

PILE INTEGRITY EVALUATIONS: THE NEED FOR SPECIFICATIONS

Pile integrity 'tests' are now required on most piling contracts. The test methods and procedures are, however, rarely specified. Consequently, integrity surveys can (and frequently are) undertaken using inappropriate testing systems which provide little, or in some cases, no information regarding the integrity of the piles. Reporting can also be misleading. Facts, arising directly from the test data, and inferences are often indistinguishable and reports rarely provide the Specifier with any indication of the limitations of its conclusions or the level of assurance afforded by the pile integrity survey.

Figures 1 & 2 show 'test' data from inadequate systems which routinely measure the response of the test system and not that of the pile. Surveys using these systems provide little assurance of pile integrity. Despite this,

and as a result of market pressures, these systems remain in widespread use.



Figures 3 & 4 show 'sonic echo' results from a sound and a defective pile, respectively. The defective pile has the same nominal dimensions as the sound pile but contains a serious neck at 2m depth - see photo. The two test results are practically identical and the major defect is thus not detectable. The sonic echo method, although widely used, was developed for checking pre cast piles for cracks incurred during driving. Sonic echo tests are not generally suitable for evaluating cast in place piles, particularly those formed in variable strata.

Figures 5 - 8 show the more sophisticated Frequency Response and Relative Impulse Response (RIR) data for the sound and defective pile above. The affect of the defect is clear. The Frequency Response and RIR methods were developed specifically for the evaluation of cast in situ piles.

In response to requests from several Local Authorities and leading Consulting Engineers, N D Technology has developed a 'model' specification for the evaluation of cast in situ piles. The Specification is generic and is designed to ensure that integrity evaluation works are undertaken to a worthwhile standard.

"Pulse Echo"

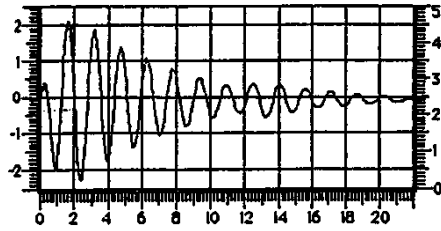


FIG 1: INADMISSIBLE DATA

"Sonic Echo"

