SITE INVESTIGATION

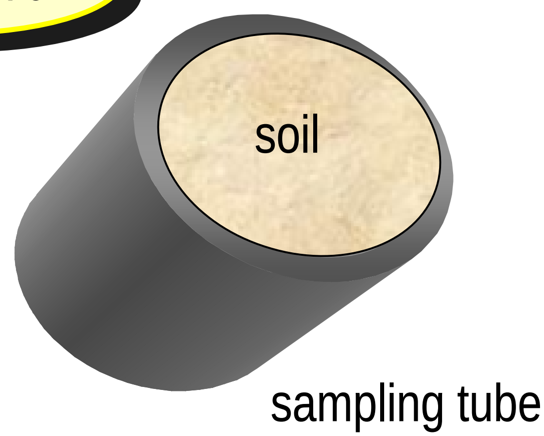
SOIL SAMPLING

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.

$A_R < 10\%$



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

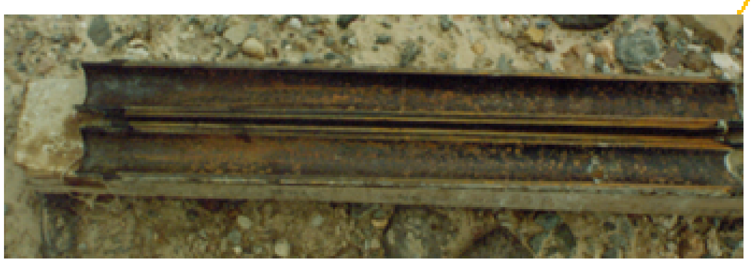
area ratio

- Thicker the wall, greater the disturbance.

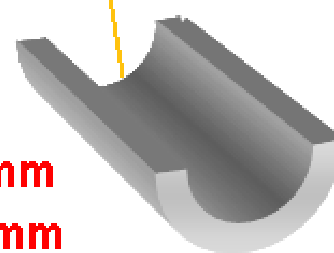
Disturbed vs Undisturbed

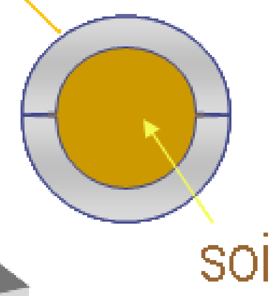
- samples (disturbed) collected in <u>split-spoon sampler</u>

A_R = 112%; use for classification

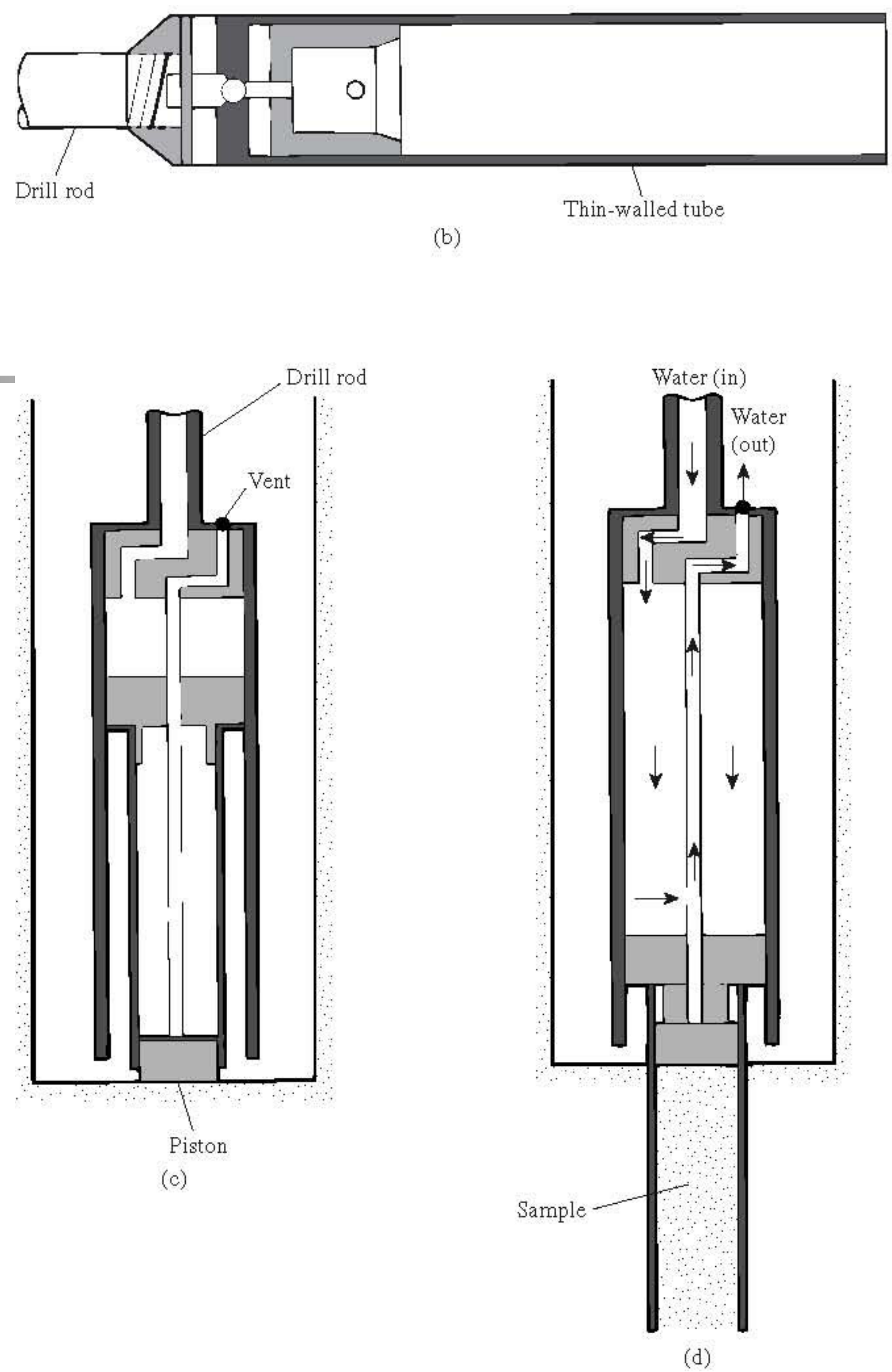


I.D. = 35 mm
O.D.= 51 mm





Sampling tools



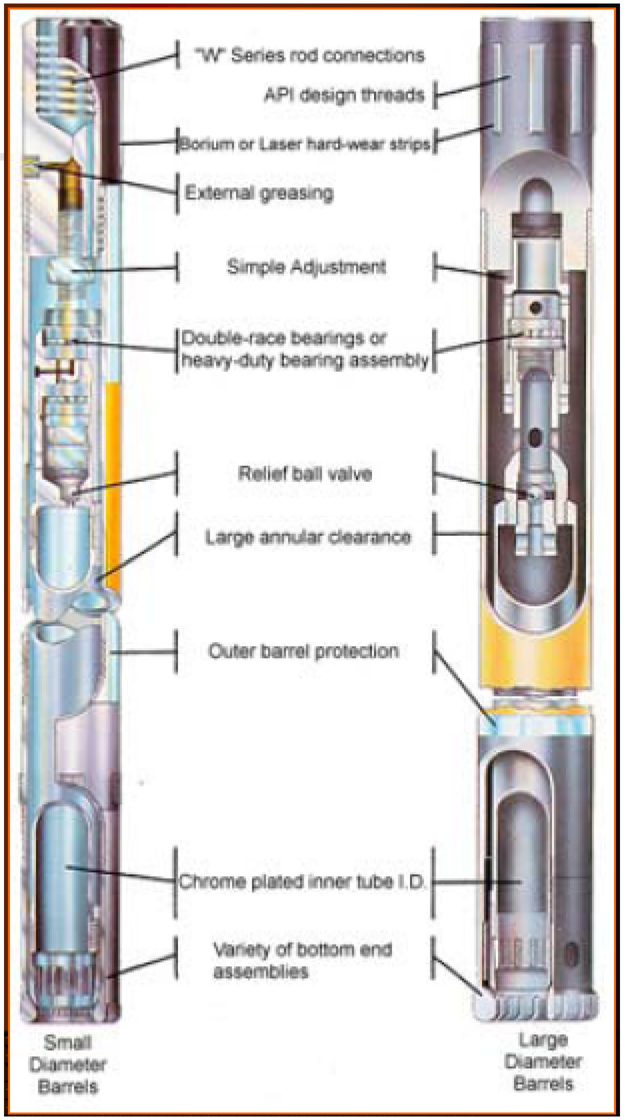
(Continued) (b) thin-walled tube; (c) and (d) piston sampler

