



humboldtmg.com

Geomechanics

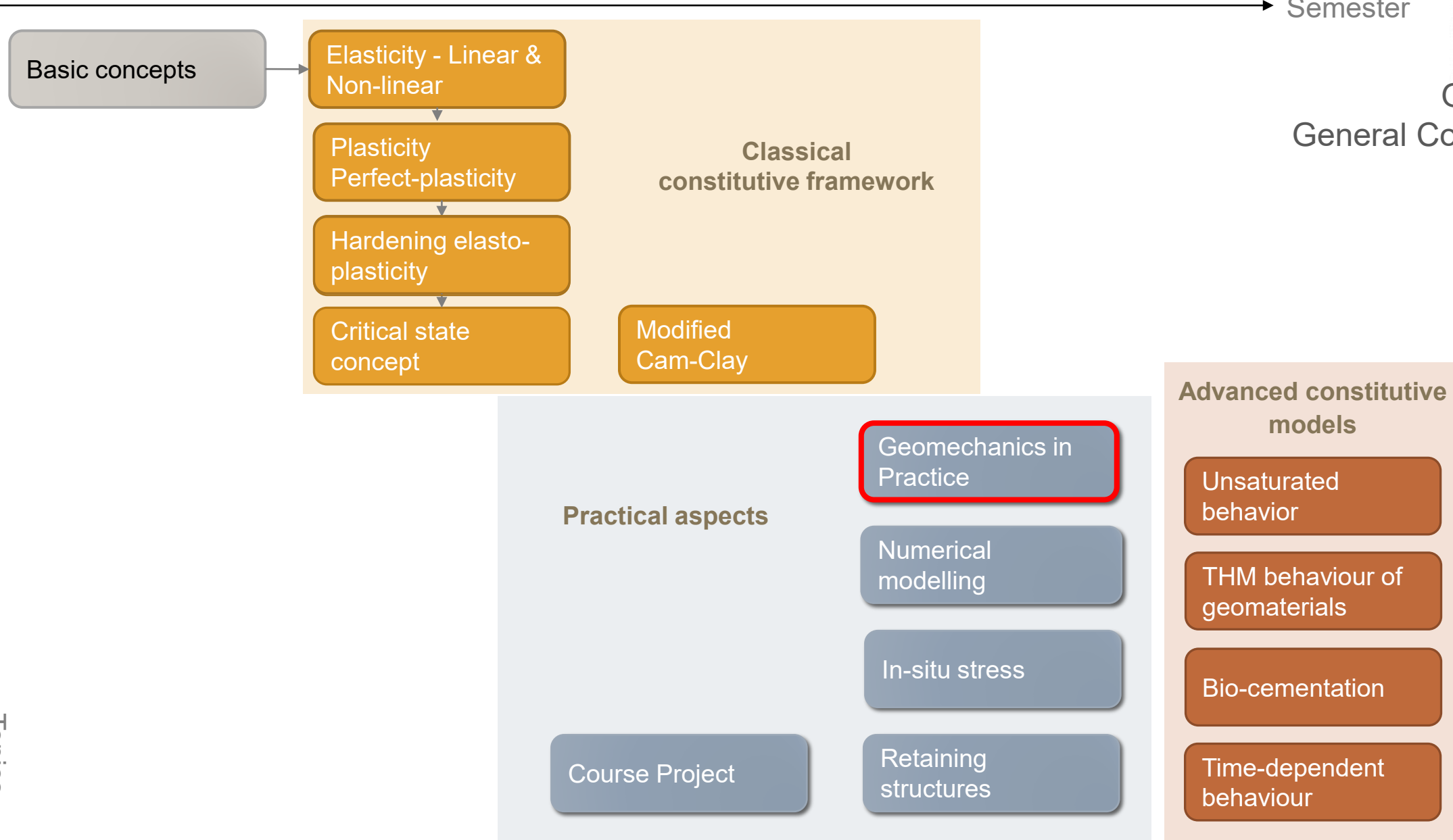
LECTURE 9

IN-SITU GEOTECHNICAL TESTING

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Laboratory of soil mechanics – Fall 2024

11.11.2024

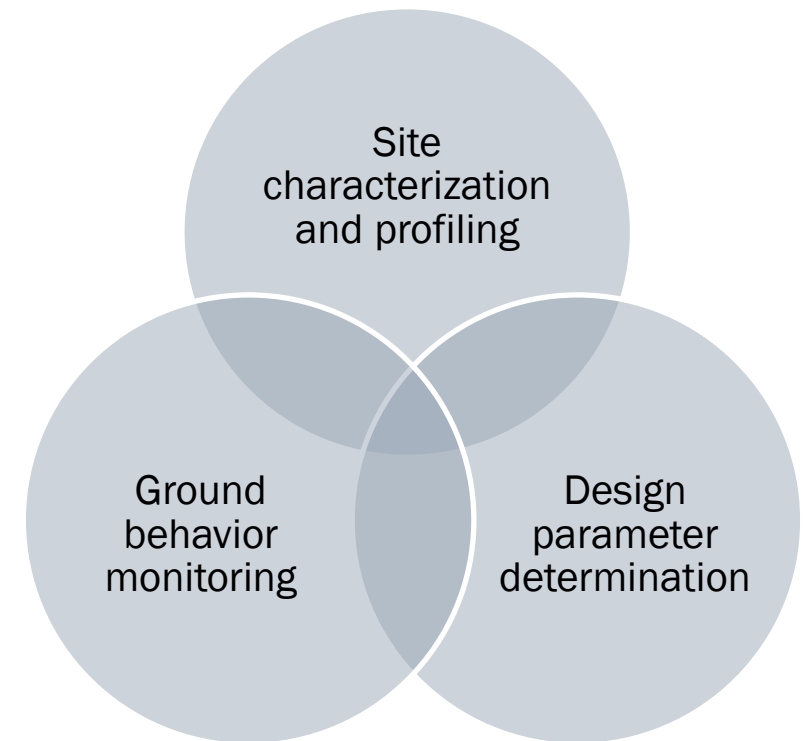


In-situ measurements: Pros & Cons

- 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.

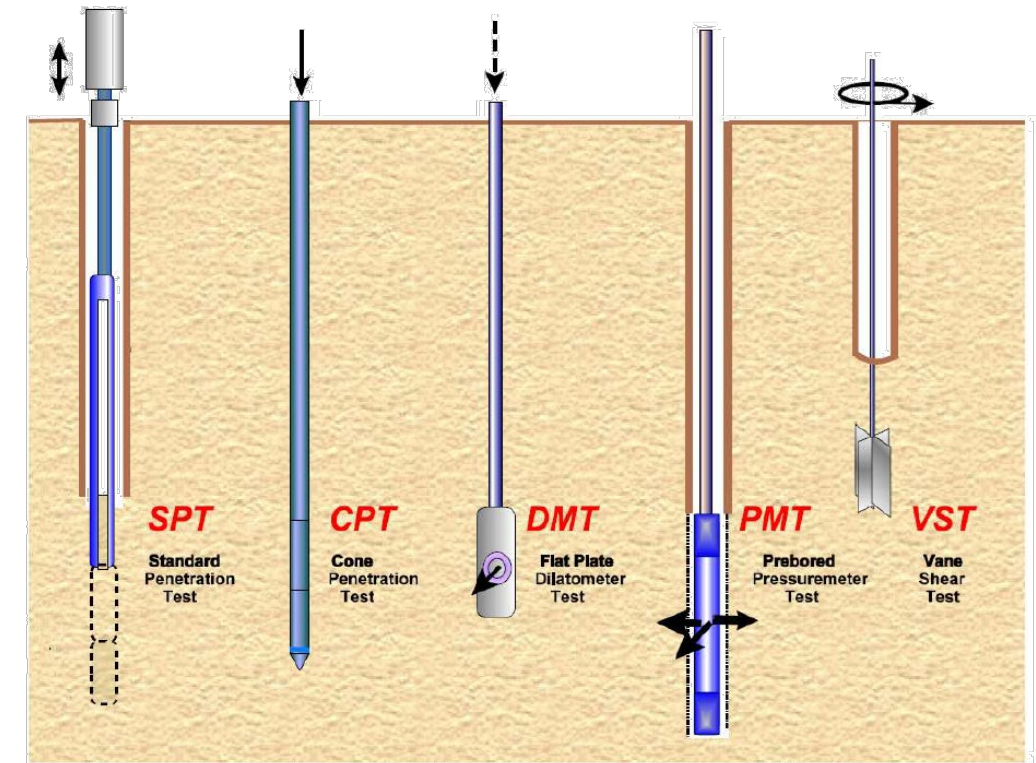
In-situ measurements: Testing and monitoring

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



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:

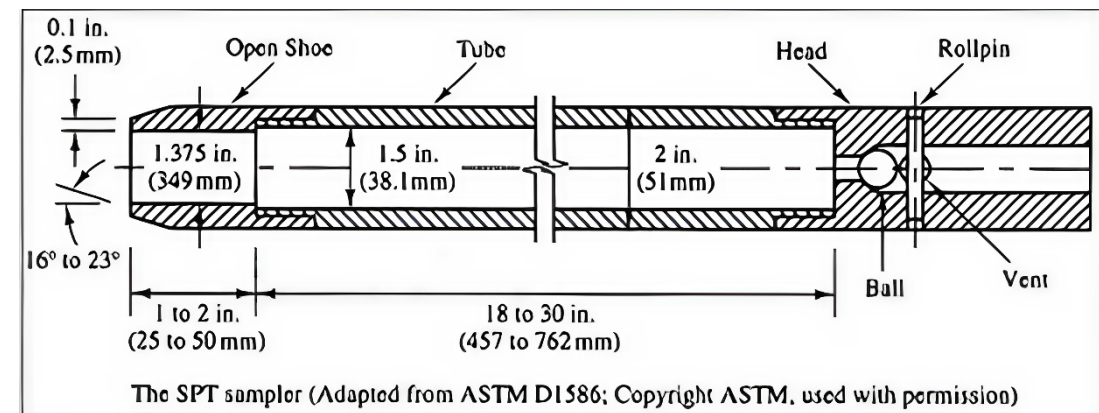
- Measure soil resistance to dynamic penetration and obtain disturbed soil samples
- Assess the in-situ relative density of sands

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

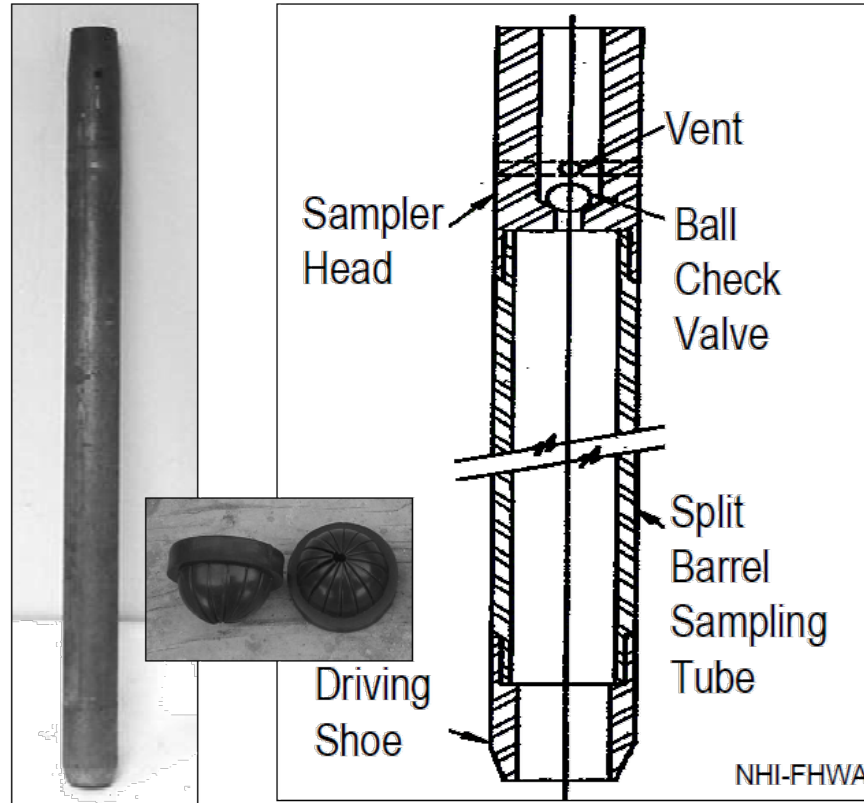
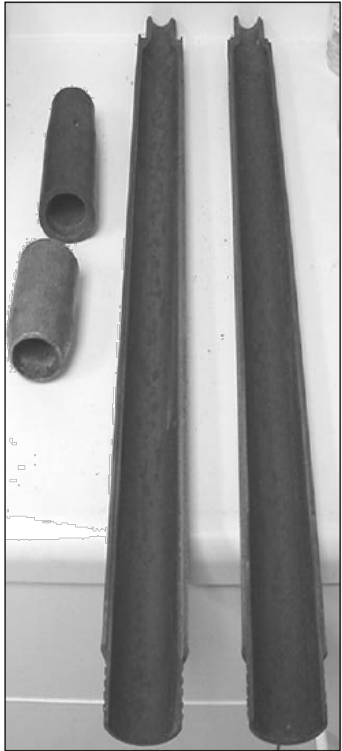


