humboldtmfg.com

Geomechanics

LECTURE 8

IN-SITU GEOTECHNICAL TESTING

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Laboratory of soil mechanics – Fall 2025

Access the QUIZ

https://etc.ch/uVAL

Geomechanics
General Course overview

Semester →
Topics ↓

Basic concepts

Classical constitutive framework

- Elasticity - Linear & Non-linear
- Plasticity Perfect-plasticity
- Hardening elasto-plasticity
- Critical state concept
- Modified Cam-Clay

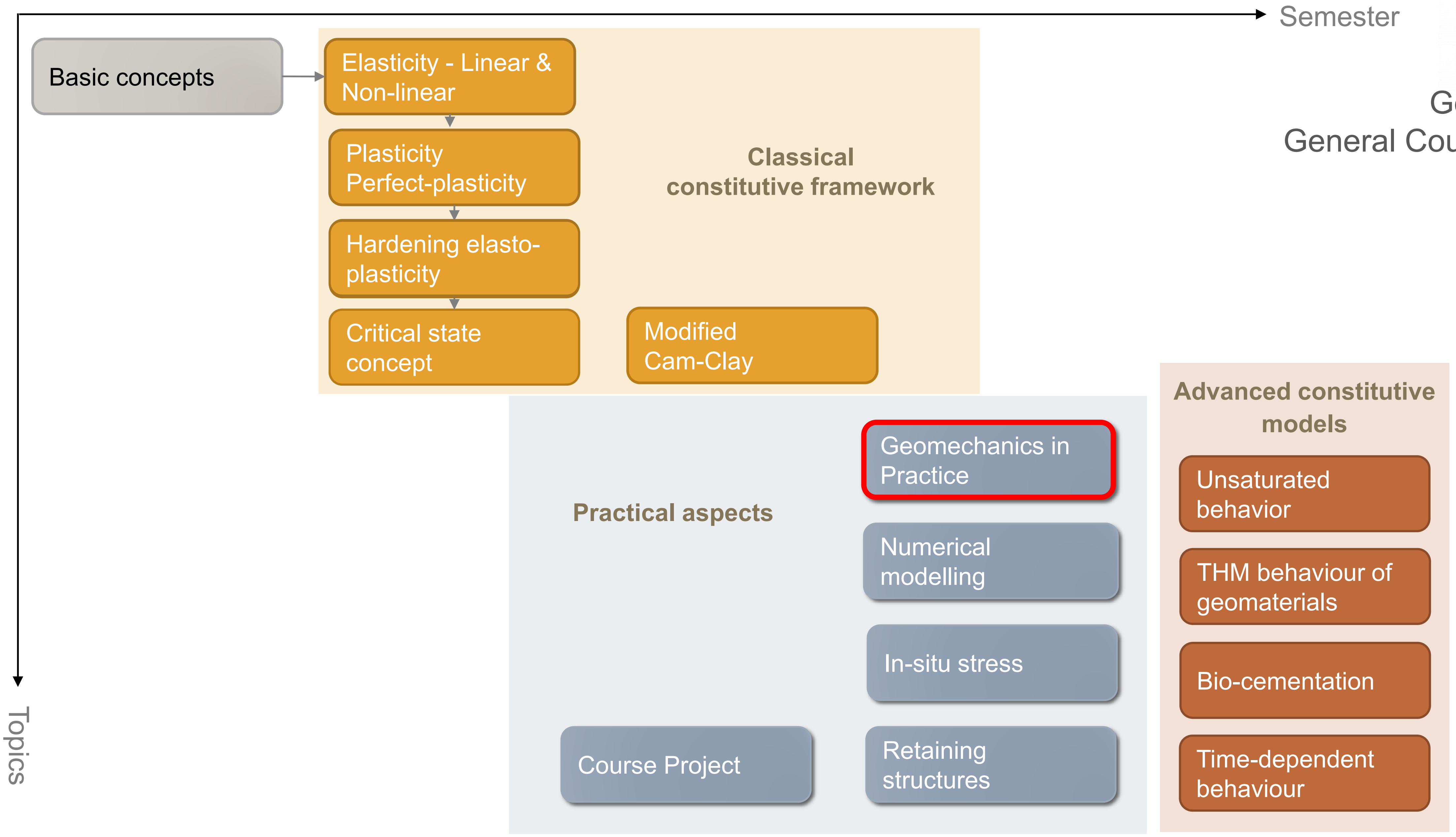
Practical aspects

- Geomechanics in Practice
- Numerical modelling
- In-situ stress
- Retaining structures
- Course Project

Advanced constitutive models

- Unsaturated behavior
- THM behaviour of geomaterials
- Bio-cementation
- Time-dependent behaviour

Geomechanics
General Course overview



In-situ measurements: Pros & Cons

i. Potentially **improved efficiency and cost effectiveness** compared to sampling and laboratory testing,

ii. **More representative data** due to larger volume of tested material and larger amount of data,

iii. **Avoiding some difficulties of laboratory testing** like sample disturbance and initial condition simulation,

iv. Possibility of testing some soils in which **undisturbed sampling** is not easily possible,

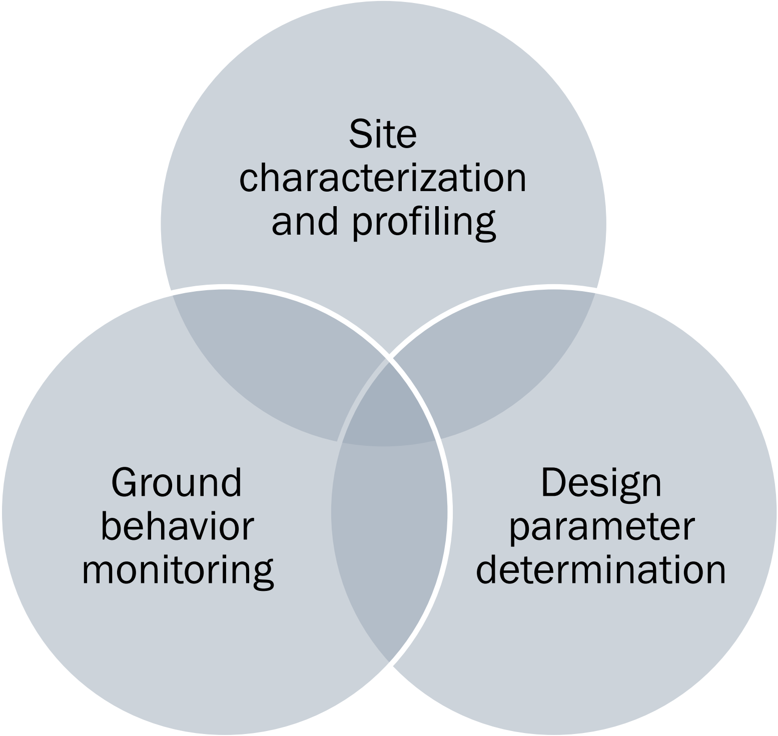
v. Evaluation of **both vertical and lateral variability**

vi. Stress/strain state and initial conditions are not precisely known.

In-situ measurements: Testing and monitoring

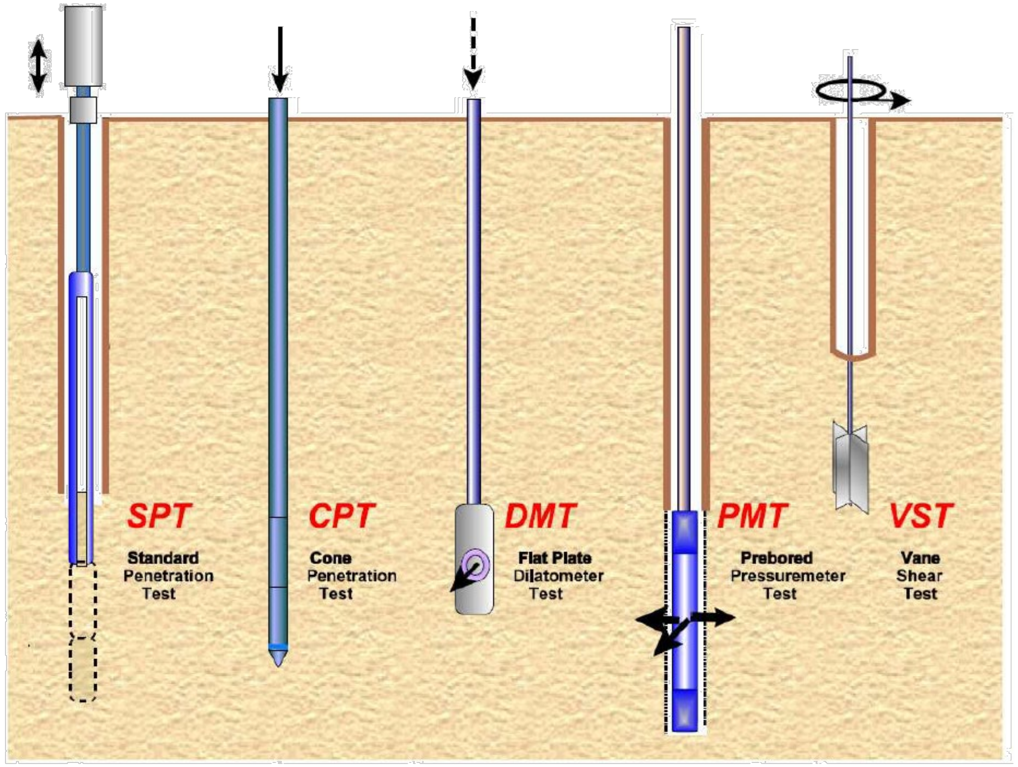
- **In-situ testing** to measure geotechnical parameters
  - Stress state
  - Strength
  - Stiffness
  - Permeability
  - etc

- **In-situ monitoring** to measure ground behavior
  - Settlement
  - Lateral movements
  - Forces and displacements
  - Total and effective stress
  - Pore water pressure
  - etc



In-situ Testing methods (among others)

• SPT	Standard penetration test	Strength
• CPT	Cone penetration test	
• CPTu	Piezocone	
• DCPT	Dynamic penetrometer	
• VST	Vane shear test	
• PMT	Ménard pressuremeter	Stiffness
• SBP	Self-boring pressuremeter	
• DMT	Flat dilatometer test	
• PP	Plate loading test	
• LFT	Lefranc test	Permeability
• LUG	Lugeon test	
• PUMP	Pumping tests	



Mayne et al., 2002

Theoretical basis and interpretation framework

i. **Empirical interpretation:** No fundamental theoretical analysis is possible due to uncontrolled condition of loading, drainage and stress state. The interpretation is largely based on empiricism from observation of prior behavior (e.g. SPT, CPT)

ii. **Semi-empirical solutions:** Some analytical relationship can be established between the geotechnical parameters and measurements; however, empirical relations are also used to simplify the variation of in-situ condition such as stress and strain variation (e.g. vane shear test)

iii. **Sound theoretical solutions:** Material parameters are defined in terms of constitutive models and sound theoretical solutions (e.g. self-boring pressuremeter)

Typical testing methods

- SPT, CPT, VANE TEST
- SELF-BORING PRESSUREMETER

Standard penetration test (SPT)

i. Empiric interpretation

Objectives:

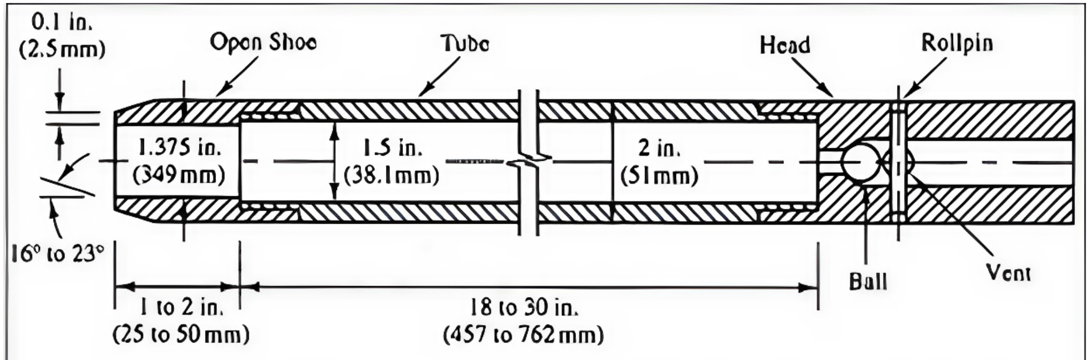
- Measure soil resistance to dynamic penetration and obtain disturbed soil samples
- Assess the in-situ relative density of sands

