HAMMER INSPECTION TOOLS

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Introduction

The pile driving hammer plays a critical role in the installation of driven piles. It must be sufficiently large to drive the pile to the specified capacity or penetration. It is also used as an inspection tool in that the blows per unit penetration are usually counted and related to pile bearing capacity.

Often the manufacturer's energy rating is used as a guide to select hammers for a specific project. Recent engineering practice generally requires a wave equation analysis to verify that the hammer can drive the pile to the desired capacity without overstressing the pile (Rausche et al., 1986). Comparison of similar hammers demonstrates that all hammers unfortunately do not provide a consistent amount of energy into the pile (Rausche et al., 1985).

Hammers which are inefficient cause a variety of problems. For the contractor, the better the hammer performs, the faster he can drive the pile. For the owner or engineer, undetected poor hammer performance is a leading cause of foundation failures. It is therefore important to all parties involved in pile driving to carefully monitor the performance of the installation equipment. Several inspection tools are now available to the profession; their advantages and limitations are discussed.

The Saximeter

The frequency of hammer blows can be measured and compared with the manufacturer's recommended operating range to confirm proper operation. This measurement can be made with a stopwatch by counting the number of blows over a short period of time like a minute.

For open end diesel hammers only, the stroke can often be calculated with sufficient accuracy from the formula

$$h = (g/8)(60/BPM)^2 - h_e \qquad (1)$$

where g is the earth gravitational acceleration, h_e is a loss (usually 0.1 m or 0.3ft), h is the ram stroke, BPM is the equivalent speed in Blows Per Minute. This formula was derived on the assumption of a free fall over distance h with a loss due to compression and impact. The actual potential energy PE available for these hammers is the product of this stroke with the ram weight W. The stroke varies depending on the pile resistance, pile length and flexibility, the amount of fuel injected by the fuel pump, friction/lubrication, and/or the state of maintenance. Since open end diesel hammers have a variable stroke, they have a variable energy and the use of the manufacturer's maximum rated energy will in general overpredict the pile capacity since the rated stroke is not usually achieved. Knowledge of the stroke is therefore considered vital to proper installation inspection.

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Note that high friction may produce an overprediction of stroke according to Eq. 1.

Unfortunately it is often not easy to visually observe the ram, and the stroke has to be estimated generally with poor resolution from a chart relating BPM to h. That chart is usually not available on site. Simultaneous measurement of blow count and blow rate is not easily accomplished by the pile inspector, making stroke determination using equation 1 a difficult assignment. Further, the stroke varies from blow to blow and the variability cannot be assessed by a stopwatch.

An electronic device which listens for and detects hammer impacts has been developed. The Saximeter (Fig. 1) accurately determines the time between successive impacts for direct use in Equation 1 to determine the stroke for each and every blow. Thus the variability and average strokes are easily determined. By pressing a control the operator obtains the average stroke (or blows per minute) since the last command. By pressing the control once for each foot (per meter or other penetration increment) and recording the average stroke and number of blows a complete pile driving record is obtained; some Saximeters are equipped with a built-in printer and depressing the control automatically prints the results. Since the Saximeter uses a remote microphone to detect hammer impacts, no attachment to the pile is required and every pile can be monitored and documented. The stroke computation from Equation 1 is only intended for open end diesel hammers and use for other hammer types should therefore be restricted to (a) determining blow rate (BPM) and (b) counting of blows automatically.

Ram Velocity Measurement

Another measure of hammer performance is the speed of the ram at impact. If this speed is known then the kinetic energy, E_k, of the ram may be computed from

$$E_k = 1/2\ M_r\ (V_1)^2 \qquad (2)$$

where V_i is the velocity of ram at impact and M_r is the ram mass. This is a better measure of hammer performance than simply taking the manufacturers rating. For hammers powered by compressors, steam, hydraulics, or cable drop systems, the E_k result, if available, allows the engineer to identify most major hammer performance problems such as excess friction or lack of motive power.

Using technology such as two detection devices placed at a small distance between each other and slightly before impact, the ram travel time between these two sensors can be measured and the velocity computed. However, kinetic energy measurement for each hammer and all blows requires this instrument to be attached to the hammer itself; a small but growing number of new designs has this capability built into the hammer. To avoid this expense for each hammer and eliminate the safety hazard this attachment poses if it should fail, the Hammer Performance Analyzer (HPA) shown in Fig. 2 was developed which makes use of radar technology. As in Fig. 3, the radar antenna is placed near the base of the pile and directed toward the moving ram. From the Doppler shift between transmitted and reflected radar signal, a voltage is generated which is proportional to the speed of the moving ram.

