APPENDIX

Driven Piles

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Gates Formula Commentary

Projects with driven pile foundations specify the “Gates Formula” to determine nominal resistance. This change was first incorporated in the “Amendments to July 1999 Standard Specifications” and is now included in the Standard Specifications\(^1\). The change is also discussed in Bridge Construction Memo (BCM) 130-4.0, *Pile Driving Acceptance Criteria*.

Why change from ENR to Gates Formula?

- Factor of safety from ENR (Engineering News Record) varies from 1/2 to 20. With low factor of safety, capacity of the pile is actually driven to be under the factored design load. Lack of capacity has resulted in excessive settlement. Extremely high factors of safety often cause damage to the pile and result in contractor claims and also is a waste of time and energy.

- California was actually one of the last States using the ENR formula.

- ENR does not properly account for down drag or the overburden effects and resistance associated with zones that may scour or liquefy.

Advantage of Gate’s Formula

- This formula predicts the static capacity of the pile significantly more accurately than the ENR Formula because it provides a significantly lower coefficient of variation.

Additionally, since the formula utilizes ultimate capacity and not an unfactored safe load, the formula can account for the effects of downdrag, scour, and liquefaction.

The Gates formula (US Customary) is:

\[
R_u = (1.83 \times (E_r)^{\frac{1}{2}} \times \log_{10}(0.83 \times N)) - 124
\]

Where:

- \(R_u\) = Calculated nominal resistance/ultimate compressive capacity in kips
- \(E_r\) = Energy rating of hammer at observed field drop height in foot pounds
- \(N\) = Number of blows in the last foot (maximum of 96)

\(^1\) 2010 SS, Section 49-2.01A(4)(b), *Pile Driving Acceptance Criteria*, or 2006 SS, Section 49-1.08, *Pile Driving Acceptance Criteria*. 
Additional Notes:

*Caltrans Memo to Designer 3-1* was updated in June 2014. During constructability reviews, it is very important that the Structure Construction reviewer checks the pile data table on the plan sheets for notes on downdrag and liquefaction.

A very good reference showing the differences in formulas (Gates, ENR, Haley, Janbu, etc) is the “Comparison of Methods for Estimating Pile Capacity, Report No. WA-RD 163.1”, Final Report dated August 1988, by the Washington State Department of Transportation. In lieu of that, examples of comparisons are shown below.
Pile Driving Formulas

**Gates Formula**

\[ P = \left( (1.83 \cdot (E_r)^{1/2} \cdot \log_{10}(0.83 \cdot N)) - 124 \right) z \]

Where,  
- \( P \) = safe load in kips  
- \( E_r \) = energy of driving in foot pounds  
- \( N \) = number of hammer blows in the last foot  
- \( z \) = conversion factor for units and safety with this formula

**Engineering News (ENR)**

\[ P = \frac{2E}{(s + 0.1)} \]

Where,  
- \( P \) = safe load in pounds  
- \( E \) = rated energy in foot-pounds  
- \( s \) = penetration per blow in inches

This formula was derived from the original Engineering News formula for drop hammers on timber piles, which was:

\[ P = \frac{WH}{(s + c)} \]

Where,  
- \( W \) = weight of ram in pounds  
- \( H \) = length of stroke in inches  
- \( c \) = elastic losses in the cap, pile, and soil in inches

It was modified to correct units and apply other factors to compensate for modern equipment.
Janbu Formula

\[ P = \left( \frac{WH}{k_u s} \right) z \]

Where,  
- \( P \) = safe load in pounds  
- \( W \) = weight of ram in pounds  
- \( H \) = length of stroke in inches  
- \( s \) = penetration per blow in inches  
- \( k_u \) = factor derived from the following,
  \[ k_u = C_d \left[ 1 + \sqrt{1 + \left( \frac{\lambda}{C_d} \right)} \right] \]
  \[ C_d = 0.75 + 0.15 \left( \frac{W_p}{W} \right) \]
  \[ \lambda = \frac{WHL}{AES^2} \]
  where,  
  - \( W_p \) = weight of pile in pounds  
  - \( L \) = length of pile in inches  
  - \( A \) = area of pile in square inches  
  - \( E \) = modulus of elasticity of pile in pounds per square inch  
  - \( z \) = conversion factor for units and safety with this formula