Common Sampling Methods

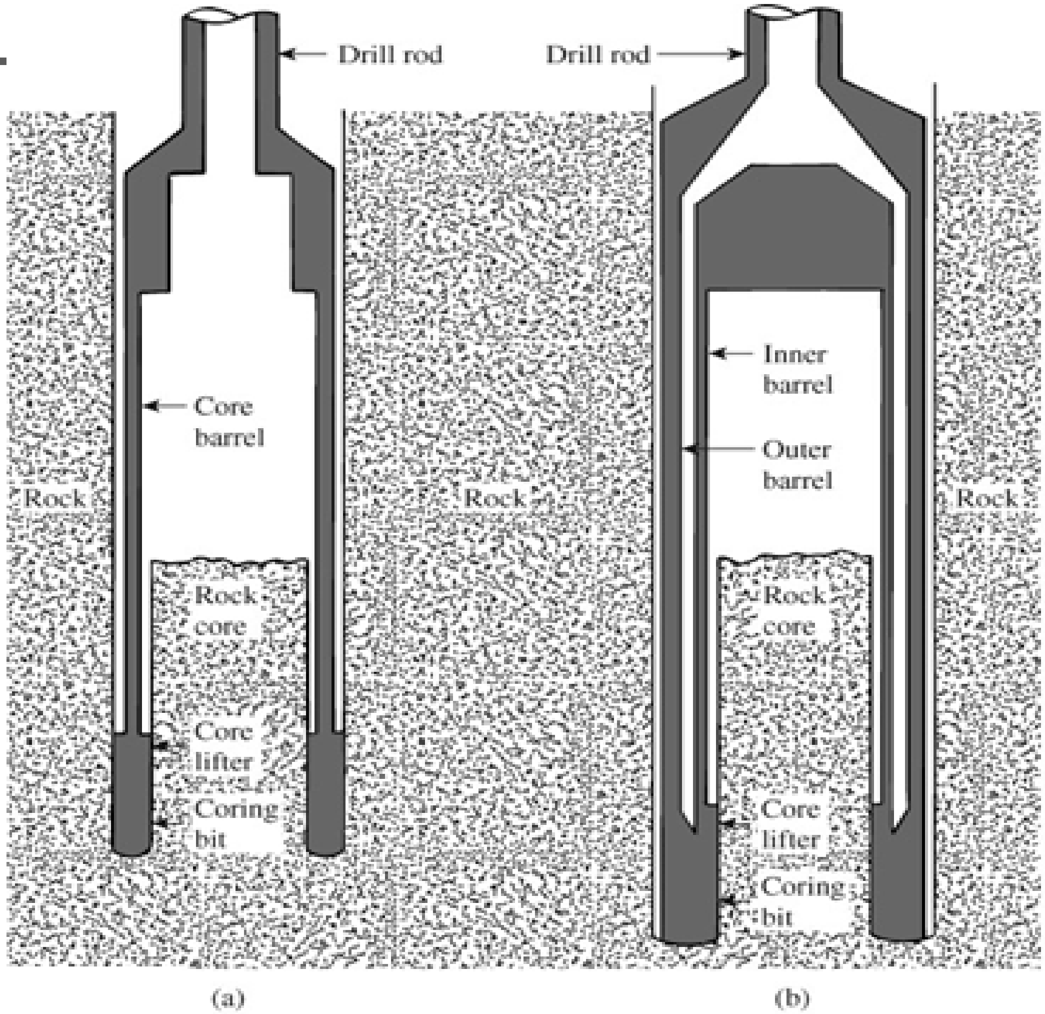
Sampler	*Disturbed / Undisturbed*	*Appropriate Soil Types*	*Method of Penetration*	*% Use in Practice*
Split-Barrel (Split Spoon)	Disturbed	Sands, silts, clays	Hammer driven	85
Thin-Walled Shelby Tube	Undisturbed	Clays, silts, fine-grained soils, clayey sands	Mechanically Pushed	6
Continuous Push	Partially 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

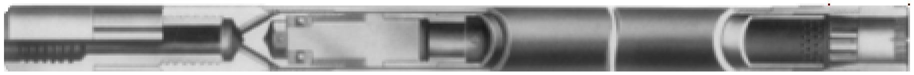
$$\text{Recovery Ratio} = \frac{\sum \text{Lengths of intact pieces of core}}{\text{Length of core advance}}$$

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

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

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 %

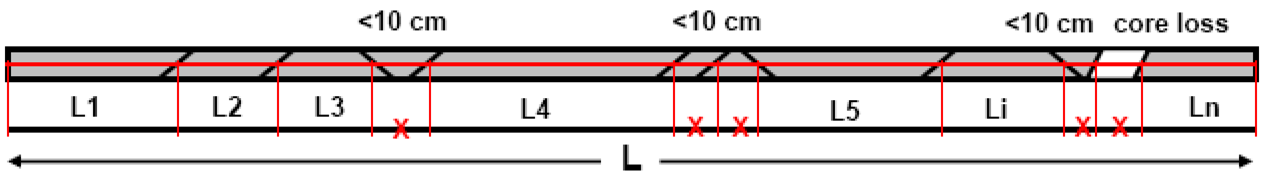
Core Recovery cm	Modified Core Recovery, cm
25	25
5	0
5	0
7.5	0
10	10
12.5	12.5
7.5	0
10	10
15	15
10	10
5	0
12.5	12.5
125	95

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.

$RQD = \Sigma Li / L \times 100\%$, $Li > 10$ cm



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

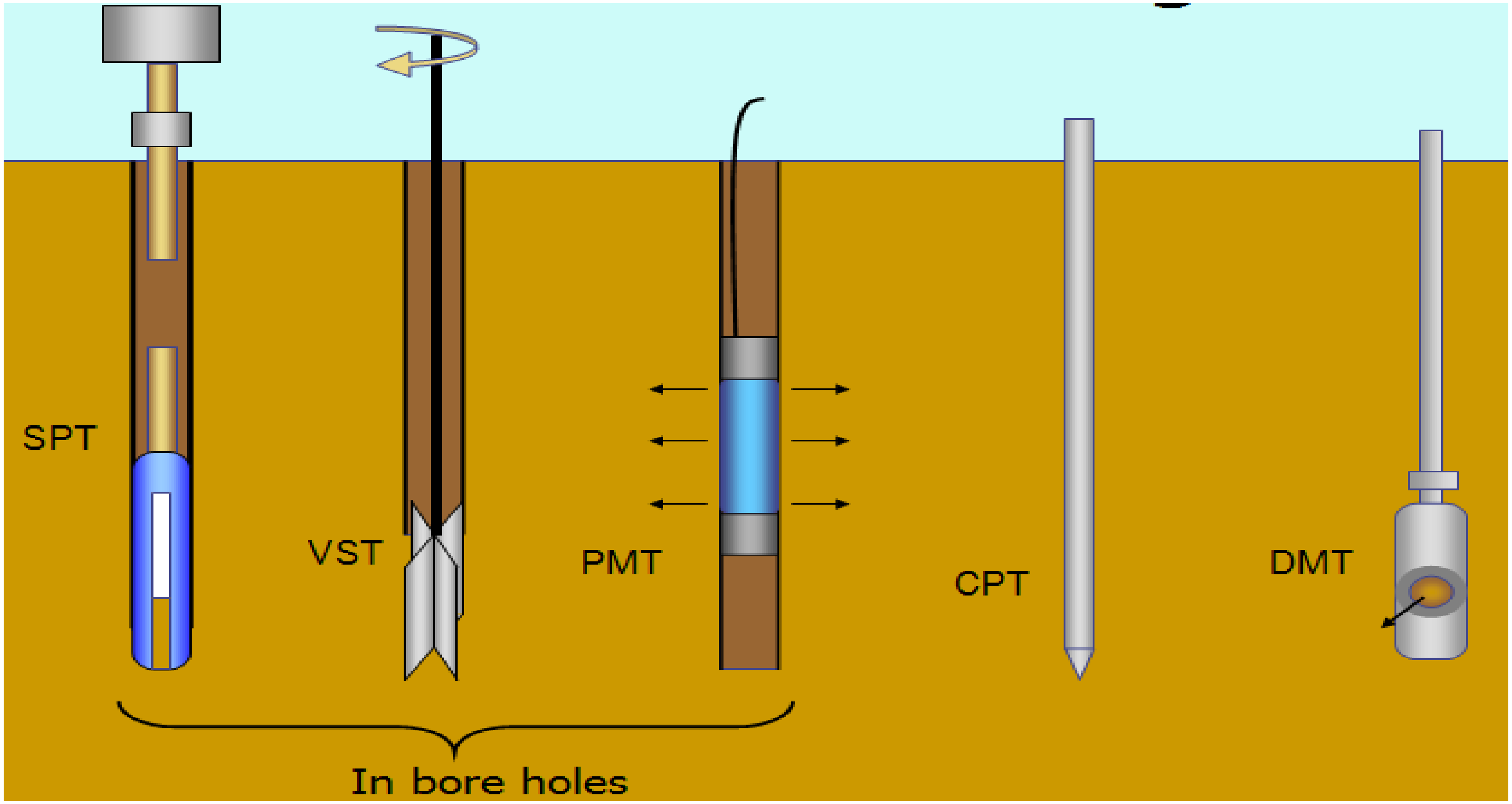
RQD	Rock Mass Quality
< 25	Very poor
25 – 50	Poor
50 – 75	Fair
75 – 90	Good
99 – 100	Excellent

