METHOD STATEMENT

HIGH STRIAN DYNAMIC TESTING OF PILE

Prepared by

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Appendix A – Test equipment
1.0 INTRODUCTION

**Dynamic load testing** (DLT) of piles is a fast and effective method of assessing foundation bearing capacity that requires instrumenting a deep foundation with accelerometers and strain transducers and analyzing data collected by these sensors.

The procedure is based on the case method of pile testing and is standardized by ASTM D4945-00 Standard Test Method for High Strain Dynamic Testing of Piles. It may be performed on driven piles, drilled shafts and other cast in place foundations. In addition to bearing capacity, Dynamic Load Testing gives information on resistance distribution (shaft resistance and end bearing) and evaluates the shape and integrity of the foundation element.

The foundation bearing capacity results obtained with dynamic load tests correlate well with the results of static load tests performed on the same foundation element.

2.0 TEST METHOD

Adequate time should be allowed for soil stabilization before testing.

Dynamic load testing (DLT) is carried out with two identical bolt-on strain and acceleration transducers (sensor) attached to a section of pile.
On concrete pile, the sensors are connected to the pile with anchor bolts. On steel pile, the sensors are bolted to the pile using threaded holes or welded mounting block.

The pile is then struck with a driving hammer or a separate drop weight. A hammer mass of about 1 to 2% of the test load is generally sufficient. The generated compressive stress wave travels down the piles and reflects from the pile toe upward. The stress waves, which are picked up by the transducers, are processed and automatically stored in the computer for further analysis and reporting.

The analysis is carried out using the signal matching program CAPWAP. Pile and soil data are modeled and a response is calculated based on one dimensional wave equation theory. The signal matching process utilizes an iterative method in which the results of each analysis are compared to the actual measured pile behavior. Appropriate dynamic soil parameters are refined until a satisfactory match is achieved. The mobilized static shaft and toe resistance of the pile can hence be derived. The signal matching program also provides a prediction of the static load displacement performance of the pile on the basis of the refined pile and soil model.

3.0 EQUIPMENT DETAILS
The pile driving analyzer (PDA) from PDI or SIMBAT MCSCO will be used for the test. Details of test equipment have been shown in Appendix A.
Appendix A

Equipment Detail
SMBAT (Simulation Battage Tester) is one of the professional indexed institutes of the exact safely diagnosis in Korea, which was duly designated by the ministry of Construction & Transportation.

**Product information**

<table>
<thead>
<tr>
<th>Name</th>
<th>SMBAT (Simulation Battage Tester)</th>
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<tr>
<td>Brand</td>
<td>MCSCO</td>
</tr>
<tr>
<td>Model</td>
<td>01–006–2005–01</td>
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<tr>
<td>Product keyword</td>
<td>SMBAT, DYNAMIC REACTION, STATIC REACTION, PERMANENT SETTLEMENT</td>
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</table>

**Product explanation (use/characteristic/merit)**

The SMBAT tests are research of soil’s elastic reaction, joint–film reaction, destructive reaction, and destructive adhesion reaction, that is, soil parameter research, and were developed to predict the change from dynamic reaction to static reaction through the test, comparing static and dynamic loading capacity with the change of various soils in many model piles, actually.

SMBAT method used pile loading tests of all rail road of T.G.V. SMBAT is newest method ended the error range of of USA’s ASTM D4945 (American Standard Test Method)

The method is widely used in the worldwide including USA and Europe. This method offers considerable advantages in term of speed and cost. SMBAT method is perfect to obtain the pile carrying capacity and very useful method can be used widely.

The method for using Dr. Smith’s wave equation also was starting to come out problems, this formula, namely, the method used by substituting drop hammering formula for bearing capacity is not difficult in application of the simple P.C, PHC pile, etc., but it has big problems as the possibility of the trust on large diameter cast-in-place pile of the big unit square measure developed these days and foundation body including various soil.

Namely, it is difficult to understand the loading test accurately as the falling wave velocity into the pile by established accelerometer meter or pile and as the measured deforcement ratio by strain gauge. This method is possible for the certain investigation in falling compressive wave, but not in rising elastic wave.

Move and more the numerical value of the rising elastic wave is different by the pile mobility of side friction from the reaction of soil, the distribution of the rising and falling wave from many experimentations is applied in the formula of wave transmit distribution on back pile. The value of the side friction mobility of pile, the value of displacement of different soil each...
other, the value of dynamic displacement of ground, namely, \( R_{dy} = F \) (free rising pile) – \( F \) (real pile) is got all from the real pile experimentation of 100’s. And for making the possibility of trust high, another instrument, namely, as composing strain location by the electric theodolite possible 10~4 measured with the accelerated meter, removes errors of rising, falling velocity caused by various soil.

