GEOTECHNOLOGY
A Universal Engineering Sciences Company

Modeling Pile Driving during Design and Construction

Presented by:

Craig K. Kaibel, P.E.
Specialty Testing Manager
ckaibel@geotechnology.com

Terms

- ASD – Allowable Stress Design
- LRFD – Load Resistance Factored Design
- Nominal Axial Resistance (LRFD) = Ultimate Capacity (ASD)
- Wave Equation Analysis Program (WEAP or GRLWEAP)
- Pile Wave Analysis = Preconstruction Wave Equation Analysis
- Dynamic Pile Testing = High-strain Dynamic Pile Testing
- Pile Driving Analyzer (PDA)

Pile Wave Analysis

- Preconstruction
  - During design – confirm designed pile is drivable
  - Pending construction – confirm contractor’s hammer can drive the pile
- Refined
  - Analysis based on high-strain dynamic pile testing results

Analysis Goals

- Achieve nominal axial resistance
- Drive pile to an acceptable terminal driving resistance
  - MoDOT's is 2 to 10 blows per inch (bpi)
  - ArDOT's is 2 to 12 bpi
  - KYTC's is two consecutive ¼-inch, or less, in 5 blows
- Drive the piles within the allowable driving stress
  - Steel piles
    - $0.9f_y$ in compression and tension
  - Precast prestressed concrete piles (ArDOT/TDOT/MDOT)
    - $0.85f'c-f_{pe}$ in compression
    - $F_{pe} + 3.0(f'c)^{0.5}$ in tension

751.36.5.11 Check Pile Drivability

Drivability of the pile through the soil profile can be investigated using Wave equation analysis program or other available software. Designers may import soil resistances from a static analysis program or input soil values directly into Wave equation analysis program to perform drivability.

If soil values are to be directly input into Wave equation analysis program, enter in values of sand and clay layers with specific values of cohesion or internal friction angle or just by uncorrected blow count values obtained from borings.

Drivability analysis shall be performed for all piles (bearing pile and friction pile) using the Delmag D19-42 hammer and the Delmag D30-32 – Heavy Hammer.

Use soil profiles from borings and mimic soil characteristics as closely as possible for computations or in software to perform drivability analysis of any kind of pile.

Structural steel HP Pile:

Drivability analysis shall be performed for two cases:

1. Box shape
2. Perimeter

Drivability shall be performed considering existing condition without considering any excavation/ disturbance (i.e., possible disturbance to top 5 feet of soil from MSE wall excavation prior to driving pile), liquefaction or future scour loss.

Hammer types:

Pile Driving Hammer Information For GRLWEAP

Hammer used in the field per survey response (2017)		
GRLWEAP ID	**Hammer name**	**No. of Responses**
41	Delmag D19-42[1]	13
40	Delmag D19-32	6
38	Delmag D12-42	4
139	ICE 32S	4
15	Delmag D30-32	2
	Delmag D25-32	2
127	ICE 30S	1
150	MKT DE-30B	1
[1] Delmag series of pile hammers is the most popular, with the D19-42 being the most widely used.		

Hammer usage in the field will be surveyed every five years. The above results will be revised according to the new survey and the most widely used hammer will be selected for drivability analysis.

