



SITE INVESTIGATION



Definition

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 purpose of a soil investigation program

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



EXPLORATION PROGRAM

The purpose of the exploration program is to determine, within practical limits, the stratification and engineering properties of the soils underlying the site. The principal properties of interest will be the strength, deformation, and hydraulic characteristics. The program should be planned so that the maximum amount of information can be obtained at minimum cost.



Steps of subsurface exploration program [Stage 1]

1. Assembly of all available information on dimensions, column spacing, type and use of the structure, basement requirements, and any special architectural considerations of the proposed building. Foundation regulations in the local building code should be consulted for any special requirements. For bridges the soil engineer should have access to type and span lengths as well as pier loadings. This information will indicate any settlement limitations, and can be used to estimate foundation loads.



Steps of subsurface exploration program [Stage 2]

2. Reconnaissance of the area:

This may be in the form of a field trip to the site which can reveal information on the type and behavior of adjacent structures such as cracks, noticeable sags, and possibly sticking doors and windows. The type of local existing structure may influence, to a considerable extent, the exploration program and the best foundation type for the proposed adjacent structure.



Steps of subsurface exploration program [Stage 3]

3.A preliminary site investigation:

In this phase a few borings are made or a test pit is opened to establish in a general manner the stratification, types of soil to be expected, and possibly the location of the groundwater table. One or more borings should be taken to rock, or competent strata, if the initial borings indicate the upper soil is loose or highly compressible. This amount of exploration is usually the extent of the site investigation for small structures.



Steps of subsurface exploration program [Stage 4]

4.A detailed site investigation:

Where the preliminary site investigation has established the feasibility of the project, a more detailed exploration program is undertaken. The preliminary borings and data are used as a basis for locating additional borings, which should be confirmatory in nature, and determining the additional samples required.



Depth of Boring

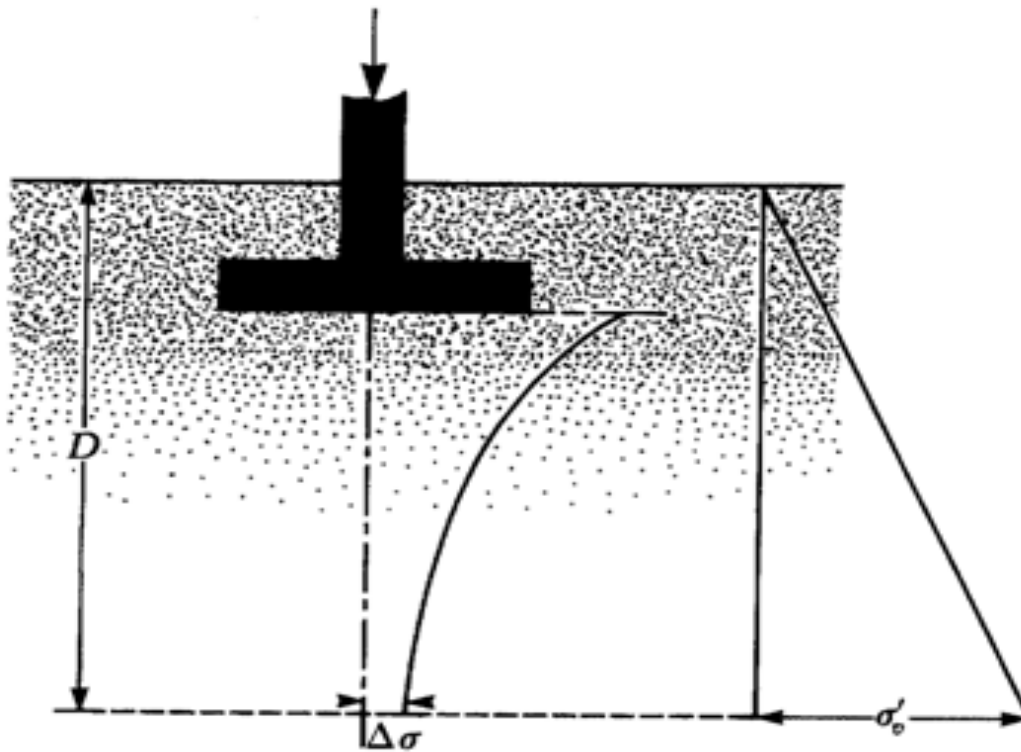
The approximate required minimum depth of the borings should be predetermined. The estimated depths can be changed during the drilling operation, depending on the subsoil encountered. To determine the approximate minimum depth of boring, engineers may use the following rule:



Depth of Boring

1. Determine the net increase of stress, $\Delta\sigma$ under a foundation with depth as shown in the Figure.
2. Estimate the variation of the vertical effective stress, σ'_v , with depth.
3. Determine the depth, $D = D_1$, at which the stress increase $\Delta\sigma$ is equal to $(1/10) q$ ($q =$ estimated net stress on the foundation).
4. Determine the depth, $D = D_2$, at which $\Delta\sigma/\sigma'_v = 0.05$.
5. Unless bedrock is encountered, the smaller of the two depths, D_1 and D_2 , just determined is the approximate minimum depth of boring required. Table shows the minimum depths of borings for buildings based on the preceding rule.

Depth of Boring



Determination of the minimum depth of boring



Depth of Boring

Depth of Boring

Building width (m)	Number of Stories				
	1	2	4	8	16
	Boring Depth (m)				
30.5	3.4	6.1	10.1	16.2	24.1
61.0	3.7	6.7	12.5	20.7	32.9
122.0	3.7	7.0	13.7	24.7	41.5



Depth of Boring

For hospitals and office buildings, the following rule could be use to determine boring depth

$$D_b = 3S^{0.7} \text{ (for light steel or narrow concrete buildings)}$$

$$D_b = 6S^{0.7} \text{ (for heavy steel or wide concrete buildings)}$$

where:

D_b = depth of boring, in meters

S = number of stories



Depth of Boring

When deep excavations are anticipated, the depth of boring should be at, least 1.5 times the depth of excavation. Sometimes subsoil conditions are such that the foundation load may have to be transmitted to the bedrock. The minimum depth of core boring into the bedrock is about 3m. If the bedrock is irregular or weathered, the core borings may have to be extended to greater depths.



Spacing Boring

There are no hard and fast rules for the spacing of the boreholes. The following table gives some general guidelines for borehole spacing. These spacing can be increased or decreased, depending on the subsoil condition. If various soil strata are more or less uniform and predictable, the number of boreholes can be reduced.



Spacing Boring

Approximate Spacing of Boreholes

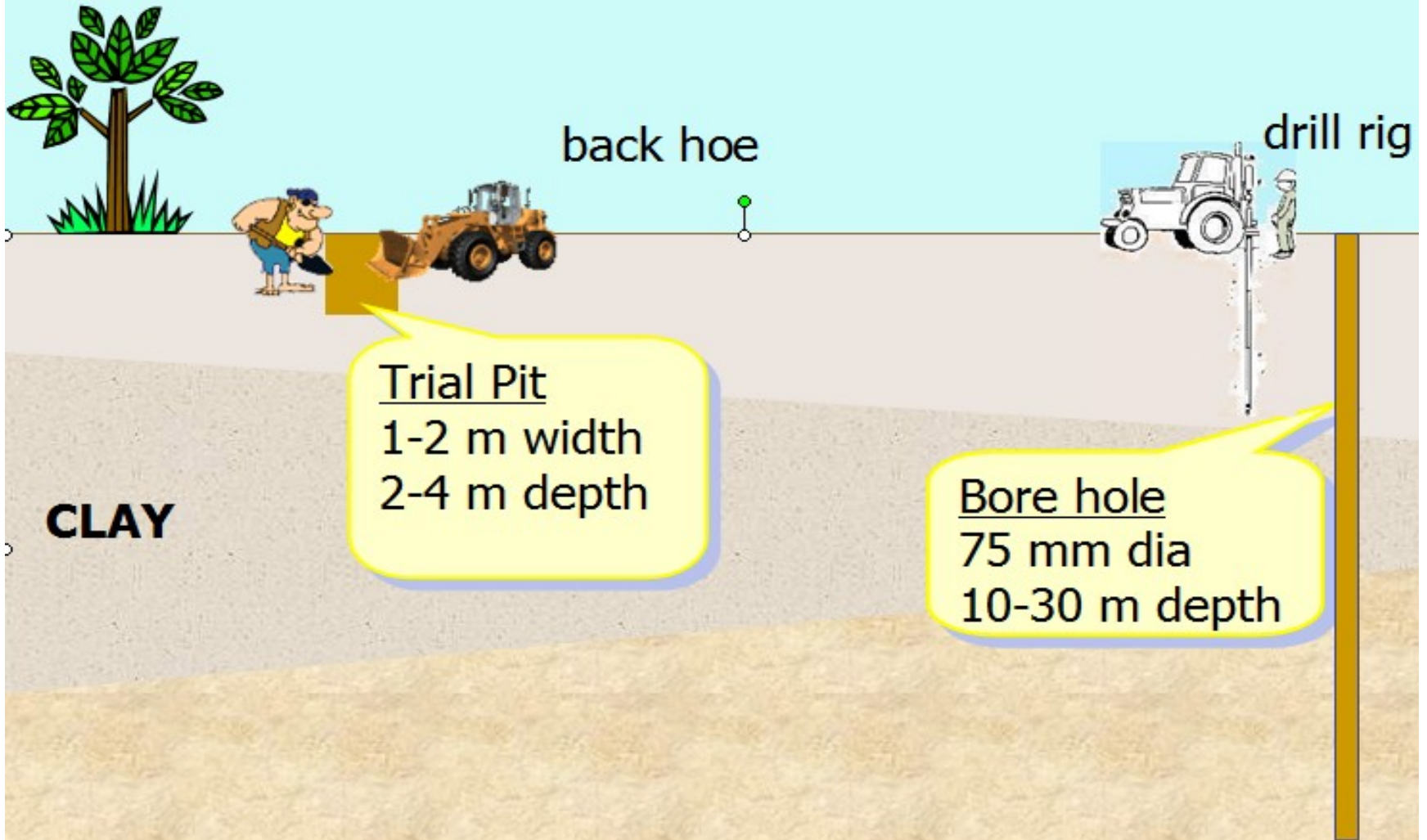
Type of project	Spacing (m)
Multistory building	10-30
One story industrial plants	20-60
Highways	250-500
Residential subdivision	250-500
Dams and dikes	40-80



