FOUNDATION ENGINEERING

UNIT I
SITE INVESTIGATION AND SELECTION OF FOUNDATION

Methods of exploration – boring technology – Depth of boring – Spacing of bore hole – Sampling – Methods -Thick, Thin wall samplers, Stationery piston sampler – Penetration tests - Bore log report – Data interpretation.

SITE INVESTIGATION AND SELECTION OF FOUNDATION

- Methods Of Exploration
- Boring Technology
- Depth Of Boring
- Spacing Of Bore Hole
- Sampling & Methods
- Penetration Tests
- Bore Log Report
- Data Interpretation.

WORK SEQUENCE

1. Site Investigation

To obtain necessary information about the soil and hydrological conditions at the site and to know the engineering properties of the soil

2. Site Reconnaissance

An visual inspection of the site and study of topographical features

3. Site Exploration

To provide reliable, specific and detailed information about the soil and ground water conditions at the site

SITE INVESTIGATION

- To obtain necessary information about the soil and hydrological conditions at the site and to know the engineering properties of the soil.
- The process of determining the layers of natural soil deposits that will underlie a proposed structure and their physical properties is generally referred to as site investigation.
- The field and laboratory studies carried out for obtaining the necessary information about the sub soil characteristics including the position of ground water table are termed as soil exploration.

Site investigation consists of:

- Preliminary survey
- Detailed investigation

Preliminary survey consists of:

- ✓ Site visit
- ✓ Local topography
- ✓ Drainage conditions
- ✓ Natural features like streams , lakes, wells etc., near by
- ✓ Adjacent constructions if any

Detailed site investigation consists of :

- Making of bore holes.
- Taking soil samples at different depths.
- Carrying out in-situ tests like penetration test, Plate load test etc.,
- Testing of soil samples in the laboratory for physical and engineering properties.

Objective of Soil Investigation

To obtain

- ✓ The sequence and the thickness of various soil layers.
- ✓ The physical and engineering properties of each of the soil layers.
- ✓ Location of water table.

Purpose of Soil Investigation

To obtain the properties of soils required for:

- ✓ Selection of type of foundation
- ✓ Design of foundation

CLASSIFICATION OF EXPLORATION

General Exploration

- ✓ To get an approximate picture of the sub-soil conditions at a relatively low cost.
- ✓ It is opted for minor & routine engineering works.

Detailed Exploration

- ✓ It is followed as a supplement to general exploration which gives detailed information's such as soil properties, ground water conditions.
- ✓ It is opted for large engineering works, heavy loads & costly foundations are involved.

METHODS OF SITE EXPLORATION

1. Open excavations
2. Borings
3. Sub-surface soundings
4. Geophysical methods

OPEN EXCAVATIONS

- Test pits and trenches can be used for all types of soils
- Cost of open excavations increased rapidly with depth
- This method is ideal for shallow depth i.e. up to 3 metres

BORING METHODS

Boring has several methods to explore the soil conditions. They are,

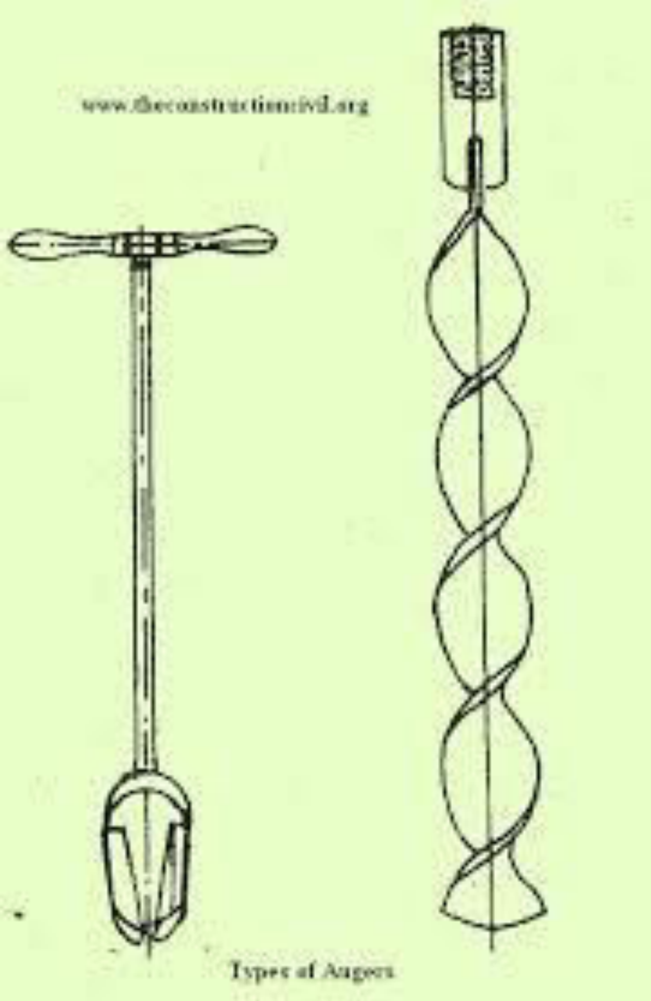
1. Auger boring
2. Auger and shell boring
3. Wash boring
4. Percussion boring
5. Rotary boring

AUGER BORING

- Augers are used in soft and cohesive soils
- Hand augers are used for depth up to 6 metres
- Mechanical augers are used for greater depths
- Recovered soil samples are badly disturbed and so they are useful for identification purpose only
- Auger boring is suitable for highway explorations at shallow depth

AUGER & SHELL BORING

- This method of boring is suitable for soft to stiff clays and sandy soils
- Augers has shell with cutting edge on teeth at the lower end can be used for hard clays
- Hand operated rigs are used for depths up to 25 m and the mechanised rigs up to 50 m.

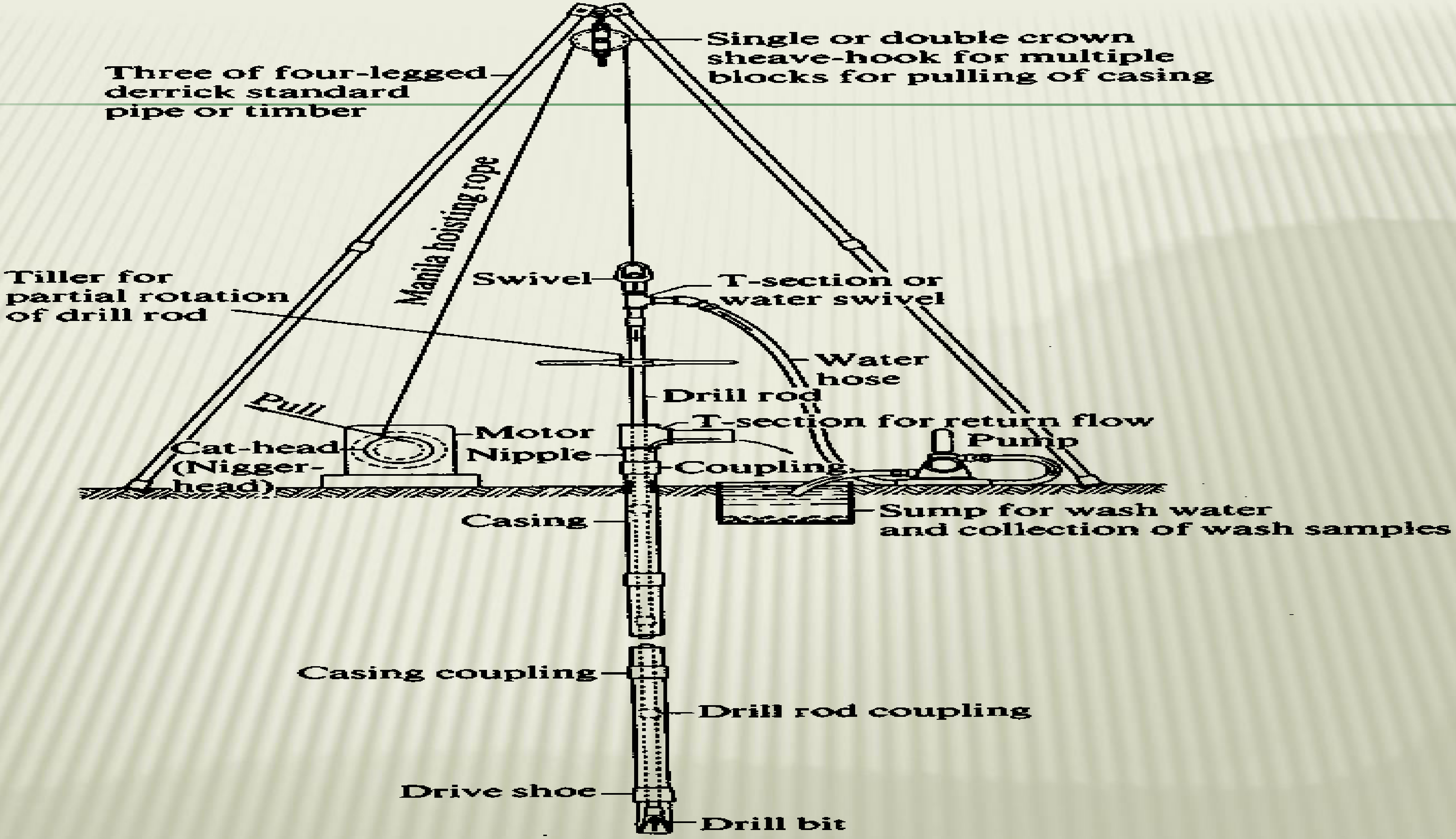


WASH BORING

- It is a fast and simple method of boring for all types of soils except rocks

WORKING PRINCIPLE:

1. Driving a casing through which a hollow drill rod with a sharp chisel or chopping bit at the lower end
2. Water is forced under pressure through the drill rod which is alternatively raised, dropped and rotated.
3. Chopping and jetting action of the bit and water disintegrates the soil
4. From which we can get soil-water slurry through the annular space b/w the drill rod & the casing
5. We can guess the soil stratification from the rate of progress and the colour of wash water


Single or double crown
sheave-hook for multiple
blocks for pulling of casing
Three of four-legged
derrick standard
pipe or timber
Manila hoisting rope
Tiller for
partial rotation
of drill rod
Swivel
T-section or
water swivel
Water
hose
Drill rod
Pull
T-section for return flow
Motor
Pump
Cat-head
(Nigger-
head)
Nipple
Coupling
Casing
Sump for wash water
and collection of wash samples
Casing coupling
Drill rod coupling
Drive shoe
Drill bit

PERCUSSION BORING

- ✓ This method is suitable for soil & rock formations
- ✓ Repeated blows of heavy chisel or chopping bit broke the rocks.
- ✓ Water is added to the hole during the boring process
- ✓ From which we can collect the soil sample

ROTARY BORINGS

- It is a very fast method of boring suitable for both soils and rocks
- A drill bit is fixed at the bottom of the drill rod and it is rotated by a chuck and is always kept in firm contact with the bottom of the hole
- Here we use bentonite solution along with water to soften the rocks
- The mud returning upwards collected for testing
- So it is called Mud rotary drilling

Rotary Drilling Rig

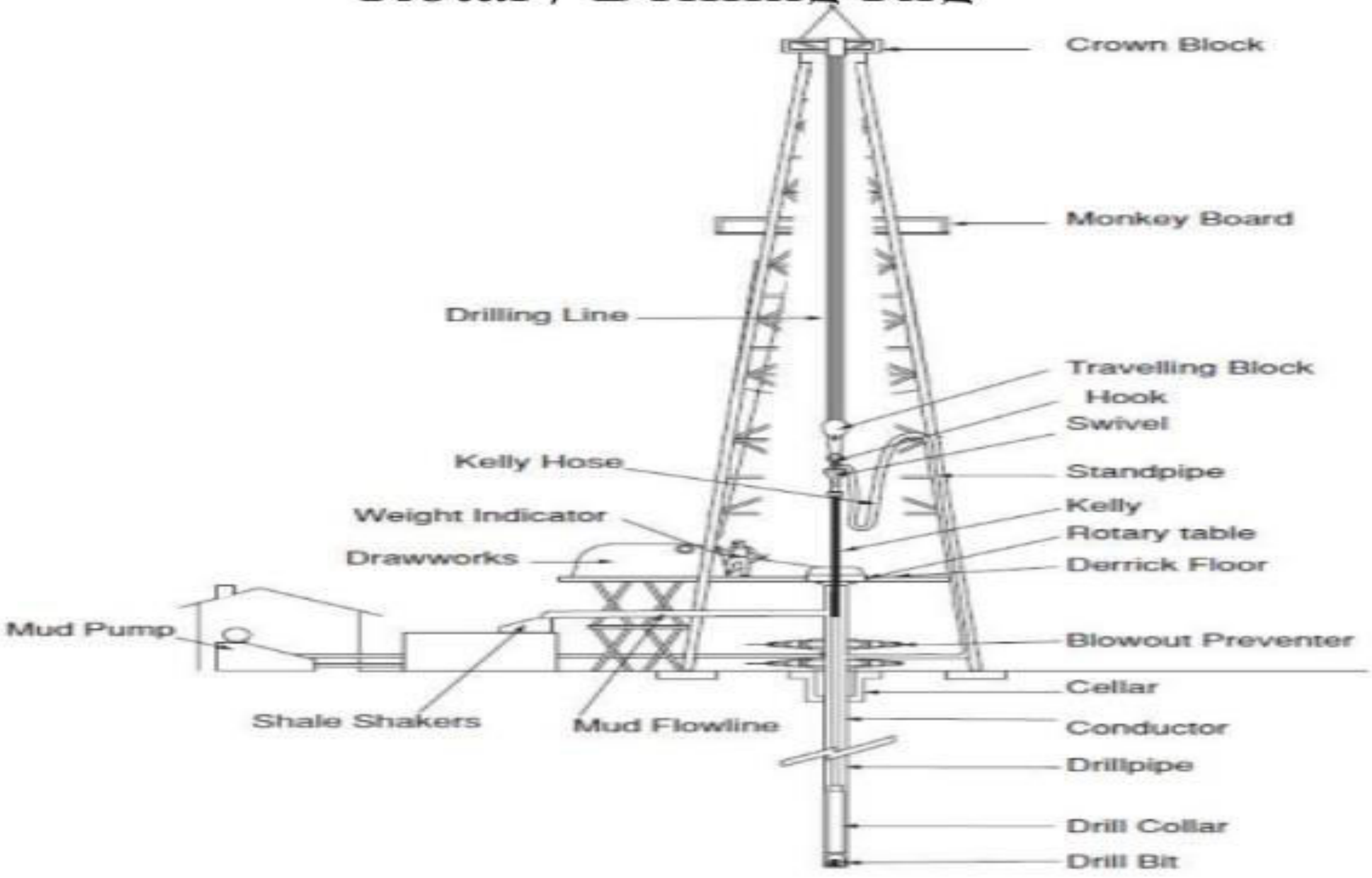


Figure 1 Rotary Drilling Rig

SUB-SURFACE SOUNDINGS

- ✓ This method is generally used for determining the consistency of cohesive soils or relative density of cohesion less soils

COMMON PROCEDURE

1. A rod encased in a sleeve is forced into the soil and the resistance to penetration or with drawl is observed.
2. Variations in this resistance shows dissimilar soil layers

ADVANTAGES

- ✓ faster and cheaper than boring
- ✓ In erratic soil conditions soundings can be used

LIMITATIONS

- ✓ Sounding gives no idea about the settlement characteristics of the soil
- ✓ Soundings alone cannot provide sufficient data for the final design

METHODS OF SUB-SURFAFCE SOUNDING

There are two common types of Sub-Surface Soundings. They are,

1. Standard Penetration Test [SPT]
2. Cone Penetration Test [CPT] or Dutch Cone Test

STANDARD PENETRATION TEST

Concept:

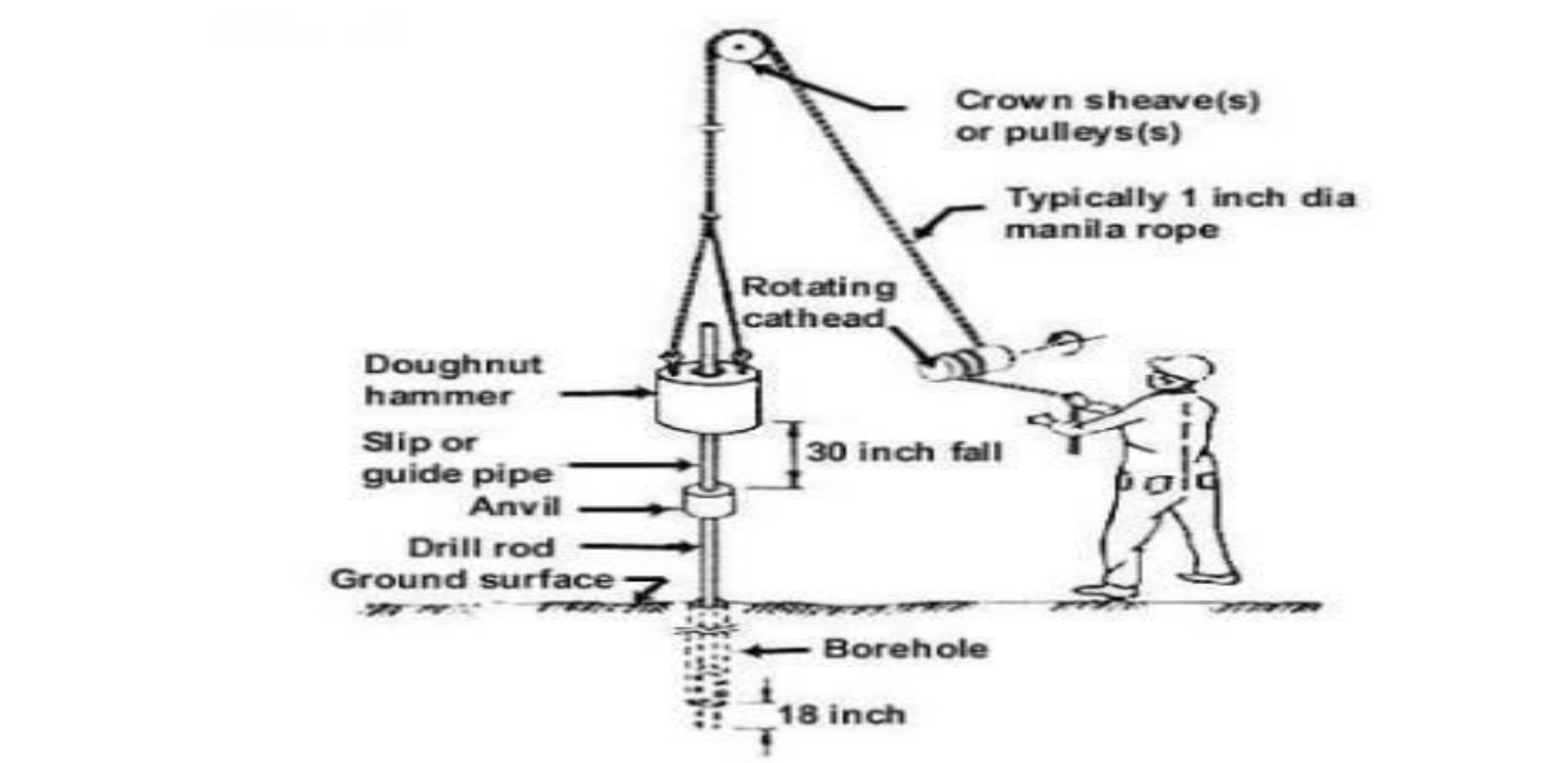
- SPT is a common in situ testing method used to determine the geotechnical engineering properties of subsurface soils.
- SPT are carried out in borehole.
- The test will measure the resistance of the soil strata to the penetration undergone.

STANDARD PENETRATION TEST

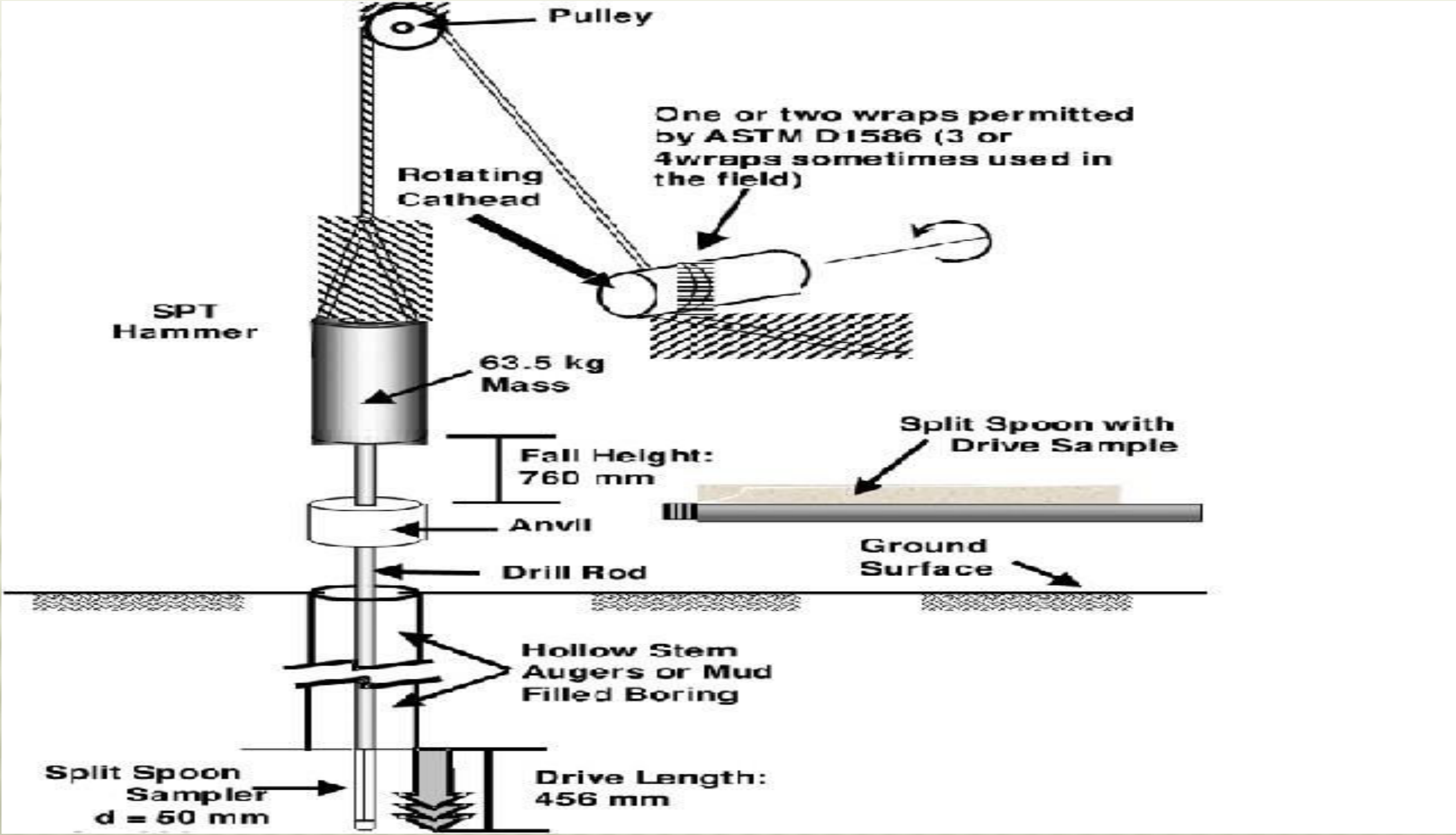
- A penetration emphirical correlation is derived between the soil properties and the penetration resistance.
- The test is extremely useful for determining the relative density and the angle of shearing resistance of cohesion less soils.
- It can also be used to determine the unconfined compressive strength of cohesive soils.

Tools for Standard Penetration Test

- Standard Split Spoon Sampler
- Drop Hammer weighing 63.5kg
- Guiding rod
- Drilling Rig.
- Driving head (anvil).

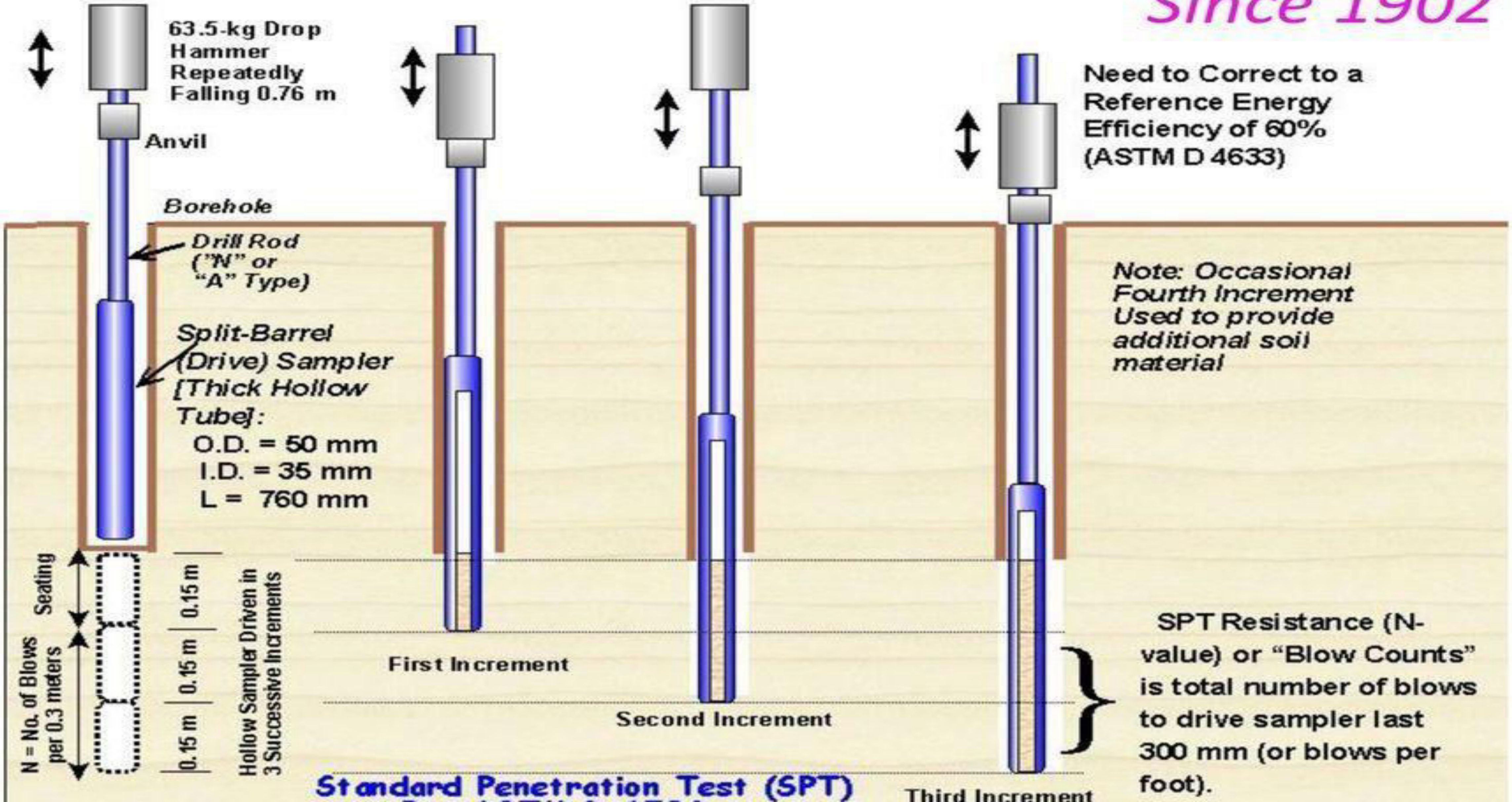


Crown sheave(s)
or pulleys(s)
Typically 1 inch dia
manila rope
Rotating
cathead
Doughnut
hammer
30 inch fall
Slip or
guide pipe
Anvil
Drill rod
Ground surface
Borehole
18 inch


Pulley
One or two wraps permitted by ASTM D1586 (3 or 4wraps sometimes used in the field)
Rotating Cathead
SPT Hammer
63.5 kg Mass
Split Spoon with Drive Sample
Fall Height: 760 mm
Anvil
Ground Surface
Drill Rod
Hollow Stem Augers or Mud Filled Boring
Split Spoon Sampler d = 50 mm
Drive Length: 456 mm

Standard Penetration Test (SPT)

Since 1902



Procedure for Standard Penetration Test

- The test is conducted in a bore hole by means of a standard split spoon sampler.
- Once the drilling is done to the desired depth, the drilling tool is removed and the sampler is placed inside the bore hole.
- By means of a drop hammer of 63.5kg mass falling through a height of 750mm at the rate of 30 blows per minute, the sampler is driven into the soil.

Procedure for Standard Penetration Test

- The number of blows of hammer required to drive a depth of 150 mm is counted.
- Further it is driven by 150 mm and the blows are counted.
- Similarly, the sampler is once again further driven by 150 mm and the number of blows recorded.
- The number of blows recorded for the first 150 mm not taken into consideration.
- The number of blows recorded for last two 150 mm intervals are added to give the **standard penetration number (N)**.

- N = No: of blows required for 150mm penetration beyond seating drive of 150mm.
- If the number of blows for 150mm drive exceeds 50, it is taken as refusal and the test is discontinued.
- The standard penetration number is corrected for **dilatancy correction** and **overburden correction**.
- Before the SPT values are used in empirical correlations and in design charts, the field 'N' value have to be corrected as per IS 2131 – 1981.

Dilatancy Correction

- Silty fine sands and fine sands below the water table develop pore water pressure which is not easily dissipated.
- The pore pressure increases the resistance of the soil and hence the penetration number (N).
- Terzaghi and Peck (1967) recommend the following correction in the case of silty fine sands when the observed value is N exceeds 15.

$$N_e = 15 + \frac{1}{2}(N - 15)$$

Where

Ne = Corrected value of overburden effect

N = actual values of blows

Overburden Pressure Correction

- From several investigations, it is proven that the penetration resistance or the value of **N** is dependent on the overburden pressure.
- If there are two granular soils with relative density same, higher ‘N’ value will be shown by the soil with higher confining pressure.
- With the increase in the depth of the soil, the confining pressure also increases. So the value of ‘N’ at shallow depth and larger depths are underestimated and overestimated respectively.

CORRECTION FOR OVERBURDEN PRESSURE

1. For p_0 <= 75 kPa

$$N' = \frac{4N}{(1+0.04p_0)}$$

2. For p_0 > 75 kPa

$$N' = \frac{4N}{(3.25+0.01p_0)}$$

Where

- N' = corrected N value
- N = observed N-value
- P_0 = over burden pressure, (kPa) = γ x D
- D = depth of testing (m)
- γ = unit weight of soil at the time of testing

Precautions taken for Standard Penetration Test

- Split spoon sampler must be in good condition.
- The cutting shoe must be free from wear and tear.
- The height of fall must be 750mm. Any change from this will affect the 'N' value.
- The drill rods used must be in standard condition. Bent drill rods are not used.
- Before conducting the test, the bottom of the borehole must be cleaned.

Advantages of Standard Penetration Test

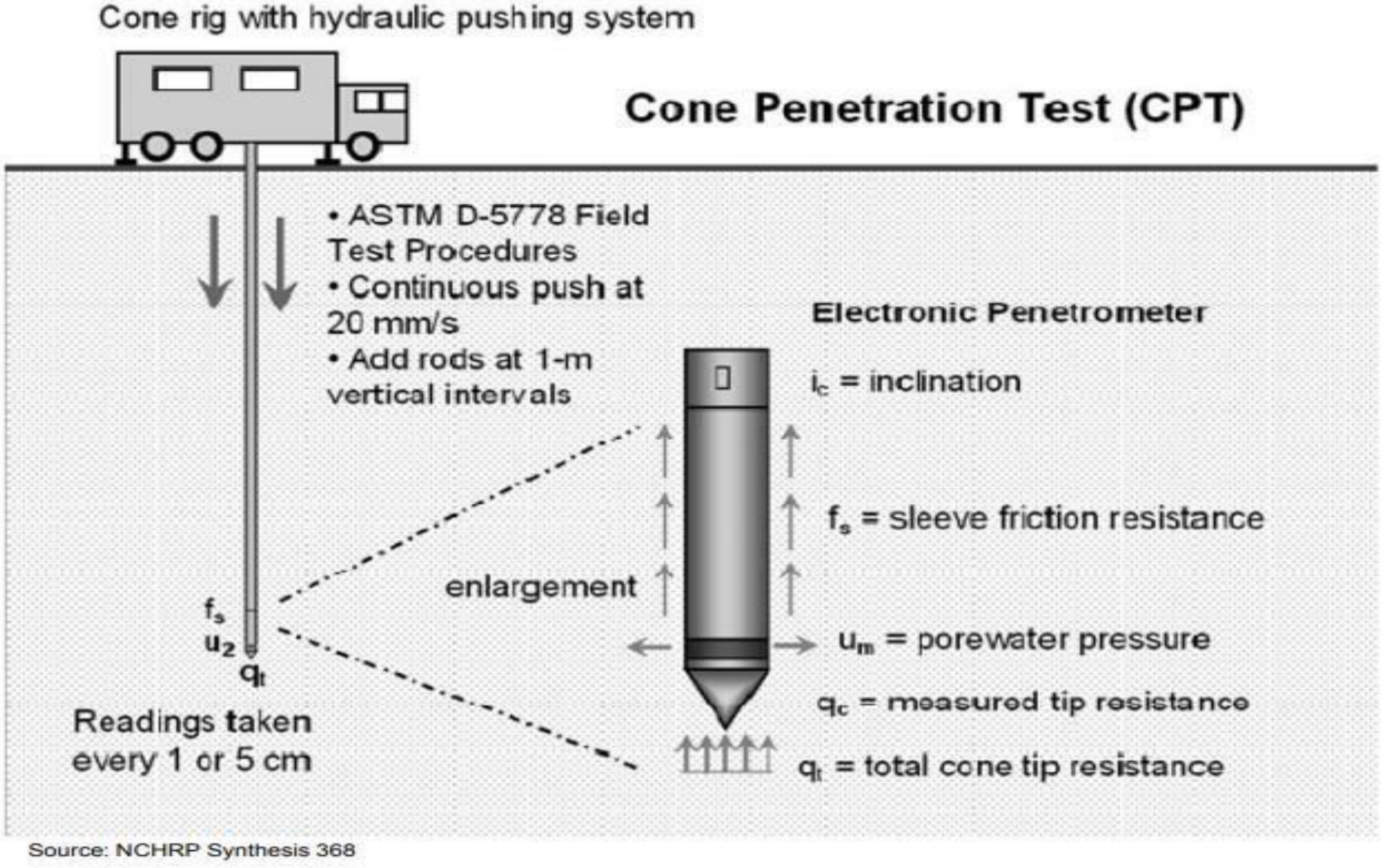
- The test is simple and economical.
- The test provides representative samples for visual inspection, classification tests and for moisture content.
- Actual soil behaviour is obtained through SPT values.
- The method helps to penetrate dense layers and fills.
- Test can be applied for variety of soil conditions.

Disadvantages of Standard Penetration Test

- The results will vary due to any mechanical or operator variability or drilling disturbances.
- Test is costly and time consuming.
- The samples retrieved for testing is disturbed.
- The test results from SPT cannot be reproduced.
- The application of SPT in gravels, cobbles and cohesive soils are limited.

Standard Cone penetration test (SCPT)

The cone penetration test has become Internationally one of the most widely used and accepted test methods for determining Geotechnical soil properties.


Cone rig with hydraulic pushing system
Cone Penetration Test (CPT)
• ASTM D-5778 Field Test Procedures
• Continuous push at 20 mm/s
• Add rods at 1-m vertical intervals
Electronic Penetrometer
i_c = inclination
f_s = sleeve friction resistance
enlargement
f_s
u_2
q_t
u_m = porewater pressure
q_c = measured tip resistance
Readings taken every 1 or 5 cm
q_t = total cone tip resistance
Source: NCHRP Synthesis 368

Cone penetration test (CPT)

Apparatus

- Steel cone
- Friction jacket
- Sounding rods
- Sounding tubes/mantle tubes
- Driving and measuring instrument

Capacity of equipment available

- 3 ton
- 10 ton
- 20 ton

Cone Penetration Test (CPT)

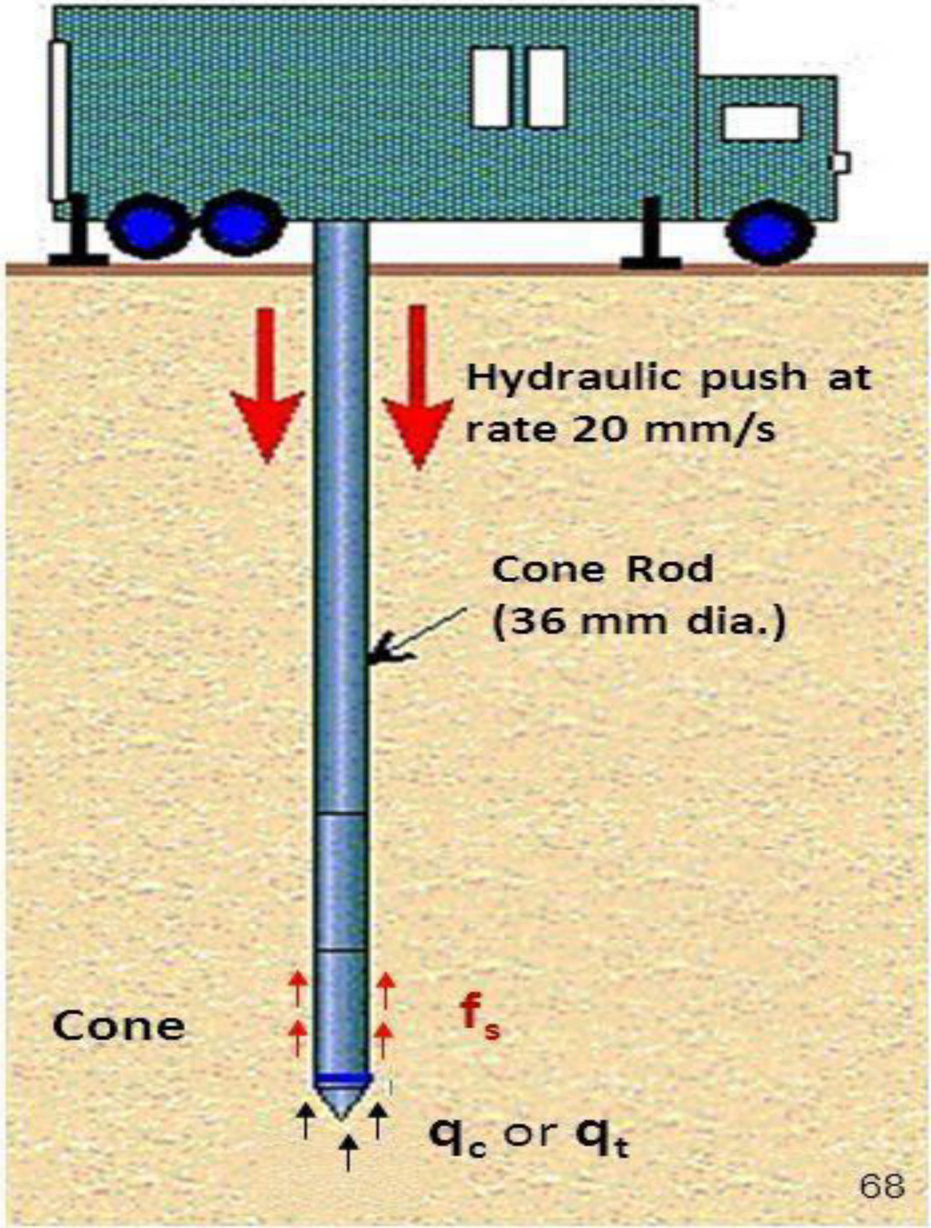
Definition

- called also "Dutch cone test“ or “Static Penetration test”.
- The test method consists of pushing an instrumented cone, with the tip facing down, into the ground at a slow controlled rate.
- Cone: 60 degree apex cone, Dia = 36 mm.

