Flat dilatometer (DMT). Seismic DMT.

Description, Execution, Applications

Silvano Marchetti
University of L'Aquila, Italy
silvano@marchetti-dmt.it
Penetration tests CPT and DMT often used today in many investigations

Fast, economical, reproducible, informative, many data, reduced scatter, cost much less than sampling & testing….

Instrumental accuracy of CPT-DMT is “laboratory-grade” (unlike SPT)
DMT components

Truck mounted penetrometer pushing the blade
DMT can also be executed with small **inexpensive** pushing machines
DMT can also be executed using a **DRILL-RIG**

Test starts from bottom of a borehole

![Diagram showing DMT test setup](image)

- Taped p-e cable
- See detail
- Torpedo
Suitable for sand, silt, clay

Can push **25 ton**

water

semi-liquid soils

hard soils
DMT BLADE

All mechanical
NO ELECTRONICS, no zero drift, no temperature effects
Blade is like an electrical switch. Can be off or on.
HOW DMT WORKS (mechanical)

Every 20 cm
DMT 30 m : ½ day

$\rho_0, \rho_1 \rightarrow \text{Id, Kd, Ed}$
$\rightarrow \text{Soil parameters (M, Cu ...)}$

REDUCTION FORMULAE

DMT Report TC16 (2001) of ISSMGE
## DMT FORMULAE

### Basic DMT Reduction Formulae

<table>
<thead>
<tr>
<th>SYMB</th>
<th>DESCRIPTION</th>
<th>BASIC DMT REDUCTION FORMULAE</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_0$</td>
<td>Corrected First Reading</td>
<td>$p_0 = 1.05 (A - Z_M + ΔA) - 0.05 (B - Z_M - ΔB)$</td>
</tr>
<tr>
<td>$P_1$</td>
<td>Corrected Second Reading</td>
<td>$p_1 = B - Z_M - ΔB$</td>
</tr>
<tr>
<td>$I_D$</td>
<td>Material Index</td>
<td>$I_D = \frac{p_1 - p_0}{(p_0 - u_0)}$</td>
</tr>
<tr>
<td>$K_D$</td>
<td>Horizontal Stress Index</td>
<td>$K_D = \frac{p_0 - u_0}{\sigma_{VO}}$</td>
</tr>
<tr>
<td>$E_D$</td>
<td>Dilatometer Modulus</td>
<td>$E_D = 34.7 (p_1 - p_0)$</td>
</tr>
<tr>
<td>$K_0$</td>
<td>Coeff. Earth Pressure in Situ</td>
<td>$K_0,DMT = (K_0 / 1.5)^{0.47} - 0.6$ for $I_D &lt; 1.2$</td>
</tr>
<tr>
<td>OCR</td>
<td>Overconsolidation Ratio</td>
<td>$OCR_{DMT} = (0.5 K_0)^{1.55}$ for $I_D &lt; 1.2$</td>
</tr>
<tr>
<td>$C_u$</td>
<td>Undrained Shear Strength</td>
<td>$C_{u,DMT} = 0.22 \sigma_{VO} (0.5 K_0)^{1.25}$ for $I_D &lt; 1.2$</td>
</tr>
<tr>
<td>$\varphi$</td>
<td>Friction Angle</td>
<td>$\varphi_{safe,DMT} = 28 + 14.6 \log K_0 - 2.1 \log^2 K_0$ for $I_D &gt; 1.8$</td>
</tr>
<tr>
<td>$C_h$</td>
<td>Coefficient of Consolidation</td>
<td>$C_{h,DMT} = 7 cm^2 / T_{flex}$</td>
</tr>
<tr>
<td>$K_h$</td>
<td>Coefficient of permeability</td>
<td>$K_h = C_h \gamma_w / M_h$ (where $M_h = K_0 M_{DMT}$)</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>Unit Weight and Description</td>
<td>(see chart)</td>
</tr>
<tr>
<td>$M$</td>
<td>Vertical Drained Constrained Modulus</td>
<td>$M_{DMT} = R_M \frac{E_D}{3}$</td>
</tr>
<tr>
<td>$U_0$</td>
<td>Equilibrium pore pressure</td>
<td>$U_0 = p_2 = C - Z_M - ΔA$</td>
</tr>
</tbody>
</table>

$Z_M$ = Gage reading when vented to atm.

