Simplify Piezometer Installations, Lower Costs
and Get Better results with

**Fully Grouted Piezometers**

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**Open Standpipe Piezometer**

- Obviously low material costs, but ……
  - Time consuming recording
  - Time-lag potential
  - Minimal and un-timely observations

- Installation sensitivity/problems
  - time consuming backfill procedures
  - complicated backfill
  - risk of incomplete backfill
**VW Piezometer Sensors**

- **Advantages**
  - instant reading, not influenced by observer
  - can be fully grouted
  - best suited for automated readings
  - calibration not influenced by lead length
  - high zero stability (minimal drift for decades)

- **Disadvantages**
  - vulnerable to over-voltage, need protection
  - calibration factors, barometric influence
  - can be damaged by over-pressure

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**Vibrating Wire Sensor**

(After Slope Indicator)
Fully grouted piezometer

- Why grout?  ...Eliminates complexity
- Why does it work?  ...It is like saturated clay!
- Works like piezo sensor pushed into clay
- Mix design?  ...Design based on cement content.
- Grout properties (new research results)

Mandrel pushed-in VWP in soft clay
Casagrande missed the point that pressure sensors are different!
Darcy’s Law for Flow

\[ \Delta q = i \times k \times A = \Delta p/L \times k \times A \]

- \( \Delta q \): flow volume
- \( i \): gradient
- \( \Delta p \): pressure differential
- \( L \): "flow path" distance
- \( k \): coefficient of permeability
- \( A \): cross-sectional area of "flow path"

Short path (2\(^{\prime}\)): (10 psi / 2 in.) \( \times 0.000,001 \) = 0.000,013 lbs/sec = 0.36 gpm
Long path (15 feet): (10 psi / 180 in.) \( \times 0.000,100 \) = 0.000,140 lbs/sec = 0.39 gpm

<table>
<thead>
<tr>
<th>Grout Type</th>
<th>Characteristics</th>
<th>( k ) (cm/sec)</th>
<th>Source</th>
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<tbody>
<tr>
<td>Neat cement</td>
<td>w/c = 0.53, ( \gamma = 112 ) pcf</td>
<td>( 10^{-7} )</td>
<td>Baroid</td>
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<tr>
<td>Bentonite chips</td>
<td>hydrated</td>
<td>( 10^{-8} )</td>
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<td>Bentonite slurry</td>
<td>6 % solids</td>
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<td>Bentonite slurry</td>
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<td>Cement-bentonite</td>
<td>water/solids = 4 to 1</td>
<td>( 10^{-6} )</td>
<td>Vaughan, 1969</td>
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<tr>
<td>Cement-bentonite</td>
<td>w : c : b = 4 : 1 : 1</td>
<td>( 5 \times 10^{+4} )</td>
<td>Vaughan, 1973</td>
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</table>

Table 2. Permeability of some grouts
Cement-Bentonite Grout

- Mix ratio by weight - 2.5 water : 1 cem : 0.37 bent + or – according to consistency
- Mix water and cement first
- Add bentonite slowly, high agitation, make grout creamy, yet pumpable (Marsh # 50-60 sec)
- Density - 80 pcf
- Water Content - >100 %
- Modulus - about 10,000 psi
- 30-day QU strength - 50 to 100 psi
- Permeability – k = 1.0E-06 cm/sec.
VWP in Grout, 200mm thickness, 288 days curing

Pressure Head in Feet vs. Lapsed Time in Minutes
Normalized Cement-Bentonite Grout Properties
(Marsh Number = 50 to 60 sec.)

Normalized Value of Density, Void Ratio & Strength

- Density (pcf) = 63.3 x
- Void Ratio = 4 x
- UCC strength = 240 x
- k (cm/sec) = 1.0E-7 x

Permeability vs. Confining Pressure
29 Day Strength

- Void ratio
  - 0.23
  - 0.34
  - 0.43
  - 0.56
  - 0.68

Water-Cement Ratio - w/c

- Normalized Value of Permeability - k

- Normalized Value of Density, Void Ratio & Strength

- Water-Cement Ratio - w/c
Fully grouted multi-level VWPs

Barometric Pressure and Rainfall, Oregon Coast

Rainfall per 12 hours, inches

10/1/99 10/31/99 12/1/99 12/31/99 1/31/00 3/1/00 4/1/00
0:00 12:00 0:00 12:00 0:00 12:00 0:00

1999 / 2000

millibars or cm of H2O

0 0.6 1.2 1.8 2.4 3 3.6 4.2 4.8
Barometric Influence or Not?

VWP - Altitude Correction
Fully Grouted Piezometer Project

Raw data for fully grouted VWP

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C-B grout: 55 gal. paddle mixer

400-m deep M-L VWP installation
Conclusions

- Cement-bentonite grout works!
- Simpler and faster installation
- Less chance of failed installation
- Works as a high air-entry filter
- It always starts out fully saturated
- Eliminates risk of bentonite “activity”
- Applicable to both boreholes and embankments