SOIL BORING

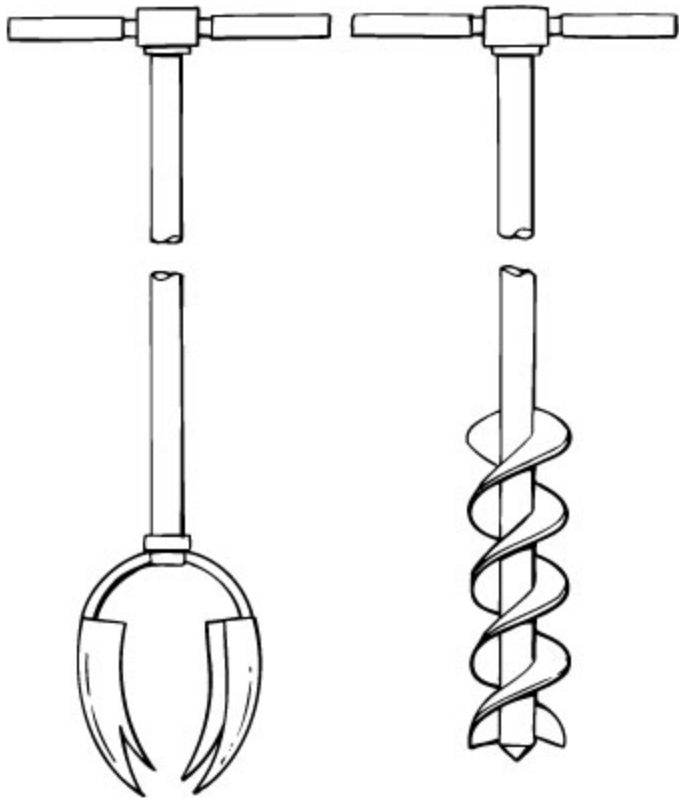
The earliest method of obtaining a test hole was to excavate a test pit using a pick and shovel. Because of economics, the current procedure is to use power-excavation equipment such as a backhoe to excavate the pit and then to use hand tools to remove a block sample or shape the site for in situ testing. This is the best method at present for obtaining quality undisturbed samples or samples for testing at other than vertical orientation.

