



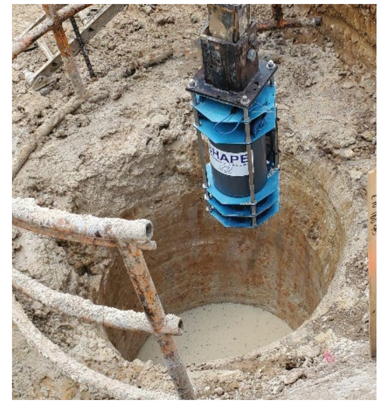



GRL Engineers, Inc.

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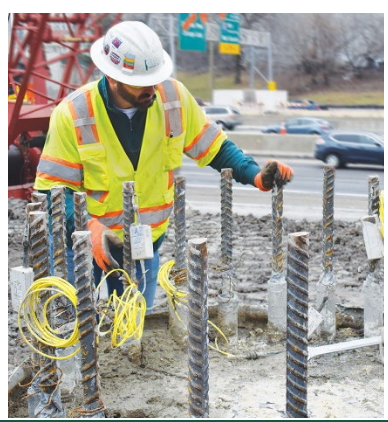


STATEMENT OF QUALIFICATIONS

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1.0 INTRODUCTION AND HISTORY

GRL Engineers, Inc, is a professional engineering firm established to provide specialized testing, analysis, and consulting services to the deep foundation industry. Under the direction of professor G.G. Goble, and with the participation of F. Rausche and G. Likins, a research project was begun in 1964 at Case Institute of Technology in Cleveland, Ohio. This research pioneered the basic concept of dynamic pile testing which is now known as the Case Method. The success of the research project provided the basis for a valuable new tool for pile design and construction control known as the pile driving analyzer (PDA). The CAPWAP® software program for deriving the soil resistance from pile top measurements was also developed as part of this research effort.

In the early 1970's, the research team began a consulting practice to provide a service based on the Case Method and utilizing the PDA for the deep foundation industry. Since its incorporation in 1975, GRL has continued to expand its capabilities in the dynamic testing field through in-house research efforts and the results of several funded studies. In 1976, the Wave Equation Analysis Program (WEAP) for pile driving evaluation was developed for the Federal Highway Administration (FHWA). This program was updated in 1980 and again in 1987 before becoming the proprietary program known today as GRLWEAP. In 1986, *The Performance of Pile Driving Systems*, was developed for and published by the FHWA. GRL has also authored the last three editions of the FHWA manual *Design And Construction Of Driven Pile Foundations* in 1996, 2006, and 2016.

GRL operates the largest dynamic pile testing firm in the world. The dynamic test methods, originally developed by the founding principles of the firm, are applied worldwide on a routine basis, both on land and offshore. The methods provide improved foundation solutions, better quality control, and often significant savings in foundation cost or construction time.

Over time, GRL's service line has also expanded to cover the vast majority of all deep foundation testing needs for driven piles, drilled shafts, auger-cast piles, micro-piles, and helical piles. GRL is an industry leading provider of integrity test methods for deep foundations including thermal integrity profiling, cross-hole sonic logging, and low strain integrity testing. We offer a variety of load testing services including our APPLE drop weight dynamic load testing system, GRL-Cells for Bi-Directional Static Load Testing, and a 1000 ton load frame and hydraulic jacks for static load testing.

With a unique history and unequaled wealth of experience, GRL is internationally recognized for major contributions to its deep foundation area of expertise.

2.0 OFFICE LOCATIONS

GRL maintains its corporate headquarters and a testing office in Cleveland, Ohio, USA. GRL is licensed to provide professional engineering services in every US state. To provide a faster response to its clients at reduced travel costs, personnel are positioned from 13 additional locations across the US.

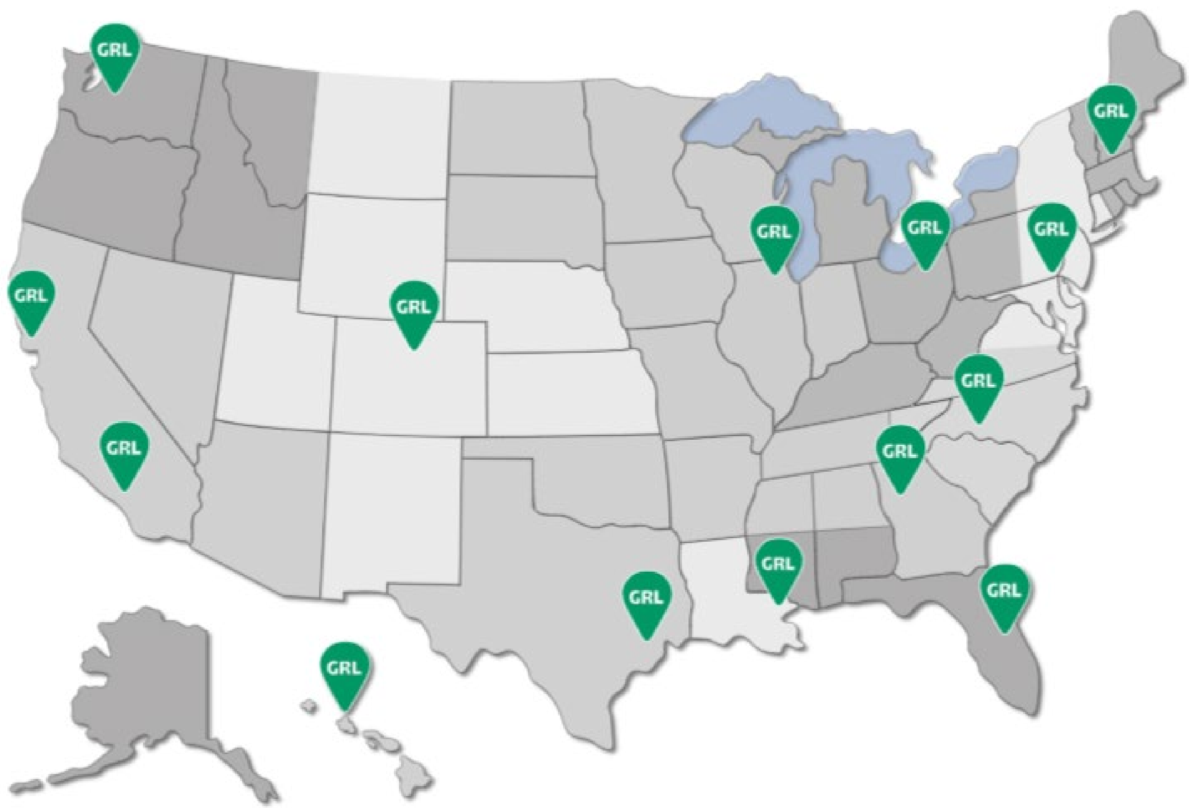

Figure 1. GRL Engineers, Inc. office locations.

GRL offices are located near Atlanta GA, Boston, MA, Charlotte NC, Chicago IL, Cleveland OH, Denver CO, Houston TX, Los Angeles CA, New Orleans LA, Orlando FL, Philadelphia, PA, San Francisco CA, Seattle WA, and Honolulu, HI.

GRL maintains corporate licensure to provide engineering services in all 50 US states as well as the District of Columbia. GRL also holds corporate licensure in five Canadian provinces.

For more information https://www.grlengineers.com/contact-us/

3.0 PROFESSIONAL STAFF

The construction industry has rapidly changing and demanding schedules. Services are often requested on short-notice, either when problems occur, or when sudden scheduling changes have to be accommodated. GRL's professional staff of over 40 civil engineers in our thirteen offices are aware of this industry requirement of immediate response and have at their disposal sufficient personnel and equipment to quickly respond whenever or wherever testing services are required.

Over half of GRL's engineers hold advanced university degrees in civil, structural, or geotechnical engineering, and are registered professional engineers. GRL personnel hold professional engineer licenses in every US state, the District of Columbia, and five Canadian provinces.

For more information https://www.grlengineers.com/our-engineers/

Our engineers with over 6 months of experience who provide dynamic testing services have completed the Pile Driving Contractors Association (PDCA) Dynamic Measurement and Analysis Proficiency Test. This exam evaluates and documents their expertise in dynamic testing data acquisition and analysis. Over 80% of GRL dynamic testing personnel have achieved a rating of Advanced or higher on this exam.

For more information, visit the Dynamic Measurement & Analysis Proficiency Test website.

4.0 SERVICES

4.1 Dynamic Pile Monitoring (PDA) includes the measurement of pile top force and velocity with a Pile Driving Analyzer (PDA) during impact pile driving or restrike testing of driven piles. Dynamic pile monitoring during pile installation (Figure 2) measures pile driving stresses, assesses pile integrity, determines hammer and driving system performance through transferred energy calculation, and evaluates the mobilized soil resistance at the time of driving. Restrike tests after an appropriate waiting period are used to determine time dependent pile capacity changes resulting from soil setup or relaxation. Tests can be performed with a GRL engineer at the project site or in real time from the office using the SiteLink® remote testing capability.

Figure 2. Dynamic Pile Monitoring with PDA 8G and wireless data transmission during pile installation.

Dynamic pile monitoring results are typically plotted as a function of pile penetration depth for initial driving sequences (Figure 3) and versus blow number for restrike events. A tabular summary of the test results (Figure 4) is also provided. CAPWAP analyses, discussed in Section 4.3, are performed on selected data sets for further evaluation of the pile capacity and the soil resistance distribution.

For more information - https://www.grlengineers.com/services/pdm/

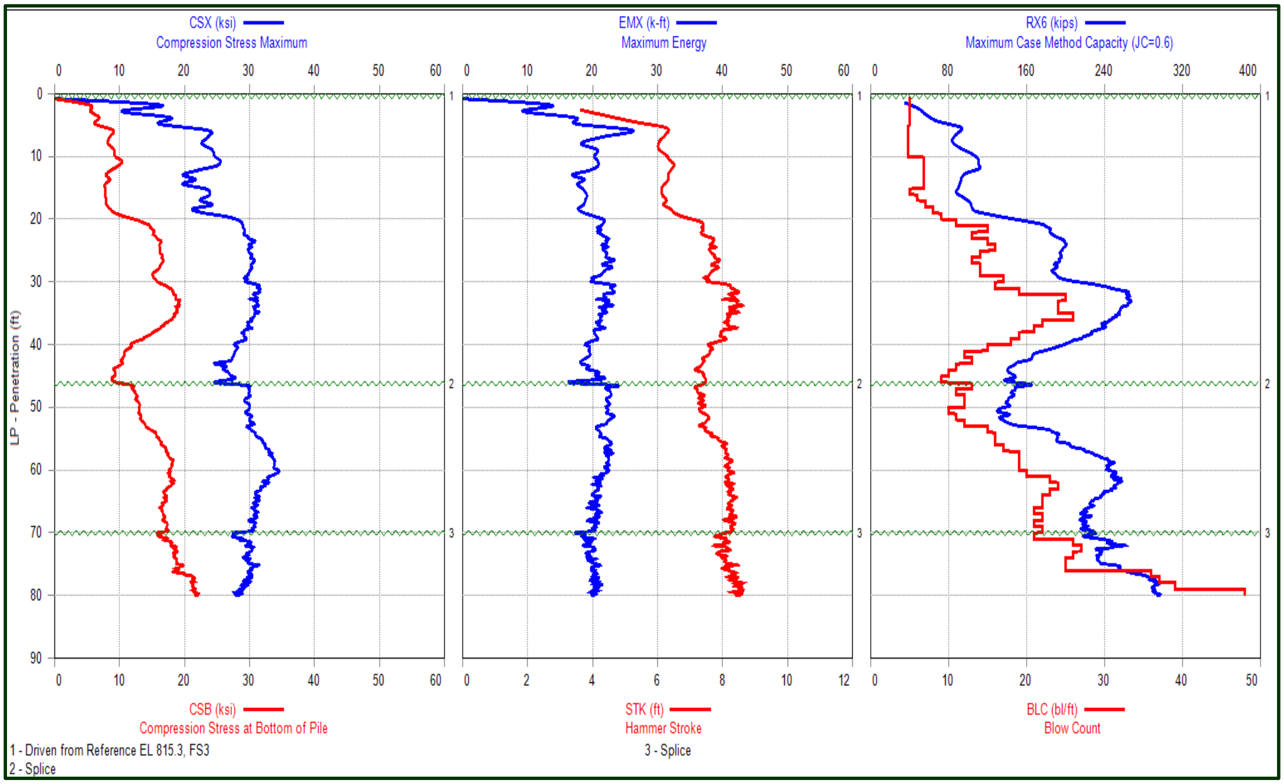

Figure 3. Dynamic pile monitoring versus pile penetration depth.

