Site Exploration and Characterization; Part II

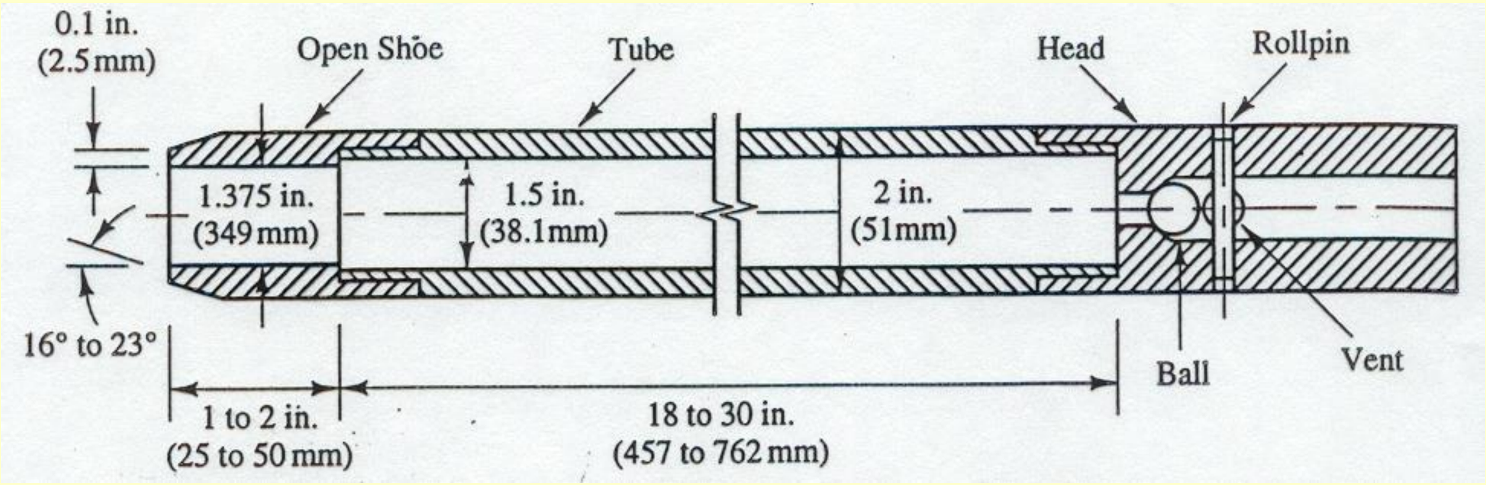
In-situ Testing

- When it is difficult to obtain “undisturbed” samples
- Cohesionless soils, Sensitive clays, Cohesive Stiff to Hard Soils
- In-situ Test Methods
  - Standard Penetration Test (SPT)
  - Cone Penetration Test (CPT)
  - Vane Shear Test (VST)

Standard Penetration Test (SPT)

- 140 lb (63.5 kg) Hammer
- 30in (76 cm) free fall
- Drive sampler over 18 inches
- Record no. of blows per each 6 inch penetration
- SPT blow count=blows for 2nd 6 inch penetration + blows for 3rd 6inch penetration

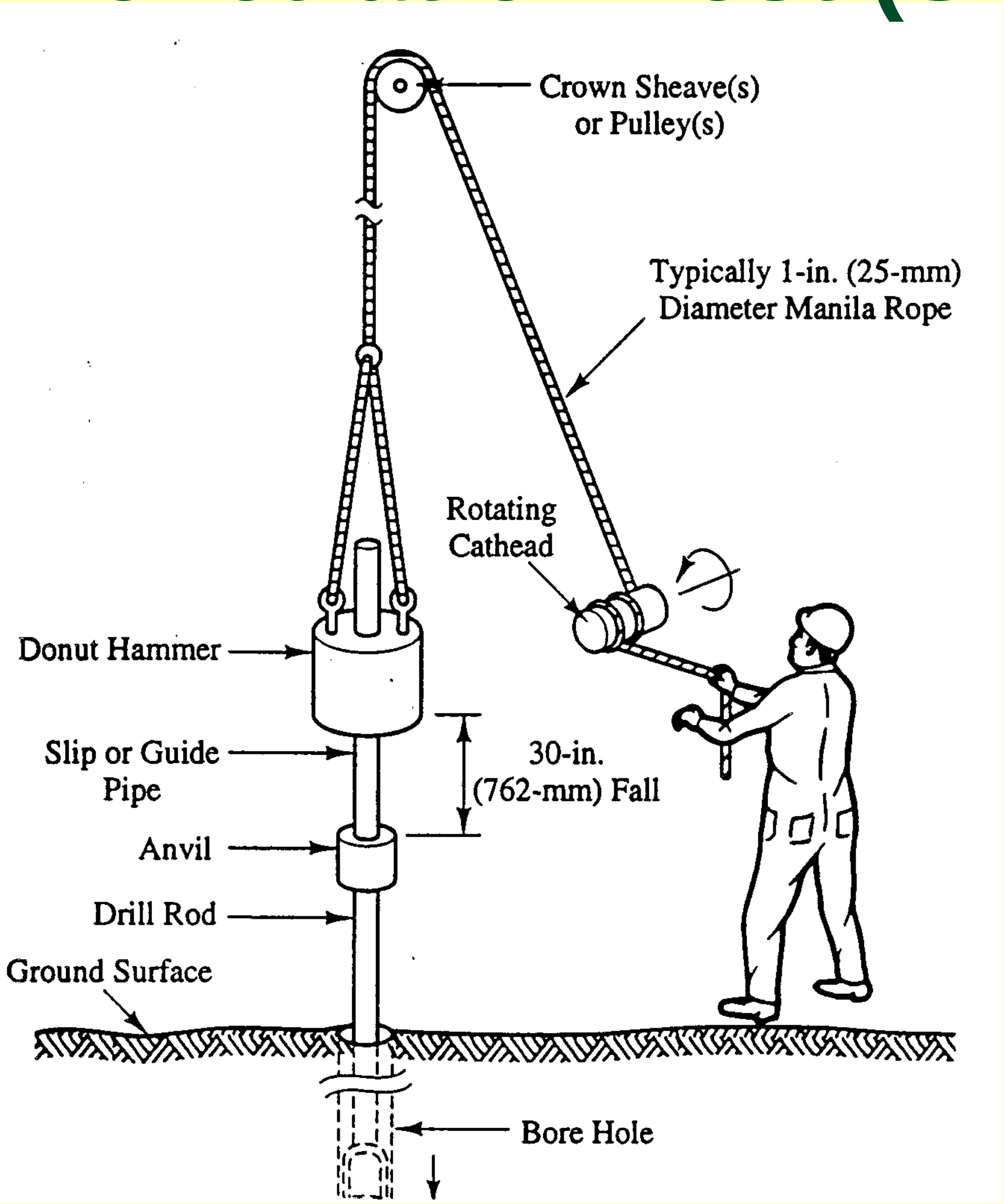
Standard Split Spoon Sampler



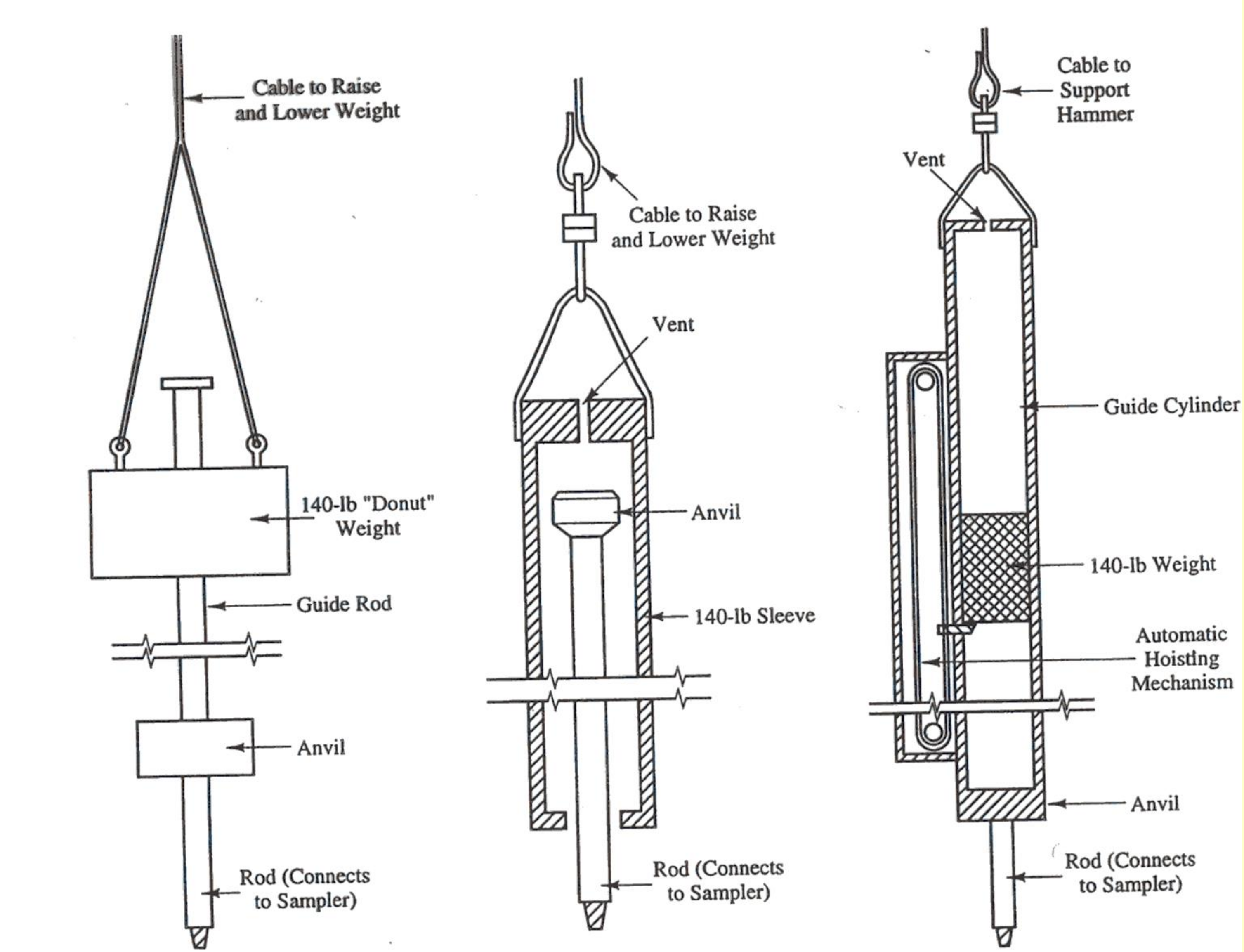
- Thick wall (0.25in) cylinder
- Sampling tube is split along the length
- Hammered into the ground

