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

- Roger A. Failmezger, P.E., F. ASCE

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.

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

**CONE**

**WEDGE**

Photographs of distortions in clay from:
- Dalglish & Scorn (Dec. 1978)
- "Quicksand"
- Deep Penetration in Clay", Jnl. ASCE
- Gross, Eng. Ind.

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**REPRODUCIBILITY of DMT**

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

<table>
<thead>
<tr>
<th>MATERIAL INDEX</th>
<th>CONSTRRAINED MODULUS (Kg/sqcm)</th>
<th>UNDR. COHESION (Kg/sqcm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ID</td>
<td>0.1 0.5 1</td>
<td>0 10 20 30 40 50 60 70 80 90 100</td>
</tr>
<tr>
<td>M</td>
<td>CLAY SILT SAND</td>
<td></td>
</tr>
<tr>
<td>Cu</td>
<td></td>
<td>0.3 0.5 0.7 0.9 1</td>
</tr>
</tbody>
</table>

NC clay Onsøy, Norway
Residual

Alluvial

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

- Calibrated 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 (%)

$P_i = 9.5$ Bars

$E_o = 90$ Bars

$E_t = 520$ Bars

$P_s = 0.6$ Bars
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

![Diagram of Borehole Shear Test Equipment]
BOREHOLE SHEAR TEST

\[ y = 0.4966x \]
\[ R^2 = 0.9868 \]

\[ y = 0.1988x + 8.8592 \]
\[ R^2 = 0.9995 \]
ROCK SHEAR TEST

\[ y = 0.2655x + 0.9646 \]

\[ R^2 = 0.9968 \]
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

<table>
<thead>
<tr>
<th>Test</th>
<th>Settlement (Cohesive)</th>
<th>Settlement (Cohesionless)</th>
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</thead>
<tbody>
<tr>
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<tr>
<td>DMT</td>
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<tr>
<td>CPT</td>
<td>2-3</td>
<td>2-3</td>
</tr>
<tr>
<td>PMT</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

**γ - RANGE of MODULUS by DMT**

*Mayne – Insitu 2001, Bali*
\( \sigma_h \) is important for SETTLEMENTS

same sand, same \( q \) : \( S_2 \ll S_1 \)

![Diagram showing settlement comparison with low and high \( \sigma_h \)]

![Graph showing predicted vs. measured settlement for SPT N<sub>60</sub> sands only]
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

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<tr>
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<th>Cohesionless</th>
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</thead>
<tbody>
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<td>3</td>
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<tr>
<td>DMT</td>
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<td>1</td>
</tr>
<tr>
<td>CPT</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>BST</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>VST</td>
<td>1</td>
<td>N/A</td>
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</table>

## Ground Improvement

<table>
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<tbody>
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<td>SPT</td>
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<td>CPT</td>
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<tr>
<td>PMT</td>
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<td>1-2</td>
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<tr>
<td>BST</td>
<td>N/A</td>
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</tr>
<tr>
<td>VST</td>
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</table>
Deep Foundations--Axial

<table>
<thead>
<tr>
<th>Test</th>
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<tbody>
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<td>1</td>
</tr>
<tr>
<td>DMT</td>
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<td>2</td>
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<tr>
<td>CPT</td>
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<td>1</td>
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<tr>
<td>BST</td>
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<td>2</td>
</tr>
<tr>
<td>VST</td>
<td>2</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Schmertmann & Hayes, ASCE Hershey, 1996
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

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>SPT</td>
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<td>3</td>
</tr>
<tr>
<td>DMT</td>
<td>1</td>
<td>1</td>
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<tr>
<td>CPT</td>
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<td>N/A</td>
</tr>
<tr>
<td>PMT</td>
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</tbody>
</table>
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