Which In-Situ Test Should I Use A Designer's Guide

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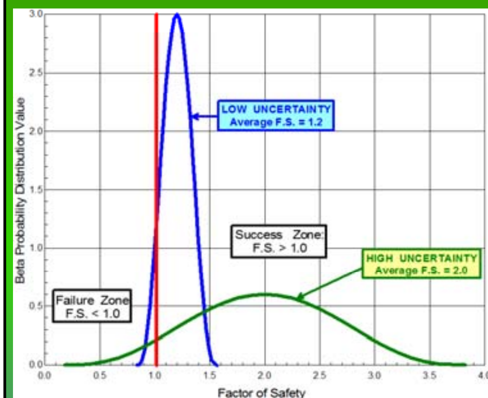
Design Uncertainty

- Design Method—How well does the method predict what will occur
  - Focus of Presentation
- Test Repeatability—Operator Skill
- Geologic Conditions—Homogeneous or Heterogeneous
  - Cannot Control—Nature of the Site
  - What makes Geotechnical Design more interesting than Structural Design (my opinion)

Reducing Uncertainty/Risk



- Select the in-situ test and design method to minimize uncertainty
- For civil engineering applications, probability distribution curves tend to be "bell" shaped
- The total area under the probability distribution curve must equal exactly 1.0.
  - Probability of success + probability of failure = 1.0
- Use term "probability of success" with owner

In-Situ Tests and Their Use in U.S.

Test	Use
SPT	Common, Rarely Calibrated, High Uncertainty
DMT	Underused, Strength and Deformation
CPT	Common, Over Rated—Pretty Graphs
PMT	Common, Harder Soils/Rock
BST	Underused, Drained Shear Strength
VST	Rare, Undrained Shear Strength of Clay
KoSBT	Rare, Ko
FHPT	New, Permeability
PLT/CTL	Rare, Deformation

SPT

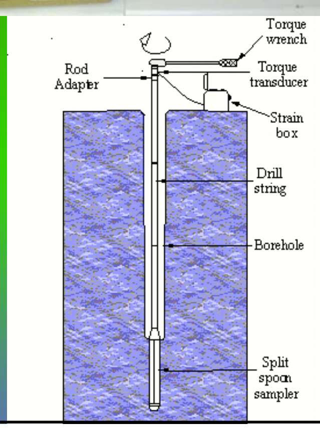
- Test has significantly changed since design correlations were made (1940-1960s)
  - Terzaghi & Peck, 1948
- Engineer must use N_{60}-values to properly use those correlations
- N_{60}-values rarely shown on boring logs
- Using only N-values leads to overly conservative and expensive designs
- SPT is a dynamic test—may not model soil's behavior to static structure loads

N_{60} (Skempton, 1986)

- Because the SPT is an operator dependent and highly variable test, should this correction be made?
  - YES, if we are going to use those numbers in our design
- A well-maintained CME Automatic hammer delivers about 95% of theoretical energy
  - Cut rope test—Schmertmann
  - Correction = 55%
- Old split spoon samplers, barrel had same ID as tip; New samplers are made for liners and barrel has a larger ID than tip
  - Less friction
  - Correction 20% (Skempton)
- Also rod length and hole size corrections

SPT Hammer Types and Approximate Energies

a) Automatic Hammer ~95% eff.,
b) Safety Hammer ~60% eff.,
c) Donut Hammer ~45% eff.
(photos from GeoServices Corp.)

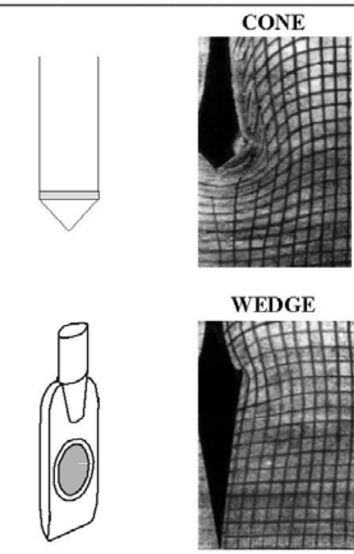


Courtesy of University of Massachusetts

Dilatometer Test

- Calibrated static deformation test
- Performed at 0.1 to 0.2m intervals (near-continuous)
- Low volumetric and shear strain induced during penetration—measures significance of lateral stress
- Accurately measures deformation modulus, drained friction angle in sands and undrained shear strength in clays
- Test Repeatability Error: 5-15%
- Easy to use from drill rig, barge, even row boat

