Overview

• Intro to solar racks and foundations
• Pile load tests
• Design process
• Design loads
  – Frost Heave
Fixed Tilt Racks
Single Axis Trackers
Dual Axis Trackers
Foundation Options

- Driven
- Helical
- Micropile (Drill & Grout)
- Screw anchors
- Concrete ballast
Pile Load Testing

- **Typical testing frequencies**
  - Anticipated subsurface variability
  - Geographic shape (spread out?)
  - Install 2-4 piles at each location with varying embedment depths.

<table>
<thead>
<tr>
<th>Size (MW)</th>
<th>Test Locations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>2-4</td>
<td>2-3</td>
</tr>
<tr>
<td>5-15</td>
<td>3-5</td>
</tr>
<tr>
<td>15-25</td>
<td>5-7</td>
</tr>
<tr>
<td>25-50</td>
<td>7-10</td>
</tr>
<tr>
<td>50-100</td>
<td>10-20</td>
</tr>
<tr>
<td>&gt;100</td>
<td>&gt;20</td>
</tr>
</tbody>
</table>
Pile Load Testing - Lateral

Westwood
Pile Load Testing - Uplift
Pile Load Testing - Compression
Pile Design Approach

1. Geotechnical investigation
2. Pile load tests
3. Basis of design
4. Determine corrosion rates
5. Build calibrated lateral loading soil model (p-y curve)
6. Develop preliminary pile design
7. Model the preliminary design using p-y curve (LPile)
   - Adjust embedment so bottom is fixed
   - Determine deflection, shear, and moment demands
8. Perform pile capacity checks per AISC
9. Optimize pile sections and reveal heights
Design Loads

- Same as any other foundation?
- Loads on the structure:
  - Code / ASCE 7: dead, **wind**, seismic, snow, rain, ice
  - Other: dynamic effects
- Loads on foundation:
  - **Frost**, expansive soils, differential settlement, negative skin friction
- Uplift and/or lateral loads will oftentimes control design
WARNING
FROST HEAVE AHEAD
Frost Heave

Air: Freezing Temperatures

Frozen layer:
Upward thrust of Ice Layer displaces soil or fractures overlying rock

Growing Ice Layer

Transition Layer
(Mixture of frozen and premelted water)

Unfrozen Subgrade Materials
# Frost Susceptibility

<table>
<thead>
<tr>
<th>Frost Group</th>
<th>Degree of Frost Susceptibility</th>
<th>Type of Soil</th>
<th>Percentage Finer than 0.075 mm (# 200) by wt.</th>
<th>Typical Soil Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>F1</td>
<td>Negligible to low</td>
<td>Gravelly soils</td>
<td>3-10</td>
<td>GC, GP, GC-GM, GP-GM</td>
</tr>
<tr>
<td>F2</td>
<td>Low to medium</td>
<td>Gravelly soils</td>
<td>10-20</td>
<td>GM, GC-GM, GP-GM</td>
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<tr>
<td></td>
<td></td>
<td>Sands</td>
<td>3-15</td>
<td>SW, SP, SM, SW-SM, SP-SM</td>
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<tr>
<td>F3</td>
<td>High</td>
<td>Gravelly Soils</td>
<td>Greater than 20</td>
<td>GM-GC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sands, except very fine silty sands</td>
<td>Greater than 15</td>
<td>SM, SC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Clays PI &gt; 12</td>
<td>-</td>
<td>CL, CH</td>
</tr>
<tr>
<td>F4</td>
<td>Very high</td>
<td>All Silts</td>
<td>-</td>
<td>ML-MH</td>
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<td></td>
<td></td>
<td>Very Fine Silty Sands</td>
<td>Greater than 15</td>
<td>SM</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Clays PI &lt; 12</td>
<td>-</td>
<td>CL, CL-ML</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Varied clays and other fine grained, banded sediments</td>
<td>-</td>
<td>CL, ML, SM, CH</td>
</tr>
</tbody>
</table>
FROST HEAVE IS REAL
Frost Heave on Piles

• Two types of frost uplift forces
  • Basal Heave – Normal force on foundation base.
  • Tangential (Adfreeze) Heave – Shear force along outer surface of foundation
• Frozen soil bonds to pile (adfreeze) and frost heave of the soils induces uplift force on the pile.
Frost Heave on Piles

\[ Q_{hv} = q_{hv} \pi B d_f \]

\[ Q_{sL} = q_{sL} \pi B (L - d_f) \]

Adfreeze Bond

- AKA: tangential heave stress
- Depends on many factors
  - Soil type
  - Ground temperature
  - Frost depth
  - Water and ice content
  - Degree of saturation
  - Foundation material (steel or concrete)
  - Rate of loading
  - Duration of loading
Adfreeze Bond

- Varies (40 kPa to 280 kPa)
- USACE (TM 5-852-4)
  - Concrete: 10 to 275 kPa
  - Steel: 7 to 185 kPa (1.5x in sand)
- Russian Building Code
  - Concrete: 50 to 130 kPa
  - Steel: 35 to 90 kPa
- Canadian Foundation Engineering Manual
  - Concrete: 65 kPa
  - Steel: 100 kPa
- More research needed!

...the **minimum allowable footing depth** in feet due to freezing is five feet in Zone I and 3-1/2 feet in Zone II.

- Does this apply to lightly loaded PV racking piles?
Limited snow cover increases frost depth
Frost Depth

Frost Depth

Frost Depth

Ref: MnDOT Materials & Road Research. Frost and Thaw Depths.
http://dotapp7.dot.state.mn.us/research/seasonal_load_limits/thawindex/frost_thaw_graphs.asp
Frost Design Loads

• Typical unfactored axial load for Southwest project: 1,500 lbs to 3,000 lbs (wind and dead load only)

• Typical unfactored frost load for Minnesota Project: 10,000 lbs to 20,000 lbs (frost!)
  • Add % of wind and subtract dead load

• Add Safety Factor
Other Design Considerations

- Flood
- Scour (wind and water)
- Corrosion allowance
- Hydrocollapse