Figure 1: The Saximeter

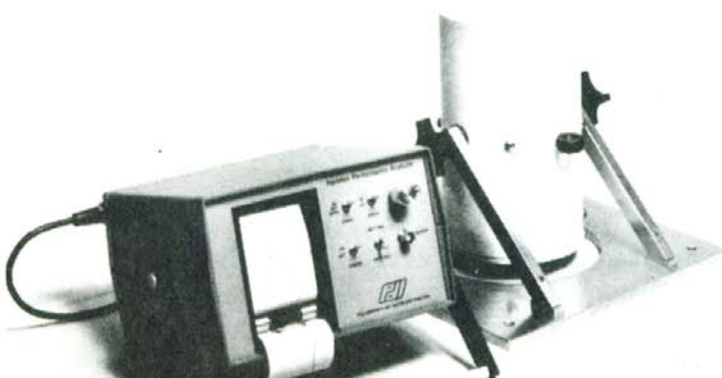

Figure 2: The Hammer Performance Analyzer

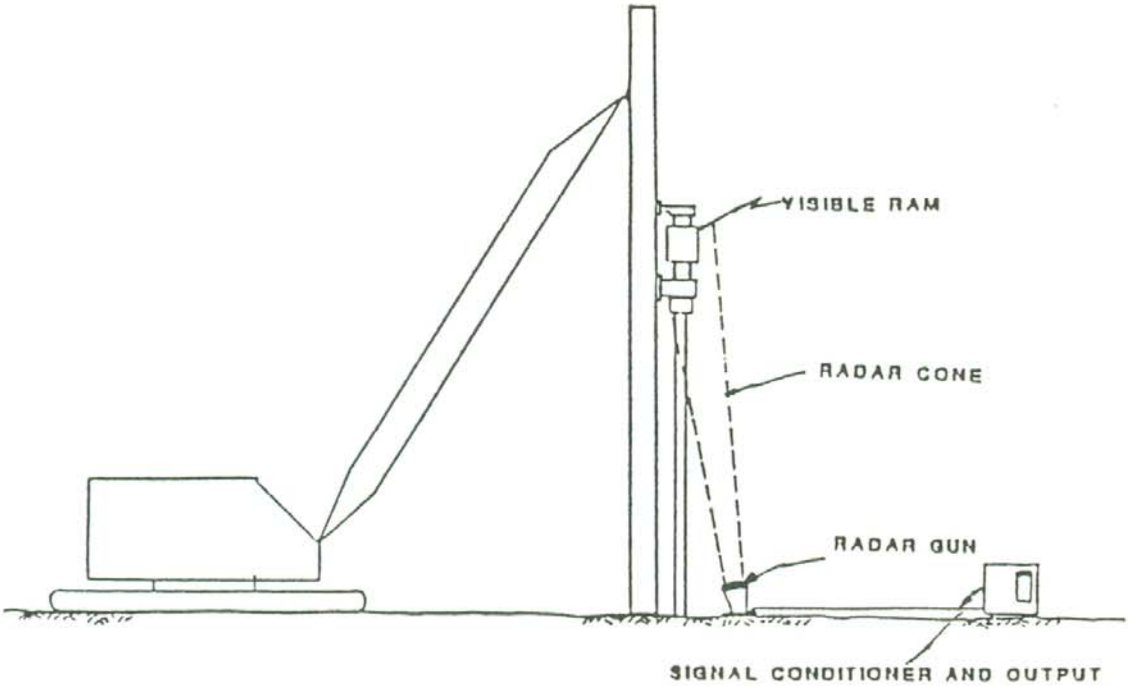

Figure 3: Operation of HPA with air/steam/hydraulic or drop hammer with visible ram.

This voltage is displayed by means of a chart recorder at either a slow speed so peak velocity for several blows can be compared as in Fig. 4a, or at a faster speed for a more detailed analysis as in Fig. 4b. Again there is no connection to the pile and measurements can be made on every pile without impeding the progress of the contractor.

The HPA represents a cost effective tool for supervising engineers to ensure continued adequate and consistent hammer performance throughout the entire pile installation. Contractors can optimize the performance of their equipment to increase productivity and increase their profits.

Another use of this device is to determine the performance of the Standard Penetration Test (SPT) hammer (Goble, 1987). A wide variety of these devices have been developed with differing mechanical trips or cathead/rope power. From a variety of measurements it can be concluded that the standard SPT is anything but standard and large variations exist between SPT rigs or operators of cathead/rope systems. These differences can be easily detected with the HPA system. The resulting N values from different systems can be rationally adjusted to give more consistent values which should result in better foundation designs. Furthermore, operators can be properly trained and supervised to give consistent performance.