However, if $ΔA$ & $ΔB$ are measured with the same gage used for current readings A & B, set $Z_M = 0$ ($Z_M$ is compensated)

$\sigma_{VO}$ = pre-insertion overburden stress

$E_D$ is NOT a Young's modulus $E$. $E_D$ should be used only AFTER combining it with $K_D$ (Stress History). First obtain $M_{DMT} = R_M E_D$, then e.g. $E = 0.8 M_{DMT}$
How the OCR and Cu correlations were derived (clay)

Experimental
1980 & 1995

Theoretical
1993 Finno

Theoretical
2004 Yu

\[ K_D = \frac{6 - 2M}{6 + M} (OCR)^{\frac{3M}{6+M}} + \frac{c_1 M}{2F^A} (OCR)^{\frac{c_2 + A}{2}} \]

Marchetti 1980

Finno Géotechnique 43 1993, N. 2

Marchetti 1980

Field measured

Theoretical range computed by Finno '93 by Strain path method and Anisotropic Bounding Space Model

Yu by Critical State Model implemented in CRISP
DERIVATION OF Cu CORRELATION

Once having OCR → Ladd’s SHANSEP 77 SOA Tokyo

\[
\left( \frac{c_u}{\sigma_v} \right)_{oc} = \left( \frac{c_u}{\sigma_v} \right)_{nc} \quad \text{OCR}^m \quad \Rightarrow \quad \left( \frac{c_u}{\sigma_v} \right)_{oc} = \left( \frac{c_u}{\sigma_v} \right)_{nc} (0.5 \ K_D)^{1.25}
\]

Using \( m \approx 0.8 \) (Ladd 1977) and \( (Cu/\sigma_v)_{nc} \approx 0.22 \) (Mesri 1975)

\[
\frac{C_u}{C_v} = 0.22 (0.5K_D)^{1.25}
\]

(Ladd: best Cu not from TRX UU but from oed → OCR → Shansep)

OCR, Ko, Cu well founded derivation. They use OCR confirmed by theory + SHANSEP
DMT results

- **I_D**: soil type (clay, silt, sand)
- **M**: Oed modulus
- **Cu**: Undr strength
- **K_D**: shape similar to OCR, helps understand history of deposit

**KD** = is $p_o$ normalized to $\sigma_v'$. 

$K_D = 2 \Rightarrow \text{NC clay}$
SEISMIC DILATOMETER: DMT with the addition of a seismic module (tube) $\rightarrow V_s$

**SDMT**

SDMT is TRUE interval (two sensors)

2 Seismograms - same blow

Operator independent

Much faster & economical than Down hole – X hole

**Instant results**
Seismic Dilatometer
SHEAR WAVE SOURCE
Example seismograms SDMT at Fucino

Delay: automatically calculated using Cross Correlation
Repeatability Vs: 1-2 %
Automatic Vs interpretation real time
DMT results

**REPEATABILITY** \( \approx 1-2\% \)

**SHEAR WAVE VELOCITY**

\[ G_0 = \rho V_s^2 \]

**mechanical DMT**

**Seismic DMT**
Diffusion: DMT used in 70 countries (°) (200 DMT in US)

Standards:  

EUROCODE 7 (2005)  
ASTM (2007)  
TC16 (1997)

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

Settlements prediction

Liquefability evaluation

Compaction control
Detecting slip surfaces in OC clay
Laterally loaded piles
Diaphragm walls “springs” for design
FEM input parameters
In situ G-γ decay curves

But before : focus on Kd sensitive to Stress History. Kd important : not many alternatives to sense SH in situ (sand). Kd is a real protagonist
• Kd by DMT is important, a real protagonist
• Not many alternatives to sense SH in situ (especially in sand).
• Yet Stress History fundamental for realistic prediction of settlements and liquefaction resistance.
Diagrams compare sensitivity of CPT-DMT to Stress History

