GEOSCIENCES TESTING AND RESEARCH, INC.

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June 6, 2016 GTR Project # 16.173

Mr. Brian Richardson
CCS Construction
138 Munson Ave
Morrisville, VT 05661

RE: Wave Equation Analysis - Pileco D19-42
Town Highway 4 over Whitney Brook Bridge Replacement
Craftsbury, Vermont

Dear Brian:

At your request, we have performed Wave Equation Analyses (WEAPs) using the program GRLWEAP^{TM} for the Pileco D19-42 single acting diesel hammer at the above-referenced project. Steel H-piles (HP12x63) are proposed for the support of the bridge. The following report summarizes our evaluation of pile drivability. Appendix A contains literature on the wave equation analysis and the GRLWEAP program. A copy of the Pile and Driving Equipment Data Form is provided in Appendix B. The WEAP results, input and assumptions, including the soil, pile, and hammer details are summarized below.

Soil

The subsurface conditions at the site based on borings B-103 and B-104 indicates sand and gravel to the top of rock. Refer to the boring logs and/or the geotechnical report for additional details regarding the subsurface conditions.

Piles

Steel H piles (HP12x63) are proposed for the support of the bridge abutments. The piles in Abutment 1 are anticipated to be 30 feet long and the required nominal resistance is 320 kips. The piles in Abutment 2 are anticipated to be 25 feet long and the required nominal resistance based on the plans is 297 kips. The cross-sectional area of the H-piles is 18.4 square inches. The piles are specified to be Grade 50 steel (yield strength of 50 ksi). The AASHTO recommended allowable compressive and tensile driving stresses are 45 ksi based on 90% of the yield strength (50 ksi). Refer to Appendix B for further details on the piles.

Hammer

A Pileco D19-42 single acting diesel hammer, with a maximum rated energy of 42.5 kip-ft (ram weight of 4.01 kips and equivalent stroke of 10.6 feet), is proposed to drive the piles. The cushion material for this hammer as reported by the contractor is Aluminum/Conbest (elastic modulus, E, of 530 ksi and coefficient of restitution, COR, of 0.8). The total cushion thickness is 2 inches and area is 227 square inches. The helmet (pile cap with insert) weight is 1.9 kips. Refer to Appendix B for further details on the hammer.

Analysis

Following the review of the pile information and construction conditions, two cases were analyzed. Case 1 is based on a pile penetration length of 30 feet with 90% end bearing, representing a pile driven to bedrock (toe quake = 0.04 inches). Case 2 is similar to Case 1, except that the pile length was decreased to 25 feet. The hammer was set at the minimum fuel setting. Standard granular quake and damping values were used in all cases.

Results

Appendix C summarizes the results of the analyses and contains the output summaries and bearing graphs for each analysis. The maximum compressive and tensile driving stresses, blow count, stroke, and transferred energy are presented.

Conclusions

The wave equation analyses indicate the following:

1. For an ultimate capacity of 320 kips, we recommend a minimum driving criterion of 6 blows per inch for 3 consecutive inches with the hammer operating at a stroke of 6 feet (corresponding to a transferred energy of around 11.5 kip-ft).

2. For an ultimate capacity of 297 kips, we recommend a minimum driving criterion of 5 blows per inch for 3 consecutive inches with the hammer operating at a stroke of 6 feet (corresponding to a transferred energy of around 11.5 kip-ft).

3. The contract drawings indicate the pile shall be seated on bedrock. Refer to boring logs for estimated elevation of bedrock.

4. We also recommend a refusal criterion of 10 blows for 1 inch for cases where the piles take up" abruptly and the stroke should be limited to 7.5 feet to maintain drilling stresses less than 45 ksi.

5. The WEAP analyses indicate that the compressive and tensile driving stresses were below the allowable limit for the cases analyzed.

6. The above recommendations are preliminary and highly sensitive to actual hammer performance. Dynamic testing will be performed to assess driving stresses, evaluate transferred energies delivered to the pile, and estimate pile capacity during driving. The

preliminary driving criteria, hammer setting and recommendations above may be modified pending the results of the dynamic testing program for Abutment 1.

This analysis does not account for variations in the soil profile significantly different from those encountered in the borings. Other factors not considered in this analysis are scour requirements, bending (due to misaligned hammer impacts), downdrag, soil setup and relaxation effects, lateral and uplift requirements, cyclic loading, effective stress changes (due to changes in the water table, excavations, and/or fills), settlement, and pile group effects. The foundation designer should evaluate if any of these issues are applicable to the foundation design.