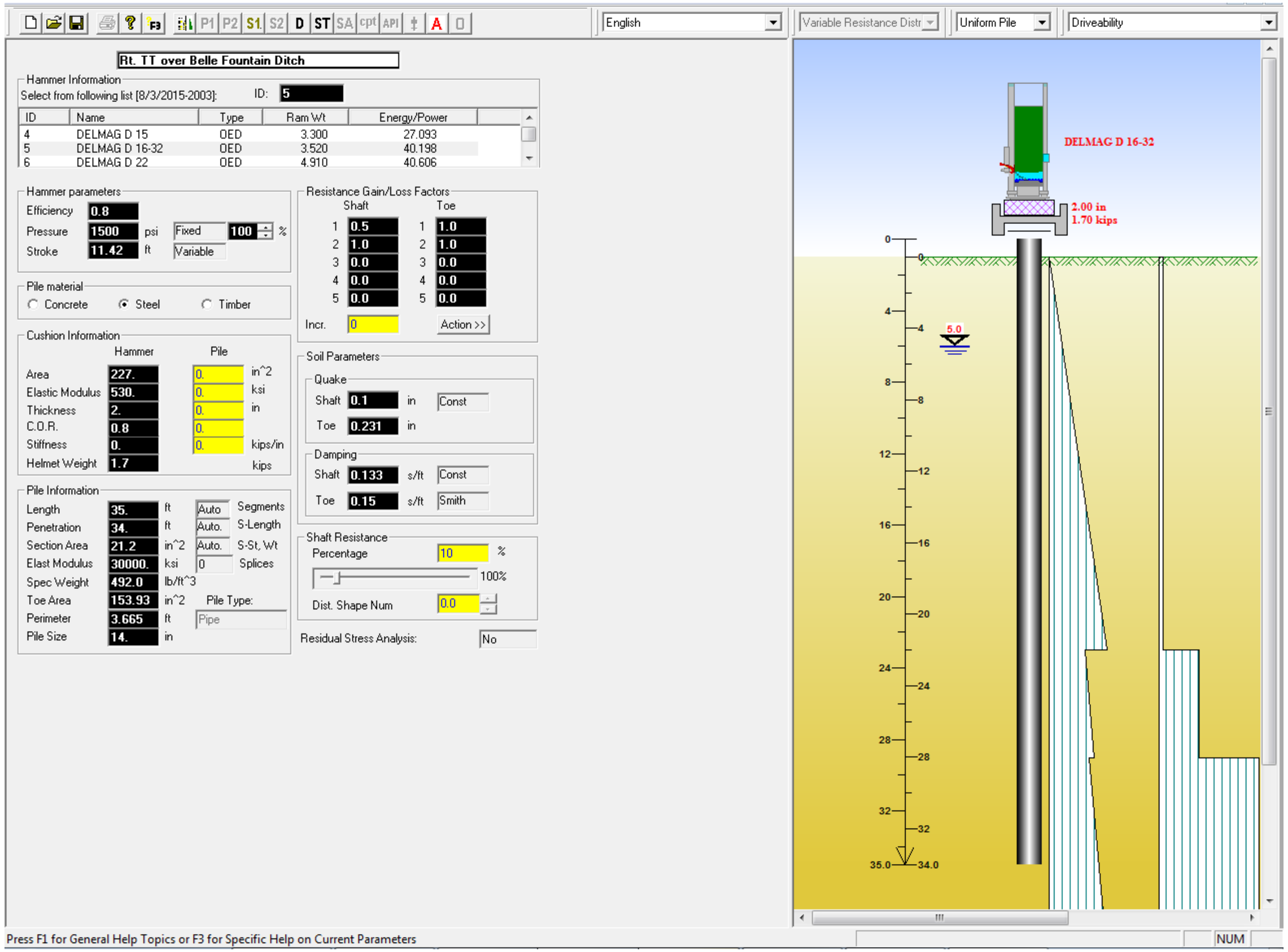
The contractor is responsible for determining the hammer energy required to successfully drive the pile to the minimum tip elevation and to reach the minimum nominal axial compressive resistance specified on the plans. The contractor shall perform a drivability analysis to select an appropriate hammer size to ensure the pile can be driven without overstressing the pile and to prevent refusal of the pile prior to reaching the minimum tip elevation. The contractor shall plan pile driving activities and submit hammer energy requirements to the engineer for approval before driving.

Practical refusal is defined at 20 blows/inch or 240 blows per foot.

Driving should be terminated immediately once 30 blows/inch is encountered.

WEAP Model

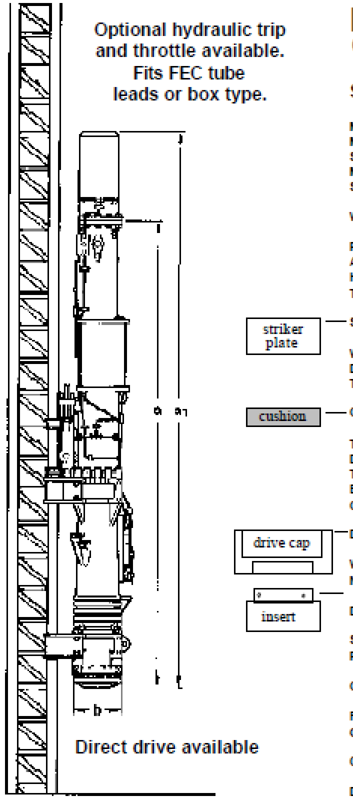
- Drive System
  - Hammer
  - Helmet assembly
  - Hammer and pile cushion
- Pile
- Soil
  - Static resistance
  - Dynamic Resistance



