Stuttgarter Geotechnik-Seminar
Monday, 16 November 2020

Applications of Dilatometer (DMT) and Seismic Dilatometer (SDMT) in Geotechnical Engineering

Eng. Diego Marchetti
Studio Prof. Marchetti
Italy
Many different tools for site investigation..

“Soil borings ... laboratory testing ... SPT ... pressuremeter (PMT) ... vane (VST) ... crosshole (CHT) ... All of these are valid and suitable ... yet at considerable cost in time and money ...”  Mayne 2009
Direct Push Technology: SCPT & SDMT increasing leadership in penetrable soils:

Direct Push Technology:
- simple
- fast
- repeatable
- continuous soil profile
- results real time

Sands:
recovering undisturbed samples very difficult

→ Direct Push Technology is the state-of-practice
Seismic Dilatometer (S + DMT)

Seismic Dilatometer (SDMT)

Flat Dilatometer 1980

Seismic Module 2004
Prof. Silvano Marchetti (1943 – 2016)

inventor of the Flat Dilatometer (1974)
Flat Dilatometer (DMT)

Flexible Steel Membrane
Φ = 60 mm

BLADE
Test Procedure

stop every 20 cm

A : Lift-off pressure

B : Pressure for 1.1 mm expansion

Deflate after B

C : Closing pressure
DMT Data: A, B and C with depth (Z)

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<td>32.20</td>
<td>1,681</td>
<td>3,643</td>
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</table>

Buzzer

Project: Catania Harbour - Test: SDMT 2
SDMT – Test Layout

Seismic module

Top Sensor

Electronics

Bottom Sensor

Penetration Machine

TRUE INTERVAL

\[
Vs = \frac{(S_2 - S_1)}{\Delta t}
\]

\[
G_0 = \rho \cdot V_s^2
\]
Shear wave velocity measurement
Generate S-wave at surface
Data transfer of seismic wave ($\approx 5$ sec)
Vs available real time
SDMT main features

SDMT

- Test execution is rapid
  - no hole (if soil is penetrable)
  - no wait time for cementation (e.g. crosshole, downhole)

- Vs interpretation
  - Automatic
  - operator independent
  - real time

Accuracy of delay (Δt) calculation
- Signals are amplified and digitized in depth → clean waves → delay Δt very clear
- True-interval (2 receivers) vs Pseudo-interval (1 receiver)
  - Trigger offset no influence on Δt calculation
  - Same wave to both receivers
SPD MT for compression wave velocity
Heavy Truck Penetrometer – most efficient

Able to push 20+ tons without lateral instability
Light Penetrometer – cost effective

Economical and easy to transport, but requires anchoring

Juan Santamaria Airport, Costa Rica
Many ways for advancing the DMT blade

Driven by Spt tripod

Pushed by drill rig

Driven by drill rig

Driven or pushed by light penetrometer
Soils testable by DMT/SDMT

DMT
- **ALL SANDS, SILTS, CLAYS**
  - Very soft soils (Su = 2-4 kPa, M=0.5 MPa)
  - Hard soils/Soft Rock (Su = 1 MPa, M=400 MPa)
  - Blade robust (safe push 25 ton)

SDMT
- All penetrable soils (like DMT above)
- Also in non penetrable soils like gravel, very dense sand, etc: inside a backfilled borehole (Totani et al 2009)
Max depth: 135 m in L’Aquila (2009)
Interpretation of the Results
Corrected readings:

to account for membrane rigidity (calibration)

DMT Field Readings

A
B
C

Corrected Readings

P₀: Corrected A reading
P₁: Corrected B reading
P₂: Corrected C reading
DMT Intermediate parameters

**Corrected Readings**

- $P_0$
- $P_1$
- $P_2$

**Intermediate Parameters**

- $I_D$: Material Index
- $K_D$: Horizontal Stress Index
- $E_D$: Dilatometer Modulus
- $U_D$: Pore Pressure Index

$I_D$, $K_D$, $E_D$, $U_D$ are definitions, not correlations !!!
Interpreted Geotechnical Parameters