The results of the wave equation analysis depend on a variety of hammer, pile, and soil input conditions. Attempts have been made to base the analysis on the best available information; however, the predicted stresses and blow counts may vary from those encountered in the field, due to the factors outline above. Further refinements may be made using the PDA™ to provide a better assessment of the pile capacity and the driving criteria at the time of driving.

This report has been prepared in accordance with generally accepted geotechnical engineering principles with specific application to this project. Our conclusions are based on applicable standards of practice, including any information reported to and/or prepared for us. No other warranty, expressed or implied, is made.

We appreciate this opportunity to work with you on this project. If you have any questions regarding this analysis, please contact us at (978) 251-9395.

Sincerely,
Geosciences Testing and Research, Inc.

Leo J. Hart
Principal

Mark C. Saunders
Geotechnical Engineer

Attachments: Appendices A through C

APPENDIX A
WAVE EQUATION LITERATURE

GRLWEAP Version 2010

Accurately Simulates Pile Driving

GRLWEAP 2010 is the software of choice for industry-leading piling professionals all around the world.

1. Calculates driving resistance, dynamic pile stresses, and estimated capacities based on field observed blow count, for a given hammer and pile system.
2. Helps select an appropriate hammer and driving system for a job with known piling, soil and capacity requirements.
3. Determines whether a pile will be overstressed at a certain penetration or if refusal will likely occur before a desired pile penetration is reached (driveability analysis).
4. Estimates the total driving time.

GRLWEAP 2010: Available in Standard and Offshore Wave versions

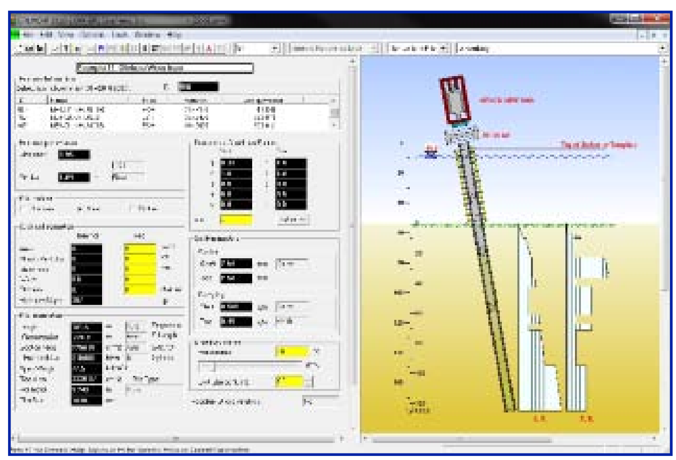
The most widely used pile driving simulation software is now more powerful and user friendly. New features improve the accuracy of predicted stresses, bearing capacities, blow counts and installation time:

- Four static geotechnical analysis options: **ST** method, **SA** method with an updated input method, **CPT** method and a method based on American Petroleum Institute **(API)** requirements.
- Variable toe area input for consideration of plugging in selected soil layers.
- Simplified input for analysis of battered piles.
- More flexible Driveability Analysis input.
- Friendlier interface with spreadsheet programs.

Exclusive Features of Offshore Wave Version:

GRLWEAP Offshore Wave Version is particularly well suited to analyze free riding hammers on non-uniform and/or inclined piles.

- Pipe Pile Builder simplifies input of complex pipe pile sections and add-ons.
- Alternate hammer location may be modeled (pile top, bottom or in-between).
- Static bending analysis for inclined pile driving.
- Fatigue Analysis output tables show stress ranges and extrema with number of occurrences for fatigue damage studies.
- Option to consider Soil Plug Weight.



Offshore Wave Input Screen.

Pile Dynamics, Inc.

Quality Assurance for Deep Foundations

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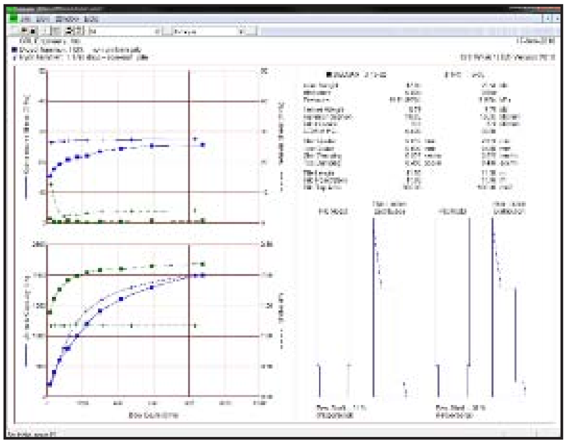
GRLWEAP Version 2010

Accurately Simulates Pile Driving

Background:

GRLWEAP - GRL Wave Equation Analysis of Pile Driving - simulates motions and forces in a foundation pile when driven by either an impact or vibratory hammer. (Replaces blow count with speed of penetration for vibratory hammers.) Its continuously updated, internet accessible hammer database featuers over 800 hammer models and extensive driving system data.