Standard penetration test (SPT)

Standard penetration test

i. Empiric interpretation

Split-Spoon Sampler



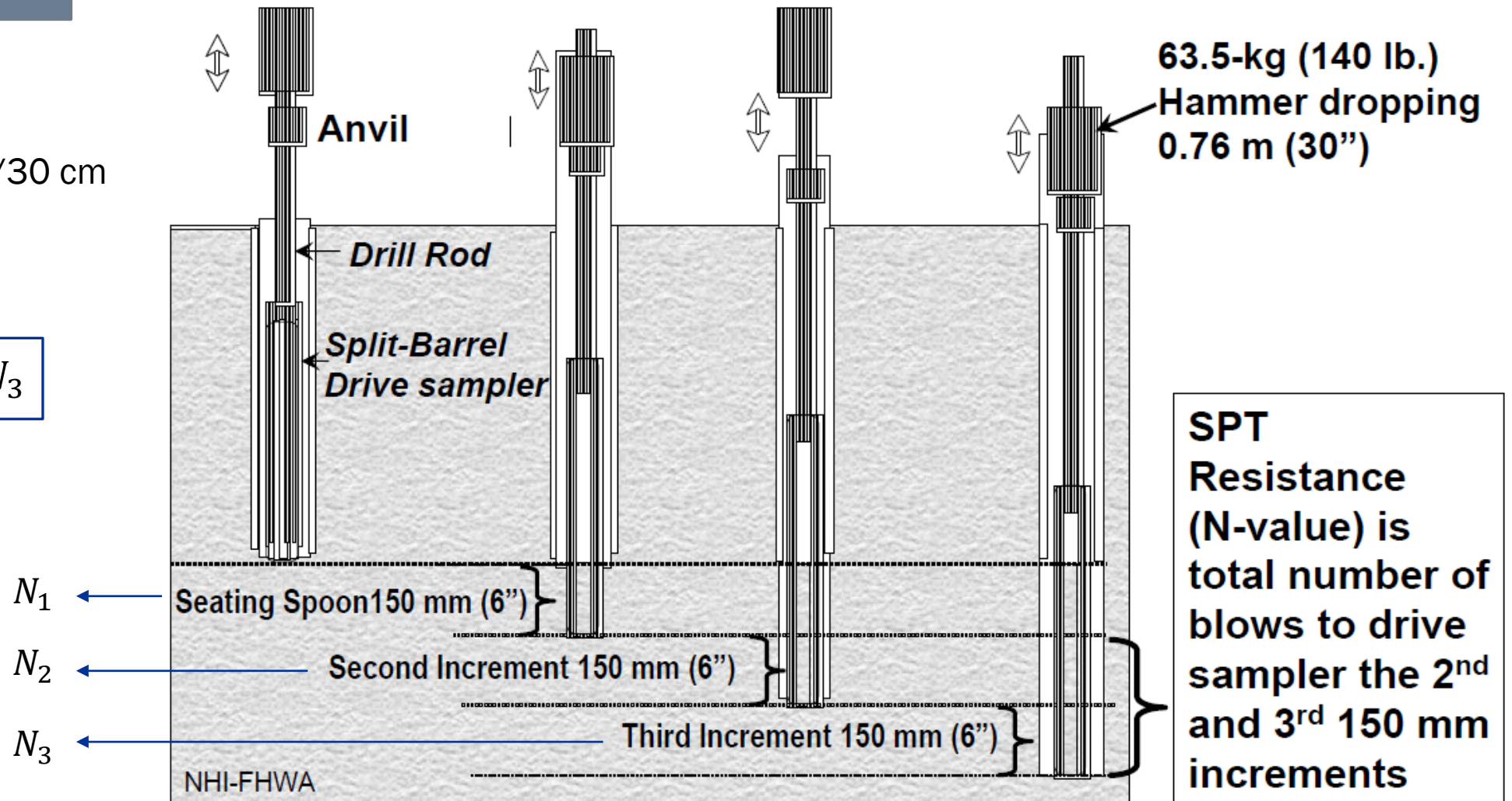
www.youtube.com

Standard penetration test (SPT)

i. Empiric interpretation

N: Number of blows/30 cm

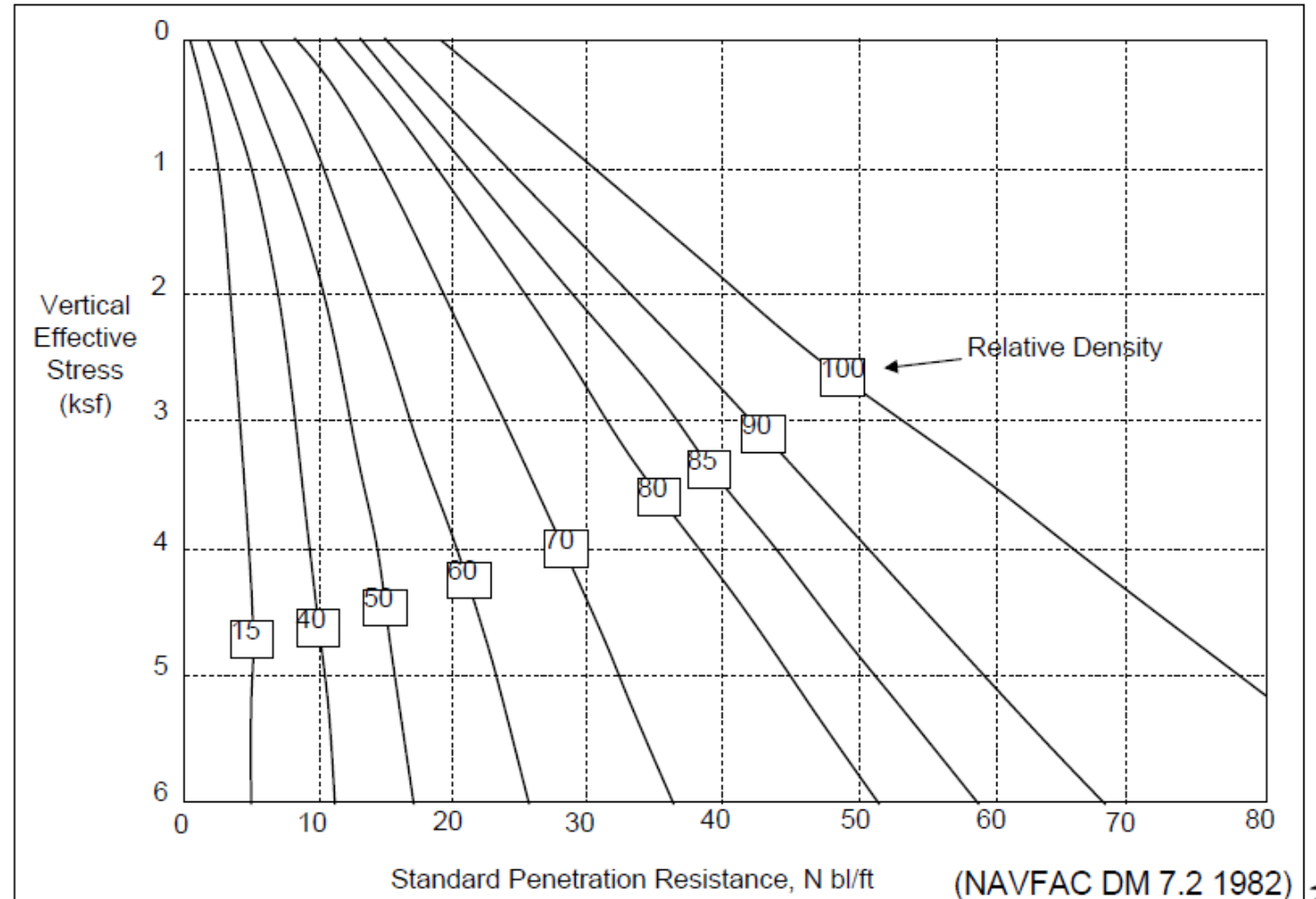
$$N_{SPT} = N_2 + N_3$$



Standard penetration test (SPT)

i. Empiric interpretation

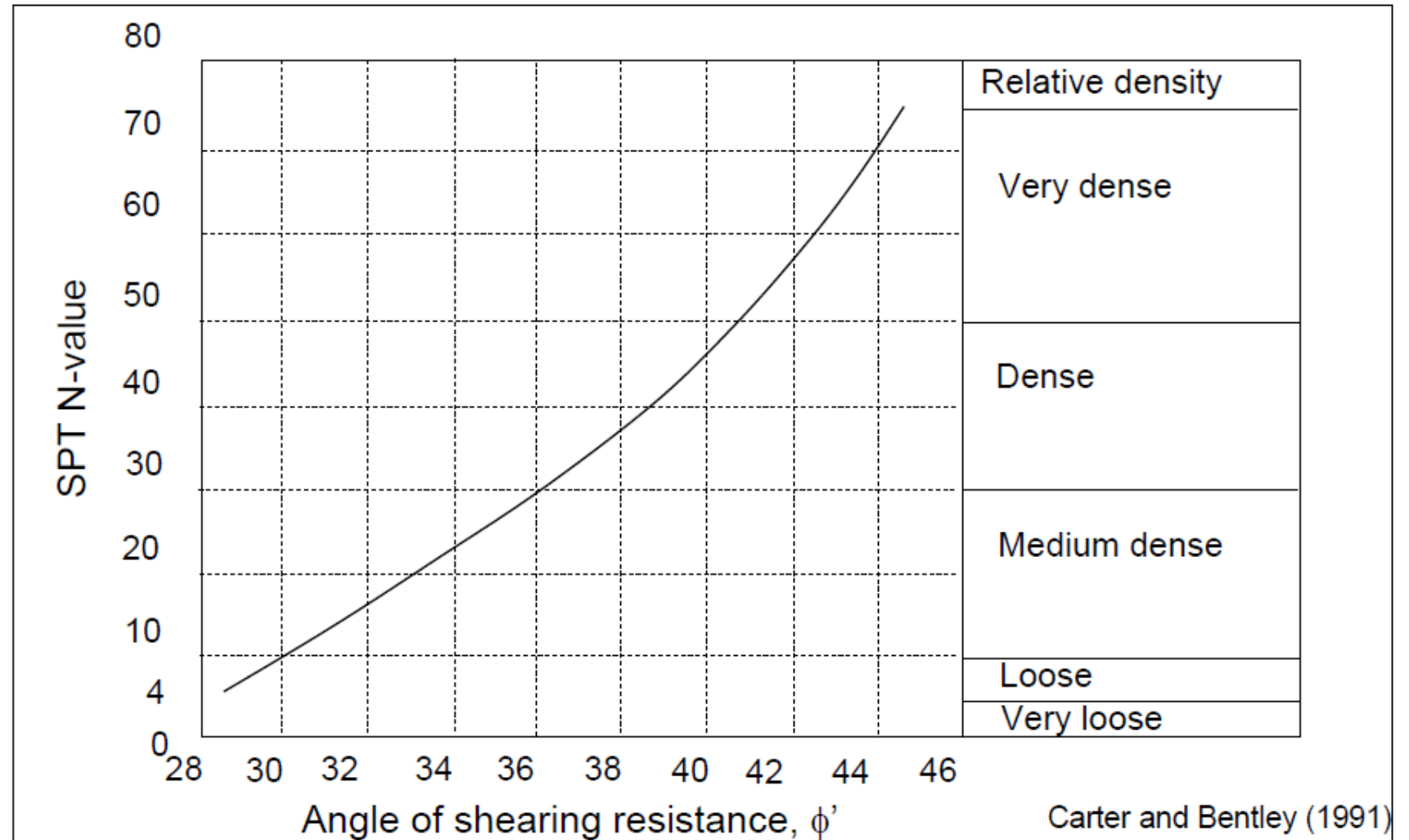
- Relative density D_R



Standard penetration test (SPT)