Concept & procedure:

- Dropping a falling weight onto the drill rods from a predefined height

Results:

- N: number of blows for each step of 15 cm



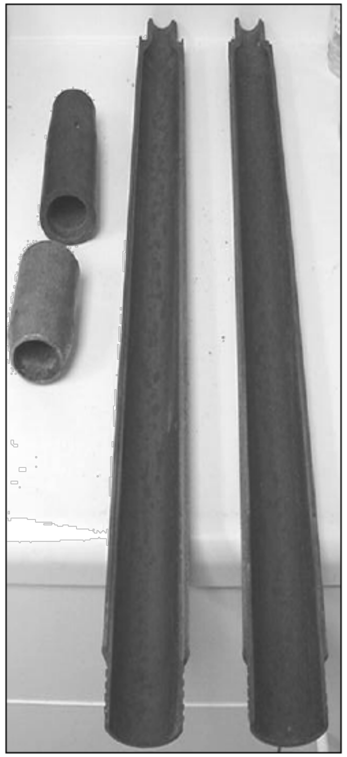
The SPT sampler (Adapted from ASTM D1586; Copyright ASTM, used with permission)

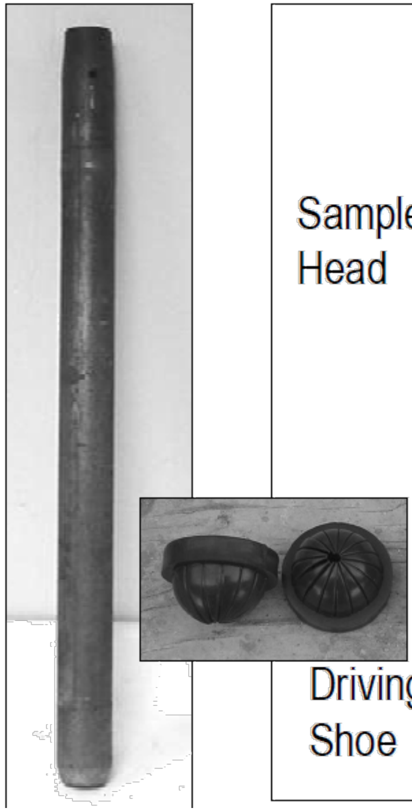
Standard penetration test (SPT)

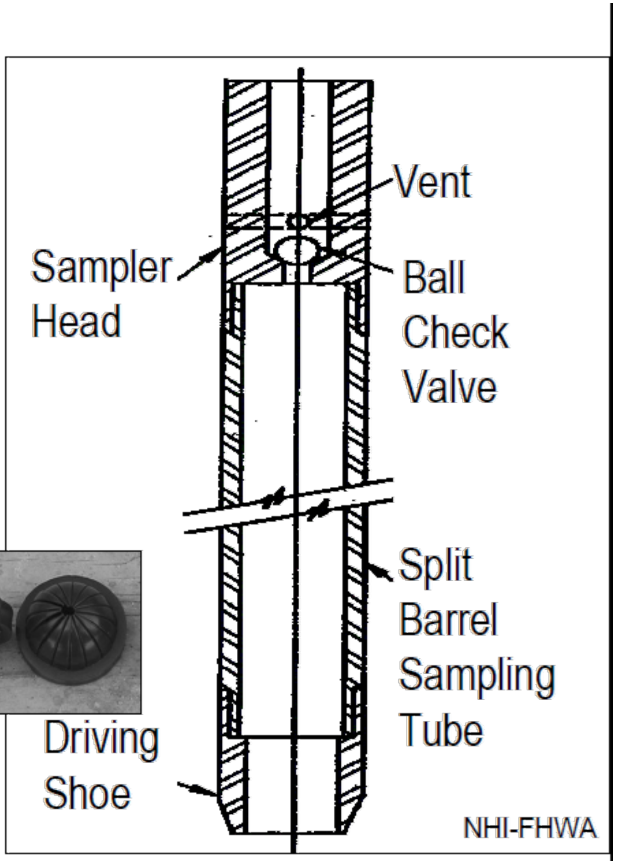
Standard penetration test

i. Empiric interpretation

Split-Spoon Sampler







www.youtube.com

Standard penetration test (SPT)

i. Empiric interpretation

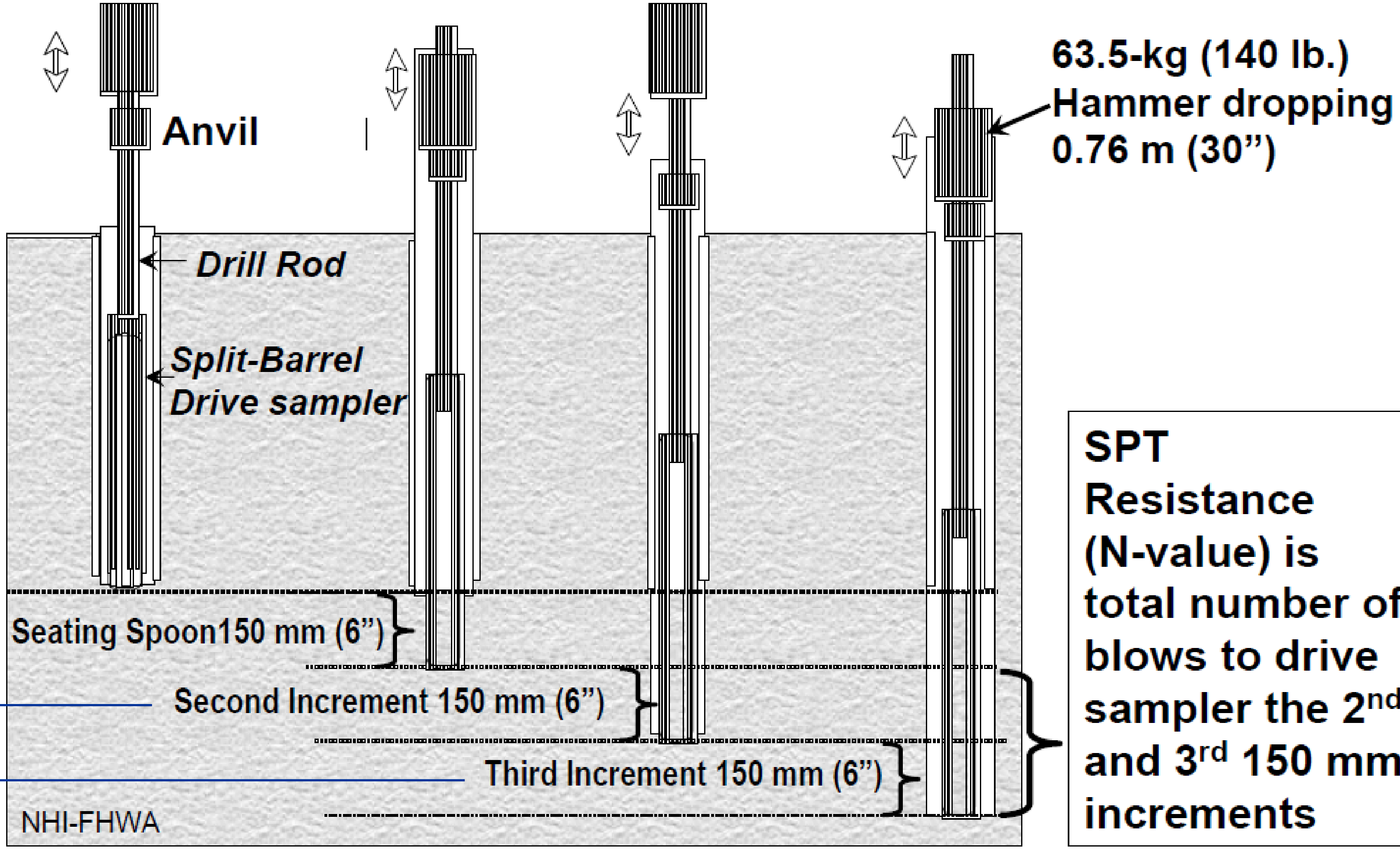
N: Number of blows/30 cm

$$N_{SPT} = N_2 + N_3$$

N_1

N_2

N_3

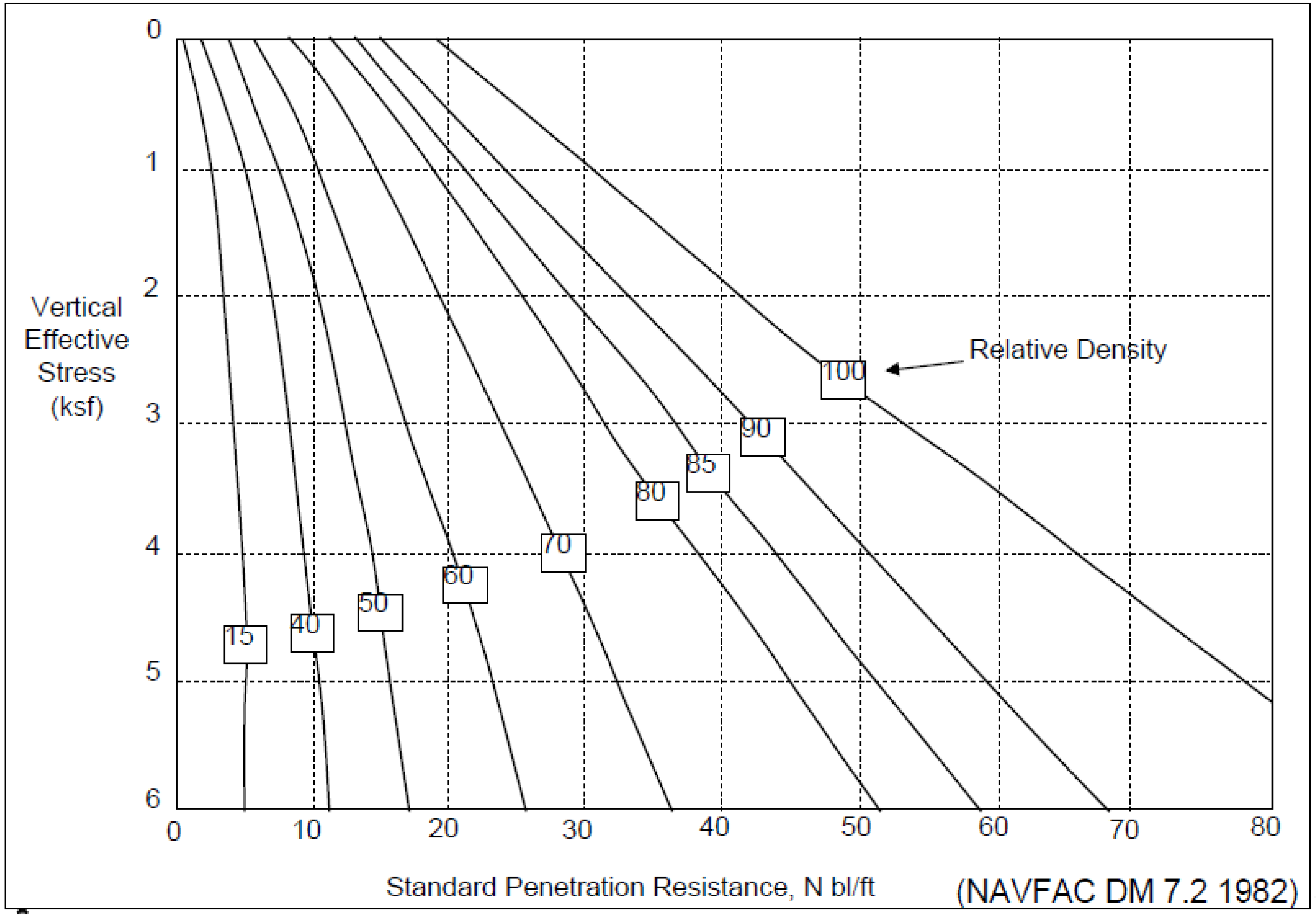


SPT Resistance (N-value) is total number of blows to drive sampler the 2nd and 3rd 150 mm increments