SOIL BORING



Boring tools

Hand tools



posthole auger

helical auger

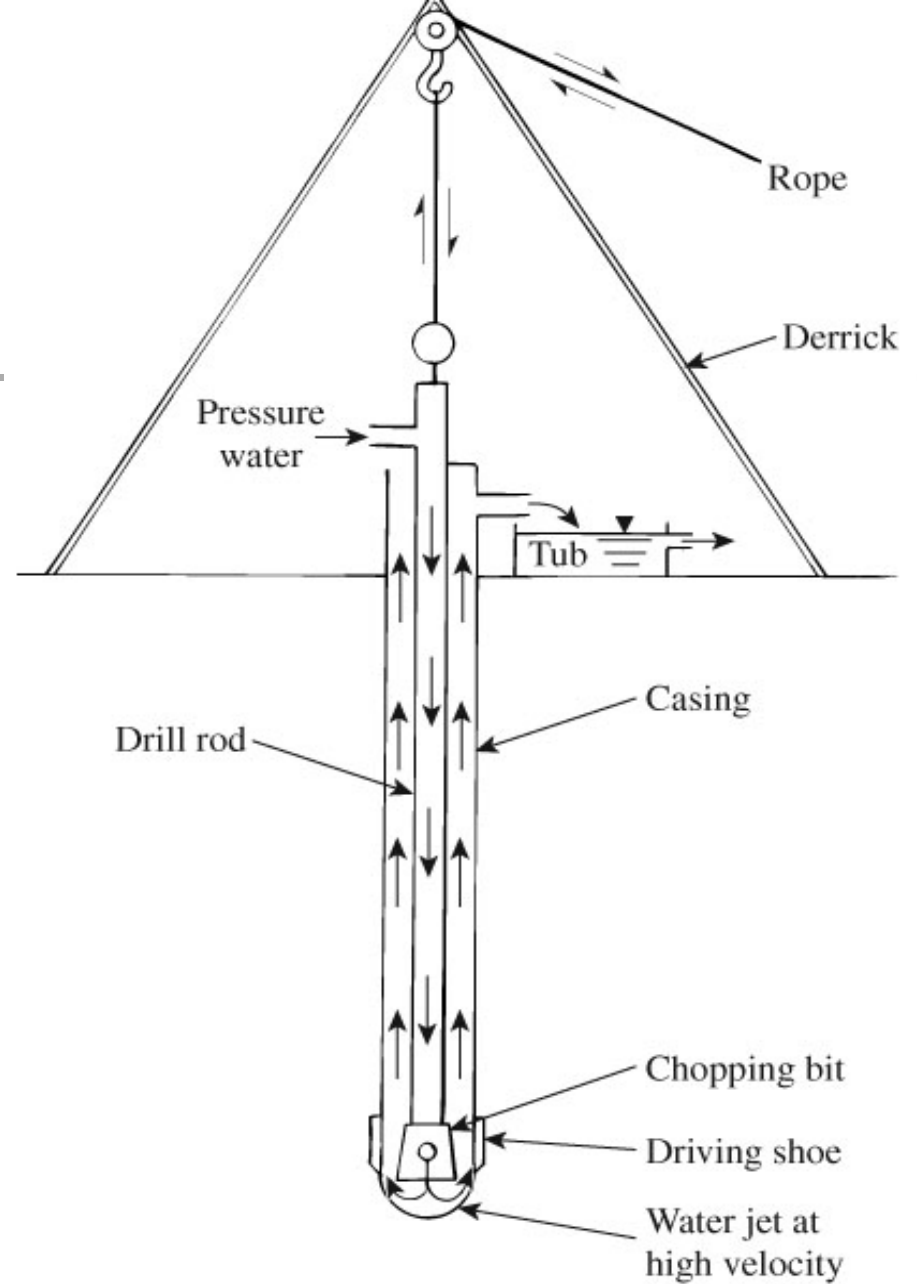
Auger boring



Power drills

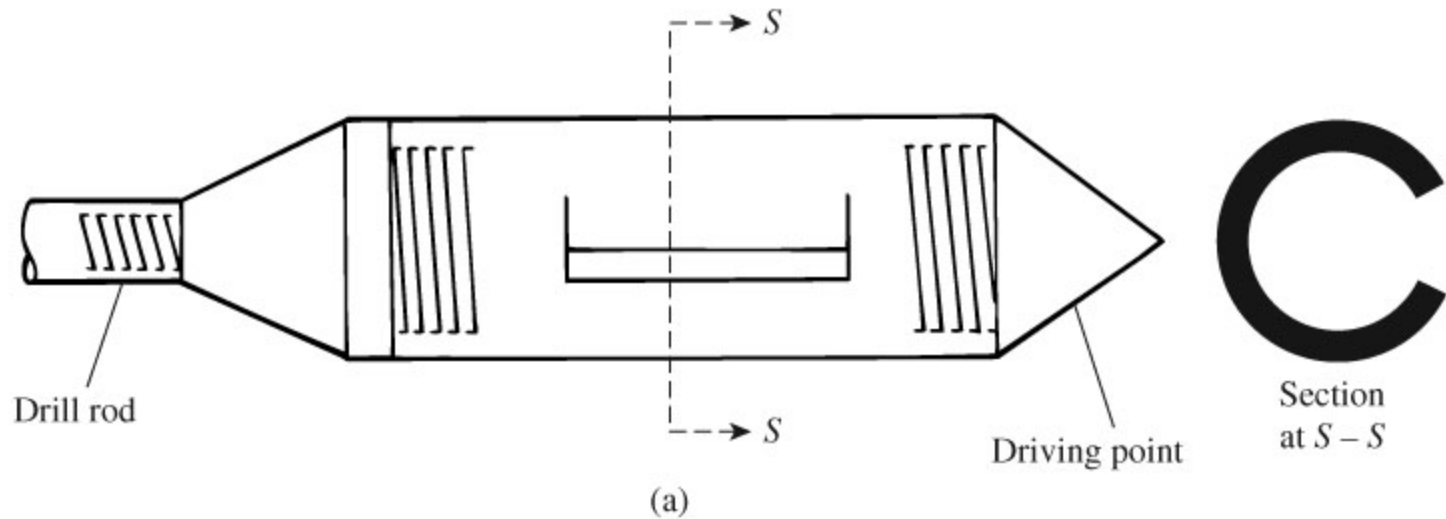


Boring tools



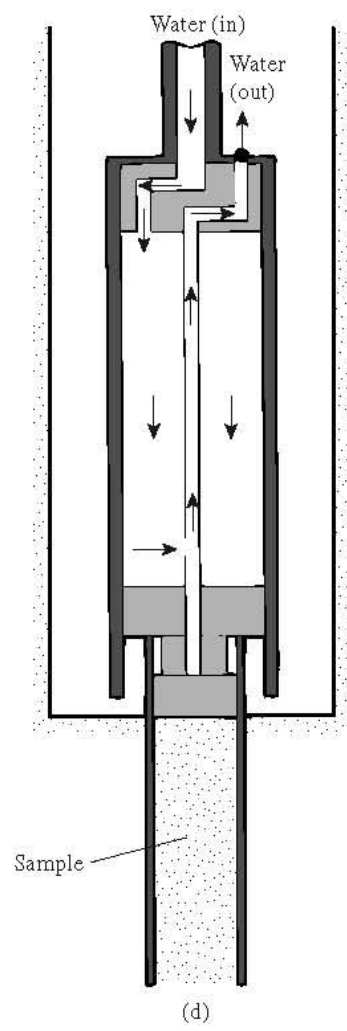
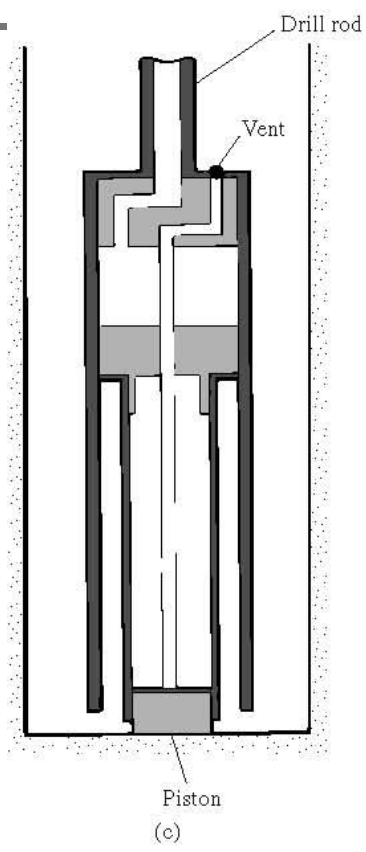
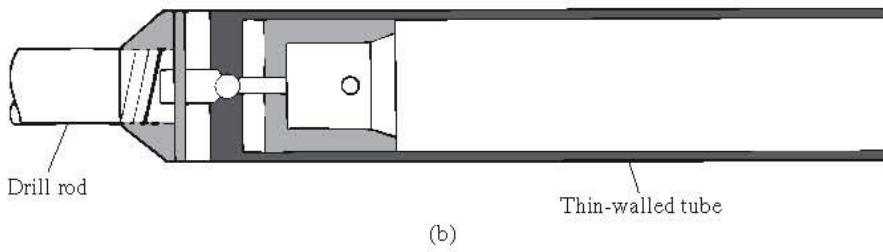
Wash boring

Boring tools



Sampling devices: (a) scraper bucket

Boring tools



(Continued) (b) thin-walled tube; (c) and (d) piston sampler



Preparation of Boring Logs

1. Name and address of the drilling company
2. Driller's name
3. Job description and number
4. Number, type, and location of boring
5. Date of boring
6. Subsurface stratification, which can be obtained by visual observation of the soil brought out by auger, split-spoon sampler, and thin-walled Shelby tube sampler
7. Elevation of water table and date observed, use of casing and mud losses, and so on
8. Standard penetration resistance and the depth of SPT
9. Number, type, and depth of soil sample collected
10. In case of rock coring, type of core barrel used and, for each run, the actual length of coring, length of core recovery, and ROD

Boring Log

Name of the Project Two-story apartment building

Location Johnson & Olive St. Date of Boring March 2, 1982

Boring No. 3 Type of Boring Hollow stem auger Ground Elevation 60.8 m

Soil description	Depth (m)	Soil sample type and number	N	w_n (%)	Comments
Light brown clay (fill)					
Silty sand (SM)	1				
	2	SS-1	9	8.2	
*G.W.T. 3.5 m Light gray silty clay (ML)	3	SS-2	12	17.6	LL = 38 PI = 11
	4				
	5	ST-1		20.4	LL = 36 $q_u = 112 \text{ kN/m}^2$
	6	SS-3	11	20.6	
Sand with some gravel (SP)	7				
End of boring @ 8 m	8	SS-4	27	9	
N = standard penetration number (below/304.8 mm) w_n = natural moisture content LL = liquid limit; PI = plasticity index q_u = unconfined compression strength SS = split-spoon sample; ST = Shelby tube sample				*Ground water table observed after one week of drilling	



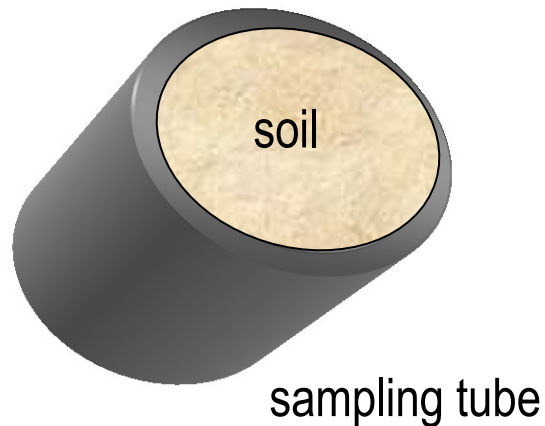
SOIL SAMPLING

Two types of soil samples can be obtained during sampling **disturbed** and **undisturbed**. The most important engineering properties required for foundation design are strength, compressibility, and permeability. Reasonably good estimates of these properties for **cohesive** soils can be made by laboratory tests on **undisturbed** samples which can be obtained with moderate difficulty. It is nearly impossible to obtain a truly undisturbed sample of soil; so in general usage the term "undisturbed" means a sample where some precautions have been taken to minimize disturbance or remolding effects. In this context, the quality of an "undisturbed" sample varies widely between soil laboratories.

Disturbed vs Undisturbed

- Good quality samples necessary.

$$A_R < 10\%$$



$$A_R = \frac{O.D.^2 - I.D.^2}{I.D.^2} \times 100 (\%)$$

area ratio

- Thicker the wall, greater the disturbance.

