EXISTING TIMBER PILE FOUNDATIONS REVISITED

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ABSTRACT

Dynamic pile testing by the Case Method is frequently used to evaluate the bearing capacity of timber piles during the installation process. Using a Pile Driving Analyzer™, these methods also provide for a safe installation by monitoring hammer performance, driving stresses, and the pile's integrity.

Dynamic test methods are quickly applied and relatively inexpensive. It is therefore possible to test a relatively large number of piles of a foundation which in turn allows the responsible engineer to reduce the overall safety factor of a foundation on the basis of a statistical analyses of the results.

The dynamic test method can also be applied to existing foundations if it is possible to bring a pile driving hammer to the site for impact loading. This paper presents two case histories where two existing timber pile foundations had to be reevaluated. In the first case, a building addition for an existing building on timber piles and the quality of the existing foundation had to be checked. In the second case, hundreds of timber piles had been installed decades earlier but the project was abandoned and the piles were never used. No records were available on the pile installation. In both cases, innovative testing and analyses by dynamic methods provided fast and cost effective solutions. A discussion of these methods, their principles, applications, and limitations is also presented.

INTRODUCTION

Pile driving is one of man's oldest engineering activities; and timber piles are the oldest of these deep foundation elements. Dynamics of bodies in motion were utilized by early pile drivers centuries before their principles were recognized and understood. It seemed common sense that the harder it was to drive a pile into the ground, the more load it would be able to carry.

In those days, time and timber were abundant and concepts such as efficiency and economy were abstracts best left for philosophers. Counting the number of blows it takes to advance the pile a given unit length into the ground during pile driving had long been an integral part of the installation process. It was not until the late 1800s that a serious attempt at understanding pile driving mechanics was undertaken (1). The results were formulated into simplified relationships which became known as Dynamic Formulae or Energy Formulae as they related the energy of the hammer to the work done on the soil. Due to their simplifying assumptions, the actual performance of such formulas is as unpredictable as pile driving itself (2), and their use is generally discouraged by knowledgeable engineers (3).

Several decades ago, it was recognized that the impact on long flexible piles is not well represented by theories of rigid bodies impacts, but rather is better modeled by one dimensional

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wave propagation. Utilizing wave propagation theories, mathematical discretization procedures, and electronic computers, a number of computer programs were written to analyze pile driving in a rational approach incorporating field observations (4). This type analysis became known as the Wave Equation and is by far more realistic and accurate than simple energy formulae.

Traditionally, "pile testing" meant a static load test. This involves the application of large static loads and the measurement of corresponding pile movement. Static load testing either proves that a pile can safely hold the designated load without excessive settlement (proof test), or establishes an allowable load based on the measured ultimate capacity. Because of the high costs involved and the lengthy time required to perform static tests, only a small percentage of piles are actually tested. On many small lightly loaded projects, the cost of static testing would be large compared with the total foundation cost and therefore is not justified economically. Therefore, alternative evaluation methods are often seriously considered.

Beginning in 1964, research was conducted at Case Institute of Technology in Cleveland, Ohio to develop an economical, practical for field use, easily portable system which calculates pile bearing capacity from electronic measurements of pile top force and acceleration during pile driving or restriking. The necessary equipment and methods were later expanded to evaluate other aspects of pile driving. Today, these procedures are collectively called the Case Method and are conveniently applied in the field by a specialty computer called the Pile Driving Analyzer ™ (PDA). Also developed during the Case research project, the CAPWAP™ method combines field measurements with wave equation type analysis to compute pile capacity, resistance distribution, and soil dynamic behavior.

In recent years, a statistical approach (5) to pile capacity evaluation based on economics of design, risk analysis and measured capacity has gained increasing acceptance. The ease and economy of obtaining data makes the application of statistical concepts both feasible and economically rewarding.

In addition to a short background discussion on dynamic testing and analyses techniques, this paper presents two case histories where old timber pile foundations had to be reevaluated.