Hiley Formula

\[ P = \left( \frac{e_f WH}{s + \frac{1}{2} (c_1 + c_2 + c_3)} \right) \left( \frac{W + n^2 W_p}{W + W_p} \right) z \]

Where,  
- \( P \) = safe load in pounds  
- \( e_f \) = efficiency of hammer (%)  
- \( W \) = weight of ram in pounds  
- \( H \) = length of stroke in inches  
- \( s \) = penetration per blow in inches  
- \( c_1, c_2, c_3 \) = temporary compression of pile cap and head, pile, and soil, respectively in inches  
- \( n \) = coefficient of restitution  
- \( W_p \) = weight of pile in pounds  
- \( z \) = conversion factor for units and safety with this formula
Pacific Coast Formula

\[ P = \frac{E_n \left( W + kW_p \right) z}{s + \frac{PL}{AE}} \]

Where,
- \( P \)= safe load in pounds
- \( E_n \)= energy of driving in inch pounds
- \( W \)= weight of ram in pounds
- \( W_p \)= weight of pile in pounds
- \( s \)= penetration per blow in inches
- \( L \)= length of pile in inches
- \( A \)= area of pile in square inches
- \( E \)= modulus of elasticity of pile in pounds per square inch
- \( k \)= 0.25 for steel piles
  - 0.10 for other piles
- \( z \)= conversion factor for units and safety with this formula
Comparison of Formulas

Given Problem Conditions

Hammer Data: Delmag D36-32
- Maximum Energy = 83,880 ft·lbs
- Ram Weight = 7,938 lbs
- Maximum Stroke = 10.42 ft
- Penetration or Set = 0.844 inches

Length of Pile = 80 feet

- Assume hard driving -

| Case 1: | 12” PC/PS concrete pile |
| Case 2: | 12 BP 53 Steel Piles |

Gates Formula

For Case 1 & 2:

\[ P = \left( (1.83 \times (E_{r})^{0.5} \times \log_{10}(0.83 \times N)) - 124 \right) \frac{1}{2(2^{(2\frac{s}{ton})})} \]

\[ = \left( (1.83 \times (83,880)^{0.5} \times \log_{10}(0.83 \times (12 / 0.844)) - 124 \right) \frac{1}{2(2^{(2\frac{0.844}{ton})})} \]

\[ = \left( (1.83 \times 289.62 \times 1.072) - 124 \right) \frac{1}{2(2^{(2\frac{0.844}{ton})})} \]

\[ = (568.122 - 124) \frac{1}{2(2^{(2\frac{0.844}{ton})})} \]

\[ = \frac{444.122 \text{ kips}}{2(2^{(2\frac{0.844}{ton})})} \approx 111.0 \text{ tons} \]

Engineering News (ENR) Formula

For Case 1 & 2:

\[ P = \frac{2E}{(s + 0.1)} \]

\[ = \frac{2(83,880.0 \text{ ft} \cdot \text{lbs})}{0.844 \text{ in} + 0.1} \]

\[ = 177,712 \text{ lbs} \approx 70 \text{ tons} \]
Janbu Formula

Case 1:

\[ P = \left( \frac{WH}{k_p s} \right) z = \frac{WH}{k_p s} \frac{1}{\frac{1}{3(2000 \text{ lb/ton})}} \]

\[ = \left( \frac{7,938 \text{ lbs}(10.42 \text{ ft} \times 12 \text{ in/ft})}{2.697(0.844 \text{ in})} \right) \frac{1}{\frac{1}{3(2000 \text{ lb/ton})}} \]

\[ = \left( \frac{435,931 \text{ lbs}}{3(2000 \text{ lb/ton})} \right) \approx 72.66 \text{ tons} \]

\[ c_d = 0.75 + 0.15 \left( \frac{W_p}{W} \right) \]

\[ = 0.75 + 0.15(11,600 \text{ lbs} / 7,938 \text{ lbs}) \]

\[ = 0.969 \]

\[ \lambda = \frac{WHL}{AE_s^2} \]

\[ = \frac{7,938 \text{ lbs}(10.42 \text{ ft} \times 12 \text{ in/ft})(80 \text{ ft} \times 12 \text{ in/ft})}{(144 \text{ in}^2)(4.4 \times 10^6 \text{ lbs/in}^2)(0.844 \text{ in})^2} \]

\[ = 2.111 \]

\[ k_u = c_d \left[ 1 + \sqrt{1 + \left( \frac{\lambda}{c_d} \right)} \right] \]

\[ = 0.969 \left[ 1 + \sqrt{1 + (2.111/0.969)} \right] \]

\[ = 2.697 \]

