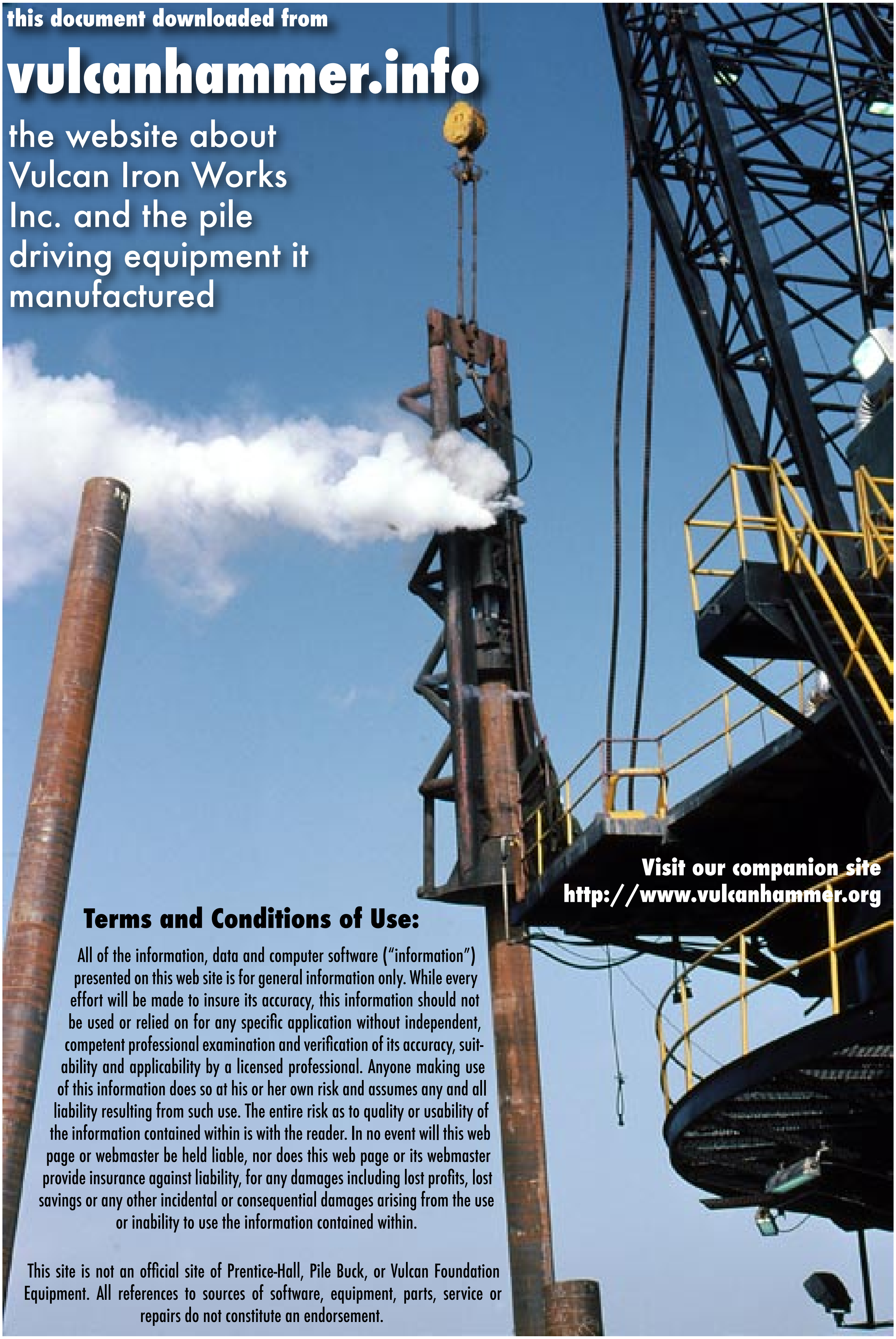

AN INVESTIGATION OF PILE DRIVING AT THE POINT VS. AT THE HEAD OF LONG OFFSHORE PILES

by

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ABSTRACT

An investigation of driving large offshore piles at the point versus driving at the head of the pile is presented in this paper. The effects of varying cushion stiffness and of multiple hammer blows are also shown. Results indicate that no increased driving ability may be expected by changing the hammer position from the head to the point.

For the pile systems, soil conditions, and hammer used in this study, it was found that increasing cushion stiffness increased the driving ability but that multiple hammer blows had little effect on driving the pile.

These results and comparisons should be of value to present day offshore oil drilling industries anticipating larger platforms in deeper water locations.

INTRODUCTION

A great amount of work has been done in the past concerning the dynamics of pile-driving. Increasing demands of the present day offshore oil industry have necessitated construction of larger platforms in deeper water, prompting the following studies:

1. A comparison of driving a large offshore pile at the point of the pile with the usual method of driving at the head.
2. The influence of capblock stiffness variation on the ability to drive the pile.

THEORY

The method of analysis used for this study was the application of the one-dimensional wave equation, first successfully accomplished by Smith (1), and now generally used for dynamic analysis of pile driving. Later improvements were presented by Samson, Hirsch, and Lowery (2). Both methods idealize the pile system as consisting of a ram (hammer), capblock (cushion), pile cap, pile, and surrounding soil, all modeled by discrete weights and internal-external springs. The pile is appropriately divided into a set of elements represented by mass and stiffness parameters with frictional soil resistance provided by a series of side springs plus a single point resistance spring.

A detailed explanation of the wave equation method is presented in the references. The computer code developed at Texas A & M University by Lowery (3) was used to perform the numerical calculations for this study.

EXPERIMENTAL METHOD

Various computer runs were executed with the hammer positioned at either the head of the pile or at the point of the pile. The effect of using a soft (asbestos) cushion versus a hard (Bongassi hardwood) cushion was investigated, providing a second variable condition. Several long runs were made to determine the validity of the Smith approximation of permanent set (maximum displacement minus a set value of soil quake). Possible effects of multiple hammer blows were studied by rehitting the pile three times in succession during a single computer run.