DYNAMIC PILE TESTING AND ANALYSIS

The following are the common objectives of dynamic pile testing:

- For the prediction of the pile's long term bearing capability, dynamic measurements are generally made during restrike, especially when the surrounding soils are fine grained and the pile capacity therefore likely to increase with time (6).

- In order to limit the possibility of pile damage, both compressive and tensile stresses should be known and are easily calculated from measurements (7).

- Pile integrity often must be checked both during and after pile installation. Piles which cannot be inspected visually can be evaluated electronically by these simple dynamic tests (8).

- Hammer-driving system performance must be checked for productivity and construction control. Inefficient hammers must be identified and replaced or corrective action taken or else unacceptably low safety factors or failed foundation could be the result (9).

All of the above objectives must be attained in the field in real time during pile driving. To be most cost effective, problem areas should be detected early and as they arise and corrective action taken at the earliest possible time.

The Case Method is widely employed today for measurements and analyses of pile driving. The Case Method includes several closed form solutions and requires the measurement of force and velocity of the pile with time under a hammer blow. For piles with little shaft resistance, a static toe resistance force-displacement graph may also be obtained from pile top measurements using a closed form addition of the one dimensional wave equation.

THE PILE DRIVING ANALYZER (PDA)

The PDA and its associated transducers were developed to routinely obtain data and perform Case Method computations in the field (10). In addition to the PDA, the system includes two each strain transducers and accelerometers bolted near the pile top. The strain transducers are frames with four resistance foil gages attached in a full bridge. Pile velocity is obtained by integrating acceleration which is measured with piezoelectric accelerometers that are mounted on a special block for electronic and mechanical isolation and ease of attachment to the pile. All transducers are reusable and are quickly bolted to timber piles using lag bolts.

The PDA is a state-of-the-art, user friendly, digital field computer. It provides signal conditioning, amplification, calibration of the measured strain and acceleration signals and computes nearly 40 Case Method results in real time immediately following each hammer blow. The calculations include the conversions of measured strains to forces and the acceleration to velocity, both as a function of time. Analog to digital conversion of force and velocity inputs are done at 10,000 Hz with options allowing for up to 4 channels of A/D. Force and velocity records are assessed for data quality and are evaluated according to the Case Method equations. Numerical computations are controlled by a 16-bit microprocessor. Results are immediately available after each blow and are output to a built-in printer. Figure 1 shows a photograph of a PDA.

The PDA can support a variety of standard peripheral equipment. Data is stored digitally in RAM, or on FM analog cassette recorders, viewed on a simple X-Y oscilloscope, and can be output to a plotter for report quality documentation. The built-in RS 232 interface sends data from the PDA to any modern computer either directly, or from remote field locations through telephone modem communications.

THE CAPWAP METHOD

The CAse Pile Wave Analysis Program (CAPWAP)™ is an analytical procedure performed interactively by the engineer using a personal computer. The latest program version uses a continuous pile model and is referred to as CAPWAPC™. It computes soil resistance forces and their distribution using pile top force and velocity measurements, recorded in the field, in a wave equation type procedure (11).

To perform a CAPWAP analysis, the pile below the transducers is modeled as a series of segments. The soil reaction forces are passive and are assumed to consist of static (elasto-plastic) and dynamic (linearly viscous) components, both along the side and under the pile toe. In this way, the soil model has at each point three unknowns: elasticity, plasticity, and viscosity. To start the analysis, a complete wave equation soil model is assumed and entered into the computer model. Then in a dynamic analysis, the hammer model is replaced by the measured velocity imposed at the top pile element; CAPWAP then calculates the force necessary to induce the imposed velocity for this soil model. Measured and calculated forces are both displayed graphically as a function of time, and if they do not agree, the soil model is changed and the analysis repeated. This iterative procedure is continued until no further improvements between measured and computed forces can be obtained. Alternatively, the force may be imposed as the boundary condition, and the velocity calculated and compared with the measurement.

