Field performance of Fully Grouted piezometers

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Past experiences

McKenna (1995): Field tests with pneumatic piezometers

- Small reading differences of about 2 kPa
- Periodical measurements -> Question: “What is the response time”?
Past experiences

Mikkelsen & Green (2003): Laboratory tests with vibrating wire piezometers

Figure 4. Vibrating wire piezometer response after 288 days cure. Piezometer embedded under 200 mm of cement-bentonite grout inside chamber. Pressure applied above grout surface and piezometer response recorded.

- Response time of a couple of minutes
- One grout and geometry -> Question: “What the response time depends on?”
Questions

1. How can we evaluate the response time?

2. Is it acceptable for a real time assessment of the stability of river embankments?
1. Laboratory testing for analysing the response time

2. Field testing for verifying the acceptability
Laboratory

Grout: water+cement+bentonite
- 2.5 - 1 - 0.3

Size: D = 7 cm
- H = 2, 4 o 8 cm

Measured pressure

Imposed pressure

O-ring seal

impermeable flexible membrane

porous stone

porewater pressure control/measurement

soil specimen

cell pressure control

porewater pressure measurement

Resistive transducer
### Laboratory

8 samples “tremied” and left curing under deaired water

<table>
<thead>
<tr>
<th>Test name</th>
<th>Pressure change</th>
<th>S2-01</th>
<th>S4-01</th>
<th>S8-01</th>
<th>S2-02</th>
<th>S4-02</th>
<th>S8-02</th>
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141 pore water pressure increments/decrements

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<tr>
<th>Sample</th>
<th>S2-01</th>
<th>S4-01</th>
<th>S8-01</th>
<th>S2-02</th>
<th>S4-02</th>
<th>S8-02</th>
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<td>36</td>
<td>38</td>
<td>50</td>
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</table>
**Laboratory**

**Step 1: flushing**
- 150 kPa

**Step 2: cell pressure increment**
- 20 kPa
- 600 kPa

**Step 3: pore water pressure change**
- Measured
- Imposed

**increment**

**decrement**

S8-01 test B
- Imposed Bottom pressure
- Measured Top pressure

S8-01 test G
- Measured Top pressure
- Imposed Bottom pressure
Definitions:

Degree of excess water pressure

\[ U_{\text{top},t} = 1 - \frac{u_{\text{etop},t}}{u_{\text{etop},0}} \]

Response time

\[ t_{95} : U_{\text{top},t95} = 0.95 \]

Assumptions:

1. water and soil incompressible;
2. Darcy’s law holds;
3. equalization volume approximately linear with the change in water pressure (by \( b \) [L²])

Response time:

\[ t_{95} = 3 \frac{Hb}{Ak_g} \]

The response time \( t_{95} \) would not rely on the pore water pressure
$t_{95} < 8 \text{ min}$

$t_{95}$ decreases with increasing $u_{average}$
Degree of excess water pressure

\[ U_{\text{top},t} = 1 - \frac{u_{\text{top},t}}{u_{\text{top},0}} \]

\[ U_{\text{top,}95} = 0.95 \]

• \( t_{95} \) depends on \( u \)

• Incompressibility and saturation are no longer valid

• \( k_g, \theta \) vary with \( u \)

• \( k_g, \Delta \theta/\Delta u \) constant for a given range of \( u \)

“Terzaghi’s equation”

\[ k_g \frac{\partial^2 u_e}{\partial z^2} = \frac{\partial u_e}{\partial t} \]

\[ \gamma_w \cdot \frac{\Delta \theta}{\Delta u_e} \]

Wetting (uw)

Drying (dw)

\[ s^*, \theta_s \]

\[ (u_a - u_w) \]
coefficient of “consolidation”

\[ c_v = \frac{k_g}{Y_w \cdot \frac{\Delta \varrho}{\Delta u_e}} \]

\[ t_{95} = \frac{1 \cdot H^2}{c_v} \]

\[ u_{\text{average}} = 20 \div 500 \text{ kPa} \]

\[ c_v = 2 \div 90 \text{ cm}^2/\text{min} \]
About 140 km of the Adige River (Bozen, Italy) flows between embankments. More than 100 piezometers and open standpipes have been used to monitor their stability.

Fully grouted piezometers would make the installation faster and easier.
Field test: right-side embankment of the Adige River @ Egna (Bozen, Italy)
Field

Soil profile

Unit A
Embarkment
Gravel with silty sand

Unit C1
Upper fluviolacustrine deposit
Sandy silt
$k_h=10^{-5}$ m/s

Unit C2
Lower fluviolacustrine deposit
Silty sand with gravel
$k_h=10^{-4}$ m/s

Adige River

217.09 m a.s.l.

Geometry

217.09 m a.s.l.

