



## Interpretation of Results from a Pile Integrity Tester (PIT)

It should be clearly understood that the main purpose of the Low Strain Dynamic Test / Pulse Echo Test / PIT test is to locate piles with major or serious defects. Such major defects can cause structural failure of the pile or shaft under working loads and are clearly unacceptable. Minor defects could be missed (and may not be important anyway to the overall load carrying performance of the pile or shaft as the soil resistance is usually the limiting factor in the pile capacity; also if the minor problem is at great depth of a friction pile since the soil resistance reduces the load at the problem location). The test can be specified even after installation is complete as it does not require access tubes or other advance planning.

It is always good to test enough piles to determine the average or normal record so other piles can be judged against this standard. Odd records require further evaluation. The amount of testing should depend on the sensitivity of the structure. For foundations where every shaft supports its own column, every pile should be tested. Since this low strain integrity test method is inexpensive and quick, it is feasible to test all piles on a given site. For piles in a group, a representative sample should be tested.

Testing while the installation is in progress is also suggested. If the project is for drilled shafts or augured piles, the concrete should be given sufficient time to harden; one week or five days is often sufficient. Driven piles can be tested immediately. For large projects, testing one day per week allows early detection of problems. Correction can then be accomplished in a least cost manner when the installation equipment is still on site and the problem area still accessible. The further construction of slabs, footings and columns can then proceed as scheduled. To wait until all piles are installed and then find problems could result in significantly higher repair costs and more significant delays.

### Data Processing and Evaluation

Random noise is most easily minimized by averaging several records. Even small defects within a short distance of the surface may distort the sensor signal with high frequencies; sensing and impacting at several pile top locations may eliminate such difficulty. For larger diameter shafts, it is recommended practice to test at several locations around the top of the shaft to inspect for local defects near the top.

Soil friction and poor concrete quality are often the greatest obstacles for successful integrity testing since they dissipate the stress wave energy. Exponential amplification with time may help overcome these problems, but only if the records contain discernable details reflected by the lower pile portion. Late-occurring vibrations imposed at the pile top are also amplified and distorted so **interpretation after amplification should be performed carefully**. The magnification factor is best kept constant on similar length piles on the same jobsite and is often chosen to make the toe reflection (if present) similar in magnitude with the initial input. If the signal exhibits ringing, try a softer blow or try to minimize other potential vibration sources.

To identify the location of a cross section change or the pile bottom, a wave speed must be assumed. The toe reflection is more obscure in piles with large or numerous shaft changes. The pile toe reflection, if observed, can be used to adjust the wave speed if the pile shaft length is known. The shaft length is



often variable, particularly for drilled shafts. If the pile has a serious defect, a full crack, or a mechanical splice with an inherent gap between sections, the stress wave might not pass this feature; then only the portion of the shaft above this location can be evaluated.

Although the acceleration curve could be interpreted, integration to velocity generally enhances the record by bringing out details otherwise overlooked. Both force and velocity have a positive value at the beginning of the record (PIT assigns a positive value to the initial input). The force returns to zero as the hammer rebounds from the pile top. A record from a perfect shaft would have the initial impact (positive sign) followed by a flat (zero) response until a reflection (usually positive sign) from the bottom is observed. In practice there is usually shaft friction which, by absorbing energy, shifts the velocity record negative after the initial impact. For a stiff concrete pile in relatively weak soil (strength compared to the concrete), the toe reflection will have the same sign (positive) as the velocity input. For a pile with a fixed end (such as a rock socket), the toe reflection may be of the opposite sign (negative) as the velocity input.

Other reflections, observed only in the velocity record, are caused by changes in the pile impedance ( $EA/C$ ), where  $E$  is the elastic modulus,  $A$  is the cross-sectional area, and  $c$  is the stress wave speed. Such reflections can be due to changes in either the cross-section or the material. A region of impedance reduction exhibits a positive reflection (same sign as initial input, which for this discussion is assumed as a positive signal); an impedance increase causes a negative reflection (opposite sign of initial input). A local decrease (neck) would have a positive reflection followed by a negative reflection (positive negative cycle). A local increase (bulb) would have a negative reflection followed by a positive reflection (negative positive cycle). The reflections must be interpreted to determine whether the associated changes are acceptable or of serious concern to the integrity of the shaft. The magnitude of the reflection is related to the size of the impedance change. The resistance level  $R$  (Low, Mid, or Hi) affects the magnitude of the response; the size of the change also influences the reflection.

A brief summary of several pile shape changes and soil resistance effects is given in the PIT manual. A more complete catalog of defects and technical papers detailing further evaluation are also given in an appendix to the PIT manual.

If the toe reflection is not apparent, then the test is only partly successful. Many of the most serious defects are in the upper portion of the shaft. Deeper defects are often judged less serious if the shaft resistance above the defect is adequate. However, any major defect is always a cause for concern. To help reveal local defects near the top of a large-diameter pile, several locations around the perimeter and center should be tested.

If a clear reflection is apparent above the pile toe, the following questions should be answered:

- a) **Is a toe signal observed?** There is at least some indication that the shaft is in one piece and that loads can be transferred to the bottom. Be careful, however, because the toe signal could be a secondary reflection from an impedance change if the change is at the midpoint of the pile shaft. Similarly, a defect at the upper third point could make a second reflection appear at the lower third point and then again at the time of the expected toe. The record must be checked for these multiple reflection possibilities. A major defect could cause structural failure of any shaft under application of loading.