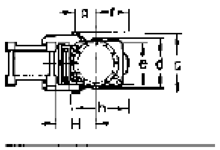
APE/SEMW Model D30-32 Single Acting Impact Hammer

German technology and ISO 9001 quality

Optional hydraulic trip and throttle available. Fits FEC tube leads or box type.



Direct drive available



MODEL D30-32 (3.0 metric ton ram)

(APE offers diesel hammers with ram weights up to 22,000 lbs.)

SPECIFICATIONS

Maximum rated energy	69,898 ft-lbs
Minimum rated energy	35,383 ft-lbs
Stroke at rated energy	10 feet 6 inches
Maximum obtainable stroke	12 feet 5 inches
Speed (blows per minute)	36-52

WEIGHTS

Piston	6,615 lbs
Anvil	1,360 lbs
Hammer weight (includes trip device)	12,155 lbs
Typical operating (weight with drive cap)	14,600 lbs

STRIKER PLATE

Weight (D^2 X 3.14/4 X 6 X .283=	675 lbs
Diameter	22.5 inches
Thickness (the 6 in above equation is thickness of plate)	6 inches

CUSHION MATERIAL

Type	Monocast MC 901
Diameter	22.5 inches
Thickness	2 inches
Elastic-Modulus	285 kips per square inch
Coeff. of Restitution	.8

DRIVE CAP (HELMET)

Weight (fits 8 by 26" leads)	1,166 lbs
Note: If using 32 inch leads the drive cap will weigh:	1,550 lbs

DRIVE CAP INSERT WEIGHT

Square box inserts size 10" through 20 inch:	1,400 lbs
Pipe inserts for pipe size 12" to 24" diameter:	2,545 lbs

CAPACITIES

Fuel tank (runs on diesel or bio-diesel)	17.70 gal
Oil tank	2.4 gal

CONSUMPTION

Diesel or Bio-diesel fuel	2.64 gal/hr
Lubrication oil	0.26 gal/hr
Grease:	Grease twice per day or after 45 minutes of continous driving

DIMENSIONS OF HAMMER

a	Length overall	207.1 inches
a	Length over cylinder extension	246.4 inches
b	Impact block diameter	22.0 inches
c	Width over bolts	30.7 inches
d	Hammer width overall	28.3 inches
e	Width for guiding- face to face	21.2 inches
f	Hammer center to pump guard	15.9 inches
g	Hammer center to bolt center	9.2 inches
h	Hammer depth overall	28.1 inches
H	Minimum clearance for leads	19.7 inches

AMERICAN PILEDRIVING EQUIPMENT, INC. APE

SHANGHAI JINTAI CO., LTD.

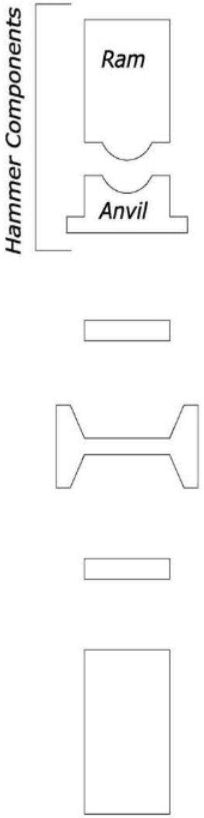
Corporate Offices
7032 South 196th
Kent, Washington 98032 USA
(800) 248-8498 & (253) 872-0141
(253) 872-8710 Fax 10/99

Visit our WEB site:
www.apevibro.com
e-mail: ape@apevibro.com

We reserve the right to modify specifications without notice.

