Effective Use of the Pile Driving Analyzer

by G. Likins

We have compiled several lists which may be of value in expanding the use of your PDA.

The first section "General Specifications for Dynamic Pile Testing by the Case Method" gives an overview of the entire measurement system. The second section "Specifications" is a sample of a dynamic pile testing specification for bid documents. The third part "Construction Control by the Pile Driving Analyzer" is a guide to how the dynamic data can be used and includes guides for limits on stress hammer evaluation, and pile integrity. It also goes into more depth on capacity determination for static test replacement and good correlation procedure as well as suggested procedures.

The last section is a compilation of a poll of PDA Users on various topics. Twenty three (23) responses were obtained out of about 55 organizations which have the equipment. A complete statistical analysis is attached.

General Specifications for Dynamic Pile Testing by the Case Method

1. Introduction

Dynamic pile testing by the Case Method may be required for a variety of reasons. Most commonly, either one or combinations of the following four items are investigated:

(a) determination of pile bearing capacity
(b) determination of pile stress during driving
(c) determination of pile integrity
(d) determination of hammer efficiency

2. Pile Driving

All tasks require that both axial pile forces and accelerations are measured under at least one hammer blow. Such a hammer blow has to be sufficiently strong to cause a permanent pile set of more than 1/20 inch for a sufficient activation of soil resistance. Smaller permanent pile sets may lead to underprediction of static capacity. Also for the determination of pile integrity, a hammer blow is needed that causes a motion of the pile tip (permanent set is not necessarily required).

3. Selection of Test Piles

Test piles are to be selected depending on the extent of the site, the variability of the soil, and the reliability of the soil investigation. In the absence of other pile test methods, a sample of 2% of all piles or eight piles, whichever is greater, shall be subjected to the dynamic test. The test piles should be uniformly distributed over the site except where geotechnical or structural considerations call for a different selection.

4. Time of Testing

For the determination of either pile stress or hammer efficiency, a realistic test situation must be given. Thus, regular production pile driving is preferrable to the short duration test of an already installed pile.

For soils that are likely to exhibit strength changes with time, restriking tests are preferrable to tests during driving. For soils for which no experience regarding setup or relaxation exists, at least two piles shall be tested both at the end of driving and after a waiting period of at least two hours in order to establish certain trends of strength changes. Decisions regarding further restrike tests shall be based on the results for such short duration restrike tests.

5. Accelerometers

Acceleration has to be measured by suitable signal pick-ups attached to the pile wall at least one pile diameter (or width) below its top. An accelerometer has to be installed in the pile's center (center of web for H-piles) or on opposite pile sides for the cancellation of bending effects.

The accelerometers have to be linear to at least 1000 g's and 10,000 Hz. In some instances, higher limits may be required.

6. Strain Transducers

If force measurements are done by strain transducers then these units have to be securely attached to the pile wall such that no slippage occurs. Bolt-on or glue-on transducers are acceptable.

A strain transducer has to be mounted at least one pile diameter (or width) below its top and in the vicinity of the accelerometer, i.e. in the geometric center of the pile cross section, or two units have to be installed at points equidistant from the center of gravity.

Strain transducers have to be linear over the whole range of possible pile strains. Attached, their natural frequency must be in excess of 10,000 Hz.

7. Force Transducers

In some instances force transducers may be a convenient alternative to strain transducers. In contrast to the strain transducer, force transducers transfer the full hammer force to the pile top. Their impedance (i.e. cross sectional area times elastic modulus divided by wave speed) shall be between 50 and 200% of the impedance of the pile at its top. The force trandsucer has to provide a signal that is linear to the axial pile top force even under eccentric load application.

8. Measurements

Measurement of force and acceleration of the pile is the basis of the Case Method. Both quantities have to be measured continuously over time. They have to be recorded on magnetic tape or equivalent medium such that components of up to 1000 Hz frequency are accurately preserved.

Time of testing must be recorded.

Pile penetration must be accurately measured. During restrike, the penetration under the first 10 blows is often of great importance. In driving situations, driving logs must be taken with emphasis on the last foot or inch of driving.

Other measurements like hammer stroke, air/steam or bounce chamber pressure, combustion pressure, etc. may be desirable but are not essential for standard Case Method tests.