Dynamic Pile Measurements

Both the Saximeter and HPA give valuable information regarding the operating characteristics of pile hammers. However, it is neither the potential nor the kinetic energy of the ram which drives the pile. There are additional

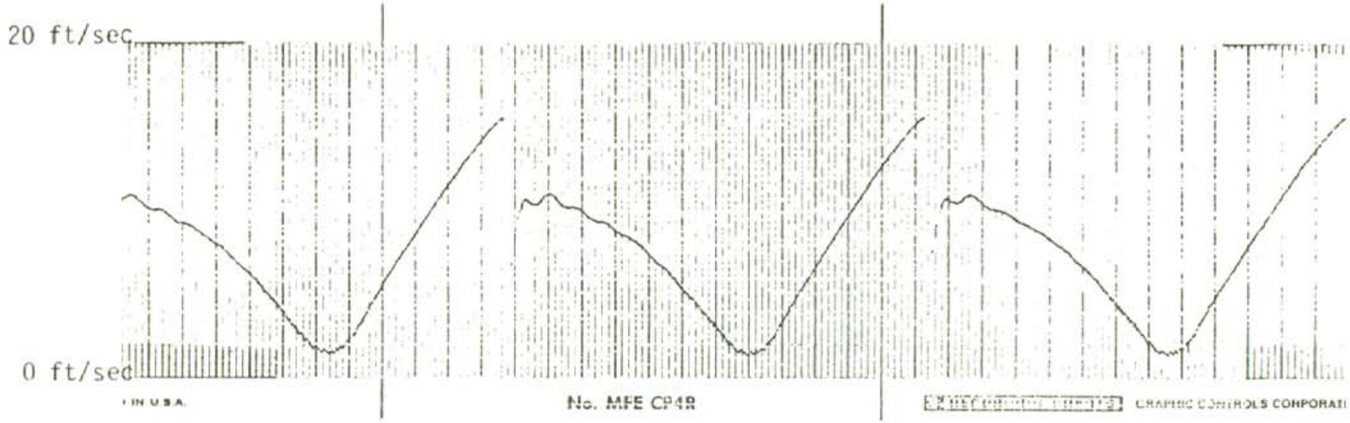

Figure 4a: Sample output at 20 ft/sec. High chart speed for air hammer 0 ft/sec.

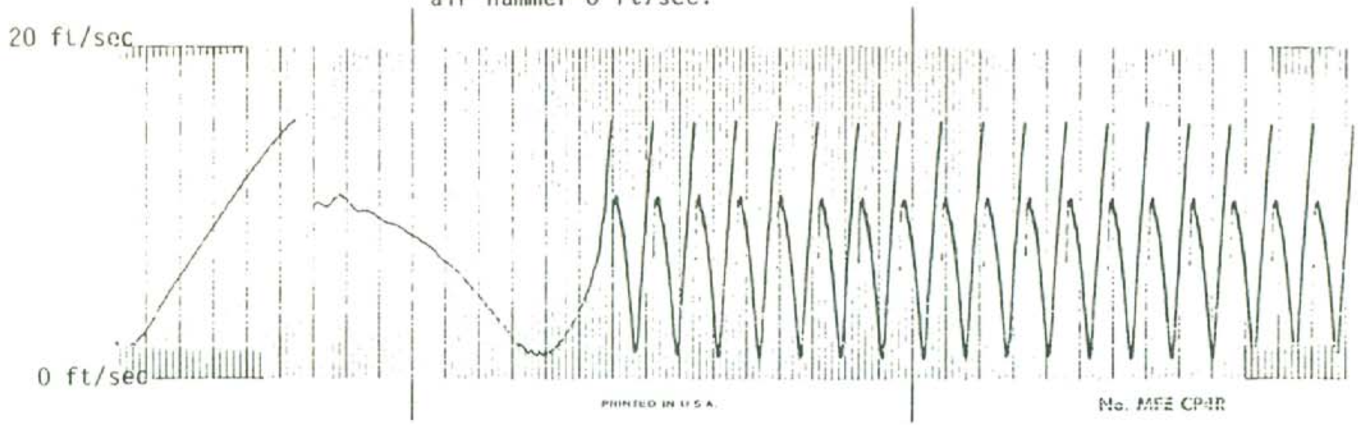

Figure 4b: Sample output showing compressed output.

losses in the helmet cushion assembly. The Pile Driving Analyzer[TM] (PDA) uses the measurement of force F(t) and velocity v(t) and computes the energy E(t) based on the amount of work done

$$E(t) = \int_0^t F(t)du = \int_0^t F(t)v(t)dt \qquad (3)$$

where the force, velocity and energy are all functions of time during the blow. The maximum value of energy calculated during the blow is of special interest and is called ENTHRU or EMX. This EMX value is the energy which is available for pile and soil compression and to produce plastic deformation of the soil. It includes the potential energy of the ram and all losses in hammer and driving assembly.

