THE PRESSUREMETER:
SOME CONTRIBUTIONS TO FOUNDATION ENGINEERING

Jean-Louis BRIAUD
President of ISSMGE
Professor, Texas A&M University, USA

• TEXAM vs Menard Pressuremeter
• PMT results vs Other Tests Results
• Shal. Found.: Scale & Embedment Effect?
• Shal. Found.: Load-Settlement Curve
• Deep Found.: Lat. Load, Reference Case
• Deep Found.: Lat. Load, Complex Cases
• Deep Found.: Vert. Load, Downdrag
• Future Work
“Everything should be made as simple as possible but not one bit simpler than that”

Albert Einstein (Safir and Safire, 1982)
USEFUL CORRELATIONS
### SAND (36 sites)

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>$E_0$ (kPa)</th>
<th>$E_R$ (kPa)</th>
<th>$p_L$ (kPa)</th>
<th>$q_c$ (kPa)</th>
<th>$f_s$ (kPa)</th>
<th>$N$ (bl/30 cm)</th>
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### CLAY (44 sites)

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<th>$E_R$</th>
<th>$p_L$</th>
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VERY POOR CORRELATIONS

SHALLOW FOUNDATIONS: SCALE & EMBEDMENT EFFECT?
THIS BEARING CAPACITY EQUATION RARELY WORKS

\[ p_u = cN_c + \frac{1}{2} \gamma BN \gamma + \gamma DN_q \]

\[ p_u = \frac{1}{2} \gamma BN \gamma \]
3mx3m Footing Load Tests up to 1200 tons
Texas A&M National Site

Jean-Louis Briaud – Texas A&M University
THIS BEARING CAPACITY EQUATION RARELY WORKS

\[ p_u = cN_c + \frac{1}{2} \gamma B N \gamma + \gamma D N q \]

\[ p_u = \frac{1}{2} \gamma B N \gamma \]
THIS BEARING CAPACITY EQUATION ALWAYS WORKS

\[ p_u = k r \]

\[ r = p_L, q_c, N, s_U \]

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SHALLOW FOUNDATIONS:
LOAD SETTLEMENT CURVE
LOAD SETTLEMENT CURVE METHOD

\[ p_f = \Gamma p_p \]
\[ s/B = 0.24 \Delta R/R \]
**PROBLEM:** A bridge abutment rests on a shallow foundation 15 m long and 3 m wide. The foundation is subjected to a vertical and centered load equal to 9000 kN. The lateral earth pressure generates a load of 900 kN on the back of the abutment. The resultant of the two forces has an eccentricity equal to 0.2 m. The soil is a sand characterized by an average pressuremeter curve.

**SOLUTION:** Load-Settlement Curve Method

\[
Q_u(t)/Q_u(t_o) = (t/t_o)^n
\]

\[
s(t)/s(t_o) = (t/t_o)^n
\]

- \(n = 0.01\) to \(0.03\) in sands
- \(n = 0.02\) to \(0.08\) in clays

---

**LONG TERM VERTICAL LOAD**

\[
Q_u(t)/Q_u(t_o) = (t/t_o)^n
\]

\[
s(t)/s(t_o) = (t/t_o)^n
\]

- \(n = 0.01\) to \(0.03\) in sands
- \(n = 0.02\) to \(0.08\) in clays
n VALUES FROM PMT TESTS

\[ \frac{\Delta R(t)}{\Delta R(t_0)} = \left( \frac{t}{t_0} \right)^{-n} \]

\[ n = -\log\left( \frac{\Delta R(t)}{\Delta R(t_0)} \right) / \log\left( \frac{t}{t_0} \right) \]

n = 0.01 to 0.03 in sands
n = 0.02 to 0.08 in clays
LONG TERM SETTLEMENT

\[ \frac{s(t)}{s(t_0)} = \left( \frac{t}{t_0} \right)^n \]

\[ t = 50 \text{ years} \]
\[ t_0 = 5 \text{ minutes} \]
\[ n = 0.03 \]

\[ \frac{s(t)}{s(t_0)} = \left( \frac{50 \times 365 \times 24 \times 60}{5} \right)^{0.03} \]

\[ s(50 \text{ years})/s(5 \text{ minutes}) = 1.59 \]
Ultimate Bearing Capacity

\[ P_L = 680 \text{ kPa at 5 m depth} \]

\[ S_u = 100 \text{ kPa at shallow depth} \]

Total pressure at 5 m = 224 kPa
Net pressure at 5 m = 141 kPa
Elastic Settlement

\[ E_0 = 30 \text{ Mpa}, \ B = 38 \text{ m}, \ p = 141 \text{ kPa}, \ \gamma = 0.35 \]
\[ S(t_0) = 0.88(1 - 0.35^2) \times 141 \times 38 / 30000 = 138 \text{ mm} \]

Long Term Settlement

\[ s(t)/s(t_0) = (t/t_0)^n \]
\[ s(t_0) = 138 \text{ mm}, \ t = 70 \text{ yrs}, \ t_0 = 5 \text{ min}, \ n = 0.045 \]
\[ S(70 \text{ years}) = 138 (70 \times 365 \times 24 \times 60 / 5)^{0.045} \]
\[ S(70 \text{ years}) = 325 \text{ mm} \]
LATERAL LOAD ON PILES: REFERENCE CASE

