

## **Federation of Piling Specialists Testing Datasheet No 16**

### **Review of Current Integrity Testing Methods**

The recent publication of the Institution of Civil Engineers, Specification for Piling and Embedded Retaining Walls (3<sup>rd</sup> Ed) in 2017 sets out the following five types of adoptable cast in situ concrete pile, barrette and wall integrity testing methods:

- impulse response method (acoustic)
- sonic echo, frequency response or transient dynamic steady-state vibration method (acoustic)
- cross-hole sonic logging method (acoustic)
- distributed fibre optic sensing methods (thermal)
- thermistor based integrity testing (thermal)

The CIRIA R144 Integrity testing in piling practice report published in 1997 individually discusses the above three acoustic integrity methods. Subsequently, the more recent Institution of Civil Engineers Manual of Geotechnical Engineering Volume II published in 2012 also individually discusses the three acoustic integrity methods. However, the thermal methods have started in a limited way to be used subsequent to publication of the Manual in 2012.

The purpose of this datasheet is to provide a direct objective comparison between the different integrity methods that can inform the appropriate selection of integrity testing method for a particular project. It should be recognized that there is no single perfect integrity testing technique. They all have limitations and advantages/disadvantages. It is important to understand these so that the most appropriate method is selected and in some cases visual inspection of the completed works may be sufficient.

The amount / frequency of integrity testing is discussed in the ICE Manual of Geotechnical Engineering (97.8.4). Other factors that should be considered when deciding the type and amount / frequency of testing include: stability of the ground, complexity of the piling methodology (e.g. rock sockets, support fluid), health & safety of the integrity testing technique, degree of redundancy in the overall foundation system and ability to undertake subsequent investigation / remedial works. In dry stable ground, visual inspection of the bore or by digital camera could also be considered.

Importance of appropriately supervised, approved construction processes carried out by competent piling contractors should not be negated by integrity testing. The integrity testing regime should be designed appropriate for each project. The technique should be designed to mitigate the main structural and durability risk to the piles.

Test Type →	Low Strain Integrity Testing	Cross Hole Sonic Logging	Thermal Profiling

