The Use of the Pile Driving Analyzer for Installing Pile Foundations

Engineers are always searching for less expensive and more expeditious methods of evaluating engineered systems and materials. Geotechnical and materials engineers are no different.

The pile driving analyzer (PDA) was developed in the 1970's as a method to directly measure dynamic pile response during driving. As the name implies, it was developed to analyze pile driving and evaluate pile driveability, including the range of stresses imparted to the pile, hammer efficiency, etc. With the development of inexpensive desktop computers, programs were written around the wave equation and estimates of pile capacity, such as CAPWAP, became a part of PDA analyses of pile installation.

PDA testing has become a regular part of pile installation on projects in southeastern Virginia especially on waterfront projects. VDOT promotes its use on bridge projects and it is more frequently specified on small projects as well. In addition, it has become increasingly used as a complete substitute for the traditional static pile load test.

Geotechnical engineers have been estimating pile capacity during the design phase of a project based on soil boring data, static analyses of pile capacity, and local experience for many years. These efforts provide a reasonable basis for design and load testing has confirmed that this type of analyses is reasonably conservative. Few pile load tests actually indicate failure at less than 200% of pile design capacity and typically only slightly more indicate failure as imminent.

The increased use of the PDA on local projects as a substitute for a traditional static pile load test is a trend that should be evaluated by the engineering community. The PDA has indicated ultimate pile capacities even after retapping that are significantly less than indicated by static analyses. We have seen underprediction ranging from a factor of 2 to 8 after a confirming load test was performed. The confirming load tests were ordered after the design engineer was lead to believe that his design is flawed due to the results of PDA testing.

Review of the ASTM Standard for PDA testing (ASTM D 4945-96) specifically addresses the issue by stating -- "This test method is used to provide data on strain or force and acceleration, velocity or displacement of a pile under impact force. The data are used to estimate the bearing capacity and the integrity of the pile, as well as hammer performance, pile stresses, and soil dynamic characteristics, such as soil damping coefficients and quake values. This test method is not intended to replace Test Method D 1143." The latter method is the static compressive pile load test.

The USDOT Federal Highway Administration publication, "A Simplified Field Method for Capacity Evaluation of Driven Piles", evaluates the use of the PDA and the methods for analyzing pile capacity, such as CAPWAP. Quoting the USDOT - "Static load testing is the only method available to determine the actual static capacity of piles." There is a strong trend where PDA results are being used as an "actual" pile capacity upon which to make decisions concerning production pile lengths. With this ongoing trend, there needs to be an awareness of what the PDA data is providing.

Figures 1 and 2 are plots of data taken from the FHWA publication and are representative of the information presented. One of the methods of estimating bearing capacity is the CAPWAP program. Figure 1 gives a comparison of actual load testing versus the results of CAPWAP analysis of pile capacity. The red box indicates the range of CAPWAP estimated pile capacity for a pile with an actual capacity of 400 kips. As shown, CAPWAP gave pile capacities of 180 to 380 kips. The same data is plotted as the ratio of load test capacity to that estimated by CAPWAP. A ratio of unity indicates an accurate estimate of actual pile capacity. A higher ratio is underprediction. As indicated, CAPWAP estimate of pile capacity in this data set was as low as 1/3 of the actual capacity. While there is some overprediction, 80% of the test results are underpredictions.