Results from a CAPWAP analysis include comparisons of measured with corresponding force/velocity curves. Numerically for each pile segment, the complete soil model including ultimate static resistance, soil quake and damping factors is tabulated. Since they are calculated during the analysis, forces, velocities, displacements, and energies may be printed, or plotted as a function of time for any location along the pile shaft. Also included in the results is a pile load *vs* movement graph from a static test simulation.

Today, their are over 150 PDA systems used by contractors, governmental agencies, and consulting engineers on an estimated 1500 job sites a year throughout the world. If the PDA is used in conjunction with CAPWAP analysis, pile capacity predictions by these dynamic tests are perceived to be within 12 per cent of the true pile load while a conventional static load test is only perceived to be accurate to within 15 per cent due primarily to inaccurate force of measurements and/or lack of a definite failure criterion. (12)

Dynamic methods, requiring only the impact of a small hand-held hammer, are also available where only the structural integrity, or length of existing piles, are verified (13).

CASE HISTORIES

Dynamic testing methods can be applied to existing piles if it is possible to bring a pile driving hammer or a drop weight to the site. Two case histories where existing timber pile foundations were evaluated are presented.

Case 1

This case study involved the reevaluation of bearing capacity of old timber piles under an existing building since an addition was planned to the structure. Two piles under two different caps were tested by the PDA and data later evaluated by CAPWAP.

The two piles tested (TP1 and TP2) had been installed in 1929 as part of the building foundation system; at the time of testing, records of pile length or installation procedure were no longer available. In preparation for the tests, the pile tops were exposed by excavation to

approximately 2.5 ft below the cap bottom. To transfer impact loads to each pile top, an 18 inch section of TP1 and 15 inches of TP2 were removed immediately below the pile cap. Two each strain transducers and accelerometers were attached near the pile tops on opposite sides for cancellation of bending effects. The impact loads were transferred into the pile through a heavy steel beam. The beam was inserted into the gap between cap and pile top; it was supported on one end by the pile top and at the other end by layers of wood blocks as shown in Figure 2. Impact loads were then applied to the test piles through this transfer beam by dropping a steel demolition ball weighing 3180 pounds. The impacts were cushioned by a 3 inch layer of wood for the first few blows of TP1 and 1.75 inch layer of wood for subsequent tests. The drop heights were varied between 2 and 5.5 ft.
Testing TP2 consisted of 3 blows with a drop height of 5 ft and one blow with a 5.5 ft drop height. The pile did not experience any permanent set during the test. Cross-sectional areas at transducer locations for TP1 and TP2 were 109 and 92 in^2, respectively, with measured material density of 70 lb/ft^3. A stress wave speed of 11,860 ft/s was assumed corresponding to a dynamic elastic modulus of 2152 ksi.

All four blows for testing TP2 were digitized and analyzed in the field using the Case Method and a PDA. Processed results indicated that during the testing of this pile, the maximum pile top compressive forces and transferred energy averaged 107 kips and 1.1 kip-ft, respectively. Figure 4 includes a plot of the pile top force and velocity traces. CAPWAP analysis performed on data representing the third blow revealed that TP2 had a length of 44.5 ft and a static bearing capacity of 118 kips with significant shaft friction. CAPWAP analysis results of distribution and measured/computed match curves are plotted in Figure 4, and a simulated static load test is presented in Figure 3. Analyses from testing TP1 showed that pile to have a length of 43.3 ft and a static capacity of 134 kips. For both piles an 8 inch tip diameter was assumed.

The pile capacities reported were considered only lower bound estimates of the true ultimate values since the pile did not move during the tests and hence the full soil resistance was not activated. These mobilized capacities were, however, sufficient for the purpose intended.

Case 2

This case involved the evaluation of existing but never used timber piles 12 years after their initial installation. No records of pile driving or pile length were available.