Measures

- Cone or Tip resistance (q_c) or (q_t)
- Sleeve friction (f_s)
- Water Pore pressure (u_b)
- Other variables e.g. Shear wave velocity (v_s)

$$\text{Friction Ratio, } F_r = \frac{f_s}{q_c}$$



CONE PENETRATION TEST [CPT]

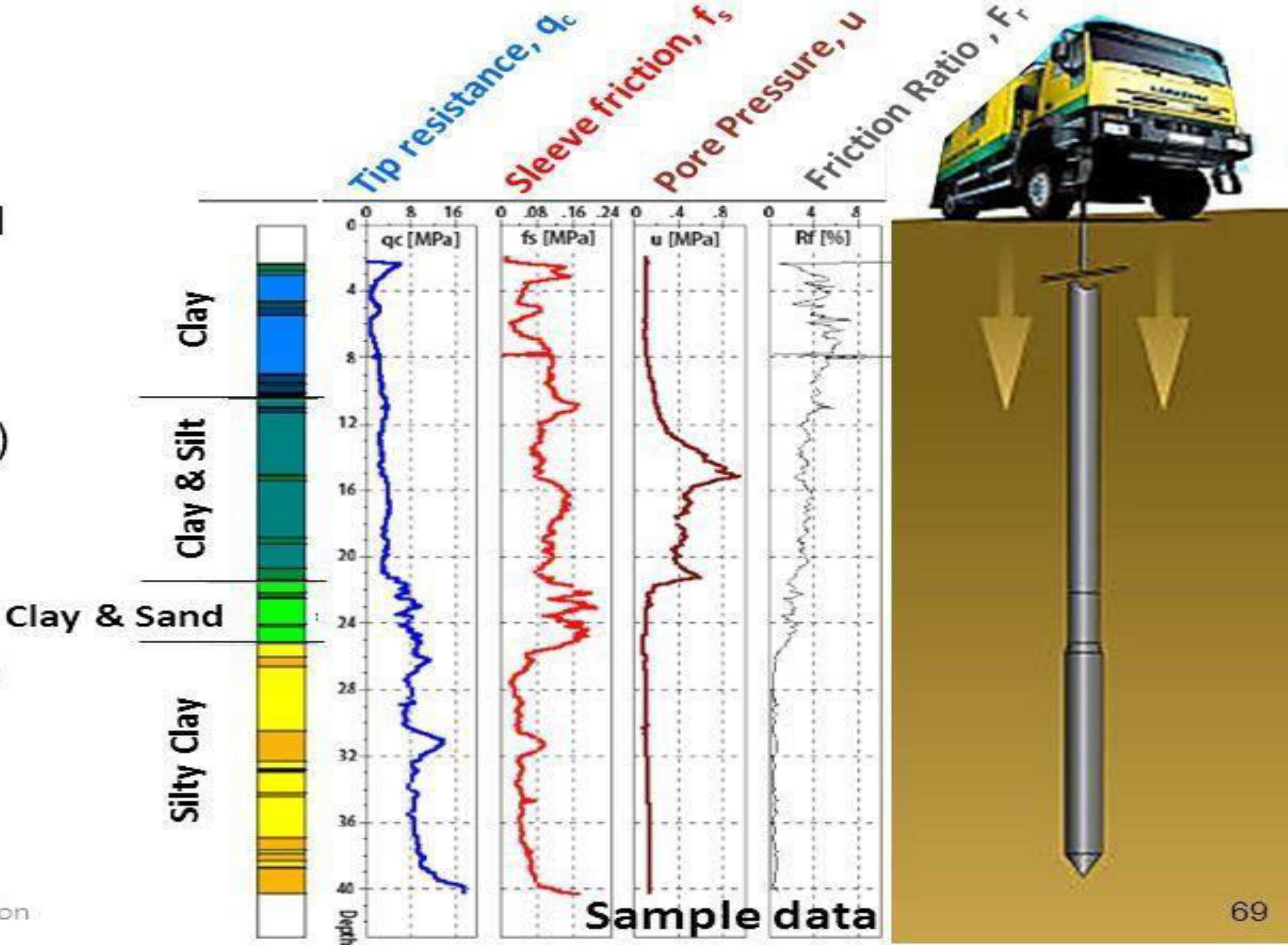
PROCEDURE

1. The test method consists of pushing an instrumented cone, with the tip facing down, Into the ground at a controlled steady rate
2. A cone with base of 3.6 cm in diameter (10 sq.cm) and an angle of 60 degree at the vortex.
3. To find out the cone resistance, the cone alone is first forced down for a distance of 8cm and the maximum value of resistance is recorded.
4. Cone resistance q_c (kg/sq.cm) is approximately equal to 10 times the penetration resistance N.
5. This test is very useful in finding bearing capacity of pits in cohesion less soil

Cone Penetration Test (CPT)

Applications:

- Soil profile (stratigraphy): soil type identification
- Estimation of geotechnical parameters (strength, compressibility, permeability)
- Evaluation of groundwater conditions (pore pressure)
- Geo-environmental: distribution and composition of contaminants



Use of CPT

- CPT are conducted to measure and evaluate characteristics of certain soils (soft sensitive silts and clays and some coarse cohesionless soils) such as:

  i) Stratification

  ii) Soil type

  iii) Relative soil density and in-situ stress conditions

  iv) Shear strength parameters

GEO-PHYSICAL METHODS

- Boring and test pits provide definite results but they are time consuming and expensive and Subsurface conditions are known only at the bore or test pit location
- So we can use geo physical methods to provide thorough coverage of the entire area.
- There are two methods of geophysical exploration. They are,

  1. Seismic or Refraction method
  2. Electrical Resistivity method

SEISMIC OR REFRACTION METHOD

WORKING PRINCIPLE

- ✓ Elastic shock waves travel at different velocities in different materials.
- ✓ Shock waves are generated at a point on the ground surface, using a sledge hammer.
- ✓ These waves travel deep into the ground and get refracted at the interface of two different materials and to the ground surface.
- ✓ The time of arrival of these waves at different locations on the ground surface are recorded by geophones, which pick up the refracted waves.
- ✓ The geophones convert the ground vibrations into electrical impulses and transmit them to a recording apparatus.
- ✓ When the distance between the vibration source and the geophone is short, the arrival time will be that of a direct wave.
- ✓ When the distance exceeds a certain value, the refracted wave will be the first to be detected by the geophone.

SEISMIC OR REFRACTION METHOD

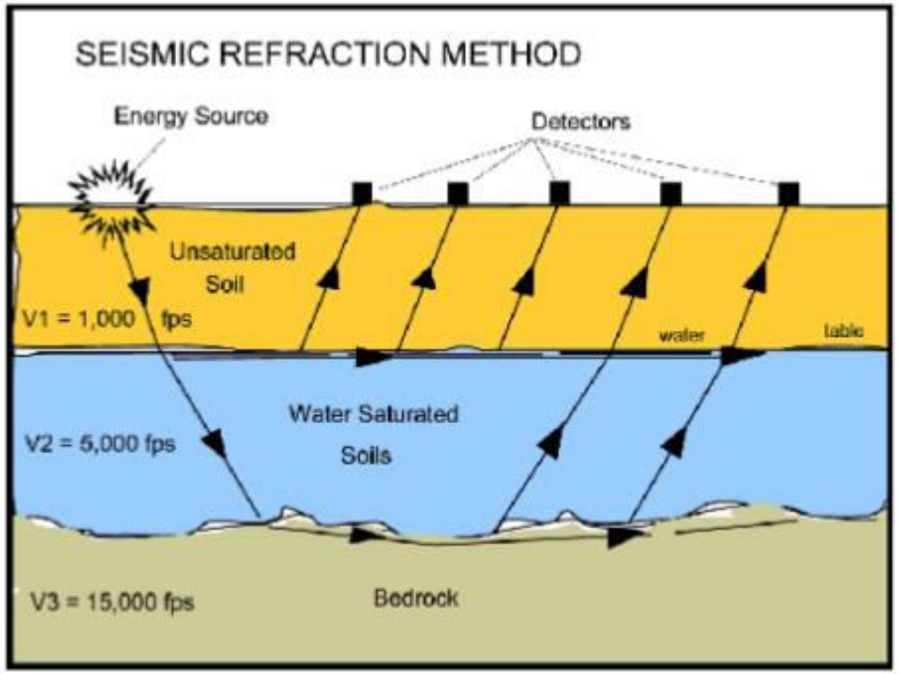


Fig. seismic refraction method

ELECTRICAL RESISTIVITY METHOD

WORKING PRINCIPLE

1. Four electrodes, usually in the form of metal spikes, are driven into the ground at the same spacing
2. The two outer electrodes are known as current electrodes, and the two inner electrodes are known as potential electrodes
3. A direct current (DC) of 50-100 milli amperes (mA) is applied between the outer electrodes, and the voltage drop or the potential difference between the inner electrodes is measured using a potentiometer
4. The mean resistivity of the soil up to a depth of D cm below ground surface is obtained by,

$$\rho = \frac{2\pi DV}{I}$$

where ,

D = is the distance b/w electrodes in centimeters (cm),

V = the voltage drop between inner electrodes in volts (V)

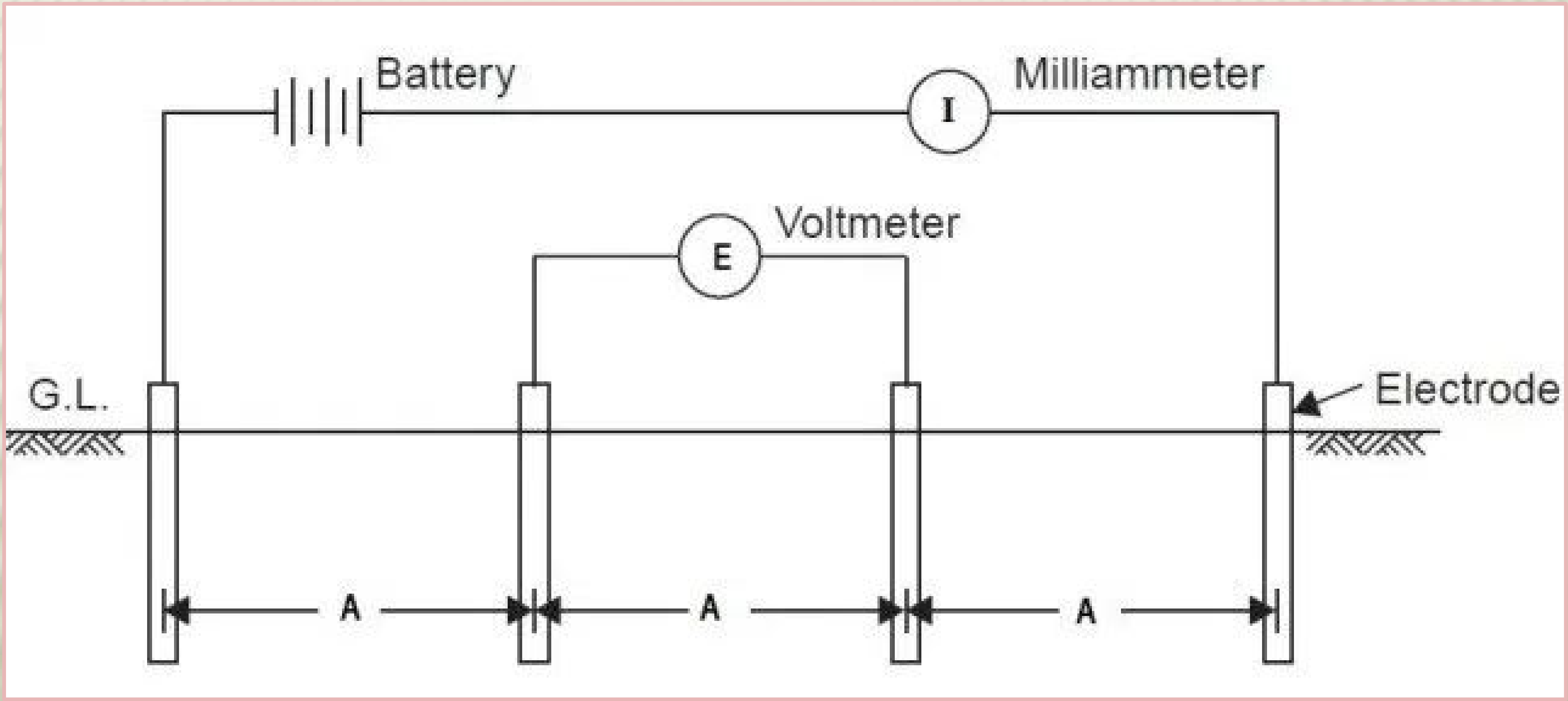
I = the current flowing b/w outer electrodes in amperes (A).

ELECTRICAL RESISTIVITY METHOD

Table 14.9 Electrical resistivity of different soils and rocks

Electrical Resistivity (Ωm)	*Type of Soil/Rock*
<100	Clay and saturated silt
100–250	Sandy clay and wet silty sand
250–500	Clayey sand and saturated sand
500–1500	Sand
1500–5000	Gravel
1000–2000	Weathered rock
1500–40000	Sound rock

ELECTRICAL RESISTIVITY METHOD



DEPTH OF BORING

Significant Depth of Boring

Exploration should be carried to a depth up to which the increase in pressure due to structural loading is likely to cause perceptible settlement or shear failure

Depth of boring Depends upon

- Type of structure
- Intensity of Loading
- Soil profile
- Physical characteristics of soil

DEPTH OF BORING ,D_B

Should extend up to the significant depth below the base of the foundation

D_B $D_f + 2B$ for square / circular footings

$D_f + 6B$ for strip / continuous footings

In the case of pile foundations,

D_B length of pile + significant depth below the base of the pile group.

D_f – Depth of footing

B – Width of footing

NUMBER OF BORINGS OR TRIAL PITS

FOR SMALLER BUILDINGS

1 bore hole or test pit in the centre of the site

FOR LARGER BUILDINGS

1 bore hole at each corner and 1 in centre

FOR VERY LARGER BUILDINGS

Areas should be divided in a grid pattern and borings are carried out at every 100 metre depends upon the soil

FOR DAM SITES

Borings are made at the intervals of 50 m spacing along the upstream.

FOR ROADS

Generally at the intervals of every 100 m, for uniform soil it is increased to every 500 m and it is decreased to 30 m for non uniform soil

HOW MANY BORE HOLES?

The number of bore holes depends on

- Type and size of the project
- Budget for site investigation
- Soil variability

Locate the bore holes where the loads are expected.

SPACING OF BORINGS

Type of project	Spacing (m)
Multistorey building	10-30
One – storey industrial plants	20-60
Highways	250-500
Residential subdivision	250-500
Dams and dikes	40-80

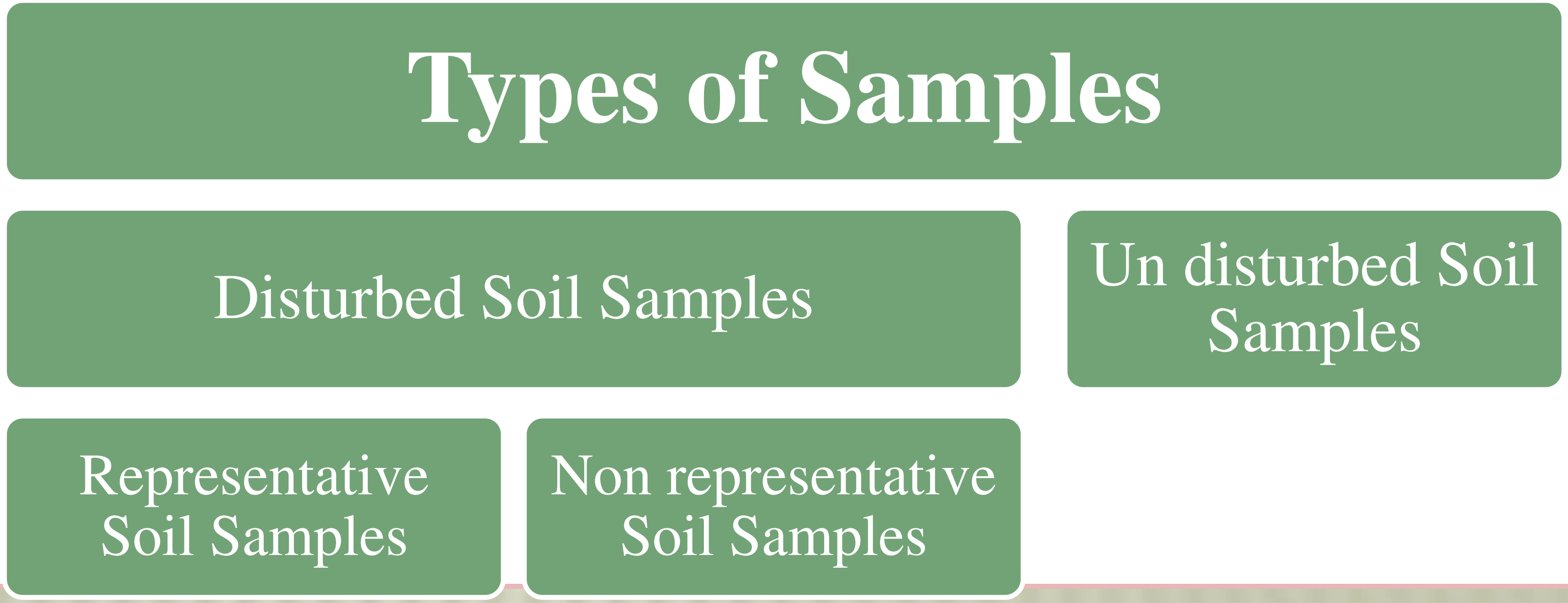
DEPTH OF EXPLORATION

FOUNDTION TYPE	DEPTH
General	1.5 to 2 times of loaded area
Pile Foundation	10 to 30 metres or more
Retaining Wall	1.5 times of base width (or) 1.5 times of height of the wall
Dams	1.5 times of base width (or) up to bed rock
Roads(cuts & Fills)	1 metre for little cut or fill (or) 2 metres below the ground or equal to the ht. of the fill or cut

TYPES OF SOIL SAMPLES

Soil samples are obtained by

- Driving or pushing a sampling tube into the ground
- An open ended cylindrical tube is known as sampling tube



DISTURBED SAMPLES:-

Soil samples in which the natural water content or structure gets modified or destroyed is known as disturbed samples.

NON-REPRESENTATIVE SAMPLES:

Mixture of soils from different layers/levels complete disturbance to soil structure and properties can not be used for any test

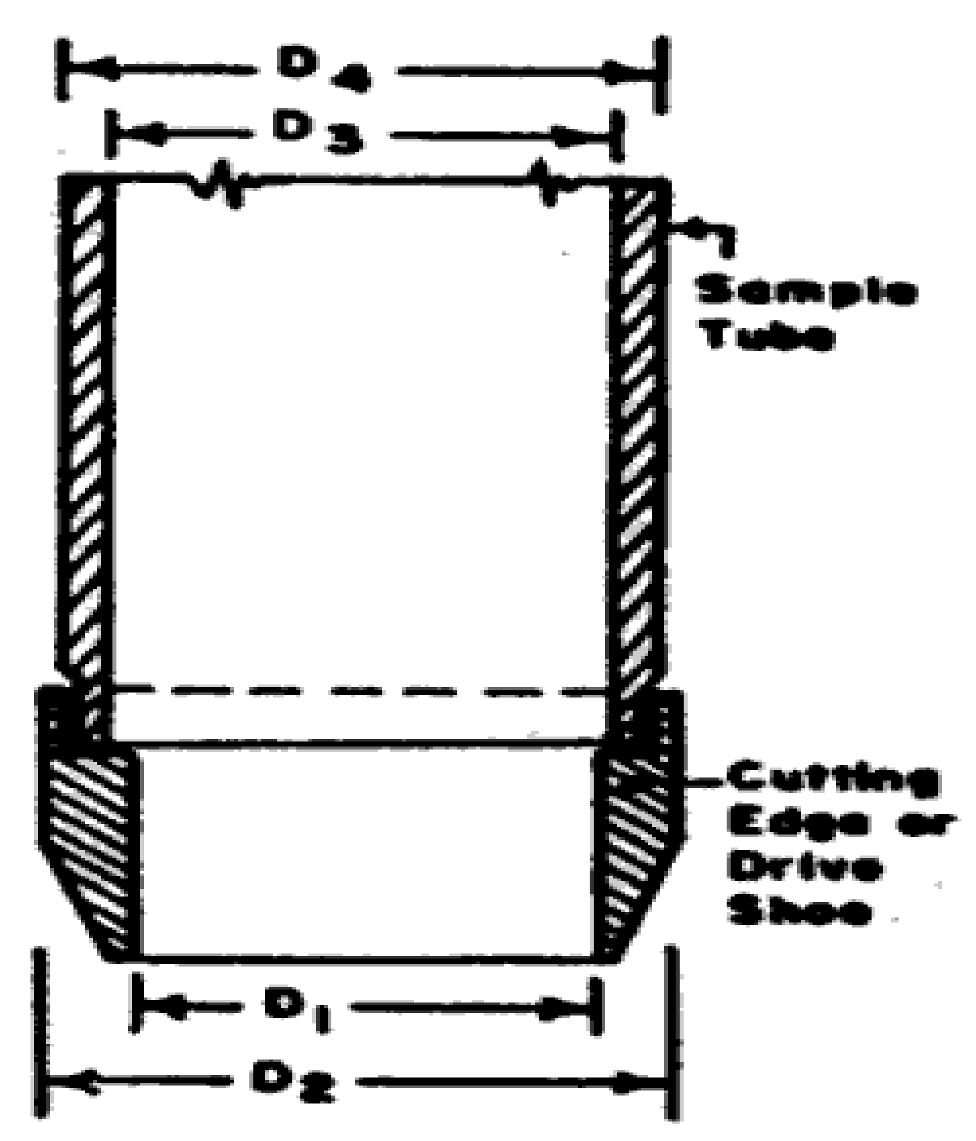
REPRESENTATIVE SAMPLES:

Disturbance to soil structure water content may or may not be changed no change in mineral constituents suitable for classification and identification tests

UNDISTURBED SAMPLES:-

Little or no disturbance to the soil structure natural structure and properties will be preserved useful for important laboratory tests like shear test, consolidation test etc.,

SOIL SAMPLER



Area ratio(A_r) = $\frac{D_2^2 - D_1^2}{D_1^2}$ X 100

Inside clearance(Ci) = $\frac{D_3 - D_1}{D_1}$ X 100

Outside clearance(Co) = $\frac{D_2 - D_4}{D_4}$ X 100

AREA RATIO FOR THE SAMPLERS

- It is defined as the ratio of the volume of soil displaced by the sampler tube in proportion to the volume of the sample.
- The disturbance to the sample depends on the dimensions of the sampler.
- Area ratio(A_r) should be as small as possible to reduce sample disturbance.
- If the ratio is less than 20 percent, it is generally agreed that the sample is undisturbed.
- If the ratio is greater than 20 percent, it is generally agreed that the sample is disturbed.

ROLES OF ‘ INSIDE CLEARENCE(C_i)’ AND ‘OUTSIDE CLEARENCE(C_o) ’

- Inside clearance(Ci) reduces friction between the soil sample and the sampler wall when the sample enters the tube.
- Outside clearance(Co) reduces friction when the sampler is driven and withdrawn after the sample is collected.

Limiting values of A_r, C_i, C_o

IS recommends:

A_r < 20% in stiff soils

<10% in sensitive clays

C_i may be 1 to 3%

C_o should be between 0 and 2%

‘RECOVERY RATIO’

Recovery ratio is the degree of disturbance of a soil during extraction.

$$\text{Recovery ratio } R_f = \frac{\text{Recovered length of sample } (L_a)}{\text{Penetration length of the sampler } (L_t)}$$

R_f is an index of sample disturbance

$R_f = 1$ no disturbance

$R_f < 1$ the sample is compressed

$R_f > 1$ the sample has swelled.

SAMPLING TECHNIQUES

Depending upon the mode of operation, the samplers can be classified as

1. Open Drive Sampler(Chunk Sample)
2. Split Spoon Sampler (Thick Wall Sampler)
3. Shelby Tube Sampler (Thin Wall Sampler)
4. Stationary Piston Sampler

OPEN DRIVE SAMPLER(CHUNK SAMPLE)

- Obtained from open pit

Sampling steps:

- ✓ During excavation a block of soil is left undisturbed
- ✓ An open ended box is placed on the block of soil sample
- ✓ The sample is cut at the base and removed
- ✓ The open top is sealed using wax and transported to laboratory

This type of samples can be taken at shallow depths of 1 to 2m

OPEN DRIVE SAMPLER

Undisturbed Samples

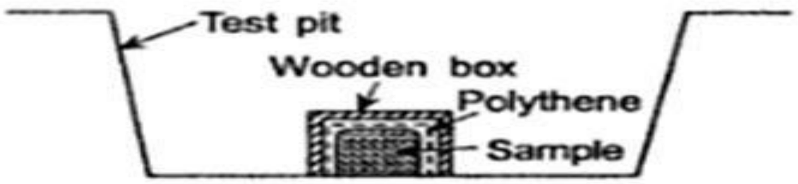


Fig. 2.5 Block sample of clay.

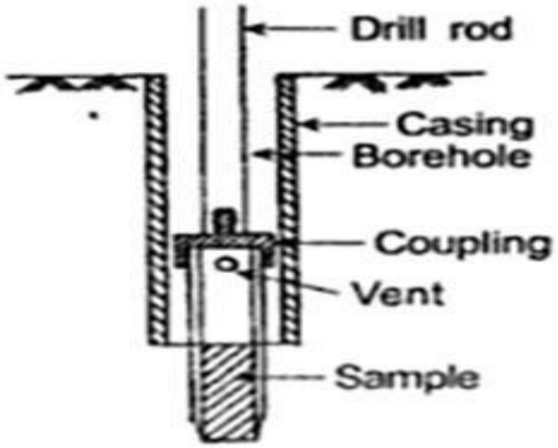


Fig. 2.6 Open drive sampler.

SPLIT SPOON SAMPLER (THICK WALL SAMPLER)

This is an open ended cylindrical tube

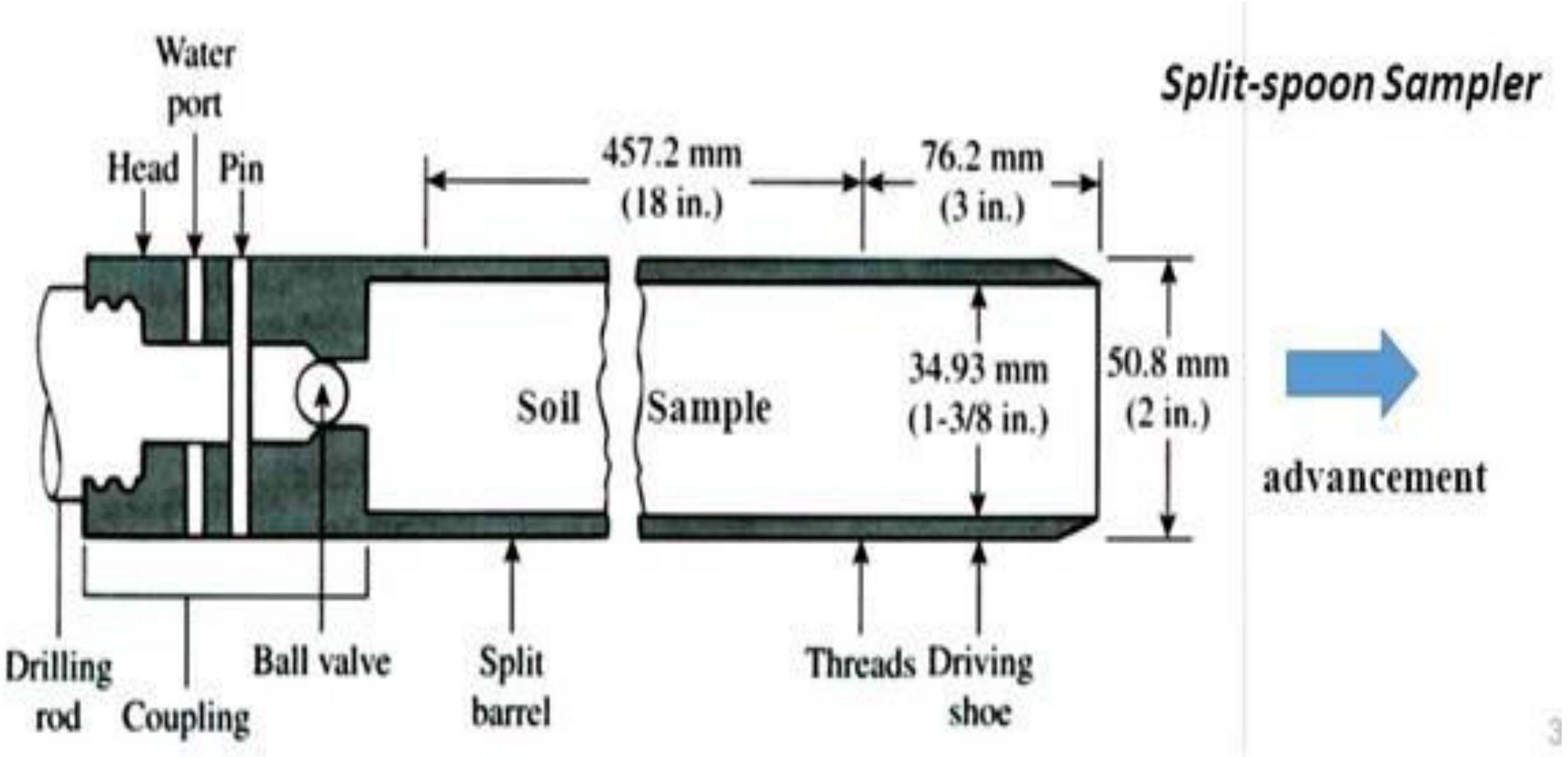
It consists of

- A cutting shoe at the bottom
- A barrel (pipe) split longitudinally into two halves
- A coupling at the top for connection to drill rods

Sampling steps:

- ✓ Same as for thin walled open drive sampling.
- ✓ After the sample is taken the two halves of the tube can be seperated to expose the sample

SPLIT SPOON SAMPLER (THICK WALL SAMPLER)



SHELBY TUBE SAMPLER (THIN WALL SAMPLER)

- The sampler is a open end steel tube with a cutting edge

Sampling steps:

- The sampler is placed at the bottom of the bore hole
- The sampler is pushed into the ground
- The sampler pulled out and the sampler with the sample is transporter to the lab.
- This type of sampling is suitable in soils having some cohesion. Not suitable in hard soils and gravels

SHELBY TUBE SAMPLER

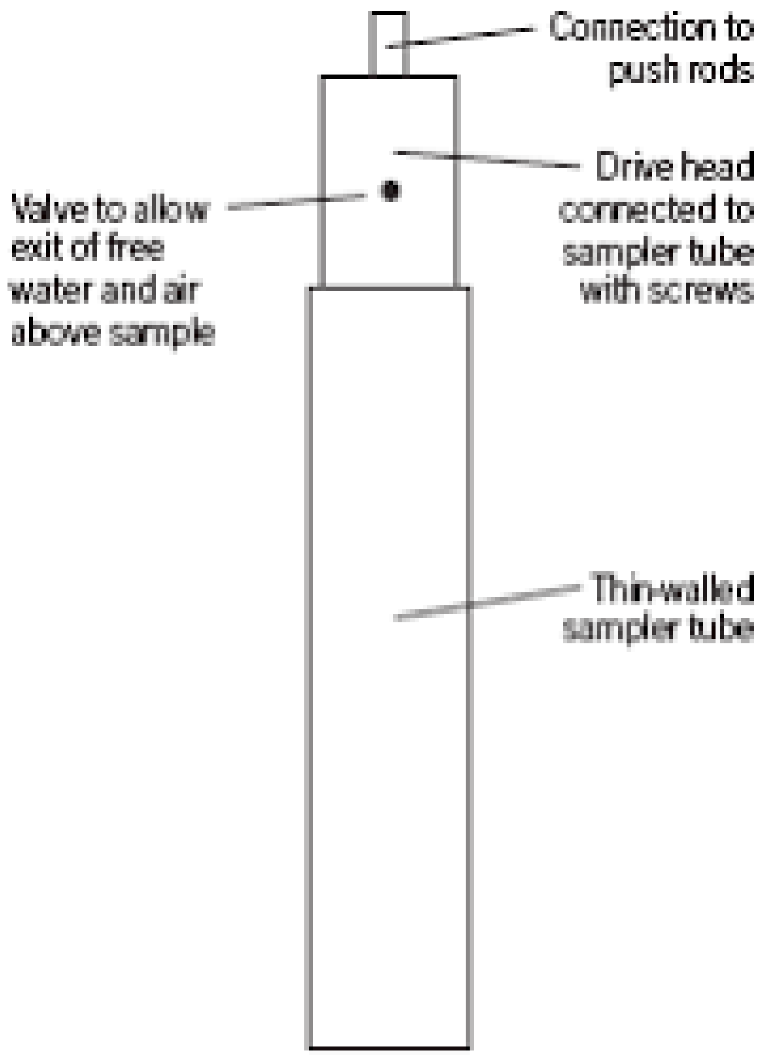


Figure 44 Shelby soil sampler

STATIONARY PISTON SAMPLER

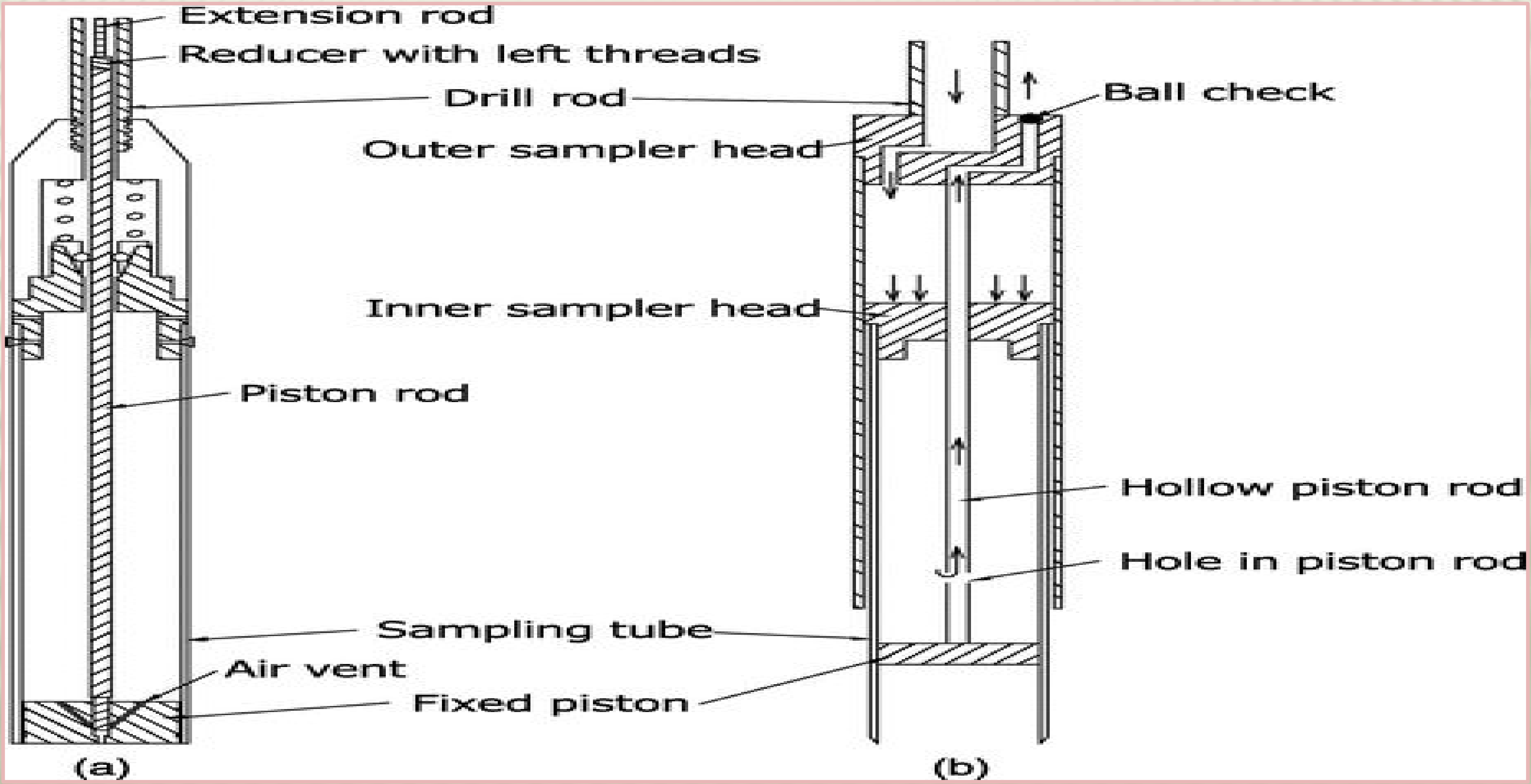
This consists of:

- Sampler tube
- Piston

Sampling steps:

- Sampler tube with the piston is placed at the bottom of bore hole
- The sampler is pushed into the soil keeping the piston at the bottom of the bore hole
- Sampler along with the piston is lifted up
- Negative pressure is created if the soil tends to move downwards. This helps to retain the sample

STATIONARY PISTON SAMPLER



BORELOG REPORT

DEFINITION :

- Information on subsurface conditions obtained from the boring operation is typically presented in the form of a boring record, commonly known as "boring log"
- It is a record, made by the driller or geologist, of the rocks penetrated in the borehole. In the laboratory, a more detailed log is prepared giving particulars relating to lithology, palaeontology, water analysis, etc.

