Technical Specification

Transport and Main Specifications
MRTS68 Dynamic Testing of Piles

October 2016

Queensland Government

Feedback: Please send your feedback regarding this document to: tmr.techdocs@tmr.qld.gov.au

Contents

1 Introduction

This Technical Specification applies to high strain dynamic testing of driven piles (driven using either MRTS65 or MRTS66) using wave equation analysis techniques. Dynamic testing of all test piles and at least one pile per pier and abutment and at least 10% of all driven piles is required in Transport and Main Roads Specifications MRTS65 *Precast Prestressed Concrete Piles* and MRTS66 *Driven Steel Piles*. Dynamic testing may also be used in the following situations:

a) to determine the load capacity of a pile and determine its condition

b) obtain the history of a pile's capacity in difficult conditions in order to determine the driving limit for subsequent piles, and

c) to facilitate the advanced analysis of PM monitoring of pile driving.

High strain dynamic testing is often referred to as PDA™ testing, however PDA™ testing is a proprietary form of high strain dynamic testing.

High strain dynamic testing should not be confused with Pile Monitoring (PM). While dynamic testing could be used as a pile monitor this is not the intent of the specification. Generally the PM data should be correlated with the dynamic testing data.

This Technical Specification shall be read in conjunction with MRTS01 *Introduction to Technical Specifications*, MRTS50 *Specific Quality System Requirements*, MRTS65 *Precast Prestressed Concrete Piles*, MRTS66 *Driven Steel Piles* and other Technical Specifications as appropriate.

2 Definition of terms and Symbols

The terms used in this Technical Specification shall be as defined in Clause 2 of MRTS01 *Introduction to Technical Specifications*.

In addition, terms listed in Table 2 are applicable to this Technical Specification.

Table 2 – Definition of Terms

Term	Details
Difficult conditions	Subsurface conditions which result in there being difficulty in determining the founding level for driven piles or in determining the capacity of driven piles.
High strain dynamic tester	A device consisting of strain gauges attached to the pile, associated electronics and software used to monitor and dynamically analyse the pile during most (if not all) of the driving process, or on subsequent restrike. For example, a Pile Driving Analyser™.
PM	Pile Monitor: Any suitable device which can measure set and pile movement and used to monitor (at least) the final set (at least the last 10 blows) of the driving process, or of subsequent restrikes.
Restrike	A restrike occurs when a pile has been driven to or below design level without achieving geotechnical capacity. If a pile in such a case is allowed to rest for at least 12 hours, the pile can be retested and is often found to have set up to such an extent that geotechnical capacity has been reached.

2.1 Notation

The following symbols are used in this Technical Specification.

Table 2.1 – Notation

Symbol	Definition
E	Secant modulus of pile at the strain level applied during the Dynamic testing.
A	Cross-sectional area of pile.
c	Stress wave speed.
F	Applied force.
ε	Measured average section strain.
A’	Cross-sectional area of the pile at the measuring location.

3 Referenced documents

The following documents are referenced in this Technical Specification.

Table 3 – Referenced documents

Number	Details
MRTS01	*Introduction to Technical Specifications*
MRTS50	*Specific Quality System Requirements*
MRTS65	*Precast Prestressed Concrete Piles*
MRTS66	*Driven Steel Piles*
ASTM D4945	*Standard Test Method for High-Strain Dynamic Testing of Deep Foundations*
AS 2157	*Piling design and Installation*

4 Quality system requirements

4.1 Hold Points, Witness Points and Milestones

General requirements for Hold Points, Witness Points and Milestones are specified in Clause 5.2 of MRTS01 *Introduction to Technical Specifications*.

The Hold Points, Witness Points and Milestones applicable to this Technical Specification are summarised in Table 4.1.

Table 4.1 – Hold Points, Witness Points and Milestones

Clause	Hold Point	Witness Point	Milestone
7.3	1. Approval of Wave Equation Analysis and assessment of required final set		
8	2. Approval of dynamic pile testing procedure		Submission of procedure for dynamic testing of piles (12 working days)
10.1		Dynamic testing of piles	

5 Interpretation and accuracy of results

Statements on the precision and accuracy of all directly measured values of strain and acceleration shall be included in the results data.