Approximately 850 southern yellow pine timber piles were driven and left for 12 years before it was decided to incorporate them into foundations for eight new buildings. They were left as driven without further top treatment and generally showed badly mushroomed pile tops apparently caused by hard driving. The soil conditions consisted of brown fine to medium sand to a depth of 5 ft. Between 5 and 25 ft the soil consisted mainly of gray silt; below which course sand to fine gravel existed. All pile tops were between 1 to 3 ft above existing ground level.

Dynamic pile testing and analyses utilizing the PDA and CAPWAP were used to evaluate groups of piles for each building. The data obtained regarding pile capacities was treated statistically (5) to determine their suitability as a foundation. Ten percent of all piles were redriven and dynamically tested. A Vulcan 30C double acting air hammer (ram weight of 3 kips and rated energy of 7.3 kip-ft) was used to restrike all test piles. The primary objective of the dynamic tests was to obtain information on pile lengths and static bearing capacity.

To test these piles, approximately 6 inches were cut off the top of each pile, and transducers were bolted 2 ft below the top. Cross-sectional areas at the transducer locations ranged between 71 and 128 in^2. The density and modulus were assumed to be 60 lb/ft^3 and 1863 ksi, respectively, and the rate of taper was assumed to be 16 percent.

Pile top movements during each test ranged from 2 to 13 inches with driving resistances between 2 to 15 blows per inch. Maximum compressive pile top forces and transferred energies averaged 120 kips and 3 kip-ft, respectively.

It was concluded from all dynamic testing that pile lengths varied from 13 to 35 ft, with the observation that piles grouped in the same area had approximately the same lengths. The damping factor required by the PDA to represent the soil dynamic behavior was determined by comparison with the CAPWAPC analyses. Mean pile static bearing capacities, by building groups, ranged between 64 and 101 kips with a standard deviation of 21 kips. The suitability of each pile group as a foundation for each building was based on measured capacities, statistical considerations, and imposed structural loads.

CONCLUSION

Dynamic pile testing by the Case Method is frequently used to evaluate the bearing capacity of timber piles. Using a Pile Driving Analyzer, these methods also provide for a safe installation by monitoring hammer performance, driving stresses and pile integrity. Data analyses by CAPWAPC offer additional information regarding resistance distribution and dynamic soil behavior.

Dynamic tests are quickly applied and relatively inexpensive. It is possible to test a relatively large number of piles of a foundation which in turn allows the responsible engineer to reduce the overall safety factor of a foundation on the basis of a statistical analyses of the results or to more accurately assess the ultimate and design pile loads.

These methods can be applied to piles where conditions make it unfeasible for traditional load testing to evaluate existing foundations, as illustrated by the two case histories presented.

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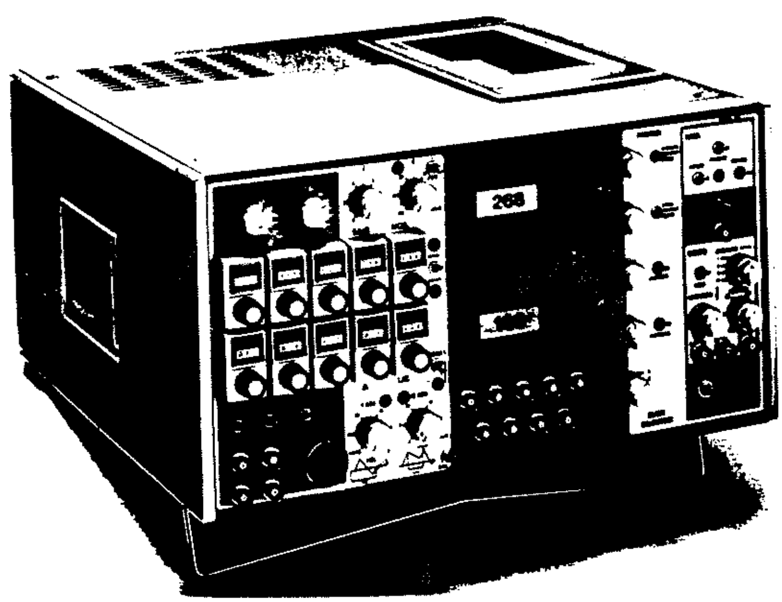

