the pile tip

$\bar{q}$ = The effective vertical pressure at the pile tip

N_q and N_q = The bearing capacity factors for deep foundation

$$\therefore \; Q_P = \left(c\,N_c + \bar{q}\,N_q\right) A_P$$

In pure cohesive soil $\phi = 0$ and $N_q = 1.0$

$$\therefore \; Q_P = \left(c\,N_c + \bar{q}\right) A_P$$

The value of 'N_C' depends upon the "$\frac{D}{B}$" ratio and it varies from 6 to 9. The value of $N_C = 9.0$ is generally used for the pile.

Q_S = The shaft resistance due to friction = $c_a\ A_S$

Here

c_a = the unit adhesion or the unit skin friction developed between the clay and pile = α c

α = the adhesion factor and

c = The average unit cohesion along the pile length

For normally consolidated clays $\alpha = 1.0$

For over consolidated clays $\alpha = 0.3$

Static Methods for Bored Pile in Sand

The bored piles are constructed by drilling a bore hole into the ground and filling it with concrete

According to the static methods

The ultimate load carrying capacity (Q_U) of a single bored pile in sandy soil is given by

a). In uniform soil is given by

$$Q_U = \bar{q}\ N_q\ A_P + K\ \frac{1}{2}\ \gamma\ D\ \text{Tan}\,\delta\ P\ D$$

b), In layered soil deposit

$$Q_U = \bar{q}\ N_q\ A_P + \sum_{i=1}^{n} K_i\ (\overline{\sigma_V})_i\ \text{Tan}\,\delta_i\ (A_S)_i$$

Here

K = The lateral earth pressure coefficient

$\overline{\sigma_V}$ = The effective vertical pressure and

Tan δ = The coefficient of friction between the sand and the pile materials

The value of 'K' is generally varies between o.3 and 0.75.

The average value of 0.5 is usually adopted.

The value of 'K' cam also be obtained from the following equation

$K = 1 - \text{Sin}\ \emptyset$

UNIT 04

EARTH SLOPE STABILITY:

Infinite and finite earth slopes – types of failures – factor of safety of infinite slopes – stability analysis by Swedish arc method, standard method of slices, Bishop‟s Simplified method – Taylor‟s Stability Number- Stability of slopes of earth dams under different conditions.

The sides of cuttings, the slopes of embankments constructed for roads, railways lines, canals etc and the slopes of earth dams constructed for storing water are examples of man made slopes. The figure shows some of the examples of man made earth slopes.

The earth slopes are further classified as

1). Infinite slopes and 2). Finite slopes.

The term infinite slope is used to designate a constant slope of infinite extent.

Slopes extending to infinity do not exist in nature.

However in practice if the height of the slope is very large, it may be considered as infinite slope.

A slope of limited extent, bounded by a base and a top surface is called a finite slope.

The examples of finite slopes are the inclined faces of embankments, earth dams, cuttings etc.

The cost of earth work would be minimum, if the earth slopes are made steepest.

However very steep slopes may not be stable.

The flat earth slopes may be stable.

But in flat earth slope the cost of earth work would increases.

Hence a compromise has to be made between the economy and safety and the earth slopes provided are neither too steep nor too flat.

The failure of a earth slope may lead to loss of life and property.

It is, therefore, essential to check the stability of the proposed earth slopes.

The **Geotechnical Engineer** should have a thorough knowledge of the various methods for checking the stability of slopes and their limitations.

Critical Surface of Failure of Soil Slope

The failure of a earth slope occurs when a large mass of soil slides along a plane or a curved surface involving a downward and outward movement of the soil mass away from the slopping surface.

The surface along which the soil mass slides when the failure of an earth slope occurs is known as **critical surface of failure.**

The sliding or slipping in a earth slope takes place mainly due to

1). The gravitational force

2). The force due to seepage water

3). Erosion of the surface of slope due to flowing water

4).The sudden lowering of water adjacent to a slope and

5). Forces due to earthquakes.

The forces which resist the failure of earth slope are shear strength of the soil and/or frictional force, depending on the soil being cohesive or cohesionless

The factors leading to the failure of earth slopes may be classified into two categories.