US-20 over SR 42 - Pier 2, Pile 16, EOID — ICE - I-19, 14" x 0.375" CEP
OP: JS — Date: 05-April-2019

AR: 16.05 in² — SP: 0.492 k/ft³
LE: 47.00 ft — EM: 30,000 ksi
WS: 16,807.9 f/s — JC: 0.90

CSX: Compression Stress Maximum — EMX: Maximum Energy
CSB: Compression Stress at Bottom of Pile — BPM: Blows/Minute
STK: Hammer Stroke — RX6: Maximum Case Method Capacity (JC=0.6)

BL#	Depth	BLC	TYPE	CSX	CSB	STK	EMX	BPM	RX6
	ft	bl/ft		ksi	ksi	ft	k-ft	bpm	kips
763	61.00	20	AV20	34.0	17.6	8.2	22	41.2	249
786	62.00	23	AV23	32.6	18.0	8.2	21	41.4	253
810	63.00	24	AV24	32.2	17.8	8.2	21	41.2	252
833	64.00	23	AV23	31.2	17.0	8.2	20	41.2	242
855	65.00	22	AV22	31.2	17.1	8.3	21	40.9	232
877	66.00	22	AV22	30.8	16.6	8.2	20	41.3	226
898	67.00	21	AV21	30.9	16.5	8.3	21	41.1	219
920	68.00	22	AV22	30.7	16.8	8.3	20	41.1	220
941	69.00	21	AV21	30.6	17.2	8.3	20	41.2	219
963	70.00	22	AV22	30.5	17.3	8.3	20	41.1	221
984	71.00	21	AV21	27.5	16.2	7.9	18	40.1	225
1010	72.00	26	AV26	29.5	17.7	8.1	19	41.6	247
1037	73.00	27	AV27	30.2	18.5	8.1	20	41.6	242
1063	74.00	26	AV26	29.6	18.5	7.9	19	41.9	234
1088	75.00	25	AV25	29.8	18.8	8.1	20	41.5	234
1113	76.00	25	AV25	30.7	19.2	8.2	20	41.4	253
1149	77.00	36	AV36	30.0	19.6	8.3	20	41.0	271
1186	78.00	37	AV37	29.7	21.3	8.4	20	40.9	290
1225	79.00	39	AV39	29.2	21.3	8.5	21	40.5	292
1273	80.00	48	AV48	28.3	21.7	8.5	20	40.5	292
			Average	30.3	18.6	8.2	20	41.1	251

Total number of blows analyzed: 528

Figure 4. Tabular summary of dynamic pile monitoring results over selected penetration depths.

4.2 Dynamic Load Testing (DLT) usually with the APPLE loading system (Figure 5), is performed to evaluate the bearing capacity of a drilled shaft, auger-cast pile, micro-pile, or helical pile. A limited number of impacts (typically 3 to 5) are applied to the deep foundation element in a dynamic load test with a drop weight system. A dynamic load test can also be performed on a driven pile using the pile driving hammer.

Figure 5. APPLE system configured with 44 ton drop weight and load cell positioned atop drilled shaft.

Dynamic load test results are subsequently analyzed with CAPWAP® analysis to assess the foundation's load-movement behavior. CAPWAP simulated static load test load-movement plots for each blow are frequently plotted sequentially to provide a load-movement envelope (Figure 6).

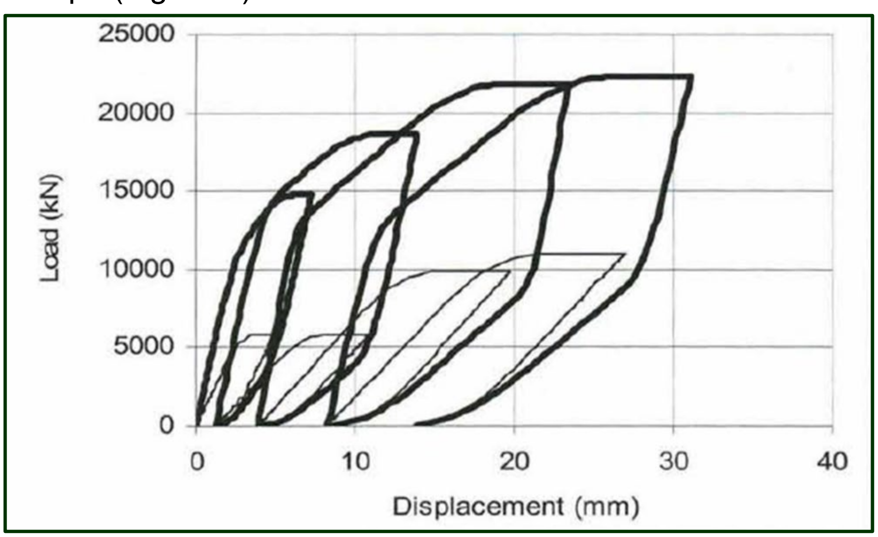

Figure 6. *Dynamic load test load-movement envelope*.

For more information - https://www.grlengineers.com/services/dlt/

4.3 CAPWAP Analysis uses a rigorous numerical signal matching process to determine the soil model from measured force and velocity records. The CAPWAP analysis procedure yields the mobilized pile capacity including the shaft resistance distribution and toe/base resistance as well as the dynamic soil parameters (quake and damping). These results are used to calculate a simulated static load test load-movement plot. The compression and tension stress levels through the pile/shaft foundation element are also obtained for the analyzed test record. Analysis output includes a graphical summary (Figure 7) of the analysis results along with numerical tables summarizing the soil resistance versus depth, pile stresses, and the pile model.

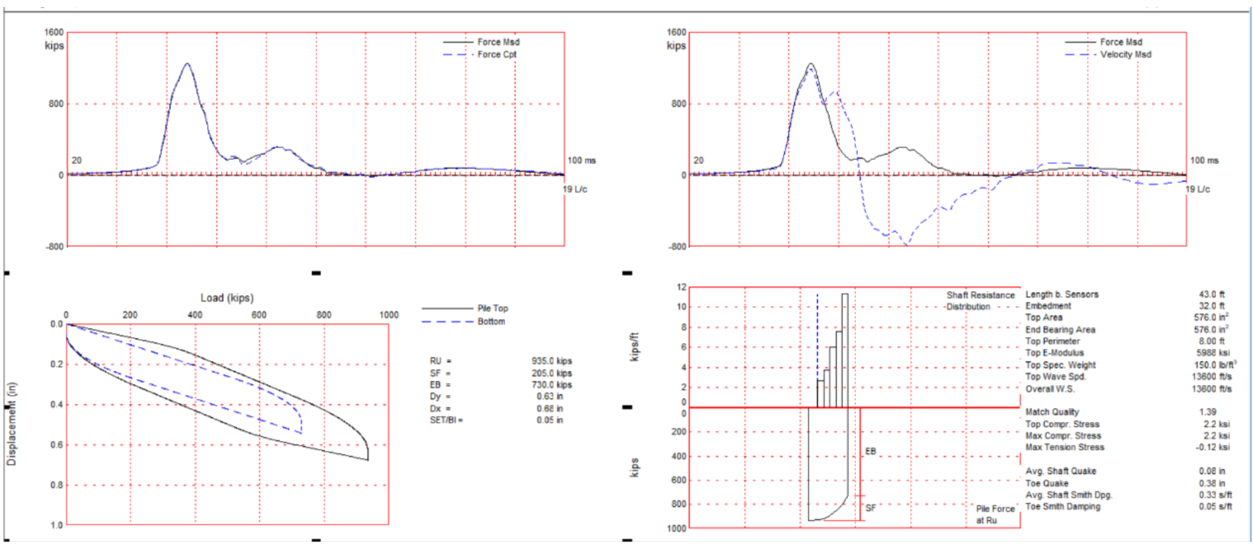

Figure 7. Final CAPWAP analysis output including load-displacement plot.

The capacity and soil resistance distribution information determined from CAPWAP analyses are frequently used to optimize pile foundation designs.

For more information: https://www.grlengineers.com/services/capwap/

4.4 GRLWEAP Analysis is a computer simulation of an impact driven pile that is used for both driving system and pile selection as well as for bearing capacity assessment. The traditional bearing graph analysis (Figure 8) provides the computed blow count, hammer stroke, compression stress, and tension stress for a given capacity. This analysis is frequently used to determine the pile driving criteria. A summary of the analysis input parameters is displayed on the right hand side of the graphical results.