i. Empiric interpretation

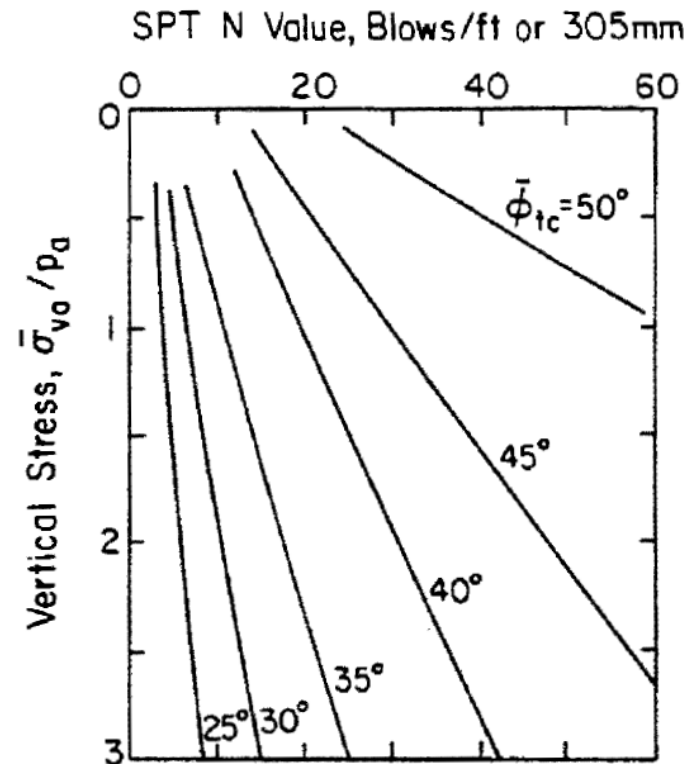
- Shear strength angle ϕ'



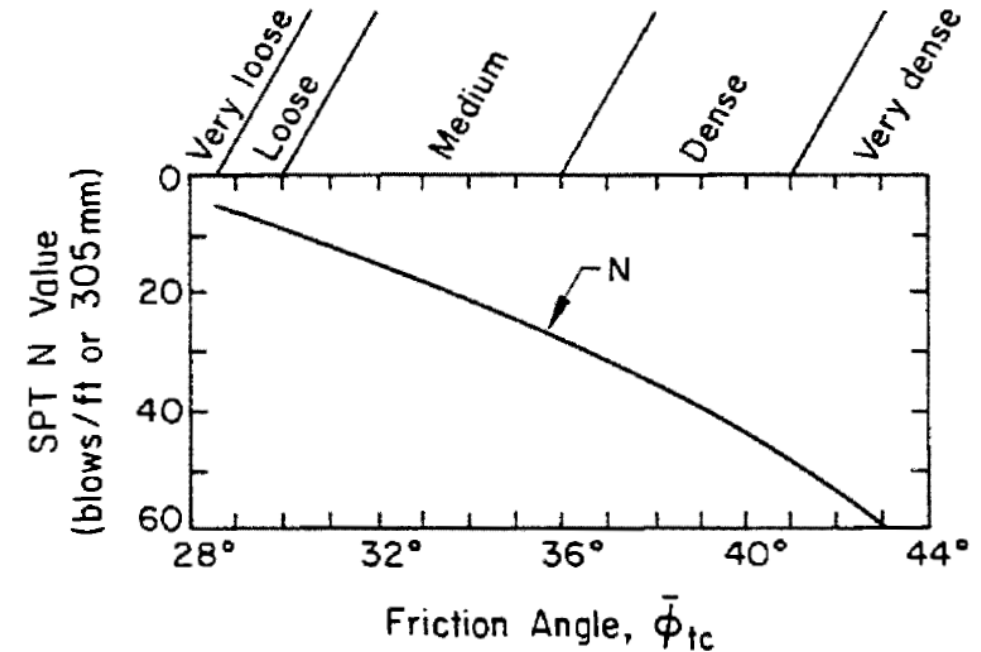
Standard penetration test (SPT)

i. Empiric interpretation

- Shear strength angle φ'



Schmertmann, 1975

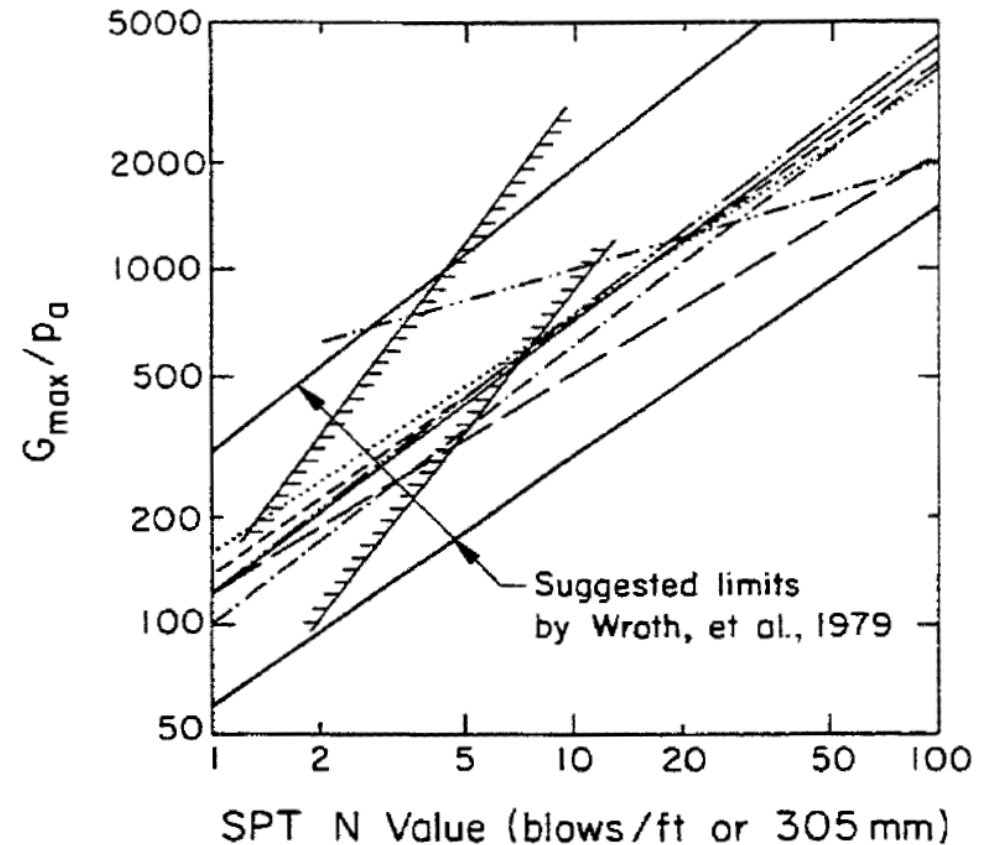


Peck, Hanson and Thornburn, 1974

Standard penetration test (SPT)