Standard penetration test (SPT)

i. Empiric interpretation

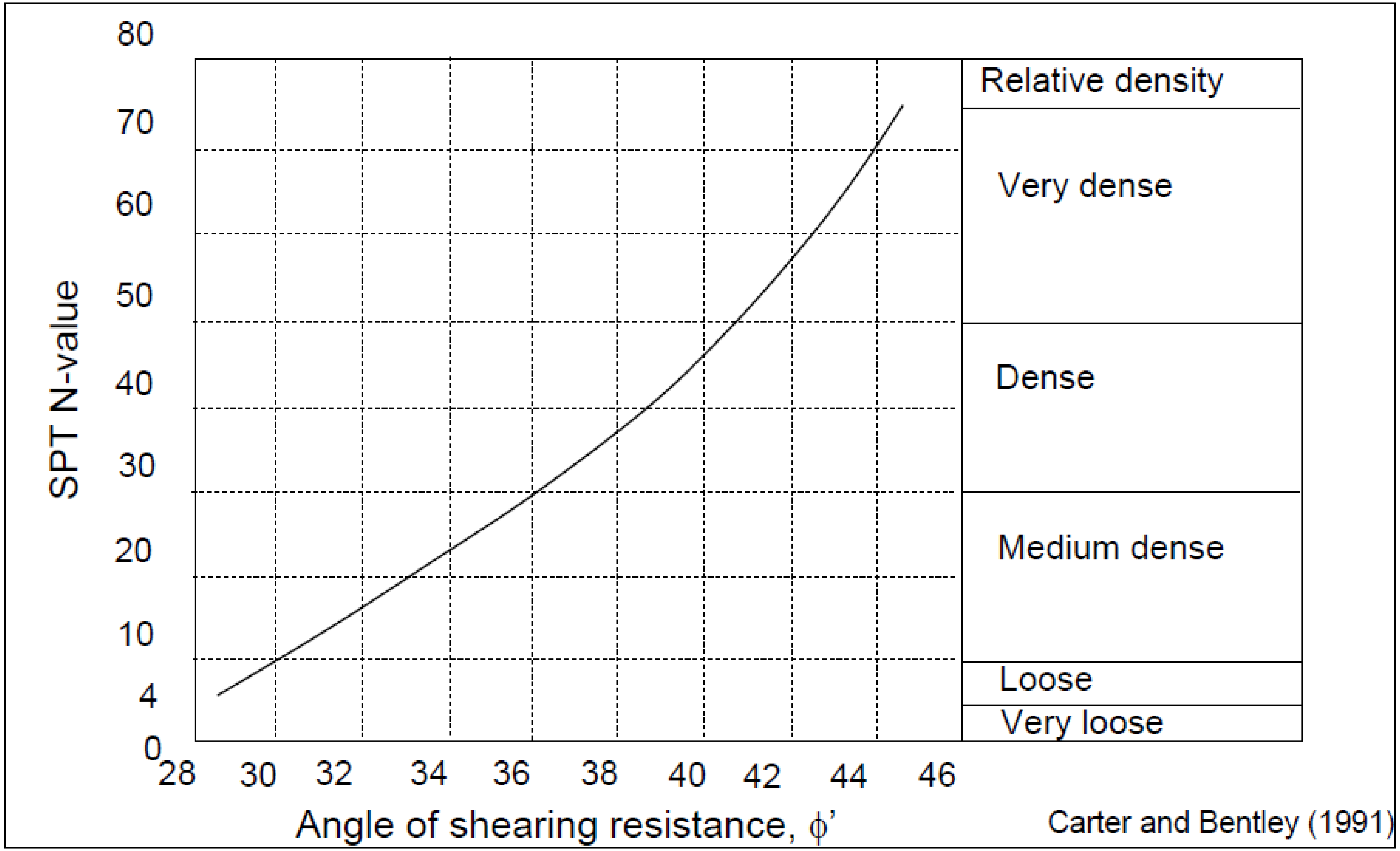
- Relative density D_R



Standard penetration test (SPT)

i. Empiric interpretation

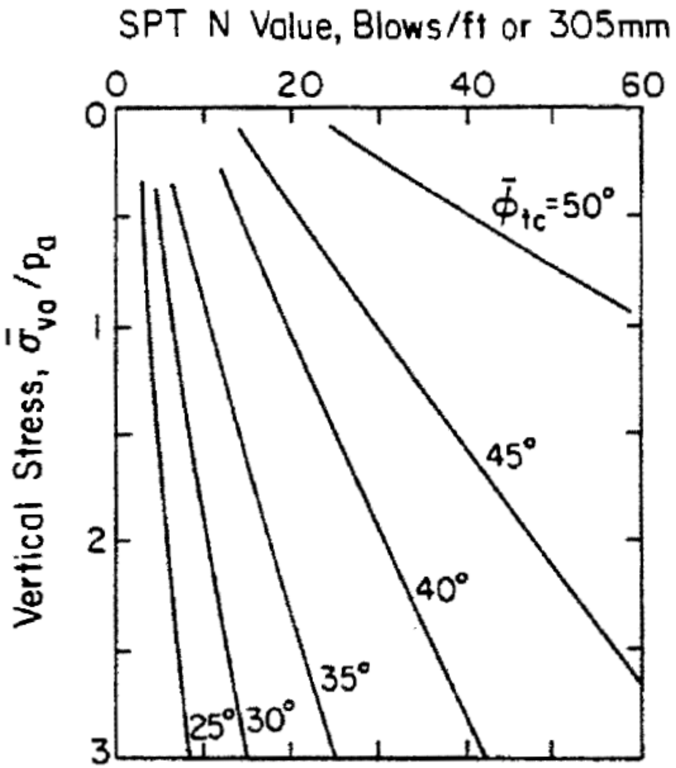
- Shear strength angle φ'



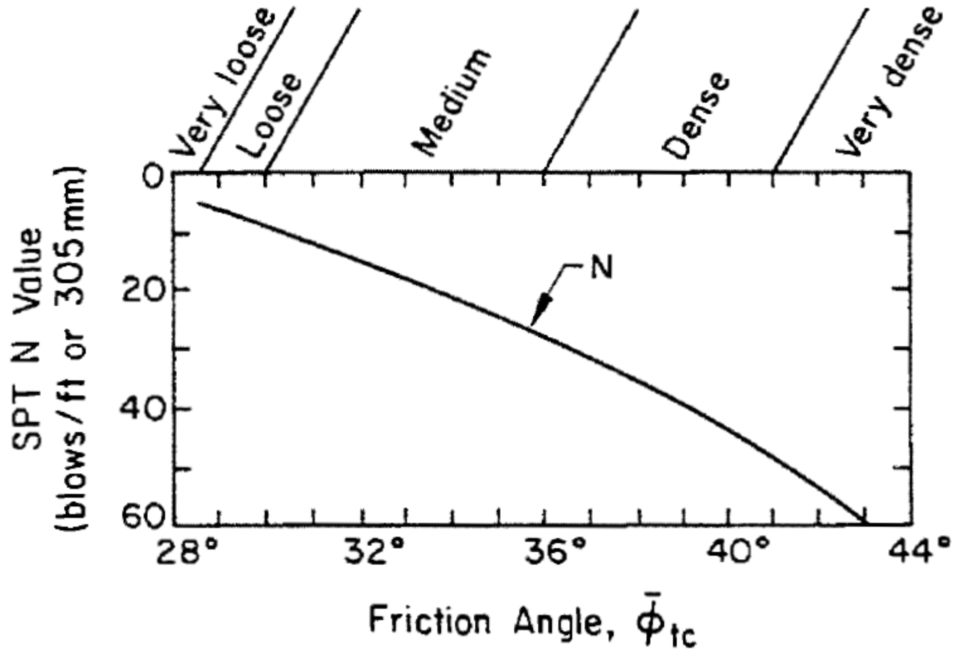
Standard penetration test (SPT)

i. Empiric interpretation

- Shear strength angle φ'



Schmertmann, 1975

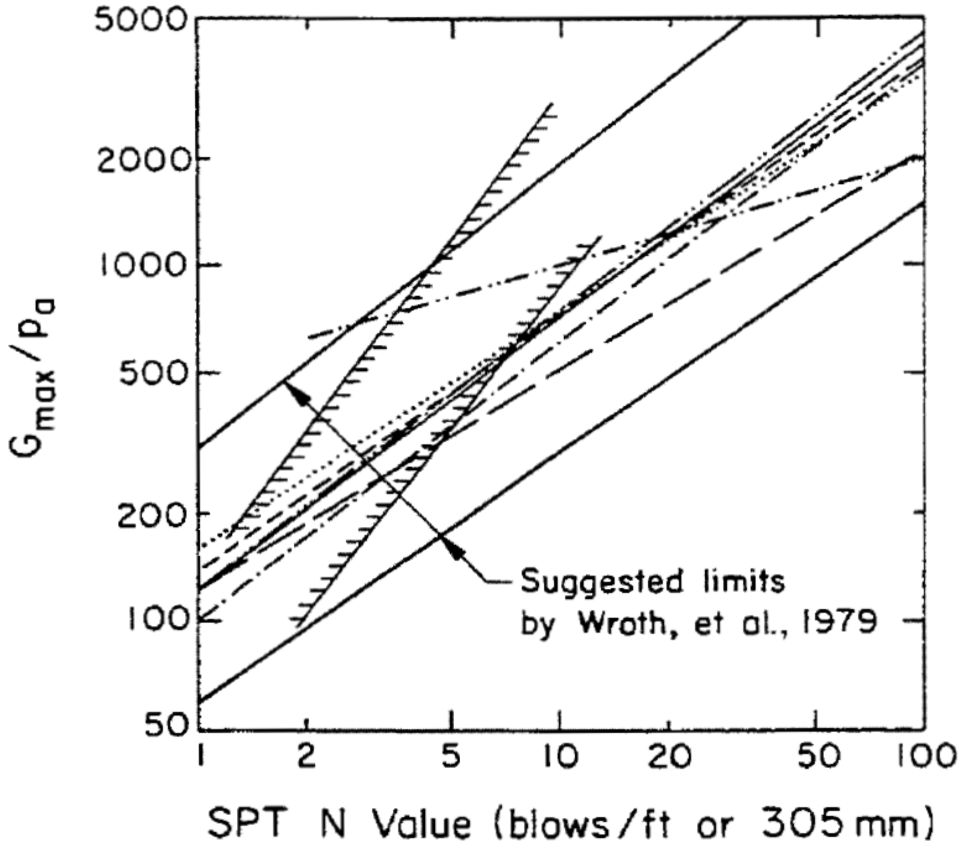


Peck, Hanson and Thornburn, 1974

Standard penetration test (SPT)

i. Empiric interpretation

- Shear modulus $G_{\max}$

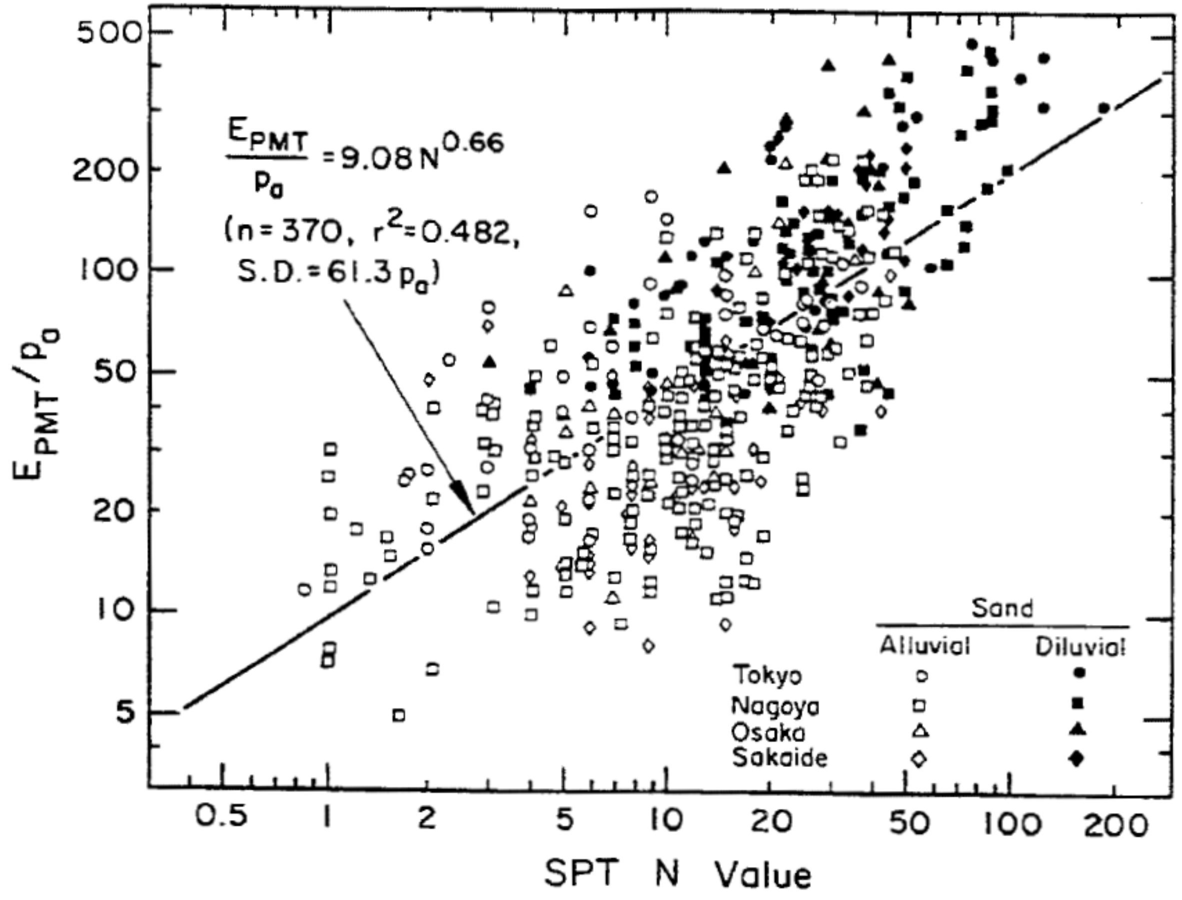


Wroth et al., 1979

Standard penetration test (SPT)

i. Empiric interpretation

- Pressuremeter modulus E_{PMT}



Ohya et al., 1982

Standard penetration test (SPT)

i. Empiric interpretation

Meyerhoff (1956)