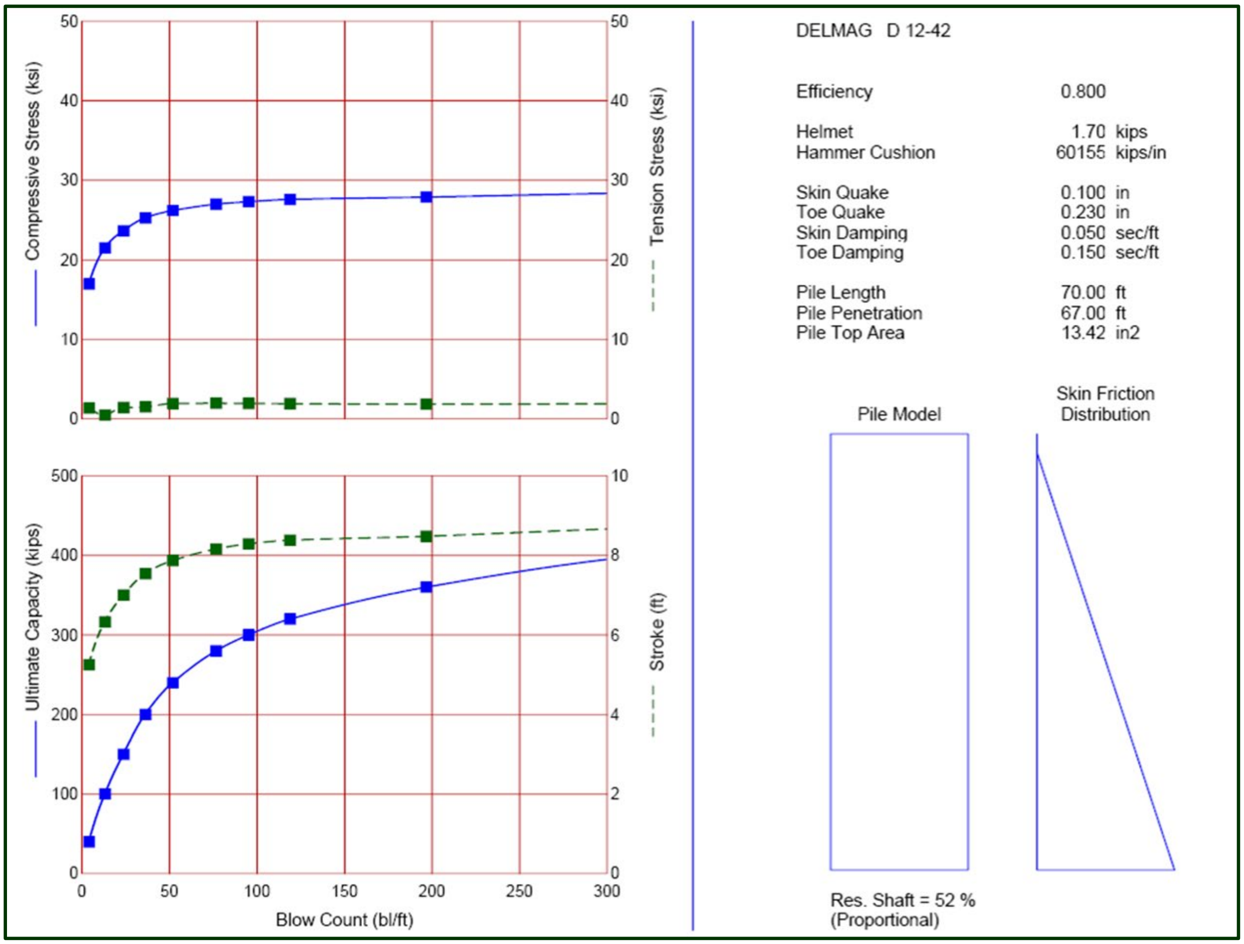

Figure 8. Example GRLWEAP bearing graph analysis result.

GRLWEAP is also routinely used for driveability analyses (Figure 9) to assess whether the blow counts and driving stresses will be acceptable for pile installation to the required pile penetration depth and capacity. A summary of the drivability results also includes a predicted driving time for the modeled conditions (Figure10). These analyses can be used for hammer selection and cost comparison among available hammer options.

For more information: -https://www.grlengineers.com/services/grlweap/

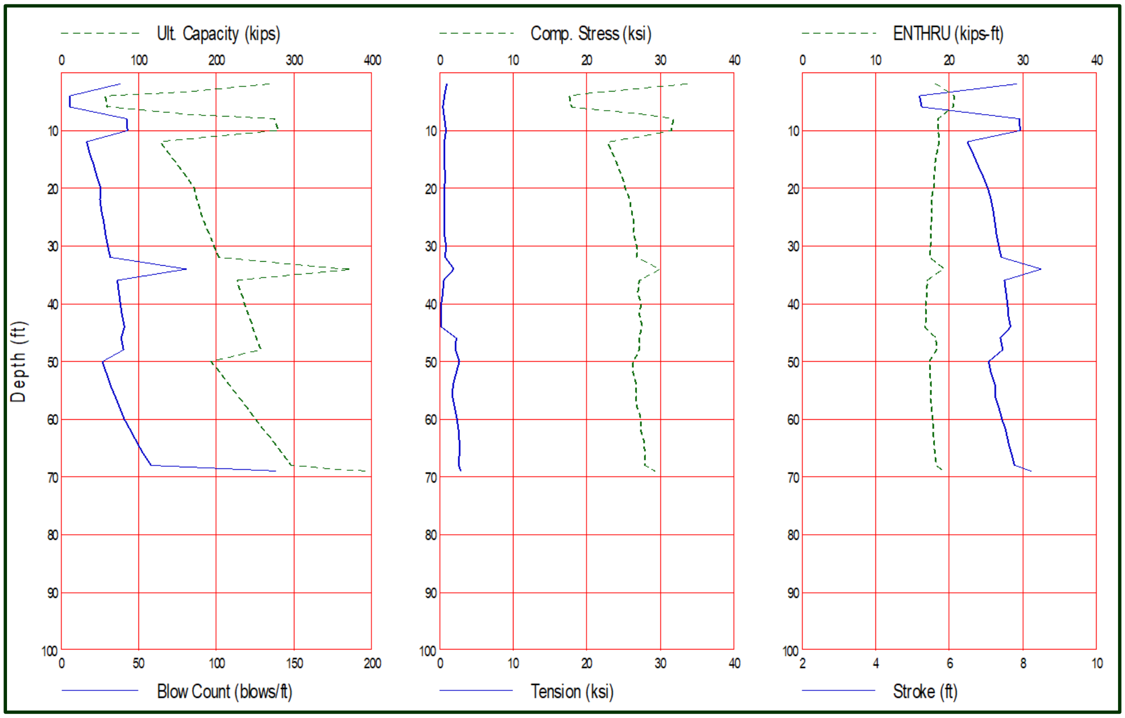

Figure 9. Example GRLWEAP driveability analysis graphical results.

GRL Engineers, Inc. — Sep 10 2018

D30-32, 14 x.375in CEP, FS4, Ru=600 kips — GRLWEAP Version 2010

Gain/Loss 1 at Shaft and Toe 0.833 / 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
2.0	36.0	0.3	35.7	-1.0	0.000	0.000	0.00	0.0
4.0	36.8	1.1	35.7	-1.0	0.000	0.000	0.00	0.0
6.0	271.3	3.4	267.9	27.4	36.661	-1.028	5.94	23.9
8.0	275.2	7.3	267.9	27.8	36.710	-1.135	5.95	23.9
10.0	280.0	12.1	267.9	28.3	36.623	-1.270	5.96	23.9
12.0	285.7	17.8	267.9	28.9	36.490	-1.447	5.98	24.0
14.0	292.3	24.4	267.9	29.7	36.276	-1.680	6.01	24.1
16.0	299.8	31.9	267.9	30.6	36.068	-1.966	6.04	24.2
18.0	308.1	40.2	267.9	31.6	35.866	-2.309	6.09	24.3
20.0	317.3	49.4	267.9	33.2	35.227	-2.703	6.07	24.2
22.0	327.4	59.5	267.9	34.6	34.923	-3.110	6.13	24.3
24.0	78.0	63.5	14.5	4.6	16.746	0.000	3.87	25.5
26.0	82.3	67.8	14.5	3.4	22.563	-0.249	4.92	42.4
28.0	86.9	72.4	14.5	3.8	23.489	0.000	5.06	41.8
30.0	91.6	77.2	14.5	4.2	24.222	0.000	5.18	41.2
32.0	96.6	82.2	14.5	4.5	24.912	0.000	5.30	40.7
34.0	101.9	87.4	14.5	4.9	25.608	0.000	5.44	40.2
36.0	107.4	92.9	14.5	5.4	26.138	-0.575	5.56	39.8
38.0	113.1	98.7	14.5	5.9	26.763	-0.825	5.69	39.3
40.0	119.1	104.6	14.5	6.4	27.221	-0.573	5.82	38.8
42.0	125.3	110.9	14.5	6.9	27.780	-0.792	5.94	38.4
44.0	131.8	117.3	14.5	7.5	28.073	-0.813	6.01	37.6
46.0	138.5	124.0	14.5	8.1	28.510	-0.562	6.13	37.2
48.0	145.4	130.9	14.5	8.7	28.998	-0.206	6.26	36.8
50.0	152.6	138.1	14.5	9.4	29.372	0.000	6.39	36.6
52.0	160.0	145.5	14.5	10.1	29.871	0.000	6.51	36.3
54.0	167.6	153.2	14.5	10.8	30.257	0.000	6.65	36.1
56.0	522.0	174.5	347.4	79.3	37.528	-1.226	9.13	41.9
57.0	575.0	187.5	387.5	121.6	38.167	-1.146	9.39	42.8

Total Continuous Driving Time 20.00 minutes; Total Number of Blows 930 (starting at penetration 2.0 ft)

Figure 10. Example GRLWEAP driveability summary with estimated driving time.

4.5 Thermal Integrity Profiling (TIP) is a method of integrity testing for drilled shafts and augercast piles. For drilled shafts, this method requires that Thermal Wire® cables be installed to the reinforcing cage (Figure 11) prior to concrete placement. For augercast piles, a center bar or cage with Thermal Wire attached is inserted post-grouting. While the concrete or grout is curing, the heat of hydration allows the interpretation of necks or inclusions (regions colder than average), bulges (regions warmer than average), variations in concrete cover, shape of the shaft, or cage alignment. TAG and TAP Edge units (Figure 12) collect temperature readings at 15 minute intervals from each wire during the curing process. The data is pushed to the Cloud for review and processing.

Figure 11. TIP wire attachment to reinforcing cage.

Figure 12. TAG and TAP Edge units on wires.

Final TIP results include plots of the shaft radius and concrete cover versus depth (Figure 13). These results may be evaluated for shaft shape and integrity, concrete quality, and for location of the reinforcing cage. The overall average temperature for all Thermal Wire readings over the embedded depths can be directly related to the overall volume of concrete installed. Shaft integrity is assessed based on the average temperature measurements from each Thermal Wire at each depth increment. If the measured average temperature versus depth is consistent, the shaft is considered to be uniform in shape and quality. Bulges can be identified as localized increases in average temperature, while insufficient concrete quality or cross section reductions can be identified as localized decreases in average temperature. Anomalies present over more than ten percent of the effective cross-sectional area are normally seen in multiple Thermal Wires at the same depth. Because soil and/or slurry pockets produce no heat, areas of soil intrusion or inclusion are indicated by lower local temperatures.

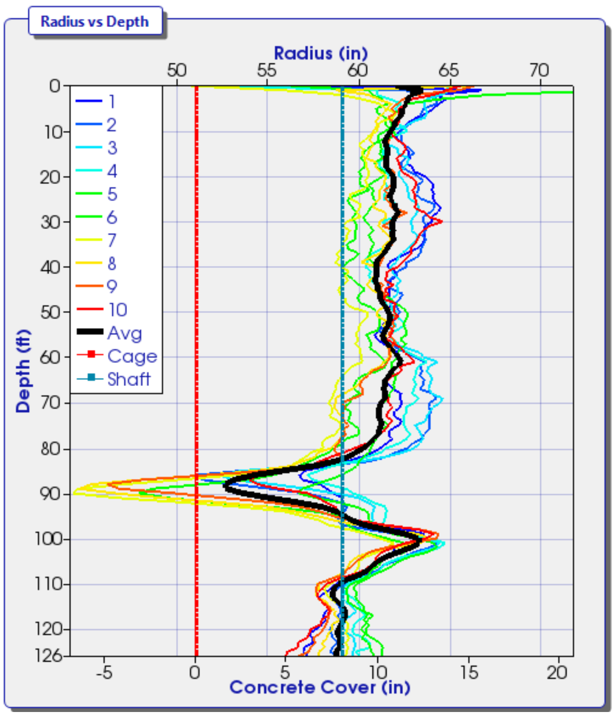

Figure 13. TIP Results: Radius vs depth.