Lee 2011, Korean Researchers.
Calibration Chamber in sand

**Diagr. 1. Effect of SH on Qc**

OCR = 1, 2, 4, 8

$\frac{q_c}{(\sigma'_v)^{0.5}}$ vs. Relative density, $D_r$ (%)

With OCR

* $q_c$ and $\sigma'_v$ are in kPa

$R^2 = 0.94$

**Diagr. 2. Effect of SH on Kd**

With OCR

OCR = 1, 2, 4, 8

Horiz. stress index, $K_D$

Relative density, $D_r$ (%)

• Kd much more reactive than Qc to Stress History

• Kd distinguish sands with SH / no SH. $Q_{cn} \approx$ less
That DMT is MORE REACTIVE TO SH CONFIRMED IN THE FIELD, during COMPACTATION (apply SH)

Jendeby 92 : during compaction of a loose sandfill found

Schmertmann (1986) & many others :
- **COMPACTATION** produces a % increase of M_{DMT} ≈ twice the % increase of Qc.
- M_{DMT} particularly suitable for evidencing the benefits of compaction
Often in compaction jobs the ratio $M_{DMT}/q_c$ is plotted before-after.

Typically the ratio increases from 5-8 (NC) to 20-25 (OC).

The fact that $M_{DMT}/Qc$ increases with compaction, indicates that $M_{DMT}$ increases at a faster rate than $Qc$, confirming higher sensitivity of DMT to SH.

The $M_{DMT}/Qc$ profiles also permit an evaluation of the achieved OCR increase, using e.g. Monaco et al. Eqn. (2014)
Schmertmann 1984 explained the different sensitivity of DMT and CPT to stress history:

"the cone appears to destroy a large part of the modification of the soil structure caused by the overconsolidation and it therefore measures very little of the related increase in modulus.

In contrast the lower strain penetration of the DMT preserves more of the effect of overconsolidation."

$Q_{cn}$ reflects essentially $D_r$ (only to minor extent stress history)

$K_D$ reflects the TOTAL effect $D_r$ plus various stress history effects such as aging, $K_o$, structure (cementation)
Sensitivity of Kd to SH important for Settlements

Jamiolkowski (Isopt-1, ‘88,1) : “without Stress History, impossible to select reliable E (or M) from Qc”

Yoshimi et al. (1975) “The NC sand specimens were six times more compressible than the prestressed sand, hence it is imperative to have information on stress history to characterize compressibility of a sand

Similar statements : Terzaghi, Leonards, Schmertmann, Robertson etc.

Application #1 DMT : predict settlements (operative modulus)
Accuracy of settlements prediction: confirmed by a large number of good comparisons measured vs DMT-predicted settlements

Silos on Danube's Bank (Belgrado)

SETTLEMENTS

Measured 63 cm  DMT predicted 77 cm (+22%)

(D. Berisavijevic 2013)
M at Sunshine Skyway Bridge. Tampa Bay – Florida USA

Modulus M from DMT: $M \approx 200$ MPa (≈1000 DMT test points)
M from laboratory: $M \approx 50$ MPa
From obs. Settlements: $M \approx 240$ Mpa

Conclusion: DMT = good evaluation of constrained modulus $M$
Schmertmann 1986 16 CASE HISTORIES.
Predicted/Observed ave : 1.18