i. Empiric interpretation

- Shear modulus $G_{\max}$

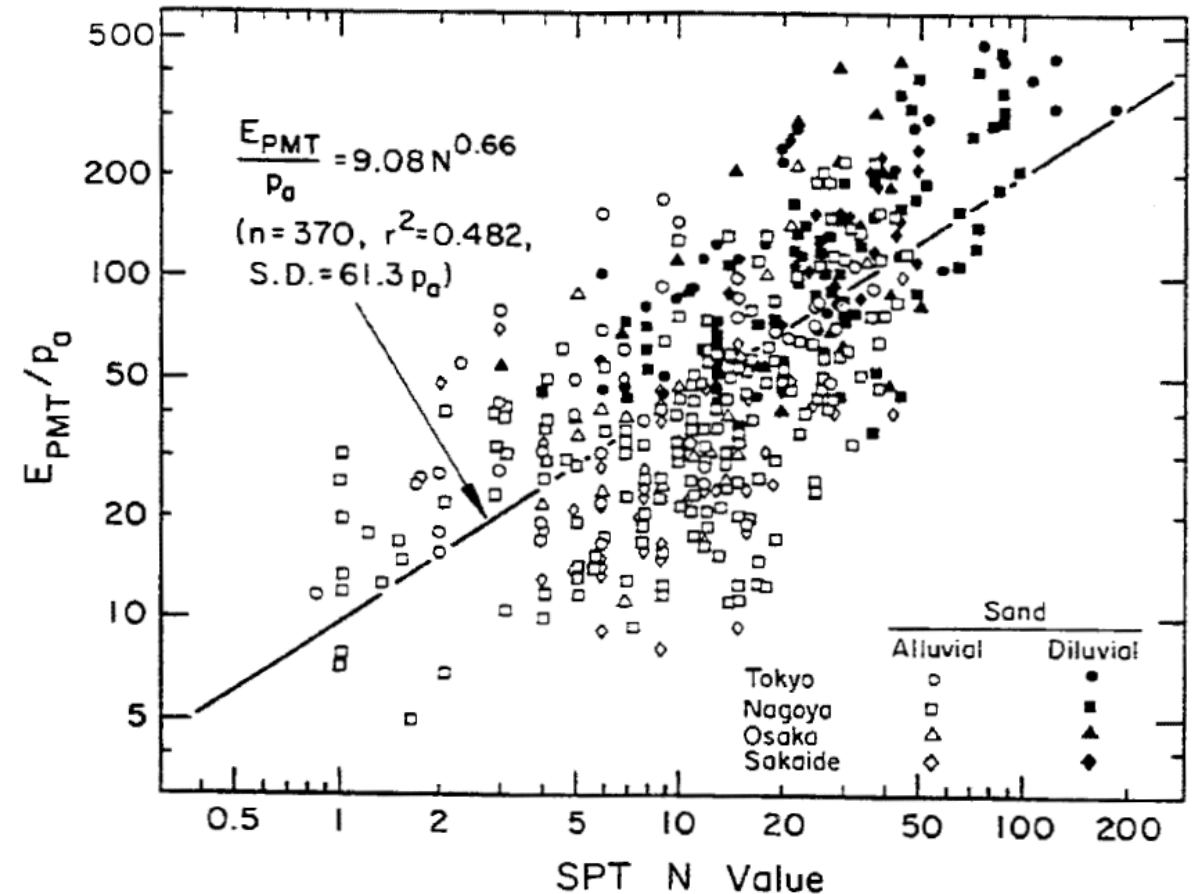


Wroth et al., 1979

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

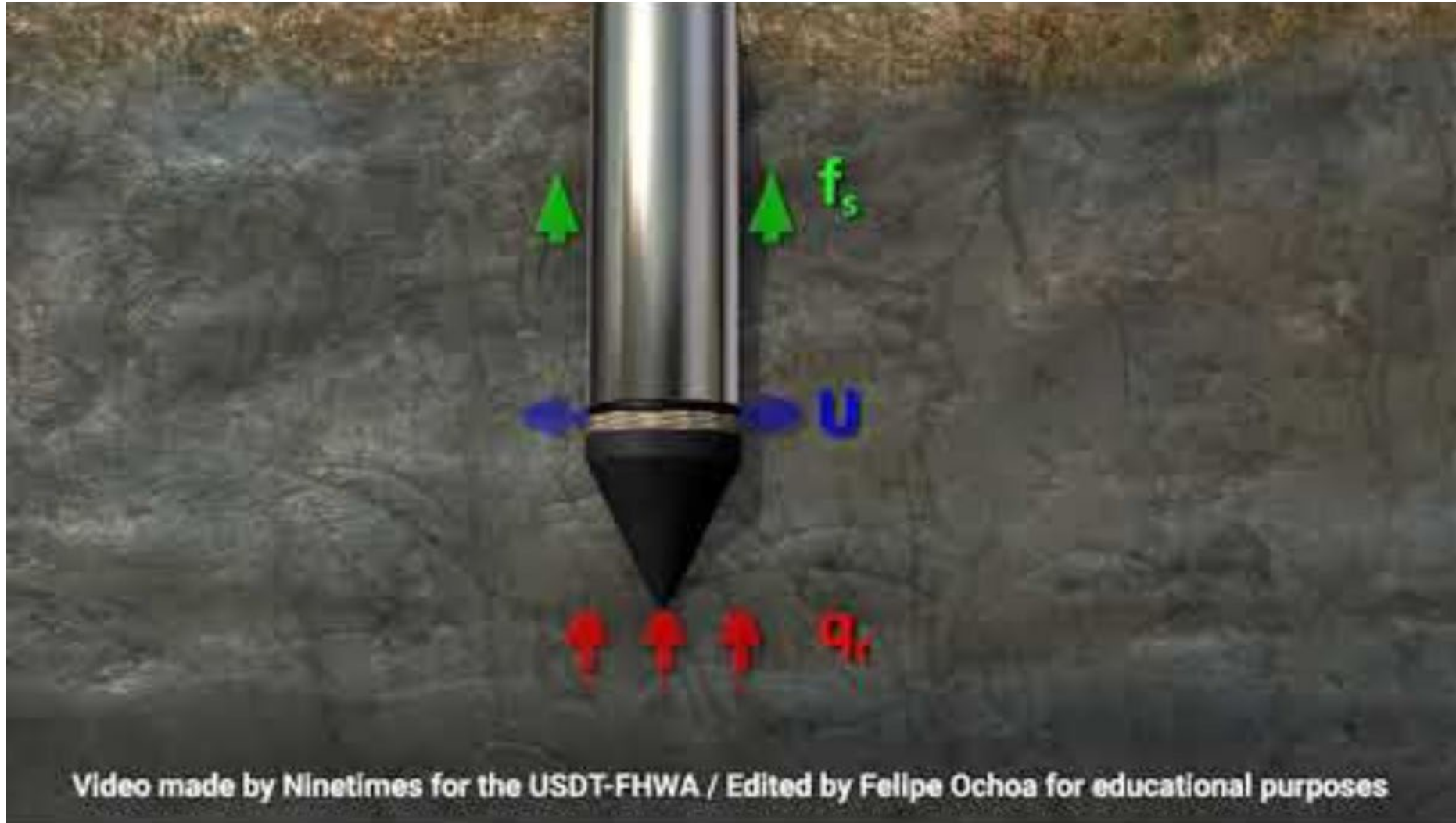


Photo: Pagani Equipment



Photo: Geomil Equipment

Cone penetration test (CPT)



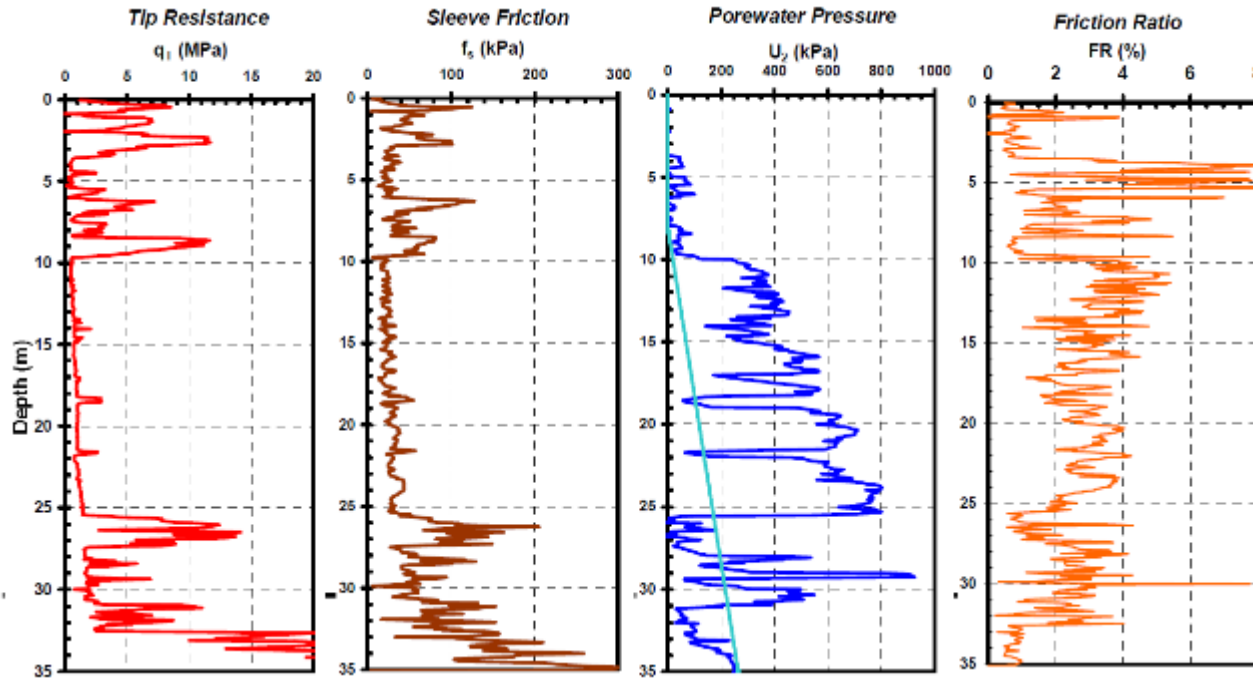
[Cone Penetration Test](#)

www.youtube.com

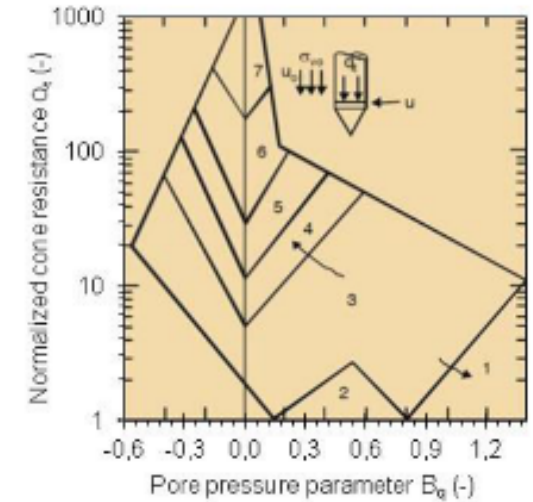
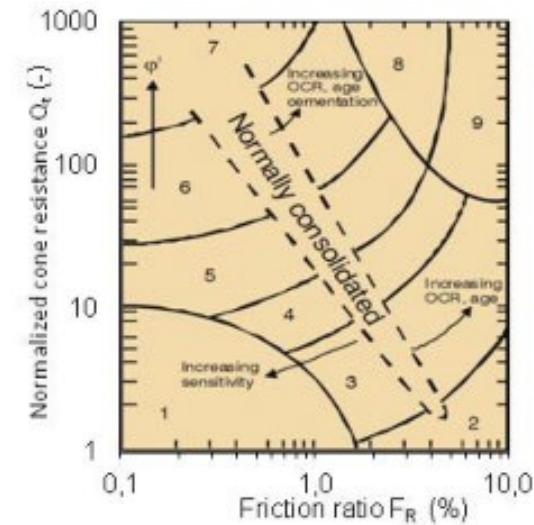
Cone penetration test (CPT)

i. Empiric interpretation

Measurements Results (CPTu)



Empirical interpretation charts



Soil classification Charts, Robertson 1990

Zone Soil Behavior Type (SBT)

1 Sensitive, fine grained

2 Organic soils - clay

3 Clay - silty clay to clay

4 Silt mixtures - clayey silt to silty clay

5 Sand mixtures - silty sand to sandy silt

6 Sands - clean sand to silty sand

7 Gravelly sand to dense sand

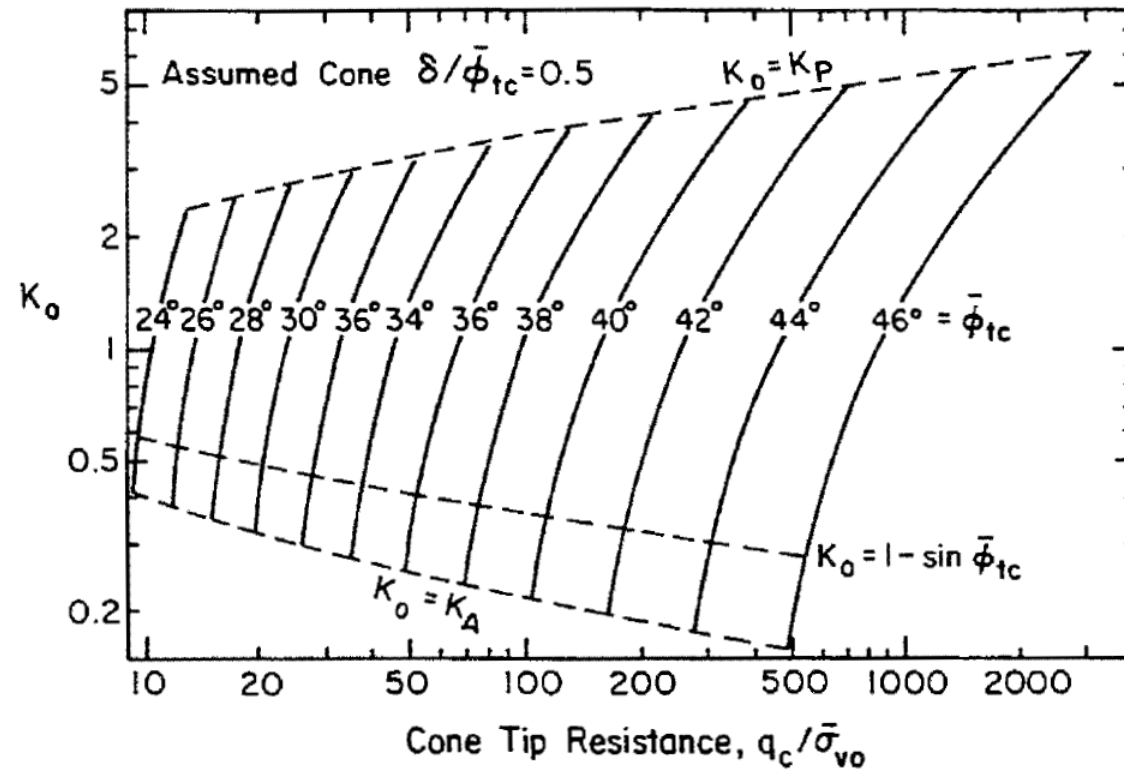
8 Very stiff sand to clayey sand *

9 Very stiff fine grained *

Cone penetration test (CPT)