During the early development of the GRLWEAP program in the 1970s and continuously since that time, the program authors have improved program performance by matching GRLWEAP results with measurements by the Pile Driving Analyzer®.



Superimposed bearing graphs compare two hammers.

GRLWEAP Output Graphics

The **Bearing Graph** depicts the relationship of capacities, pile driving stresses and stroke versus blow count. It can be used to estimate the pile bearing capacity given an observed blow count; the required blow count for a specified capacity; or the maximum capacity that a hammer-pile-soil system can achieve.

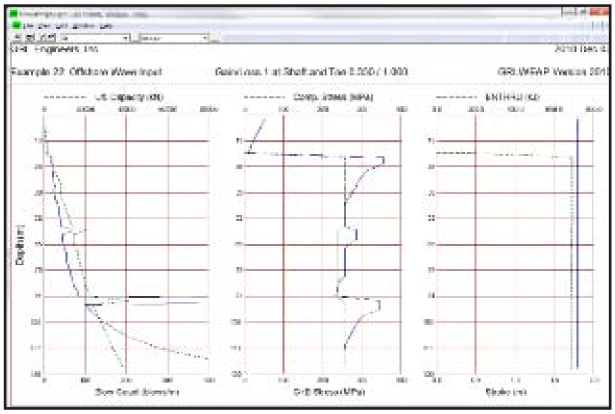
The **Driveability Graph** is a plot of capacity, blow count and dynamic stress extrema versus depth. It allows for consideration of pile add-ons, hammer energy and efficiency changes, cushion deterioration, soil resistance degradation and soil setup during driving interruptions. The numerical summary also includes an estimate of driving time based on the calculated number of blows and on the hammer blows per minute rate.

The **Inspector's Chart** compares stroke (or hammer energy) versus blow count for a single capacity value. Inspector's Charts are used for diesel hammers and external combustion hydraulic (ECH) hammers to determine, for a given bearing capacity, the required blow count versus variable hammer energy.

The **Variables vs. Time** graph shows any calculated quantity as a function of time for comparison with measurements or illustration of stress wave propagation.

Computational process features:

- Smith-type lumped mass hammer and pile model with Newmark predictor-corrector type analysis.
- Realistic non-linear stress-strain analysis of pile with splices, slacks, cushions, and other material interfaces.
- Basic Smith-type soil model with several research extensions.
- Bearing graph analysis with proportional, constant shaft or constant toe resistance.
- Thermodynamic analysis for diesel hammers.
- Iterative diesel hammer analysis for stroke calculation.
- Residual stress (multiple blow) analysis.
- Multi-material analysis for composite piles.
- Two-pile analysis for mandrel driven piles.
- Static soil analysis based on soil type, SPT N value, CPT data files or API method.



Driveability Graph

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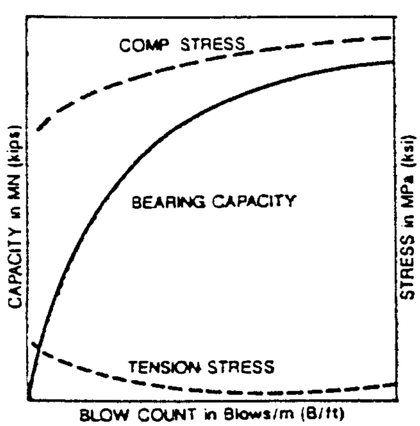
GRL Software: **W**ave **E**quation **A**nalysis of **P**iles

GRLWEAP™, GRLINP, GRLGRF Programs

PROGRAM HISTORY AND BACKGROUND

In 1955 E.A.L. Smith of the Raymond Pile Driving Company presented a concept of pile driving analysis by the wave equation. Smith had developed a rational and complete analysis method for the design and construction control of impact driven piles was the development of a rational and complete approach which included:

- A pile model based on the one-dimensional wave equation.
- A soil model including a static elasto-plastic and a dynamic viscous component.
- A model for relatively simple hammers.
- A computational procedure which yielded a bearing graph, *i.e.*, a relationship between both ultimate capacity and pile stresses and pile set per blow.
- Recommendations for all model parameters.



The Bearing Graph

The first calculations were performed by Smith manually[1]. However, not long after his first paper was published, he developed a computer program which was the first non-military application of electronic computation in engineering. Thus, while "Wave Equation" really means a differential equation, this term has become synonymous with a numerical analysis procedure.