DETAILS IN BORELOG PERIOD :

1. Description or classification of various soil and rock type
2. Ground water table details
3. Test data

CHECKLISTS IN BORELOG REPORT

1. Introduction
2. Description of the proposed structure
3. Location and geological condition of the site
4. Methods of exploration
5. Number of borings, their depth and location
6. General description of sub-soil condition as obtained from the SPT and cone test
7. Details and results of the laboratory test conducted
8. Depth of ground water table and its fluctuations
9. Discussions of the results
10. Recommendation about allowable bearing pressure, depth and type of foundation
11. Conclusions and limitations of the investigations

SAMPLE BORELOG REPORT

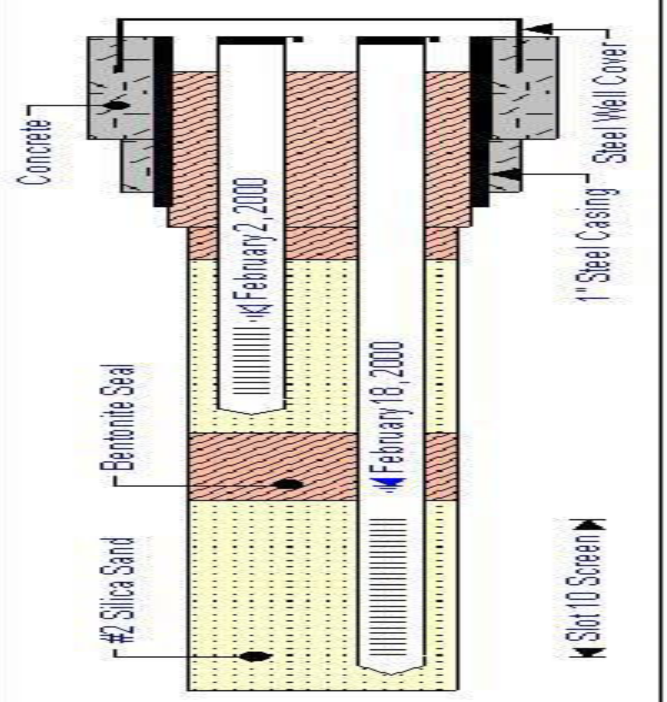
ACME

ACME Consulting Limited
44 Canadian Oaks Drive
Whitby, Ontario

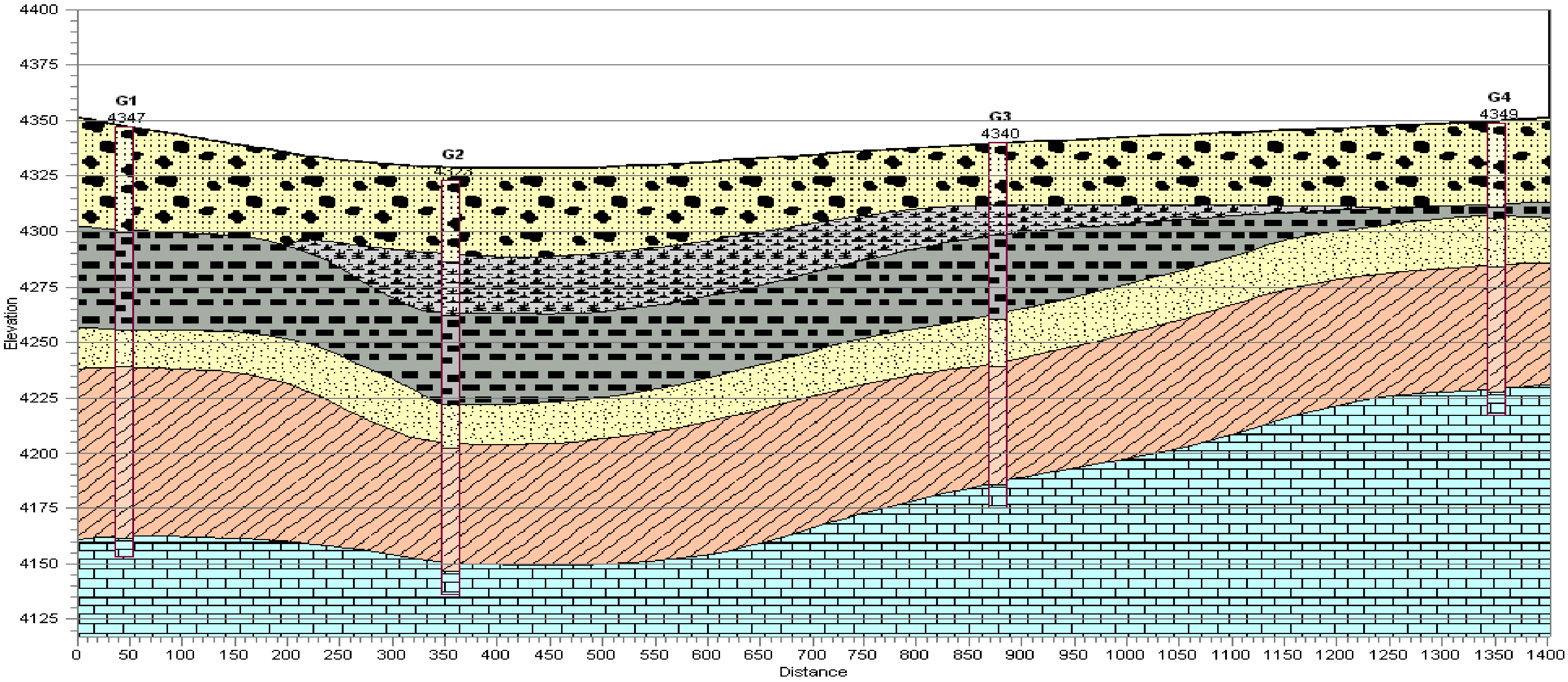
Log of Borehole:

Project No.:
Project: Port Sidney Oil Terminal
Client: Inter-Island Gas
Location: Port Sidney
Enclosure: 1
Project Manager: M. Fraser

SUBSURFACE PROFILE				SAMPLE				Well Completion Details
Depth (ft / m)	Symbol	Description	Depth/Elev.	Number	Type	Recovery	Vapour	
-1		Ground Surface	102 / 1 / 101 / 0					
1		**Asphalt**						
		Fill Sand and gravel fill, some organic debris.	98 / 3	1		40	180	
3		**Sandy Silt** Moist, brown to grey sandy silt with embedded gravel.	96 / 5	2		30	220	
5, 7 (2 m), 9		**Sand** Medium to fine sand, occasional clay lenses. ***Strong hydrocarbon odour.***	90 / 11	3		75	380	
				4		60	450	
				5		55	315	
11, 13 (4 m)		**Clay** Mottled brown and grey silty clay. Some sandy lenses.	87 / 14	6		80	210	
15, 17, 19 (6 m)		**Sand** Compact, coarse to medium sand. Shell fragments.	82 / 19	7		45	125	



Drilled By: ABC Drilling Company
Drill Method: H/S Auger
Drill Date: 02-06-2000
Hole Size: 12"
Datum: Local
Sheet: ***1 of 1***



GAEA Technologies
44 Canadian Oaks Dr.
Whitby, ON L1N 6W8
CANADA

Project: Tutorial

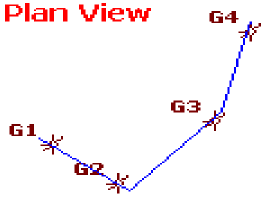
Project Number: 2000-001
Location: Someplace, somewhere
Drawn By: M. Fraser
Date: 11/02/2000

Scale Bar
0 200

Legend

Till
Coal
Clay
Peat
Sand
Limestone

Plan View



DATA INTERPRETATION

- Data Interpretation refers to the process of determining the significance of important information, such as survey results, experimental findings, observations, narrative report.

Example: Bore hole data interpretation

- ✓ Borehole is small diameter vertical hole drilled into ground to take samples for soil investigation and evaluation.
- ✓ Errors in borehole data interpretation for site investigation is discussed.
- ✓ Borehole data is used to specify suitable types of foundation for structure.
- ✓ While boreholes are interpreted, certain errors are highly likely to be made which could be fatal for the foundation and safety of the structure.

ERRORS IN BOREHOLE DATA INTERPRETATION

Misinterpretations of boreholes include:

- ✓ Interpreting folded strata as straight strata
- ✓ Drift underlain by unexplored rock
- ✓ Overloading due to lack of dip assessment
- ✓ Bedrock misinterpretation
- ✓ Improper interpretation of strata formation
- ✓ Misinterpretation of soil profile

SELECTION OF TYPE OF FOUNDATION BASED ON SOIL CONDITIONS

Type of foundation depends on:

- Soil conditions at the site
- Type of the super structure like buildings, water tanks , chimneys, Bridges etc.,
- The magnitude of loads
- Type of load like vertical , lateral , static, dynamic , earthquake loads etc.,
- Ground water conditions
- Environmental factors like structure in river beds , sea , hill slopes etc.,

SELECTION OF FOUNDATION

S.No	Soil Condition	Preferable Foundation Type
1	Compact Sand Deposit To A Greater Depth	Spread Footings
2	Firm Clay Or Silty Clay To A Greater Depth	1. Spread Footings 2. Pile Foundation (If Uplift Forces Are Observed)
3	Soft Clay To A Greater Depth	1.Spread Footing For Low & Medium Loading 2. Deep Foundations For Heavy Loadings
4	Loose Sand	Raft Foundation
5	Soft Clay But Firmness Increases With Depth	1.Friction Piles Or Pier Foundations 2. Raft Or Mat Foundations Also Considered
6	Hard Clay	Piers Or Pile Foundations
7	Rock Surface	Foundations Directly Laid On Rock Surface

FACTORS AFFECTING THE SELECTION OF FOUNDATION

1. Loads from building
2. Type of soil
3. Type of structures in neighbourhood
4. Type of foundations

LOADS FROM BUILDING

- In case of low rise building with large span, the extent of loading is relatively modest, so shallow foundation is preferred in this case.
- While high-rise building with short span has high loads. Therefore, deep foundation is required in such cases. Deep foundation is provided because ground at greater depth are highly compacted.
- In case of framed structure multi-storey building, where loads are concentrated at the point of application, the use of pads and piles are common. Where, loads of the buildings are uniformly distributed, like from masonry claddings, the piles are not needed.

FACTORS AFFECTING THE SELECTION OF FOUNDATION

TYPE OF SOIL :

- Where soil close to the surface is capable of supporting structure loads, shallow foundations can be provided.
- Where the ground close to surface is not capable of supporting structural loads, hard strata is searched for, and in some cases, it may be very deep, like in case of multi-storey buildings, where loads are very high. So, deep foundations are suitable for such cases.
- Field up ground have low bearing capacity, so deep foundation is required at that place, whereas uniform stable ground needs relatively shallow foundation.

FACTORS AFFECTING THE SELECTION OF FOUNDATION

TYPE OF STRUCTURES IN NEIGHBOURHOOD:

- The selection of foundation for building construction can also be done based on the type of foundation selected for the buildings in the neighbouring buildings for the same types.
- Based on the success or failure of foundations for such buildings, decision can be taken for the selection of foundation.

TYPE OF FOUNDATIONS:

- Types of foundation such as isolated foundations, combined footings, pile foundations and raft or mat foundations etc.
- Based on the type of soils and loads from the buildings can be selected based on suitability and requirement.

THANK YOU...

UNIT II
SHALLOW FOUNDATION

Introduction – Location and depth of foundation – Codal provisions – bearing capacity of shallow foundation on homogeneous deposits – Terzaghi's formula and BIS formula – factors affecting bearing capacity – problems – Bearing capacity from in-situ tests (SPT, SCPT and plate load) Allowable bearing pressure – Seismic considerations in bearing capacity evaluation. Determination of Settlement of foundations on granular and clay deposits – Total and differential settlement – Allowable settlements – Codal provision – Methods of minimizing total and differential settlements.

Introduction:

A foundation transfers the loads from the superstructure to the soil safely. The foundations are designed such that:

- The soil does not fail in shear and
- Settlement is within the safe limits

Foundations may be grouped into two categories:

- ✓ Shallow foundations
- ✓ Deep foundations

Shallow foundations

- The depth of foundation is small
- $D_f \leq B$
- $(D_f / B) \leq 1$ (for shallow foundation)
- $1 < (D_f / B) \leq 15$ (for moderate shallow foundation)
- Construction in open excavations
- Isolated square, rectangular, circular footings, continuous wall footings, raft or mat foundations are examples of shallow foundation

Deep foundations

- Loads are transmitted over large depth
- Pile foundation is an example
- $D_f > B$
- $(D_f / B) > 15$

Types of shallow foundations

- Isolated footing, square , rectangular or circular
- Continuous or strip or wall footing
- Combined footing - rectangular or trapezoidal
- Strap footing
- Raft / mat foundation

1. SPREAD FOOTING:

- A spread footing also called as isolated footing, pad footing and individual footing is provided to support an individual column.
- A spread footing is circular, square or rectangular slab of uniform thickness.
- Sometimes, it is stepped or haunched to spread the load over a large area.

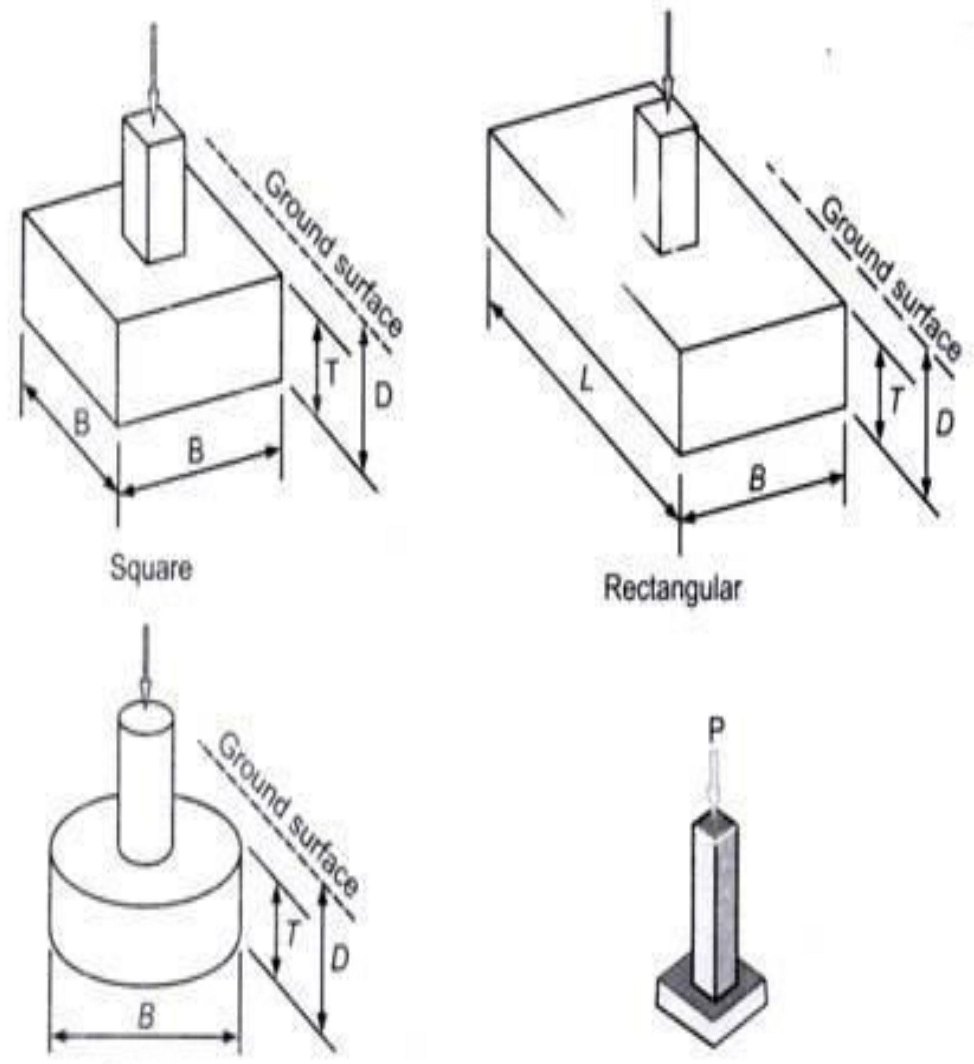


FIG. 11.4 Spread footing

2. CONTINUOUS FOOTING:

- A strip footing is provided for a load-bearing wall.
- A strip footing is also provided for a row of columns which are so closely spaced that their spread footings overlap or nearly touch each other.
- In such a case, it is more economical to provide a strip footing than to provide a number of spread footings in one line.
- A strip footing is also known as continuous footing.

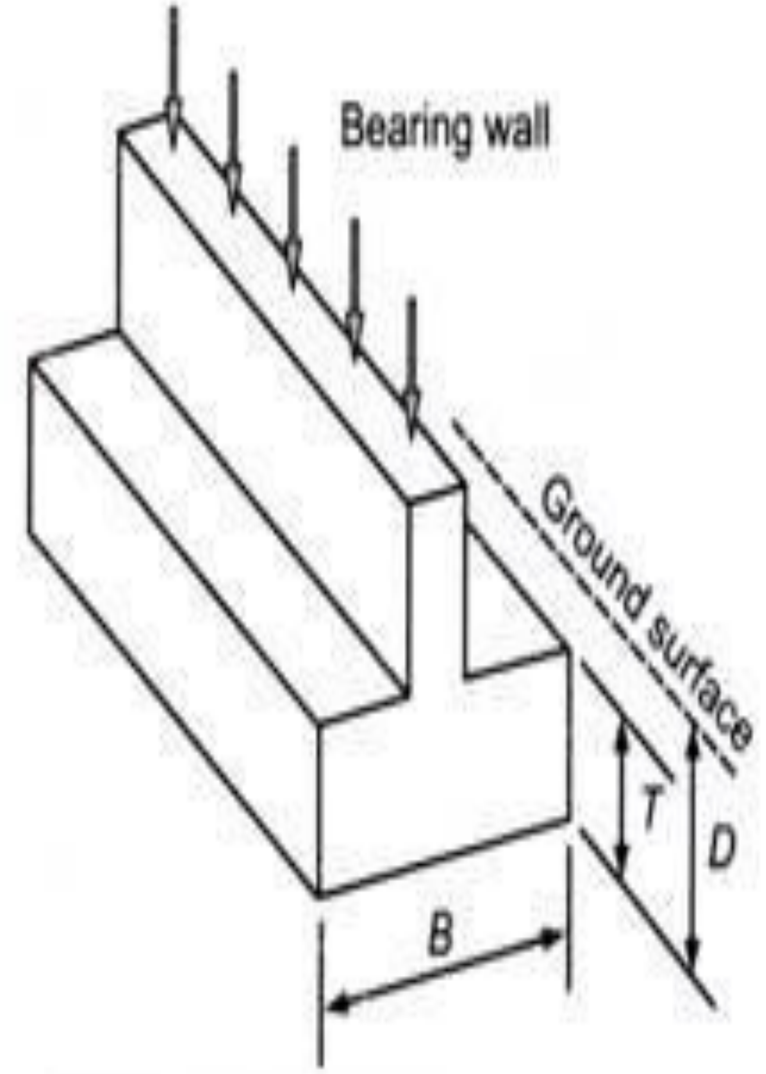


FIG. 11.7 Continuous footing

3. COMBINED FOOTING:

- A combined footing supports two columns.

- It is used when the two columns are so close to each other that their individual footings would overlap.

- A combined footing is also provided when the property line is so close to one column that a spread footing would be eccentrically loaded when kept entirely within the property line.

- By combining it with that of an interior column, the load is evenly distributed. A combined footing may be rectangular or trapezoidal in plan.

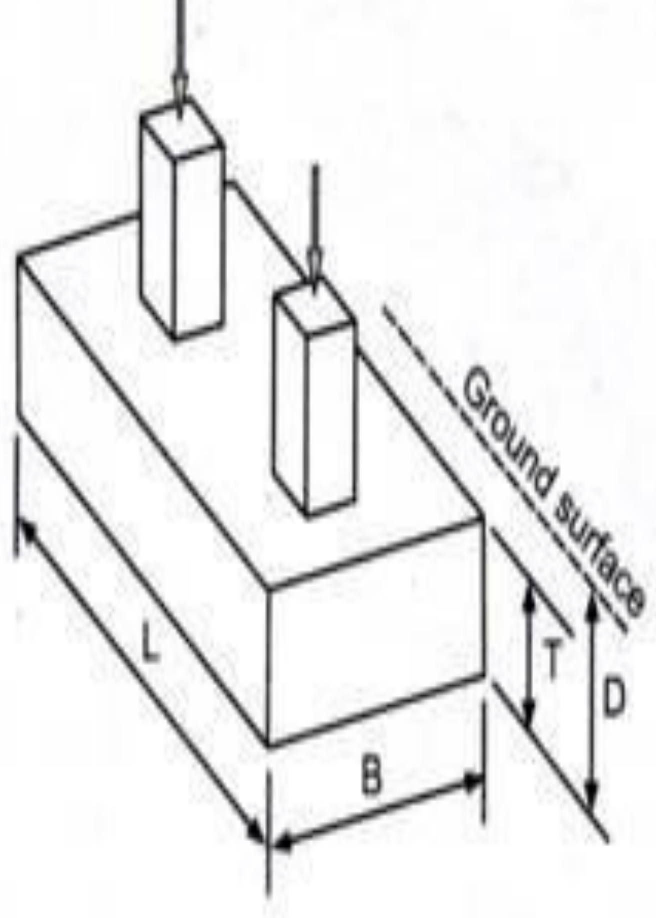


FIG. 11.6 Combined footing

4. STRAP FOOTING:

- A strap (or cantilever) footing consists of two isolated footings connected with a structural strap.
- The strap connects the two footings such that they behave as one unit.
- The strap is designed as a rigid beam. The individual footings are so designed that their combined line of action passes through the resultant of the total load.
- A strap footing is more economical than a combined footing when the allowable soil pressure is relatively high and the distance between the columns is large.

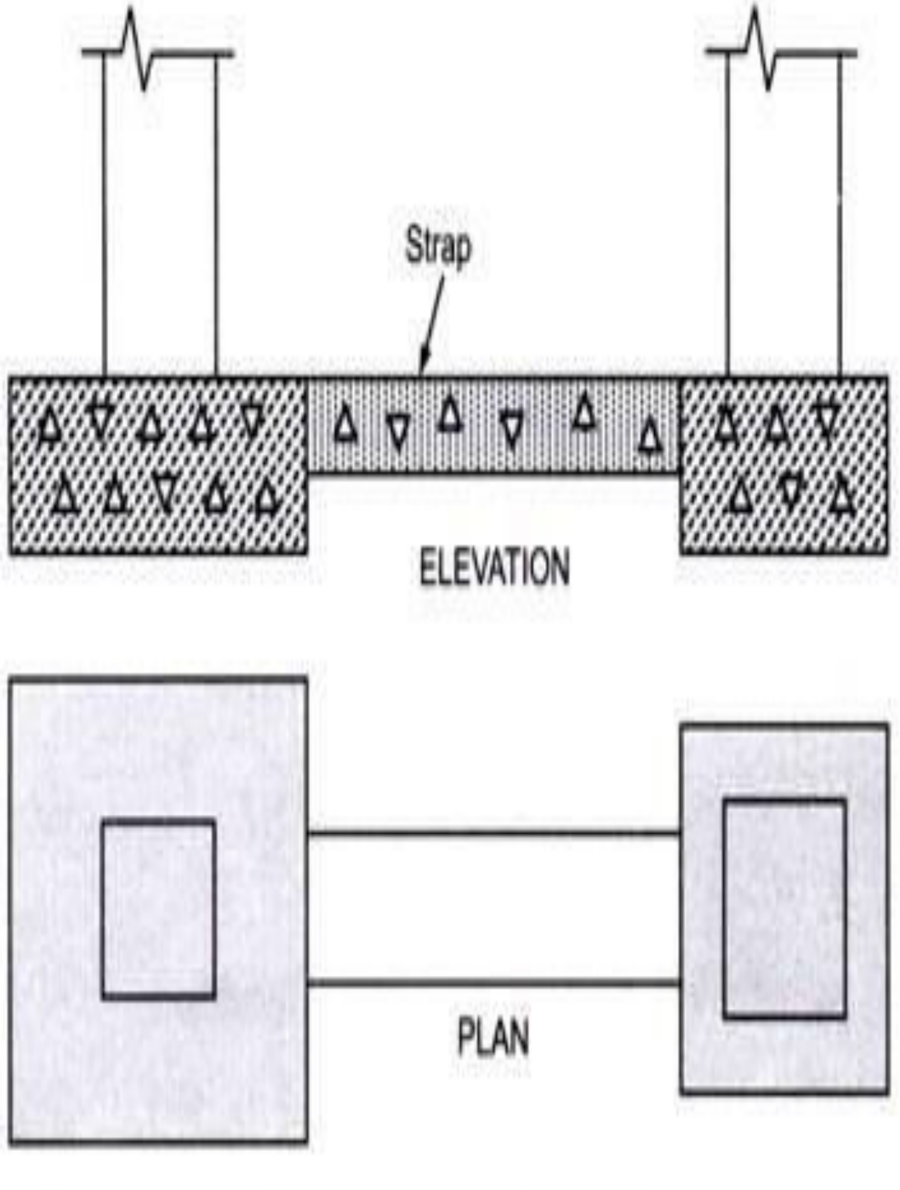


FIG. 11.5 Strap footing

5. RAFT FOOTING:

- A mat or raft foundation is a large slab supporting a number of columns and walls under the entire structure or a large part of the structure.
- A mat is required when the allowable soil pressure is low or where the columns and walls are so close that individual footings would overlap or nearly touch each other.
- Mat foundations are useful in reducing the differential settlements on non-homogeneous soils or where there is a large variation in the loads on individual columns.

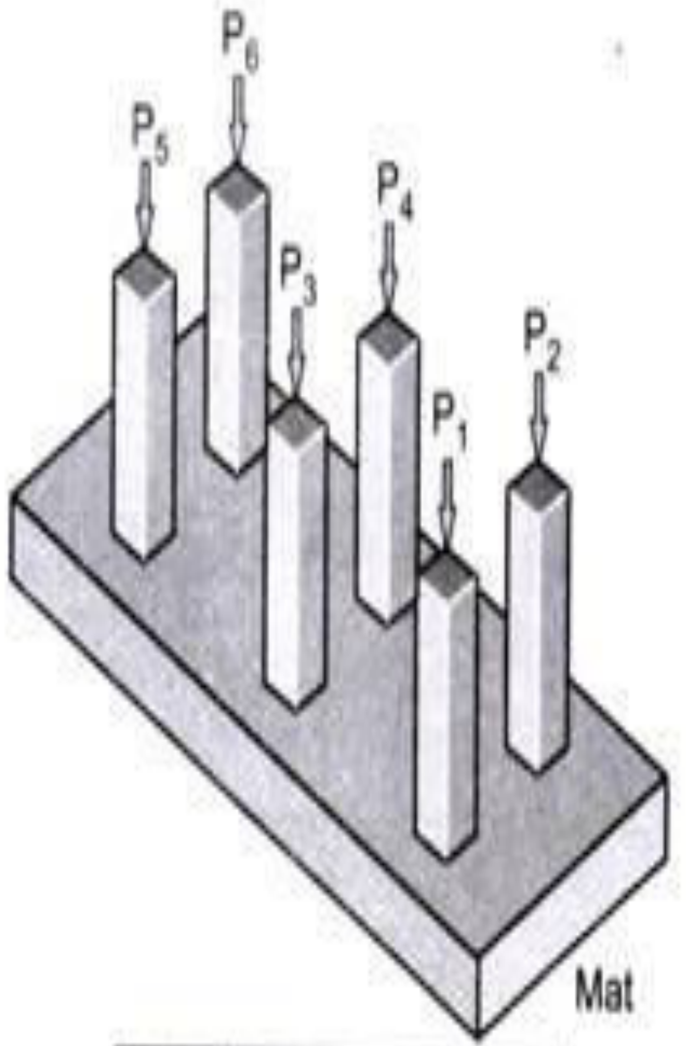


FIG. 11.8 Mat footing

Types of Deep Foundations:

(i) Pile foundation

(ii) Pier foundation

(iii) Well or cassion foundation

(i) Pile foundation:

Pile foundation is a long and slender structural element which transfers the load of the structure to some firm stratum at a considerable depth below ground surface.

(ii) Pier foundation:

Piers are large diameter piles which distributes the load of the structure along the entire depth of soils in which it is located.

(iii) Well or cassion foundation:

Well or cassion is a large size hollow box or well which is sunk deep into the ground to support heavy loads. The load carrying capacity of such foundation is very large. It transfers the load of the structure to the soil through end bearing and skin friction. Such foundations are generally used in bridges.

Depth of foundation:

- At a depth where the soil is adequately strong
- Minimum depth = 50cm below ground level
- Below the depth of scour in foundations in river beds
- Below the zone of moisture change i.e ,below the zone of seasonal variation of water content
- Below the zone of frost heave in areas where temperature goes below zero.

General factors to be considered for determining depth of foundation are:

- ✓ Load applied from structure to the foundation
- ✓ Bearing capacity of soil
- ✓ Depth of water level below the ground surface
- ✓ Types of soil and depth of layers in case of layered soil
- ✓ Depth of adjacent foundation

Rankine's formula provides the guidance on minimum depth of foundation based on bearing capacity of soil.

$$D_{min} = \frac{q}{\gamma}\left[\frac{1 - \sin\phi}{1 + \sin\phi}\right]^2$$

Where Ø is the angle of repose

q = Intensity of load at the base of footing (t/m^2 or kN/m^2)

γ = Unit weight of soil (t/m^3 or kN/m^3).

Location of foundation:

a) Footings in sloping ground

b) Adjacent footings at different levels

c) Footings of new structures adjacent to old building

Footings in sloping ground:

When foundation is to be located on a sloping ground, the depth of foundation should be such that a line drawn from the bottom edge of the the foundation at angle of 30° and at a horizontal distance of 90 cm should not intersect, as shown in figure.

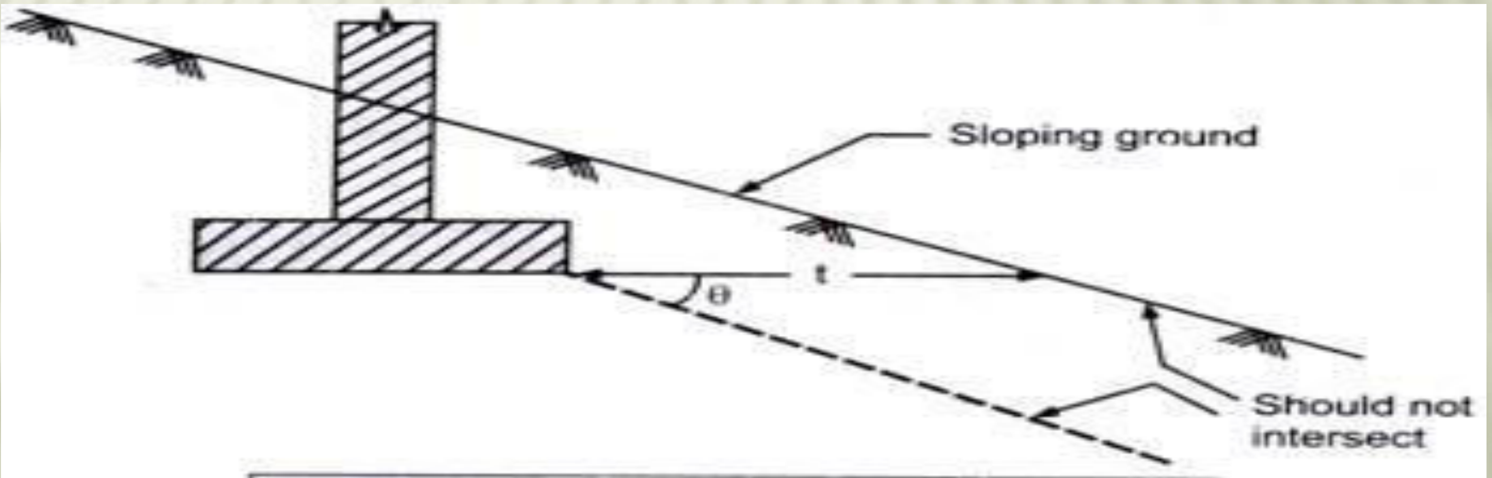


FIG. 11.11 Footing on sloping ground

Adjacent footings at different levels

- If a construction is to be made near an adjacent property line, the foundation should be so located that it should not extend into adjacent property line to avoid legal disputes.
- If a new foundation is to be laid near a existing structure, then the bottom edge of the near foundation must be at minimum distance 'S' away from the old foundations where S is the larger of the two foundations widths.
- The depth of new foundation should be such that the line drawn from the bottom edge of old foundation (at 30° for average soil and 45° for soft soil) should not intersect the bottom edge of the new foundation as shown in the figure.

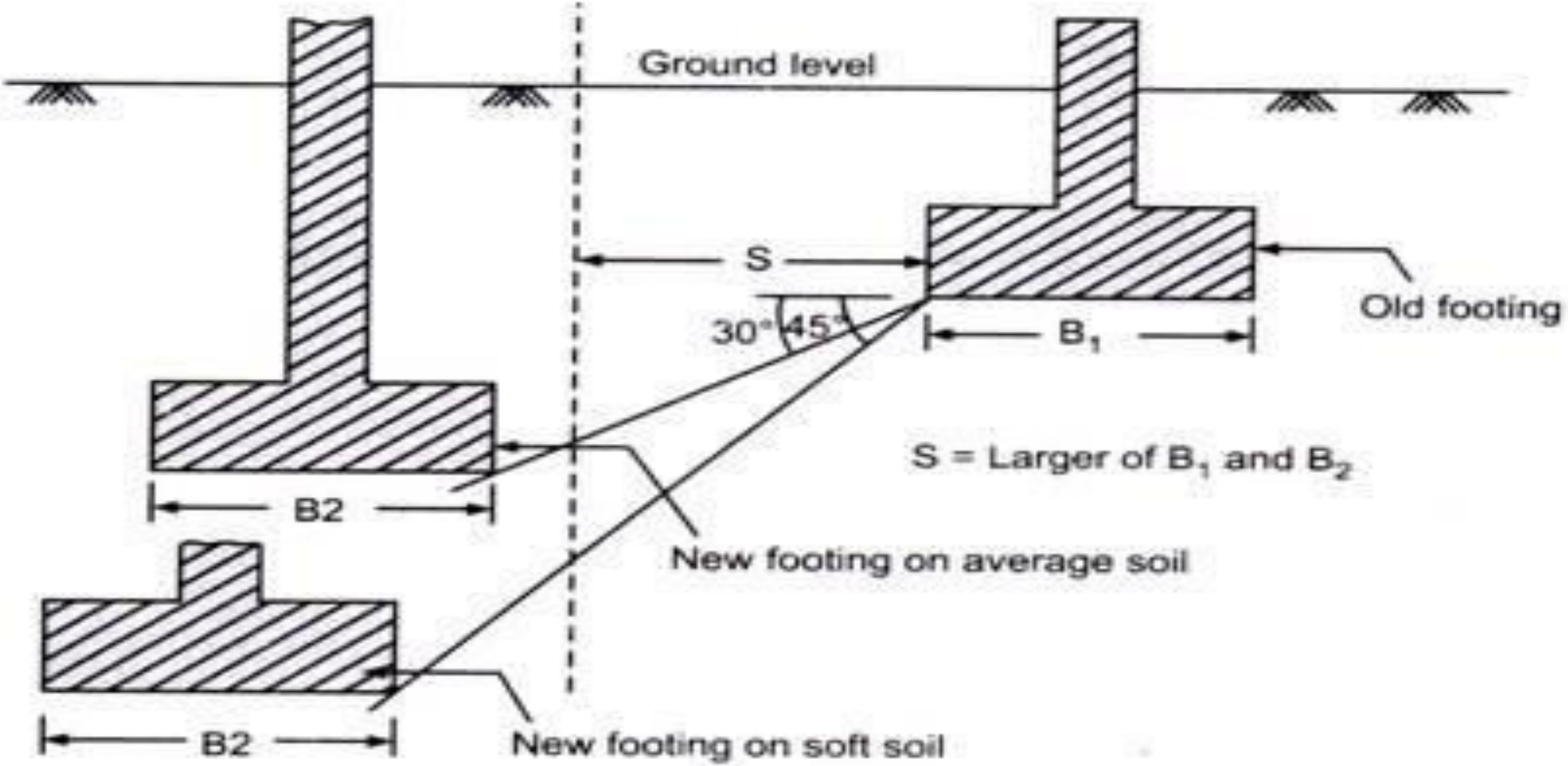


FIG. 11.10 Locating new footing adjacent to existing structure

Foundations at different level:

In situations where bottom of the foundations of a structure are at different level, BIS makes the following recommendations:

(a) For footing in granular soil, a line drawn between the lower adjacent edges of adjacent foundations should not have a slope steeper than 2 H: 1 V, as shown figure.

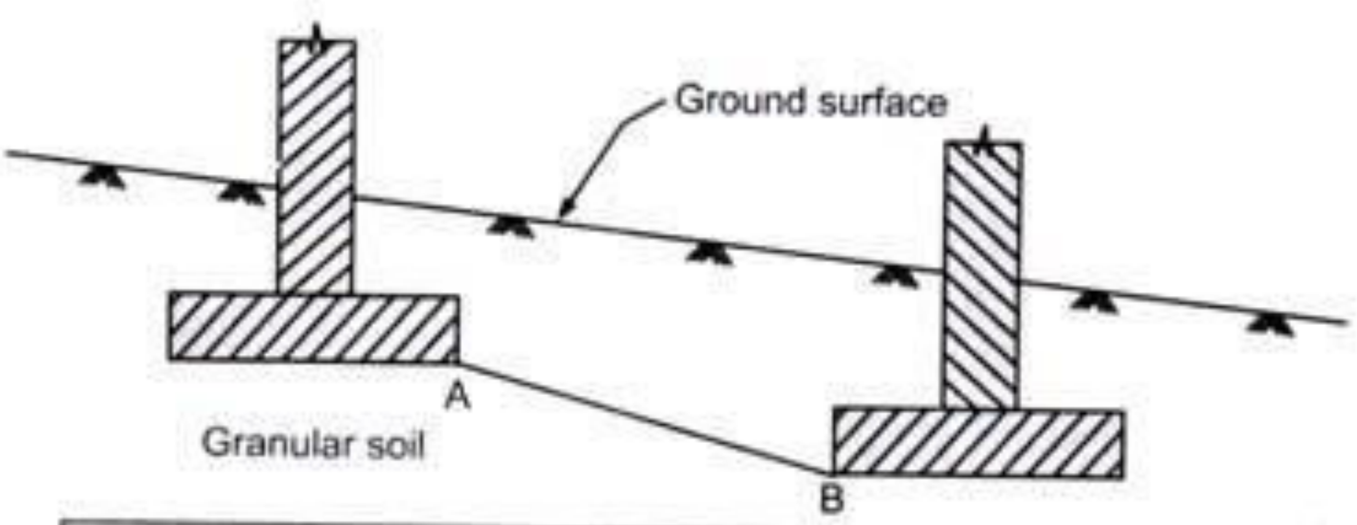


FIG. 11.12 Foundations at different level in granular soils

(b) For footing in clay soils, a line drawn between the lower adjacent edge of the upper footing and upper adjacent edge of lower footing should not have a slope steeper than 2H: 1 V as shown in figure.

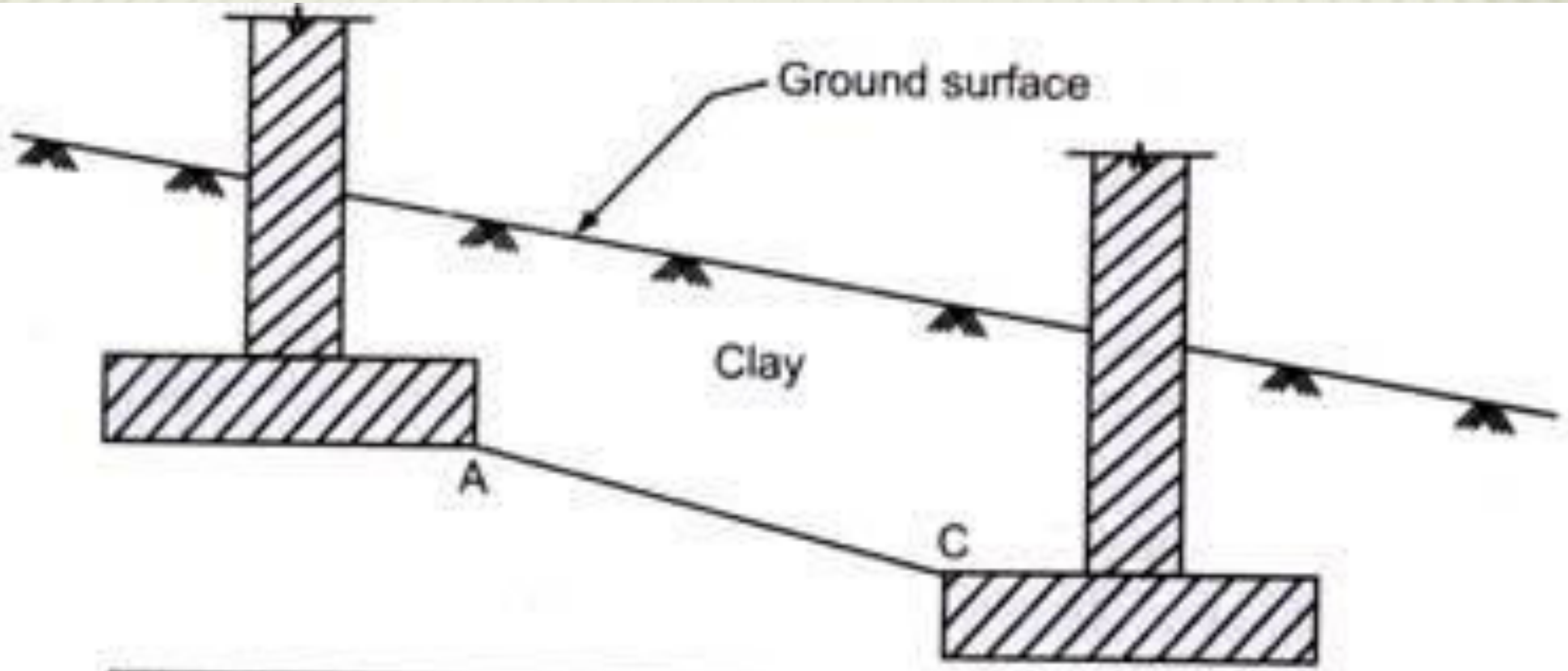


FIG. 11.13 Foundations at different levels in clay soils

Requirements of a safe / satisfactory foundation

A foundation must satisfy the following criterion

1. **Location and depth criterion** – Must be properly located and founded at a proper depth as per codal provisions
2. **Bearing capacity criterion** – The loading pressure on the foundation should be less than the bearing capacity by an adequate margin. A factor of safety of 3 is usually adopted.

i e , loading pressure ,q < net bearing capacity / 3 (factor of safety)

3. **Settlement criterion** – The settlement of the foundation under the applied load should be less than the permissible settlement prescribed in building codes

BEARING CAPACITY

- Bearing capacity is the power of foundation soil to hold the forces from the superstructure without undergoing shear failure or excessive settlement.
- When a foundation is loaded it settles. This settlement increase more or less linearly with the increase in loading pressure
- Beyond a certain loading pressure, the foundation settles rapidly or sinks into the ground causing rupture of the ground.
- This loading pressure at which the failure by rupture of the ground takes place is termed as 'Bearing capacity' of the foundation.

BASIC DEFINITION

1. GROSS PRESSURE INTENSITY

Gross pressure intensity (**q**) is the intensity of pressure at the base of foundation due to load from super structure, self weight of foundation and overburden, if any.

2. NET PRESSURE INTENSITY

Net pressure intensity (**q_n**) is gross pressure intensity minus the over burden pressure at the level of base of foundation prior to excavation.

$$q_n = q - \Upsilon D$$

Where,

Υ = Effective unit weight of foundation soil

D = Depth of foundation

3. ULTIMATE BEARING CAPACITY

Ultimate bearing capacity (**q_f**) is the minimum gross pressure intensity at which the soil at the base of foundation fails by shear.

