DYNAMIC TESTING SERVICES (SINGAPORE) PTE LTD

METHOD OF STATEMENT FOR PDA TESTING ON BORED PILE / MICRO PILE

OFFICE ADDRESS:-
1 Pemimpin Drive #05-10 One Pemimpin Singapore 576151
Tel: 65-6337 8212 Fax: 65-6694 5926

METHOD OF STATEMENT
FOR PDA TESTING ON BORED PILES / MICRO PILE

1.0 INTRODUCTION

1.1 Dynamic Testing Service (Singapore) Pte Ltd (DTS) provides specialist dynamic pile testing service. DTS own and operate the PDA/CAPWAP system of testing, which involves state-of-the-art equipment and computer software. This system has been used by DTS for testing of piles in Australia, Singapore, Malaysia, Hong Kong and Thailand. DTS is an accredited laboratory by SAC-Singlas for PDA test.

1.2 The PDA field data acquisition and computer unit has its own in-built self checking system and all force and acceleration transducers are fully calibrated in advance.

1.3 The PDA/CAPWAP system was developed by Pile Dynamics Inc, Ohio, USA and has been in use for more than 15 years. Details on the system are attached in Appendix 1.

2.0 PILE MONITORING AND PREPARATION

2.1 Pile instrumentation and monitoring will be performed using the PDA/CAPWAP system according to the ASTM standard D4945-12.

The system involves a Pile Driving Analyser (PDA), which is manufactured by Pile Dynamic Incorporated, USA. Measurements of the force and velocity signal induced in the pile during pile driving are collected by strain and accelerometer transducers, which are fixed near the pile head (at least 1.5 diameter away from pile top). For each blow struck to the pile the PDA signal processor conditions the output from these transducers and passes it to the processing section of the PDA. The PDA has an in-built program, which calculates over 30 pile driving variables based on the data obtained from each blow. These variables include maximum pile top force, displacement and velocity, estimates of pile static and dynamic capacity.

2.2 In order to conduct PDA testing, transducers need to be attached to the pile to be tested. PDA force and velocity transducers will be attached at approx. 1.5 dia below the head of the pile and at two locations diametrically opposite each other. At each location one force transducer and one accelerometer will be attached to the pile.

2.2.1 Special precautions will have to be taken to conduct proper PDA test on bored piles such as:-

i. Build up section of pile should have higher strength concrete preferably grade 40 or above. Minimum strength of concrete before testing should be 30N/mm^2 or more.

ii. Bored pile to be tested to be encased with steel casing at the top section (1m – 2m from pile top) of pile in order to strengthen the concrete pile for hammer impact.

iii. Drop height of hammer proposed to be carefully calculated using dynamic Hiley formula by specialist testing firm to prevent overstress during testing.

iv. Hammer to be aligned vertically to prevent eccentric stress developed at hammer impact. Hammer guide is recommend to be used.

v. Proposed drop height will have to be adjusted (revised/increased) on site if stress measured during testing is too high/low after first hammer blow. Note that desired static capacity may not be achieved if energy imparted onto pile is insufficient.

2.3 The PDA monitoring equipment will be set up in the vehicle or shaded protected area at certain distance from the pile. A main cable connecting the PDA unit to the pile top transducers will be run from the unit to the gauges.

2.4 The piles are recommended to be tested to 2 times working load for working pile. This is to prevent any overstress in the pile during hammer impact. The ultimate static capacity should be higher than 2 times working load. The soil skin friction set-up effect may be taken into consideration in the long term and therefore pile capacity can increase with time.

3.0 DATA PROCESSING AND CAPWAP ANALYSIS

3.1 Under each hammer blow, the analyser will be triggered and data acquisition will begin at this time. The PDA automatically processes each blow recorded during monitoring and can display computed values of over 30 pile variables on command.

3.2 The PDA automatically checks each blow for pile integrity and provides a warning of any damage detected along the length of the pile. In the event of any damage being detected the PDA will automatically indicate the location of the damage and the severity of the damage.

3.3 The pile top force and velocity signals recorded in the field will be processed and a representative blow will be selected for further analysis using the CAPWAP suite of computer software.

