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Increasing the Ability to Drive Long Off-Shore Piles

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Abstract

Because offshore pile foundations are being required to support ever-increasing axial loads, two of the most important questions the Design Engineer must answer is whether or not it will be possible to drive these piles to the design penetration, or whether jetting or drilling will be required, and also, what static resistance to penetration will the soil afford at final penetration. Not only are other methods more expensive than driving alone, they also introduce major uncertainties in the load capacity of the pile.

This paper discusses how pile make-up, size and type of hammer, and driving accessories affect the ability to drive long offshore piles, and how the resistance to penetration may be determined. The one-dimensional wave equation was used to determine the significance of changes in parameters such as the cross-sectional area of the pile, cushion stiffness, ram weight and velocity, and others.

Although it might be expected that increasing the ram weight or ram velocity would be the major influences on increasing the ability to drive a given pile, it was found in this study that in many cases, increasing the cross-sectional area of the pile was of far greater importance. Also, the cross-sectional area was always found to be of importance in utilizing any increase of hammer energy.

It was further determined that for a given hammer, an increase in the cushion stiffness or coefficient of restitution could often be used to greatly increase the ability of a given pile to be driven.

Probably the most significant conclusion shown by this study is that by use of the wave equation the Design Engineer can for the first time determine quantitatively, rather than only qualitatively, the effects of any of the numerous variables involved, i.e., how much any variable affects the ability of a pile to be driven.

References and illustrations at end of paper

Introduction

During the past several years, the use of the wave equation to investigate the dynamic behavior of piling during driving has become more and more popular. Widespread interest in the method was begun in 1960 by E.A.L. Smith(1), who proposed a numerical solution to be handled by high-speed digital computers, which permitted the investigation of such factors as ram weight, ram velocity, cushion and pile properties, and dynamic behavior of soils during driving. Since this time, a vast amount of experimental data has been taken to determine accurate input values for this method and a multitude of full-scale pile tests have been correlated which now permits an accurate analysis of the dynamic behavior of piles during driving.

At the present time, a number of the major oil companies and construction firms are using the wave equation to answer such questions as:

1. Can a given hammer drive a pile to the required depth of penetration?

2. What driving stresses will be induced in the pile and hammer?

3. What rate of penetration will the proposed hammer provide, and consequently, how long will the installation require?

4. What changes in the hammer, driving accessories, pile configuration, or installation procedure can be made to improve the situation?

Pile Driving Hammers

One of the most important questions to be answered in the installation of large offshore piles regards the size of hammer necessary to successfully drive the pile to the required penetration. Unfortunately, the driving capability of any hammer is greatly influenced by numerous factors. Many cases have been reported in which the selected hammer was unable to drive the piles to the design penetration. Several examples of this are reported by Daigle(2) and McClelland(3).

The wave equation was used to analyze three offshore pile driving hammers: the Vulcan 020, 040, and 060 hammers. The results of this analysis are shown in Figure 1. In each case, all variables such as the hammer efficiency, cushion stiffness, and other input data required for the wave equation solution were held constant.

As noted in Figure 1, although the energy output of the Vulcan 040 and 060 hammers are respectively 2 and 3 times that of the Vulcan 020 hammer, in no case was the driving capacity of the 020 doubled or tripled by the use of the larger hammers. Actually, the 300 percent increase in energy from a Vulcan 020 to an 060 hammer increased the driving resistance by only 20 percent.

The demands of present offshore construction often require that these piles be driven to resistances of 3,000 tons or more. These requirements cannot usually be achieved with existing hammers, and it is obvious that larger hammers will eventually have to be built. Fortunately, the wave equation can be used to study these hammers.

Figure 2 shows the results of a parametric study of the ability of large drop hammers to drive a typical pile. These curves give the relationship between the rate of penetration and the ram weight and velocity or drop height. For a given ram weight, the rate of penetration increases with an increase in initial ram velocity. For a fixed velocity or drop height, the rate of penetration increases as the ram weight increases. Working conditions, safety, and physical limitations of equipment dictate that the drop height be limited. Existing steam hammers presently utilize a maximum drop height of 3 ft. (14 ft. per sec. initial velocity) and a ram weight of 80 kips, whereas diesel hammers have maximum drops of around 10 ft. (20 ft. per sec. initial velocity) with 10 kip rams. The curves illustrate that only the Vulcan 080 hammer could be used to drive the given pile. In contrast, the figure indicates that by using a 310 kip ram with a 4 ft. drop, the pile could be driven at 25 blows per ft., giving a thirteen-fold increase in driving rate while increasing the hammer energy by a factor of only 3.9 or less than 4.

This limited study indicates that large capacity piles can be driven with the proper equipment.

Cushions

Cushions are normally used to reduce the stresses in both the hammer and pile during driving. Common cushioning materials include hard and soft woods, plywood, asbestos, rope, and micarta and aluminum discs. The most significant properties of a cushion include its stiffness and coefficient of restitution.

Figure 3 shows the effect of varying the cushion stiffness. For the pile shown, an increase in the cushion stiffness increased the ability to drive the pile, especially at high soil resistances.