<table>
<thead>
<tr>
<th>No</th>
<th>Location</th>
<th>Structure</th>
<th>Compressible soil</th>
<th>Settlement (mm)</th>
<th>Ratio DMT/meas.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Tampa</td>
<td>Bridge pier</td>
<td>HOC Clay</td>
<td>15</td>
<td>1.67</td>
</tr>
<tr>
<td>2</td>
<td>Jacksonville</td>
<td>Power Plant</td>
<td>Compacted sand</td>
<td>14</td>
<td>1.07</td>
</tr>
<tr>
<td>3</td>
<td>Lynn Haven</td>
<td>Factory</td>
<td>Peaty sd.</td>
<td>185</td>
<td>1.02</td>
</tr>
<tr>
<td>4</td>
<td>British Columbia</td>
<td>Test embankment</td>
<td>Peat org. sd.</td>
<td>2850</td>
<td>0.71</td>
</tr>
<tr>
<td>5a</td>
<td>Fredricton</td>
<td>Surcharge 3' plate building</td>
<td>Sand Sand Quick cl. Silt</td>
<td>15</td>
<td>0.73</td>
</tr>
<tr>
<td>5b</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5c</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6a</td>
<td>Ontario</td>
<td>Road embankment building</td>
<td>Peat Peat</td>
<td>275 270</td>
<td>1.09 0.97</td>
</tr>
<tr>
<td>6b</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Miami</td>
<td>4' plate</td>
<td>Peat</td>
<td>71</td>
<td>1.31</td>
</tr>
<tr>
<td>8a</td>
<td>Peterborough</td>
<td>Apt. bldg Factory</td>
<td>Sd. &amp; si.</td>
<td>48</td>
<td>1.21</td>
</tr>
<tr>
<td>8b</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.18</td>
</tr>
<tr>
<td>9</td>
<td></td>
<td>Water tank</td>
<td>Si. clay</td>
<td>31</td>
<td>0.97</td>
</tr>
<tr>
<td>10a</td>
<td>Linkoping</td>
<td>2x3 m plate 1.1x1.3m plate</td>
<td>Si. sand Si. sand</td>
<td>5</td>
<td>1.34</td>
</tr>
<tr>
<td>10b</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.33</td>
</tr>
<tr>
<td>11</td>
<td>Sunne</td>
<td>House</td>
<td>Silt &amp; sand</td>
<td>8</td>
<td>1.25</td>
</tr>
</tbody>
</table>

**AVE : 1.18**

1986 - Proc. In Situ '86 ASCE Spec. Conf. VIP, Blacksburg, p.303
Lacasse & Lunne (1986) of NGI compare observed vs DMT-predicted settlements of a silos on sand in Norway.


DILATOMETER TESTS IN SAND

Suzanne Lacasse M.ASCE and Tom Lunne

ABSTRACT

The paper presents two applications of the dilatometer test in sands: control of compaction and determination of constrained modulus.

Twelve dilatometer tests were carried out before and after compaction of a 15 m high sand deposit. The tests were run as a method for compaction control and to determine the strength and compressibility characteristics of the sand. The results suggest that the compaction was effective over at least a 14 meter depth. The compaction resulted in increases in in situ horizontal stress, resistance to compression and effective friction angle.

Constrained moduli derived from dilatometer tests on a loose sand compared very well with moduli determined from backcalculations of the settlement of silos
Paul Mayne Prof. at Georgia Tech (2005) compares observed vs DMT-predicted settlements of a building in residual soil in Atlanta

Unexpected but foreseeable mat settlements on Piedmont residuum

Paul W. Mayne, Professor, Georgia Institute of Technology, USA

ABSTRACT: A large mat foundation was constructed to support a 13-story dormitory on Piedmont residual silty soils in Atlanta, Georgia. Prior to construction, the geotechnical consultant of record estimated maximum expected settlements of the mat on the order of 1.8 inches (46 mm), while the building proceeded to deflect as much as 10 inches (250 mm) at the center and 5 inches (127 mm) at the corners near the end of construction. Details on the case history are reviewed by an outside observer and placed within the context of geotechnical practice. In addition to routine soil borings, the use of enhanced in-situ testing (in this case, flat dilatometer tests) in concert with elastic continuum solutions would have provided calculated values in line with the observed performance.
Research embankment D=40 m (Venezia)

Comparison $M_{\text{DMT}}$ vs $M_{\text{back-calculated}}$ from LOCAL vertical strains measured under center

Treporti test embankment

- Start of construction: 12 September 2002
- End of construction: 10 March 2003
- Removal: April 2008

