› PILE DRIVING MONITOR

PDM

BECAUSE EVERY PILE IS IMPORTANT

AFT
ADVANCED FOUNDATION TECHNOLOGIES

TYPICALLY 90–95% OF PILES ON DRIVEN PILING PROJECTS ARE UNTESTED

OUR PHILOSOPHY

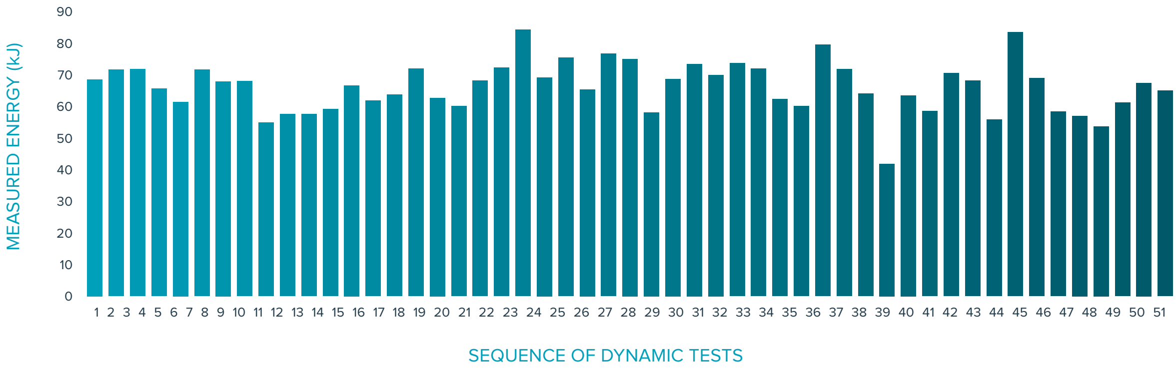
The philosophy behind the development of the PDM is that piled foundations are designed and perform as a system and that the construction and verification processes should reflect this. We believe that every pile on a project is important and that all piles should be installed to the highest standard of safety and quality without compromising productivity.

WHY USE PDA AND PDM ON DRIVEN PILING PROJECTS?

On most driven piling projects a relatively small sample of piles (generally 5% - 10%) are PDA tested to accurately determine the capacity of the pile and the efficiency of the hammer during installation of that pile. The remaining 90% to 95% of piles on the project are untested and are accepted on the basis of manual measurement of blow count or set and temporary compression and estimation of capacity via standard driving formulas, often unrelated to the dynamic test results.

For this approach to verifying pile capacity to be successful and safe:

1. the efficiency of energy transfer from the hammer to the pile must be constant over the life of the project and not drop below the PDA-measured efficiencies, and,
2. the dynamic formula must either be accurate or consistently underestimate capacity



SOLVING THE EFFICIENCY VARIABILITY PROBLEM

Years of dynamic testing on driven piling projects around the world has shown that hammer efficiency routinely varies by 30% or more over the life of a project. The above graph shows the recorded energy transfers on a project with a single model of hydraulic hammer, with final set always taken using the same stroke. Delivered energies (EMX) varied between 42 and 85kJ which were -37% to +27% about the average in this particular case.

Regardless of whether piling control for all the piles not PDA tested is by or Wave Equation, blow count or dynamic formula, the relationship between Capacity, Energy and Movement (as some function of blow count, set or temporary compression) can be generalized in the following way :

$$\text{Capacity} = f\left(\frac{\text{Energy}}{\text{Movement}}\right)$$

If the energy measured in PDA testing is assumed to apply to all piles, the capacity estimates for untested piles will have an error range which reflects the energy variability - in the case of this particular project an error range of +37% to -27%. This error alone exceeds the safety provided by the capacity reduction factor of 0.75 as a typical value!

Using a standard pile driving formula (for instance the traditional Hiley Formula) and an assumed value of hammer efficiency, and coefficient of restitution is even more unreliable than assuming a constant energy from PDA site measurements.

The PDM measures pile position up to 4000 times per second. That allows the PDM to not only measure pile set and temporary compression accurately, but also allows it to measure the pile velocity-time response (one of the two PDA measurements). This allows the PDA and PDM responses to be correlated, so that the PDM can then measure the energy delivered to every pile as a routine part of the monitoring and therefore overcome this common but unrecognized problem.

SOLVING THE DYNAMIC FORMULA RELIABILITY PROBLEM

PDA testing every pile on a project would be expensive and disruptive. Current practice on driven piling projects is typically to accept the 90-95% of piles not PDA tested by simple methods – traditional pile driving formulas based on assumed energy, and measurement of set (and temporary compression).

What is generally not recognized is that dynamic formulas measure driving resistance, not static capacity. The driving resistance is of course greater than static resistance, which means that putting aside the issue of energy estimation, driving formulas intrinsically overestimate pile capacity.