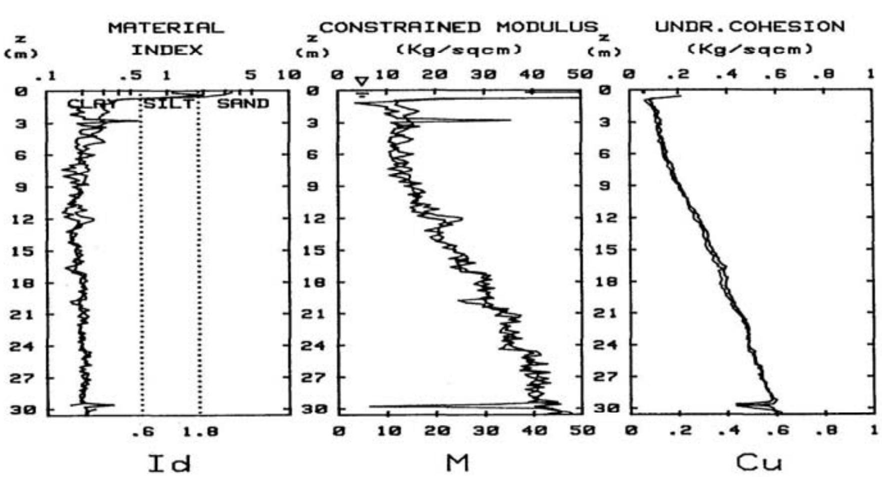
DISTORTIONS due to INSERTION



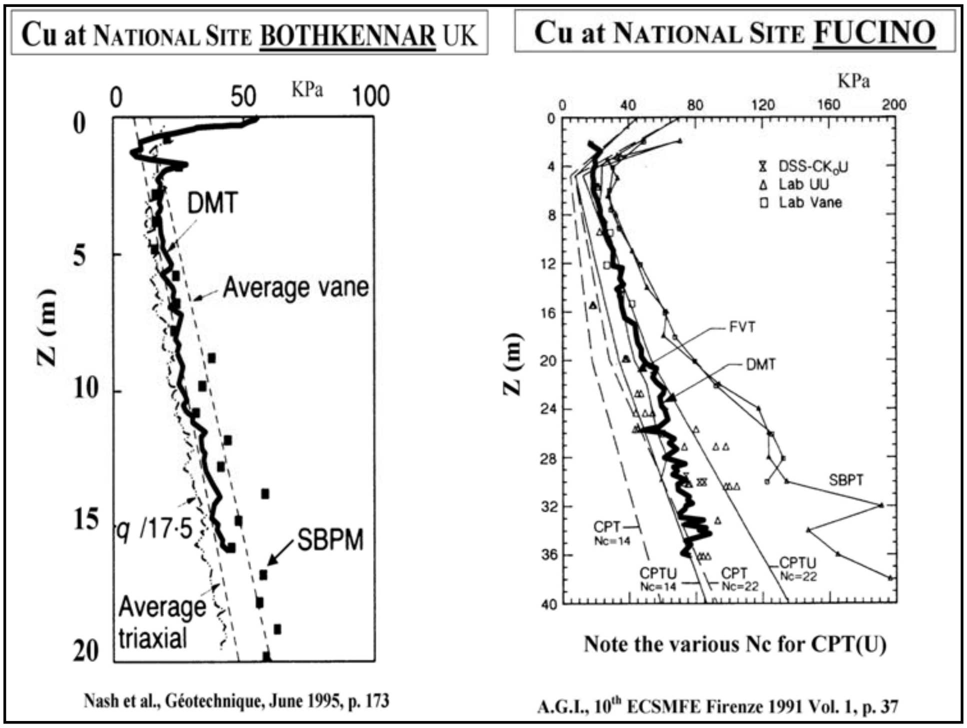
Photographs of distortions in clay from : Baligh & Scott (Nov. 1975) "Quasi-Static Deep Penetration in Clay", Jnl. ASCE Geot. Eng. Div.

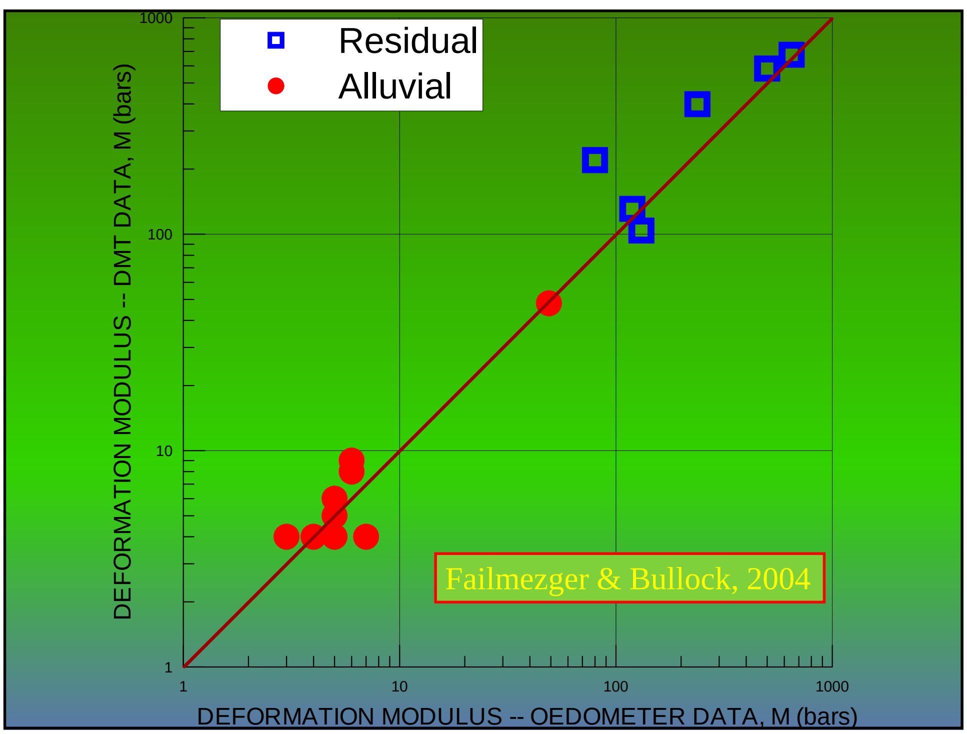
REPRODUCIBILITY of DMT

Cestari (SGI), Lacasse (NGI), Lunne (NGI), Marchetti (Aq)