Where geotechnical data exists, the analysis must take cognisance of the results of the geotechnical investigation to determine the relevant analysis parameters.

Any analysis submitted for approval or in support of the load capacity of a previously driven pile, the Administrator reserves the right to determine the values of any parameters used, and may request that the analysis be revised using these modified parameters.

Raw acceleration measurements may be in error, and must be corrected in order to establish a velocity-time response which is more accurate than the raw and uncorrected acceleration measurements. Blows that are applied eccentrically to the pile head, or not in line with the pile axis may result in inaccurate estimates of the average section response, especially if only two sets of gauges are used. Ensuring well directed hammer blows, and using four sets of gauges rather than two sets maximizes data accuracy as well as providing greater measurement redundancy. Average section strain-time and acceleration-time responses or their derived stress/force/velocity response must also be established.

Computing mobilised soil resistance requires consideration of time and soil effects and the input of additional parameters and its accuracy depends on the accuracy of such consideration and input.

6 Extent of work

Where directed by the Administrator, dynamic testing of piles using wave matching analysis shall be used to confirm the ultimate pile capacity as determined by the Hiley Formula as quoted in MRTS65 and MRTS66.

The number of piles to be dynamically tested shall be as stated in Clause 1 of Annexure MRTS68.1. Note however this may be increased by the generic requirements in either MRTS65 or MRTS66 when the Contractor elects to use a different hammer than the design hammer.

The location of piles to be dynamically tested shall be as stated in Clause 2 of Annexure MRTS68.1 or as otherwise directed by the Administrator.

7 Application of dynamic testing of piles

7.1 General

Dynamic testing of piles is applicable to individual piles to determine that the pile has sufficient geotechnical strength to resist the applied design loads. It is applicable to deep foundation units which function in a similar manner to foundation piles regardless of their method of installation, provided that they are receptive to high strain impact testing.

7.2 Determination of the load capacity of a driven pile

Piles may be tested immediately following driving, or on a restrike basis, in both cases the method of analysis is the same.

Where dynamic testing is carried out in order to determine the load capacity of an existing pile, a wave matching analysis, based on the measurements recorded during re-strike, shall be submitted to the Administrator for consideration.

After driving, and before a pile's capacity is considered to be conforming, an analysis of the recorded data shall be carried out to confirm the values assumed during driving. Such an analysis shall be carried out on all piles tested.

Should the analysis indicate that any dynamically tested pile has a capacity less than that specified, then that pile shall be re-driven immediately using the final set assessed from the analysis. Alternatively, the Administrator may require that the pile be restruck in order to assess time dependent effect on pile capacity (setup or relaxation). Restrike testing shall be at the discretion of the Administrator.

7.3 Piles in difficult conditions

Where dynamic testing of piles is carried out in order to determine the driving limit for piles in difficult conditions, an analysis, based on the measurements recorded during driving, including driving stresses, shall be carried out to obtain a history of a pile's capacity over the driven length. An assessment shall then be made of the above analysis, the pile driving records and the available geotechnical information to determine the required final set for subsequent piles. The complete analysis and assessment of the required final set shall be submitted to the designer for approval. A copy of the approved complete analysis and assessment of the required final set shall be provided to the Administrator. **Hold Point 1**

> It would be expected that the Designer would give a response within three working days. The Administrator would be expected to submit the analysis report including the designers comments to TMR as part of the as constructed data as required by Clause 11 and MRTS50.

Following approval by the Designer of the analysis assessment of the required final set, subsequent piles may be driven to the estimated final set, but not less than the minimum penetration as shown in the Drawings. Should the Contractor wish to proceed with driving piles prior to approval of the analysis, he does so at his own risk, and if, as a result of the final analysis further driving is required this shall be undertaken at the Contractors risk and expense.

Values of soil parameters shall be varied during analysis (wave analysis) to provide a range of outputs. After driving, and before the analysis is considered to be representative of the pile in the existing environment, an analysis of the recorded data shall be carried out to confirm the values assumed during driving. Such an analysis shall be carried out on all piles tested. Any estimate of pile capacity based on dynamic testing data using closed form solutions such as the Case Method shall be taken as indicative only, and shall not form the sole basis of pile acceptance.

