GZA
GeoEnvironmental, Inc.

Engineers and Scientists

June 5, 2014
File No. 02.0171991.00

Mr. Arty St. Onge
A.L. St. Onge Contractor, Inc.
P.O. Box 65
82 Fuller Road
Montgomery, Vermont 05470-0065

249 Vanderbilt Avenue
Norwood
Massachusetts
02062
781-278-3700
FAX 781-278-5701
http://www.gza.com

Re: Wave Equation Analyses
Hyde Park Culv(26)
Hyde Park, Vermont

Dear Mr. St. Onge:

At your request, GZA GeoEnvironmental, Inc. has performed the following Wave Equation Analyses (WEAP) for the above referenced project. These analyses were performed in general accordance with the project specifications. A copy of the GRLWEAP output is attached and the WEAP input parameters are summarized below:

- Hammer- APE D19-42 single acting diesel hammer with a ram weight of 4,189 lbs. and a maximum rated stroke of 11.3 feet, yielding a maximum rated energy of 47,132 ft-lbs. The APE D19-42 is equipped with a ratchet style fuel pump with four settings. The fuel pump settings are designed to limit the ram stroke to 5.6 feet, 7.4 feet, 9.3 feet, and 11.2 feet (open) yielding rated energies of 23,566 ft-lbs., 31,107 ft-lbs., 39,119 ft-lbs., and 47,132 ft-lbs, respectively. The APE D19-42 is modeled operating on each of the above fuel settings to develop the required nominal resistance for the pile type detailed below. The hammer cushioning material reportedly consists of 2 inches of nylon.

- Pile - 30 foot long, Grade 50 steel HP12x74 piles are modeled. The cross sectional steel area for this pile type is 21.8 square inches. The specified nominal resistance is 585 kips based on dividing the maximum factored design load of 380 kips by a performance factor of 0.65. The maximum allowable driving stress for this pile type is 45 ksi (i.e., $0.9f_y$).

- Soil - Based on the subsurface information provided and the anticipated driving conditions, the soil resistance profile is modeled as 90% end bearing and 10% skin friction triangularly distributed along the lower 10 feet of the pile.

- Analysis Two analyses model the above hammer-pile-soil system.

  1. Variable capacity analyses which develop a driving resistance based on the most efficient hammer stroke with the APE D19-42 operating on each fuel setting.

  2. Constant capacity analyses which develop a driving resistance based on a varied hammer stroke.

- Results The results of these analyses are tabulated below:

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Nominal Pile Resistance: 585 kips

Pile Hammer	Fuel Setting	Blow Count (bpi)	Ram Stroke (ft)	Compressive Stress (ksi)	Transfer Energy (kip-ft)
APE D19-42	1	11 bpi	7.8 ft.	40.5 ksi	16.1 kip-ft
	2	9 bpi	8.6 ft.	42.8 ksi	18.5 kip-ft
	3	7 bpi	9.5 ft.	45.2 ksi	21.3 kip-ft
	Open (4)	6 bpi	10.3 ft.	47.4 ksi	24.2 kip-ft

Notes:

1. The maximum allowable driving stress for Grade 50 steel is 45 ksi (i.e., $0.9f_y$).

The results tabulated above indicate that the APE D19-42 open-end diesel hammer, operating on fuel setting 1 or fuel setting 2, can drive the specified HP12x74 Grade 50 steel piles to the required nominal resistance of 585 kips without overstressing the pile section. Fuel setting 3 and fuel setting 4 (open) indicates the potential for excessive driving stresses (i.e. 45.2 ksi and 47.4 ksi, respectively).

Based on the above results and our experience with these type driving conditions, the preliminary recommended driving resistance is 11 blows per inch with the APE D19-42 operating on the fuel setting 1 (rated 5.6 foot ram stroke) and providing a ram stroke of approximately 8.0 feet. The maximum estimated driving stress of 40.5 ksi is within the allowable limits for Grade 50 steel. We recommend that this driving criterion be developed for a minimum of 3 consecutive inches. It is our understanding the driving criterion will be verified with the specified dynamic pile-testing program.