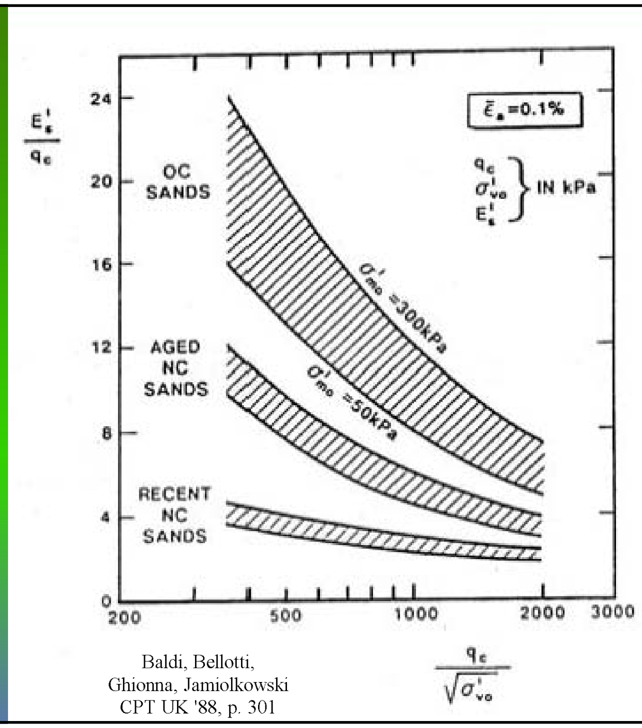
NC clay Onsoy, Norway


Cu at NATIONAL SITE BOTHKENNAR UK
0
50
KPa
100
Z (m)
DMT
Average vane
q /17·5
SBPM
Average triaxial
Nash et al., Géotechnique, June 1995, p. 173
Cu at NATIONAL SITE FUCINO
KPa
Z (m)
DSS-CK0U
Lab UU
Lab Vane
FVT
DMT
SBPT
CPT Nc=14
CPTU Nc=14
CPT Nc=22
CPTU Nc=22
Note the various Nc for CPT(U)
A.G.I., 10th ECSMFE Firenze 1991 Vol. 1, p. 37


Residual
Alluvial
DEFORMATION MODULUS -- DMT DATA, M (bars)
DEFORMATION MODULUS -- OEDOMETER DATA, M (bars)
1
10
100
1000
Failmezger & Bullock, 2004

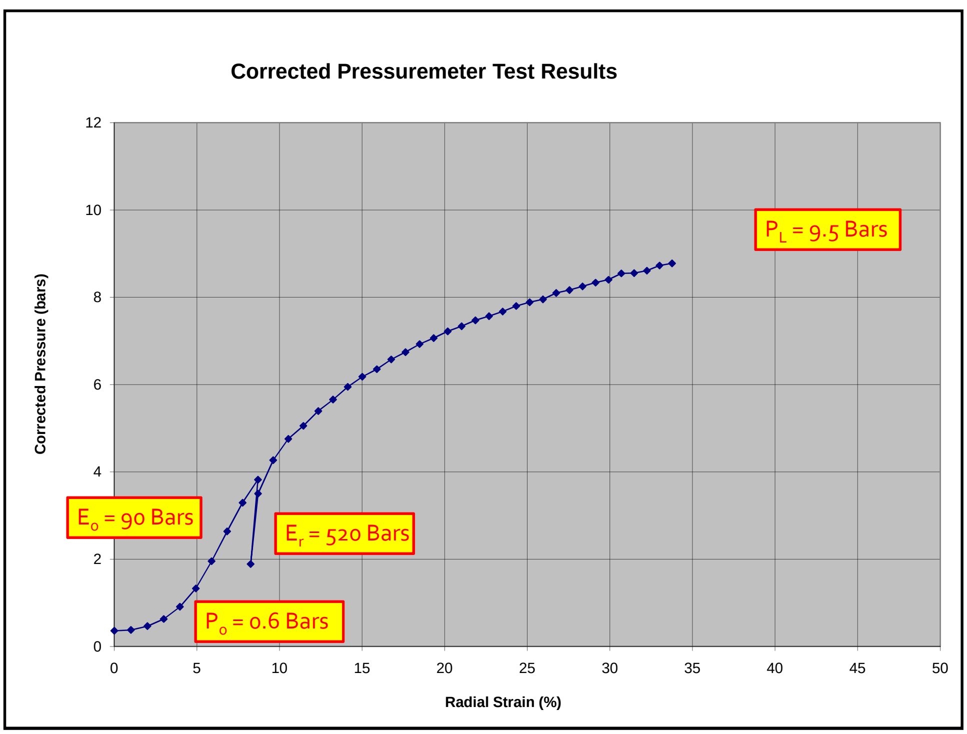
Electric Cone Penetration Test

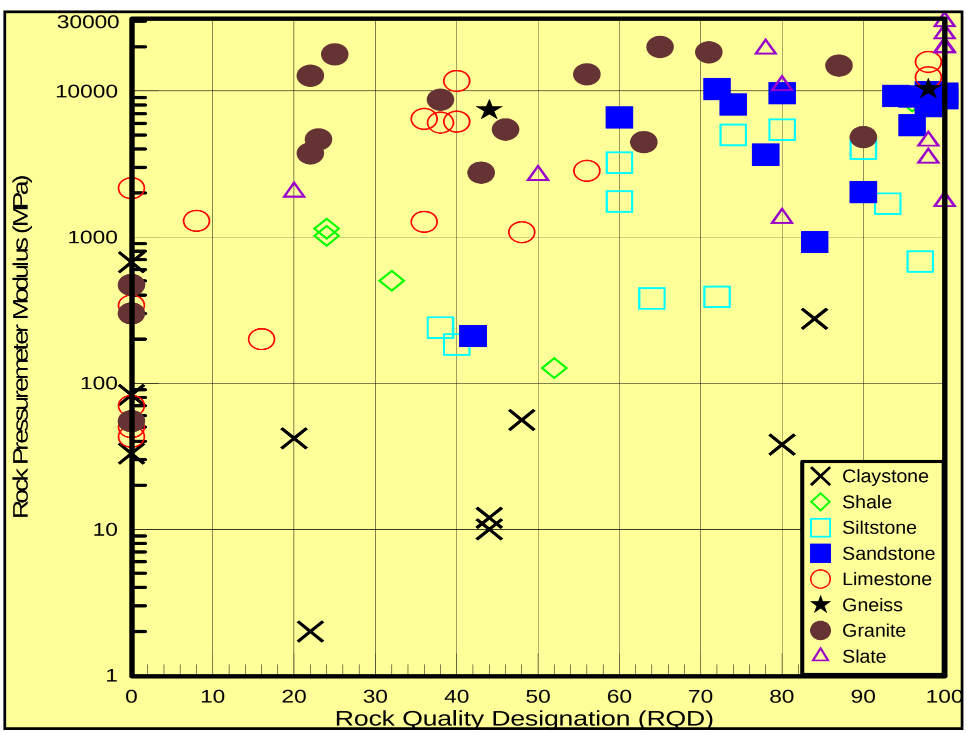
- Calibrated quasi-static penetration test
- Data collected at 0.01 to 0.05m intervals (continuous test)
- Most Accurate Test for Stratigraphy
- Rapidly characterize sites—identify critical soft zones—find top of rock
- Vertical pile capacity—ideal model
- Test Repeatability Error: 5-15%