The effect of variations in coefficient of restitution of the cushion is illustrated in Figure 4. As might be expected, the more efficient cushion increases the ability to drive the pile at all levels of resistance since less energy is absorbed in the cushion.

Driving Accessories

The weight of the pile cap can have a significant influence on the ultimate soil resistance to which a hammer may drive a pile. Figure 5 gives the wave equation results for two hammers driving the same pile. The pile cap weight was varied as shown.

In the case of the 020 hammer, increasing the pile cap weight from 5 kips to 25 kips resulted in a 12% decrease in the ultimate resistance to which the pile could be driven, whereas an increase to 45 kips resulted in a 26% loss in ultimate resistance. This phenomena can be explained by the fact that the energy available to drive the pile was reduced by the work done on the pile cap. The results obtained for the Vulcan 060 are also indicated in Figure 7.

Pile Configuration

One of the more effective methods of increasing the ability of a pile to be driven is to increase its stiffness by increasing its cross-sectional area. Figures 6 and 7 illustrate typical results found by increasing the wall thicknesses of given piles.

As was noted in Figure 1, tripling the energy of a Vulcan 020 hammer increased the ability to drive the pile only 20 percent. In contrast, as illustrated in Figures 6 and 7, tripling the cross-sectional area of the pile increases the ability of the 020 hammer to drive the pile approximately 60 percent, and increases the ability of the 060 hammer to drive the pile by 100 percent.

It is interesting to note that Figure 6 illustrates that at low soil resistances (less than 1200 kips) the lighter pile drives easier than the heavier pile. This is because at low resistances, the pile moves a large distance per blow, and the increased mass of the heavier pile traveling through this displacement absorbs much of the energy output of the hammer. However, at a higher resistance, the number of blows per foot becomes sufficiently large (i.e., the penetration per blow becomes so small) that the additional capacity of the heavy pile to transmit the stress wave through the soil far exceeds the inertial effects, thus making it easier to drive.

Conclusions

The use of the one-dimensional wave equation for the solution of problems concerning the driving of offshore piles has been demonstrated. It was used to determine the significance of changes in parameters such as the cross-sectional area of the pile, cushion stiffness, ram weight, etc.

Although it might be expected that increasing the ram weight or ram velocity would be the major influences on increasing the ability to drive a given pile, it was found in this study that in many cases, increasing the cross-sectional area of the pile was of far greater importance. The cross-sectional area was also found to be of importance in utilizing any increase of hammer energy.

It was further determined that for a given hammer, an increase in the cushion stiffness or coefficient of restitution could often be used to increase the ability of a given pile to be driven.

The weight of the pile cap was found to have a significant influence on the resistance to which a pile can be driven. If the pile cap approaches the weight of the hammer's ram a decrease in ultimate soil resistance of approximately 12% can be anticipated.

The feasibility of developing a drop hammer to drive a pile to a capacity of 3000 tons or more was demonstrated.

The most significant conclusion to be drawn from the study is that through the use of the wave equation the design engineer can for the first time determine quantitatively, rather than qualitatively, the effects of any of the numerous variables involved, i.e., how much any variable affects the ability of a pile to be driven.

References

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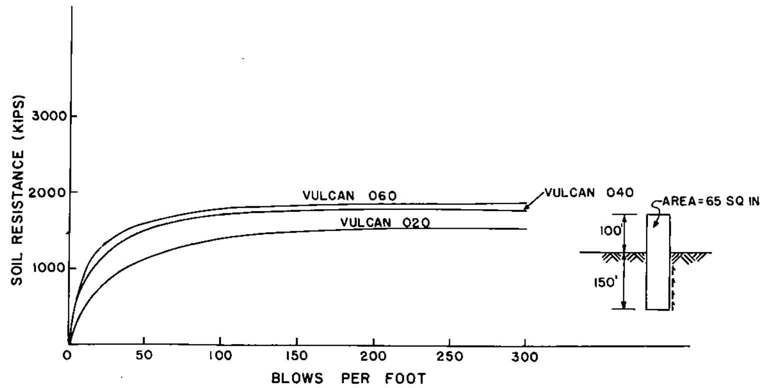

