Main Roads
Technical Standard

MRTS68

Dynamic Testing of Piles

June 09

Queensland Government

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Dynamic Testing of Piles

1 INTRODUCTION

This Standard applies to the dynamic testing of piles using wave equation analysis techniques to –

a) determine the load capacity of a previously driven pile; or

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

This Technical Standard shall be read in conjunction with MRTS01 *Introduction to Technical Standards*, MRTS50 *Specific Quality System Requirements* and other Technical Standards as appropriate.

This Technical Standard forms part of the Main Roads Specifications and Technical Standards Manual.

2 DEFINITION OF TERMS

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

3 REFERENCED DOCUMENTS

There are no Australian Standards referenced in this document.

4 QUALITY SYSTEM REQUIREMENTS

4.1 Hold Points, Witness Points and Milestones

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

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

Table 4.1 – Hold Point s, 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 (14 days).
10.1		Dynamic testing of piles.	

5 INTERPRETATION AND ACCURACY OF RESULTS

Statements on the precision and accuracy of directly measured values of strain and acceleration are included in this Standard.

The values of stress, force, velocity, developed energy and displacement which are derived by computation from the measured acceleration and force or strain, are somewhat less accurate. 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.

In any wave equation 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 modified parameters.

6 EXTENT OF WORK

Where directed by the Administrator, dynamic testing of piles using wave equation analysis shall be used to confirm the ultimate pile capacity as determined by the Hiley Formula.

The number of piles to be dynamically tested shall be as stated in Clause 1 of Annexure MRTS68.1.

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 vertical piles to determine their performance rating. 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 Previously Driven Pile

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

After driving, and before a pile's capacity is considered to be conforming, a laboratory 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 subsequent laboratory analysis indicate that any dynamically tested pile has a capacity less than that specified, then that pile shall be re-driven using the final set assessed from the revised wave equation analysis incorporating the soil parameters derived from the laboratory analysis, the pile driving records and the available geotechnical information.

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, a wave equation analysis, based on the measurements recorded during driving, 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

Following approval by the designer of the wave equation 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.

Values of soil parameters shall be varied during testing to provide a range of outputs. After driving, and before the analysis is considered to be representative of the pile in the existing environment, a laboratory 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 subsequent laboratory 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 wave equation analysis incorporating the soil parameters derived from the laboratory analysis, the pile driving records and the available geotechnical information.

8 TESTING PROCEDURE

The Contractor shall submit to the Administrator at least 14 days before piling is to commence, a procedure for dynamic testing of piles. Milestone The procedure shall be based on the requirements of this Standard. 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. 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 conventional 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 shall be capable of generating a net measurable pile penetration, or an estimated mobilised static resistance in the bearing strata which exceeds the working load of the pile for a minimum period of 3 milliseconds.

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 the same location and diametrically opposed on the longitudinal axis of the pile so that the measurements are not affected by bending of the pile. When near the upper end of the pile, they shall be attached a distance of between 1.5 and 3 pile diameters from the pile head.

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

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

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

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 –

$$\text{Pile impedance} = \frac{E \times A}{c}$$

where –

E = modulus of elasticity of pile;

A = cross-sectional area of pile; and

c = strain wave speed.

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.

9.2.2.3 Strain Transducers

Where strain transducers are used, a minimum of two of such devices shall be attached to the pile at the same location and diametrically opposite each other.

The transducers shall be securely attached by bolting or gluing 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 in excess of 10 kHz.

The measured strain shall be converted to force using the formula –

$$F = \varepsilon \times E \times A$$

where –

F = applied force;

ε = measured strain;

E = modulus of elasticity of the pile; and

A = cross-sectional area of the piles at the measuring location.

9.2.3 Acceleration, Velocity and Displacement Transducers

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 above 10 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 1 kHz and 10 kHz. Accelerometers for use on steel piles shall function linearly to an appropriate level.