i. Empiric interpretation

- At-rest earth pressure coefficient K_0

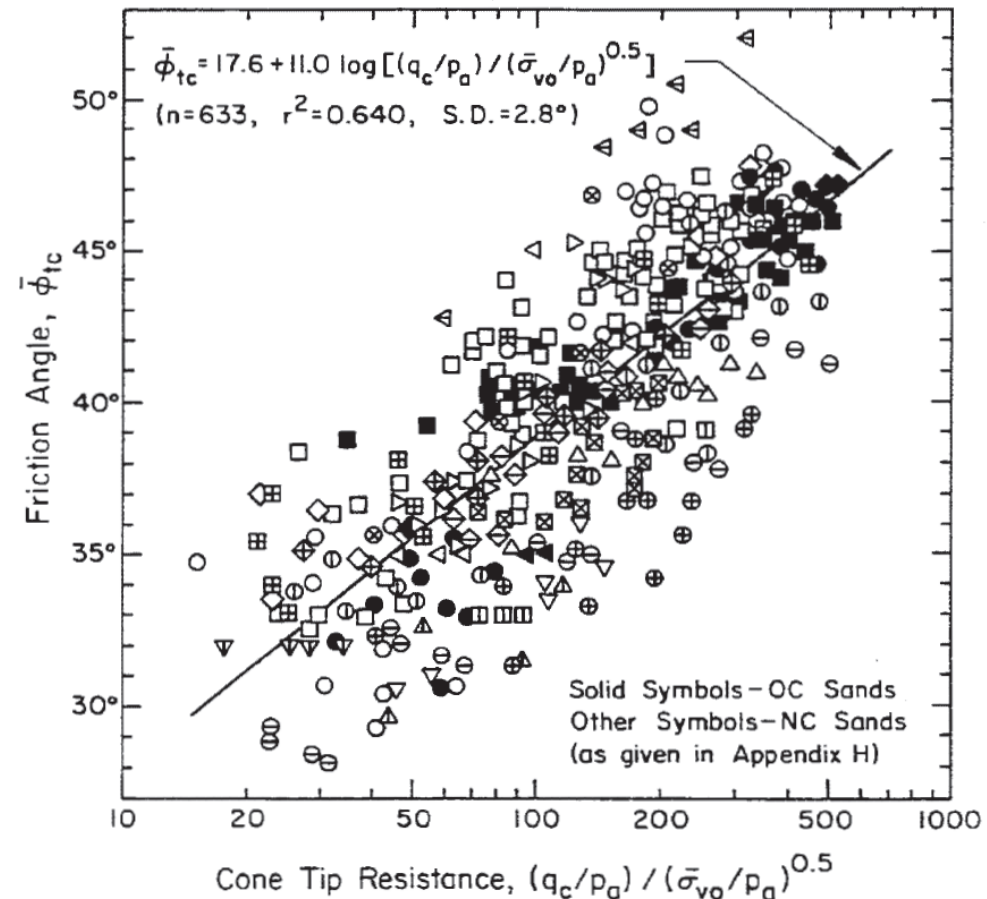


Marchetti, 1985

Cone penetration test (CPT)

i. Empiric interpretation

- Shear strength angle φ'



Mair and Wood, 1987

The vane shear test

iii. Semi-empiric solution

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

Concept & procedure:

- Push into ground
- rotate at a slow rate $6-12^\circ / \text{min}$
- 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

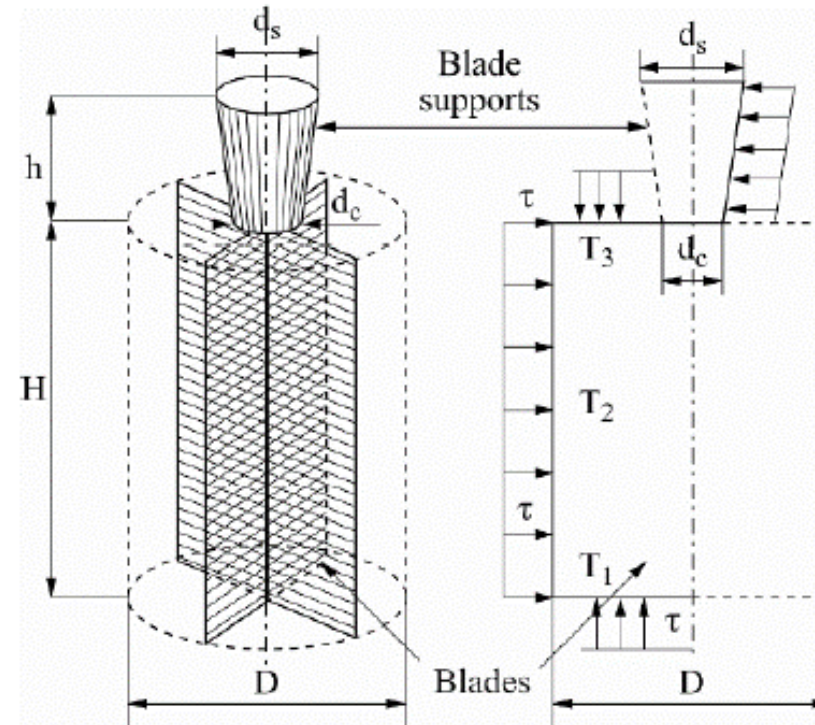
$$C_u = T / [\pi d^2 (h/2 + d/6)]$$

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

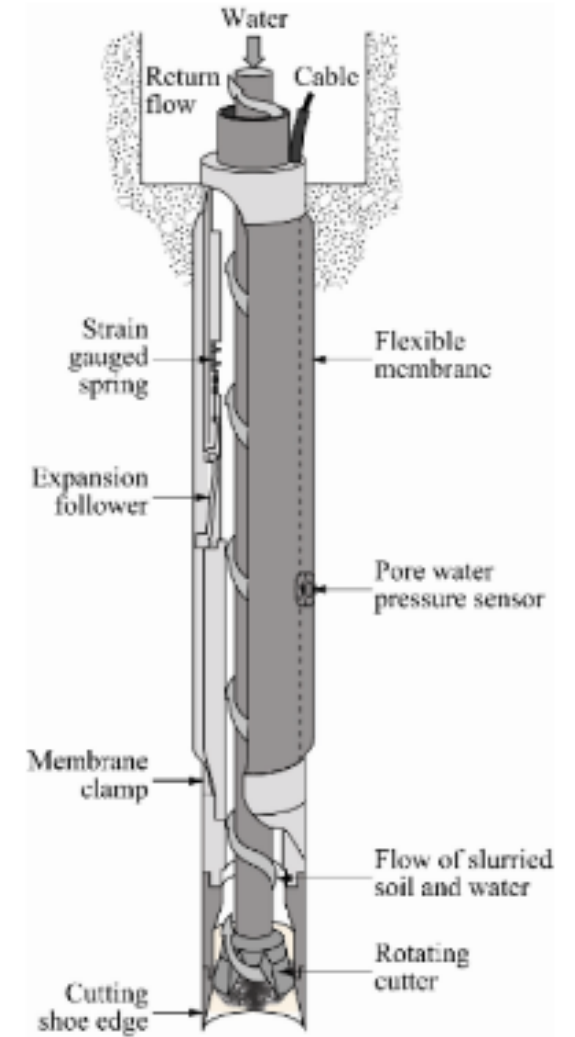
Objective: to determine the stress-strain relationship (strength and stiffness parameters)

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

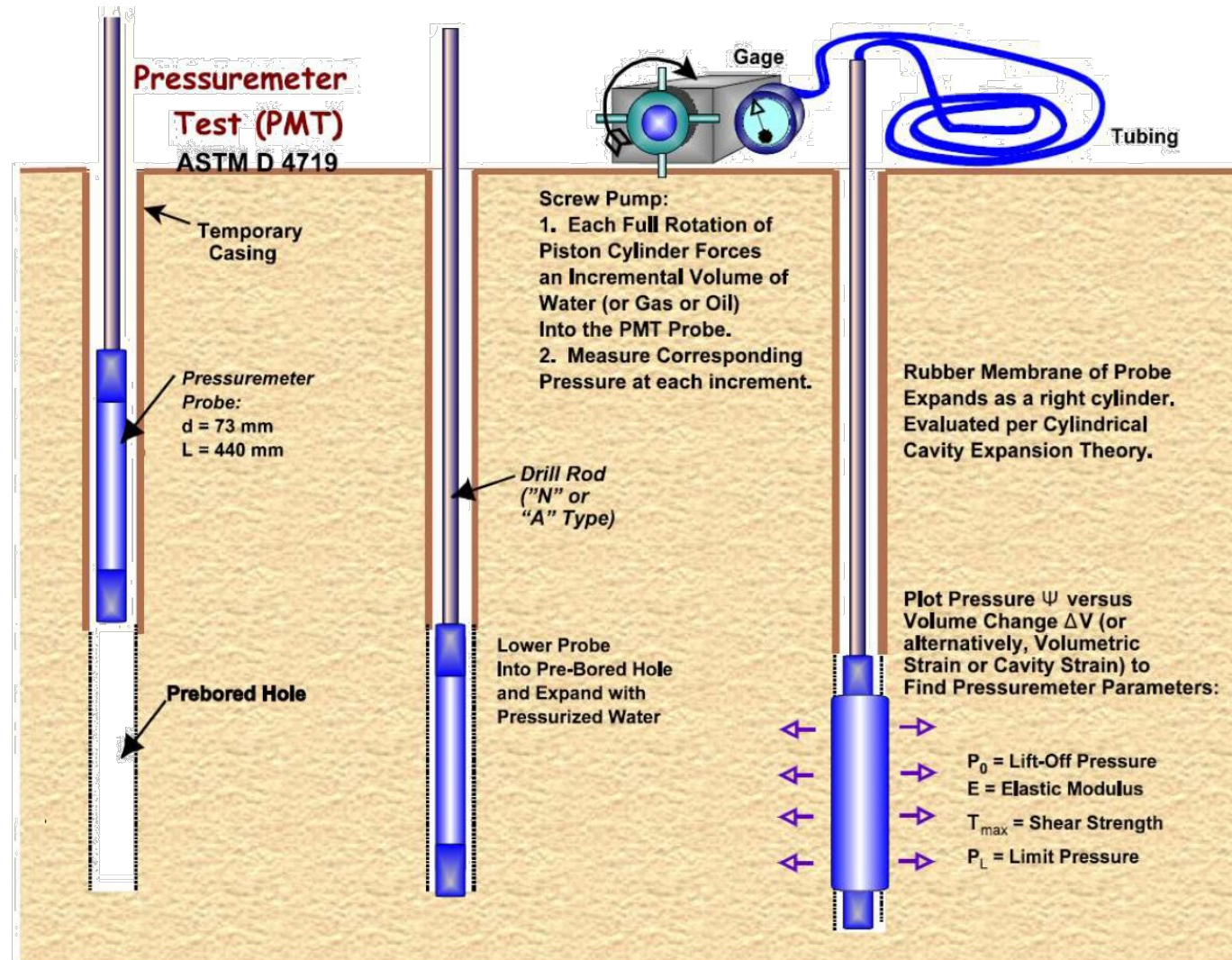
Different types of pressuremeter:

