PILES

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Introduction to the Dynamics of Pile Testing

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Piles are frequently required for a wide range of buildings, bridges, towers, dams,and other massive structures. A variety of pile types installed by different driving equipment of all types and even layered soils makes establishing a safe but economical installation difficult. Traditionally, static analysis, probe piles, dynamic formulae, and static testing are used to verify pile foundations. With computers and modern electronic measurements, improved techniques for analysis and construction control are now available to obtain a safe and economical solution.

Background

Pile capacity may be estimated from static analysis based on soil mechanics principles and CPT and/or SPT field tests. Unfortunately, different soil testing and evaluation methods produce widely different solutions.

Static testing involves the application and measurement of static loads and pile movements. In practice, static testing either proves the pile can safely hold the service load (proof test), or establishes an allowable load based on the capacity. Unfortunately, proof testing is more prevalent, resulting in greater foundation costs due to unnecessarily long piles. Because of the relatively high costs and time required for static test, generally only a few piles are tested. The capacity or failure definition is also the subject of considerable discussion and measurements often contain substantial errors (Fellenius, 1980).

For centuries, engineers have tried to use dynamic formulae to estimate capacity. Dynamic formulae are inaccurate due to their over-simplicity in modelling the hammer, driving system, pile, and soil. In fact, most foundation engineers today agree that dynamic formulae are dangerously unreliable.

Wave Equation Analysis of Piles (WEAP)

Taking advantage of wave propagation theories, in the 1950's, a discrete numerical solution with realistic hammer, pile and soil models was developed (Smith 1960) and became known as the "Wave Equation" to which various improvements have been added (Goble and Rausche, 1986). Based upon assumptions of hammer efficiency and soil properties, the computerized solution assumes a capacity and computes a penetration resistance (blow count) and stresses, producing a so-called bearing graph. Soil strength changes with time (set-up or relaxation) due to remolding or pore pressure dissipation, should be considered; at every site, some piles should be restruck and the penetration resistance recorded. Although the wave equation is an excellent tool, because the solution depends on assumptions, the only method to assure accurate results is the measurement of hammer and/or pile performance during pile driving or during restrike to confirm the input assumptions.

Dynamic Measurements

Pile hammers are complex devices. Extensive studies (Rausche et al., 1985b) show considerable scatter of efficiency values for different hammers making measurements a necessity. Observations of the ram travel during operation (stroke, blows per minute, etc.) is recommended. By detecting the sound of and time between hammer blows, the Saximeter calculates the blows per minute (or ram stroke for single acting diesel hammers). By employing radar technology, a Hammer Performance Analyzer can measure the ram velocity with time (Likins, 1988).

The techniques most widely employed today for both measurement and analysis of piles were developed by Professor G.G. Goble at Case Institute of Technology, hence collectively the Case Method (Rausche et al., 1985a). The Case Method requires the measurement of pile force and velocity during a hammer blow. Reusable transducers are quickly attached to any pile type; driven, drilled shaft, or caisson. These data are sufficient for evaluating pile driving stresses, pile integrity, hammer performance, and pile capacity. All these closed-form solution results are computed in a fraction of a second for each hammer blow by the Pile Driving Analyzer (PDA) in the field.

Capacity Methods

Using wave propagation theory and assuming a uniform elastic pile, the Case Method total soil resistance (R) active during pile driving can be calculated. This total resistance, R, is the sum of static, S, (displacement dependent) and dynamic, D, (velocity dependent) components. To extract the static resistance, the following must be carried out: (A) elimination of the damping component; (B) correction for early unloading of shaft resistance; (C) time dependent soil strength changes (i.e., set-up or relaxation); and (D) no, or very small, pile penetration will mobilize only a portion of the total resistance. The method and these considerations have been thoroughly covered (Rausche et al., 1985a).

CAPWAP is a further numerical analysis method for confirming the PDA calculated pile capacity. To start the CAPWAP analysis, a wave equation soil model is assumed and entered with the hammer model replaced by the measured velocity. CAPWAP then calculates the force necessary to induce the imposed velocity. If the computed and measured forces do not agree, the soil model is changed and the analysis repeated (Rausche et al., 1972). This alternative process is repeated until no further improvement in the force match can be obtained. Results indicate the static soil resistance distribution, quake and damping factors, and stresses along the pile shaft. The CAPWAP analysis can therefore be used to confirm the wave equation soil assumptions.

