THE PILE DRIVING ANALYZER:

FIELD TESTING AND DATA INTERPRETATION

By

Garland Likins

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The first and foremost thought for any field work is to acquire quality data for without it the results are also suspect. This means to me that the engineer should place his primary emphasis on the collection of good data.

TRANSDUCER VERIFICATION

The first step is to confirm that the transducers are functioning properly. Tap the transducers as described in the PDA manual and observe their performance; replace or repair defective units. Also regularly check the cables and their connections (wiggling the wire near the connector while observing the F1-F2-V1-V2 analog outputs directly on the scope for spikes or other unusual characteristics - with PDA connected to X-Y scope, attach the VERTICAL BNC in Scope directly to the F1 etc analog output.) The cable connectors and main cable connections (particularly where the cable hangs at the pile top) can and should be checked in the same manner; sufficient spare cables and connectors should be available on site to replace defective units as required. The transducers should be firmly attached to steel piles as the high acceleration if it causes slippage will result in inconsistent and therefore erroneous data; for concrete pile the transducers need not be tightened quite as much as overtightening may result in pulling of the anchors instead. It is therefore important to be sure to firmly seat the anchors. It is important to have both strain signals working since bending usually makes the strain signals on opposite sides quite different; if a strain transducer quits partway through a test, it should be replaced as soon as possible with a good working unit. Since the acceleration signals are very similar, generally one good unit is all that is required for a successful test.

DATA QUALITY CHECKING

To confirm good quality data, put the PDA expansion (temporarily) to one

(1) and check for consistency; for similar hammer blows, the data should also look similar. The velocity trace in particular should not be jumping around; each individual accelerometer can be checked with the Accelerometer Selector Switch. If one accelerometer seems to be performing much better than the other, it is better to use only that accelerometer only than corrupt your data by averaging with a bad signal. Also check for proportionality of the major input rise (the peaks don't have to match for diesel hammers due to precompression).

In the field, I always begin with the transducer selection switches in B (Both) position rather than the AU (Automatic) position, which I consider acceptable only for the very inexperienced. I feel that by watching the scope display that I can select or judge the performance of the transducers as described above much better than the PDA which only looks for open or shorted circuits (or for very high acceleration spikes which causes the warning lights to turn on sometimes for every blow in steel to steel impacts or in some underwater applications; this is annoying to me in that I would have to hit the reset button for every blow if in the AU position). If I determine that the velocity is relatively unstable from blow to blow, I then switch to A1 or A2 in the hope of finding one accelerometer which is functioning properly. I spend by far the largest portion of my time during the hammer operation in observing the scope where I can view the data quality and assess other features such as bending, tension, large quake cases, friction distribution, damage, wavespeed, and capacity determination methods.

For slow rise times, impedance increases just below the transducer location, gages near the ground elevation, and high friction in the upper soil layers, the force can be higher than the velocity at the time of the first peak. For impedance decreases just below the transducers the velocity can be higher than the force. It should be noted that if at all possible the transducers should not be attached near (either above or below) an impedance change as the stress path can rapidly change through this area. Just as at the pile top, the transducers should if at all possible be attached at least 2 and preferably 3 or more diameters below the top or impedance change. In general the farther from the pile top the gages are attached, the better quality the data becomes (the only difference this makes to the results is that the maximum energy EMX is slightly reduced due to the energy required to compress the pile above the transducers). For concrete piles with little cushion and high accelerations, a change to the normal (Hi G) accelerometers may also produce better data.

TRANSDUCER CALIBRATION

It should go without saying that the calibration settings for F1-F2-A1-A2 must be correct. The field settings of EA/C, MC/L, L/C, DELTA, J, and PEAK do not affect the data going to the tape recorder and can be easily readjusted later in the laboratory to their correct values with no loss of confidence (except that the field results would be wrong!). The calibration settings however must be correct requiring that the calibrations of the transducers be accurately known and that the wavespeed c used in the F1-F2 inputs be known; this c value is the c at the gage location (and be the same c exactly as used in the EA/C setting) which can be different than the average c value used in the overall wave return (L/C setting) due to cracks etc. It can be concluded in the study of strain transducer recalibrations that the calibration of any individual transducer is thought to be reliable to within about five percent (see data presentation on this accuracy in the 1988 Users Notes); Based on a series of tests on GRL transducers, I do not find recalibration periodically to be necessary. Recalibration should be done after repairs and must be done after any gage replacement. If any transducer consistently fails to give good proportionality with the velocity, then it also should be recalibrated to verify its accuracy. It is unlikely that the redundant transducers (two systems namely strain and acceleration) could produce proportional data if both were not working properly and had good calibration. No data is easily available to verify the accuracy of the accelerometer calibration, although PDI/GRL in their work usually assume if an adjustment is required for proportionality the strain is adjusted due primarily to its susceptibility to bending and local stress concentration influences. If there is any doubt about the PDA calibration itself, the built in CAL feature can be used to compare values with known inputs as described in the PDA manual; we do recommend that the CAL check be done on a periodic basis as it takes little time and will detect any problem with the PDA itself.