Please note that the project documents imply that the specified HP12x74 steel piles are to be driven to bedrock. Based on our experience with this type of driving condition, the piles may take-up abruptly as they develop end-bearing on competent bedrock. If the pile driving system should demonstrate refusal conditions (i.e., sudden increase in ram stroke and penetration resistance), we recommend a refusal criteria of 10 blows per half-inch (10 blows/0.5") penetration with the APE D19-42 operating at a minimum stroke of 8.0 feet.

If you have any questions or require additional information, please contact the undersigned.

Very truly yours,

GZA GEOENVIRONMENTAL, INC.

Michael Deery
Michael Deery
Project Engineer

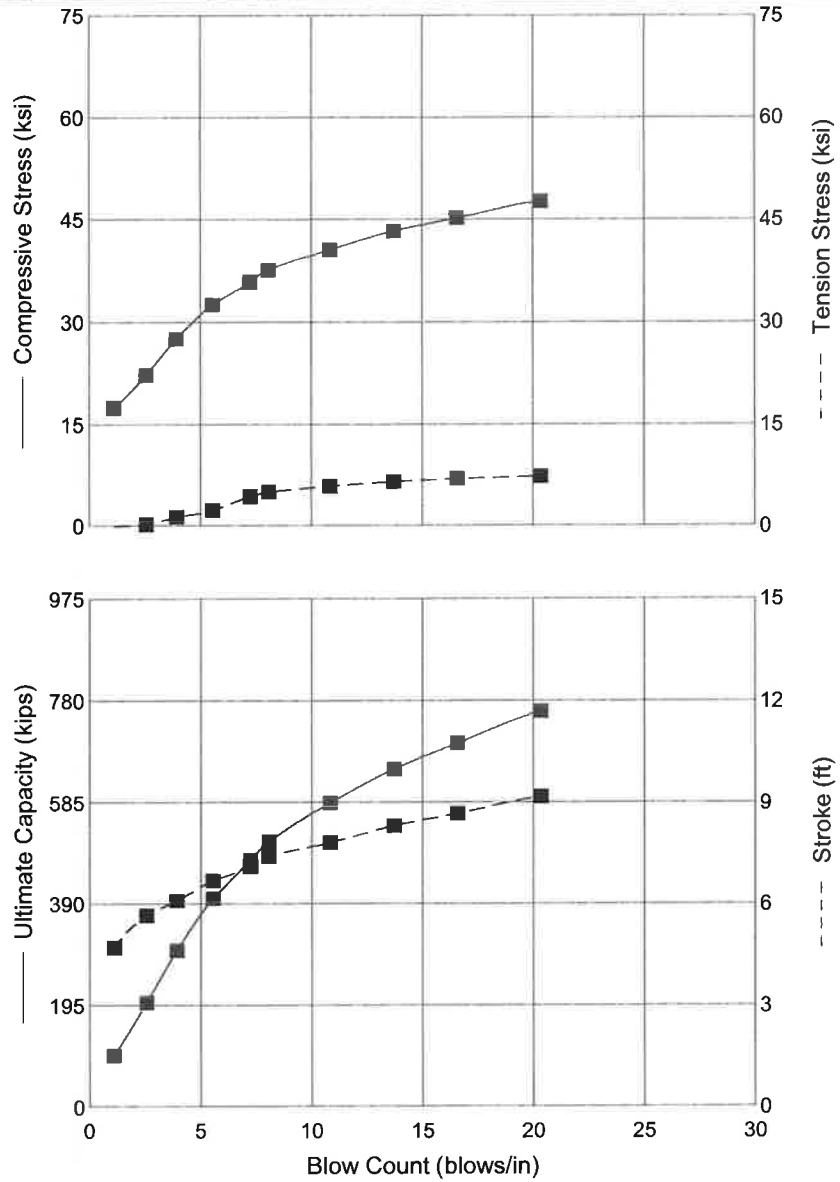
Bradford W. Roberts
Consultant/Reviewer

John E. Regan
Principal

MJD/BWR:idm
Attachments: Wave Equation Analysis Results

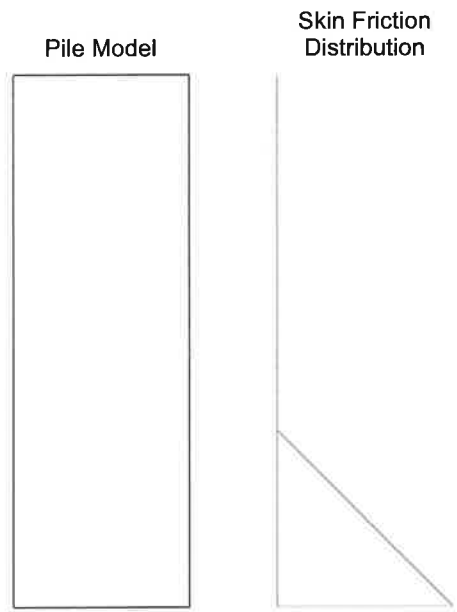
GZA GeoEnvironmental Inc.
Hyde Park D19-42 fs#1 30'HP12x74 VC

05-Jun-2014
GRLWEAP Version 2010



APE D 19-42

Ram Weight	4.19	kips
Efficiency	0.800	
Pressure	1247 (73%)	psi
Helmet Weight	3.00	kips
Hammer Cushion	34825	kips/in
COR of H.C.	0.920	
Skin Quake	0.100	in
Toe Quake	0.040	in
Skin Damping	0.050	sec/ft
Toe Damping	0.150	sec/ft
Pile Length	30.00	ft
Pile Penetration	25.00	ft
Pile Top Area	21.80	in2



Res. Shaft = 10 %
(Proportional)

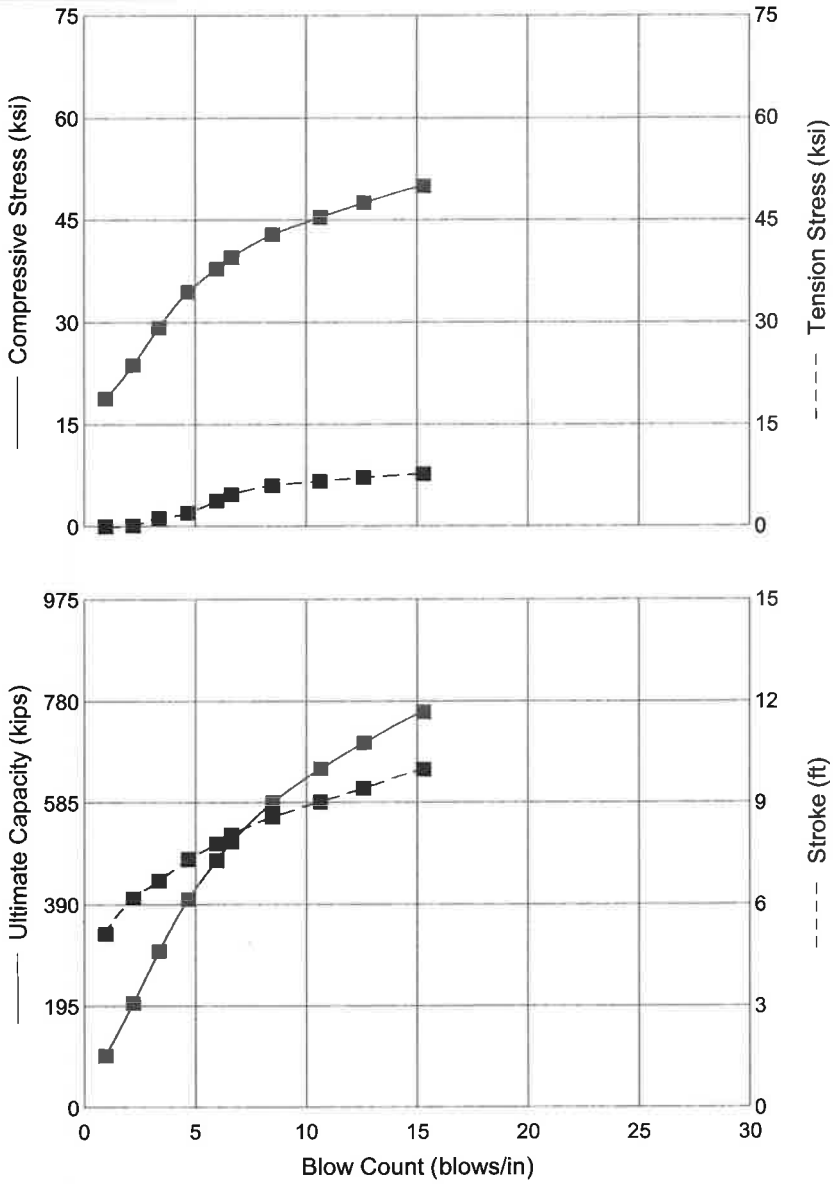
GZA GeoEnvironmental Inc.
Hyde Park D19-42 fs#1 30'HP12x74 VC