Standard Split Spoon Sampler

Standard Penetration Test (SPT)



Types of SPT Hammers



SPT: Automatic Trip Hammer

Corrections to SPT blow Counts

Factors affecting SPT blow count:

- Hammer Efficiency (See Table 4.3)
- Borehole diameter (See Table 4.4)
- Type of sampler (See Table 4.4)
- Rod length (See Table 4.4)

TABLE 4.3 SPT HAMMER EFFICIENCIES (Adapted from Clayton, 1990).

Country	Hammer Type (per Figure 4.10)	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
US	Safety	2 turns on cathead	0.55–0.60
	Donut	2 turns on cathead	0.45
Venezuela	Donut	Cathead	0.43

TABLE 4.4 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

SPT Correction Factors

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

- hammer efficiency (E_m) …. Table 4.3
- bore hole diameter (C_B)…….Table 4.4.
- sampler correction (C_S) ……Table 4.4
- rod length (C_R) ………Table 4.4

SPT Overburden Correction

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

$$(N_1)_{60} = N_{60}\sqrt{\frac{100\ kPa}{\sigma'_z}} \qquad \text{(SI)}$$

Use of SPT Data

- To Determine Relative Density, D_r
  - From AASHTO Chart
  - From Eq. (4.3) p.122
- To determine ϕ
  - From Figure 4.11 (p.123)
- To determine C
  - From AASHTO Chart

$$D_r = \sqrt{\frac{(N_1)_{60}}{C_P C_A C_{OCR}}} \times 100\%$$

$$C_P = 60 + 25 \log D_{50}$$

$$C_A = 1.2 + 0.05 \log\left(\frac{t}{100}\right)$$

$$C_{OCR} = \mathrm{OCR}^{0.18}$$

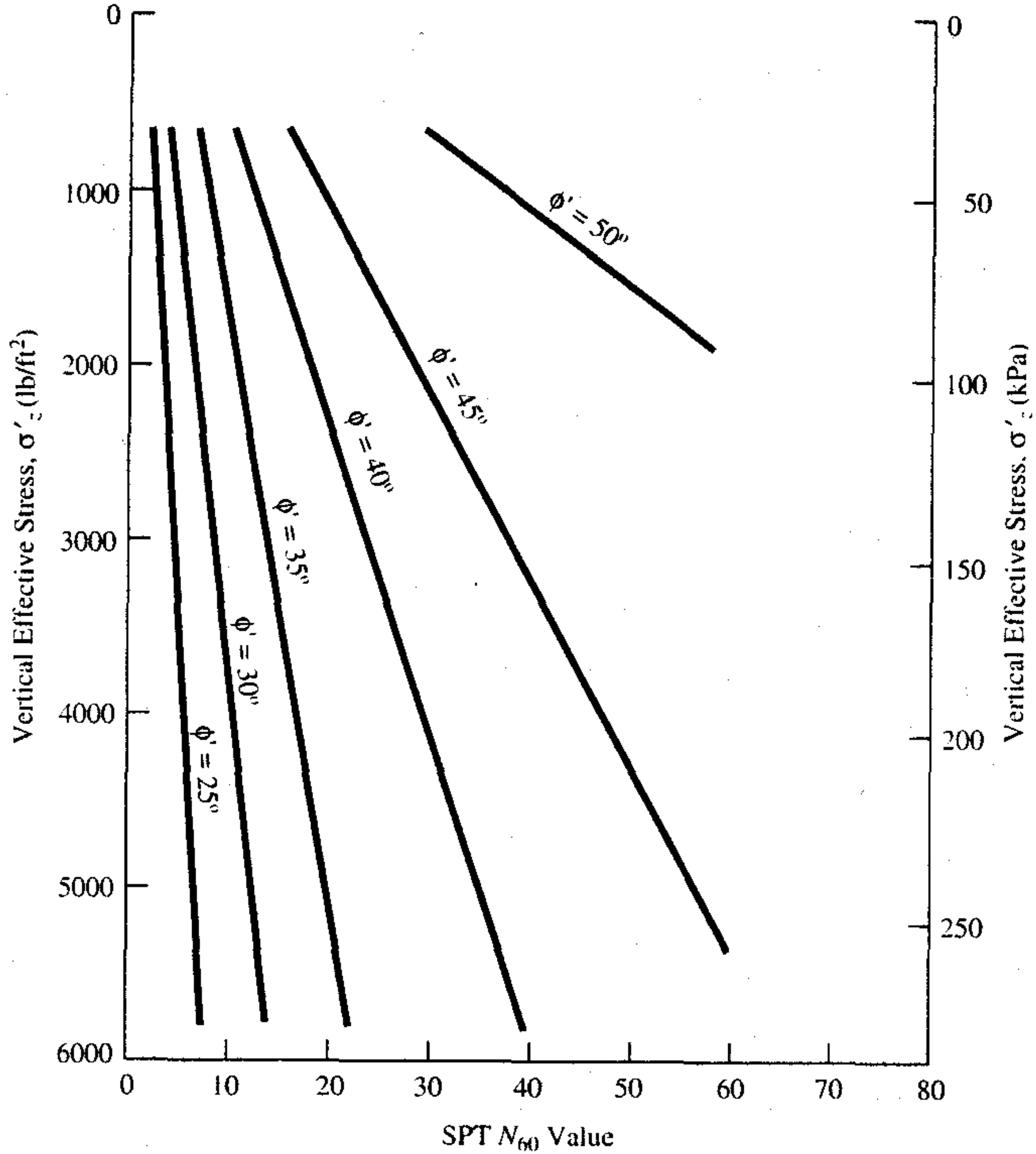
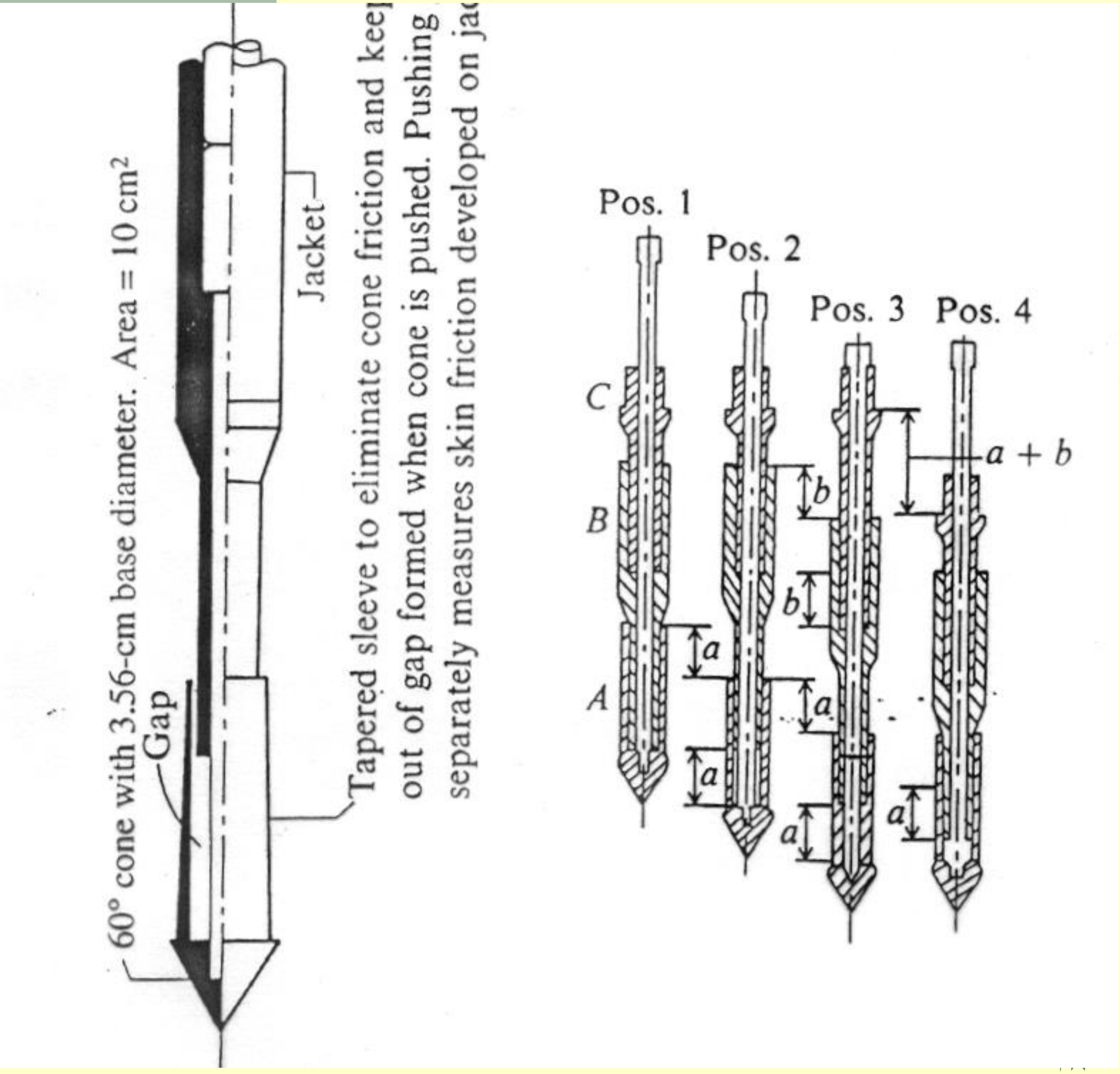


