APPENDIX

E 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:

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

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

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

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,

$$k_u = C_d \left[1 + \sqrt{1 + \left(\lambda / C_d\right)}\right]$$

$$C_d = 0.75 + 0.15\left(W_p / W\right)$$

$$\lambda = \frac{WHL}{AEs^2}$$

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

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

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:

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

$$= \left((1.83 * (83{,}880)^{1/2} * \log_{10}(0.83 * (12/0.844)) - 124\right)\frac{1}{2\left(2\,{}^{\text{kip}}/_{\text{ton}}\right)}$$

$$= \left((1.83 * 289.62 * 1.072) - 124\right)\frac{1}{2\left(2\,{}^{\text{kip}}/_{\text{ton}}\right)}$$

$$= (568.122 - 124)\frac{1}{2\left(2\,{}^{\text{kip}}/_{\text{ton}}\right)}$$

$$= \frac{444.122 \text{ kips}}{2\left(2\,{}^{\text{kip}}/_{\text{ton}}\right)} \approx \underline{\underline{111.0 \text{ tons}}}$$

Engineering News (ENR) Formula

For Case 1 & 2:

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

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

$$= 177{,}712 \text{ lbs} \approx \underline{\underline{70 \text{ tons}}}$$

Janbu Formula

Case 1:

$$P = \left(\frac{WH}{k_u s}\right) z = \left(\frac{WH}{k_u s}\right)\frac{1}{3(2000\,{}^{\text{lbs}}\!/\!_{\text{ton}})}$$

$$= \left(\frac{7{,}938\text{ lbs}(10.42\text{ ft}\times 12\,{}^{\text{in}}\!/\!_{\text{ft}})}{2.697(0.844\text{ in})}\right)\frac{1}{3(2000\,{}^{\text{lbs}}\!/\!_{\text{ton}})}$$

$$= \left(\frac{435{,}931\text{ lbs}}{3(2000\,{}^{\text{lbs}}\!/\!_{\text{ton}})}\right) \approx \underline{\underline{72.66\text{ tons}}}$$

$$c_d = 0.75 + 0.15(W_p / W)$$
$$= 0.75 + 0.15(11{,}600\text{ lbs}/7{,}938\text{ lbs})$$
$$= 0.969$$

$$\lambda = \frac{WHL}{AEs^2}$$
$$= \frac{7{,}938\text{ lbs}(10.42\text{ ft}\times 12\,{}^{\text{in}}\!/\!_{\text{ft}})(80\text{ ft}\times 12\,{}^{\text{in}}\!/\!_{\text{ft}})}{(144\text{ in}^2)(4.4\times 10^6\,{}^{\text{lbs}}\!/\!_{\text{in}^2})(0.844\text{ in})^2}$$
$$= 2.111$$

$$k_u = c_d\left[1 + \sqrt{1 + (\lambda / c_d)}\right]$$
$$= 0.969\left[1 + \sqrt{1 + (2.111/0.969)}\right]$$
$$= 2.697$$

Case 2:

$$P = \left(\frac{WH}{k_u s}\right) z = \left(\frac{WH}{k_u s}\right)\frac{1}{3(2000\,{}^{\text{lbs}}\!/\!_{\text{ton}})}$$

$$= \left(\frac{7{,}938\text{ lbs}(10.42\text{ ft}\times 12\,{}^{\text{in}}\!/\!_{\text{ft}})}{2.581(0.844\text{ in})}\right)\frac{1}{3(2000\,{}^{\text{lbs}}\!/\!_{\text{ton}})}$$

$$= \left(\frac{455{,}578\text{ lbs}}{3(2000\,{}^{\text{lbs}}\!/\!_{\text{ton}})}\right) \approx \underline{\underline{75.93\text{ tons}}}$$

$$c_d = 0.75 + 0.15(W_p / W)$$
$$= 0.75 + 0.15(4{,}240\text{ lbs}/7{,}938\text{ lbs})$$
$$= 0.830$$

$$\lambda = \frac{WHL}{AEs^2}$$
$$= \frac{7{,}938\text{ lbs}(10.42\text{ ft}\times 12\,{}^{\text{in}}\!/\!_{\text{ft}})(80\text{ ft}\times 12\,{}^{\text{in}}\!/\!_{\text{ft}})}{(15.58\text{ in}^2)(30\times 10^6\,{}^{\text{lbs}}\!/\!_{\text{in}^2})(0.844\text{ in})^2}$$
$$= 2.861$$

$$k_u = c_d\left[1 + \sqrt{1 + (\lambda / c_d)}\right]$$
$$= 0.830\left[1 + \sqrt{1 + (2.861/0.830)}\right]$$
$$= 2.581$$