Case 2:

\[ P = \left( \frac{WH}{k_p s} \right) z = \frac{WH}{k_p s} \frac{1}{\frac{1}{3(2000 \text{ lb/ton})}} \]

\[ = \left( \frac{7,938 \text{ lbs}(10.42 \text{ ft} \times 12 \text{ in/ft})}{2.581(0.844 \text{ in})} \right) \frac{1}{\frac{1}{3(2000 \text{ lb/ton})}} \]

\[ = \left( \frac{455,578 \text{ lbs}}{3(2000 \text{ lb/ton})} \right) \approx 75.93 \text{ tons} \]

\[ c_d = 0.75 + 0.15 \left( \frac{W_p}{W} \right) \]

\[ = 0.75 + 0.15(4,240 \text{ lbs} / 7,938 \text{ lbs}) \]

\[ = 0.830 \]

\[ \lambda = \frac{WHL}{AE_s^2} \]

\[ = \frac{7,938 \text{ lbs}(10.42 \text{ ft} \times 12 \text{ in/ft})(80 \text{ ft} \times 12 \text{ in/ft})}{(15.81 \text{ in}^2)(30 \times 10^6 \text{ lbs/in}^2)(0.844 \text{ in})^2} \]

\[ = 2.861 \]

\[ k_u = c_d \left[ 1 + \sqrt{1 + \left( \frac{\lambda}{c_d} \right)} \right] \]

\[ = 0.830 \left[ 1 + \sqrt{1 + (2.861/0.830)} \right] \]

\[ = 2.581 \]
Hiley Formula

Case 1:

\[
P = \left( \frac{e_j WH}{s + \frac{1}{2}(c_1 + c_2 + c_3)} \right) \left( \frac{W + n^2 W_p}{W + W_p} \right)^z \times 2.75(2000 \text{ lbs/ton})
\]

\[
= \left( \frac{1.00(7,938 \text{ lbs})(10.42 \text{ ft} \times 12 \text{ in/ft})}{0.844 \text{ in} + \frac{1}{2}(0.37 \text{ in} + 0.53 \text{ in} + 0.10 \text{ in})} \right) \left( \frac{7,938 \text{ lbs} + (0.25^2)(11,600 \text{ lbs})}{7,938 \text{ lbs} + 11,600 \text{ lbs}} \right)^{\frac{1}{2.75(2000 \text{ lbs/ton})}}
\]

\[
= \frac{355,090 \text{ lbs}}{2.75(2000 \text{ lbs/ton})} \approx 64.6 \text{ tons}
\]

Case 2:

\[
P = \left( \frac{e_j WH}{s + \frac{1}{2}(c_1 + c_2 + c_3)} \right) \left( \frac{W + n^2 W_p}{W + W_p} \right)^z \times 2.75(2000 \text{ lbs/ton})
\]

\[
= \left( \frac{1.00(7,938 \text{ lbs})(10.42 \text{ ft} \times 12 \text{ in/ft})}{0.844 \text{ in} + \frac{1}{2}(0.0 \text{ in} + 0.48 \text{ in} + 0.10 \text{ in})} \right) \left( \frac{7,938 \text{ lbs} + (0.55^2)(4,240 \text{ lbs})}{7,938 \text{ lbs} + 4,240 \text{ lbs}} \right)^{\frac{1}{2.75(2000 \text{ lbs/ton})}}
\]

\[
= \frac{662,508 \text{ lbs}}{2.75(2000 \text{ lbs/ton})} \approx 120.5 \text{ tons}
\]
Pacific Coast Formula

