

UNIVERSITY OF GONDAR

INSTITUTE OF TECHNOLOGY

CIVIL ENGINEERING

DEPARTMENT

Foundation Engineering

(CoTM-3172)

FOR CONSTRUCTION

TECHNOLOGY AND MANAGEMENT

Lecture 1

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I. INTRODUCTION

Foundations: their importance and purpose

All engineered construction resting on the earth is carried by an interfacing element called a *foundation*.

The foundation is the part of an engineered system that transmits to, and into, the underlying soil or rock the loads supported by the foundation and its self-weight

FOUNDATION ENGINEERING

foundation engineer is responsible to design and analyze foundations.

Thorough understanding of **Geotechnical** (soil mechanics, geology, foundation engineering) and **structural** (analysis, design in reinforced concrete and steel, etc.) engineering is mandatory for a safe and economical design of foundations.

THE FOLLOWING STEPS ARE THE MAJOR STEPS IN FOUNDATION DESIGN

1. Locate the site and the position of load.
2. Physically inspection of the site
3. Establish the field exploration program
4. Determine the necessary soil design parameters
5. Design the foundation using the soil parameters from step 4

FOUNDATIONS: CLASSIFICATIONS

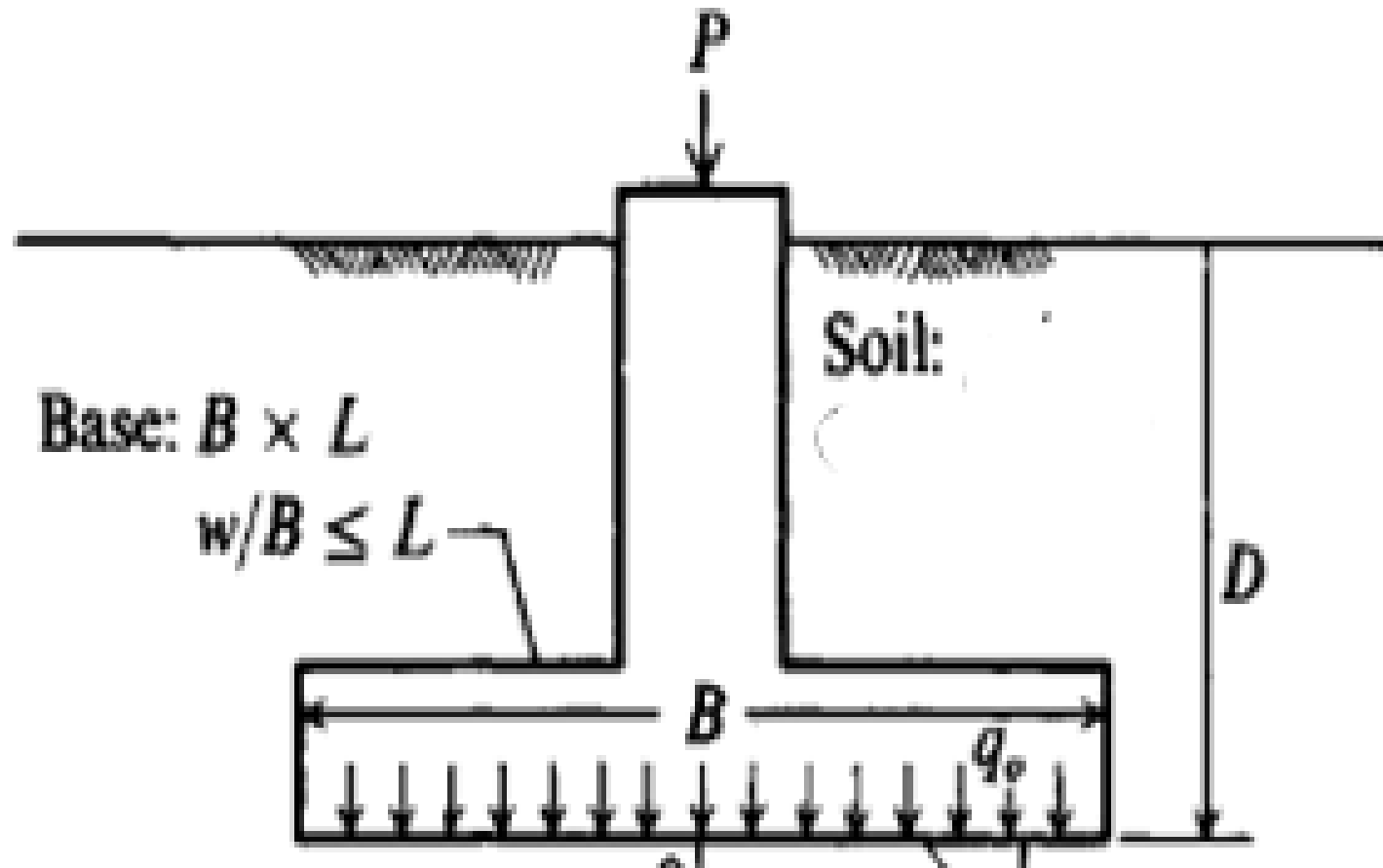
- ◎ *Shallow foundations*—termed bases,
 - footings,
 - spread footings,
 - or mats.

Generally $D/B \leq 1$ where,

D: depth of foundation

B: width (breadth, diameter) of foundation

CONT.

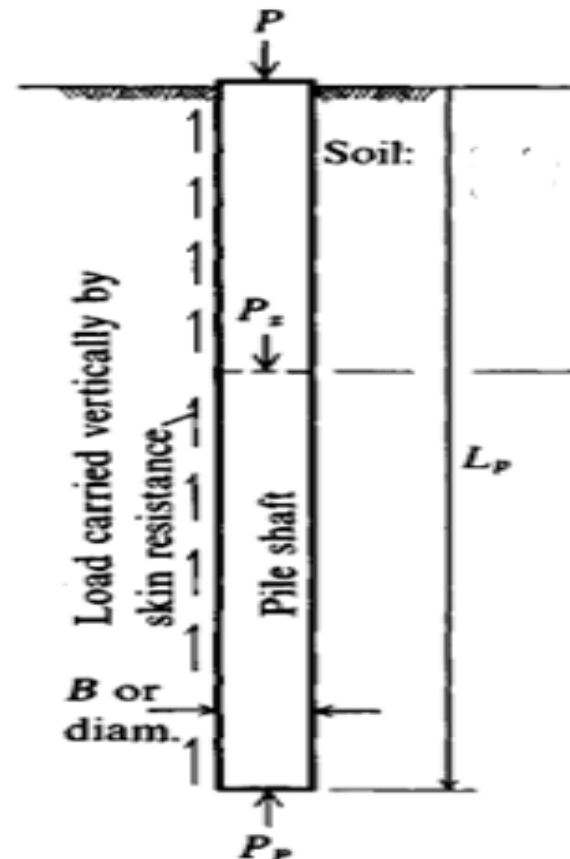


CONT.

- ◉ **Deep foundations**—piles, drilled piers, or drilled caissons. $L_p/B \geq 4+$

L_p : Length of pile

B : width (breadth, diameter) of foundation



Foundation types and typical usage

Foundation type	Use	Applicable soil conditions
Shallow foundations (generally $D/B \leq 1$)		
Spread footings, wall footings	Individual columns, walls	Any conditions where bearing capacity is adequate for applied load. May use on a single stratum; firm layer over soft layer or soft layer over firm layer. Check settlements from any source.
Combined footings	Two to four columns on footing and/or space is limited	Same as for spread footings above.
Mat foundations	Several rows of parallel columns; heavy column loads; use to reduce differential settlements	Soil bearing capacity is generally less than for spread footings, and over half the plan area would be covered by spread footings. Check settlements from any source.

Deep foundations (generally $L_p/B \geq 4^+$)

Floating pile	In groups of 2 ⁺ supporting a cap that interfaces with column(s)	Surface and near-surface soils have low bearing capacity and competent soil is at great depth. Sufficient skin resistance can be developed by soil-to-pile perimeter to carry anticipated loads.
Bearing pile	Same as for floating pile	Surface and near-surface soils not relied on for skin resistance; competent soil for point load is at a practical depth (8–20 m).
Drilled piers or caissons	Same as for piles; use fewer; For large column loads	Same as for piles. May be floating or point-bearing (or combination). Depends on depth to competent bearing stratum.

FOUNDATIONS: GENERAL REQUIREMENTS

Foundation design depends on the type and purpose of the structure and soil type. The general requirements are;

- Allowable stress
- Allowable settlement
- Economical design(feasibility)

ADDITIONAL REQUIREMENTS

- Adequate depth to avoid lateral squeezing and weak soil zone (seasonal volume change zone)
- Expansive soil condition
- overturning, sliding, and any uplift (flotation).
- corrosion or deterioration
- later changes in site or construction

ASSIGNMENT 1

1. Differentiate between spread footing, wall footing, combined footing , strip footing , and strap footing.
2. Define pile foundation , Pile cap, drilled pier and/or caisson.

1. SOIL EXPLORATION AND TESTING

- Obtaining information on the soil exposed at the ground surface, evaluate the sub-surface conditions by taking samples by boring or by digging exploratory pits is defined by *soil exploration*.
- Purpose: Identification of stratification and important engineering properties
 - Strength, deformation and hydraulic
- Information needed: for decision on foundation type, bearing capacity, settlement estimation, identification of environmental problem and pertinent solution.

OBJECTIVES OF SOIL EXPLORATION

1. Determination of the nature of the deposits of soil, depth and thickness of the various soil strata and their extent in the horizontal direction,
2. The location and fluctuations of GWT,
3. Obtaining soil and rock samples from the various strata,
4. Determination of the engineering properties of the soil and rock strata that affect the performance of the structure, and
5. Determination of the in-situ properties by performing field tests.