Hiley Formula

Case 1:

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

$$= \left(\frac{e_f WH}{s + \frac{1}{2}(c_1 + c_2 + c_3)}\right)\left(\frac{W + n^2 W_p}{W + W_p}\right)\frac{1}{2.75(2000\,{}^{\text{lbs}}\!/_{\text{ton}})}$$

$$= \left(\frac{1.00(7{,}938\text{ lbs})(10.42\text{ ft} \times 12\,{}^{\text{in}}\!/_{\text{ft}})}{0.844\text{ in} + \frac{1}{2}(0.37\text{ in} + 0.32\text{ in} + 0.10\text{ in})}\right)\left(\frac{7{,}938\text{ lbs} + (0.25^2)(11{,}600\text{ lbs})}{7{,}938\text{ lbs} + 11{,}600\text{ lbs}}\right)\frac{1}{2.75(2000\,{}^{\text{lbs}}\!/_{\text{ton}})}$$

$$= \frac{355{,}090\text{ lbs}}{2.75(2000\,{}^{\text{lbs}}\!/_{\text{ton}})} \approx \underline{\underline{64.6\text{ tons}}}$$

Case 2:

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

$$= \left(\frac{e_f WH}{s + \frac{1}{2}(c_1 + c_2 + c_3)}\right)\left(\frac{W + n^2 W_p}{W + W_p}\right)\frac{1}{2.75(2000\,{}^{\text{lbs}}\!/_{\text{ton}})}$$

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

$$= \frac{662{,}508\text{ lbs}}{2.75(2000\,{}^{\text{lbs}}\!/_{\text{ton}})} \approx \underline{\underline{120.5\text{ tons}}}$$

Pacific Coast Formula

Case 1:

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

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

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

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

$$= \frac{343{,}511\ \text{lbs}}{4(2000\ ^{\text{lbs}}\!/_{\text{ton}})} \approx \underline{\underline{42.94\ \text{tons}}}$$

Case 2:

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

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

$$= \frac{83{,}880\text{ ft}\cdot\text{lbs}(12\,{}^{\text{in}}/_{\text{lbs}})\left(\frac{7{,}938\text{ lbs} + 0.25(4240\text{ lbs})}{7{,}938\text{ lbs} + (4240\text{ lbs})}\right)}{0.844\text{ in} + \frac{P(80\text{ ft}\times 12\,{}^{\text{in}}/_{\text{ft}})}{(15.58\text{ in}^2)(30\times 10^6)}} \times \frac{1}{4(2000\,{}^{\text{lbs}}/_{\text{ton}})}$$

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

$$= \frac{430{,}395\text{ lbs}}{4(2000\,{}^{\text{lbs}}/_{\text{ton}})} \approx \underline{\underline{53.8\text{ tons}}}$$

Table E-1. Results of Pile Driving Formula Comparison Pile Formula	Pile Length	CASE 1 12" PC/PS Concrete Pile 80.0 ft	40.0 ft	CASE 2 HP12x53 Steel Pile 80.0 ft	40.0 ft
GATES		111.0 tons	111.0 tons	111.0 tons	111.0 tons
ENR		70 tons	70 tons	70 tons	70 tons
JANBU		72.7 tons	91.5 tons	75.9 tons	92.7 tons
HILEY		64.6 tons	88.0 tons	120.5 tons	135.7 tons
PACIFIC COAST		42.9 tons	63.5 tons	53.8 tons	73.3 tons

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

Check: Hammer Energy per *2010 Standard Specification* 49-2.01A(4)(b), *Pile Driving Acceptance Criteria.*

From the Gates Equation,

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

Rearranging for N:

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

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

$$= \frac{10^{\left(\frac{514}{530} \right)}}{0.83}$$

$$= \frac{10^{0.9698}}{0.83}$$

$$= 11.23 \approx 11 \text{ blows/ft}$$

s = penetration per blow in inches

$$= N^{-1}(12 \text{ in/ft})$$

$$= (11.23 \text{ blows/ft})^{-1}(12 \text{ in/ft})$$

$$= 1.07 \text{ in/blow} > 0.125 \text{ in/blow}$$

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

$\text{Observed Field Drop Height} = 6\text{ ft}$

From the Gates Equation,

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

Rearranging to solve for N:

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

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

$$N = \frac{10^{\left(\frac{390+124}{1.83\sqrt{47{,}628}} \right)}}{0.83} = \frac{10^{\left(\frac{514}{399} \right)}}{0.83} = \frac{10^{1.287}}{0.83} = 23.33 \approx 23\ \text{blows/ft}$$

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.