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



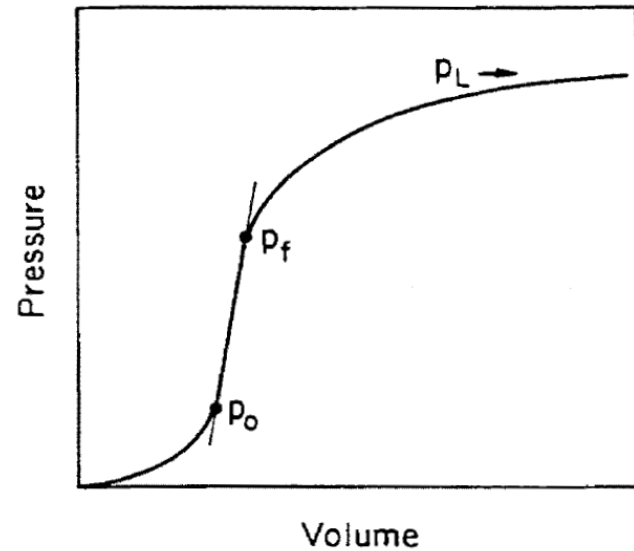
Monnet 2015 - Cambridge In-situ

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

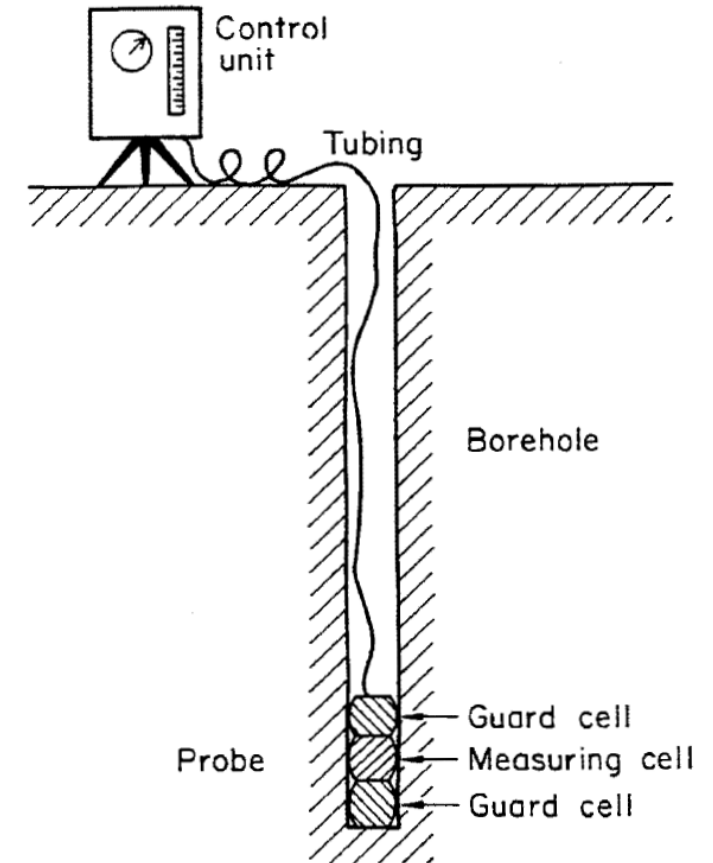


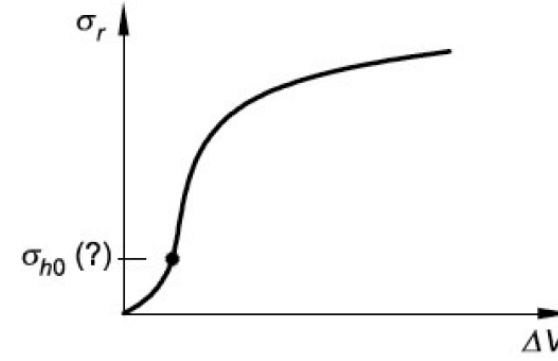
Figure C-1. Menard Pressuremeter Equipment

Baguelin et al., 1978

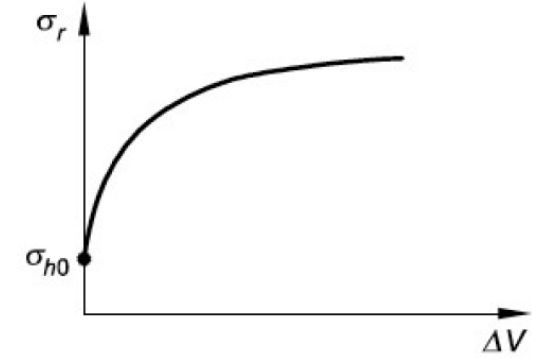
Self-Boring pressuremeter

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



(a) Menard



(b) Self-boring

Pressuremeter test

i. Empiric interpretation

- Shear strength angle φ'

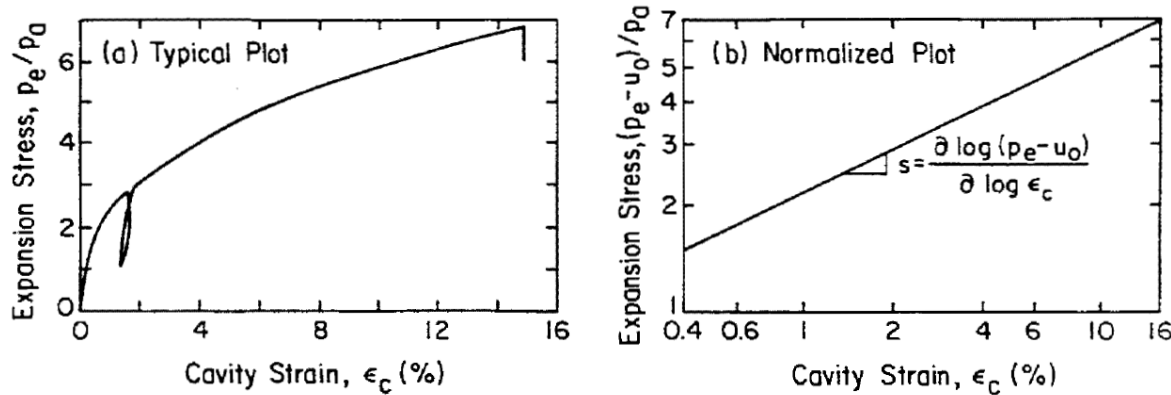
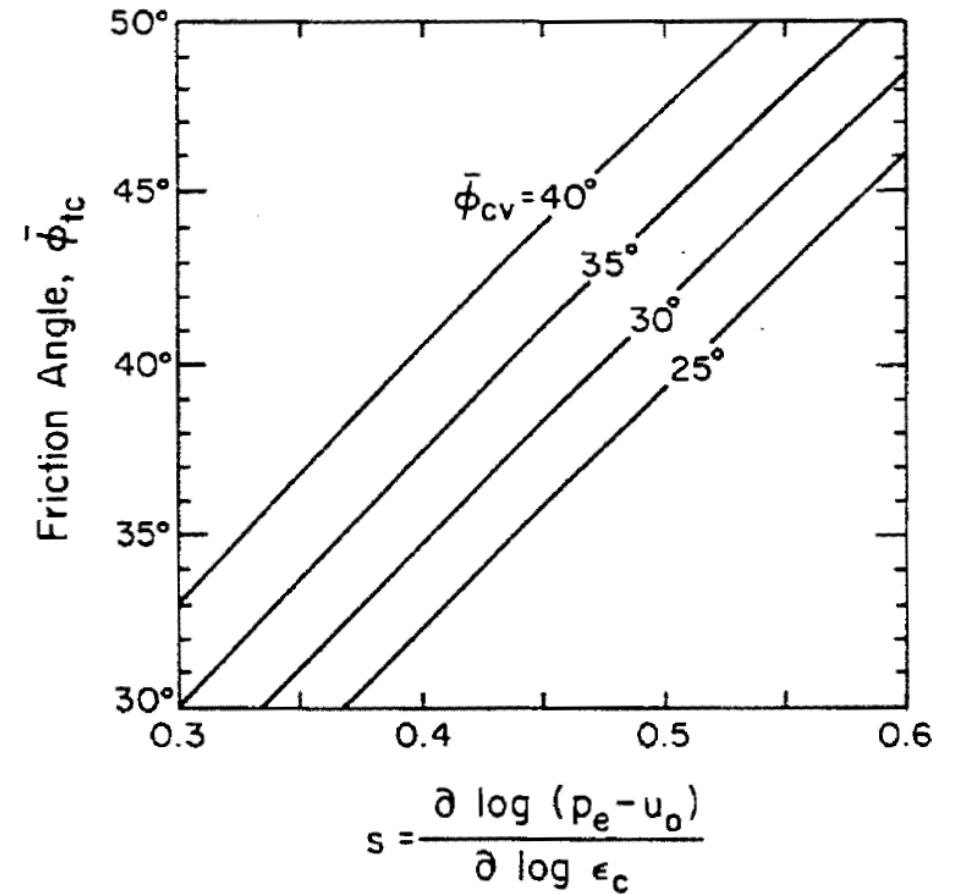


Figure 4-18. PMT Data Representations

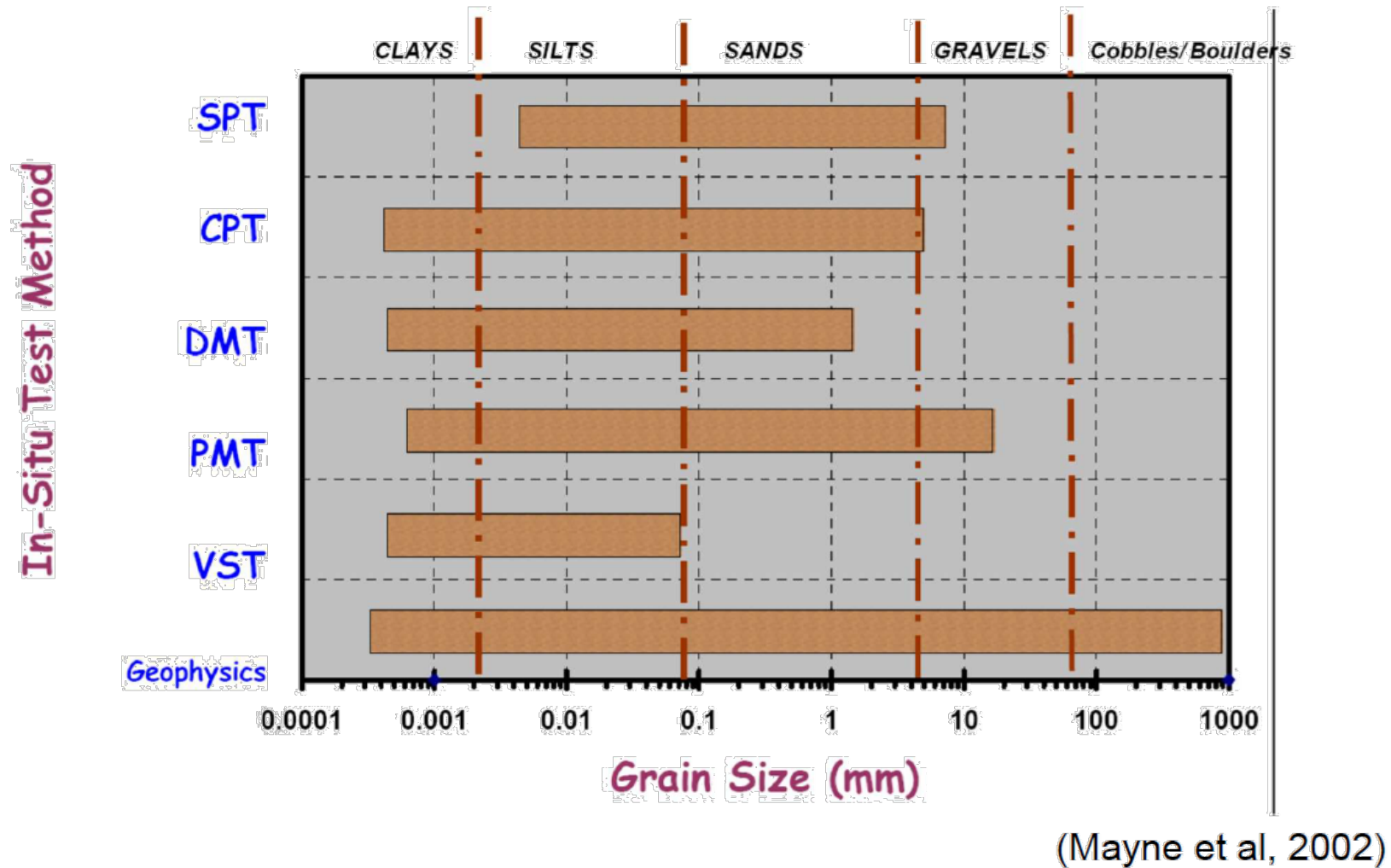
Mair and Wood, 1987



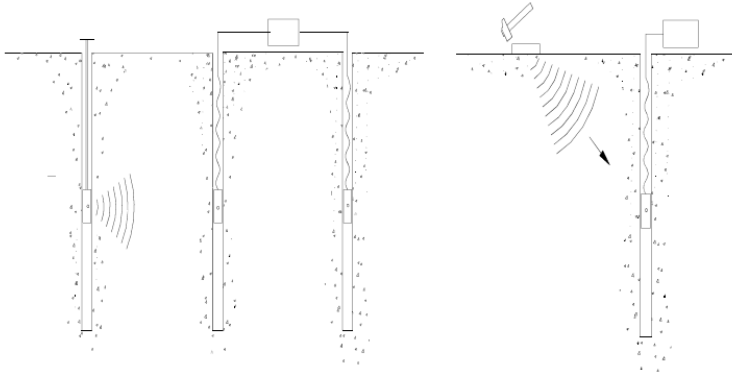
Mair and Wood, 1987

φ'_{tc} = triaxial compression friction angle
 φ'_{cv} = constant volume friction angle