Pile Driving Equipment Data Sheet

Project: Route J Over Little Niangua River
Structure Name: A8575
Contract No.: J5S0276
Pile Driving Contractor: Lehman Construction Company, LLC



Hammer

Manufacturer: Delmag
Model: D19-42 Type: Diesel
Serial No.: Unknown
Rated Energy: 43.2 kip-ft at 10.8 length of stroke
Modifications: Unknown

Capblock (Hammer Cushion)

Material: Aluminum
Thickness: 2 inches Area: 227 in^2
Modulus of Elasticity (E): 530 ksi
Coefficient of Restitution (e): 0.8

Pile Cap

Helmet
Bonnet
Anvil Block
Drivehead

Weight: 1.9 lbs

Pile Cushion

Cushion Material: N/A
Thickness: N/A Area: N/A
Modulus of Elasticity (E): N/A
Coefficient of Restitution (e): N/A

Pile

Pile Type: HP 12X53 Weight/foot: 53 lbs
Wall Thickness: N/A Taper: N/A
Cross Sectional Area: 15.6 in^2
Design Pile Capacity: 252 kips
Length (in leads): Unknown
Description of Splice: Full Penetration

Tip Treatment Description: Reinforced

Note: If mandrel is used to drive the pile, attach separate manufacturer's detail sheet(s) including weight and dimensions.

