Dewatering
Outline of Presentation

- Introduction
- Applications
- Design
- Examples
Introduction
Purposes for Dewatering

- For construction excavations or permanent structures that are below the water table and are not waterproof or are waterproof but are not designed to resist the hydrostatic pressure.

- Permanent dewatering systems are far less commonly used than temporary or construction dewatering systems.
Common Dewatering Methods

- Sumps, trenches, and pumps
- Well points
- Deep wells with submersible pumps
Sumps, Trenches, and Pumps

- Handle minor amount of water inflow

- The height of groundwater above the excavation bottom is relatively small (5ft or less)

- The surrounding soil is relatively impermeable (such as clayey soil)
Wet Excavations

- Sump pumps are frequently used to remove surface water and a small infiltration of groundwater.

- Sumps and connecting interceptor ditches should be located well outside the footing area and below the bottom of footing so the groundwater is not allowed to disturb the foundation bearing surface.

- In granular soils, it is important that fine particles not be carried away by pumping. The sump(s) may be lined with a filter material to prevent or minimize loss of fines.
Dewatering Open Excavation by Ditch and Sump

INITIAL WATER TABLE

LOWERED WATER TABLE

SUMP PUMP
DITCH
SUMP

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Well Point Method

- Multiple closely spaced wells connected by pipes to a strong pump

- Multiple lines or stages of well points are required for excavations more than 5m below the groundwater table
Single Stage Well Point System
Single Stage Well Point System
Typical Well Point System

Johnson (1975)
Deep Wells with Submersible Pumps

- Pumps are placed at the bottom of the wells and the water is discharged through a pipe connected to the pump and run up through the well hole to a suitable discharge point.

- They are more powerful than well points, require a wider spacing and fewer well holes.

- Used alone or in combination of well points.
Applicability of Dewatering Systems
Applications
Permanent Groundwater Control System

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Deep Wells with Auxiliary Vacuum System
Buoyancy Effects on Underground Structure

Xanthakos et al. (1994)
Recharge Groundwater to Prevent Settlement
Sand Drains for Dewatering A Slope

- Groundwater table due to sand drains
- Average head at line of sand drains due to pumping wells or wellpoints
- Original groundwater table in silt
Grout Curtain or Cutoff Trench around An Excavation

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Design
Design Input Parameters

- Most important input parameters for selecting and designing a dewatering system:
  - the height of the groundwater above the base of the excavation
  - the permeability of the ground surrounding the excavation
Depth of Required Groundwater Lowering

- The water level should be lowered to about 2 to 5 feet below the base of the excavation.
Methods for Permeability

- Empirical formulas
- Laboratory permeability tests
- Borehole packer tests
- Field pump tests
Darcy’s Law

Average velocity of flow
\[ v = k\frac{h}{L} \]

Actual velocity of flow
\[ v_a = \frac{v}{n} \]

Rate (quantity) of flow
\[ q = kA = k\frac{h}{L}A \]
## Typical Permeability of Soils

<table>
<thead>
<tr>
<th>Soil or rock formation</th>
<th>Range of k (cm/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravel</td>
<td>1 - 5</td>
</tr>
<tr>
<td>Clean sand</td>
<td>$10^{-3}$ - $10^{-2}$</td>
</tr>
<tr>
<td>Clean sand and gravel mixtures</td>
<td>$10^{-3}$ - $10^{-1}$</td>
</tr>
<tr>
<td>Medium to coarse sand</td>
<td>$10^{-2}$ - $10^{-1}$</td>
</tr>
<tr>
<td>Very fine to fine sand</td>
<td>$10^{-4}$ - $10^{-3}$</td>
</tr>
<tr>
<td>Silty sand</td>
<td>$10^{-5}$ - $10^{-2}$</td>
</tr>
<tr>
<td>Homogeneous clays</td>
<td>$10^{-9}$ - $10^{-7}$</td>
</tr>
<tr>
<td>Shale</td>
<td>$10^{-11}$ - $10^{-7}$</td>
</tr>
<tr>
<td>Sandstone</td>
<td>$10^{-8}$ - $10^{-4}$</td>
</tr>
<tr>
<td>Limestone</td>
<td>$10^{-7}$ - $10^{-4}$</td>
</tr>
<tr>
<td>Fractured rocks</td>
<td>$10^{-6}$ - $10^{-2}$</td>
</tr>
</tbody>
</table>
Effective Grain Size ($D_{10}$) of Soil, mm