State of Packing	Relative Density	Standard Penetration Resistance (N)	Static Cone Resistance (q_c)	Angle of Internal Friction (ϕ')
	Percent	Blows / ft	Tsf or kgf/cm^2	Degrees
Very Loose	< 20	< 4	< 20	< 30
Loose	20 – 40	4 –10	20 – 40	30 – 35
Compact	40 – 60	10 –30	40 – 120	35 – 40
Dense	60 – 80	30 – 50	120 – 200	40 – 45
Very Dense	> 80	> 50	> 200	> 45

Standard penetration test (SPT)

i. Empiric interpretation

- Undrained shear strength

Soil Consistency	SPT N	S_u (psf)	S_u (kPa)
Very Soft	< 4	< 250	< 12
Soft	2 – 4	250 – 500	12 – 25
Medium	4 - 8	500 – 1000	25 – 50
Stiff	8 – 15	1000 – 2000	50 – 100
Very Stiff	15 – 30	2000 – 4000	100 – 200
Hard	> 30	> 4000	> 200

Terzaghi et al. (1996)

Cone penetration test (CPT)

i. Empiric interpretation

Objectives: to estimate the geotechnical engineering properties of soils and subsurface stratigraphy.

Concept & procedure:

- pushing the cone into the ground at a standard rate of 1 to 2 cm/s
- Keep the sleeve stationary and measure the tip resistance
- Penetrating cone and sleeve together and measure the total resistance

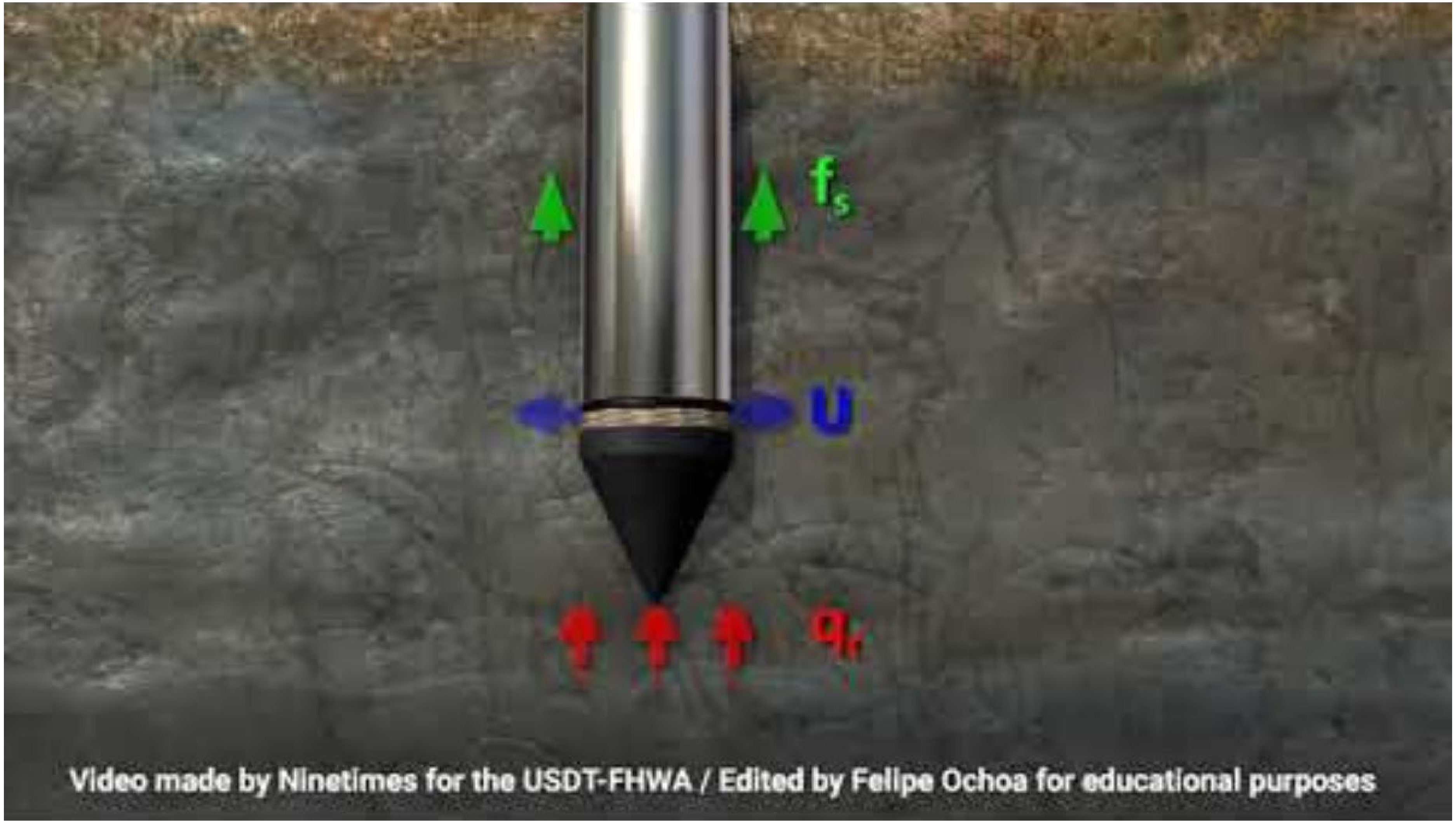
Results:

- Profile log of Tip and sleeve resistance, induced water pressure (CPTu) and eventually, shear wave velocity (SCPTu)
- Friction ratio: Ratio of the skin friction divided by tip resistance

Photo: Pagani Equipment

Photo: Geomil Equipment

Cone penetration test (CPT)



Cone Penetration Test

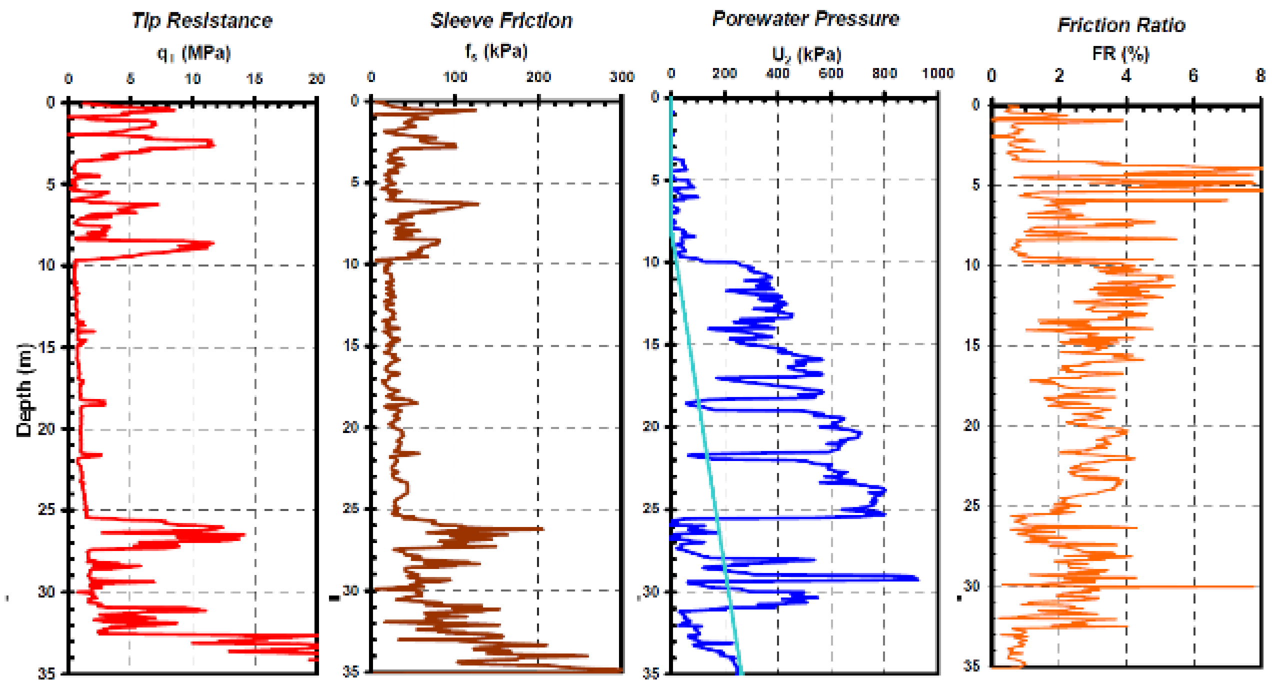
www.youtube.com

Cone penetration test (CPT)

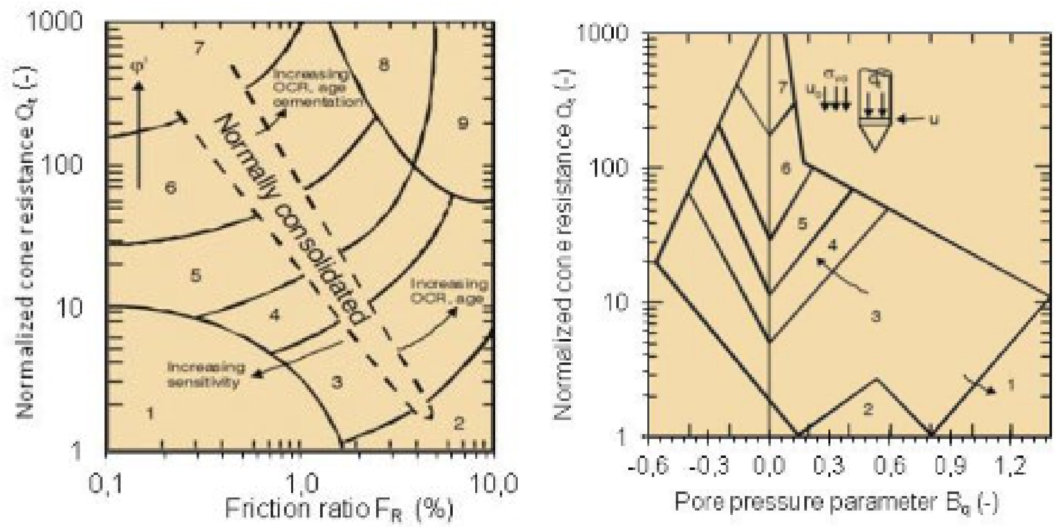
i. Empiric interpretation

EPFL

Measurements Results (CPTu)