PURPOSES OF SOIL EXPLORATION

- i. Selection of alternative construction sites or the choice of the most economical sites.
- ii. Selection of types and depth of foundation suitable for a given structure.
- iii. Establishing construction methods for changing subsoil conditions.
- iv. Evaluating the load-bearing capacity of foundations.
- v. Determining potential foundation problems (e.g., expansive soil, collapsible soil, sanitary landfill, and so on).
- vi. Establishing the probable settlement of a structure.
- vii. Predicting the lateral earth pressures.
- viii. Evaluation of the safety of existing structure.
- ix. Location and selection of construction materials.

CONT.

The soil exploration should provide the following data: -

- Soil parameters and properties of different layers (e.g. for classification, bearing capacity or settlement calculation)
- Thickness of soil layers and depth to bedrock (stratification of soil)
- Location of ground water level

PLANNING SOIL INVESTIGATION PROGRAM

The purpose of soil investigation program is to study the engineering properties of the soil and to determine design parameters.

The cost of inadequate data by neglecting site investigation is considerably more than the cost of investigation.

- ◉ The planning of an exploration program depends upon
 - The nature of soil strata
 - The type of structure
 - The importance of structure

PURPOSE OF THE PLANNING OF INVESTIGATION PROGRAM

- ⦿ Planning: Maximize information and minimize cost!
 - International practice shows soil exploration can cost 0.5 to 1% of total project cost.
 - A conservative design tending to save on exploration cost does not guarantee, safety and even economy.
- ⦿ Erratic soil does not necessarily imply need for extensive boring. The aim in this case should be establishment of general picture of stratification with conservative design ultimately.
- ⦿ Maximize Use of Available information

STEPS IN PLANNING OF A SUBSURFACE EXPLORATION PROGRAM

I. Assembly available information on

- ✓ tentative layout, function, special features, etc. This may involve consulting different maps and preliminary drawings
- ✓ type and use of the structure
- ✓ general topography
- ✓ geological character of the site

⦿ **II. Reconnaissance/Appraisal:** - involves walk over site to reveal cracks, sags, sticking doors & windows, etc.; type of existing structures; gully trenches; rock outcrops; any other relevant information.

III. Preliminary site investigation: - few borings to establish general formation; one or a few deep boreholes to competent strata if upper soil is loose;

- ❖ data should suffice for preliminary design & identification of construction method (sheeting, diaphragm wall, pile wall, tiebacks, etc.); suitability of site & economy established

IV. Detailed site investigation: - For complex projects or where the soil is of poor quality and/or erratic, a more detailed investigation may be undertaken. This may involve sinking several boreholes, taking soil samples for laboratory investigations, conducting sounding and other field tests.

CONT.

- ◉ Purpose of detailed investigation is to refine design and decide on any special construction methods; investigation extent depends on preliminary data; generally, it involves more investigation with one or more boreholes to competent rock.

METHODS OF EXPLORATION

- Depending on the function, size, and importance of the structure, one or more of the following exploration methods can be employed
 - Direct methods/Open pits, trial pits and/or trenches
 - Semi direct methods-Sinking boreholes and sampling

Indirect methods

- Field tests -sounding or penetration tests
- Laboratory tests
- Geophysical investigation
- Geological investigation

TEST PIT AND TRENCHES

⦿ Advantages

- Cheap,
- fast,
- enable direct visual inspection
- Good samples can be extracted

⦿ Disadvantages

- Shallow investigation

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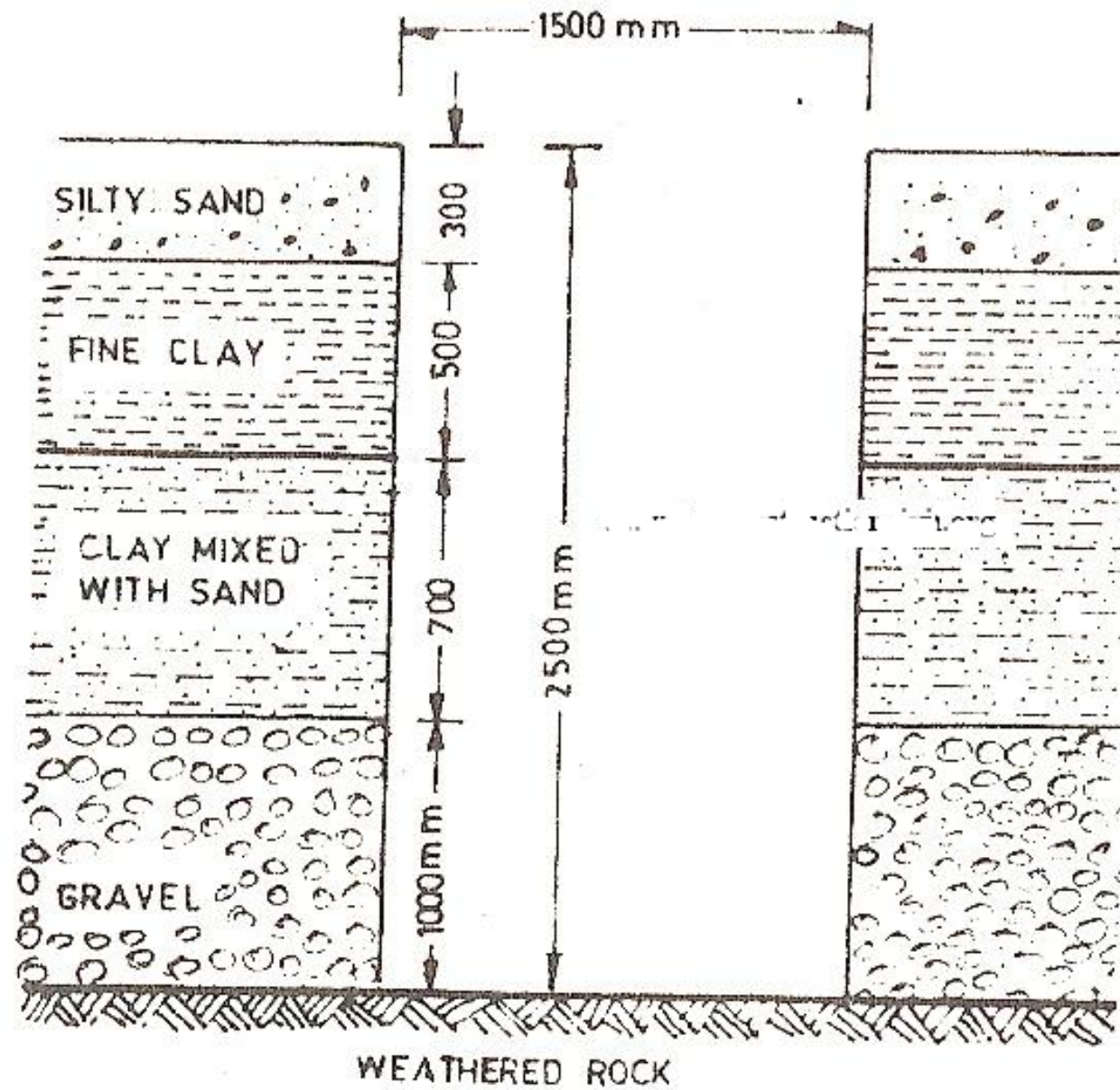


Fig. Test Pit

BORING METHODS

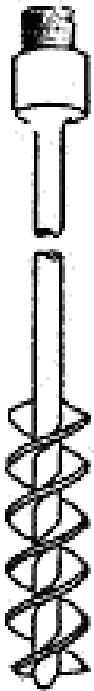
- ◎ Boring has two phases:
 - i. Advancing hole and
 - ii. Sampling.
- ◎ Many techniques available: Dependent on material encountered and purpose.
 - Advancing techniques: Auger boring, wash boring, percussion drilling, rotary drilling, continuous sampling, displacement method, etc.
 - Sampling techniques: Spiral, bucket, hollow-stem augers, solid- and split-spoon samplers, Shelby-tube (thin wall), stationary piston, single- and double tube rock core barrels.

BORING METHODS...

- ❑ Two Major Problems: Caving of wall & heaving of bottom.
- ❑ Heaving: occurs in all holes due to stress release; serious below GWT due to seepage; use of drilling fluid maintained above GWT helps.
- ❑ Caving: serious in cohesionless deposits and below GWT; also in jointed rock below GWT depending on degree of weathering at the joints; thus, use of casings or drive pipes below GWT is common.