1). The factors which cause an increase in the shear stress in the soil slope

The shear stress in soil mass may increase due to weight of water causing saturation of soils, surcharge loads, seepage pressure or any other cause. The stresses are also increased due to steepening of slopes either by excavation or by natural erosion.

2). The factors which cause an decrease in the shear strength of the s

The loss of shear strength of soil may occur due to an increase in the water content, increase in pore water pressure, shock or cyclic loads, weathering or any other cause.

Most of natural slope failures occur in rainy season, as the presence of water causes both increase in the shear stress and decrease in shear strength of soil.

Basic Assumptions in the Stability Analysis of Earth Slopes

The following assumptions are generally made in stability analysis of earth slopes.

1). The soil mass is assumed as homogeneous.

2). The stress system is assumed to be two-dimensional. The stresses in the third direction (perpendicular to the section of the soil mass) are taken as zero.

3). It is assumed that Coulomb's equation for shear strength is applicable and the strength parameters **C** and Ø are known.

5). The conditions of plastic failure are assumed to be satisfied along the critical failure surface.

In the analysis of stability of earth slopes,

1). The resultant force of all the forces trying to cause the failure is determined.

2). An estimate is also made on the available shear strength trying to resist the failure.

The factor of safety of the earth slope is determined from the available resisting forces and the forces causing the failure.

DIFFERENT FACTORS OF SAFETY

In the stability analysis of earth slopes, the following factors of safety are normally used.

1). Factor of safety with respect to shear strength (F_s)

2). Factor of safety with respect to cohesion (F_c)

3). Factor of safety with respect to friction ($F_{\emptyset}$)

1). Factor of safety with respect to shear strength (F_s)

The factor of safety with respect to shear strength (F_s) is defined as the ratio of the maximum shear strength (**s**) to the average value of mobilized shear strength (τ_m).

Thus $F_s = \frac{s}{\tau_m}$ ------------ (1)

Here F_s = The factor of safety with respect to shear strength

s = The maximum shear strength and

τ_m = The mobilised shear strength (equal to applied shear stress)

In terms of cohesion intercept (C) and the angle of shear resistance ($\emptyset$)

The maximum shear strength = s = $C + \bar{\sigma} \tan \emptyset$ and

The mobilised shear strength = $\tau_m = C_m + \bar{\sigma} \tan \emptyset_m$

Here C_m = The mobilised cohesion and

$\emptyset_m$ = The mobilised angle of shear resistance and

$\bar{\sigma}$ = The effective pressure

$$\therefore \quad F_s = \frac{C + \bar{\sigma} \tan \emptyset}{C_m + \bar{\sigma} \tan \emptyset_m} \quad \text{----------------------} \ (2)$$

But $\frac{C}{C_m}$ = The factor of safety with respect to cohesion (F_c)

$\therefore F_s = F_c$ --------------- (7)

Similarly from equation (6) we get

$$\frac{\bar{\sigma} \tan \phi}{F_s} = \bar{\sigma} \tan \phi_m$$

$$\therefore \quad F_s = \frac{\bar{\sigma} \tan \phi}{\bar{\sigma} \tan \phi_m}$$

But $\frac{\bar{\sigma} \tan \phi}{\bar{\sigma} \tan \phi_m}$ = The factor of safety with respect to friction = F_ϕ

$\therefore F_s = F_\phi$ ------------------------ (8)

From equations (7) and (8) we get

$$F_s = F_c = F_\phi$$

Therefore in the stability analysis of earth slopes, generally the three factors of safety are taken as equal.

TYPES OF EARTH SLOPE FAILURES

The earth slope may have any one of the following failures.

