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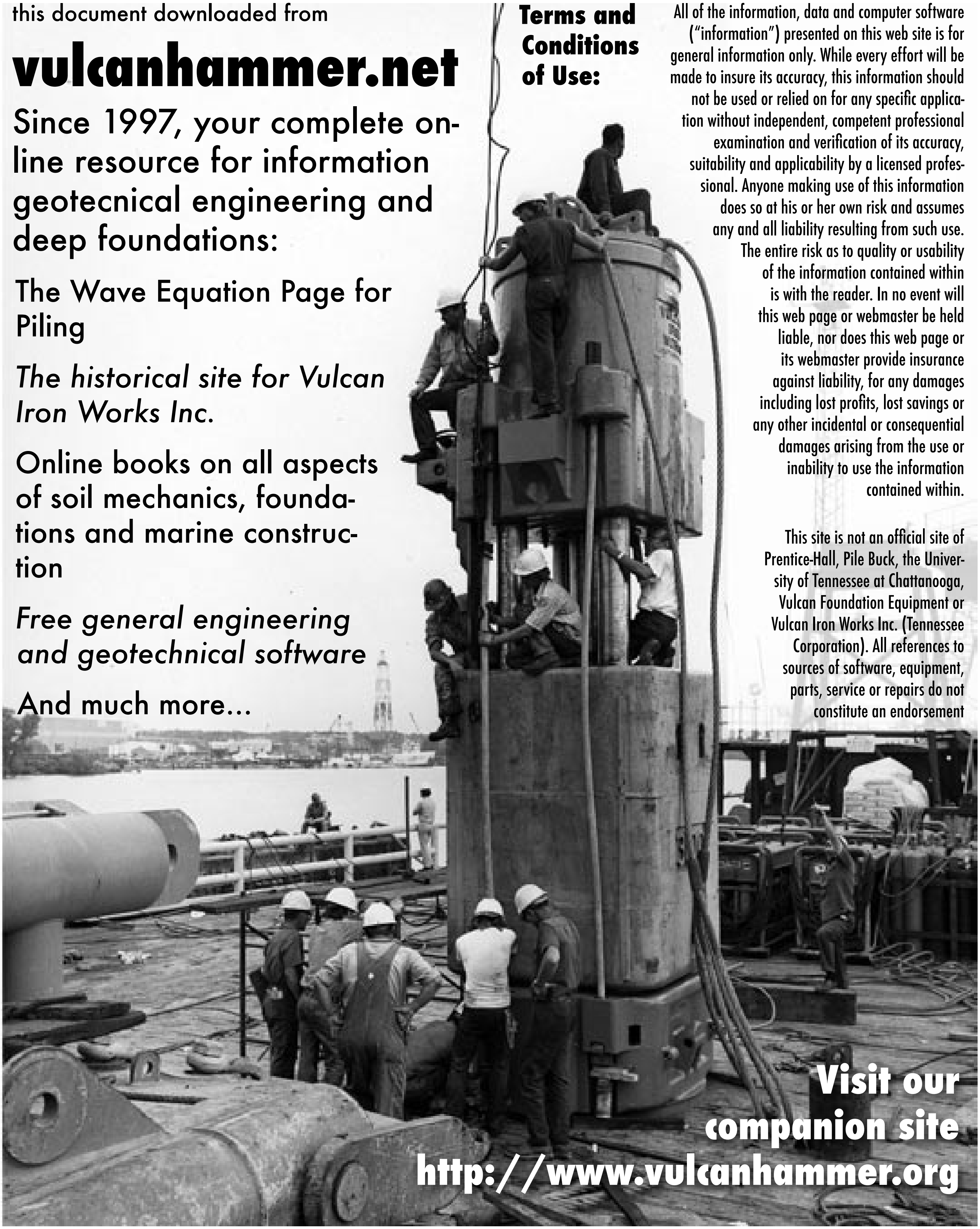

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CATEGORY B

ELECTRONIC COMPUTER PROGRAM ABSTRACT

TITLE OF PROGRAM WESWEAP -- Wave Equation Analysis for Piles	**PROGRAM NO.** 741-F3-R0010

PREPARING AGENCY U. S. Army Engineer Waterways Experiment Station, Geotechnical Laboratory, P. O. Box 631, Vicksburg, MS 39180

AUTHOR(S)	**DATE PROGRAM COMPLETED**	**STATUS OF PROGRAM**	
		PHASE	**STAGE**
G. G. Goble and Frank Rausche WES Contact: Hugh M. Taylor, Jr.	July 1976	INIT	OP

A. PURPOSE OF PROGRAM

The program performs wave equation analysis of piles driven by a single blow of any type of impact hammer. Conventional pile and soil models were used in addition to both a thermodynamic model for diesels and refined mechanical hammer models. The program can be used to predict impact stresses in piles during driving and to estimate static soil resistance on piles at the time of driving.

B. PROGRAM SPECIFICATIONS

The program development was aimed at providing a simple input and both a flexible and extensive output that include automatic plotting capabilities. The computer language is FORTRAN IV.

C. METHODS

The pile and driving systems are represented by a series of discrete masses and springs. The soil is modeled by a spring and a dashpot attached to each mass. The soil resistance so represented are linear elastic plastic. The elastic resistances are linearly proportional to the element velocity for the velocity. By using Newton's Second Law, accelerations and displacements are calculated and the computation proceeds to the next time increment.

D. EQUIPMENT DETAILS

E. INPUT-OUTPUT

A short input and long or complete input forms are available. Common hammer property data are stored in a file. Input data is reprinted, options of printed and plotted parameters are available, and time plots are optional.

F. ADDITIONAL REMARKS

Manuals by the Federal Highway Administration that describe this program and its use are: Vol. I, Background, Report No. FHWA-IP-76-14.1; Vol. II, Users Manual, Report No. FHWA-IP-76-14.2, Vol. III, Program Documentation, Report No. FHWA-IP-76-14.3; and Vol. IV, Narrative Presentation, Report No. FHWA-IP-76-14.4.