Figure 4.11 Empirical correlation between N_{60} and ϕ' for uncemented sands (Adapted from DeMello, 1971).

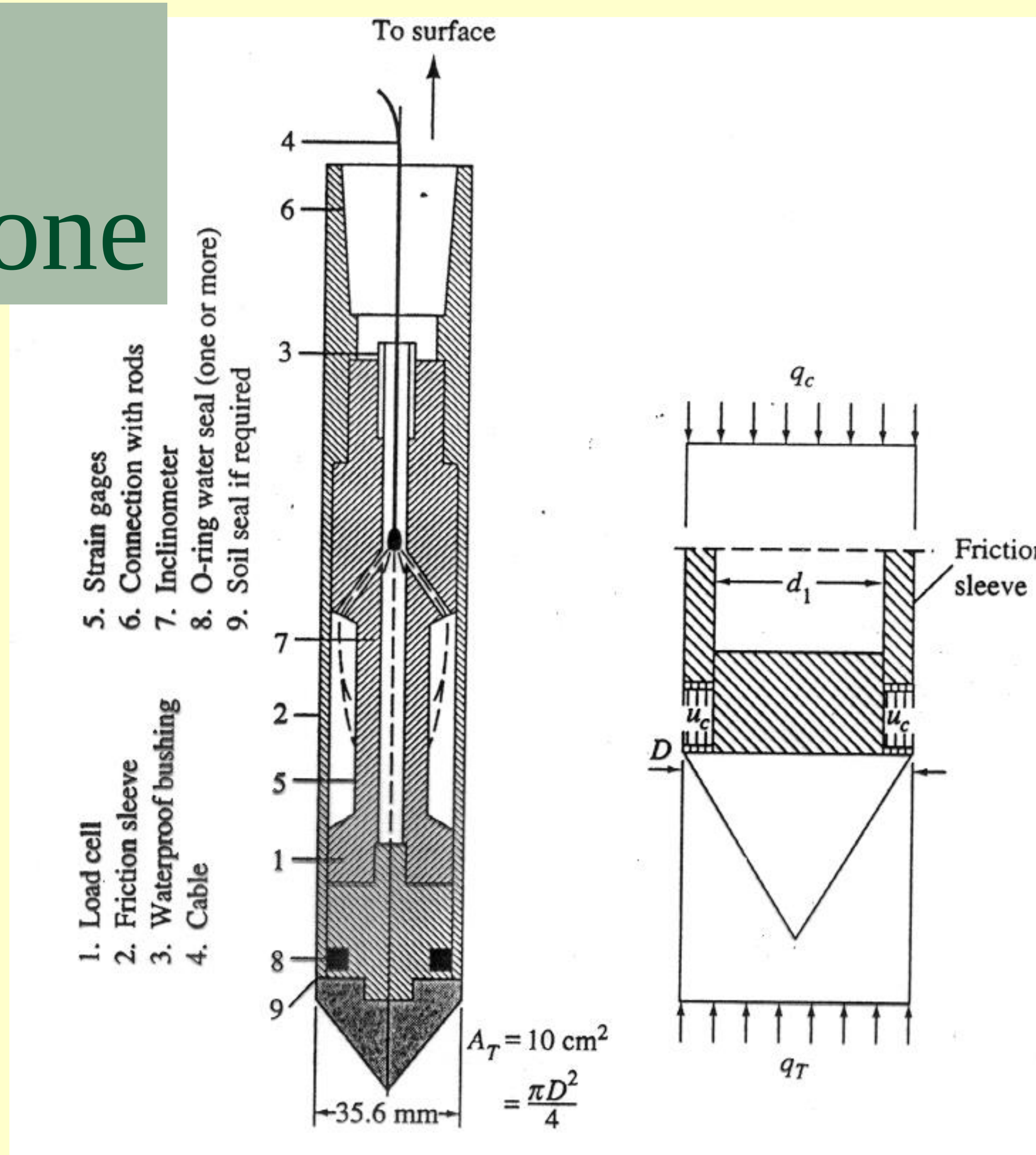
Cone Penetration Test (CPT)

- Originally Developed in Netherlands 1930s
- Further developments in 1950s
- “Dutch Cone”
- ASTM D 3441
- Types of CPT devices
  - mechanical cone
  - electric cone
  - piezocone