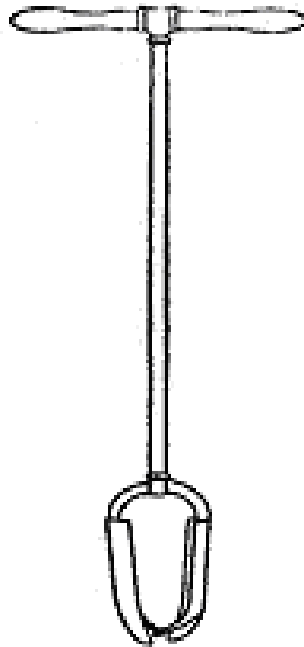
AUGER BORING

❖ Hand operated augers - up-to depth of ≤ 10



(a)

Helical Auger



(b)

post hole auger

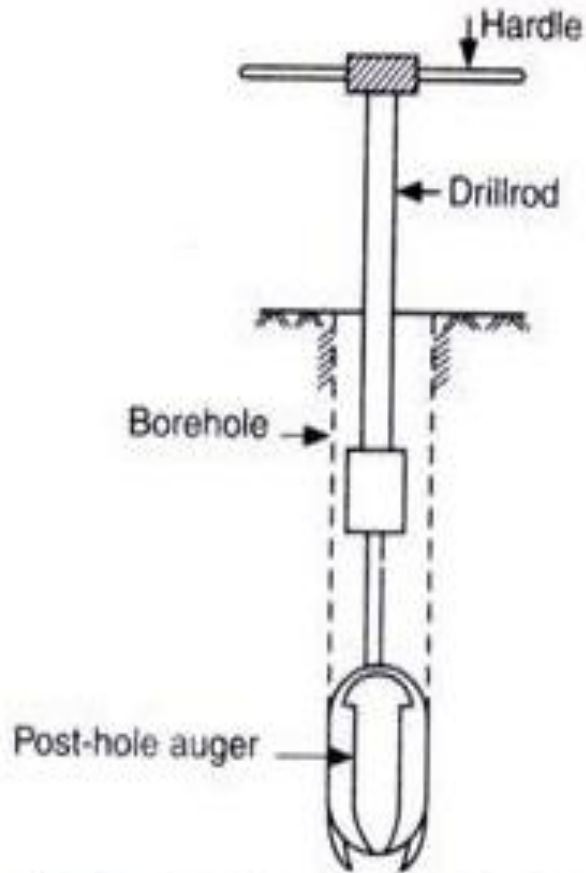


FIG. 10.1 (a) Auger boring

AUGER BORING... CONT



(c) Gravel auger



(e) Open and closed
Sprial augers



(f) Flot sprial shoe
Barrel auger

POWER OPERATED AUGERS

- ◉ Need power for rotation & pressure;
- ◉ Varying size and capacity in two major categories: flight augers (5 to 120cm Φ) & bucket-type augers (30 to 240cm Φ).
 - ◉ **Bucket-type augers**: Open top; slotted & toothed bottom; the big sizes can accommodate an inspector.
 - ◉ **Flight augers**: Single-flight, double-flight, high spiral, conveyor- or continuous-flight, and hollow-stem augers;
 - ✓ attaching additional height of spiral in the single- and double-flight augers is common to save time;

... CONT

- **Conveyor-flight auger**: Deep penetration can be attained - up to 30m;
Mixing up of material is a disadvantage.
- **Hollow-stem augers**: Internal diameter ranges between 7cm and 16 cm; consists of a steel tube with spiral blades; also suitable for loose deposits below GWT;
 - Tube serves as casing; high quality samples can be retrieved;
 - SPT can be conducted.

POWER AUGERS:

Penetration 3 to 7m

- a) single-flight earth auger;
- b) double flight earth-rock auger;
- c) double-flight rock auger;
- d) high spiral auger

Penetration at least 30m (up to 100m)

- a) Conveyor flight auger
- b) Bucket auger
- c) Hollow-stem auger

WASH BORING

- ◉ hole is advanced to a short depth,
- ◉ casing pipe is driven in the ground to prevent the sides of the bore hole from caving in,
- ◉ Boring is continued by using chopping bit
- ◉ Water is forced under pressure through the drill rod which is alternatively raised and dropped, and also rotated
- ◉ Bit is replaced by sampler during sampling.
- ◉ Due to its jetting and chopping action soil is loosened.
- ◉ The loosened soil is forced up-to the ground surface in the form of soil water slurry
- ◉ Depth of boring could be up to 60m or more

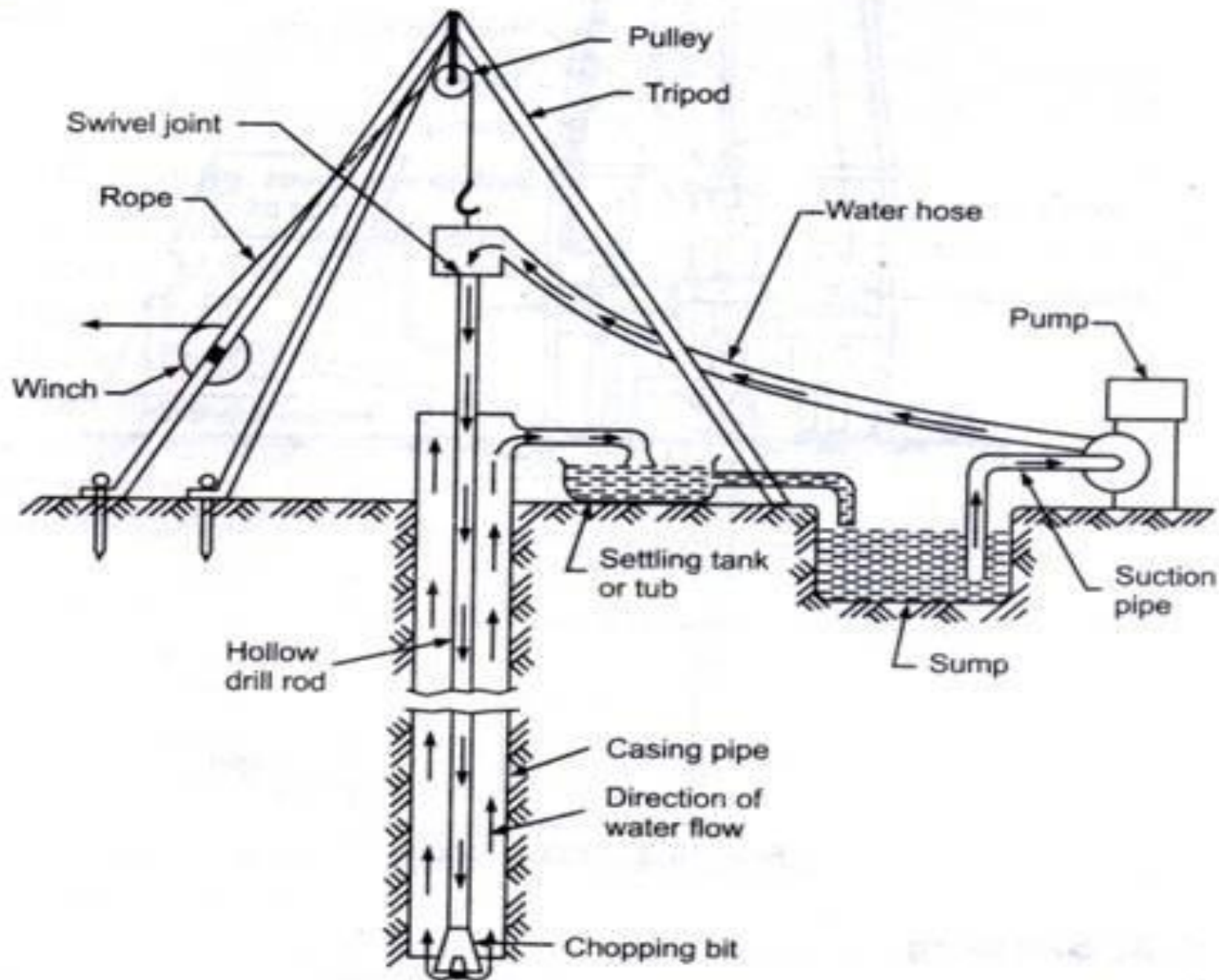
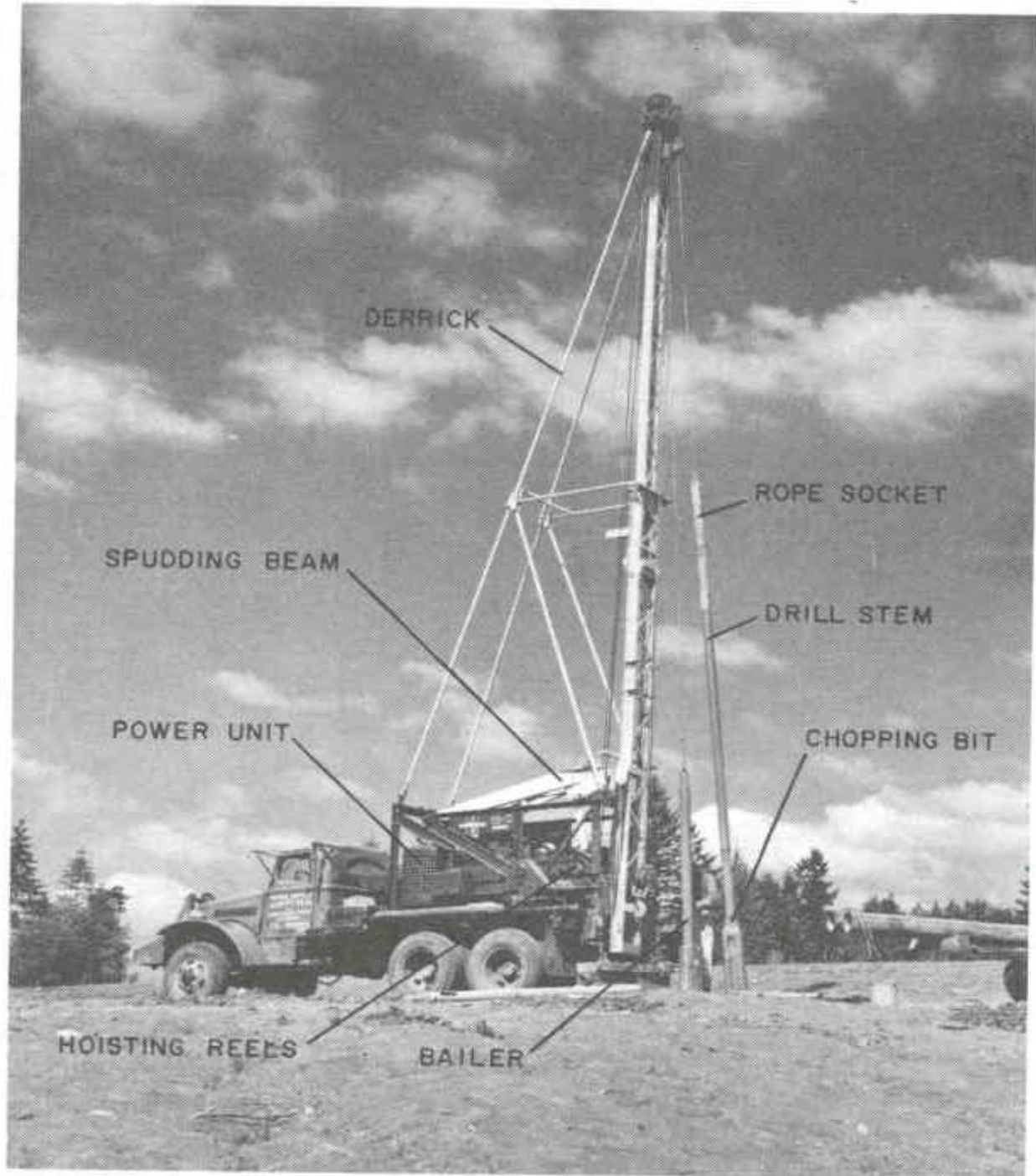


