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The Economics of Pile Testing

When designing a pile foundation system, engineers have a wide range of choices, including the ultimate load per pile and pile size (type, length, and diameter). The required pile capacity depends on the applied loading from the superstructure and the test method of for verification of pile capacity.

Introduction and Static Pile Testing

Safety factors are assigned to prevent failure. Logically, less testing performed increases risk, while more testing reduces risk, and less risk is desirable. Similarly, more accurate test method reduce risk, while less accurate methods increase risk. For a given static load test curve, different methods of evaluation can yield either a low failure load (conservative approach) or a high failure load. In the extreme case where every pile is tested with a very accurate method (e.g. static load test) with a conservative definition of failure, then the safety factor can be significantly reduced because the uncertainty of pile performance and therefore the risk is reduced. Unfortunately, it is not practical to statically test every pile.

Safety factors are either (a) "global" for working load designs, or (b) "partial" for load factor designs. In general, the ultimate pile strength must exceed the maximum pile loading or else the pile will fail (e.g. settlements will be excessive). Different loading conditions have different uncertainty and therefore different applied "load factors". For example, the dead weight load of a structure can be rather accurately calculated while the live loadings due to wind, earthquake or temporary loads can be highly variable (and are often prescribed by local codes).

Static load testing is the traditional method to evaluate the pile capacity (usually limited by the soil strength). Static testing is generally accurate when performed properly. There are publications indicating measuring accuracy should be within 20% of the true value, and the reliability of results is improved if a good recently calibrated load cell is specified. Even with "perfect measurements", interpretation of the resulting load-settlement graph can give several different ultimate loads depending on the evaluation method (e.g. Davisson, Chin, Butler-Hoy, double tangent, slope, etc).

However, static load testing is expensive, particularly at higher loads, and also time consuming. In fact, project delays due to the time required for static testing are often more costly than the test cost itself. In any case, static testing is usually limited to a very small sample of piles on any site (typically one percent or less on large projects). To avoid failure, the test pile is often driven harder or installed with greater care than production piles. This often results in the apparent pile safety factor being much larger than required, and a "proof test" to only twice the working load does not fail but rather responds basically elastically. Thus, in the usual case, the test pile must be loaded well beyond the required ultimate capacity to fail the pile and assess the true ultimate pile capacity.

Unfortunately, all production piles are then usually driven to the same criteria as the test pile, resulting in extra cost to the foundation. For example, with a column working load of 1200 tons and a pile design load of 50 tons, then 24 piles would be needed in this design to safely support the column. The test pile can be loaded to a 100 ton proof load for the required safety factor of 2. However, if the pile were loaded past the 100 ton proof load, thus finding say a failure load of 160 tons, then applying the same safety factor of 2 results in an allowable working load of 80 tons per pile and only 15 piles are then required (instead of 24) for a significant savings. Thus, the foundation cost can be reduced if the true ultimate capacity of the pile can be accurately determined. For large projects special test programs performed in advance of final design can be quite effective if higher working loads or shorter piles can be proven. For moderately sized projects the first production piles are often used as test piles and some adjustment and cost savings are possible. For smaller projects with few piles, the cost of one static test can approach or even exceed the cost of the pile installation. In this case, some low cost method of evaluation is sufficient.

In conclusion, the risk of totally unacceptable foundation failures makes some form of capacity evaluation absolutely necessary. The cost of testing can often pay for itself in reduced foundation costs.

Dynamic Pile Testing

Dynamic pile testing has become a routine method of pile capacity evaluation. Starting in 1964, Dr. George Goble and his colleagues at Case Western Reserve University developed the method and then formed Pile Dynamics in 1972 to provide the equipment and software. This Case-Goble Method requires measuring force and velocity of the pile during hammer impact. The data collection device called a "Pile Driving Analyzer®" (PDA) and associated CAPWAP® software are unquestionably the industry standard for dynamic pile testing. Extensive correlations between static and dynamic testing during the research program proved the ability of the dynamic testing. Continuing correlation studies have shown similar accuracy. After establishing such a correlation, dynamic testing has been then used to replace additional static load tests on the same site. In many cases and with sufficient experience, many dynamic pile testers have completely replaced static test by PDA testing only.