### Equipment Spec

- **Enclosure**: Overall dimensions 380X130X300mm, Unit weight 5kg
- **Acquisition**
  - 3 channel, 12 bit acquisition at 50 KHz sampling rate
  - Pre-trigger on each channels, force, acceleration, displacement
  - User adjustable gain
- **Sensors**
  - 2 Accelerometers as the resolution of 1mV/G
  - 2 strain gauges for force measurement
- **THEODOLITE**
  - Measuring distance: 10 m
  - Measuring span: 400 mm
  - Resolution: 100 μm
  - Band pass: 20 KHz
  - Required power: 65W From DC 12V
- **Others**
  - Exclusive notebook PC
  - 2 sets of DC 12V adaptor
  - Case to carry and protect the whole equipment
  - Elevation tripod for theodolite
  - Analysis software
  - User’s manual
Measure:
Bearing Capacity
Pile Integrity
Hammer Performance
Pile Stresses

with the Pile Driving Analyzer®
Pile Driving Analyzer® Model PAL

PAL-R Remote and PAL-L Local
Compact Economical Data Capture and Analysis

Technological advancements have allowed Pile Dynamics to develop a smaller version of the Pile Driving Analyzer—the PAL. The PAL is available in two models, remote PAL-R and local PAL-L. Both models are housed in a small, rugged, light-weight enclosure. The PAL has no keyboard; all input is entered through a touch screen.

SPECIFICATIONS: Models PAL-R and PAL-L:
• Two channels of strain data acquisition
• Two channels of acceleration data acquisition and two integrators of acceleration to velocity
• PCMCIA removable flash memory card
• High contrast touchscreen display doubles as keyboard
• Serial port
• Size: 110mm by 175mm by 200mm
• Weight: 3.2 kg
• Power: Internal battery for approximately 8 hrs. of operation; 12VDC from car battery or 100-240 VAC with 12VDC converter

PAL-R: Foundation Testing from the Office

The PAL-R is a PDA that can be operated from a remote location. When this model is used, a trained piling crew attaches sensors to the pile, connects them to the PAL-R, then connects the PAL-R into the modem connection on a cell phone. The cell phone sends the data to a remote computer running PDA-W software for real-time analysis. Typed messages may be sent to and from the field without interrupting data transmission.

Engineers can control the operation of the PAL-R and perform dynamic tests without leaving the office. This avoids travel time and expense and also allows CAPWAP analysis and report writing to begin immediately. This time-saving benefit also expedites the engineer's recommendations, making them available sooner.

For situations when a cell phone connection is unavailable or not desirable, two other modes of operation of the equipment are possible: data collection only (stored data is transmitted at a later time) and local mode (direct connection to a laptop running PDA-W software on-site, with the testing engineer present).

PAL-L: For Small Jobs and Backup

The PAL-L is used by the engineer on-site. During data collection or review, force and velocity data are displayed on the screen. Once the sensors are placed on the pile, the PAL-L monitors and records the installation of the pile in real time. The user chooses four or fifteen parameters for continuous calculation and display for each hammer blow. Up to 1650 records can be stored on the standard PCMCIA card. Multiple interchangeable memory cards make the data storage unlimited.

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Specifications subject to change.
Printed in U.S.A.
Pile Driving Analyzer® — PAK

Over the past 30 years, dynamic pile testing has grown from a research activity at Case Institute of Technology (under the direction of Dr. G. G. Gode) to a worldwide accepted and routinely applied method of inspection and quality assurance for deep foundations. The value of this method has been recognized by engineers, contractors, and government agencies in specifications (such as ASTM D4945) in numerous countries. While originally developed for driven piles, the method has also been successfully transferred to the testing of cast-in-place piles or drilled shafts. The Pile Driving Analyzer (PDA) testing system and CAPWAP® analysis software are now recognized as the industry standard for high strain dynamic testing.

The PAK is very compact and cost effective, and at a moment’s notice is easily transported by airplane as hand carried luggage to remote sites. High quality sensors require minimal pile preparation and are quickly attached to any pile type; sensors are reusable. The PAK itself is operational in minutes, and is easy to learn and operate, providing answers after each blow to make crucial decisions during pile installation. Data collected is stored automatically and is later easily retrieved for further review. Calculated results for every blow are stored in a file; the system includes the capability to summarize these results for professional reporting.

Data can be further evaluated by the (optional) CAPWAP program which can be installed in the PAK. CAPWAP uses the measured force and velocity data with a pile model to (automatically) calculate the dynamic soil behavior and a simulated static load test curve.