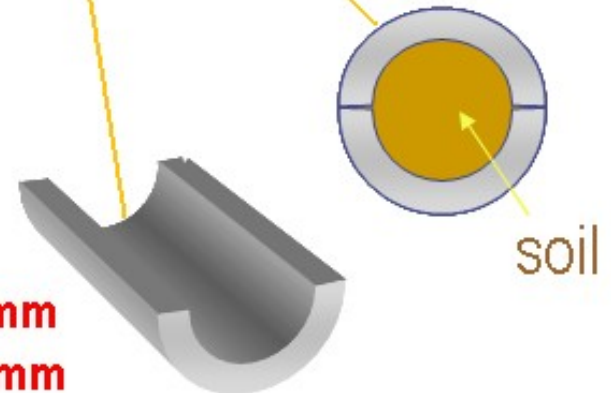
Disturbed vs Undisturbed

- samples (disturbed) collected in split-spoon sampler

$A_R = 112\%$; use
for classification



I.D. = 35 mm
O.D. = 51 mm

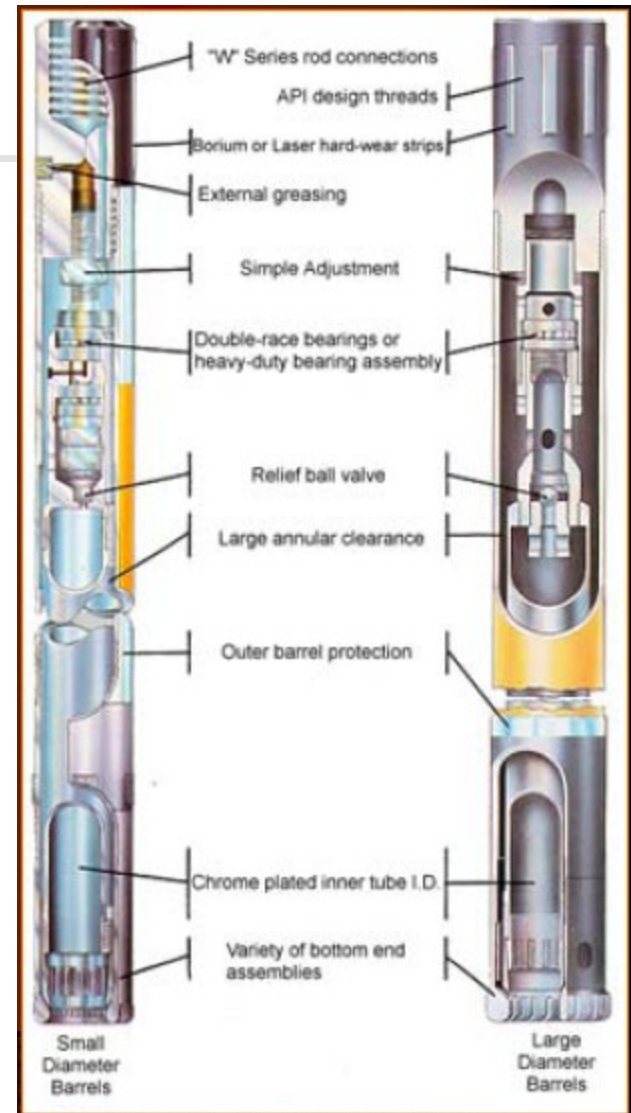


Common Sampling Methods

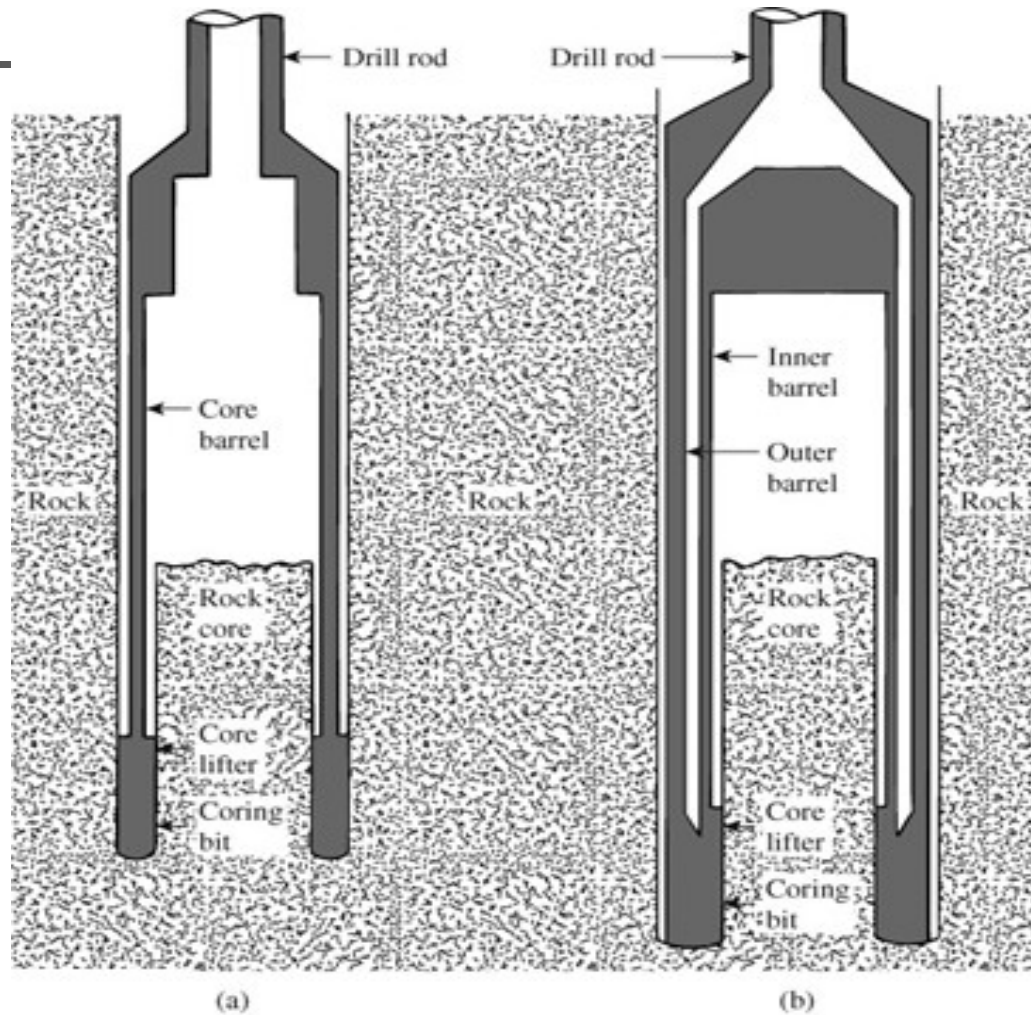
<i>Sampler</i>	<i>Disturbed / Undisturbed</i>	<i>Appropriate Soil Types</i>	<i>Method of Penetration</i>	<i>% Use in Practice</i>
Split-Barrel (Split Spoon)	Disturbed	Sands, silts, clays	Hammer driven	85
Thin-Walled Shelby Tube	Undisturbed	Clays, silts, fine-grained soils, clayey sands	Mechanically Pushed	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

ROCK SAMPLING

- Rock cores are necessary if the soundness of the rock is to be established.
- small cores tend to break up inside the drill barrel.
- Larger cores also have a tendency to break up (rotate inside the barrel and degrade), especially if the rock is soft or fissured.



Rock coring



Rock coring: (a) single-tube core barrel; (b) double-tube core barrel



ROCK SAMPLING - Definition

$$\text{Recovery Ratio} = \frac{\sum \text{Lengths of intact pieces of core}}{\text{Length of core advance}}$$

$$\text{RQD} = \frac{\sum \text{Lengths of intact pieces of core} \geq 10.16 \text{ cm}}{\text{Length of core advance}}$$

Rock Core Drilling

- Done with either tungsten carbide or diamond core bits
- Use a double or triple tube core barrel when sampling weathered or fractured rock
- Used to determine Rock Quality Designation



Diamond coring bit



core barrel

Rock Quality Designation RQD

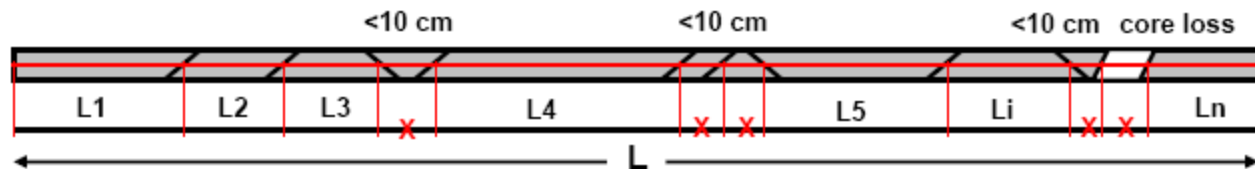


Rock Quality Designation

RQD

Rock Quality Designation (RQD) is defined as the percentage of rock cores that have length equal or greater than 10 cm over the total drill length.

$$RQD = \sum L_i / L \times 100\%, \quad L_i > 10 \text{ cm}$$



$$RQD = (L1 + L2 + \dots + Ln) / L \times 100\%$$

RQD	Rock Mass Quality
< 25	Very poor
25 – 50	Poor
50 – 75	Fair
75 – 90	Good
99 – 100	Excellent

Example on Core Recovery & RQD

- Core run of 150 cm
- Total core recovery = 125 cm
- Core recovery ratio = $125/150 = 83\%$
- On modified basis, 95 cm are counted
RQD = $95/150 = 63\%$

Core Recovery cm	Modified Core Recovery, cm
25	25
5	0
5	0
7.5	0
10	10
12.5	12.5
7.5	0
10	10
15	15
10	10
5	0
12.5	12.5
125	95



GROUND WATER TABLE LEVEL

Groundwater conditions and the potential for groundwater seepage are fundamental factors in virtually all geotechnical analyses and design studies. Accordingly, the evaluation of groundwater conditions is a basic element of almost all geotechnical investigation programs. Groundwater investigations are of two types as follows:

- Determination of groundwater levels and pressures.
- Measurement of the permeability of the subsurface materials.