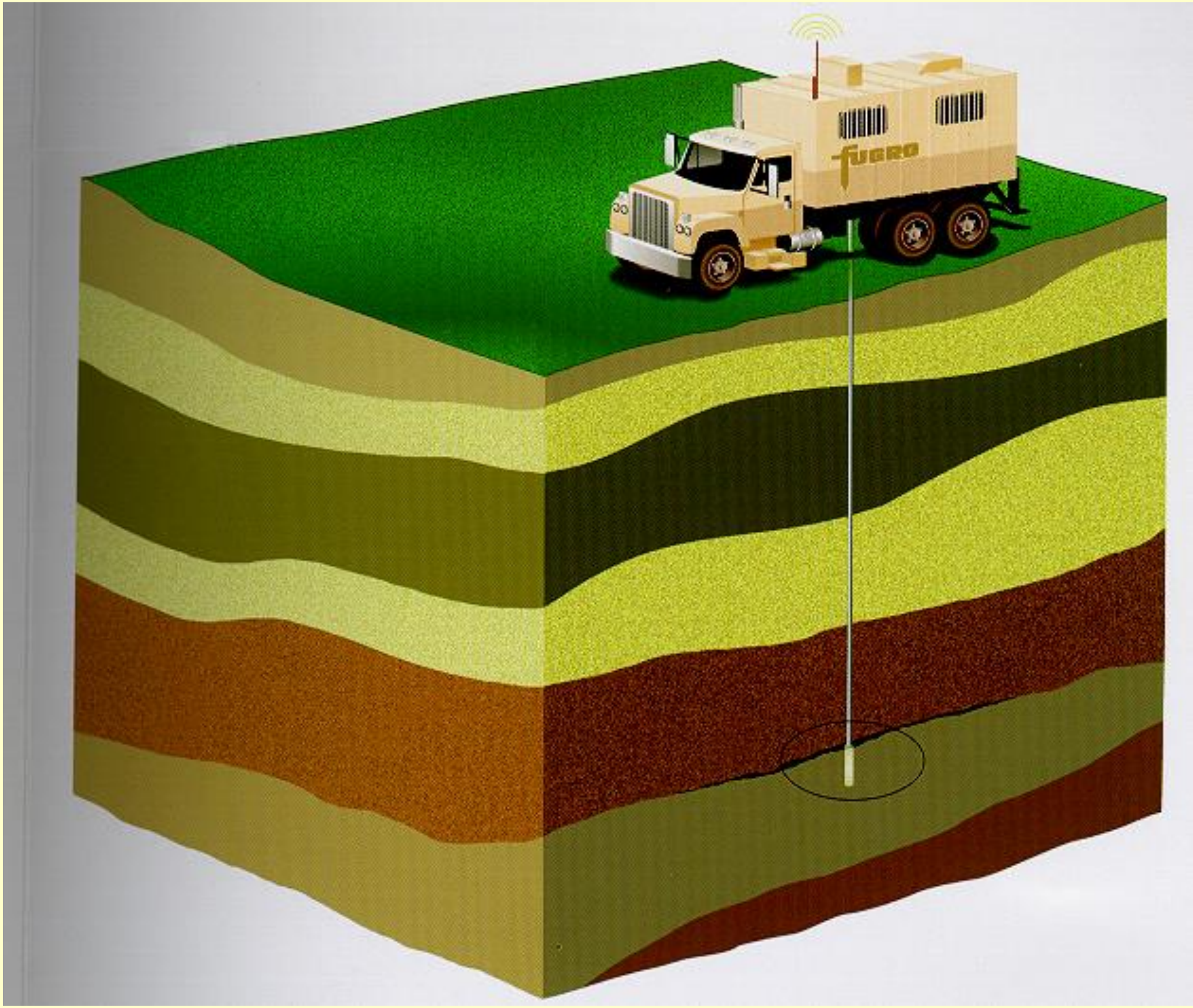
Mechanical Cone



Electrical Cone



Cone Penetrometer


FUGRO

CPT Truck

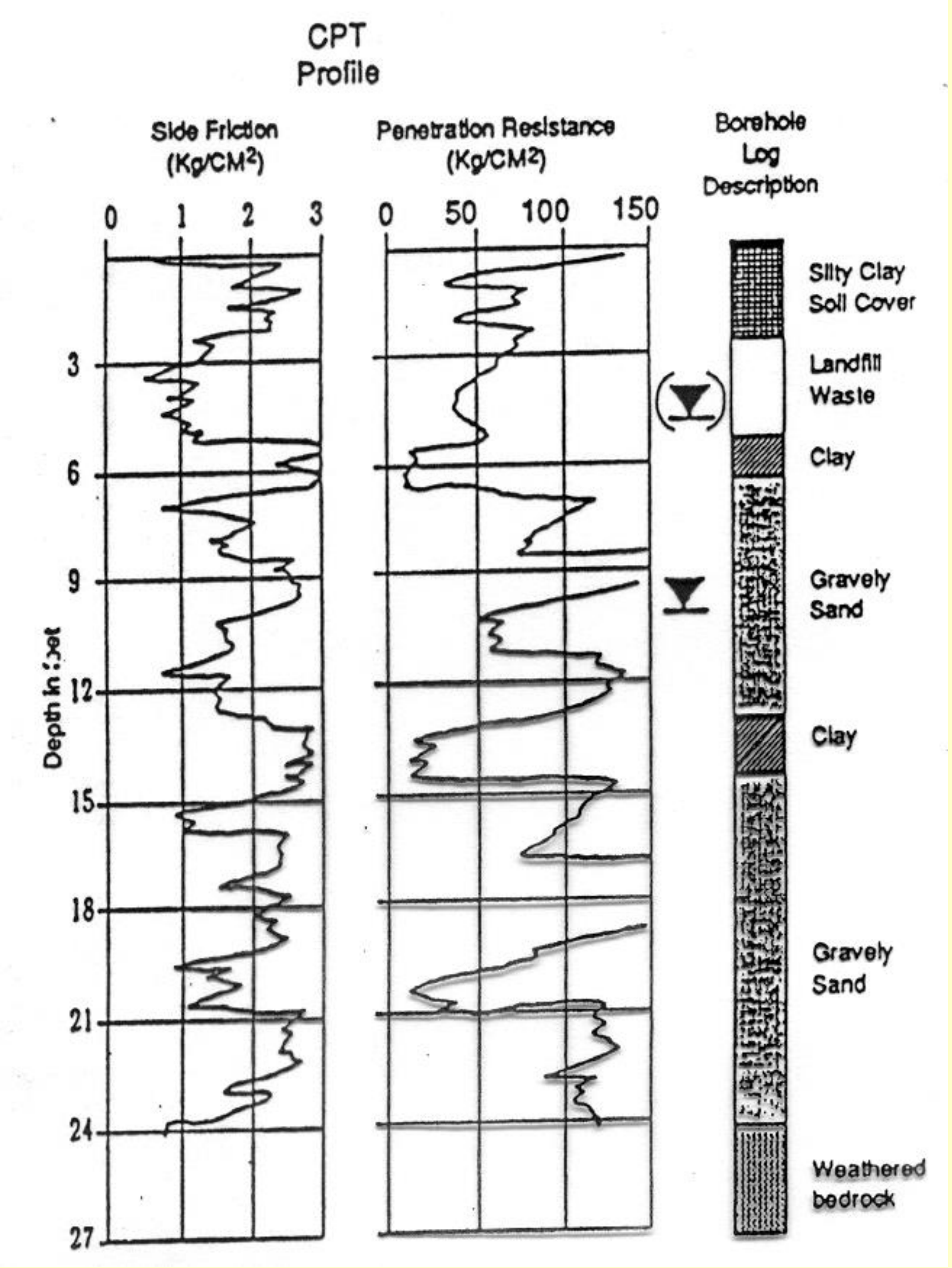
Crawler Type CPT Truck

CPT Truck; Interior

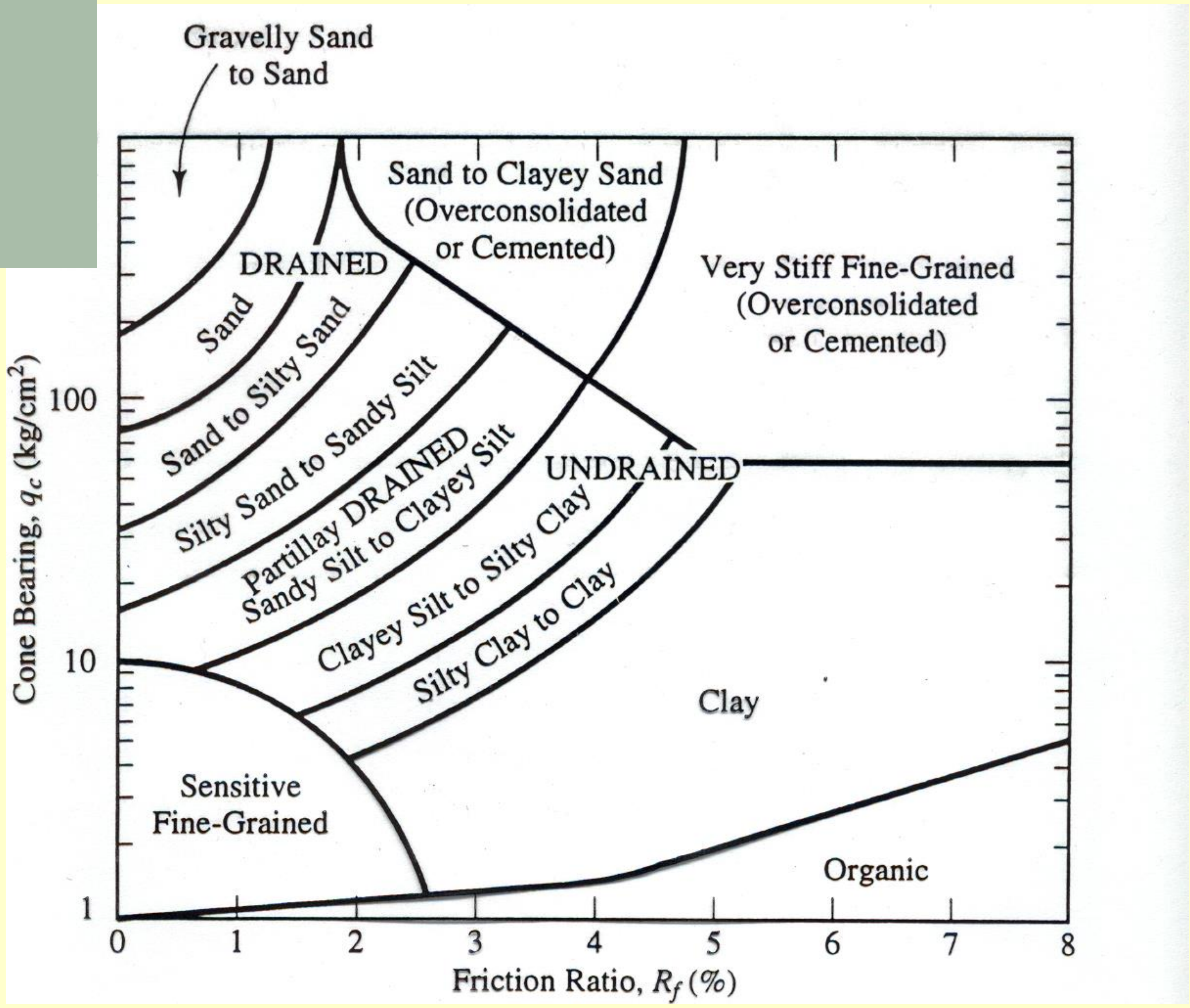
Cone Penetration Test (CPT)

- Measures:
  - Cone Resistance, q_c
  - Sleeve Resistance, f_{sc}
- Typical CPT results

Typical CPT Data



Use of CPT Data



CPT Versus SPT

- CPT: Advantages over SPT
  - provides much better resolution, reliability
  - versatility; pore water pressure, dynamic soil properties
- CPT: Disadvantages
  - Does not give a sample
  - Will not work with soil with gravel
  - Need to mobilize a special rig

Vane Shear Test

- Originally developed by Swedish Engineer, John Olsson in 1920s
- Now Standardized as ASTM D2573
- Specially suited for soft, sensitive clays
- Quick test, used to determine undrained shear strength

Vane Shear Test

- Drill test hole
- Insert vane
- Rotate head
- Measure torque
- Relate resistance to soil shear strength