4. NET ULTIMATE BEARING CAPACITY

Net ultimate bearing capacity (**q_{nf}**) is the minimum net pressure intensity at which the soil at the base of foundation fails by shear.

$$q_{nf} = q_f - \Upsilon D$$

5. NET SAFE BEARING CAPACITY

Net safe bearing capacity (**q_{ns}**) is the maximum net pressure intensity to which the soil at the base of foundation can be subjected without risk of shear failure.

$$q_{ns} = q_{nf} / F$$

Where, F= factor of safety against shear failure.

6. SAFE BEARING CAPACITY

Safe bearing capacity (**q_s**) is the maximum gross pressure intensity to which the soil at the base of foundation can be subjected without risk of shear failure.

$$q_s = q_f / F$$ or more appropriately,

$$q_s = q_{ns} + \Upsilon D$$ or,

$$q_s = (q_{nf} / F) + \Upsilon D$$

7. ALLOWABLE BEARING PRESSURE

Allowable bearing pressure (**q_a**) is the maximum gross pressure intensity to which the soil at the base of foundation can be subjected without risk of shear failure and excessive settlement detrimental to the structure.

$$q_a = q_{na} + \Upsilon D$$

Where,

q_{na} = net allowable bearing pressure.

Types of shear failure of foundation soils

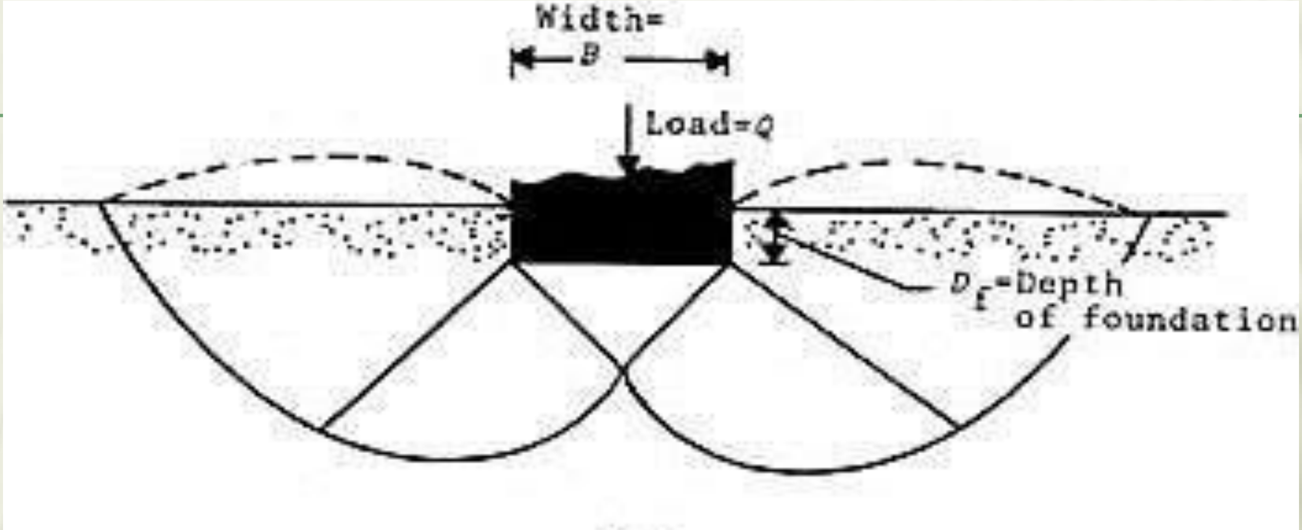
Depending upon the compressibility of soil and depth of footing with respect to its breadth (i.e D/B Ratio).

When the ultimate bearing capacity of the soil is reached, it may fail in one of the following three failure mode depending upon the type of soil and depth to width ratio of the footing (i.e. D/B)

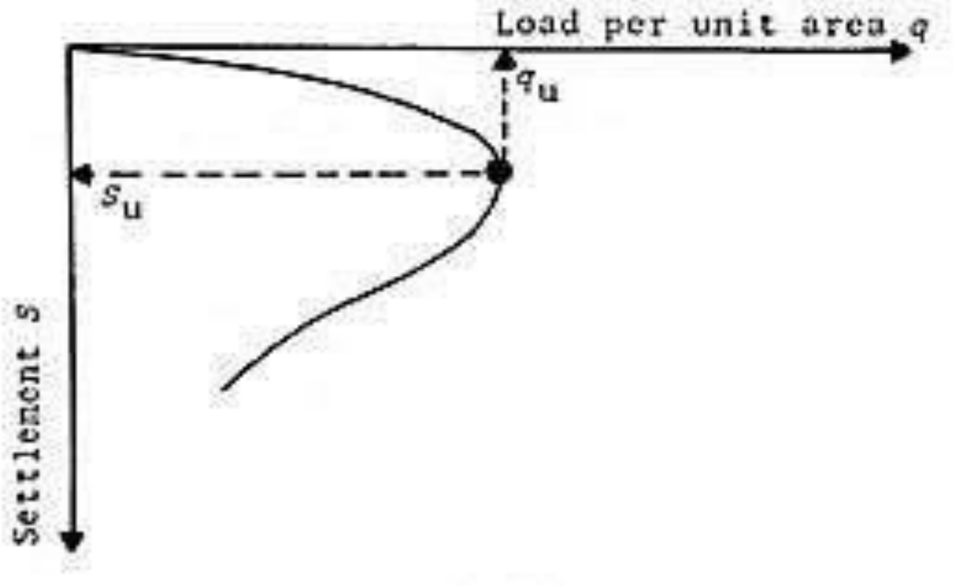
- General shear failure
- Local shear failure
- Punching shear failure

General Shear Failure

- This type of failure occurs in stiff clay or dense sand.
- In this type of failure, failure takes place at a very small strain.
- The load settlement curve shows a well-defined peak.
- At failure entire soil mass within the failure wedge participates and well defined rupture surfaces develop.
- The failure is accompanied by a considerable bulging of sheared mass of soil.
- There is only marginal difference between the load causing local shear failure and general Shear failure.
- General shear failure is accompanied by low strain ($e<5\%$) in a soil with considerable ($\phi>36^{o}$) and large N ($N > 30$) having high relative density ($I_D > 70\%$).


Width=
B
Load=Q
D_f=Depth
of foundation

(a)


Load per unit area q
q_u
s_u
Settlement S

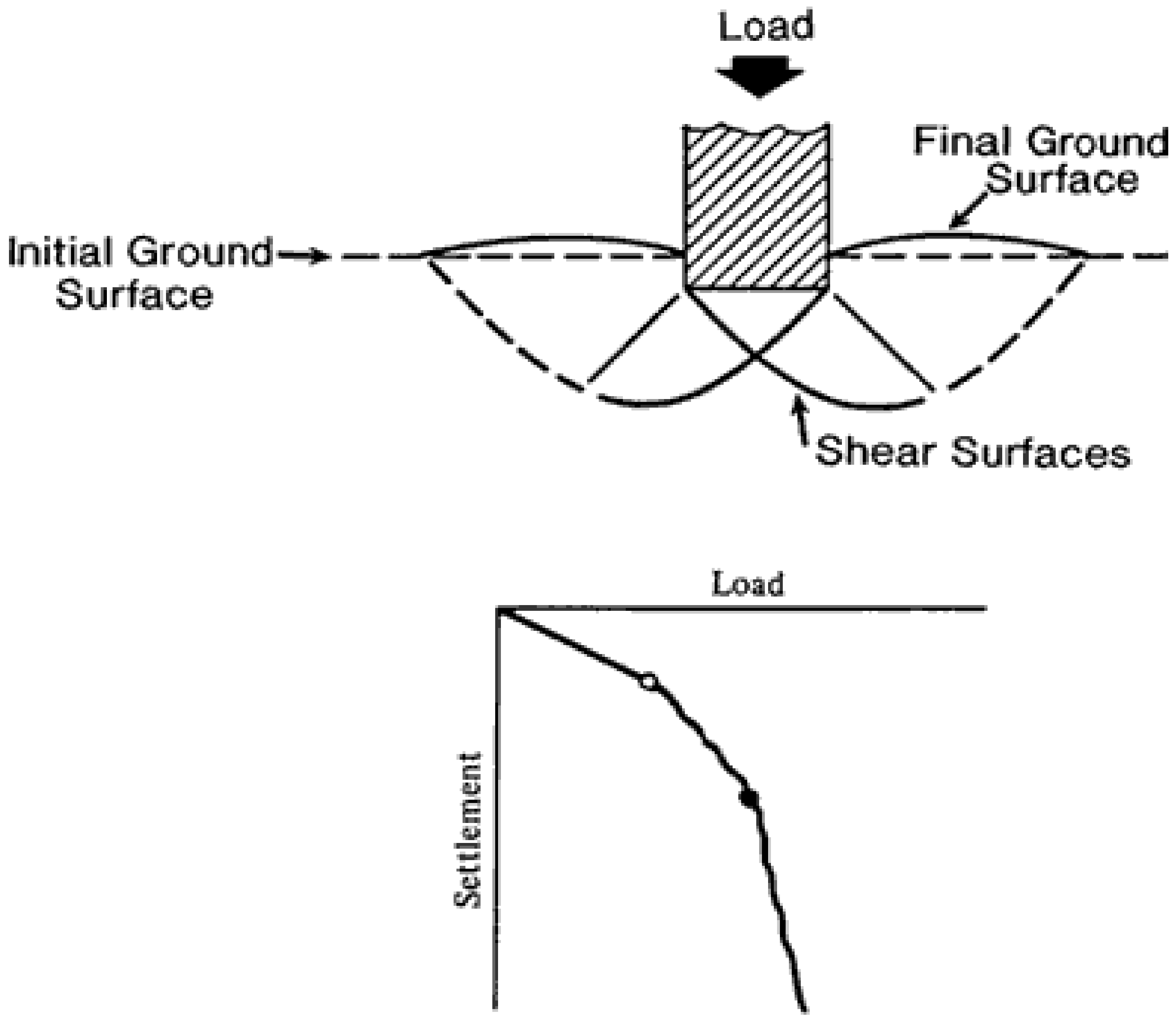
(b)

The following are some characteristics of general shear failure

- Continuous, well defined and distinct failure surface develops between the edge of footing and ground surface.
- Dense or stiff soil that undergoes low compressibility experiences this failure.
- Continuous bulging of shear mass adjacent to footing is visible.
- Failure is accompanied by tilting of footing.
- Failure is sudden and catastrophic with pronounced peak in curve.
- The length of disturbance beyond the edge of footing is large.
- State of plastic equilibrium is reached initially at the footing edge and spreads gradually downwards and outwards.

Local Shear Failure

- This type of failure occurs in medium dense sand with relative density between 35 – 70 %.
- In this type of failure, failure takes place at a very large strain.
- The load settlement curve does not show a well-defined peak.
- At failure only a small portion of soil underneath the footing participates and well-defined rupture surfaces develop only at points directly below the footing.
- Bulging of soil at surface begins when strain exceeds about 8 %.
- The curve shows increase in resistance after failure.
- Local shear failure is accompanied by large strain (e> 10 to 20%) in a soil with considerably low (ϕ<28) and low N (N < 5) having low relative density (I_D> 20%).

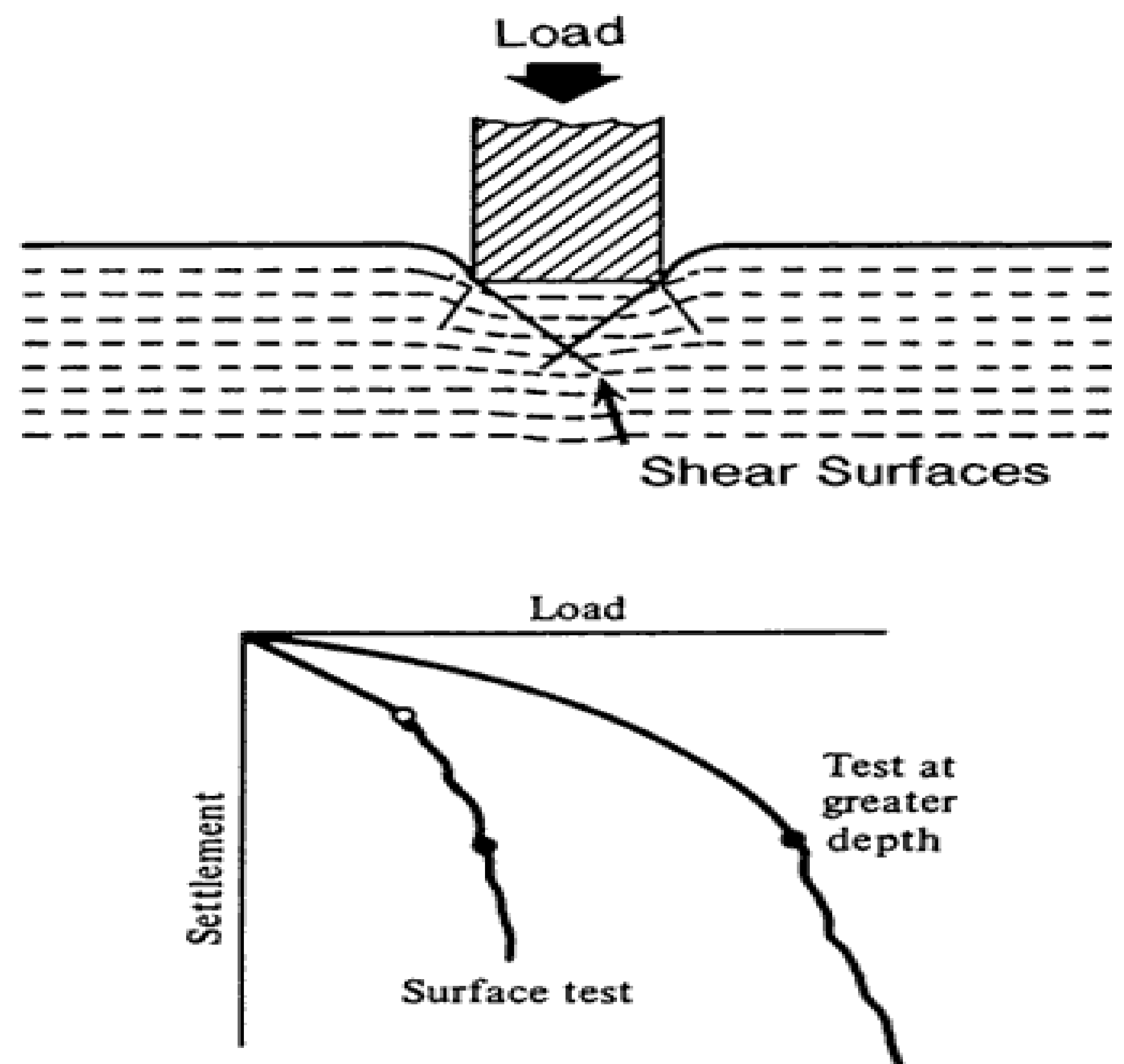

Load
Final Ground
Surface
Initial Ground
Surface
Shear Surfaces
Load
Settlement

The following are some characteristics of local shear failure

- A significant compression of soil below the footing and partial development of plastic equilibrium is observed.
- Failure is not sudden and there is no tilting of footing.
- Failure surface does not reach the ground surface and slight bulging of soil around the footing is observed.
- Failure surface is not well defined.
- Failure is characterized by considerable settlement.
- Well defined peak is absent in p - Δ curve.

Punching Shear Failure

- This type of failure occurs in loose sand or soft clay with relative density less than 35 %.
- In this type of failure, footing penetrates into the soil without any bulging in the soil at the surface.
- Increase in vertical load increases the vertical movement and compression in the foundation soil.
- The failure is accompanied by vertical shear around the perimeter of the footing.
- At failure, soil outside the loaded area does not participate and there will be no movement of soil on the sides of the footing.


Load
Shear Surfaces
Load
Settlement
Test at greater depth
Surface test

The following are some characteristics of punching shear failure

- This type of failure occurs in a soil of very high compressibility.
- Failure pattern is not observed.
- Bulging of soil around the footing is absent.
- Failure is characterized by very large settlement.
- Continuous settlement with no increase in P is observed in curve.

TERZAGHI'S BEARING CAPACITY ANALYSIS –

Terzaghi (1943) analysed a shallow continuous footing by making some assumptions –

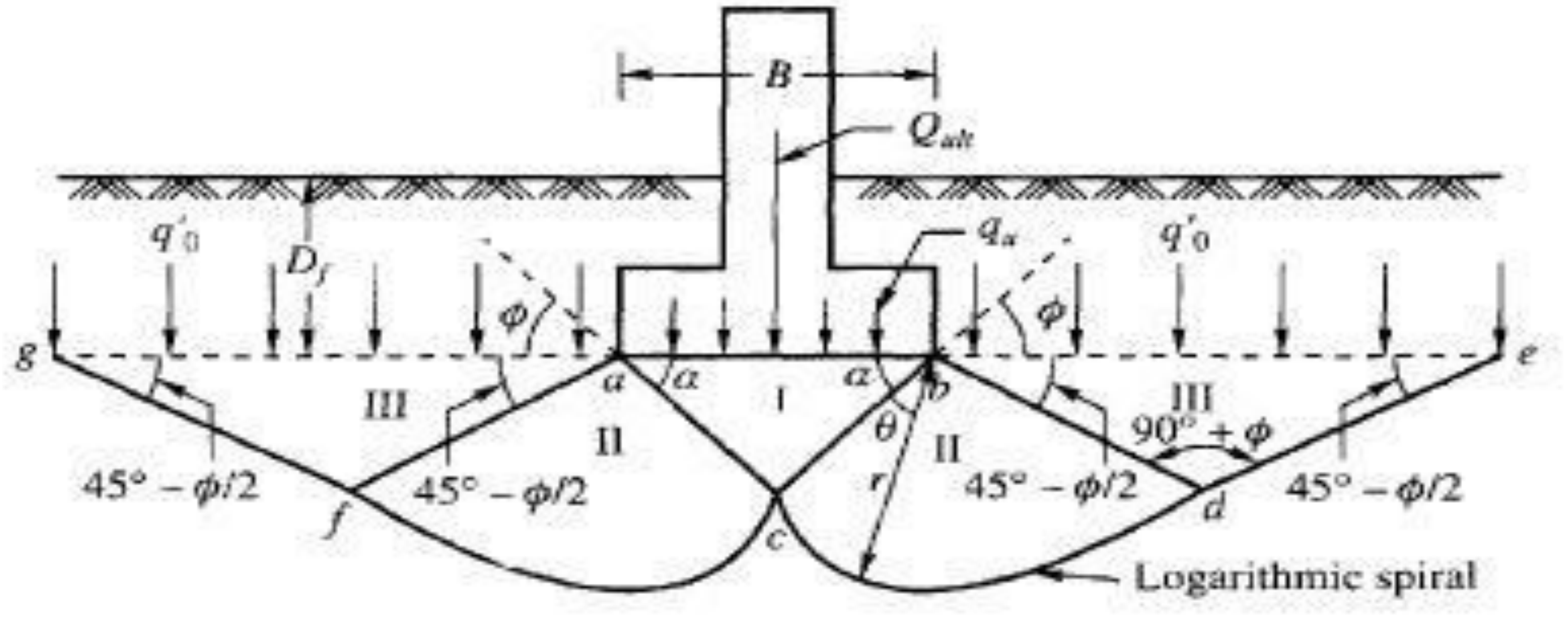


Figure 12.6 General shear failure surface as assumed by Terzaghi for a strip footing

Mechanism of Failure

The shapes of the failure surfaces under ultimate loading conditions are given in Fig. The zones of plastic equilibrium represented in this figure by the area may be subdivided into

1 . Zone I of elastic equilibrium

2. Zones II of radial shear state

3. Zones III of Rankine passive state

Terzaghi’s formula for bearing capacity

Terzaghi’s theory for bearing capacity is based on the following assumptions:

- ✓ The footing is a long strip or continuous footing
- ✓ The footing rests on a homogeneous , isotropic soil having c and ø
- ✓ The ground surface is horizontal
- ✓ The load is vertical and concentric
- ✓ The soil fails by ‘general shear’
- ✓ The base of the footing is rough
- ✓ The soil mass above the footing base can be replaced by an equivalent surcharge

Based on the above assumptions, the 'ultimate bearing capacity' or the 'gross ultimate bearing capacity' for a continuous footing q_u is give as

$$q_{u\ gross} = c\ N_c + \gamma\ D_f\ N_q + 0.5\ \gamma\ B\ N_r$$

where,

c = cohesion

γ = unit weight of the soil

D_f = depth of foundation / footing

B = width of footing

N_c, N_q, Nγ - bearing capacity factors. These are function of ø ; these values are read from the chart

$$q_{u\ net} = q_{u\ gross} - \gamma\ D_f$$

$$q_{u\ gross} = c\ N_c + \gamma\ D_f\ (N_q - 1) + 0.5\ \gamma\ B\ N_r$$

Factors affecting bearing capacity:

c ,ø ,γ of the soil

Depth , D_f and width,B of footing / foundation

(a) shape (square , rectangular , circular)

(b) mode of failure (general shear ,local shear)

(c) depth of water table

Shape of foundation

Modification for square , rectangular and circular footings

for square / rectangular footing

$$q_{u\ net} = 1.2\, c\, N_c + \gamma\, D_f\, (N_q - 1) + 0.4\, \gamma\, B\, N_\gamma$$

for Circular footing

$$q_{u\ net} = 1.2\, c\, N_c + \gamma\, D_f\, (N_q - 1) + 0.3\, \gamma\, B\, N_\gamma$$

B = smaller size of the rectangular footing / diameter of the circular footing

Mode of failure:(local shear failure)

The equation for bearing capacity is obtained based on general shear failure. Local shear failure occurs in loose sand and soft clays. In such cases the cohesion value is taken as 2/3 c and the bearing capacity factors are read from the dotted line curves of the chart.

Accordingly, the equate for bearing capacity is written as

for continuous footing

$$q_{unet} = 2/3\ c\ N'_c + \gamma\ D_f\ (N'_q - 1) + 0.5\ \gamma B\ N\gamma'$$

for square / rectangular footing

$$q_{unet} = 1.2 * 2/3\ c\ N_c' + \gamma\ D_f\ (N'_q - 1) + 0.4\gamma B\ N'_\gamma$$

for circular footing

$$q_{unet} = 1.2 * 2/3\ c\ N_c' + \gamma\ D_f\ (N'_q - 1) + 0.3\ \gamma B\ N'_\gamma$$

Effect of water table

The position of W.T. affects the bearing capacity.

The effect of W.T is illustrated for a rectangular footing. The effect is incorporated in the same manner in all other cases.

when water table is more than ‘B’ below base

No effect of W.T on bearing capacity

BIS (IS) formula for bearing capacity

IS : 6403 – 1981 has recommended the following formula which accounts for (i) shape of footing (ii) depth of footing (iii) inclination of load

$$q_{unet} = c\,N_c\,S_c\,dc\,i_c + \gamma\,D_f\,(Nq - 1)\,S_q\,d_q\,i_q + 0.5\,\gamma\,B\,N_\gamma\,S_\gamma\,d_\gamma\,i_\gamma$$

S_c , S_q , S_r ----------shape factors

d_c , d_q , d_r -------------depth factors

i_c , i_q , i_r ----------------inclination factors

consideration of W.T , local shear failure are done the sand way as in Terzaghi's eqn

FACTORS AFFECTING BEARING CAPACITY

- Total and differential settlements
- Location of ground water
- Initial stresses
- Nature of soil
- Physical and engineering properties of soil
- Nature of proposed foundation
- Size and shape of the foundation
- Depth of foundation below the ground surface
- Rigidity of the foundation structure

PLATE LOAD TEST

- Plate load test is performed to determine the ultimate load bearing capacity of soil over the in-situ conditions.
- The plate load test is mandatory in case of designing foundation over the sandy and clayey soil.
- This test gives the highest rate of accuracy determining the safe bearing capacity of soil in case of shallow foundations.
- This test determines the Ultimate Bearing capacity of Soil, Settlement of foundation & Allowable bearing pressure of soil.
- Plate load test is suitable for Cohesion less soil as in case of Cohesion soil the settlement takes place in longer duration which this test is not suitable.

- In this test, the square rigid plate having dimensions 300mm x 300mm or Circular rigid plate having dia 300mm (larger dia plates may also used if the soil is in very loose condition) is placed on a foundation and load is applied in increments on the plate with the help of hydraulic jack.
- Then the settlement per each load increment is recorded to calculate the bearing capacity of the soil.

Varieties in Plate load test and their durations:-

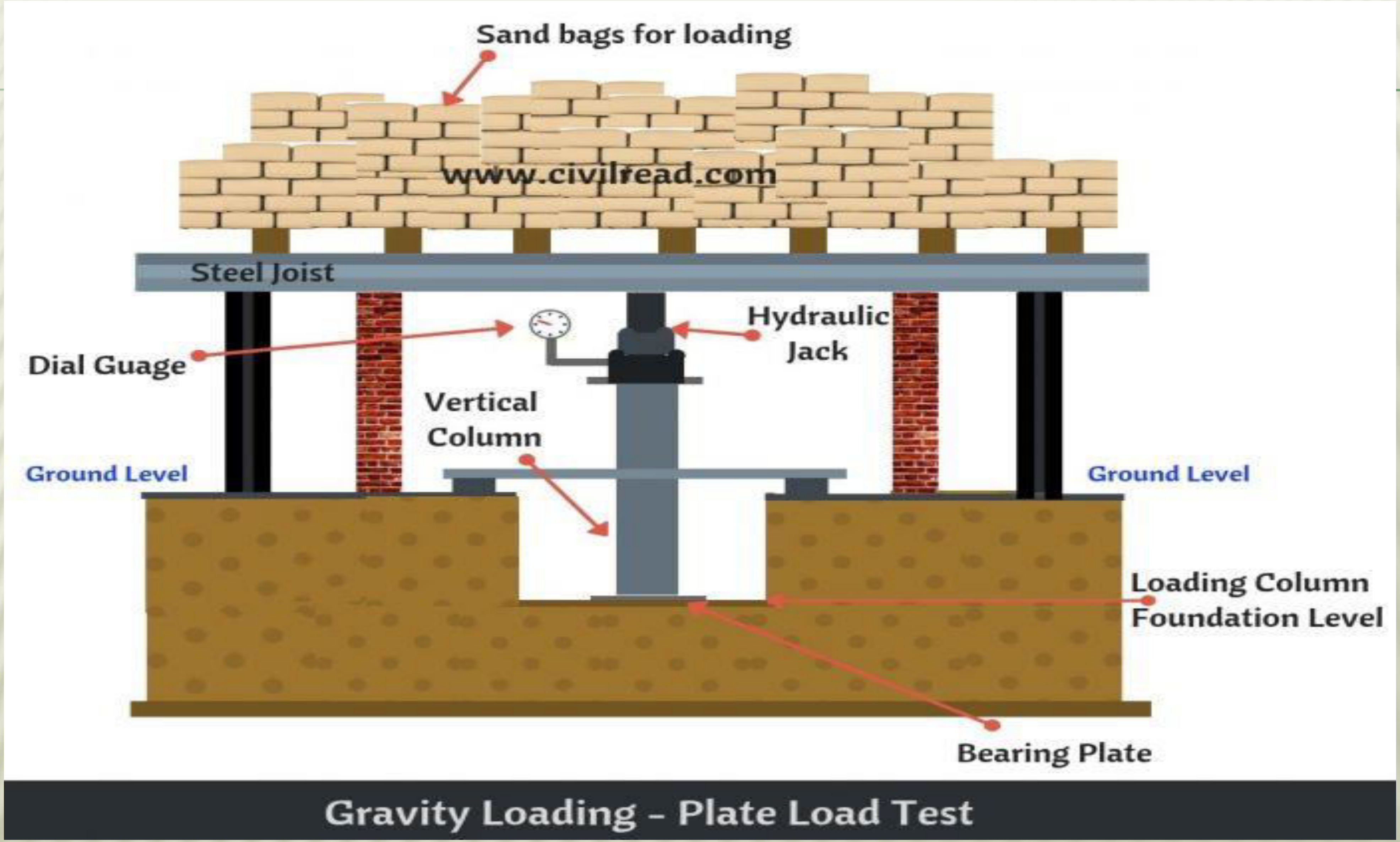
Plate load test is performed under two variations:

1) Gravity load test (Reaction Loading method)
2) Reaction truss method

- The total duration required to perform a complete test varies from 6-7 days which includes installations, test, dismantling.
- The results of the test in case of soft strata can be obtained within a few hours whereas in case of hard strata it might take close to a couple of days.

1.Gravity load test

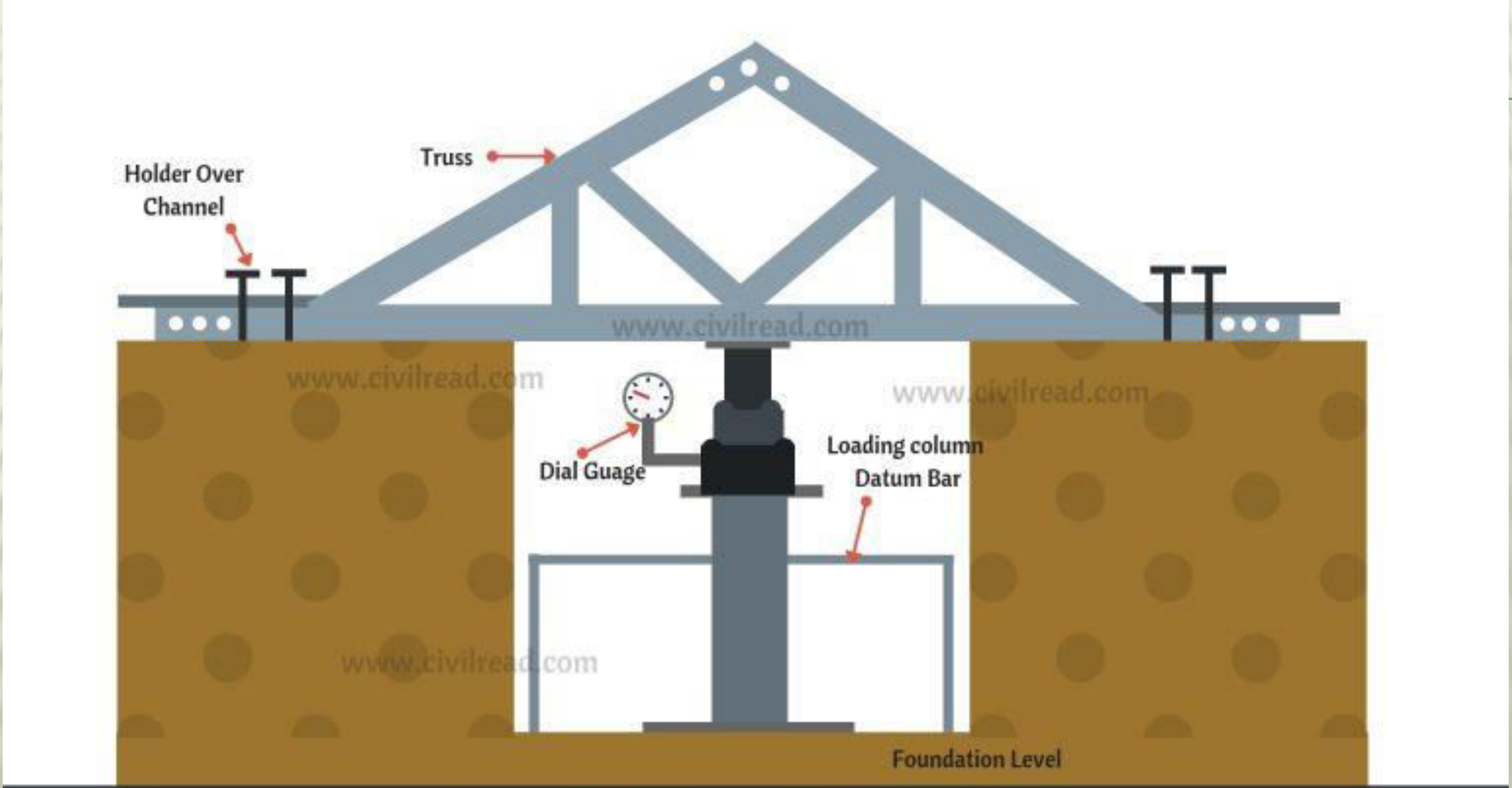
- In this type of method, a rigid platform is utilized to transfer loads through loading of sandbags or concrete blocks.
- These blocks and sandbags act as a dead weight, and whole arrangement rests upon vertical columns.
- The hydraulic jack is provided in between the rigid plate and top of the column to transfer the load properly.



Sand bags for loading
www.civilread.com
Steel Joist
Hydraulic Jack
Dial Guage
Vertical Column
Ground Level
Ground Level
Loading Column
Foundation Level
Bearing Plate
Gravity Loading – Plate Load Test

2.Reaction truss method

- In this method, the reaction generated through jack is borne by reaction truss installed over it.
- The undesirable movement of truss is controlled by soil anchors or nails fixed into the soil with the help of hammers.
- The most commonly observed truss is made of mild steel sections.
- In order to curb later movement, truss is locked with guy ropes.



Reaction Truss Method - Plate Load Test

PLATE LOAD TEST APPARATUS / EQUIPMENT

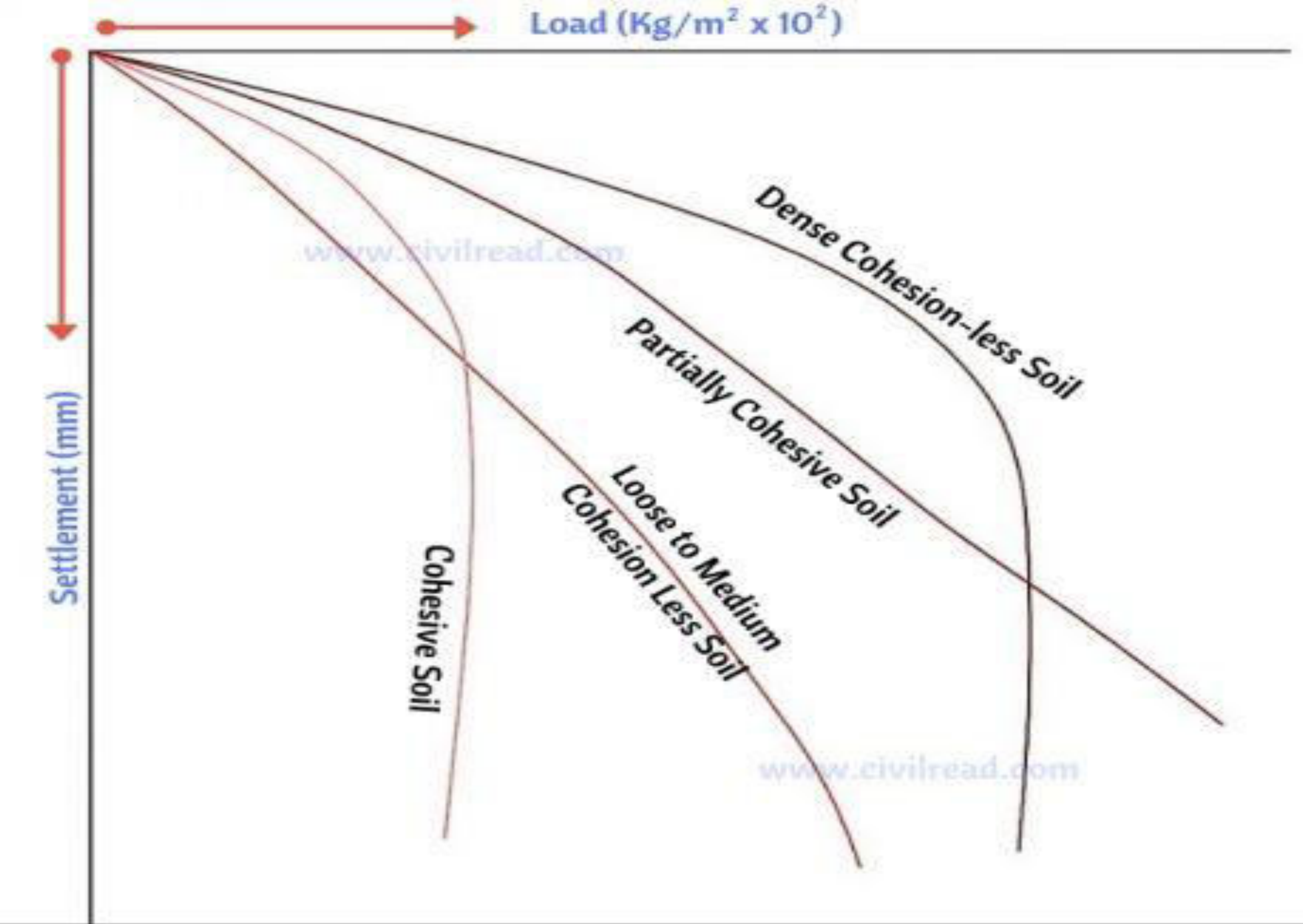
- Excavating tools
- Hydraulic jack (ball socket type with 50 T capacity)
- Mild steel plate (25 mm thickness & (30*30) cm)
- Dial gauges (minimum 3)
- Reaction beam and reaction truss with soil nails
- Plum Bob (To determine center)

PLATE LOAD TEST PROCEDURE

- The pit is excavated over the site of test with the size of 1.5×1.5m and to the depth of proposed foundations.
- One needs to find the centre of excavated pit and portion to the size of the plate is eroded to the depth 1-2 cm.
- Ensure that the foundation area must be 5 times the area of plate and the seating load of 0.07Kg/cm² is applied to prevent undulations below the plate.
- The eroded portion is filled with rock dust in order to counter undulations and that of plate installed is completely horizontal which on later is checked by tube level.
- Spacers are installed over the hydraulic plate on which hydraulic jack is installed.
- The hydraulic jack in order to counter the load applies pressure which in result leads to transmission of pressure over the plate.
- Setting load of 7kN/m² is applied for some time and released. This is followed by the application of safe load with an increment of 30%.
- In case of loading through truss, both free sides are anchored with soil nails with uniformly loading at the ends.

Results recording:

- Dial gauges arranged at the bottom of the pit record are used to record settlement at every 5 minutes for first 30 minutes and every 10 minutes for rest 30 minutes.
- The observation are made until 25 mm settlement is observed which can take few hours for clayey and soft soil or even up-to couple of days for hard strata.



Load Settlement Curve

PLATE LOAD TEST OBSERVATION SHEET

Project name:

Site location:

Depth of testing:

Depth of water table:

Date of testing:

Load (kN)	Time	Settlement dial gauge -1			Settlement dial gauge - 2		
		Dial gauge reading	Settlement (mm)	Cumulative settlement	Dial gauge reading	Settlement (mm)	Cumulative settlement

CALCULATION OF BEARING CAPACITY OF SOIL

The whole process of calculating bearing capacity of soil using plate load test data consists of the following 4 primary steps.

Step-1 (Plotting a Load-Settlement Curve)

Step-2 (Finding Ultimate Bearing Capacity)

Step-3 (Calculating Safe Bearing Capacity)

Step-4 (Calculating Settlement of Proposed Footing)

STEP-1 (PLOTTING A LOAD-SETTLEMENT CURVE)

After performing the plate load test, plot a load settlement curve on arithmetic scale, with applied **pressure** in kN/m2 **in x-axis** and corresponding **settlement** (in mm) **in y-axis**.

STEP-2 (FINDING ULTIMATE BEARING CAPACITY)

After drawing the load settlement curve, the next step is to identify the failure point on the load settlement curve.

STEP-3 (CALCULATING SAFE BEARING CAPACITY)

In order to calculate safe bearing capacity of the soil, divide the ultimate bearing capacity of soil by a suitable factor of safety.

Safe bearing capacity of soil = Ultimate bearing capacity / Factor of safety

The values of factor of safety normally used are **2**, **2.5** or **3** depending upon the site condition and importance of the structure.

STEP-4 (CALCULATING SETTLEMENT OF PROPOSED FOOTING)

The following formula as suggested by **Terzaghi and Peck** is used to calculate the settlement of footing **for granular soil**.

$$S_f = S_p[B_f (B_p + 0.3)/B_p(B_f + 0.3)]^2$$

For clayey soil the following equation can be used.

$$Sf = Sp*(B/Bp)$$

Where,

Sp = Settlement of plate, mm

Sf = Settlemnt of footing, mm

Bp = Width or dia of plate, m

B = Width of footing, m

Allowable bearing pressure (or) stress and loadand resistance factor design:

There are two design procedures used in practice in North America.

- ✓ Allowable stress design (ASD
- ✓ Load and resistance factor design (LRFD).

In ASD, the ultimate load (stress) resistance is determined, and then this is divided by a factor of safety (FS) to obtain the allowable load (stress).