PILE SYSTEM DATA

(see figure 1)

Hammer: Vulcan 060, Weight = 60 kips
Energy = 180 kip-ft.
Stroke = 3 ft.
Velocity = 12.4 ft./sec.
Efficiency = 80%

Cushion: (1) Asbestos K = 1769.8 kips/in. (soft)
E = 40.0 ksi.
(2) Bongassi K = 10578.8 kips/in. (hard)
E = 239.1 ksi.

Capblock: Steel, Weight = 40.18 kips

Pile: Steel, Diameter = 54 in.
Wall thickness = 2 in.
Total length = 300 ft.
Penetration = 200 ft.
Element length = 10 ft.
Element weight = 11.1 kips
Element K = 81680 kips/in.

Soil: Clay, Quake = 0.1 in.
Soil damping constants:
J_s = 0.2 sec./ft. (shear on side of pile)
J_p = 0.01 sec./ft. (point compression)
RUP - 10% of RUT
where RUT = Total static soil resistance on pile
and RUP = Static soil resistance on pile point.

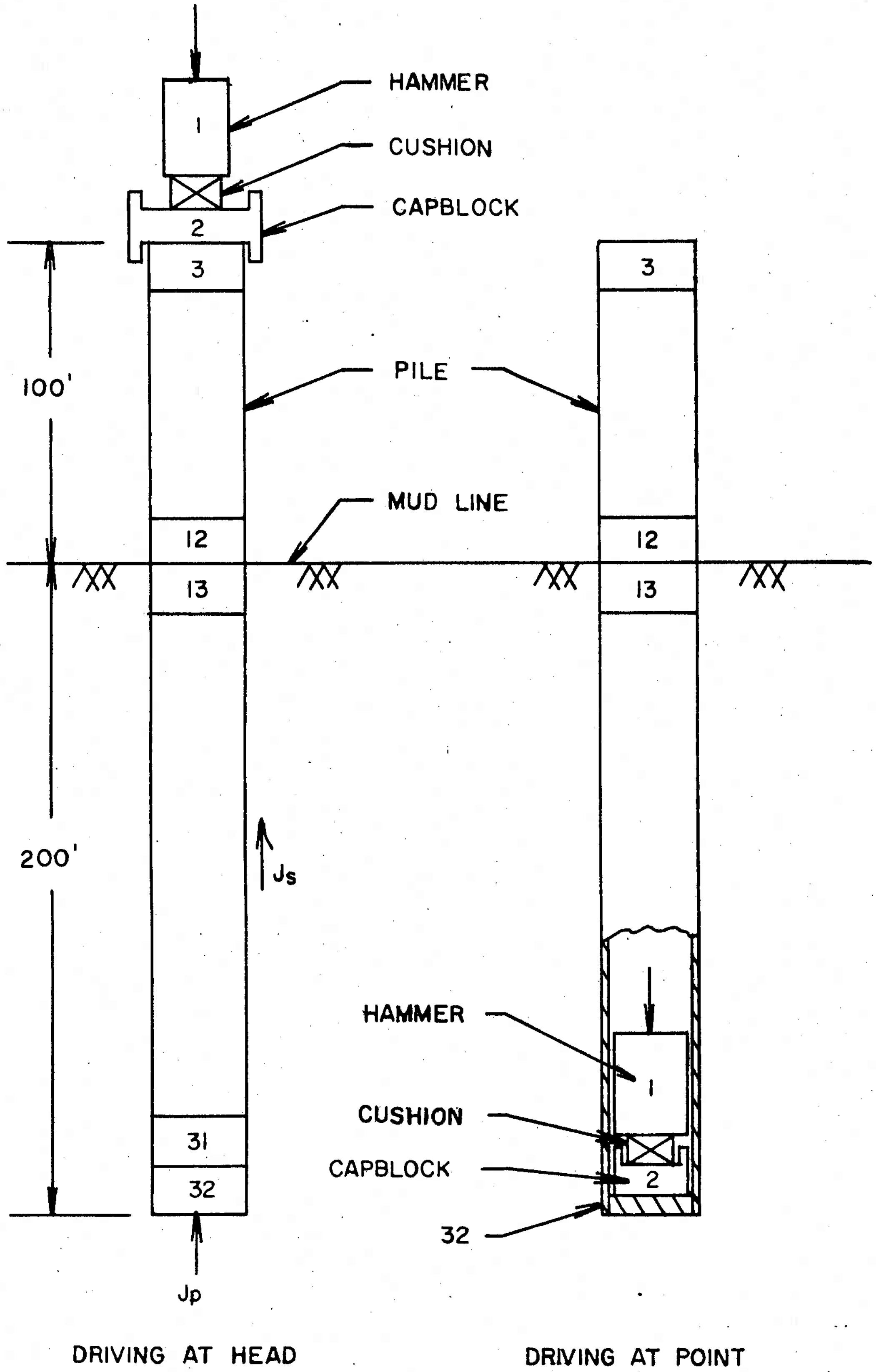


FIG. I MODEL OF PILE SYSTEM

DISCUSSION OF RESULTS

The computer code by Lowery (3) has the capability to simulate driving a pile with the hammer and driving accessories positioned at other than the pile head, such as at the point of the pile as has been done for this study. With the given input data for the hammer and pile systems, computer runs were made for driving at the head and at the point of the pile using both asbestos and bongassi cushions for several different soil resistances. Plots were then made showing driving ability versus soil resistance as shown in figures 2 and 3. The soil resistance value represents the total static soil resistance at the time of driving. The Smith method of approximating permanent set as maximum displacement minus a value of quake was used for a set of regular runs. A second set of long runs were made to determine the validity of the Smith approximation. For these long runs, the pile displacements were allowed to settle out so that the final displacement value could be taken directly as the permanent set of the pile. The time-displacement records of these runs are shown in figures 4 and 5 along with a comparison with the permanent set as computed by the Smith approximation.