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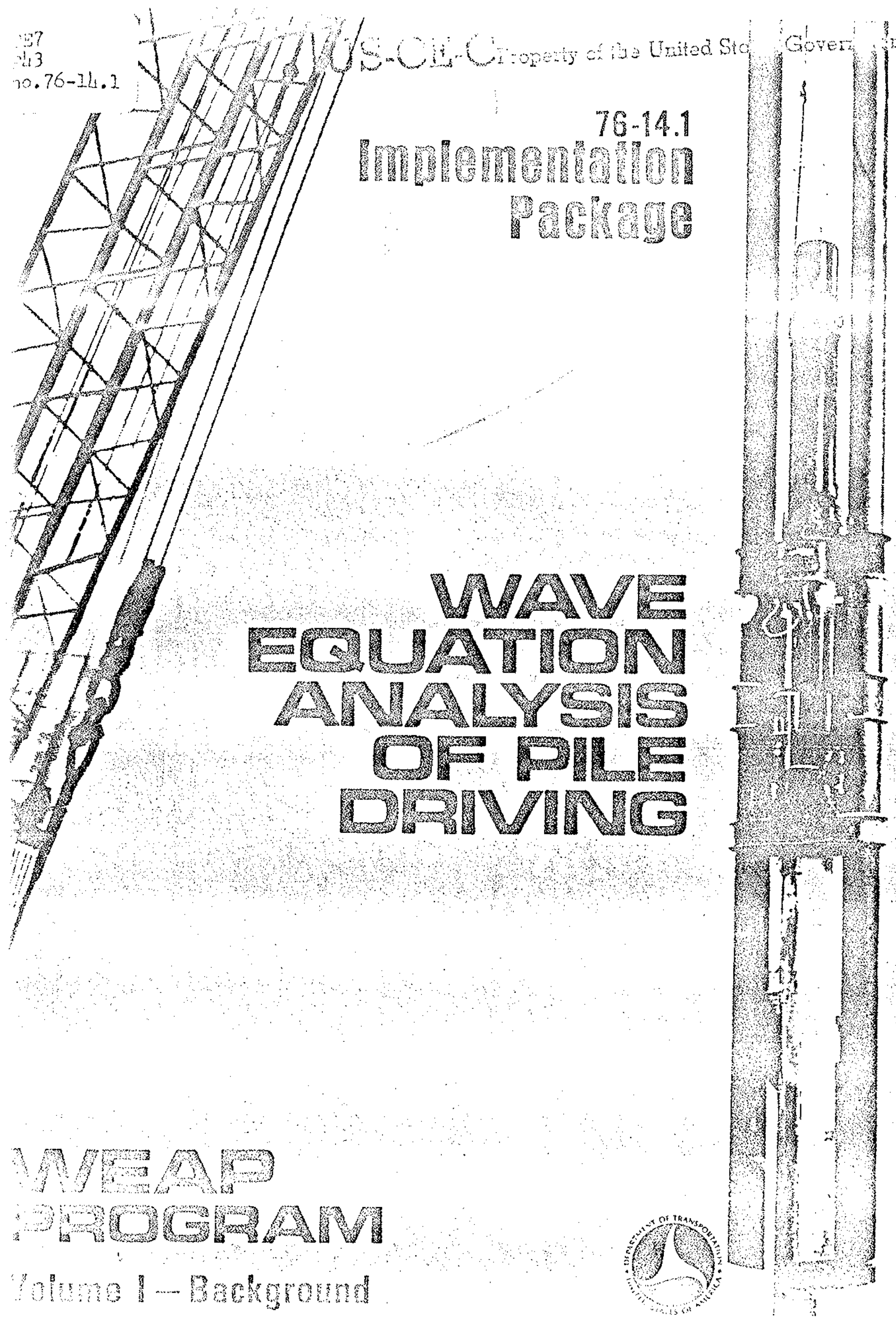

76-14.1
Implementation Package

WAVE EQUATION ANALYSIS OF PILE DRIVING

WEAP PROGRAM

Volume I — Background

U.S. DEPARTMENT OF TRANSPORTATION
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16. Abstract

A computer program was written and tested that performs a realistic Wave Equation Analysis of Piles driven by any type of impact hammer. Conventional pile and soil models were used in addition to both a thermodynamic model for diesel and refined mechanical hammer models.

The program development was aimed at providing a simple input and both a flexible and extensive output that includes automatic plotting capabilities. Pile Driving Hammer data were prepared and stored in a file for most of the commonly encountered models. The computer language is FORTRAN IV.

The program was extensively tested against measured pile top force and velocity data and against measured diesel combustion pressure and stroke.

This volume is the first in a series. The others in the series are:

Vol. No.	FHWA No.	Short Title	NTIS(PB) No.
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3	IP-76-14.3	Program Documentation	
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PREFACE

During the past 15 years wave equation computer programs have enjoyed a gradual but continual increase in use for the analysis of pile driving. The motivation for the preparation of the WEAP program (Wave Equation Analysis of Piles) came from problems which were experienced by the New York Department of Transportation when they attempted to implement routine wave equation analyses into their pile driving practice. They used a program prepared by the Texas Transportation Institute. In spite of the fact that this program is probably the most widely used wave equation program in the United States, serious difficulties were encountered in that unrealistic stresses were sometimes obtained for piles driven by diesel hammers.

The authors of this report have performed extensive research studies on pile driving emphasizing the measurement of force and acceleration during driving. These measurements involving piles driven by all types of hammers have been made for several states including New York. In order to take advantage of these measurements the Federal Highway Administration contracted with the authors to prepare a wave equation program which would accurately model the diesel hammer. Several years have passed since the TTI program was developed, so it could be expected that other general improvements could be introduced into the program for all types of hammers. Finally the large volume of available measurements of force and acceleration at the pile top were used to test the program performance. No currently available program has been subjected to such a demanding and thorough testing.

This report is presented in four volumes. The first presents a general discussion of the use of the wave equation and how this particular program models the hammer-pile-soil system. Emphasis is placed on a discussion of the operation of diesel hammers and how that operation is modeled by WEAP. The second volume provides a description of program input and output and can serve as a user's manual for the program. It is strongly recommended that all users read Volume I prior to the User's Manual so that they will understand the assumptions contained in the program and how it is intended that it be used. The third volume was prepared to aid the computer operator during the initial stages of program and data file loading. It also contains a flow chart which may be of interest to those users who want to study the program in greater detail. The fourth volume contains the three parts of a lecture which is also available in the form of a tape/slide show. The contents of this narrative report deal with background, models and applications of the Wave Equation.

ACKNOWLEDGEMENTS

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RESEARCH REPORT

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CHAPTER 1

INTRODUCTION

The purpose of this report is to describe the development, modeling and basic ideas behind a computer program called WEAP (Wave Equation Analysis of Piles) which was developed under contract with the Federal Highway Administration. This study was conducted to serve the following purposes:

(a) To produce a program for analyzing a pile driven by a diesel hammer using a thorough model of both the thermodynamic and mechanical hammer operation.

(b) To improve and refine existing techniques for wave analysis of piles driven by air-steam hammers.

(c) To study the performance of the program by comparing computed values of pile top force and velocity with those measured previously by the Case project (1)[+].

(d) To provide a program that requires minimal effort for the preparation of input data for "typical" cases and puts the volume of output information in the control of the user.

The wave equation concept is not new. Smith (2,3) first proposed the use of this discrete method for modeling the hammer-pile-soil system. Among the researchers that have further contributed to the advancement of the art are Forehand and Reese (4) and Samson et al (5). Probably the largest research efforts were made by the Texas Transportation Institute of Texas A&M University (6,7)* (TTI). The program versions that they created were pub-

---

* Only two of the large number of their reports are referenced here.

[+] Numbers in paranthesis pertain to references listed at end of text.

lished and made generally available in the United States.

When the TTI program was written, air-steam hammer operation was of primary interest and concern. Therefore, it is not surprising that results were much less satisfactory when diesel hammer systems were analyzed. Particularly the prediction of driving stresses for these cases has been found to be unsatisfactory by many program users.