- LRFD is based on reliability methods considering the uncertainties in loads, soil resistance, method of analysis, and construction.
- The loads are multiplied by load factors, usually greater than one in different combinations, and the ultimate soil resistance is multiplied by a factor, called the performance factor, usually less than one.
- The governing equation for design based on LRFD is

$$\sum_i \rho_i P_i < \varphi_i R_i$$

COMPONENTS OF SETTLEMENT:

1. Elastic settlement (Si)
2. Consolidation settlement (Sc)
3. Secondary consolidation settlement (Ss)

Total settlement = Immediate Settlement + Consolidation Settlement

- ✓ Immediate settlement or elastic settlement takes place during or immediately after the construction of the structure.

Consolidation Settlement occurs over a period of time. Consolidation settlement occurs in cohesive soils due to the expulsion of the water from the voids.

$$S_{Consolidation} = S_{primary} + S_{secondary}$$

Primary Consolidation

Volume change is due to reduction in pore water pressure

Secondary Consolidation

Volume change is due to the rearrangement of the soil particles

Uniform settlement

When all points settle with equal amount, then the settlement is called uniform settlement

ALLOWBLE SETTLEMENT:

Average settlement ranging from 20 mm to 300 mm have been permitted in engineering practice ,depending on the type of soil, structure, construction type.

According to IS 1904 permits tolerable settlement S as under,

	Sand	clay
(a) Isolated foundations	60 mm	75 mm
(b) Raft foundations	65 mm	100mm

According to British code permits tolerable settlement S as under,

	Sand	clay
(a) Isolated foundations	50 mm	75 mm
(b) Raft foundations	75 mm	125 mm

Methods of minimizing settlement and differential settlement:

- ✓ Preloading or pre-compaction to decrease compressibility.
- ✓ Decreasing the effective load by floating foundation effect.
- ✓ Increasing the depth of foundation (in sandy soils) to take advantage of increasing modulus of soil.
- ✓ Use of piles or piers.
- ✓ In-situ reinforcement of bearing layer.

UNIT III

FOOTINGS AND RAFTS

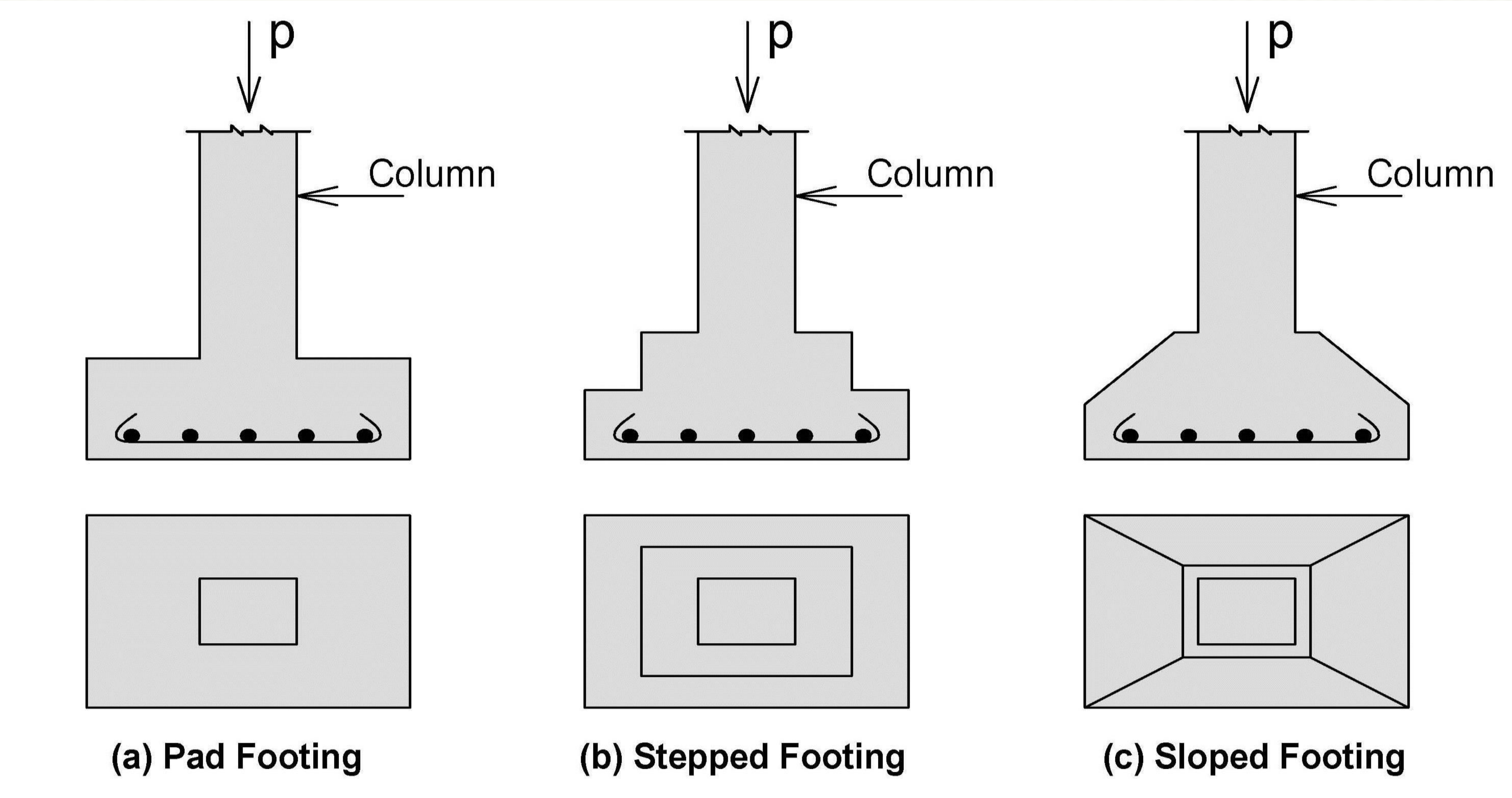
Types of footings – Contact pressure distribution: Isolated footing – Combined footings – Types and proportioning – Mat foundation – Types – Proportioning of footing – Floating foundation.

TYPES OF FOOTINGS

- Spread or isolated or pad footing
- Strap footing
- Combined footing
- Strip or continuous footing
- Mat or raft footing

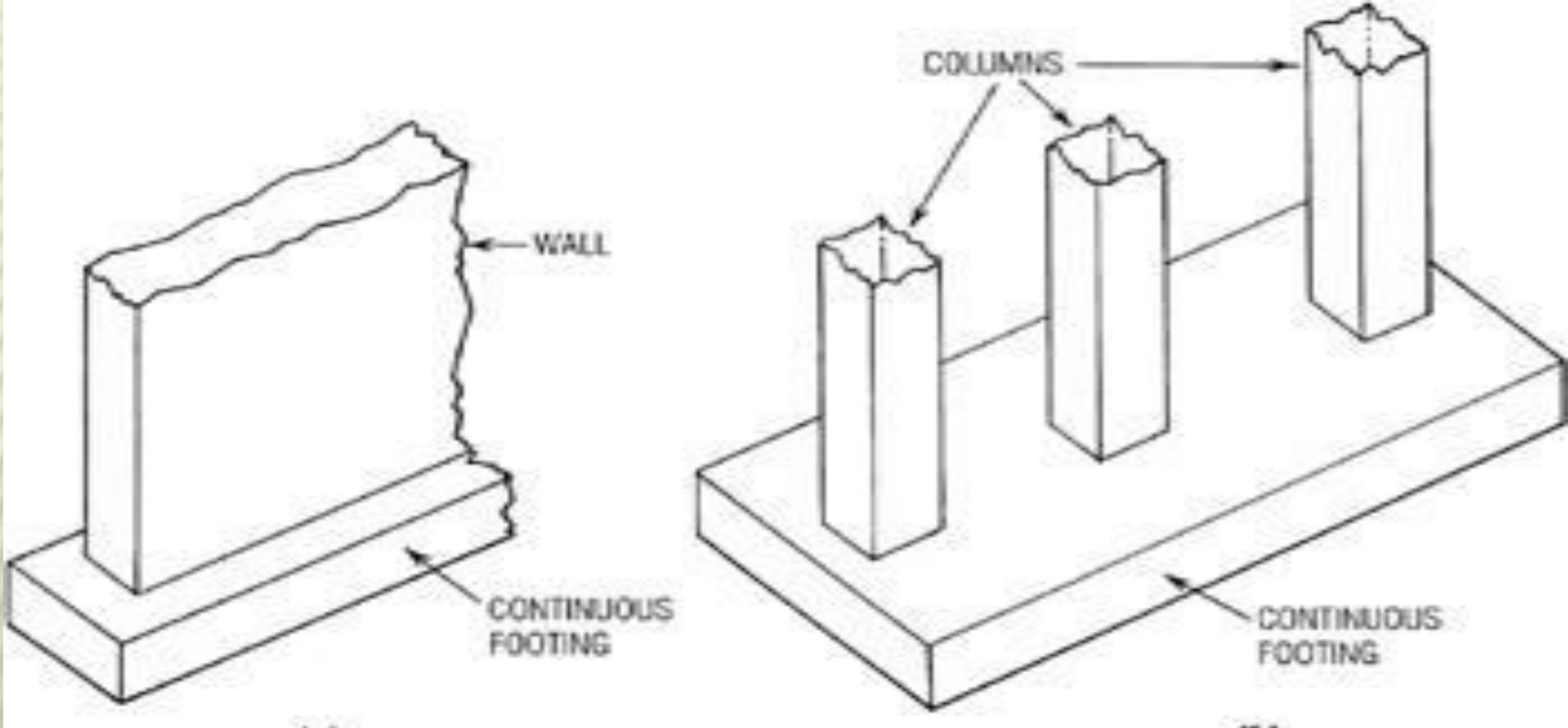
SPREAD FOOTING OR ISOLATED OR PAD FOOTING

- ✓ It is circular, square or rectangular slab of uniform thickness. Sometimes, it is stepped to spread the load over a larger area.
- ✓ When footing is provided to support an individual column, it is called “isolated footing”.


p
Column
p
Column
p
Column
(a) Pad Footing
(b) Stepped Footing
(c) Sloped Footing

STRIP FOOTING OR CONTINUOUS FOOTING

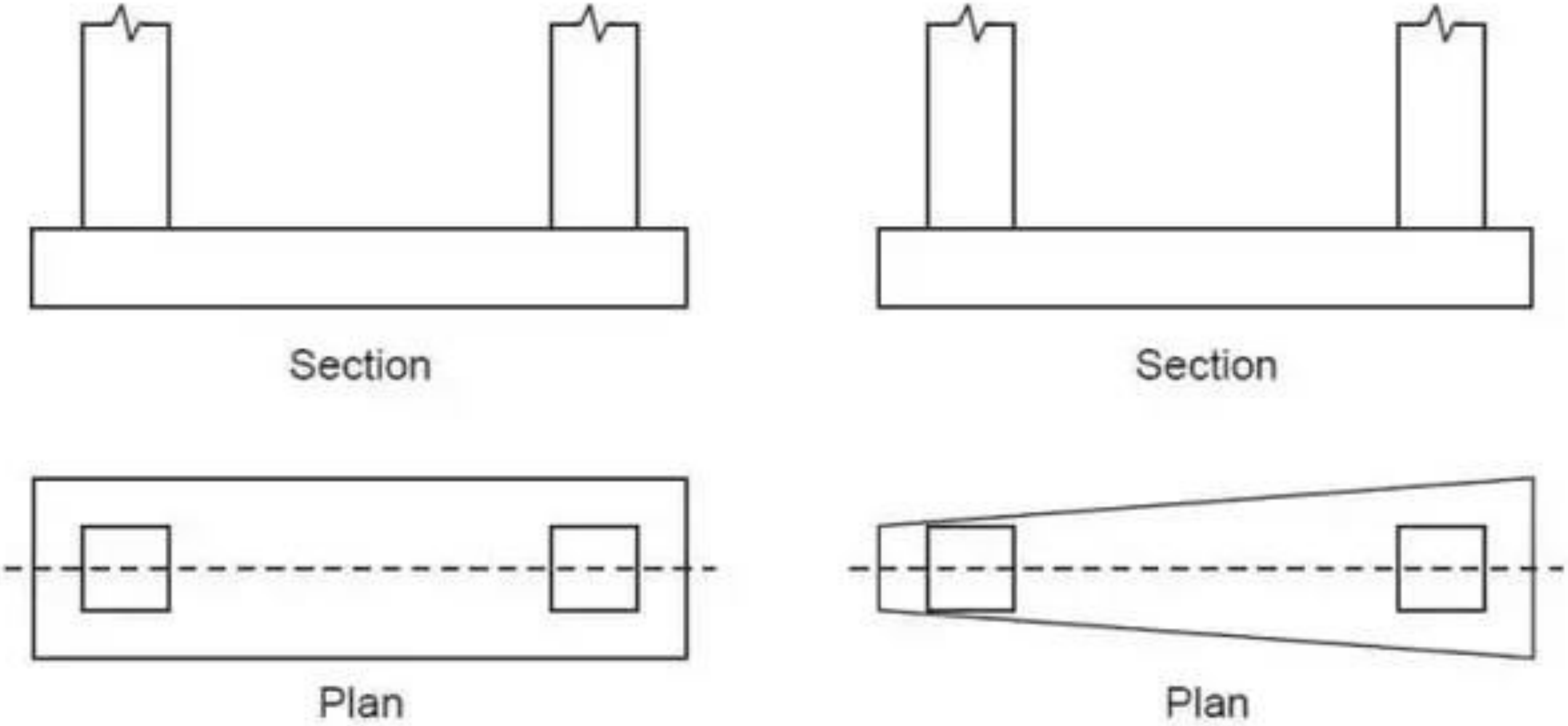
- A strip footing is another type of spread footing which is provided for a load bearing wall.
- A strip footing can also be provided for a row of columns which are so closely spaced that their spread footings overlap or nearly touch each other.
- In such cases, it is more economical to provide a strip footing than to provide a number of spread footings in one line. A strip footing is also known as continuous footing.



(a)
(b)

COMBINED FOOTING

- It supports two columns as shown in figure below. It is used when the two column are so close to each other that their individual footings would overlap.
- A combined footing is also provided when the property line is so close to one column that a spread footing would be eccentrically loaded when kept entirely within the property line.
- By combining it with that of an interior column, the load is evenly distributed. A combine footing may be rectangular or trapezoidal in plan.
- Trapezoidal footing is provided when the load on one of the column is larger than the other column.

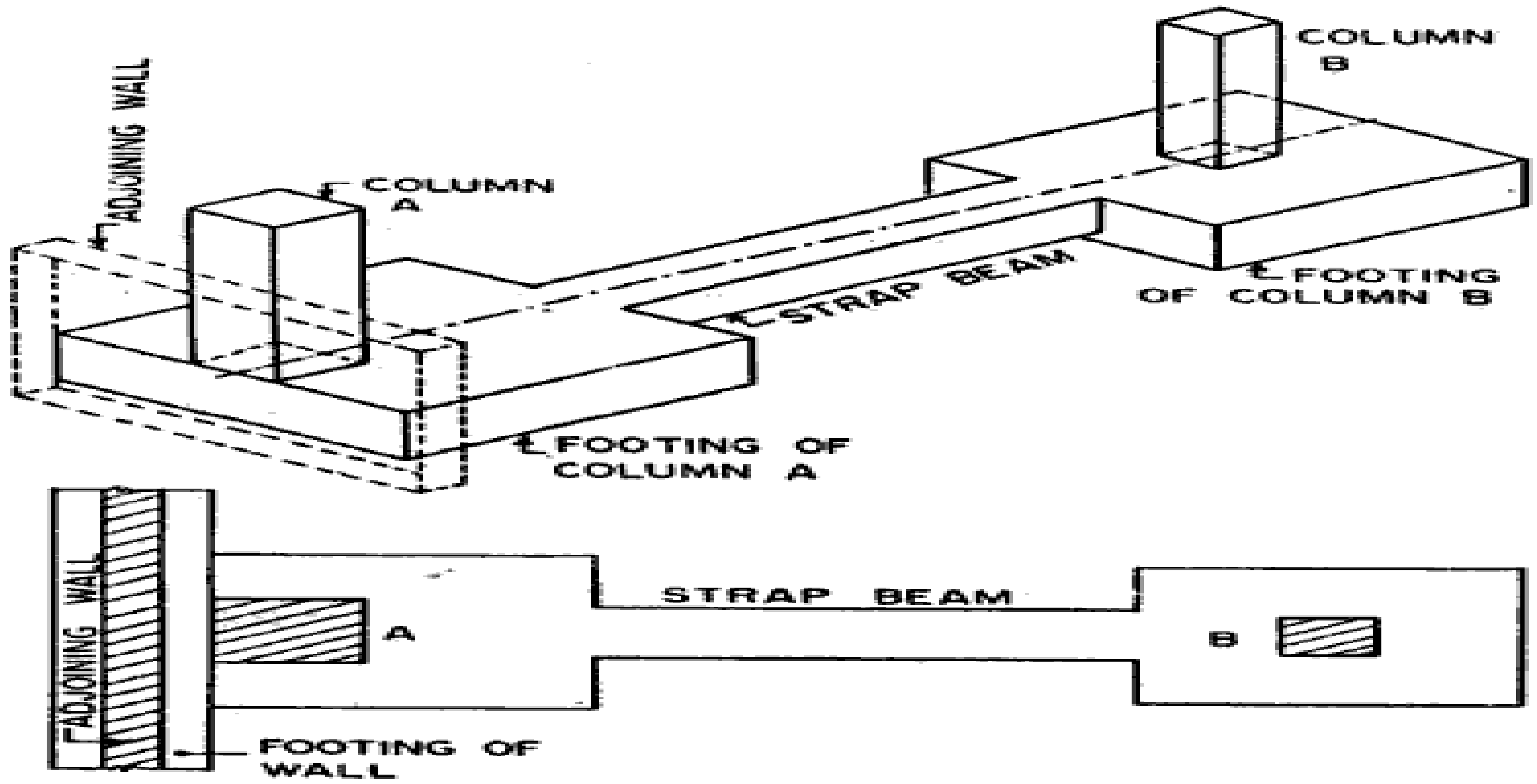


(a) Rectangular combined footing

(b) Trapezoidal combined footing

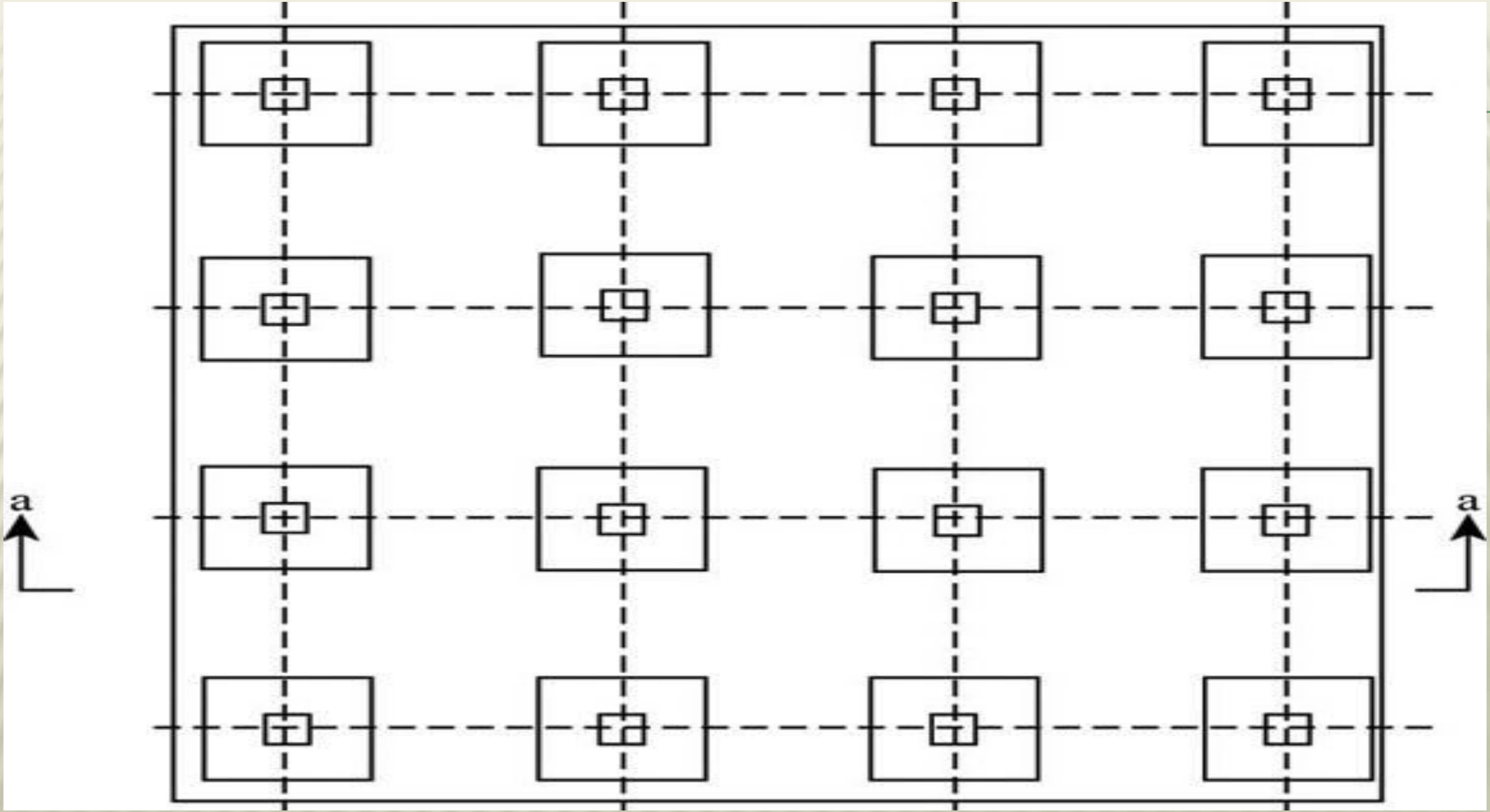
STRAP FOOTING

- It consists of two isolated footings connected with a structural strap or a lever, as shown in figure below.
- The strap connects the footing such that they behave as one unit. The strap simply acts as a connecting beam.
- A strap footing is more economical than a combined footing when the allowable soil pressure is relatively high and distance between the columns is large.


COLUMN B
ADJOINING WALL
COLUMN A
STRAP BEAM
FOOTING OF COLUMN B
FOOTING OF COLUMN A
STRAP BEAM
A
B
ADJOINING WALL
FOOTING OF WALL

MAT OR RAFT FOOTING

- ✓ It is a large slab supporting a number of columns and walls under entire structure or a large part of the structure.
- ✓ A mat is required when the allowable soil pressure is low or where the columns and walls are so close that individual footings would overlap or nearly touch each other.
- ✓ Mat foundations are useful in reducing the differential settlements on non-homogeneous soils or where there is large variation in the loads on the individual columns.


a
a

CONTACT PRESSURE DISTRIBUTION

Contact Pressure

On the underside of the footing, the soil reaction produce a upward pressure which is assumed uniform in deriving different relationship for soil-structure interaction problem. This pressure is called contact pressure.

FACTORS INFLUENCING CONTACT PRESSURE

The actual distribution of contact pressure depends upon a number of factors such as

1) Elastic properties of footing

2) Elastic properties of soil

3) Thickness of footing

Different characteristics of contact pressure distribution under flexible and rigid footings are described below:

Contact Pressure On Saturated Clay

1. ***Flexible Footing***
2. ***Rigid Footing***

CONTACT PRESSURE ON SATURATED CLAY

Flexible Footing

When a footing is flexible, it deforms into shape of bowel, with the maximum deflection at the center. The contact pressure distribution is uniform.

Rigid Footing

When a footing is rigid, the settlement is uniform. The contact pressure distribution is minimum at the center and the maximum at the edges. The stresses at the edges in real soils can not be infinite as theoretically determined for an elastic mass. In real soils, beyond a certain limiting value of stress, the plastic flow occurs and the pressure becomes finite.

CONTACT PRESSURE ON SATURATED CLAY

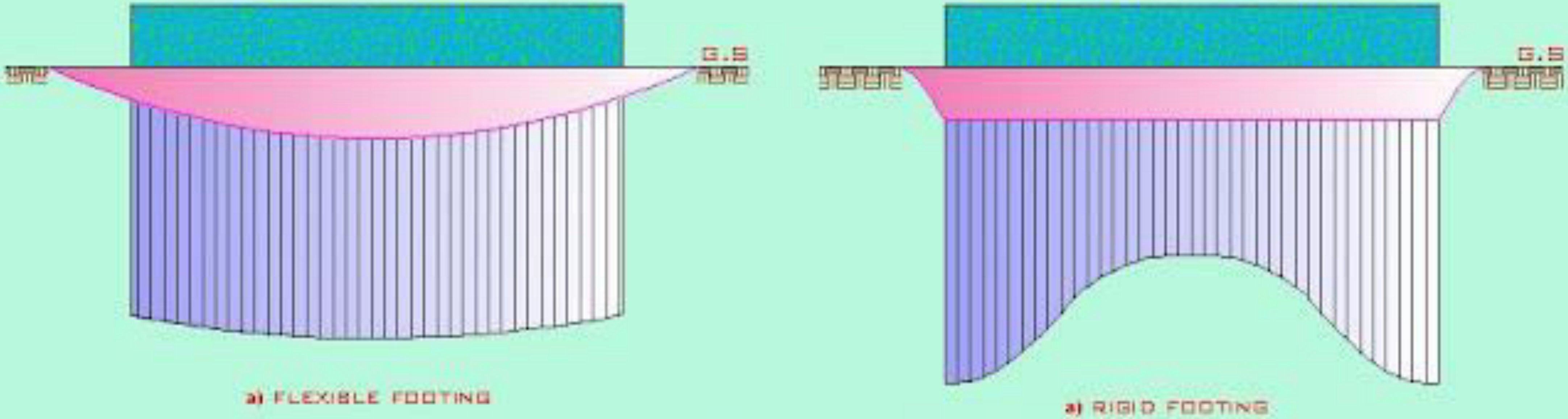


FIG. 1 CONTACT PRESSURE ON SATURATED CLAY

CONTACT PRESSURE ON SAND

Flexible footing

- In this case, the edges of flexible footing undergo a large settlement than at the centre.
- The soil at the centre is confined and, therefore, has a high modulus of elasticity and deflects less for the same contact pressure. The contact pressure is uniform.

CONTACT PRESSURE ON SAND

Rigid footing

- **I**f the footing is rigid, the settlement is uniform. The contact pressure increases from zero at the edges to a maximum at the centre.
- The soil, being unconfined at edges, has low modulus of elasticity. However, if the footing is embedded, there would be finite contact pressure at edges.

CONTACT PRESSURE ON SAND

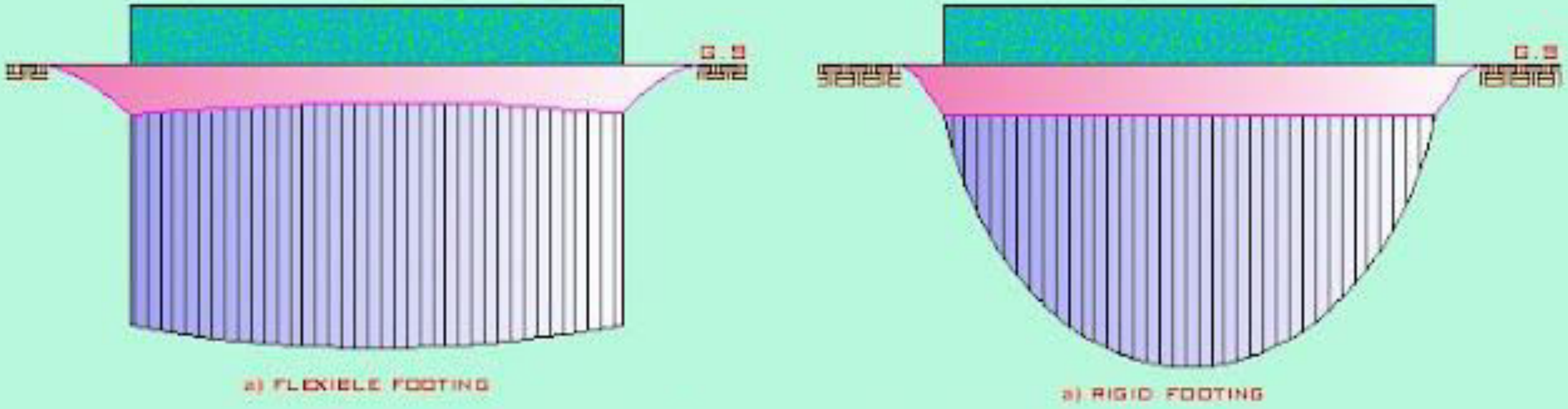


FIG. 2 CONTACT PRESSURE ON SAND.

CONSEQUENCE OF ASSUMING UNIFORMITY IN PRESSURE

- For convenience, the contact pressure is assumed to be uniform for all types of footings and all types of soils if load is symmetric.
- The above assumption of uniform pressure distribution will result in a slightly unsafe design for rigid footing on clays, as the maximum bending moment at centre is underestimated.
- It will give a conservative design for rigid footings on sandy (cohessionless) soils, as the maximum bending moment is overestimated.

UNIFORM PRESSURE DISTRIBUTION

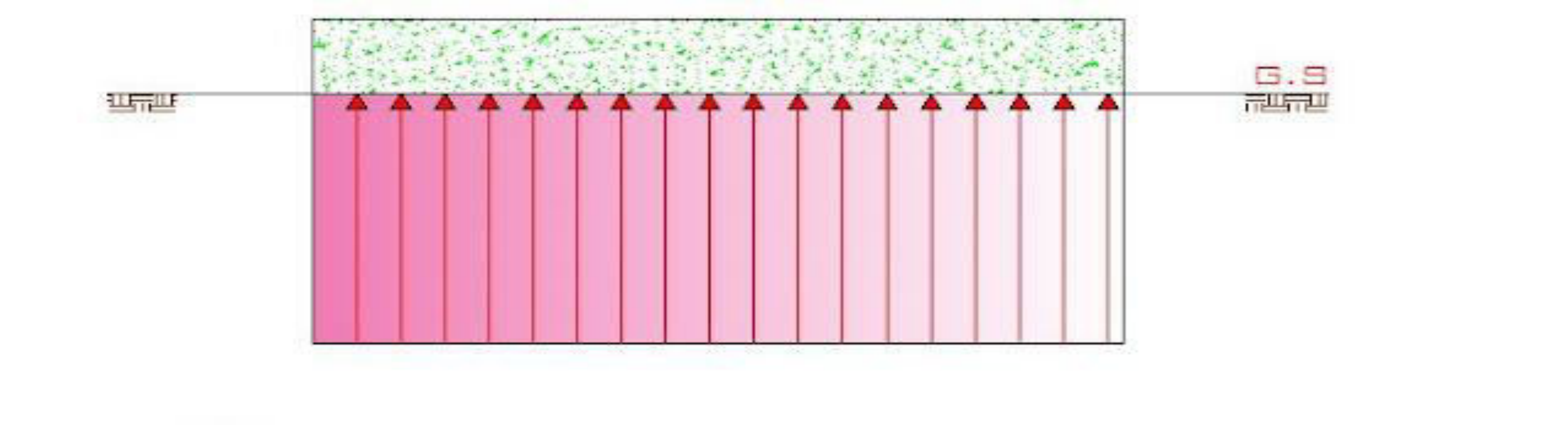


FIG. 2 UNIFORM CONTACT PRESSURE.

TYPES OF RAFT FOUNDATION:

FLAT TYPE:

- In this type of mat foundation a mat of uniform thickness is provided.
- This type is most suitable when the column loads are relatively light and the spacing of columns is relatively small and uniform.

FLAT PLATE THICKENED UNDER COLUMN:

- When the column loads are heavy this column is thickened to provide enough thickness for negative bending moment and diagonal shear.
- Sometimes instead of thickening a slab, a pedestal is provided under each column above the slab to increase the thickness.

BEAM AND SLAB CONSTRUCTION:

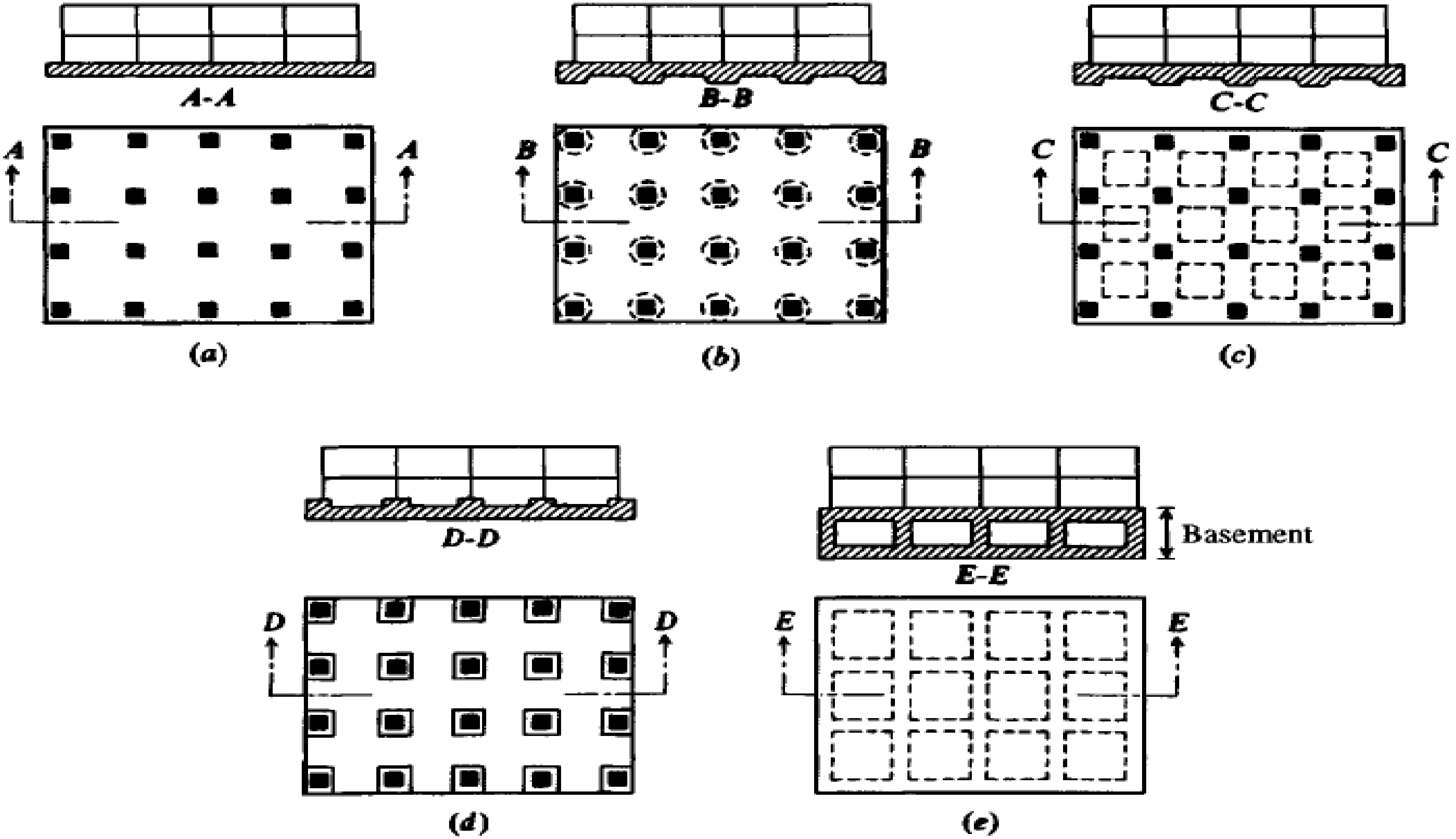
- In this type of construction, the beams run in two perpendicular directions and a slab is provided between the beams. The columns are located at the intersection of beams.
- This type is suitable when the bending stresses are high because of large column spacing and unequal column loads.

BOX STRUCTURES:

- In this type of mat foundation, a box structure is provided in which the basement walls acts as a stiffeners for the mat.
- Boxes may be made of cellular construction or rigid frame consisting of slabs and basement walls. This type of mat foundation can resist very high bending stresses.

MATS PLACED ON PILES:

- ✓ The mat is supported on the piles in this type of construction. This type of mat is used where the soil is highly compressible and the water table is high.
- ✓ This method of construction reduces the settlement and also controls buoyancy.


A-A
A
A
(a)
B-B
B
B
(b)
C-C
C
C
(c)
D-D
D
D
(d)
Basement
E-E
E
E
(e)

ADVANTAGES:

- The foundation and ground floor slab is poured at the same time so which reduces our construction time and material.
- It requires less excavation.
- It is provided where the shallow foundation is possible but the condition of the soil is poor.
- Reduces the cost of constructing a floor slab (But not fully economical).
- It helps in the transferring of loads over a wide area.
- It shows good resistance and cannot slide during the flood.
- We can handle more heavy loads as compared to other types of foundation.

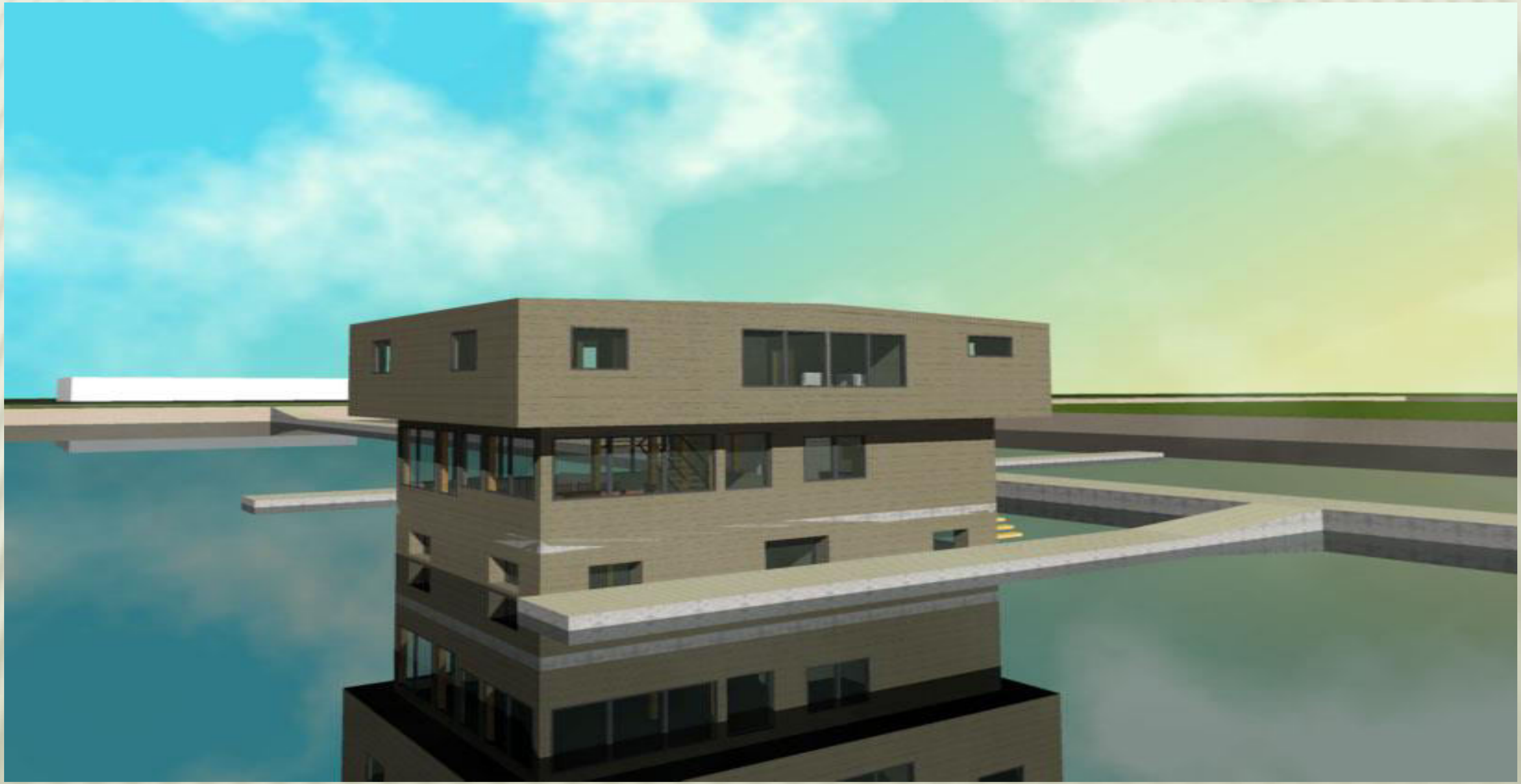
DISADVANTAGES:

- Raft foundation requires a large quantity of steel and concrete.
- This foundation is costly (Volume of footing was increasing).
- It is not suitable and used for domestic home construction.
- Special measurement is needed in case of concentrated loads.
- In the mat foundation, skilled laborers are required.

