Foundation Support Cost:
Applications to Driven-Pile Design

Pile Driving Contractors Association
2015 Professor’s Driven Pile Institute

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Topics Outline

• Support Cost
  – Define
  – Driven-Pile Support-Cost Components
    • Pile
      – Based on Available (Installed) Support
      – Based on Utilized Support
    • Cap
    • Construction-Control Method ("CCM")
    • System
  – Case History Examples
Support’Cost (Sũ•pōrt’Kŏst)

The cost of an installed or constructed foundation element, component, or system, divided either by its available (i.e., installed), or utilized, allowable load/factored resistance, usually expressed in dollars per allowable ton (i.e., how many dollars one ton of support costs).
Support Cost (Sũ•pōrt’Kŏst)

• As a normalized parameter, allows direct (apples-to-apples) economic comparison of different foundation design and testing alternatives:
  – Shallow vs. deep (e.g., spread footings vs. piles)
  – Deep vs. deep (e.g., drilled piers vs. piles)
  – Pile type vs. pile type (e.g., concrete vs. pipe piles)
  – Pile section vs. pile section (e.g., 10.75” vs. 12.75” diameter; 0.250” vs. 0.500” wall)
  – Allowable pile load vs. allowable pile load (e.g., 70T vs. 150T)
  – Construction control methods (dynamic formula, wave-equation analysis, dynamic load testing, and static load testing)
Deep Foundation System Components

Column Design Load

Column

Cap

Piles
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Pile Support Cost Based on Available (Installed) Support

\[
Pile Support Cost = \frac{Pile Installation Cost}{Allowable Pile Load}
\]

In general, higher allowable pile loads result in lower pile support costs:

- Spread “invested” pile length required to penetrate through poor soils over more capacity.
- In competent soils, capacity generally increases faster with depth than does cost.
# Pile Support Cost

Pile Support Cost = \( \frac{\text{Pile Installation Cost}}{\text{Allowable Pile Load}} \)

<table>
<thead>
<tr>
<th>Pile Installation Cost</th>
<th>Allowable Pile Load</th>
<th>Pile Support Cost per Ton of Available Support</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1,500 per pile</td>
<td>50-ton allow. load</td>
<td>$30 / allowable ton of available support</td>
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<tr>
<td>$3,000 per pile</td>
<td>150-ton allow. load</td>
<td>$20 / allowable ton of available support</td>
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## WKG² Pile Support Costs

<table>
<thead>
<tr>
<th>Project</th>
<th>Pile Type</th>
<th>Allowable Pile Load, tons</th>
<th>Pile Support Cost, dollars per allowable ton installed</th>
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<td>12.75 x 0.365</td>
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<td>11.52</td>
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<tr>
<td>B</td>
<td>16-inch Monotube</td>
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<tr>
<td>C</td>
<td>12.75 x 0.312</td>
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</table>
Pile Support Costs – WKG\(^2\) Projects

\[ y = 90.662x^{-0.402} \]

\[ R^2 = 0.712 \]

Pile Support Cost, dollars per available ton

Allowable Pile Load, tons (safety factor = 2.0)
Pile Support Costs – WKG² Design-Build

Various:
- Pile Diameters (10.75- and 12.75-inch-O.D.)
- Safety Factor (from 2.0 to 2.5)
- Installation Criteria (WEAP, Modified EN)
- Subsurface Conditions (from till at 4 feet, to 60 feet of organic silt)

Equations:
- \( y = 245.41x^{-0.5529} \) with \( R^2 = 0.4787 \)
- \( y = 35.326e^{-0.0058x} \) with \( R^2 = 0.5423 \)
Payback on “Invested” Pile Length

Spread pile length “invested” to penetrate through poor soils over more capacity returned.

Invested length becomes smaller portion of total installation, cost-effectiveness increases.
Allowable Pile Load

Allowable load might increase at a greater rate than embedded length/cost (e.g., 20% additional length/cost may yield more than 20% additional capacity).
Production Piles Cost vs. Toe Elevation – 12.75x0.375 Pipe Pile
Pile Support-Cost Profile Determination

![Graphs showing cost profile determination](image-url)
Pile Support Cost
Allowable Load

Pile Support Cost
Allowable Load

Pile Support Cost vs. Allowable Load
Achieving Higher-Allowable-Load Piles

Geotechnical

- Use larger section, larger hammer, drive piles “harder,” perhaps deeper.
- Incorporate soil/pile set-up:
  - Use displacement pile.
  - Adjust testing program (wait longer to test, restrike testing, etc.).
- Perform testing to reduce geotechnical safety factor (e.g., from 3.0 to 2.0).

Structural

- Perform testing to increase permissible material stresses (e.g., steel from 9 or 12 ksi, to 16 ksi).
- Use higher-strength concrete (e.g., in concrete-filled pipe piles from 3,000 or 4,000 psi, to 6,000 psi).
So use the highest practical allowable load piles at every location on every project, right?