3.4 After the completion of the CAPWAP analysis the PDA field estimates of static capacity can be refined and analyser data can be calibrated to the CAPWAP analysis. This will effectively refine the real time PDA estimates of static capacity, which will be available for subsequent piles monitored. CAPWAP will also give you the skin friction distribution and end bearing resistance of pile and predicted load settlement curve under static loading.

3.5 The PDA and subsequent CAPWAP analysis will indicate the amount of static capacity that is actually mobilized during any one blow delivered to the pile during testing. In order to fully mobilize all available pile static capacity a pile set in excess of 3 – 4 mm per blow is required. Should the pile set be less than 3 – 4 mm, or the soil quakes be in excess of the normal 3 – 4 mm then not all of the static pile resistance will be mobilized during any one blow and the subsequent CAPWAP and PDA analysis will under predict a true static capacity of the pile.

This provides some in-built conservatism to the capacities indicated by the PDA and CAPWAP system in the event of small set being recorded. If this is the case the PDA system is regarded as a proof test, not a full load test.

4.0 REPORTING

4.1 On completion of all field work, a final report covering all aspects of the pile monitoring and analysis work will be prepared. This report will incorporate results of the PDA monitoring, and results of all CAPWAP computer analyses. The results of the CAPWAP analyses will be compared to the PDA results and correlations will be drawn between the CAPWAP data and the PDA field monitoring results. Results from PDA test will be calibrated against the static load test results if results are available, to obtain a better correlation and comparison with the static.

4.2 Results which can be obtained in report are as follows:-

4.2.1 **Static capacity of piles** (compression or tension) mobilized.

4.2.2 **Simulated load settlement curve** under static load.

4.2.3 **Pile integrity** (any defects, necking, crack or any irregularities in pile shaft)

5.0 COMPANY EXPERIENCE

5.1 Dynamic Testing Service (Singapore) Pte Ltd has been in operation in Singapore since early 1990 providing dynamic pile testing services to the local construction industry. More than 500 over piles (RC piles, Steel Pipe piles and Bored piles) are dynamically tested each year as a supplement or substitute method of test to conventional static load test.

6.0 RECOGNITION OF PDA TEST

PDA test is well recognized in the following international standards:-

- ASTM (American Standard of Testing Materials) standard D4945-12
- ICE Piling Specifications (UK)
- BS8004 (British Standard Foundation code – 7.5.2)
- Canadian Foundation Engineering Manual (1992 – Canadian Geotechnical Society).

==========

APPENDIX 1

(PDA SYSTEM)

