In the Age of Great Innovation, a Great Oversight: Water and its Control

Benjamin S. Rivers, PE
Geotechnical Engineer
Nature’s Grader
Water and Its Control

Water’s Influence

Observations

Investigations, analysis and practice

Summary
Influence of Water

- Added or Increased Water Pressure
- Decreased Effective Stress => Decreased Frictional Resistance
- For Fine-grained soils: Increased Water Content => Decreased Undrained Shear Strength
- For poorly placed fill soils: Change in water-content => Change in weight.
- Erosion (External & Internal)
- Other Affects – Degradation, dissolution, etc.
Water Pressure and Resultant Force

\[ U = 0.5 \gamma_w h^2 \]

![Diagram showing the relationship between force (U) and pressure head (h) with a graph illustrating how force increases with pressure head.](image-url)
Effective Stress and Frictional Resistance

\[ R_{\text{Shear}} = N \times \tan(\phi) \]
Atterberg Limits

- Water Content
- Undrained Shear Strength

Conceptual Changes in Soil Phases as a Function of Water Content
**Weight-Volume**

**△ Water Content**

**△ Total Weight**

Example:

Void Ratio = 0.85

Range of Water contents:  From 15% to 30%

Change in Total Unit-Weight:  105pcf to 120pcf

Change in weight over 30’X30’ area (1’ deep) = 13500lbs = 6.8 tons
So what are we missing?

Some observations…
Dynamic World…Dynamic Conditions

\[ P = 0.5 \gamma w h^2 \]
Fluctuations of Water Levels

![Graph showing water level fluctuations over time]

- **Measured Water Level**
- **Mean Annual Water Level**

<table>
<thead>
<tr>
<th>Date</th>
<th>Water Table Depth (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/1/00</td>
<td></td>
</tr>
<tr>
<td>7/1/00</td>
<td></td>
</tr>
<tr>
<td>11/1/00</td>
<td></td>
</tr>
<tr>
<td>3/1/01</td>
<td></td>
</tr>
<tr>
<td>7/1/01</td>
<td></td>
</tr>
<tr>
<td>11/1/01</td>
<td></td>
</tr>
<tr>
<td>3/1/02</td>
<td></td>
</tr>
<tr>
<td>7/1/02</td>
<td></td>
</tr>
<tr>
<td>11/1/02</td>
<td></td>
</tr>
<tr>
<td>3/1/03</td>
<td></td>
</tr>
</tbody>
</table>
Wall Drainage Measures

Common Assumptions...

- No build-up of water pressures
- “Free-draining” backfill
- Rankine Earthpressures
**Seepage Effects**

(a) Flow Net for Vertical Blanket Drain (Terzaghi)

(b) Pore Pressure Diagram from Equipotential Lines

(c) Pressure on Plane from Pore Pressure Diagram

**Fig. 16-6.** Flow net and pore pressure diagram for retaining wall with vertical back drain rain water seeping into horizontal ground surface. (Huntington)
Wall Drainage Measures

Wall Backfill

Retained Backfill

Face chimney drain

Chimney drain

Collection and Drain Pipes

Outlet Pipe

Weep hole

Foundation Soil
Blanket Drain

- Original Ground
- Highway Embankment
- Blanket Drain
- Removal of Unsuitable Materials
- Seepage
- Pipe
Observations - Summary

• Forgetting the limitations of our assumptions
• General lack of understanding with groundwater flow and control
• Design considerations and details sometimes afterthoughts
Groundwater Investigations

Groundwater Impacts…

Design
  Strength/Stability
  Long-term Performance

Foundation Construction

Earthwork Construction

Possible regulatory issues
Purpose Groundwater Investigations

Determine groundwater piezometric heads (water pressure)

Determine long term changes

Obtain groundwater samples
Piezometers/Observation Wells

**Observation/Monitoring Well:**

Measures the water level or water table or an aquifer (intersects the water table)

**Piezometer:**

Measures the pressure in an aquifer or at a special horizon of the geological profile at a specific point
Single and Nested Piezometers

- Driven Well Point
- Nested Wells in Separate Boreholes
- Dual Installation in Single Borehole

Diagram showing layers of sand and silt with seals at the bottom.
Field Permeability Tests

Borehole Seepage tests:
- Falling water level method
- Rising water level method
- Constant water level method

Slug tests

Well Pumping tests

Pressure Packer tests
Figure 12.10 Equipotentials and streamlines of groundwater flow to drains in deep homogeneous soils
A: small diameter drain, large K; B: large diameter drain, small K (Childs 1943)

<table>
<thead>
<tr>
<th>SOIL HOMOGENEITY</th>
<th>SOIL PROFILE</th>
<th>POSITION OF DRAIN</th>
<th>THEORY</th>
<th>EQUATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Homogeneous</td>
<td>top of impermeable layer</td>
<td>Hooghoudt Drainage</td>
<td>$q = \frac{4K(L-D^2)}{L^2}$</td>
<td></td>
</tr>
<tr>
<td>Homogeneous</td>
<td>above impermeable layer</td>
<td>Hooghoudt</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Homogeneous</td>
<td>Heterogeneous with variable depth</td>
<td></td>
<td>$q = \frac{4K(L-D^2)}{L^2}$</td>
<td></td>
</tr>
<tr>
<td>Three layers</td>
<td>at interface of water table</td>
<td>Hooghoudt</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Replacing Layer</td>
<td>intermediate layer</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Two layers</td>
<td>interlayer</td>
<td>Ernst</td>
<td>$h = \frac{D}{D_1} + \frac{D^2}{8K} - \frac{D}{u} \ln \frac{D_1}{u}$</td>
<td></td>
</tr>
</tbody>
</table>

Figure 8.7 Summary of the steady-state equations

Figure 12.19 Drains with entrance resistance (symbols as defined for Equations 12.17–12.19)
Drainage Control Systems - Examples

- Initial Ground water Level
- Compact Backfill
- Geotextile
- Drainage Material
- Perforated Pipe
- Suppressed Ground water Level
- Excavation
- Cut
- Projected Highway
- Embankment
- Natural Ground
- Permeable Layer
- Horizontal Drains
- Unstable Soil
- Drainage Wells
- Ground Surface
- Original Ground
- Highway Embankment
- Removal of Unsuitable Materials
- Blanket Drain
- Seepage
- Pipe
Summary

• Simplicity – Control Water
• Details are very affordable
• Drainage systems typically provide great benefit at very little expense
• Renewed emphasis and understanding is needed
Pool Fund Study – Subsurface Drainage for Landslide and Slope Stabilization - WADOT (Lead State)

Objectives:
- Provide best practices and guidance for subsurface drainage applications for slope stabilization, including subsurface investigation and testing, groundwater-flow characterization, analysis, drain configurations and design, installation methods, monitoring, and maintenance.

- Evaluate new applications of existing and innovative materials and technologies for stabilizing slopes using subsurface drainage.
NHI 132081: Slope Maintenance & Slide Restoration Course

For: Federal, State and local maintenance, geotechnical and operations engineers, geologists, asset management specialists, and maintenance managers and supervisors involved in assessing, maintaining, managing and repairing cut-slopes, fill-slopes and associated features.
Course Goals:

• Conditions and mechanisms that effect deterioration and stability of slopes
• Roles and responsibilities of maintaining, managing, and repairing highway slopes
• Communication and coordination between the various responsible parties and disciplines.
Coarse Goals (continued):

• Costs associated with preventative slope maintenance measures and repair costs after failure
• Fundamental elements, benefits and limitations of Slope and Rock Fall Hazard Management Systems
• Methods used to prevent and repair slope distress and failures
Questions?