Intermediate Parameters

- $I_D$
- $E_D$
- $K_D$
- $U_D$

Interpreted Geotechnical Parameters

- $M$: Constrained Modulus
- $Cu$: Undrained Shear Strength (clay)
- $K_0$: Earth Pressure Coeff (clay)
- $OCR$: Overconsolidation Ratio (clay)
- $\Phi$: Safe floor friction angle (sand)
- $\gamma$: Unit weight and description
- $U$: Pore pressure (sand)
- Drained vs Undrained behaviour
## DMT Formulae (1980 - today)

<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>PARAMETER NAME</th>
<th>FORMULA /DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>First Reading</td>
<td>Membrane lift-off pressure</td>
</tr>
<tr>
<td>B</td>
<td>Second Reading</td>
<td>Pressure for 1.1 mm membrane expansion</td>
</tr>
<tr>
<td>C</td>
<td>Third Reading</td>
<td>Membrane closing pressure</td>
</tr>
<tr>
<td>ΔA</td>
<td>Membrane Calibration (A in free air)</td>
<td>Suction as positive pressure</td>
</tr>
<tr>
<td>ΔB</td>
<td>Membrane Calibration (B in free air)</td>
<td>Inflation as positive pressure</td>
</tr>
<tr>
<td>[T, A]</td>
<td>Dissipation Test Readings</td>
<td>A-readings with time (at specific depth)</td>
</tr>
<tr>
<td>P₀</td>
<td>Corrected First Reading</td>
<td>[ P₀ = 1.05 (A + \Delta A) - 0.05 (B - \Delta B) ]</td>
</tr>
<tr>
<td>P₁</td>
<td>Corrected Second Reading</td>
<td>[ P₁ = B - \Delta B ]</td>
</tr>
<tr>
<td>P₂</td>
<td>Corrected Third Reading</td>
<td>[ P₂ = C + \Delta A ]</td>
</tr>
<tr>
<td>I₀</td>
<td>Material Index</td>
<td>[ I₀ = \frac{P₁ - P₀}{P₀ - U₀} ]</td>
</tr>
<tr>
<td>Kₒ</td>
<td>Horizontal Stress Index</td>
<td>[ Kₒ = \frac{P₀ - U₀}{\sigma' v₀} ]</td>
</tr>
<tr>
<td>Eₒ</td>
<td>Dilatometer Modulus</td>
<td>[ Eₒ = 34.7 \times (P₁ - P₀) ]</td>
</tr>
<tr>
<td>U₀</td>
<td>Pore Pressure Index</td>
<td>[ U₀ = \frac{P₂ - U₀}{P₀ - U₀} ]</td>
</tr>
<tr>
<td>Tₚ</td>
<td>Dissipation Flex Point</td>
<td></td>
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</table>

### Field Readings

- **I₀**: Material Index
- **Kₒ**: Horizontal Stress Index
- **Eₒ**: Dilatometer Modulus
- **U₀**: Pore Pressure Index
- **Tₚ**: Dissipation Flex Point

### Corrected Readings

- **P₀**: Corrected First Reading
- **P₁**: Corrected Second Reading
- **P₂**: Corrected Third Reading

### Intermediate Parameters

- **I₀**: Material Index
- **Kₒ**: Earth Pressure Coefficient
- **OCR**: Overconsolidation Ratio
- **Su**: Undrained Shear Strength
- **Φ**: Friction Angle
- **M**: Vertical Drained Constrained Modulus

### Interpreted Geotechnical Parameters

- **Cₜ**: Coefficient of Consolidation
- **Kₚ**: Coefficient of Permeability
- **U₀**: Equilibrium Pore Pressure

### SBT chart and \((\gamma / \gamma_{w})\)

![SBT chart](image)

\( I_D \) contains information on soil type

**CLAY**

\[
\frac{P_1}{P_0} \approx 1.1-1.3
\]

**SAND**

\[
\frac{P_1}{P_0} \geq 2.5
\]