SETTLEMENTS

- Measured 36 cm
- DMT predicted 29 cm ($\Delta = 24\%$)
Possible reasons DMT predicts well settlement

1. Wedges deform soil << cones
2. Modulus by mini load test relates better to modulus than to penetr. resistance
3. Availability of Stress History parameter Kd. (DMT is a 2-parameter test. Fundamental to have both: Ed and Kd)
4. The soil is loaded at a lower, more appropriate, strain level

⇒ Need moduli, not strength!
Strain levels imposed by DMT and other in-situ tests

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

Range for Deformation Analyses
Region for Bearing Capacity and Stability Calculations

Mayne 2001
As soon as DMT is completed… settlement are calculated

Various types of foundation

building  

viaduct  

pile  
group
SETTLEMENT CALCULATION

\[ M_{\text{DMT}} + 1-D \text{ method} \]

\[ S_{1-\text{DMT}} = \sum \frac{\Delta \sigma_v}{M_{\text{DMT}}} \Delta z \]

Calculation every 20 cm, not because thicker layers are inadequate. It is just more convenient, since Mdmt available in the computer every 20 cm.
e.g. for a building possible to select at end of DMT: adopt

Shallow foundation → Piles

Ave load ≈ 10 kPa / floor

If $s = 3\text{ cm (or 4 or 5)} \rightarrow \text{no piles (ok shallow)}$
Liquefiability evaluations also in need of information on Stress History / Aging

Jamiolkowski et al. (S. Francisco 1985) :

"Reliable predictions of sand liquefiability ...require... some new in situ device [other than CPT or SPT], more sensitive to effects of past STRESS-STRAIN HISTORIES"
CRR by CPT correlations: some ??


Youd & Idriss 2001 (NCEER Workshops) ➔ use 2 or more tests for a more reliable evaluation of CRR.

Idriss & Boulanger (2006) "The allure of relying on a single approach (e.g. CPT - only) should be avoided".
.. difficult situation ... lab too is problematic..

**Latest Research 2014**

NO LABORATORY TESTS ARE SUITABLE FOR LIQUEFACTION ESTIMATION.

Only suitable FIELD TESTS MUST be used.

- **2014** Panel Discussion at Geo-Congress, ASCE
  Panelists: Prof. Idriss, Prof. Boulanger, Prof. Robertson, Prof. Cetin, Prof. Finn, Prof. Green, Prof. Stokoe, Prof. Mayne

- But already Peck (1979): it is "manifestly impossible" to obtain a completely undisturbed sample
Liquefaction Resistance CRR: is today estimated by two separate methods

CRR from **CPT**

CRR from **DMT**

However these are one-to-one correlations.

(°) Robertson 2012 ..progresssively abandon SPT... crude unreliable...
Better to estimate CRR based at the same time on $Q_c$ and $K_D$

CRR in two Steps:
1. Estimate CRR from $Q_{cn}$ using everyday CPT correlations.
2. Then, if $K_d$ is high, increase CRR; if $K_d$ is low, reduce CRR.

Get $CRR = f(Q_c, K_D)$
(unpublished J. Asce 2015)
If sand has Fine content, Cementation…: adding $K_D$ to $Q_{cn}$, for CRR, may not be sufficient.

E.g. cementation can be **ductile** (toothpaste-like) or **fragile** (glasslike).

Fine Content: possibly effects $\approx$ as ductile cementation.

Clearly too many unknowns. It may be not sufficient to add the $K_D$ information to $Q_{cn}$.

Go could possibly help: high $Go/ Q_c$ and/or high $Go/ M_{DMT}$ also indicators of cementation.

Even modulus $E_D$ from DMT could possibly help.

A lot additional study necessary $\Rightarrow$ multi-parameter
Cemented soils: higher $G_0 / M_{DMT}$ and $G_0 / Qc$ than sedimentary soils (black) (Schnaid 2004, Rocha et al. 2015).

Possible reason of High $V_s$: cemented contacts of the grains allow a faster transmission.