Pressuremeter Test

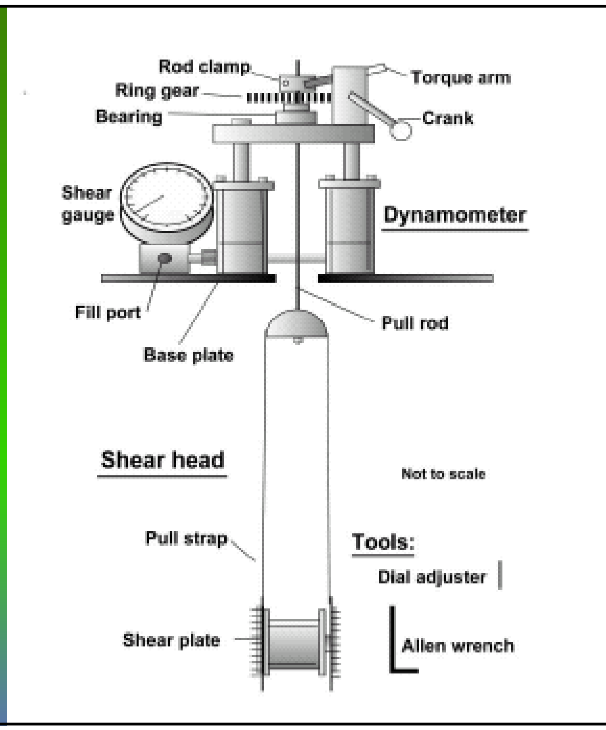
- <u>Calibrated</u> static deformation test
- Requires high quality undisturbed borehole
- Test interval => 1.5 meter (5 feet)
- Good for non-penetrable soils and rock
- Large case study data base used for development of design correlations


Corrected Pressuremeter Test Results
Corrected Pressure (bars)
Radial Strain (%)
0
2
4
6
8
10
12
0
5
10
15
20
25
30
35
40
45
50
P_L = 9.5 Bars
E_o = 90 Bars
E_r = 520 Bars
P_o = 0.6 Bars

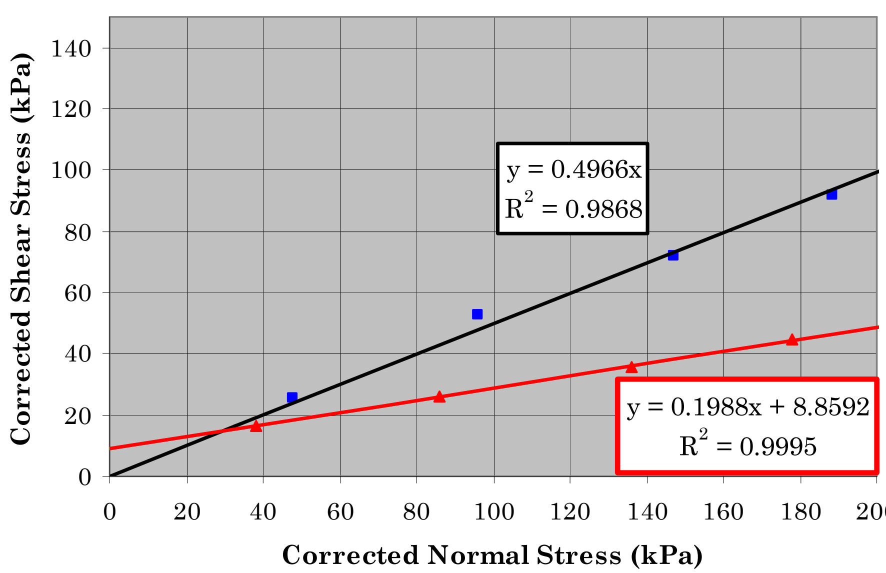

Rock Pressuremeter Modulus (MPa)
30000
10000
1000
100
10
1
0
10
20
30
40
50
60
70
80
90
100
Rock Quality Designation (RQD)
Claystone
Shale
Siltstone
Sandstone
Limestone
Gneiss
Granite
Slate