SILT falls in between

**Definition:**

\[
I_D = \frac{(P_1 - P_0)}{(P_0 - U_0)}
\]
**I_D contains information on soil type**

### Material Index

```
<table>
<thead>
<tr>
<th>Z (m)</th>
<th>P₀ (bar)</th>
<th>P₁ (bar)</th>
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<td>6.00</td>
<td>7.02</td>
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<tr>
<td>...</td>
<td>...</td>
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</table>
```

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**Diagram:**

- **CLAY**
- **SILT**
- **SAND**

Fiumicino 2005
\( K_D \) contains information on stress history

\[
K_D = \frac{(P_0 - U_0)}{\sigma'_v}
\]

same formula as \( K_0 \): \((P_0 - U_0) \rightarrow \sigma'_h\)

\( K_D \) is an ‘amplified’ \( K_0 \), because \((P_0 - U_0)\)

is an ‘amplified’ \( \sigma'_h \), due to penetration

\( K_D \) well correlated to \( K_0 \) & OCR (clay)
$K_D$ contains information on stress history.

$K_D = 2$ in NC clay (OCR = 1)

$KD > 2$ in OC clay (OCR > 1)

$K_D$ stress history index
$K_D$ contains information on stress history

Material Index

Horizontal Stress Index

Taranto 1987
CLAY: $K_D$ correlated to OCR

$$OCR = \left(0.5 \cdot K_D\right)^{1.56}$$  
Marchetti 1980 (experimental)

Experimental
Kamei & Iwasaki 1995

Theoretical
Finno 1993

Theoretical
Yu 2004

Marchetti 1980

$K_D = \frac{6 - 2M}{5 + M} (OCR)^{3M/6 + M} + \frac{c_1 M}{2^{1/2}} (OCR)^{5 + M}$

Yu by Critical State Modél implemented in CRISP
CLAY: $K_D$ correlated to $K_0$

$$K_0 = \left(\frac{K_D}{1.5}\right)^{0.47} - 0.6$$  Marchetti 1980 (experimental)

Experimental
Marchetti (1980)

Theoretical
2004 Yu

\begin{itemize}
\item Weald clay
\item Kaolin
\item London clay
\end{itemize}

Marchetti 1980

Yu 2004
ISC-2
Porto

Yu by Critical State Model implemented in CRISP
Example: $\sigma'_h$ relaxation behind a landslide ($K_0$)

Case History (2002):
Landslide in Milazzo, Sicily

\[ \sigma'_h \text{ obtained using } K_0 \text{ from DMT} \]
**ED** contains information on deformation

**Theory of elasticity:**

\[ ED = \text{elastic modulus of the horizontal load test performed by the DMT membrane (D = 60mm, 1.1 mm expansion)} \]

\[ ED = 34.7 \cdot (P_1 - P_0) \]

**Gravesen S.** "Elastic Semi-Infinite Medium bounded by a Rigid Wall with a Circular Hole", Danmarks Tekniske Højskole, No. 11, Copenhagen, 1960, p. 110.

**ED** not directly usable \(\rightarrow\) corrections (penetration, etc)
M obtained from $E_D$ using information on soil type $I_D$ and stress history $K_D$
M Comparison from DMT and from Oedometer

Virginia - U.S.A.

ONSOY Clay - NORWAY

Tokyo Bay Clay - JAPAN

Norwegian Geotechnical Institute (1986). "In Situ Site Investigation Techniques and interpretation for offshore practice". Report 40019-28 by S. Lacasse, Fig. 16a, 8 Sept 86

Failmezger, 1999

Su in clay (Ladd 1977 Tokyo)

Ladd: best Su measurement not from TRX UU !!
best Su: oedometer $\rightarrow$ OCR $\rightarrow$ SHANSEP

\[
\left( \frac{\text{Su}}{\sigma'_v} \right)_{OC} = \left( \frac{\text{Su}}{\sigma'_v} \right)_{NC} \cdot \text{OCR}^m
\]

\[
\text{OCR} = \left( 0.5 \cdot K_D \right)^{1.56}
\]