Pile Dynamics, Inc. (PDI) designs all its equipment to be rugged and endure harsh construction conditions. Reliability is proven by hundreds of PDI units in the field, and our strong commitment to quality products and support. The PAK is designed for the professional engineer or researcher and comes with a full one year warranty under normal use.

PDI's solid international reputation is the result of quality products, decades of dedicated engineering research, and commitment to technical support of its clients, including suggestions and advice on unusual applications and data interpretation. Training is available and continued education courses are offered on a regular basis at various locations around the world.

Results for each hammer blow
- Bearing capacity from Case Method
- Skin friction and toe resistance
- Maximum compression stress, acceleration, velocity, and displacement
- Maximum tension stress in pile
- Computed estimate of stress at pile bottom
- Pile structural integrity; extent and location of damage
- Maximum energy transferred to pile
- Hammer cushion stiffness for air hammers/steel piles
- Blows per minute for hammer check
- Scaled display forces, velocities, energy, displacement, resistances, downward and upward waves with time markers for wave speed check
- Warnings and other “expert advice”
- Tests driven piles, drilled shafts and SPT soil samplers
- Results in either SI, metric, or English units

User-friendly operation
- Single component; PDA set-up and ready-to-use in minutes
- “Expert system” software for real time advice and warnings
- Self checking set-up procedure
- Automatic signal conditioning requires no electronic knowledge
- Automatic data storage
- Automatic data presentation software
- Automatic CAPWAP signal matching software (optional)

Hardware
- Robust briefcase style enclosure
- Size: 155 x 320 x 365 mm (6.1 x 12.6 x 15.2 inches)
- Weight: 8 kg (17.5 lbs.)
- Temp: 0° to 40° C, operating; -20° to 65° C, storage
- Power: 12V DC car battery, and/or 100 - 240V AC
- Complete with both softside luggage for airplane carry on and transit case for checked baggage shipments
- Full one year warranty

Field Equipment
- Four strain channels
- Two piezoresistive acceleration and two piezoelectric acceleration channels
- Four velocity integrators
- Automatic balancing of all signals
- Robust transducers quickly attached to pile; connected by single cable to PDA
- Underwater transducer systems available
- Analog input/output capability

Digital specifications
- PC compatible processor with DOS
- 8 Mb RAM
- 3.5" 1.4 Mb floppy
- 350 Mb hard disk
- High contrast VGA backlit LCD display for all lighting conditions
- Built-in VGA external monitor port
- Built-in membrane "keyboard"
- Built-in external keyboard port; external keyboard provided
- Serial and parallel ports
- Built-in 12 bit A/D converter, 8 channels at up to 20 kHz each

PDI has been internationally recognized for its contributions to dynamic pile testing methods. Pile Dynamics, Inc. also supplies other products for inspection of deep foundations:
- Pile Integrity Tester™ for pile integrity evaluation using a hand held hammer
- Pile Installation Recorder™ to automatically document installation of driven and CFA piles
- Sautometer™ for blow count logging and/or to determine stroke of open end diesel hammers
- SPT Analyzer™ to evaluate energy transfer and dynamic soil properties from SPT samplers
- Angle Analyzer™ to continuously display alignment and increase pile driving productivity
- Hammer Performance Analyzer™ uses Doppler radar to measure hammer kinetic energy

Specifications subject to change without notice
CAPWAPC™ PROGRAM

CAse Pile Wave Analysis Program — Continuous Version

In the late 1960’s, under the sponsorship of the Ohio Department of Transportation, a program was developed at Case Institute of Technology in Cleveland, Ohio (1), which determined the Smith (2) soil resistance parameter from pile top measurements. Originally, a large computer automatically solved the problem for relatively short piles.

CAPWAPC™ modeled the pile as a series of springs and masses. For long piles the numerical performance of this model was not satisfactory. Thus, in the early 1980’s, after the need for offshore pile analyses had increased, the pile was subdivided into continuous segments and calculations were made with a traveling wave algorithm.

CAPWAPC determines that set of soil resistance parameters which produces a best match between measured and computed pile top force and velocity. Rather than modeling and analyzing the hammer, one of the two measured curves is used as a pile top boundary condition. The complementary quantity is computed and compared with the appropriate measured curve. The soil is represented by three parameters: ultimate resistance, quake and damping. CAPWAPC is based on the premise that best agreement between measured and computed pile top curves is achieved with a set of soil resistance parameters which most accurately models the actual soil behavior. Obviously, as in all dynamic pile testing, the resulting values represent the soil at the time of driving.