Should subsequent analysis indicate that any dynamically tested pile has a capacity less than that specified, then all piles installed on the basis of the results of that test pile shall be re-driven using the final set assessed from the revised matching equation analysis incorporating the soil parameters derived from the analysis, the pile driving records and the available geotechnical information.

8 Testing procedure

The Contractor shall submit to the Administrator at least 12 working days before piling is to commence, a procedure for dynamic testing of piles. **Milestone** The procedure shall be based on the requirements of this Technical Specification. Dynamic pile testing shall not commence until the procedure has been approved by the Administrator. **Hold Point 2**

Dynamic testing shall be carried out during initial driving to ensure pile driving does not overstress piles and to establish acceptance criteria for other driven, but untested piles. As required by MRTS65 or MRTS66 PM testing shall also be performed at end of drive on dynamically tested piles in order to establish correlations between dynamic testing and PM data.

Restrike testing may be required in order to assess time dependent effects (set up or relaxation). No re-strike testing shall be accepted without the prior written approval of the Administrator.

9 Equipment requirements

9.1 Equipment for applying impact force

The equipment for applying the impact force shall be a pile driving hammer. It shall be positioned so that the impact is applied axially to the head of the pile and concentric with the pile.

The pile driving hammer used shall be either a conforming hammer or an alternative hammer, as defined in MRTS65 or MRTS66.

> Usually the same pile hammer as that used or proposed to be used on the project will be used for dynamic testing.

9.2 Equipment for obtaining dynamic measurements

9.2.1 General

The equipment shall include transducers, which are capable of independently measuring strain and acceleration versus time at specific locations along the pile axis from the moment of impact until the pile comes to rest.

The transducers shall be placed at between two and three pile diameters below the pile head. Where the pile head is close to or below ground level, or water level, the transducers may be placed closer to the pile head as long as the data quality is specifically assessed and demonstrated to be suitable. Measurements will necessarily be affected by bending, however, in determining an average section strain or acceleration in the presence of bending, the use of four sets of transducers is recommended. Where it can be shown that the Contractor is able to align the hammer and pile with sufficient accuracy to minimise bending the use of two sets of transducers may be allowed at the discretion of the Administrator.

Care shall be taken to ensure that the equipment is securely attached to the pile so that slippage does not occur.

The equipment shall be in calibration and have an accuracy of 2% throughout the applicable range. If damage is suspected during use, the transducers shall be re-calibrated or replaced.

Equipment which is out of calibration, or which cannot be demonstrated to be calibrated or is damaged in such a way that the calibration may be affected shall be recalibrated prior to use.

Usually a calibration certificate or other evidence of regular calibration shall be provided. Other evidence may include a calibration procedure from the QA system under which the equipment is used combined with evidence that the QA calibration procedure has been routinely used.

9.2.2 Force and strain transducers

9.2.2.1 General

Force measurements shall be made by either force transducers in accordance with the requirements of Clause 9.2.2.2 or strain transducers in accordance with the requirements of Clause 9.2.2.3.

9.2.2.2 Force transducers (see also ASTM D4945)

Where force transducers are used, the transducers shall be placed between the pile head and the driving hammer.

Force transducers shall have an impedance between 50% and 200% of the pile impedance where pile impedance is defined by the formula:

Pile impedance = $\frac{E.A}{c}$

Where the terms are as defined in Table 2.1.

The output signal shall be linearly proportional to the axial force even under eccentric load application. The connection between the force transducers and the pile shall have the smallest possible mass and least cushion necessary to prevent damage.

Force transducers are now rarely used.

9.2.2.3 Strain transducers (see also ASTM D4945)

Strain measurements will necessarily be affected by bending, however, in determining an average section strain or acceleration in the presence of bending, the use of four set of transducers is recommended. Where it can be shown that the Contractor is able to align the hammer and pile with sufficient accuracy to minimise bending, the use of two sets of transducers may be allowed. The transducers shall be securely attached by bolting so that no slippage occurs.