Note: $k_h$ based on field pumping tests

Permeability vs. Effective Grain Size

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Constant Head Test

\[ k = \frac{QL}{hAt} \]
Falling Head Test

\[ k = \frac{aL}{A\Delta t} \ln \left( \frac{h_1}{h_2} \right) \]
Laboratory Test Methods

Rigid wall test

- AASHTO T215; ASTM D 2434
- Typically for sandy & granular soils ($k > 10^{-3}$ cm/s)
- Not recommended for low permeability soils ($k < 10^{-6}$ cm/s)

Flexible wall test

- ASTM D 5084
- Typically for soils ($k < 10^{-3}$ cm/sec)
Flexible vs. Rigid Wall

• In rigid walled permeameters
  – Simpler apparatus
  – Leakage along side-wall possible, especially if sample shrinks
  – May use double ring equipment to discount side-wall leakage

• In flexible walled permeameters (triaxial cells)
  – No side leakage
  – Effective stress (hence k) varies
Shelby Tube Permeameter

- Device designed to use a 6-in section of a standard 3-in diameter Shelby tube
- Ideal for testing loose sands and other materials

(Durham Geo Slope Indicator)
Compaction Permeameter

- uses standard 4 in and 6 in compaction molds for falling or constant head permeability tests

(Durham Geo Slope Indicator)
Rigid Wall Permeameter

Double ring permeameter introduced to measure k without including sidewall leakage which would lead to high estimates of k.
Double Ring Permeameter

- A standard 4 in compaction mold
- A stainless steel sleeve in the base divides the sample into two equal portions, allowing measurement of the permeant flow from the center and perimeter of the sample concurrently
- Flow is monitored with two 5 ml pipettes

(Durham Geo Slope Indicator)
Flexible Wall Permeameter

- Cell pressure
- No loading piston
- Top plate
- Perspex walls
- Soil
- O-ring
- Flow lines with valves
- Top cap
- Bottom cap
- Flexible membrane
- Bottom plate

- Different $\sigma'$ at top and bottom of specimen
Flexible Wall Permeameter
Permeability Testing

- Usually test soils with very low permeability coefficient (<$10^{-9}$ m/s)

\[ v = -ki = -k \frac{dh}{dl} \]

- To make testing practical, increase $i$
- But high $i$ may cause
  - cracking in soil
  - unrepresentative flow regime (Darcy not true anymore)
  - internal erosion
  - edge leakage in test apparatus
## Recommended Maximum Hydraulic Gradient

<table>
<thead>
<tr>
<th>$k$ (cm/sec)</th>
<th>$i_{max}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1 \times 10^{-3} – 1 \times 10^{-4}$</td>
<td>2</td>
</tr>
<tr>
<td>$1 \times 10^{-4} – 1 \times 10^{-5}$</td>
<td>5</td>
</tr>
<tr>
<td>$1 \times 10^{-5} – 1 \times 10^{-6}$</td>
<td>10</td>
</tr>
<tr>
<td>$1 \times 10^{-6} – 1 \times 10^{-7}$</td>
<td>20</td>
</tr>
<tr>
<td>$&lt; 1 \times 10^{-7}$</td>
<td>30</td>
</tr>
</tbody>
</table>
Field Pumping Test