Prior to the development of the WEAP program the performance of wave equation programs was tested either by analysis of simple cases where closed form solutions giving force-time relationships were available, or for real cases where the predicted capacity was compared so that measured in a static load test. Since only a few cases with oversimplified hammer systems can be solved in closed form, the primary testing was against load test results. Such a comparison involves only one parameter in a domain where more than twenty are unknown and must be found. To make matters worse, the system is non-linear and simplifying assumptions, interpolations and extrapolations do not always hold. Other problems such as time - dependent characteristics of the soil, numerical defects of the discrete model and inadequate soil modeling can also yield erroneous results. While large volumes of measurements have been published by the Case Research Project, apparently this data was not used to any substantial degree in checking the performance of other programs. One of the tasks of the project reported here was to subject the program to extensive testing by comparing measured and calculated force and velocity records at the pile tope for a wide variety of hammer and pile types.

As indicated above, the principal goal of this work was to improve analysis capabilities for diesel hammers. The WEAP program differs from the TTI program for diesel hammers in that, first, WEAP includes the determination of the gas pressure in the combustion chamber using a thermodynamic analysis rather than a constant, specified pressure and, secondly, the hammer stroke is calculated in the dynamic analysis rather than being specified in advance. Diesel hammers can operate at a wide variety of strokes that cannot be estimated in advance by intuitive means. Moreover, the hammer's effectiveness is strongly dependent on the stroke.

In Chapter 2 of this report the basic use of the wave equation is discussed. Real hammer performance is discussed in Chapter 3 and the model for hammer operation is described with emphasis placed on diesel hammers. The soil model is also described and an alternate approach to that used by Smith is presented. Some further elaboration on diesel hammer operation is contained in Appendix A.

The information necessary for the preparation of the program input data is described in Chapter 4 (and also in the User's Manual). Chapter 5 gives a general description of the program organization and flow. The extensive study of program performance which compares calculated and measured values of force and velocity for 17 different test piles is reported in Chapter 6. Chapter 7 gives some conclusions and recommendations.

CHAPTER 2

BASIC OPERATION AND USE OF THE WAVE EQUATION

For over 100 years foundation engineers have used dynamic formulas to estimate pile bearing capacity (or the inverse, to estimate the required blow count for a specified capacity). The use of these formulas has been severely criticized since all of them have been proven grossly inaccurate and unreliable. Their use persists in spite of the criticism because of their simplicity and the lack of something better. Also, some dynamic means of capacity prediction will continue to be required since pile design loads have tended to increase making static load tests increasingly difficult to perform.

In order to place the wave equation in context it is appropriate to review the use of a dynamic formula. Consider a typical example

$$R = \frac{2\ Wh}{S + C} \qquad (2.1)$$

where R is the design load, W is the ram weight, h is the ram stroke, S is the permanent set of the pile per hammer blow and C is a term which represents the energy losses and carries the same units as set. Contained in the constant of equation 2.1 is a theoretical factor of safety of 6 plus the quantities necessary to make the units correct. The product Wh usually is used to represent the rated hammer energy. This formula can be represented by the curve shown in Figure 2.1. The design pile capacity is given as a function of blow count and is known as a bearing graph. A number of applications can be visualized. When a particular blow count is observed and the rated hammer

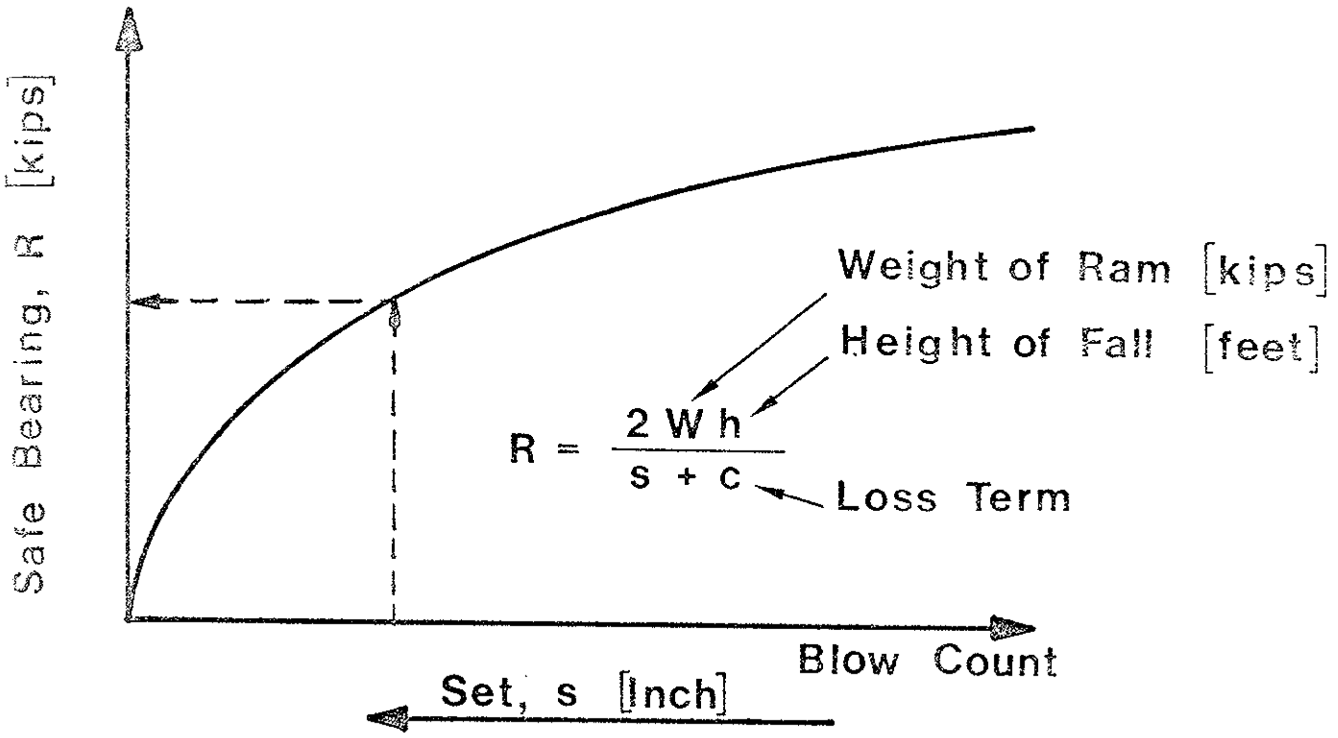

FIGURE 2-1: A BEARING GRAPH DERIVED FROM THE ENGINEERING NEWS FORMULA

energy is known, then with an estimate of loss the pile capacity can be determined as shown in Figure 2.1. Of course, the reverse path is also possible. The blow count required for a specified capacity can be determined.

The other common problem is the selection of equipment. For a particular job the capacity is usually specified. Then for a given driving system (rated hammer energy and estimated losses) the blow count can be determined. If this blow count is not judged to be satisfactory, the equipment can be changed.

