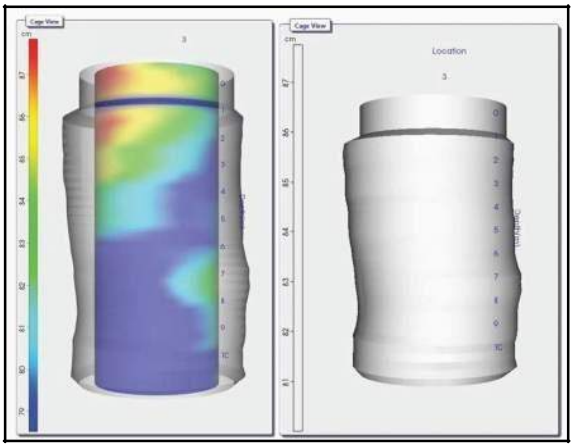
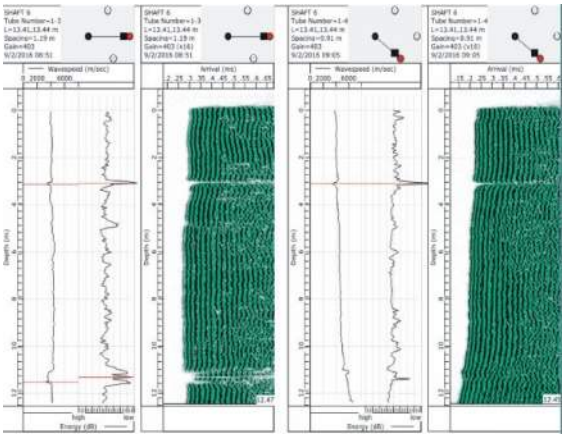
Several non-destructive test methods have been developed to assess pile integrity in different pile types including driven steel, timber, pre-stressed concrete piles; and bored cast-in-place (CIP) or auger cast piles. Each method has advantages and limitations in terms of simplicity, accuracy and cost. The simplest tests allow for quick detection of major defects in production piles after construction. More advanced test methods can provide details on abnormalities and damage, but they require instrumentation of test piles before construction. These tests are typically used for QA/QC programs targeting a representative number of production piles. For driven piles the main concerns are pile shaft or pile tip damage. The main concern for bored CIP concrete piles is possible instability of the soil walls of drilled shafts. Wet or sensitive soil can fall into a pile excavation and be removed during drilling, causing a void in the exposed wall which fills with concrete and creates a bulge in the shaft. A far worse situation can occur if the wet or sensitive soil collapses into the shaft when the pile hole is being filled with concrete, causing a soil inclusion or "necking" in the pile shaft which reduces the pile section.

THERMAL INTEGRITY PROFILING (ASTM D7949)



Thermal Integrity Profiling (TIP) is a new method of determining the structural soundness of a prepared CIP concrete test pile based on measuring the heat generated by concrete hydration of the shaft. Wire strings fitted with temperature sensors are attached to the reinforcing steel cage of the test pile prior to placement in the pile excavation. The sensor strings typically extend the full length of the pile and are attached to data loggers which collect temperature data versus depth in the pile shaft as the concrete cures over the initial 72 hour period. Regions of the shaft with higher temperatures indicate hydrating concrete is present; and cooler regions around the pile shaft indicate the presence of soil. If a cool region is detected within the pile shaft, it indicates a possible soil inclusion in the shaft. TIP readings can be used to determine the final shaft shape and cage alignment with depth as shown pictorially in the figure above. Unlike a CSL test, **TIP** measurements extend to the concrete/soil interface outside the rebar cage, so the **TIP** test method can detect the size and location of both necking and bulging. The sensor strings can be cut off after testing.

CROSSHOLE SONIC LOGGING (ASTM D6760 | ACI 228.2R)



Crosshole Sonic Logging (CSL) is an established method of determining the structural soundness of a drilled CIP concrete shaft in a prepared test pile. Prior to pile installation, a number of **CSL** access tubes are attached to the reinforcing steel cage of the test pile prior to placement in the pile excavation. The rebar cage is lowered into the shaft and the access tubes are filled with water and capped. The concrete is placed and allowed to cure for about 7 days before testing. During the test, an ultrasonic transmitter and receiver are lowered down two access tubes at constant elevations with the transmitter giving off a signal. The relative energy, waveform and time lag of the sound is measured at regular intervals and graphed. Comparing the graphs from combinations of paired tubes allows the shaft condition between the access tubes to be mapped. The main limitation of the **CSL** method is that the shaft measurements are between the access tubes inside the rebar cage, so the test can only detect necking when soil sloughs into the shaft. **CSL** testing cannot detect bulges in the shaft outside of the rebar cage, but when assessing pile soundness, the presence of necking is a far greater concern than budging. After testing the access tubes are grouted.