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LATERAL LOAD-DEFLECTION CURVE

LOAD
$H_{ou}/F$

DEFLECTION

SETTLEMENT

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ULTIMATE HORIZONTAL LOAD, $H_{ou}$

$$H_{ou} = \frac{3}{4} \ p_l \ B \ D_v$$

$p_l$ = limit pressure from PMT
$B$ = projected pile width
$D_v = (\pi/4) \ l_o$ with $l_o = (4EI / K)^{1/4}$ for $L > 3 \ l_o$
$D_v = L/3$ for $L < l_o$
$E$ = modulus of pile material
$I$ = moment of inertia of pile
$K = 2.3 \ E_o$
$E_o$ = PMT first load modulus of soil
$L$ = pile length
HORIZONTAL DISPLACEMENT $y_o @ H_{ou}/3$

$$y_o = \frac{2}{L} \frac{H_o}{l_o} K \quad \text{for} \quad L > 3l_o$$

$$y_o = \frac{4}{L} \frac{H_o}{K} \quad \text{for} \quad L < l_o$$

$H_o = H_{ou}/3$ = horizontal load at ground surface
$K = 2.3 \ E_o$ = horizontal modulus (line load/deflection)
INTERACTION DIAGRAM FOR COMBINED HORIZ. LOAD AND OVERTURNING MOMENT

ANY COMBINATION OF H AND M ON THE DIAGRAM GIVES THE SAME DEFLECTION
LATERAL LOAD ON PILES: COMPLEX CASES

\[ \frac{H(t)}{H_0(t)} = \left(\frac{t}{t_0}\right)^n \]

\[ \frac{y_0(t)}{y_0(t_0)} = \left(\frac{t}{t_0}\right)^n \]

\( n = 0.01 \) to \( 0.03 \) in sands
\( n = 0.02 \) to \( 0.08 \) in clays
n VALUES FROM PMT TESTS

\[ \frac{\Delta R(t)}{\Delta R(t_0)} = \frac{(t/t_0)^n}{\log(t/t_0)} \]

n = \frac{-\log(\Delta R(t)/\Delta R(t_0))}{\log(t/t_0)}

n = 0.01 to 0.03 in sands
n = 0.02 to 0.08 in clays

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CYCLIC LATERAL LOAD

\[ y_N = y_1 N^a \]

\( a \) averages 0.1 for clays (one way and two way)

\( a \) averages 0.08 for sands under one way loading

\( a \) averages 0 for sands under two way loading

\[ \frac{\Delta R_N}{\Delta R_1} = N^a \]

\( a = \log \left( \frac{\Delta R_N}{\Delta R_1} \right) / \log N \)

PMT only applicable to one way cyclic loading
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LATERAL LOAD NEAR A TRENCH
$H_{\text{trench}} = \lambda H_{\text{no trench}}$
Acceleration of truck

Vehicle Acceleration
Impact Force (X, Y and Z directions)

50ms Vehicle Force

<table>
<thead>
<tr>
<th>Time (sec)</th>
<th>X-dir</th>
<th>Y-dir</th>
<th>Z-dir</th>
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Full-scale K-12 Test and Numerical simulation

(LS-DYNA) Drucker-Prager $\gamma = 21$ kN/m$^2$, $E = 50$ MPa, $c = 20$ kPa, $\phi = 40^\circ$, $\psi = 20^\circ$
3m embedded Single Post in Very Dense Sand

Drucker-Prager $\gamma = 22$ kN/m$^3$, $E = 32$ MPa, $c = 4$ kPa, $\phi = 40^\circ$, $\psi = 15^\circ$

Soil pressure (x-direction)

Drucker-Prager $\gamma = 22$ kN/m$^3$, $E = 32$ MPa, $c = 4$ kPa, $\phi = 40^\circ$, $\psi = 15^\circ$
Numerical Simulation Matrix - Single post in sand

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<thead>
<tr>
<th>Num</th>
<th>Energy level</th>
<th>Soil Strength</th>
<th>E (Mpa)</th>
<th>γ (kN/m³)</th>
<th>φ</th>
<th>ψ (kPa)</th>
<th>Depth</th>
<th>Remark</th>
<th>Results</th>
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<td>21</td>
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<td>15</td>
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<td>3</td>
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Design Chart For Single Post in Sand
Pile Ult. Capacity
\[ Q_u = 706 + 1000 \]
\[ Q_u = 1706 \text{ kN} \]

Assume Neutral Pt.

\[ w_p = w_s \]

Find Load Distrib.

\[ Q_t + Q_d = Q_p + Q_f \]

Calculate Pile Mmt.

\[ w_p \neq w_s \]
TIEBACK WALLS

EARTH PRESSURE COEF. Vs MOVEMENT / HEIGHT
So what!

Too complicated!

THE PREBORING PRESSUREMETER

DISADVANTAGES

- Influence of borehole quality
- Uncontrolled drainage
- Limited use for slopes and walls
THE PREBORING PRESSUREMETER

ADVANTAGES

• Can be done in many soils
• Gives in situ stress strain curve
• In situ “load test”
• Inexpensive equipment
• Quality of test from shape of curve
• Laterally loaded piles
• Shallow foundations
• End bearing piles