To obtain a reliable capacity prediction from dynamic pile testing, some very basic guidelines must be followed. Obviously, the dynamic testing measurements must be of good quality. Generally this is easily accomplished with the PDA system. Next, the dynamic test must produce a minimum set per blow so that the soil has been loaded past its useful elastic limit load into the plastic zone and thus mobilize the full practical soil strength. In cases where the set per blow is very small (e.g. large "blow count"), the dynamic pile test will only activate a portion of the full soil strength and thus will underpredict the true ultimate capacity (this is analogous to a "static proof test"). To assure full activation, the hammer energy and maximum applied force must be sufficiently large. Finally, it is known that pile capacity often changes with time after installation. Generally the pile capacity increases, particularly for fine grained soils due to pore pressure effects. Capacity decreases are occasionally observed, such as for piles in dense saturated silts or weathered rock. To measure these time dependent capacity effects, the pile should be tested by restrike after an appropriate waiting time after driving. Testing at end of driving and at restrike assesses the capacity change. Testing at various wait times can establish the capacity as a function of time.

There are many advantages of dynamic pile testing. As a supplement to or replacement for static tests, dynamic testing takes far less time to perform and thus reduces the costs. The time required on site for a PDA test is not much different than that required for driving the pile. A typical restrike test requires only positioning on the test pile and applying a few hammer blows. Compared with the days of time required for static testing, the time saved speeds the construction process. Typically many piles can be tested for a daily consulting fee of $1500 or less (plus the cost of the contractor). By testing either during driving in cohesionless soils, or by restriking piles of different lengths in cohesive soils, the optimum pile length or pile capacity can be established, both often producing savings of more than the cost of the testing. Site variability is easily assessed by testing piles in various locations around the site.

In addition to capacity evaluation, dynamic pile testing provides valuable additional information not otherwise obtainable. Driving stresses which are too large can result in pile damage. The PDA easily measures pile top compression stresses and can calculate tension stresses for concrete piles and pile bottom compression for piles driven to rock or other hard layers. If stresses are too high, adjustments to the hammer or driving procedures can be made for a safer pile installation. If stresses are low, then there may be an inefficient use of the pile material. Pile integrity is evaluated by the PDA for both location and extent of damage, if any.

Proper hammer performance is extremely important for driven piles. Engineers rely on the blow count (or set per blow) as a driving criteria for pile acceptance, thus implicitly assuming that the hammer is performing properly. Good hammer energy also increases the contractor's productivity. Therefore everyone benefits from good hammer performance. By monitoring the pile during driving we can assure the hammer is performing properly. By testing periodically throughout larger projects we can assure that the hammer energy for production piles maintains its consistency during the entire project and that the same initial driving criteria can be used for all piles with confidence. Periodic testing allows for additional checking for site variability and to investigate the cause of "problem piles" (piles that are too short or too long or that have unusual blow count records) to determine if the problem is the hammer or the pile or the soil.

The "Cost" of Dynamic Pile Testing

So what is the cost of a dynamic pile test? The answer depends on several factors. The first question is "do I have enough piling project work to justify buying the equipment and perform testing in-house, or would I rather obtain a testing service from some established testing house?" Government agencies appear equally split on this issue (depends on operational philosophy and personnel). When specifications require the contractor to obtain testing, most contractors prefer to hire a testing service from a reputable test agency, although as design-build becomes more popular, in-house testing by the contractor becomes a good alternative. Consulting engineers decide based upon their normal amount of in-house piling work. As mentioned earlier, the consulting fee from a dynamic testing consultant is $1500 per day, or perhaps less if the service is "local". Usually several piles are tested per day, so the per pile cost is further reduced. If the service provider has significant travel time and airfare expenses, then these charges can increase the first day charges for any trip to perhaps $3000 or more. If the number of piles tested is very large, or if extensive additional CAPWAP analysis (typically $300 each) are required, then report costs increase in proportion to the extra effort required for the project (but the extra efforts and costs presumably have benefitted the project and so are justified). Still the cost per test remains relatively modest. Even with charges for the contractor's time, compared with conventional static tests particularly for large loads, the monetary cost and construction time (or pile length) saved often results in substantial overall savings.