The use of the Smith approximation for permanent set, maximum point displacement minus quake, has been shown in the past to be valid when piles are hit at the head. Care must be taken, though, when the pile is driven with the hammer at the point. For that case, the maximum mudline displacement must be used instead of the point displacement to avoid the effects of tension elongation of the pile below the mudline when hit at the point. Otherwise, the pile will seem to drive better at the point than at the head (for a single blow only) when actually the pile is only being elongated below the mudline and not

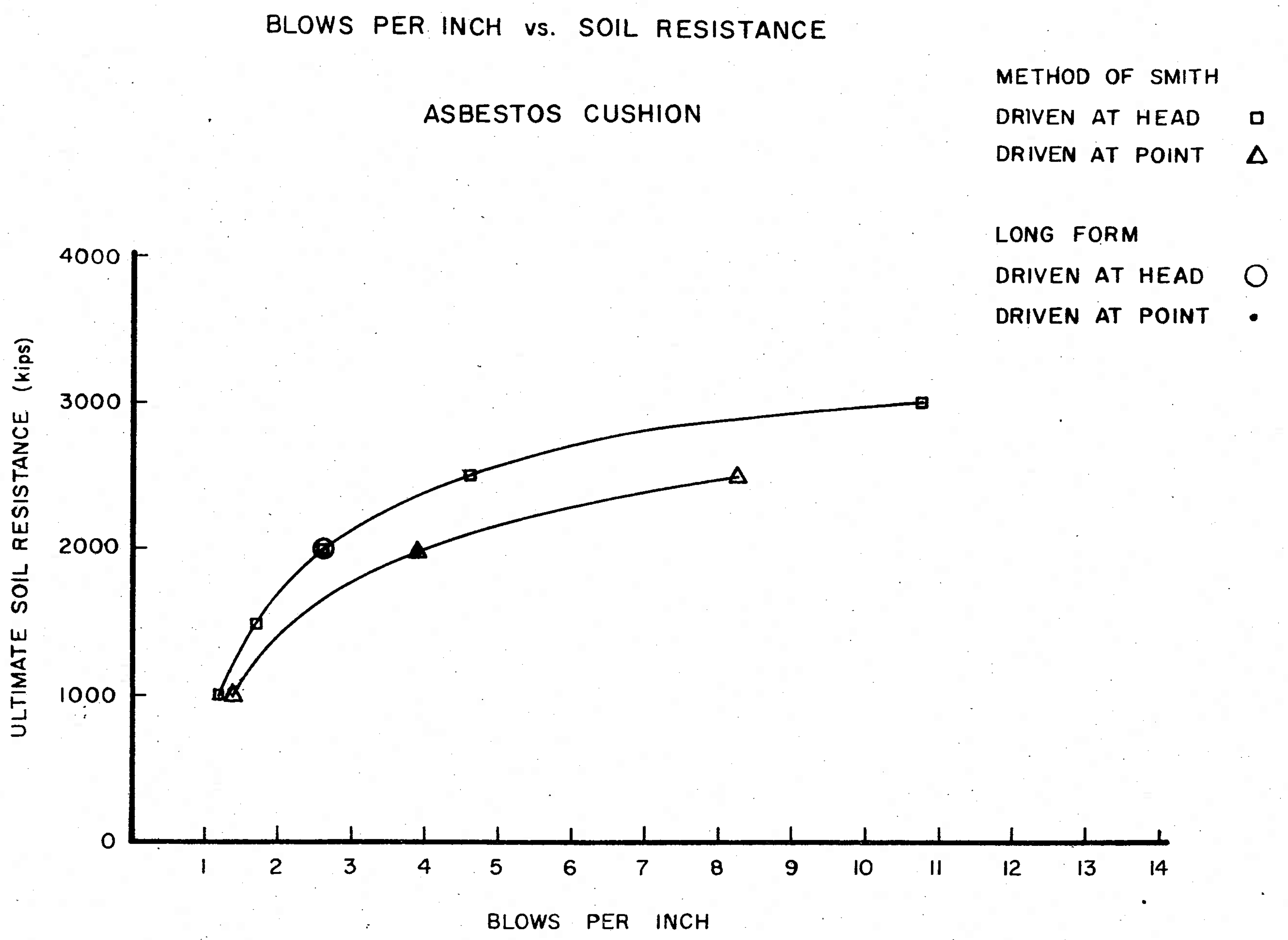

BLOWS PER INCH vs. SOIL RESISTANCE
ASBESTOS CUSHION
METHOD OF SMITH
DRIVEN AT HEAD
DRIVEN AT POINT
LONG FORM
DRIVEN AT HEAD
DRIVEN AT POINT
ULTIMATE SOIL RESISTANCE (kips)
4000
3000
2000
1000
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
BLOWS PER INCH