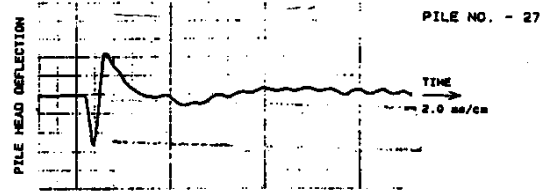


FIG 2: INADMISSIBLE DATA

Sonic Echo

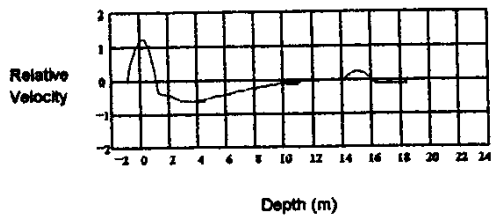


FIG 3: 15m SOUND PILE

Sonic Echo

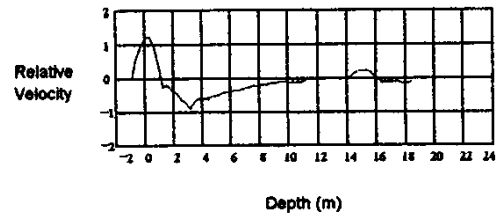


FIG 4: NECK DEFECT @ 2m

Frequency Response

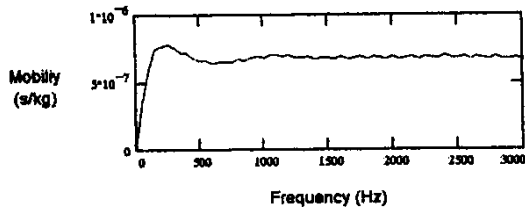


FIG 5: 15m SOUND PILE

Frequency Response

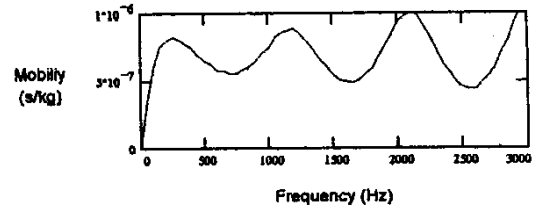


FIG 8: NECK DEFECT @ 2m

RIR Reflectogram

Visualization

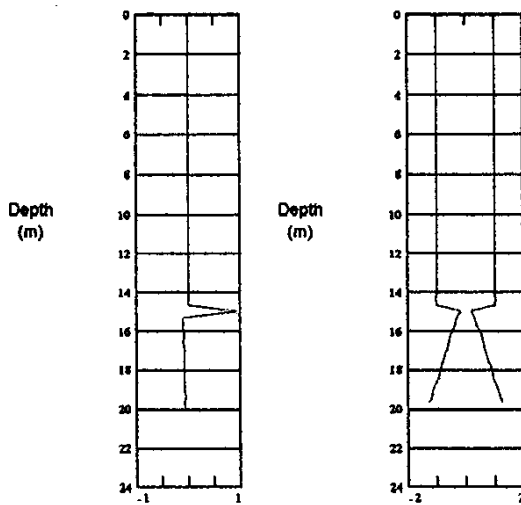


FIG 7: 15m SOUND PILE

RIR Reflectogram

Visualization

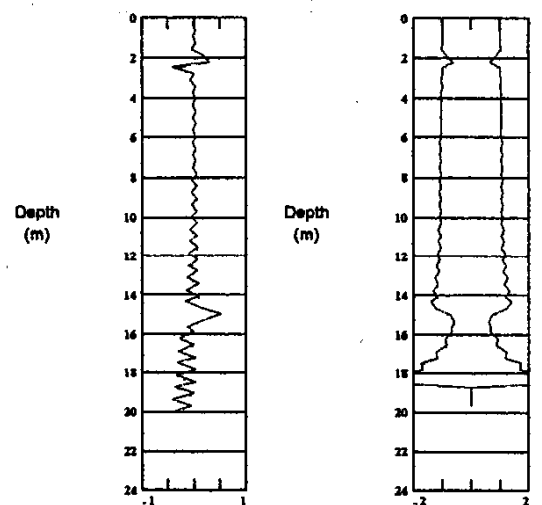


FIG 8: NECK DEFECT @ 2m

Specification for the non destructive integrity evaluation of piles
 Specification NDT/PIESpec - 198

Purpose of Works

The survey is to serve as a screening process to identify acoustically anomalous piles which can then be then be subject to further engineering scrutiny.

The survey data will be used as a factor in assessing the constructed quality of each pile and not as final proof of the serviceability of each pile.

Specialist Test Organization

The works shall be carried out an approved and independent Specialist.

The Specialist must supply all necessary personnel and plant to undertake the work.

Test Method

All piles shall be evaluated by the Relative Impulse Response (RIR) method as specified in detail in the following sections. The following methods shall not be used: Sonic Echo, TNO, PIT, Pulse Echo, Transient Dynamic Response.

Compliance

The test organization may be requested for the following to demonstrate compliance with the specification:

- 1) Calibration certificates for the impulse hammer, vibration transducer and digital signal processing unit, or a whole system calibration.
- 2) An example test report.
- 3) Computer simulations of the pile responses at the site to be surveyed:
 - a) The Frequency Response (FR) of an infinitely long pile at the given site
 - b) The FR and Relative Impulse Response (RIR) of pile of the design length.
 - c) The FR and RIR of a pile containing a 30% reduction in impedance at a depth 3m which extends to a depth of 3.25m.

Test Equipment

The test equipment shall comprise a vibration transducer, an impulse hammer and a digital signal processor.

The vibration transducer shall measure the pile head velocity.

The impulse hammer shall impart and measure an impulsive force to the pile head.

The digital signal processor shall simultaneously acquire both the force and velocity signals and facilitate storage of the digital data for post processing and reporting.

The measuring system and both transducers shall have dynamic ranges of at least 60 dB and flat frequency responses over the minimum bandwidth of 20 - 2500 Hz.

Site Measurements and Computations

At least the following shall be computed on line and on site for each pile.

The axial frequency response of the pile expressed as Mobility **M** ($\text{kg} \cdot \mu\text{s}^{-1}$) versus frequency (Hz).

The pile head dynamic stiffness **K** ($\text{MN} \cdot \text{mm}^{-1}$)



The pile head characteristic impedance Z ($\mu\text{s.kg}^{-1}$) as computed from the geometric mean of the mobility spectrum from 100 Hz to 1000 Hz.

The frequency response shall be measured over the following minimum bandwidths:

- Piles with diameters $\leq 900\text{mm}$, 0-2000 Hz bandwidth
- Piles with diameters $> 900\text{mm}$, 0- 1000 Hz bandwidth

Additional computations

The Relative Impulse Response (RIR) of each pile shall be computed from the measured data.

The RIR is defined as the reflection coefficient between the actual pile and a nominal pile of infinite length embedded in the same strata.

RIR shall be processed to produce graphs of Reflection Coefficient versus depth and root Impedance versus depth. The latter shall be used to produce a visualization of the in-situ pile form.

Site Reporting Requirements

An initial evaluation of the piles shall be undertaken frequency response or (if available) the RIR site data.

Each pile shall be assigned an initial classification. The classification signifies the acoustic status of each pile and what further actions are required (if any) on completion of the site survey. The classifications and their meanings are defined in the table below.