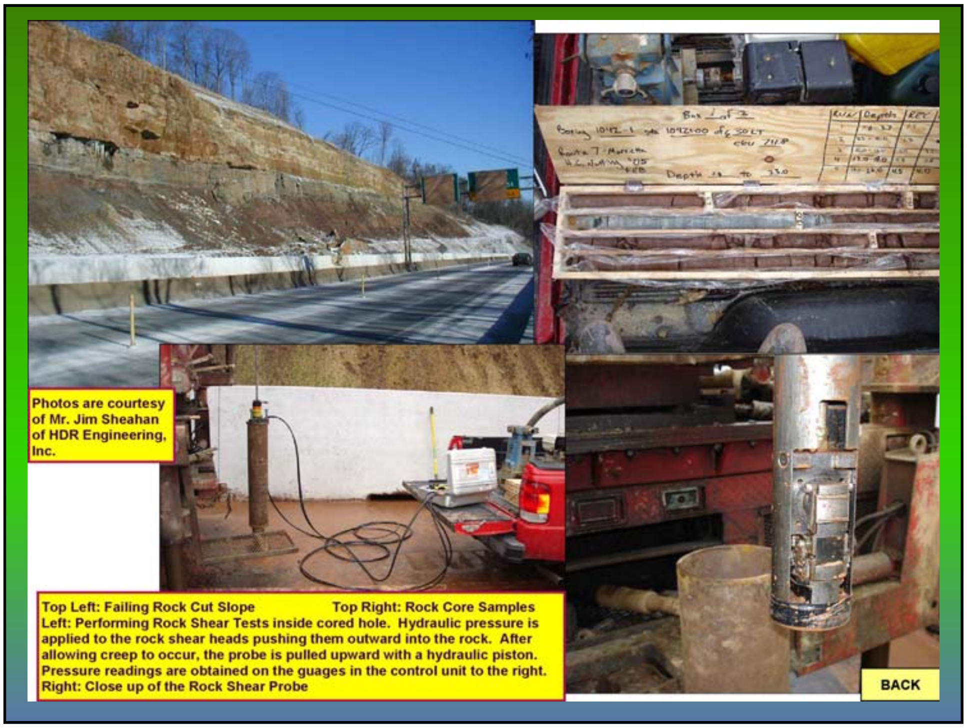
Borehole Shear Test

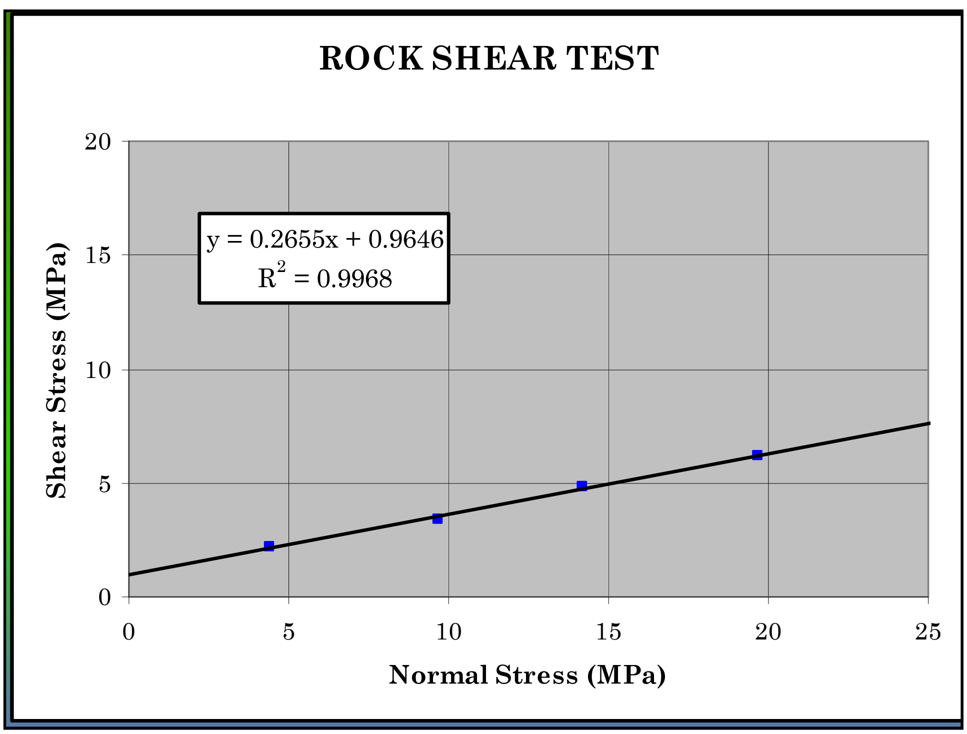
- Calibrated static test
- Accurately measures drained shear strength in sand and clay
- Least Squares Coeff. of Correlation > 0.98
- Compares very well with laboratory triaxial shear strength test results
  - Like a Direct Shear Test against Borehole Sidewalls
- Requires minimal disturbance to borehole sidewalls



BOREHOLE SHEAR TEST




Photos are courtesy of Mr. Jim Sheahan of HDR Engineering, Inc.
Top Left: Failing Rock Cut Slope
Top Right: Rock Core Samples
Left: Performing Rock Shear Tests inside cored hole. Hydraulic pressure is applied to the rock shear heads pushing them outward into the rock. After allowing creep to occur, the probe is pulled upward with a hydraulic piston. Pressure readings are obtained on the guages in the control unit to the right.
Right: Close up of the Rock Shear Probe
BACK


ROCK SHEAR TEST
y = 0.2655x + 0.9646
R2 = 0.9968
Shear Stress (MPa)
Normal Stress (MPa)
0
5
10
15
20
25

Choosing In-Situ Tests for Design

- What are the critical design problems?
- Must match the in-situ test to solve those problems
- Historically, each in-situ test was developed to solve a geotechnical problem
- In-situ tests will always save money on significant projects

Shallow Foundation Design

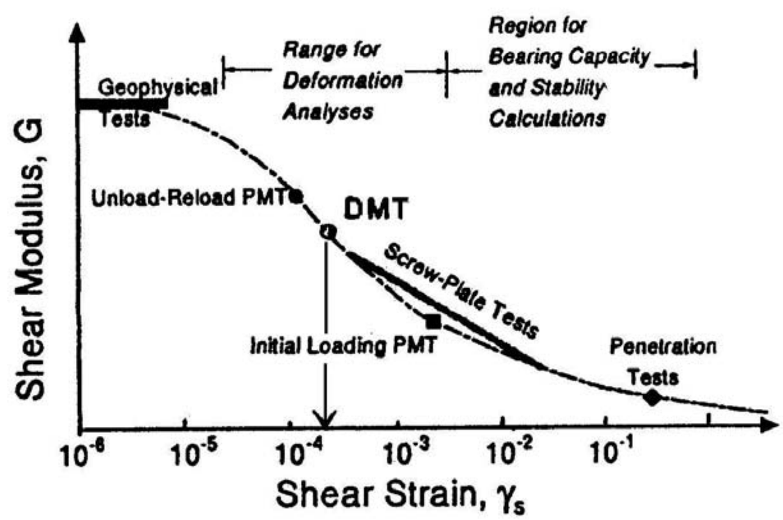
- Geotechnical engineers have an obligation or duty to their clients to prove that a shallow foundation will not work before recommending a deep foundation
- "Allowable bearing capacity" shown in reports is a bit of a misnomer as settlement (deformation) rather than bearing capacity (strength) usually controls design