The shortcomings of the dynamic formulas can be placed in three categories. In general, these three categories are good for evaluation of all dynamic procedures for capacity determination:

1. The dynamic formulas do a poor job of representing the driving system. Though the rated energy is the most important hammer parameter, it is the only one included. Some dynamic formulas include other parameters such as ram weight but they have not proven to be more accurate. An attempt is made to consider the driving system with the loss term, C, but this approach is greatly oversimplified. Since only a rated performance is included the dynamic formula does not attempt to deal with poor equipment performance.

2. All effects of pile flexibility are neglected since in its derivation the dynamic formula assumes a rigid pile.

3. The soil resistance is assumed to be constant. This kind of soil model is certainly far to simple to even approximately represent a real soil.

In view of the above inadequacies, it is not surprising that an unexpected blow count is observed when driving begins on a job. The questions that commonly arise are: Is the bearing capacity sufficient? Would further driving produce pile damage? Is the hammer performing properly? Is the driving system of the correct size?

However, the observation of blow count is a very convenient way to gage the quality of the pile installation. Therefore, the wave equation approach was developed. The one dimensional wave equation can be derived by applying Newton's Second Law to a rod element of infinitesimal length. It is written

$$\rho \frac{\partial^2 u}{\partial t^2} = E \frac{\partial^2 u}{\partial x^2} \qquad (2.2)$$

where ρ is the material mass density, E is the modulus of elasticity of the material and u is the axial displacement of a point on the rod at location x and time t. Thus, $\partial^2 u/\partial t^2$ is the acceleration and $\partial^2 u/\partial x^2$ is the strain gradient at x and t.

Using this continuous form of the wave equation for pile analysis is usually not practical for the real boundary conditions which must be handled. However, a similar equation can be derived if elements of finite length, ΔL, are chosen having mass, $m = \rho A \Delta L$ and spring stiffness, $K = {}^{EA}/\Delta L$. Here A is the pile cross sectional area. Newton's Second Law leads to

$$ma = K (\Delta u_t - \Delta u_b) \qquad (2.3)$$

where a is the acceleration of the mass and Δu_t and Δu_b are the compression of the springs at the top and bottom, respectively, of the mass under consideration.

The Wave Equation (the term Wave Equation is the name that has been attached to computer programs for discrete dynamic pile analysis. In the remainder of this report, this usuage will be adopted) makes use of the concept of equation 2.3 by representing the pile and driving system (Figure 2.2a) by a series of masses and springs as shown in Figure 2.2b. The soil is modeled by a spring (R, Static) and a dashpot (R, Dynamic) attached to each mass. The soil resistances so represented are shown in Figure 2.2c and are linear elastic plastic for the spring where the maximum force, R_u, is reached at a displacement q, called the quake, and linearly proportional to the element velocity for the dashpot (commonly known as the damping force).

The analysis proceeds by giving the ram an initial velocity. At each element the displacement can be calculated for a small time increment with element velocities determined from the previous time increment. With these displacements and velocities the forces acting on each mass can be determined. They arise from the pile spring deformations, from the soil spring deformation and from the dashpot force. Using Newton's Second Law in the form represented in Equation 2.3 the mass accelerations can be calculated and by integration also the velocity. The computation then proceeds to the next time increment.

In application a set of soil forces R_u and damping forces are assigned at each element. Then the ram is given it's rated impact velocity and the dynamic computation outlined above is continued through successive time

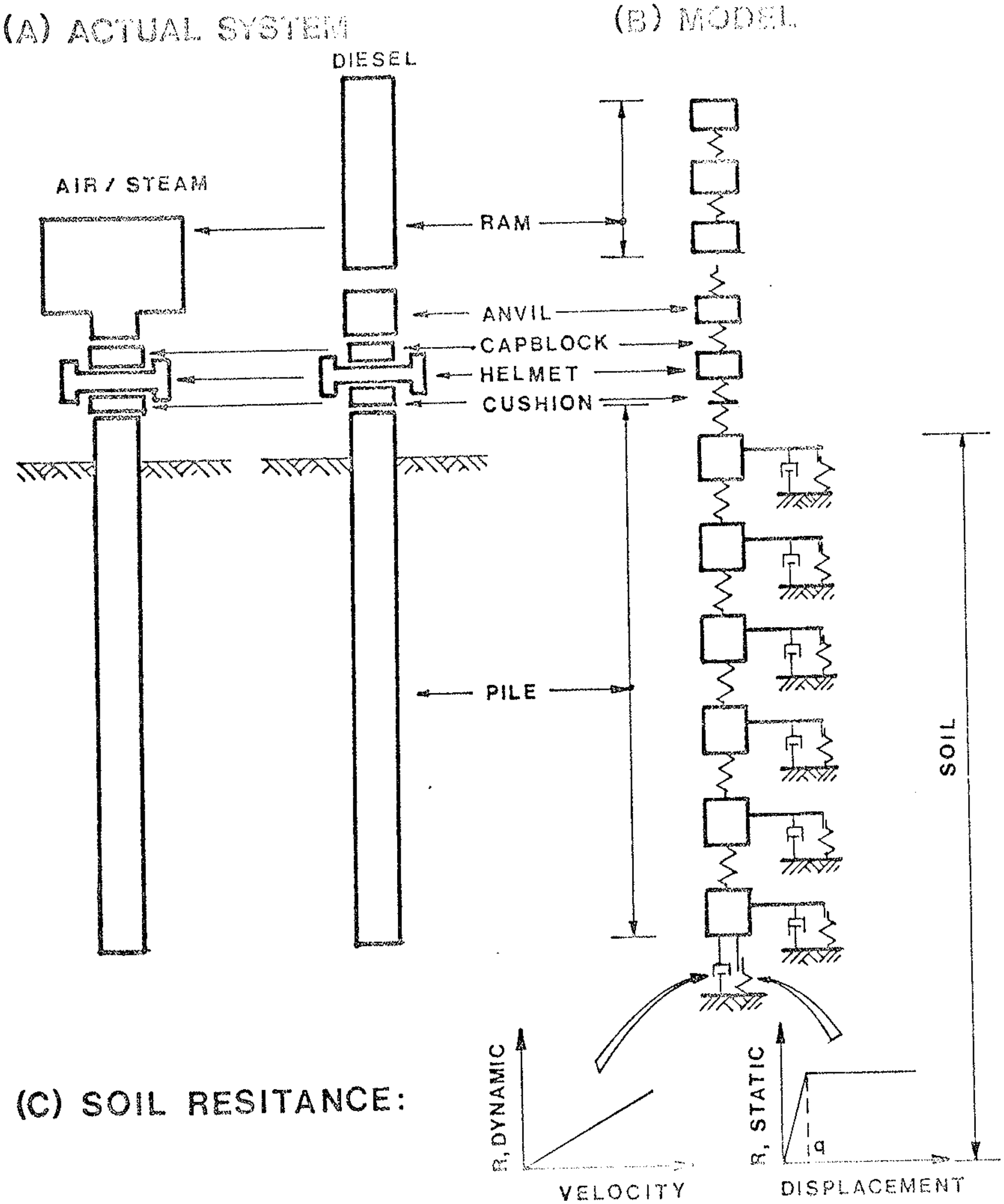

FIGURE 2-2: (A) THE SYSTEM TO BE ANALYZED;
(B) THE WAVE EQUATION MODEL AND
(C) THE COMPONENTS OF THE SOIL RESISTANCE MODEL

increments until all soil forces are less than R_u. The total permanent displacement will have then been calculated and a point on the bearing graph is known. The capacity value is known as R_{ut} and is equal to the sum of the R_u values at each element. The blow count is obtained from the calculated permanent set. In this procedure the permanent set (or blow count) is determined for a set of assigned resistances. However, the bearing graph is plotted, by tradition, with the blow count as the independent variable. A variety of R_{ut} values can be used to calculate the total shape of the bearing graph.