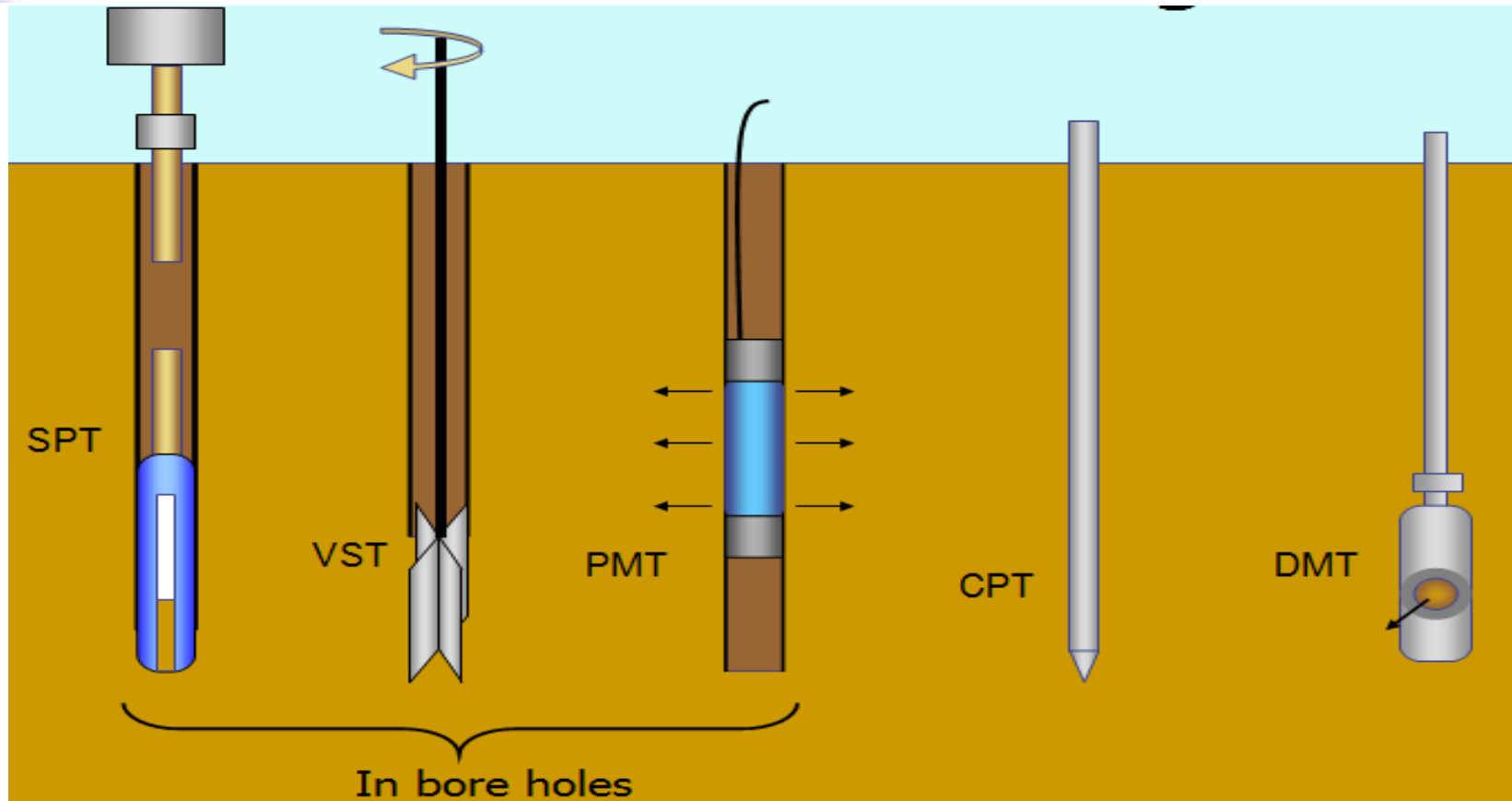


FIELD STRENGTH TESTS

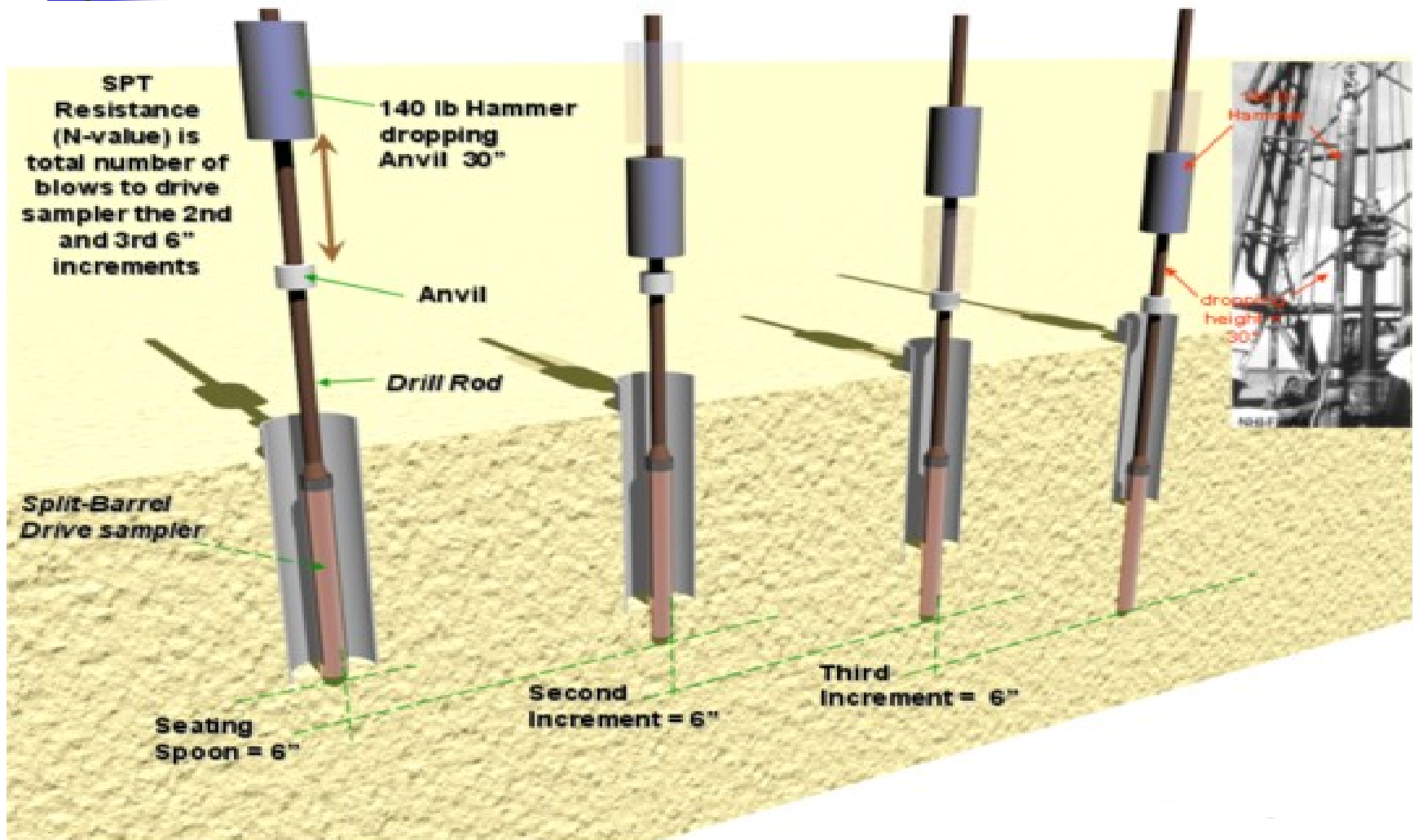
The following are the major field tests for determining the soil strength:

1. Vane shear test (VST).
2. Standard Penetration Test (SPT).
3. Cone Penetration Test (CPT).
4. The Borehole Shear Test (BST).
5. The Flat Dilatometer Test (DMT).
6. The Pressure-meter Test (PMT).
7. The Plate Load Test (PLT).

FIELD STRENGTH TESTS



Standard Penetration Test (SPT)



Standard Penetration Test (SPT)

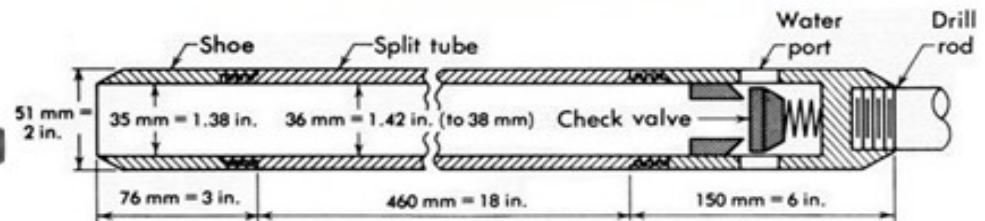
Drop Hammer



Split Spoon



Drill Rig





Standard Penetration Test (SPT)

Corrections are normally applied to the SPT blow count to account for differences in:

- **energy imparted** during the test (60% hammer efficiency)
- **the stress level** at the test depth

The following equation is used to compensate for the testing factors (Skempton, 1986):



Standard Penetration Test (SPT)

$$N_{60} = 1.67 E_m C_b C_r N$$

where N_{60} = SPT N -value corrected for field testing procedures

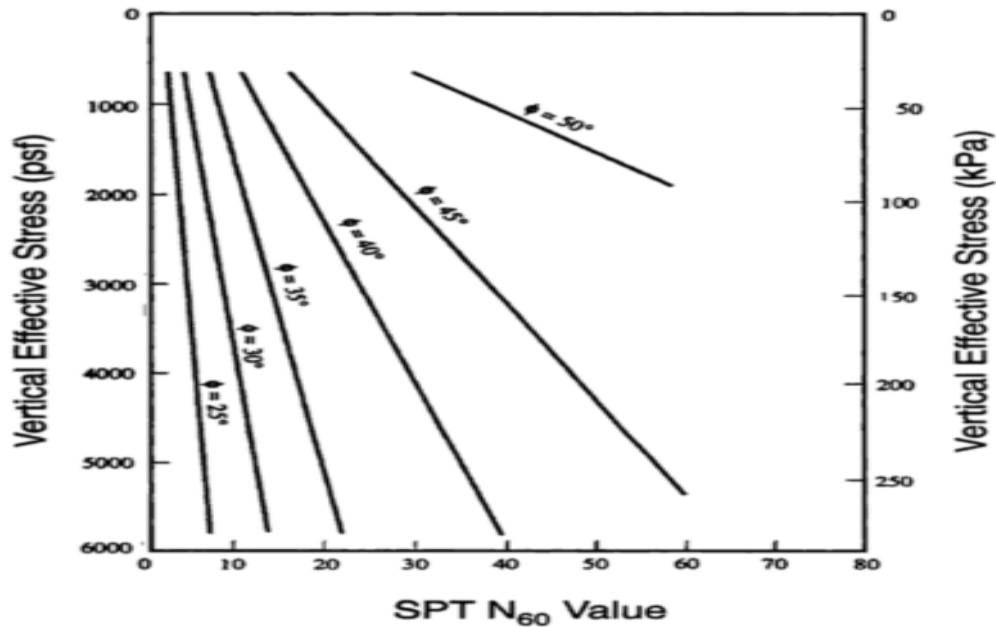
E_m = hammer efficiency (for U.S. equipment, E_m equals 0.6 for a safety hammer and equals 0.45 for a doughnut hammer)

C_b = borehole diameter correction ($C_b = 1.0$ for boreholes of 65- to 115-mm diameter, 1.05 for 150-mm diameter, and 1.15 for 200-mm diameter hole)

C_r = rod length correction ($C_r = 0.75$ for up to 4 m of drill rods, 0.85 for 4 to 6 m of drill rods, 0.95 for 6 to 10 m of drill rods, and 1.00 for drill rods in excess of 10 m)