FIG. 10.2 Wash boring

PERCUSSION DRILLING

- Power operated.
- Common in drilling water wells, boring in rocks and hard soil.
- Involves alternate raising & dropping of heavy drilling tools, pouring of water and periodical bailing or pumping of slurry; type of bit depends on material encountered.
- Advantageous in coarse granular deposits with boulders and in cavernous limestone.
- A major disadvantage: the heavy blows can disturb soil to a significant depth; difficult to detect thin layers.

- Truck-mounted Percussion drilling rig



ROTARY DRILLING

- Power operated.
- Uses rotation & pressure for advancement.
- Employed only when deep bore holes are required in difficult formations with boulders and fractured rock or water logged sand.
- Bentonite mud/slurry or casing necessary if caving is a problem.
- Various drill heads may be employed: auger heads; grinding heads; coring bits; etc
- undisturbed samples can be obtained
- Maximum depth of drilling is 80 to 150m.

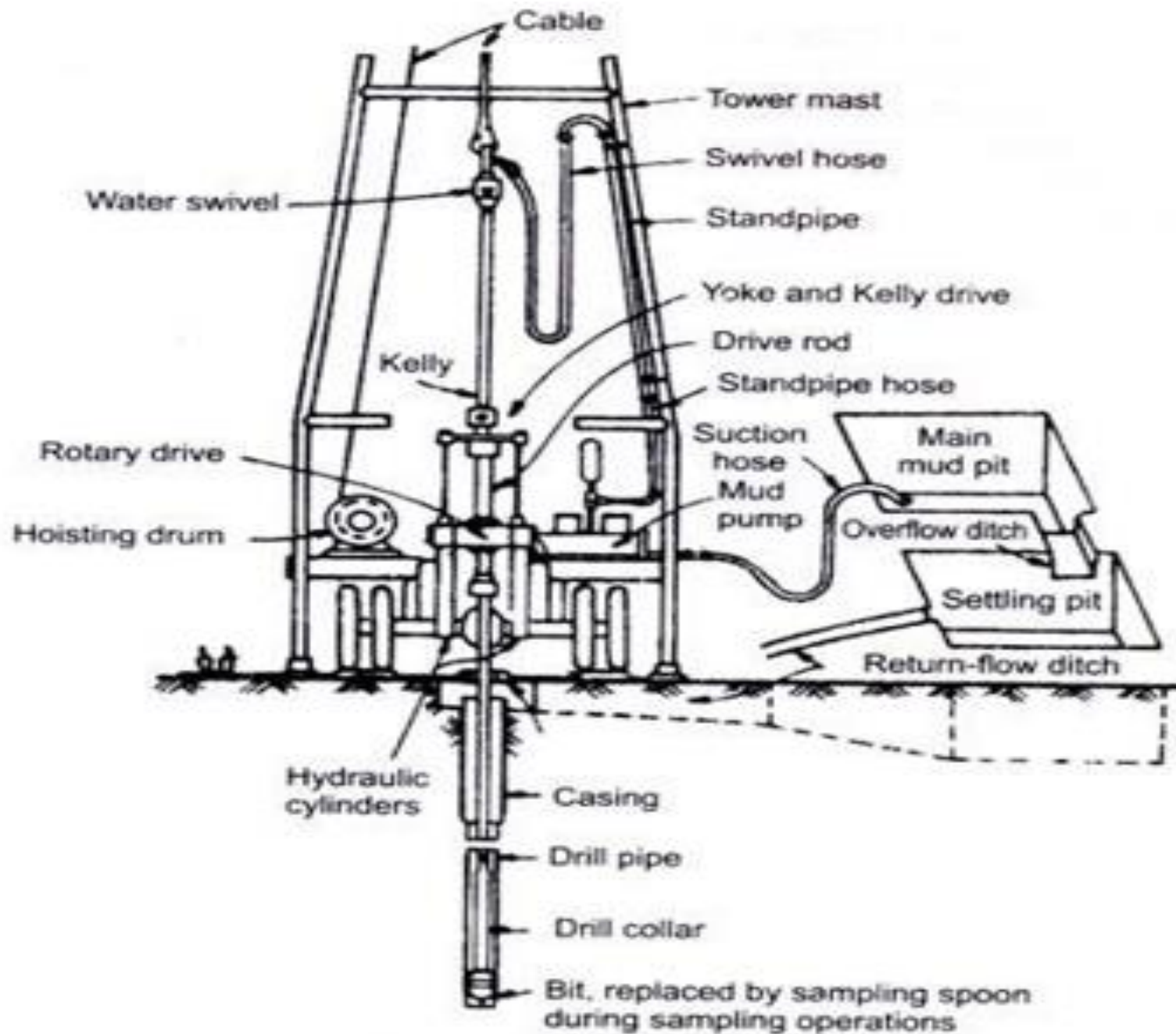


FIG. 10.3 Rotary boring

SOIL SAMPLING

Two types of soil samples

1. Disturbed but representative:

- Structure could be lost but should contain all constituents in proper proportion;
- Employed for identification, *performing classification tests such as sieve analysis, Atterberg limits*, compaction tests and locating borrow materials

2. Undisturbed samples:

- High care exercised to preserve in-situ structure of soil
- Area ratio may not exceed 13%

For shearing resistance and stress-deformation characteristics of a deposit (cohesive soils)

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Area ratio, A_r :

$$A_r = \frac{\phi_o^2 - \phi_i^2}{\phi_i^2} \times 100\%$$

■ ϕ_o is outer diameter

■ ϕ_i is inner diameter

➤ represents the amount of soil that is displaced when a sampler is forced into the ground. The area ratio should be kept as low as possible.

- ✓ For stiff formation, $ar > 20\%$
- ✓ For soft soil, $ar, \leq 10\%$ or less

Reading Assignment

- ⊙ Auger boring
- ⊙ Wash boring
- ⊙ Percussion drilling
- ⊙ Rotary drilling

Boring methods

TYPES OF SAMPLERS

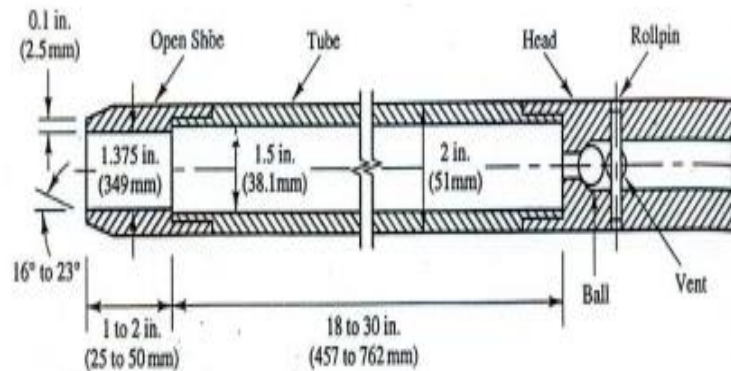
It is virtually impossible to obtain totally undisturbed samples. Sample disturbance may be reduced by using an appropriate type of sample tube.

a good sampler is the one, which is able to collect as less undisturbed soil samples as possible

SPLIT SPOON SAMPLER



Standard Split Spoon Samplers



Open sampler with soil sample and cutting shoe



Stainless steel and brass retainer rings



- ☆ used to obtain disturbed samples in all types of soils.
- ☆ used in conjunction with the *Standard Penetration Test* (SPT)
- ☆ sampler is driven with a 63.5-kg (140-lb) hammer dropping from a height of 760 mm (30 in).
- ☆ Steel or plastic sample retainers are often required to keep samples of clean granular soils in the split-barrel sampler.