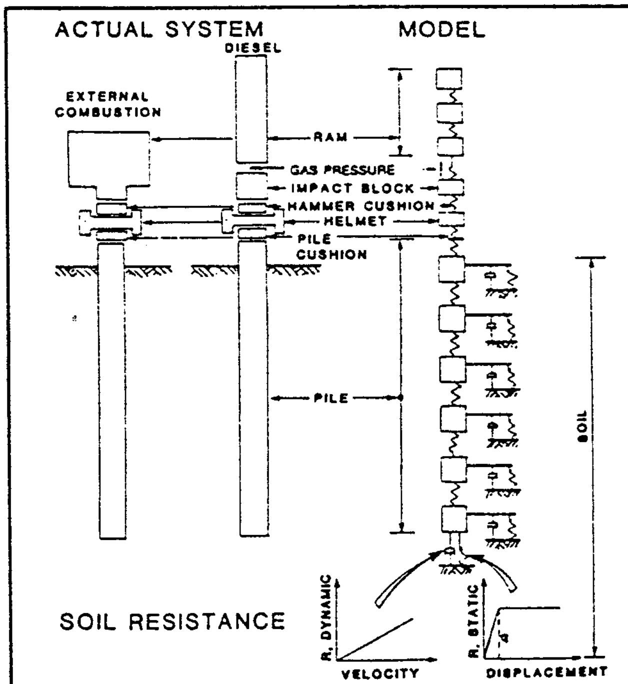
After Smith several researchers investigated the correlation of predictions of bearing capacity with static load test results[2]. These efforts confirmed the soundness of the basic approach. Thus, starting in 1974, the Federal Highway Administration sponsored further work. One of the objectives of these efforts was the realistic modeling of diesel hammers. With a large amount of data available from earlier research, the research team at *Case Institute of Technology*, now working at GRL, developed the WEAP program[3].

In 1986 the program was further improved for the FHwA by the incorporation of a residual stress analysis based on the work of Hery[4] and Holloway[5].

WEAP was also adapted to personal computers and new findings about hammer performance were incorporated in the program and its hammer data file. This work plus additional correlations lead to the WEAP87 package which included both a mainframe and a PC computer program, an expanded hammer data file and extensive documentation[6].

The GRLWEAP program package includes the basic WEAP87 code plus several additional powerful options. The preprocessor GRLINP and the postprocessor GRLGRF make this software particularly user friendly.

1. Smith, E.A.L., "Impact and Longitudinal Wave Transmission," *Transactions ASME*, August, pp. 963-973, 1955
2. Forehand, P.W., and Reese, J.L., "Prediction of Pile Capacity by the Wave Equation, "*Journal of te SM and F Division, ASCE*, Vol. 90, 1964
3. Goble, G.G., and Rausche, F., WEAP Program Documentation, National Information Service, Washington, D.C., 1976
4. Hery, P., "Residual Stress Analysis in WEAP," *MSCE Thesis*, University of Colorado, Boulder, 1983
5. Holloway, D.M., Clough, G.W., and Vesic, A.S., "The Effects of Residual Stresses on Pile Performance Under Axial Loads," *Proceedings*, 10th Annual Offshore Technology Conference, Houston, TX, 1978
6. Goble Rausche Likins and Associates, Inc., GRLWEAP Documentation, Cleveland, 1988