05-Jun-2014
GRLWEAP Version 2010

Ultimate Capacity kips	Maximum Compression Stress ksi	Maximum Tension Stress ksi	Blow Count blows/in	Stroke ft	Energy kips-ft
100.0	17.41	0.00	1.1	4.71	13.85
200.0	22.22	0.23	2.6	5.65	13.10
300.0	27.51	1.29	3.9	6.10	13.22
400.0	32.54	2.31	5.6	6.69	14.07
475.0	35.87	4.33	7.3	7.12	14.76
510.0	37.60	4.97	8.1	7.41	15.34
585.0	40.53	5.84	10.8	7.82	16.07
650.0	43.27	6.51	13.7	8.32	17.06
700.0	45.24	6.96	16.6	8.68	17.82
760.0	47.64	7.30	20.3	9.17	18.82

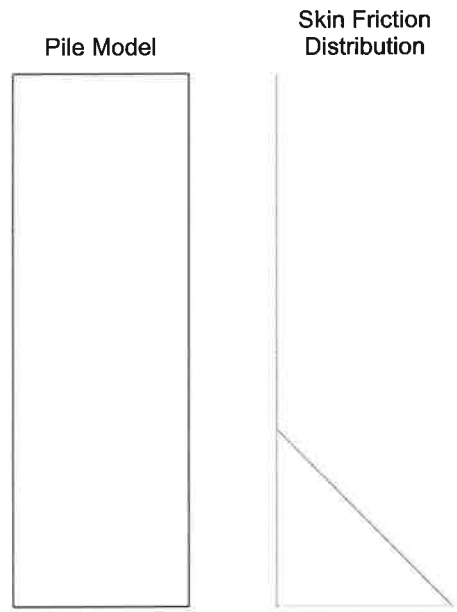
GZA GeoEnvironmental Inc.
Hyde Park D19-42 fs#2 30'HP12x74 VC

05-Jun-2014
GRLWEAP Version 2010



APE D 19-42

Ram Weight	4.19	kips
Efficiency	0.800	
Pressure	1385 (81%)	psi
Helmet Weight	3.00	kips
Hammer Cushion	34825	kips/in
COR of H.C.	0.920	
Skin Quake	0.100	in
Toe Quake	0.040	in
Skin Damping	0.050	sec/ft
Toe Damping	0.150	sec/ft
Pile Length	30.00	ft
Pile Penetration	25.00	ft
Pile Top Area	21.80	in2



Res. Shaft = 10 %
(Proportional)