THIN-WALLED TUBE SAMPLER

- commonly used to obtain relatively undisturbed samples of cohesive soils for strength and consolidation testing

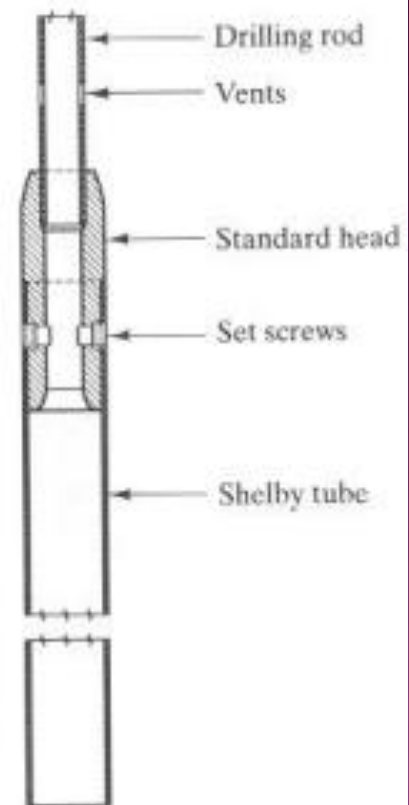


Shelby Tube (Thin-wall) Sampler

Thin wall **0.0625 in** sampling tube
Sampler pushed into the ground hydraulically
Sample extruded from tube and
"Undisturbed" soil sample is obtained

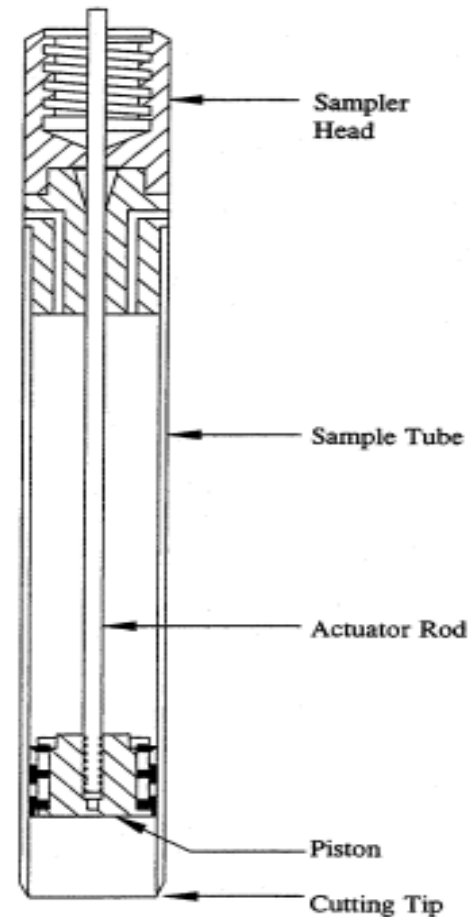
Sealing of Sampling Tube

After removing the sampler from ground, it is sealed on both sides using melted wax to preserve moisture



PISTON SAMPLERS

- ✓ basically a thin-wall tube sampler with a piston, rod, and a modified sampler head
- ✓ particularly useful for sampling soft soils where sample recovery is often difficult although it can also be used in stiff soils
- ✓ Hydraulically driven samplers



Summary of common sampling methods

<i>Sampler</i>	<i>Disturbed / Undisturbed</i>	<i>Appropriate Soil Types</i>	<i>Method of Penetration</i>	<i>% Use in Practice</i>
Split-Barrel (Split Spoon)	Disturbed	Sands, silts, clays	Hammer driven	85
Thin-Walled Shelby Tube	Undisturbed	Clays, silts, fine-grained soils, clayey sands	Mechanically Pushed	6
Continuous Push	Partially Undisturbed	Sands, silts, & clays	Hydraulic push with plastic lining	4
Piston	Undisturbed	Silts and clays	Hydraulic Push	1
Pitcher	Undisturbed	Stiff to hard clay, silt, sand, partially weather rock, and frozen or resin impregnated granular soil	Rotation and hydraulic pressure	<1
Denison	Undisturbed	Stiff to hard clay, silt, sand and partially weather rock	Rotation and hydraulic pressure	<1
Modified California	Disturbed	Sands, silts, clays, and gravels	Hammer driven (large split spoon)	<1
Continuous Auger	Disturbed	Cohesive soils	Drilling w/ Hollow Stem Augers	<1
Bulk	Disturbed	Gravels, Sands, Silts, Clays	Hand tools, bucket augering	<1
Block	Undisturbed	Cohesive soils and frozen or resin impregnated granular soil	Hand tools	<1

LABORATORY TESTING

Useful in providing reliable data for calculating **ultimate bearing capacity** of soils, **stability** and **settlement behavior** of foundation, and for **determining physical characteristics** of soils.

The common laboratory tests that concern the foundation engineers are;

- ◉ Grain size analysis
- ◉ Atterberg limits
- ◉ Natural moisture content
- ◉ Unit weight
- ◉ Unconfined compression test
- ◉ Direct shear test
- ◉ Tri-axial compression test
- ◉ Consolidation test
- ◉ Compaction test
- ◉ Chemical analysis

ASSIGNMENT 2

Prepare a short summary on the above mentioned soil lab tests including the

- ◉ Purpose
- ◉ Instrument/equipment
- ◉ Procedure

GROUND WATER MEASUREMENT

Importance of groundwater level measurement:

- ⦿ Groundwater level is an indicative of type of soil and its permeability
- ⦿ In waterlogged areas, dewatering is required for soil exploration. So measurement of groundwater level enables the geotechnical engineer- in-charge to decide about the type of dewatering units required for the site.
- ⦿ Groundwater level affects many important phases in the design and construction of foundation. So it must be measured with accuracy in each project.

DEPTH AND NUMBER OF BORINGS

DEPTH OF BORING:

The depth to which boreholes should be sunk is governed by the depth of soil affected by foundation bearing pressures.

According to Tomlinson;

Widely spaced pad foundation = $1.5B$

Raft foundation = $1.5B$

Closely spaced Strip foundation = $1.5W$

Group of pile foundation = $1.5B$ (width of pile group)

Pile foundation on rock > 3m

Depth of boring for buildings in shallow foundation (Sowers, 1979)

S. No.	Subsurface condition	Minimum depth of boring
1.	Poor	$6S^{0.7} + D$
2.	Average	$6S^{0.7} + 5D$
3.	Good	$3S^{0.7} + D$

where

S = No. of stories

D = Anticipated depth of foundation.

NUMBER (SPACING) OF BORINGS

Spacing of boreholes according to Teng

Project	Distance between boring (m)			Minimum number of boring for each structure
	Horizontal stratification of soil			
	Uniform	Average	Erratic	
Multi-story building	45	30	15	4
One or two story building	60	30	15	3
Bridge piers, abutments, television towers, etc	-	30	7.5	1 or 2 for each foundation unit
Highways	300	150	30	
Borrow pits (for compacted fill)	150- 300	60- 150	15-30	57

Table 2: Spacing of boreholes according to Das .

Type of project	Spacing, m
Multistory building	10 - 30
One-story industrial plants	20 - 60
Highways	250 – 500.
Residential subdivision	250 – 500.
Dams	40 - 80

Table 18.1 Spacing of Borings (Sowers and Sowers, 1970)

<i>S.No.</i>	<i>Nature of the project</i>	<i>Spacing of borings (metres)</i>
1.	Highway (subgrade survey)	300 to 600
2.	Earth dam	30 to 60
3.	Borrow pits	30 to 120
4.	Multistorey buildings	15 to 30
5.	Single story factories	30 to 90

Note : For uniform soil conditions, the above spacings are doubled; for irregular conditions, these are halved.

Borehole layout and frequency

Most Projects are either of:

1. Isolated small structures:
pylons, radio masts,
small houses (one borehole
may be sufficient)
2. Compact projects: buildings,
dams, bridges,
small landslips (require at least
four boreholes;
deep and closely spaced)
3. Extended Projects: motorways,
railways, reservoirs,
land reclamation schemes
(shallower more widely
spaced boreholes)

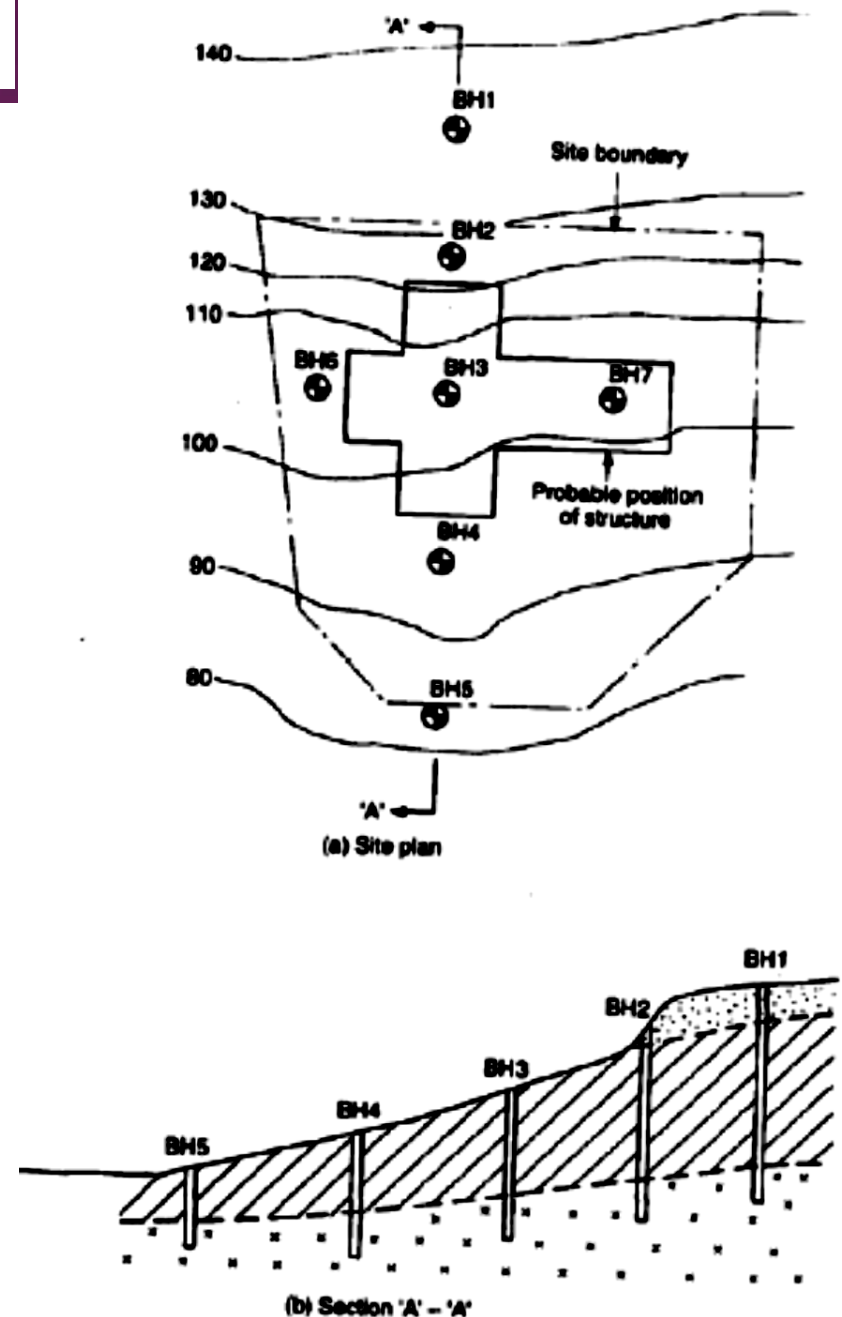


Fig. 1.4 Alignment of boreholes.

