The Need for Quality Testing

By Garland Likins, President, Pile Dynamics, Inc.

Any deep foundation needs both sufficient structural strength and geotechnical capacity. Foundations that lack either aspect create problems that require remediation, and remediation is very expensive, particularly once the structure the foundation supports is in place.

Structural defects can be detected by various non-destructive testing (NDT) methods. Depending upon foundation diameter and length, the structural integrity of drilled shafts and augercast piles can be evaluated by cross-hole sonic logging, low strain integrity testing, or thermal integrity profiling. However, for many projects, NDT testing of drilled foundations may not be specified or may be limited to a relatively small percentage of the foundation elements.

For driven piles, defects are relative rare. Generally the pile driving log of blow count versus depth, taken as standard practice on every project, already gives assurance that pile integrity is adequate - as PDCA says, "a driven pile is a tested pile". If there is any doubt, dynamic testing can be used to evaluate if a defect might be present and, if present, its severity.

Deep foundations, while often necessary, can also be expensive. Finding the optimum solution that has sufficient capacity, yet not overly excessive capacity so the foundation is efficient economically, is a challenge designing engineers regularly face. The capacity of driven piles can be estimated several ways.

The American Association of State Highway and Transportation Officials (AASHTO) has required load and resistance factor design (LRFD) since 2007. Their guideline document uses resistance factors that reflect current perception of accuracy among the various capacity evaluation methods.

For static analysis methods of driven piles, resistance factors are relatively low (which are equivalent to high safety factors), reflecting the high statistical uncertainty of these methods. Different static analysis methods have different resistance factors, reflecting varying uncertainty. Static analysis is necessary in the design phase for bidding, but is rarely the controlling criteria for driven piles. Static analysis is however a common method for the design of drilled deep foundations. Since drilled foundations use generally conservative factors, they usually are not the most cost effective solution.

The AASHTO resistance factors for dynamic formula (0.40) and wave equation analysis (0.50) for driven piles are somewhat higher (equivalent to lower safety factors), but the highest resistance factors (lowest safety factors) are reserved for the actual field testing methods of static load testing (0.75) and dynamic pile testing (0.65 for minimal amounts of testing, and 0.75 if all piles are tested). If both static and dynamic testing are used on the same project, the resistance factor is the highest (0.80). AASHTO requires "signal matching" (e.g. CAPWAP©) for dynamic testing.

AASHTO's suggested resistance factor (0.65) for dynamic testing is only a guideline for State Departments of Transportation (DOT) to adopt. States with more experience or confidence may adopt other factors. For example, Ohio DOT (ODOT) tests mainly during installation and uses a higher resistance factor of 0.70, recognizing that long term service capacity will generally be higher with time. ODOT regularly conducts dynamic tests on driven piles for all new bridge foundations not driven to bedrock. For the years 2006 through 2010, ODOT spent an average of $22,600,000 per year on driven piles, and $408,000 for dynamic testing, slightly less than 2% of the pile cost. Static testing costs averaged $41,000 per year on typically one project per year. The total testing cost is minimal compared with the cost savings achieved through using higher resistance factors and the benefits to the public of a solid foundation.

Driven production piles are installed to the same criteria (usually a blow count) as the test pile that successfully passed the static or dynamic testing. However, only a limited percentage of piles are actually tested; the remaining production piles are assumed to be equivalent to the test piles since they are installed to the same criteria. Inspection quality in recording the blow count logs on production piles should not be compromised.

Static testing in compression should be conducted according to the guidelines of ASTM D 1143; similar standards for static uplift tests are in ASTM D 3689 and for lateral tests in ASTM D 3966.

For static testing, this article will focus on the axial compression test of D 1143. The reaction system should be installed at least the specified 5 pile diameters (or minimum 8 ft) distance from the test pile. Reaction piles that are installed by vibratory hammers may significantly reduce the test pile capacity, an undesired and uneconomical result, particularly if the reaction piles are installed after the test pile and below the pile tip (this should be avoided). Reference frames for the displacement measurement similarly must be supported far from the pile with the same distance requirements as the reaction piles. Spherical bearing plates and a properly calibrated load cell should always be used, and are required for compression tests over 100 tons. Failure to follow the ASTM guidelines and produce less than quality testing is likely to result in errors in the test result, misleading conclusions, and possible physical danger to the testing personnel.

Static test results (curve of load versus pile movement) for driven piles are usually evaluated by the Davisson method, which is generally quite conservative. Drilled shafts often are evaluated by more liberal failure definitions, so either the design for drilled shafts should be kept very conservative or the structure must be capable of tolerating larger settlements.

It is often desired to obtain load-transfer information to evaluate the soil resistance distribution. This can be accomplished through strain measurements along the driven pile or drilled foundation length. In a driven pile, these strain measurements are converted to force by multiplying by the known area and elastic modulus values. For drilled foundations, this conversion can be more problematic due to uncertainties in the area (and even elastic modulus) of drilled foundations as a function of length. Naturally this strain measurement is performed at extra cost, but the cost can often be justified on a large project when trying to optimize the design for highest capacity at lowest cost for production piles.