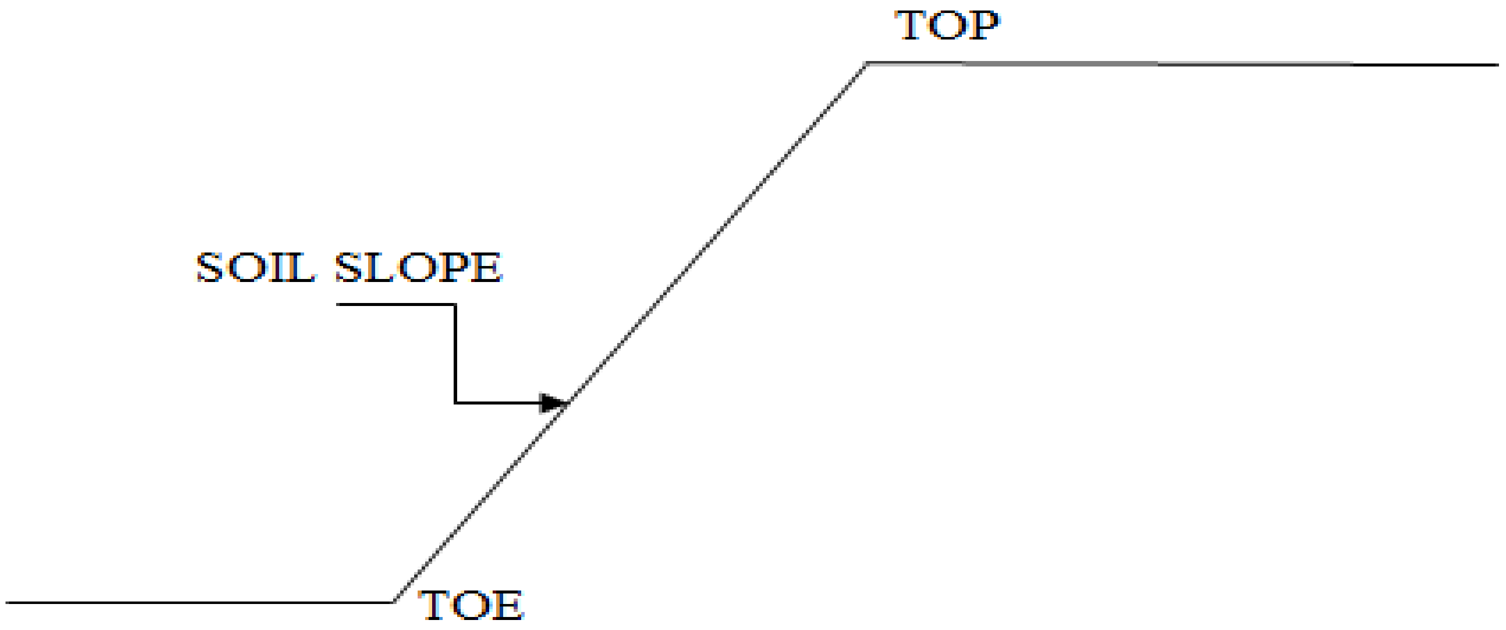
1). Rotational failure.