Submitted by: Geotechnology, Inc. Date: 12/20/18

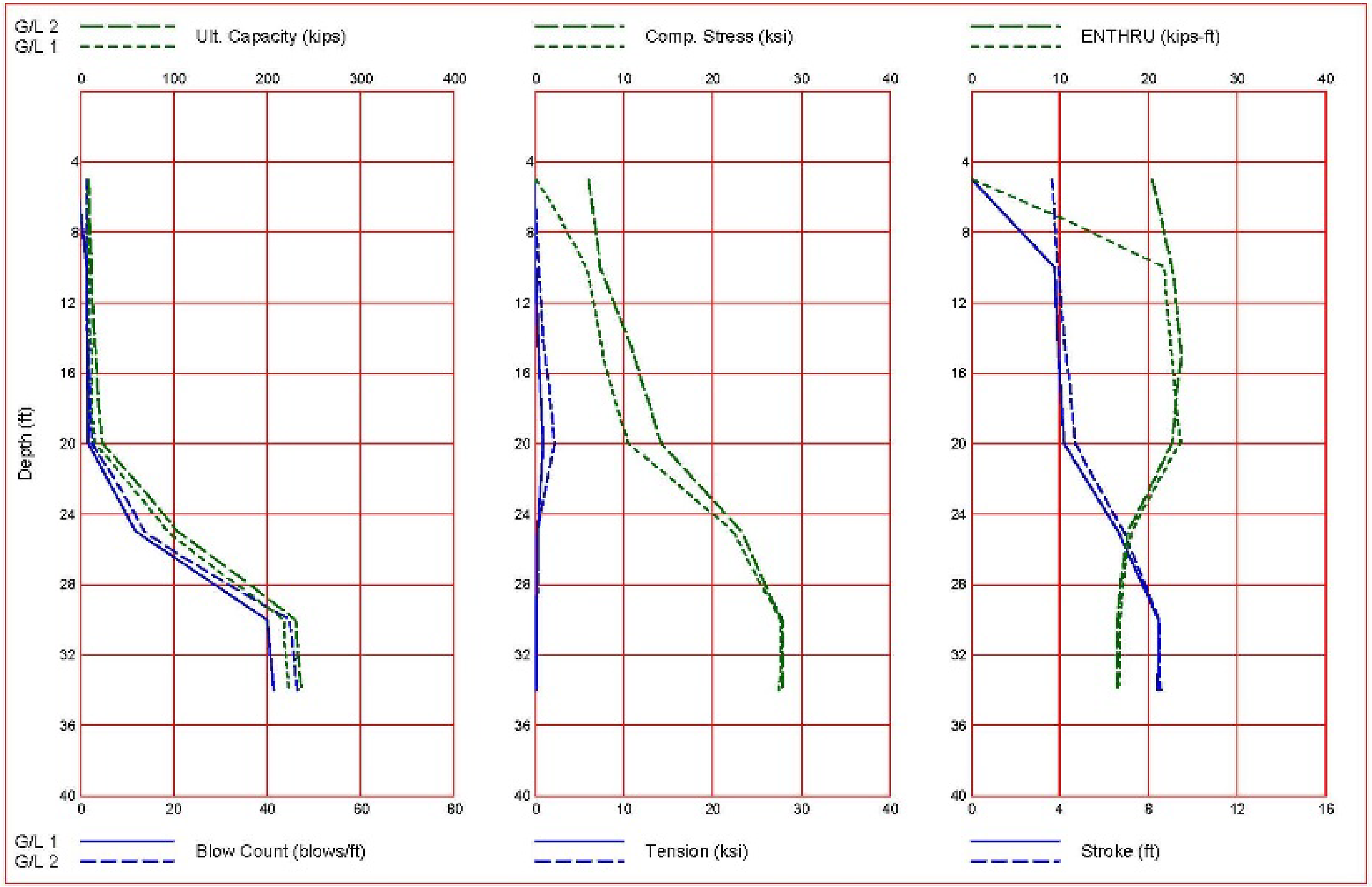
Analysis Types

- Driveability
  - Gain/loss factors
    - Clay = 0.5
    - Sand = 0.8
- Bearing Graph
  - Proportional
  - Constant Side
  - Constant End
- Inspector's Chart

Bents 1 and 4

Geotechnology, Inc.
Rt. TT over Belle Fountain Ditch
Gain/Loss 1 at Shaft and Toe 0.500 / 1.000

Apr 07 2016
GRLWEAP Version 2010
Gain/Loss 2 at Shaft and Toe 1.000 / 1.000



Geotechnology, Inc. Apr 07 2016
Rt. TT over Belle Fountain Ditch GRLWEAP Version 2010

Gain/Loss 1 at Shaft and Toe 0.500 / 1.000

Depth ft	Ultimate Capacity kips	Friction kips	End Bearing kips	Blow Count blows/ft	Comp. Stress ksi	Tension Stress ksi	Stroke ft	ENTHRU kips-ft
5.0	8.2	0.5	7.7	-1.0	0.000	0.000	0.00	0.0
10.0	9.8	2.1	7.7	1.3	5.815	0.000	3.78	21.8
15.0	12.4	4.7	7.7	1.5	7.623	-0.416	3.95	22.7
20.0	16.0	8.3	7.7	1.7	10.487	-0.889	4.22	23.6
25.0	93.4	13.0	80.4	11.8	22.372	-0.303	6.64	18.1
30.0	218.5	18.5	200.0	40.1	27.718	-0.205	8.49	16.8
34.0	223.4	23.4	200.0	41.4	27.485	-0.112	8.43	16.6

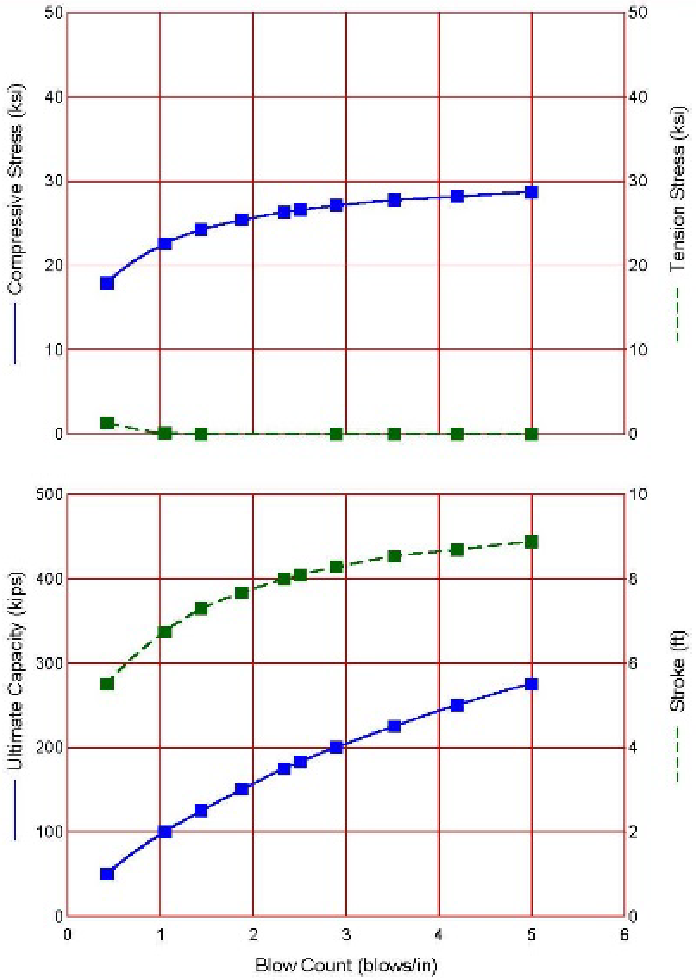
Total Continuous Driving Time 8.00 minutes; Total Number of Blows 343 (starting at penetration 5.0 ft)

