Summary and Review of Part I of the Symposium on Pile Foundations

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•IN HIS PAPER on the various types of piles and their characteristics and general use, Grand has the task of setting the stage for the remaining papers. His responsibility is to tell what we thought we already knew about piling. He has traced the historical development of pile usage and the purpose of pile foundations. He cautions that there is a need for complete subsurface investigation and then lists pile types with their physical characteristics. His list, although not fully complete, is comprehensive enough to cover those piles that constitute the majority of installations. Grand also includes in his paper suggestions as to where and for what purpose the numerous types of piles are to be used and also where they are not to be used.

Many practicing engineers will want to know the relative cost of the different types of piling and that magic formula for picking the right pile to do a specific job. This is just too dependent on factors such as locality, specific soil conditions, previous area practices, available equipment, size of job, local contractors' interests, and competition. The engineer will always need his past experience to make that last decision, but Grand's paper is helpful in showing the available alternatives. I only wish he had started his paper with the following comment: The most important decision to be made concerning piling is whether it is needed in the first place.

Mosley and Raamot compare the values of ultimate resistance for 3 dynamic formulas with that computed by the wave equation. This work was confined to the Engineering-News formula, the Hiley formula, the Eytelwein formula, and the wave equation. While elaborating on the limitations of dynamic pile-driving formulas (and who can say that they do not have major limitations), the authors feel that, of solutions currently available, the wave equation offers the only reliable method. They have plotted results with variables of pile materials, size, length, soil resistance, and pile hammers. Can any engineer read this paper and still go back with confidence to his dynamic formula?

However, one must recognize Mosley and Raamot's recent dedication to development of the wave equation (could this explain their partiality?) and remember that dynamic pile formulas have served useful purposes in many areas for many engineers (usually because of past experience and with moderate-weight piles and low-energy hammers). We have always recognized the shortcomings of the various dynamic pile-driving formulas. Mosley and Raamot tell us to do something about it and point the direction.

The heart of any pile-driving system is the pile hammer, and in his paper on hammers and driving methods Gendron describes the most commonly used pile hammers and speculates on driving systems of the future. Because of the simplicity of its operation, drop hammers are still in use, although the economical demands placed on the modern pile contractor do not encourage their use.

Gendron describes the single-acting, double-acting, and differential hammers. The single-acting hammers are simple and reliable, developing consistent energy when the stroke is controlled. From the contractor's point of view, they have a major advantage of a large ratio of weight of ram to total weight of hammer and are mechanically reliable and low in maintenance. Because a faster hammer was desired the double-acting

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hammer was developed (100 to 250 blows per minute compared with 60 to 75 blows per minute for a single-acting hammer). It strikes a relatively high-velocity blow that some theoretical studies have shown to be inefficient in the driving of heavy piles. The differential hammer overcomes the deficiencies of the single- and double-acting hammers, yet maintains some of their advantages. They are the hammers of today according to the author.

Gendron also describes the diesel hammer, which is a single piece of equipment combining the hammer and its power source. Much is yet to be learned about the measured output of a diesel hammer; but contractors are increasing their use of it, and it is here to stay. However, foundation engineers must become more "comfortable" with this hammer before it has universal acceptance.

In addition to his discussion of hammers, Gendron also covers the associated equipment such as cap blocks and cushions and highlights the Micarta-aluminum cushion, which is widely used today. The author discusses vibrators, hydraulic hammers, and the probable need for very high-energy hammers to handle the ever-growing need for larger and heavier piling.

More experience and results are needed on vibratory hammers before one can predict whether their use will either lessen or increase soil vibrations adjacent to the pile installation. In addition, there are many "tricks of the trade" for increasing or decreasing hammer energy output, and a quality installation requires quality inspectors trained in the use and mechanics of the pile hammers.

Hirsch, Lowery, Coyle, and Samson state, "The numerical computer solution of the one-dimensional wave equation can be used with reasonable confidence for the analysis of pile-driving problems." That statement appears to me to be a little too optimistic. If they limit their statement and say that this equation is a tremendous aid to the selection of pile hammer, related equipment, and pile material and size, then I have no argument. In fact, I am amazed at how much help we can get from the wave equation and wonder why it is not used more. I believe that a large number of pile installation problems will disappear with its general understanding and adoption.

The authors have developed a computer program based on Smith's procedure to provide the engineer a numerical solution of one-dimensional wave equation. The computer solution will also predict the impact stresses during driving as well as the soil resistance of a pile at the time of driving. The authors also find from the Michigan pile study that the accurate energy output for pile-driving hammers can be obtained. They demonstrate that driving accessories significantly affect the piling behavior. For this reason their selection should be carefully considered and analyzed whenever possible.

It was found in the investigations that stress-strain curves for a cushion block were not linear as was assumed by Smith. However, it was noted, surprisingly, that for a given material the dynamic curves during the loading of the specimen were almost identical to the corresponding static curves. As such, static can best be used to determine cushion stiffness but not for coefficient of restitutions. It was also fortunately found that, even if a linear force-deformation curve were assumed for a cushion, the wave equation predicts accurately the shape and magnitude of the stress wave as long as the loading portion is based on the secant modulus of elasticity of the material.

A comparison of the results of field test and numerical solutions was encouraging. The results of experiments in the laboratory compare accurately with numerical solutions. The effect of pile dimensions on the ability to drive the pile varied greatly. It was found that the stiffer the pile is the greater soil resistance to penetration it can overcome.

It does appear that the wave equation has demonstrated its usefulness in picking the optimum combination of hammer, cap block, and cushion for a particular application. However, some engineers may question whether it has as yet proven to be a reliable indicator of the "dynamic" pile resistance. We must remember that the variables that that go into the equation have a significant effect on its results. For example, it is critical that we know the characteristics of the soil, the hammer, and the cushion. Consideration should also be given to what stresses should be allowed for the various pile materials.