A possibly useful info on cementation.
SDMT provides Go (small strain modulus) & Mdmt (working strain modulus). Two points of the G-γ curve. May help select the design G-γ curve. (Mayne & Martin 1999)
SEAFLOOR DILATOMETER to run DMT from sea bottom

WATERDEPTH up to 100 m
PUSH CAPACITY 7 ton
Max test depth is the depth penetrable with 7 ton push.

Shipped by air (50 Kg)
4 bolts
7 ton ballast (built locally)

7 ton ballast (built locally)
Seafloor DMT lifted
Seafloor DMT lowered in water: rods pre-charged
SEAFLOOR DILATOMETER

An alternative “model” of ballast (Roger Failmezger Apr 2015, Virginia)
Detecting slip surfaces in clay slopes (look for $K_d \approx 2$)

1. SLIDING
2. REMOULDING
3. RECONSOLIDATION (NC STATE)
4. INSPECT $K_d$ PROFILE

Method permits to verify if an OC clay slope contains active or quiescent slip surfaces (Totani et al. 1997)

Useful to know: Old slip surface may reactivate – $\phi_{\text{residual}}$
Validation of DMT-$K_D$ method

LANDSLIDE "FILIPPONE" (Chieti)

DOCUMENTED SLIP SURFACE

$K_d \approx 2$

LANDSLIDE "CAVE VECCHIE" (S. Barbara)

DOCUMENTED SLIP SURFACE (inclinometers)

$K_d \approx 2$
The practitioner’s Dream

Geotechnician just assign the elementary in situ data raw data (inequivocally measured)

The 3 independent parameters (if CPT & DMT) are \( Q_c \) \( K_d \) \( E_d \)

Model specialist (able to avoid pitfalls) prepare FEM

Assign to each mesh element:

\[
Q_c \quad K_d \quad E_d
\]
Website: www.marchetti-dmt.it
More and more CPT & DMT replace laboratory for everyday jobs.

Sensitivity of DMT’s Kd to Stress History is important. There are not many Stress History tools.

Stress History is indispensable for good predictions of settlements and liquefaction.
A large number of comparisons confirm that DMT predicts well settlement.

Good estimates of settlements permit a better and more economical design. E.g. entity of settlement helps decide: piles or shallow foundations? Info = $
**$K_D$ leads to a more economical design**

$K_D$ reflects benefits of Stress History on settlement and liquefaction. SH scarcely sensed by other tools, which ignore SH $\Rightarrow$ benefits are wasted.

Two sites same $Q_c$, different $K_D$: Site 2 much “stronger”

In Site 2, Stiffness & CRR can be much higher
The best estimates of liquefaction resistance CRR are obtained using at the same time Qcn - CPT and $K_D$ - DMT.

$$CRR = f(Qcn, K_D)$$

In general: Multiparameter better than one-to-one correlations. Soil has many unknowns: need multiple responses
DMT is very simple

No electronics, no saturation, no deairing, no area correction...

V. easy to run, short training time (≈ 3 hrs)

Highly repeatable. Any operator gets same results

No need highly skilled workers
Highlights of the conference include:

- **Prof. Roger Frank** (ISSMGE president) Welcome speech
- **Prof. J. Schmertmann**’s dinner talk
- **Prof. M. Jamiołkowski**: use of SDMT in the Zelazny Most dam in Poland
- **Prof. F. Schnaid**: use of DMT and SDMT in tailings dam

Sofar 120 abstracts from 32 Countries
Conference venue in the town center

Parco dei Principi Grand Hotel & Spa • Roma

© 2014 Parco dei Principi Grand Hotel & SPA
Via G. Frescobaldi, 5 - 00198 Rome, Italy
Ph. (+39) 06 854421 - Fax (+39) 06 8845104

www.dmt15.com
Rome touristic attractions
St. Peters and Pope Francesco
END
Thank you
Slides for possible discussion
Sensitivity to $\sigma_h$ of $f_s$ and $K_D$