Vane Shear Test

- Relationship between S_u and applied Torque:

$$S_u = \frac{6T_f}{7\pi d^3}$$

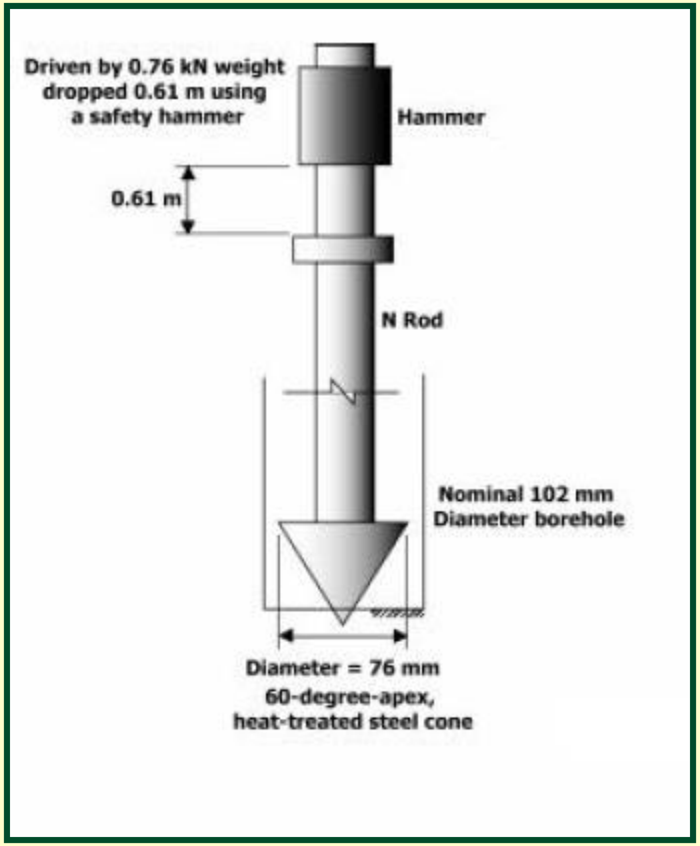
- Relationship between Su and applied Torque (after correction factor):

$$S_u = \frac{6\lambda T_f}{7\pi d^3}$$

Drilling and Sampling

Texas Cone Penetrometer

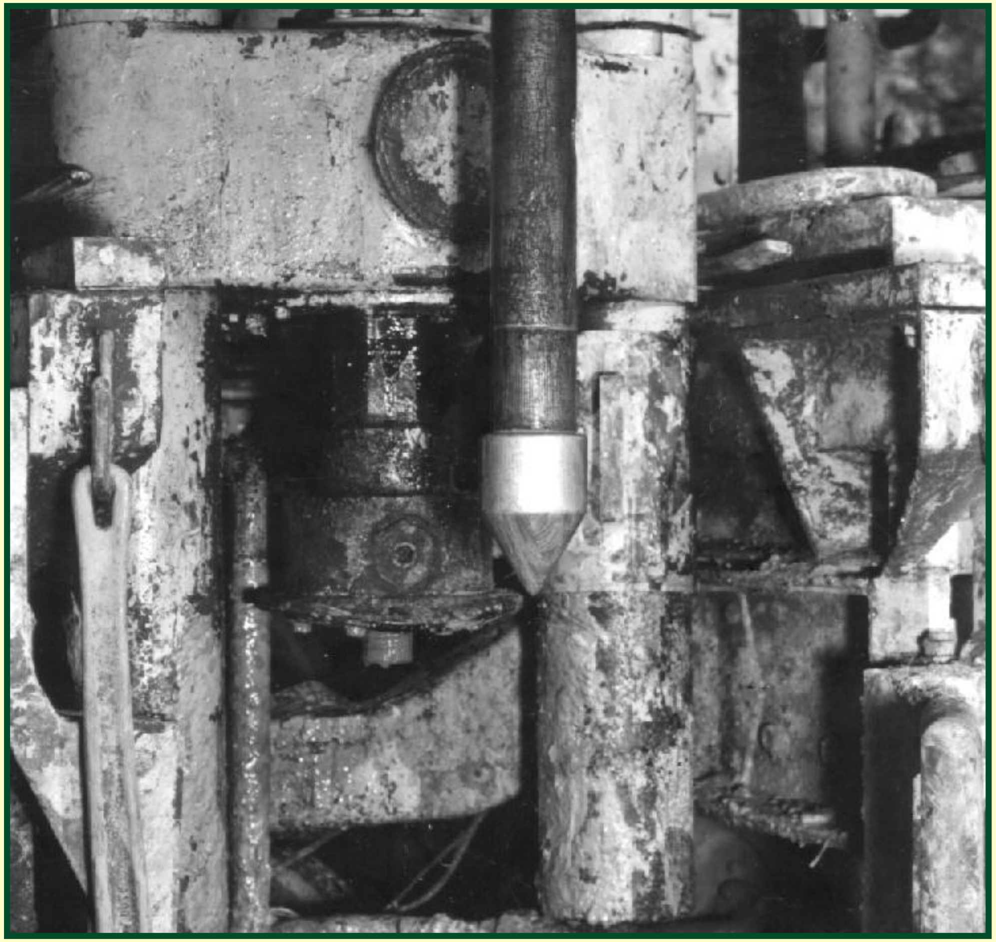
- Developed in 1949
- Useful for wide range of SOIL and ROCK types and strengths
- Design Charts related TCP values to soil bearing strength