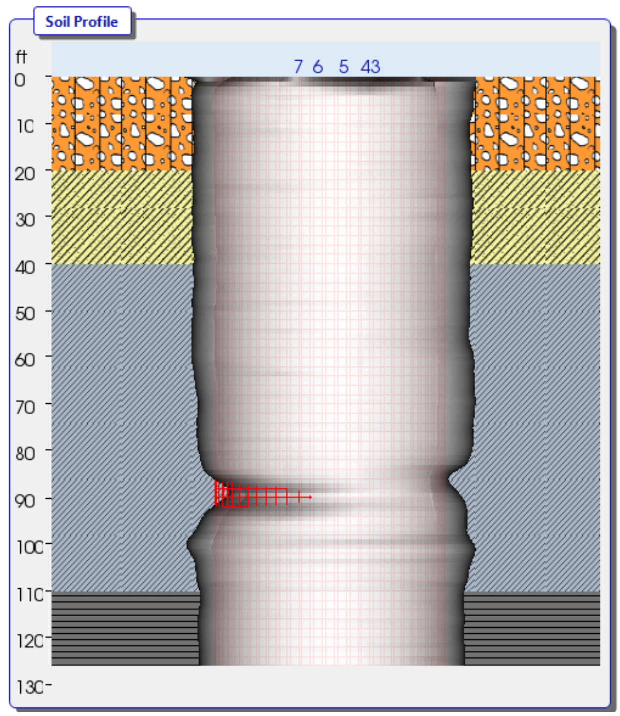

Figure 14. TIP Results: 3D shaft interpretation.

Reinforcement cage location is estimated based on the relative temperature difference between an individual Thermal Wire and the average of all wires. Higher individual Thermal Wire temperatures indicate the wire is closer to the center of the shaft, or near a local bulge, while lower individual Thermal Wire temperatures indicate the wire is closer to the soil-shaft interface, or a local defect. By viewing diametrically opposite Thermal Wire results, instances where a lateral shift of the reinforcing cage has occurred can be determined, if one wire temperature is higher than average and the diametrically opposite wire temperature is lower than average. A three-dimensional depiction (Figure 14) of the shaft shape is also reported.

For more information - https://www.grlengineers.com/services/tip/

4.6 Crosshole Sonic Logging (CSL) is an alternate method of integrity testing for drilled shafts. It requires that access tubes be attached to the reinforcing cage prior to cage installation in shaft and pouring concrete. High frequency acoustic waves are generated from a transceiver in one of the tubes and received by transceivers in other tubes as all probes are pulled upward (Figure 15) from the bottom of the access tubes. The arrival time and magnitude of the received signals (Figure 16) identify the quality of the concrete between tube pairs.

Figure 15. Typical field set-up of CSL test.

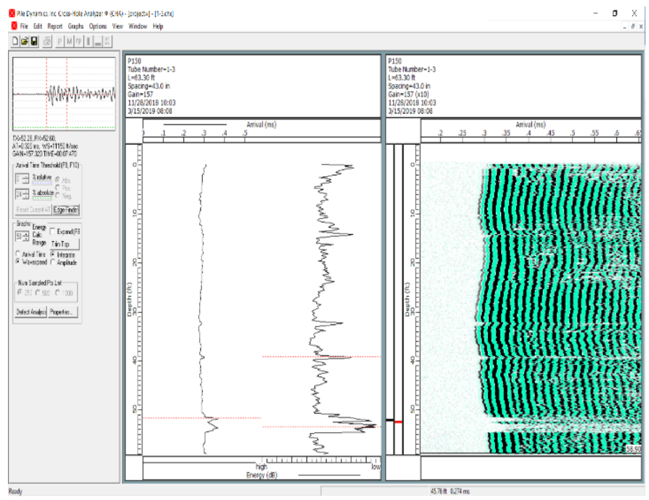

Figure 16. Analysis software showing first arrival time (FAT), energy, and waterfall diagram (right).

Anomalous areas are identified by a delay in the first arrival time or a decrease in the signal energy. Tomography analyses using the PDI-TOMO software can be used to evaluate zones with delayed first arrival times. Selected slices (Figure 17) through the shaft display the effective shaft area having a concrete wave speed greater than the user selected threshold for lower concrete quality.

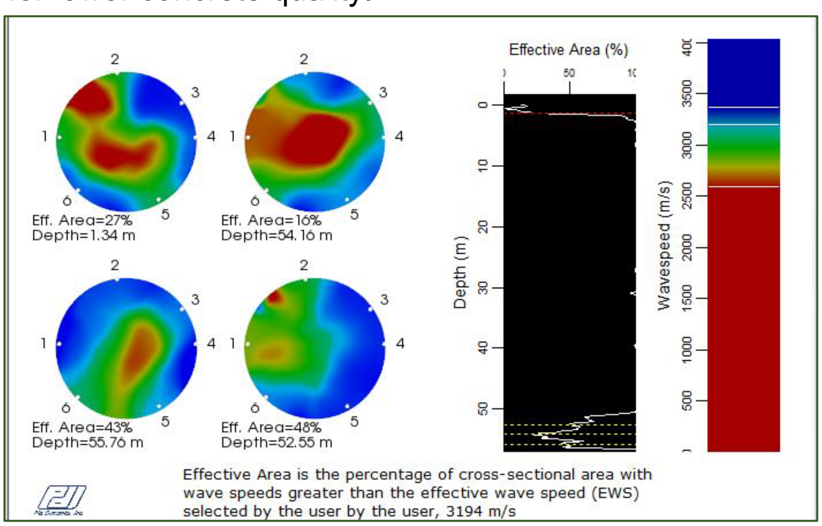

Figure 17. PDI-TOMO analysis results.

For more information – https://www.grlengineers.com/services/csl/

4.7 Gamma Gamma Logging (GGL) is a non-destructive test method used to assess the concrete integrity of drilled shafts. GGL provides highly repeatable test results, while objectively evaluating integrity and relative concrete quality inside and outside of the reinforcing cage through gamma-density correlation. GGL is a relatively quick test with no depth restrictions, and is typically performed three to seven days or more after concrete placement.

Drilled shafts are prepared for GGL testing by attaching 2-inch O.D., Schedule 40, PVC access tubes to the steel reinforcing cage (Figure 18) prior to cage insertion into the shaft excavation and concrete placement. GGL identifies locations of potential shaft anomalies through statistical analysis. In cases where GGL testing was not initially planned, it can be performed in core holes drilled through the concrete.

GRL engineers report Gamma-Gamma Logging results on a density vs depth plot (Figure 19) in accordance with CALTRANS CT-233 test standard.

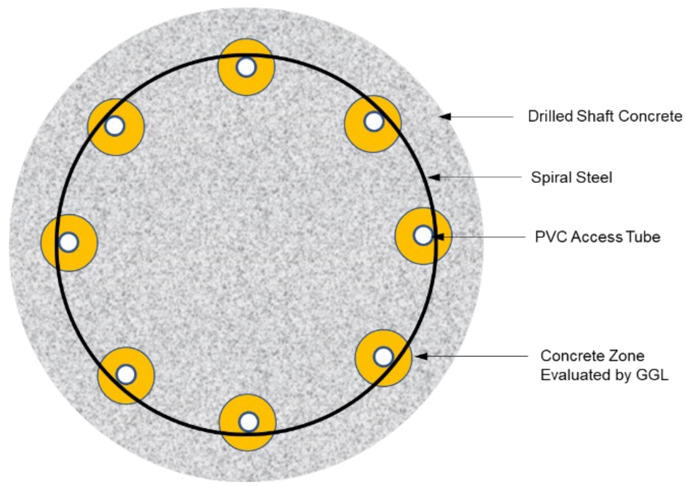

Figure 18. GGL evaluation set up.

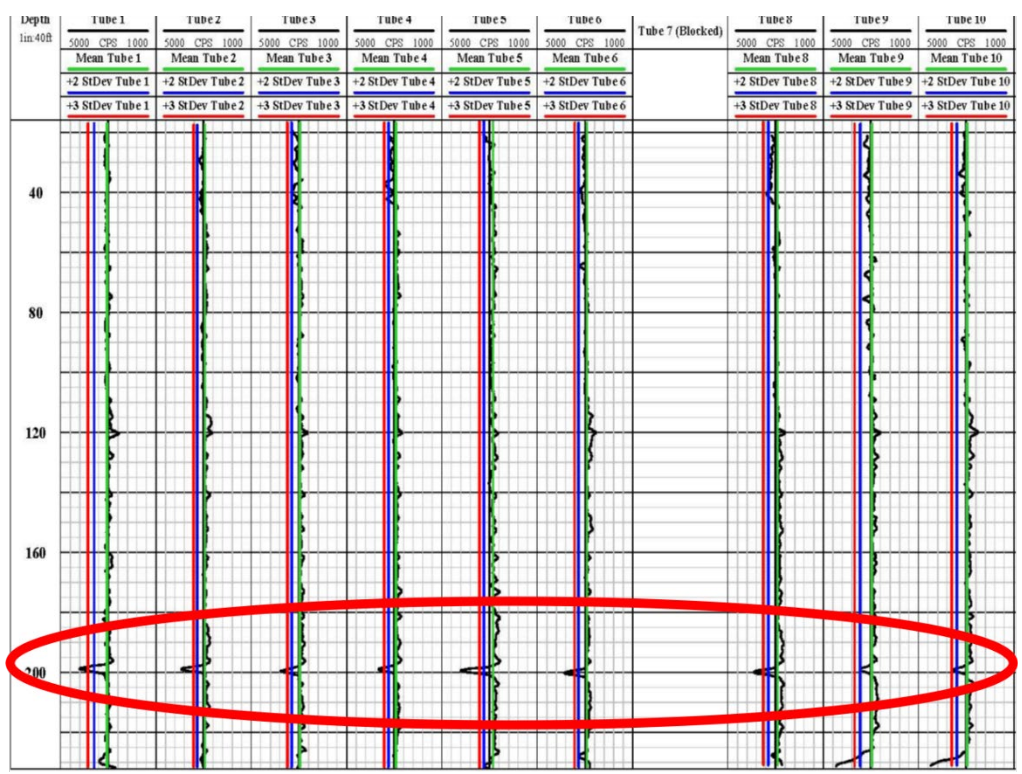

Figure 19. GGL results on a density vs depth plot.

4.8 Pile Integrity Testing (PIT) of concrete piles, timber piles, and drilled shafts is performed by impacting the surface of the deep foundation with a hand-held hammer and measuring the shaft response with a surface mounted accelerometer (Figure 20). The test results can be analyzed using either the pulse echo method or the transient response method. In a pulse-echo test result (Figure 21), significant positive reflections occurring prior to the time of the toe reflection are indicative of significant defects. Pile integrity testing is very economical. Many piles can be tested in a day to provide an assessment of the structural integrity of a deep foundation.