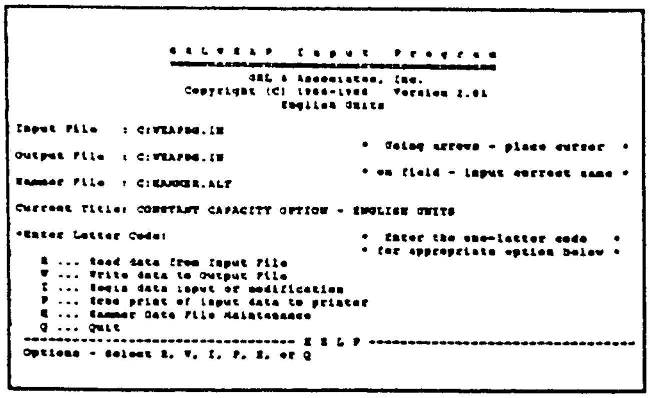


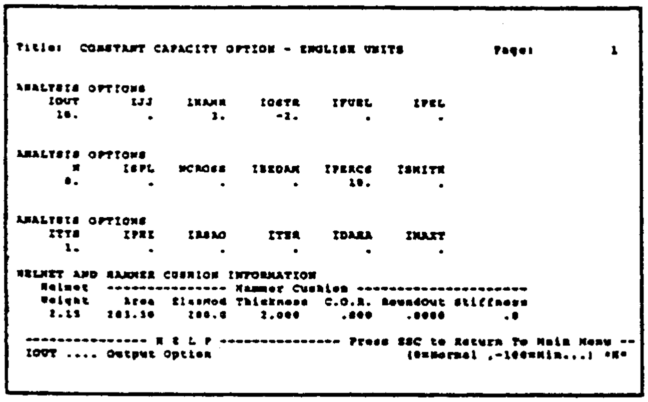
The Analysis Model

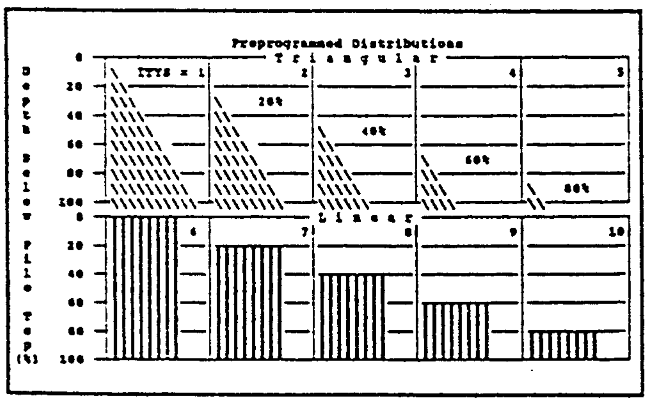
Goble Rausche Likins and Associates, Inc.

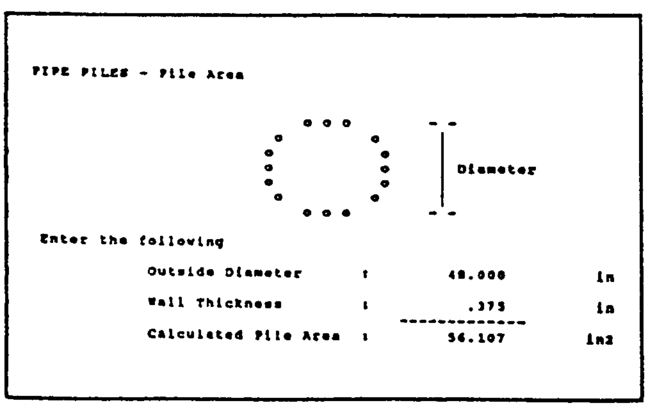
4535 Emery Industrial Parkway
Cleveland, Ohio 44128

phone: (216) 831-6131 fax: (216) 831-0916 telex: 985-662









The GRLINP program offers a maximum of conveniently available help and a simple input preparation. Basically, GRLINP offers on the main screen the following functions:

- Read and modify an existing GRLWEAP input data file.
- Accept keyboard input and write a new GRLWEAP input data file.
- Search for and display data contained on the hammer data file.
- Accept keyboard input and modify or create hammer data files.
- Provide the user help in the form of short variable descriptions and complete data tables (including hammer listings, helmet weights, cushion sizes and properties, pile types and cross section calculator and soil dynamic parameters).
- Check all input data and request extended input depending on user selected options.

The four screens shown on this page give examples of the method of input preparation, help and options. The first screen contains the main menu, file names and title entry. Menu options include file reading, writing, hammer maintenance and normal data entry.

The second screen shows the first page of data requests. Simple cursor movement control allows the user to choose any of the displayed quantities for which a short help message is displayed at the bottom of the screen. Additional help becomes available by striking the "H" key. Examples of such help screens are shown, first the "canned" shaft resistance distributions and second a pipe pile area calculator (calculators for other pile cross sections are also available).

GRLWEAP Hardware Requirements

GRLWEAP is a batch mode type program adapted to IBM-PC computers or compatible machines. The PC must be equipped with at least 528 kb of memory and two disk drives. Math coprocessor, hard drive and screen graphics adaptor are highly recommended accessories. GRLGRF is only helpful if either a graphics adaptor and printer or an HP 7400 series plotter is available. PC analyses by GRLWEAP are convenient and quick with an AT or 386 type machine, however, for those wishing to use a main frame, the WEAP87 source code is also available.