Figure 1: The Pile Driving Analyzer

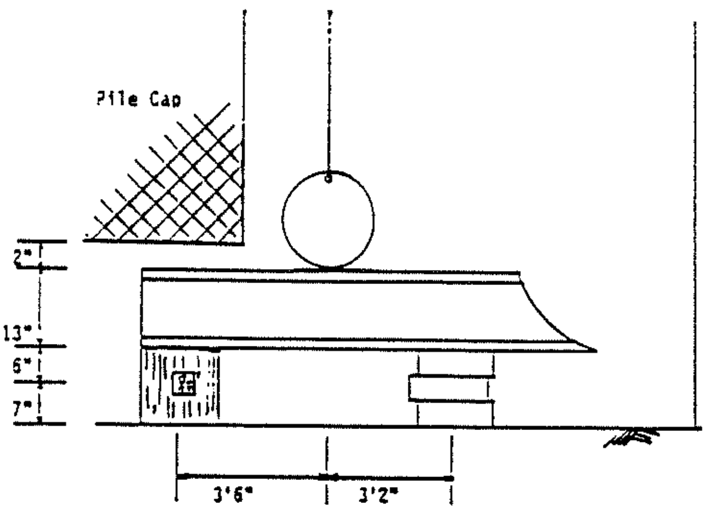

Figure 2: Case 1 Testing Configuration

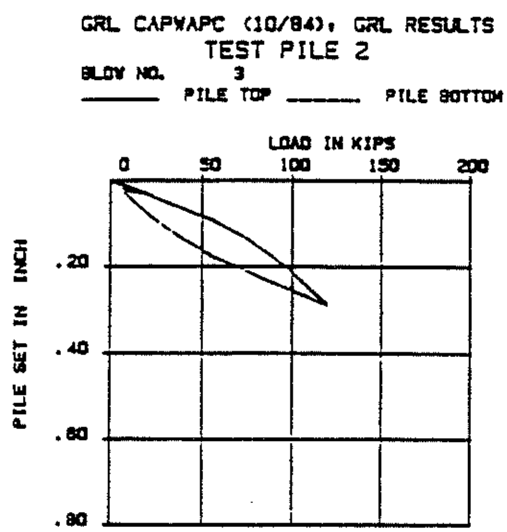

Figure 3: CAPWAPC Simulated Static Load Test, TP2, Case 1