FIG. I A TYPICAL COMPARISON OF PILE DRIVING HAMMERS

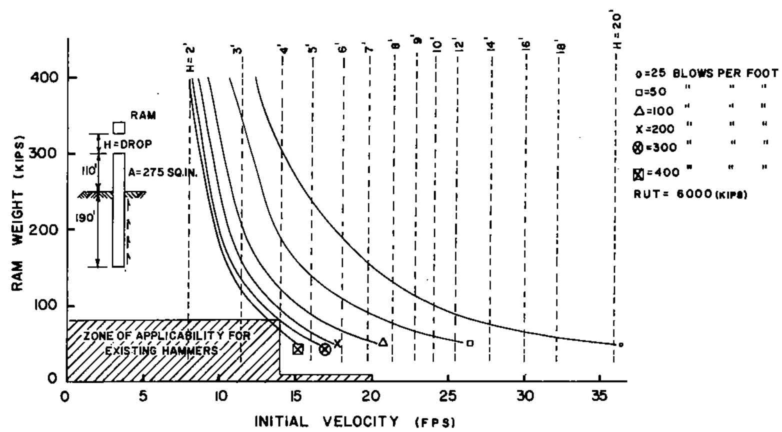

FIG. 2 RAM WEIGHT VS INITIAL VELOCITY

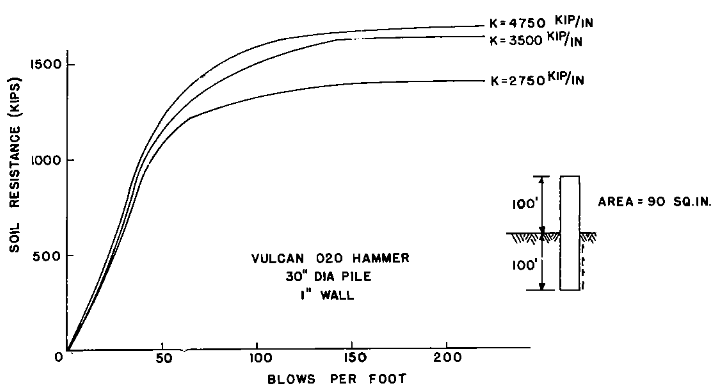

FIG. 3 EFFECT OF CUSHION STIFFNESS

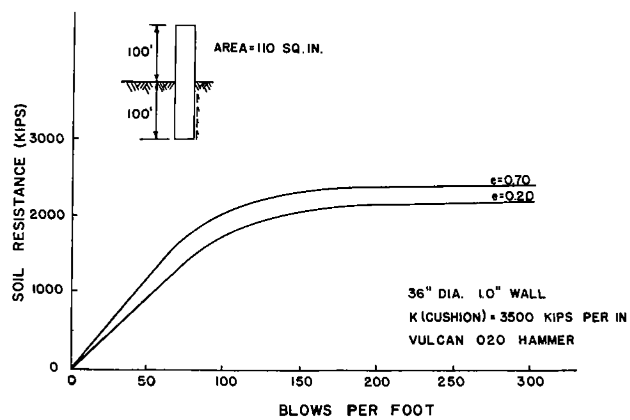

FIG. 4 EFFECT OF COEFFICIENT OF RESTITUTION (e)

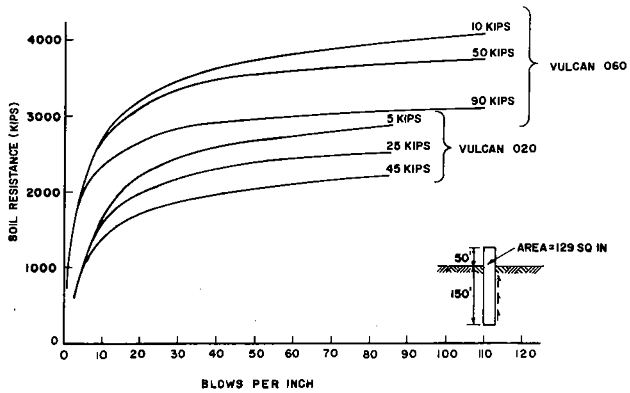

FIG. 5 EFFECT OF PILE CAP WEIGHT

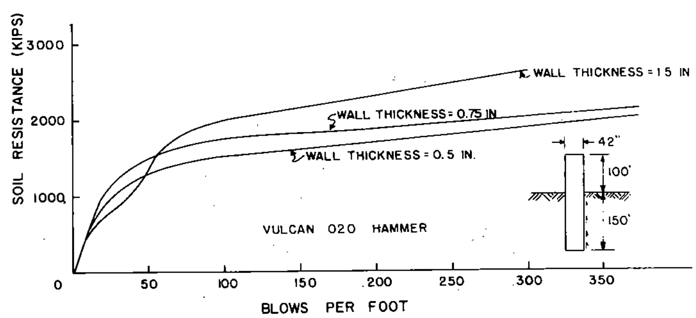

FIG. 6 EFFECT OF WALL THICKNESS

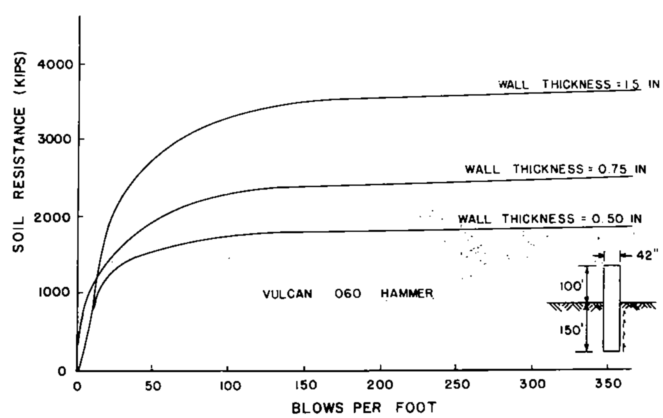

FIG. 7 EFFECT OF WALL THICKNESS