DATA RECORDING

The data recording can be accomplished now with the GCX PDA version in digital form. In fact, for that system the analog tape recorder is not really necessary. The advantage of digital recording is that the data collected and saved is exactly that observed in the field rather than filtered (and gain changed) by the analog recording. Also the laptop computers now available can be easily taken to the field and therefore those with the CAPWAP capability can perform this analysis on site (although this takes some time away from the actual data collection unless done in the evening at the hotel instead of watching TV etc). The cost of the laptop is also considerably less than the tape recorder while the size is comparable. There are some disadvantages also to be considered. First if the microprocessor fails for any reason (anyone have the generator run out of gas at a critical moment?) prior to saving the data on disk and closing the file, then all data collected is lost permanently. For restrikes, every blow can be saved; during driving, the number of blows to drive the pile should be estimated and the blow sample frequency chosen accordingly (this can be adjusted during driving, e.g. by switching to saving every blow for the last 10 blows of driving) so that only representative blows are actually saved. It takes approximately six seconds per blow at 9600 baud to transfer the data. File setup/closing and XTALK commands can easily double the time required to save a series of blows.

The tape recorder can easily save every blow and data is still collectable even if the microprocessor fails provided the signal conditioning still works. For new PDA purchases, the new owner may not need the tape recorder (and thus save cost), particularly if this is his second system and his first system already has a recorder. The storage option has some appeal even to those with recorders. We at PDI/GRL still would take our recorders to the site as a backup since the recorders are available and relatively small and lightweight. The data recorded on the 7 channel TEAC tape recorder should include F1, F2, F avg, Comp (flutter on channel 4), V1, V2, and V avg (with voice override on channel 7); this allows replay inspection for bending, and for selection of a single velocity if the average is of marginal quality.

With the field data acquisition now covered, let us turn our attention to data interpretation.

DATA INTERPRETATION

We should always be looking at the maximum forces so that the driving stresses can be determined. The maximum force FMX is the compression force at the transducers and needs little explanation; the force could be slightly higher just above a point of high shaft resistance, but this increase would be modest and not likely to cause pile damage compared with the local contact stresses due to non perfect alignment. For piles with high cross sectional increases, wave equation studies should be made to find a stress amplification factor. The tension force is generally of interest for concrete piles and usually only during easy driving although for large quake soils high tension stresses can still be a problem even for refusal driving. CTN now (Program versions 880415 and later) only considers the tension returning from the toe for both first and second peak cases; CTX (newly added 880415 and printed only in the COMPLETE printout) also considers the downward tension wave late in the blow and if this is larger is printed as a positive value.

Pile damage is generally noted by a BTA value less than 100. If the pile is short or the rise time very long, the PDA cannot check for damage at all and the value 200 is printed to distinguish this condition. If BTA is less than 100 and is selected for printing, a third time marker dot is output to the scope. If damage is indicated by the PDA, the operator should immediately note its suggested location on the pile from the third (middle) time dot marker, and probably stop the hammer to prevent further possible damage. The first question to ask is if the pile is nonuniform, or if a splice detail is causing a false indication. Earlier blows can be reinvestigated to view if the problem area is getting worse. If the problem is very near the pile bottom, perhaps the indicated length or wavespeed is slightly in error; again check earlier blows or pile records. If the pile is a closed end pipe, drop a tape inside to measure the length or a light (mirror) lowered will allow visual inspections. Replay the forces and check if bending is severe enough in the records to cause a minor disturbance in the data and therefore a false indication. Remember that the data is only checked for damage between one rise time after the peak until one rise time before 2L/c.

Hammer performance should also be evaluated. The most important factor is EMX, the maximum transferred energy. Comparison of EMX with the potential energy Wh (or manufacturer's rating) is generally all that is necessary. Further analysis is possible by looking at the momentum calculations as given in the PDA manual (MFO is generally preferred to MWO). If the RAM WT is input, the maximum velocity of the ram before impact VRI is calculated and can be printed; this value can be used to compute the kinetic energy of the ram to find if losses are primarily in the hammer or the lower driving assembly. The force FCP and the stiffness KCP in the hammer cushion can also be computed if the CAP WT is input. The hammer cushion stiffness can be further evaluated by plotting the load deflection graph (PLOT V with FCP being printed). These FCP and KCP values are generally only correct for air/steam/hydraulic/drop hammers on steel piles; use to other systems is possible with less accuracy but the PDA User is encouraged to refer to 1987 Cleveland Users Day notes.