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



SPT

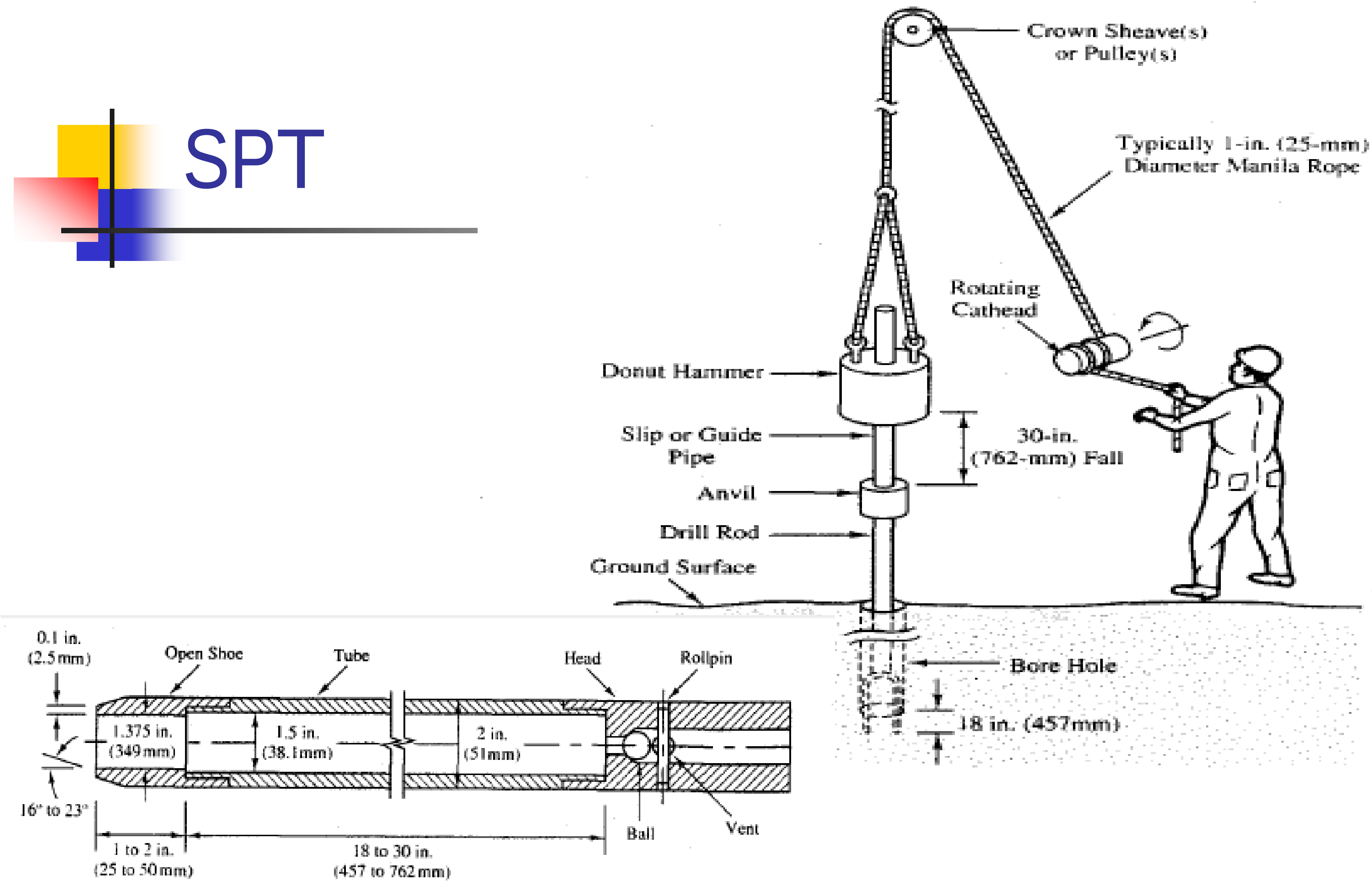
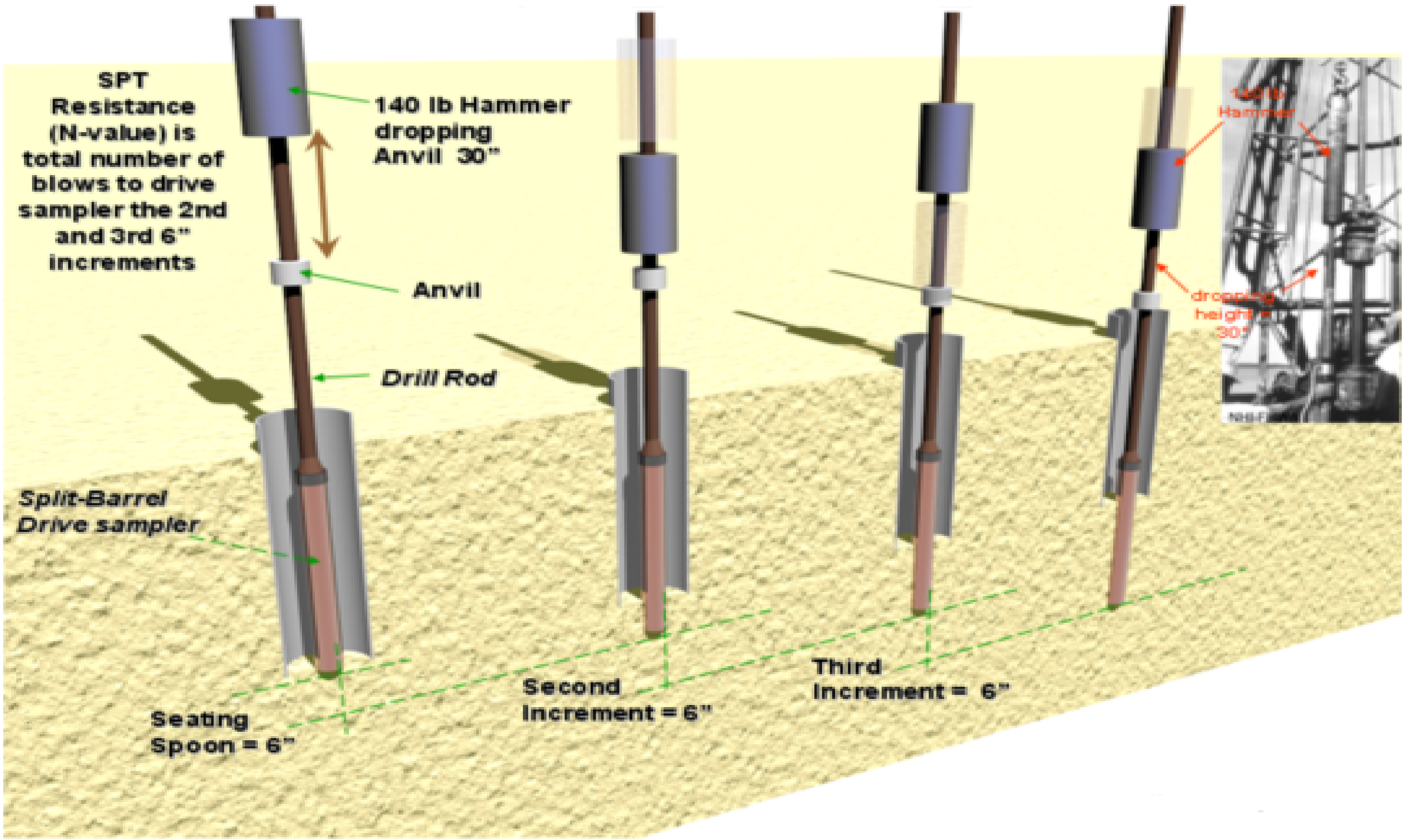
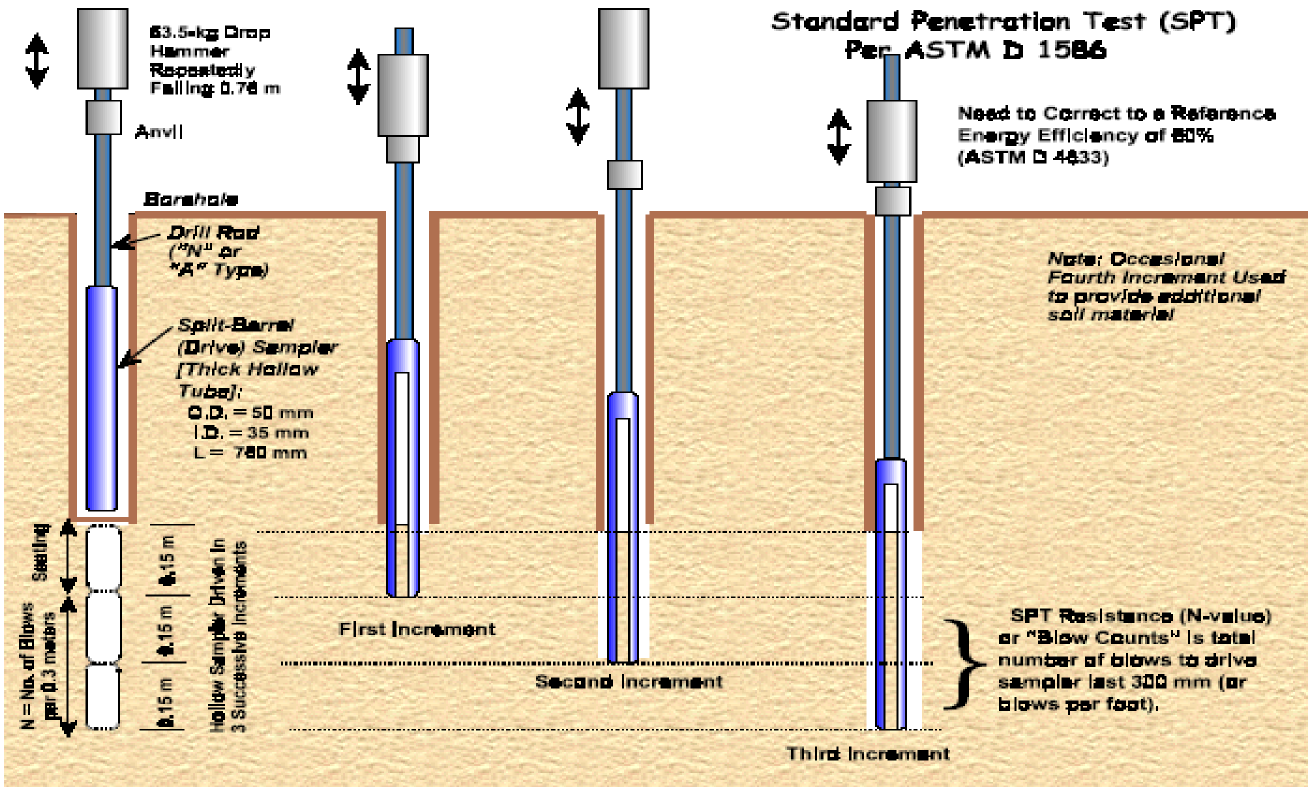