In addition to the bearing graph the wave equation also gives stresses in the pile and they can also be shown as a function of blow count.

In practice, the wave equation bearing graph can be used in a manner quite similar to the dynamic formula bearing graph. In addition, driving stresses can be rationally limited. While the shape of the two curves are quite similar the differences are substantial. A particular wave equation bearing graph is associated with a single driving system pile type, soil profile and a particular pile penetration. If any one of the above items are changed, the bearing graph changes.

The above description summarizes very briefly the operation of traditional wave equation programs such as the TTI program. The system model will be described in greater detail in Chapter 3. The operation of the WEAP program will also be described emphasizing those aspects which are different.

The stroke of a diesel hammer should not be specified as an input quantity as was done in the above description. In the WEAP program the mathematical model is constructed like that shown in Figure 2.2 except that a combustion chamber force is introduced between the ram and the anvil. The program operation begins by dropping the ram from some initial preassigned height. The ram velocity at the exhaust ports can be calculated directly from the free fall distance. When the exhaust ports are closed by the ram it continues to fall against the confined gas in the combustion chamber. In this stage the gas pressure and ram velocity are calculated incrementally. The gas pressure can be determined from the gas law since the volume is known as the ram falls. When impact occurs, and the velocity at impact has been calculated, a dynamic analysis of the general type described above is performed. Shortly after impact ignition occurs in the combustion chamber and the pressure and temperature are given an appropriate increase. At some stage in the calculation separation occurs between the ram and the anvil. The computation now continues until the exhaust port is passed at a known velocity. From this velocity the rebound stroke can be calculated. If the initial stroke is not the same as the rebound the computation is repeated using the rebound stroke as the initial stroke in the next cycle. Convergence usually occurs in two or three cycles.

A bearing graph similar to that previously described is obtained except that stroke and pile stresses are also included. An example is shown in Figure 6 of the User's Manual.

A variation of this concept is necessary for hammers which do not have a definite fuel setting and for which the combustion pressure is not known a priori. In such cases, the stroke is usually kept as desired by adjusting the fuel amount. (In easy driving the stroke is probably always limited by the maximum combustion energy available). To model this process the stroke has to be specified and maximum combustion pressure is adjusted until the rebound stroke equals the specified one.

Now consider the three problems with the dynamic formula as they relate to the wave equation:

1. The driving system can be represented with considerable realism. The various dynamic parameters used to describe the system must be available. Of course, the wave equation cannot be expected to recognize a poorly performing hammer.

2. The pile is accurately represented.

3. The soil model is a substantial improvement over that used in the dynamic formula. However, it is still extremely simple and crude. Even for this simple model it is very difficult to obtain soil constants. Therefore, greater complexity hardly seems justified.

The use of either dynamic formula or the wave equation requires the accurate determination of blow count. Particular care must be used if the driving resistance is changing rapidly. Often when time dependent strength changes occur, it is desirable to restrike the pile. Here the blow count at the very beginning of restrike must be determined since it can be expected to change with driving.

CHAPTER 3

MATHEMATICAL MODELS

3.1 Introduction

In this chapter the construction and operation of pile driving hammers will be discussed. After the hammer operation has been described, the mathematical model which has been developed to represent it will be presented. Since the most important contribution of this report is probably the diesel hammer portion, it will be presented first.

The model used to represent the other parts of the driving system, the pile and the soil will also be described in considerable detail.

In general, the variables used to describe the system will be the same as those used in the program. While this approach is somewhat unwieldly---- here it has substantial advantages for those readers who need to become deeply involved with the program.

3.2 Hammer

3.2.1 Working Principle of the Open End Diesel Hammer

The Open End Diesel hammer (OED) operates on a two stroke diesel cycle. The hammer is started by raising the ram with a lifting mechanism. At the upper end of its travel the lifting mechanism is tripped, the ram is released and descends by gravity. At the time the ram bottom passes the exhaust ports a certain volume of air, VIN, is trapped and is compressed (Figure 3-1a). Usually before the time of exhaust port closure a certain amount of fuel is squirted into the cylinder. Some hammers inject an atomized