- Phreatic level before pumping
- Phreatic level after pumping
- Test well
- Observation wells
- Impermeable layer
- Test well
- Observation wells
- Impermeable layer

Symbols:
- r:
- r1:
- r2:
- q:
- h:
- h1:
- h2:
- dh:
- dr:
Observation Wells

NAVFAC (1982)

NOTE
Test sections may be perforated with slots or drilled holes.
Permeability from Field Pumping Test

Permeability

\[ k = \frac{q \ln \left( \frac{r_1}{r_2} \right)}{\pi \left( h_1^2 - h_2^2 \right)} \]
Dupuit-Thiem Approximation for Single Well

\[ Q = \frac{\pi k (H^2 - h_w^2)}{\ln(R/r_0)} = 1.366 k \left( \frac{H^2 - h_w^2}{\log(R/r_0)} \right) \]

\[ y^2 - h_w^2 = \frac{Q \ln(r/r_0)}{\pi k} \]
Height of Free Discharge Surface

\[ h_s = \frac{C(H - h_0)}{H} \]

Ollos proposed a value of \( C = 0.5 \)
Influence Range

Sichardt (1928)

\[ R = C'(H - h_w)\sqrt{k} \]

C = 3000 for wells
or 1500 to 2000 for single line well points

H, h_w in meters and k in m/s
Forchheimer Equation for Multiwells

Forchheimer (1930)

\[ Q = \frac{\pi k (H^2 - y^2)}{\ln R - (1/n) \ln x_1 x_2 ... x_n} \]

Circular arrangement of wells

\[ Q = \frac{\pi k (H^2 - y^2)}{\ln R - \ln a} \]
Height of Free Discharge Surface

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Estimation of Flow Rate
– Darcy’s Law

\[ Q = 1.571k \left( \frac{(H-h_0)(H+h_0)(R+r_0)}{R-r_0} \right) \]

Cedergren (1967)
Estimation of Flow Rate
– Well Formulas

\[ Q = 1.366k \frac{H^2 - h_0^2}{\log(R / r_0)} \]

Cedergren (1967)
Estimation of Flow Rate
– Flow Nets

\[ Q = 3.14k(H - h_0)(R + r_0) \frac{n_f}{n_d} \]

\( n_f = \) number of flow channels
\( n_d = \) number of head drops

Cedergren (1967)
## Capacities of Common Deep Well Pumps

<table>
<thead>
<tr>
<th>Min. i.d. of well pump can enter (in.)</th>
<th>Preferred min. i.d. of well (in.)</th>
<th>Approximate max. capacity (gal/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>5</td>
<td>90</td>
</tr>
<tr>
<td>5 5/8</td>
<td>6</td>
<td>160</td>
</tr>
<tr>
<td>6</td>
<td>8</td>
<td>450</td>
</tr>
<tr>
<td>8</td>
<td>10</td>
<td>600</td>
</tr>
<tr>
<td>10</td>
<td>12</td>
<td>1,200</td>
</tr>
<tr>
<td>12</td>
<td>14</td>
<td>1,800</td>
</tr>
<tr>
<td>14</td>
<td>16</td>
<td>2,400</td>
</tr>
<tr>
<td>16</td>
<td>18</td>
<td>3,000</td>
</tr>
</tbody>
</table>

Mansur and Kaufman (1962)
Rate of Flow into A Pumped Well or Well Point

Approximate formula

\[ Q = 44 \sqrt{kr_w h_0} \]

- \( k \) = permeability, ft/min
- \( r_w \) = effective radius of the well, ft
- \( h_0 \) = depth of immersion of well, ft

Bush (1971)
Typical Well Point Spacing in Granular Soils

NAVFAC (1982)
Typical Well Point Spacing in Stratified Soils

NAVFACT (1982)
Spacing of Deep Wells

- The spacing of deep wells required equals the perimeter of the excavation divided by the number of wells required
Well Point Pump

Discharge check valve
Float control tank
Pump suction
Water tank
Vacuum pump
Air separator
Centrifugal pump