PILE DRIVING (US Customary)

Blows Per Foot using Gates Formula

SC-4809 (Rev. 02/12/15)

Bridge/Structure No.: 53-2975 Project No. 07-1199U4

Bridge/Structure Name: Eastside Underpass Br. (LRT)

Abut/Bent/RW/SW No.: Abut 1

Blue font = input/changeable data

Hammer Data

Hammer Type: ICE 120S

Ram Weight (lbs) = 12000 lbs

Nominal Resistance[†] (kips) = 668 kips

GATES Formula

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

—OR—

$$N = \frac{10^{\left(\frac{R_n+124}{1.83\sqrt{E_r}}\right)}}{0.83}$$

where: R_n = nominal driving resistance, kips
E_r = energy developed by hammer at observed stroke (ft-lbs)
N = number of hammer blows in the last foot (max. ≤ 96)

E_r = WH

where: W = ram weight (lbs)
H = stroke or drop height of hammer (ft)

(H) Stroke (feet)	(E_r) Energy (ft-lbs)	(N) Blows (per foot)	
	-	-	
10.5	126,000	21	
10.0	120,000	23	
9.5	114,000	25	
9.0	108,000	27	
8.5	102,000	30	
8.0	96,000	33	
7.5	90,000	36	
7.0	84,000	41	
6.5	78,000	47	
6.0	72,000	54	
5.5	66,000	64	
5.0	60,000	78	
4.5	54,000	98	
4.0	48,000	128	
3.5	42,000	176	
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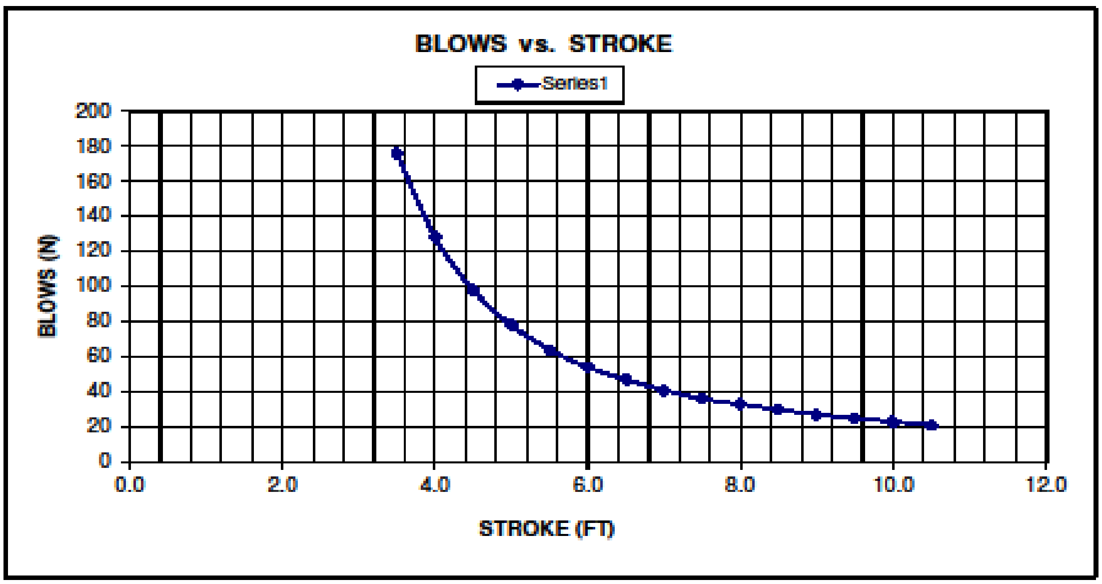


[†]*S.S. 49-2.01A(4)(b): Where the pile nominal driving resistance is not shown, drive the pile to the nominal resistance shown. (SS 2010)*

Figure E-1. Gates Formula Excel Spreadsheet.