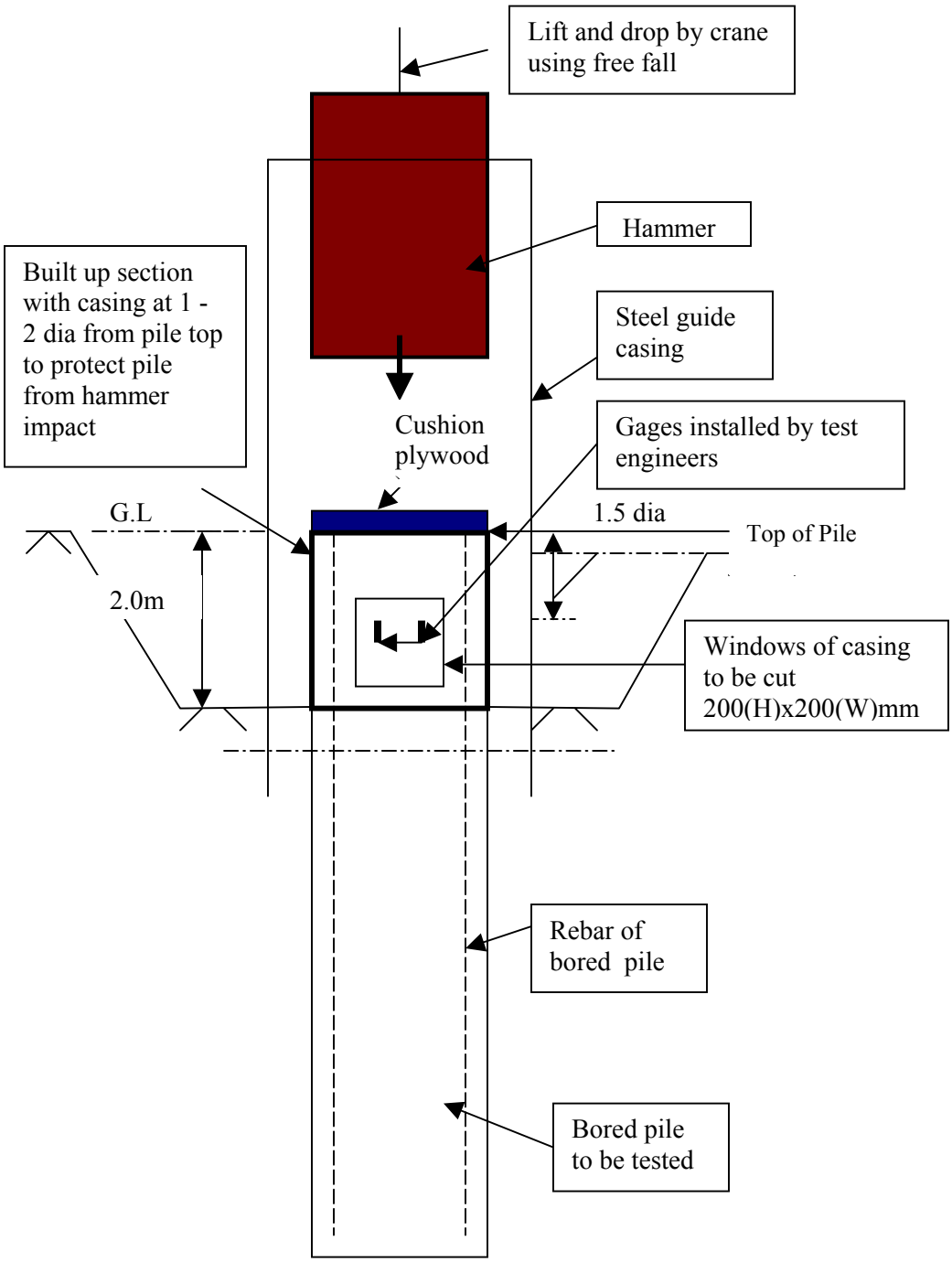


Fig 1:DETAILS OF PDA TEST SETUP FOR BORED PILE

EXAMPLE OF DROP HEIGHT FOR PDA TEST ON PILES:

Project Name :

Client :

HILEY FORMULA FOR BORED PILE

Pile reference : P199

Dia. of pile (mm)	900	Test load 2.0 x WL (tons)	780.0
Dia. of rebar (mm)		Length, L (mm)	23800
No. of rebar (mm)		EM of steel, E (t/cm^2)	2100
Set (mm)	1	EM of grout (t/cm2)	353
Efficiency (%)	0.35	SP of steel (t/m^3)	7.85
Hammer weight (tons)	8.5	SP of concrete (t/m^3)	2.4
Working load (tons)	390.0		

Area of steel, A (cm^2)	Area of concrete (cm^2)	Area (Total) (cm^2)	Elastic Modulus (EM) (tons/cm^2)
0.0	6361.7	6361.7	353

Tc (mm)	Wave Speed, c (m/s)	Drop Height (mm)	Specific Density (SP) (ton/m^3)
8.3	3800	1345.9	2.40

Proposed drop height = 1.4 m

Notes : -

Hiley formula : Ru = Energy /(set + Tc/2)

This formula obtained from simplified Hiley formula published by Prof.Bengt B Bromes

Energy = efficiency x drop height x weight hammer

Set = assumed permanent displacement (usually about 1 - 2mm/blow)