CAPACITY DETERMINATION

This is usually the biggest challenge facing the engineer, and potentially the most costly if he makes a mistake. However it is also the most rewarding when the PDA can reduce the amount of expensive static testing or determine that the length and therefore the cost of a pile foundation can be significantly reduced.

It is impossible to give guidelines that generally apply to all situations. The PDA operator should carefully read all applicable sections of the PDA manual (especially Chapter 1, the section on J selection, and Appendix A). Another paper on capacity methods is included in these Users notes and shows how the various computations are performed and to a lesser extent their applications. It should also be mentioned that the 2L/c time period must be correctly determined and entered or else very large errors in some cases (particularly those with clearly distinguishable reflections at 2L/c) may result.

A "dynamic formula" method QULT which uses the EMX and DMX measured values is available in "REPROC" last output with "COMPLETE" printout. The user is left to pick the correct QULT value from the current blow count, all other values are definitely not correct. Although we do not recommend these formulas as a general rule, this one contains some measured values, and may at least give an indication of the potential benefit to be gained at the very high blow counts. RLT is the limiting value of QULT and is available as a printer selection also (note that RLT is not the same as RTL which is RSP with a J of zero). Again we do not recommend the reliance upon this result but offer it only for reference purposes.

For piles with very little skin friction, the RAU method is (theoretically at least) the perfect method to use as all theories are correct and the user does not have to select a damping constant. It makes no difference if it is easy or refusal driving; the key is that the force and velocity should be proportional for the first 2L/c.

The RSP methods (RS1 for peak 1, RS2 for peak 2, and RSM for peak max) are the original methods for which the empirical damping factors based on soil type were determined (note that this implies that the soil is properly identified, preferably by grain size analysis, and that the soil at the boring is similar to that at the pile location). Unfortunately, for very low blow counts, this method is also very sensitive to the J factor in that small changes in J can result in large changes in capacity. Also for large quake soils or high blow counts (small set per blow), the full toe resistance may not be fully active at the time of the first return; a small delay will sometimes cure this, and as a special note, for concrete piles which often have 2 peaks due primarily to the nonuniform compression of the pile cushion, selection of the second peak almost always leads to a better solution. Viewing the RT-RS curves on the scope and adjusting the J until a smooth, preferably flat curve is obtained also may help; however as the shaft friction increases, this technique becomes less reliable. As a small note on shaft friction, the SFT computation makes no allowance for damping.

The RMX method searches the entire record for the maximum resistance during the entire blow and thus overcomes some of the limitations of the RSP methods for large blow count, small blow count, or high quake situations. Although the temptation exists, I do not like to use damping factors less than 0.4 with this method without substantial proof from CAPWAP or a static test that a lower damping factor correlates well. Higher damping factors may sometimes be necessary, although logic (instinct) tells me that factors above about 0.7 are the result of unusual soil conditions (for which I wouldn't object to recommending a static test). For friction piles in clay (where high J factors are normally appropriate), the full resistance should be active during the first 2L/c cycle anyway (RSP = RMX); in the case of high shaft friction in clay and high end bearing, the friction may only be available after a setup period and seen during restrike, while the end bearing is easiest determined from the end of driving. A summation of the two cases may in some instances be possible and give a better indication of the total capacity available during service conditions.

The newest method, RA2, has shown considerable promise in determining the ultimate load even for piles with moderate shaft friction and this method does not require the selection of a damping factor. Results are generally in good (not necessarily great) agreement with results from CAPWAP and therefore the method deserves at least a casual consideration on every project and often has proven to be the best method available; if the RA2 differs from the results of the damping factor methods, then further investigation is clearly warranted. If the pile is proceeding through a layered soil, this method has the additional advantage that the damping factor does not affect the result.

For piles with very high friction, such that the velocity goes negative prior to 2L/c, most all of the above methods become unsatisfactory and the unloading method RSU may be beneficial. However, CAPWAPC should be used as soon as possible to verify the correct procedures.