Figure 1 - *Load Test Versus CAPWAP Predictions*

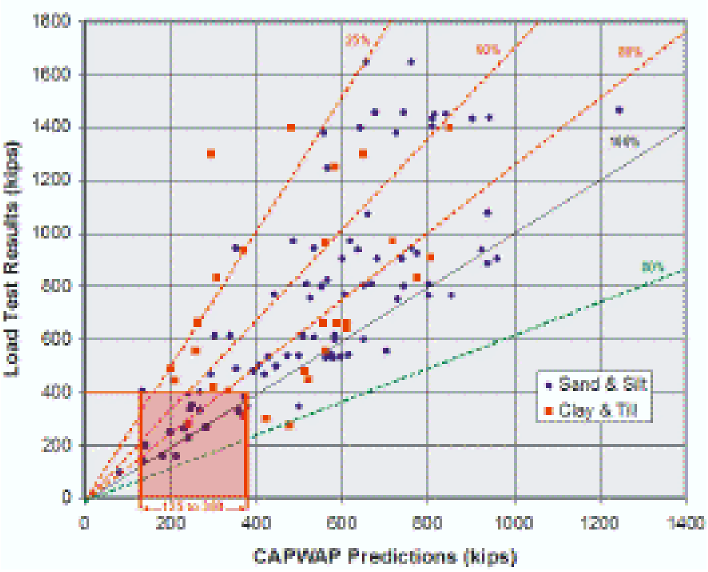
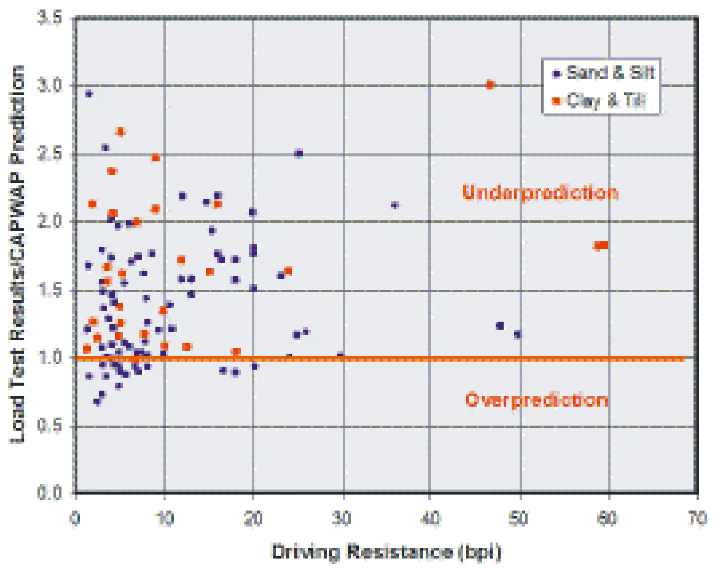


Figure 2 - *Load Test/ CAPWAP Ratio Versus Driving Resistance*



Case Histories

International Parkway Bridge Expansion, Virginia Beach, Virginia

This bridge was a part of the conversion of International Parkway from a 2 lane roadway to 4 lanes. There was an existing bridge across a drainage canal. A new bridge was to be constructed paralleling the existing span. The new bridge was designed to be supported on 60 ton prestressed concrete piles. The original bridge used the same size piles driven to the same sand bearing stratum also with a 60 ton capacity.

The PDA was used as a replacement for a traditional pile load test. The PDA indicated that not only could the pile not achieve an ultimate capacity of 120 tons for a safety factor of 2, it could not achieve an ultimate capacity of 60 tons -- the design load. This caused the project to stop as the contractor alerted the City of Virginia Beach and the design team that the design was flawed. Fortunately, an actual traditional compressive load test was performed for the original bridge. It was carried to 120 tons with only 0.17 inch of deflection. This indicated that the pile could actually carry significantly more than 60 tons. GER used the load test data to show the PDA had grossly underpredicted actual pile capacities.

In this case, the traditional load test allowed the project to proceed after significant concern about design flaws.

Lucas Creek Bridge Replacement, Newport News, Virginia

This project was the replacement of the existing Lucas Creek Bridge and realignment of Lucas Creek Road. The bridge was designed using both 12-inch square and 18-inch square concrete piles. The PDA was used to provide pile capacities instead of a traditional load test. The PDA results were erratic, but it indicated that the 18-inch piles had only a 40 kip ultimate capacity. As suggested by GER during our review of the planned testing program, a standard pile load test was performed on the 18-inch pile with the lowest capacity estimated by the PDA. This was Test Pile TP-3 with an end-of-drive estimated capacity of 40 kips that was substantially less than all other test piles by a factor of 3 to 5. The pile was loaded to 320 kips and deflected about 0.4 inch without failure. Our analysis of the test data using a hyperbolic curve analyses by the Chin method indicates an ultimate capacity closer to 390 kips. The PDA underestimated the actual capacity by a factor of almost ten.

USS Wisconsin Berthing, Norfolk, Virginia

The battleship USS Wisconsin is now berthed at the National Maritime Museum (Nauticus) in Norfolk, Virginia. The project required an underwater cantilever retaining wall to support an existing retaining wall and Nauticus for dredging as well as mooring dolphins and an access way from the museum to the ship. The PDA was used to determine pile capacity during construction. It indicated that the design length was inadequate to support the design loads. In this case, there was not a traditional load test to use to confirm the design. These piles were driven into the Yorktown formation that is well documented and used by geotechnical engineers for decades as the pile bearing stratum in many projects. Numerous traditional load tests have been performed to confirm static analyses of pile capacity. Strength and load carrying capacities are well known for this bearing stratum.

Since the PDA was the sole source of pile capacity, the design engineer was forced to lengthen all production piles to conform with the PDA results.

There are numerous case histories where the PDA has confirmed the design load. The question being asked -- Should it be a complete substitute for traditional compressive load testing?

Why So Much Variation in Results?

When the data indicate a wide range of possible pile capacity from the PDA, a reasonable question is -- Why?