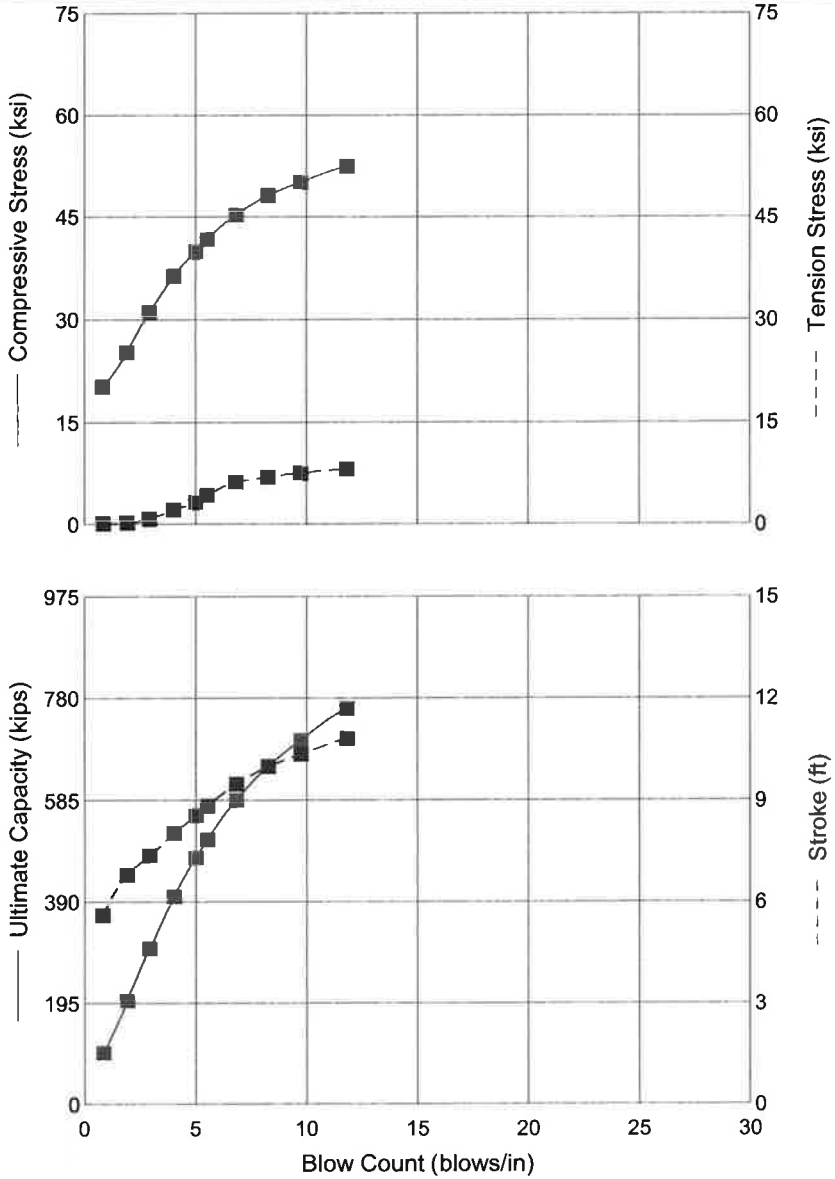
GZA GeoEnvironmental Inc.
Hyde Park D19-42 fs#2 30'HP12x74 VC

05-Jun-2014
GRLWEAP Version 2010

Ultimate Capacity kips	Maximum Compression Stress ksi	Maximum Tension Stress ksi	Blow Count blows/in	Stroke ft	Energy kips-ft
100.0	18.75	0.03	1.0	5.15	16.49
200.0	23.67	0.18	2.2	6.20	15.45
300.0	29.21	1.29	3.4	6.72	15.49
400.0	34.43	2.01	4.7	7.33	16.34
475.0	37.81	3.77	6.0	7.80	17.04
510.0	39.49	4.75	6.6	8.07	17.52
585.0	42.81	6.03	8.5	8.59	18.51
650.0	45.40	6.67	10.6	9.03	19.35
700.0	47.48	7.22	12.6	9.43	20.16
760.0	49.99	7.74	15.3	9.98	21.29

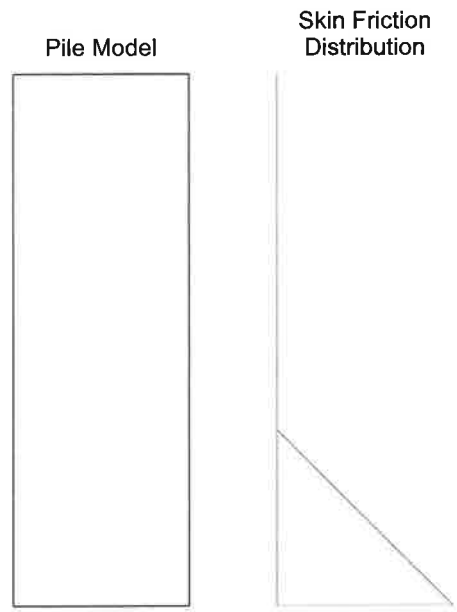
GZA GeoEnvironmental Inc.
Hyde Park D19-42 fs#3 30'HP12x74 VC

05-Jun-2014
GRLWEAP Version 2010



APE D 19-42

Ram Weight	4.19	kips
Efficiency	0.800	
Pressure	1539 (90%)	psi
Helmet Weight	3.00	kips
Hammer Cushion	34825	kips/in
COR of H.C.	0.920	
Skin Quake	0.100	in
Toe Quake	0.040	in
Skin Damping	0.050	sec/ft
Toe Damping	0.150	sec/ft
Pile Length	30.00	ft
Pile Penetration	25.00	ft
Pile Top Area	21.80	in2