Dynamic pile testing is routinely used on driven pile projects beyond the very small ones. Capacity is estimated at the time of the testing (e.g. end of drive or during restrike), including resistance distribution information. On smaller projects, such as smaller highway bridges, testing is often performed only during driving or with restrikes after a few hours. This is generally a conservative approach, but since the bridge foundation has only a few piles, the entire installation of the bent or abutment piles may only take a day or two, so elaborate testing programs are not justified.

Since capacity often increases substantially with time due to set-up, particularly in fine grain or cohesive soils, the optimum foundation design and minimum foundation costs would benefit from a restrike test program on larger projects. Bullock (2005) clearly shows the benefits of even multiple restrikes during the first day in projecting the capacity with time to aid in decision making. Komurka (2003) demonstrates how the set-up and resistance distribution information from CAPWAP signal matching can be used to minimize "support costs", which are defined as the cost per unit load supported, and thus lower the overall foundation costs.

The usefulness of dynamic testing for driven piles is not limited to capacity evaluation and minimizing foundation costs. As previously mentioned, it can evaluate if a pile has

sustained damage. It can reveal driving stresses in both compression and tension for every blow during installation of driven piles; tension stress information is particularly important for concrete piles. Knowing the driving stresses allows the installation procedure to be adjusted to prevent damage. The energy transferred from the hammer to the pile can be measured to assess hammer performance and reveal if there are any hammer deficiencies.

The direct output of dynamic testing, however, is measured forces and velocities of the pile as a function of time, which must then be evaluated to extract the pile capacity and other solutions. While the benefits and reliability of the dynamic testing method are well proven, a well-qualified engineer properly versed in the theory underlying the test method is required for optimum foundation solutions and reliable pile installation guidance.

Solutions are only valid for data of good quality, and data of good quality cannot be assessed by the unknowledgeable. Dynamic testing should not be treated as a "black box" technology. Only engineers with a good grasp of all aspects of dynamic testing should perform dynamic testing. Inadequate ability may result in either not knowing when data quality is unsatisfactory (garbage in, garbage out) or dispensing bad advice, particularly when faced with a situation outside the tester's experience base.

Concerning quality of dynamic testing, the testing engineer has traditionally been on site during the test, but technology now allows remote testing with the equipment on site but engineer in the office, connected to the site via internet. Since there is a growing demand for testing due to LRFD requirements, remote testing by experienced engineers offers an efficiency and cost advantage, avoids scheduling conflicts, and allows quicker results because of reduced travel time. Obtaining results faster leads to earlier decisions, keeping the project on schedule.

The key to good testing is knowledge. Knowledge can come from sufficient formal personal training, specific seminars or group workshops, mentoring by an experienced knowledgeable associate, or extensive personal study of manuals and published literature.

How does a contractor, an owner such as a highway department, or a consultant desiring dynamic testing service determine the ability of a dynamic testing consultant? They may assess the quality of the testing results and the dynamic testing consultant by educating themselves at seminars or workshops - PDCA has been offering dynamic testing workshops typically twice per year for several years, and many specifiers or others seeking services have benefited from these learning opportunities.

Another alternative to assessing and assuring ability is evaluation of the testing engineer's knowledge by a standardized proficiency test. Such a test should evaluate all aspects of state-of-the-art dynamic testing including knowledge of theory, evaluation of data quality, interpretation of the data, applications of the method, and signal matching, which is state-of-the-practice.

Pile Dynamics has developed a "Dynamic Measurement and Analysis Proficiency Test" to evaluate the knowledge of dynamic testing practitioners, and PDCA will help provide opportunities for those desiring to take this proficiency test, including workshops to review important material about dynamic testing. Pile Dynamics and PDCA encourage all engineers doing dynamic testing to take this proficiency test so they can assess their own level of knowledge.

Depending on how well those that take and pass the test do, certificates stating rankings of BASIC, INTEMEDIATE, ADVANCED, MASTER or EXPERT will be granted by PDCA and Pile Dynamics. Although this proficiency certificate has no expiration date and no yearly renewal fee, it does suggest that engineers scoring at lower levels should be motivated to improve their knowledge and improve their ranking. The goal of every testing engineer should be to provide the highest quality service, and that is only possible if the engineer obtains a broad knowledge of the method and can rightly apply the knowledge.

It is recommended that those entities seeking services insert into project documents requirements that the testing firm demonstrate minimum standards of knowledge, such as achieving at least the ADVANCED ranking on this proficiency test for the engineer responsible for issuing the report. Several State DOT's have already adopted this general approach. Such requirements will then cause the testing engineers to increase their understanding and as a result the overall quality of dynamic testing services will improve, benefiting the project and the project owner. ▽

Photos courtesy of Garland Likins, President, Pile Dynamics, Inc.