Figure 20. Typical low strain pile integrity test

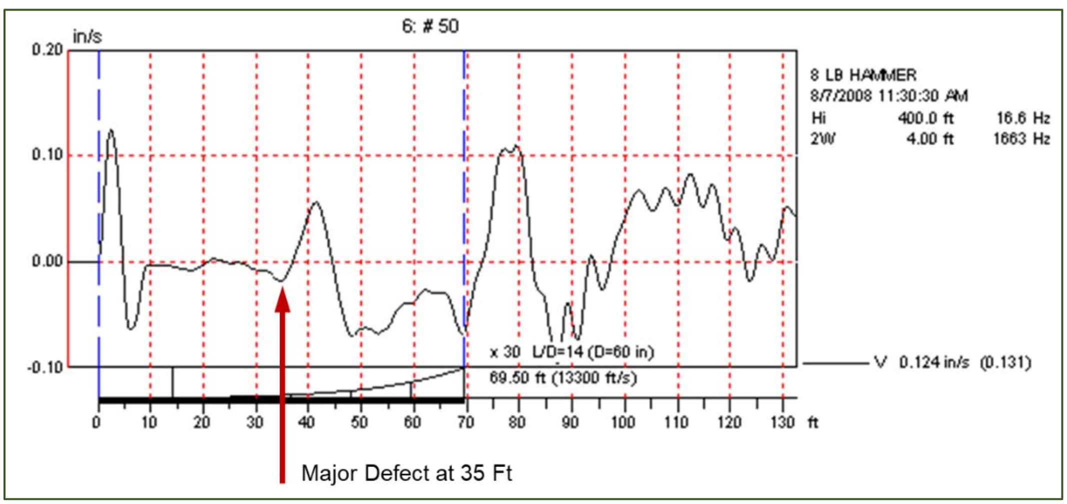

Figure 21. Representative pulse echo low strain integrity test record with reflection from a major deflect.

For more information – https://www.grlengineers.com/services/pit/

4.9 Static Load Testing (SLT) is frequently performed to validate foundation design assumptions. Axial compression load tests (Figure 22) or axial tension load tests can be performed to determine the resistance provided by a deep foundation element. Lateral load tests can be performed to evaluate a foundation's deflected shape under lateral load. GRL performs both highly instrumented static load tests to meet the need of design stage load tests, as well as basic load tests, for construction quality assurance. GRL can also provide a 1000 ton loading beam for axial compression or uplift tests.

A load-movement plot (Figure 23) of the applied load determined from the jack pressure gage and load cell versus the deep foundation head movement determined by LVDTs, digital dial gages, or mechanical dial gages is used to assess the capacity of the deep foundation under axial compression, axial tension, or lateral load.

From external or embedded strain gage instrumentation, the load-transfer profile (Figure 24) can be obtained. This information can be used to optimize the foundation penetration depths for the required loads. With additional instrumentation, the deflected shape versus pile length (Figure 25) and/or the head rotation can be determined in a lateral load test.

Figure 22. Reaction pile load frame for an axial compression load test.

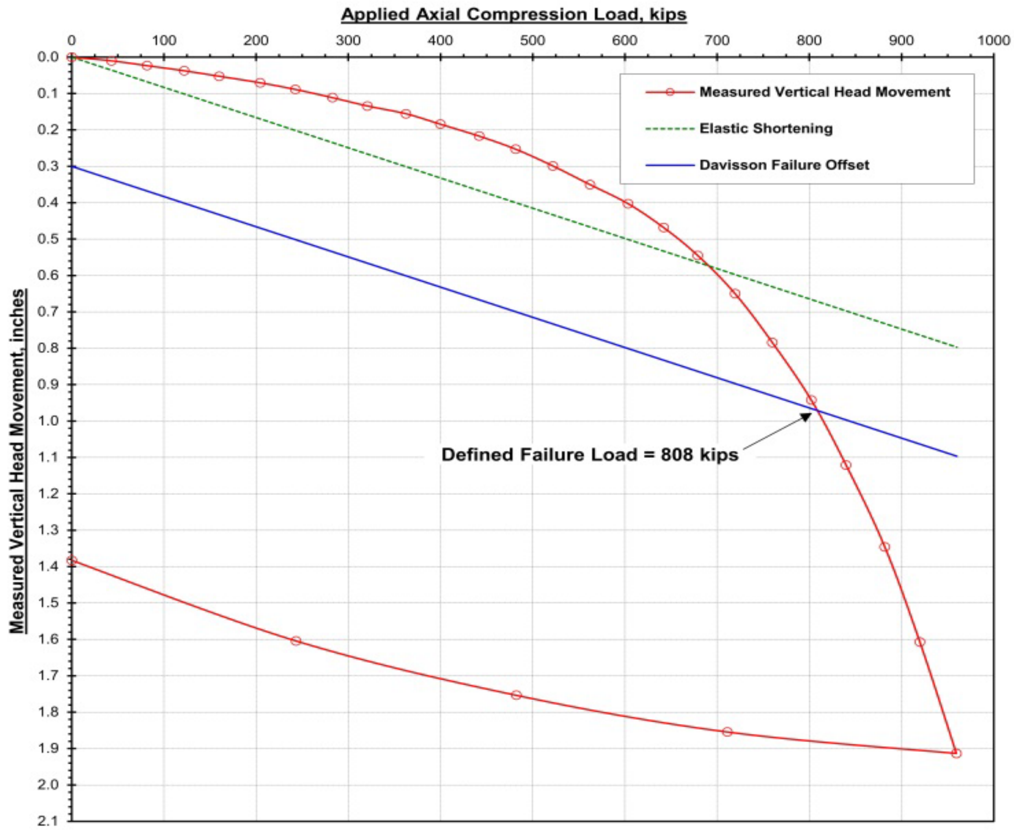

Figure 23. Load-movement plot from axial compression load test.

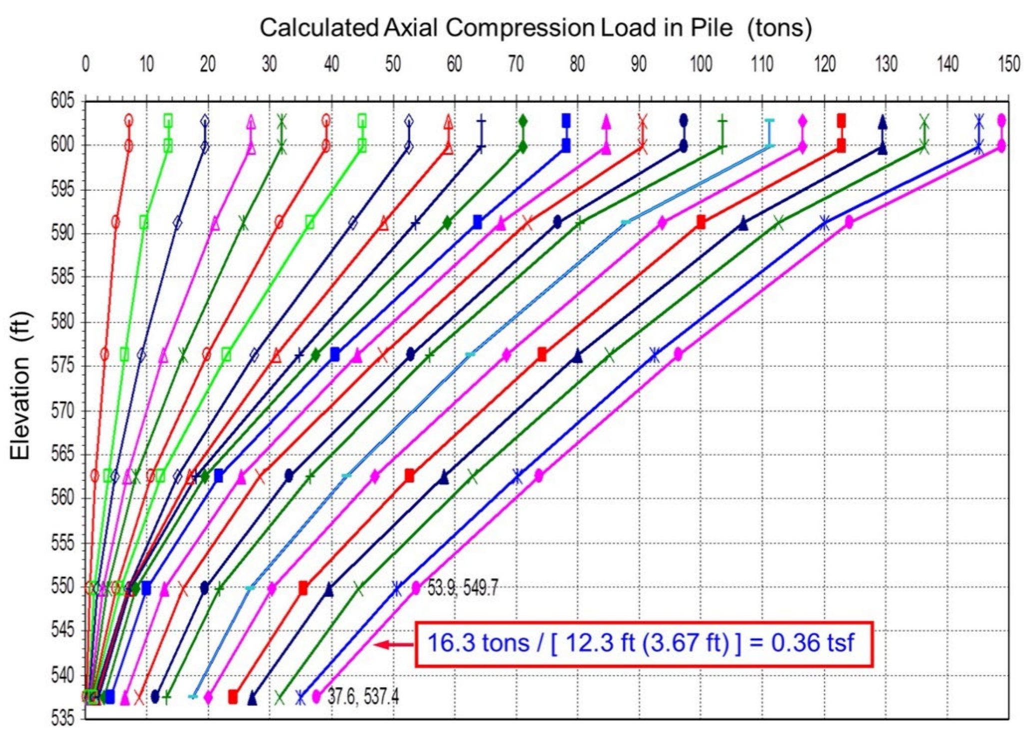

Figure 24. Load-transfer plot from strain gage instrumentation in an axial compression test.

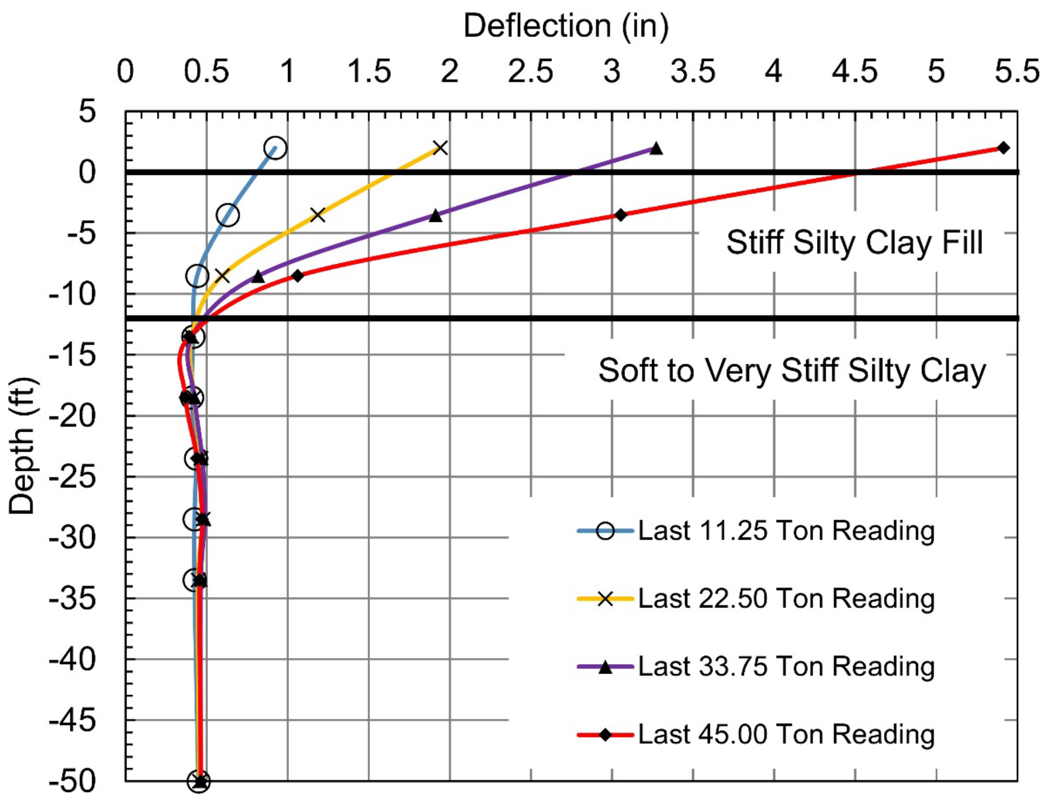

Figure 25. Deflected shape versus depth from instrumented lateral load lest.

For more information https://www.grlengineers.com/services/slt/

4.10 Bi-Directional Static Load Testing (BDSLT) is used to load test drilled shafts and augercast piles. The GRL-Cells are attached to the reinforcing cage (Figure 26), lowered into the shaft excavation, and cast into the shaft during concrete placement. The GRL-Cell is a piston type jack that statically loads the deep foundation in two directions, upwards and downwards, from the cell location. Depending on the shaft diameter and required load, one or more GRL-Cells may be used to configure the jack assembly. When located at the soil/rock resistance balance point in the soil profile, a maximum test load of up to twice the jack assembly capacity can be achieved.