Res. Shaft = 10 %
(Proportional)

GZA GeoEnvironmental Inc.
Hyde Park D19-42 fs#3 30'HP12x74 VC

05-Jun-2014
GRLWEAP Version 2010

Ultimate Capacity kips	Maximum Compression Stress ksi	Maximum Tension Stress ksi	Blow Count blows/in	Stroke ft	Energy kips-ft
100.0	20.12	0.08	0.9	5.62	19.47
200.0	25.11	0.22	1.9	6.80	18.11
300.0	30.99	0.74	3.0	7.38	18.02
400.0	36.27	2.04	4.0	8.03	18.86
475.0	39.84	3.17	5.0	8.55	19.65
510.0	41.59	4.18	5.5	8.84	20.15
585.0	45.21	6.11	6.8	9.47	21.29
650.0	48.07	6.84	8.3	9.99	22.34
700.0	50.03	7.47	9.7	10.35	23.00
760.0	52.35	8.03	11.8	10.82	23.92

GZA GeoEnvironmental Inc.
Hyde Park Culv(26) D19-42 30'HP12x74 VC

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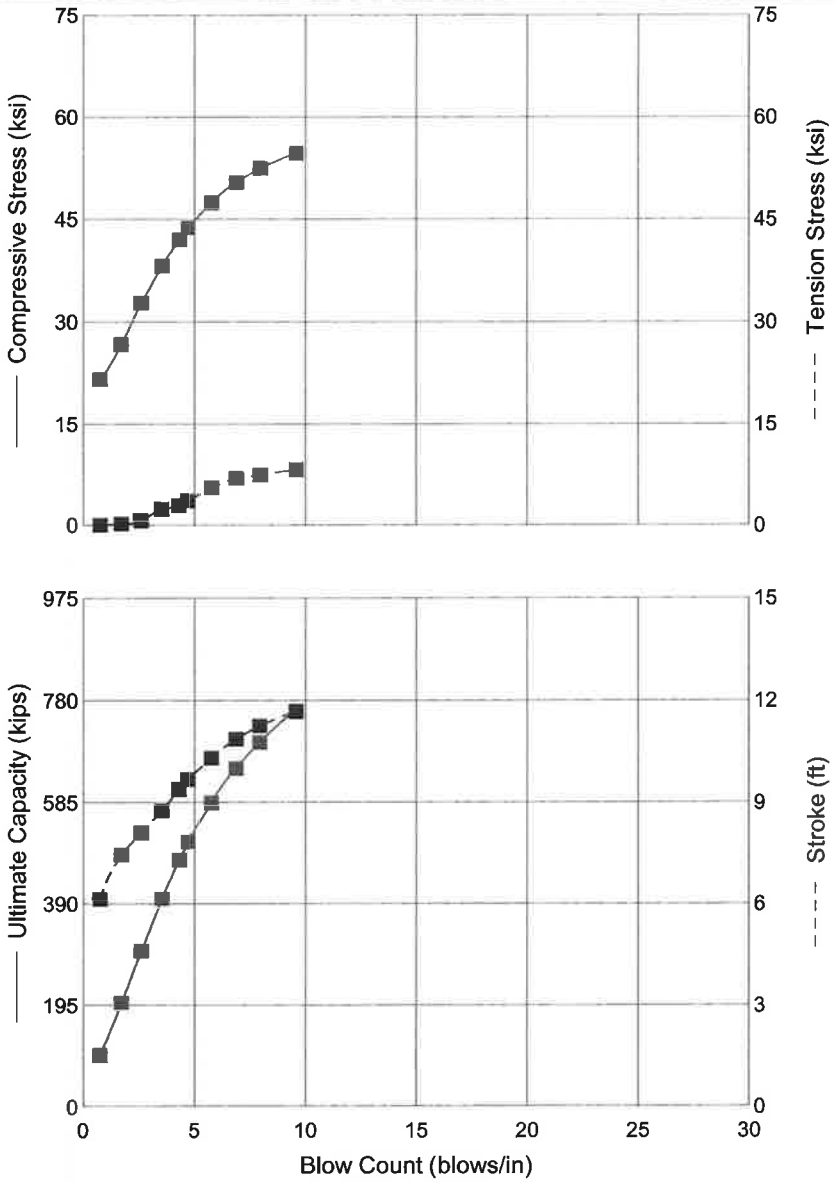
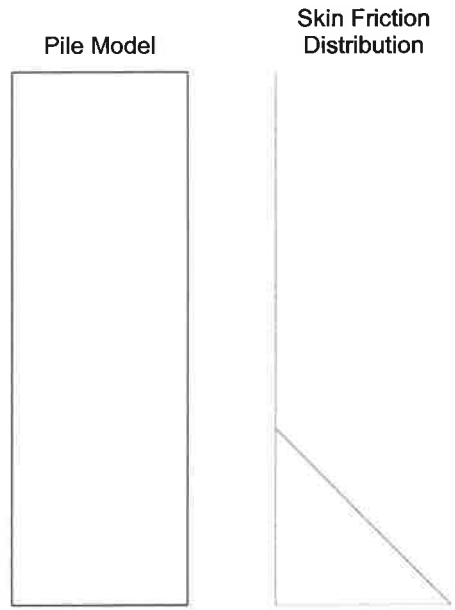