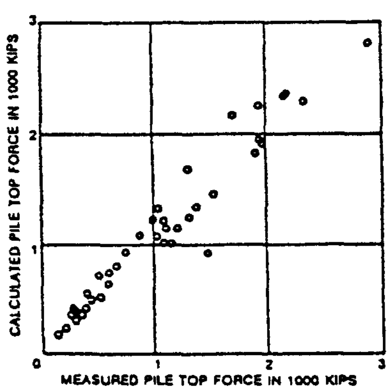
PROGRAM CAPABILITIES

GRLWEAP is a batch mode program, *i.e.*, the user writes a data file containing **all input data** and then runs the program. The batch mode operation has the advantage of allowing an engineer to prepare up to 10 data sets which then can be analyzed in a single run without further user involvement. Also the user may prepare input with a variety of programs such as simple line editor or the more sophisticated **GRLINP** program.

The program **documentation** contains *Background Report, Users Manual, Installation Manual, Microcomputer Input/Output Information* and examples in both English (ft, kips) and SI (m, kN) units. The Users Manual contains a wealth of data which greatly reduces the effort in the preparation of the analysis. This data is also summarized in the GRLINP help files.

GRLWEAP **output** is written to the screen, printer and/or disk file. Screen output includes all numerical results, *e.g.*, the bearing graph data, graphics of various pile variables as they are calculated, and the bearing graph. Of course, the graphics output may also be sent to a graphics printer. The written disk file can be read by the **GRLGRF** program for additional output to screen, graphics printer or plotter. Of particular value is the **Hammer Data File** which contains more than 240 entries and the related collection of driving system parameters (helmet weights, cushion materials) which have been compiled and preprogrammed for user convenience.

WEAP already contained a number of special features which were retained in GRLWEAP. For example, the numerical integrations are performed according to a predictor-corrector algorithm. Hammer components, cushions, and splices are modeled with a partially non-linear force-deformation relationship. In this way very satisfactory correlations of predicted and measured maximum pile top forces were achieved as shown in the figure on the left.

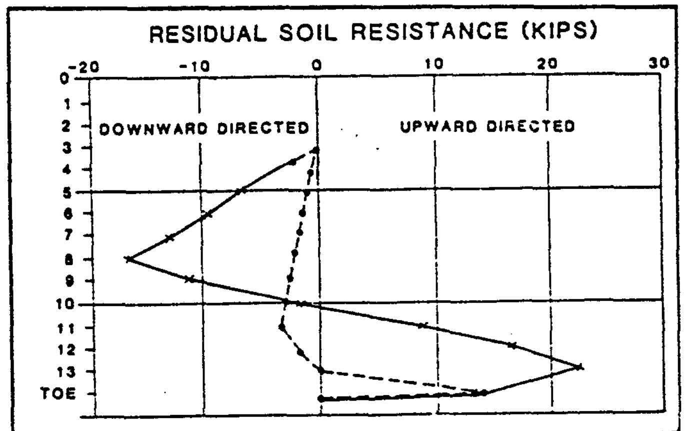


Pile Top Force Correlation

GRLWEAP also offers a variety of important analysis options. The user may choose a **Standard Analysis**, *i.e.*, an analysis at a given depth. The standard analysis can be done with either **fixed toe resistance**, or with **fixed skin resistance**, or with both **variable skin and toe resistance**. Alternatively, the pile is analyzed as it penetrates into the ground by the so-called **Capacity *vs* Depth Analysis.** This analysis requires input of friction, end bearing, quake, and damping values. The program calculates at each required depth the total shaft resistance subject to a reduction factor to model dynamic effects. From shaft and toe resistance it subtracts the dead weight components (hammer assembly, impact block, helmet, pile above grade). The resulting blow count, stresses and other results can be plotted by GRLGRF (see last page).

There are **three diesel hammer options.** The first calculates **stroke for fixed Maximum Combustion Pressure** (MCP). The second gives **MCP for a fixed stroke.** For the third option a **variable MCP yields a variable stroke given a single capacity,** *e.g.*, the required design load times the safety factor. The last option is for construction control and leads to a required blow count for an observed stroke and blow count. The corresponding modified bearing graph can be plotted by GRLGRF.

Another important option produces a **Residual Stress Analysis** (RSA). For RSA several blows are consecutively analyzed.



Residual Forces for Flexible (x) and Stiff (•) Pipe Pile

After each analysis the final pile and soil deformations are saved and used as initial values for the next blow. Thus, the RSA includes the energy remaining in pile and soil between blows which leads to lower blow counts (higher predicted capacities) and higher calculated stresses than the traditional WEAP approach. RSA is recommended for very flexible piles.

SOFTWARE SUPPORT

GRL's engineers pride themselves with providing the best possible service to GRLWEAP users. Updates are provided and questions are answered regarding program installation, program performance and applications, for one year after program purchase. Important findings about GRLWEAP are regularly published in the **GRL NEWSLETTER.** Support is extended beyond the initial one year period if the user opts to receive continued support. User recommendations for program enhancements or improvements of general interest are included in program updates.