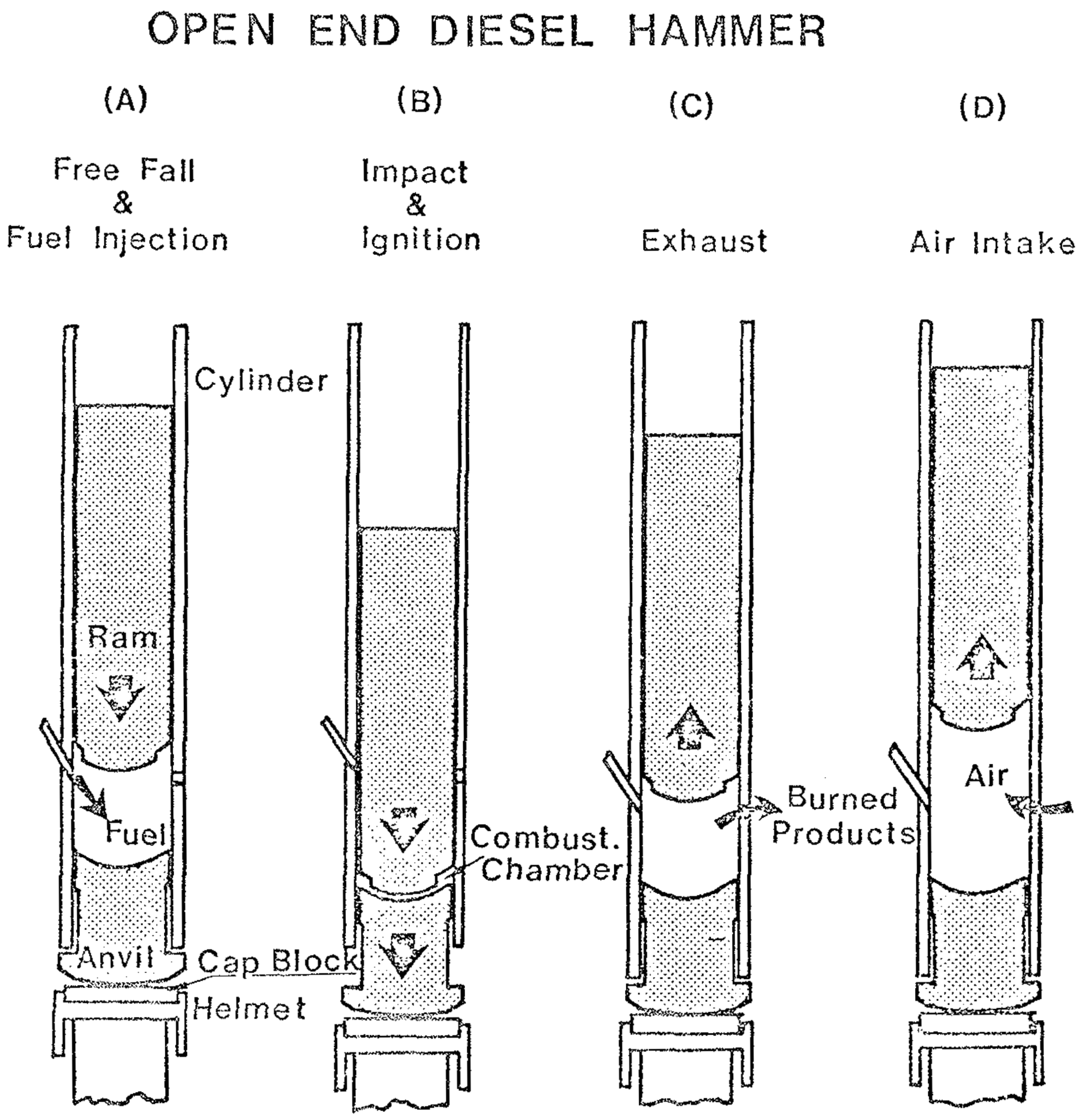

FIGURE 3-1: WORKING PRINCIPLE OF THE OPEN END DIESEL HAMMER

fuel later in the cycle when the combustion chamber pressure is higher.

When the ram impacts against the anvil the air is compressed to a final volume (VFIN). The fuel is splattered by the impact into this final volume (if fuel atomization was not used) and combustion starts at some time after impact (combustion delay). This delay is due to the time that is required for the fuel to mix with the (hot) air and to ignite. More volatile fuels might have a shorter combustion delay than heavier ones. Combustion occurring before impact is called preignition and can be caused by the wrong fuel type or an overheated hammer. For Open End Diesel Hammers preignition is usually considered to be undesirable.

During impact, anvil, capblock and pile top are rapidly driven downward (Figure 3-1b) leaving the cylinder with no support. Thus, it starts to descend by gravity.

Pile rebound and combustion pressure push the ram upwards. When the exhaust ports are cleared some of the combustion products are exhausted leaving in the cylinder a volume of burned gases at ambient pressure that is equal to VIN (Figure 3-1c). As the ram continues upward fresh air, which is drawn in through the exhaust ports, mixes with the remaining burned gases (Figure 3-1d).

Depending on the reaction of the pile and the energy provided by combustion the ram will rise to some height (stroke). It then descends again by gravity to start a new cycle.

3.2.2 The Mechanical Model of the Open End Diesel Hammer

In order to properly model the mechanics of the OED hammer the following characteristic properties must be considered in addition to those described above:

(a) The ram is relatively long and flexible.

(b) Metal to metal impact occurs between ram and impact block.

(c) Energy losses occur on all interfaces of hammer components which transmit the impact.

The capblock, helmet and, if present, the cushion will be considered as a part of the hammer. The helmet is usually a rather heavy steel form that adapts to the pile top. The capblock is cushioning material between anvil and helmet while a cushion is sometimes inserted between helmet and pile top.

Figure 3-2 shows both an actual pile driving hammer (a) and its model (b). The ram was divided into M elements to account for its flexibility. Anvil and cap were represented by one mass each. The spring stiffness above the anvil was determined by the lowest ram element stiffness combined with that of the anvil. Thus, if HM(I) denotes the mass of the I-th hammer segment the following relations hold:

$$HM(I) = \frac{W_R}{M\ g} \quad \text{for } I \leq M \qquad (3\text{-}1)$$

where W_R is the weight of the ram (assumed to be uniform) and g is 32.2 ft/s^2.