Drilling and Sampling

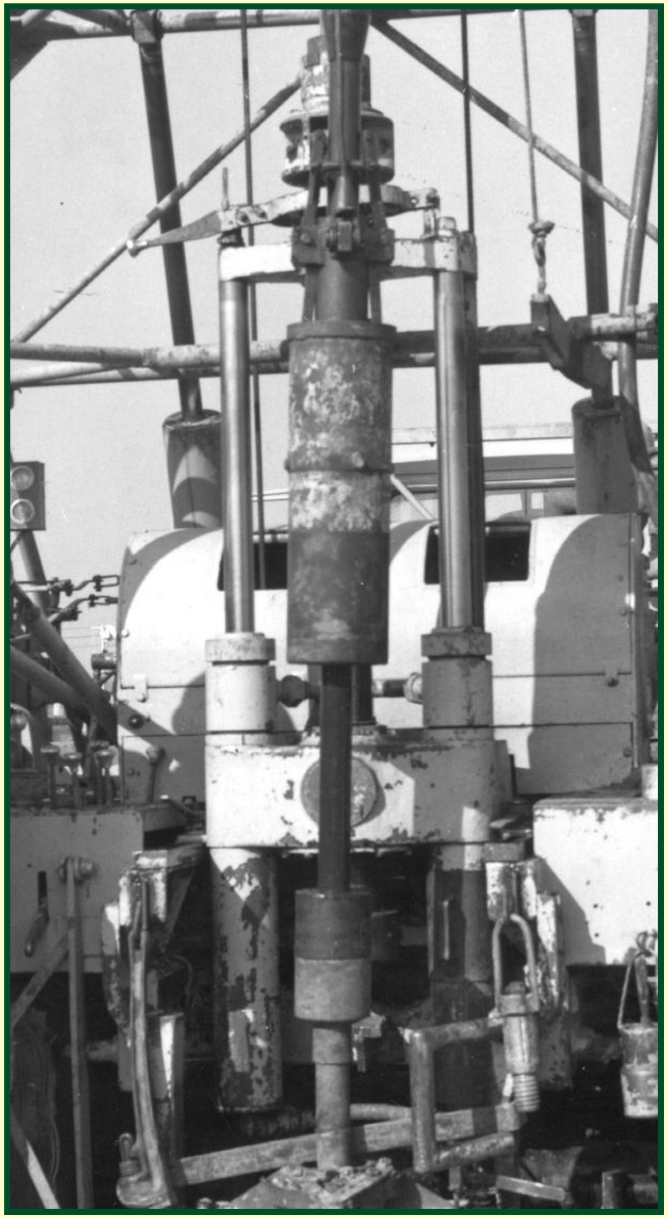
Texas Cone Penetrometer

- 3” diameter hardened steel cone
- 60 degree point



Drilling and Sampling

Texas Cone Penetrometer



DRIVING FORCE

- 170 Pound hammer, 24” drop
- 6” penetration or 50 blows, and repeat

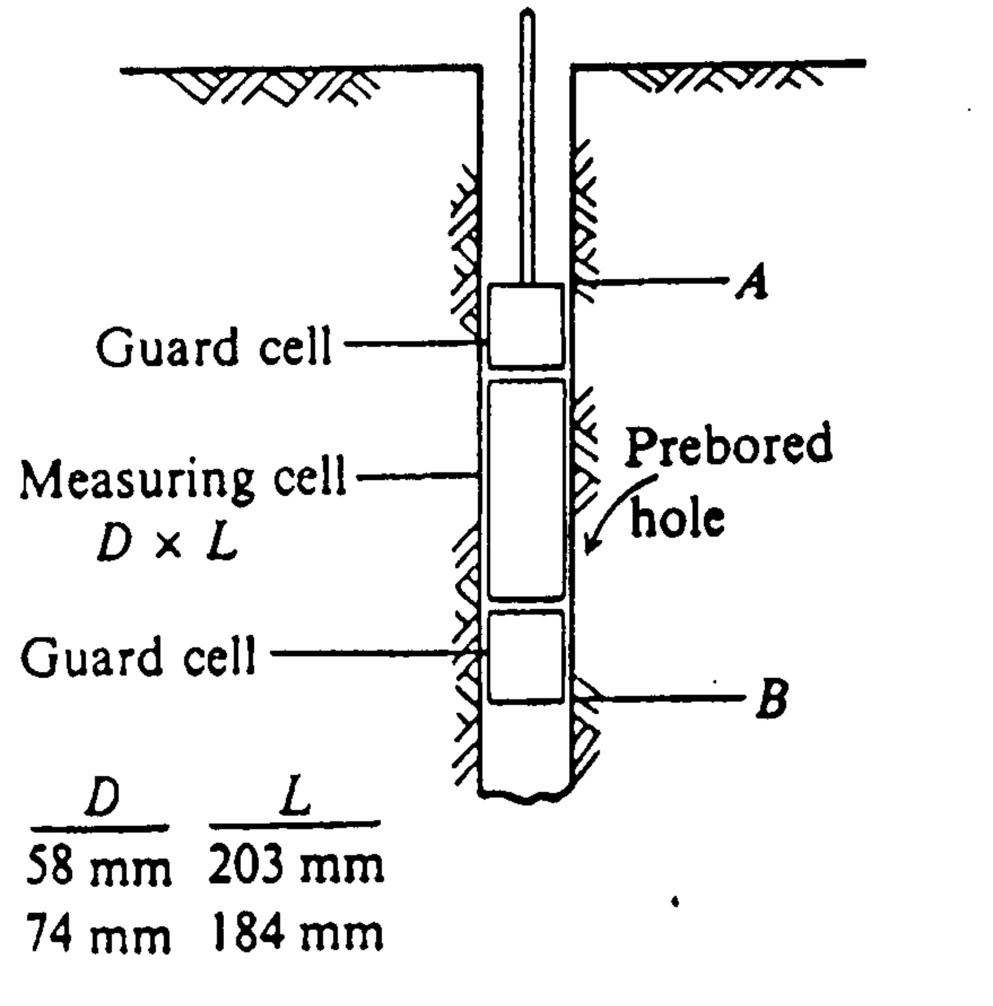
Drilling and Sampling

Texas Cone Penetrometer

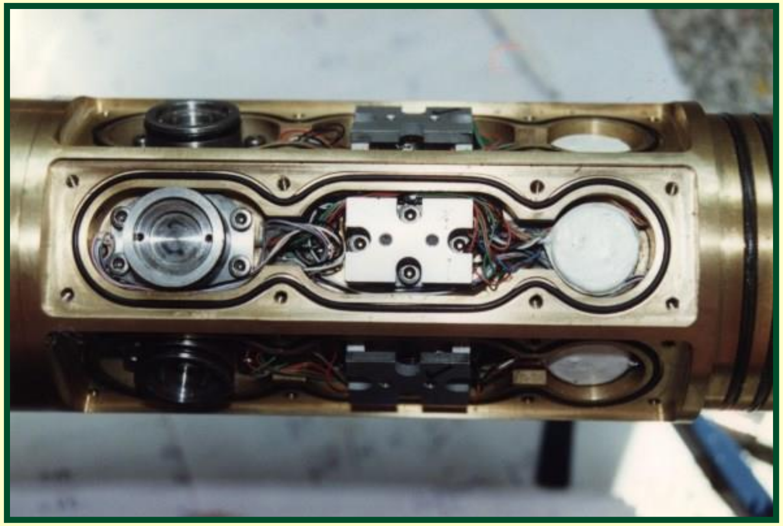
PROCEDURE

- Seat penetrometer cone
- Make reference marks
- Drive cone 12 inches into soft materials or 100 blows into hard materials

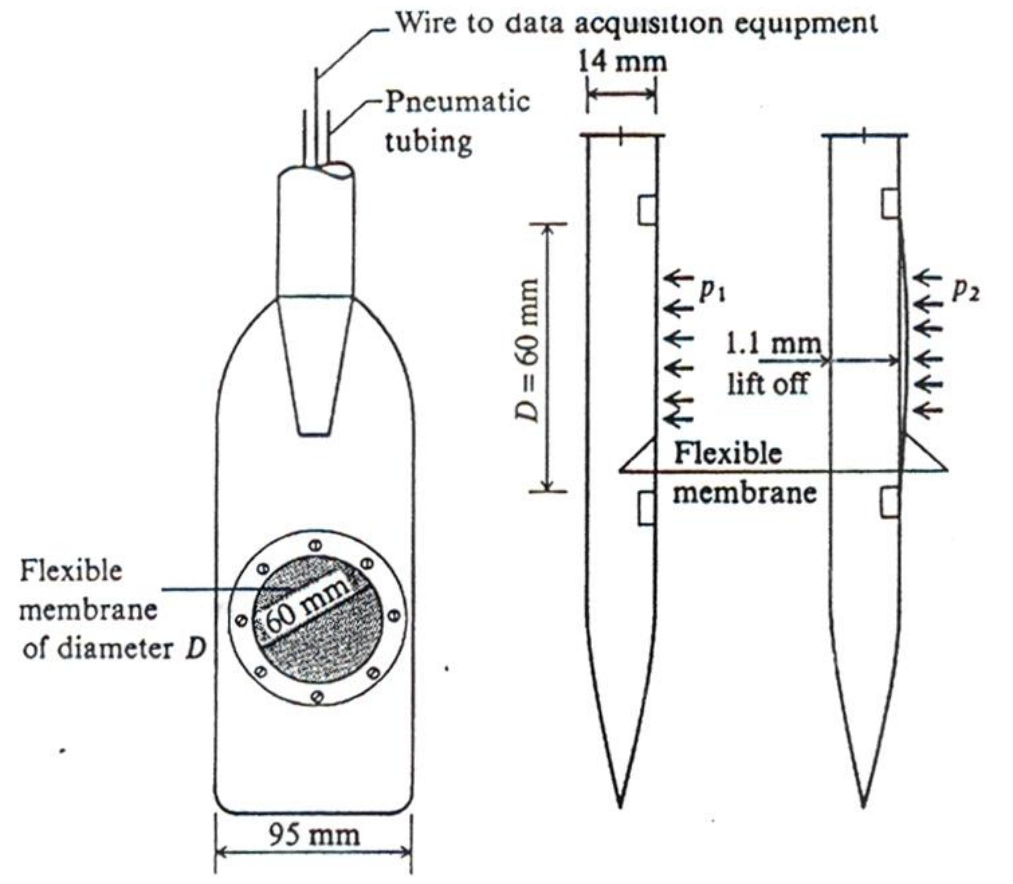
Pressuremeter



Pressuremeter Test

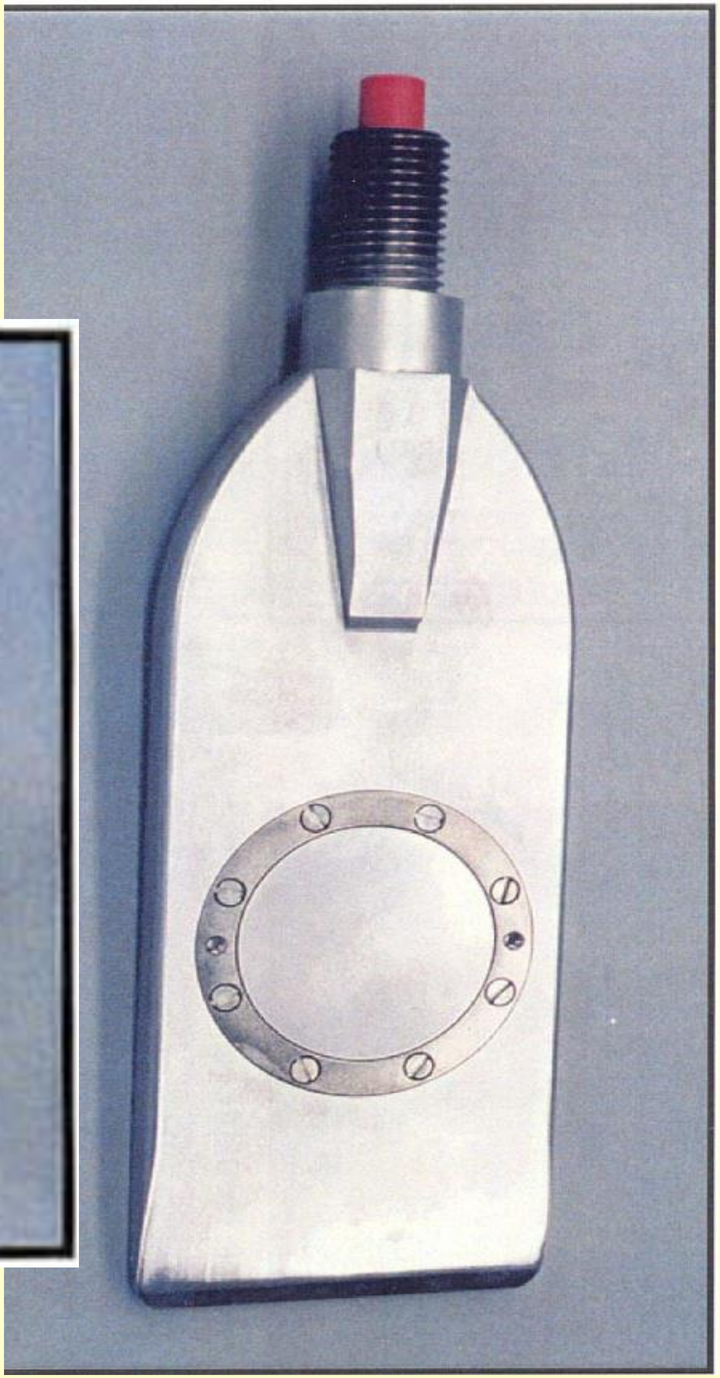


Flat Plate Dilatometer



(a) Marchetti dilatometer [*After Marchetti* (*1980*)].