Using $m \approx 0.8$ (Ladd 1977) and $(\text{Su}/\sigma'_v)_{NC} \approx 0.22$ (Mesri 1975)

\[
\text{Su} = 0.22 \sigma'_v \left( 0.5 \cdot K_D \right)^{1.25}
\]
Su comparisons from DMT and from other tests

**Recife - Brazil**

- **Su (kPa)**
  - 10 20 30 40 50 60 70
  - Triaxial UU - C
  - Triaxial CIU - C
  - DMT-Marchetti, 1980
  - CPTU-Lunne et al., 1985 - N\textsubscript{AU}
  - PMT-Powell, 1990

**Skeena Ontario – Canada**

- **Cu**
  - Undr. Cohesion (Kg/sq cm)
  - FV
  - gravel?
  - shells?

**Tokyo Bay Clay - Japan**

- **Cu**
  - Undr. Cohesion (Kg/sq cm)

- Mekechuk J. (1983). "DMT Use on C.N. Rail Line British Columbia", First Int.Conf. on the Flat Dilatometer, Edmonton, Canada, Feb 83, 50
CPT: different profiles according to \( N_c (=14-22) \)
Pore water pressure: C Readings ($P_2$)

Schmertmann 1988 (DMT Digest No. 10, May 1988, Fig. 3)

### SAND

- $P_2 \approx U_0$
- Drainage ($\approx$ piezometer)
- $U_D \approx 0$

### CLAY

- $P_2 > U_0$
- No drainage ($\approx$ highlights $\Delta u$)
- $U_D > 0$

**Definition:**

$$U_D = \frac{(P_2 - U_0)}{(P_0 - U_0)}$$
EXAMPLE OF SDMT TESTS IN SAND

Catania Harbour - 2012
SDMT TESTS IN SAND  (Catania 2012)

Material Index

DMT Soil Behavior Type

Corrected C - Reading

Pore Pressure Index

<table>
<thead>
<tr>
<th>Material Index</th>
<th>DMT Soil Behavior Type</th>
<th>Corrected C - Reading</th>
<th>Pore Pressure Index</th>
</tr>
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<tbody>
<tr>
<td>CLAY</td>
<td>SILT</td>
<td>SAND</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Depth [m]</th>
<th>ID</th>
<th>E_d [MPa]</th>
<th>Depth [m]</th>
<th>ID</th>
<th>P_2 [MPa]</th>
<th>Depth [m]</th>
<th>U_d</th>
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<td>0.5</td>
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<td>1.0</td>
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<td>1.0</td>
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<td>1.5</td>
<td>3</td>
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<td>4</td>
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<td>2.0</td>
<td>4</td>
<td>2.0</td>
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</table>

- SDMT 1
- SDMT 2
- SDMT 3
- SDMT 4
- SDMT 5
DMT Dissipation Test

Test procedure:
- Stop penetration (origin $T = 0$ s)
- Repeat only A readings (deflate)

NO MEMBRANE EXPANSION

<table>
<thead>
<tr>
<th>$T$ [min]</th>
<th>$A$ [kPa]</th>
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<tbody>
<tr>
<td>0.280</td>
<td>1,040</td>
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<tr>
<td>0.600</td>
<td>966</td>
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<tr>
<td>0.870</td>
<td>921</td>
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<td>1.350</td>
<td>868</td>
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<tr>
<td>2.430</td>
<td>776</td>
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<tr>
<td>4.600</td>
<td>674</td>
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</table>
Dissipation test in cohesive soils estimate *coefficient consolidation & permeability*

\[ C_h \approx \frac{7 \text{ cm}^2}{T_{\text{flex}}} \]

\[ k_h = \frac{C \times \gamma_w}{M} \]

**Time (min)**

<table>
<thead>
<tr>
<th>( \sigma_h ) (kPa)</th>
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<td>1200</td>
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<td>500</td>
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<tr>
<td>400</td>
</tr>
<tr>
<td>300</td>
</tr>
</tbody>
</table>