<p><b>Geometry of coverage and range of applicability.</b></p>	<p>The test is undertaken from the pile head and returns information about the integrity of the pile shaft.</p> <p>The coverage of the technique is dependent on many factors including impact wavelength, pile head preparation, pile uniformity and surrounding soil conditions. However, as a general rule, the depth of identification of significant anomalies is limited to approximately 30 times the pile diameter.</p> <p>Typically, therefore, the test is less effective on mini piles (have a diameter of 250mm or less). The test is also less effective on piles where the diameter is greater than the impact wavelength (in the case of 1500mm diameter piles and above) and is, therefore, unlikely to return any useful information about the base of the pile.</p> <p>The results may be compromised by the presence of a high density of steel in the pile and the technique is not applicable for testing piles through slabs or pile caps. The test is not effective on wall piles.</p>	<p>The test is undertaken between parallel access tubes, returning information about the quality of the concrete between each pair of tubes.</p> <p>The coverage of the technique is dependent on the placement of these access tubes and typically investigates the quality of the concrete within the core of a pile (i.e. concrete external to the tubes is not tested).</p> <p>The depth of investigation is limited to the depth of tube placement which can be extended to the full depth of the pile. Drilling out the base of the tubes can also enable the interface between the ground and the pile base to be investigated.</p> <p>The technique is effective when access tubes can be spaced between 0.3m and 1.5m apart. Testing pairs of tubes up to 2.5 – 3.0m apart is possible, but the results obtained can be significantly compromised.</p> <p>The test is applicable to barrettes, piles and walls.</p>	<p>The technique evaluates the integrity of the concrete mass surrounding temperature sensors, embedded within the pile.</p> <p>The coverage of the technique is dependent on the placement of the temperature sensors and typically investigates the cover zone of the pile plus an area of the internal core.</p> <p>The depth of evaluation is limited to the depth of cable placement.</p> <p>Cables should typically be spaced up to 1.0m apart. An even number of cables is recommended, with cables diametrically opposite each other to allow for better identification of anomalies.</p> <p>The test is applicable to barrettes, piles and walls.</p>
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<p><b>Time and duration of testing</b></p>	<p>Tests are carried out once concrete has cured, typically after 7 days.</p> <p>Piles can be re-tested so long as the pile heads remain accessible.</p> <p>The test is quick with typically up to 30 prepared piles being tested in a day.</p> <p>Results are issued after interpretation.</p>	<p>Tests are carried out once concrete has cured, typically after 7 days.</p> <p>Piles can be re-tested at any time so long as there is still access to the tubes and they have been protected. Once a satisfactory result has been obtained, the tubes are typically grouted up, after which no further testing can be undertaken.</p> <p>The test is relatively quick with typically up to 15 piles being tested in a day.</p> <p>Results are issued after interpretation.</p>	<p>Testing is carried out during the initial phase of concrete hydration, typically 0 – 48 hours.</p> <p>Re-testing after the concrete has cured is not possible.</p> <p>The continuous test is undertaken as piles are constructed.</p> <p>Results are issued after interpretation.</p>
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<p><b>Data &amp; Interpretation</b></p>	<p>The test records the acoustic properties of the pile in response to a small (low strain) excitation of the pile head.</p> <p>It is well suited for identifying major structural cracks or very significant anomalies (e.g. necking) in the upper pile shaft. Significant responses at an intermediate depth can sometimes mask responses from a greater depth.</p> <p>The test is influenced by construction details and ground conditions which needs to be taken account of in the analysis.</p> <p>Well established criteria exist for interpreting the results.</p> <p>A number of different data acquisition systems and software packages are available, presenting data in time domain (Sonic Echo) or frequency domain (Transient Dynamic Response).</p> <p>Whilst interpretation of data from Sonic Echo and Transient Dynamic Response methods is different, both suffer the same depth limitations.</p>	<p>The test measures the transit time and attenuation of an acoustic signal between parallel access tubes.</p> <p>The results are affected by the signal path length as well as the modulus and density of concrete between tubes.</p> <p>Well established criteria are available which define the typical variations in signal arrival time and attenuation/amplitude that can be considered anomalous.</p> <p>The three dimensional size of an anomaly can be determined from tomography profiling. This facilitates a structural assessment of the integrity of the as-built pile.</p>	<p>The test measure the heat produced during the concrete hydration process over the depth of the pile.</p> <p>The results can also be influenced by construction details such as box outs, concrete placement methods, concrete mix and ground / groundwater conditions. These factors need to be taken account of in the analysis.</p> <p>The technique is a new and developing technology. Criteria for evaluating the results of thermal profiling are currently emergent and subjective. More research and field trials are required to bring robustness and industry confidence to the evaluation criteria.</p> <p>As well as providing information about the concrete, the test can also provide information about the alignment of the reinforcement cage and shape of the pile/panel.</p>
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<p><b>Construction requirements</b></p>	<p>Access is required to the whole pile head, which needs to have been trimmed down to sound concrete.</p> <p>The sequencing of testing is important to ensure that the testing is carried out before placement of reinforcement cages.</p>	<p>Steel access tubes filled with water are required from which the measurements can be taken. These are installed in piles selected for testing, normally attached to the inside of the reinforcement cage over the full depth of the pile. This will generally necessitate a full length cage.</p> <p>As a rule of thumb for circular piles, there should be one access tube for every 0.3m of pile diameter.</p> <p>Consideration needs to be given to steel congestion, tremie pipe position and protection of the tubes (e.g. caps and connections). The tubes are normally filled with grout once the testing has been completed.</p> <p>The test is susceptible to debonding of the sonic logging tubes whilst concrete is still green, issues at the joints and channelling of bleed water. The installation of access tubes within the concrete does provide a potential remedial option for some defects.</p>	<p>Strings of thermistors or fibre optic cables are attached to the reinforcement cage on selected piles. These are typically attached after it has been fabricated and requires a full length reinforcement cage.</p> <p>A similar rule of thumb for the number of cables within a circular pile can be followed, allowing for 1 cable per 0.3m of pile diameter.</p> <p>The durability of the different systems is improving but consideration needs to be made for protecting the sensors, during placement and of any data acquisition units above ground.</p>
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<p><b>Health &amp; safety</b></p>	<p>The relatively straightforward nature of the low strain integrity test results in there being very few health and safety risks directly associated with it.</p> <p>However, proper management of health and safety is required to ensure that the working environment for the testing technician, including access to the pile position, is both safe and not detrimental to their long term wellbeing.</p>	<p>Although carrying out the cross hole sonic logging test is relatively straightforward and low risk, it is the installation of the access tubes which need care consideration for a health and safety point of view.</p> <p>Where reinforcement cages are to be spliced together, based on current technology, there is a significant risk to those installing the reinforcement of serious hand / arm injuries.</p> <p>In order to reduce the risks to reasonably practicable levels, it is essential that the full range of testing options is carefully considered.</p>	<p>The addition of thermal sensors to reinforcement cages is relatively straightforward and low risk.</p> <p>Careful management of health and safety on site is required to ensure that monitoring cables do not pose trip hazards and that the monitoring technicians are able to carry out their works in a safe and healthy environment.</p>
<p><b>Supply chain</b></p>	<p>There is a well established supply chain, however, the technical knowledge of the test house and experience of the technician play an important role in the collection of quality records and correct analysis of data.</p>	<p>There is a well established supply chain, however, the technical knowledge of the test house and experience of the technician play an important role in the collection of quality records and correct analysis of data.</p>	<p>Commercially available systems for thermal profiling are available but both the availability and number of practitioners is still developing.</p>

<b>Summary</b>	Low Strain Integrity Testing is a simple, quick, low cost test with limited ability for whole pile integrity evaluation. Best suited to identifying major structural defects in the upper pile shaft for piles in stable homogeneous ground.	Cross Hole Sonic Logging is a well-established integrity test with proven evaluation criteria. Safety consideration for mitigation of manual cage assembly required.	Thermal Profiling is a developing integrity technique with improved manual cage assembly health & safety benefits. It also offers the possibility of providing information about more than just the integrity of the concrete. Criteria for evaluating the results of thermal profiling are currently emergent and subjective.
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