PRESSUREMETER MODULUS : RELATIONSHIP AND CORRELATIONS BETWEEN ELASTIC, PSEUDO ELASTIC AND CYCLIC E-MODULUS AS DEFINED BY L. MÉNARD

MODULES ÉLASTIQUES, PSEUDO-ELASTIQUES ET CYCLIQUES DANS L’ESSAI PRESSIOMETRIQUE MÉNARD : HISTORIQUE ET PERTINENCE ACTUELLE

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MPM Test in a open hole: the conventional « S » shaped curve

Readings plot including Pressure and Volume Loss and giving the Bell-shaped secant Modulus Curve

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MPM « S » shaped curve is often underconsidered in front of so-called SBP self boring pressuremeter tests

Nevertheless, it is not obvious that this « better » shape could be only due to soil compression during insertion of SBP probe (Cassan, 1978)

Baguelin et al., The Pressuremeter, 1978

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MPM test inside the self-bored slotted tube STAF: raw data plot

« lift-off » Pressure

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Start of a Selfbored MPM test: corrected curve

EM = 28.67 MPa

$\sigma_{hs}$ theoretical 0.067MPa
$k=0.5 \gamma / \gamma_w = 1.8$

$\sigma_{hs}$ « measured » 0.086MPa
(« $p_{OM}$ »)

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MPM test in a self-bored slotted tube and micro-pressure increments after lift-off contact pressure

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Zoom on the small deformations just after $p_0$ in this selfbored MPM test.
The same test plot in $(\varepsilon, p)$ axes, and $E_M$ modulus in $(\varepsilon, E_{Ms})$ or $(\varepsilon, E_{Mt})$ axes.
The complete $G/G_0$ $S$ curve in a single MPM test

Figure 4. La première « courbe en S » totale $E/E_{\text{max}}$ fonction de $\varepsilon$, mesurée et interprétée, obtenue à l'aide d'un seul essai pressiométrique.
1 cyclic loading in soil (sand)
Multiple cyclic loading in soil (sand)

Ensemble de l’essai

Détail sur les cycles

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1 cyclic loading in soft rock

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2 cyclic loadings in hard rock
Relationship between different moduli

- **E\textsubscript{M}** modulus as defined by L. Ménard appears to be the lowest value in front of all others possible definitions or measurements of a modulus:
  - 1/2 to 1/3 of a SBP modulus, this one being defined on a smaller deformation range
  - 40% of E\textsubscript{Max} (i.e. E\textsubscript{Max}/E\textsubscript{M} = 2.5) in the test taken as exemple for decreasing E/E\textsubscript{Max} all along the test (in sandy-clayey chalk)
  - Ec1/E\textsubscript{M} = 2.7 for a single cycle in sand (slide 10)
  - Ec1/E\textsubscript{M} = 2.5 and Ec14/E\textsubscript{M} = 7.2 for a multiple cyclic test in sand (slide 11)
  - Ec1/E\textsubscript{M} = 3.0 for a single cycle in soft rock (slide 12)
  - Ec1/E\textsubscript{M} = 1.34 and Ec2/E\textsubscript{M} = 1.47 for two cycles in very hard rock (slide 13)
  - E\textsubscript{Oedo}/E\textsubscript{M} can vary from 1 to 4
  - E\textsubscript{Young}/E\textsubscript{M} = 2, 3, 4, 5, 6 (or more ?) for expected values for this hypothetical elastic modulus of soils.

- Ménard developed from the 60\textsuperscript{ies} a corpus of formulas to get settlement and displacement using E\textsubscript{M} and \( \alpha \) rheological coefficient. The oedometric method was during decades the only other alternative, up to the arise of systematic use of E Young modulus in “modern” FEM calculations.
The Ménard empirical $\alpha$ factor is defined as a function of

- Soil type on a clay-sand axis
- Soil status on a consolidation-weathering axis

both reflecting the $E_M/p^{*}\_LM$ ratio

The relationship with oedometer test is $\alpha = E_M / E^+$

Further the relation between settlement and foundation width depends on the type and structure of the foundation soils.