FLOATING FOUNDATION

- A building support on soft soil that consists of a stiff reinforced concrete slab which distributes the concentrated loads by columns to the soil so that the pressure intensity on the soil is nowhere more than the acceptable amount.
- The weight of the building approximately equal to the full weight of soil and water removed from the site of the building.
- The water level has not changed the neutral pressure are therefore unchanged.
- Settlements are caused by an effective vertical pressure

- When the soil is so soft that even friction piles will not support the building load, the final option is the use of a **floating foundation**, making the building like a boat that obeys Archimedes' principle—it is buoyed up by the weight of the earth displaced in creating the foundation.
- Floating foundations consist of flat reinforced concrete slabs or mats or of reinforced concrete tubs.



UNIT IV

PILE FOUNDATION

Types of piles and their function – Factors influencing the selection of pile – Carrying capacity of single pile in granular and cohesive soil – static formula – dynamic formulae (Engineering news and Hileys) – Capacity from insitu tests (SPT and SCPT) – Negative skin friction – Group capacity and efficiency (Feld's rule, Converse – Labarra rule and block failure) – Settlement of pile groups – Interpretation of pile load test (routine test only) – Under reamed piles – Capacity under compression and uplift.

PILES

PILES

- ✓ Piles are the long slender members either driven or cast in situ
- ✓ Piles are subjected to vertical or lateral loads or a combination of vertical and lateral loads
- ✓ Piles are also used to take up uplift loads
- ✓ Piles may be used as a single pile or a group of piles

CLASSIFICATION OF PILES

CLASSIFICATION BASED ON THE FUNCTION

a. Friction piles
b. End bearing piles
c. Compaction piles
d. Anchor piles
e. Tension piles
f. Fender & Dolphin piles
g. Batter piles
h. Sheet piles

CLASSIFICATION OF PILES

CLASSIFICATION BASED ON MATERIALS USED &COMPOSITION

1. Concrete piles
    - i. precast piles
    - ii. Cast in situ piles
        - a. Driven cast in situ piles
        - b. Bored cast in situ piles
2. Timber piles
3. Steel piles
4. Composite piles
    - i. Steel & Concrete piles
    - ii. Timber & Concrete piles

CLASSIFICATION OF PILES

FRICTION PILES

Friction piles are used to transfer loads to a depth of a friction load carrying material by means of skin friction along the length of the piles

END BEARING PILES

End bearing piles are used to transfer load through water or soft soil to a suitable bearing stratum

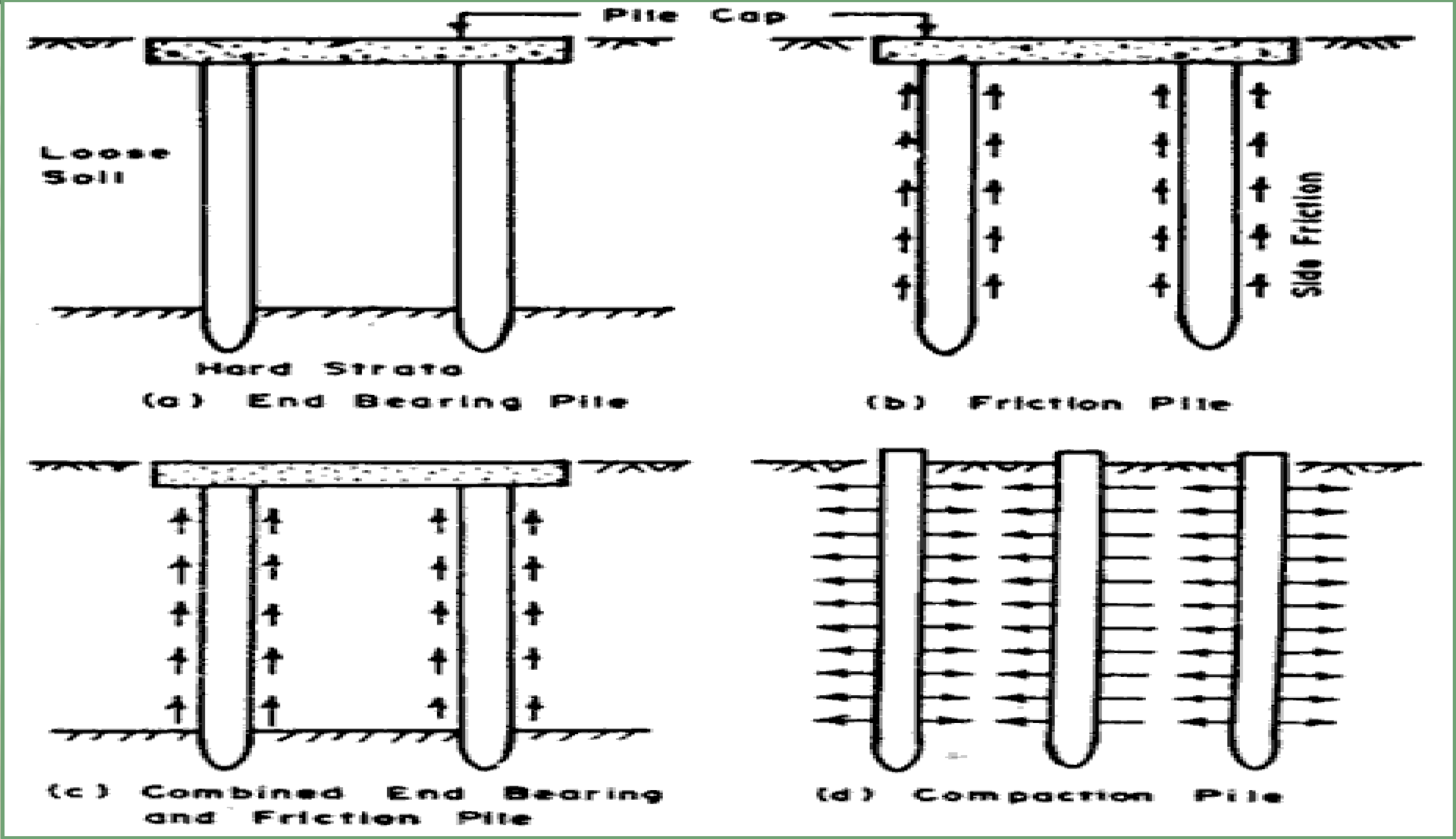
COMPACTION PILES

Compaction piles are used to compact loose granular soil, thus increasing their bearing capacity

Compaction piles themselves do not carry any load. Hence it is used to compact the soil

The pile tube driven to compact the soil is gradually taken out and sand is filled in its place. Thus forming a “Sand Pile”

CLASSIFICATION OF PILES



CLASSIFICATION OF PILES

TENSION PILES

Tension piles anchor down the structures subjected to uplift due to hydrostatic pressure or due to overturning moment and hence it is also called as “Uplift piles”

ANCHOR PILES

Anchor piles provide anchorage against horizontal pull from sheet piling or other pulling forces

FENDER PILES & DOLPHINS

Fender piles & Dolphins are used to protect water front structures against the impact from ships or other floating objects

CLASSIFICATION OF PILES

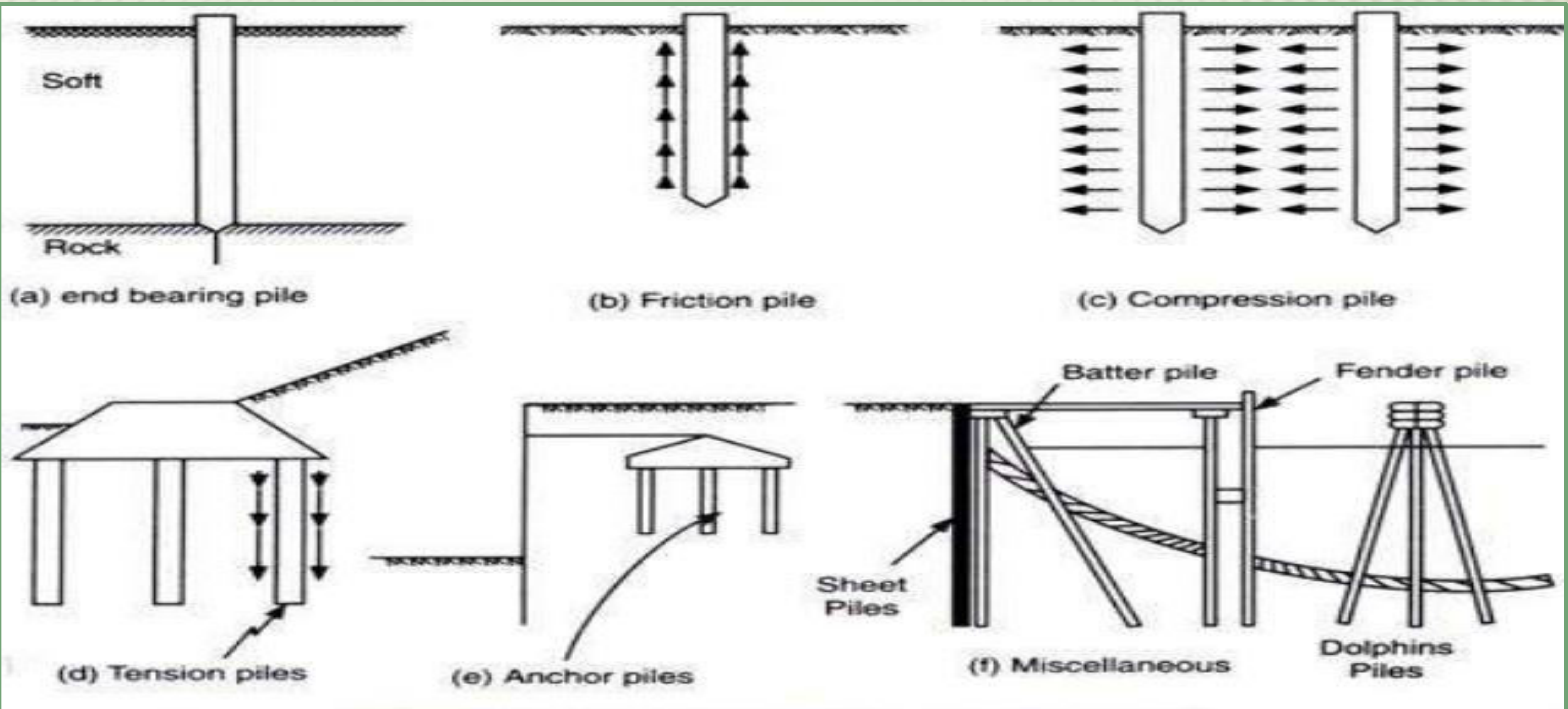
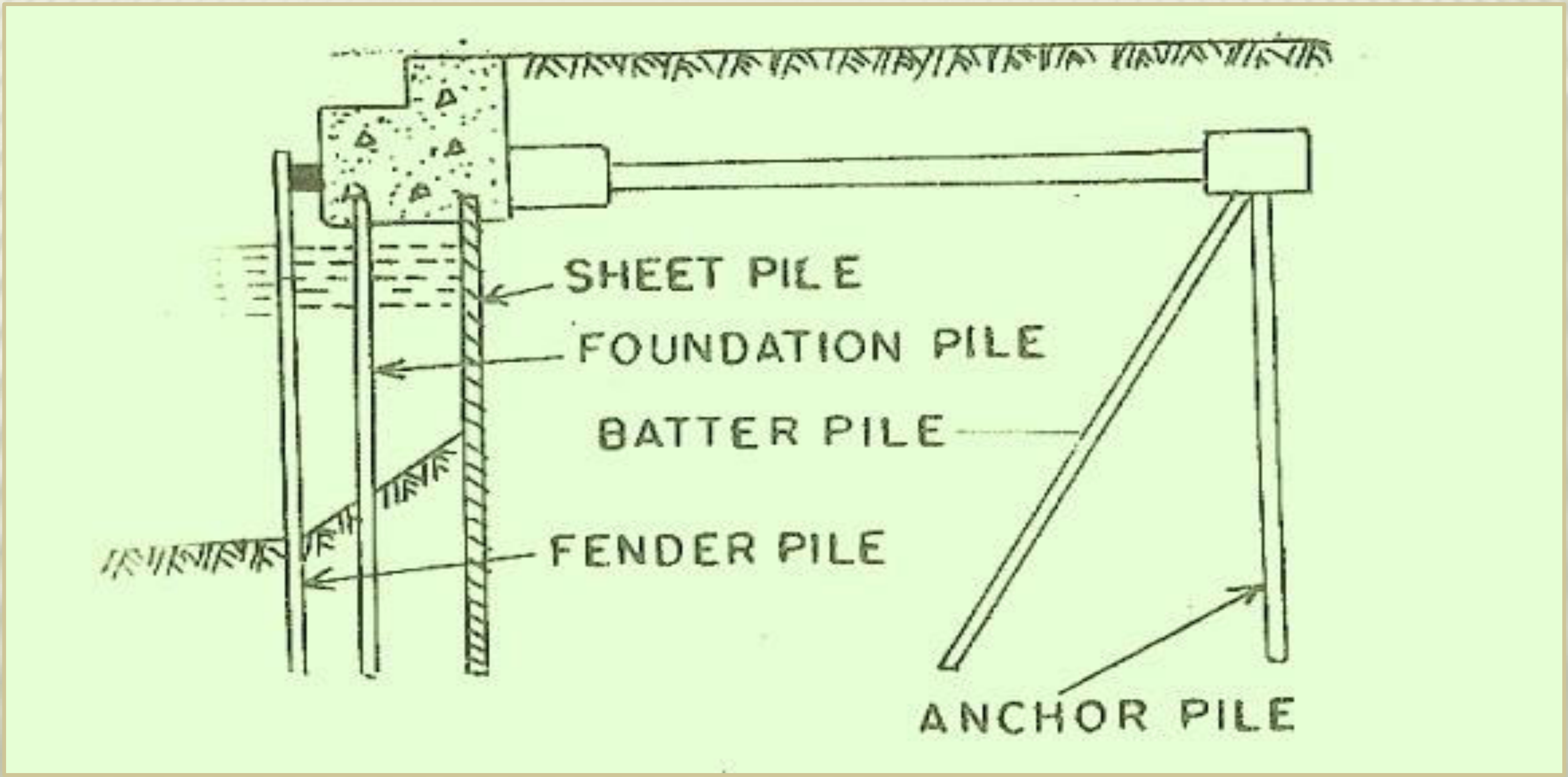


FIG. 11.15 Classification based on function

CLASSIFICATION OF PILES



CLASSIFICATION OF PILES

SHEET PILES

Sheet piles are commonly used as bulkheads or as impervious cut-off to reduce seepage and uplift under hydraulic structures

BATTER PILES

Batter piles are used to resist large horizontal or inclined forces

CONCRETE PILES

Concrete piles are either precast or cast in situ piles. These piles are cast and cured in a casting yard and the piles are transported to the site of work for driving

i. Precast piles

ii. Cast in situ piles

CLASSIFICATION OF PILES

CLASSIFICATION OF PILES

PRECAST PILES

- Precast piles may be made of uniform sections with pointed tips
- Tapered piles may be manufactured when greater bearing resistance is required
- Normally square or octagonal sections are manufactured

CAST IN SITU PILES

- The cast in situ piles are generally used for maximum design load of 75 tonnes
- They are installed by pre excavation thus eliminating vibrations due to driving and handling stresses
- They are further classified as

  a. Driven cast in situ piles

  b. Bored cast in situ piles

CLASSIFICATION OF PILES

DRIVEN CAST IN SITU PILES

Driven cast in-situ concrete piles are constructed by driving a closed-ended hollow steel or concrete casing into the ground and then filling it with concrete

The casing may be left in position to form part of the pile, or withdrawn for reuse as the concrete is placed

BORED CAST IN SITU PILES

Bored cast in situ pile is constructed by digging a hole in the ground by suitable means such as percussive or rotary method with the use of temporary or permanent casing or drilling mud.

After that, the construction is finalized by filling the hole with reinforced concrete.

CLASSIFICATION OF CAST IN SITU PILES

SIMPLEX PILE

It is a tube of cast of diameter 40 cm, has an underneath heel, it is banged underground by an automatic hammer until reaching the arable land for the establishment, then concrete is poured inside it and banged by another hammer

This pile can bear about 40 – 50 ton.

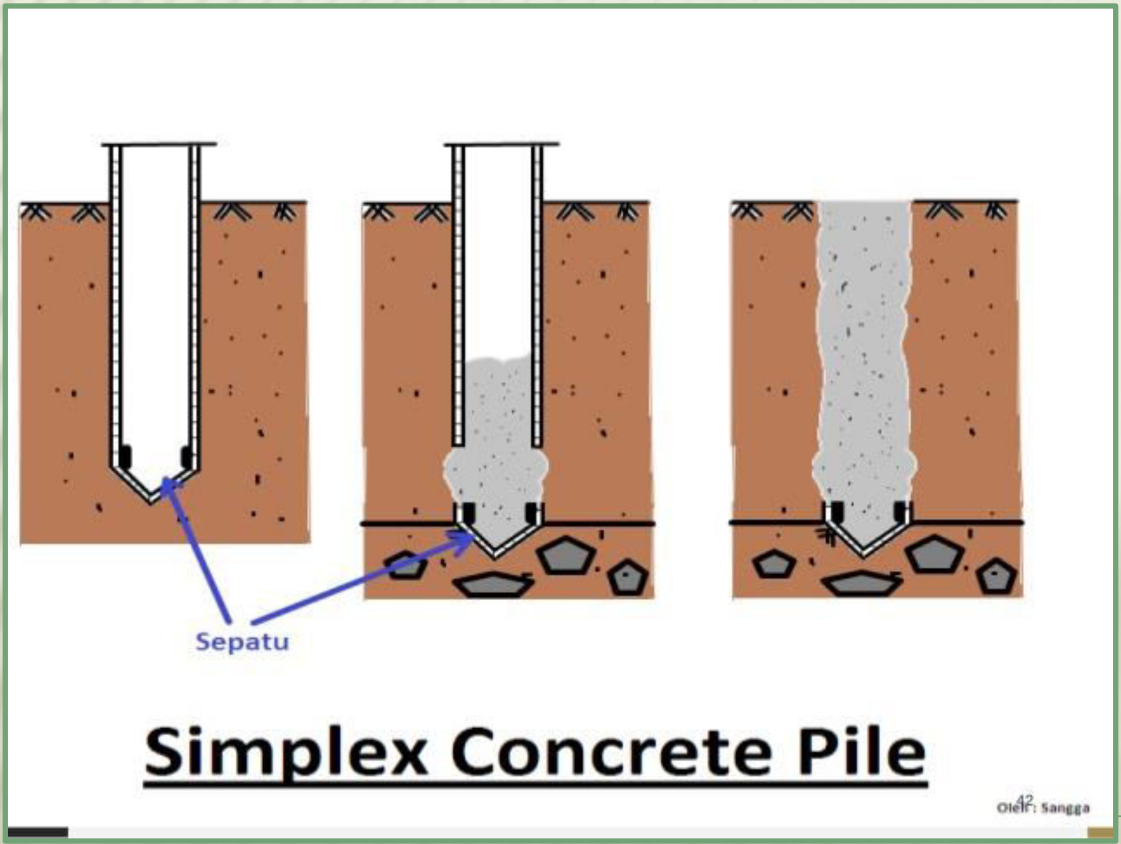
FRANKIE PILE

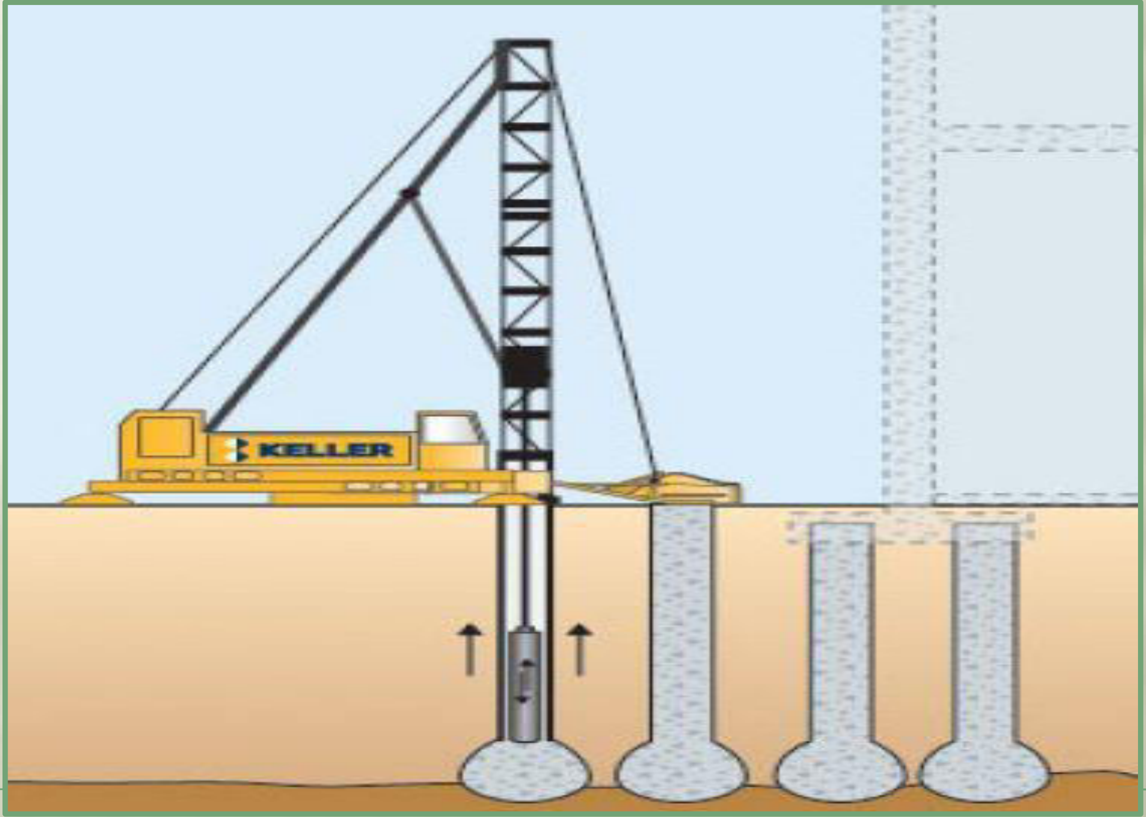
It is a number of tubes entering each other in order to easily access to great depths within the earth

This pile can carry a load of 50 – 80 ton.

CLASSIFICATION OF CAST IN SITU PILES

SIMPLEX PILE	FRANKIE PILE





CLASSIFICATION OF CAST IN SITU PILES

VIBRO PILE

It is a steel pipe of diameter 40 cm, has a conical heel with a separate flange, it is banged underground by an automatic hammer until reaching the arable land for the establishment, then the heel is removed and put into a tube, after that concrete is poured

This pile can bear about 60 ton.

UNDER REAMED PILE

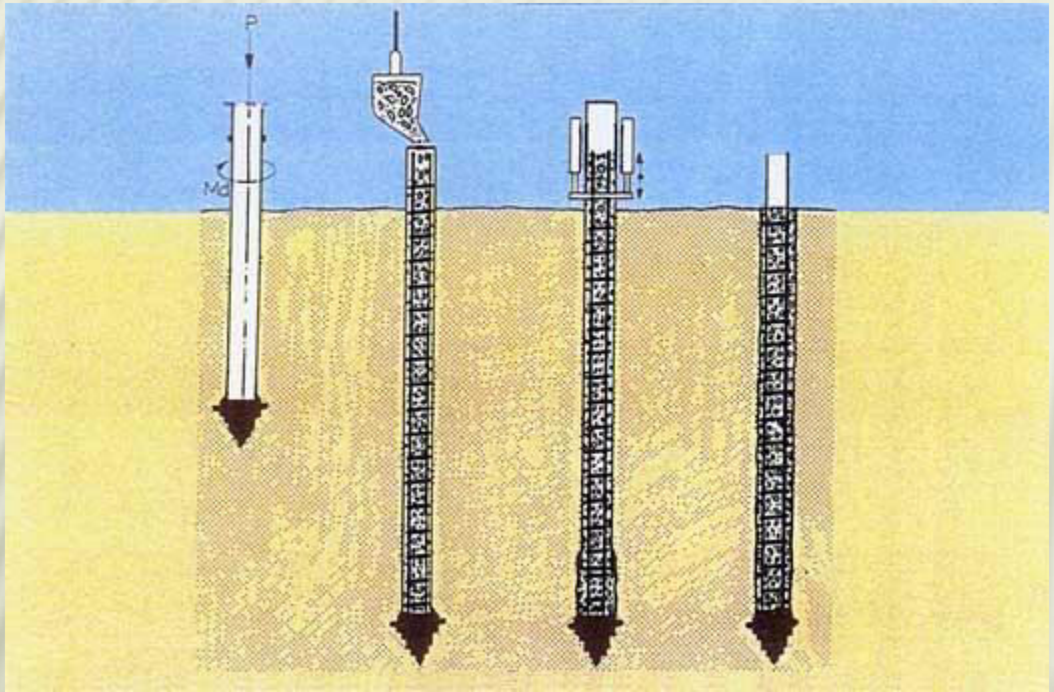
This pile is used at black clayey soil and lands of non residual soil, so this soil is very dangerous to be established on it.

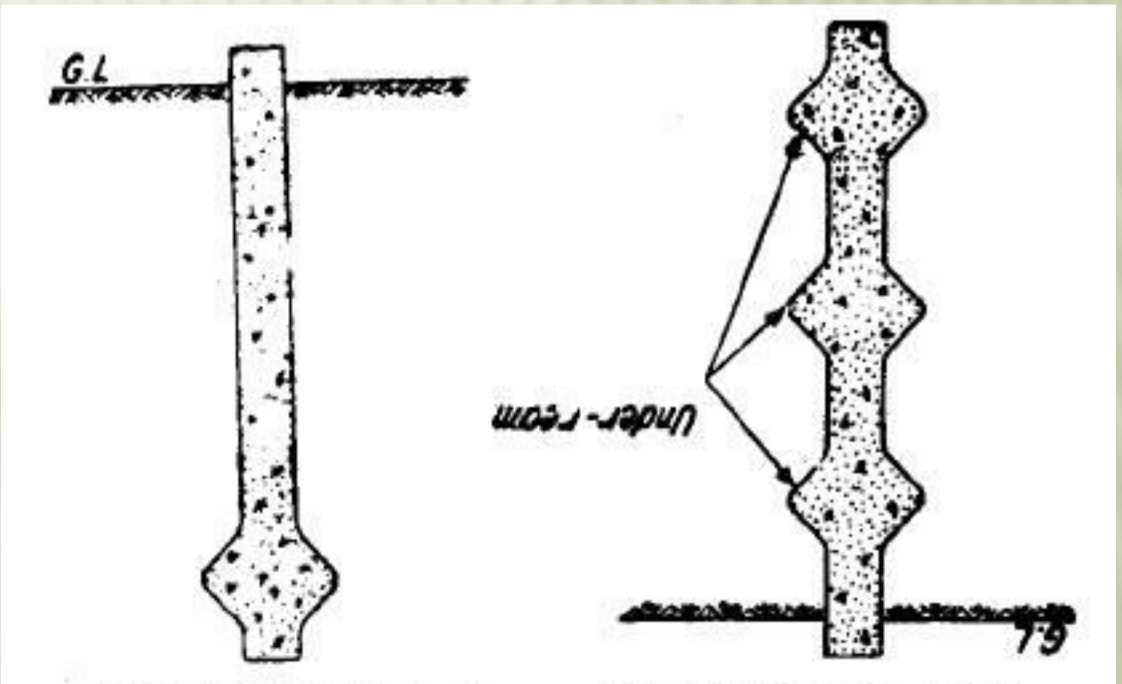
Piles with open tubes without heel, then concrete are poured inside the tube

The pipe has a diameter of 40 cm and an average concrete well of 12 to 15 meters depending on the level of land to be established

VIBRO PILES

UNDER REAMED PILES





(a) Single-bulb cast *in-situ* pile

(b) Multi-bulb piles

CLASSIFICATION OF CAST IN SITU PILES

STRAUSS PILE

Which is very similar to the Simplex pile but without a heel

Soil can be removed from the tubes by special devices and concrete is poured instead of soil

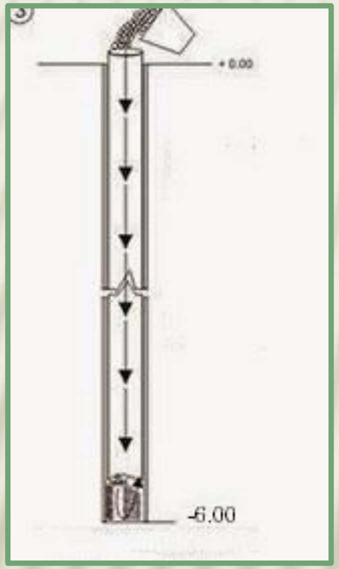
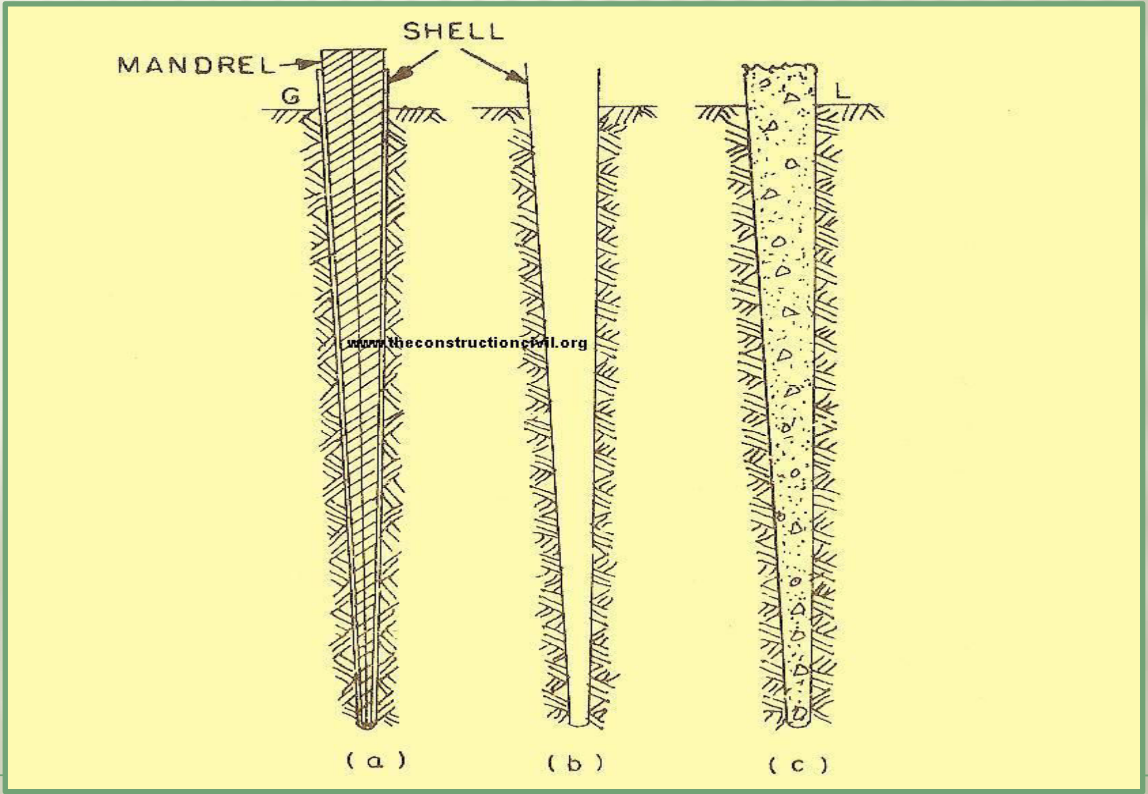
The maximum load that can be carried by these piles is from 20 – 25 ton.

RAYMOND PILE

Which consists of cylindrical chips inside each other with a diameter of 40 – 60 cm at the top of the pile and 20 – 28 cm at the bottom.

It is banged inside by a Mandrill and the cylindrical chips are leaved in the soil and filled with concrete.

CLASSIFICATION OF CAST IN SITU PILES

STRAUSS PILE	RAYMOND PILE
	

CLASSIFICATION OF PILES

TIMBER PILES

- Timber piles are made of tree trunks with the branches trimmed off which should be of sound quality and free of defects
- The length of the pile may be of 15m or more
- Diameter at the butt end may varies from 30 to 40 cm
- Diameter at the tip end should not be less than 15cm

STEEL PILES

- Steel piles are usually rolled H-Shapes or Pipe piles.
- H-piles are proportioned to withstand large impact stresses during hard driving
- The optimum load range on steel piles is 400 to 1200KN

COMPOSITE PILES

The upper and lower portions of composite piles are made of different materials

1. Steel and Concrete
2. Timber and Concrete

CLASSIFICATION OF PILES

STEEL-CONCRETE PILE

TIMBER-CONCRETE PILE

CLASSIFICATION OF PILES

TIP END OF THE TIMBER PILE

BUTT END OF THE TIMBER PILE

CLASSIFICATION OF PILES

PIPE STEEL PILES

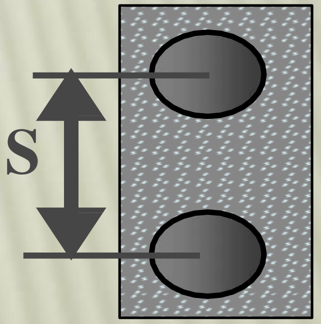
H STEEL PILES

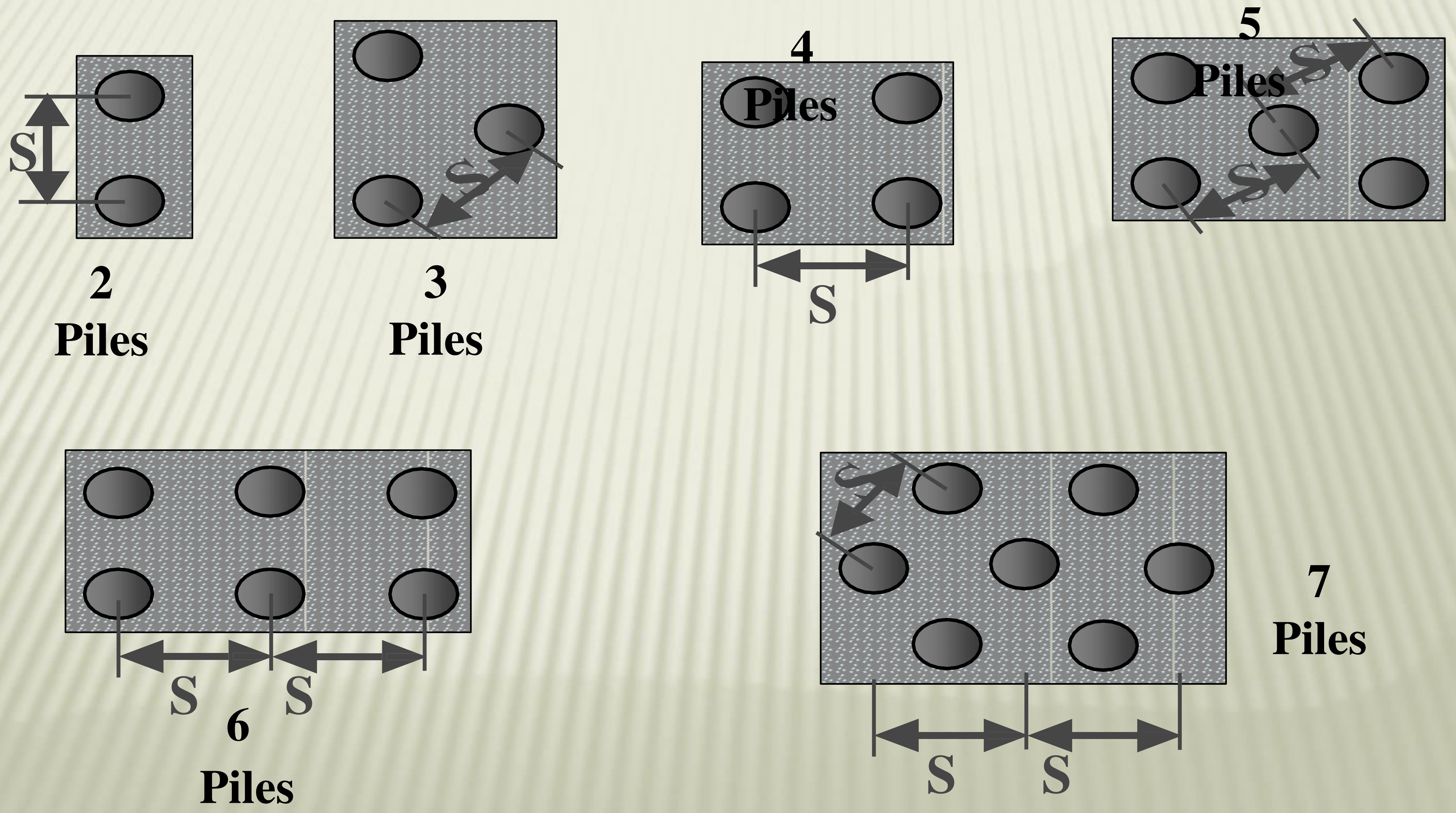
FACTORS AFFECTING THE SELECTION OF PILES

- Type, size, and weight of the structure to be supported.
- Physical properties of the soil at the site.
- Depth to a stratum capable of supporting the piles.
- Possibility of variations in the depth to a supporting stratum.
- Availability of materials for piles.
- Number of piles required.
- Facilities for driving piles.
- Comparative costs in place.
- Durability required.
- Types of structures adjacent to the project.
- Depth and kind of water, if any, above the ground into which the piles will be driven.

PILE SPACING

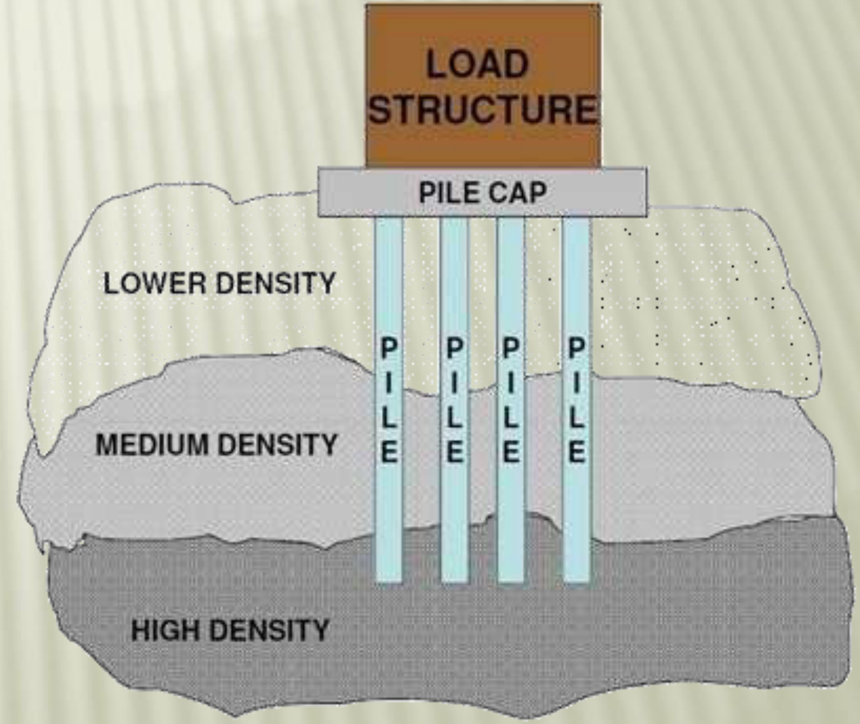
- The center to center distance of successive piles is known as pile spacing.
- It has to be carefully designed by considering the following factors,
  - Types of piles and Material of piles
  - Length of piles
  - Grouping of piles
  - Load coming on piles
  - Obstruction during pile driving
  - Nature of soil through which piles are passing.
- The spacing between piles in a group can be assumed based on the following:
  - 1- Friction piles need higher spacing than bearing piles.
  - 2- Minimum spacing (S) between piles is 2.5.
  - 3- Maximum spacing (S) between piles is 8.0.




S
2
Piles
S
3
Piles
4
Piles
S
5
Piles
S
S
S
S
6
Piles
S
S
S
7
Piles

GROUP OF PILES

- Most pile foundations contain group of piles instead of single pile.
- The piles forming the group of piles may be arranged in square, rectangular, triangular or circular as per the requirement.
- **The bearing capacity of pile group may not be necessarily equal the sum of the bearing capacity of individual piles forming a group.**



EFFICIENCY GROUP OF PILES

- The efficiency of a pile group is define as the ratio of the load carrying capacity of the pile group to the sum of the load carrying capacities of the individual piles.