FIELD/INSITU TESTS

- The main problem associated with the laboratory tests of soils are **disturbance** during sampling and transportation so to overcome these problems several in-situ tests have been developed.
- These tests are valuable means of determining the **relative densities; shear strengths and bearing capacities of soils** directly without disturbing effects of boring and sampling.

The most commonly used field tests are

- Penetration or sounding tests
- Vane shear test
- Plate loading test
- Pile loading test

PENETRATION OR SOUNDING TESTS

- Penetration tests are the most useful tests.
- They are conducted mainly to get information on the **relative density** of soils with little or no cohesion.
- relative density of a soil stratum is directly proportional to the resistance of the soil against the penetration.
- correlations between values of penetration resistance versus **angle of internal friction (ϕ), bearing pressure, density and modulus of compressibility** have been developed.

CONT.

Penetration tests are classified as

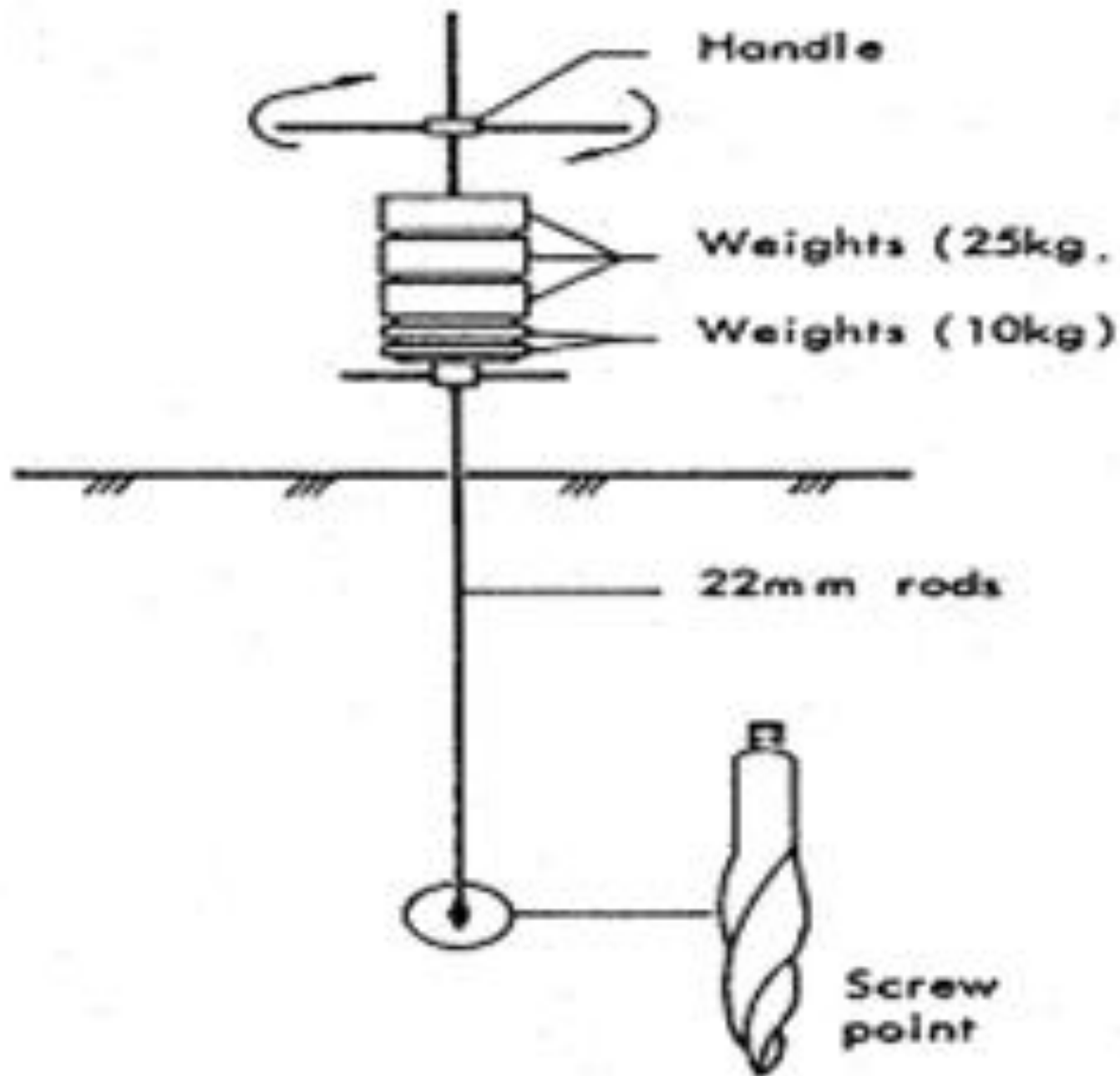
- ◉ static and
- ◉ dynamic penetration tests

Static Penetration Tests

1. Swedish Weight Sounding Test:

This method of testing is widely used here in Ethiopia.

The test consists of weights: 5,10,10, 25,25, and 25kgs($\Sigma=100$ kg), screw point, driving rod (ϕ 20 to 22 mm), made up of 100cm parts, and a rotating handle.



TEST PROCEDURE

- The tip of the road is placed on the ground
- 5 kg load is applied to the road and checks the penetration, if no penetration the load is increased in the order of 15 , 25, 50, 75, 100 kg respectively.
- If the road does not penetrate the ground even after 100 kg load, the handle continues to be rotated. The number of half turns needed to make penetrate 25 cm is recorded.
- If the penetration after 25 half-turns is less than 5cm the rod is unloaded and driven down by a 5 to 6kg hammer.

CONT.

- The correlation between density of frictional soils and consistency of cohesive soils and ht/m (half-turns per meter) are as given below.

<u>Frictional Soils (density)</u>		<u>Density (kN/m³)</u>
Very loose	<50ht/m	11-16
Loose	50 -150ht/m	14.5 - 18.5
Medium	150 - 300ht/m	17.5 - 21
Dense	300 - 500ht/m	17.5 - 22.5
Very dense	> 500ht/m	21 - 24

CONT.

Cohesive Soils

Density (kN/m³)

(density)

Soft	0 ht/m	16 - 19
Firm	0 - 100 ht/m	17.5 - 21
Stiff	100-200 ht/m	19 - 22.5
Very stiff	200 - 500 ht/m	19 - 22.5
Hard	>500 ht/m	19 - 22.5

EXAMPLE

Example

1. Number of ht/m in non cohesive soils =250
Soil unit weight 18 kN/m³
2. Number of ht/m in cohesive soils =160
Soil unit weight 19.5 kN/m³

2.STATIC CONE PENETRATION TEST (DUTCH CONE PENETROMETER TEST)

- The test consists of a cone (apex angle 60^0 , overall diameter 35.7mm, end area 10cm^2 , rods ($\frac{5}{8}$ " ϕ), casing pipe ($\phi \frac{3}{4}$ ").
- The rod is pushed hydraulically into the ground at a rate of 10mm/sec.
- The pressure exerted on the rod is measured with a proving ring, manometer or a strain gauge.
- Readings are usually taken every 20cm. From this test point resistance and skin frictional resistance can be determined separately.

The correlation between the cone (point) resistance and relative density of frictional soils are given below

Relative Density	Point Resistance (kN/m^2)
Very loose soil	< 2500
Loose soil	$2500 - 5000$
Medium dense	$5000 - 10,000$
Dense	$10,000 - 15,000$
Very dense	$> 15,000$

CONT.