Site Classification	Select when	Required Actions by Main Contractor
OK REVIEW	No impedance anomalies are present Assessment of pile is pending receipt of further information or data requires further processing	None, proceed as normal Obtain final assessment of pile before proceeding to incorporate pile in the works
TRIM & RETEST	Anomaly is present at pile head which precludes evaluation of the underlying pile shaft	Retrim pile to sound concrete and schedule a retest
ANOMALOUS	A reduction of impedance below that appropriate for the nominal pile shaft has been detected	Obtain Engineer's instruction before proceeding to incorporate pile

A list shall be prepared which shows for each pile surveyed the pile number and its initial acoustical classification. The list shall be presented to the Main Contractor by the test engineer before leaving site

Detailed Analysis of test data

The nominal characteristic impedance value for the pile shaft shall be estimated from consideration of the pile diameter, the concrete mix and the pile age at the time of the test. The RIR shall be computed between the test data and a pile of infinite length and nominal characteristic impedance, founded in the prevailing strata. The RIR shall be used to locate any reductions in impedance below the nominal value for the pile.

Acoustical classification of piles



The RIR data shall be used to provide a final acoustical classification for each pile using the categories defined below:

Classification	Meaning
OK	Pile is acoustically satisfactory. i.e. the pile is of at least the nominal impedance to the full penetration of the test
(OK)	Pile is acoustically anomalous, but may be regarded as satisfactory subject to certain stated conditions. e.g. subject to verification of pile bored length, inspection of pile top, satisfactory cube results etc.
ANOMALOUS	Pile is acoustically anomalous. i.e. pile contains a reduction in pile impedance below that appropriate for the pile diameter and concrete properties within the penetration of the test

Piles with classifications other than OK shall be subject to the review by the Engineer.

Formal Reporting

Timescales

A formal report shall be prepared for each site visit. The report shall issued not later than 3 working days after the site visit.

Format

The report shall be of the following format:

- 1) A summary table of results
- 2) A summary of how many piles were evaluated this visit and cumulatively from previous visits
- 3) General text describing the capabilities and limitations of the tests and explanations and/or definitions of any special terms used.
- 4) The RIR test data

Information to be presented for each pile

- 1) The installed pile length.
- 2) The nominal pile diameter.
- 3) The concrete mix.
- 4) The length of steel reinforcing.
- 5) A description of the strata in which the pile is founded giving horizon levels relative to piling platform level (PPL) and strength indices (i.e. SPT, Cu, CPT etc.)

Where information was unavailable at the time of reporting write "not advised".

Test data to be provided for each pile

- 1) The pile head level at which the test was undertaken with respect to piling platform level (PPL).
- 2) The time and date of the test.
- 3) The approximate age of the pile when tested.
- 4) Any relevant site observations.
- 5) The assumed bar velocity within the pile as derived from the pile age and concrete mix used in the analysis.
- 6) The assumed values of soil shear wave velocity (m,s-1) used in the analysis.

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- 7) A judgement of the quality of the measured data as affected by the pile preparation expressed as low, medium or high.
 - 8) The expected penetration depth of the test.
 - 9) Graphs of reflection coefficient versus depth (reflectogram) and square root of impedance versus depth (pile profile visualization). The visualization shall be reconstructed to the expected penetration of the test.
 - 10) The acoustical classification of each pile.

Reporting of Anomalies

Where an anomaly is found, the following shall be stated:

- 1) The depth of the anomaly below test level.
- 2) The suspected nature of the anomaly (if appropriate).
- 3) Factors to corroborate 2).
- 4) Suggested actions.

PILE PREPARATION

- 1) All piles to be surveyed in any one site visit shall be prepared fully in advance in accordance with the following sub sections.
- 2) The piles shall have attained the following ages before scheduling the PIE survey. The pile ages depend upon the concrete mix:
C30 MPa or greater with not more than 25% cement replacement - 3 days.
All other mixes - 5 days.
- 3) The piles may be surveyed from cast level or cut off level. For piles cast to ground level (e.g. CFA and driven cast in-situ piles) the former is recommended.
- 4) The pile tops shall be left clean and free from debris and surface water. Unrestricted vertical access shall be given to the pile heads. Reinforcing cages for ground beams / pile caps must not be placed until the survey has been completed.
- 5) If blinding is to be placed, the blinding concrete in contact with the pile shall not exceed a thickness of 10% of the pile diameter.
- 6) The pile heads shall be prepared (if necessary) to provide an approximately level surface, perpendicular to the pile axis, over at least 75% of the pile cross section. The concrete within this surface shall be hard and free from laitence and fractured, loose material. This may be checked by tapping the surface with a small hammer and checking that it rebounds cleanly and that no material breaks off. If the piles are trimmed, the final trimming of the piles shall be with small air tools, CP9 or similar.
- 7) If the piles have been exposed, the length of the exposed section above the reduced ground level shall not exceed 3 pile diameters.