Dynamic Pile Testing

The delays and expenses of static testing are leading reasons why dynamic testing is often requested as a replacement for or supplement to static tests. Several piles can be tested per day, and therefore dynamic testing is very cost effective. As many soils change strength with time, restriking the pile after a waiting period often results in more economical foundations for piles with set-up (capacity increase) or prevents major problems due to relaxation (capacity loss). "Refusal" driving may underpredict the capacity (similar analogy to static proof tests with small movement only indicting that part of the capacity has been mobilized). Dynamic testing also provides extra information on hammer performance, driving stresses, and pile integrity which is not available by static testing alone. The driving criterion is usually established with one particular hammer but can be extended to all types of other hammers, of the same make or different, by comparing capacity and transferred energy results from the PDA.

Most problems on a piling site are due to the hammer system since the installing equipment is also relied upon for construction control. Therefore, all larger projects should have a well planned programme of periodic dynamic monitoring to confirm consistent hammer performance and soil conditions across the site. In particular, since the trend in recent years has been to higher capacity piles. When hammer problems occur, early detection is critical to the foundation quality.

On many concrete pile projects, the pile shaft integrity is confirmed using Low Strain Testing by a small hand-held hammer (Rausche et al., 1988). The pile Integrity Tester™ hardware and software, developed for this function, present results in both time and frequency domain. This method is simple and quick but only investigates shaft integrity and is subject to some limitations. The test can be economically applied to a large number of piles to establish typical records, minimize misinterpretations of single results, and assure good quality control.

Dynamic pile testing methods have become widely accepted within the last decade and benefit all parties associated with a pile project. Since dynamic testing with the PDA and CAPWAP is so flexible, engineers are creatively adapting this technique to their specific projects. The engineer is presented with much more information to assist in design and construction control. The contractor obtains information on the performance of his hammer system which can be used to reduce driving time and lower his costs. Knowledge of stresses and pile integrity, can lead to procedures to reduce damage. The owner is assured of a higher quality foundation since more piles are tested. The faster dynamic testing reduces construction time and is less expensive than static tests. Testing indicator piles often verifies adequate capacity at smaller penetration depth for reduced time and cost of the foundation. If problems are detected, they can be corrected early in a project at comparatively modest cost and reduce legal problems or construction claims.

Because of the lower cost and additional information provided, dynamic pile testing has been rapidly gaining acceptance worldwide. The research begun in 1964 led to the formation of Pile Dynamics, Inc. in 1972 to further develop and promoted the equipment and methods. Through extensive efforts of education, training, and strong client support, over 200 PDA units have been placed into operation in 30 countries with about 2000 projects being tested yearly. As engineers have realized the benefits, this has further resulted in inclusion in specifications and codes of practice by many agencies governing pile testing.

Summary

Static testing to failure is ideal to assess static bearing capacity but is very expensive and time consuming, limiting the number of piles tested. Wave Equation is excellent for **predicting** the dynamics of pile driving if assumptions are realistic. Dynamic measurements and analysis can **verify** these assumptions. On site, the Case Method with a Pile Driving Analyzer can calculate pile capacity, monitor hammer performance and piles stresses, and investigate pile integrity. Because of their flexibility and low cost, dynamic testing methods may be applied to a relatively large percentage of the piles to cut costs, increase pile loads, or eliminate problems. The Pile Integrity Tester can evaluate shaft integrity of all piles at a reasonable cost.

A well conceived and properly executed testing programme will give engineers, contractors, and owners confidence in the behaviour of the foundation. Installation difficulties will be detected early in the project and corrected. Decisions and production driving will be kept on schedule, minimizing delays, unnecessary costs, and claims aiding the project toward timely completion to the satisfaction of the owner. Dynamic pile testing has become both routine and widespread as specifications and codes of practice recognize the value of this powerful technique.

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