According to Meyerhof:

$$N = 1/4 (C_{kd})$$

Where

N = Standard penetration number

C_{kd} = Static Cone resistance (kg/cm²)

For sand, modulus of compressibility (E_s) can be estimated from cone resistance from the following relationship.

$$E_s = 3/2 (C_{kd})$$

EXAMPLE

Point resistance of a soil to Static cone penetration test = 12000 kN/m^2

$N =$

$E_s =$

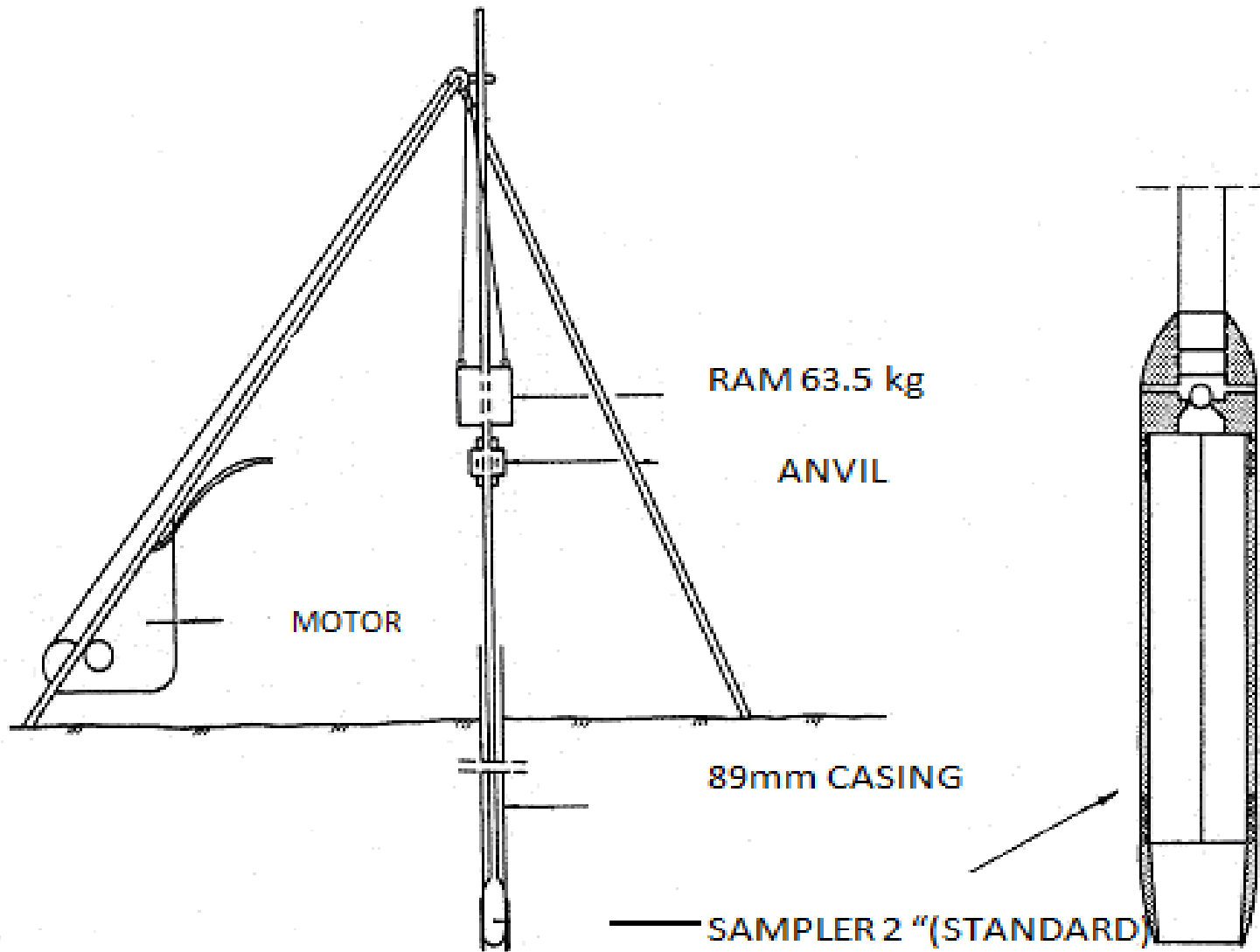
DYNAMIC PENETRATION TESTS

1) Standard Penetration Test (SPT):

- This is the most common field/insitu test
- The test is especially suited for cohesionless soils as a correlation has been established between the SPT value and the angle of internal friction of the soil
- measures the resistance of the soil to dynamic penetration by a 50mm to 150mm diameter split spoon sampler which is driven into the soil at the at desired depth.

CONT.

- The sampler is attached to drill rods and the dynamic driving force is a 63.5kg mass falling through a height of 76cm onto the top of the rod.
- The sampler is initially driven 15cm below the bottom of the borehole.
- It is then further driven 30cm.
- The number of blows required to drive the last 30cm is termed as the standard penetration value denoted by N



Standard penetration test (SPT) equipment

Correlation between Number of blows (N),
Angle of Internal Friction (ϕ) and Relative
Density of Frictional Soils (Terzaghi and
Peck)

N	0 - 4	4 -10	10-30	30 - 50	> 50
ϕ	$<28^{\circ}$	$28 -30^{\circ}$	$30-36^{\circ}$	$35 - 40^{\circ}$	$>42^{\circ}$
Relative Density	Very loose	Loose	Medium	Dense	Very dense

Correlation between Number of blows (N), Unconfined Compressive Strength and Consistency of Cohesive Soils. (Terzaghi and Peck).

N	0 -2	2 - 4	4 - 8	8 -15	15-30	>30
$q_u(\text{kN/m}^2)$	0 -25	25 -50	50 -100	100 -200	200-400	>400
Consistency	Very soft	Soft	Medium	Stiff	Very stiff	Hard

CORRECTION TO BE APPLIED TO MEASURED VALUES OF SPT

- I. When **SPT** is made in fine saturated sands, saturated silty sands, or saturated silts, correction is usually made for possible build up of **pore water pressure**. The SPT values, greater than 15 are modified as follows

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

Suggested by Terzaghi and peck (1948)

where N= corrected SPT value
 N'= Observed SPT value

CONT.

- II. The other type of correction is known as correction for overburden pressure. This correction is applied only to cohesionless soils (dry, moist or wet). The correction suggested by Gibbs and Holtz and widely used is as follows.

$$N = \frac{345' N'}{(\sigma_o' + 69)} \leq 2N', \text{ for } \sigma_o' \leq 276 \text{ kN/m}^2$$

$$N = \frac{35N'}{(\sigma_o' + 7)} \leq 2N', \text{ for } \sigma_o' \leq 28 \text{ kN/m}^2$$

σ_o' = effective overburden pressure in kN/m²

Terzaghi and Peck also give the following correlation between SPT value, D_r , and ϕ :

Condition	N	D_r	ϕ
Very loose	0 - 4	0 - 15%	$< 28^\circ$
Loose	4 - 10	15 - 35%	$28^\circ - 30^\circ$
Medium	10 - 30	35 - 65%	$30^\circ - 36^\circ$
Dense	30 - 50	65 - 85%	$36^\circ - 42^\circ$
Very dense	> 50	$> 85\%$	$> 42^\circ$

For clays the following data are given:

Consistency	N	Q_u (kN/m ²)
Very soft	0-2	< 25
Soft	2-4	25-50
50-100Medium	4-8	50-100
Stiff100	8-15	100-200
Very stiff	15-30	200-400
Hard	> 30	> 400

2) Dynamic Cone Penetration Test

used to determine the relative resistance offered by the different soil layers.

- The cone is fixed to the bottom of a rod by pushed fit.
- The cone is driven into the ground in the same way as a SPT is performed.
- The number of blows required to penetrate 30 cms depth is called as N_c value.
- In the case of dynamic cone penetration test no borehole is used.
- The maximum depth suggested for this test is about 6 m.

CONT.

To judge the consistency of soil from N_c values, the general practice is to convert N_c to N values of SPT

$$N_c = N/C$$

where

N = blow count for SPT

N_c = blow count for dynamic cone

C = Constant, lies between 0.8 and 1.2 when bentonite is used.

$N_c = 1.5N$ for depths up to 3m

$N_c = 1.75N$ for depths between 3m and 6m

N_c Values need to be corrected for overburden pressure in cohesionless soils like SPT

VANE SHEAR TEST

- ❖ This test is useful in determining the in-place **shear strength of very soft and sensitive clays**, which lose a large part of their strength when even slightly disturbed by the sampling operation.
- ❖ The strength parameter obtained is undrained shear strength, C_u .

CONT.

- A hole is drilled to the desired depth
- The vane is carefully pushed into the soil.
- A torque necessary to shear the cylinder of soil defined by the blades of the vane is applied by rotating the arm of the apparatus with a constant speed of 0.5 degree/sec.
- The maximum torque is then measured from which the shearing strength is determined.

CONT.

From the measured maximum torque one may estimate the shearing resistance of the tested clay from the following formula

$$\tau = \frac{T}{\pi \left[D^2 \frac{H}{2} + \frac{D^3}{12} \right]}$$

where T = Torque τ = shear strength (N/mm²)

D = Diameter of Vane

H = Height

Since for quick condition $\tau = C_u$, one ultimately arrived the in-situ value of cohesion