FIG. 2

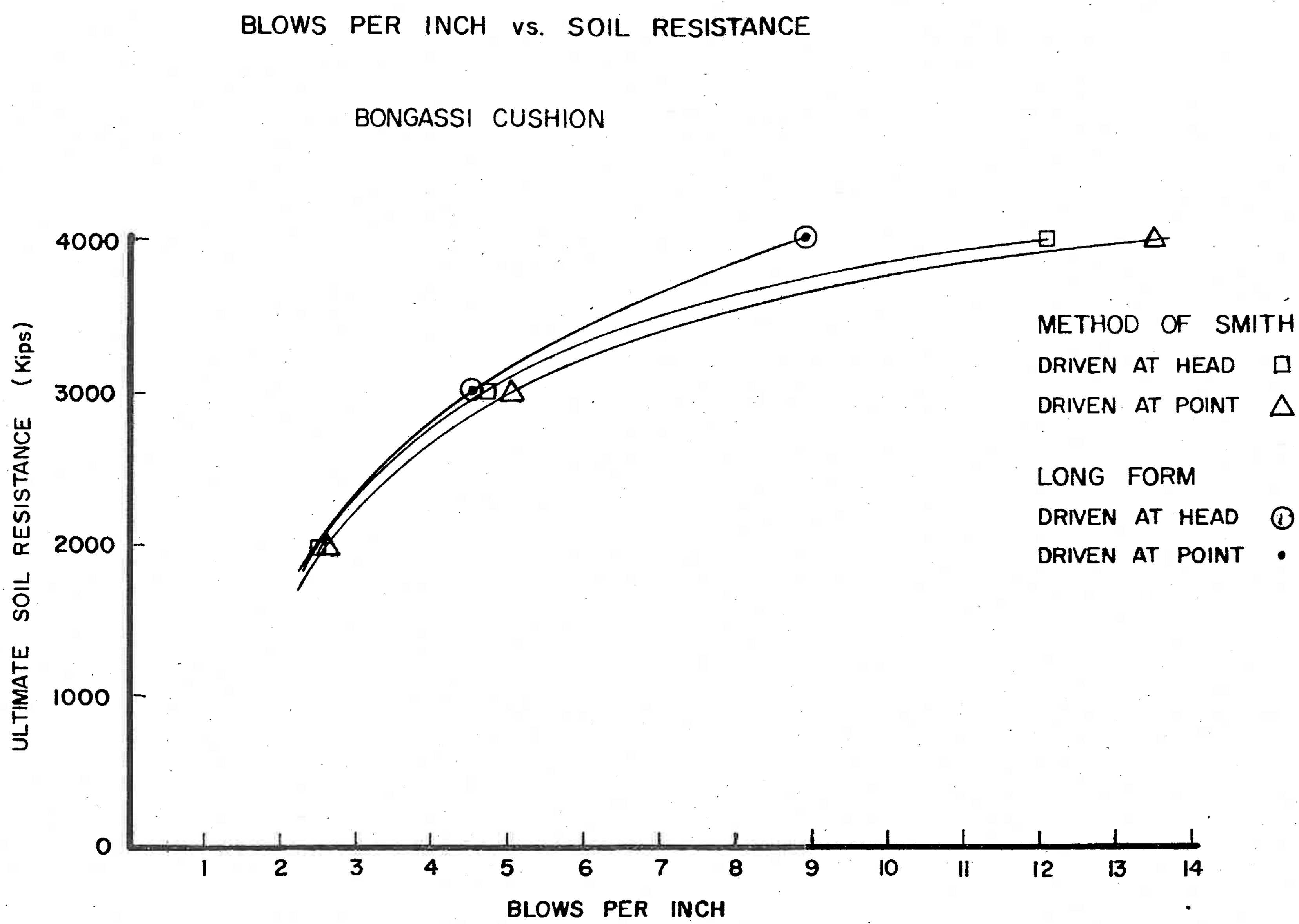

BLOWS PER INCH vs. SOIL RESISTANCE
BONGASSI CUSHION
ULTIMATE SOIL RESISTANCE (Kips)
4000
3000
2000
1000
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
BLOWS PER INCH
METHOD OF SMITH
DRIVEN AT HEAD
DRIVEN AT POINT
LONG FORM
DRIVEN AT HEAD
DRIVEN AT POINT