APPENDIX B
PILE AND DRIVING EQUIPMENT DATA FORM

Contract #: 16.173

Structure Name and/or No.:

Project: T.H. 4 over Whitney Brook Bridge Replacement

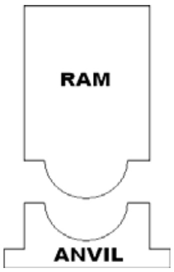
Pile Driving Contractor or Subcontractor:

City/State: Craftsbury, Vermont

CCS Construction

(piles driven by)

Hammer Components



Hammer

Manufacturer: Pileco Model: D19-42

Type: OED Serial No.:

Rated Energy: 42 kip-ft at 10.6 ft Length of stroke

Modifications:

Capblock (Hammer Cushion)

Material: Conbest/Aluminum

Thickness: 2 in 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 kips

Pile Cushion

Material: N/A

Thickness: Area:

Modulus of Elasticity (E):

Coefficient of Restitution (e):

Pile

Pile Type: HP12x63

Length : 25 to 30 feet

Weight/ft.: 63lb/ft

Wall Thickness: N/A Taper: N/A

Cross Sectional Area: 18.4 Sq. inches

Ultimate Capacity: 297 and 320 kips

Description of Splice: N/A

Tip Treatment Description: Reinforced tip

Submitted by: MCS Date: 6/6/2016

PILE AND DRIVING EQUIPMENT DATA FORM

APPENDIX C
GRLWEAP BEARING GRAPHS AND OUTPUT SUMMARIES

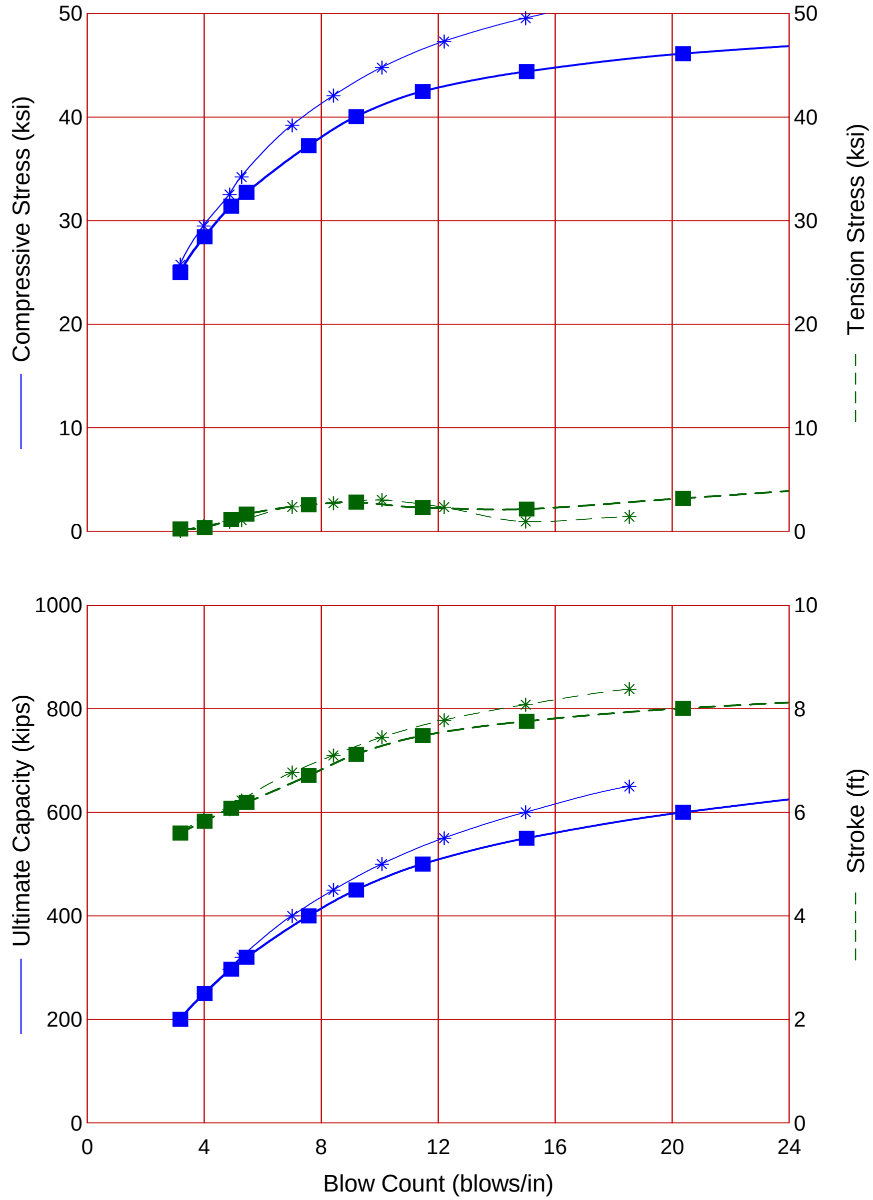
Geosciences Testing & Research Inc

■ 16.173 Craftsbury Case 1

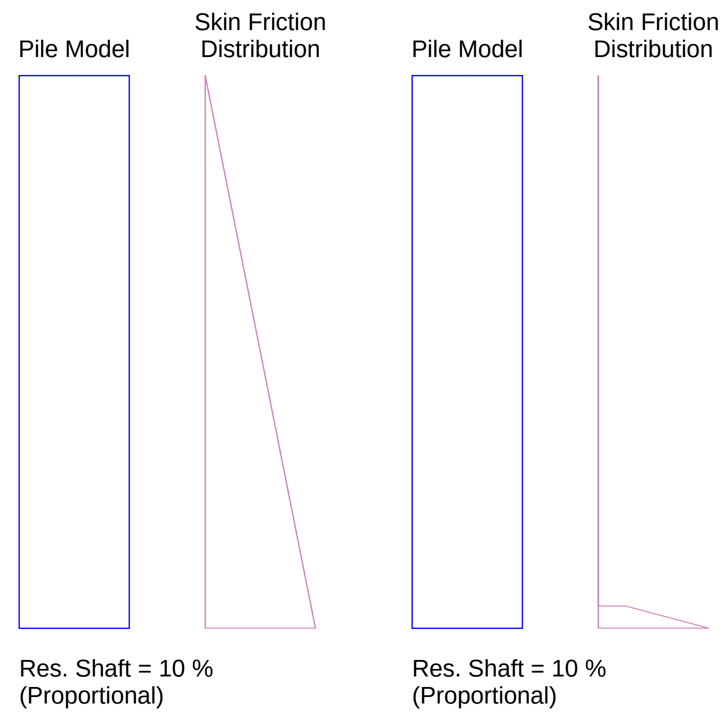
✳ 16.173 Craftsbury Case 2

06-Jun-2016

GRLWEAP Version 2010



	■ PILECO D19-42		✳ PILECO D19-42	
Ram Weight	4.01		4.01	kips