The strain transducers shall have a linear output over the entire range of possible pile strains and shall have a natural frequency when attached to the pile in excess of 2 kHz.

The measured average strain shall be converted to force using the formula:

$F = \varepsilon.E.A'$

Where the terms are as defined in Table 2.1.

9.2.3 Acceleration, velocity and displacement transducers (see also ASTM D4945)

Velocity measurements shall be obtained using accelerometers, provided that the signal can be processed by integration by the equipment used for reducing data.

A minimum of two accelerometers with a resonant frequency on the pile above 2 kHz shall be used.

The accelerometers shall be attached securely to the pile by bolting or gluing so that no slippage occurs.

Accelerometers for use on concrete piles shall function linearly to at least between 1 kHz and 10 kHz. Accelerometers for use on steel piles shall function linearly to at least between 2 kHz and 20 kHz.

Either alternating current or direct current accelerometers may be used. If alternating current devices are used, the time constant shall be at least one second.

Alternatively, velocity or displacement transducers may be used to measure velocity, provided that they are equivalent in performance to the accelerometers specified above.

9.2.4 Equipment for recording, reducing and displaying data

9.2.4.1 General

The recording and display equipment shall be capable of transforming the signals from the measuring transducers to graphical representation of force and velocity versus time. It is desirable to also determine the acceleration and displacement of the energy developed in the pile.

The equipment shall include a computer and/or digital data storage device for displaying the force and velocity traces, and for recording the data for future analysis.

Where applicable, equipment shall be in calibration prior to use.

9.2.4.2 Measuring frequency

The signals from the transducers shall be recorded electronically in digital form such that frequency components have a low pass cut-off frequency of 1.5 kHz. Digital data shall be recorded at least at a frequency of 10 kHz and preferably 20 kHz for each data channel.

9.2.4.3 Display equipment

Equipment for displaying the signals from the transducers shall be used on site at all times during testing. The display equipment shall be safe and accessible to the Administrator during testing.

9.2.5 Signal transmissions

Signals from the transducers shall be transmitted to the equipment for recording, reducing and displaying the data by means of a system which limits electronic or other interference to less than 2% of the maximum signal.

The signals arriving at the recording, reducing and display equipment shall be linearly proportional to the measurements obtained at the pile.

10 Obtaining dynamic measurements

10.1 General

Dynamic testing of piles shall be a Witness Point. **Witness Point**

Where dynamic testing of piles is carried out either for test piles and for routine pile driving, depth measurements, drop heights, sets, compression and tension stresses shall be recorded throughout the entire driving length of the pile.

Where dynamic testing is carried out in order to determine the bearing capacity of an existing pile, dynamic measurements shall be recorded over a minimum of 10 impacts during initial re-driving. Dynamic properties shall then be determined from 1 or 2 representative impacts among these 10. A

sufficiently long period of time shall be allowed to elapse after the end of initial driving so that any pore water pressure and soil strength changes have occurred. Further geotechnical conditions, such as underlying compressible layers, shall also be considered in determining whether the dynamic properties so determined are truly representative of the conditions.

10.2 Preparation of pile for dynamic pile testing

The pile shall be marked clearly at appropriate intervals.

Appropriate transducers shall be securely attached to the pile by bolting.

The pile shall be pitched and the equipment for applying the impact force shall be positioned so that the force is applied axially and concentrically with the pile.

The equipment for recording, reducing and displaying data shall be set up so that it is operational. An internal calibration check shall be carried out and the force and velocity signals shall be reset to zero.

If set rebound measurements are not recorded by the dynamic testing device then, the PM (or other remote measurement device with equivalent or superior performance specifications) shall be used to measure set and rebound remotely.