If not, why not?
Topics Outline

• **Support Cost**
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    • Cap
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    • System
  - Case History Examples
Pile Support Cost Based on Utilized Support

\[
P = \frac{P}{3} + \frac{P}{3} + \frac{P}{3}
\]

Pile Installation Cost = Structure Design Load Resisted by Pile

Indicates *design efficiency* (how well the piles’ allowable load and support cost, along with the minimum required number of piles, matches the design column load).

Optimum design efficiency generally results from using the optimum allowable pile load.
Pile Support Cost: Design Efficiency

Based on Available Support

Installed Cost = $5,000
Allowable Pile Load = 250T

\[
\frac{5,000}{250^T} = \text{$20.00 per available ton}
\]

Based on Utilized Support

Large Resisted Loads

Structure Design Load = 700T

\[
\frac{3 \times 5,000}{700^T} = \text{$21.43 per structure design ton}
\]

Small Resisted Loads

Structure Design Load = 300T

\[
\frac{3 \times 5,000}{300^T} = \text{$50.00 per structure design ton}
\]
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Cap Support Cost

\[
\text{Cap Support Cost} = \frac{\text{Cap Construction Cost}}{\text{Structure Design Load Assigned to Cap}}
\]

Higher allowable pile loads result in fewer piles, smaller caps, and therefore lower cap support costs.

Minimum cap support cost results from using the minimum required number of piles.
Cap Support Costs

Column Load, kips

Cap Support Cost, dollars per structure design ton

50-Ton Piles
75-Ton Piles
100-Ton Piles
150-Ton Piles
200-Ton Piles
250-Ton Piles
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## Construction-Control Method Support Cost

<table>
<thead>
<tr>
<th>Approx. Column Load, tons</th>
<th>Pile Depth, feet</th>
<th>Ultimate Pile Capacity, tons</th>
<th>Construction Control Method (&quot;CCM&quot;)</th>
<th>Allowable Pile Load, tons</th>
<th>Allowable Pile Load Count per Cap</th>
<th>Approx. Pile Load, tons</th>
<th>Approx. Pile Load Count per Cap</th>
<th>Pile Cost per Cap (at $47/ft)</th>
<th>Pile Support Cost, $/structure design ton</th>
<th>Approx. Cost per Cap</th>
<th>Approx. Cap Support Cost, $/structure design ton</th>
<th>CCM Cost for 4 Caps, $/structure design ton</th>
<th>CCM Support Cost per Cap, $/structure design ton</th>
<th>Total Foundations' Cost, $/structure support ton</th>
<th>Total Foundation Support Cost, $/structure support ton</th>
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Note: Construction-Control Methods (driving criteria development):
- **DF** = Dynamic Formula
- **WE** = Wave Equation
- **DLT** = Dynamic Load Test
- **SLT** = Static Load Test

(Adapted from Hannigan et al., 2006)
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System Support Cost

Total Foundation Cost
\[ \sum \text{Structure Design Loads} \]

Measures overall cost-effectiveness of deep foundation system. Provides basis for comparison among viable design, installation, and construction-control method options, or with other projects.
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Photo 9: Five-Level Section of Interchange Core  
Marquette Interchange – Milwaukee, Wisconsin

Photo: Bob Wazniak, Safety Engineer, WisDOT
### Estimated Foundations Support Costs

- **30-inch-diameter**
- **9.625-inch Oil Casing Piles plus**
- **9,000-psf Spread**
- **60-inch-diameter**

**Column Load, kips**

**Foundation Element Support Cost, dollars per allowable ton installed**

- 0
- 1,000
- 2,000
- 3,000
- 4,000
- 5,000
- 6,000

**Support-Cost Application – WEPCO OCPP**
Support-Cost Application – WEPCO OCPP

Estimated Foundations Support Costs

- 9.625-inch Oil Casing Piles
- 30-inch-diameter
- 60-inch-diameter

Foundation Element Support Cost, dollars per allowable ton installed

Column Load, kips

10,000-psf Spread

9.625-inch Oil Casing
Support-Cost Application – Miller Park

200-Ton Monotube® Piles

130’

Bedrock

30’

Rock-(Socketed Drilled Pier

?
Estimated Deep Foundations Support Cost vs. Depth to Bedrock

- 150-Ton 16" Monotube (overburden)
- 150-Ton 12.75" Pipe (overburden)
- 150-Ton 13.375" Oil Casing (overburden)
- 200-Ton 16" Monotube (overburden)
- 200-Ton 13.375" Oil Casing (overburden)
- 14HP89 H-Pile (rock)
- 5-Foot-Diameter Rock Pier (rock)
Estimated Deep Foundations Support Cost vs. Depth to Bedrock

- 150-Ton 16" Monotube (overburden)
- 150-Ton 12.75" Pipe (overburden)
- 150-Ton 13.375" Oil Casing (overburden)
- 200-Ton 16" Monotube (overburden)
- 200-Ton 13.375" Oil Casing (overburden)
- 14HP89 H-Pile (rock)
- 5-Foot-Diameter Rock Pier (rock)

Depth Below Elevation 590 to Bedrock, feet
Questions / Comments?