Empirical interpretation charts



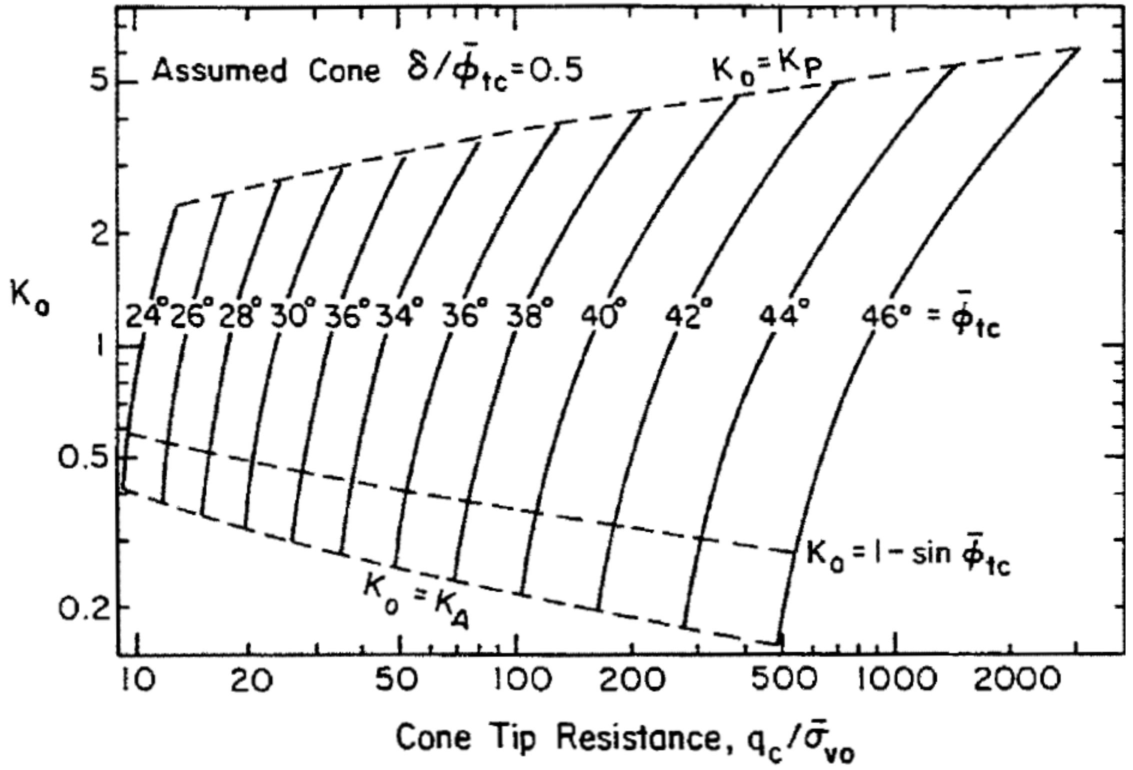
Soil classification Charts, Robertson 1990

Zone	Soil Behavior Type (SBT)				
1	Sensitive, fine grained	4	Silt mixtures - clayey silt to silty clay	7	Gravelly sand to dense sand
2	Organic soils - clay	5	Sand mixtures - silty sand to sandy silt	8	Very stiff sand to clayey sand *
3	Clay - silty clay to clay	6	Sands - clean sand to silty sand	9	Very stiff fine grained *

Cone penetration test (CPT)

i. Empiric interpretation

- At-rest earth pressure coefficient K_0

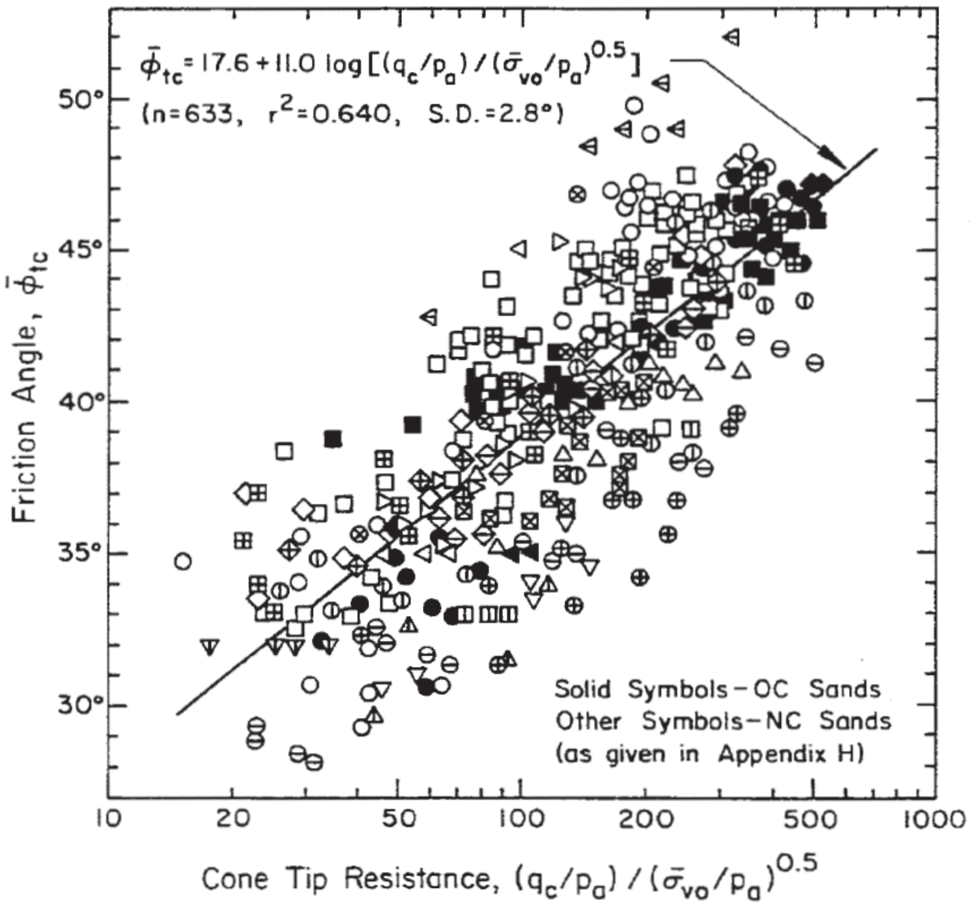


Marchetti, 1985

Cone penetration test (CPT)

i. Empiric interpretation

- Shear strength angle φ'



Mair and Wood, 1987

The vane shear test

Objectives: to estimate the undrained shear strength of fully saturated clays without disturbance.

Concept & procedure:

- Push into ground
- rotate at a slow rate 6-12° /min
- Measure the torque
- Continue until failure
- Measure the maximum torque
- Continue for remolded state

Photo: Controls Group

The vane shear test – Results and interpretation

Measured values

Torque = (1) + (2)

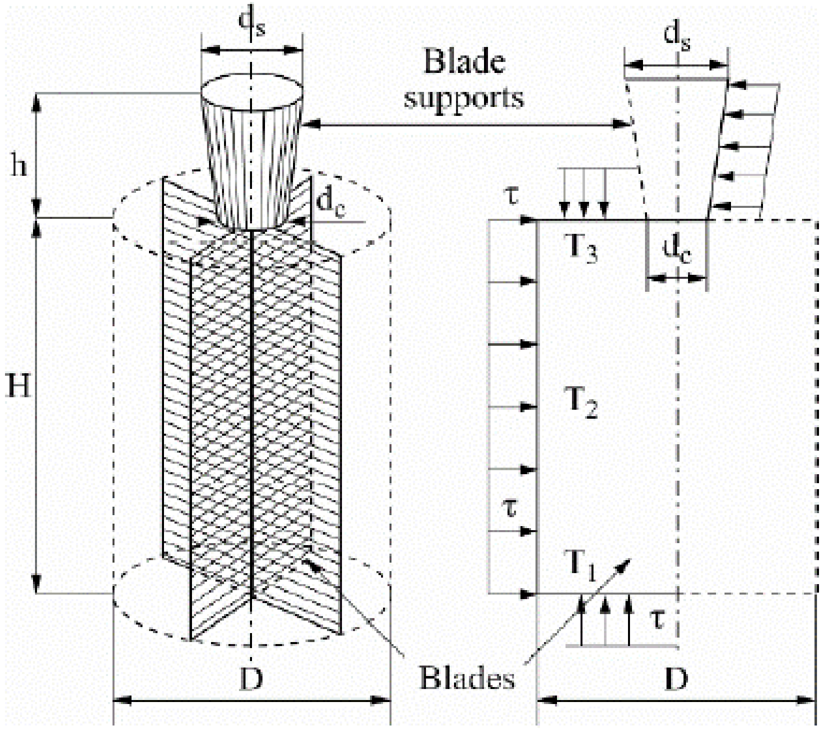
(1): moment of shear resistance force on the side of the cylindrical failure surface

(2): moment of shear resistance force at the two ends of the cylindrical failure surface

Interpretation

$C_u = T / [\pi d^2 (h/2 + d/6)]$

C_u	Undrained shear strength of the soil
T	Maximum torque at failure
h	height of the vane
d	diameter of the vane



Monnet 2015

Pressuremeter test

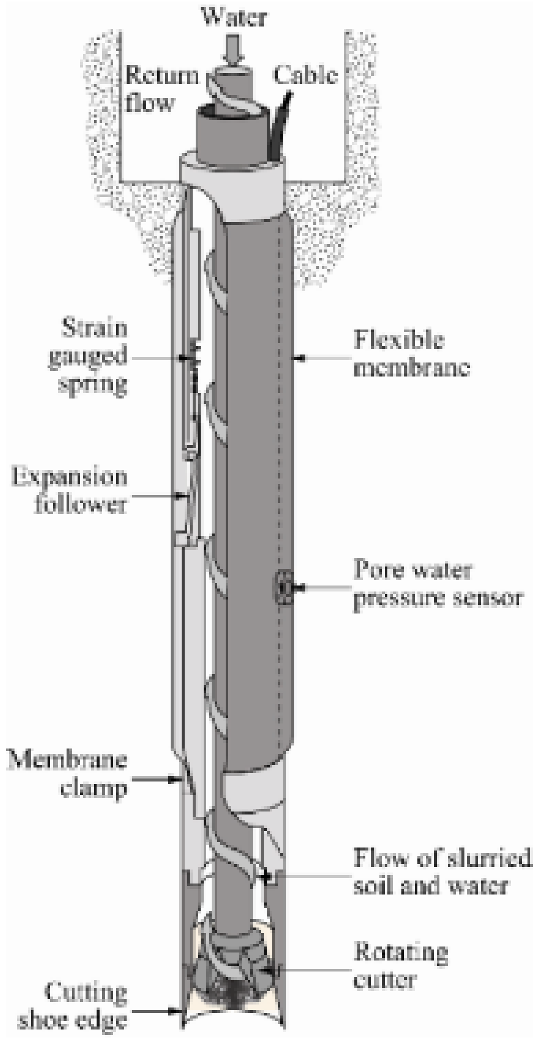
Objective: to determine the stress-strain relationship (strength and stiffness parameters)

Concept & procedure:

1. Inserting the probe into ground (or borehole)
2. Inflate the membrane
3. Keep pressure constant
4. Increase in volume measured
5. Continue for Loading-unloading

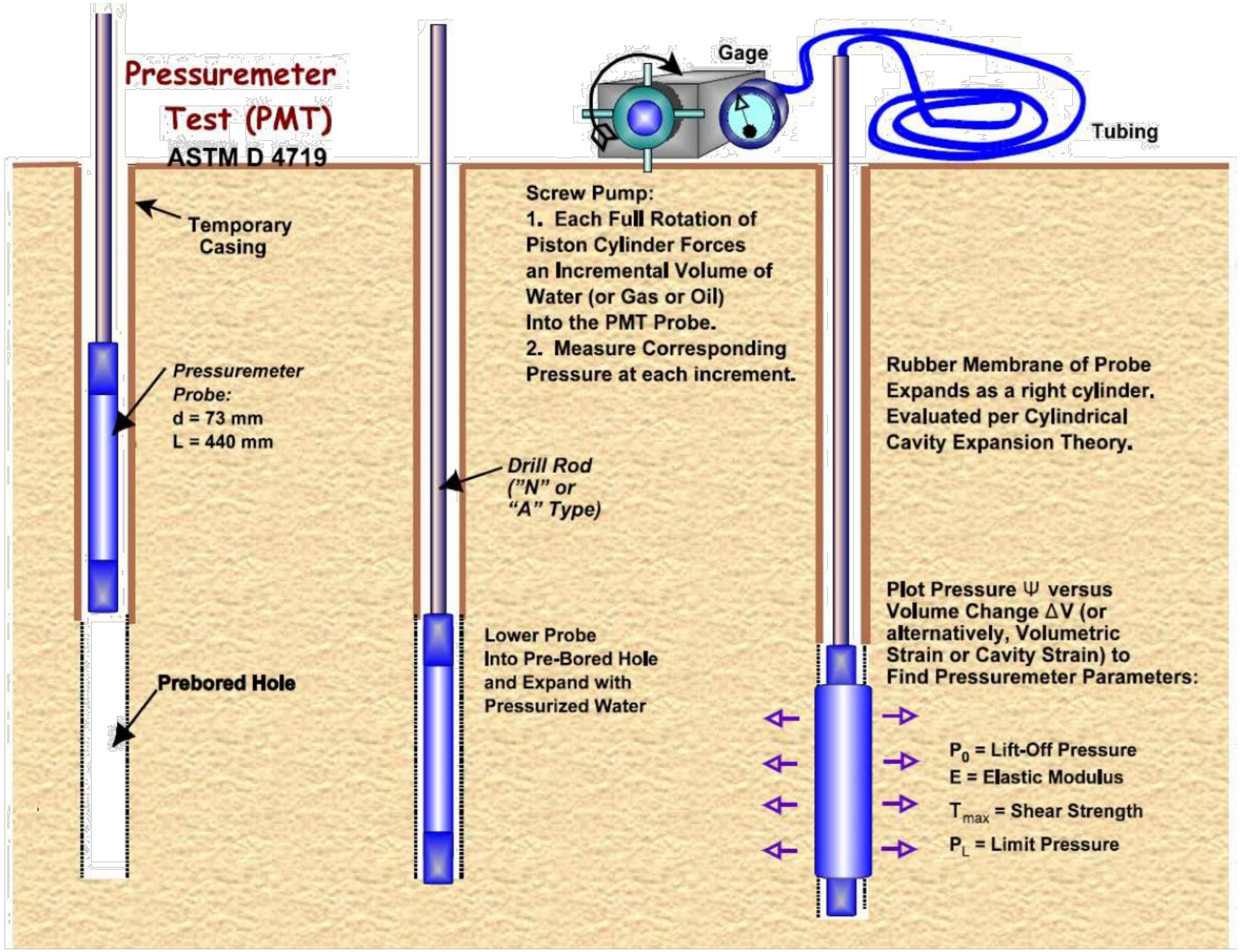
Different types of pressuremeter:

- Borehole (pre-bored) pressuremeter (Ménard)
- Self-boring pressuremeter
- Displacement (push) pressuremeter



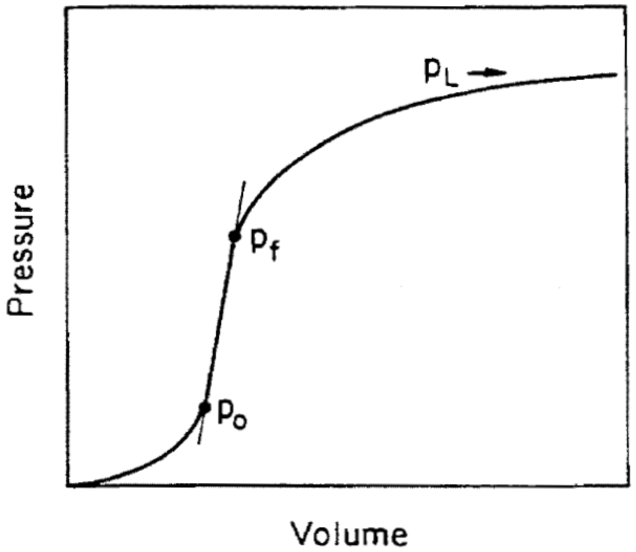
Monnet 2015 - Cambridge In-situ

Pressuremeter test



(Mayne et al., 2002)

Self-Boring pressuremeter



- p_0: recompression of disturbed soil is complete.
  Often assumed as the in-situ horizontal stress.

- p_f: inflation point corresponding to a yield pressure.
  Soil behaviour changes from pseudo-elastic to plastic.

- p_L: limit pressure after which the curve becomes asymptotic

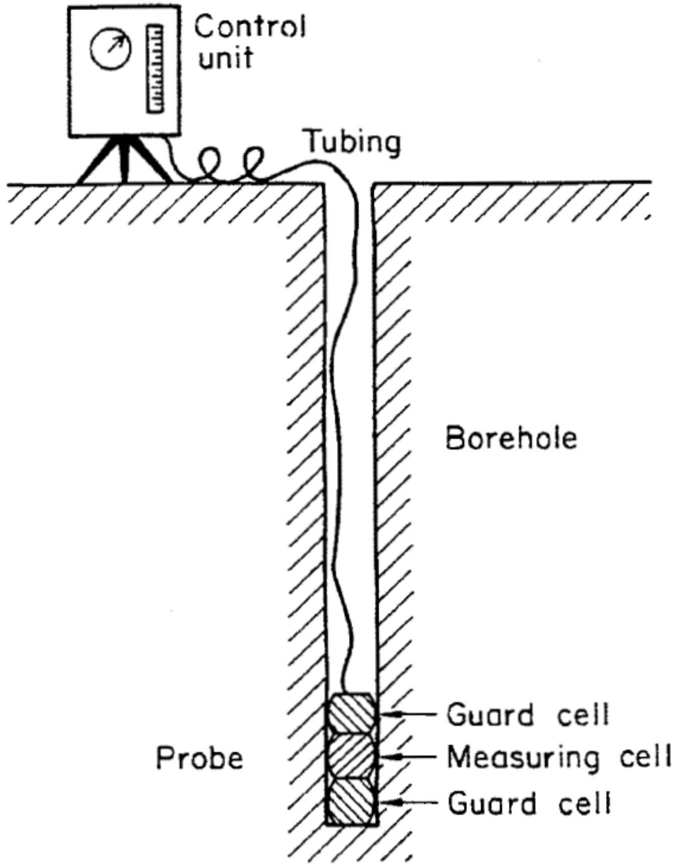


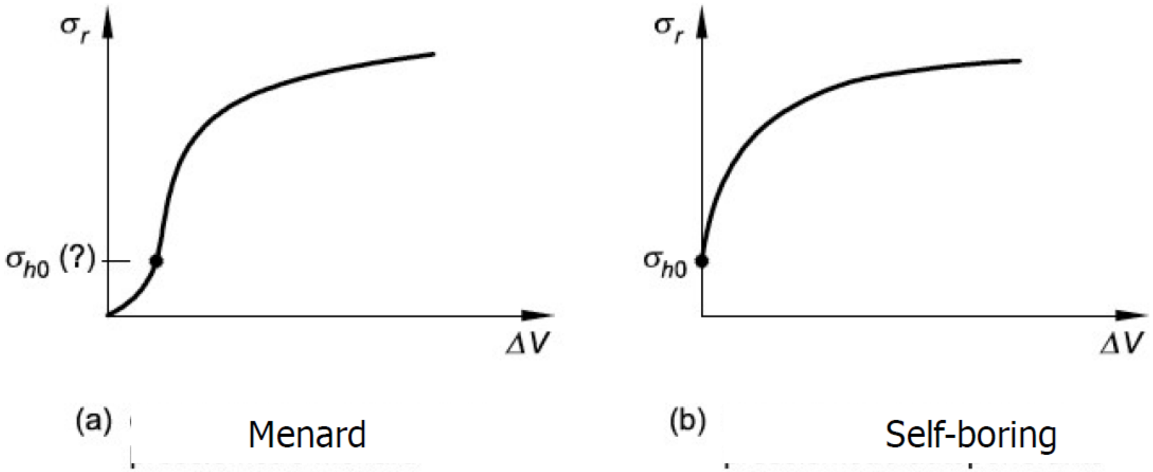
Figure C-1. Menard Pressuremeter Equipment

Baguelin et al., 1978

Self-Boring pressuremeter

iii. Theoretical interpretation

- Estimation of at rest earth pressure K_0
- Direct measurement of the effective horizontal stress (Self-boring pressuremeter)
- Lift-off pressure and Limit pressure evaluation
- Elastic modulus evaluation



Pressuremeter test

i. Empiric interpretation

- Shear strength angle φ'

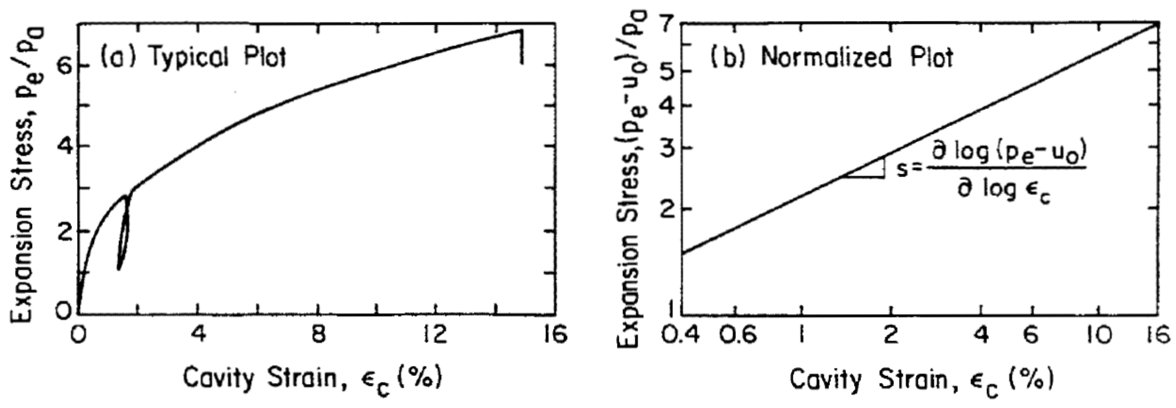
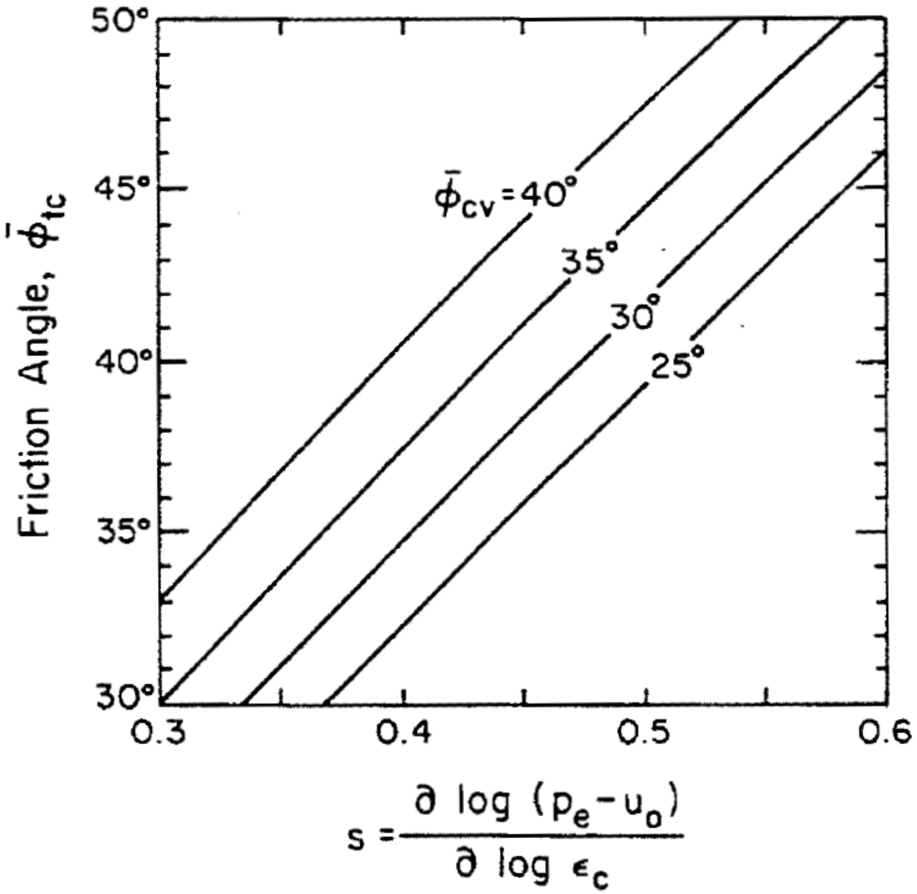