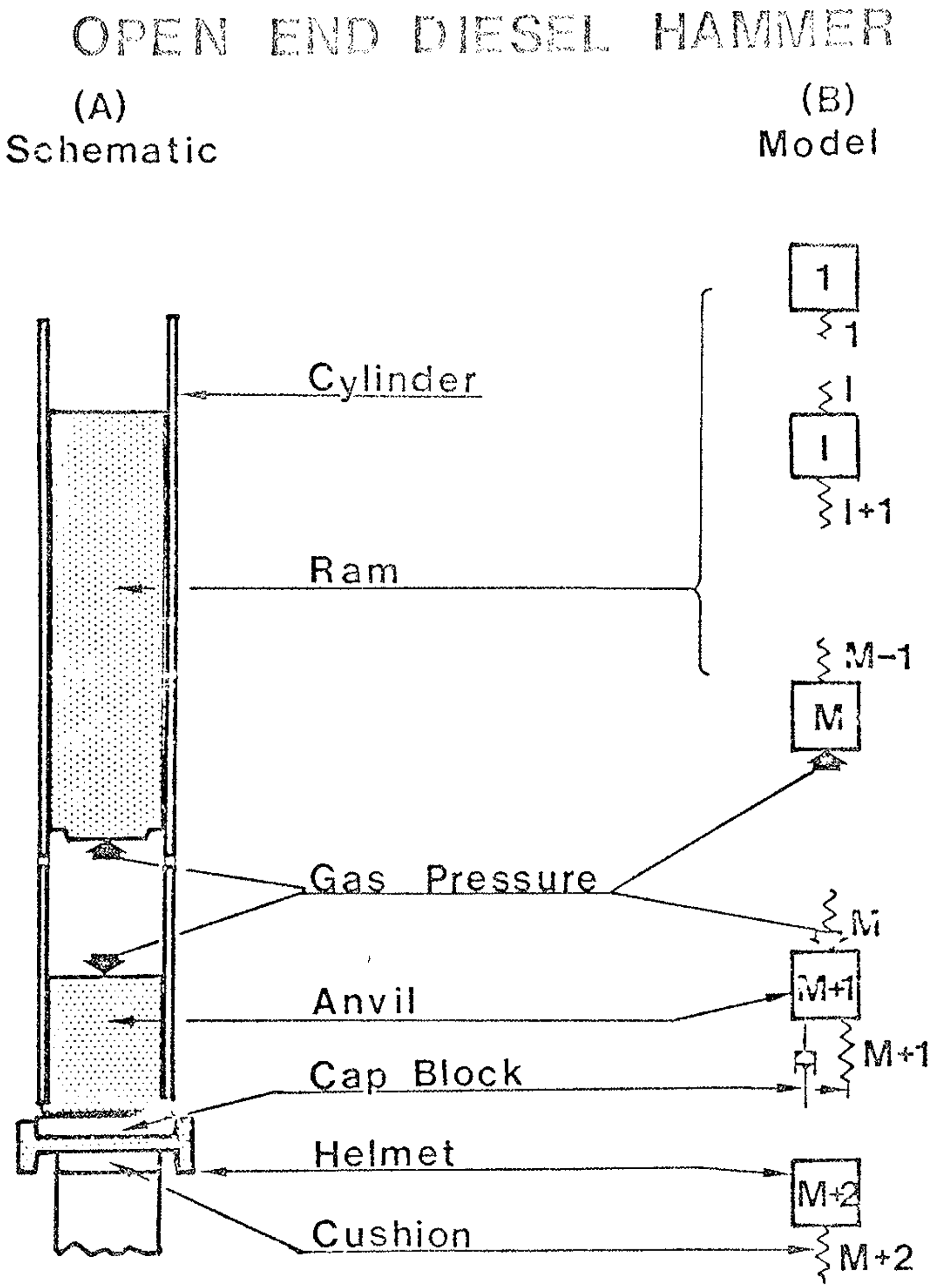

FIGURE 3-2: (A) SCHEMATIC AND (B) MODEL OF OPEN END DIESEL HAMMER

Similarly one obtains

$$HM(M+1) = \frac{W_A}{g} \qquad (3\text{-}2)$$

and

$$HM(M+2) = \frac{W_c}{g} \qquad (3\text{-}3)$$

with W_A and W_c being the weight of the anvil and capblock, respectively. Thus, the hammer model always consists of M+2 elements. M depends on the length of the ram. Initial studies showed that ram segments of two to three feet in length yield sufficient accuracy.

The springs connecting the hammer masses have the following stiffnesses (if the ram is uniform):

$$STH(I) = \frac{A_R\ E}{L_R}\ M \qquad I \leq M \qquad (3\text{-}4)$$

with A_R, L_R and E being the cross sectional area, length and elastic modulus of the ram, respectively. Furthermore,

$$STH(M) = \frac{\left(\frac{A_R M}{L_R}\right)\ \left(\frac{A_A}{L_A}\right)}{\frac{A_R}{L_R}\ M + \frac{A_A}{L_A}}\ E \qquad (3\text{-}5)$$

with A_A and L_A being cross sectional area and length of the anvil, respectively. Note that STH(M) is the spring against which the ram impacts.

Since energy losses are usually associated with such an impact, the unloading stiffness of the anvil spring is:

$$\overline{STH(M)} = \frac{STH(M)}{EANV^2} \tag{3-6}$$

where EANV is the coefficient of restitution of the anvil. Similarly, if ECAP is the coefficient of restitution of the capblock the unloading stiffness of the capblock spring is:

$$\overline{STH(M+1)} = \frac{STH(M+1)}{ECAP^2} \tag{3-6a}$$

STH(M+1) depends solely on the cushion properties in the capblock. If there is a cushion at the pile top with ECUS as a coefficient of restitution, then:

$$\overline{STC} = \frac{STC}{ECUS^2} \tag{3-6b}$$

This stiffness must be combined with that of the pile top element for which

$$\overline{STP(1)} = \frac{STP(1)}{ETOP^2} \tag{3-6c}$$

(the definition of STP(1) will be given below). In this way a combined pile top and cushion stiffness is obtained:

$$STH(M+2) = \frac{(STC)(STP(1))}{STC + STP(1)} \tag{3-7}$$

For unloading the corresponding expressions can be found when the values of Equations (3-6b) and (3-6c) are used.

As a deviation from the usual approach the loading stiffness, say STH was always calculated as $(EA/L)(e^2)$, e being the coefficient of restitution. Then the unloading slope, $\overline{STH}$, becomes EA/L. In other words, if $k = EA/L$ is the stiffness of a segment or component as determined in a compression test, then k is used as the unloading stiffness in the dynamic application. The effect is a lower stiffness during loading. It is felt that this approach is justified in light of local plastification during the rapid compression which is not present during the expansion phase of the material. The program uses this approach for all springs where coefficient of restitution is less than 1.

Special consideration was given to the fact that the slope of a stress-strain curve of cushioning material usually is gradually increasing and does not - at zero stress - start with its maximum value. Similarly, the force deformation curve of two colliding bodies such as the ram impacting against the anvil cannot show an ideal elastic behavior.

It is neither possible nor necessary to provide a quantitatively exact model. Qualitatively, though, the curves can be rounded and the result can be judged by comparison with measurements.

For this reason three displacement values, DS, were assumed for anvil, cap and cushion. For a deformation less than or equal to DS the stiffness, ST, was assumed to be linearly increasing with the deformation (Figure 3-3a). Thus, the modified stiffness is:

$$ST = STH(I) \; \frac{DKH(I-1) - DKH(I)}{DS} \, , \quad I = M, M+1, M+2 \qquad (3-8)$$

