WORK INSTRUCTIONS FOR ENGINEERS

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OP-016. PROCEDURE FOR PILE INTEGRITY TEST (PIT)

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GENERAL

16.1.1 PIT is an integrity test method for foundation piles. It is a so-called Low Strain Method (since it requires the impact of only a small hand-held hammer) and also referred to as a Non-Destructive Method. The evaluation of PIT records is conducted either according to the Pulse-Echo or the Transient Response Procedure.

16.1.2 The concept of the test is based on wave propagation through the cross sectional area of the pile which detected changes in **pile impedance** (Young's Modulus multiplied by Area divided by wavespeed, Z=EA/c). A hammer blow generates a compression wave at the pile head at t=0 (initial blow). The result for the pile tested is an acceleration or velocity curve plotted as a function of time.

16.1.3 The test has certain limitations and should be used with care by considering other site and subsoil information available. The limitations of the test will be discussed in section 16.5.

DESCRIPTION OF METHOD

16.2.1 The Low Strain Methods of dynamic pile testing may be applied to any concrete pile either driven or cast in-situ. They require as a minimum the impact of a small hand held hammer on the shaft top and the measurement of the shaft top motion. For the Transient Response Method the measurement of hammer force is also necessary.

16.2.2 The motion record, more specifically the pile top velocity as a function of time, must be displayed during the test and produced on hard copy. Where high soil friction forces are present, an integration with exponentially increasing magnitude should be applied to the velocity signal such that the pile toe reflection is enhanced. In general, several records should be averaged, however, the test engineer is responsible for assuring that consistent records are included in the average. The averaged, amplified velocity is the standard result of the Sonic Pulse Echo Method. In addition to the velocity record as a function of time, the amplified and averaged difference between velocity and force may also be depicted. This graph would provide additional information as to the quality near the pile top.

APPARATUS

16.3.1 Low Strain Pile Integrity test shall be carried out using a small impact device (hammer), sensitive accelerometer, compact special purpose P.I.T Collector with 16-bit A/D, full built-in data interpretation.

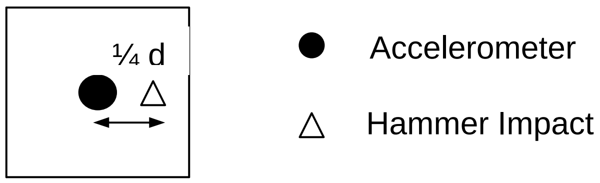
16.3.2 The contractor shall level the pile head and its cross section.

16.3.3 The test involves the attachment of an accelerometer on the pile top using an adhesive material. After the attachment, a special rubber-tipped hand-held hammer is used to generate a "low strain" compressive impact wave.

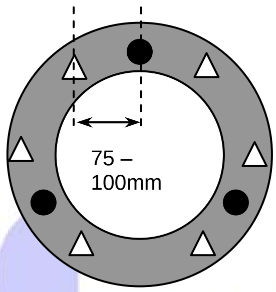
PILE TOP PREPARATION AND CHECKLIST

16.4.1 Ensure that the pile top is relatively smooth and free from water, dirt or other debris. The testing technician shall clean a portion of the pile top for the attachment of an accelerometer if necessary.

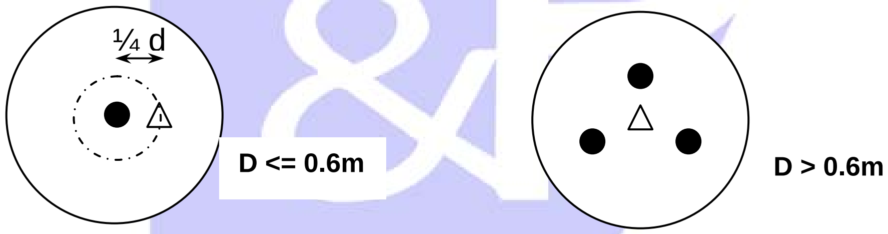
16.4.2 For square piles (less commonly tested), testing point shall be at the middle of the pile with the hammer impact preferably approximately ¼ d away from the accelerometer, as shown below:



16.4.3 For piles with hollow annulus (Spun Piles), testing point shall be at three equally spaced out points with the hammer impact not being too close to the accelerometer, as shown below:



16.4.4 For Cast in-situ Reinforced Concrete Pile / Bored Piles, testing point(s) shall be at least in the following configurations.