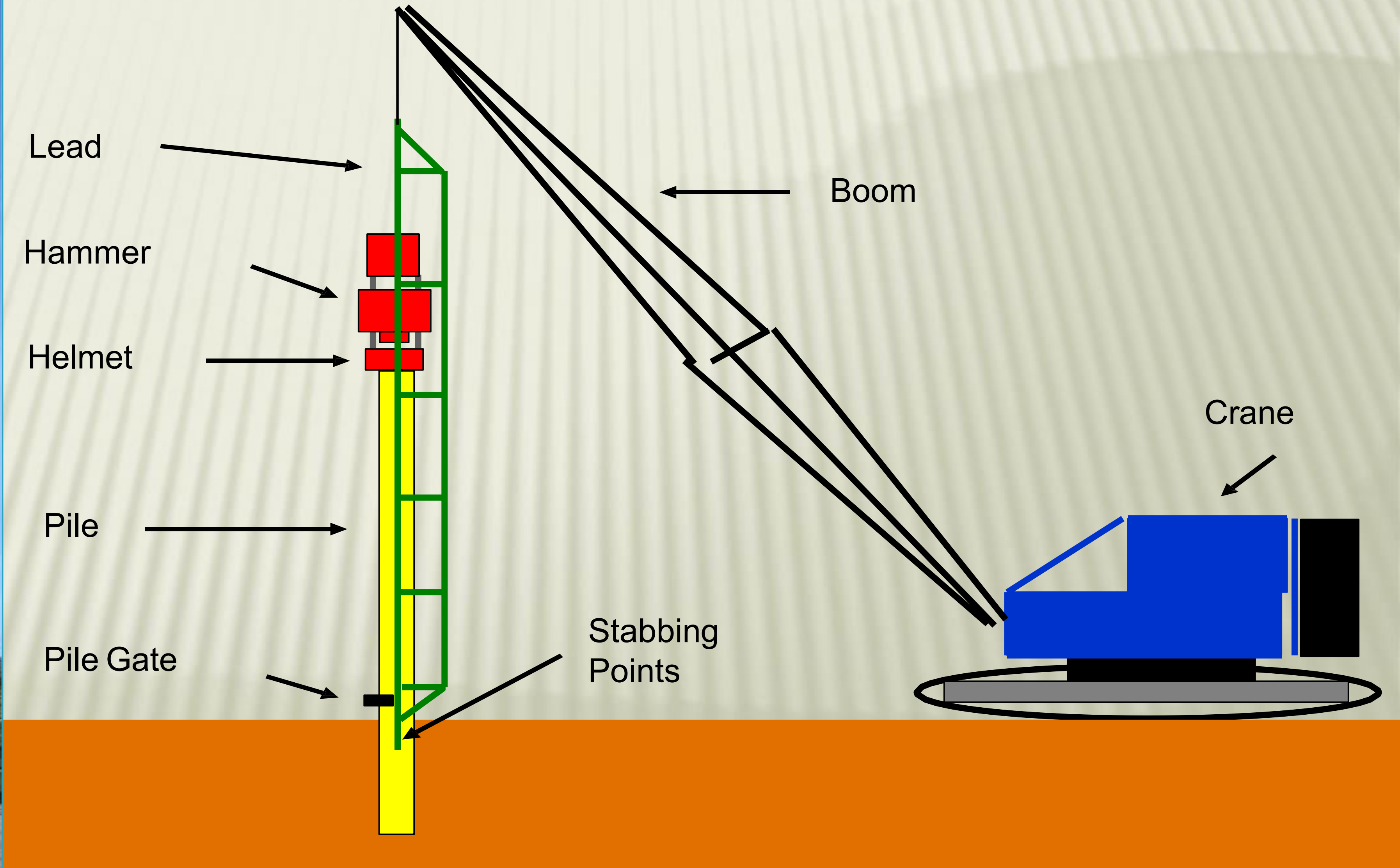
$$E_g = \frac{Q_{gu}}{\Sigma Q_u}$$

- Factors of Group Efficiency:
  - The number, length, diameter, and spacing of the piles
  - The load transfer mode (friction vs. bearing)
  - The sequence of installation
  - The soil type
  - The interaction, if any, between the pile cap and the soil
  - The direction of the applied load

PILE DRIVING

- The process of forcing the piles into the ground without excavation is termed as the pile driving.
- The piles should be driven vertically.
- However, a tolerance of eccentricityof 2 % of the pile length is permissible.
- The eccentricity is measured by means of plumb bob.
- The hammer is guided between two parallel steel members known as leads.

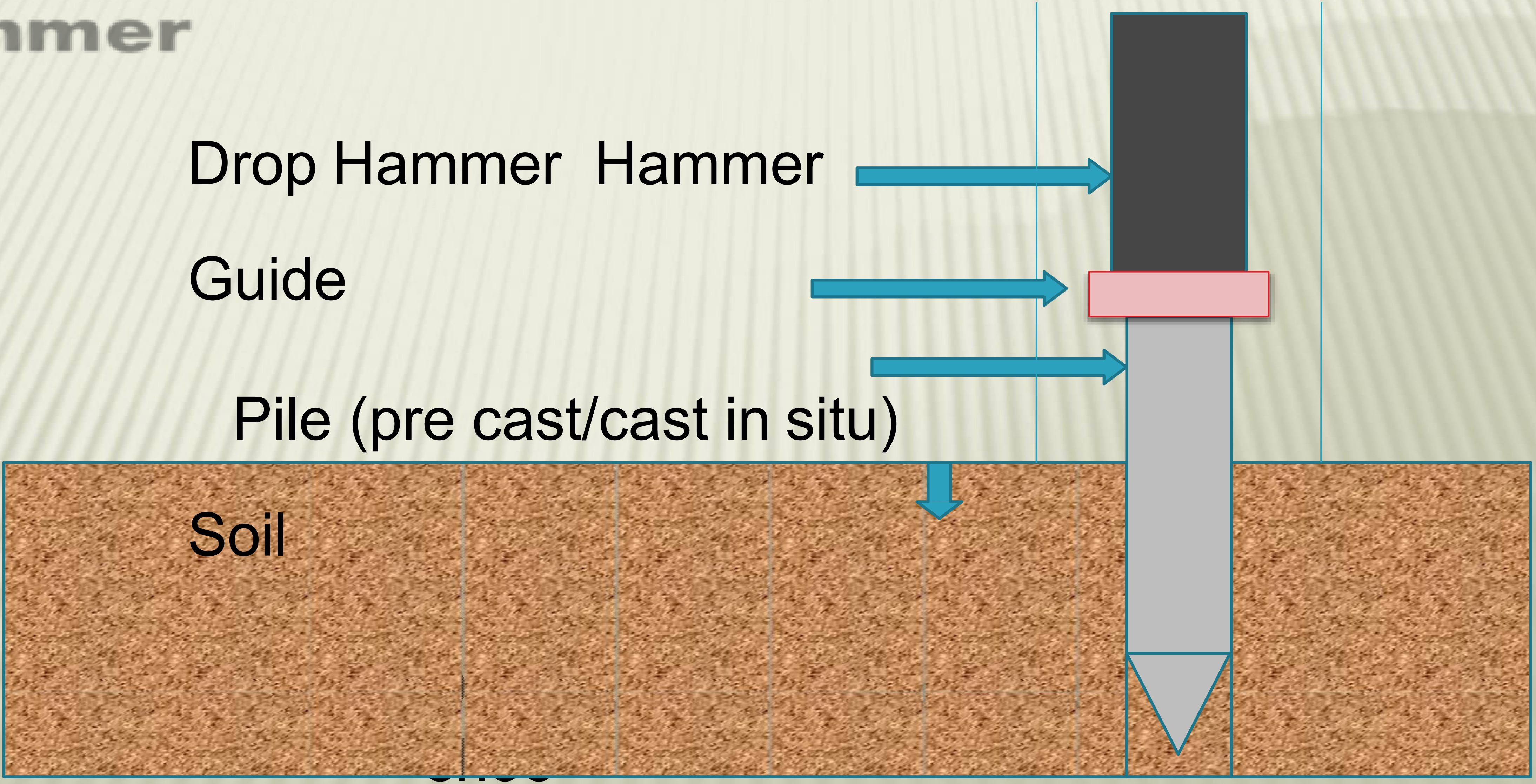
Pile Driving System



PILE HAMMER

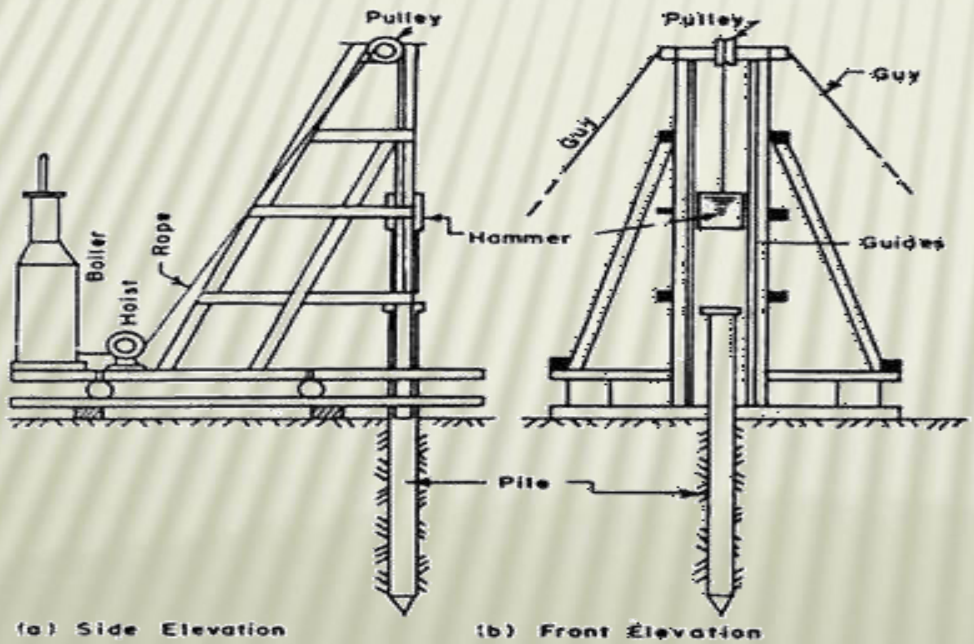
- Drop hammer.
- Single acting hammer.
- Double acting hammer.
- Diesel hammer.
- Vibratory hammer.

Schematic sketch of pile driving with hammer



DROP HAMMER

- Low operation
- Low equipment cost
- Simple



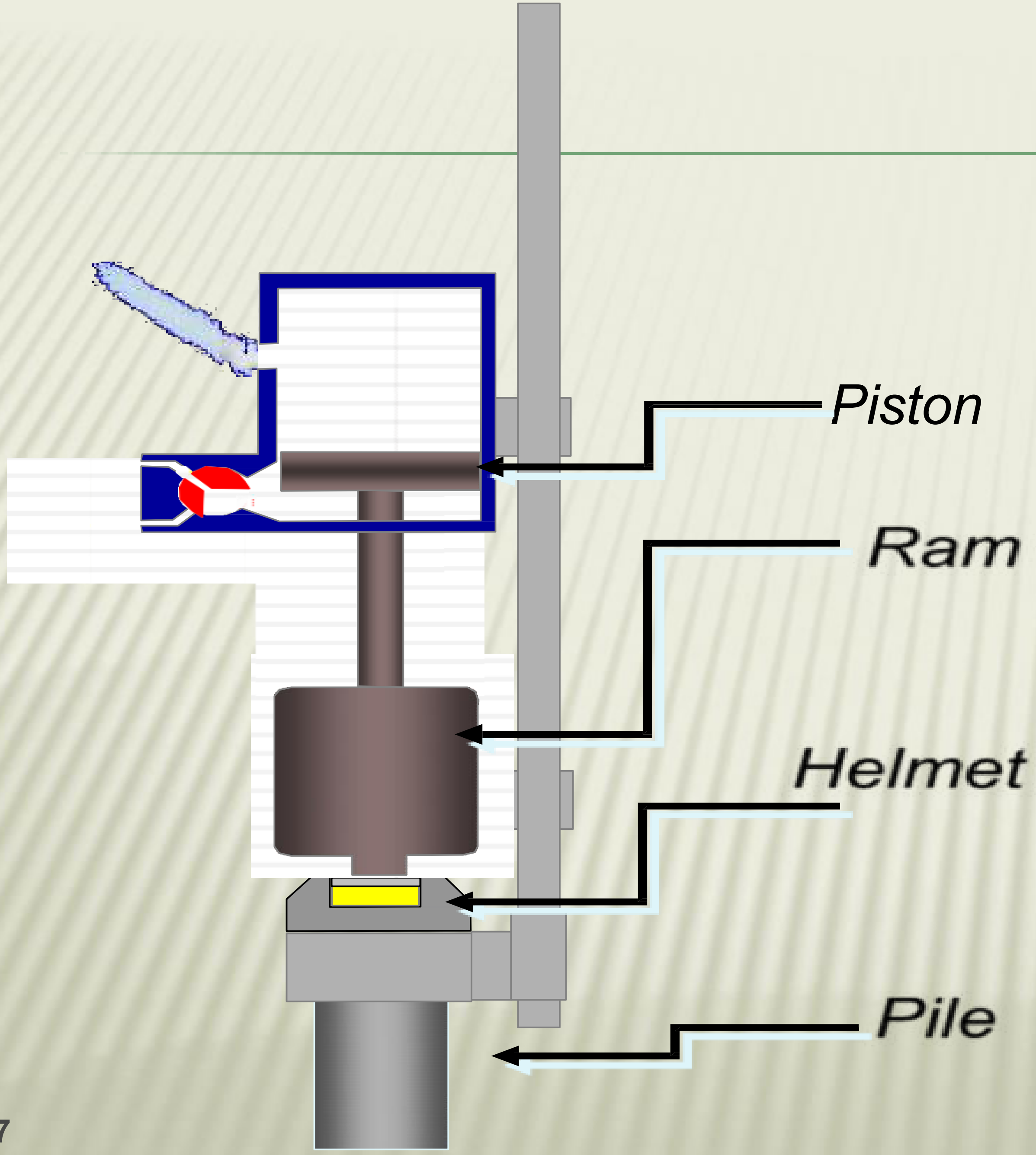
DROP HAMMER

- A hammer (or ram or monkey) is raised by winch and allowed to fall or drop by gravity on the top of the pile.
- The drop hammer is provided with lugs so that it can slide in the leads.
- A lifting eye or hook is provided to tie it with the rope.
- The weight of drop hammer varies from **0.5 to 2 tones** (5 to 20 kN).
- The height of fall may vary from **1.5 to 3 meters**.
- The number of blows that can be imparted varies from **4 to 8 per minute.**

SINGLE ACTING HAMMER

- If the hammer is raised by steam, compressed air or internal combustion, but is allowed to fall by gravity along, it is called a single acting hammer.
- The energy of such hammer is equal to the weight of the ram times the height of fall.
- The weight of single acting hammer is about **2 tonnes (20kN).**
- The fall is about **1 meter.**
- the number of blows of the hammer may vary from **50 to 60 per minute.**

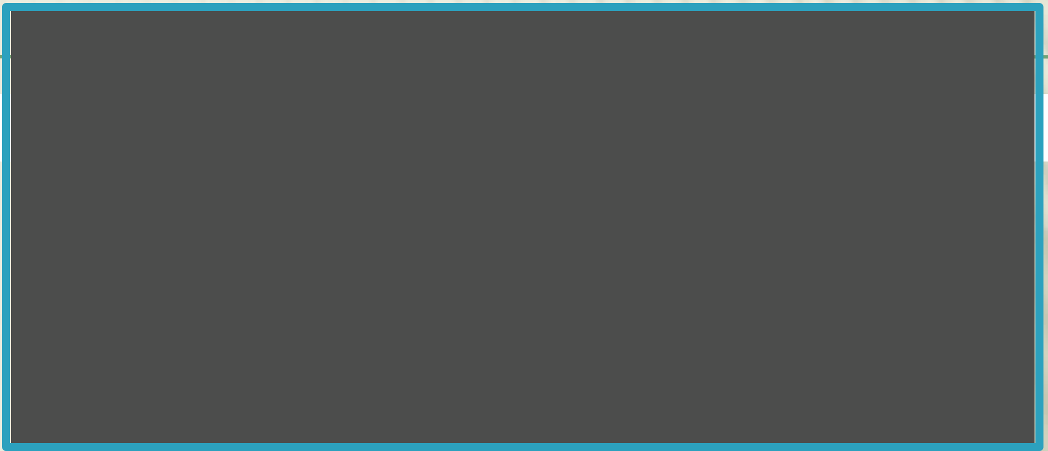
SINGLE ACTING HAMMER



DOUBLE ACTING HAMMER

- The double acting hammer employs steam or air for lifting the ram and for accelerating the downward stroke.
- The weight of the hammer is only **500 kg (5 kN)** but because of accelerating effect of steam (or air) pressure, it has an effect of a weight of **3 tonnes (30. kN).**
- It operates with succession of rapid blows, the number varying from **100 to 200 blows per minute.**
- For light hammers, the number of blows may be even as high as **300 per minute.**
- The pile driving is very quick.
- These hammers are very useful for driving piles under water.

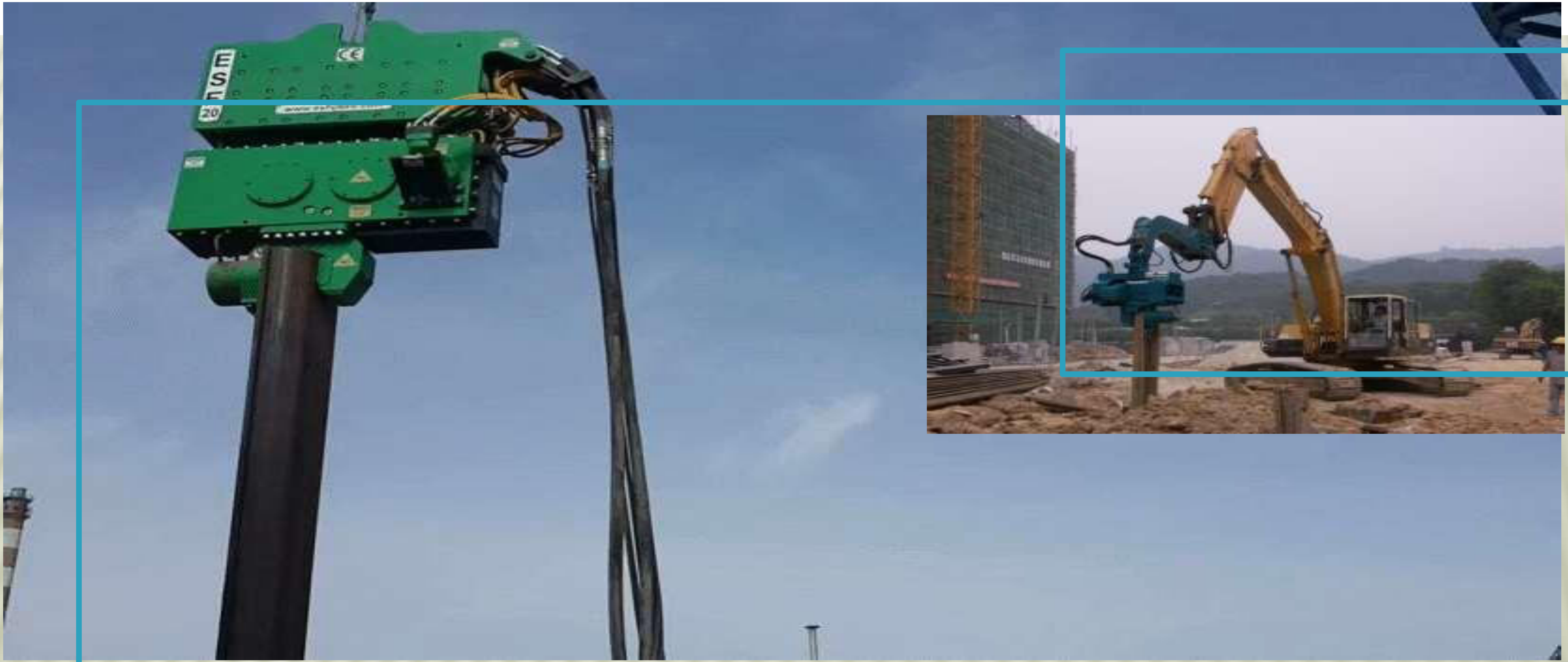
DIESEL HAMMER



- The diesel hammer is a small, light weight self-contained and self-acting type, using gasoline for fuel.

- The total driving energy is the sum of the impact of the ram plus the energy delivered by explosion.

VIBRATORY HAMMER



PILE HAMMER

- **If the driving has to be carried out by hammer, then following factors should be take into consideration.**
  - The size and weight of the pile.
  - The driving resistance which has to be overcome to achieve the desired penetration.
  - The available space and head room in the site because the hammer has to be dropped from certain height.
  - The availability of cranes.
  - The noise restrictions which may be in force in the locality.

PILE DRIVING FORMULAS

- The ultimate load carrying capacity, or ultimate bearing capacity (**Q_f**) of a pile is defined as ***the maximum load which can be carried by a pile and at which the pile continues to sink without further increase of load.***
- The allowable load **Q_a** is the safe load which the pile can carry safely and is determined on the basis of
  - Ultimate bearing, resistance divided by appropriate factor of safety.
  - The permissible settlement,
  - Overall stability of the pile foundation.
- The load carrying capacity of a pile can be determined by the following methods.
  - Dynamic formulae
  - Static formulae

DYNAMIC FORMULAE

- Used for precast concrete piles.
  - When a pile hammer hits the pile, the total driving energy is equal to the weight of hammer times the height of drop or stroke.
  - In addition to this, in the case of double acting hammers, some energy is also imparted by the steam pressure during the return stroke.
- The total downward energy is consumed by the work done in penetrating the pile and by certain losses.
  - The various dynamic formulae are essentially based on this assumption.

DYNAMIC FORMULAE

Engineering New Formula:

$$Q_a = \frac{WH}{F(S + C)}$$

Qa = allowable load
W = weight of hammer (KG)
H = height of fall (CM)
F = factor of safety = 6
S = final set (penetration) per blow,
(Usually taken as average penetration, cm per blow for the last 5 Blows of hammer or last 20 blows for steam hammer.)
C = empirical constant.
= 2.5 cm for drop hammers, and
= 0.25 cm for single or double acting hammers.

For drop hammer

$$Q_a = \frac{WH}{6(S + 2.5)}$$

For single acting steam hammer

$$Q_a = \frac{WH}{6(S + 0.25)}$$

For double acting hammer

$$Q_a = \frac{(W + ap)H}{6(S + 0.25)}$$

a= effective area of piston (cm^2)
P=mean effective steam pressure (kg/cm

DYNAMIC FORMULAE

Hiley's Formula (IS formula):

- Indian standard IS: 2911 (Part I) : 1964 gives the following formula based on original expression by Hiley :

$$Q_f = \frac{\eta_h \cdot W \cdot H \, \eta_b}{S + \frac{C}{2}}$$

Q_f = ultimate load on pile.
W = weight of hammer in kg
H = height on drop of hammer, in cm
S = penetration or set, in cm, per blow
C = total elastic compression= C1 + C2 + C3
C1,C2, C3 = temporary elastic compression of dolly and packing, pile and soil respectively.
η_h = efficiency of hammer, variable from 65 percent for same double acing steam hammers to 100 percent for drop hammers released by trigger.
η_b = efficiency of hammer blows (i.e. ratio of the energy after impact to striking energy of ram).

STATIC FORMULAE FOR PILE CAPACITY

Pile capacity is the sum of the side resistances, Qs and the base resistance, Qp and is given by,

$Q_u = Q_s + Q_p$

$Q_u = f_s A_s + q_p * A_p$

fs – unit side resistance ie side resistance / unit area

q_p – base resistance / unit area

A_s – lateral surface area of the pile

A_p – base area of the pile

FOR PILES IN CLAY

f_s = ἀc

q_p =1.2 C Nc = 9c

(as piles are long , accounting for the depth N_c =7.5)

ἀ – adhesion factor or shear mobilization factor

c – cohesion

FOR PILES IN SAND

$f_s = k\ \gamma\ L/2 * \tan \delta$ (average resistance in a homogeneous soil)

where,

k - coefficient of lateral earth pressure(k = 1 to 2 for driven piles ; 0.4 for bored piles)

γ – unit wt . of soil

L – length of pile

δ – angle of wall friction = 1/3 to 2/3 ø

FOR A C – Ø SOIL

fs = ἀc + k γ L/2 tan δ-------------------(1)

$q_p = \gamma L (N_q - 1)$ (neglecting the N_γ term as 'B' is small)

PILE CAPACITY BASED ON PENETRATION TEST DATA:

Applicable in driven piles in sand. Tip resistance, q_p is obtained using 'SPT', 'N' values as

q_p = 40N (L/D) kN/m^2

N – observed SPT 'N' value at the pile tip

Average skin resistance is obtained as:

fs = 2 N_{av} kN/m^2

fs = q_c / 2 kN/m^2

N_{av} – average SPT 'N' over the length of pile

q_c – average cone resistance over the length of pile. Ultimate pile capacity is obtained as

$Q_u = f_s A_s + q_p * A_p$

Piles in layered soils

$Qu = Q_{s1} + Q_{s2} + Q_{s3}$

Uplift capacity of piles in clay

$Q_{uplift} = f_s A_s / F$ + Weight of pile

Negative skin friction:

- ✓ Negative skin friction is the downward drag on the pile surface
- ✓ In highly compressible soils, the soil moves downward relative to the pile. This causes a downward drag force. This is called negative skin friction.

Negative skin friction F_n on a single pile in clay, is given by,

$F_n = \acute{\alpha}\ C\ A_s$ in clays

Negative skin friction in pile groups F_{ng} in clays

$Fng = c\ A_s + \gamma\ L\ A_p$

Group capacity

Pile are used in a group as foundation. A typical pile group. Piles are usually spaced at 2 to 3 times the pile diameter.

Group action

Settlement of the group > settlement of the single pile for the same load / pile. It is because, the stressed zone in a group extends to a larger depth as shown in Fig. Therefore, a larger depth of soil gets compressed.

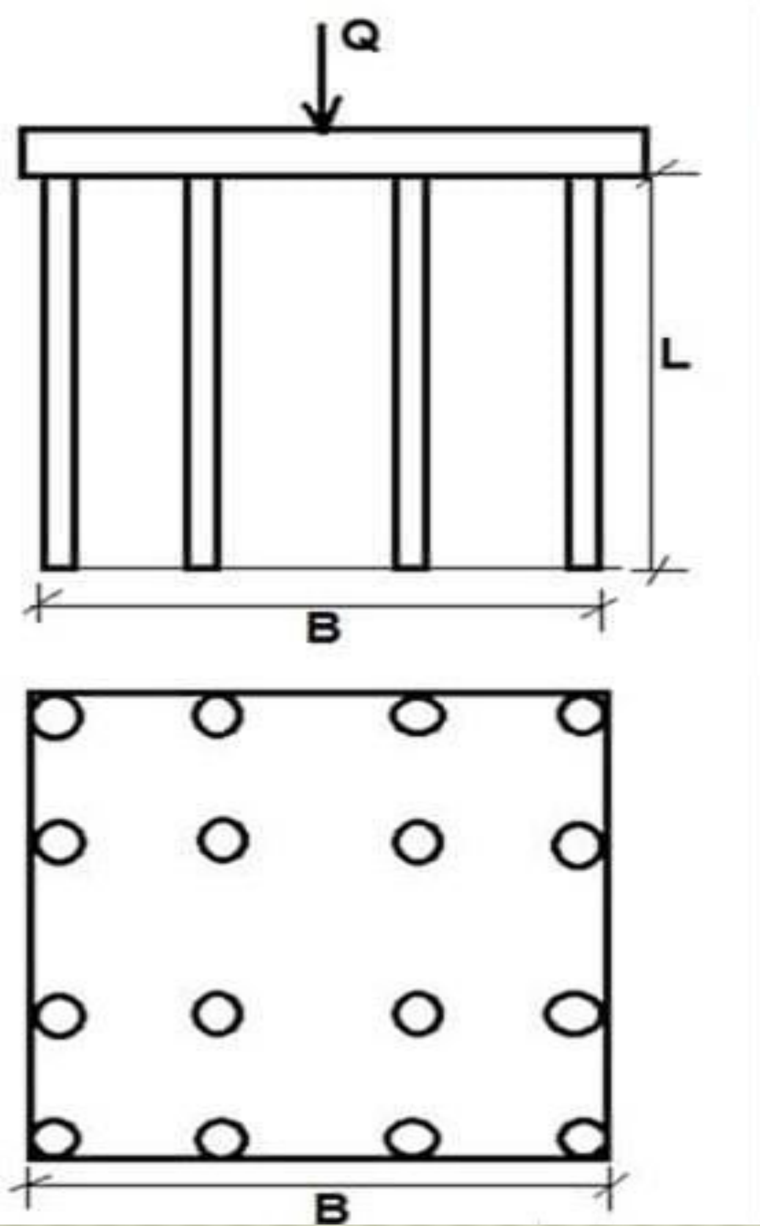
Group capacity may not be the sum of the individual pile capacity. The group capacity is obtain using group efficiency, Eg which is given as,

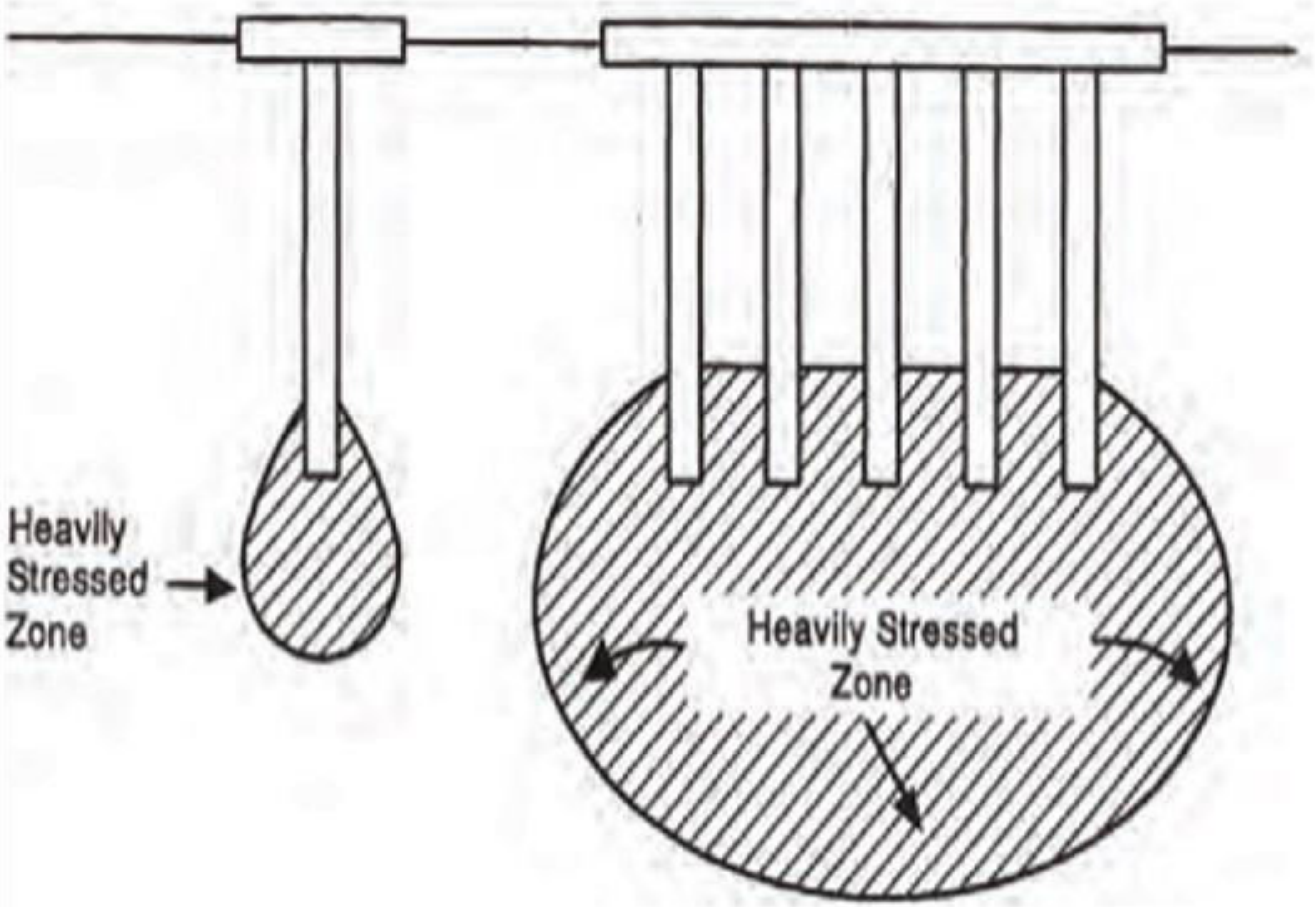
$E_g = Q_{ug} / nQ_u$

Q_{ug} = Group capacity

n = number of piles

Q_u = single pile capacity





Deeper Zone of Influence for End Bearing Shaft Group (after Tomlinson, 1994)

Group capacity can be obtained using

- Group efficiency formulae
- Block failure criteria

Group efficiency formulae:

Converse – Labarre formula

θ [(n-1)m + (m-1)n]

Where, m – number of column in a group

n – number of rows

θ – $\tan^{-1}$ d/s in degrees

d – dia of piles

s – c/c spacing of piles

Feld's – Rule:

For every adjoining pile, (including a diagonal one) the capacity of the pile is reduced by 1/16.

Block failure criteria

Group efficiency for piles in sand is usually more than one. In clays, the group capacity is obtained as:

$Q_{ug} = C\, N_c\, A_p + C\, A_s$

where,

A_p = Area of the base of the pile group

$N_c = 9$

C = Cohesion

A_s = Lateral surface area of the pile group.

Group capacity is the minimum of:

Q_{ug} – group capacity as a block = $n * Q_u$

Q_u – Single pile capacity ; n – number of piles

Load test on piles:

Load tests are of two types:

Initial load test : Test on a pile which does not become a part of the foundation.

Routine test : A test on a pile which is a part of foundation

Pile load test consists of :

- An arrangement to take the reaction
- Jack for loading
- Dial gauge for measurement of settlement

Test procedure:

- ✓ Load is applied in increments
- ✓ Load increment is above 1/5th of Q_{safe}
- ✓ Settlement is noted from dial gauge readings
- ✓ Loaded up to failure

Test results:

A load Vs settlement plot is made

Estimation of allowable load

Allowable load on pile is obtained as minimum of the following ;

1. 2/3 of the load at 12mm settlement
2. 50% of the load at which the settlement is 10% of the pile diameter

Settlement of the pile Group

Pile Group in clays;

Friction piles in clay.

Load is assumed to be transferred on an equivalent raft at2/3 L from the top. Settlement is computed as for the rafts.

Point bearing in clays.

Load is assumed to be transferred on an equivalent raft at the base of the piles.

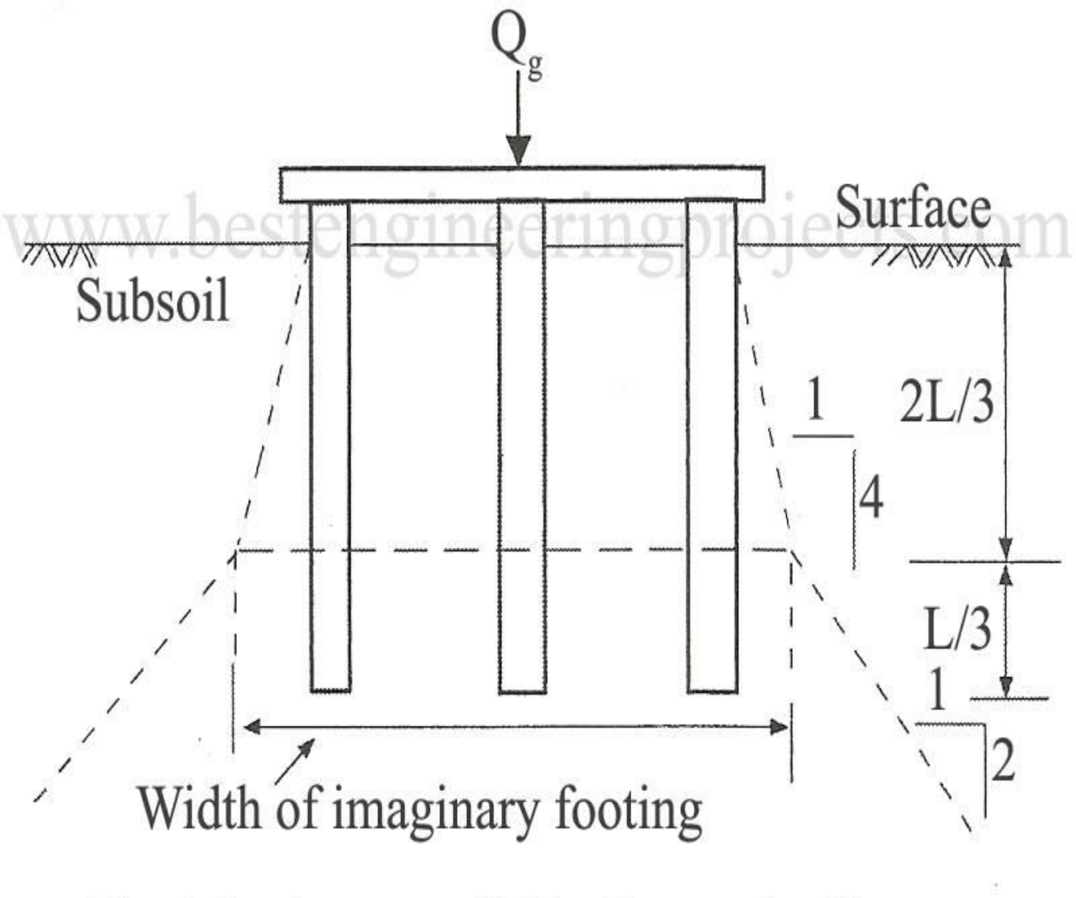


Fig 1 Settlement of Pile Groups in Clay

UNDER REAMED PILES

- **Under reamed piles** are bored cast-in-situ concrete **piles** having one or more number of bulbs formed by enlarging the **pile** stem. These **piles** are best suited in soils where considerable ground movements occur due to seasonal variations, filled up grounds or in soft soil strata.
- The **under-reamed piles** are connected by a reinforced concrete beam, known as capping beam or grade beam.
- Provision of **under reamed** bulbs has the advantage of increasing the bearing and uplift capacities. It also provides better anchorage at greater depths. These **piles** are efficiently **used** in machine foundations, over bridges, electrical transmission tower foundation sand water tanks.

Piles Group in sand:

Equivalent rafts are assumed as above. Settlement is computed in the same manner as for rafts/ footings using SPT or SCPT values.