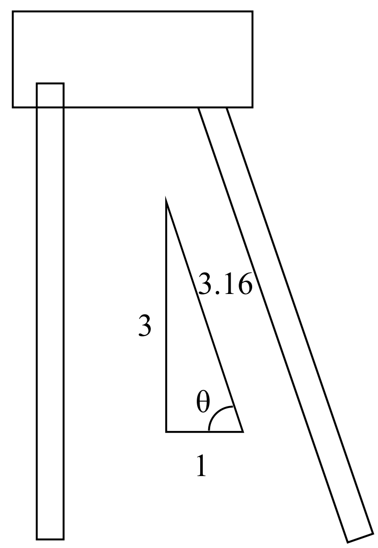
Example 3: Calculations for Establishing a Battered Pile Blow Count Chart

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

$\text{Observed Field Drop Height} = 9 \text{ ft}$

As in the previous example, rearranging the Gates Formula gives,

$$N = \frac{10^{\left(\frac{R_u + 124}{1.83\sqrt{E_r}}\right)}}{0.83} = \frac{10^{\left(\frac{390+124}{1.83\sqrt{67{,}775.8}}\right)}}{0.83} = \frac{10^{\left(\frac{514}{476}\right)}}{0.83} = \frac{10^{1.0798}}{0.83} = 14.48 \approx \underline{\underline{14 \text{ blows/ft}}}$$

$$\theta = \sin^{-1}\left(\tfrac{3}{3.16}\right) = 71.565^\circ$$

$$E_r = 7938 \text{ lbs}\left(9 \text{ ft} \times \sin 71.565^\circ\right) = 67{,}775.8 \text{ ft} \cdot \text{lbs}$$

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

Pile Data Table

Location	Pile Type 360 = 15.5"	Design Loading	Nominal Resistance		Design Tip Elevation	Specified Tip Elevation
			Compression	Tension		
Abut 1	900C Alt "X"	625 kN	1250 kN	0 kN	−24.2(1),−8.8(2)	−24.2
Bent 2	900C Alt "X"	625 kN	1250 kN	400 kN	−23.3(1),−11.2(2),−19.9(3)	−23.3
Bent 3	460 mm Square = 18"	400 kN	800 kN	0 kN	−18.35(1)	−18.35
Bent 4	460 mm Square	425 kN	850 kN	0 kN	−18.7(1)	−18.7
Bent 5	460 mm Square	425 kN	850 kN	0 kN	−18.7(1),−16.3(2)	−18.7
Bent 6	460 mm Square	425 kN	850 kN	0 kN	−18.7(1)	−18.7
Bent 7	460 mm Square	425 kN	850 kN	0 kN	−18.25(1)	−18.25
Bent 8	460 mm Square	425 kN	850 kN	0 kN	−18.25(1)	−18.25
Bent 9	460 mm Square	425 kN	850 kN	0 kN	−18.4(1)	−18.4
Bent 10	460 mm Square	400 kN	800 kN	0 kN	−18.4(1),−12.0(2)	−18.4
Abut 11	900C Alt "X"	400 kN	800 kN	0 kN	−19.9(1),−6.2(2)	−19.9

Design tip elevation is controlled by the following demands: (1)Compression, (2)Lateral, (3)Tension
The estimated downdrag load is 295 kN at abutment 1; 242 kN per pile at bent 2; 377 kN per pile at Bent 3; 243 kN per pile at bent 4, 5 and 6; 351 kN per pile at bent 7 and 8; 329 kN per pile at bent 9 and 10; and 367 kN per pile at abutment 11. For use of Gates formular, Ultimate pile capacity = Nominal resistance + 2xdowndrag load.

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 = Nominal resistance + 2 x downdrag

Therefore:
R_u = Nominal resistance + 2 x downdrag
R_u = 1250 KN + (2 * 242KN) = 1734 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, www.hmc-us.com, …etc;

Pile hammer data:
Max Energy Output = 83880 ft.lbs = 83880 * 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 = 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 × free-fall acceleration × height = $m \cdot g \cdot H = E_r$

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

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

N = Number of blows per 300 millimeters (maximum of 96)