Carson (1961)
Head vs. Discharge for Pump

Carson (1961)
Head vs. Discharge for Pump

Carson (1961)
Bottom Stability of Excavation

\[ \gamma Z > \gamma_w (h + Z) \]

Caltrans
Settlement of Adjacent Structures

\[ \delta = \frac{H}{1+e_0} C_c \log \frac{\sigma'_v + \Delta \sigma}{\sigma'_o} \]

\[ \Delta \sigma = \Delta h \gamma_w \]

\[ \Delta h = \text{reduction of groundwater level} \]
Examples
240m length x 150m width x 21m depth

Plan View & Cross-Section

Glacial outwash sands and gravel
\( k = 4.7 \times 10^{-3} \text{ cm/sec} \)

Very stiff lacustrine clay
\( k = 8.1 \times 10^{-6} \text{ cm/sec} \)

Xanthakos et al (1994)
Design Requirement

Lower the groundwater table to 1.5m below the bottom of the excavation
Equivalent Radius and Influence Range

Equivalent radius of excavation

\[ r_0 = \sqrt{\frac{800 \text{ ft} \times 500 \text{ ft}}{\pi}} = 357 \text{ ft} \quad \text{112.5m} \]

Height of water level in well

\[ h_0 = 160 - 70 - 5 = 85 \text{ ft} \quad \text{25.5m} \]

Influence range

\[ R = C'(H - h_w)\sqrt{k} = 3000 \times (140 - 85) \times 0.3 \times \sqrt{4.7 \times 10^{-5}} \]
\[ = 340 \text{m} = 1130 \text{ft} \quad \text{339m} \]
Rate of Flow in Wells

Using Darcy’s law

\[ Q = 1.57lk \frac{(H - h_0)(H + h_0)(R + r_0)}{R - r_0} \]

\[ = 1.57 \times 0.00925 \times \frac{(140 - 85)(140 + 85)(1130 + 357)}{1130 - 357} \]

\[ = 346\text{ft}^3 / \text{min} = 2592\text{gal} / \text{min} \]

Single well formula

\[ Q = \frac{1.37k(H^2 - h_0^2)}{\log(R - r_0)} = \frac{1.37 \times 0.00925 \times (140^2 - 85^2)}{\log(1130 / 357)} \]

\[ = 313\text{ft}^3 / \text{min} = 2350\text{gal} / \text{min} \]
Flow Rate into Wells using Flow Net

\[ Q = 3.14k(H - h_0)(R + r_0) \frac{n_f}{n_d} \]

\[ = 3.14 \times 0.00925 \times (140 - 85) \times (1130 + 357) \frac{3}{30} \]

\[ = 238 \text{ft}^3 / \text{min} = 1782 \text{gal} / \text{min} \]
A pump test indicates that the field permeability $k = 9.2 \times 10^{-4}$ cm/sec and the radius of influence $R = 2200$ ft. The new solutions based on the pump Test results are

<table>
<thead>
<tr>
<th>Method</th>
<th>Darcy’s law</th>
<th>Well formula</th>
<th>Flow net</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q (gal/min)</td>
<td>370</td>
<td>290</td>
<td>360</td>
</tr>
</tbody>
</table>
Layout of Deep Wells

Xanthakos et al (1994)
Multiple Wells

\[ Q = \frac{\pi k (H^2 - y^2)}{\ln R - \ln a} = \frac{3.14 \times 0.00181 \times (140^2 - 85^2)}{\ln 2200 - \ln 357} \]

\[ = 38.7 \text{ ft}^3/\text{min} = 290 \text{gal/min} \]

290/8 = 36.3 gal/min per well

Deep well size:

4” dia. for 36.6 gal/min

Header pipe:

4” dia. for 5 x 36.6 gal/min = 181 gal/min

Discharge pump:

4” dia. Pump for 290 gal/min