Test results (Figure 27) include upper and lower bearing plate movement versus load at the jack assembly location. Bi-directional static load testing is the most economical methods to perform a high capacity static load test.

Figure 26. Installation in drilled shaft.

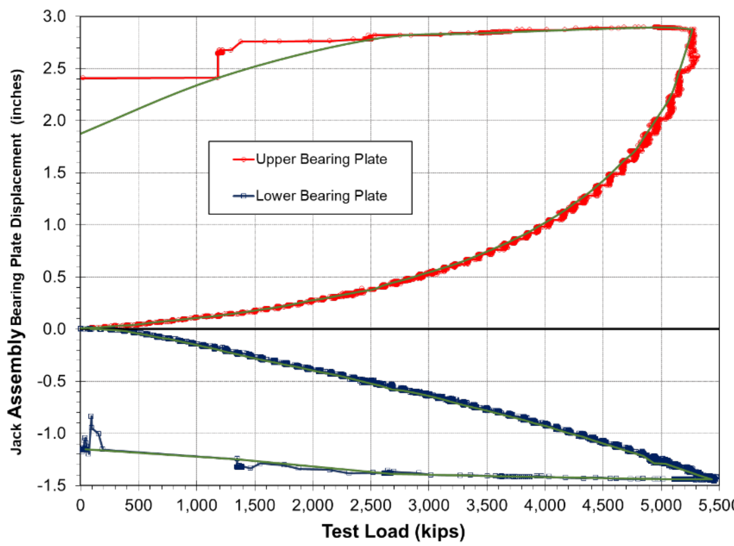

Figure 27. Upper and lower bearing plate displacement.

A bi-directional test shaft or pile is typically heavily instrumented. Strain gages are attached to the reinforcing cage or center bar at multiple levels in the deep foundation. Movements of the shaft head, top bearing plate, lower bearing plate, and shaft toe are measured during the test. From these measurements, a calculated axial internal compression force profile (Figure 28) indicative of the load-transfer behavior and soil / resistances is obtained. Derived t-z, q-z behavior from the test is used to develop an equivalent top loading curve (Figure 29).

For more information https://www.grlengineers.com/services/bdslt/

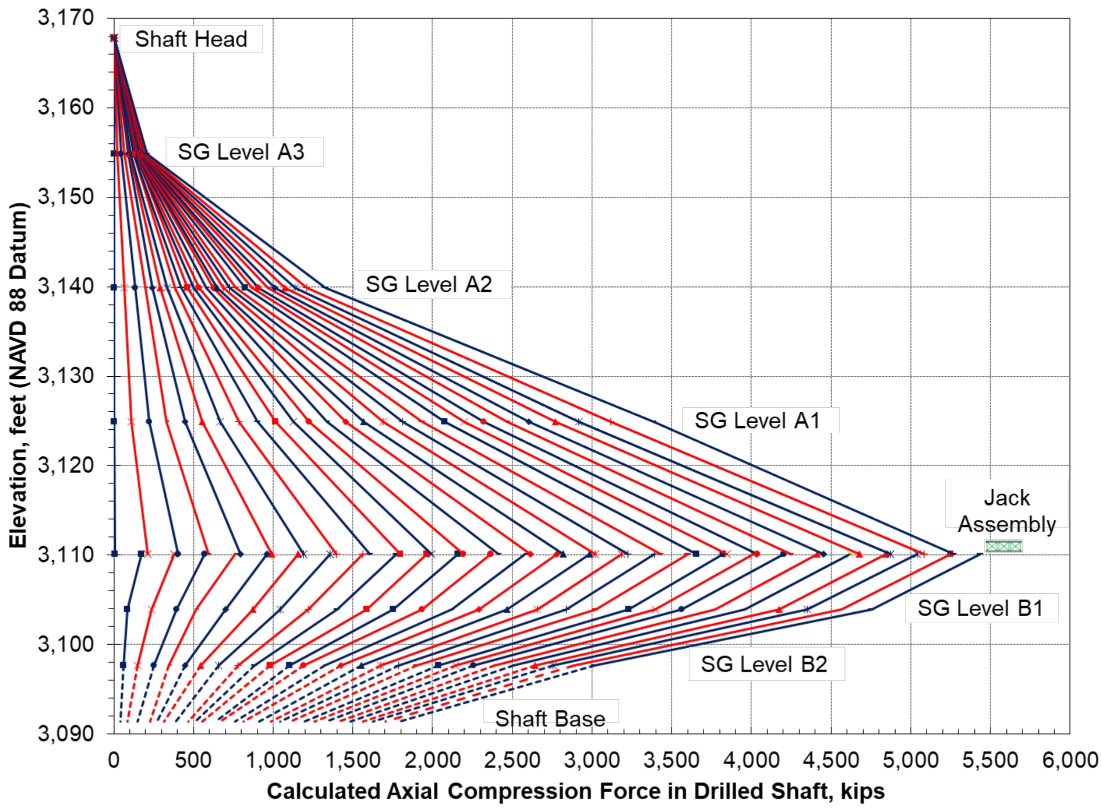

Figure 28. Calculated axial internal compression force profiles.

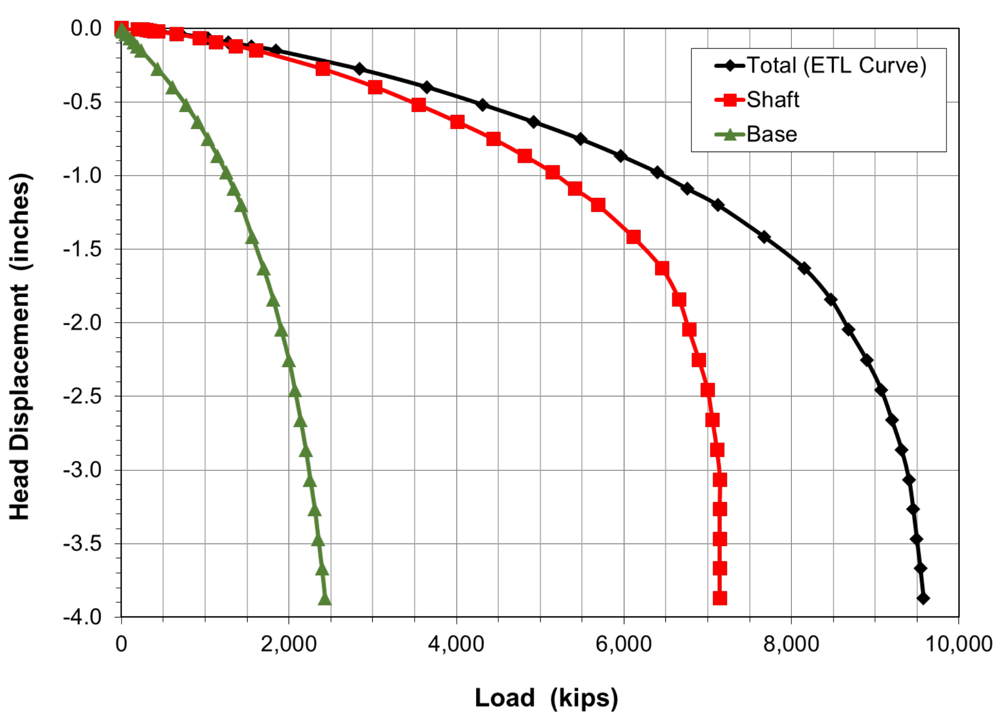

Figure 29. Equivalent top loading curve with shaft and base resistances.

4.11 Drilled Shaft Verticality, Radii, Profile, and Excavation Volume tests are performed by GRL to determine the characteristics of a wet pour or dry, drilled shaft excavation. GRL uses the appropriate **SH**aft **A**rea **P**rofile **E**valuator, or SHAPE device, which can be quickly attached to the drill rig Kelly bar or winch system, and then lowered into the shaft excavation (Figure 30). The SHAPE device for wet pours uses eight ultra-sonic signals to scan the sides of the shaft excavation, whereas the SHAPE for dry shafts uses Lidar sensors. Scan results (Figure 31) from the each of four profiles provides a quick check of the drilled shaft verticality, radii, and shape. The combined results are used to calculate the drilled hole volume. During the test, all collected data is stored within the SHAPE device's internal memory allowing for cable free data collection in the shaft excavation. Tests can be performed with a GRL engineer at the site or from the office in real time using the SiteLink capability.

Figure 30. SHAPE moving over shaft excavation.

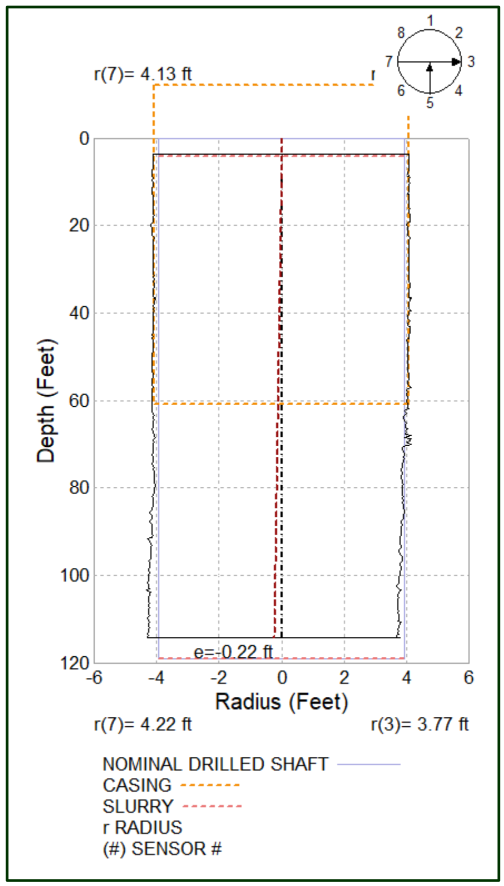

Figure 31 One SHAPE profile of radius vs depth.

For more information – https://www.grlengineers.com/services/shape/

4.12 Drilled Shaft Base Cleanliness Evaluations are an important part of drilled shaft or bored pile construction. The cleanliness of the shaft base is important for shafts that derive a significant amount of their total capacity from base resistance. Base cleanliness is also important to minimize concrete contamination risks from excessive debris material. GRL performs base cleanliness checks prior to placing the reinforcing cage and shaft concrete using the **S**haft **QU**antitative **I**nspection **D**evice or SQUID. This device quickly attaches to the drill rig Kelly bar (Figure 32). The tests provide a quantitative assessment of the drilled shaft base condition using the SQUID's three penetrometers and three displacement plates. For small shafts a single test is typically performed. For shafts greater than five feet in diameter, tests are typically performed in the center of the shaft and in the four perimeter quadrants. When the Kelly bar weight is applied, the device measure penetrometer force as a function of penetrometer depth into the materials at the shaft base (Figure 33). From these measurements the base cleanliness and debris thickness can be evaluated and reported. Tests can be performed with a GRL engineer at the project site or in real time from the office using the SiteLink capability.

Figure 32. SQUID moving over shaft excavation.