FIG. 3

PLOT OF POINT DISPLACEMENTS vs. TIME

PILE DRIVEN AT HEAD

ULTIMATE SOIL RESISTANCE = 4000 kips

BONGASSI CUSHION

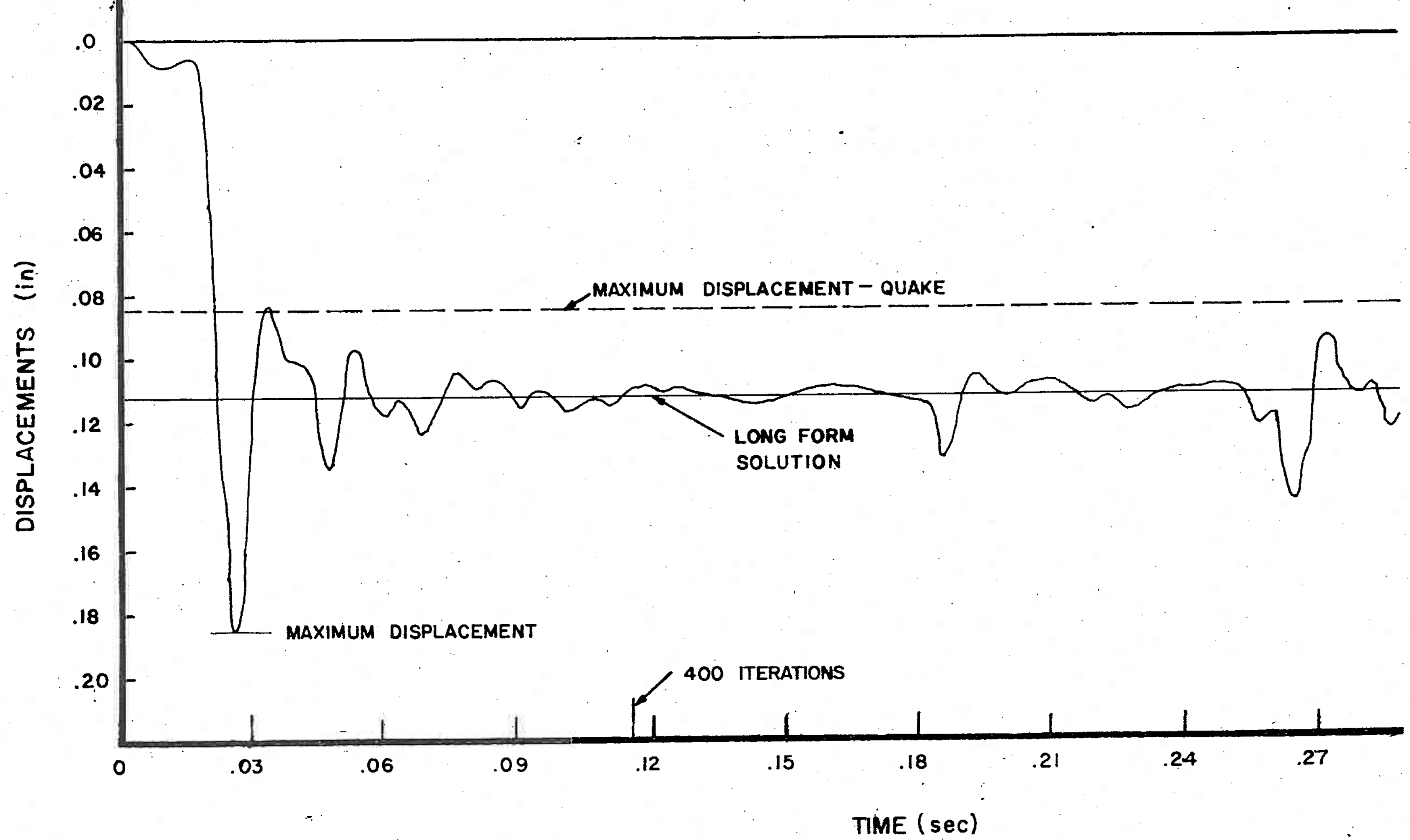


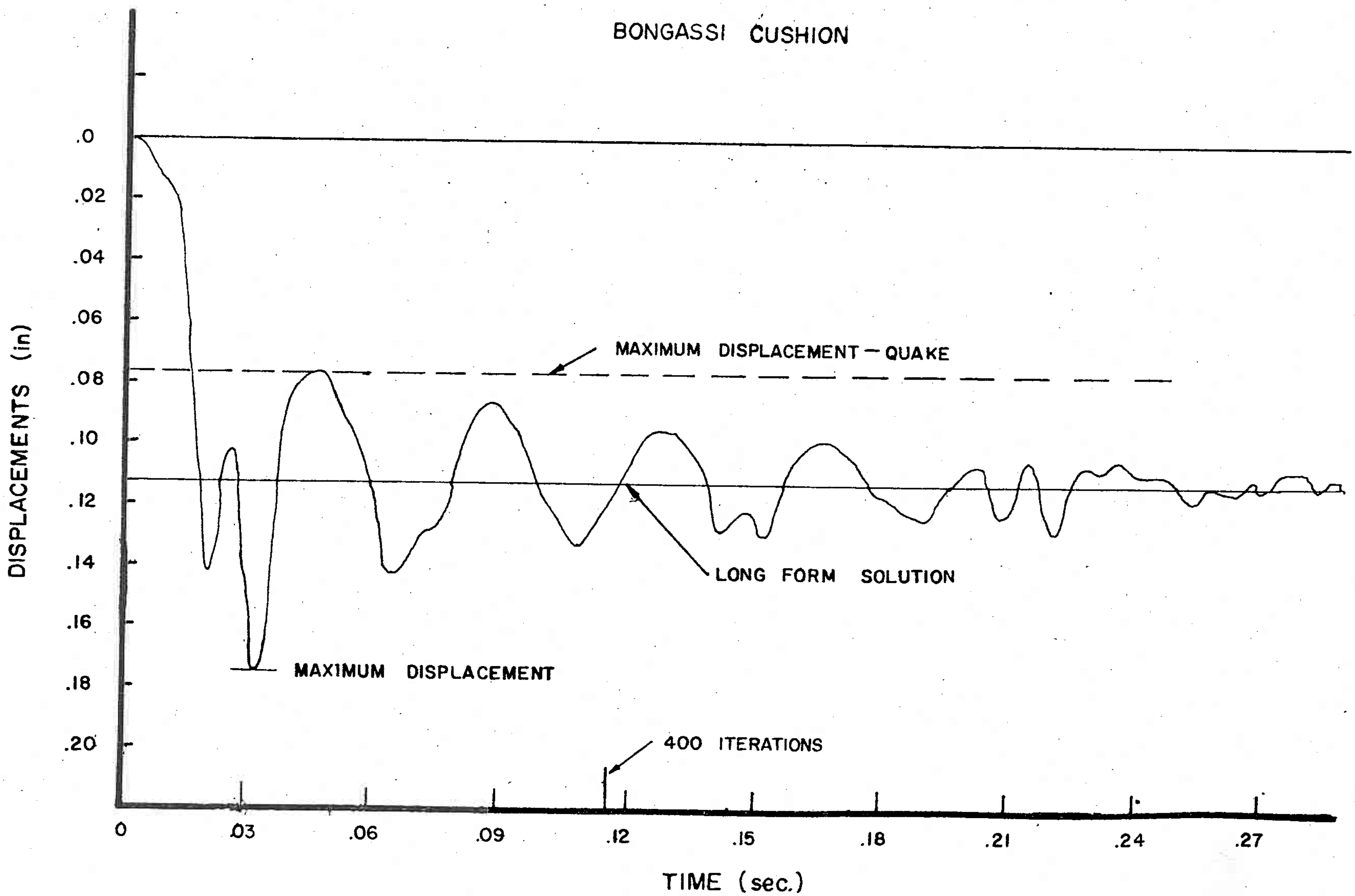
FIG. 4

PLOT OF MUD LINE DISPLACEMENTS vs. TIME

PILE DRIVEN AT POINT

ULTIMATE SOIL RESISTANCE = 4000 kips

BONGASSI CUSHION



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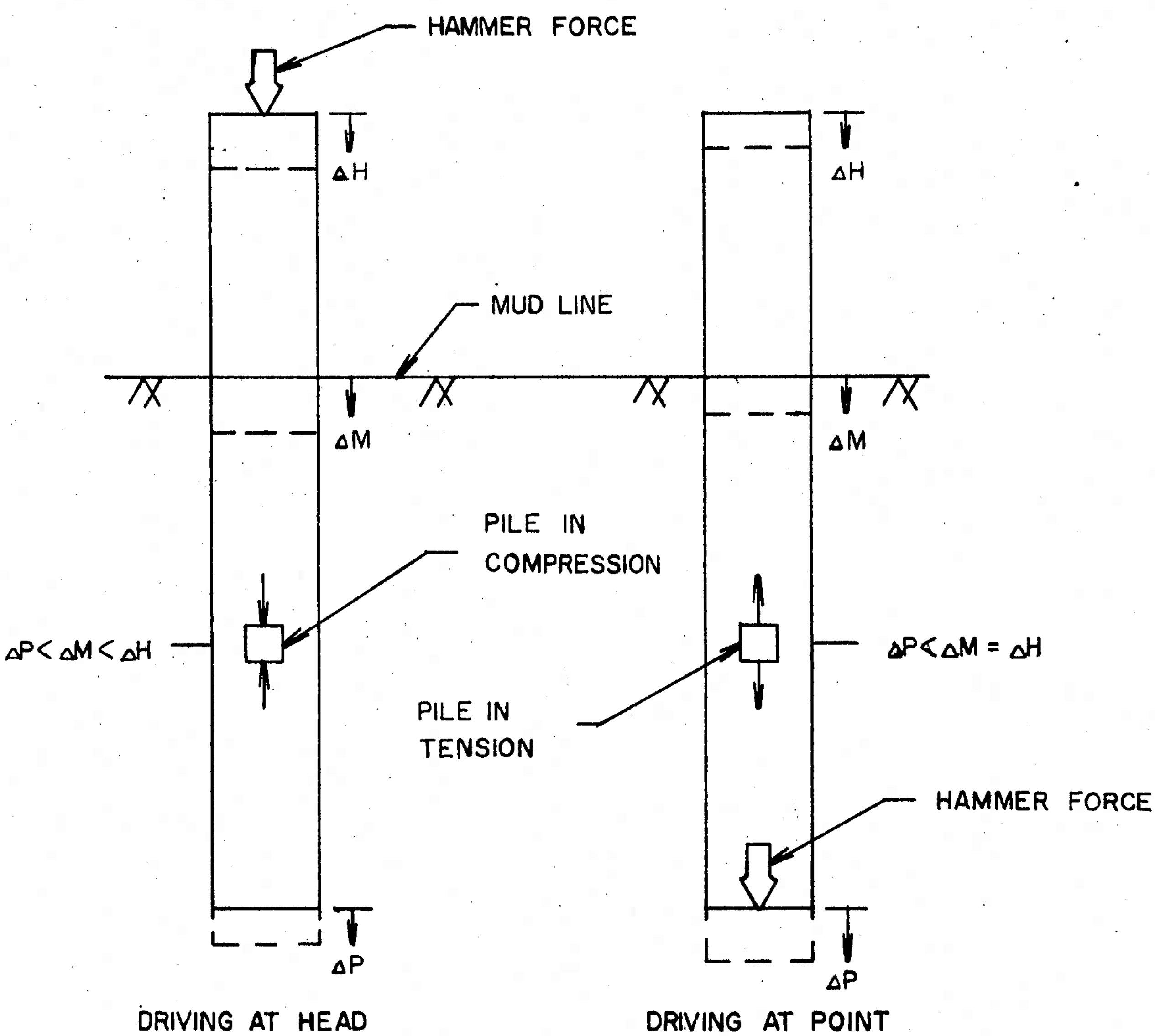
being displaced as much at the head or mudline, where it really counts. This effect is shown schematically in figures 4, 5, and 6. The resulting data is plotted on figure 2, driving ability versus driving resistance. The data using the Smith method and the data from the long runs plotted up very closely except near refusal.

For all cases run, the effect of gravity was included with care taken to initialize the displacements of each of the masses in the system to zero at time zero to prevent fictitious initial stresses in the pile.

Very little difference was observed between driving at the point of the pile or at the head using the bongassi cushion. Driving at the head, however, appeared definitely better using the asbestos cushion. It was also noted that the driving ability for this soil condition and pile was improved considerably when using the bongassi cushion as compared to the asbestos cushion as can be seen comparing figures 2 and 3.

For a more complete comparison of the pile driving systems, the effect of multiple hammer blows was added to the investigation. To determine the best compatible time computer-wise for applying the second and subsequent hammer blows, long runs were made with the pile being hit at the head and at the point. It was found that the pile displacements damped out fairly well at approximately 400 iterations for both cases, as shown in figures 4 and 5. Multiple hammer blow runs were made rehitting the pile at 400 and 800 iterations. Displacement versus time curves are given in figures 7, 8, and 9, showing very little effect of multiple hammer blows. It had been feared that the residual stresses induced in the portion of the pile below the mudline might have greatly affected the results of subsequent blows. However, as shown in figure 9, the mudline displacements for the pile driven at the point were almost the same as the point displacements