Flat Plate Dilatometer



Comparison of In-Situ Test Methods

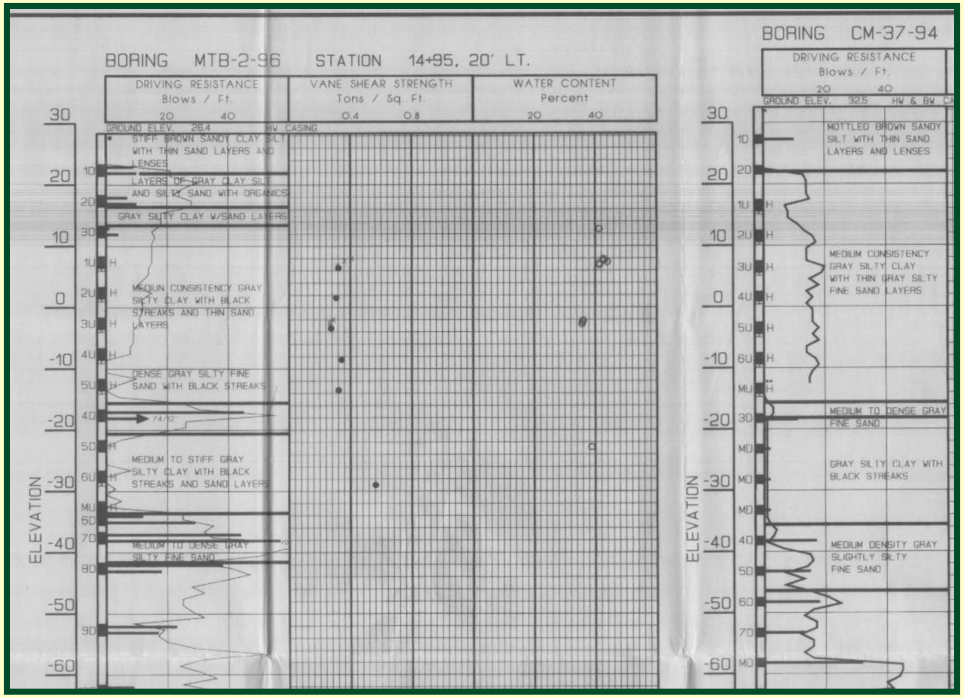
- Table 3.5
- Simplicity & ruggedness
- Ease of Testing
- Resolution
- Basis for Interpretation
- Types of Soils
- Equipment Availability
- Potential for Future Development

TABLE 3.5 ASSESSMENT OF IN-SITU TEST METHODS (Adapted from Mitchell, 1978; used with permission of ASCE)

	Standard Penetration Test	Cone Penetration Test	Pressuremeter Test	Dilatometer Test	Becker Penetration Test
Simplicity and Durability of Apparatus	Simple; rugged	Complex; rugged	Complex; delicate	Complex; moderately rugged	Simple, rugged
Ease of Testing	Easy	Easy	Complex	Easy	Easy
Continuous Profile or Point Values	Point	Continuous	Point	Point	Continuous
Basis for Interpretation	Empirical	Empirical; theory	Empirical; theory	Empirical; theory	Empirical
Suitable Soils	All except gravels	All except gravels	All	All except gravels	Sands through boulders
Equipment Availability and Use in Practice	Universally available: used routinely	Generally available; used routinely	Difficult to locate; used on special projects	Difficult to locate; used on special projects	Difficult to locate; used on special projects
Potential for Future Development	Limited	Great	Great	Great	Uncertain

Reliability & Validity of Field Penetration Test Data

- Do you KNOW you have <u>reliable</u> results?
- Do you KNOW you have <u>ANY</u> results?
- Correlations with other test methods



Ex Situ vs. In Situ Testing

<u>Ex-Situ (Laboratory) Tests</u>

- *ex-situ* -- “out of its original place”
- Laboratory testing is the <u>most common</u> method for measuring soil and rock properties
- Numerous examples...

- Moisture content
- Unit weight
- Sieve analysis
- Atterberg limits
- Compaction
- Hydraulic conductivity
- Consolidation
- Direct shear
- Triaxial shear
- Unconfined compression

Ex-Situ (Laboratory) Tests

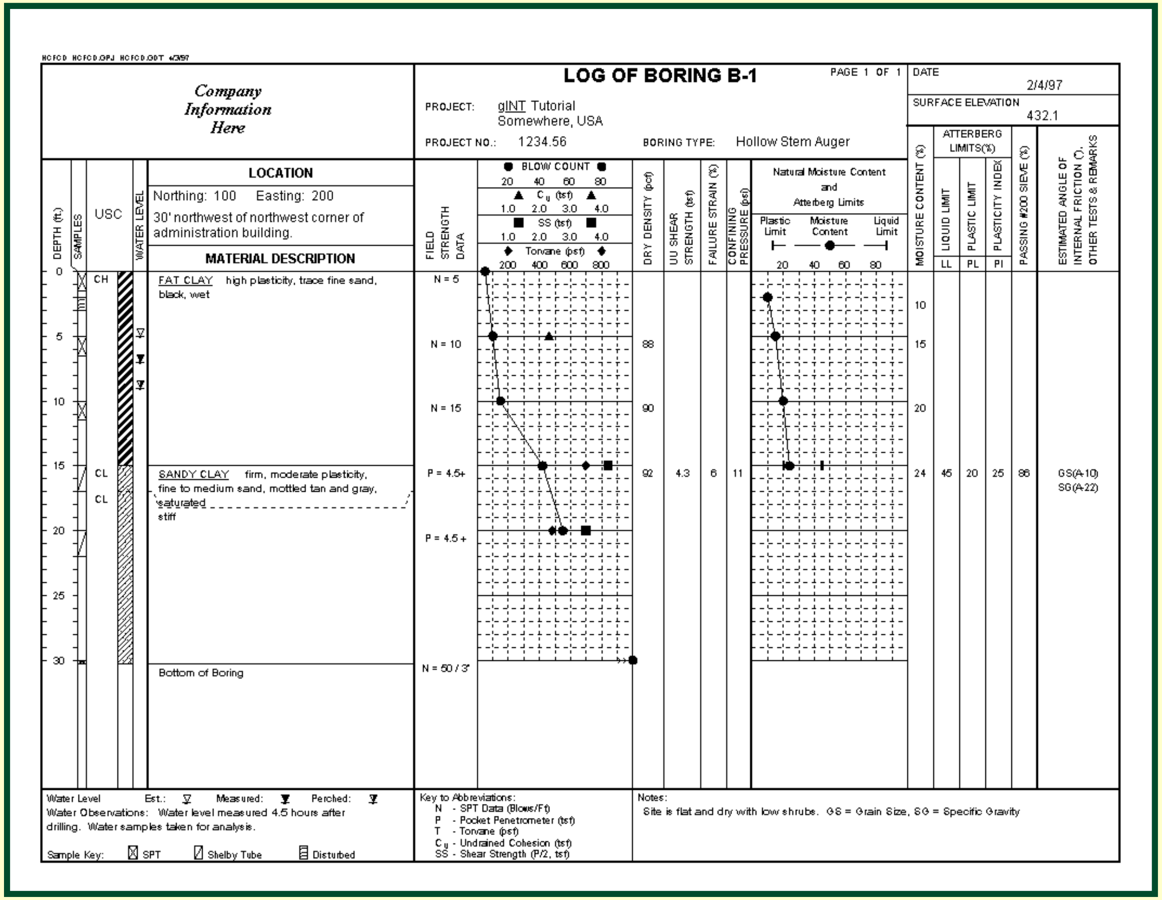
Ex-Situ (Laboratory) Tests

Data Presentation

Data Presentation

Scope of Information

- Log of Boring
  - Soil Test Boring Records
  - Test Pit Records
- Data Included
  - Field
  - Laboratory
- Software Based Programs



HCFCD HCFCD.GPJ HCFCD.GDT 4/3/97

Company Information Here

LOG OF BORING B-1

PAGE 1 OF 1

DATE 2/4/97

SURFACE ELEVATION 432.1

PROJECT: gINT Tutorial
Somewhere, USA

PROJECT NO.: 1234.56

BORING TYPE: Hollow Stem Auger

LOCATION

Northing: 100 Easting: 200

30' northwest of northwest corner of administration building.