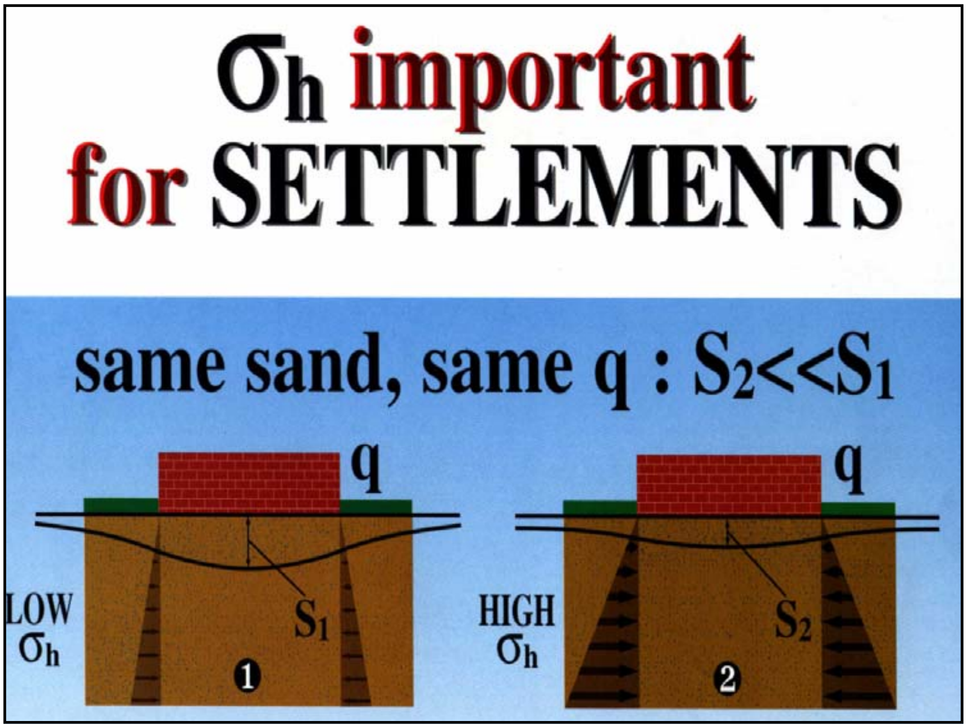
Shallow Foundations

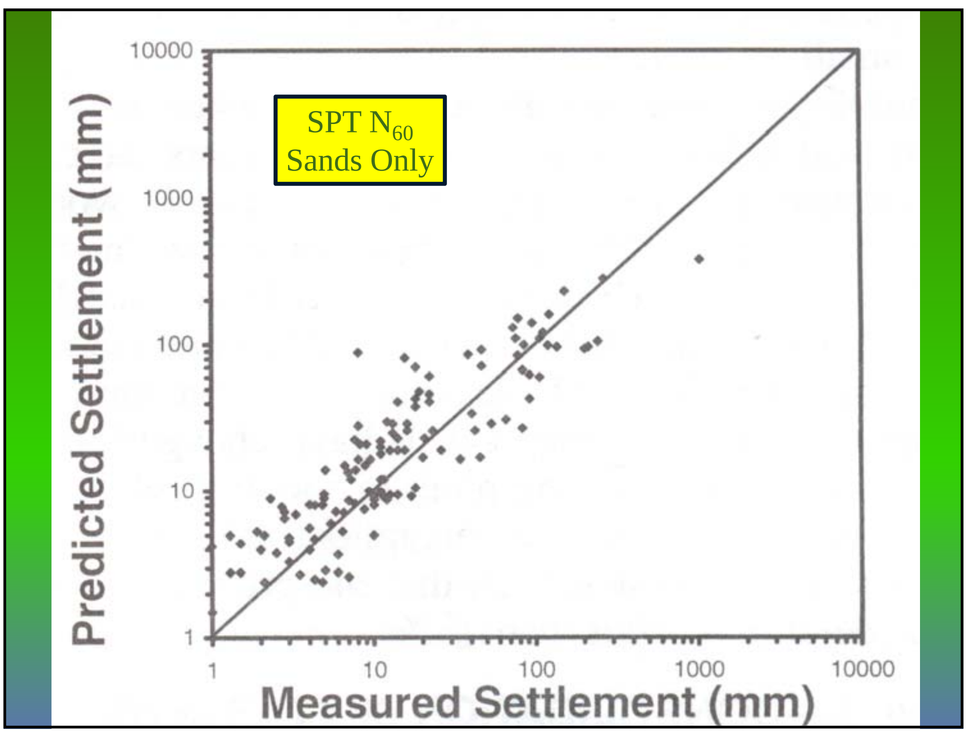
Test	Settlement (Cohesive)	Settlement (Cohesionless)
SPT	N/A	3
DMT	1	1
CPT	2-3	2-3
PMT	1	1

γ - RANGE of MODULUS by DMT

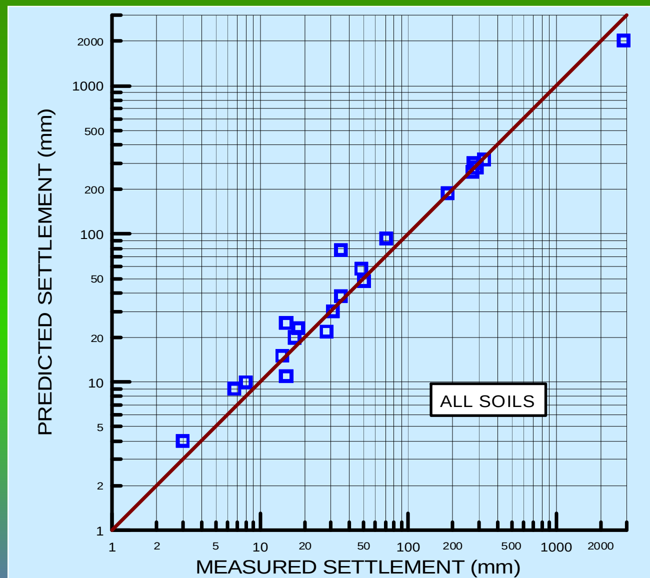
Mayne – Insitu 2001, Bali




σh important
for SETTLEMENTS
same sand, same q : S2<<S1
q
q
LOW
σh
S1
1
HIGH
σh
S2
2