2). Translational failure   and

3). Compound failure

4). Wedge failure   and

5). Miscellaneous failures

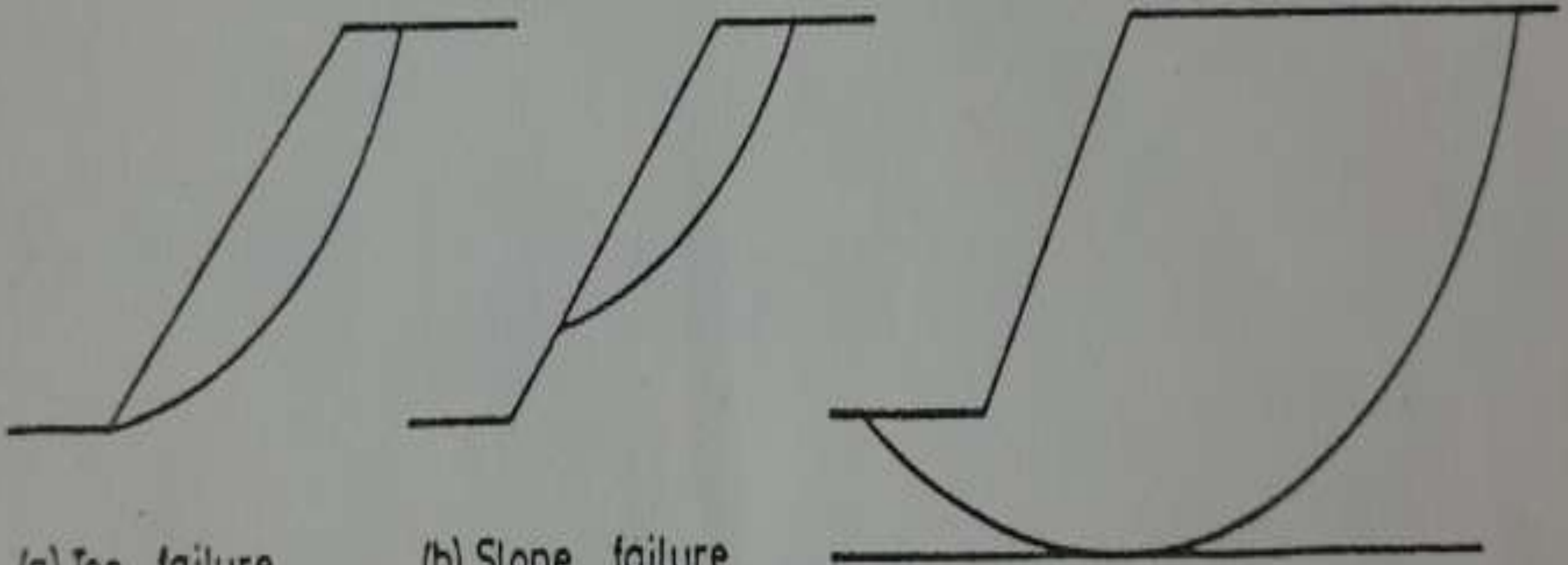

TOP
SOIL SLOPE
TOE

1). Rotational failure.

This type of failure occurs by rotation along a slip surface by downward and outward movement of the soil mass

The slip failure is generally circular for homogeneous soil conditions and non-circular in case of non-homogeneous soil conditions.

Rotational slip failures are further sub-divided into the following three types.



(a) Toe failure

(b) Slope failure

(c) Base failure

a). Toe failure, in which the failure occurs along the surface that passes through the toe as shown in figure

b). Slope failure, in which the failure occurs along the surface that intersects the slope above the toe as sown in figure.

c). Base failure, in which the failure surface passes below the toe as shown in figure.

2). Translational failure.

A constant earth slope of unlimited extent and having uniform soil properties at the same depth below the free surface is known as an infinite slope.

Translational failure occurs in an infinite slope along a long failure surface parallel to the slope as shown in figure.

The shape of the failure surface is influenced by the presence of any hard stratum at a shallow depth below the slope surface.

Translational failures may also occur along the slopes of layered materials.