ΔH = MAXIMUM DISPLACEMENT AT HEAD

ΔM = " " " MUD LINE

ΔP = " " " POINT

FIG. 6

PLOT OF POINT DISPLACEMENTS vs. TIME FOR PILE HIT THREE TIMES IN SUCCESSION

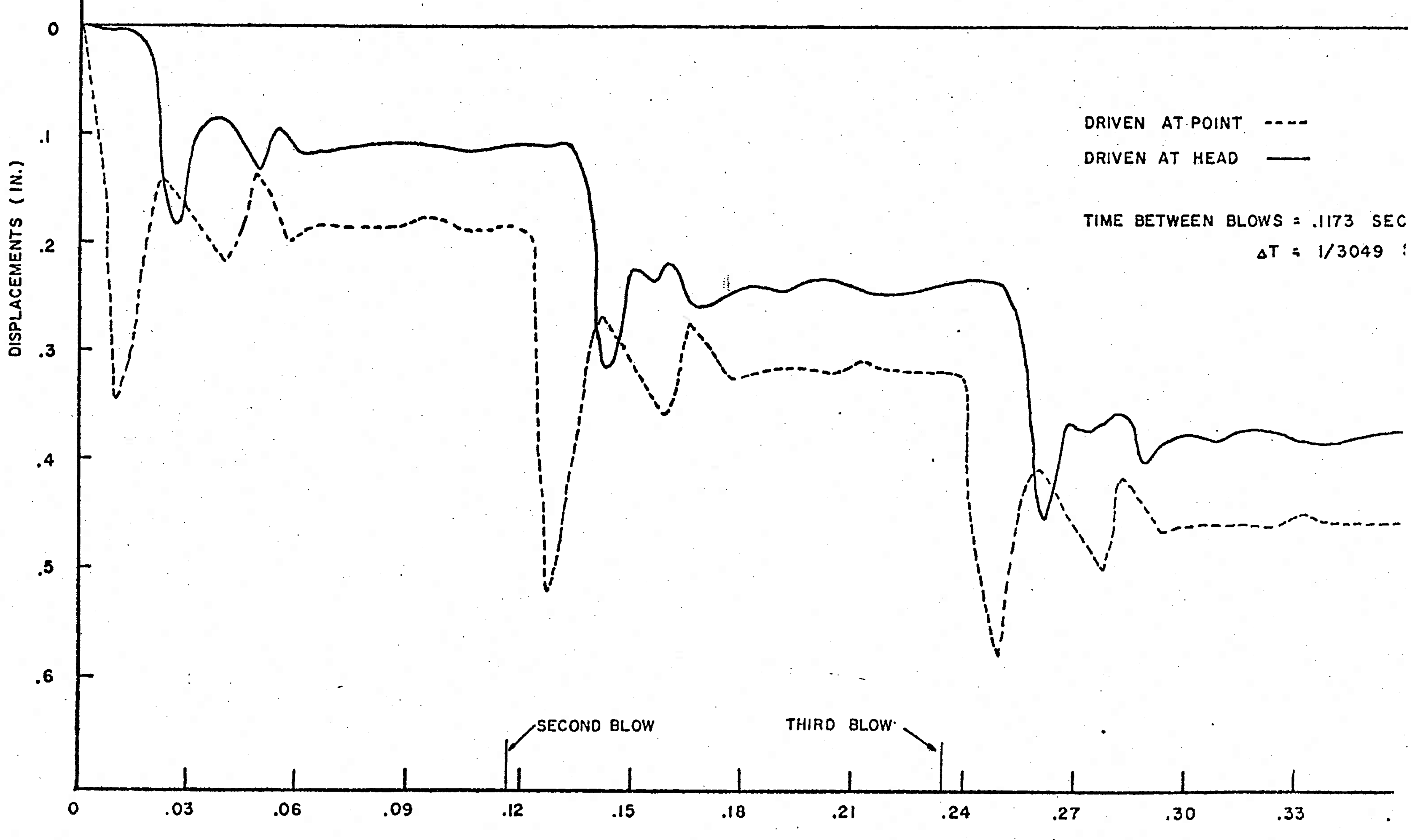


Fig. 7

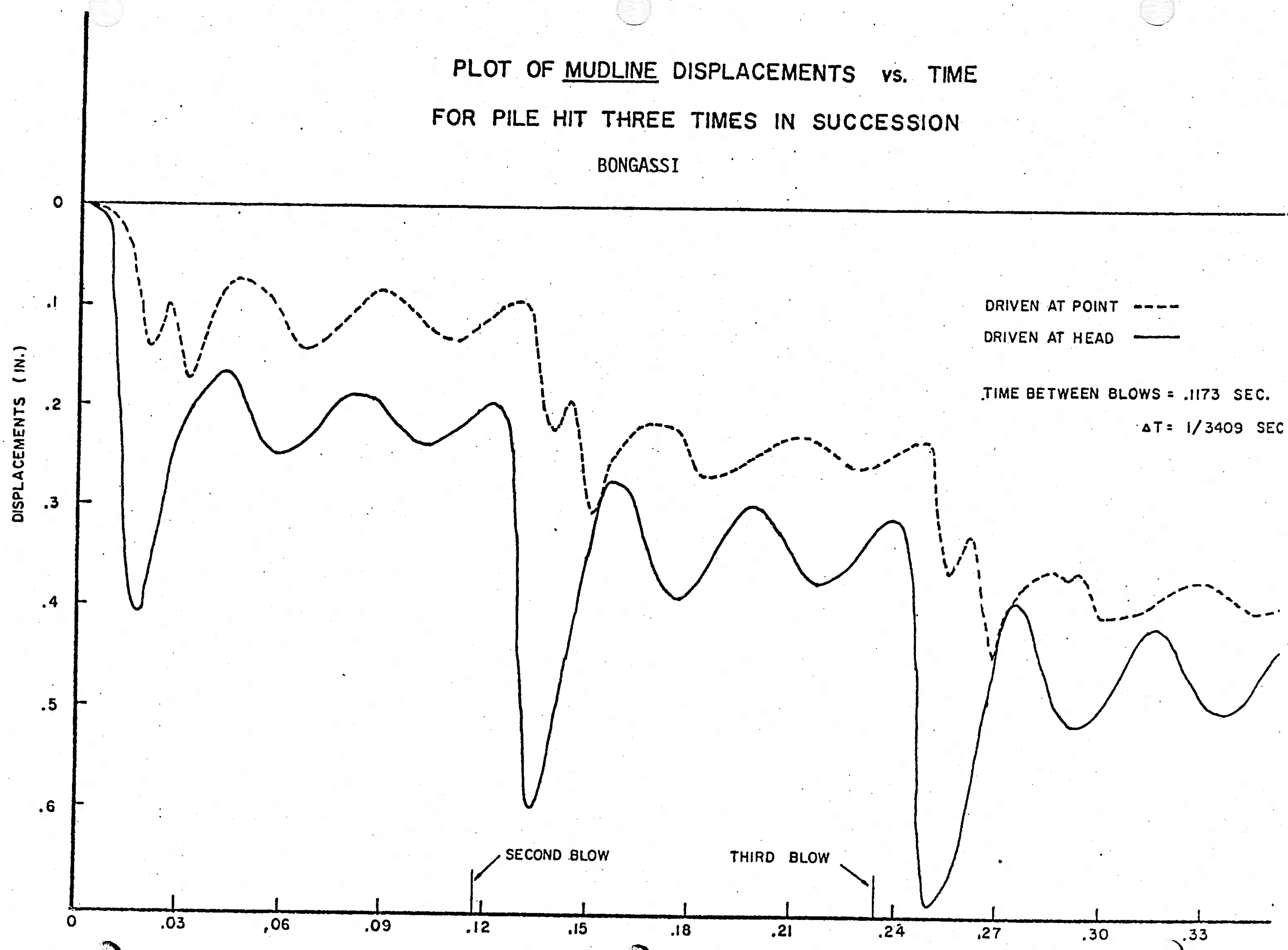

PLOT OF MUDLINE DISPLACEMENTS vs. TIME
FOR PILE HIT THREE TIMES IN SUCCESSION
BONGASSI
DRIVEN AT POINT
DRIVEN AT HEAD
TIME BETWEEN BLOWS = .1173 SEC.
ΔT = 1/3409 SEC
DISPLACEMENTS (IN.)
0
.1
.2
.3
.4
.5
.6
SECOND BLOW
THIRD BLOW
0
.03
.06
.09
.12
.15
.18
.21
.24
.27
.30
.33
(SEC.)