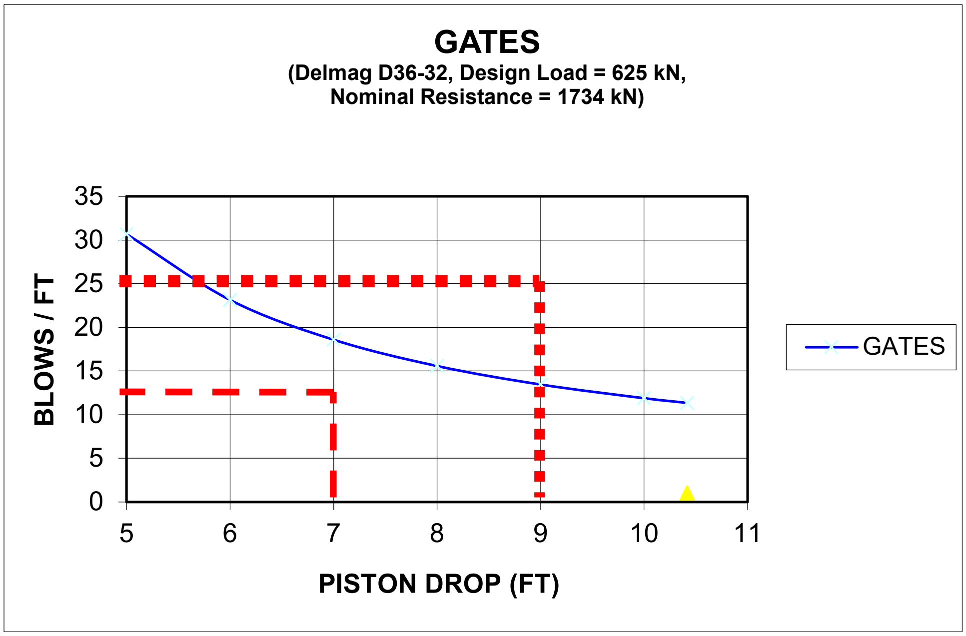
$$N = \frac{10^{\left(\frac{R_u + 550}{7\sqrt{E_r}}\right)}}{0.83}$$

Set up table:

Hammer Type:	Delmag D 36-32
Design Load:	625kN
Nominal Resistance:	1734kN
Max Energy	113724Joules
Ram Weight	3600.6Kg

PISTON DROP (ft)	PISTON DROP (m)	ENERGY (joules)	Blows Per Last 300 mm. GATES
10.417	3.18	112151	11
10	3.05	107661	12
9	2.74	96895	13
8	2.44	86129	16
7	2.13	75363	19
6	1.83	64597	23
5	1.52	53831	31
4	1.22	43064	45
3	0.91	32298	79

Set up graph:



Meets Bearing Value

Not Good

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[2]

--Impact Hammer Minimum Energy "not less 3mm/blow at the specified bearing value…"

Use the Gates formula again…

$$R_u = (7 * (E_r)^{1/2} * \log_{10}(0.83 * N)) - 550$$

Find N.

Using E_r = 3600.6 kg * 9.81 * 3.18 = 112,323 Joules

R_u = 1250 KN + (2 * 242KN) = 1734 KN

N = 11 blows/ 300 mm

s = Penetration per blow in millimeters

= 300 mm/11 blows

≈ 27.0 mm > 3 mm **OK**.

[2] 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,

$$H = 4.01\left({}^{60}\!/_{\text{bpm}} \right)^2 - 0.3$$

$$H = \text{hammer stroke in feet}$$

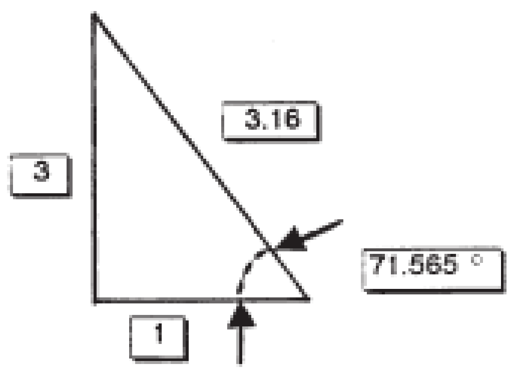
$$\text{bpm} = \text{field observation of hammer blows per minute}$$

$$\begin{aligned} H &= 4.01\left({}^{60}\!/_{\text{bpm}} \right)^2 - 0.3 \\ &= 4.01\left({}^{60}\!/_{43\text{ bpm}} \right)^2 - 0.3 \\ &= 7.81 - 0.3 \\ &= 7.51 \approx \underline{\underline{7.5\text{ ft}}} \end{aligned}$$