**wedge vs cone (dissipation)**

- **cone**  
  From \( u(t) \) in a singular highly disturbed point

- **wedge**  
  From a \( \approx \) mini embankment
  Larger volume in a less disturbed zone

Totani et al. (1998)
**Dissipation test in cohesive soils**

estimate *coefficient consolidation & permeability*

\[ C_h \approx \frac{7 \text{ cm}^2}{T_{\text{flex}}} \]

\[ k_h = \frac{C}{M} \times \gamma_w \]

---

**wedge vs cone (dissipation)**

- **cone**
  - From \( u(t) \) in a singular highly disturbed point

- **wedge**
  - From a \( \approx \) mini embankment
  - Larger volume in a less disturbed zone

---

*Totani et al. (1998)*

ISO (2017). ISO/TS 22476-11, Geotechnical investigation and testing - Field testing Part 11: The Flat Dilatometer Test, 9 pp


NATIONAL STANDARDS:

- **Italy**: Consiglio Superiore Lavori Pubblici (2009), Protezione Civile (2008)
- **Sweden**: Swedish Geotechnical Society SGF report (1994)
- **France**: ISO/TS 22476-11:2005(F)
- **China**: TB10018 (2003), GB50021 (2003), DGJ08-37 (2012)
- ..
SDMT used in over 80 countries (*)

(*) Algeria, Angola, Argentina, Australia, Austria, Bahrain, Bangladesh, Belgium, Bolivia, Bosnia, Brazil, Bulgaria, Canada, Czech Republic, China, Chile, Cyprus, Colombia, Costa Rica, Croatia, Denmark, Ecuador, Egypt, United Arab Emirates, Estonia, Finland, France, Germany, Greece, Guadalupe, Guatemala, Honduras, Hong Kong, Hungary, India, Indonesia, Iran, Ireland, Israel, Italy, Japan, Kazakhstan, Korea, Kosovo, Kuwait, Lithuania, Malaysia, Mauritius, Mexico, Myanmar, Netherland, New Zealand, Norway, Oman, Panama, Peru, Paraguay, Philippines, Poland, Portugal, Romania, Russia, Saudi Arabia, Serbia, Singapore, Slovenia, South Africa, Spain, Sri Lanka, Sweden, Switzerland, Taiwan, Thailand, Tunisia, Turkey, United Kingdom, United States of America, Venezuela, Vietnam.
Main SDMT applications

- Settlements of shallow foundations
- In situ G-\(\gamma\) decay curves
- QA of soil improvement
- Slip surface detection in OC clay
- Liquefaction resistance (CRR)
- Laterally loaded piles (P-y curves)
- Diaphragm walls (springs model)
- FEM input parameters (es. Plaxis)
- Vs for soil sample quality assessment
Settlements Prediction (Modulus)
SETTLEMENTS PREDICTION

- **1-D approach** (classic Terzaghi)
- Primary settlement at working loads \((Fs \approx 2.5-3\) to b.c.\)
Many publications & case histories of good agreement between measured and DMT-predicted settlements / moduli:

- **Failmezger** (2020)
- **Godlewski** (2018)
- **McNulty & Harney** (2014)
- **Berisavijevic** (2013)
- **Vargas** (2009)
- **Bullock** (2008)
- **Monaco** (2006)
- **Lehane & Fahey** (2004)
- **Failmezger** (1999, 2000, 2001)
- **Crapps & Law Engineering** (2001)

- **Tice & Knott** (2000)
- **Woodward** (1993)
- **Iwasaki et al.** (1991)
- **Hayes** (1990)
- **Mayne & Frost** (1988)
- **Schmertmann** 1986,1988)
- **Steiner** (1994)
- **Leonards** (1988)
- **Lacasse and Lunne** (1986)
- ..
- ..
Observed vs. Predicted Settlements by DMT
Silos on Danube Bank (Belgrade)

Silo founded on mat 100 m x 23 m, with qnet = 160 kPa
DMT Settlement prediction: 77 cm
Measured Settlement: 63 cm
DMT +22%