16.4.5 Check the pile make-up to determine whether the failure zone falls at the pile joint or at anywhere along the pile body.

16.4.6 For spun pile with a hollow annulus in the middle, re-check the results (if necessary) by carrying out a plumb test using a steel rod tied at the end of a measurement tape or lower down a torchlight into the annulus of the spun pile to observe whether there is any exposed reinforcement or displacement at the pile joint. Record the depth where the plumb test is terminated. This step also can be performed prior to PIT test to determine whether further confirmation is required using PIT test.

16.4.7 For spun pile with a hollow annulus in the middle, re-check the results (if necessary) by carrying out a plumb test using a steel rod tied at the end of a measurement tape or lower down a torchlight into the annulus of the spun pile to observe whether there is any exposed reinforcement or displacement at the pile joint. Record the depth where the plumb test is terminated. This step also can be performed prior to PIT test to determine whether further confirmation is required using PIT test.

LIMITATIONS

Before interpreting the velocity signals, it is necessary to understand the limitations of pile integrity test so that a reasonable interpretation could be made. The limitations of PIT test are as follows:

a) Impedance changes

A reflection may not be detected if there are gradual changes or small local changes in pile cross section. Figure 1 illustrates some typical profiles which are not detectable by the test while Figure 2 illustrates typical profiles which are detectable by the test. Since impedance changes depend upon several interrelated properties of the pile, it is not possible to recognize whether a particular impedance change is due to changes in the cross-sectional area or quality of material, soil changes or some combination of all these.

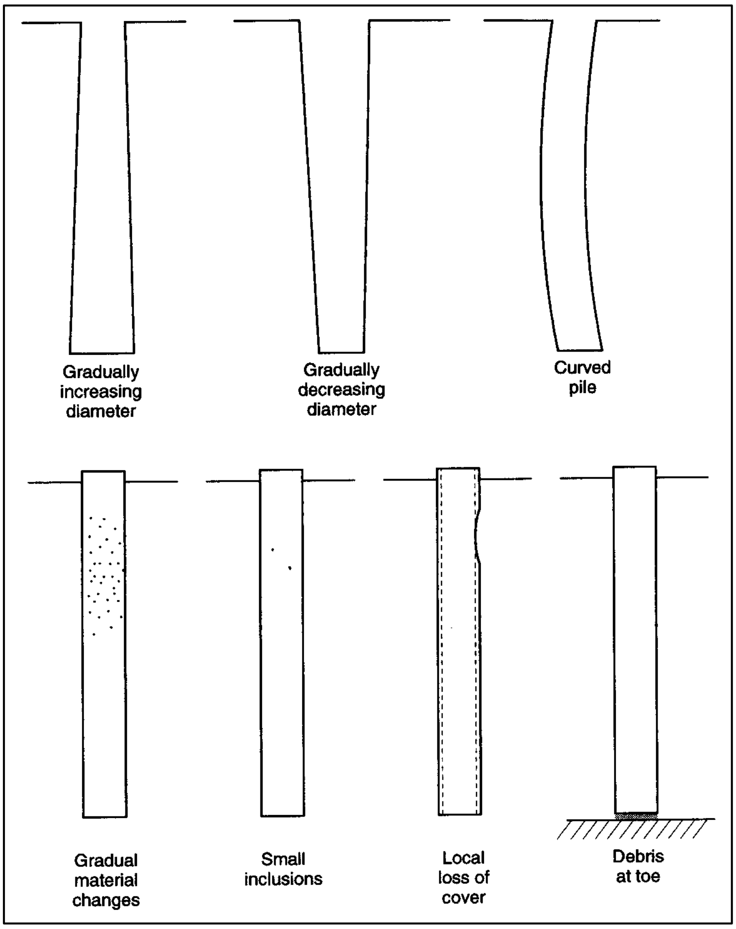


Figure 1: Defects not detectable by Pile Integrity Test (Turner, 1997)