Settlement of the pile group is also found from pile load test data as below,

$S_g / S_i = [(4B + 2.7) / (B+3.6)]^2$

where,

S_g – Settlement of pile group;

S_i = Settlement of single pile for the same load / pile in group

B = Width of pile group in meters

Features and Details of Under Reamed Piles:

Diameter of the pile = 20 to 50cm

Bulb Diameter = 2 to 3 times of dia. of the pile

Pile Length = 3 to 8m

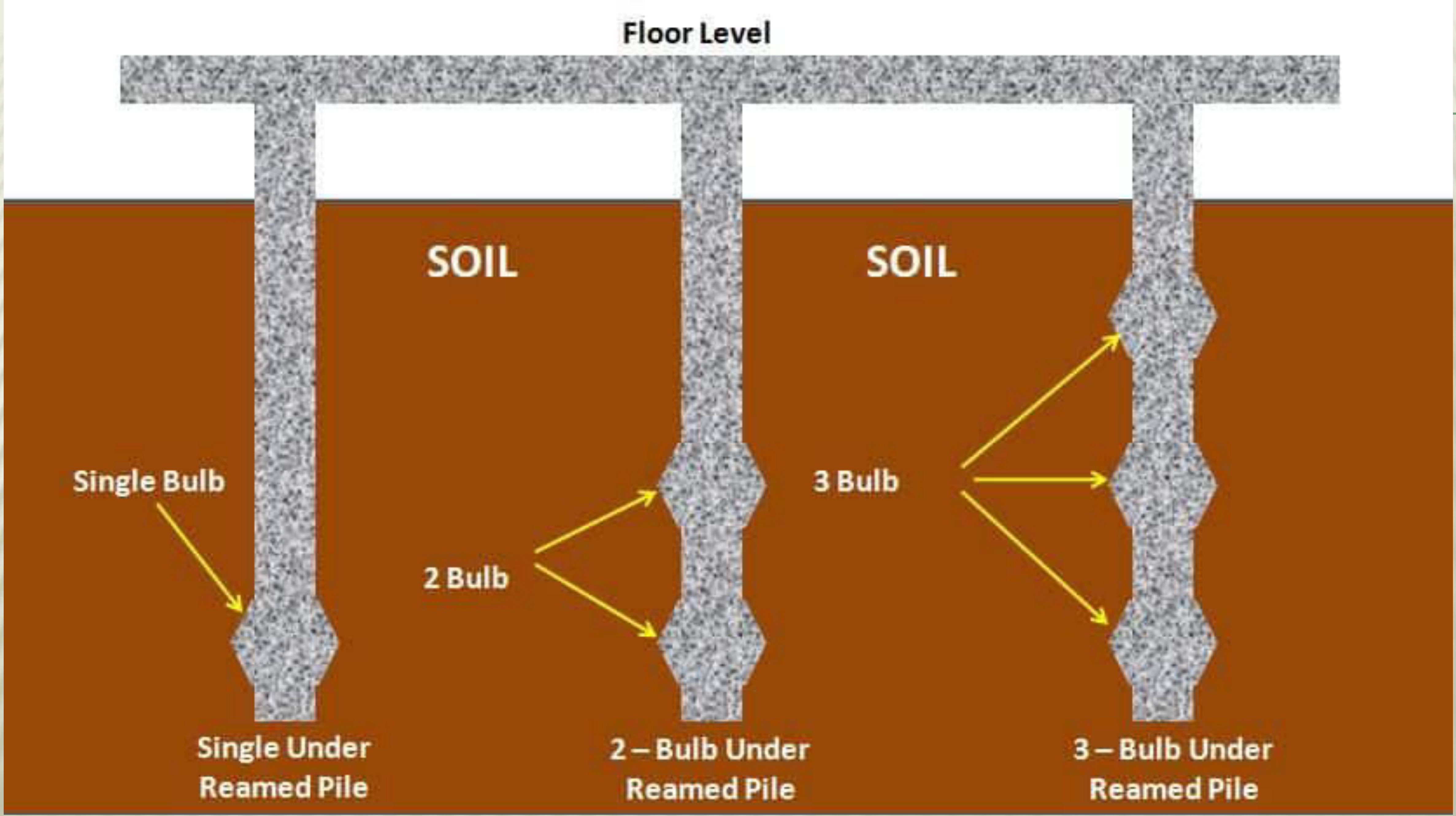
Space between 2 piles = 2 to 4m

Spacing between 2 bulbs = 1.25 to 1.5 times of bulb dia.

The load-carrying capacity = 20 to 40 ton

Increasing load-carrying capacity:

1. By putting more bulbs
2. By increasing the dia. of the bulb
3. By increasing the length of the pile
4. By providing proper reinforcement

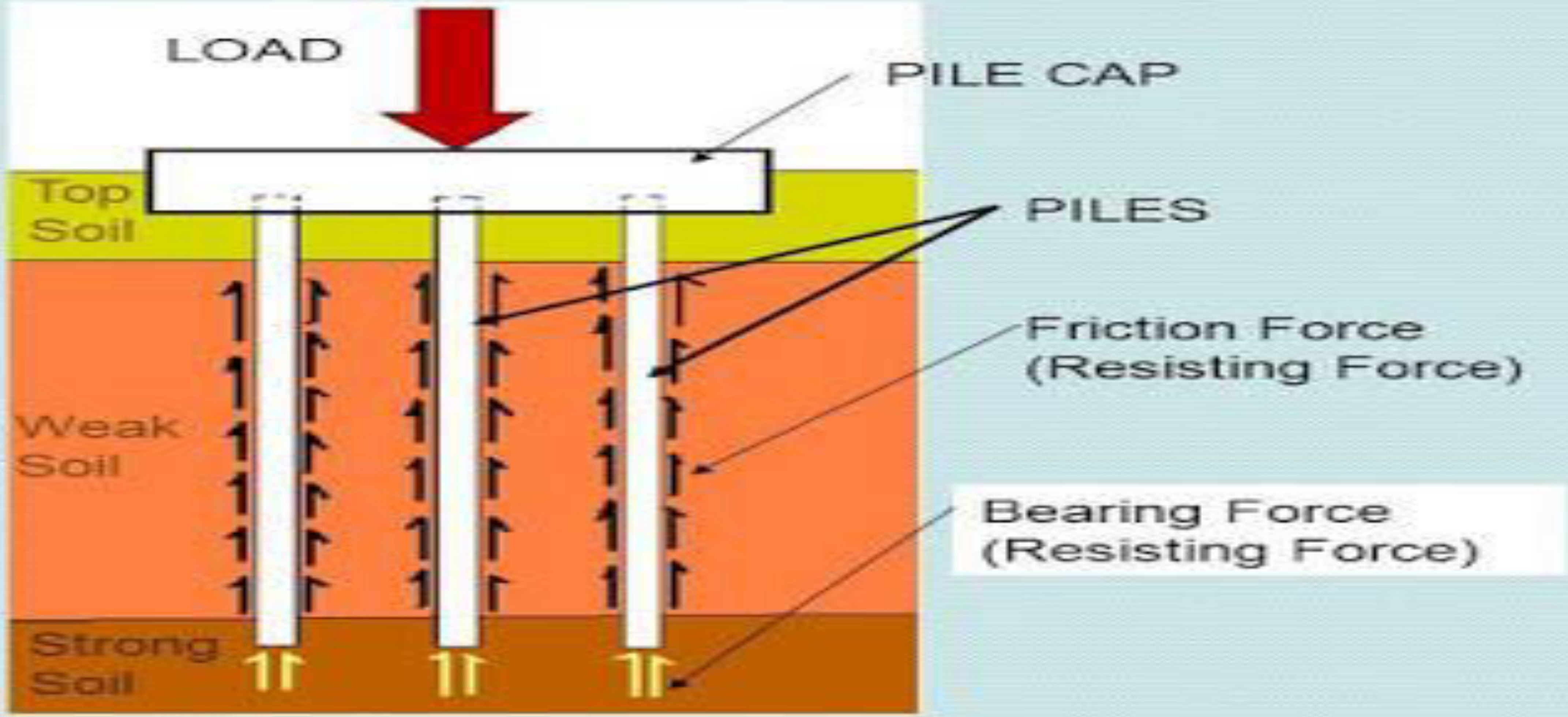


Floor Level
SOIL
SOIL
Single Bulb
2 Bulb
3 Bulb
Single Under
Reamed Pile
2 – Bulb Under
Reamed Pile
3 – Bulb Under
Reamed Pile

PILE CAP

- A **pile cap** is a thick concrete mat that rests on concrete or timber **piles** that have been driven into soft or unstable ground to provide a suitable stable foundation.
- It usually forms part of the deep foundation of a building, typically a multi-story building, structure or support base for heavy equipment, or of a bridge. The cast concrete pile cap distributes the load of the building into the piles. A similar structure to a pile cap is a "raft", which is a concrete foundation floor resting directly onto soft soil which may be liable to subsidence.
- **Piles** are used to carry the load of the structure deep into the ground, and **pile caps** form the solid foundation on which the piers are then built.

Deep Foundation



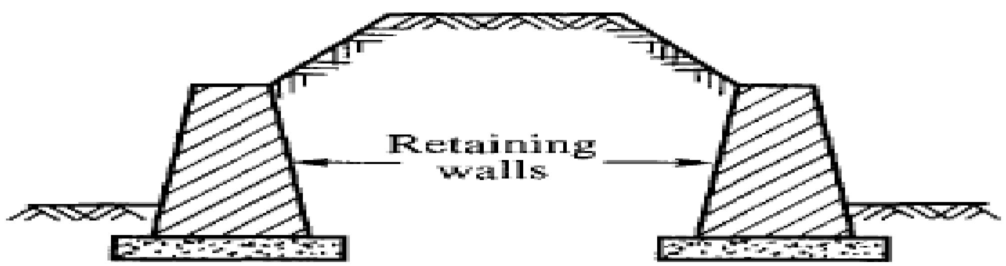
UNIT 5

RETAINING WALLS

Plastic equilibrium in soils – active and passive states – Rankine's theory – cohesionless and cohesive soil – Coulomb's wedge theory – Earth pressure on retaining walls of simple configurations – Culmann Graphical method – Stability analysis of retaining walls.

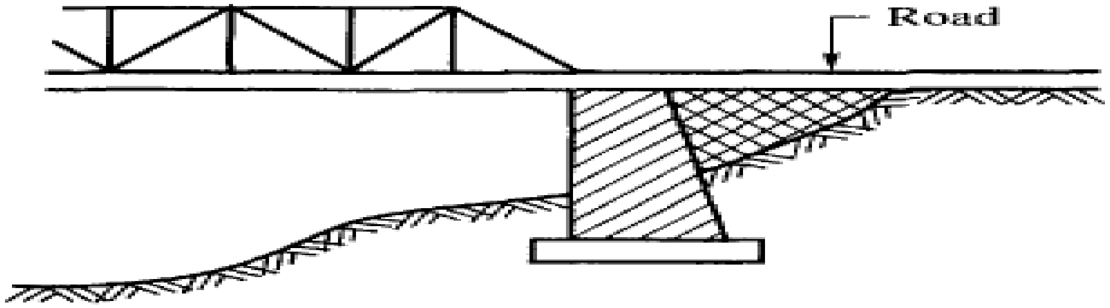
RETAINING WALLS

- Structures that are built to retain vertical or nearly vertical earth banks or any other material are called retaining walls. Retaining walls may be constructed of masonry or sheet piles.
- Gravity walls resist movement because of their heavy sections. They are built of mass concrete or stone or brick masonry.
- In all these cases, the backfill tries to move the wall from its position. The movement of the wall is partly resisted by the wall itself and partly by soil in front of the wall.

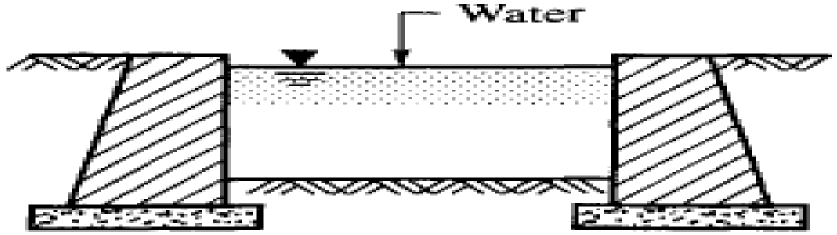


(a) Embankment

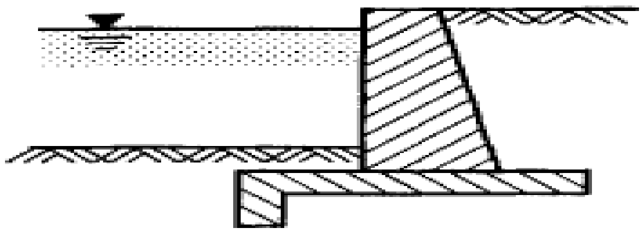
(b) Cut



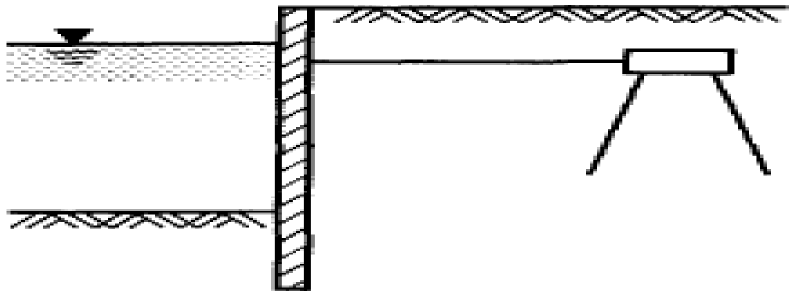
(c) A bridge abutment



(d) Water storage

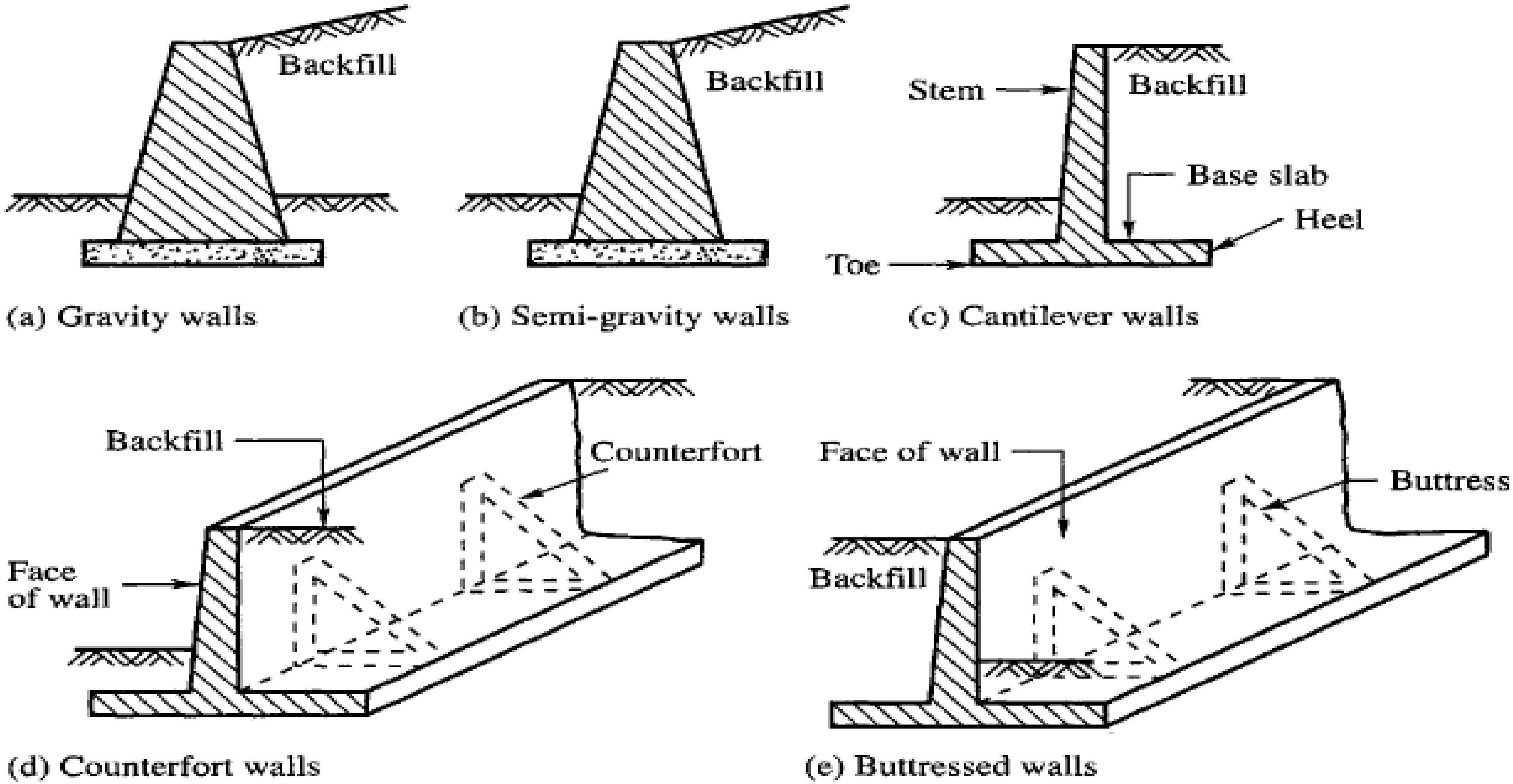


(e) Flood walls



(f) Sheet pile wall

VARIOUS TYPES OF RETAINING WALLS



Earth pressure

A soil mass retained by a wall exerts a pressure on the wall. This pressure P is called ‘earth pressure’. The magnitude of this earth pressure depends on the movement of the wall.

Earth pressure at rest-

- When there is no movement of wall, the soil is in a state of rest, ie., there is no strain in the soil. The pressure corresponding to zero lateral strain is called 'earth pressure at rest' and is given by,
- $p_0 = k_0 p_v$
- Where, p_o – earth pressure at rest at depth 'z' below G L
- k_o - coefficient of earth pressure at rest
- p_v -effective vertical pressure at depth 'z'
- Example situation : A basement wall ; Lateral movement of the wall is prevented.

Active earth pressure

When a wall moves away from the back fill, the earth pressure reduces. Beyond certain movement, the earth pressure reaches a minimum value. This minimum pressure is known as 'active earth pressure', and is given by

$$p_a = k_a \, p_v$$

Where, p_a – active earth pressure

k_a – coefficient of active earth pressure

Ex : Retaining wall on a hill slope; Bridge abutments

Passive earth pressure

When a wall moves towards the back fill, the earth pressure increases. Beyond certain movement, it reaches a maximum and is known as 'passive earth pressure'.

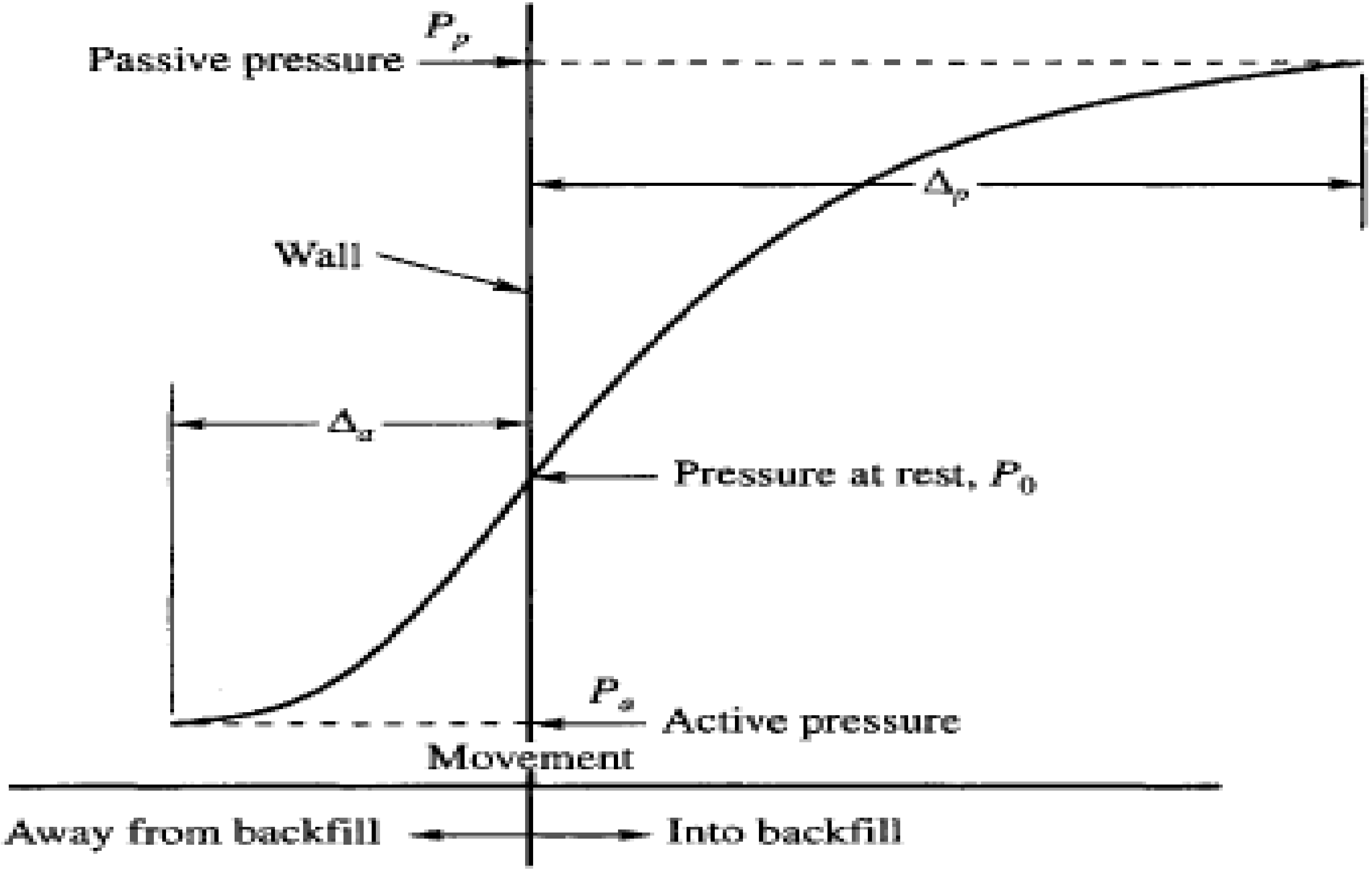
Ex: Anchored sheet pile walls ; Anchors are subjected to passive pressure.

Passive earth pressure is given by,

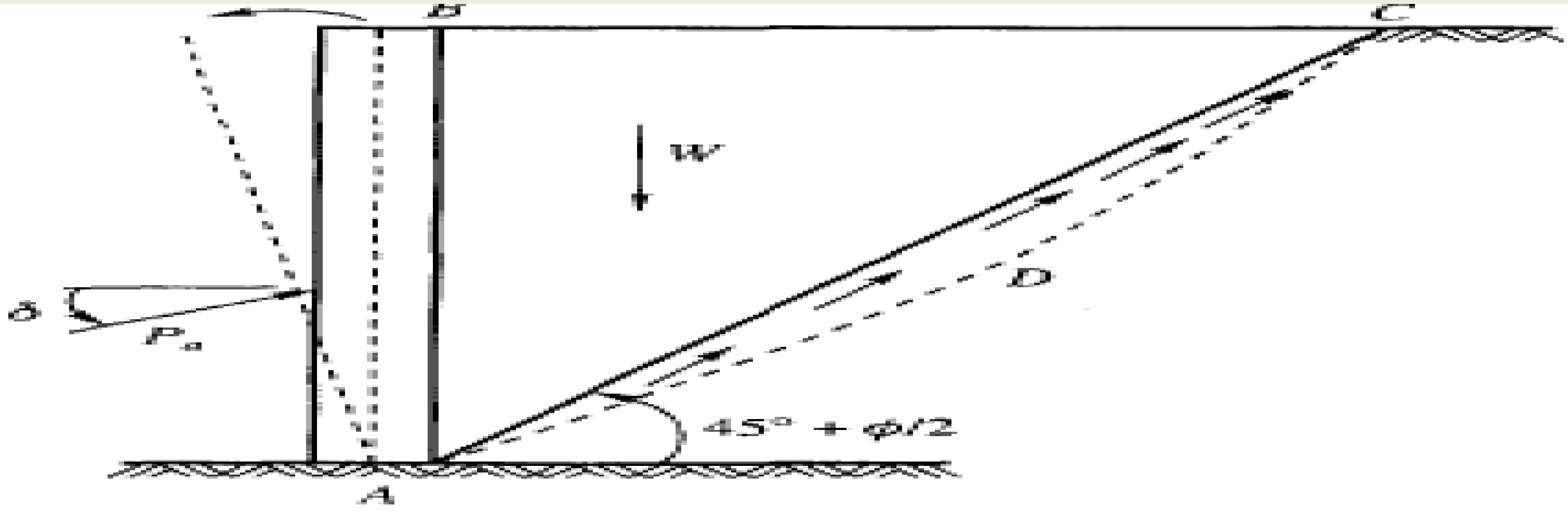
$p_p = k_p * p_v$

Where, p_p – passive earth pressure

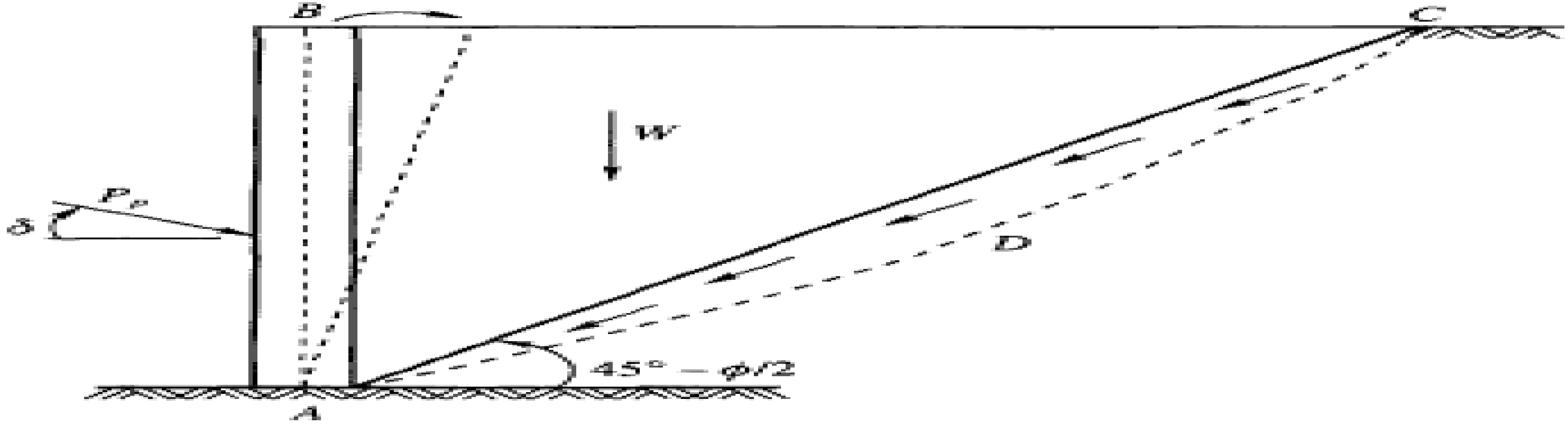
k_p – coefficient of passive earth pressure



P_p
Passive pressure
Δ_p
Wall
Δ_a
Pressure at rest, P_0
P_a
Active pressure
Movement
Away from backfill
Into backfill



(a) Active earth pressure



(b) Passive earth pressure

The coefficients, k_0, k_a , k_p are obtained as:

k_0 = 1- sin ø or μ/ (1- μ)

k_a = (1-sin ø) / (1+ sin ø)

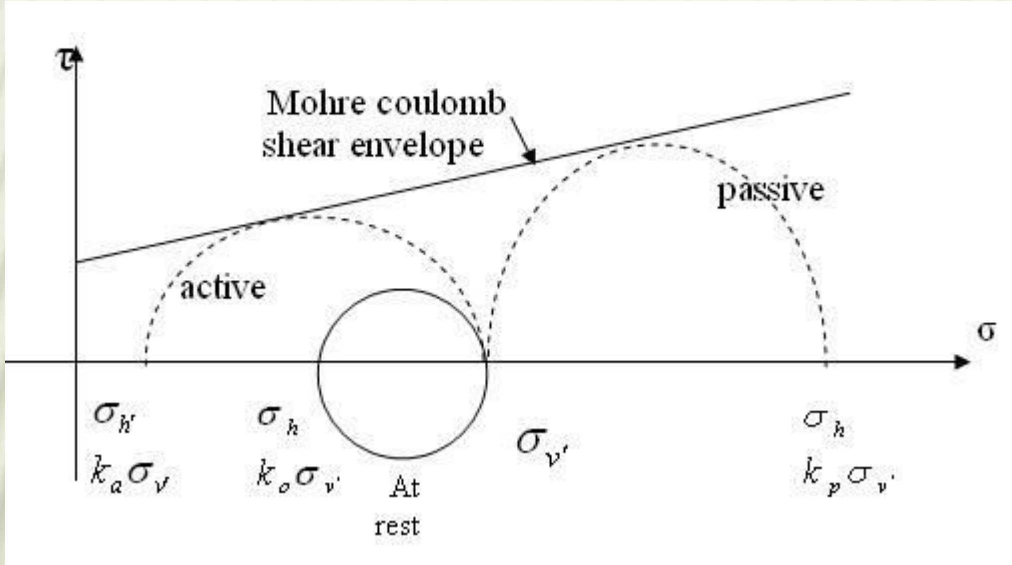
k_p =(1+ sin ø)/(1- sin ø)

Where ø – angle of shearing resistance

States of plastic equilibrium:

A soil mass is in a state of plastic equilibrium if every part of it is at the verge of failure

This is illustrated with the help of Mohr's stress diagram



I – Earth pressure at rest condition

II – Active earth pressure condition - Active state of plastic equilibrium

III – Passive earth pressure condition - Passive state of plastic equilibrium

Rankine’s Earth Pressure Theory

Assumptions:

- ✓ The soil mass is a semi – infinite, homogeneous ,dry cohesion less soil
- ✓ The ground surface is plane and horizontal
- ✓ The back of the wall is vertical and smooth
- ✓ The soil mass is in a state of plastic equilibrium

Limitation of Rankine’s Theory

1) The wall surface is assumed smooth. But in masonry walls, the surface is rough. The error due to this assumption is very large.
2) Wall back is taken as vertical. But in most retaining walls, the wall back is inclined. In such cases, Rankine’s theory is not applicable

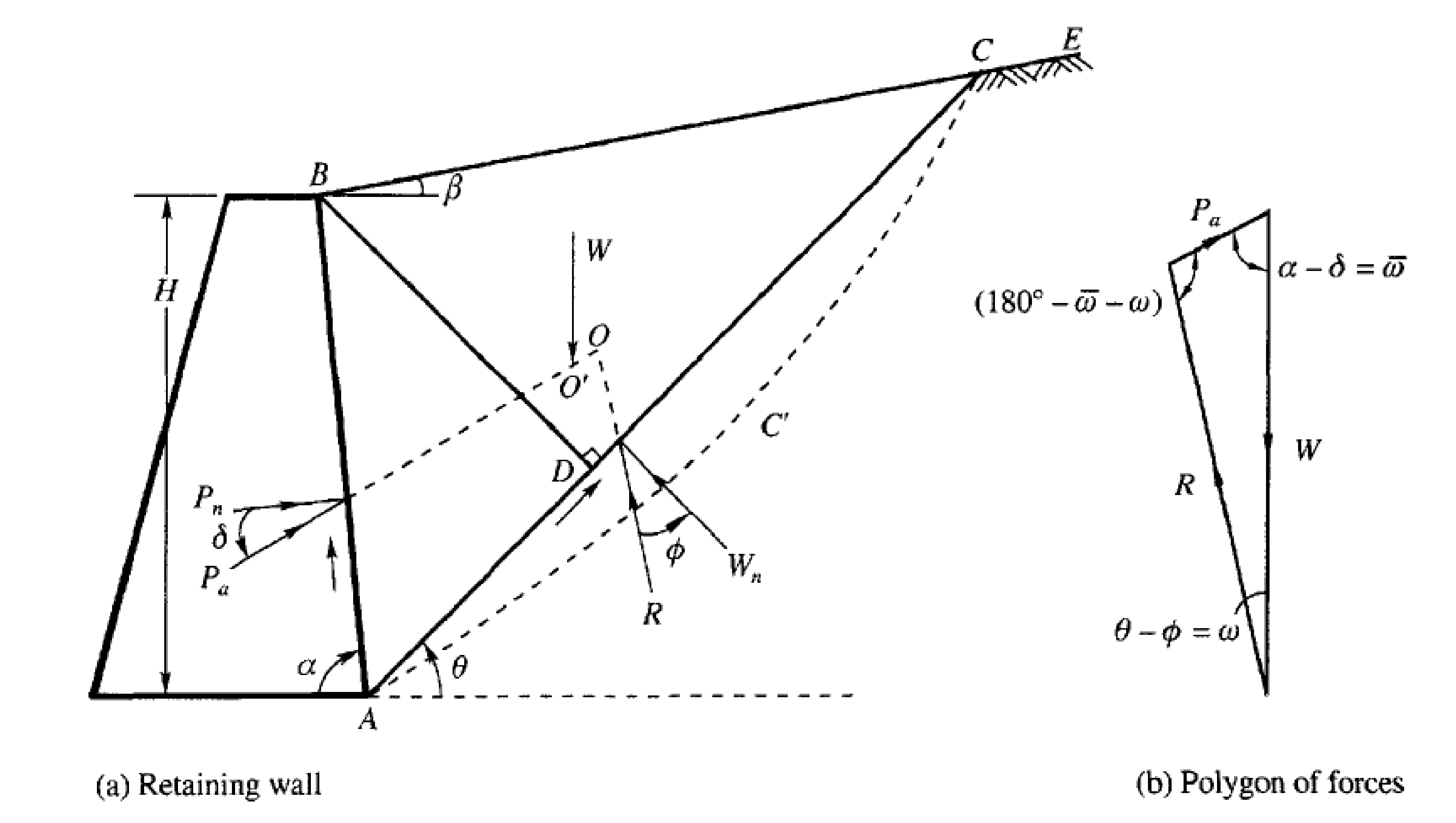
COULOMB'S WEDGE THEORY

- COULOMB'S(1776) developed a method for the determination of the earth pressure in which he considered the equilibrium of the sliding wedge which is formed when the movements of the retaining wall takes place.
- The active case the sliding wedge moves downward and outward relative to the backfill.
- In passive case the sliding moves upwards.
- The lateral pressure on the wall is equal and opposite to the relative forces extended by the wall in order to keep the sliding wedge in equilibrium

ASSUMPTIONS :

1. The soil is isotropic and homogeneous
2. The rupture surface is a plane surface
3. The failure wedge is a rigid body
4. The pressure surface is a plane surface
5. There is wall friction on the pressure surface
6. Failure is two-dimensional and
7. The soil is cohesionless

COULOMB'S -ACTIVE STATE-COHESIONLESS



COULOMB'S - ACTIVE STATE

- In Fig AB is the pressure face
- The backfill surface BE is a plane inclined at an angle ß with the horizontal
- α is the angle made by the pressure face AB with the horizontal
- H is the height of the wall
- AC is the assumed rupture plane surface, and
- θ is the angle made by the surface AC with the horizontal
- The weight of the wedge W length of the wall may be written as
- W = γA, where A = area of wedge ABC

- As the pressure face AB moves away from the backfill, there will be sliding of the soil mass along the wall from B towards A.
- The sliding of the soil mass is resisted by the friction of the surface.
- The direction of the shear stress is in the direction from A towards B.
- lf P_n is the total normal reaction of the soil pressure acting on face AB,
- The resultant of Pn and the shearing stress is the active pressure Pa making an angle δ with the normal.
- Since the shearing stress acts upwards, the resulting Pa dips below the normal.
- The angle δ for this condition is considered positive.

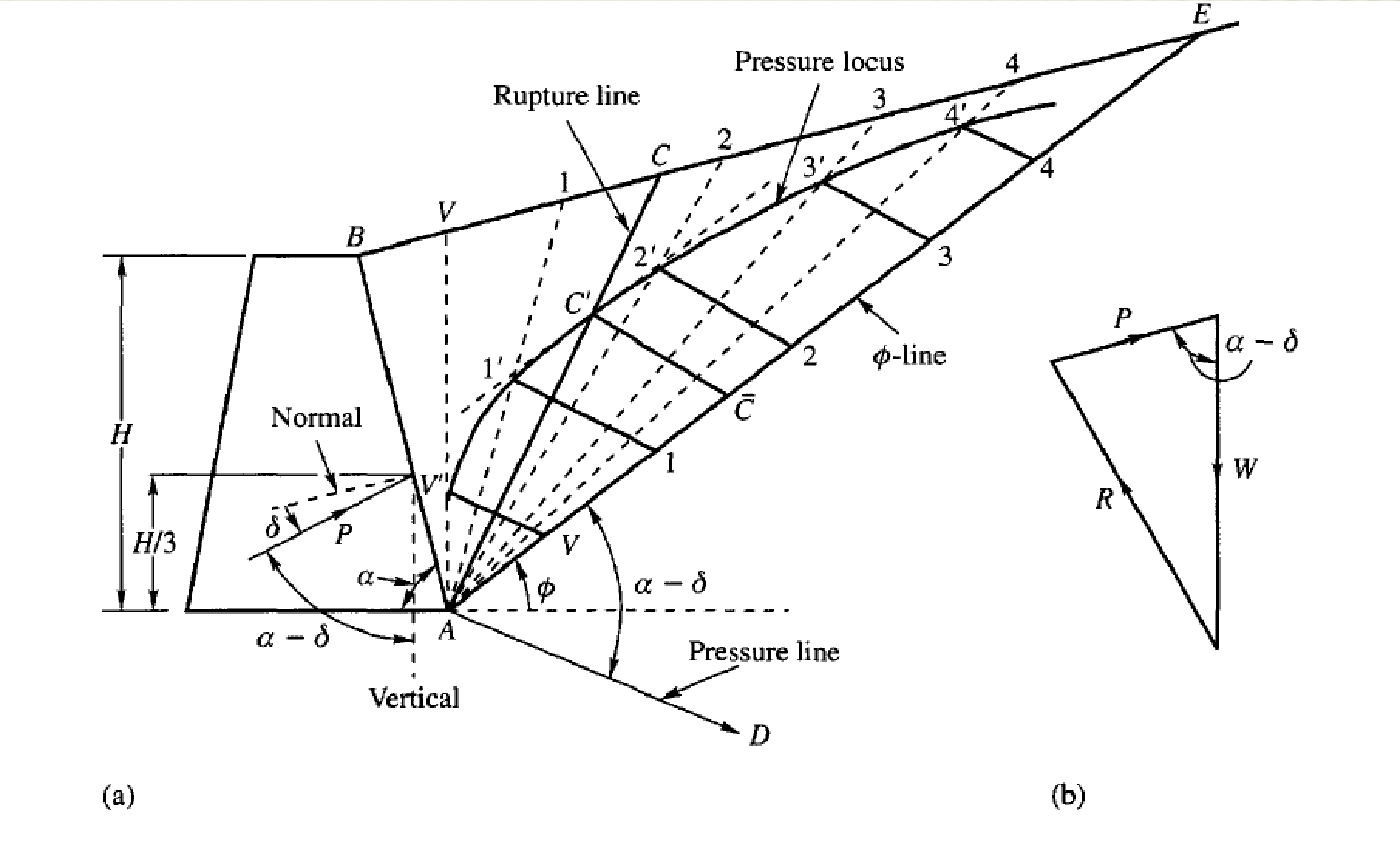
- ✓ As the wedge ABC ruptures along plane AC, it slides along this plane.
- ✓ This is resisted by the frictional force acting between the soil at rest below AC, and the sliding wedge.
- ✓ The resisting shearing stress is acting in the direction from A towards C.
- ✓ If W_n is the normal component of the weight of wedge W on plane AC, the resultant of the normal Wn and the shearing stress is the reaction R.
- ✓ This makes an angle ϕ with the normal since the rupture takes place within the soil itself.

CULMANN'S METHOD

- The active earth pressure based on Coulomb's earth pressure theory can be obtained using Culman's graphical procedure
- The procedure consists of following steps
- Draw the wall to a chosen scale and the surface of the back fill
- Draw a line AF making an angle ø with horizontal
- Draw AD making an angle of (90 – δ – ά) with AF
- Choose trial sliding surfaces AC_1, AC_2, etc
- Compute the weight of sliding wedges, BAC_1, BAC_2, etc and mark the same as 1, 2, 3 etc choosing an appropriate weight scale (ie.eg 1 cm = 10kN)

- Draw lines parallel to AD from 1, 2, 3 etc to cut AC_1, AC_2, AC_3 etc at E_1, E_2, etc
- Join E_1, E_2, E_3 etc by a smooth curve. This is called Culman's curve
- Draw a tangent to the Culman's curve parallel to AF. Let it touch the curve at E
- Draw a line parallel to AD from E to obtain EP
- The length EP multiplied by the weight scale gives the active earth thrust.

CULMANN'S METHOD- GRAPHICAL REPRESENTATION



ACTIVE PRESSURE BY CULMANN'S METHOD FOR COHESIONLESS SOILS

Culmann's (1866) method is the same as the trial wedge method. In Culmann's method, the force polygons are constructed directly on the ϕ-line AE taking AE as the load line.

The procedure is as follows:

1. Draw ϕ -line AE at an angle ϕ to the horizontal.
2. Lay off on AE distances, AV, A1, A2, A3, etc.

   to a suitable scale to represent the weight of wedges ABV, A51, AS2, AS3, etc. respectively.
3. Draw lines parallel to AD from points V, 1, 2, 3 to intersect assumed rupture lines AV, Al,A2, A3 at points V", I',2', 3', etc. respectively.

4. Join points V, 1', 2' 3' etc. by a smooth curve which is the pressure locus.

5. Select point C' on the pressure locus such that the tangent to the curve at this point is parallel to the ϕ-line AE.

6. Draw C'C parallel to the pressure line AD. The magnitude of C'C in its natural units gives the active pressure Pa.

7. Join AC" and produce to meet the surface of the backfill at C. AC is the rupture line. For the plane backfill surface, the point of application of Pa is at a height of H/3 from the base of the wall.

STABILITY OF RETAINING WALLS

1. Check for sliding

2. Check for overturning

3. Check for bearing capacity failure

4. Check for base shear failure

The minimum factors of safety for the stability of the wall are:

1. Factor of safety against sliding =1.5

2. Factor of safety against overturning = 2.0

3. Factor of safety against bearing capacity failure = 3.0