At this point, I should mention that on practically every project that we acquire data from, we perform at least one CAPWAP to confirm our field methods; for larger projects with more piles tested, we generally perform CAPWAP for about 20 to 40 percent of the piles, although usually only for the data at the end of drive or begin of restrike. Unit friction values and the determination of friction versus end bearing, and analysis of both EOD and BOR cases often allow for more sophisticated recommendations regarding the total capacity, optimum driving criteria or pile length. Further discussion of the great benefits of CAPWAP are beyond the intended scope of this paper (the user is referred to other papers on this subject in this 1988 Users Day) except to say that this confirmation by an independent analysis can often detect unusual conditions not noted simply by PDA testing and is therefore usually well worth the investment.

It should be obvious by now to you, the experienced PDA User, that the capacities determined represent the ultimate capacity at the time of testing (ie EOD or BOR). Restrike tests are therefore considered very important especially if good correlation is to be achieved between the dynamic test and a static load test. If the static load test is not run to failure, then only a lower bound solution can be given; similarly if the blow count is very high (low set per blow, typically less than 3mm/blow or greater than 10 blows per inch) then the dynamic test's ultimate capacity may be low. The optimum waiting period for the restrike varies depending on the pile type and soil type; some report that testing reveals that capacities are still increasing after more than a year, while on other projects no observable setup is ever noticed. Knowledge of the soil type, whether the soil is saturated, and local experience can be used as guides for how long the period before restrike tests should be.

Although less common (fortunately), some soils exhibit relaxation or a reduction of capacity as a function of time. Some suspected cases are in reality due to hammer performance being poor at the end of driving causing relatively high blow counts, and being better at the beginning of a restrike or redrive resulting in relatively lower blow counts; the PDA can easily identify these cases by looking at the hammer performance indicator EMX.

There are cases where capacity reduction is very real and the PDA User should be very aware of this potential as loss of capacity can result in foundation failure and the ensuing legal implications. Three cases quickly come to mind. First is the case of piles driven to some shale bedrock. If the shale is weathered, the potential is generally greater for relaxation. These shales have been widely identified in many parts of North America and the assumption is they exist in other parts of the world as well; losses in capacity of up to half the end of drive capacity have been observed! (There goes the typical safety factor used in the USA!) The second case is for displacement piles driven into very dense soils (often silts) with little shaft friction; the high end bearing at the end of driving reduces with time, the soil beneath the toe springs back since the friction is unable to keep the toe in a compressed condition. In a third situation, negative pore water pressure during driving would cause artificially high effective stresses and end bearing. Reductions may also be due to pore pressure changes. In any case, one day restrikes are often not sufficient, especially in shale, as the relaxation process often takes a week or more to fully develop. Some later restrike test (with or without PDA testing) should be performed with a very careful measurement of the set for the first few blows which can then be compared with the end of drive blow count.

PLOTTING CAPABILITIES

The PDA can be connected to HP 7400 series plotters (or compatible units) to produce report quality graphs. The baud rate can be set to 9600 baud for both PDA and plotter. The primary plot available is accessed through the PLOT F - SEND command sequence. This plot contains as time functions the Force and Velocity, Waves Up and Down, Resistance at up to 4 different damping factors, and the Energy and Displacement. The time scale is selected with the scope expansion selector; the vertical scale is now also user selectable with the display quantity selector as described below.

The PEBWAP analysis can also be obtained with the PLOT V - SEND command sequence. The scales are automatically determined. PEBWAP plots the force versus displacement at the bottom of the pile and is intended for piles with small shaft friction. Inspection of the plot can lead to conclusions regarding the ultimate capacity, soil stiffness or quake value for the pile toe, and the appropriate damping factor (the best J often makes an elastic-plastic response as modeled by wave equation etc).

The Capblock (hammer cushion) load deflection curve can also be plotted as noted earlier with the PLOT V - SEND - FCP commands.

DATA TRANSFER

The RS232 interface can be used to communicate directly to the plotter as described above. It can also send digital data for the blows to computers for CAPWAP analysis; this sending can be done either directly or through modem communications using the (preferred) XTALK program. If the PC is available in the field (laptop or portable unit), the digital storage of blows can be performed; the data printed in the field by the PDA can also be output during data collection (or captured during a laboratory replay of the data) and also retained using XTALK in a file. This file can then be plotted to produce a visual summary of the project using the program PDAPLOT as described at this PDA Users Day.

NEW PDA PROGRAM FEATURES

I should mention that if you have an older program version, there are many improvements available to you with the newer versions. These improvements may (depending on how old your version actually is) include:

1) COMPLETE works even in B AVG

2) Can start PDA even in channel 1 mode; note channel 1 mode computations are meaningless and therefore this mode is intended only as a fast sampling data collection tool. The array can however be plotted (EXP=1 whole array of 100 msec; EXP=2 the first 50 msec; EXP=5 or 10 the last 50 msec).