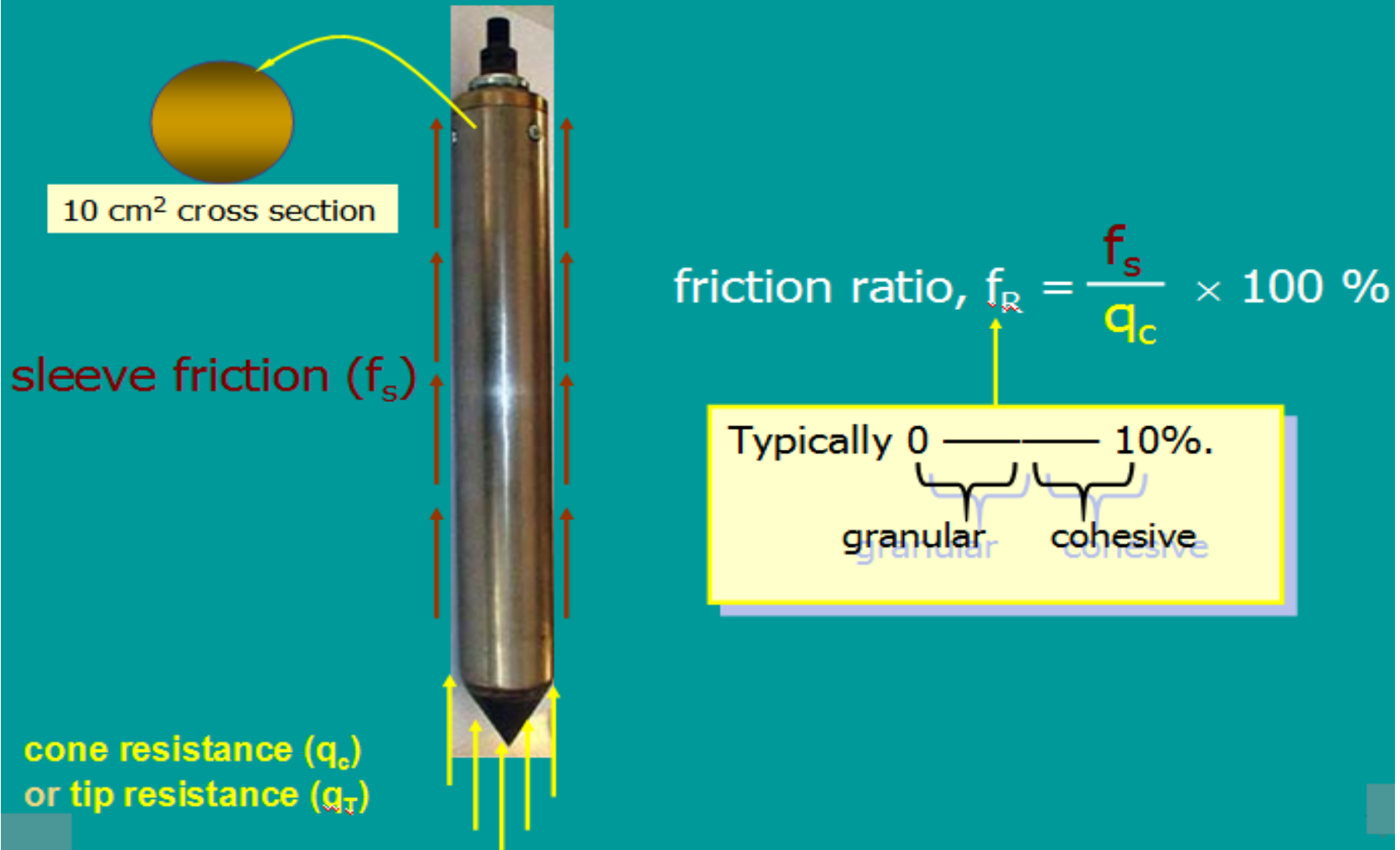
N = measured SPT N -value

Standard Penetration Test (SPT)

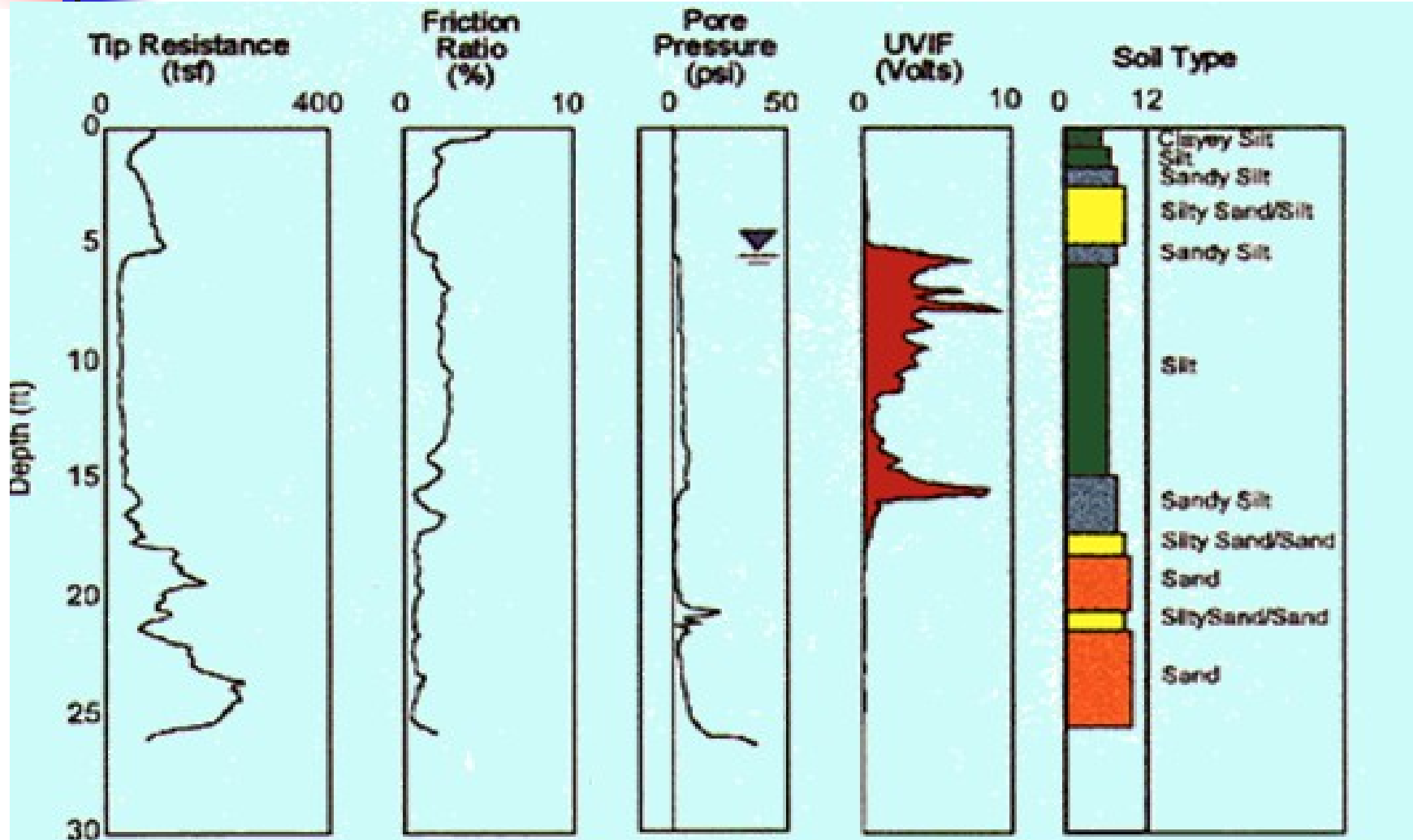


Empirical correlation between SPT N_{60} value, vertical effective stress, and friction angle for clean quartz sand deposits. (Adapted from DeMello, 1971; reproduced from Coduto, 1994.)

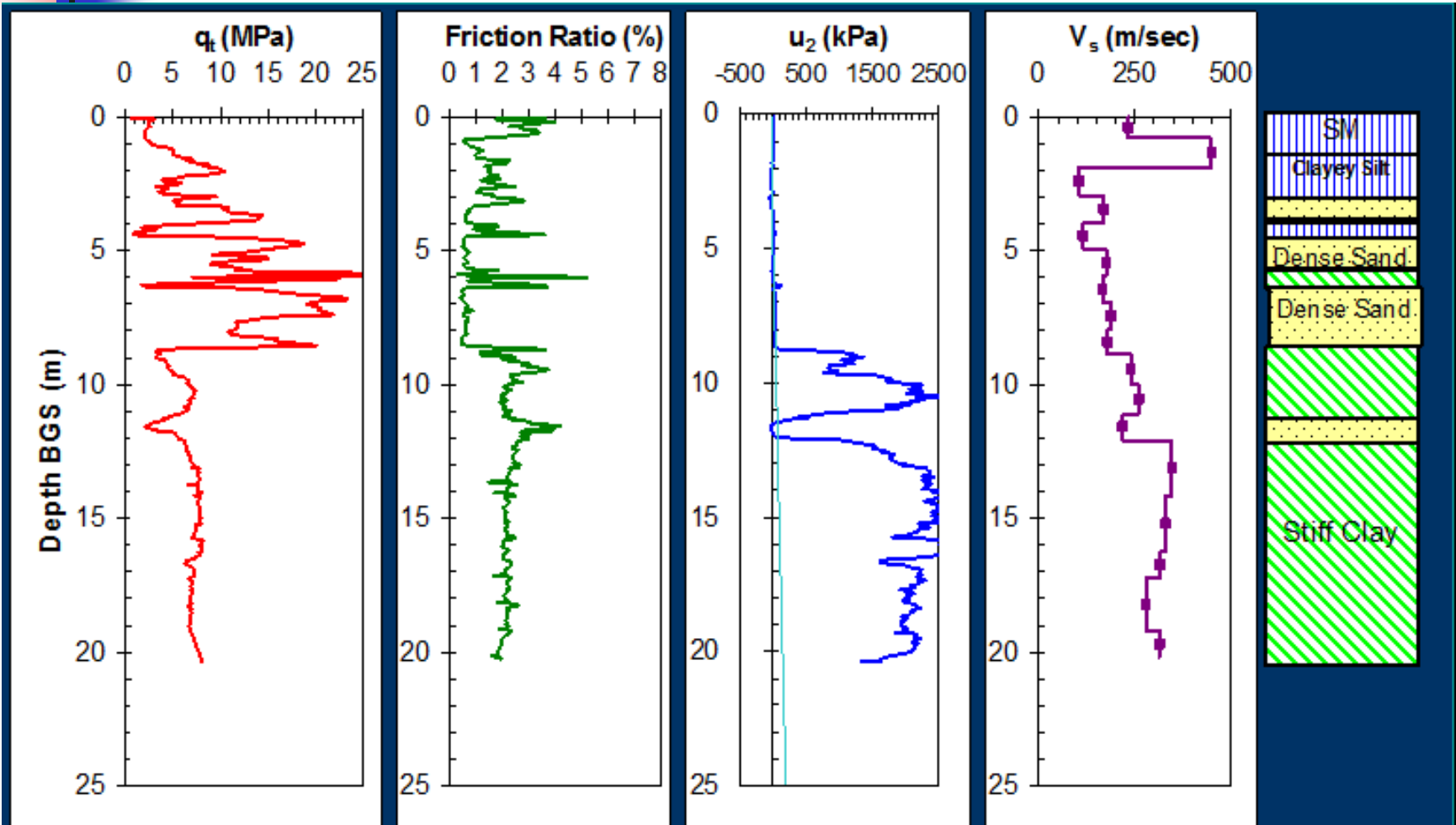
Cone Penetration Test (CPT)