Fig. 8

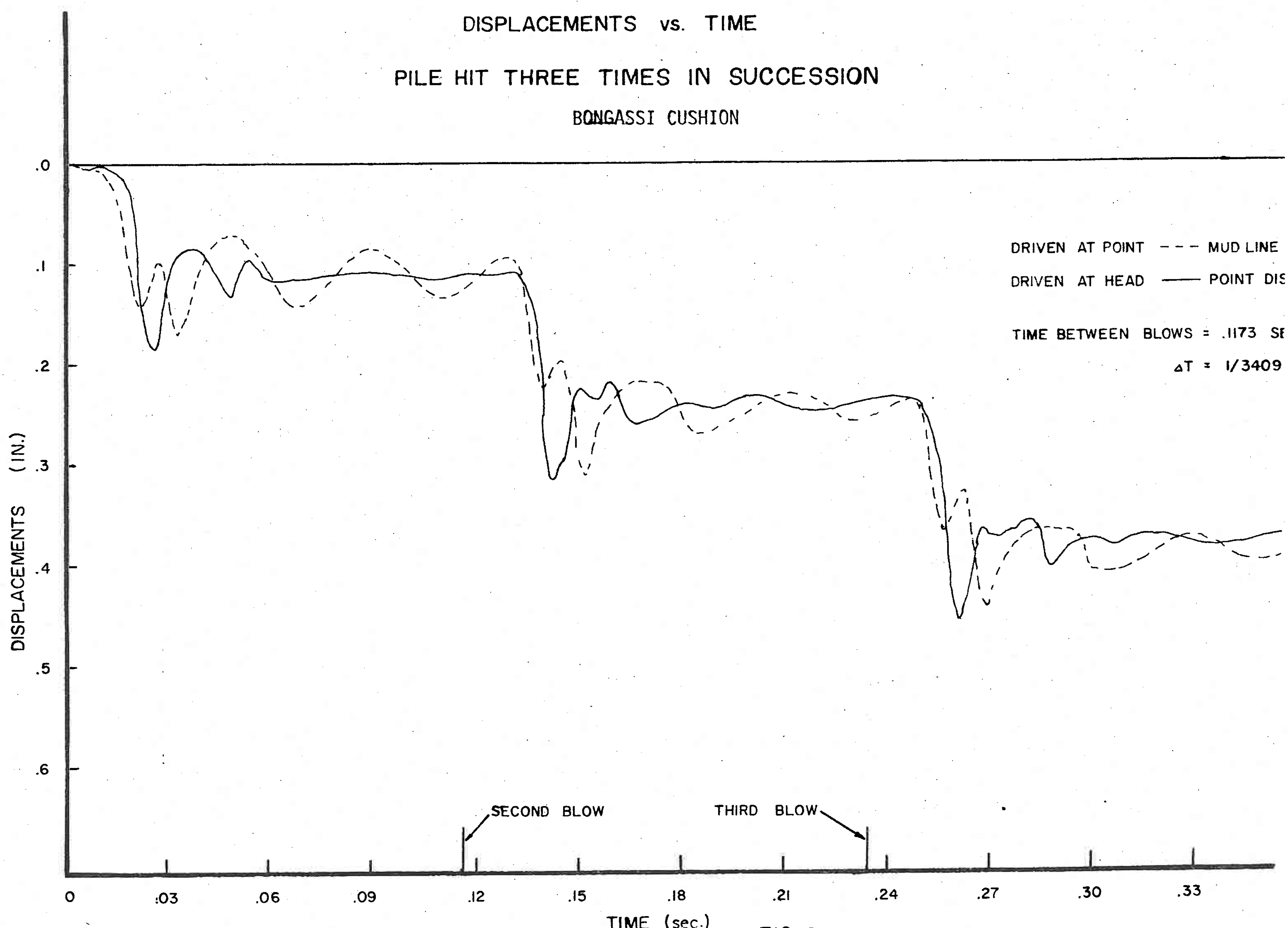

DISPLACEMENTS vs. TIME
PILE HIT THREE TIMES IN SUCCESSION
BONGASSI CUSHION
DRIVEN AT POINT - - - MUD LINE
DRIVEN AT HEAD —— POINT DIS
TIME BETWEEN BLOWS = .1173 SE
ΔT = 1/3409
DISPLACEMENTS (IN.)
.0
.1
.2
.3
.4
.5
.6
SECOND BLOW
THIRD BLOW
0
.03
.06
.09
.12
.15
.18
.21
.24
.27
.30
.33
TIME (sec.)

FIG. 9

for the pile driven at the head, other parameters being the same. For that comparison, the effects of tension in the point-driven pile and of compression in the head-driven pile were both considered. Thus, theoretically, driving at the point and at the head could have identical results.

CONCLUSIONS

The wave equation analysis of pile-driving has been utilized in this study to determine whether it would improve the ability to drive long offshore piles by driving at the point of the pile rather than at the head as is the usual case at the present time. For the pile systems, soil conditions, and hammer assumed in this investigation, the following conclusions have been reached:

1. No benefits in increased driving ability may be obtained by driving at the point of the pile rather than at the head for either soft or stiff cushions.
2. Increasing the stiffness of the capblock cushion increases the ability to drive the pile although the stiffness should be kept within reasonable limits to prevent high driving stresses in the pile.
3. The effects of multiple hammer blows on the pile are negligible. Although the driving ability may not be increased by placing the hammer at the point of the pile instead of at the head, other possible advantages of point-driving may be considered, such as the ability to drive piles during bad weather conditions.

REFERENCES

1. Smith, E. A. L., "Pile-driving Analysis by the Wave Equation", Transactions, ASCE, no. 3306, Vol. 127, 1962, pp. 1145-1193.

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