Either alternating current or direct current accelerometers may be used. If alternating current devices are used, the time constant shall be at least 1 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, reducing 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 an oscilloscope or oscillograph for displaying the force and velocity traces, a tape recorder or equivalent for obtaining a record for future analysis and a means to reduce the data.

The equipment for recording, reducing and displaying data shall be capable of making an internal calibration of force, velocity and time scales. No error shall exceed 2%.

9.2.4.2 Recording Equipment

The signals from the transducers shall be recorded electronically in either analog or digital form such that frequency components have a low pass cut-off frequency of 1.5 kHz (- 3 dB). When digitising, the sample frequency shall be at least 5 kHz for each data channel.

9.2.4.3 Equipment for Reducing Data

The equipment for reducing the signals from the transducers shall be an analog or digital computer capable of at least the following functions –

a) Force Measurements

The equipment shall provide signal conditioning, amplification and calibration for the force measurement system. If strain transducers are used, the equipment shall be able to compute the force. The force output shall be continuously balanced except during the impact event and the electronic system shall be reset to zero between impacts;

b) Velocity Measurements

If accelerometers are used, the equipment shall integrate the acceleration over time to obtain velocity. If displacement transducers are used, the equipment shall differentiate the displacement over time to obtain velocity. The equipment shall zero the velocity value between impacts, and shall adjust the velocity record to account for the transducer drift during the impact event; and

c) Signal Conditioning

Signal conditioning for force and velocity shall have equal frequency response curves to avoid phase shifts.

9.2.4.4 Display Equipment

The equipment for displaying the signals from the transducers shall consist of an oscilloscope or oscillograph on which the force and velocity versus time can be observed for each hammer blow. This equipment may receive the signals from the transducers directly, or after they have been processed by the equipment for reducing the data. The equipment shall be adjustable to reproduce a signal having a range of duration of between 5 and 200 milliseconds. Both the force and velocity signals shall be reproduced for each blow and the equipment shall be capable of holding and displaying the signal from each selected blow for a minimum period of 30 seconds.

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 cable or equivalent, 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 in order to determine the driving limits of subsequent piles in difficult conditions, measurements and sets shall be recorded throughout the entire driving operation 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

The pile shall be marked clearly at appropriate intervals.

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

The strain wave speed of the pile shall be determined in accordance with the provisions of Clause 10.3.

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 required to be obtained, a removable recording sheet shall be attached to the pile and a horizontal reference beam shall be installed in the ground adjacent to the pile. A baseline shall be drawn on the recording sheet adjacent to a mark on the reference beam.

10.3 Determination of Strain Wave Speed

The strain wave speed of a pile shall be determined, where necessary, in accordance with the provisions of this clause.

The pile shall be placed on supports or level ground clear of adjacent piles or other obstructions. An accelerometer shall be attached to one end of the pile. The other end of the pile shall be struck with a sledge hammer of suitable weight. Care shall be taken not to damage or dent the pile.

The accelerometer signal shall be recorded and displayed. The time between acceleration peaks shall be measured for as many cycles of reflection as possible and an average determined. The strain wave speed shall be calculated by dividing the appropriate travel length of the strain waves by the average time.

10.4 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 number of blows per minute delivered by the hammer;

d) for double acting diesel hammers the air pressure in the pressure line to the hammer; and

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

10.5 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.

10.6 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 and minimum acceleration shall be obtained directly from the accelerometer signal or by differentiation of the velocity versus time record.

The displacement of the pile shall be obtained from the pile driving record, the set rebound curve and the displacement transducer or by differentiation of the velocity versus time record.

The maximum and final energy developed 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 laboratory computer analysis.

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 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 capblock 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;

vii) final penetration resistance;

viii) penetration for last two series of 5 blows with the hammer;

ix) penetration resistance during restrike;

x) when capblock replaced (indicated on log);

xi) when pile cushion replaced (indicated on log);

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;

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 and final energy,

viii) the one-dimensional wave theory used for the analysis of the pile driving;

ix) the variables entered into the wave theory equation, such as damping, quake, and resistance;

x) the computed bearing capacity of the pile at the time of testing; and

xi) 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.