Cone Penetration Test (CPT)



Cone Penetration Test (CPT)



Cone Penetration Test (CPT)

SCPT Correlations

In Clays,

$$c_u = \frac{q_c - \sigma_{vo}}{N_k}$$

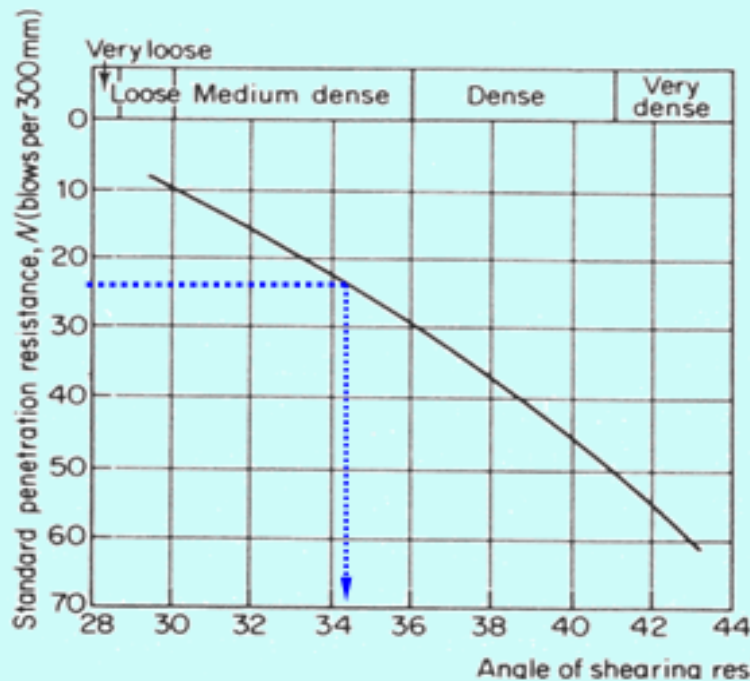
N_k → cone factor (15-20);
varies with cone

In Sands,

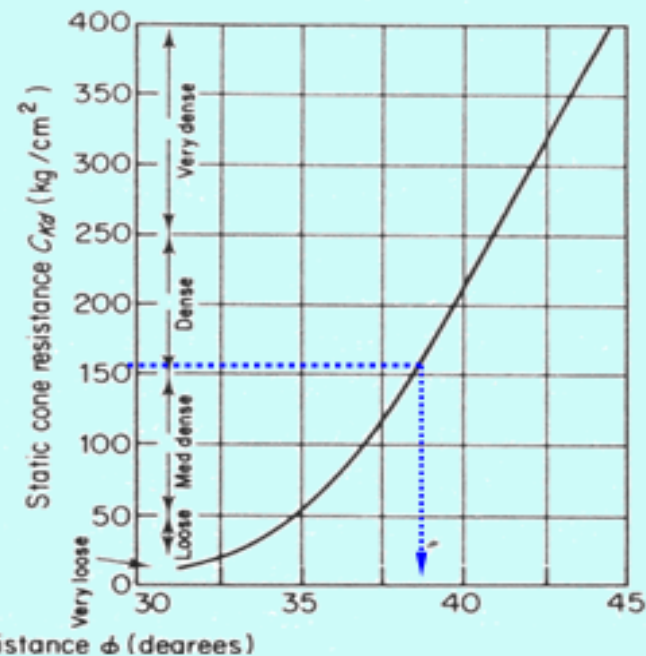
$$E = 2.5-3.5 q_c \quad (\text{for young normally consolidated sands})$$

Cone Penetration Test (CPT)

ϕ' from SPT/CPT in Granular Soils



After Peck et al. (1974)

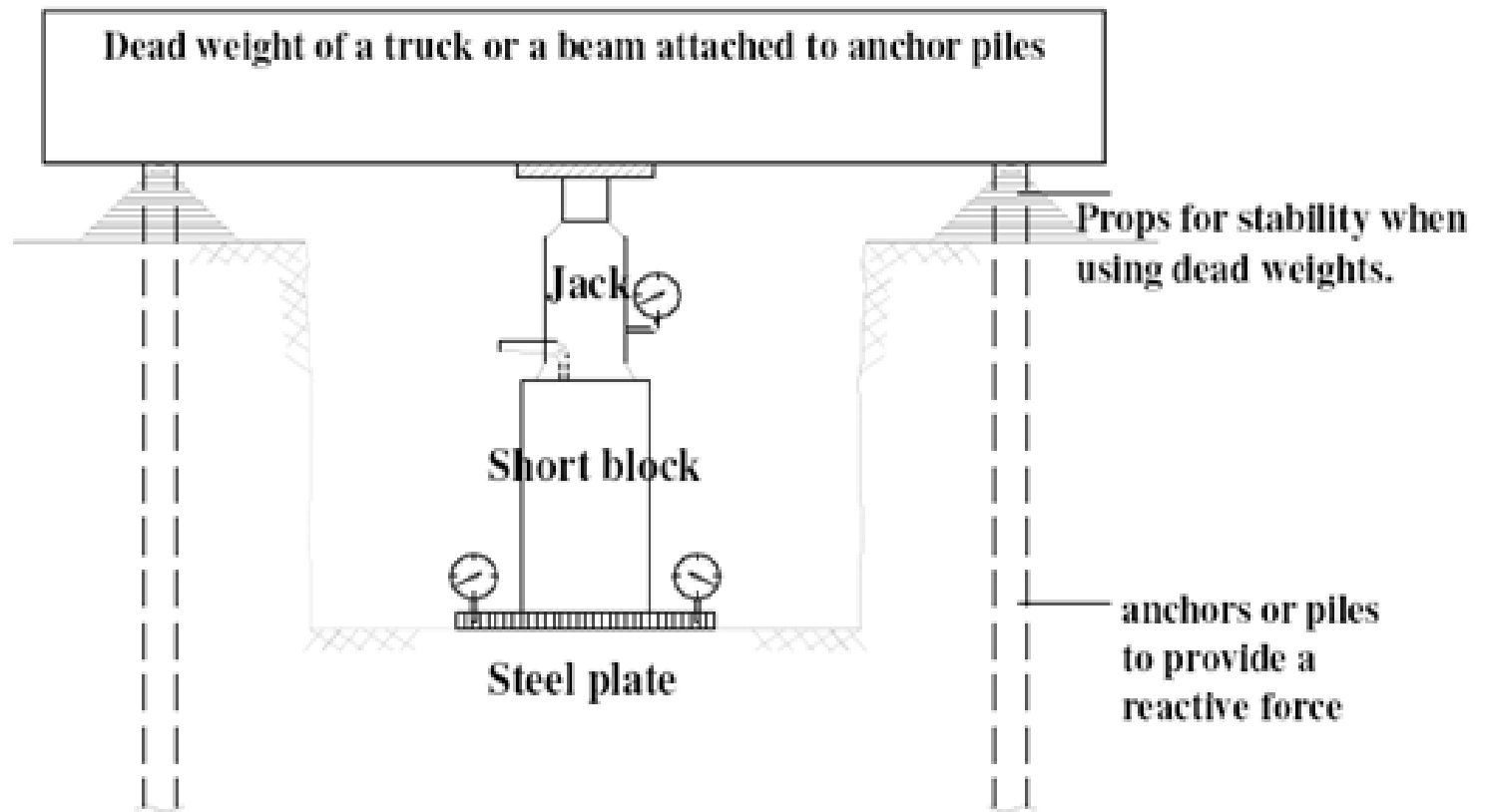


After Meyerhof (1976)

The Plate Load Test (PLT)