Figure 4-18. PMT Data Representations

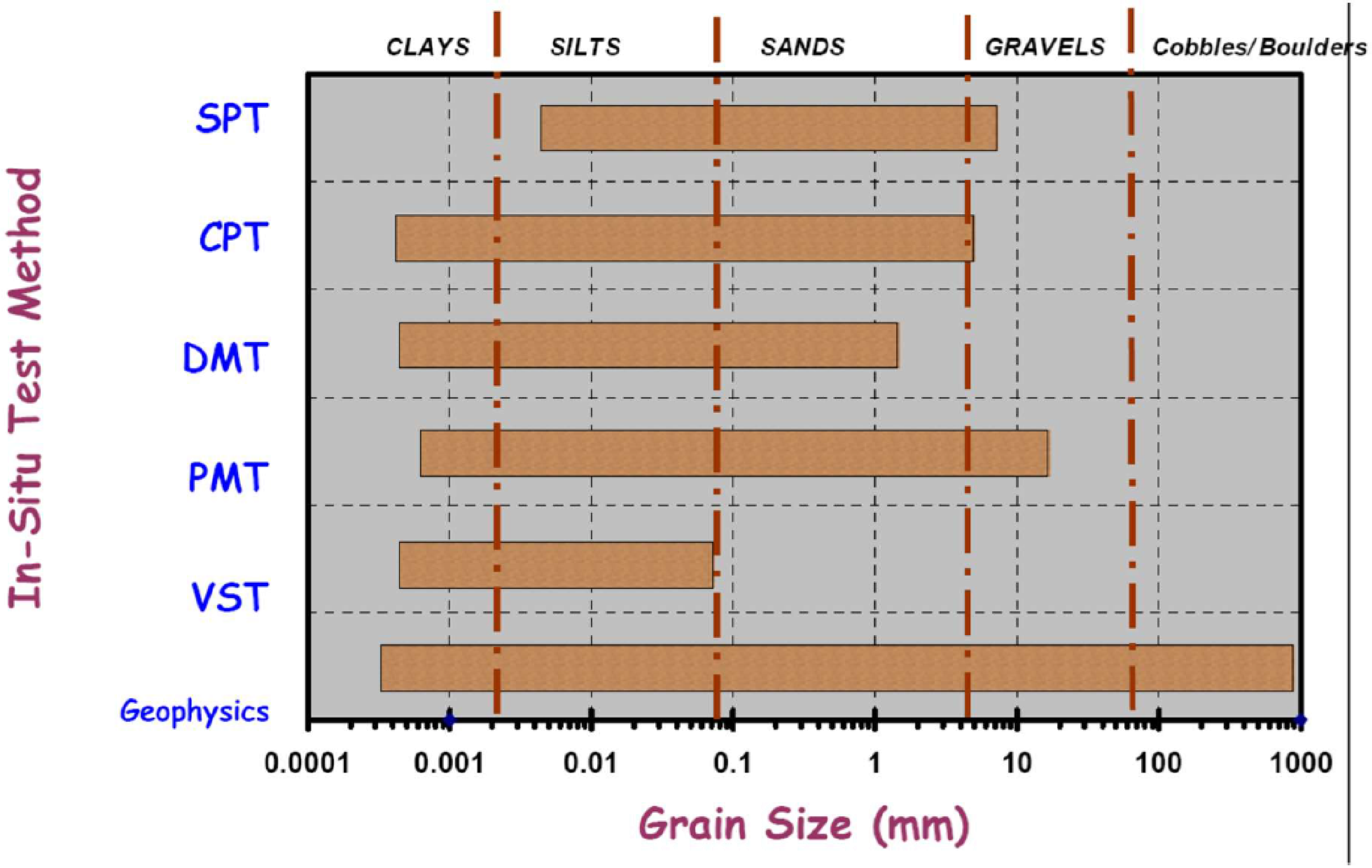
Mair and Wood, 1987



Mair and Wood, 1987

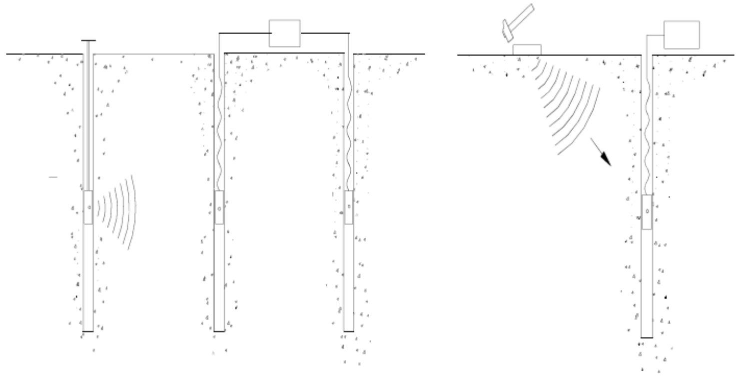
$\varphi'_{tc} = triaxial\ compression\ friction\ angle$
$\varphi'_{cv} = constant\ volume\ friction\ angle$

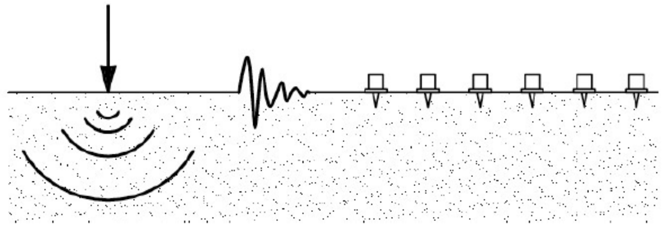
Applicability of in situ tests



(Mayne et al, 2002)

In-hole vs surface methods

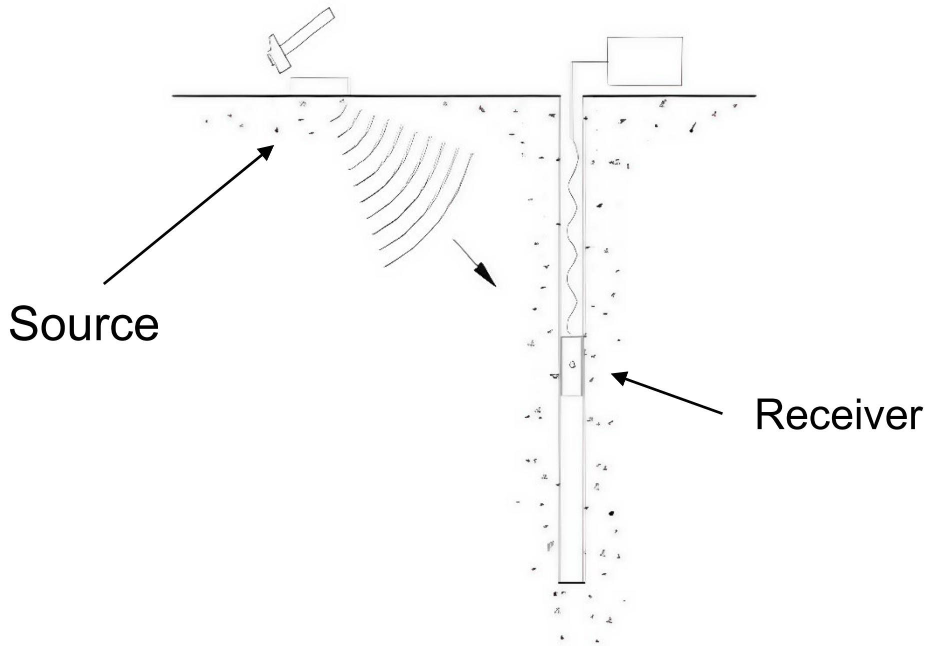




Cross-Hole test (CHT)
Down-Hole test (CHT)
Seismic cone (SCPT)
Seismic Dilatometer (SDMT)
P-S Suspension Logging
Vertical Seismic Profiling (VSP)

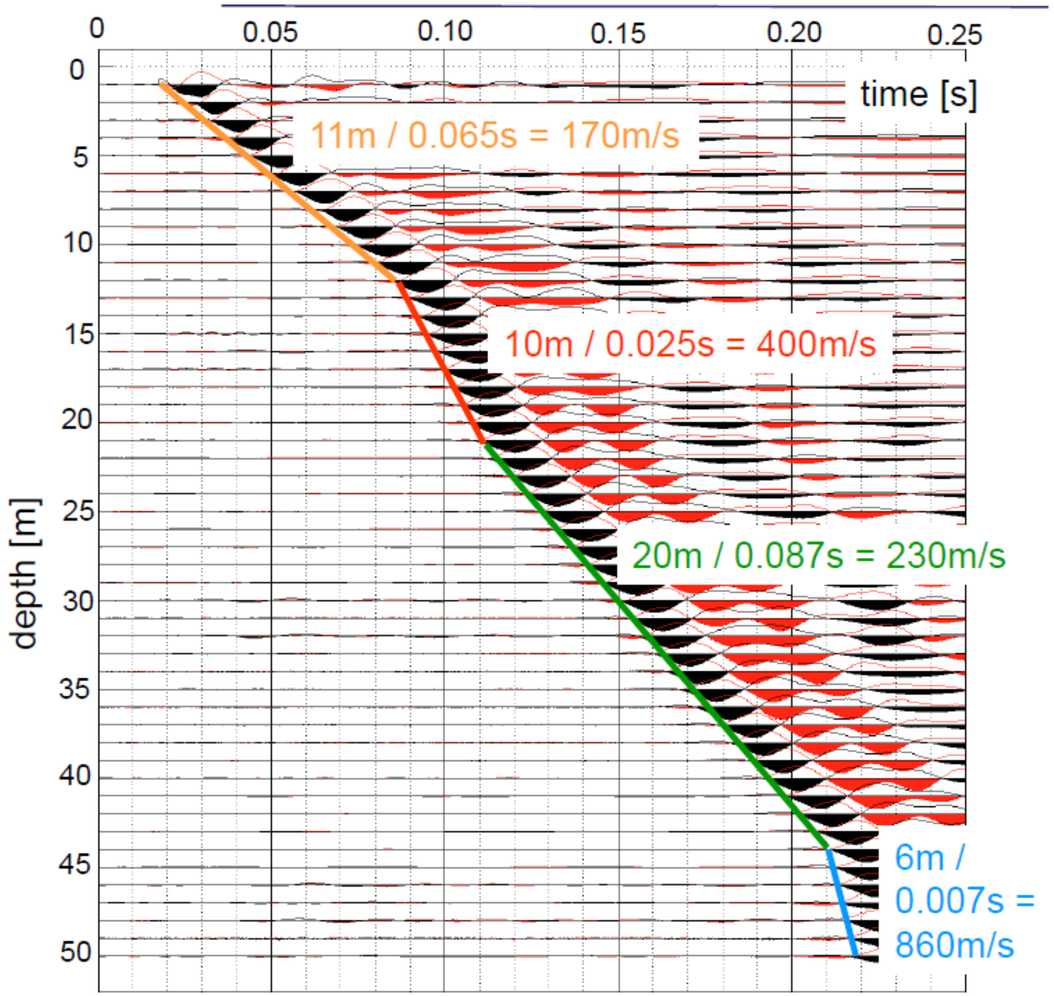
Surface Waves Methods (SASW, MASW, microtremors)
Seismic refraction (P-waves or SH-waves)
Seismic reflection (P-waves or SH-waves)

Down-Hole test (DHT)

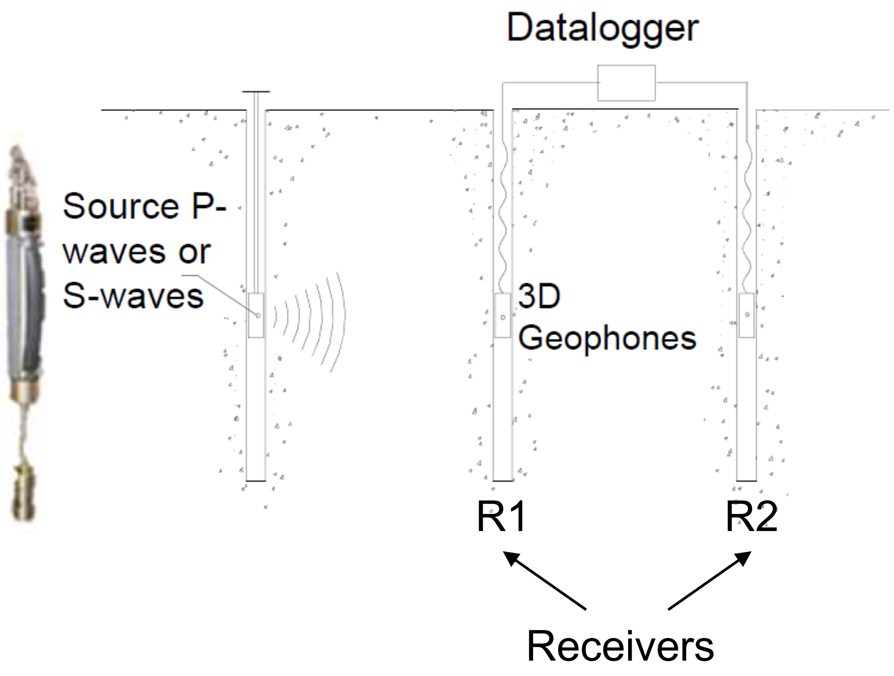


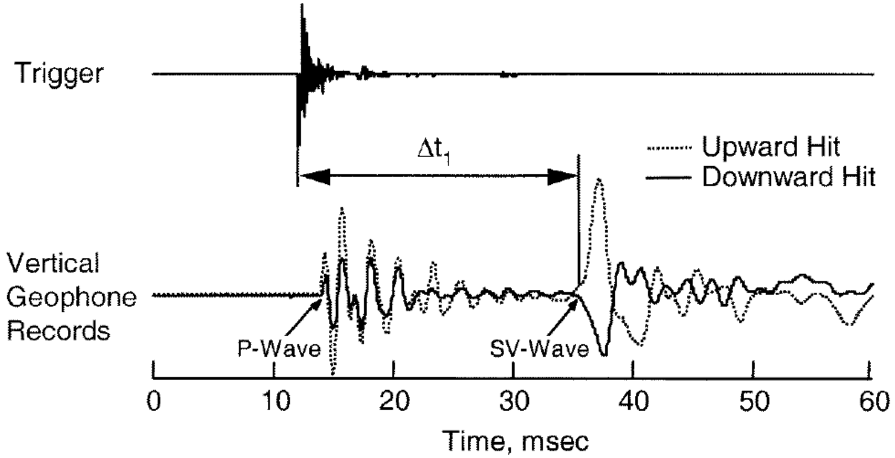
$$V = \frac{\Delta z}{\Delta t}$$

Example of simplified interpretation:

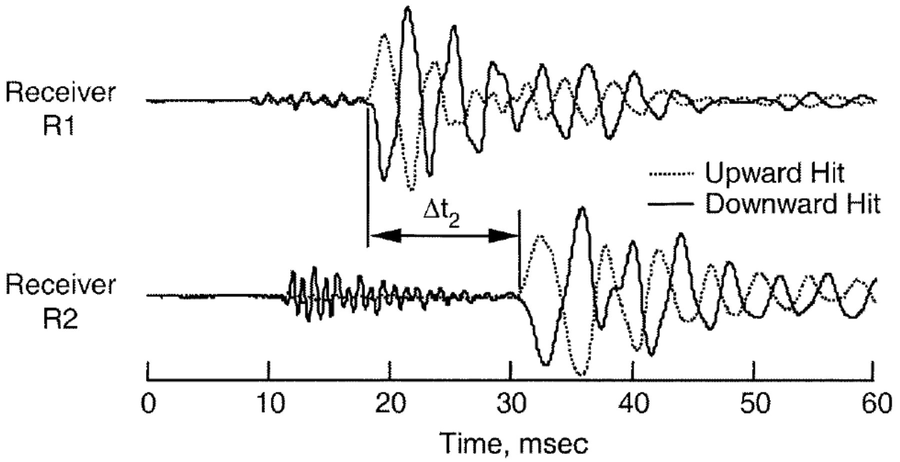


Cross-Hole test (CHT)



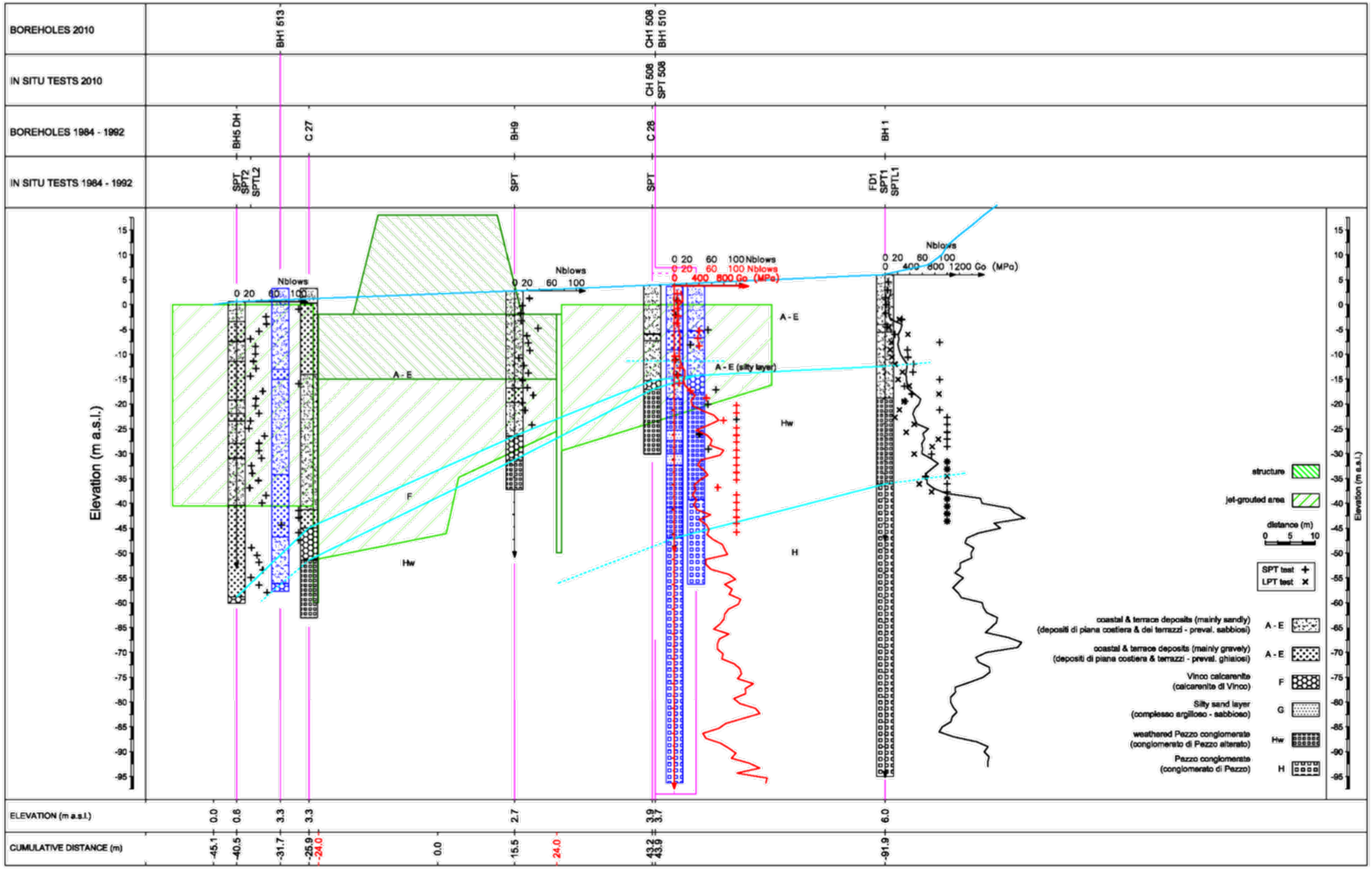


a. Record Illustrating a Direct Travel Time Measurement of an SV Wave

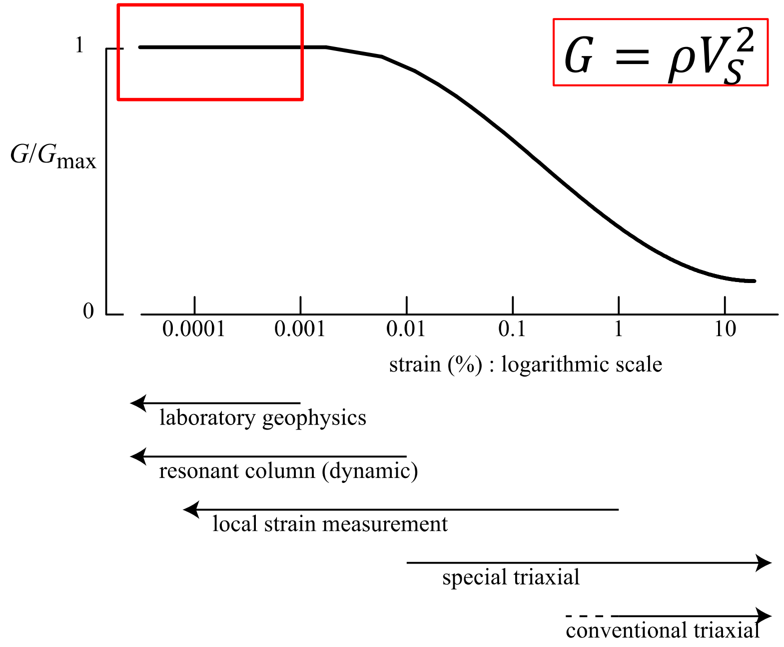


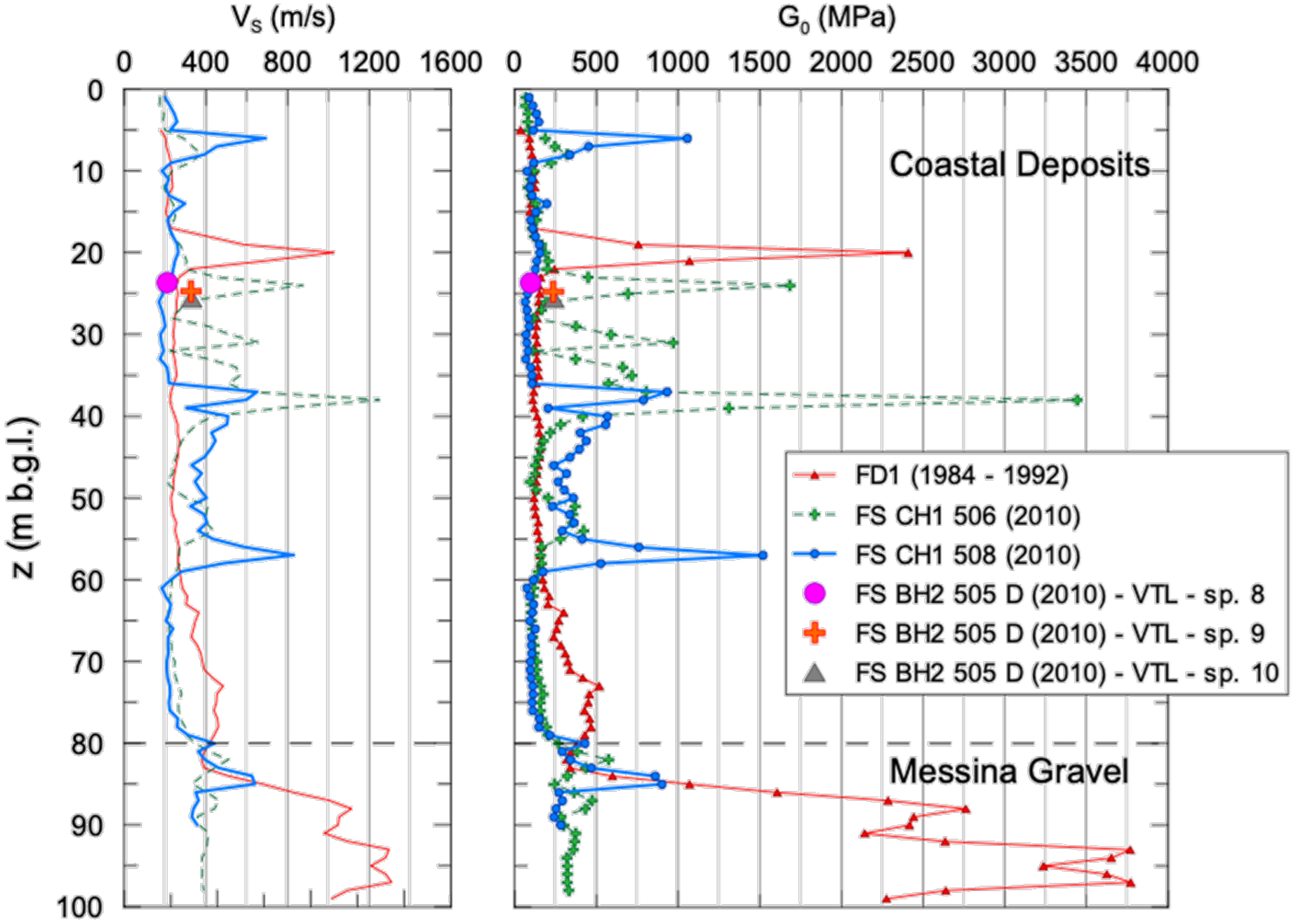
after Santamarina and Stokoe, 2000

Case study: Messina Bridge



Case study: Messina Bridge





Concluding remarks

- Essential role of in-situ measurements in geotechnics
- In-situ measurements for site characterization, design parameter determination, and ground behavior monitoring
- Choice of in-situ testing method based on Design requirement, Type of material & Practical considerations
- Theoretical basis and interpretation framework: (i) Empirical interpretation, (ii) Semi-empirical solution, (iii) sound theoretical solution

Thank you for your attention