D. Berisavijevic, 2013
Sunshine Skyway Bridge – Tampa Bay – Florida

(Schmertmann – Asce Civil Engineering – March 1988)

World record span for cable stayed post-tensioned concrete box girder concrete construction

M from DMT $\approx 200$ MPa  ($\approx 1000$ DMT data points)
M from laboratory: $M \approx 50$ MPa
M from observed settlements: $M \approx 240$ MPa
$\Rightarrow$ DMT good estimation of $M$ in this site
Observed vs. Predicted Settlements by DMT
Dormitory Building 13 storeys (Atlanta - USA)

Mayne, 2005

Settlements profile: Measured vs DMT predicted
(Piedmont residual soil)

Distance (meters)

0 10 20 30 40 50 60 70 80 90 100

0 50 100 150 200 250 300

DMT observed

Mayne, 2005

SPT Settlement prediction: 46 mm
DMT Settlement prediction: 250 mm
Observed Settlement: 250 mm

SPT → error is large and unsafe !!!
“..comparison of settlement values measured at the structures with respect to those obtained by dilatometer data and observations (28 structures). It should be added that the given set of buildings was limited to structures with shallow foundation..”
Example of SDMT measurements and a ‘real time’ Settlements Prediction at a demonstration site for a workshop

Bogotà (Colombia - 2015)
Example of SDMT tests in Clay

SDMT Workshop in Colombia (May 2015, Bogotà)
STRESS HISTORY PARAMETERS

Overconsolidation Ratio

Preconsolidation Pressure

Earth Pressure Coefficient

Horizontal Effective Stress

OCR >> 1 → TOP CRUST

OCR ~ 1 → NC Clay
Settlements Calculation: Load information

Load Area Type: Isolated
Shape of Load Area: Rectangle

Rectangular Load Area:
- Short Side: 15 m
- Long Side: 30 m
- Uniformly Distributed Load: 30 kPa
- Total Vertical Load: 13500 kN
- Depth of Load Area Base: 2 m

CROSS SECTION:
- $q = 30 \text{ kPa}$
- $L = 30.0 \text{ m}$
- $Z_a = 2.0 \text{ m}$

TOP VIEW:
- $V = 13500 \text{ kN}$
- $B = 15.0 \text{ m}$
- $L = 30.0 \text{ m}$
Settlements Calculation: Soil information

Soil parameters from DMT Uni file

<table>
<thead>
<tr>
<th>Test Name</th>
<th>Firm</th>
<th>Customer</th>
<th>Job</th>
<th>Site</th>
<th>Remark</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>SDMT 1</td>
<td>CONFERENCIA ESCUELA COLOMBIAN</td>
<td>MARCHETTI</td>
<td>UNIVERSIDADE ESCUELA COLOMBIAN</td>
<td>BOGOTA’ COLOMBIA</td>
<td></td>
<td>8 MAG 2015</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Z [m]</th>
<th>M [MPa]</th>
<th>Sigma'v [kPa]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.20</td>
<td>35.7</td>
<td>3</td>
</tr>
<tr>
<td>0.40</td>
<td>41.5</td>
<td>7</td>
</tr>
<tr>
<td>0.60</td>
<td>14.5</td>
<td>10</td>
</tr>
<tr>
<td>0.80</td>
<td>4.4</td>
<td>13</td>
</tr>
<tr>
<td>1.00</td>
<td>11.2</td>
<td>16</td>
</tr>
<tr>
<td>1.20</td>
<td>8.4</td>
<td>19</td>
</tr>
<tr>
<td>1.40</td>
<td>5.1</td>
<td>23</td>
</tr>
<tr>
<td>1.60</td>
<td>7.3</td>
<td>26</td>
</tr>
<tr>
<td>1.80</td>
<td>7.1</td>
<td>29</td>
</tr>
<tr>
<td>2.00</td>
<td>8.2</td>
<td>32</td>
</tr>
<tr>
<td>2.20</td>
<td>9.0</td>
<td>36</td>
</tr>
<tr>
<td>2.40</td>
<td>9.0</td>
<td>39</td>
</tr>
<tr>
<td>2.60</td>
<td>7.9</td>
<td>42</td>
</tr>
<tr>
<td>2.80</td>
<td>8.0</td>
<td>46</td>
</tr>
<tr>
<td>3.00</td>
<td>7.7</td>
<td>49</td>
</tr>
</tbody>
</table>
## Settlements Calculation