APE D 19-42

Ram Weight	4.19	kips
Efficiency	0.800	
Pressure	1710 (100%)	psi
Helmet Weight	3.00	kips
Hammer Cushion	34825	kips/in
COR of H.C.	0.920	
Skin Quake	0.100	in
Toe Quake	0.040	in
Skin Damping	0.050	sec/ft
Toe Damping	0.150	sec/ft
Pile Length	30.00	ft
Pile Penetration	25.00	ft
Pile Top Area	21.80	in2



Res. Shaft = 10 %
(Proportional)

GZA GeoEnvironmental Inc.
Hyde Park Culv(26) D19-42 30'HP12x74 VC

05-Jun-2014
GRLWEAP Version 2010

Ultimate Capacity kips	Maximum Compression Stress ksi	Maximum Tension Stress ksi	Blow Count blows/in	Stroke ft	Energy kips-ft
100.0	21.51	0.09	0.8	6.14	22.79
200.0	26.67	0.29	1.7	7.46	21.07
300.0	32.73	0.69	2.6	8.12	20.87
400.0	38.12	2.32	3.5	8.75	21.62
475.0	41.95	2.84	4.3	9.38	22.59
510.0	43.76	3.60	4.7	9.68	23.14
585.0	47.40	5.60	5.8	10.30	24.18
650.0	50.33	6.97	6.9	10.86	25.14
700.0	52.41	7.49	7.9	11.25	25.90
760.0	54.60	8.27	9.6	11.67	26.68

