Dynamic load testing using **Pile Driving Analyser (PDA)** equipment is a high-strain non-destructive load test method which can be performed during or after pile installation using conventional pile driving equipment. This test can be applied to driven steel, driven timber and even concrete piles (eg. pre-stressed driven concrete piles, drilled shafts, auger cast piles).

PDA equipment calculates the velocity and force signals obtained from accelerometers and strain transducers attached to the pile during driving. This data is analyzed using CAPWAP software to calculate the pile capacity. PDA testing can be undertaken during initial driving or during re-strike drives after allowing soil setup on the pile for a suitable period of time. PDA testing is undertaken in conformance with ASTM Standard D4945.

BENEFITS AND ECONOMICS OF PDA TESTING

Since introduction of the 2006 Alberta Building Code, pile foundations have been designed using Ultimate Limits State design. Ultimate pile capacity estimates are factored using the Geotechnical Resistance Factors (GRF) in the National Building Code of Canada. A conventional pile design uses a GRF of 0.4, but with PDA testing the GRF may be increased to 0.5. This means smaller or shorter piles can carry the same loads as conventionally designed piles, translating into direct savings of about 20 percent on pile materials and installation costs. Even greater savings can be achieved with length optimization to eliminate splices.

Example 1: A medium sized industrial plant project with 800 driven steel piles was originally designed based on a GRF of 0.4. A design review and PDA test pile program was undertaken on the 219 to 406 mm pipe piles. Since pile cap connection details were already designed, the pile diameters were not changed, but the lengths were reduced by 15% from the design depths of 10 to 18 m. The original design called for over 150 splices for piles over 15 m, but final installations were done no splices. PDA testing verified the design capacities were achieved. The original piling budget was **$1.45M**. The reduction of the piling costs was about $300,000. The cost of the PDA testing program was $50,000 including 4 days of test pile installations at $20,000. The net savings for this project was over **$200,000**.

Example 2: A small building project with 46 driven steel piles was designed based on a GRF of 0.4. The 273 mm pipe piles were to be driven to refusal in weak bedrock at 8 to 12 m. Standard 12 m pile lengths were proposed with 1 m stickup. During initial driving, the resistance at 11 m embedment did not meet the original termination criteria, suggesting splicing was required to extend the piles 2 to 3 m deeper. After a few days of setup, PDA testing was undertaken to verify the pile capacities. Only 3 of the 46 piles needed to be extended. The original pile budget was **$75,000**. The proposed budget to splice and extend the piles was **$37,000**. The cost of extending 3 piles was less than $5000 and the cost of the PDA testing including the piling contractor was $12,000. The net savings for this project was over **$20,000**.

Example 3: A major industrial plant project with 3700 large driven steel piles was designed assuming PDA verification required to use a GRF of 0.5. Based on typical experience, a rejection rate of 8% was budgeted for pile installation issues to be corrected by abandoning and adding piles. The rejection rate was reduced to 3% using PDA for damage prevention and pile capacity verification. The piling budget was **$45M**. The total savings related to reducing rejection rates was about **$2.2M.** This savings was 2.6 times larger than the final PDA testing costs that were already required in order to use a GRF of 0.5.

Similar results have been experienced on many other projects. As a result, PDA technology is rapidly gaining acceptance in the local construction industry. To service this growing demand, ParklandGEO currently has 8 PDA units servicing Western Canadian projects; which is about 15% of all the PDA units in Canada.

PDA TESTING AND CAPWAP BASICS

The information that PDA testing can provide includes: verification of pile capacity at the time of testing; data for developing termination criteria for design loads; assessment of energy transfer and driving efficiency; measurement of stress levels induced on the pile during driving; and assessment of pile integrity and possible damage. There are three basic types of PDA tests on driven piles:

- testing of a pile for the full installation.
- testing of a pile at end of initial drive (EOID).
- testing of the pile several days after initial drive (ie. “Re-strike”).

Testing during the full drive of a pile will provide a complete record of the pile installation, including the ability to assess initial capacity and pile integrity along the full length of the installed pile. Testing at the end of installation only verifies the EOID capacity.

Re-Strike Testing and Soil-Pile Setup

In many soil profiles, the capacity at EOID is unlikely to be the ultimate capacity for a pile. Pile driving can produce excess pore pressures around the pile shaft which allows for easier installation. As a result, PDA testing during initial drive will usually produce lower capacity results. After driving, the pore pressures dissipate and the friction acting on the pile shaft increases. This capacity gain is called “soil-pile setup”. The setup gain can be measured by comparing the PDA capacity results from EOID and Re-strike testing. In some wet soils, the setup gain in capacity can be in the order of 50 to 100 percent.