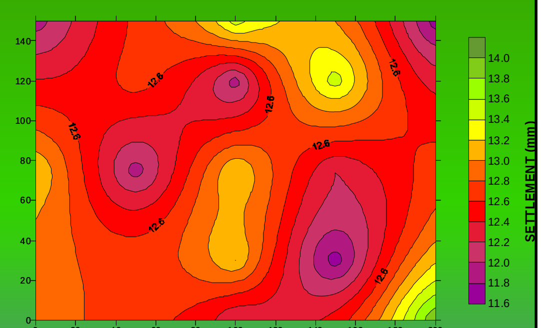

SPT N60
Sands Only
Predicted Settlement (mm)
Measured Settlement (mm)
1
10
100
1000
10000

Dilatometer Predicted Settlements after Schmertmann (1986) and Hayes (1986)



Ideal Spread Footing Design

- Design each footing individually for its column load so that an even amount of settlement occurs under the structure
- Each test hole is a prediction
- Use a weighted average for column not adjacent to in-situ test locations

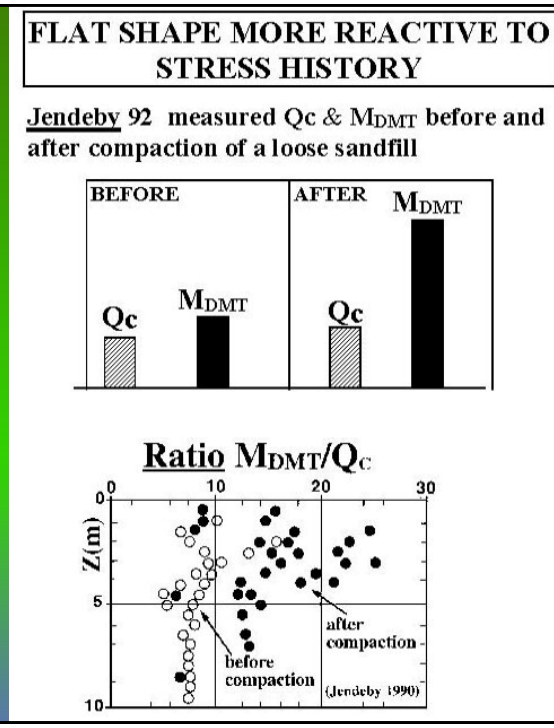


Slope Stability

Test	Cohesive	Cohesionless
SPT	3	3
DMT	1	1
CPT	3	2
BST	1	1
VST	1	N/A

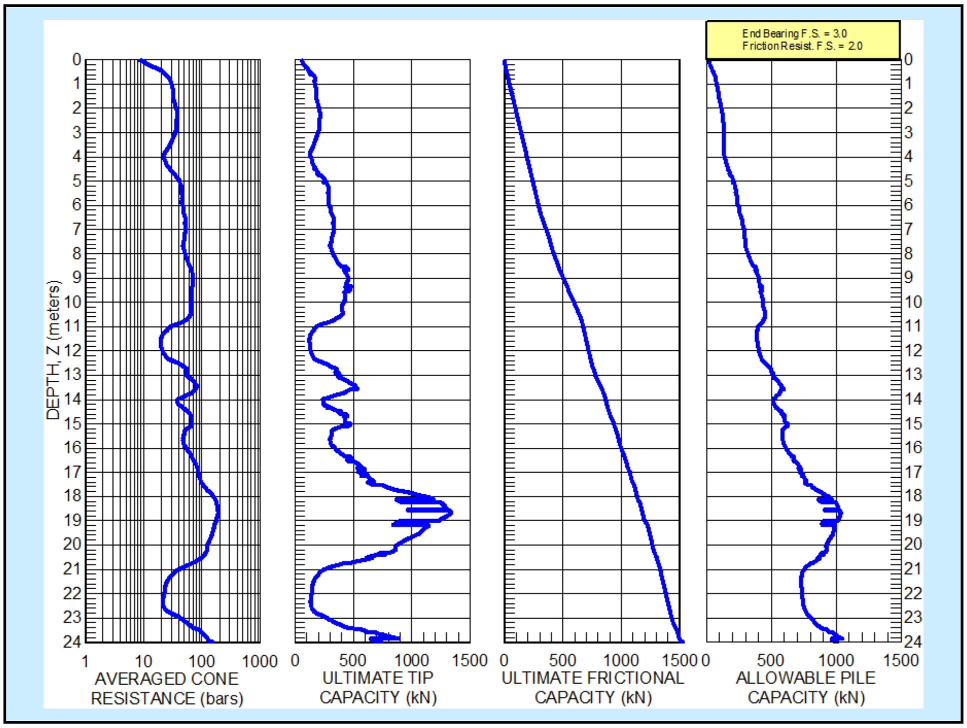
Ground Improvement

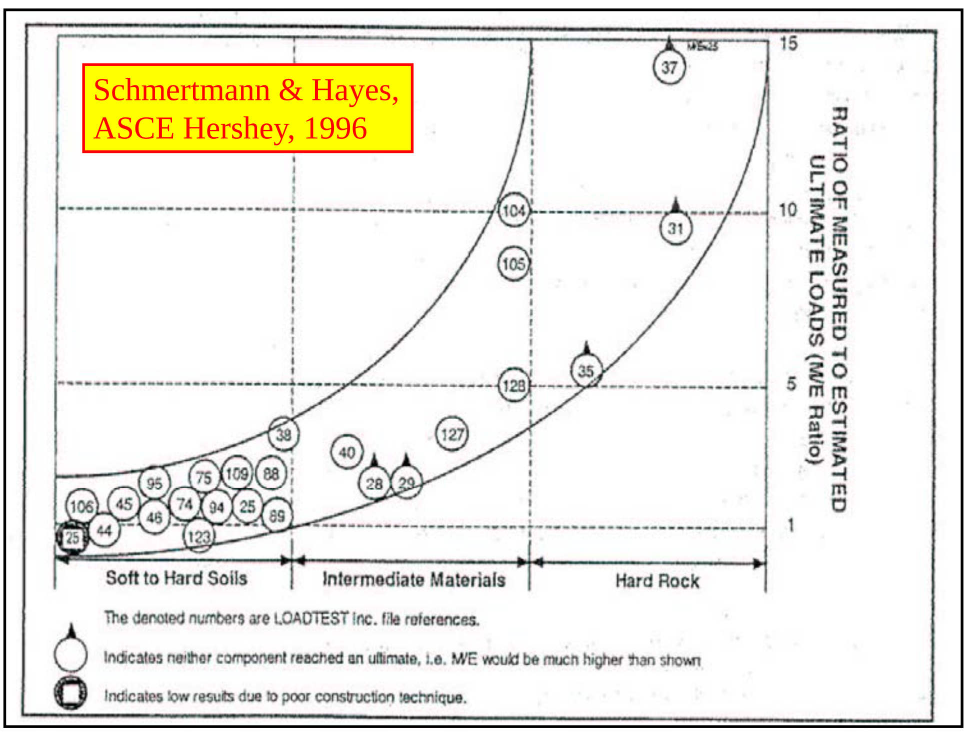
Test	Cohesive	Cohesionless
SPT	3	2-3
DMT	1	1
CPT	1-2	1-2
PMT	1-2	1-2
BST	N/A	1
VST	1	N/A



Deep Foundations--Axial

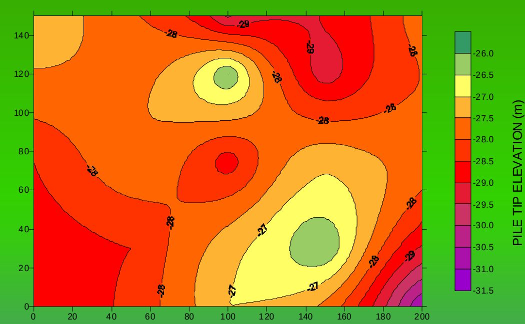
Test	Cohesive	Cohesionless
SPT	1	1
DMT	2	2
CPT	1	1
PMT	1	1
BST	2	2
VST	2	N/A


End Bearing F.S. = 3.0
Friction Resist. F.S. = 2.0
DEPTH, Z (meters)
AVERAGED CONE RESISTANCE (bars)