Figure 4.8 The SPT sampler (Adapted from ASTM D1586; Copyright ASTM, used with permission).

Standard Penetration Test (SPT)



Standard Penetration Test (SPT)



SPT, Refusal

In conducting SPT, refusal is declared if

1. Number of blows of the hammer are more than 50 during any one of the three 6 inch penetration

2. Number of blows of the hammer are more than 100

3. There is no advancement of the sampler for 10 successive blows of the hammer

Interpretation of SPT-N value for Cohesionless Soil

Description	**Very Loose**	**Loose**	**Medium**	**Dense**	**Very Dense**
Relative density, D_r	0 – 0.15	0.15 – 0.35	0.35 – 0.65	0.65 – 0.85	0.85 – 1.00
Standard Penetration Test value, *N*	**0 – 4**	**5 – 10**	**11 – 30**	**31 – 50**	**51 – UP**
Approximate angle of internal friction, ϕ (degree)	25 – 28	28 – 30	30 – 35	35 – 40	38 – 43
Approximate range of moist unit weight, γ (pcf)	70 – 100	90 – 115	110 – 130	110 – 140	130 – 150
Submerged unit weight, γ_{sub}	60	55 – 65	60 – 70	65 – 85	75

Interpretation of SPT-N value for Cohesive Soil

Description	Very Soft	Soft	Firm	Stiff	Very Stiff	Hard
Unconfined compressive strength, q_u (tsf)	0 – 0.25	0.25 – 0.5	0.5 – 1.0	1.0 – 2.0	2.0 – 4.0	4.0 – UP
Standard Penetration Test value, *N*	**0 – 2**	**3 – 4**	**5 – 8**	**9 – 16**	**17 – 32**	**33 – UP**
Approx. range of saturated unit weight, γ_{sat} (pcf)	100 – 120		100 – 130	120 – 140		130^+

Correction to SPT-N values

We can improve the raw SPT data by applying certain correction factors, thus significantly improving its repeatability. The variations in testing procedures may be at least partially compensated by converting the N recorded in the field to N_{60} as follows (Skempton, 1986):

$$N_{60} = \frac{E_m C_B C_S C_R N}{0.60} \tag{3.1}$$

where:

N_{60} = SPT N-value corrected for field procedures
E_m = hammer efficiency (from Table 3.3)
C_B = borehole diameter correction (from Table 3.4)
C_S = sampler correction (from Table 3.4)
C_R = rod length correction (from Table 3.4)
N = SPT N-value recorded in the field

Many different hammer designs are in common use, none of which is 100 percent efficient. Some common hammer designs are shown in Figure 3.26, and typical hammer efficiencies are listed in Table 3.3. Many of the SPT-based design correlations were developed using hammers that had an efficiency of about 60 percent, so Equation 3.1 corrects the results from other hammers to that which would have been obtained if a 60 percent efficient hammer was used.

Types of SPT Hammers

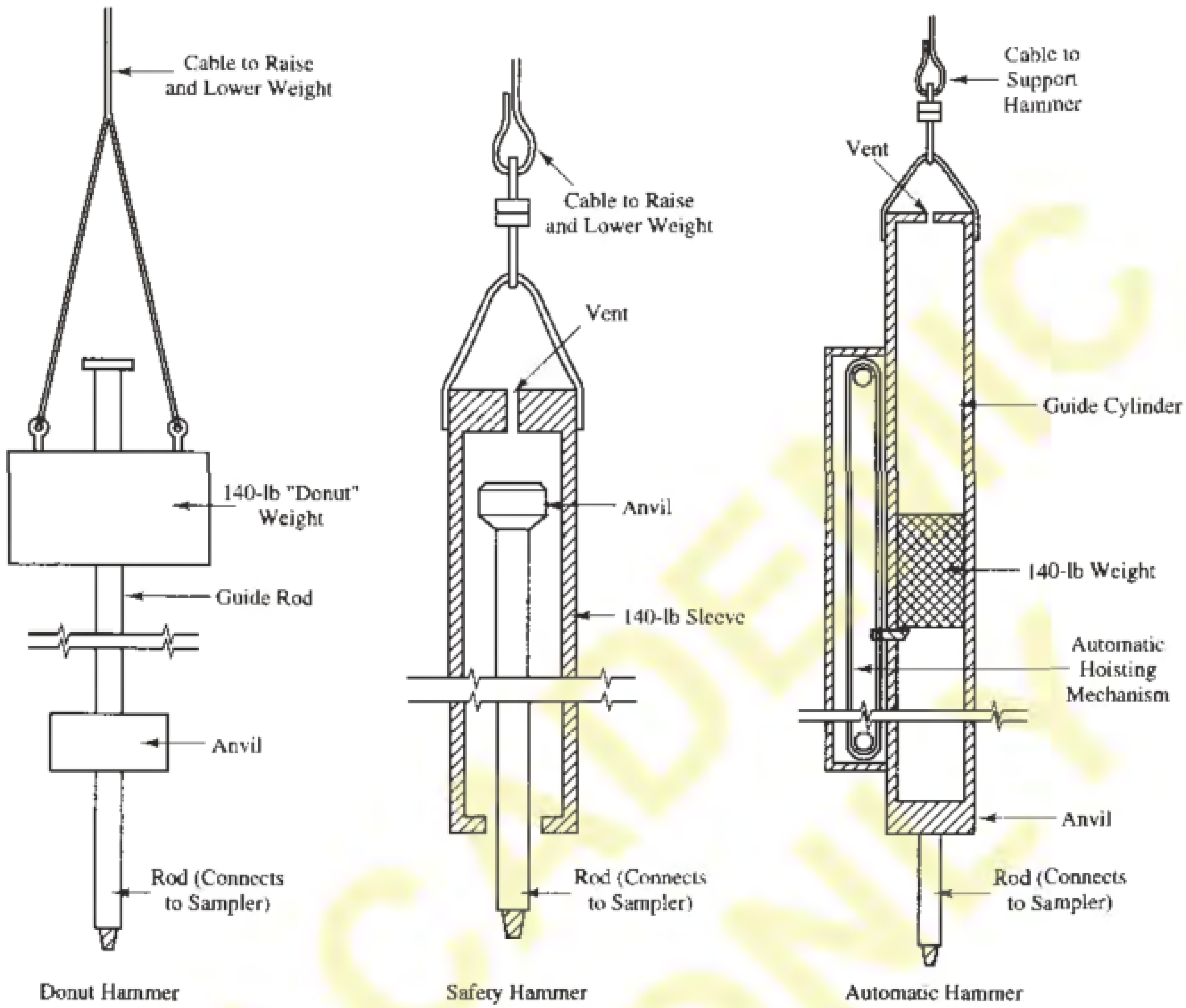


Figure 3.26 Types of SPT hammers.