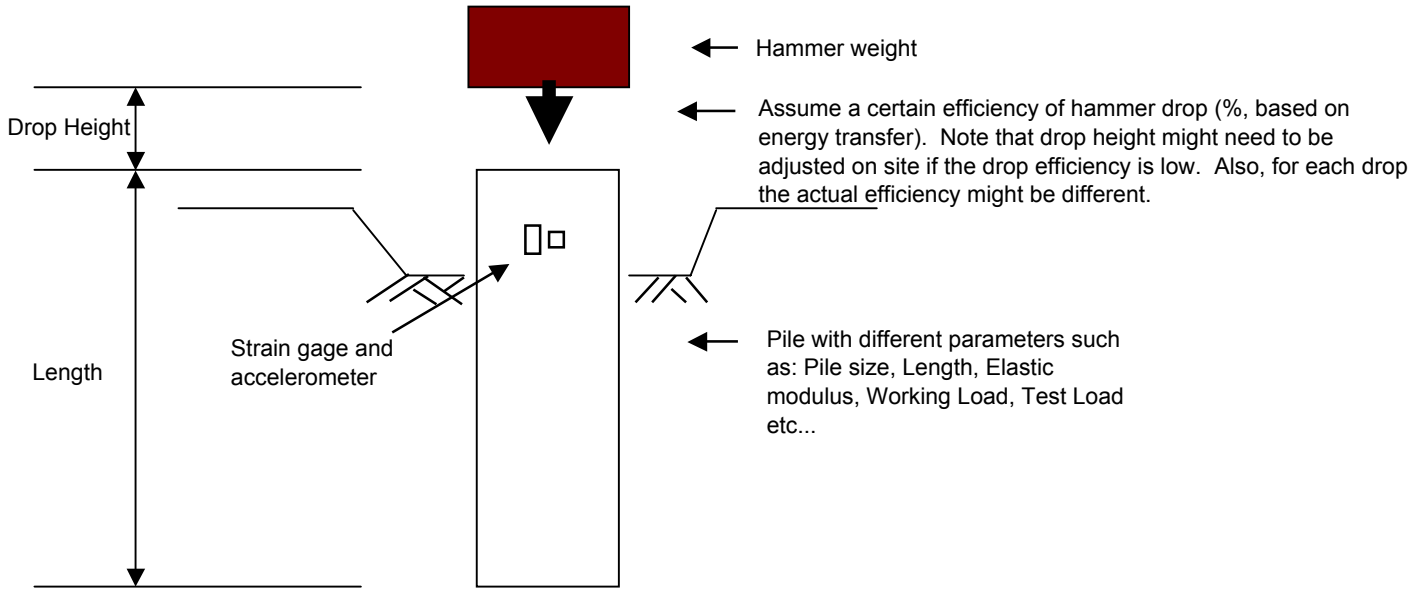
Temporary compression, Tc = can be calculated from P L / A E x k, where k = 1 (may varies from 0.2 - 1.0)

For bored pile test we ignore area of steel. EM of concrete = 353 - 400 t/cm^2

Wave speed of concrete = 3800m/s (may varies from 3600 ~ 4600m/s, calculate from EM = SP x c^2 / 9.81 x 10^{-4})

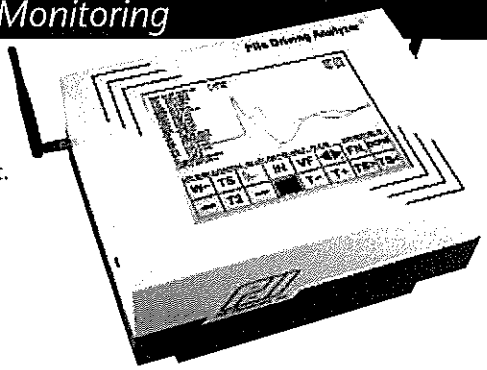
Where, EM = Elastic Modulus

, SP = Specific Density



Pile Driving Analyzer® (PDA) Model PAX

For Dynamic Load Testing and Dynamic Pile Monitoring



Bearing capacity of all types of deep foundations.

The Pile Driving Analyzer (PDA) acquires data from **accelerometers** and **strain transducers** attached to a pile or shaft. The tests require the impact of a pile driving hammer or, if that is not available, of a suitable drop weight.

High Strain Dynamic Tests per ASTM D4945 - quick, reliable and non-destructive

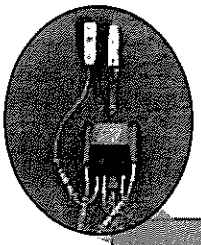
Dynamic Load Test

- Results: **Bearing capacity, structural integrity assessment**
- PDA data analyzed with the CAPWAP® software
- Excellent correlation with static load tests
- Performed on drilled shafts, continuous flight auger, cast-in-situ or driven piles on a restrike

Dynamic Pile Monitoring

- Results: **Capacity at the time of testing (Case Method and iCAP™), driving hammer performance, driving stresses, pile integrity**
- Performed during driving
- Helps establish the Driving Criterion
- Contributes to safe and economical production pile installation

The PAX may also evaluate the energy of SPT Testing Equipment by force and velocity measurements, per ASTM D4633 (optional SPT program).