Fully-grouted FGP

Traditional TP

Data logger

Water table on 14.03.11

Bentonite seal

Fine gravel pack

Unit A Embankment

Unit C1 Upper fluviolacustrine deposit

Unit C2 Lower fluviolacustrine deposit

Cement-clay grout

Gravel with silty sand

209.52

204.97

210.49

204.09

4 m

a: upper piezometers “not recoverable”

b: lower piezometers “recoverable”
Unit A
Embankment

Unit C1
Upper fluvio-lacustrine deposit

Unit C2
Lower fluvio-lacustrine deposit

Adige River

Field

Soil profile

Grain size distribution

217.09 m a.s.l.

Sand y silt
$k_h=10^{-5}$ m/s

Silty sand
with gravel
$k_h=10^{-4}$ m/s

Gravel with silty sand

Clay
Silt
Fine
Medium
Coarse
Sand
Fine
Medium
Coarse
Gravel
Fine
Medium
Coarse
Cobble
Materials

Fully grouted Piezometer

Grout:
water 2.5
cement 1
clay 0.45

Traditional Piezometer

Gravel pack:
fine gravel 2-6 mm (1.25 m height)

Bentonite seal:
bentonite pellets

Geometry

Fully grouted FGP

Traditional TP

Water table on 14.03.11

Bentonite seal

Fine gravel pack

Cement-clay grout

217.09 m a.s.l.

210.49
209.52
204.97
204.09

4 m
Field

a: Upper piezometers “not recoverable” (type Sisgeo P235S1)

- resistive transducer, absolute;
- filter: ceramic, diameter 15 mm e pore size 0.25 μm;
- FS: 100 kPa.
Field

a: Upper piezometers “not recoverable” (type Sisgeo P235S1)

The filter screwed underwater

Transducer fastened upside-down
Field

b: Lower peizometers “recoverable” (type Sisgeo P252C)

- resistive transducer, absolute;
- filter: sinterized, pore size 40 mm;
- conical tip fitted with o-ring;
- FS: 200 kPa;
- Casagrande filter 200 mm (P101);
- blind pipe 1.5”.
Field

FGP: installation (March 2011)

1. Instrumentation insertion
   - Drill casing
   - Transducer
   - Standpipe
   - Casagrande filter

2. Grouting bottom-up
   - Drill casing
   - Transducer
   - Standpipe
   - Casagrande filter

3. Drill casing retrieving
## Hydraulic conductivity

<table>
<thead>
<tr>
<th>Material</th>
<th>$k_v$ or $k_h$ (m/s)</th>
<th>Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grout</td>
<td>$K_v/k_h \times 10^{-10}$</td>
<td>Laboratory/field, falling head;</td>
</tr>
<tr>
<td>Sandy silt C1</td>
<td>$k_h \times 10^{-5}$</td>
<td>field, falling head</td>
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<tr>
<td>Silty sand with gravel C2</td>
<td>$k_h \times 10^{-4}$</td>
<td>field, falling head</td>
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$k_{	ext{grout}} \ll k_{	ext{soil}}$
## Hydraulic conductivity

<table>
<thead>
<tr>
<th>Material</th>
<th>$k_v$ o $k_h$ (m/s)</th>
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<tbody>
<tr>
<td>Grout</td>
<td>$K_v/k_h$ $10^{-10}$</td>
<td>Laboratory/field, falling head;</td>
</tr>
</tbody>
</table>

**Laboratory:** $1.3 \times 10^{-10}$ m/s after 15 days

**Field:** $4.0 \times 10^{-10}$ m/s

![Graph showing hydraulic conductivity over time](image-url)
Field Measurements:

May 19 to May 31, 2011

a: upper piezometers
   “not recoverable”

b: lower piezometers
   “recoverable”

Coherent with downward seepage

Not coherent with downward seepage
Field Measurements: June 10 to July 11, 2011

Hydraulic heads

Differences

Differences

Coherent with downward seepage

Adige River
Conclusions 1/2

- Very good conformance of fully grouted piezometers in terms of response time (some minutes, depending on the drainage path);

- Response time could be calculated with $c_v = 2 \div 90 \text{ cm}^2/\text{min}$. It depends on stiffness, hydraulic conductivity, degree of saturation;

- In the field, small differences in hydraulic head were calculated between fully grouted and traditional piezometers;

- Differences should be due to different response times and/or gravel pack height;

- Response time of fully grouted piezometers resulted acceptable to monitor the stability of river embankments
Conclusions 2/2

✓ Fully grouted method provides an easier and faster installation, more precise control of transducer depths.

✓ The use of “standpipe + Casagrande filter” allows the use of a transducer with large pore sinterised filter, making easier its saturation.

✓ With the “standpipe + Casagrande filter” the transducer may be retrieved.

✓ Fully grouted piezometers must be avoided when the average value of pore water pressure in an interval depth is needed.
Thank you!