Case 1:

\[
P = \frac{E_n \left( \frac{W + kW_p}{W + W_p} \right)^z}{s + \frac{PL}{AE}}
\]

\[
E_n \left( \frac{W + kW_p}{W + W_p} \right) = \frac{1}{s + \frac{PL}{AE}} \times 4(2000 \text{ lbs/ton})
\]

\[
P = \frac{83,880 \text{ ft} \cdot \text{lbs}(12 \text{ in/lbs}) \left( \frac{7,938 \text{ lbs} + 0.1(11,600 \text{ lbs})}{7,938 \text{ lbs} + (11,600 \text{ lbs})} \right)}{0.844 \text{ in} + \frac{P(80 \text{ ft} \times 12 \text{ in/lbs})}{(144 \text{ in}^2)(4.4 \times 10^6)}} \times \frac{1}{4(2000 \text{ lbs/ton})}
\]

\[
= \frac{468,711 \text{ in} \cdot \text{lbs}}{0.844 \text{ in} + P(1.52 \times 10^{-6} \text{ in/lbs})} \times \frac{1}{4(2000 \text{ lbs/ton})}
\]

\[
= \frac{343,511 \text{ lbs}}{4(2000 \text{ lbs/ton})} \approx 42.94 \text{ tons}
\]
Case 2:

\[
P = \frac{E_n\left(\frac{W + kW_p}{W + W_p}\right)}{s + \frac{PL}{AE}}
\]

\[
= \frac{E_n\left(\frac{W + kW_p}{W + W_p}\right)}{s + \frac{PL}{AE}} \times \frac{1}{4(2000 \text{ lbs/ton})}
\]

\[
= \frac{83,880 \text{ ft} \cdot \text{lbs}(12 \text{ in/ft})}{0.844 \text{ in} + \frac{P(80 \text{ ft} \times 12 \text{ in/ft})}{(15.58 \text{ in}^2)(30 \times 10^6)}} \times \frac{1}{4(2000 \text{ lbs/ton})}
\]

\[
= \frac{743,720 \text{ in} \cdot \text{lbs}}{0.844 \text{ in} + P(2.1 \times 10^{-6} \text{ in/lbs})} \times \frac{1}{4(2000 \text{ lbs/ton})}
\]

\[
= \frac{430,395 \text{ lbs}}{4(2000 \text{ lbs/ton})} \approx 53.8 \text{ tons}
\]
<table>
<thead>
<tr>
<th>Pile Formula</th>
<th>Pile Length</th>
<th>CASE 1</th>
<th>CASE 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>80 ft</td>
<td>40 ft</td>
<td>80 ft</td>
</tr>
<tr>
<td>GATES</td>
<td>111.0 tons</td>
<td></td>
<td>111.0 tons</td>
</tr>
<tr>
<td>ENR</td>
<td>70 tons</td>
<td></td>
<td>70 tons</td>
</tr>
<tr>
<td>JANBU</td>
<td>72.7 tons</td>
<td>91.5 tons</td>
<td>75.9 tons</td>
</tr>
<tr>
<td>HILEY</td>
<td>64.6 tons</td>
<td>88.0 tons</td>
<td>120.5 tons</td>
</tr>
<tr>
<td>PACIFIC COAST</td>
<td>42.9 tons</td>
<td>63.5 tons</td>
<td>53.8 tons</td>
</tr>
</tbody>
</table>
Example 1: Calculation of Minimum Hammer Energy

Given:

Hammer Data: Delmag D36-32
Ram Weight = 7938 lbs
Manufacturer’s Maximum Energy Rating = 83,880 ft·lbs
Nominal Resistance = 390 kips


From the Gates Equation,

\[ R_u = (1.83 \times (E_r)^{1/2} \times \log_{10}(0.83 \times N)) - 124 \]

Rearranging for \( N \):

\[ N = \frac{10^{\left(\frac{R_u + 124}{1.83 \times \sqrt{E_r}}\right) \times 0.83}}{0.83} \]

\[ N = 10^{\left(\frac{390 + 124}{1.83 \times 83,880}\right) \times 0.83} \]

\[ = 10^{\left(\frac{514}{530}\right) \times 0.83} \]

\[ = 10^{0.9698} \]

\[ = 11.23 \approx 11 \text{ blows/blow} \]

\( s = \) penetration per blow in inches
\[ = N^{-1}(12 \text{ in/}^n) \]
\[ = (11.23 \text{ blows/blow})^{-1}(12 \text{ in/}^n) \]
\[ = 1.07 \text{ in/blow} > 0.125 \text{ in/blow} \]

\[ \therefore \] proposed hammer meets the minimum energy requirements of 2010 Standard Specification 49-2.01C(2), Driving Equipment.
Example 2: Calculations for Establishing a Blow Count Chart

Given:

Hammer Data: Delmag 36-32
Ram Weight = 7938 lbs
Maximum Stroke = 10.42 ft

Nominal Resistance = 390 kips

Assumption(s): $E_r = \text{Ram Weight} \times \text{Observed Field Drop Height}$