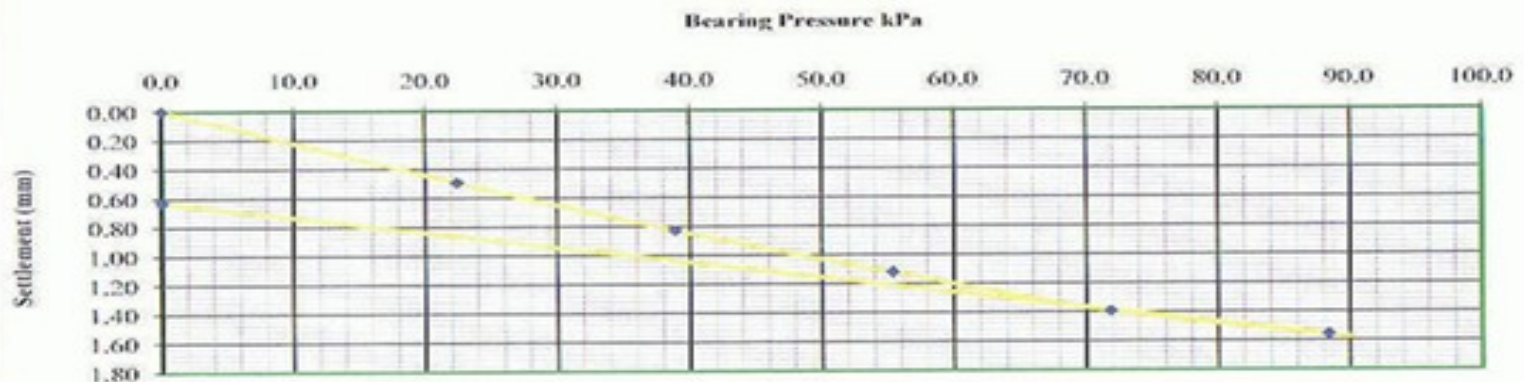
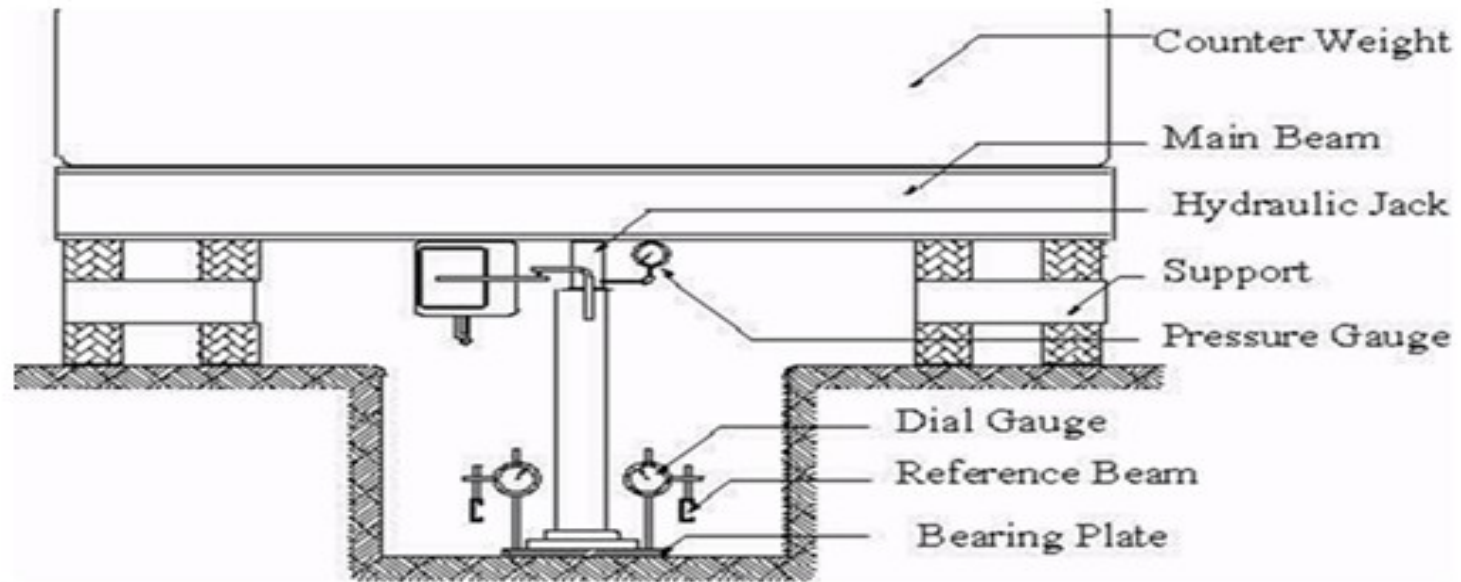


The Plate Load Test (PLT)



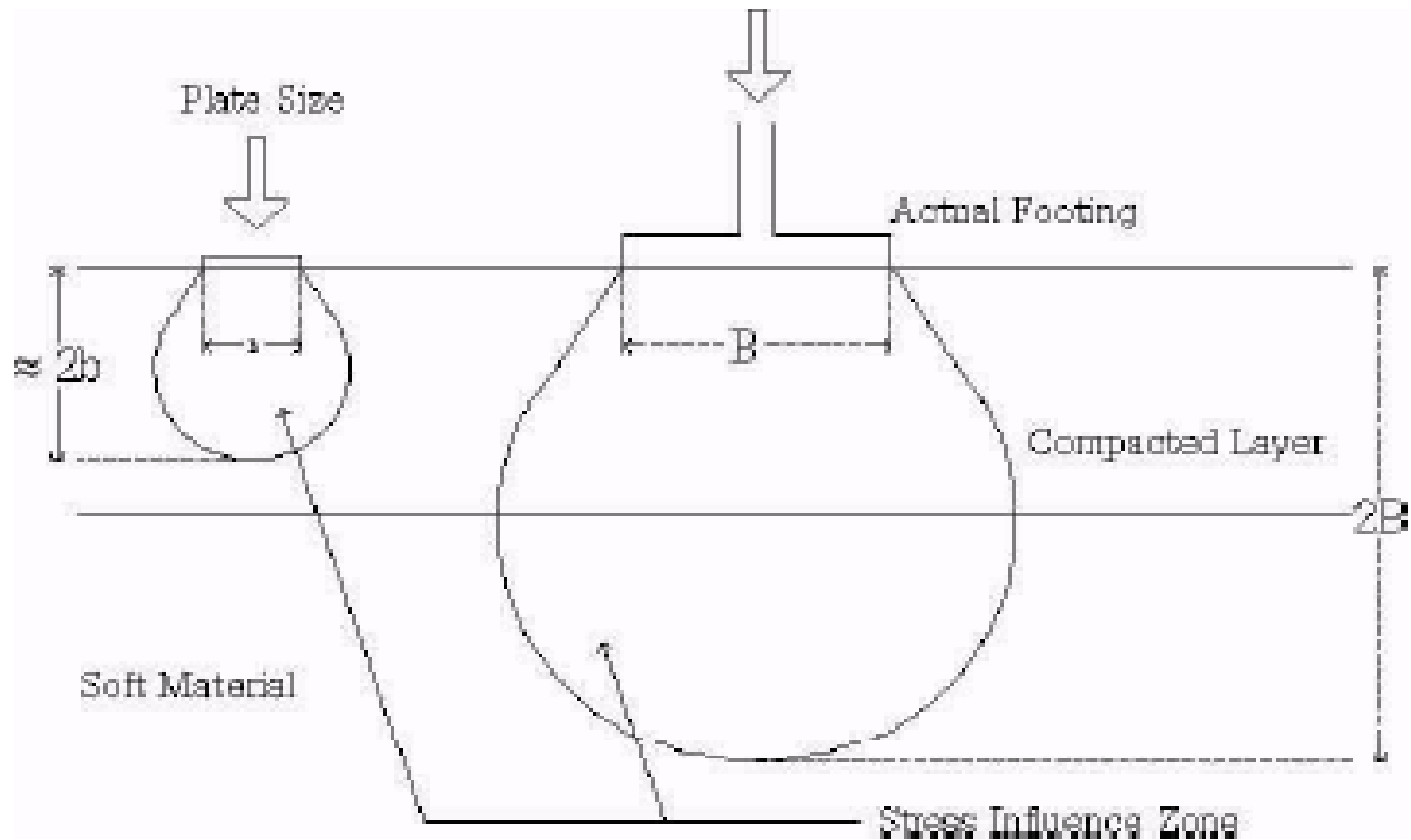
Several dial gauges attached to an independent suspension system to record plate settlements with each increment of the jack load.

The Plate Load Test (PLT)



The Plate Load Test (PLT)

Scale Effect in Foundation Design





Geotechnical Design Reports

- At the end of all subsoil exploration programs, the soil and/or rock specimens collected from the field are subjected to visual observation and appropriate laboratory testing. After the compilation of all of the required information, a soil exploration report is prepared for the use of the design office and for reference during future construction work. Although the details and sequence of information in the report may vary to some degree is depending on the structure under consideration and the person compiling the report.



Subsoil Exploration Report

1. A description of the scope of the investigation
2. A description of the proposed structure for which the subsoil exploration has been conducted
3. A description of the location of the site, including any structures nearby, drainage conditions, the nature of vegetation on the site and surrounding it, and any other features unique to the site
4. A description of the geological setting of the site
5. Details of the field exploration—that is, number of borings, depths of borings, types of borings involved, and so on
6. A general description of the subsoil conditions, as determined from soil specimens and from related laboratory tests, standard penetration resistance and cone penetration resistance, and soon
7. A description of the water-table conditions
8. Re commendations regarding the foundation, including the type of foundation recommended, the allowable bearing pressure, and any special construction procedure that may he needed; alternative foundation design procedures should also be discussed in this portion of the report
9. Conclusions and limitations of the investigations



Subsoil Exploration Report

The following graphical presentations should be attached to the report:

1. A site location map
2. A plan view of the location of the borings with respect to the proposed structures and those nearby
3. Boring logs
4. Laboratory test results
5. Other special graphical presentations