Hammer Efficiencies

TABLE 3.3 SPT HAMMER EFFICIENCIES (Adapted from Clayton, 1990).

Country	Hammer Type	Hammer Release Mechanism	Hammer Efficiency E_m
Argentina	Donut	Cathead	0.45
Brazil	Pin Weight	Hand Dropped	0.72
China	Automatic	Trip	0.60
	Donut	Hand dropped	0.55
	Donut	Cathead	0.50
Colombia	Donut	Cathead	0.50
Japan	Donut	Tombi trigger	0.78 - 0.85
	Donut	Cathead 2 turns + special release	0.65 - 0.67
UK	Automatic	Trip	0.73
USA	Safety	2 turns on cathead	0.55 - 0.60
	Donut	2 turns on cathead	0.45
Venezuela	Donut	Cathead	0.43

Corrections for different Factors

TABLE 3.4 BOREHOLE, SAMPLER, AND ROD CORRECTION FACTORS (Adapted from Skempton, 1986).

Factor	Equipment Variables	Value
Borehole diameter factor, C_B	65 - 115 mm (2.5 - 4.5 in)	1.00
	150 mm (6 in)	1.05
	200 mm (8 in)	1.15
Sampling method factor, C_S	Standard sampler	1.00
	Sampler without liner (not recommended)	1.20
Rod length factor, C_R	3 - 4 m (10 - 13 ft)	0.75
	4 - 6 m (13 - 20 ft)	0.85
	6 - 10 m (20 - 30 ft)	0.95
	> 10 m (> 30 ft)	1.00

Correction for Overburden

The SPT data also may be adjusted using an *overburden correction* that compensates for depth effects. Tests performed near the bottom of uniform soil deposits have higher N-values than those performed near the top, so the overburden correction adjusts the measured N-values to what they would have been if the vertical effective stress, σ_z', was 100 kPa (2000 lb/ft^2). Chapter 10 will discuss σ_z' and how to compute it, but for now think of it as a compressive stress produced by the weight of the overlying soil. Until then, the value of σ_z' will be given in any problem statements.

The corrected value, $(N_1)_{60}$, is (Liao and Whitman, 1986):

$$(N_1)_{60} = N_{60}\sqrt{\frac{2000\ \text{lb/ft}^2}{\sigma_z'}} \qquad (3.2 - \text{English})$$

$$(N_1)_{60} = N_{60}\sqrt{\frac{100\ \text{kPa}}{\sigma_z'}} \qquad (3.2 - \text{SI})$$

Example 3.2

A standard penetration test has been conducted in a coarse sand at a depth of 16 ft below the ground surface. The blow counts obtained in the field were as follows: 0–6 in: 4 blows; 6–12 in: 6 blows; 12–18 in: 6 blows. The tests were conducted using a USA-style donut hammer in a 6 in diameter boring using a standard sampler with the liner installed. The vertical effective stress at the test depth was 1500 lb/ft^2. Determine $(N_1)_{60}$

Solution

$$N = 6 + 6 = 12$$

$E_m = 0.45$ per Table 3.3
$C_B = 1.05$ per Table 13.4
$C_S = 1.00$ per Table 13.4
$C_R = 0.85$ per Table 13.4

$$N_{60} = \frac{E_m C_B C_S C_R N}{0.60} = \frac{(0.45)(1.05)(1.00)(0.85)(12)}{0.60} = 8$$

$$(N_1)_{60} = N_{60}\sqrt{\frac{2000\ \text{lb/ft}^2}{\sigma'_z}}$$

$$= (8)\sqrt{\frac{2000\ \text{lb/ft}^2}{1500\ \text{lb/ft}^2}}$$

$$= \mathbf{9} \quad \Leftarrow \textit{\textbf{Answer}}$$

SPT CORRECTED BLOW COUNTS

N_F	C_B	C_S	C_E	C_R	C_N	$(N_1)_{60}$
16	1	1.2	0.75	0.85	1.40	17.17
25	1	1.2	0.75	0.85	1.32	25.22
22	1	1.2	0.75	0.95	1.24	23.41
26	1	1.2	0.75	0.95	1.18	26.18
25	1	1.2	0.75	0.95	1.12	23.90
21	1	1.2	0.75	0.95	1.06	19.11
24	1	1.2	0.75	1	1.02	21.93
26	1	1.2	0.75	1	0.97	22.71
30	1	1.2	0.75	1	0.89	24.08
31	1	1.2	0.75	1	0.83	23.02
29	1	1.2	0.75	1	0.77	20.04
27	1	1.2	0.75	1	0.72	17.44
19	1	1.2	0.75	1	0.67	11.52
22	1	1.2	0.75	1	0.64	12.57
28	1	1.2	0.75	1	0.60	15.13
28	1	1.2	0.75	1	0.57	14.35
31	1	1.2	0.75	1	0.54	15.11
35	1	1.2	0.75	1	0.52	16.26
34	1	1.2	0.75	1	0.49	15.09
33	1	1.2	0.75	1	0.47	14.02
30	1	1.2	0.75	1	0.46	12.47

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.

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 he 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

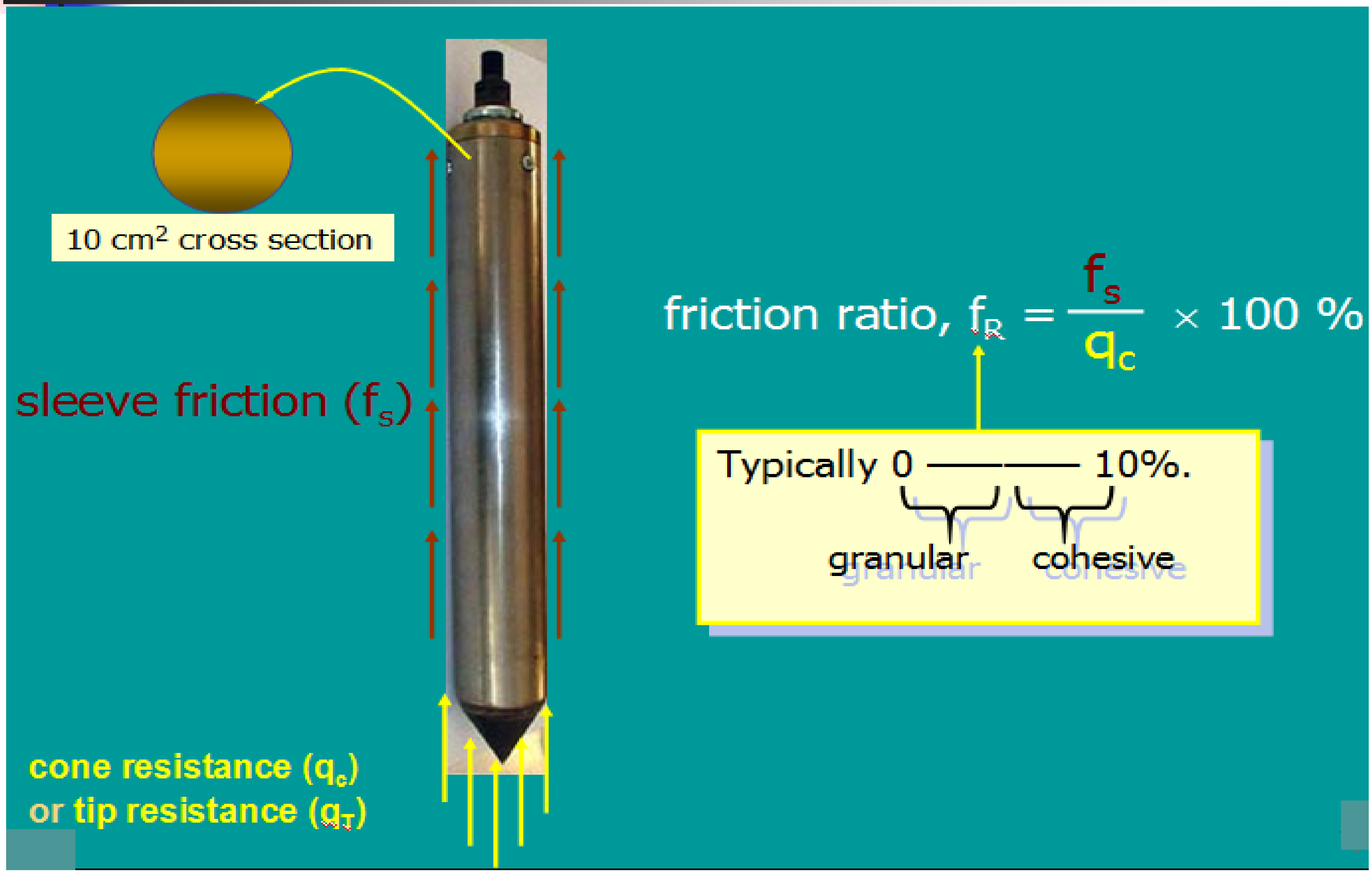
Boring No.: 3 Type of Boring: Hollow stem auger Ground Elevation: 60.8 m