Case Wave Analysis Program (CAPWAP) Analysis

PDA tests only provide direct measurements for the forces and motions at the pile head. The static and dynamic soil parameters and distribution of forces/ motion over the pile shaft and toe are not directly measured. To verify the static component of pile resistance, CAPWAP analysis is performed on field data from a selected representative hammer blow from the PDA test record. CAPWAP analysis resolves three unknowns: the internal pile forces, pile motions and external forces. Soil parameters and pile shaft/toe resistance distributions are estimated and adjusted through an iterative process in the CAPWAP software to plot a computed wave response. The process is repeated until a reasonable match is achieved between the CAPWAP wave curve and with the measured wave response from the field data (ie. signal matching). The final CAPWAP result provides a “corrected” resistance result for the pile, the pile shaft and the pile tip. A significant amount of judgement has to be applied during the CAPWAP analysis to ensure that the final results make sense in terms of the available soil and groundwater information for the site.

Test Frequency and Practical Considerations

To allow the use of a GRF of 0.5, a representative amount of PDA testing needs to be performed. For typical building projects at least 2 to 5 percent of the piles should be PDA tested. For Alberta Transportation bridge projects 10 percent of the piles need to be tested for design verification (or 5 percent can be tested for basic quality assurance at a GRF of 0.4). It should be understood that while PDA testing is relatively unobtrusive, some loss of production may be experienced during testing. If testing is performed during production piling, it is recommended to clearly identify in the tender document that PDA testing will be undertaken, in order to avoid contractor claims for delays. It should also be expected to allow for at least 24 to 48 hours for final verification of piling criteria based on CAPWAP analysis. Alternatively, initial PDA testing can be performed during a separate test pile program completed prior to production piling.

PDA TESTING AND CAPWAP BASICS - CON'T

The Value of Experience and Proficiency in PDA Testing

The field data from dynamic testing must be evaluated to determine detailed pile capacity information and other assessment issues such as pile integrity or damage. The evaluation process of signal matching is resolved in CAPWAP software by adjusting roughly 20 variables for pile materials and geotechnical parameters. Using the CAPWAP software, these input parameters are used to adjust the shape of the wave curve model for the test blow until it is a close fit with the shape of the measured wave response from the field. CAPWAP software rates signal matching for model solutions using a Match Quality Ratio (MQR). The data quality does not always allow a close match, but ideally the MQR should be less than 4.

The goal of analysis is to get a CAPWAP solution with a low MQR value using reasonable, site specific pile material and soil parameters. It is possible to get CAPWAP capacity estimates that are in the order of 30 to 50% different from the actual capacity, depending on how and how well the field response curve is matched. It should also be understood, it is possible to get a capacity estimate with a good MQR using a mix of parameters that have little resemblance to actual field conditions. Since there are so many input parameters, a significant amount of geotechnical judgement has to be applied to ensure results make sense in terms of the soil and groundwater conditions. Two very experienced PDA engineers will never get the exact same pile capacities from the same field data, but it is expected their solutions will be relatively close (within 5%).

Manufacturers provide training on their PDA equipment and software, but there are no regulatory qualifications required to undertake PDA testing. Any consultant, contractor or agency can purchase PDA equipment and use it for Quality Assurance (QA) or Quality Control (QC) purposes.

- QA is used to verify Owners are getting a foundation that meets their project requirements (QA); or
- QC is can be used by a piling contractor to show he has provided the foundation they offered (QC).

Common practice is for piling contractors to arrange PDA testing, and this service was usually provided by third party consultants. More recently, some contractors are doing their own QC testing and providing these PDA results for QA purposes. Since PDA data can be subject to a wide range of interpretation, it is suggested that Owner's should contract or at least specify a qualified third party PDA provider for QA work; or have a qualified third party engineer review contractor provided PDA results used for pile acceptance.

Due to the complexity of PDA/CAPWAP analysis, we believe it is necessary to stress the proper application of this technology requires solid experience supported by good technical knowledge of both piling and soils. To reinforce this point, we provide the following excerpt from a 2011 paper written for Pile Driver Magazine by Garland Likins, the President of PDI Inc., the primary manufacturer of PDA equipment used in Canada.

> *"Solutions are only valid for data of good quality, and data of good quality cannot be assessed by the unknowledgeable. Dynamic testing should not be treated as a "black box" technology. Only engineers with a good grasp of all aspects of dynamic testing should perform dynamic testing. Inadequate ability may result in either not knowing when the data quality is unsatisfactory (garbage in - garbage out) or dispensing bad advice, particularly when faced with a situation outside the tester's experience base."*
>
> *http://www.pile.com/reference/PileDriver/PD_Q2_2011_pg59-62.pdf*

In recognition of these issues, PDI Inc. developed the **"Dynamic Measurement and Analysis Proficiency Test"** for engineers providing PDA services. They test and maintain a PDA proficiency list of individual engineers on **www.pdaproficiencytest.com**. In the USA and Canada, many government agencies and consultants currently specify PDA testing has to be supervised by an engineer with an "Advanced" Proficiency Level or better; and at least five years of direct PDA testing and analysis experience. ParklandGEO currently have two engineers who meet these qualifications; including **Dr. Mohamed El-Marassi, P.Eng.** the senior engineer of ParklandGEO's PDA Testing Group.