MATERIAL DESCRIPTION

DEPTH (ft.)	USC	MATERIAL DESCRIPTION	FIELD STRENGTH DATA	DRY DENSITY (pcf)	UU SHEAR STRENGTH (tsf)	FAILURE STRAIN (%)	CONFINING PRESSURE (psi)	MOISTURE CONTENT (%)	LIQUID LIMIT (LL)	PLASTIC LIMIT (PL)	PLASTICITY INDEX (PI)	PASSING #200 SIEVE (%)	ESTIMATED ANGLE OF INTERNAL FRICTION (ϕ), OTHER TESTS & REMARKS
0	CH	FAT CLAY high plasticity, trace fine sand, black, wet	N = 5					10					
5			N = 10	88				15					
10			N = 15	90				20					
15	CL	SANDY CLAY firm, moderate plasticity, fine to medium sand, mottled tan and gray, saturated	P = 4.5+	92	4.3	6	11	24	45	20	25	86	GS(A-10) SG(A-22)
	CL	stiff											
20			P = 4.5+										
30		Bottom of Boring	N = 50 / 3"										

BLOW COUNT: 20 40 60 80; C_u (tsf): 1.0 2.0 3.0 4.0; SS (tsf): 1.0 2.0 3.0 4.0; Torvane (psf): 200 400 600 800

Natural Moisture Content and Atterberg Limits: Plastic Limit, Moisture Content, Liquid Limit; 20 40 60 80

ATTERBERG LIMITS(%)

Water Level Est.: ∇ Measured: ▼ Perched: ▼
Water Observations: Water level measured 4.5 hours after drilling. Water samples taken for analysis.

Sample Key: SPT, Shelby Tube, Disturbed

Key to Abbreviations:
N - SPT Data (Blows/Ft)
P - Pocket Penetrometer (tsf)
T - Torvane (psf)
C_u - Undrained Cohesion (tsf)
SS - Shear Strength (P/2, tsf)

Notes:
Site is flat and dry with low shrubs. GS = Grain Size, SG = Specific Gravity

Log of Boring

Required Information

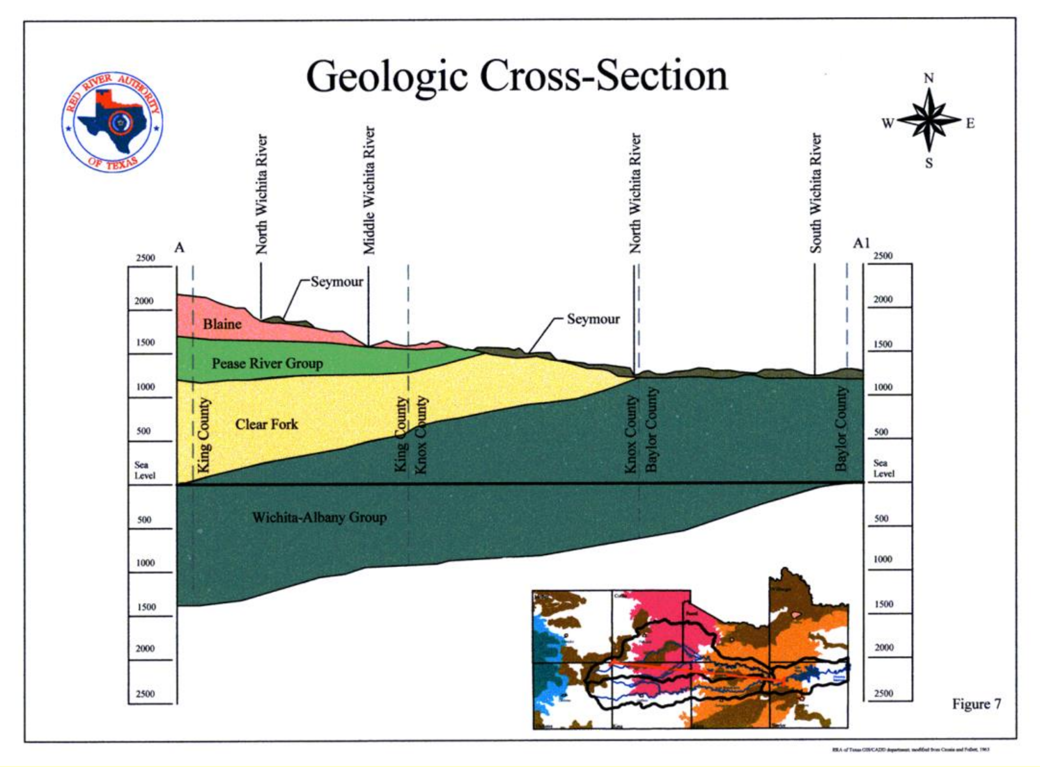
- Drilling & Sampling Depths & Methods
- Field Test Data
- Drilling Notes
- Soil appearance, stratification
- "A complete record…"
- Pass/Fail

"If it's not written down, it didn't happen..."

Data Presentation

Cross Sections

- Source is soil boring logs
- Yields a 2D or 3D rendering of the subsurface
  - Interpolation
  - Extrapolation
  - Guesswork
- Helps visualize the subsurface



Philosophy of Exploration

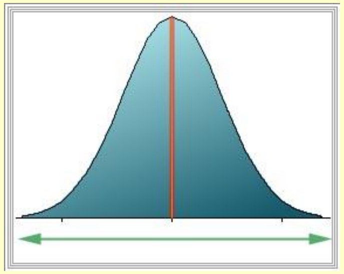
Philosophy of Exploration

The Blind Men and the Elephant

John Godfrey Saxe

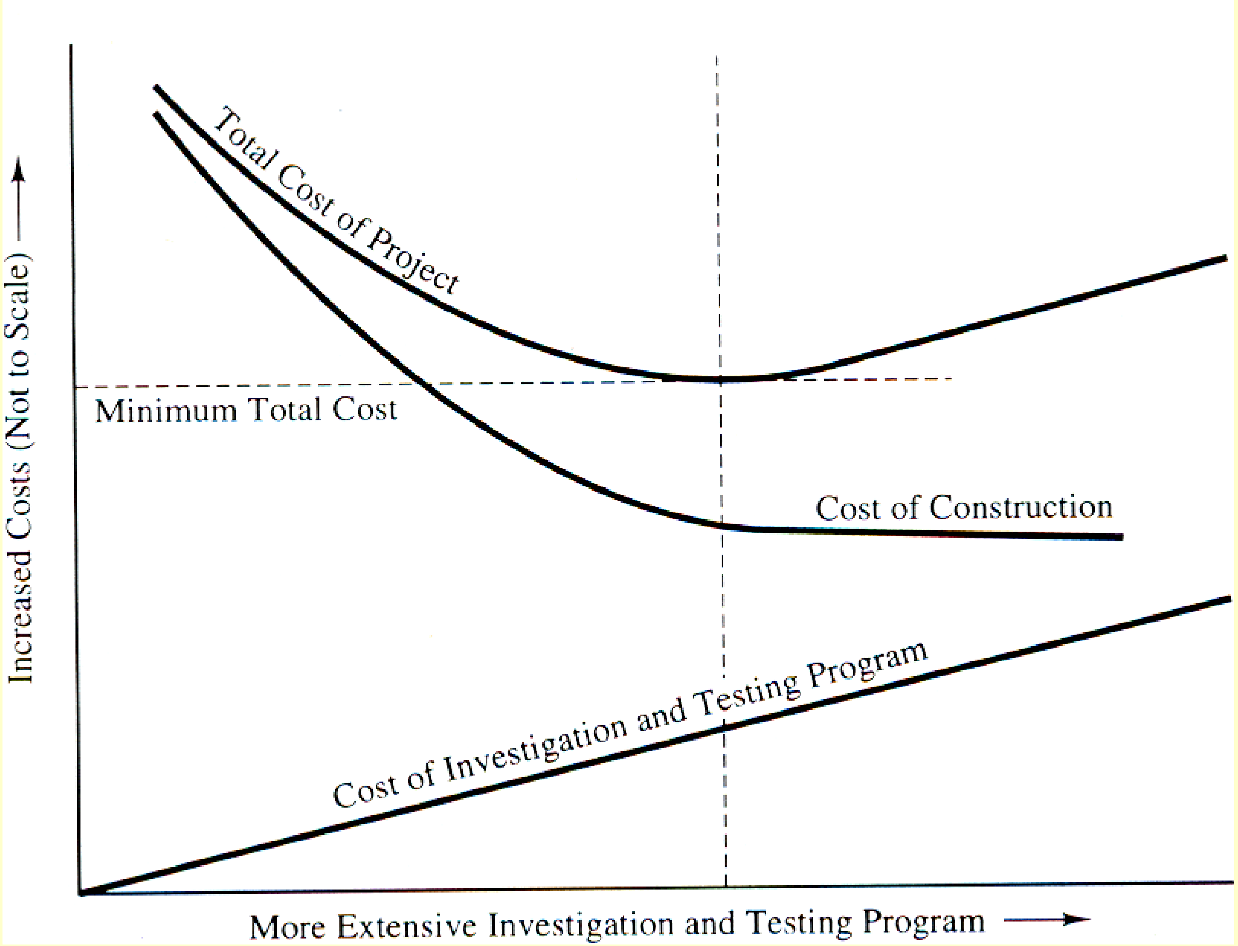
(1816-1887)

Uncertainty vs. Risk



- More often than not, you develop your exploration ***not*** to find out the subsurface conditions of the site, but to validate and refine your assumptions of what you believe are the likely subsurface conditions at the site.
- The exploration becomes an exercise in reducing uncertainty / risk.
- "Much, you do not know."

Economics


Total Cost of Project
Minimum Total Cost
Cost of Construction
Cost of Investigation and Testing Program
Increased Costs (Not to Scale)
More Extensive Investigation and Testing Program

Balancing Cost & Risk

"The [scope of a subsurface exploration] for any particular site is a difficult problem which is closely linked with the relative cost of the investigation and the project for which it is undertaken."

VNS Murthy: ***Geotechnical Engineering: Principles and Practices of Soil Mechanics and Foundation Engineering***