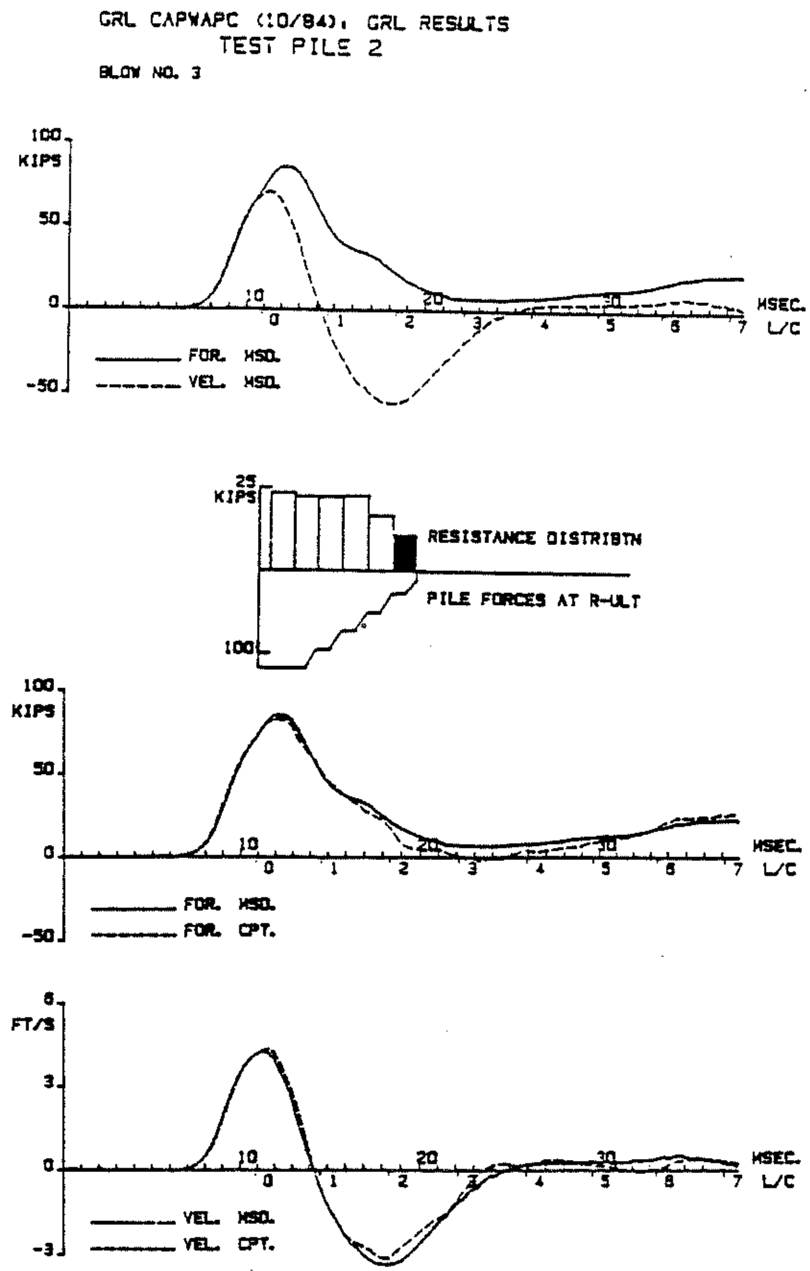

Figure 4: CAPWAPC Plotted Results, TP2, Case 1

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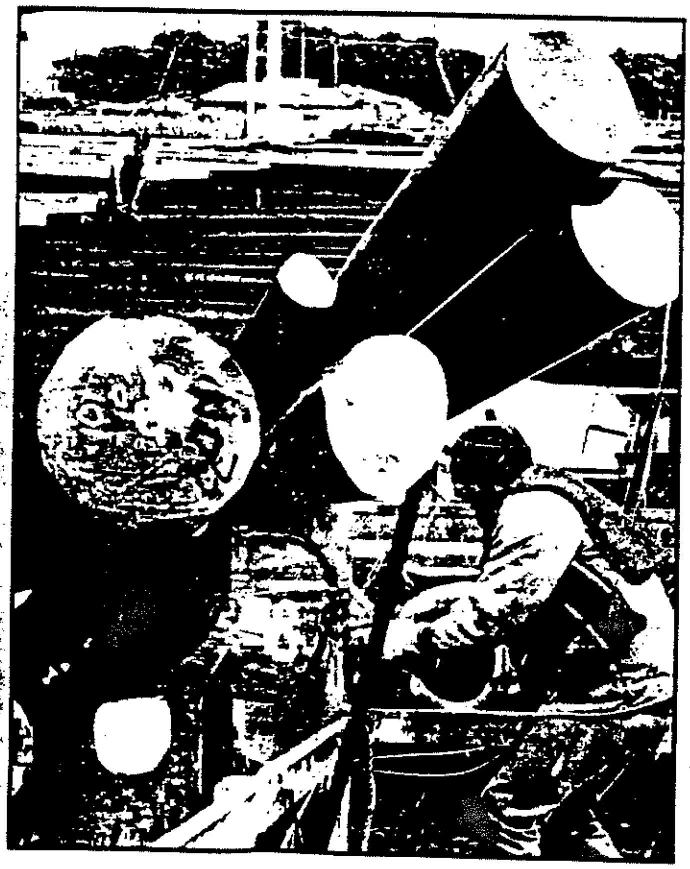

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