The PDA was originally designed to evaluate pile driveability. Can the hammer install the pile without damage to the design depth? To provide a prediction of pile capacity, assumptions have to be made. The damping, quake and other input factors are the key.

These factors are chosen based on the soil test borings performed at the site and the types of soils indicated. Values are assigned to the input factors based on these soils. The data from the PDA testing is used to predict the ultimate capacity of the pile. Even load-settlement plots are generated that simulate a compressive load test. The input data are based on correlations with soil type. Site specific data is not available upon which to choose the input factors. Here is where the differences begin. Site specific input factors, such as damping, can be obtained from the results of a static compressive load test. With no load test, site specific factors are not known. The analyses can be performed with changes in the input factors to determine the sensitivity of these factors and their effect on the predictions.

Other site specific factors, such as rapid pore pressure response during driving and restriking, and their effect on the dynamic analyses are not known, but have no effect on a properly conducted static load test. We should remember that we are using a dynamic method to evaluate a static property.

The literature documents the underprediction issues of the PDA. Authors are proposing new methods where they use actual load tests results to refine PDA predictions with these new methods. Once again, the traditional load test is used as the basis for all predictive methods.

Conclusions

Where does this lead? The PDA is a very useful tool in evaluating the ability of pile driving equipment to install piles to the desired depth without damage. It can be used to show the variability of likely pile capacity across the site by using the PDA on several test piles installed at boring locations spread across the site. It can be calibrated to be more site specific by calculating input factors from static compressive load tests. Once the output data correlates with the load test results, confidence can be gained in other PDA predictions. It can be used to change the length of piles when test results indicate a savings can be made. This is usually of value on large projects when a small reduction in pile length can result in big savings because of the large number of piles driven.

Can it be used to substitute for a traditional compressive load test. Obviously, it is being done. Should it be done? The literature would indicate that the answer is -- not yet. This newsletter is to inform the final decision maker when this substitution is made, that underprediction is typical, not the exception. When PDA results indicate the design load is too high, should the design be changed, the answer is likely -- no.

For small projects with a limited number of piles, the cost savings of using a higher safety factor, employing the PDA in lieu of tradition load testing, the answer may well be -- yes. The savings may be real.

There are projects where the PDA has been deemed as accurately predicting the load carrying capacity of piles or its use would not have become commonplace. There should be some analysis of the safety factors being employed on the static computations. If geotechnical engineers are forced to use higher safety factors so as to not be "perceived" to be erroneous when the PDA is used, we are wasting client’s resources and not pushing design to the level we have come to expect.

Another issue is that when obviously flawed results are provided by the PDA, the operator should indicate that it is not providing proper results in these soils at this site. Geotechnical engineers in this area are experienced enough not to make such a large error in pile capacity. To continue to present the PDA as always accurate, brings into question its value on all projects.

The PDA is perceived as less costly than a traditional static load test. A value analysis should be performed on the net savings when longer or more piles are used. Some questions should also be asked as to why a test pile costs twice that of a production pile to install. In addition, the use of the quick loading method in ASTM D1143 allows a traditional compressive load test to be performed in about 2 hours -- not days.

There will be those who stand by the PDA being used in local construction as a complete substitution for traditional load testing. If the PDA indicates that actual conditions will only support 80% to 90% of the design load, should we really change the design or increase production pile lengths. Again, the answer is likely -- no.

Perhaps we need to change our standard practice where the load test has been used as the ultimate definer of production pile capacity. Typically, a test pile program is performed and the test pile with the lowest driving resistance is chosen to be load tested. If this pile indicates the design load has been achieved, production pile installation commences.

With the PDA substituting for traditional load testing, this could be modified. If the PDA indicates that the PDA predictions are above, at, or near design load, production pile installation can commence with no design changes. If it indicates a major difference, traditional load testing must be conducted to confirm PDA results.

The PDA is a great tool, if used properly and within the current state of the art. The value in PDA testing is in the ability to test a large number of piles instead of just one or two. The variability in load capacity across a site can be evaluated with the goal of lowering the safety factor used for the project. It should be remembered that a safety factor is applied due to the unknown. The PDA reduces the level of the unknown.

The analysis of PDA data should continue to be refined. Traditional load testing should still the basis for this refinement and at this moment in time -- still the ultimate definition of pile design load.

Another note. Regardless of how individual pile capacity is analyzed, piles are usually in groups. Pile group behavior is paramount. Piles with adequate capacity installed in sand above a clay layer, could settle within a group if not properly designed. Neither the PDA nor load testing will predict such behavior.

We, as engineers, just need to simply ask ourselves -- "What does the PDA data really mean and how do we use it?"

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