The EMX value can be used to compare the overall effectiveness of any pile hammer system. Comparison between different hammers on the same project can determine the best driving criteria for each hammer even if the test pile program did not include these hammers, provided of course that the hammer used for the test program was also monitored and its EMX values known.

It is often helpful to know why the EMX value may be low. A solution derived from impulse-momentum considerations has been developed to solve for the maximum ram velocity prior to impact (Likins, 1982). The condition of zero velocity in the pile top also corresponds with zero velocity of the ram and helmet; since momentum is conserved in any system (in the absence of external input), the original momentum of the ram at impact must at that time be transferred into the pile as an impulse. Therefore, the impact velocity of the ram can be obtained from the expression

$$V_i = (1/m_r) \int_0^{t_o} F(t)\, dt \qquad (4)$$

where t_o is the first time of zero pile velocity after impact. Comparison of these results with conventional wave equation assumptions shows good agreement. The V_i determined by this method in the PDA is generally lower than that obtained by radar HPA for air or steam powered hammers as the HPA considers only the velocity prior to impact and not the injection of motive pressure into the hammer just before and during the hammer blow; the PDA result is considered a better input into wave equation models as it considers the net hammer enery available during the blow. This is not a deterrent for using the HPA as it gives good relative hammer performance information and can be calibrated to the PDA result.

Many engineers rely on the wave equation analysis to set driving criteria or to assess pile capacity and driveability. This has been especially true for the installation of oil platforms. In addition to the actual hammer efficiency which can be obtained from either the PDA or HPA, another important input is the cushion stiffness. In offshore projects, determination of this stiffness by measurement of force on the pile and numerous wave equation parameter studies has often been used as the basis for determining when the hammer cushion should be replaced. Using free body force equilibrium considerations and the pile top force and velocity measurements, the force in the hammer cushion can be directly computed for steel piles; using the same measurements and the conservation of momentum, the displacement in the cushion can also be obtained (Rausche et al., 1985). By plotting the force versus the displacement in the hammer cushion, a complete loading history of the hammer cushion (also called the capblock) can be obtained as shown in the example of Fig. 5 and the stiffness can be directly determined. This analysis has been included in the PDA and the stiffness can be output for each hammer blow in real time.

Additional measurements on the helmet can result in the direct computation of the load deflection of the pile top cushion for concrete piles. An example of this method can be seen in Fig. 6.