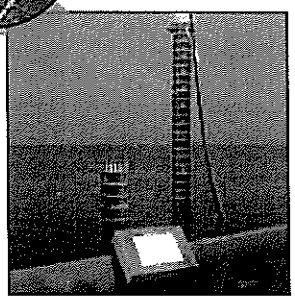


Smart accelerometer and strain transducer, offshore version.

PAX Wireless Mode

- All cables from the test pile to the PDA are eliminated
- Uses Pile Dynamics Smart Sensors and Wireless Transmitters
- Smart Sensors communicate their calibration value to the PAX, eliminating entry errors
- Signal transmission of up to 100 m (330 ft)
- Reduced volume and weight of the PDA system, simplified field setup

The PAX may also be used with cabled (traditional) accelerometers and strain transducers.



PAX in Wireless Mode at Offshore job.

SiteLink™ *(Remote Testing)*

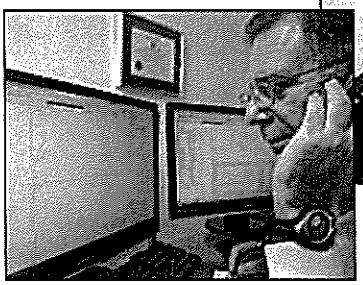
- The engineer performs High Strain Dynamic Tests from any office
- Real time field to office data transmission via Internet (PDA-R mode)
- All field measured signals and results on a computer running PDA-W software
- Simple PAX field setup may be performed by a technician
- Improves testing efficiency:
- Eliminates engineer's travel time, delays and expenses and down time on the job
- Allows immediate data analysis with CAPWAP and faster reporting of results

Pile Dynamics introduced the idea of collecting dynamic testing data from a job site and immediately transmitting it to a remote office computer back in the late 1990s, and was granted a patent for the first remote data transmitting PDA in 2001.*

*Remote Pile Driving Analyzer U.S. Patent No. US 6,301,551 B1

The PAX may also be used by a field engineer on location, displaying results, measured signals and all variables of interest on the PAX screen (PDA-L mode with iCAP).

PAX arrives at job for SiteLink.



Receiving test data with SiteLink.

Quality Assurance for Deep Foundations

30725 Aurora Road Cleveland Ohio 44139 USA

tel: +1-216-831-6131 fax: +1-216-831-0916

Email: info@pile.com www.pile.com

Pile Dynamics, Inc.

Pile Driving Analyzer® (PDA) Model PAX

For Dynamic Load Testing and Dynamic Pile Monitoring

Available as PAX-4 or PAX-8

Most High Strain Dynamic Tests require only 2 strain transducers and 2 accelerometers installed near the top of the foundation. These 2 pairs of sensors are sufficient to obtain the force and velocity records needed for the PDA calculations, thus making four channels of data acquisition (as in the PAX-4) adequate for the test.

Eight channels of data acquisition (PAX-8) – 4 strain transducers and 4 accelerometers - are recommended for dynamic tests of augered cast-in-place / continuous flight auger piles, drilled shafts and spiral-welded pipes. Eight channels are also essential for dynamic measurements to be made simultaneously on follower and pile, and when a pair of accelerometers and strain transducers is installed at a second location along the length of the foundation (for example by embedding sensors near the toe of a concrete pile). If a drop weight is to be instrumented to measure force by Newton's Law, then eight channels are also required. The PAX-8 has both PE and PR accelerometer connections.