ULTIMATE TIP CAPACITY (kN)
ULTIMATE FRICTIONAL CAPACITY (kN)
ALLOWABLE PILE CAPACITY (kN)


Schmertmann & Hayes, ASCE Hershey, 1996
RATIO OF MEASURED TO ESTIMATED ULTIMATE LOADS (M/E Ratio)
Soft to Hard Soils
Intermediate Materials
Hard Rock
The denoted numbers are LOADTEST Inc. file references.
Indicates neither component reached an ultimate, i.e. M/E would be much higher than shown
Indicates low results due to poor construction technique.

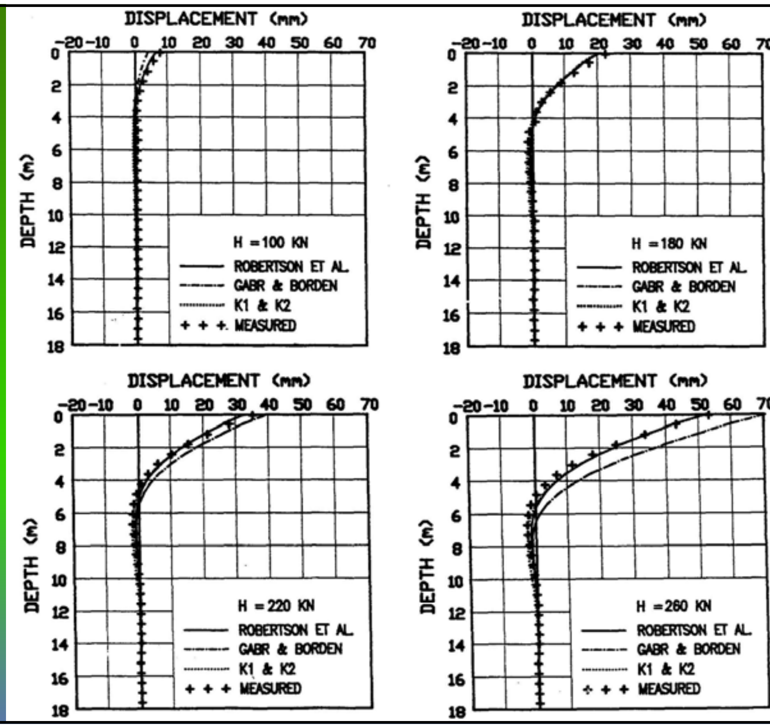
Ideal Vertical Pile Capacity Design

- Choose the number and depth of pile so that their allowable capacity equals the column load
- Use a weighted average technique for columns not adjacent to CPT sounding



Deep Foundations--Lateral

Test	Cohesive	Cohesionless
SPT	3	3
DMT	1	1
CPT	N/A	N/A
PMT	1	1



Conclusions

- Shallow Foundations—Use DMT & PMT
- Slope Stability Design—Use BST, DMT, VST
- Ground Improvement—Use DMT & CPT
- Deep Foundation Axial Capacity—Use SPT & CPT
- Deep Foundation Lateral Capacity—Use DMT & PMT