Vane Shear Test

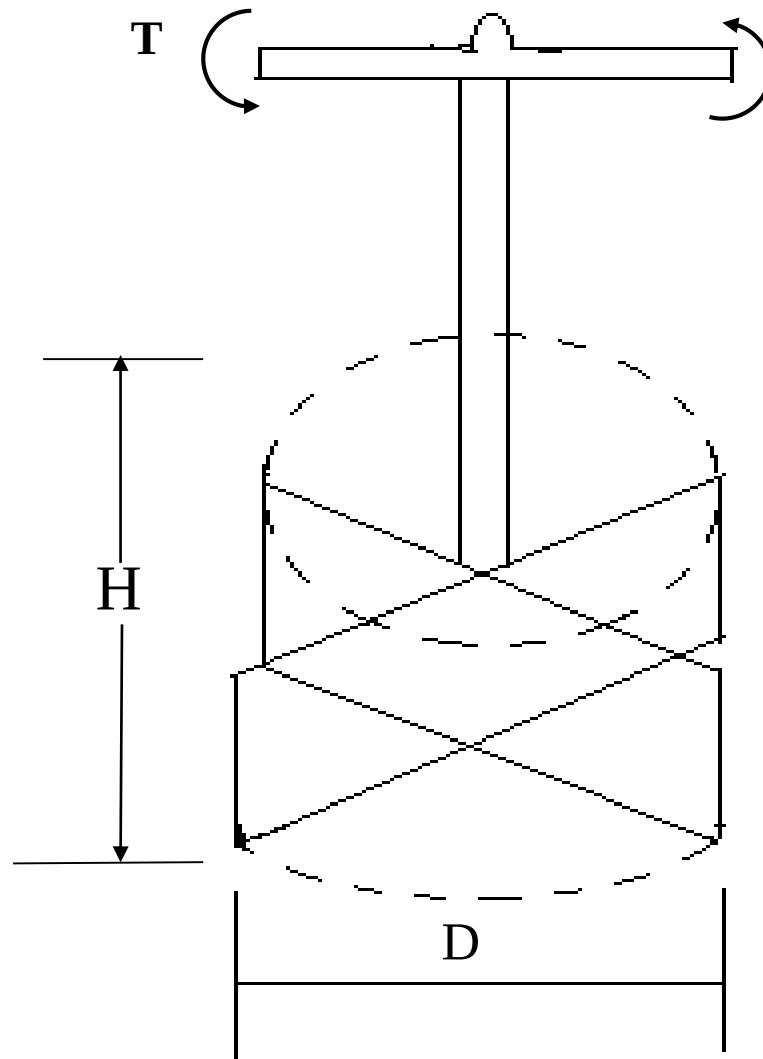
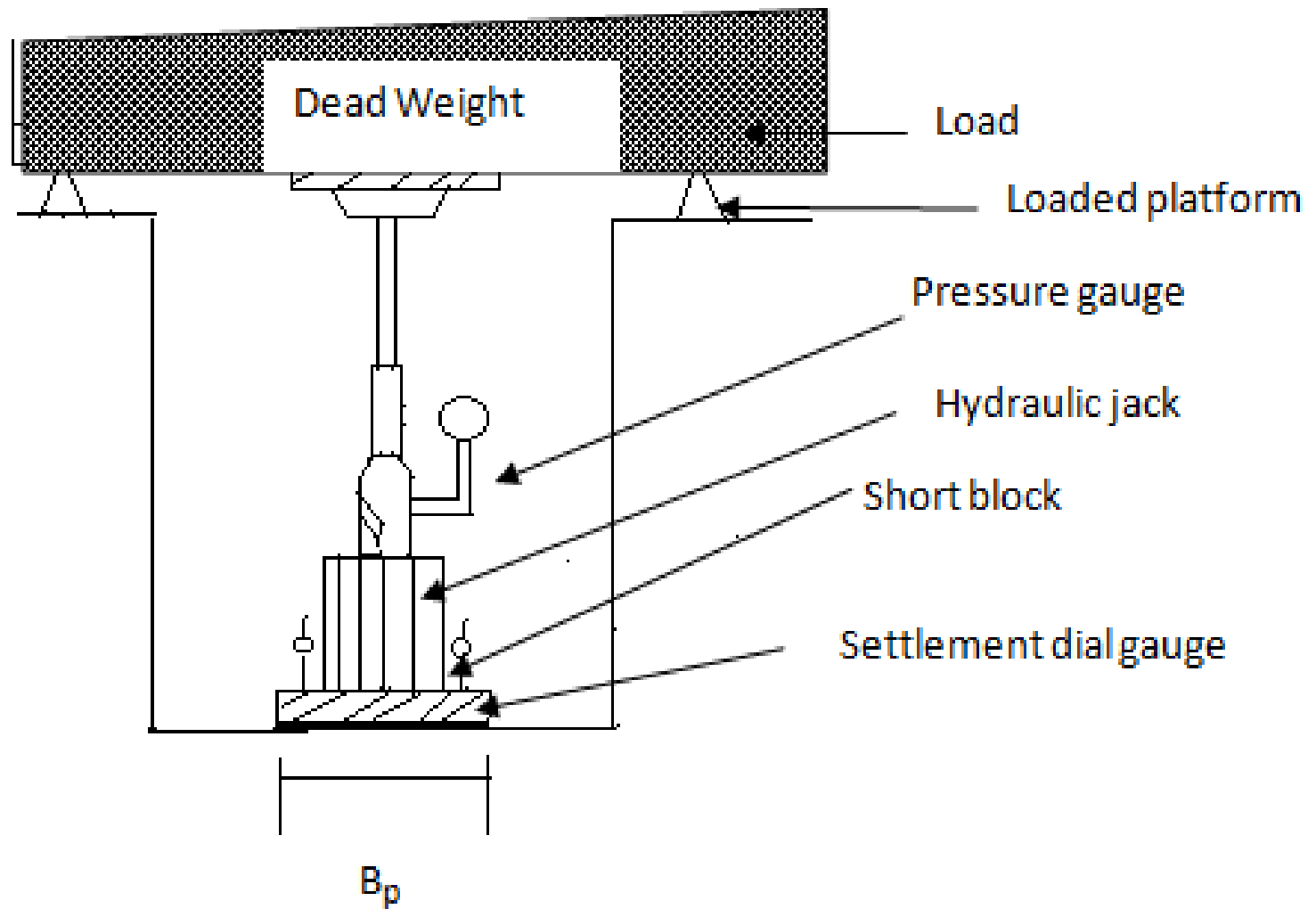


PLATE LOADING TEST

In this test a gradually increasing static load is applied to the soil through a steel plate, and readings of the settlement and applied load are recorded, from which a relationship between **bearing pressure and settlement** for the soil can be obtained.



- Bearing capacity of non-cohesive soil is determined from settlement consideration.

Bearing pressure (kPa)

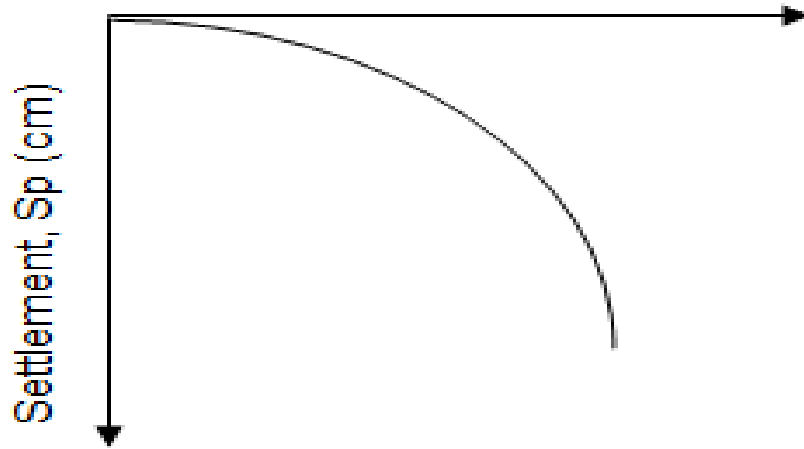


Plate loading test, test result

If the maximum permissible settlement, S , of a footing of width B_f is given, the settlement, S_p , of a plate of width B_p under the same intensity of loading is given by

$$S = \frac{S_p (2B_f)^2}{(B_f + B_p)^2}$$

CONT.

The settlement of footing in clay is normally determined from principles of consolidation. However from plate load test, the approximate settlement of footing of width B can be determined using the following expression

$$S = S_p \frac{B_t}{B_p}$$

LIMITATION OF PLATE LOADING TEST

- ◉ Plate loading test is of short duration. Hence consolidation settlement does not fully occur during the test.
- ◉ For settlement consideration, its use is restricted to sandy soils, and to partially saturated or rather unsaturated clayey soils.
- ◉ Plate loading test can give very misleading information of the soil is not homogeneous within the effective depth (depth of stress influence) of the prototype foundation.
- ◉ Plate loading test should not recommended in soils which are not homogeneous at least to depth of $1\frac{1}{2}$ to 2 times the width of the prototype foundation

PILE LOADING TEST

- This is the most reliable means for determining the **load carrying capacity of a pile**.
- The load arrangement and testing procedure are more or less similar to the plate-loading test.
- From the results of this test the allowable bearing capacity and load-settlement relationship of a group of friction piles can be estimated.

GEOPHYSICAL METHODS

- Comprise the seismic and resistivity methods.
- These methods are usually limited to establishing location of bedrock underlying softer material (by seismic method)
- or locating gravel or sand deposits (by resistivity method).
- The seismic method is based on the fact that sound waves travel faster through rocks than through soils. The resistivity method makes use of the fact some soils (e.g. soft clays) have low electrical resistivity than others (e.g. sand or gravel).
- These methods are normally employed as preliminary or supplementary to other methods of exploration.

DATA PRESENTATION AND REPORTING

Data presentation

The results of borings, samplings, penetration tests and laboratory tests of a site are usually plotted graphically on a sheet of drawing paper.

The graphical presentation should include.

- ⦿ A plot plan, showing the location of all boreholes, test pits, etc and their identification number.
- ⦿ A separate plot, showing the soil profile as established from the drillings or test pits records.

CONT.

- Soil profiles along given lines in the ground surface, showing the boundaries between identifiable soil layers, variation of thickness of firm bottom layer, thickness of soft clay layers etc.
- The penetration number, the unconfined compression strength, Atterberg limits, natural moisture content, and other appropriate laboratory data may be shown on each boring on the soil profile.
- The location of ground water table should also be shown on the soil profile.

SOIL EXPLORATION REPORT

A soil exploration report should contain all available data from bore holes, test pits, field and laboratory tests and site observation. Most reports have the following contents.

1. Introduction: - Purpose, scope of investigation, type of investigation carried out.
2. General description of the site: - general configuration and surface features of the site.
3. General geology of the area.
4. Description of soil conditions found in bore holes (and test pits)

CONT.

1. Laboratory test results.
2. Discussion of results of investigation in relation to foundation design and constructions.
3. Conclusion: - recommendations on the type and depth of foundations, allowable bearing pressure and methods of construction.

ASSIGNMENT 3

Refer to a project (anywhere) and prepare/revise a soil investigation/exploration report following the above mentioned standards.