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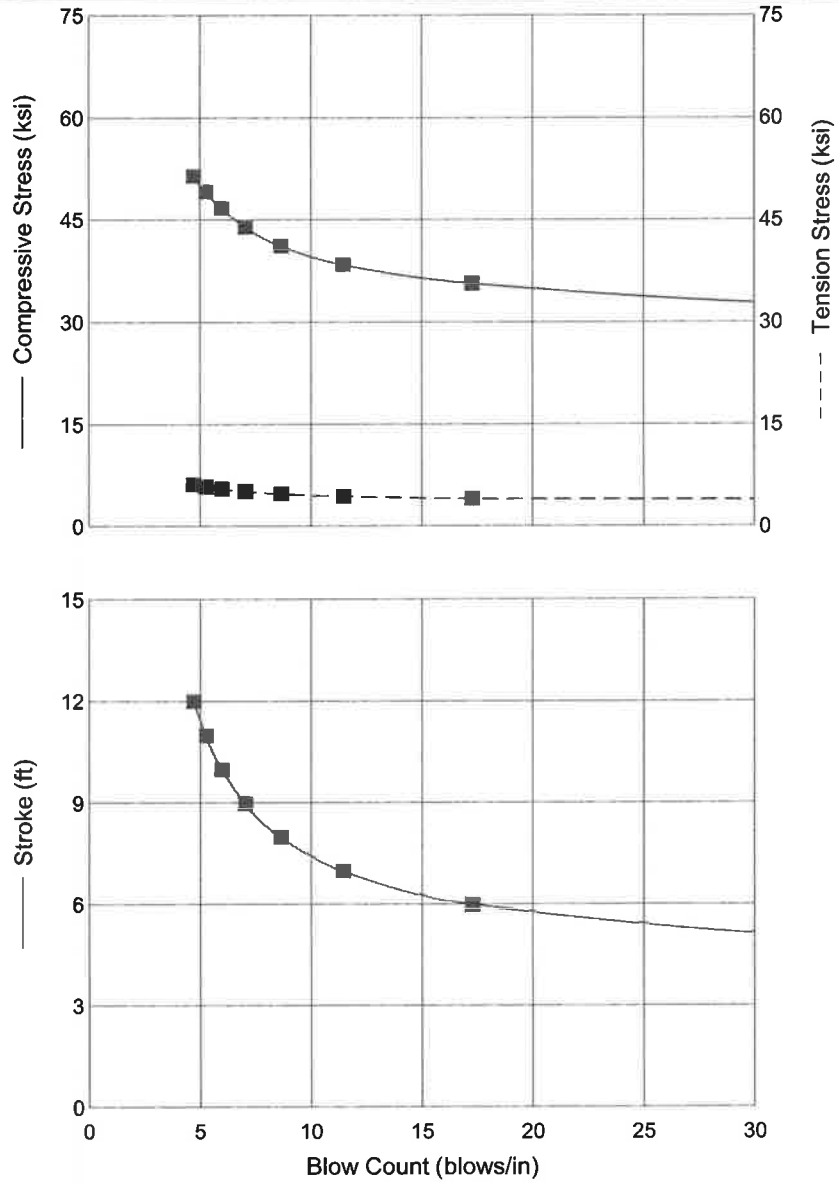
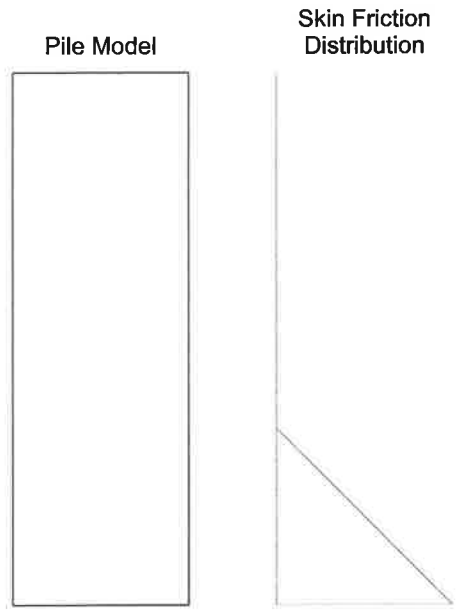
Hyde Park Culv(26) D19-42 30'HP12x74 CC

05-Jun-2014
GRLWEAP Version 2010



APE D 19-42

Capacity	585.0	kips
Ram Weight	4.19	kips
Efficiency	0.800	
Pressure	1710 (100%)	psi
Helmet Weight	3.00	kips
Hammer Cushion	34825	kips/in
COR of H.C.	0.920	
Skin Quake	0.100	in
Toe Quake	0.040	in
Skin Damping	0.050	sec/ft
Toe Damping	0.150	sec/ft
Pile Length	30.00	ft
Pile Penetration	25.00	ft
Pile Top Area	21.80	in2



Res. Shaft = 10 %
(Proportional)

GZA GeoEnvironmental Inc. 05-Jun-2014
Hyde Park Culv(26) D19-42 30'HP12x74 CC GRLWEAP Version 2010

Ultimate Capacity kips	Maximum Compression Stress ksi	Maximum Tension Stress ksi	Blow Count blows/in	Stroke ft	Energy kips-ft
585.0	22.08	3.04	9999.0	3.00	4.56
585.0	28.18	3.62	9999.0	4.00	7.18
585.0	32.38	3.94	36.9	5.00	9.95
585.0	35.68	4.13	17.3	6.00	12.67
585.0	38.38	4.40	11.5	7.00	15.35
585.0	41.15	4.77	8.7	8.00	18.02
585.0	43.98	5.14	7.0	9.00	20.71
585.0	46.61	5.50	6.0	10.00	23.35
585.0	49.09	5.84	5.3	11.00	25.98
585.0	51.47	6.16	4.7	12.00	28.63