Software

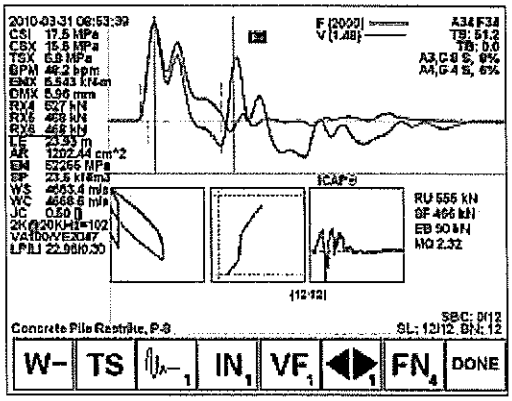
The Pile Driving Analyzer is furnished with:

PDA software suite: PDA-W with iCAP™, PDIPLOT, PDI-Curves

- **PDA-W** processes PAX data files, either in real time or after the conclusion of the test. PDA-W data is interpreted for soil resistance at the time of the test, and, for driven piles, compression stresses induced at top and bottom, tension stresses along the shaft, energy transferred to the foundation and pile integrity. PDA-W calculates over 200 parameters in real time and compares them with user specified target values. PDA-W also permits the creation of a driving log, and issues quality alerts during data acquisition.

- **iCAP** calculates capacity at the time of testing through a signal matching procedure performed during Pile Driving Monitoring. Because it is based on CAPWAP® logic, it is a step beyond capacity determined by the Case Method. With no user interaction, iCAP extracts the soil behavior from dynamic measurements, computes capacity at the time of test, and produces a simulated static load test graph in real time.

- **PDIPLOT** generates tables and plots of up to six PDA results versus blow number, length or elevation. It provides the statistical summary output required by ASTM D4945.



iCAP screen in the field.

- **PDI-CURVES** combines plots of Force-Velocity versus time (required by ASTM D4945), and of other quantities from multiple PDA-W files in one single document.

CAPWAP uses force and velocity records measured by the PDA sensors to, by signal matching, determine resistance distribution and dynamic soil response and simulate a static load test. Hundreds of comparisons demonstrate the excellent correlation of CAPWAP analysis with static load testing results. CAPWAP analysis of PDA data is standard practice for Dynamic Load Testing.

GRLWEAP is a wave equation analysis program that simulates pile driving. It can be used to select the hammer for pile driving or to evaluate the suitability of a drop weight system for the Dynamic Load Test of a drilled shaft.

Engineers around the world have been using the PDA for more than 35 years. High Strain Dynamic Tests performed with the Pile Driving Analyzer are standardized by ASTM 4945 and are recognized by, among others:

- National Codes of Australia, Brazil, Canada, China, Egypt, Qatar, United Kingdom and Eurocode 7
- International Building Code (USA)
- Specifications of the American Association of State Highway Officials, US Federal Highway Administration and most US Departments of Transportation
- Specifications of regional, provincial or municipal governments in Argentina, Mexico and the Philippines
- Manuals and Codes of Practice of US organizations such as American Society of Civil Engineers, Deep Foundations Institute and Pile Driving Contractors Association.

Please contact Pile Dynamics for information on compliance with standards from other countries.

Other PAX Features: small, weighs about 5 kg, 6 hour internal battery. High visibility touch screen display doubles up as control panel and keyboard. For complete current specifications visit www.pile.com/specifications.

Quality Assurance for Deep Foundations

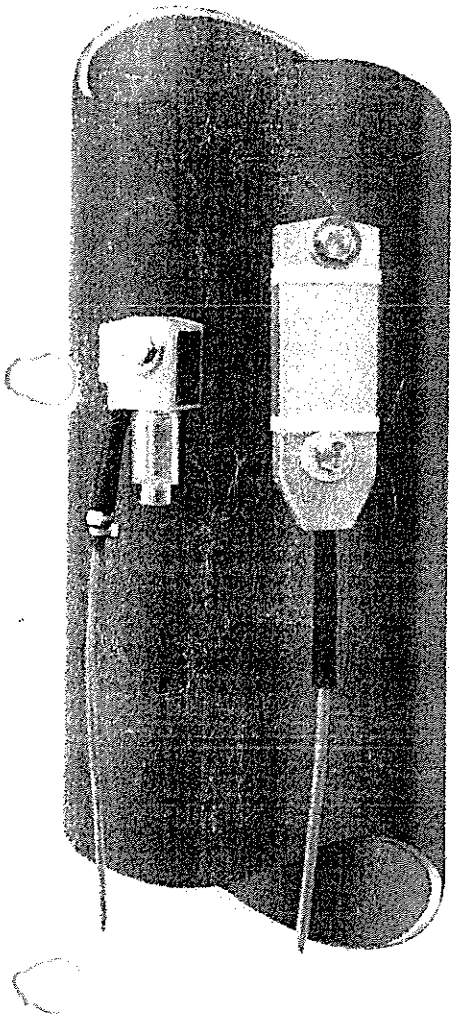
30725 Aurora Road Cleveland Ohio 44139 USA

tel: +1-216-831-6131 fax: +1-216-831-0916

Email: info@pile.com www.pile.com

Pile Dynamics, Inc.