Gain/Loss 2 at Shaft and Toe 1.000 / 1.000

Depth ft	Ultimate Capacity kips	Friction kips	End Bearing kips	Blow Count blows/ft	Comp. Stress ksi	Tension Stress ksi	Stroke ft	ENTHRU kips-ft
5.0	8.8	1.0	7.7	1.3	6.079	0.000	3.63	20.4
10.0	11.9	4.1	7.7	1.4	7.310	-0.320	3.95	22.7
15.0	17.0	9.3	7.7	1.8	11.122	-1.100	4.29	23.7
20.0	24.3	16.6	7.7	2.5	14.219	-2.202	4.70	22.7
25.0	104.0	23.6	80.4	13.7	23.290	-0.227	6.89	17.6
30.0	230.3	30.2	200.0	44.8	27.869	-0.099	8.53	16.5
34.0	236.1	36.1	200.0	46.5	27.868	-0.034	8.56	16.5

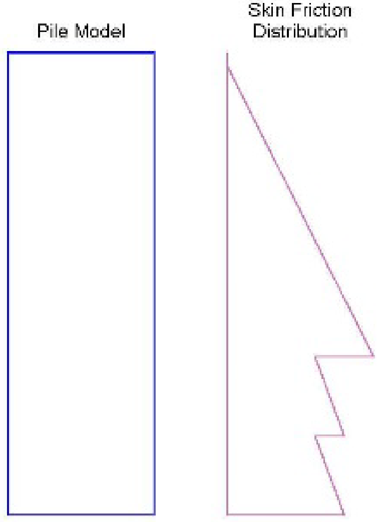
Total Continuous Driving Time 9.00 minutes; Total Number of Blows 395 (starting at penetration 5.0 ft)

Geotechnology, Inc.
Rt. TT over Belle Fountain Ditch



DELMAG D 16-32

Ram Weight	3.52	kips
Efficiency	0.800	
Pressure	1500 (100%)	psi
Helmet Weight	1.70	kips
Hammer Cushion	60155	kips/in
COR of H.C.	0.800	
Skin Quake	0.100	in
Toe Quake	0.231	in
Skin Damping	0.133	sec/ft
Toe Damping	0.150	sec/ft
Pile Length	35.00	ft
Pile Penetration	34.00	ft
Pile Top Area	21.20	in2



Res. Shaft = 15 %
(Proportional)

Bents 1 and 4

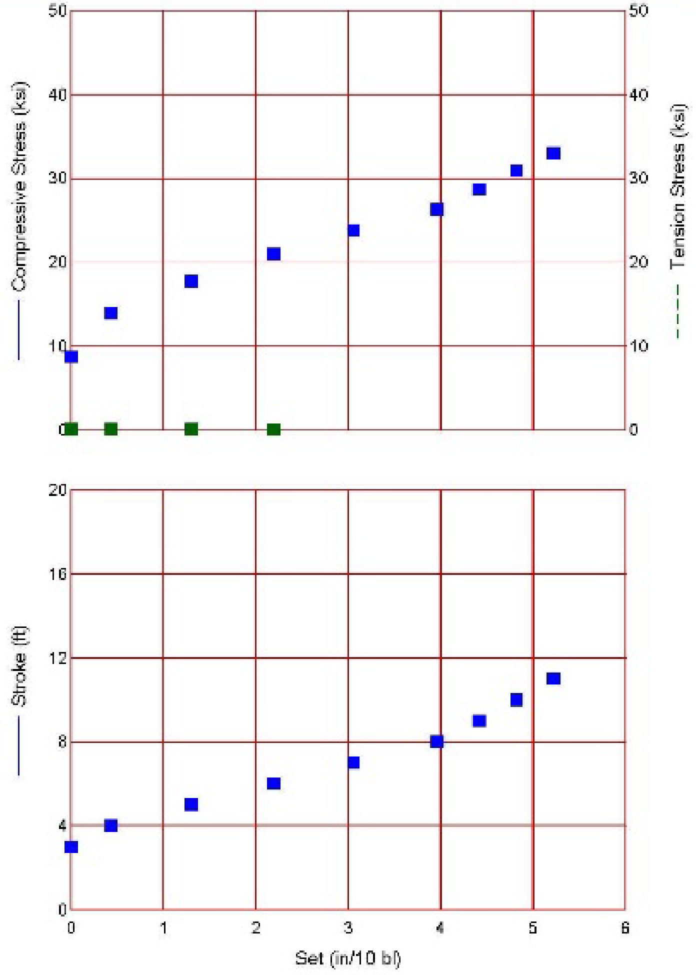
Geotechnology, Inc. 07-Apr-2016
Rt. TT over Belle Fountain Ditch GRLWEAP Version 2010