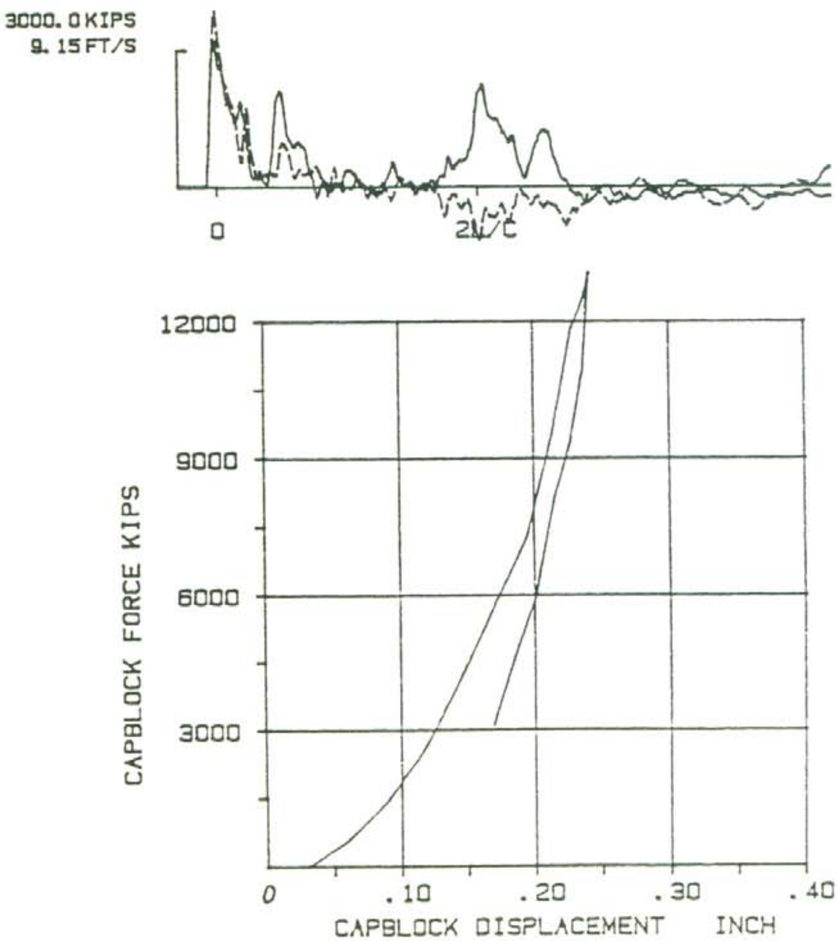

Figure 5: Hammer cushion (capblock) load deflection curve from pile top measurements by the PDA.

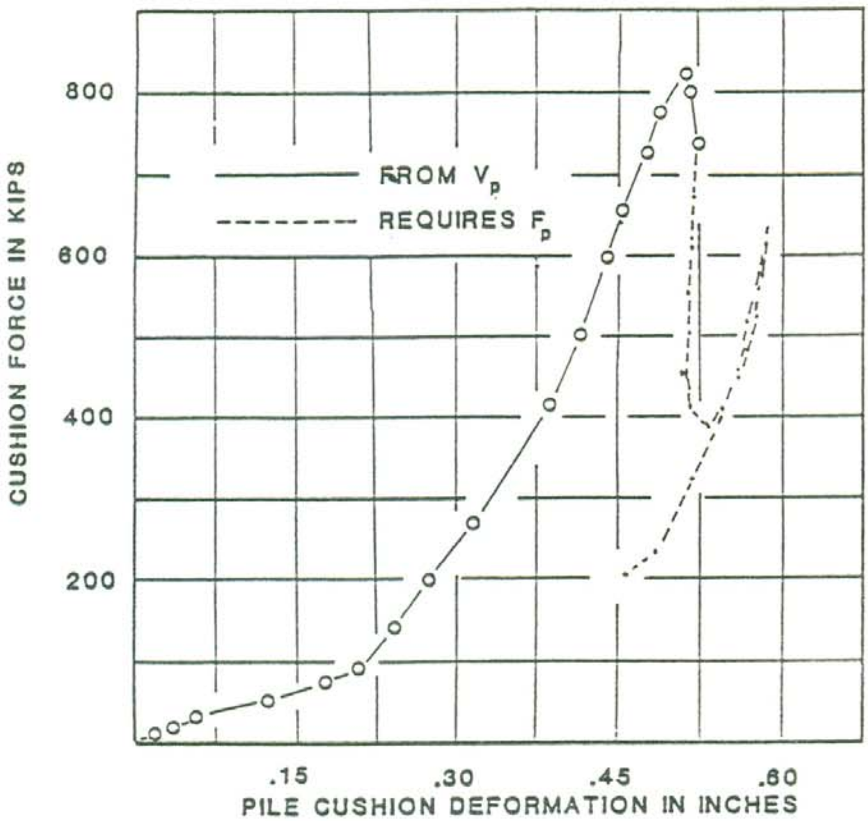

Figure 6: Force deformation curve from helmet and pile top measurements for 7.5 (190 mm) thick plywood cushion.

The PDA also provides information on ultimate pile capacity, tensile and compressive driving stresses, and structural integrity of the pile. These are clear advantages in that with this system most any problem relating to pile installation can be assessed (Likins et al., 1988). However, the PDA requires that transducers be attached to the pile. While this attachment using reuseable transducers can be made in typically less than ten minutes per pile, it generally means that only five to ten percent of all piles are actually tested by this method although testing all piles can be and has been performed in special cases. Selected piles spaced throughout the entire installation period are tested by the PDA, while Saximeter or HPA measurements can be easily performed for all piles providing valuable documentation especially when correlated with the more extensive PDA system.

Summary

Hammer inspection tools like the Saximeter can monitor the stroke of open end diesel hammers or the blow rate of any hammer type. The ram velocity can be measured directly with the radar based Hammer Performance Analyzer. With the Pile Driving Analyzer the energy transferred to the pile can be determined, the ram impact velocity calculated, and the dynamic cushion load deflection properties obtained. With the use of any or all of these hammer inspection tools, the pile installation becomes less mysterious and rational procedures for the improvement of installation equipment and procedures become possible.

As pile design loads increase, the testing of driven piles becomes more crucial to satisfactory pile foundation performance. Since the installing hammer is directly related to this process, the monitoring and confirmation of proper hammer performance assists all parties involved: the contractor can improve the efficiency of his driving system for better productivity while the engineer is assured of adequate pile bearing capacity.

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