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	
	3	SS-2	12	17.6	$LL = 38$ $PI = 11$
*G.W.T. 3.5 m	4				
Light gray silty clay (ML)	5	ST-1		20.4	$LL = 36$ $q_u = 112\ kN/m^2$
	6	SS-3	11	20.6	
Sand with some gravel (SP)	7				
End of boring @ 8 m	8	SS-4	27	9	

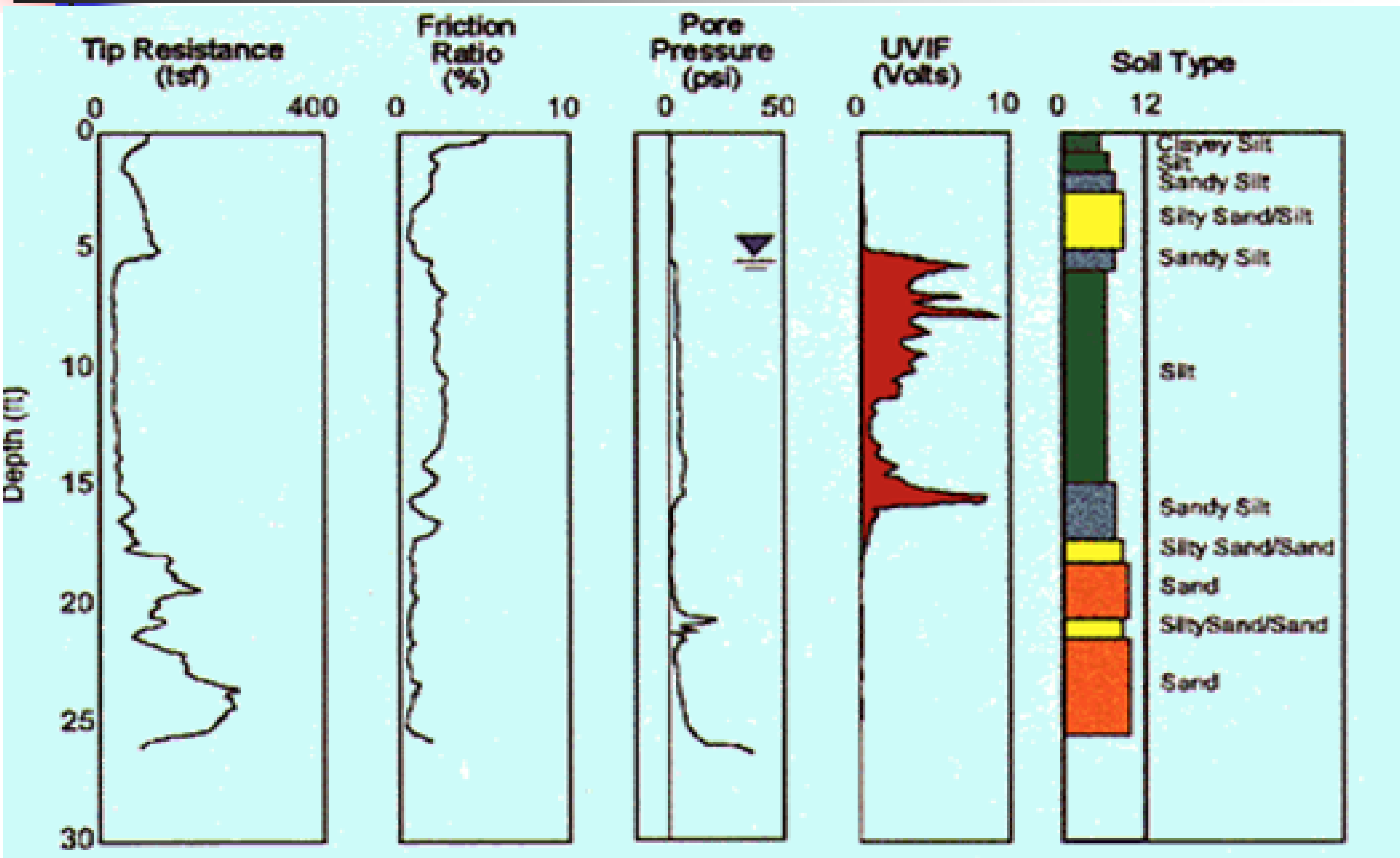
N = standard penetration number (below/304.8 mm)
w_n = natural moisture content
LL = liquid limit; PI = plasticity index
q_u = unconfined compression strength
SS = split-spoon sample; ST = Shelby tube sample

*Ground water table observed after one week of drilling

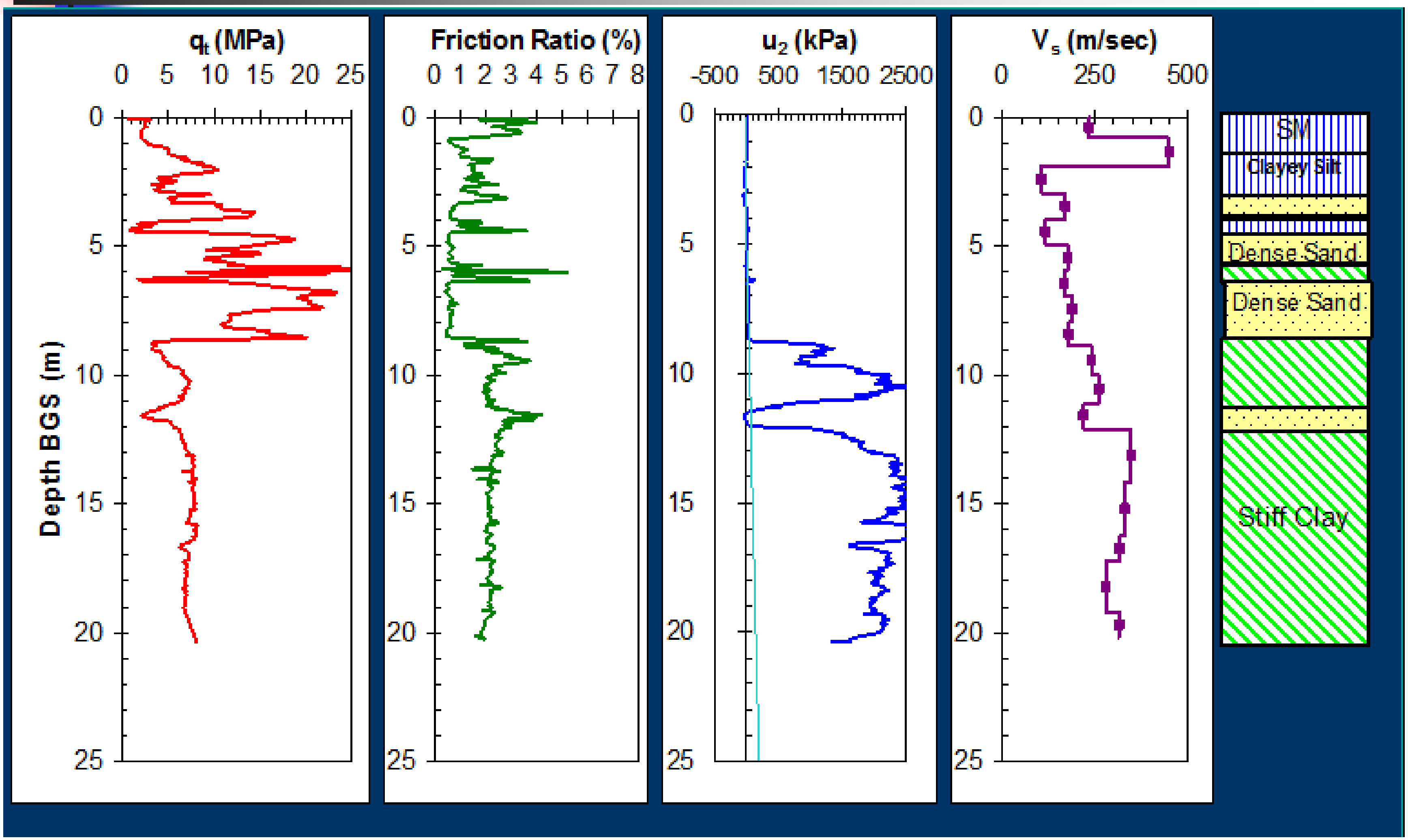
Cone Penetration Test (CPT)