Efficiency	0.800		0.800	
Pressure	1150 (73%)		1150 (73%)	psi
Helmet Weight	1.90		1.90	kips
Hammer Cushion	60155		60155	kips/in
COR of H.C.	0.800		0.800	
Skin Quake	0.100	in	0.100	in
Toe Quake	0.040	in	0.040	in
Skin Damping	0.050	sec/ft	0.050	sec/ft
Toe Damping	0.150	sec/ft	0.150	sec/ft
Pile Length	30.00		25.00	ft
Pile Penetration	30.00		25.00	ft
Pile Top Area	18.40		18.40	in2



16.173 Craftsbury Case 1

Ultimate Capacity kips	Maximum Compression Stress ksi	Maximum Tension Stress ksi	Blow Count blows/in	Stroke ft	Energy kips-ft
200.0	24.99	0.23	3.2	5.60	11.00
250.0	28.44	0.36	4.0	5.83	11.15
297.0	31.39	1.15	4.9	6.08	11.45
320.0	32.73	1.66	5.5	6.19	11.55
400.0	37.24	2.55	7.6	6.71	12.37
450.0	40.04	2.82	9.2	7.12	13.11
500.0	42.47	2.30	11.5	7.48	13.89
550.0	44.39	2.15	15.0	7.76	14.56
600.0	46.12	3.19	20.4	8.01	15.17
650.0	47.53	4.65	28.6	8.23	15.69

16.173 Craftsbury Case 2

Ultimate Capacity kips	Maximum Compression Stress ksi	Maximum Tension Stress ksi	Blow Count blows/in	Stroke ft	Energy kips-ft
200.0	25.75	0.04	3.2	5.61	10.91
250.0	29.48	0.53	4.0	5.86	11.08
297.0	32.52	0.94	4.9	6.06	11.21
320.0	34.21	1.09	5.3	6.23	11.47
400.0	39.21	2.37	7.0	6.77	12.29
450.0	42.06	2.72	8.4	7.10	12.87
500.0	44.78	3.03	10.1	7.45	13.52
550.0	47.30	2.34	12.2	7.78	14.12
600.0	49.55	0.95	15.0	8.08	14.65
650.0	51.61	1.42	18.5	8.38	15.17