3) If J=0, then only one resistance curve is plotted for maximum plotting speed. Resistances less than zero are plotted as zero (still show negative on scope to aid J selection). Force scale for resistance plot now independent of F,V and Wave scale and correct even when EA/C and MC/L are not equal.

4) If in B AVG mode, an "A" is printed at the end of each data line (although if the data is nonproportional the "F" or "V" still takes preference and will be printed in that case rather than the "A") denoting that the printout is the result of an average.

5) Energy plot works with all expansion settings.

6) The Delta dial with peak MAX makes the first time dot go to the left. This helps greatly for wavespeed and or 2L/c determinations with Wave Up and Wave Down on the scope. Checking rise to fall

times as outlined in the PDA manual is the only and preferred method we use to set the 2L/c time.

7) When sending a single blow (non extended memory mode), the printer now prints the blow number being sent for ease of documenting. Incidentally, it is always then the scope data which is sent.

8) The middle position of the 4-5 column selector no longer causes printing of junk on powerup.

9) The data column headings are now always printed <u>after</u> settings.

10) Plotting can be aborted during the plot using the ABORT switch (hold the switch until it takes effect and the ABORT message is printed.

11) Plotting is now significantly faster due to (a) less labeling and (b) skipping selected data points in the early and late portions of the record where the signals are not changing quickly. L/c marks correct even in 4 channel mode.

12) Scales can be user selected when plotting using the scope data selection switch: RT-RS doubles the scale (half the plot height) while if E-D is selected, the scales are halved (doubles the plot height). This allows for data which is near the automatic cutoff limits to be adjusted so that all plots from the same project can have the same scale.

13) The CTX routine has been added and is printed only in the COMPLETE mode (along with FTN, MF1 and MW1). CTX includes the downward tension computation which is printed as a positive number if this is the maximum while a negative value is printed if the upward tension is larger. CTN includes only the upward tension computation.

14) The PEBWAP displacement scale (accessed with PLOT V - SEND) has been improved.

15) The data headings are now printed when changed when in B AVG.

16) Extended memory storage has been added. 97 blow capability if in 2 channel Fast, 45 blows otherwise. See the enclosed description for the use of this feature.

There may be other minor changes which I have overlooked. Additional change requests will be considered if they are submitted to us. Changing the program is as simple as replacing the program card. Check your program version with the printer on during powerup; if your version is older than 880415, please contact us so that we may update your PDA.

FIELD PRECAUTIONS

Safety should be of primary concern to us all. If you think there is a safety problem, correct the problem before continuing. A few precautions are listed below.

A) Use safety equipment.

1. Hard hat
2. Safety glasses (while drilling especially)
3. Ear protection
4. Safety belt while climbing leads
5. Steel toe boots
6. Work gloves when climbing for better grip and in cold climates to keep hands warm
7. Life vest when working over water
8. Protective clothing for cold and rain

B) Be careful of power source.

1. Ground all equipment
2. Don't drill while in leads
3. Don't drill while standing in water or set up equipment when you have to stand in water to operate
4. Don't cut the power cord. Disconnect properly

C) Do not stand near operating hammer as a variety of parts of potentially large size could fall and cause serious injury. So-called set-rebound graphs are especially discouraged as you must stand so close to the pile (PDA DMX and blow per inch can give you equivalent information.

D) Be careful when piles are being lifted. This is usually one of the most dangerous times on any site. Always watch during this process and be prepared (plan exit route) in case of failure.

E) When working near the pile or hammer, make sure hammer weight is resting on ground or pile and hammer will not stop. Anytime you must climb the leads, make sure contractor is aware you are doing this so he doesn't start the hammer.

F) For pipe piles, <u>never</u> place your arm (or head) inside the pipe to attach a bolt if the hammer is above the pile; if the hammer should drop (cable breaks, crane breaks or operator error), you would sustain serious injury. For pipe piles we always drill and tap the holes so everything is accessible from the outside.

G) For large projects or high climb situations, you should consider having a member of the piling crew attach your transducers. They are skilled in their profession and with some instruction on the ground can handle the task by themselves.

H) Be careful of moving construction equipment and stay clear of crane when rotating.

I) Do not look directly at welding operation. Also be careful when torch is used nearby.

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Goble Rausche Likins and Associates, Inc.

Pile Dynamics, Inc.

4535 Emery Industrial Parkway Cleveland, Ohio 44128

Phone (216) 831-6131 Fax (216) 831-0916 Telex 985-662 (pile dyn wvht)