Ultimate Capacity kips	Maximum Compression Stress ksi	Maximum Tension Stress ksi	Blow Count blows/in	Stroke ft	Energy kips-ft
50.0	17.92	1.32	0.4	5.50	20.35
100.0	22.56	0.13	1.0	6.74	17.92
125.0	24.25	0.03	1.4	7.29	17.47
150.0	25.38	0.00	1.9	7.67	17.01
175.0	26.29	0.00	2.3	7.99	16.79
183.0	26.57	0.00	2.5	8.09	16.71
200.0	27.09	0.04	2.9	8.28	16.64
225.0	27.74	0.04	3.5	8.53	16.63
250.0	28.19	0.04	4.2	8.69	16.65
275.0	28.69	0.05	5.0	8.88	16.74

Bents 1 and 4

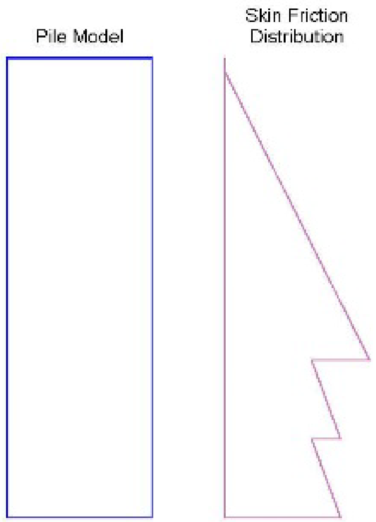
Geotechnology, Inc.
Rt. TT over Belle Fountain Ditch

07-Apr-2016
GRLWEAP Version 2010



DELMAG D 16-32

Capacity	183.0	kips
Ram Weight	3.52	kips
Efficiency	0.800	
Pressure	1500 (100%)	psi
Helmet Weight	1.70	kips
Hammer Cushion	60155	kips/in
COR of H.C.	0.800	
Skin Quake	0.100	in
Toe Quake	0.231	in
Skin Damping	0.133	sec/ft
Toe Damping	0.150	sec/ft
Pile Length	35.00	ft
Pile Penetration	34.00	ft
Pile Top Area	21.20	in2



Res. Shaft = 15 %
(Proportional)

Bents 1 and 4

Geotechnology, Inc.
Rt. TT over Belle Fountain Ditch

07-Apr-2016
GRLWEAP Version 2010

Ultimate Capacity kips	Maximum Compression Stress ksi	Maximum Tension Stress ksi	Set in/10 bl	Stroke ft	Energy kips-ft
183.0	8.74	0.13	0.0	3.00	1.60
183.0	13.94	0.13	0.4	4.00	4.28
183.0	17.75	0.10	1.3	5.00	7.08
183.0	20.97	0.06	2.2	6.00	10.04
183.0	23.79	0.00	3.1	7.00	13.14
183.0	26.35	0.00	4.0	8.00	16.56
183.0	28.71	0.00	4.4	9.00	18.96
183.0	30.92	0.00	4.8	10.00	21.25
183.0	33.03	0.00	5.2	11.00	23.67

Is damage avoidable?

Final Thoughts

- Ram weight and stroke affects pile stress
- Piles to rock
  - LRFD Hard Rock
  - MoDOT Hard Rock
- Short piles vs. long piles
- Hammer energy vs. transferred energy

Questions