### Settlements [mm]

<table>
<thead>
<tr>
<th>Settlements Calculation Point</th>
<th>Settlements [mm]</th>
<th>Z Stop [m]</th>
<th>$\Delta \sigma/\sigma'V$</th>
</tr>
</thead>
<tbody>
<tr>
<td>below the center</td>
<td>225.5</td>
<td>30.80</td>
<td>0.027</td>
</tr>
<tr>
<td>below the corner</td>
<td>79.8</td>
<td>30.80</td>
<td>0.017</td>
</tr>
<tr>
<td>below the median point of short side</td>
<td>121.5</td>
<td>30.80</td>
<td>0.019</td>
</tr>
<tr>
<td>below the median point of long side</td>
<td>144.6</td>
<td>30.80</td>
<td>0.024</td>
</tr>
</tbody>
</table>
Settlements: graph below center of load
Main differences CPT-DMT
1. Flexibility in penetration

*CPT – measurements performed at fix penetration rate of 2 cm / sec*

→ penetrometer required

→ penetration rate may influence results

*DMT – no requirement on penetration rate. Measurements when blade is not moving.*

→ penetrometer, drill rig, floating barge, etc

→ measurements independent of penetration rate
2. Probe shape and soil distortion

Blade penetration causes less distortion than cone penetration, preserving the original state of the soil → less disturbance

Baligh & Scott (1975)
3. Sensitivity to $\sigma_h$ of CPT(SPT) and DMT

Hughes & Robertson (Canadian Journal August 1985)
4) **SANDS**: Stress History effects ON CPT & DMT

**Effect of SH on normalized** $Q_c$ (CPT)

- Graph showing $q_c/(\sigma'_v)^{0.5}$ vs. Relative density, $D_r$ (%)
- $R^2 = 0.94$
- $q_c$ and $\sigma'_v$ are in kPa

**Effect of SH on** $K_D$ (DMT)

- Graph showing Horiz. stress index, $K_D$ vs. Relative density, $D_r$ (%)
- Different OCR values: OCR=8, OCR=4, OCR=2, OCR=1

---

Lee 2011, Eng. Geology – CC in sand

**$K_D$ sensitive to Stress History**
5. DMT (like PMT): Modulus direct measurement

CPT (SPT) measures resistance and correlates to stiffness with a factor ranging significantly: $\sim (3 - 27)$
6. DMT: direct measurement of modulus in the soil loaded at the strain level for deformation analysis

Mayne (2001)

SPT & CPT
Factor ???
Nc: 3 – 27

Range for Deformation Analyses

Region for Bearing Capacity and Stability Calculations

Shear Modulus, G

Shear Strain, $\gamma_s$

Geophysical Tests
Unload-Reload PMT
Flat DMT
Screw-Plate Tests
Initial Loading PMT
SPT & CPT Penetration Tests

Mayne (2001)
G-gamma decay curves (in situ)
**G₀ and M_{DMT} on the G - γ decay curve**

SDMT ➔ G₀ - small strain modulus (from Vs)

M_{DMT} - working strain modulus (γ = 0.05 – 0.1 %)

G₀ / M_{DMT} may provide an in situ estimate of the G-γ decay curve

Tentative estimation of $G - \gamma$ decay curve

\[ \frac{G}{G_0} = \frac{1}{1 + \left( \frac{G_0}{G_{DMT}} - 1 \right) \gamma_{DMT}} \]

SDMT experimental data used to assist the construction of a hyperbolic equation

Good agreement between hyperbolic SDMT estimation and laboratory stiffness decay curve

Amoroso et al. 2014

requires further validation
Quality Assessment of Soil Improvement
In the last decades the DMT has been increasingly used in compaction jobs to quantify the gain in soil improvement.