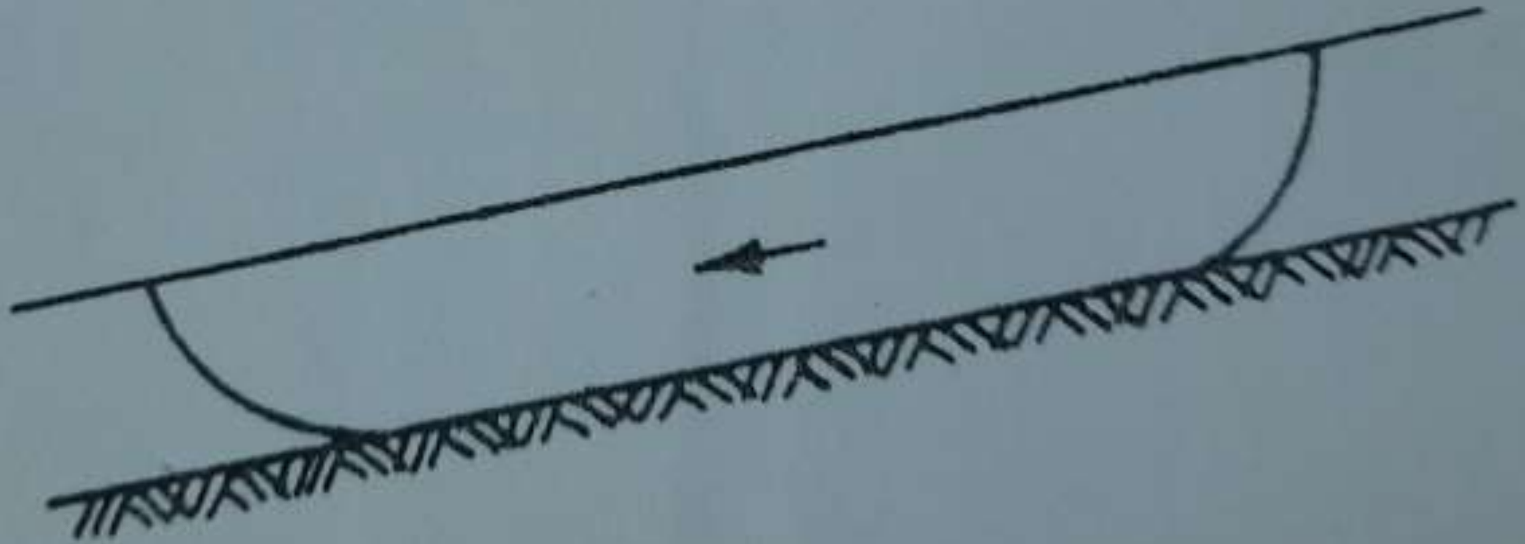


Fig. 18.3. Translational Failure.

3). Compound failure. The compound failure is a combination of the rotational failure and translational failure as shown in figure.

A compound failure surface is curved at the two ends and plane in the middle portion.

A compound failure generally occurs when a hard stratum exists at considerable depth below the toe.

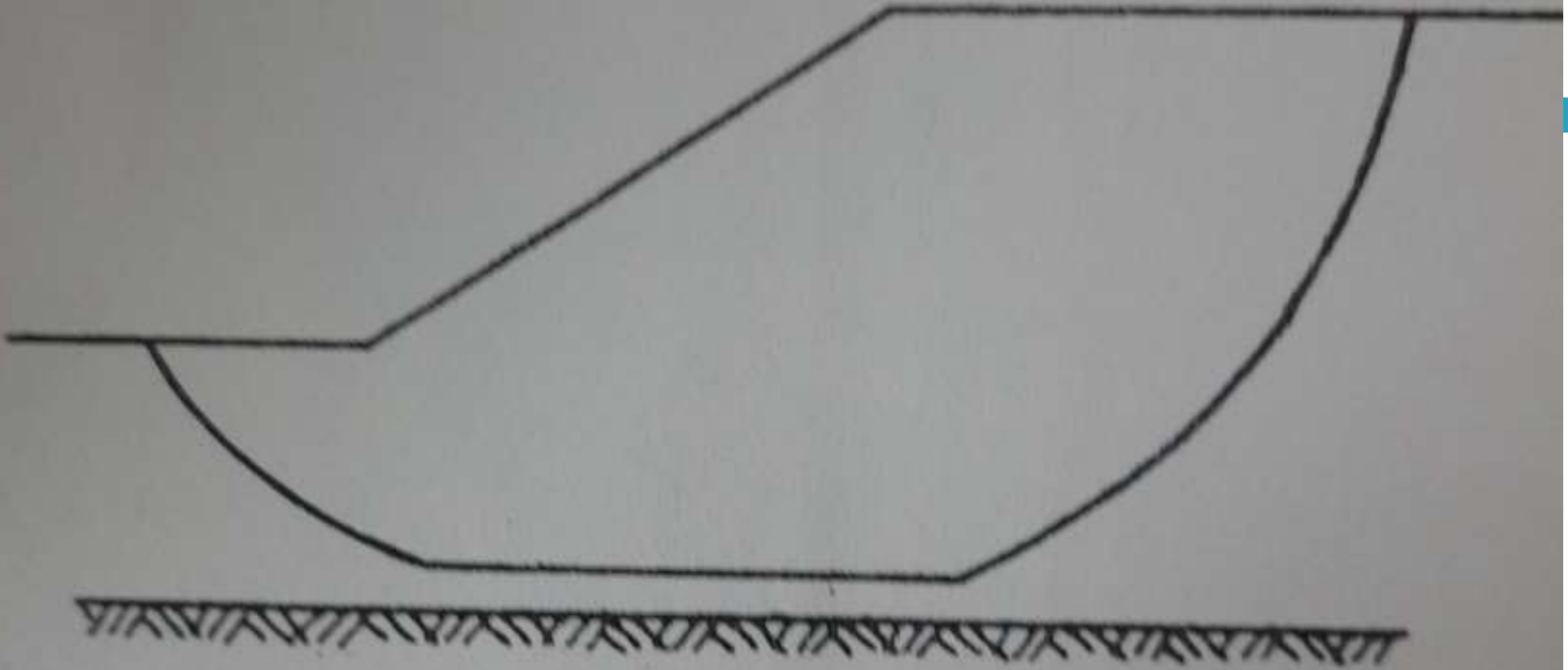


Fig. 18.4. Compound Failure.