Cone Penetration Test (CPT)



Cone Penetration Test (CPT)



Cone Penetration Test (CPT)

SCPT Correlations

In Clays,

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

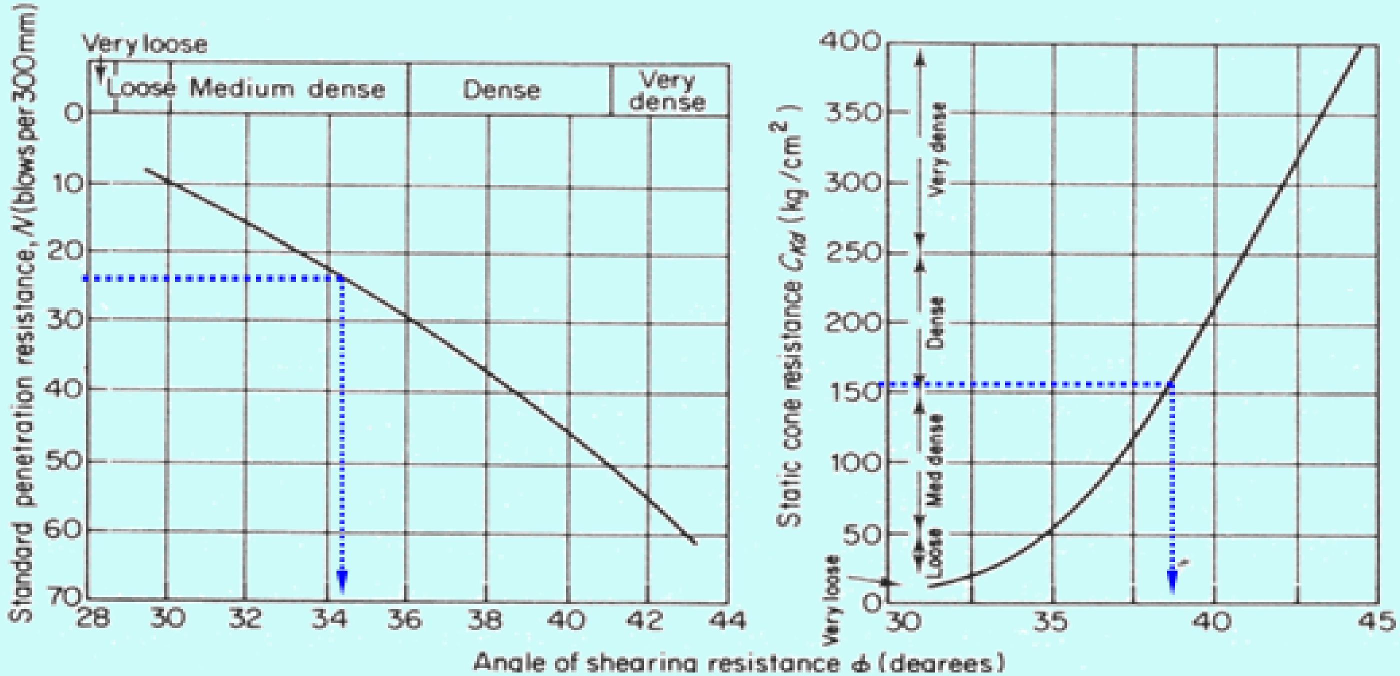
N_k → cone factor (15-20); varies with cone

In Sands,

E = 2.5-3.5 q_c (for young normally consolidated sands)

Cone Penetration Test (CPT)

φ′ from SPT/CPT in Granular Soils

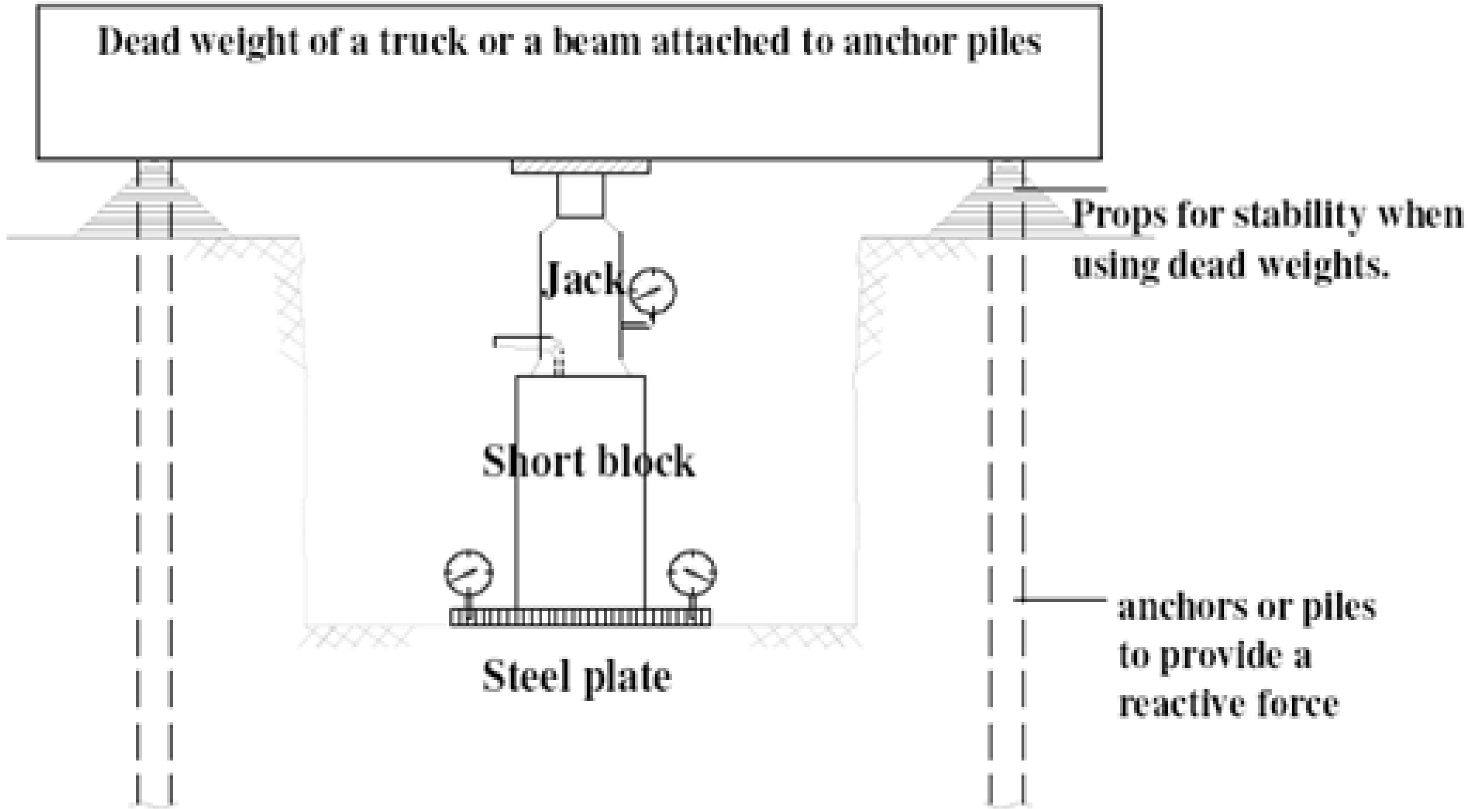


After Peck et al. (1974)

After Meyerhof (1976)