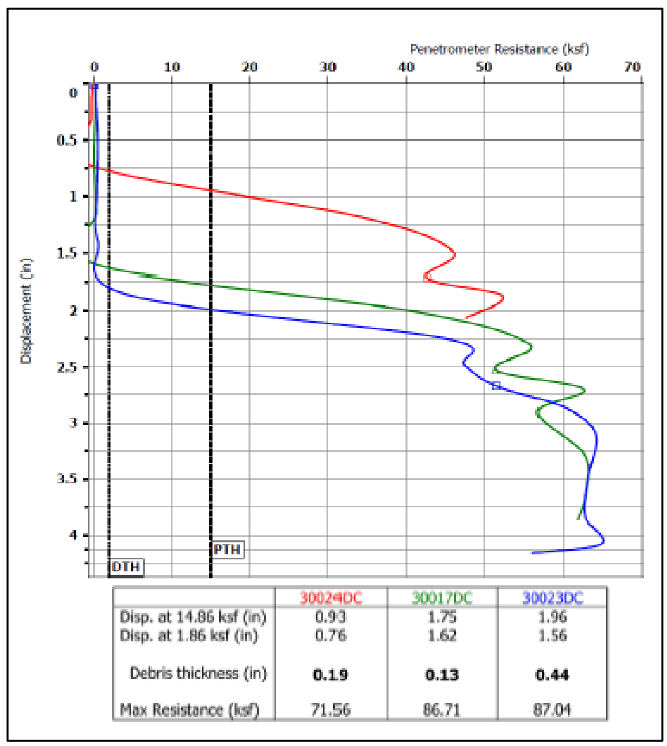

Figure 33 SQUID test resistance vs displacement results from one test location.

For more information – https://www.grlengineers.com/services/squid/

4.13 SPT Energy Measurements are used to calibrate soil boring rig hammers. The Standard Penetration Test (SPT) consists of driving a split spoon sampler 18 inches into the soil with a 140 pound weight dropped from 30 inches. The number of blows required to drive the sampler the last 12 inches is termed the SPT N value, which is used to assess the soil strength. There are several types of SPT hammers used in the industry. Depending upon the hammer type, SPT hammers can transfer from 45% to 95% of the rated energy into the drill rod.

Many design procedures require the N value to be based on a standard energy transfer to the drill rod of 60%. An SPT N_{60} value can be obtained by multiplying the recorded N value by the ratio of the measured energy transfer divided by 210 ft-lbs, 60% of the theoretical energy transfer of 350 ft-lbs. GRL provides energy measurement services (Figure 34) on SPT hammers for general drill rig calibration purposes as well as for site specific studies which may use the N_{60} results to identify soil layers subject to liquefaction in seismic events.

Figure 34. Energy measurements being acquired on the drill string during SPT soil sampling.

For more information – https://www.grlengineers.com/services/spt/

4.14 Becker Energy Measurements are made on Becker Penetration Tests (BPT) which are commonly used to characterize the liquefaction characteristics of gravel and cobble materials. The BPT consist of driving a 5-$^{1}/_{2}$, 6-$^{5}/_{8}$, or 9 inch O.D. drill string into the ground with a small, truck-mounted diesel hammer (Figure 35). GRL performs both convention energy measurements at the top of the Becker drill string as well as an instrumented Becker Penetration Test (iBPT) with energy measurements at both the top and bottom of the drill string. From the top and bottom energy measurements, a normalized Becker blow count, or N_{B30} value, is computed. The N_{B30} can be correlated to the SPT N_{60} value for liquefaction assessment.

Figure 35. Energy measurements being acquired on the drill string during Becker Penetration Testing.

GRL uses PDA Model 8G units with the SPT Analyzer software package when collecting iBPT energy transfer measurements near the top and bottom of the drill string. These iBPT energy measurements can be transferred to the SPT Analyzer via either wired or WiFi technology.

iBPT energy transfer measurements to the top and bottom of the Becker drill string versus depth (Figure 36) as well as an equivalent SPT N_{60} profile versus depth are reported (Figure 37).

For more information – https://www.grlengineers.com/services/becker/

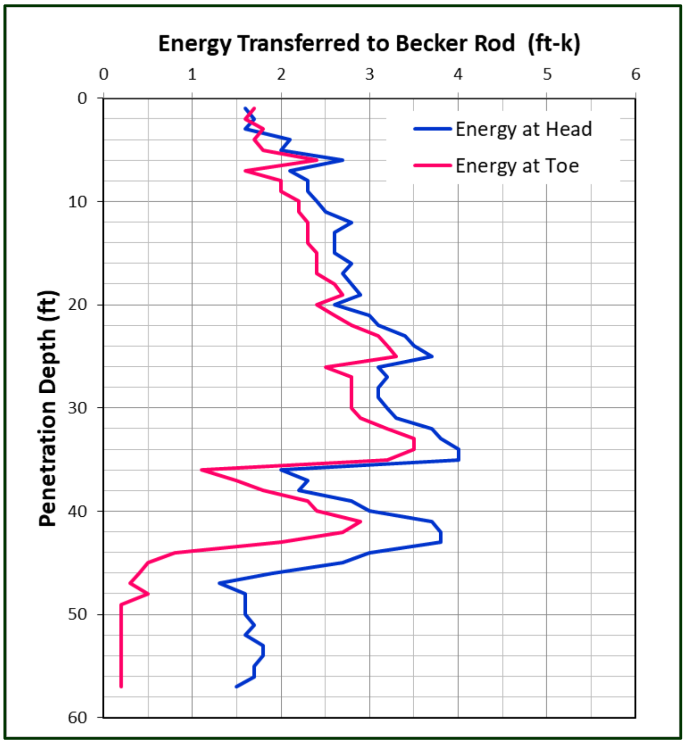

Figure 36. iBPT energy measurements versus depth.

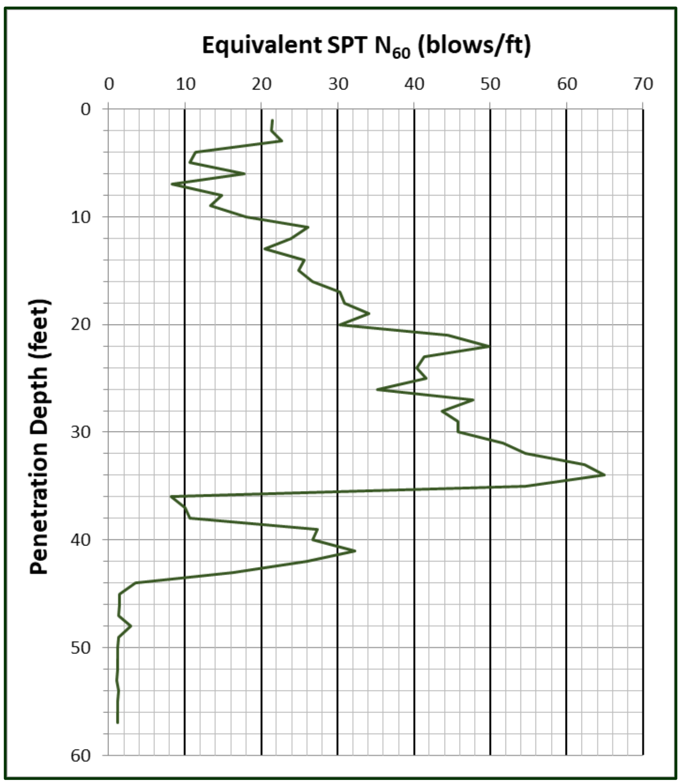

Figure 37. Equivalent SPT N_{60} values versus depth.

4.15 Offshore Oil Platforms and Offshore Wind Turbine Foundations are installed in challenging construction environments where reliability of the test measurements is essential due to project time and cost considerations. While the test method and the analysis procedures are the same as those described in Sections 4.1, 4.3, and 4.4, offshore projects require backup test systems and highly experienced personnel to staff the round the clock construction activity. GRL has performed dynamic pile monitoring on over 250 offshore projects around the world (Figure 38, Figure 39). In the US, these projects have been located in the Gulf of Mexico, the Pacific Ocean offshore California, and in Cook Inlet, Alaska. GRL has also performed offshore dynamic pile monitoring services in the Arabian Sea, Bay of Bengal, Bay of Cambay, Bay of Campeche, Black Sea, Bohai Sea, Caribbean Sea, Caspian Sea, East China Sea, Lake Maracaibo, North Sea, Persian Gulf, Red Sea, South Atlantic Ocean, and the South China Sea. Dynamic pile monitoring services have been performed with conventional above water PDA gages as well as up to 600 feet below sea level with our waterproof underwater PDA gages and cables.

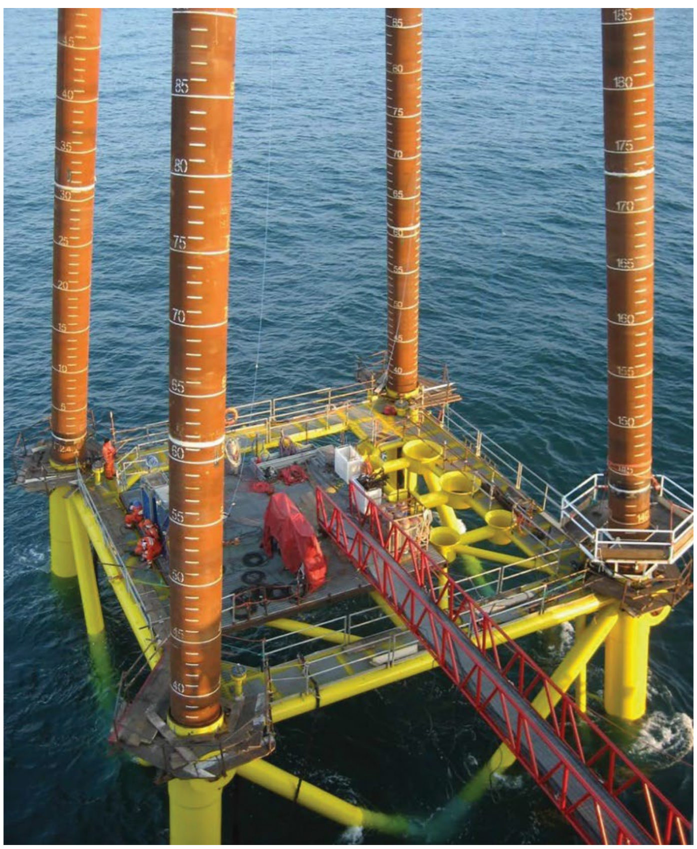

Figure 38.Offshore Platform

Figure 39. Platform with Underwater Testing.

For more information – https://www.grlengineers.com/services/oft/

4.16 Parallel Seismic Testing (PST) is performed by GRL to evaluate unknown foundation lengths. A minimum two-inch diameter borehole must be drilled within 24 inches of the foundation to be tested. The borehole must also extend well below the expected toe of the deep foundation element. Since the foundation length is unknown, the borehole termination depth must be carefully selected. A PVC pipe is inserted into the borehole. Both the PVC pipe and the surrounding borehole must be filled with water. The pile top is struck with an instrumented hammer while a hydrophone is incrementally lowered down the cased hole (Figure 40). The stress wave travels down the pile and outward through the soil. At each test depth, the wave arrival at the hydrophone is plotted versus time (Figure 41). When the hydrophone is positioned below the foundation termination depth, the wave must travel an increasingly greater distance through soil. The plot of wave arrival time versus depth will have a change in slope corresponding to the termination depth of the foundation element.