Seidel (2015) has proposed a Dynamic Reduction Factor to correlate dynamic formulas to PDA/ Capwap capacity. The DRF is set-dependent rather than constant, because the ratio of dynamic to static capacity reduces as the pile approaches refusal. The PDM offers DRF-correction for all Dynamic Formulas, for improved reliability.

GAME-CHANGING EVALUATION OF PILE INTEGRITY

By analysing the velocity response of the pile after impact, the PDM can identify the tell-tale tension reflections from pile damage. This is the same response which the PDA measures to estimate pile integrity, but in the case of PDM, only the velocity effect is measured.

In current practice, pile damage is only detected in the 5 to 10% of piles which are typically PDA tested, or where a pile is specifically tested because of the piling crew's suspicion of damage. With the PDM, every pile can be screened for damage with subsequent confirmation by PDA testing if required.

SAFETY FIRST

A CURRENT TECHNIQUE

Current practice for assessment of pile capacity in many countries requires the measurement of Set and Temporary Compression (TC) directly on the pile during installation. Working in close proximity to piling hammers presents significant safety risks to personnel such as high noise, falling debris from hammers or leaders and spalling concrete from the pile head.

The UK Federation of Piling Specialists (FPS) in association with the European Federation of Foundation Contractors (EFFC) analyzed some 4000 piling accidents. For driven piling projects, falling objects were the 3rd most common reason for accidents.

By remotely measuring pile set and temporary compression to an accuracy of 0.1mm at distances of up to 15m from the pile, the PDM eliminates the need for workers to stand under working piling hammers and eliminates hazards associated with falling objects and substantially reduces noise levels. This is a significant improvement to the health and safety of workers on driven piling projects.

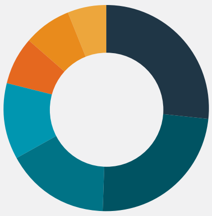
The clear and persistent message which underlies every Safety Plan, site induction and toolbox meeting is that the primary goal should be ELIMINATION of risk. The hierarchy of safety measures places risk elimination at the apex, with the current practice of providing the worker with personal protective equipment being categorised as the lowest level of control.

The South Australian Department of Transport and Infrastructure, in their report "Infrastructure Works at Night Operational Instruction 21.7" identifies piling as the construction activity which generates the highest maximum noise levels, by a significant margin.

A worker at 1m from the hammer impact source may be subjected to a noise level of 130dB, which attenuates to 110dB at 10m from the pile. Every 3dB reduction is equivalent to a halving of noise energy, therefore a 20dB reduction represents 1/128th of the noise energy.

The PDM provides a substantial opportunity for improving worker health and safety on driven piling projects by removing them from the area of highest risk.

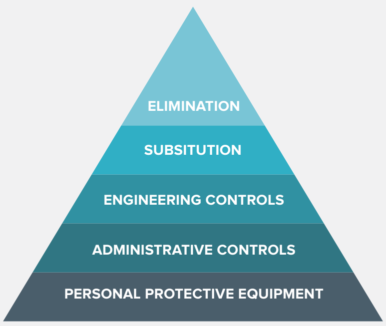
PILING DRIVEN, STEEL SHEET PILING



FPS and EFFC safety statistics

- Slip, trip or fall on same level
- Struck by falling object
- Struck by moving machine or equipment
- Fall from height
- Contact with moving machinery
- Damage to eyes
- Struck by moving object

EFFECTIVENESS CONTROL



EASY SETUP

SETUP AND OPERATION

The PDM has been designed from the ground up to be construction friendly – robust, user friendly and efficient. The PDM can be mounted on a tripod or placed on the ground 5m to 15m from the pile. For an experienced operator, the time for a PDM test is comparable to taking a traditional set card measurement.

The PDM uses optically safe infrared lasers to track a disposable reflective sticker adhered directly to the pile. Because the maximum pile movement occurs before the ground vibrations reach the PDM, and the final set measurement is taken after the vibrations have passed, the set and temporary compression measurements are accurate to ±0.1mm or better at a distance of 10m from the pile.

The PDM also houses a tri-axial accelerometer which allows ground vibrations from piling works to be monitored and peak ground accelerations (PGA) and peak particle velocities (PPV) reported for each pile (under development).

SOFTWARE

The PDM software comes preloaded onto a tablet PC, provided with every PDM. Communication between the Tablet and PDM is wireless to maximise flexibility and minimise trip hazards on site. This also provides the opportunity for the tablet to be cabin-mounted. An option for connection via USB cable is also provided.

Two software modules are available. The base model is for projects which are controlled by standard driving formulas or Wave Equation bearing graphs. The advanced model is for projects in which the full QA benefit of PDA and PDM testing is being implemented.

The basic software module allows measurement and display of set, and temporary compression for every blow. These measurements are used in the pre-programmed standard pile driving formulas to provide real-time sign-off reports. The basic version relies on user-input of hammer details including stroke and efficiency. The reliability of capacity estimates are limited to the efficacy of the driving formula used and the reliability of user inputs.