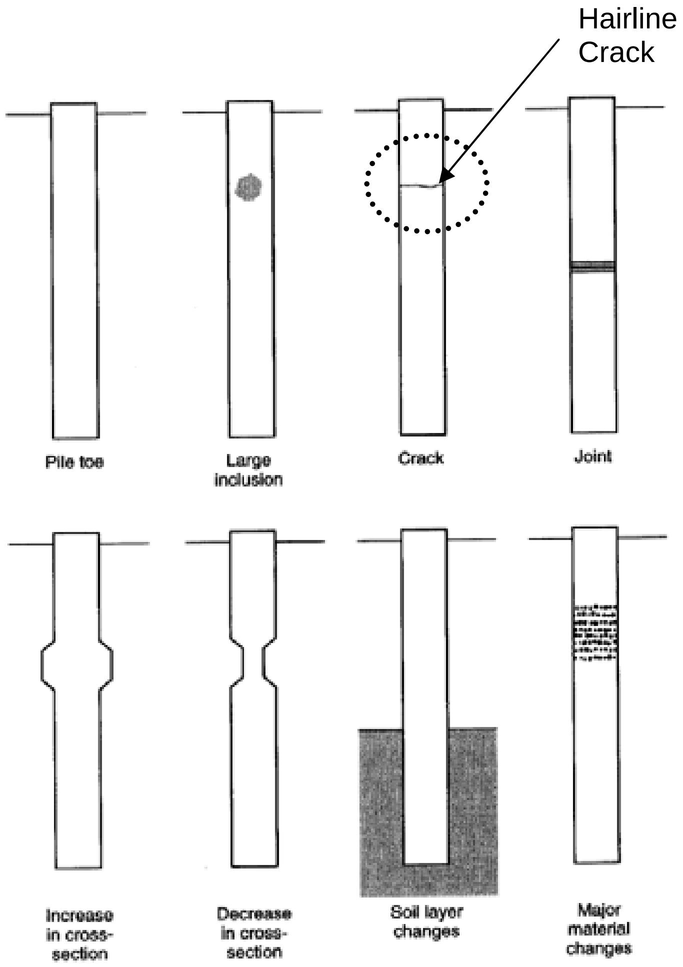


Figure 2: Defects detectable by Pile Integrity Test (Turner, 1997)

b) Reflection from the toe of the pile

If no toe reflection is discernible in the signal, the pile toe may be embedded in material which has similar impedance to that of the pile, therefore making the interpretation of the pile length not possible. On the other hand, if energy reaches the pile toe, the magnitude of the toe response should indicate the toe condition. However, care should be taken such that same magnification is applied throughout the signals for consistency.

c) Static bearing capacity

One of the major limitations of the method is that the test does not provide any information about the static bearing capacity of the pile. It is only able to measure the low-strain pile head stiffness from frequency response testing with force measurement. The pile head stiffness parameter should not be used to determine the absolute value of the bearing capacity of a pile.

FIRST INTERPRETATION (FROM ALL REPORTS AVAILABLE)

The recorded acceleration values are integrated to obtain the velocity signals.

The velocity signals are then plotted against time.

The time taken for the wave to travel from the top, reflected at the bottom and reaching the top again is 2L/c, where L is the length of the pile and c is the wave speed.

Since the first arrival of the signal from the pile toe is at 2L/c, the duration of the signal from zero to 2L/c represents 2 times the full length of the pile.

Generally, the wave speed ranges around 4400 m/s and 3600-3800 m/s for precast concrete piles / spun piles and cast-in-situ concrete piles respectively. Wave speed however, does vary, depending on the concrete quality.

To enhance the velocity signal towards the bottom of the pile, amplification was applied in an exponential manner with unity value at the top and maximum intensity at the time 2L/c after impact.

In general, relatively sharp defined reflections are attributed to impedance changes, whereas slower changing is normally caused by soil.