Features of the new CAPWAPC™ program include:

- Interactive or automated mode
- Matching of forces, velocities or upwards traveling waves
- Case Method bearing capacity based on a closed form solution
- PEBWAP (Pile End Bearing Wave Analysis Procedure) which calculates pile toe resistance vs. pile toe movement for end bearing piles
- Comprehensive numerical and graphics output
- CAPWEAP, a wave equation analysis using pile top measurements instead of a hammer model
- Static analysis for a load-set curve based on the CAPWAPC results

GRL offers CAPWAPC analyses by its experienced engineers. However, the program is compatible with the Pile Driving Analyzer™ and may be acquired by its users in executable form. It requires the following hardware:

- IBM-PC, XT, AT or compatible including 640 k-byte memory, math coprocessor, 2 disk drives (312 k-byte minimum), parallel and serial ports. The preferred configuration includes a high clock rate, a hard disk and Hercules compatible monographs.
- HP 74-series or compatible plotters.
- Printer, preferably graphics printer.

The CAPWAPC program package includes GRLWAVE (wave equation), DATPRO, digitizing software and other utilities. Program updates are made available approximately twice a year.

References and Additional Reading:

Correlation of CAPWAP computed and measured static load test curves based on the research work performed at Case Institute of Technology (1970).

Correlation of ultimate bearing capacity values from CAPWAP and load tests based on the research work at Case Institute of Technology.
CAPWAPC™ PROGRAM

Pile Variable Histories
The example shows forces and velocities at three different locations. However, displacements, resistance forces and even transferred energies as computed during the last trial analysis may also be graphed.

Graphics Mode
The CAPG-version of CAPWAPC includes screen graphics for both trial analyses and final results. The program allows for substantial time savings, usually with sufficient resolution.

Static Pile Top Load vs. Deflection
As a final result, a static analysis may be performed using Ru and quake values from CAPWAPC. The load-set curve is usually computed for the dynamic pile toe movement and therefore includes the rebound portion of the test.

CAPWEAP
Similar to a conventional wave equation, CAPWEAP produces a bearing graph which relates bearing capacity and pile stresses to blow count. The analysis uses the CAPWAPC predicted static and dynamic soil resistance parameters. However, the action of the hammer is represented by the measured pile top quantities.

Goble Rausche Likins and Associates, Inc.
4535 emery industrial parkway cleveland, ohio 44128
phone 216/631-6131 fax 216/631-0916 telex 985-662 (pile dyn wvht)
Final Matches

Computed and measured pile top force and/or velocity comparisons demonstrate the quality of the final result. Also, for trial analyses, the upward travelling wave (one half of force minus proportional velocity) may be computed and compared with the measured one.

Resistance Distribution Plot

It shows the final static resistance results underneath measured force and velocity with matching time and length scales.

Pile Profile and Pile Model Table

This output includes all relevant pile data including iteratively determined tension and compression slacks, pile structural damping and average wave speed.

<table>
<thead>
<tr>
<th>Depth</th>
<th>Area</th>
<th>E-Modulus</th>
<th>Spec. Weight</th>
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<tbody>
<tr>
<td>ft</td>
<td>in²</td>
<td>KIPS/in²</td>
<td>KIPS/ft³</td>
</tr>
<tr>
<td>1</td>
<td>00</td>
<td>18.40</td>
<td>30000.0</td>
</tr>
<tr>
<td>2</td>
<td>137.00</td>
<td>18.40</td>
<td>30000.0</td>
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<table>
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<tr>
<th>Segment</th>
<th>Depth B.G.</th>
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<th>Compressive Slack</th>
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<tbody>
<tr>
<td>No.</td>
<td>ft</td>
<td>KIPS/ft/s</td>
<td>Inch</td>
<td>Inch</td>
</tr>
<tr>
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<td>3.34</td>
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<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>41</td>
<td>137.00</td>
<td>32.8</td>
<td>0.000</td>
<td>0.000</td>
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</table>

Pile Damping (%) .0, Time Incr (ms) .199, Wave Speed ft/s 16810.8

Extrema Table

It lists maxima of compression and tension forces and stresses, velocities, displacements and even transferred energies at a limited number of points. Absolute stress maxima are shown including their location and time of occurrence.

<table>
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<tr>
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<td>1</td>
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<td>1.304</td>
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<td>4</td>
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<td>8</td>
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<td>29</td>
<td>96.9</td>
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<td>.590</td>
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<td>.460</td>
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<td>40</td>
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<td>4.67</td>
<td>10.5</td>
<td>.412</td>
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Absolute 76.9 29.99 (T= 25.0 ms)
3.3 1.14 (T= 55.5 ms)