Strain and Motion Sensors from Pile Dynamics



Pile Dynamics, Inc. (PDI) has provided Pile Driving Analyzer® equipment since 1972. Measurements require axially accurate strain and acceleration signals at high microstrain (με) and high "g" levels which are converted to force and velocity for further analysis. PDI has continually updated and refined this capability resulting in accurate calibrations to NIST (U.S.A. national bureau of standards) and repeatable measurements using an economic system of reusable sensors which are quickly attached to any pile with minimal preparation. Systems with extra cable length and/or full waterproofing for deep depth underwater testing are available on request.

Strain Transducer Specifications:

Effective Gage Length:	3 inch (76 mm); 2 inch (50 mm) version as option
Size:	4.5 x 1.4 x .4 inch (115 x 35 x 11 mm)
Material:	Aluminum (optional: steel transducer for structural or static testing)
Circuit:	Full bridge; 2 pair shielded cable (standard length: 3 ft; 900 mm)
Sensitivity:	380 με/mV/V typical (individual calibration included)
Strain Range:	Nominally 2,000 με when firmly attached (limit 8,000 με)
Shock Range:	Nominally 5000 g's
Temperature Range:	-50° to 120°C Operating
Options:	Full waterproofing, extra cable length, quick connectors
Attachment Method:	Bolts to quickly attach to pile (see reverse page)
Optional:	C-clamps or mounting tabs and adhesive for structural testing

PDI Strain Transducers are also used in static load monitoring and/or structural monitoring such as for measurements on highway bridges, lock gates and other civil structures.

Piezoelectric Accelerometer Specifications:

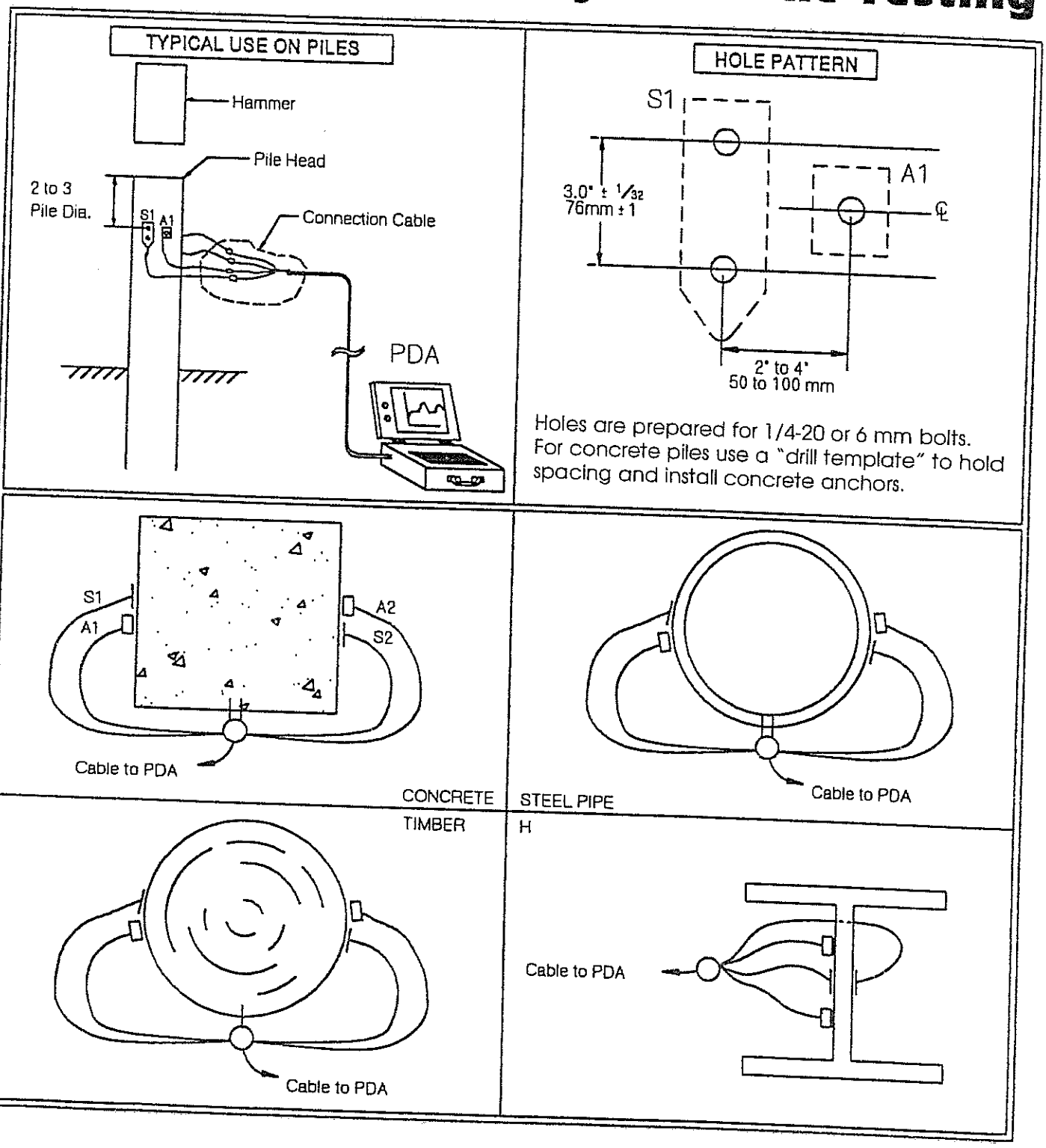
Mounting:	To special aluminum block (1 x 1 x 1 inch: 25 x 25 x 25 mm)
Circuit:	Integral impedance converting electronics; shielded cable (3 ft; 900 mm)
Sensitivity:	Nominally 1.0 mV/g with 10 V.D.C. bias voltage input
Range:	5,000 g's (Limit 10,000g's)
Frequency Range:	0.25 to 7000 Hz (Resonant Frequency: > 40 kHz for accelerometer)
Temperature Range:	-50 to 120°C Operating
Time Constant:	Nominally 3 s
Options:	Full waterproofing, extra cable length, quick connectors
Attachment Method:	Bolts to quickly attach to pile (see reverse page)

Piezoresistive Accelerometer Specifications:

Mounting:	Inside special aluminum block (1.25 x 1 x 0.75 inch: 30 x 25 x 20 mm)
Circuit:	Full bridge, 2 pair shielded cable (3 ft; 900 mm)
Sensitivity:	Nominally 0.07 mV/g with 6.4 V.D.C. input
Range:	10,000 g's (Limit 15,000g's)
Frequency Range:	DC to 3 kHz (accelerometer resonant Freq: 5 kHz critically damped))
Temperature Range:	-50 to 90°C Operating
Options:	Extra cable length, quick connectors
Attachment Method:	Bolts to quickly attach to pile (see reverse page)

Pile Dynamics, Inc.
4535 Renaissance Parkway
Cleveland, Ohio 44128, U.S.A.
Tel: (216) 831-6131
Fax: (216) 831-0916
Email: info@pile.com
http://www.pile.com

Sensor Installation for Dynamic Pile Testing



Pile Dynamics, Inc.

4535 Renaissance Parkway
Cleveland, Ohio 44128, U.S.A.
Tel: (216) 831-6131
Fax: (216) 831-0916
Email: info@pile.com
http://www.pile.com

Sensors are quickly bolted to any pile type, usually about 2 to 3 pile diameters below the pile top. Strain transducers are attached symmetrically on the pile to account for bending effects. Accelerometers should be attached near the strain transducers. Attachment is typically with drilled and tapped holes for steel pipe piles, clearance holes with bolt/nut for steel H piles, lag bolts for timber piles, or by installing embedded anchors for concrete piles.