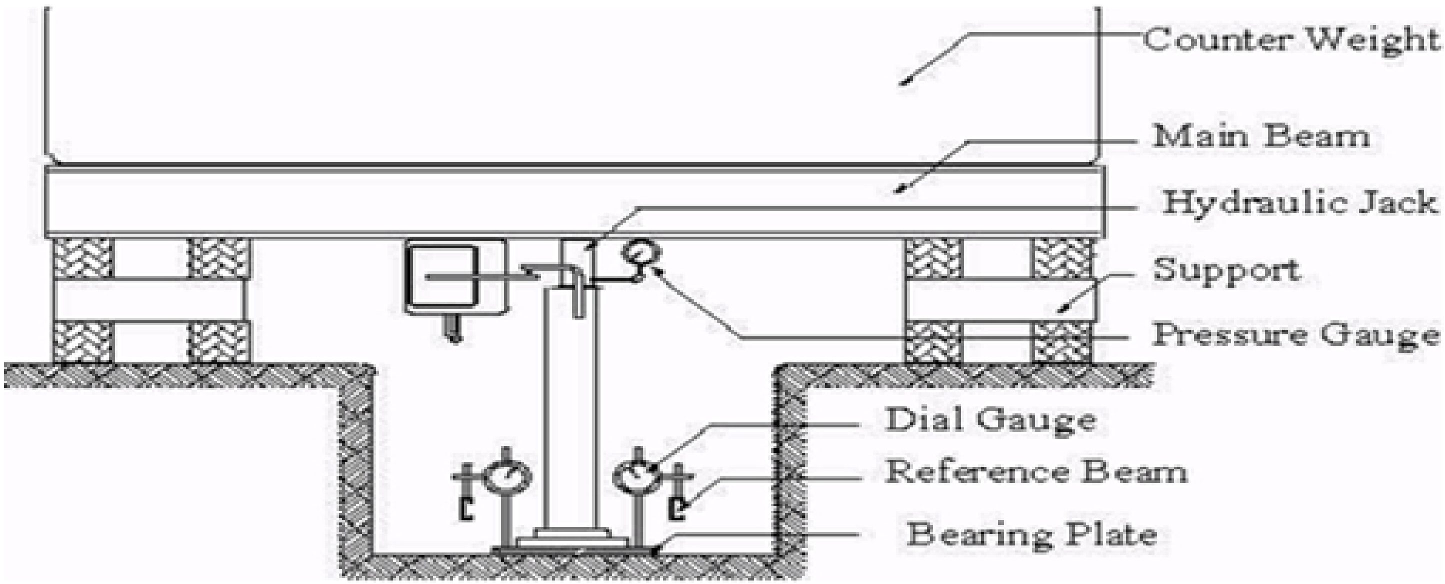
The Plate Load Test (PLT)

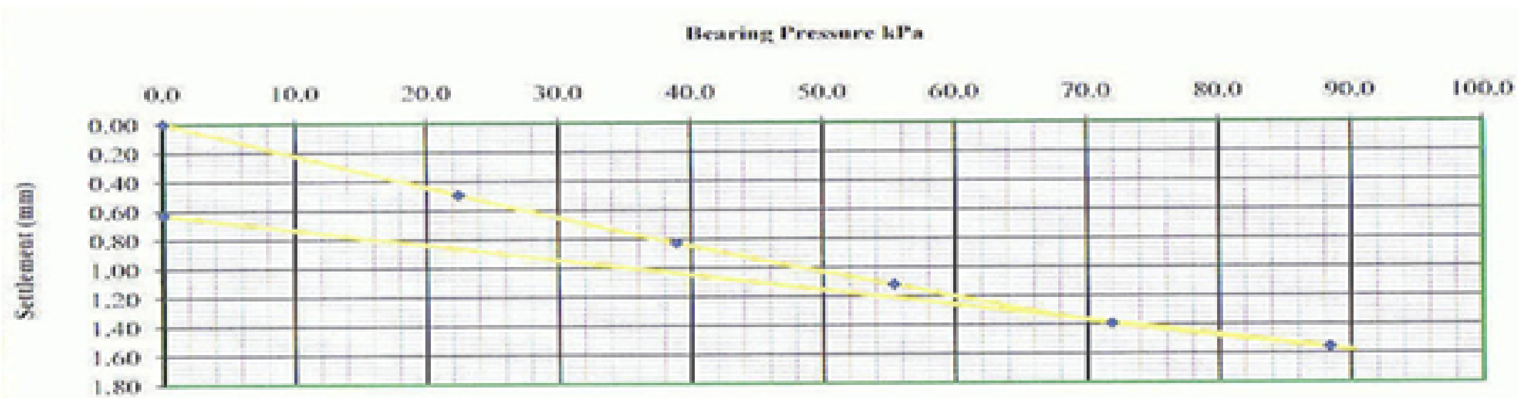
The Plate Load Test (PLT)



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

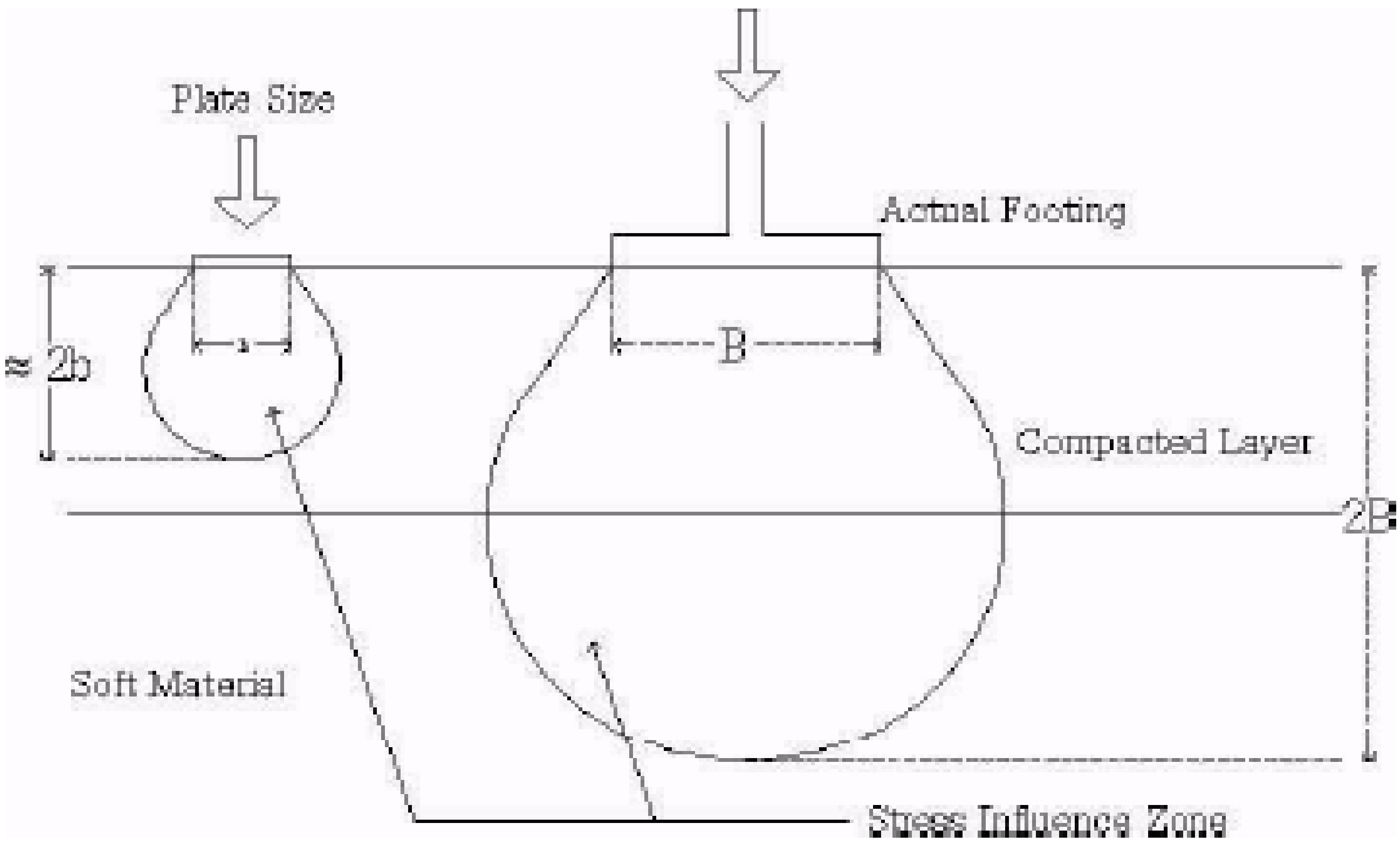
The Plate Load Test (PLT)





The Plate Load Test (PLT)

Scale Effect in Foundation Design



Other In-situ Tests

- Pressure meter, Dilatometer and other test consult Clarke Manual