9. Data Processing

It is essential that immediate field processing be done for identification of malfunctions. The following must be done in real time (e.g. by the aid of the Pile Driving Analyzer):

9.1 Balance force continuously except when a rapid variation of force (occurrence of impact) is sensed.

9.2 Integrate acceleration over time to obtain velocity.

9.3 Display force and velocity on an oscilloscope or other suitable device which is capable of displaying the records as they occur.

9.4 Integrate the product of force and velocity over time (transferred energy).

9.5 Determine maxima of force, acceleration, velocity, transferred energy, force at maximum velocity and minimum force (tension at point of measurement).

9.6 Determine pile bearing capacity under each blow according to Case Method (see Appendix A). The choice of damping parameter J must be based on experienced judgement and extensive soil data.

9.7 Print selected results from 9.5 and 9.6.

9.8 Check force-velocity proportionality; causes of deviations, e.g. pile damage as described in Appendix A, must be investigated.

9.9 Determine maximum pile tension force at locations other than the pile top according to the method described in Appendix A.

10. Presentation of Results

The experienced engineer may give a summary of results immediately in the field. In complicated cases further evaluation may be necessitated either because of a difficult soil condition, an unusual pile geometry, or other unexpected problems with data interpretation. Additional work may be necessary in the laboratory if pile or soil conditions require a CAPWAP analysis (see Appendix A), if difficult pile geometry exists or if other unusual circumstances are encountered.

The final results are to be submitted in written form after careful evaluation by the experienced engineer.

SPECIFICATIONS

We are often requested to provide a specification for our dynamic testing methods. It should be recognized that each project has items which make it unique as to the needs of testing; of course, one of the advantages of testing with the Pile Driving Analyzer is its inherent flexibility in adapting to specific site dependent needs. The following is a sample of a dynamic pile testing specification.

An acceptable alternative to the static pile load tests is dynamic testing by the Case-Goble Method as performed using a Pile Driving Analyzer.

Scope and sequence of testing services to be as follows:

A. Perform initial wave equation analysis based on

   1. Subsurface conditions at the site
   2. Type of pile to be installed and required pile capacity
   3. Pile Driving equipment to be utilized

B. Drive not less than ** piles at locations specified by the engineer using driving criteria established by the wave equation as a guide (subject to change due to actual hammer performance and expected soil strength changes via setup or relaxation). Dynamic testing shall be made during the final ** feet of driving.

   1. (Alternate for fine grain soils). Install ** piles to varying penetrations and/or driving resistances and retest as in C.

C. Evaluate test piles after a minimum waiting period of ** (hours, days, depending on soil description) by restriking the piles and simultaneously performing dynamic reading using the Pile Driving Analyzer. Restrike testing is considered essential for service load capacity determinations. The piles should be tested with a minimum wait period of 12 hours or extra piles should be tested which have been previously installed to identical criteria and have had the specified waiting period.

D. Test at least ** additional piles during ** additional construction control visits. Piles shall be tested during initial installation and/or restrike of in-place piles as soil conditions dictate. Further dynamic tests should be made if

   1. The hammer system is replaced or modified
   2. The pile type is changed
   3. Different behavior from the standard practice is observed to determine if hammer, pile or soil changes exist
   4. Design loads are modified

E. Based on results of the field data from the Pile Driving Analyzer, the following should be reviewed:

   1. Driving stresses (compression or tension)
   2. Hammer system efficiency
   3. Pile structural damage
   4. Bearing capacity

F. Perform supplementary wave equation analysis using the measured data and use CAPWAP on at least ** percent of the piles tested, including ** piles in the initial program to verify the calculations of the Pile Driving Analyzer.

G. Submit written report or summary of results upon completion of the field testing.

It is mandatory that the testing be performed by experienced, qualified civil engineers.

It should be recognized that each site has unique characteristics. Judgements should be made, even during the testing program, by the experienced engineer performing the test as to deletions or additions to a "standard" program which will result in the most benefit.

Construction Control by the Pile Driving Analyzer

Suggestions for PDA Application

Force/velocity records from PDA should be used to check:

A. Stresses In Piles

1. Compression stress should be limited to 0.9 Fy, but should be at least 140 MPa (20.0 ksi) for steel or 15 MPa (2.0 ksi) for concrete so that driving is efficient.

2. Tension stresses in prestressed concrete piles should be limited to 7 MPa (1.0 ksi) to prevent pile damage. This is approximately the level of prestress in prestressed piles.