- b) **Are signals from other piles similar?** Perhaps the soil profile is responsible. Alternate weak or strong soil layers can cause the pile shape to be non-uniform. For example, drilling in a loose granular layer may produce an oversize hole; if the shaft is then extended into a stiff cohesive layer, the size of the hole might only be nominal. The change from oversize to nominal may appear as a reduction but is not detrimental to pile quality. Reductions in friction can generate a response which resembles those from a cross section reduction.
- c) **How close to the top are the changes?** If the change is very close to the top, it may be partially hidden in the initial velocity rise. A problem may be indicated by a curve whose initial portion is unusually wide; early reflections may be superimposed upon or overlapped with the impact signal. A smaller hammer may give better definition. The additional measurement of force and comparison with the velocity is a better method of detection for changes close to the pile top.
- d) **Did drilling records, volume records, or driving observations indicate potential problems?** Construction records often reveal obstructions, unusual driving records, concrete volume, cold joints, and other facts that help to interpret the PIT record.

Once the data are collected, plots should be made of all records and included in a report. Data from PITs manufactured in 2003 or later are stored on a PCMCIA card. This data can be downloaded directly by inserting the card into a PCMCIA slot in a laptop (or with the provided card reader). Final processing of the data is then done in the PIT-W software program.

The PIT Collector models prior to 2003 can be attached through a serial port to an HPGL-compatible plotter or laser printer. A serial output cable is provided with those models. Data is usually also transferred to a PC by this serial link and the transfer software provided. These old style data files can be saved as permanent records of the testing, but also can be plotted by the PITSTOP program (DOS) which contains the PITPLOT option. PITPLOT can plot up to 6 records on a single page (including full documentation of all processing parameters). The Multiplot feature in PITSTOP can plot as many per page as the user desires (reduced documentation of processing parameters). This old style data can be imported into the PIT-W program.

To summarize, the prime purpose of any integrity test is the investigation for potential major defects in the shaft which could prove fatal to the performance of the foundation. This brief overview is not intended as a complete guide to pile integrity testing, its use or application. It should be noted that neither the PIT nor the low strain integrity testing method in general can yield information that the record does not contain. A defect may not always yield a clearly recognized signal if the pile top is not properly prepared. In general, however, with good clean repetitive records, **a definite major reflection positively identifies a pile impedance change**, which may be associated with a major defect (defects have positive sign reflections, where "positive" is of the same sign as the initial input pulse).

With the above thoughts firmly in mind, you must now get data to evaluate.

### **Use and Interpretation Review and Summary**

Following are a few simple general rules for use and interpretation when testing bored piles, CFA or augercast piles.

**The data collection effort is extremely important (as the manual emphasizes) if data evaluation is**



**to be meaningful. The accelerometer must be firmly attached. Probably you should reattach accelerometer every time between acquiring sets of records to make sure.** The top concrete can and always should be evaluated visually for hardness and for contaminated concrete. If contaminated concrete is observed, it should first be removed (pile top cut-off) prior to test. For any pile it is helpful to have more than one record from this pile so you can compare consistency of results.

For projects with many piles and especially on large projects, it often helps to compare results from different piles and spot the unusual cases. Use the same magnification for piles of similar length on same project. Magnification factors (MA) usually are chosen so that toe response is similar magnitude to input. The toe response has the same sign as the input (positive from PIT) if the pile strength is greater than soil strength; toe reflection could be of opposite sign for piles with rock sockets and high resistance.

Note that a defect (reduction of section or strength) along the shaft length generally has a "positive" reflection (reflection of same sign as input velocity). If it is a local defect (reduction in impedance such as a reduction in stiffness or reduced area), it has a positive-negative cycle. Local bulbs (section increase) have a negative-positive cycle. Slow changes are usually due to soil resistance effects and usually go negative (opposite sign of input).

Defects near pile top may be superimposed on the input and may be difficult to interpret, but fortunately if they are near surface, they can be investigated by excavation in many cases. Near top defects produce an apparent input which is wider; compare the pulse width for all piles on site for the same hammer. Abnormally large pulse widths could be from a near top defect. For large piles, you should test at several locations around the pile top to search for local defects.

PIT is a tool to help investigate pile integrity. While in some cases data of a particular pile are sufficient to make definite conclusions, often the construction records and soil profile are helpful. Look at construction records and construction volumes and compare with PIT records. For augercast piles, it is particularly interesting to look at incremental volume versus depth records from installation, such as those produced by automated monitoring equipment (such as the Pile Installation Recorder by Pile Dynamics). Compare PIT results with soil profile to see if there are reasons for consistent characteristics in the records. For example weak soils may allow for increase in size and if over a stiff layer then if size returns to nominal dimension, then that would look like a relative decrease.

Processing should not make LO pass filter (or SMOOTH) too high (values of 2 m or less are preferred); in recent times a "Wavelet" analysis is preferred. If Wavelet is used, the LO pass filter should be set to zero, and the Wavelet input should be about equal to the input pulse width (typically one meter). The HI pass filter should not be too low (values of 50 m or more are preferred) so that overall record is not greatly distorted.

June 1998 (minor revisions July 2003, March 2011)