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hat Happens When Hammer Hits Pile
Now it can be told:

Up to now no one had been known to solve manually the complicated wave equation as it applies to action of a pile under the blow of a hammer. Today it takes but seconds to solve "mechanically" for driving resistance information such as plotted here.

Electronic digital computers are solving the wave equation to answer the question . . .

What Happens When Hammer Hits Pile

Edward A. Smith
Chief Mechanical Engineer
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It is now possible, thanks to electronic digital computers, to calculate in a practical and economical manner what happens at the instant a hammer hits a pile. As a result, it is possible to determine far more accurately than ever before the allowable resistance of a particular hammer to a predetermined number of blows per inch, as well as driven against a definite number of ultimate driving resistance.

This knowledge is of course important because, in a majority of cases, in-place driving resistance may be found with a factor of safety of 3 or 4. To determine the safe bearing capacity of a pile, exceptions occur with items that either "set up" or "jelly" under driving, so a knowledge of wave characteristics is essential, but in the

in the pile, the ability to compute the driving resistance accurately will greatly improve the engineer's position in determining the safe bearing value of a pile.

All this is now possible because electronic digital computers are available to solve in numerical methods the difficult math involved in applying the wave equation to pile driving problems.

- The Wave Equation - The wave equation itself is not new - it has been known to mathematicians for many years. In general, it describes how waves progress from one point to another, specifically, it may be used to illustrate the wave action produced in a long object by a force suddenly applied at one end. In his book "Theory of Elasticity" (McGraw-Hill, 1944) Timoshenko showed how the wave equation might be used to calculate longitudinal wave action in a uniform beam.

Furthermore, the idea of applying the wave equation to pile driving is not new. In 1940 and in 1941, A. F. Cunnings referred to the subject, and credited D. V. Isac of Australia with being, in 1931, the first to suggest its application to pile driving. Cunnings also stated that the British Building Research Board in 1938 demonstrated that the behavior of full sized piles under actual field conditions can be predicted by means of the wave theory.

Yet, the wave theory has not, until very recently, been applied to pile driving. The reason for this is simple, and was given by Cunnings - the calculations involved were too difficult. As given by Timoshenko, the wave equation:

$$\frac{\partial^2 u}{\partial t^2} = c^2 \frac{\partial^2 u}{\partial x^2}$$

is a second order partial differential equation. For very simple cases, as
when a known force is suddenly applied at one end of a uniform steel rod, the 
equation can be solved by ordinary 
calculus. But when the equation is 
complicated by considerations of the 
actions of the ram, the cap block, the 
pile, and the ground, the problem 
becomes so difficult that no one has been 
known to solve it.

- Computers to rescue—However, the 
picture has been changed in the last 
few years by the development of elec-
tronic digital computers such as the 
Sperry Rand "Univac" and the IBM 
"704," Not only can these machines 
solve the wave equation as applied to 
pile driving—but they can do it in a 
matter of seconds.

The Raymond Concrete Pile Co., 
working in conjunction with IBM, has 
made over 250 such computations in-
volving various combinations of pile 
and hammer types. The mathematical 
methods used have been checked in 
ways and proved reliable. From 
the results of these calculations, the 
writer will draw some conclusions, sub-
ject to the following qualifications:

1. The importance of variations in 
ground characteristics as explained in 
a previous paragraph must be con-
sidered as a limiting factor in arriving 
at definitive conclusions.

2. In applying the wave theory to 
pile driving, it is possible, with the 
computers, to include side friction as 
part of the calculation and in the im-
mediate future this will be done, but 
thus far the calculations have been 
made on the basis of an end bearing 
pile with no side friction.

It is not the intent of the writer 
to offer a new and different pile for-
nuila. The problem is far too compli-
cated to be expressed accurately by 
a single reasonably simple formula. Pos-
sibly a formula could be devised with 
certain constants that would be 
changed to suit different types of driv-
ing conditions, but, for now at least, 
the results of the calculations are pre-

cented only in graph form.

- Conclusions—Graph No. 1 shows 
ultimate driving resistances for various 
lengths and weights of straight-sided 
steel piles driven with a No. 1 Vul-
now it can be told

V. Hiley formula and the wave equation for No. 7, George Monopol.
In general the wave equation the Hiley formula is 1.5 times as for a light pile of 3.
by No. 4 and No. 7 show that the wave equation as the Hiley formula is 3.36 times as
it disagrees with the wave formula No. 4 shows that the wave equation of maximum pile action
for a light pile is entirely inaccurate. This is the condition shown in
Eq. No. 5. However, it is
not true in the case that the case for that it is possible to the pile to be in compres
section. It is possible to the pile to be in compres
section. It is impossible to the rest of the pile is actually
section. This is very different from
assumption.

No. 7 shows a comparison on
a site load basis between the wave
equation with a factor of safety of 3
and certain formulas employing the
recommended or usual factors of safety.

From all these data it must be con-
cluded that the Hiley formula tends to
denature the heavy or long pile and to
favor the light and short pile. This
corresponds because the Hiley for-

mula is shown by the Wave Equation
calculations to contain incorrect as-
sumptions as follows:

1. It assumes that the compression
depth, the compression of the full length of the pile, and the elastic
compression of the ground all occur
at one and the same instant of time.
This is reasonably accurate for a light
pile, but inaccurate for a very heavy
pile.

2. It assumes that the percentage of
energy transmitted from the hammer
to the pile is dependent on the relative
weights of the ram and the entire pile.
This assumption is reasonably accurate
for a short pile, but inaccurate for a
long pile.

pile formulas that have been proposed
and used. No one of them can be ac-
curate for all types and lengths of piles
because they all fail to consider the
effects of wave action. The newly ac-
quired ability to solve the wave equa-
tion as applied to pile driving offers a
means of obtaining a truly mathemati-
cal solution.

In due course it is expected that ad-
ditional calculations will be made cov-
ing a variety of hammer and pile types,
and that the results will be published
in the form of tables, resembling
logarithmic and trigonometric tables.
Meanwhile, it is hoped that the graphs
here presented will prove both infor-
mativ and provocative.

Compliments of

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