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PILE DRIVING ANALYSIS—SIMULATION OF HAMMERS, PILE, AND SOILS

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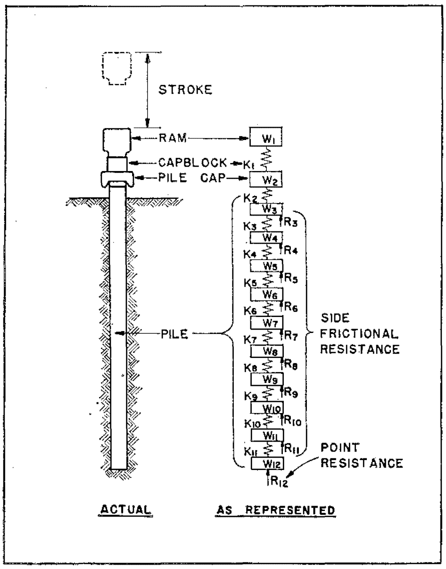

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Pile Driving Analysis—Simulation of Hammers, Pile, and Soils

by

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Introduction

The problem of pile driving analysis has been of great interest to engineers for many years. After the first method for predicting the load bearing capacity of a pile was proposed, pile driving became one of the most hotly debated fields in engineering.

In 1960, E. A. L. Smith proposed the first practical solution to pile driving analysis based on sound mathematical methods. His method was based on a numerical solution to the wave equation and was capable of including the effects of any of the parameters known to be involved in pile driving analysis. It was completely general and applicable to tapered, stepped, and composite piles of any material, to nonlinear soil resistance and soil damping, and to pile systems involving several cushions and helmets.

Smith's method of analysis was of immediate interest to the Texas Highway Department and Bureau of Public Roads who have sponsored extensive and continuous research concerning pile driving analysis by the wave equation.

Objectives

The specific objectives of this research were:

1. To review and summarize Smith's original method of analysis and to derive a more general solution.

2. To determine the effect of the elasticity of the ram on the solution.

3. To compare results given by the wave equation with those found in laboratory experiments and field tests.

4. To determine the dynamic properties of cushions subjected to impact loads.

5. To study the effects of internal damping in the pile and its significance.

6. To illustrate the significance of the parameters involved, including the internal damping and spring rate of the cushion, ram velocity, material damping in the pile, soil damping and quake, and to determine the quantitative effect of these parameters where possible.

7. To illustrate the use of the wave equation in determining the impact characteristics of the materials involved.

8. To study the effect of hammer energy and if possible to recommend a simple yet accurate method for determining the actual energy output for various hammers.

The Numerical Method of Analysis and Its Application

The numerical solution proposed by Smith is based on idealizing the actual hammer-pile-soil system as a series of concentrated weights connected by weightless springs as shown in the cover illustration. As shown by Smith, the idealized system is readily solved by the use of numerical methods and high speed digital computers.

In order to obtain the objectives in this report, it was necessary to significantly modify Smith's original solution. These modifications are discussed in detail in the report.

Comparison with Field Tests

One of the most important parameters involved in pile driving is the velocity of the ram immediately before impact, since it significantly affects both driving stresses and permanent set of the pile. Although maximum rated energies are suggested by manufacturers of pile driving hammers, these values are arbitrarily reduced to various degrees because of the lack of a consistent method of determining the actual energy output.

In order to study the influence of the driving hammer, experimental solutions reported by the Michigan State Highway Commission were compared with solutions given by the wave equation. Among the variables compared were the permanent set of the pile, displacement of the head of the pile, resistance to penetration at the time of driving, force at the head of the pile, and energy output of the hammer. The effect of the instrumentation used to record experimental data was also studied.

Comparisons with Laboratory Experiments

The properties of cushion materials were determined by using both the wave equation and experimental data obtained for a full scale pile tested under laboratory conditions. The ram and pile were freely suspended horizontally by cables in order to eliminate the effects of soil resistance. Strain gages placed at intervals along the pile were used to record stresses at various points for comparison with stresses predicted by the wave equation, and to determine the dynamic spring rates and coefficients of restitution for various cushion materials. These data were also used to determine the relative significance of material damping in the pile.

Conclusions

1. Pile driving analysis is an extremely complex problem involving a multitude of variables including the kind of hammer, driving appurtenances, cushion types, properties and

dimensions of the pile, and properties of the supporting soil medium. At this time (1968), only the numerical solution to the wave equation proposed by Smith is capable of accounting for all of the parameters involved.

2. When the wave equation is compared with the results of laboratory experiments and field tests, Smith's method is found to be relatively accurate.

3. The elasticity of the ram was found to have a negligible effect on the solution except in the case of steel-on-steel impact, which occurs in diesel hammers. The problems solved indicate that if the elasticity of the ram of a typical diesel hammer is disregarded, a conservative solution for driving stresses and permanent set of the pile will result; if the elasticity of the ram is accounted for, maximum compressive driving stress and maximum point displacements may be reduced around 20%.

4. It is possible to determine much valuable information using the wave equation even though values for certain key parameters are unknown. For example, several problems can be solved in which the unknown parameter is varied. From the results, the significance of the parameter can be determined, and the range in which the actual solution lies can be established.

5. Comparisons with the Michigan pile study indicate that a relatively simple yet accurate method of determining the energy output for pile driving hammers can be used. It was found that for the cases investigated, a simple equation relating energy output for both diesel and steam hammers could be used. This equation is as follows:

$$E = (W_R)\ (h)\ (e)$$

where W_R is the ram weight, h is the observed total ram stroke (or the equivalent stroke for double acting steam hammers and closed end diesel hammers), and e is the efficiency for the hammer in question. The efficiencies determined during the course of this investigation were 100% for diesel hammers, 87% for double acting steam hammers and 60% for single acting steam hammers. The writers feel that 60% is unusually low for the single acting hammer and do not recommend it as a typical value. An efficiency of 75 to 85% as reported by Chellis is believed to be a more typical value for a single acting steam hammer.

6. Although the most accurate correlations are obtained when the actual dynamic stress-strain curve of the cushion material is used, the nonlinear behavior involved makes this impractical. Further, the use of a linear stress-strain curve having a slope defined by the secant modulus of the material is sufficiently accurate. The dynamic coefficient of restitution for the cushion materials was found to agree with commonly recommended values.

7. The effect of internal damping in concrete and steel piles was negligible for the cases studied, although it can be accurately accounted for using the wave equation.