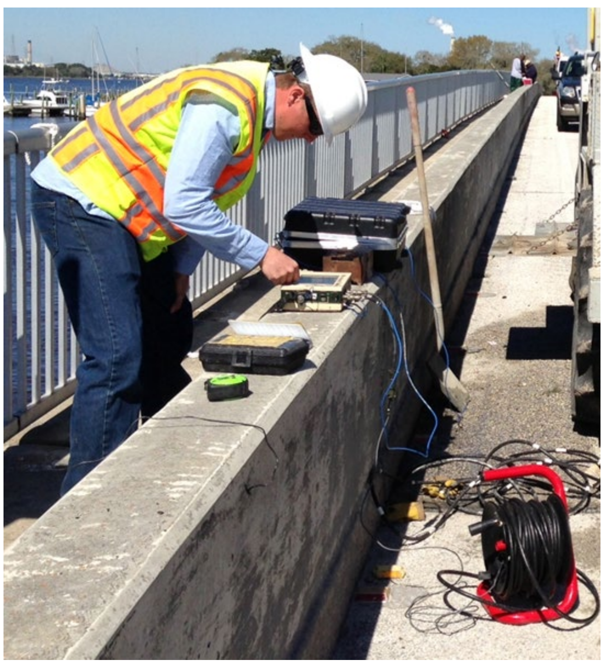

Figure 40. Parallel seismic test equipment.

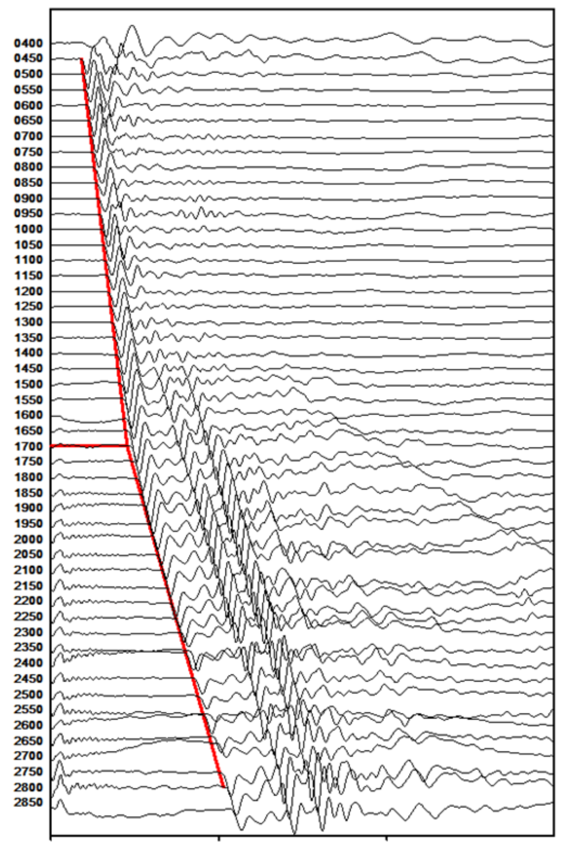

Figure 41. Parallel seismic test results.

For more information – https://www.grlengineers.com/services/eef/

4.17 Length Inductive Test Equipment (LITE) services are provided by GRL to assess the length of unknown steel foundations (Figure 42). The test can be performed on steel sheet piles, H-piles, pipe piles, cased portions of drilled shafts, and in some instances highly reinforced drilled shafts. The LITE probe is lowered into a PVC cased drilled hole located within 18 inches of the foundation (Figure 43). The LITE detects whether metal is present or not present with the effective radius. Data interpretation is straightforward. Provided the probe senses the proximity of metal, it will display a high voltage. Once the LITE probe is below the steel or steel reinforced foundation depth, the absence of detected metal will cause a zero or negative value which can be used to ascertain the foundation length (Figure 44).

Figure 42. LITE System.

Figure 43 LITE probe in PVC borehole.

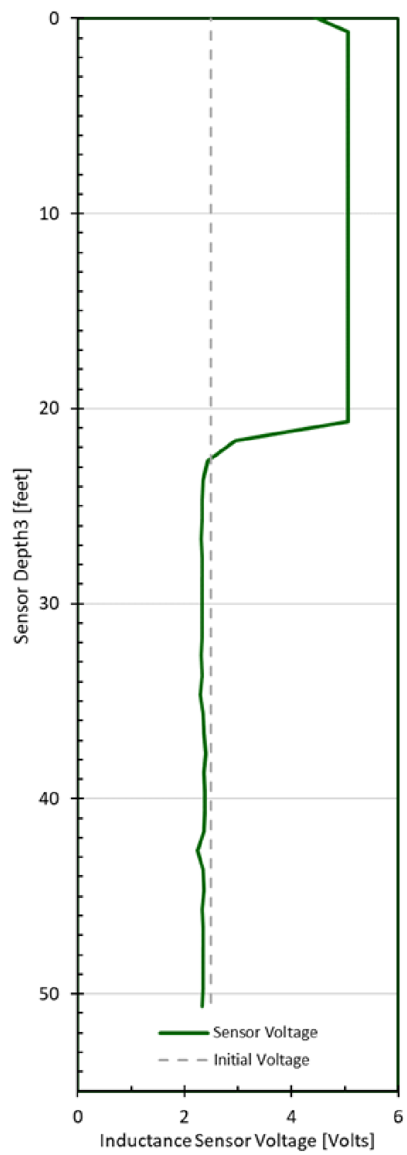

Figure 44. LITE Results.

For more information – https://www.grlengineers.com/services/eef/

4.18 Other Consulting Services - GRL also offers other consulting services such as comprehensive training of deep foundation testing methods to engineers worldwide, and review of deep foundation test results obtained from third parties.

5.4 SERVICES

GRL uses state-of-the-art testing equipment for all of its service offerings. Our test equipment includes:

Dynamic Pile Monitoring

Pile Driving Analyzer Model 8G (PDA). - For dynamic pile monitoring services, GRL engineers use the Pile Driving Analyzer Model 8G with a selection of WiFi, Bluetooth, or cabled connection between the PDA and the pile top gages. Data from multiple external or embedded gage locations can also be simultaneously acquired.

Dynamic Load Testing

Pile Dynamics Analyzer- Dynamic Load Tester (PDA-DLT) - For dynamic load testing services, GRL uses the Pile Driving Analyzer Model 8G with the DLT software package. For DLT applications, data from multiple external or embedded gage locations can also be simultaneously acquired. This software package also readily accommodates our APPLE drop weight systems and top transducers or APPLE load cells.

APPLE Dynamic Load Test System (APPLE) - APPLE dynamic load test systems include a guide frame, a modular ram and a free release mechanism. The rams of some APPLE systems may be instrumented, or a load cell may be used to simplify force measurements. Available ram weights range from 1 to 80 tons. A dynamic load test capacity of up to 4000 tons in soil and 8000 tons in rock can be mobilized by these systems. ($R_{ultimate}$ = ram weight / 0.02 in soil, and ram weight / 0.01 in rock)

Apple Load Cells - For dynamic load tests, a top transducer or load cell can facilitate testing speed as well as improve the quality of the collected data. GRL has 12 load cells ranging from 10 to 36 inches in diameter with a corresponding maximum force range from 400 to 14,000 kips. The load cell size and maximum force range is matched to the deep foundation size and capacity.

Bi-Directional Load Testing

GRL-Cells for Bi-Directional Static Load Tests - GRL Engineers developed and use the GRL-Cell, manufactured in Cleveland, OH. GRL-Cells are available in a multitude of sizes with jack capacities of 350, 500, 750, 1100, 1500, 2000, 2500, and 3500 tons. All cells have a standard stroke of nine inches. Bi-directional cells can be used individually or in groups to satisfy test load requirements.

Static Load Testing

Static Load Tester (SLT) - For static and bi-directional load tests, GRL uses the Static Load Tester data acquisition system. This system consists of a SLT tablet and multiple SLT data logger boxes. Each data logger has twelve analog and four digital channels. Multiple data logger boxes can be connected to accommodate greater data acquisition needs. A wired or WiFi connection can be used between the data loggers and the SLT tablet. Real time test data can also be viewed in the Cloud by authorized off-site personnel.

Jacks, Pumps, Load Cells and Spherical Bearing Plates - GRL maintains an inventory of jacks, pumps, load cells. and spherical bearing plates to support static load testing projects. Jack capacities ranging from 30 to 1100 tons are available.

Static Load Test Beams - Load test beams with a maximum beam capacity of 1000 tons are available as part of our static load testing service.

Integrity Testing

Cross-Hole Analyzer (CHA) - For cross-hole sonic logging, GRL engineers use either the Cross-Hole Analyzer, Model CHAMP-Q or CHAMP, to evaluate drilled shaft concrete quality and integrity. The CHAMP-Q is a multi-probe system that allows up to four transceiver probes to be pulled simultaneously allowing six profiles to be tested with one pull. The CHAMP is a conventional two probe system consisting of one transmitter probe and a receiver probe. The CHAMP system is sometimes used in cases where shaft access is difficult, or where test setup space or conditions are limiting.

Thermal Integrity Profiling (TIP) - For thermal integrity projects, GRL uses Thermal Wire cables connected to a TAG and TAP-EDGE data collectors to evaluate concrete or grout integrity. The TAG unit uses WiFi to collect the data from each TAP-Edge unit and pushes the collected data to the Cloud. This system significantly reduces GRL's analysis and reporting time as the Cloud data is regularly updated allowing data analysis to begin as soon as the shaft has reached its peak temperature. Real time test data can also be viewed in the Cloud by authorized off-site personnel.

Gamma Gamma Logging (GGL) – For Gamma Gamma Logging tests, GRL uses a test probe containing a low-level radioactive source at the probe tip and a shielded detector located 15 inches away is lowered into a PVC access tube to assess the concrete density surrounding the tube. Drilled shafts are prepared by attaching 2-inch outer diameter, Schedule 40, PVC access tubes to the steel reinforcing cape prior to cage insertion in to the shaft excavation and concrete placement. The access tubes should be located at last 2-inches from longitudinal reinforcement, with several tubes installed in a pile for ample readings.

Pile Integrity Tester (PIT) - Low strain integrity testing projects are performed with the Pile Integrity Tester model PIT-Q, PIT-QFV, or PIT-X. These systems include accelerometers and instrumented hammers. Depending on whether acceleration or acceleration and force data is collected, data can be processed using either the sonic pulse echo method or the transient response method.

Drilled Shaft Services

Base Cleanliness – For drilled shaft base cleanliness evaluations, GRL uses the **S**haft **QU**antitative **I**nspection **D**evice or SQUID. This 475 lb device quickly attaches to the drill rig Kelly bar.

Shaft Verticality, Radii, Profile, and Excavated Hole Volume - GRL uses the **SH**aft **A**rea **P**rofile **E**valuator or SHAPE device to asses shaft verticality, radii, profile, and excavation volume. The 80 lb SHAPE device can quickly be attached to the drill rig Kelly bar for testing.

Unknown Foundations

Parallel Seismic – For unknown foundation length tests, GRL uses a modified PIT-QFV unit and software package to perform parallel seismic testing. This system includes an instrumented hammer and a hydrophone.

Length Inductive Test Equipment (LITE) – For unknown steel foundation length evaluations, GRL uses the LITE system with its inductive sensor and volt meter.

Pile Integrity Tester (PIT) - For unknown foundation length tests, GRL also uses the Pile Integrity Tester model PIT-Q, PIT-QFV, or PIT-X and its associated hammers and accelerometers.

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