Observed Field Drop Height = 6 ft

From the Gates Equation,

$$R_u = (1.83 \times (E_r)^{1/2} \times \log_{10}(0.83 \times N)) - 124$$

Rearranging to solve for $N$:

$$N = \frac{10^{(R_u+124/1.83 \sqrt{E_r})}}{0.83}$$

$E_r = 6 \text{ ft}(7938 \text{ lbs}) = 47,628 \text{ ft} \cdot \text{lbs}$

$$N = 10^{\left(\frac{390+124}{1.83 \sqrt{47,628}}\right)}$$

$$N = 10^{\left(\frac{514}{399}\right)}$$

$$N = 10^{1.287}$$

$$N = 23.33 \approx 23 \text{ blows/ft}$$

Calculations for the chart data are completed by using the Excel spreadsheet, *Pile Equation-Gates.xls*, downloaded from the SC Intranet website. See next page for calculation results of the spreadsheet.
Figure E-1. Gates Formula Excel Spreadsheet.
Example 3: Calculations for Establishing a Battered Pile Blow Count Chart

Given:

Hammer Data: Delmag 36-32
Ram Weight = 7938 lbs
Maximum Stroke = 10.42 ft
Nominal Resistance = 390 kips

Battered pile: 1:3

Assumption(s): $E_r = \text{Ram Weight} \times \text{Observed Field Drop Height}$

Observed Field Drop Height = 9 ft
As in the previous example, rearranging the Gates Formula gives,

\[
N = 10 \frac{\left( \frac{R_s + 124}{1.83} \sqrt{E_r} \right)}{0.83} \quad \theta = \sin^{-1}\left(\frac{3}{3.16}\right) = 71.565^\circ
\]

\[
= 10 \frac{390 + 124}{1.83 \sqrt{6775.8}} \quad E_r = 7938 \text{ lbs}(9 \text{ ft} \times \sin 71.565^\circ)
\]

\[
= 10 \frac{514}{476} \quad = 6775.8 \text{ ft} \cdot \text{lbs}
\]

\[
= 10^{1.0798} \quad = 14.48 \approx 14 \text{ blows}/\text{ft}
\]

Calculations for the chart data are completed by using a MODIFIED value of $E_r$, modified as shown above for the batter angle, in the Excel spreadsheet, *PileEquation-Gates.xls*. 
Example 4: Calculations for Piles with Downdrag

The following metric example has downdrag:
(Example submitted by Joy Cheung, P.E., and Anh Luu, P.E.)

Island Parkway Overcrossing – Rte 101/Ralston Interchange
EA 04-256804, Oversight Project

The Pile Data Table from the contract plans show:
Bent 2 Piles – Class 900C Alt “X” (Pile Data Table)
Nominal Resistance (Compression) = 1250 KN
Estimate Down Drag Load = 242 KN
Ultimate Pile Capacity = $R_u = \text{Nominal resistance} + 2 \times \text{downdrag}$

Therefore:

$R_u = \text{Nominal resistance} + 2 \times \text{downdrag}$

$R_u = 1250 \text{ KN} + (2 \times 242 \text{KN}) = 1734 \text{ KN}$

Contractor’s proposed hammer:
Delmag D36-32

Pile Hammer Data - (per specs, Contractor provides data)
Also see Bridge Construction Memo 130-4.0, *Pile Driving Acceptance Criteria.*
Internet: [www.pileco.com](http://www.pileco.com), [www.hmc-us.com](http://www.hmc-us.com), …etc;

Pile hammer data:
Max Energy Output = 83880 ft.lbs = 83880 \times 1.3558 = 113724.5 Joules
Ram Weight = mass = 7938 lbs = 3600.6 kg
Maximum obtainable stroke/Piston Drop = height = 10’5” = 3.18 m

Find:
\( E_r = \text{Energy rating of hammer at observed field drop height in Joules} \)

**It is generally accepted that the energy output of an open-end diesel hammer is equal to the ram weight times the length of stroke.**

Gravitational potential energy = mass \( \times \) free-fall acceleration \( \times \) height = \( m \cdot g \cdot H = E_r \)

\( E_r = 3600.6 \text{ kg} \cdot 9.81 \cdot 3.18 = 112,323 \text{ Joules} < 113,724 \) (Max Energy)