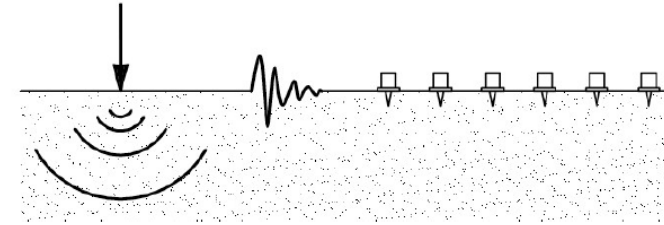
Applicability of in situ tests



In-hole vs surface methods

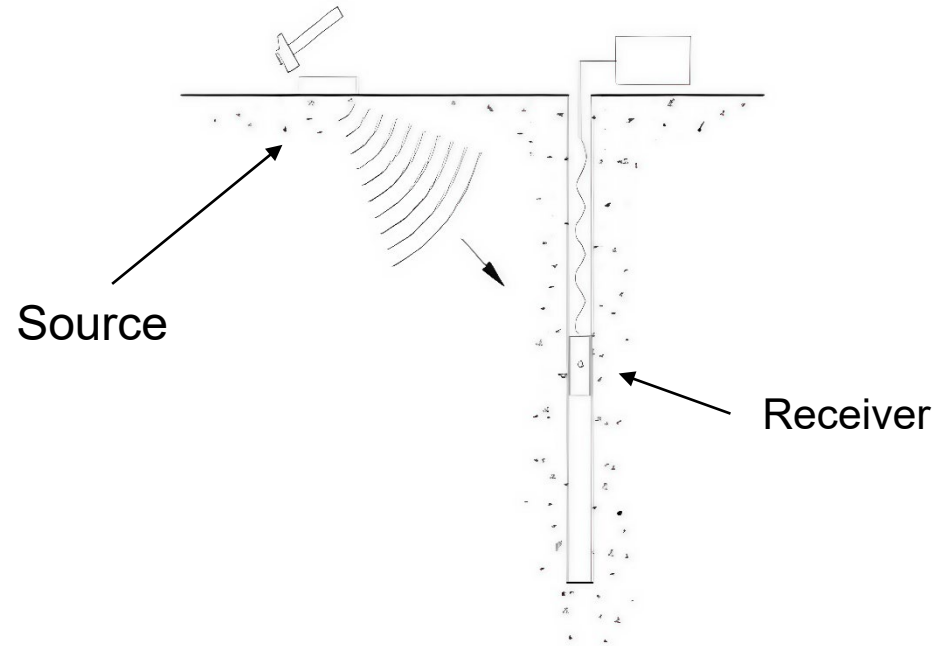


Cross-Hole test (CHT)
Down-Hole test (CHT)
Seismic cone (SCPT)
Seismic Dilatometer (SDMT)
P-S Suspension Logging
Vertical Seismic Profiling (VSP)



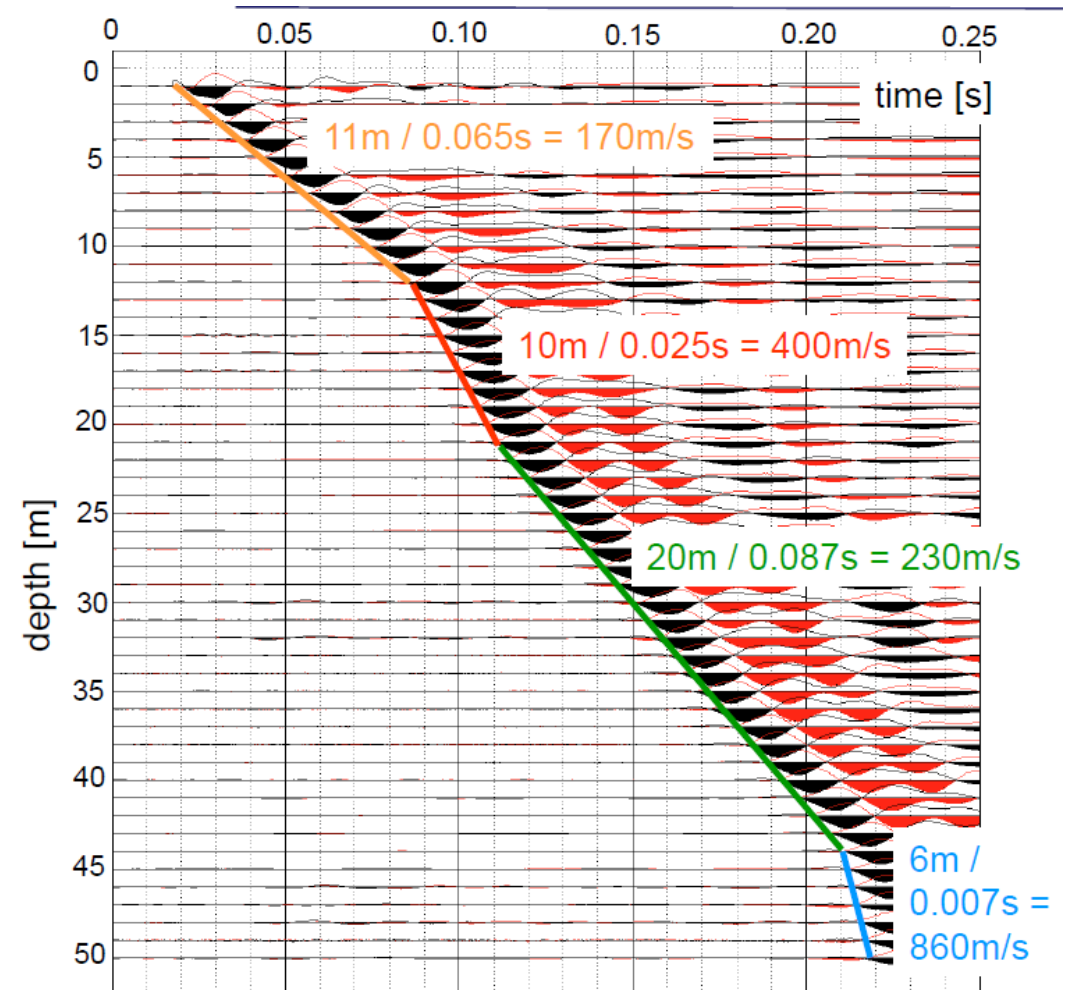
Surface Waves Methods (SASW, MASW, microtremors)
Seismic refraction (P-waves or SH-waves)
Seismic reflection (P-waves or SH-waves)

Down-Hole test (DHT)

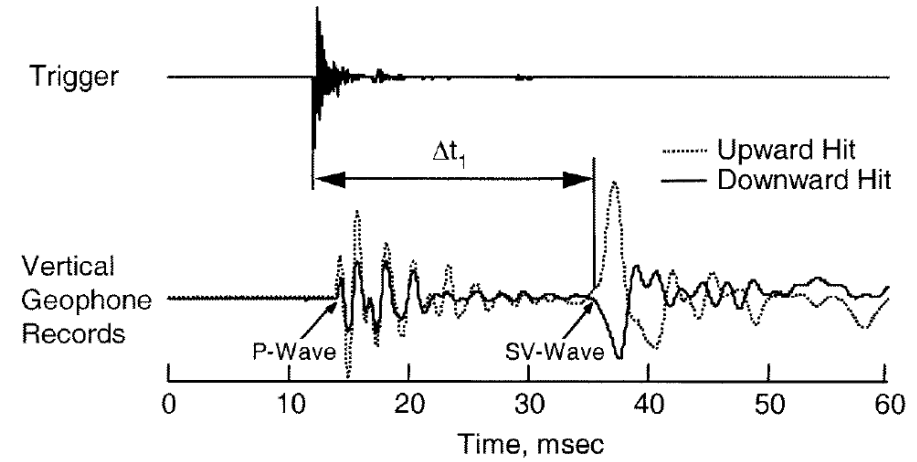
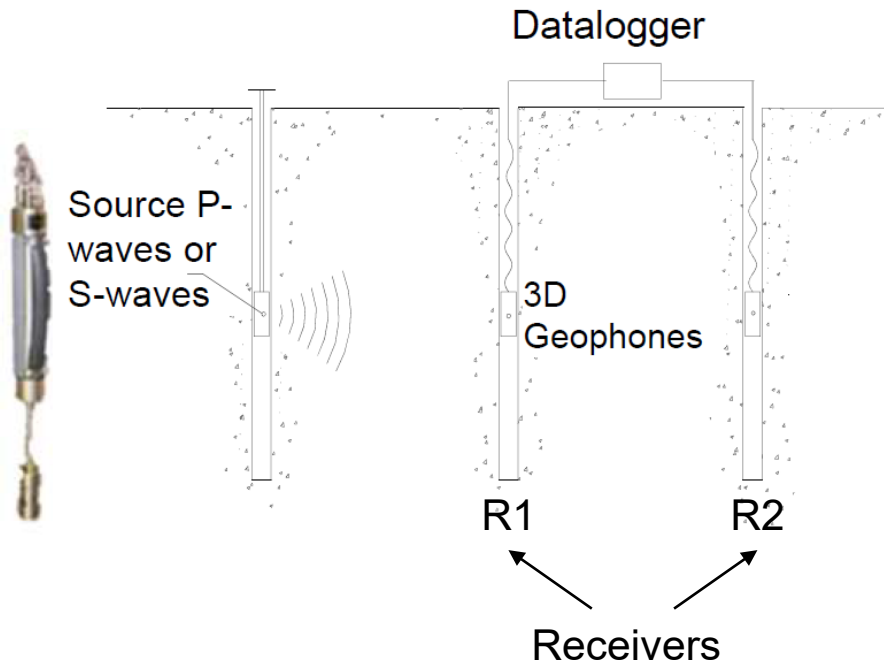


$$V = \frac{\Delta z}{\Delta t}$$

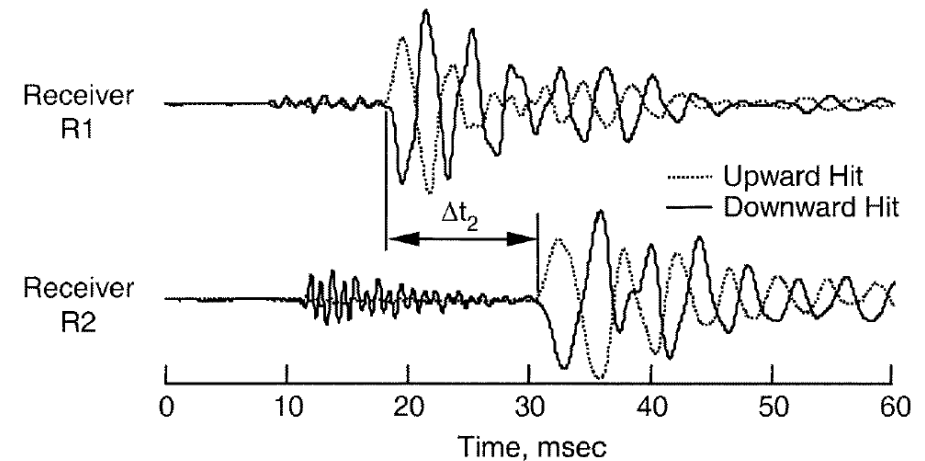
Example of simplified interpretation:



Cross-Hole test (CHT)

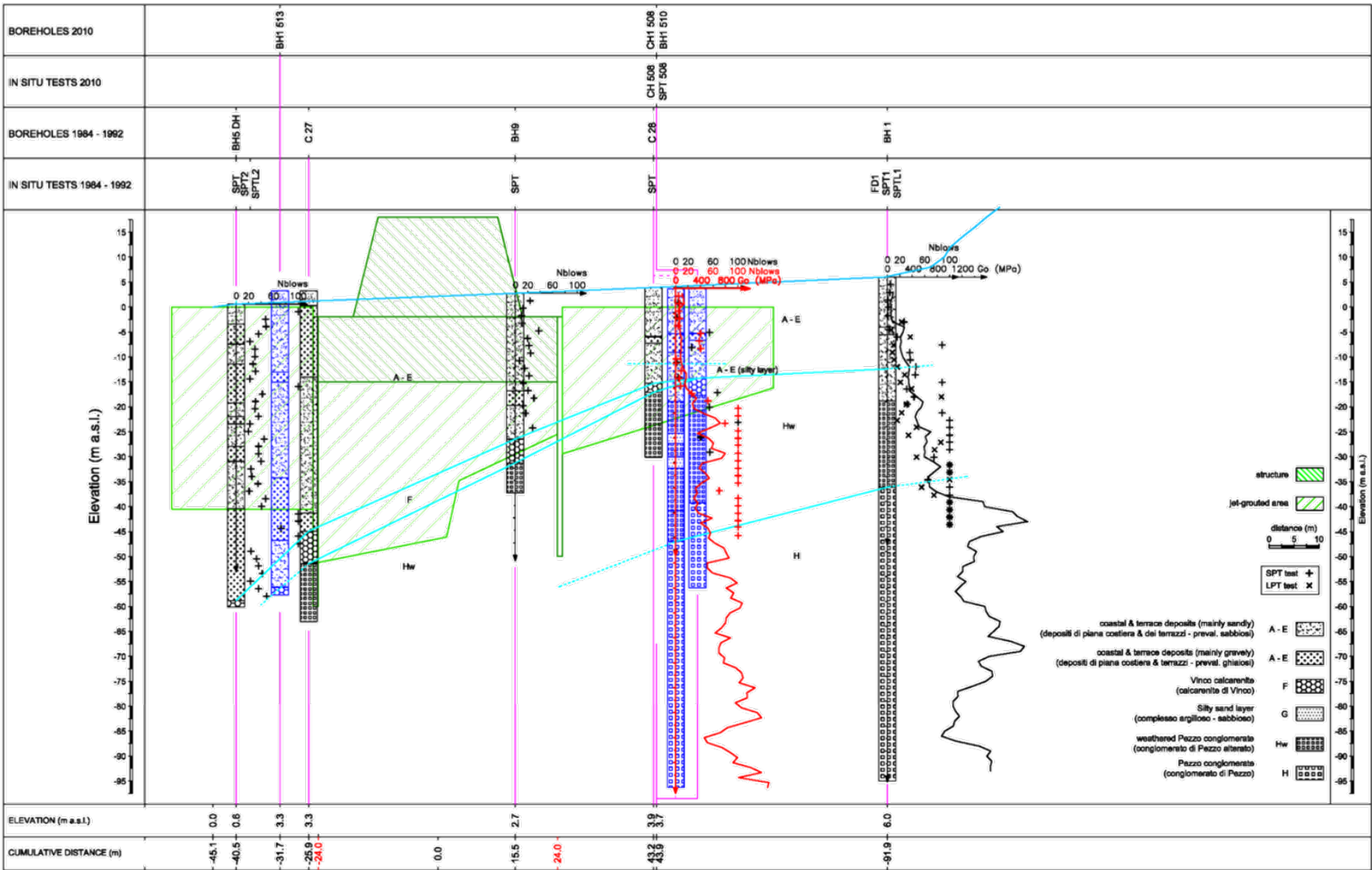
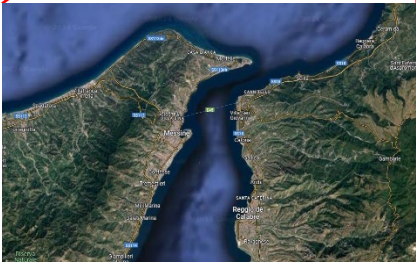
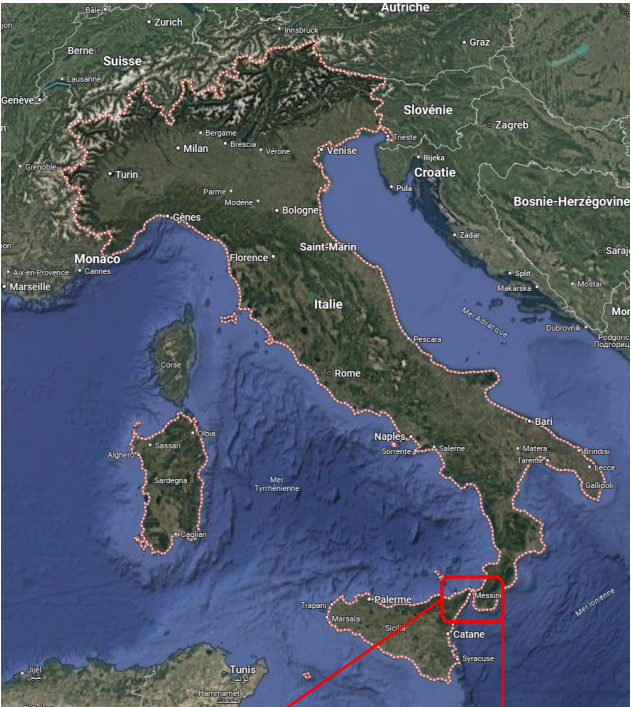


a. Record Illustrating a Direct Travel Time Measurement of an SV Wave

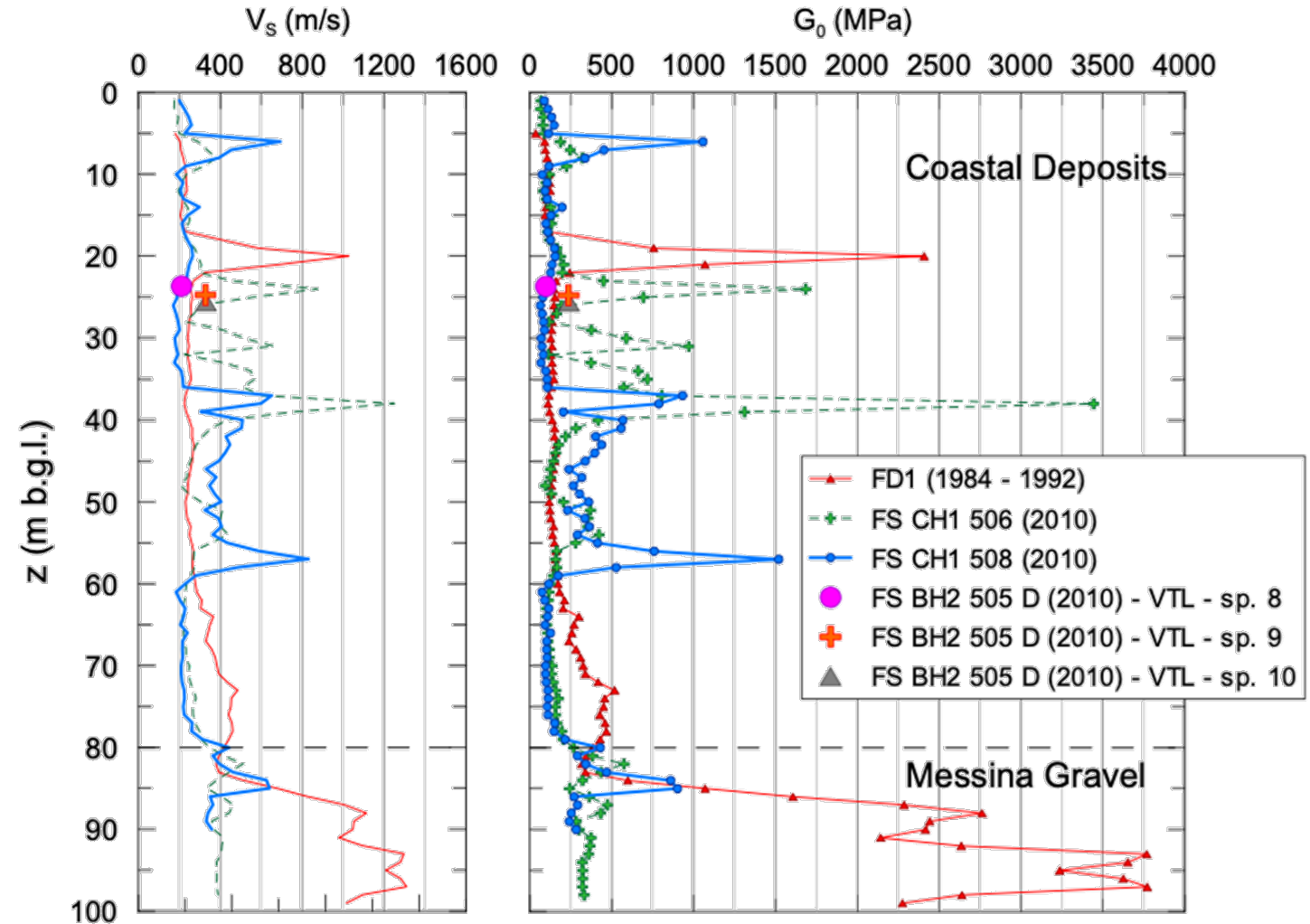
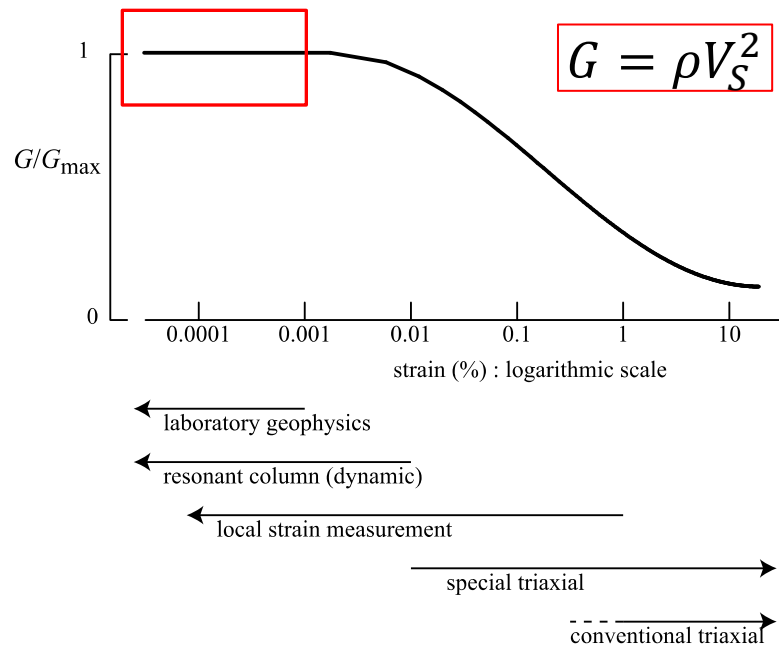


after Santamarina and Stokoe, 2000

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