**Ground Reinforcement**
- Stone Columns
- Soil Nails
- Micropiles
- Jet Grouting
- Ground Anchors
- Geosynthetics
- Fibers
- Lime Columns
- Vibro-Concrete Columns
- ..

**Ground Improvement**
- Surface Compaction
- Drainage/Surcharge
- Electro-osmosis
- Compaction grouting
- Blasting
- Dynamic Compaction
- ..

**Ground Treatment**
- Soil Cement
- Lime Admixtures
- Flyash
- Dewatering
- Heating/Freezing
- Vitrification
- ..
Loose sandfill - container terminal in Belgium

Resonant vibrocompaction technique

Van Impe, De Cock, Massarsch, Mengé - New Delhi (1994)
“Figure 3 illustrates how well resin injections improved the soil and how well $K_D$ and $M$ detected such improvements” (Failmezger 2017)
Aim of DMT & CPT tests: to confirm OC of vibrocompaction, detected also by very high Vs (400-500 m/s)

“..hydraulically filled silty fine calcareous sand dredged from sea bed, underlain by sedimentary rock of very weak sandstone and siltstone..”
DMT for Compaction Control - Palma Jumeirah Dubai

E. Sharif (2015)
Slip surface detection in OC clay slopes
DMT-$K_D$ method ➔ Verify if an **OC clay slope** contains **active** (or old **quiescent**) slip surfaces

1. Sliding
2. Remoulding
3. Reconsolidation (NC State)
4. Inspect $K_D$ profile

(Totani et al. 1997)
Validation of DMT-$K_D$ method

Landslide "Filippone" (Chieti 1997)

DOCUMENTED SLIP SURFACE
Validation of DMT-$K_D$ method

Landslide ‘St. Barbara’ (AR)

DOCUMENTED SLIP SURFACE
**K_D to detect slip surface**

**Inspection of K_D profile before and after the landslide**

*before: K_D > 4*

*after: K_D ≈ 2*

*Peiffer, 2016 - ISC’5 Conf.*
MEDUSA DMT
ONSHORE AND OFFSHORE SOIL TESTING
Medusa DMT: Automated Dilatometer

- Battery Power Pack (24h operational)
- Electronic Board
- Hydraulic Motorized Syringe:
  - Electric Engine
  - Piston
  - Cylinder
- Pressure Transducer
- Blade with standard dimensions

patent no. 18457.0137.US0000
Medusa DMT vs. Traditional DMT

- No gas tank
- No control unit
- No pneumatic cable
- No operator required for inflation
Medusa DMT: example of test cycle

T = 0 when penetration stops and test cycle begins
Dissipation test before membrane expansion

Motorized syringe able to maintain membrane in the A position $\rightarrow$ monitoring $\sigma_h$ with time

![Graph showing dissipation test for 100 sec (repeated A)]
Medusa DMT validation in a Tailing’s Dam

(Poland - November 2019)
Main Characteristics:

- **Geomaterial:** wastes copper mine
- **Maximum dam height:** 66+ m
- **Total volume stored:** 558x10^6 m^3
- **Storage rate:** 29x10^6 m^3/year
- **Area covered:** 14.0 km^2
- **Total Dam’s length:** 14.3 km
- **Operation time:** 1977-2042
Medusa DMT validation in Zelazny Most

Zelazny Most Tailings Dam (Poland)
November 2019
Medusa DMT at Zelazny Most – Poland
(November 2019)
Medusa DMT at Zelazny Most – Poland
(November 2019)

Partially Draining Layers
(Niche Silts)

Significant dissipation during test execution:
→ Readings lower than expected
→ Readings require corrections

Medusa enables to detect this behaviour monitoring $\sigma_h$ with time prior to standard DMT readings

F. Schnaid Mitchell Lecture for ISC’6 (delayed for COVID19)
Technical Questions
Email: diego@marchetti-dmt.it

Documentation
website: www.marchetti-dmt.it

Commercial Information
E-shop: www.marchettidilatometershop.com