** For battered pile, \( E_r = m \cdot g(H \cdot \sin \theta) \)

\( N = \text{Number of blows per 300 millimeters (maximum of 96)} \)

\[
N = 10 \left( \frac{r + 550}{\sqrt{E_r}} \right) \div 0.83
\]

Set up table:

<table>
<thead>
<tr>
<th>Hammer Type: Delmag D 36-32</th>
<th>Design Load: 625kN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal Resistance: 1734kN</td>
<td>Max Energy 113724Joules</td>
</tr>
<tr>
<td>Ram Weight 3600.6Kg</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PISTON DROP (ft)</th>
<th>PISTON DROP (m)</th>
<th>ENERGY (joules)</th>
<th>GATES</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.417</td>
<td>3.18</td>
<td>112151</td>
<td>11</td>
</tr>
<tr>
<td>10</td>
<td>3.05</td>
<td>107661</td>
<td>12</td>
</tr>
<tr>
<td>9</td>
<td>2.74</td>
<td>96895</td>
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</tr>
<tr>
<td>8</td>
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<td>7</td>
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</tr>
<tr>
<td>6</td>
<td>1.83</td>
<td>64597</td>
<td>23</td>
</tr>
<tr>
<td>5</td>
<td>1.52</td>
<td>53831</td>
<td>31</td>
</tr>
<tr>
<td>4</td>
<td>1.22</td>
<td>43064</td>
<td>45</td>
</tr>
<tr>
<td>3</td>
<td>0.91</td>
<td>32298</td>
<td>79</td>
</tr>
</tbody>
</table>

Set up graph:
A very good spreadsheet (PileEquation-Gates.xls) used to calculate blows per foot using the Gates equation can be found on the OSC Intranet Homepage under, “Downloads/Forms”.

Continue calculations:
Contract Specifications<sup>2</sup>
--Impact Hammer Minimum Energy “not less 3mm/blow at the specified bearing value…”

Use the Gates formula again…
\[ R_u = \left( 7 \times (E_r)^{0.5} \right) \times \log_{10}(0.83 \times N) - 550 \]

Find N.
Using \( E_r = 3600.6 \text{ kg} \times 9.81 \times 3.18 = 112,323 \text{ Joules} \)
\[ R_u = 1250 \text{ KN} + (2 \times 242\text{KN}) = 1734 \text{ KN} \]

\( N = 11 \) blows/ 300 mm
\( s = \) Penetration per blow in millimeters
\( = 300 \text{ mm}/11 \text{ blows} \)
\( \approx 27.0 \text{ mm} > 3 \text{ mm} \) OK.

---

<sup>2</sup> 2010 SS, Section 49-2.01C(2), Driving Equipment, or 2006 SS, Section 49-1.05, Driving Equipment.
Note: An upper limit is not specified for the Contractor to furnish an approved hammer having sufficient energy to drive piles at a penetration rate of not less than 1/8 inch per blow at the required bearing value.
Example 5: Estimate Hammer Stroke of a Single Acting Hammer

Given:

Hammer Data: Delmag 36-32
Ram Weight = 7938 lbs
Maximum Stroke = 10.42 ft

From Field Observations: Ram Blows per Minute (bpm) = 43

From the SAXIMETER Formula,

\[
H = 4.01 \left( \frac{60}{\text{bpm}} \right)^2 - 0.3
\]

\(H\) = hammer stroke in feet

bpm = field observation of hammer blows per minute

\[
H = 4.01 \left( \frac{60}{43 \text{ bpm}} \right)^2 - 0.3
\]

\[
= 4.01 \left( \frac{60}{43} \right)^2 - 0.3
\]

\[
= 7.81 - 0.3
\]

\[
= 7.51 \approx 7.5 \text{ ft}
\]
Example Battered Pile Blow Count Chart

BATTERED PILE

PILE CAPACITY 140000 POUNDS
HAMMER D 30-23
PISTON WEIGHT 6,600 POUNDS

\[ E = W \times H \times \sin 71.565^\circ \]

<table>
<thead>
<tr>
<th>STROKE FEET</th>
<th>BLOWS PER FOOT</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>15.0</td>
</tr>
<tr>
<td>9.5</td>
<td>15.9</td>
</tr>
<tr>
<td>9</td>
<td>16.9</td>
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Figure E-2. Example Field Acceptance Charts.