Field measurements and the pile driving analyzer

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INTRODUCTION

The Pile Driving Analyzer (PDA) has become the standard tool for inspecting pile installations. The original research beginning 20 years ago was directed toward obtaining pile capacity as a supplement to and later as a replacement for expensive static tests. More recently, the abilities to measure hammer performance, tension and compression driving stresses, and pile integrity have expanded the need and use of this equipment. Since the wave theory methods used have been thoroughly documented (ref 1 to 7), this paper will discuss the electronics and uses of the PDA.

The entire PDA system consists of transducers which are attached to the pile, the PDA which provides signal conditioning and computational capacity, and optional external devices for recording the signals. The Pile Driving Analyzer is shown in Figure 1. A schematic of this system is given in Figure 2.

TRANSDUCERS

The transducer system most commonly used and essential for good data are bolt-on units which make data acquisition easy and economical since they are indefinitely reusable on all types and sizes of piles. The entire preparation and gage attachment processes usually take less than 15 minutes. The accelerometers are piezoelectric devices with built-in amplifiers to reduce noise. They are mounted on specially designed blocks which provide electronic ground isolation and a rigid base with characteristics to eliminate the frequencies above 20000 Hz which cause resonance.

The strain transducers were developed by comparisons with foil gages glued directly to the pile surface. Four foil gages are attached at stress concentration points of the flexible aluminum frames for maximum output. The gages used are 350 ohm dynamic gages, connected in a full bridge. A shielded seven wire hookup is used for the best possible accuracy and low noise.

PDA ANALOG SYSTEM

The Pile Driving Analyzer contains two major sections: the Analog System and the Digital System (Figure 2). In the Analog System, each transducer has its own signal conditioning. The strain signals have DC offsets removed, are amplified, filtered and cali-

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brated. Each accelerometer is conditioned by its own current limited supply and the signal sent to a specially designed integrator. The individual velocities initially have a feedback system which keeps the velocity near zero; the first stage of the auto balancing between blows is very slow. A calibration section internally self-checks the PDA calibration. The PDA can record and accept analog signals on FM tape recorders.

Both strain and acceleration signals are subjected to low pass filtering with a matched frequency response to 1600 Hz (-3dB, with slow rolloff to -10dB at 3000 Hz) which assures no phase shifts. Studies to 5000 Hz show that the PDA limits are satisfactory for conventional hammer blows. By comparison, response for typical commercial signal conditioners is 1000 Hz at -3dB.

The signals go to the warning section to check for high strains, line noise, transducer open or short circuits, and ratios of individual inputs to check for excessive bending, and the strain velocity ratio to check for proportionality. If activated, warning lights are lit and the infractions are also printed.

The engineer can select which transducer signals to average and send to the digital section or have the PDA determine which transducers to use based on the warning indicators. When the signals exceed a minimal threshold early in a blow, both analog and digital trigger signals are generated. The analog trigger is returned to the signal conditioning and all further balancing, feedback systems, leakage, etc, are turned off for the remainder of the blow. Thus, unlike commercial auto-balancing signal conditioning and integrators, no degradation of the signals is made. Approximately 300 milliseconds after triggering, the signals are quickly reset to zero for the next blow. The digital trigger is used by the digital section during A/D conversion.

That these two independent transducer and signal conditioning systems produce theoretically correct proportional strain and velocity signals is, of course, the ultimate proof that the entire system is perfectly developed for pile dynamic measurements.

PDA DIGITAL SYSTEM

The Central Processing Unit (CPU), a state-of-the-art Motorola 68000 microprocessor, controls the digital section and performs computations. The PDA stores data for multiple blows in RAM (Random Access Memory) and contains operating instructions and computation procedures in EPROM (Erasable Programmable Read Only Memory). The computer program was written in the highly flexible language "C" and can be modified to later add upgrading features.

For the analog to digital data acquisition of the strain and velocity signals, the microprocessor multiplexes these signals to an A/D converter with 12 bit resolution where each are sampled at 10000 Hz until 1024 samples each have been obtained (200 samples in pretrigger memory and the remaining 824 filled sequentially after the CPU senses a trigger pulse). Alternately, options allow 4 channels of A/D for inspection of individual strains to evaluate bending, combustion pressures for diesel hammers, measured strains at other locations, etc. The analog calibration pots (for pile impedance and length, wavespeed, damping, etc.) are also multiplexed through the A/D to complete the input.

The address bus consists of 16 address bits which are decoded to address the different boards. The decode section uses address lines from the CPU and strobe signals to enable the board the CPU is requesting. Digital data is relayed on a full 16-bit data bus allowing for faster and more accurate computations. The 16 bit bus is necessary because computational devices without this bus lack the speed for real time computations.

The output is sent to a 1802 microprocessor where the printout is converted, buffered and sent to a built-in printer capable of 2-1/2 lines per second of five full four-digit numbers. These results are selectable from over 30 different dynamic parameters and can be changed even between blows by simply switching to a new selection. The 1802 system also automatically documents all input and output selections and contains a blow counter. The LCD visual displays get their data from the same port.