10.3 Recording data

The following data shall be recorded during dynamic testing:

a) the number of impacts for a specific penetration

b) the drop of the ram or ram travel length of the impact applying equipment

c) the mass of the ram

d) the number of blows per minute delivered by the hammer

e) for double acting hammers the pressure in the pressure line to the hammer

f) a series of force and velocity measurements which shall be reduced and displayed in real time

g) set and rebound (measured remotely with PM or equivalent device)

h) the condition and thickness of the packers

10.4 Data quality checks

For confirmation of data quality:

a) the force and the product of velocity and impedance of the pile (as defined in Clause 9.2.2.2) shall be periodically compared at the moment of impact for agreement, and

b) the force and velocity versus time plots shall be compared over a series of consecutive impacts for consistency, and

c) internal calibration checks shall be performed at the beginning and end of each data set.

10.5 Analysis of measurements

The maximum and minimum impact forces and velocities shall be recorded for the selected representative blows. The impact force and velocity shall be obtained from the equipment for reducing and displaying data.

The maximum energy transferred to the pile at the location of the transducers shall be calculated.

The recorded data shall be analysed manually or in a field computer by use of a recognised one-dimensional wave equation analysis to compute the mobilised resistance. The recorded data shall also be subjected to wave matching computer analysis. Wave matching analysis shall take precedence over field estimates.

By the application of proper engineering judgment, the results of the analysis shall be used to assess:

a) the bearing capacity and integrity of the pile

b) the driving system performance

c) the maximum dynamic driving stresses on the pile, and

d) the static soil resistance distribution on the pile.

Normally there is better correlation between mobilised resistance and bearing capacity where there is a measurable net penetration per impact.

11 Reporting

A report of the dynamic testing of each pile shall be prepared.

The Contractor shall provide a complete report, including digital data, to the Administrator for forwarding on to the Executive Director (Structures) as required by MRTS50.

The report shall include the following information, where applicable:

a) General
   i. project identification
   ii. project location
   iii. test site location
   iv. owner
   v. structural engineer
   vi. geotechnical engineer
   vii. pile Contractor
   viii. test boring Contractor
   ix. designation and location of nearest test boring with reference to test pile
   x. log of nearest test boring
   xi. horizontal control datum, and
   xii. vertical control (elevation) datum.

b) Pile installation equipment
   i. make, model, type, size and recent service history of hammer
   ii. weight of hammer and ram
   iii. stroke of ram

iv. rated energy of hammer

v. rated capacity of compressor

vi. type, dimensions and stiffness values of cap block and pile cushion

vii. weight and dimensions of drive cap and follower

viii. size of predrilling or jetting equipment

ix. type, size, length and weight of mandrel, and

x. detailed specifications of any special arrangement for applying impact.

c) Pile installation

i. date driven (installed)

ii. operating pressure for double-acting and differential type hammers

iii. throttle setting for a diesel hammer during testing

iv. fuel type for a diesel hammer

v. description of special installation procedures used, such as piles cased off

vi. driving records (of all blows monitored)

vii. final penetration resistance

viii. penetration for the last 10 blows with the hammer

ix. penetration resistance during restrike

x. when cap block replaced (indicated on log)

xi. when pile cushion replaced (indicated on log), and properties of the cushion

xii. cause and duration of interruption to pile installation, and

xiii. notation of any unusual occurrences during installation.

d) Dynamic testing

i. detailed description of all components of the equipment for obtaining dynamic measurements and equipment for recording, reducing and displaying data

ii. data tested

iii. test pile identification

iv. the modulus of elasticity, density and strain wave speed of test pile,

v. sequence of pile driving test carried out, such as end of initial driving, beginning of restrike, lengths of pile being driven, length embedded and length below equipment for obtaining dynamic measurements

vi. penetration resistance during dynamic testing (of all blows monitored)

vii. the range, average and standard deviation of the measurements of the:

- maximum and minimum impact force
- maximum computed tension in the pile

- impact velocity
- maximum acceleration
- final displacement, and
- maximum energy.

viii. the assumed accuracy (precision) of all field measurements and derived values

ix. the one-dimensional wave theory used for the analysis of the pile driving

x. the variables entered into the wave theory equation, such as damping, quake and resistance

xi. the computed bearing capacity of the pile at the time of testing, and

xii. comments on the integrity of the pile.

12 Supplementary requirements

The requirements of MRTS68 *Dynamic Testing of Piles* are varied by the supplementary requirements given in Clause 3 of Annexure MRTS68.1.