$f_s$ highly unstable, being what is left after an enormous stress reduction

\[ \sigma_{h,sleeve} \]
low and undetermined

1. $\sigma_{h,situ}$

\[ \sigma_h \]

ZONE OF HIGH RESIDUAL STRESSES OBSTACLE to $\sigma_h$ (ARCHING)
Hughes & Robertson Cnr. G.J. Aug. 85

CIRCULAR PROBE

FLAT PROBE

Very Stiff Prestressed Cylinder

Sharp Transition

• No sharp transition
• Little arching
SENSITIVE to $\sigma_h$
MDMT inclusive of $\sigma_h$
Note: $f_s$ & $K_D$ much in common both reflect $\sigma_h$ against probe

$K_D$ measures $\sigma_h$ directly (i.e. $p_o$)
$f_s$ indirectly, transforming $\sigma_h$ to $F_{\text{vertical}}$

Thus $f_s \approx$ an attenuated $K_D$, weaker and much less stable and direct. And repeatability...
$K_D$ evidences Stress History crusts nearly unfelt by $V_S$. $V_S \approx$ insensitive to SH suggests lesser ability of $V_S$ to profile SH, hence liquefiability & CRR

\[
\begin{array}{|c|c|}
\hline
\text{MATERIAL INDEX} & \text{CONSTRAINED MODULUS} & \text{UNDRAINED SHEAR STRENGTH} & \text{HORIZONTAL STRESS INDEX} & \text{SHEAR WAVE VELOCITY} \\
\hline
0 & 10 & 20 & 30 & 40 \\
\hline
\end{array}
\]

- CLAY
- SILT
- SAND

Catania Sand

$K_D$ crust

"lazy"

$V_s$ (m/s)
Comparisons $V_s$ measured by SDMT with $V_s$ estimated by mechanical DMT using the previous diagram (L’Aquila)

Amoroso (2013) compares correlations $V_s$ from DMT and $V_s$ from DMT. Concludes: $V_s$ estimates from DMT are closer (a two parameter test)
Clay. Initial idea (1980) : investigate $E_d$-$E_u$. Problem: $E_{u,\text{lab}}$ too dispersed, impossible set up correlations. Hence $\rightarrow E_d$-$M$. Link $E_d$-$M$ presumably weaker, but at least can be tested.

NOTE. $E_d$-$M$ must be a complex function of many variables, among them the Skempton p. p. parameters A & B and anisotropy ($E_d$ horizontal, M vertical), which in turn depend on soil type ($\sim$represented by $I_d$) and on OCR ($\sim$ represented by $K_d$) $\Rightarrow$ some basis to expect at least some degree of correlation $E_d$-$M$ using $I_d$ and $K_d$ as parameters.

Final word: real world observation. Large number case histories favourable comparisons measured vs DMT-predicted settlements - or $M_{dmt}$-$M_{\text{reference}}$.

Lambe et al (Jnl ASCE March 1977 “Foundation Performance of Tower of Pisa” p.246) : “Drained moduli of saturated clays are typically about one-third to one-fourth the undrained values”. Hence a broad connection drained-undrained stiffness already invoked in the past.
Legitimate to use $M = \text{constant}$ if $\Delta \sigma'_V$ large?

\[ M = \frac{E_{oed}}{1/mv} = \frac{\Delta \sigma'_V}{\Delta \varepsilon_V} \quad \text{(at } \sigma'_v) \]

Except highly structured clays (sharp break), $M$ variation across $p_c$ is moderate.

Error in assuming $M \sim \text{constant}$: often acceptable (other methods for $M$: not infrequent error factors 2-5)
Ed must be corrected to obtain M

\[ M = R_m \cdot E_d \quad \text{with} \quad R_m = f(K_d, I_d) \]

Don’t use \( E_d \) as Young’s Modulus

\( R_m \) has various correction tasks

Distortion \quad \text{Horiz to vertical} \quad \text{Drained Undrained}

Once \( E_d \) is converted to \( M \), Young’s \( E' \approx 0.8-0.9 \ M \) (elasticity)