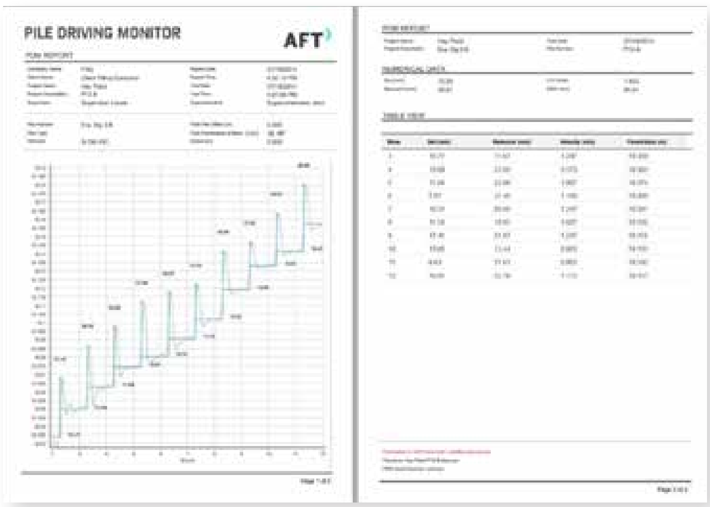
The advanced software package also includes real-time display of transferred energy, capacity, pile velocity and pile integrity based on guided correlations with PDA testing at the site.

Results for both basic and advanced modes can be reviewed on screen and reported immediately on site to expedite sign off. The results comprise graphical results simulating a normal set card, full numerical summary tables with project and pile details. Data security has been woven into the software so that the authenticity of the results can be ensured.

Software Developments

The advanced software package is being progressively extended with the following modules under active development:

- Full drive blow counting
- Monitoring of piles driven from floating barges, with tidal movement compensation
- Continuous monitoring mode for static pile testing;
- Direct hammer monitoring for efficiency calculation for hammers with visible rams;
- Vibratory hammer monitoring for frequency, amplitude and penetration rate



GENERAL SPECIFICATIONS

Weight (including battery)	4 kg
Dimensions (width, height, depth)	172 x 200 x 342 mm
Operating temperature	-10 to +40 °C
IP Classification	IP65
Optics	
Transmitters	4 pcs IR-LED
Measuring FOV (Field-of-view)	50 mrad (vertical, 50 cm /10 m)
Pointers	2 pcs Class 2 visible laser, 635nm
Reflector(s)	
6 to 10 m (optimum)	3M Diamond Grade tape
Extended range <6m, >10m	Tape reduced or increased in width accordingly
Sampling rate	100 to 4000 Hz
Accelerometer, tilt & rotate	
Static measuring range	±50 °
Supply power	
Battery (removable)	Ultralife UBBL25, Li-ion 10.8V, 4.8Ah
Charger	Mascot 2240LI/3CELL
Power Connector	Amphenol (IP67), 11-14 V DC IN
Trigger interface	Active LOW, 0 to max 5V
Data interfaces	
WLAN	Lantronix xPico Wi-Fi
USB	LTW, B-type female connector
— USB Cable included	5m
Current consumption (12 V, typ.)	
Idle mode	85 mA typ.
Measuring (4000Hz / WLAN)	175 mA typ.
Measuring (4000Hz / USB)	150mA typ.
— With pointers on	+30 mA typ.

WARNINGS AND CLASSIFICATIONS

CLASS 1 LED-DEVICE

Classification IEC 60825-1:2007

CLASS 2 LASER-DEVICE

Classification IEC 60825-1:2007

Class 2: "visible-light lasers (400–700 nm) limited to max 1 mW continuous wave"

Product specifications may be subject to change without notification.

OPERATIONAL CHARACTERISTICS

Offset Distance Range	6m to 20m maximum from pile
Recommended range	6m to 10m from pile
Recommended Max Rotational Deviations	
From horizontal plane	1V : 10H
From vertical plane	1H : 10V
Recommended accuracy in Offset	10mm or better
Notional Displacement Accuracy	±0.1mm within recommended range
Notional Velocity Accuracy	±0.1m/s within recommended range and at 1kHz conditioning
Recommended Mounting	Solid placement on sand bag on ground or on survey tripod
Sampling rate for pile monitoring	4000Hz ± 0.2%

SECURITY FEATURES

SOFTWARE

Code protection	Code is encrypted, and runs on a virtual CPU, which makes it a black-box to data hackers.
Console binding	Each copy of software is coded to bind to its tablet console. Illegal copy software will not work in other environments.
Digital output	All data files are protected by encryption.
Client logo	Hardwired into every report

HARDWARE

Secure connection	Standard WPA2, password protected
Anti-Amendment Report	Key values of the site report (input identification and output results) are encrypted into a QR code. Through current validation utility authorities can tell whether or not a report is modified. The utility will later be available as a phone app.

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