HIGH STRAIN DYNAMIC PILE TESTING (ASTM D4945)

High Strain Dynamic Pile Testing using **Pile Driving Analyzer (PDA)** equipment is a non-destructive test method used primarily to assess the capacity of a pile during or after initial installation. High strain **PDA** testing is performed using a large pile driving hammer to apply a compressive stress wave down the pile shaft. The impact of the hammer produces pile penetration or movement. **PDA** equipment measures the velocity and force signals obtained from accelerometers and strain transducers attached to the pile shaft during driving. This data is analyzed using **CAPWAP** software to calculate the pile capacity along the shaft and at the toe. The **PDA** equipment also assesses the wave response for possible indications of damage which can often be located by depth and roughly quantified. **PDA** testing can be applied during installation of driven steel, driven timber, pre-stressed driven concrete piles. **PDA** testing can also be performed on prepared CIP concrete test piles after installation once the concrete has gained sufficient strength. When testing CIP concrete piles using the **PDA** method, the top of the pile shaft needs to be projected above grade and cast within a steel casing to strengthen the top of the pile and avoid damage during driving. In terms of pile integrity, PDA testing is most often used to assess suspect piles for acceptance or rejection (ie. non-vertical, mis-aligned, mushroomed piles, etc.)

LOW STRAIN PILE INTEGRITY TESTING (ASTM D5882)

Low-strain Pile Integrity Testing is a non-destructive test method which involves producing a compressive stress wave by hitting the top of the pile with a small hand-held hammer. The stress wave propagates down the shaft and is reflected back to top of the pile when it encounters either the pile toe or a non-uniformity in the shaft. The reflection waves are measured by **Pile Integrity Tester (PIT)** equipment attached to the pile. Structurally sound concrete shafts should have reflection wave from shaft toe with only minor variations of the record amplitudes between impact and toe reflection. Major variations in the reflection wave could indicate pile damage. Foundation evaluation with **PIT** test data requires careful interpretation along with installation observations such as concrete volumes and pile excavation logs, because results are not always conclusive. If the shaft material has a high resistance; or the shaft is relatively long compared to the diameter; or if the shaft has numerous cross-sectional changes, it is difficult to draw conclusions regarding the length or integrity of the entire shaft. **PIT** testing is limited to assessment of major shaft defects or material changes, but the test can be performed on any concrete production pile so it is often undertaken as part of a QA/QC program for CIP concrete piles.

PARKLANDGEO EXPERIENCE

ParklandGEO has extensive experience with advanced pile capacity and integrity testing methods. Our personnel have PDA and/or PIT testing experience on over 2000 sites located across Alberta, British Columbia and Saskachewan. ParklandGEO personnel have training in both CSL and TIP pile integrity testing methods. Most recently, ParklandGEO undertook CSL and PDA testing for the South West Calgary Ring Road project in Calgary, AB. In July 2013, ParklandGEO participated in the first Thermal Integrity Profile test performed in Canada for the ATCO Eastern Alberta Transmission Line project. The following is a brief listing of ParklandGEO pile integrity projects:

- **South West Calgary Ring Road**, Ongoing, Calgary, AB (CSL, PIT, PDA on CIP and DS Piles)
- **Peace River Bridge Twinning** (PDA on DS Piles)
- **Peace River Pile Wall**, Peace River Alberta (TIP on CIP Piles)
- **Static Load Test Pile**, Edmonton Alberta (TIP on a CIP Pile)
- **McLeod River Rosevear Road Crossing**, Yellowhead County, AB - 2016 (CSL Testing on CIP Piles)
- **St. George's Island 12th Street Bridge**, Calgary, AB - 2016 (CSL Testing on CIP Piles)
- **Timberlands CO-OP Project**, Red Deer, AB - 2016 (PIT Testing on CIP Piles)
- **Frere Antoine School**, Edmonton, AB - 2015 (PIT Testing on CIP Piles)
- **Capital Power - Genesee DSI Silo Foundation**, Warburg, AB - 2015 (PIT Testing on CIP Piles)
- **Potash Corp - Rocanville Expansion Project**, Sask. (PIT on CIP Piles)
- **Suncor Fort Hills OPP and E&T Projects** - 2014/2015 (PDA Testing on DS Piles)
- **ATCO Eastern Alberta Transmission Line** - 2013/2015 (PDA, PIT, TIP Testing on DS and CIP Piles)
- **South East Stoney Trail**, Calgary, AB - 2011/2013 (PDA Testing on DS Piles)