<table>
<thead>
<tr>
<th>Type of material</th>
<th>Peat</th>
<th>Clay</th>
<th>Alluvium</th>
<th>Sand</th>
<th>Sand &amp; gravel</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$E/p_l$</td>
<td>$\alpha$</td>
<td>$E/p_l$</td>
<td>$\alpha$</td>
<td>$E/p_l$</td>
</tr>
<tr>
<td>Over consolidated</td>
<td>&gt; 16</td>
<td>1</td>
<td>&gt; 14</td>
<td>2/3</td>
<td>&gt; 12</td>
</tr>
<tr>
<td>Normally consolidated</td>
<td>1</td>
<td>9 - 16</td>
<td>8 - 14</td>
<td>1/2</td>
<td>7 - 12</td>
</tr>
<tr>
<td>Weathered or altered</td>
<td>7 - 9</td>
<td>1/2</td>
<td>1/2</td>
<td>1/3</td>
<td>1/4</td>
</tr>
</tbody>
</table>

Baud & Gambin, 18th ICSMGE TC102
Does Ménard empirical $\alpha$ factor remain useful for settlement prevision?
The question arises, mainly due to:

- The wrong use of FEM codes requiring $E_{\text{Young}}$’s moduli
- FEM users compelled to create various ways to get so-called $E$ moduli from PMT,
e.g. in recent Standard NF P94-261 for shallow foundations, fixed ratios for $E_{\text{Young}}/E_M$ are given:

<table>
<thead>
<tr>
<th></th>
<th>Clay, Silt</th>
<th>Sand</th>
<th>Gravels</th>
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</thead>
<tbody>
<tr>
<td>overconsolidated</td>
<td>3</td>
<td>3</td>
<td>4.5</td>
</tr>
<tr>
<td>n. consolidated</td>
<td>4.5</td>
<td>4.5</td>
<td>6</td>
</tr>
</tbody>
</table>
A direct relationship between $E_{\text{Young}}$ & $p^*_{LM}$ (independant from both $E_M$ and $\alpha$)

$$E_Y \approx \frac{E_M}{\alpha^2} + \alpha = \left(\frac{E_M}{p^*_{LM}}\right)^{\frac{1}{2}}$$

$$k_E^2 \cdot \left(\frac{p^*_{LM}}{p_0}\right)^{\frac{1}{4}}$$

(Ménard & Rousseau, Sols-Soils n°1, 1962)  
(Baud & Gambin, 18th ICSMGE, 2013)

$$\frac{E_Y}{p^*_{LM}} = k_E^2 \cdot \left(\frac{p^*_{LM}}{p_0}\right)^{\frac{1}{2}}$$

with $3 < k_E < 5$ and a question to explore about $k_E$: a constant value for all soils, or dependant from other soil properties (void ratio, OCR, dilatancy...) ? NEXT TIME !

Baud, Gambin, Heintz, ISP7, Hammamet 2015
1) NON-ELASTICITE DU SQUELETTE DES SOLS

Matériau linéairement élastique :

\[ \sigma_{\text{oct}} = K \cdot \varepsilon_{\text{oct}} \]
\[ \tau_{\text{oct}} = G \cdot \gamma_{\text{oct}} \]

Squelette d’un sol :

\[ \sigma_{\text{oct}} = \mathcal{F}(\varepsilon_{\text{oct}}, \gamma_{\text{oct}}) \approx A \cdot \varepsilon_{\text{oct}} + B \cdot \gamma_{\text{oct}} \]
\[ \tau_{\text{oct}} = \mathcal{H}(\varepsilon_{\text{oct}}, \gamma_{\text{oct}}) \approx C \cdot \varepsilon_{\text{oct}} + D \cdot \gamma_{\text{oct}} \]

par suite de la dilatance.

Le module d’Young d’un sol n’existe pas

2) PAS DE REVERSIBILITE TOTALE OU COMPLETE

L’utilisation de modèles élasto-plastiques est toujours approchée

_for any soil, Young’s modulus do not exist_
Resume of proposals of this contribution:

• The famous S shape curve $G/G_0$ versus $\epsilon$ can totally be plotted from a very little deformation ($10^{-4}$) to failure ($\epsilon$ around 1) in a single self-bored MPM test obtained by the STAF method, and the new high precision automatically regulated GeoPAC pressuremeter."

• The shape of this curve is only roughly in the S shape, it also includes a middle part of pseudoelastic deformation. Some tests exhibit 2 successive rates of PMT creeping, correlated with the end of this pseudoelastic range.

• Cyclic stresses on the largest part of this pseudoelastic range brings that soils behaviour becomes progressively quasi-elastic, although never perfectly. But this elastic behaviour disappears after some hours and soil returns to its “virgin”, hyperbolic (non elastic) behaviour.

• These constant observations are repeatable in different types of soils. It is a validation of the original conceptions of L. Ménard about the $E_M$, pressuremeter modulus and the rheological coefficient $\alpha$, more valuable for the analysis of soil deformation than any "Young" E-modulus, because soils never exhibit a Young's modulus.

Baud, Gambin, Heintz, ISP7, Hammamet 2015
These proposals help the **direct** use of PMT curves in FEM programs.

**Thank you for your attention**

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