If the agency acquires the equipment and software to provide in-house services, the costs for initial purchase price of the equipment and software can vary from about $57,000 for PAK hardware with CAPWAP software to as little as $30,000 for a PAL-L system only alone (CAPWAP services are then obtained from others at $300 per analysis on an as needed basis). However, the PDA equipment and CAPWAP software can be used to test thousands of piles over a period of years thus amortizing the initial costs over time to a very small amount per pile.

There are suppliers who provide equipment only. Since CAPWAP is a vital part of any successful dynamic test program, testing systems lacking CAPWAP ability or access to it are essentially useless and highly dangerous and thus should be avoided even if offered free (the risk and thus liability of foundation failure makes such low budget purchases extremely costly). Only the CAPWAP program has been subjected to extensive correlations with static load tests; claims about other software from other suppliers are not substantiated in the literature. PDI focuses on feedback from correlations with static tests because we are concerned with the result reliability. Thus through this experience built over many years, the need for static tests to establish a correlation is reduced and often eliminated. Eliminating or reducing the number of static tests is a very large potential savings in both time and money.

In reality, the main cost for doing the test in-house is not the cost of the equipment but rather is the continuing cost of the engineer assigned to perform the testing. Thus, the efficiency of the engineer's time is of critical importance in any true cost evaluation. The engineer will only be as efficient as the hardware and software allows. The Pile Dynamics PDA and CAPWAP are now Windows based systems which are very user friendly and very powerful, with over 30 years of experience contained in them. The efficiency and effectiveness of CAPWAP is particularly unique. CAPWAP has several "automatic" features which easily guide the user to a solution, all in a matter of a few minutes, allowing the engineer to be very efficient in his evaluations.

Pile Dynamics concentration on high strain dynamic pile testing has led to our PAL-R model of the PDA which can send data remotely from the field to the office. This is a major advantage since it improves the engineer's efficiency. He can monitor several projects from different cities on the same day from his office. A technician can go to the field to attach sensors to the pile, or the pile crew is alternately capable of sensor attachment and sending the data. Thus, the engineer's travel to the site and waiting on site are eliminated for routine testing. The engineer concentrates only on the data collection when the hammer is in operation and because the travel time back to the office is eliminated, he can immediately begin data evaluation with CAPWAP and issue decisions and his report much faster. This remote operation feature is offered exclusively by Pile Dynamics and those now using this system highly value this ability.

New engineers may be needed from time to time. Thus there is a continuing need for training. Many "example data sets" have been collected that can be used for further training and self-study. PDI has developed many powerpoint lectures for the training process. Training assistance can be arranged at any time with PDI, or through local PDI representatives if desired. PDI has a policy of strong client support, with a long history to prove this. The principals have always offered their comments and application advice free of charge, even years after a client has purchased the equipment. PDI performs data review, and often even CAPWAP analysis, on a free basis for users of PDI equipment. This service is invaluable to the user. Since 1979, Pile Dynamics has offered "PDA Users Days" on at least an annual basis. Users Days provide the PDA engineer an opportunity to learn about the most recent research and new methods and features, as well as an opportunity to share testing experience with others from around the world. Users Days have been arranged in the USA every year, and in Europe and Asia at least every second year. A newsletter is published two or three times per year with technical articles. Our "PDA Advice" notes are sent to all PDA users and highlights important considerations for PDA testing.

From another viewpoint, what is the "cost" to you, the engineer, of not testing the piles? If there is no testing, there are often significant extra costs from piles being overdriven and having very high safety factors resulting from less than optimum designs. Even worse, there could be even more expensive foundation failures if the pile capacity is not adequate. Is one static test sufficient for large sites or where soil variability is large? How do you assess the reliability of "problem piles" where the penetration is too large, or too small, or where blow counts during installation are unusual?

Quality assurance is vital to serve your client well and to minimize your risks associated with any foundation designed by empirical evaluations of soil investigation parameters. Increasing the percentage of piles tested can be accomplished at modest cost using dynamic testing, and the benefits in reducing risk, reducing the foundation costs, or lowering safety factors through modern LRFD design procedures far outweigh the costs of dynamic pile testing. You can rely on the proven worldwide leader in dynamic pile testing, Pile Dynamics, Inc. to supply you with quality testing equipment, the very best CAPWAP software for data analysis, and technical support whenever and to whatever extent you may request.

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