4). Wedge failure (or) Plane failure

A failure along an inclined plane is known as plane failure or wedge failure or block failure.

A wedge failure is similar to translational failure in many respects.

However, unlike translational failure which occurs in an infinite slope, the wedge failure may occur even in a finite slope consisting of two different materials or in a homogeneous slope having cracks, fissures, joints or any other specific planes of weakness.

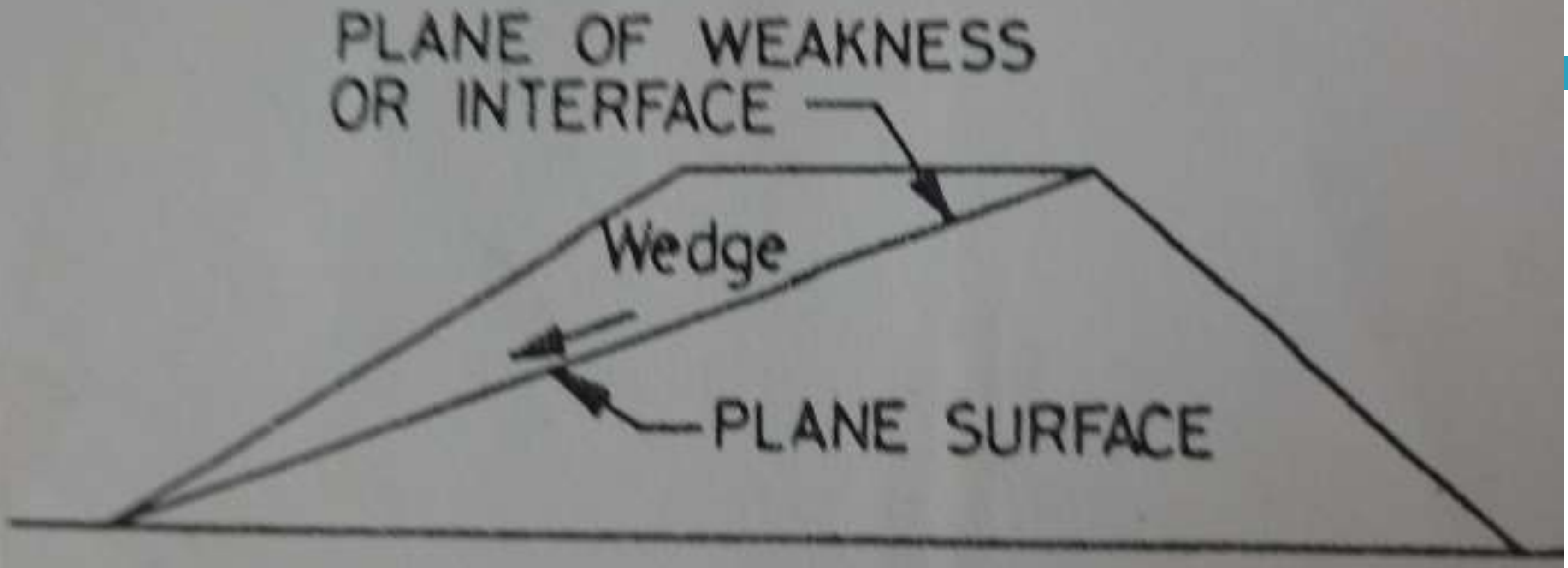


Fig. 18.5. Wedge Failure.

5). Miscellaneous failures.

In addition to above four types of failures, some complex types of failures in the form of spreads and flows may also occur.

Stability Analysis
of
An Infinite Earth Slope
of
Cohesionless Soil

The stability analysis of an infinite slope of cohesionless soil will depend upon

Whether the soil is dry or submerged or has steady seepage, as explained below.