Example Battered Pile Blow Count Chart

BATTERED PILE

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



E = W * H * SIN 71.565 °

STROKE FEET	BLOW S PER FOOT
10	15.0
9.5	15.9
9	16.9
8.5	18.0
8	19.3
7.5	20.8
7	22.6
6.5	24.6
6	27.1
5.5	30.2
5	34.0

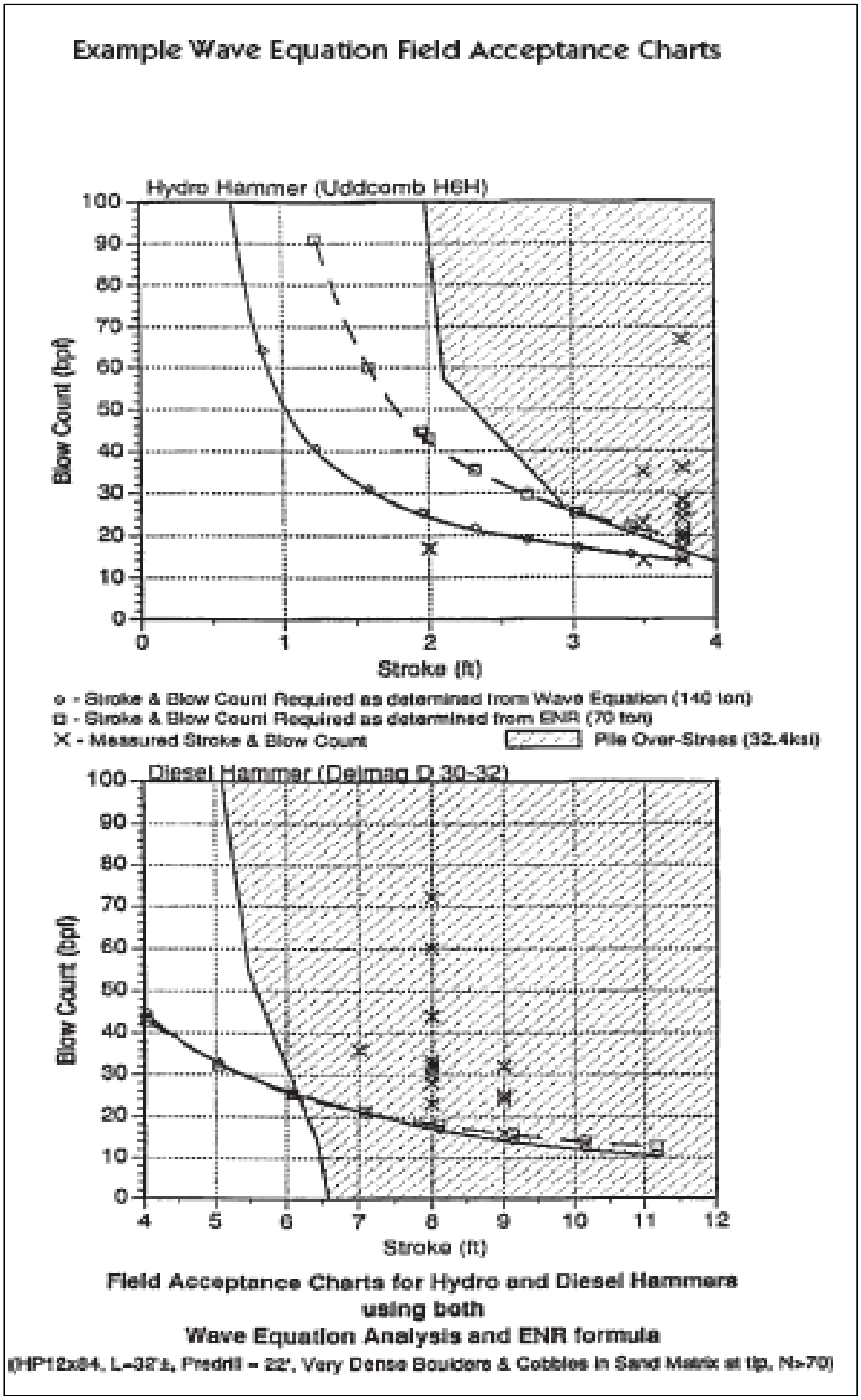


Figure E-2. Example Field Acceptance Charts.