B. Pile Intregrity

Piles should be inspected by PDA. Force-velocity records for damaged piles with the integrity factor, BETA, less than 0.6 are broken and should be replaced. Piles with higher BETA values may be assigned capacity reductions based on BETA after careful data analysis. Piles with a BETA value greater than 0.9 shall have full capacity.

C. Hammer Performance

Hammers are rated on their potential energy, Wh (W = ram wieght, h = ram stroke). The stroke varies for diesel hammers and can be found by

$$h[\text{meters}] = 1.22\ T^2 - 0.1$$

or

$$h[\text{ft}] = 4.01\ T^2 - 0.3$$

where T = 60/(blows per minute).

The maximum energy transferred into the pile, EM (measured by PDA) will typically be 30 to 50 percent of the actual potential energy, Wh. Hammers with less than 25 percent are either in need of repair, need a more effective hammer cushion, or better pile-hammer alignment control. Energy losses for concrete pile may be somewhat larger due to the pile top cushion.

D. Pile Bearing Capacity

Capacity on site from PDA using Case Method at time of testing:

1. When driving, the PDA gives the capacity of remoulded soil.

2. If a long term static service load is wanted, the pile must be

tested after a wait period for soil strength changes (from re-consolidation, dissapation of excess pore pressure developed during driving, etc.) to be complete. On most sites, these changes are complete after two days.

Restrike testing is <u>always</u> recommended for about 2/3 of the piles tested. The remaining 1/3 should be tested at the end of driving to assess strength changes, driving stresses, etc.

3. Damping factor from

   a. Correlation of soil particle size (typically for bottom length equal to 5 pile diameters) from boring.

   b. Back calculate J (the only unkwown) from ultimate load of a load test run to failure or the ultimate load as computed by CAPWAP and the dynamic measurements of capacity (RT with J = 0) and input forces

$$J = (RT-RS)/(F1+IV1-RT)$$

   c. Can investigate sensitivity by varying J factor by ± 0.1 to 0.2 (low ranges for coarse material, higher ranges for fine soils, i.e., silts and clay).

E. Suggested Procedures

1. Test at least five percent of all piles (or a minimum of five piles on small jobs). More testing should result in higher confidence and therefore reduced safety factor. Testing of ten percent of the total number of piles is recommended for normal project.

2. Drive the piles to wave equation result (not Hiley formula). Test piles during end of driving and also restrike after wait to assess soil setup changes. If the capacity in restrike tests is different than that required, the driving criteria can be adjusted. Keep accurate records of blows/meter (or set/10 blows in hard driving or at beginning of restrike) so that comparison with piles which are not tested can be made.

3. When possible, run the static tests to failure to assist in the determination of the damping factor J as in note 3 of section D above. Static tests should be made as early as possible during the project. If a maintained load test to only twice the design load is made, a second quick load or CRP test to failure could be made after the proof test at very little additional expense or time.

4. After the dynamic data is obtained, perform an additional wave equation analysis using WEAP (contains the correct model of diesel hammer) to match field observations of maximum force, energy, stroke (from blows/minute) and capacity and blow

count.

5. Setup can be determined from

   a) results from PDA at end of driving and beginning of restrike or

   b) carefully comparing measured blow counts with WEAP analysis (not as accurate).

6. All piles should be driven to wave equation blow counts and PDA indicated capacity so that final capacities of the piles have a safety factor greater than 2.0. Note that final capacity inclues setup so piles do not have to be driven to full final capacity at the end of driving.

7. Twice as many piles should be restruck using the PDA as those tested by the PDA during driving. Restrikes of 10 to 15 blows is usually sufficient. Piles should be selected for restrike on a basis of unusual blow count behavior in driving, short and long penetrations compared with neighboring piles and several control piles.

8. PDA testing should be made for about two or three days at the start of the project preferably after a couple of indicator piles have been driven so that excessive wait or standby of PDA on site is minimized. Further PDA testing can then be limited to basically restrikes of the selected piles at a frequency of approximately one day of PDA testing every two weeks for construction control (restrike of 10 piles should take less than two hours of contractor time).

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CAPWAP Analyis Using the Characteristics Approach
By Frank Rausche

Hammer Performance Measurements
By Frank Rausche

Dynamic Compaction Tests
By Anthony Calomino and Frank Rausche

Effective Use of the Pile Driving Analyzer
By Garland E. Likins, Jr.

Evaluating the Performance of Pile Driving Hammers
By Garland E. Likins, Jr.