The scope system takes the digital information directly from RAM as requested. This request is initiated by a DMA (Direct Memory Access) line which halts the microprocessor temporarily so that data can be acquired by the scope section from RAM. The scope system obtains the data and generates the analog sweep (X), and the analog vertical deflection (Y) from a D/A convertor. The outputs are then continuously sent to any inexpensive X-Y oscilloscope which avoids the need for costly storage. The user can select either strain and velocity, wave down and wave up, energy, displacement or resistance (with and without damping) as functions of time to be output to the scope, stripchart, or X-Y plotter.

The RS232 interface sends digital data from the PDA to any modern computer, terminal, plotter, or printer with RS232 capability. It can also be sent from remote field locations by a modem through telephone connections to central computers. Thus, data transmission for CAPWAP is easily accomplished without delays due to travel from the site. The PDA uses a digital plotter to produce a report quality graphic summary of the dynamic data, including the computed pile bottom force displacement relationship (4).

SYSTEM CONSIDERATIONS

If dynamic pile testing is to be a routine part of all pile projects, then it has to be quickly applied. Every blow must be analyzed in real time to avoid delays to the contractor. The PDA system has many practical advantages, especially since wave theory methods have been sufficiently developed to solve in closed form solution for hammer and soil properties and pile stresses.

The PDA is a state-of-the-art digital microcomputer. Unnecessary overhead, operating systems, video terminal inputs, etc. which are not required were eliminated and floating point software added to analyze each blow at speeds in excess of 120 blows per minute, a rate unmatched by general purpose data acquisition systems. Speed of operation is very important for statistical confidence. Hammer performance changes from blow to blow. During driving, distress occurs quickly as a pile punches through into a soft layer or suddenly encounters rock; damage usually develops quickly and can be caught in an early acceptable stage if every blow is monitored. Finally every blow must be analyzed during restrike since remoulding in many soils has major effects from blow to blow.

Any unit shipped to and operating in this difficult environment must be rugged and compact; the PDA was designed as a single small package. The system contains no disks or other components which are either dirt or temperature sensitive. Its reliability is demonstrated by past history; the PDA has been solving problems on over 2000 different projects during the past 15 years.

The system was designed to support a variety of standard peripheral equipment. Data is stored on either analog FM tape recorders (reel-to-reel or cassette) or digital recorders. Any inexpensive X-Y or time base oscilloscope, stripchart or analog plotter can be used. The PDA is compatible with modern computational and display devices; the telecommunication for CAPWAP and digital plotter features are particularily useful.

Finally, the PDA is a very user friendly system. The user need not have any working knowledge of computer systems; the controls are functionally grouped on a single control panel and can be quickly changed even between hammer blows (the PDA automatically documents these changes on the printout) to adjust to rapidly changing conditions. The strain velocity data are displayed on the oscilloscope at a theoretical proportional scale with impact and 2L/c time markers making data quality assessment very accurate. The ability to observe resistance during the blow as a time function for every blow aids damping evaluation. The scope features, the internal self-calibration, other automatic PDA operations and warning features make field data collection very easy and practically insures error free results.

USES OF DYNAMIC TESTING

Using closed form solutions to wave theory, the PDA solves for activated soil resistance (remoulded strength during driving or service load including setup and relaxation by restrike), tension and compression stresses, pile integrity and hammer performance. Immediate printout for each blow provides a complete investigation of the hammer-pile-soil system during driving or restrike.

Although better than dynamic formulae, wave equation results are only as accurate as the available soil and hammer input data. The PDA system can verify the assumed input or provide correct data for improved analysis. The PDA is often used to check driving stresses or measure hammer performance for qualifying hammers. Recent work has resulted in the ability to calculate ram kinetic energy at impact and cushion stiffness properties. The system can inspect the pile for structural damage without extraction.

With the PDA system, static testing can be reduced or eliminated. For very small projects where no static testing is performed, or on large piles or offshore projects where testing is prohibitively expensive, PDA tests provide a low cost inspection tool. For major projects with multiple static tests, some static tests can be replaced with several dynamic tests, increasing quality control with substantial savings. Preliminary test programs prior to using the first production piles of a job have improved numerous foundations by monitoring stresses and preventing damage, and indicating hammer system improvements, pile penetration reductions, and driving criteria improvements.

BENEFITS OF TESTING

Since the PDA is so flexible, the above is not a complete list of uses. Engineers are creatively adapting this equipment to their specific projects. Similarly, it is not possible to briefly describe all the benefis. It is clear that dynamic tests benefit all parties associated with a pile project.

The engineer is presented with much more information to assist in design and construction control. The more extensive information can be used easily with load factor design and statistical procedures to reduce safety factors (8,9), reducing the overall project cost. If problems are detected, they can be corrected early in a project at comparatively modest cost.