An impedance decrease resulting in a positive wave, usually means the presence of soft toe, while an impedance increase causes a negative wave, which is considered as hard toe. Thus, necking or inclusions appears as a positive-negative cycle at the pile shaft.

Attached is Table 1 showing all the typical reflectograms for sample signals of defective piles.

SECOND INTERPRETATION (PET, PILE ECHO TESTER SYSTEM)

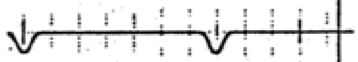
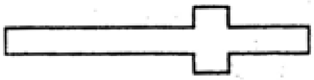
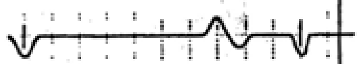
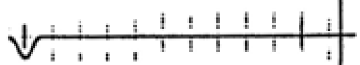
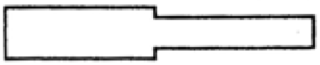
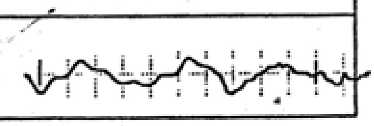
As mentioned earlier, the concept of the test is based on wave propagation through the cross sectional area of the pile which detect changes in pile impedance (Young's Modulus multiply by Area divided by wavespeed).

A hammer blow generates a compression wave at the pile head at t=0 (initial blow). This is detected as the dip in the velocity trace at 0.0m. The wave travels down the pile until it reaches the pile toe. The pile toe represents a reduction in pile impedance. Therefore, a tension wave is reflected from the toe, which travels back to the pile head and is detected by the accelerometer and recorded as the dip in the signal.

For a crack or necking in the pile, the trace will dip below, then immediately rises above the zero line at the defect location. The initial dip is a characteristic response in pile impedance and occurs as the stress wave passes from the original into the reduced cross sectional area. This is immediately followed by the rise to a level above the zero line. The rise in the trace is caused by a reflected compression wave, which is generated by the relative increase in impedance as the wave passes out of the crack and back into the original pile cross sectional area.

For an enlargement/bulb, the trace rises above the zero line and then immediately dips below. The dip is caused by a reflected tension wave which is generated by the relative decrease in impedance as the wave propagates out of the local increase in pile cross sectional area.

TABLE 1: TYPICAL REFLECTOGRAMS

PILE PROFILE	DESCRIPTION	REFLECTOGRAM
	Straight pile, free end, length as expected	
	Straight pile, fixed end, length as expected	
	Straight pile, free end, shorter than expected	
	Increased impedance	
	Decreased impedance	
	Locally increased impedance	
	Locally decreased impedance	
	High L/D ratio and/or high skin friction -no toe reflection	
	Multiple reflections from mid-length discontinuity - toe reflection indiscernible	
	Irregular profile - irregular reflectogram	

Note: In the reflectogram, the direction below the axis is positive (compressive).

ACCEPTANCE AND REJECTION

Shafts with only insignificant reflections from locations other than the pile toe and with a clear pile toe reflection may be accepted.

Where no clear toe reflection is apparent, the experienced test engineer shall state to which depth the test appears to be conclusive.

Where significant reflections from locations above the pile toe are observed, a quantification of the irregularity must be attempted by the test engineer. If such reflection indicates a significant pile impedance reduction, the pile must be rejected.

If the record is complex, the results may be deemed questionable. Construction records (concrete usage, grout pressure records, soil borings) may be valuable in results interpretation or additional numerical analysis modeling may be used to quantify the record.

REMEDIAL ACTION

Rejected or questionable piles may be replaced.

Questionable piles may also be subjected to further testing, e.g., static load testing, dynamic load testing, core drilling, beta-ray logging, ultra-sonic logging, etc.

Remedial action may include pressure grouting through core holes. If the pile top appears questionable, further pile top cut-off and retesting may be advisable. If a majority of piles diagnose as "questionable", complete pile excavation or another test method may be necessary for pile acceptance.

REFERENCE

Turner, M. J. (1997). Integrity testing in piling practice. London, Construction Industry Research and Information Association.