The contractor obtains information on the performance of his hammer system. By evaluating effects of changes (cushion, maintenance, etc.) he can improve his overall efficiency, resulting in reduced driving time, lower blow count criteria, and therefore lower costs and increased profit. Knowledge of stresses and pile integrity, if a problem and generally bid as a contractor expense, can lead to procedures to reduce damage. Improving hammer performance can result in a lower bid for the next project, increasing chances of obtaining further work; this is particularly true when the PDA is specified and the contractor knows it may assist in solving any new problems which may occur.

The owner is assured of a higher quality foundation since more piles are tested. The faster dynamic testing reduces construction time and is much less expensive than static tests. Structural integrity is verified. In many soils, adequate capacity is determined at smaller penetrations which reduces pile length and therefore time and cost. It has been observed that the number and amount of claims is reduced since facts are available early in the project; speculation by lawyers is eliminated.

CONCLUSIONS

The hardware to routinely monitor pile driving has been adequately developed and described. The Pile Driving Analyzer is a simple reliable system capable of quickly solving a variety of questions commonly associated with pile foundations. Dynamic testing helps engineers, contractors, and project owners arrive at the best possible foundation at a lower cost and in less time.

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FIGURE 1: PILE DRIVING ANALYZER

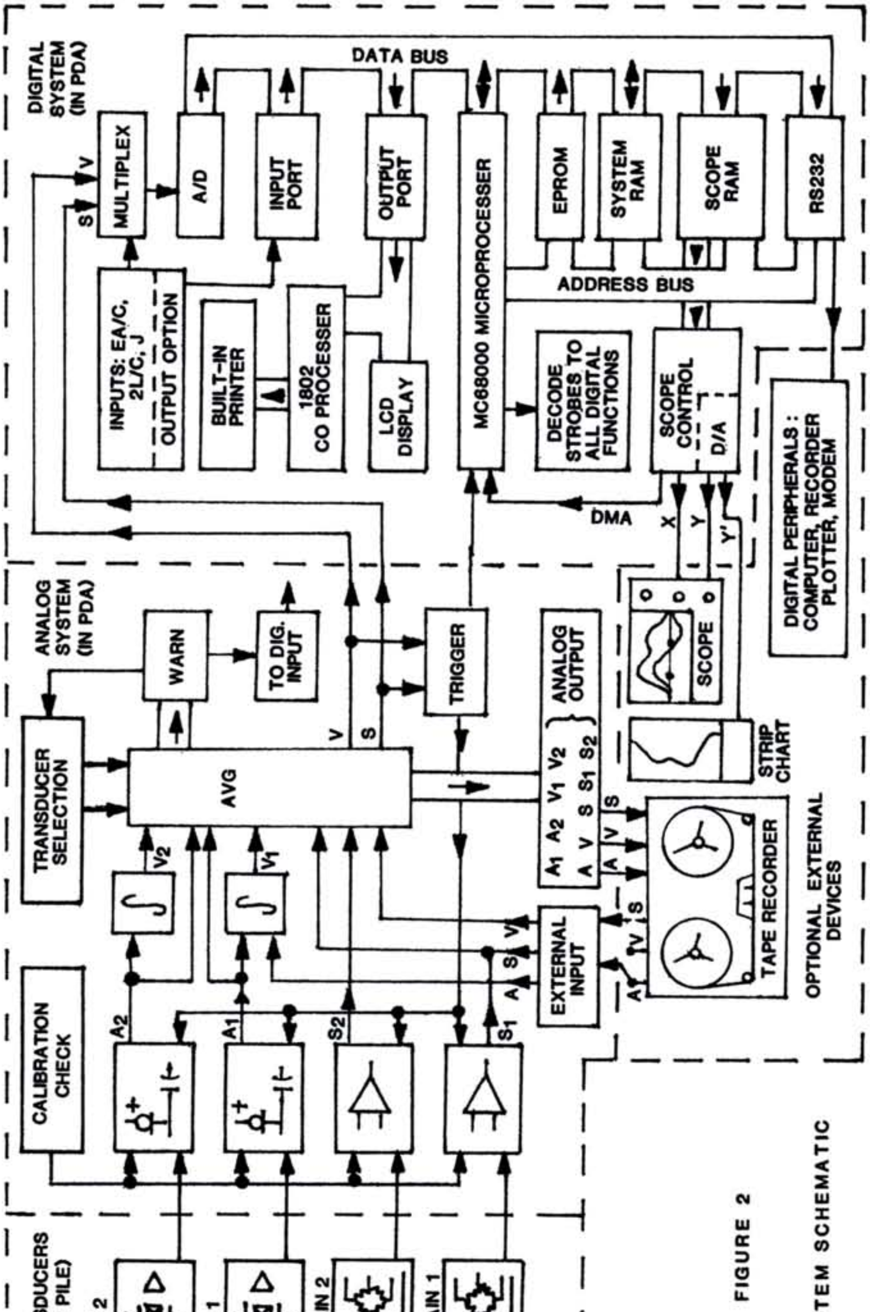

FIGURE 2

SYSTEM SCHEMATIC