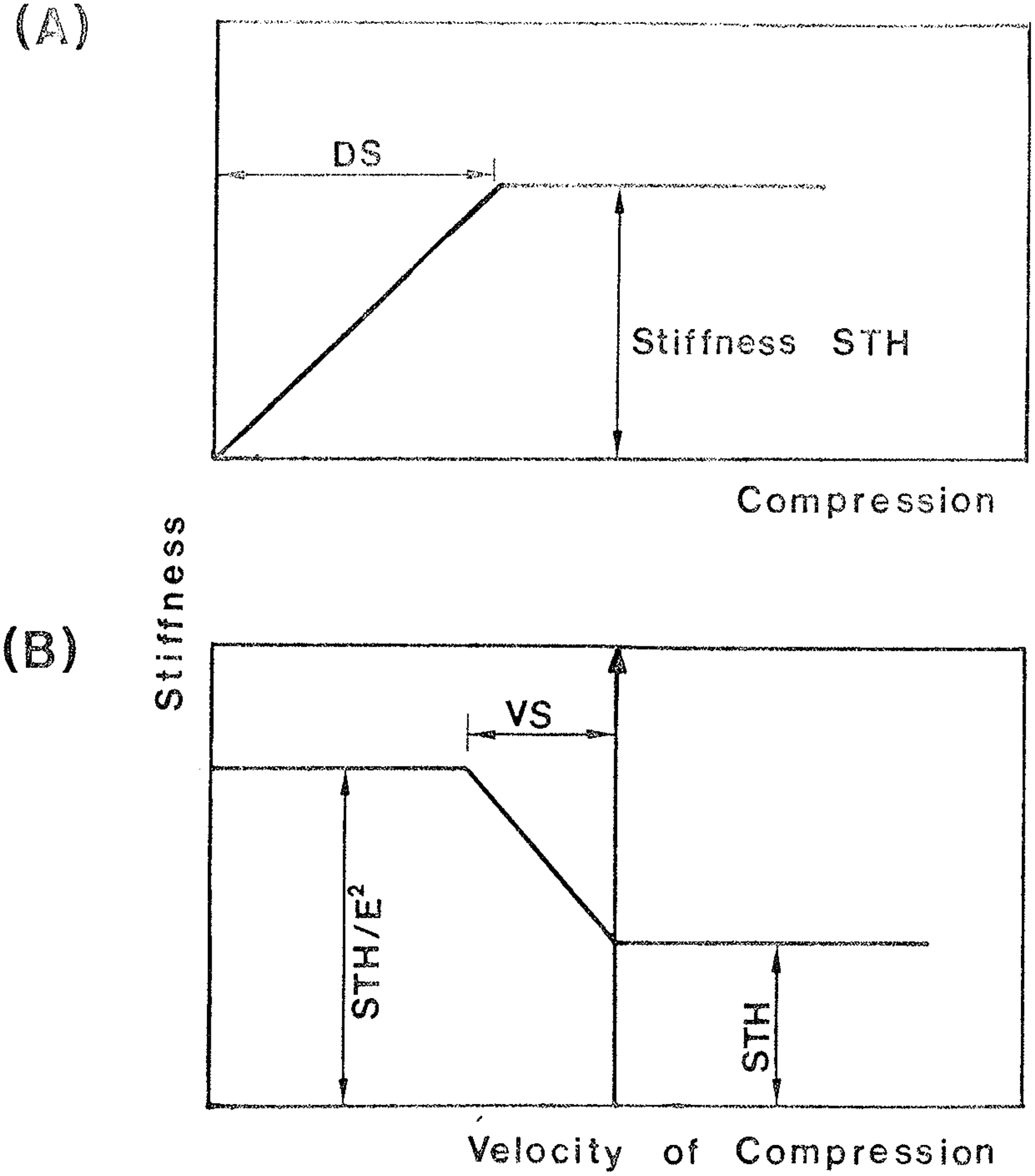

FIGURE 3-3: (A) STIFFNESS VS. COMPRESSION RELATION (B) STIFFNESS VS. COMPRESSION VELOCITY RELATION; BOTH FOR DRIVING SYSTEM COMPONENTS

which is valid for DS > DNH(I-1) - DNH(I), with DNH(I) being the displacement of a hammer element, I, at a certain time. Modifications of this formula have to be made where the deformation becomes small during unloading. A load deformation curve obtained by going through several cycles of loading, unloading and separation is shown in Figure 3-4.

Another point of concern was the change of slope of the load deformation curve when the velocity changes sign. This change was programmed such that the stiffness of hammer springs M, M+1 and M+2 was changing linearly from the low to the high value between 0 and a negative compression velocity, VS (see Figure 3-3b), which was set at -0.5 ft/sec (0.15 m/sec).

In addition to the bilinear spring a dashpot was added to model the capblock. The dashpot constant was set at 2% of the ram's critical damping value $(2\sqrt{STH(1)(HM(1))})$. This damper is present more to improve the discrete model's accuracy than for physical reasons. It was found that agreement with measured data improved when using such a dashpot. An additional dashpot was not used with the cushion since the pile top already contains one in it's model (see 3.3).

3.2.3 The Thermodynamic Model of the OED Hammer

The thermodynamic model is divided into four parts: (a) compression, (b) combustion delay, (c) ignition and (d) expansion. These four phases are illustrated in Figure 3-5.

Compression begins when the ram has fallen to the level of the exhaust ports. The ram velocity is then:

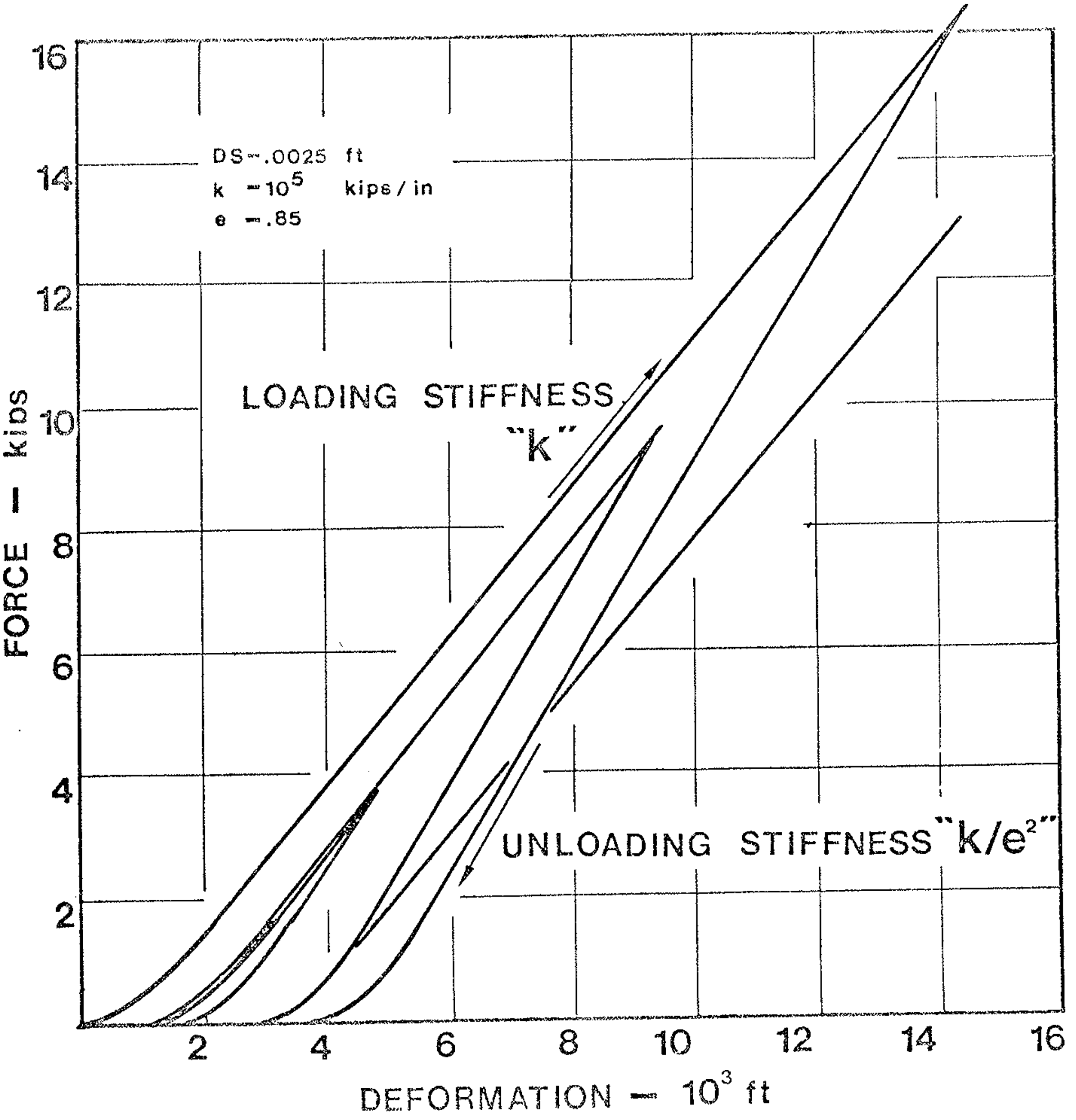

FIGURE 3-4: EXAMPLE OF FORCE VS. DEFORMATION RELATION FOR COMPONENTS OF DRIVING SYSTEM

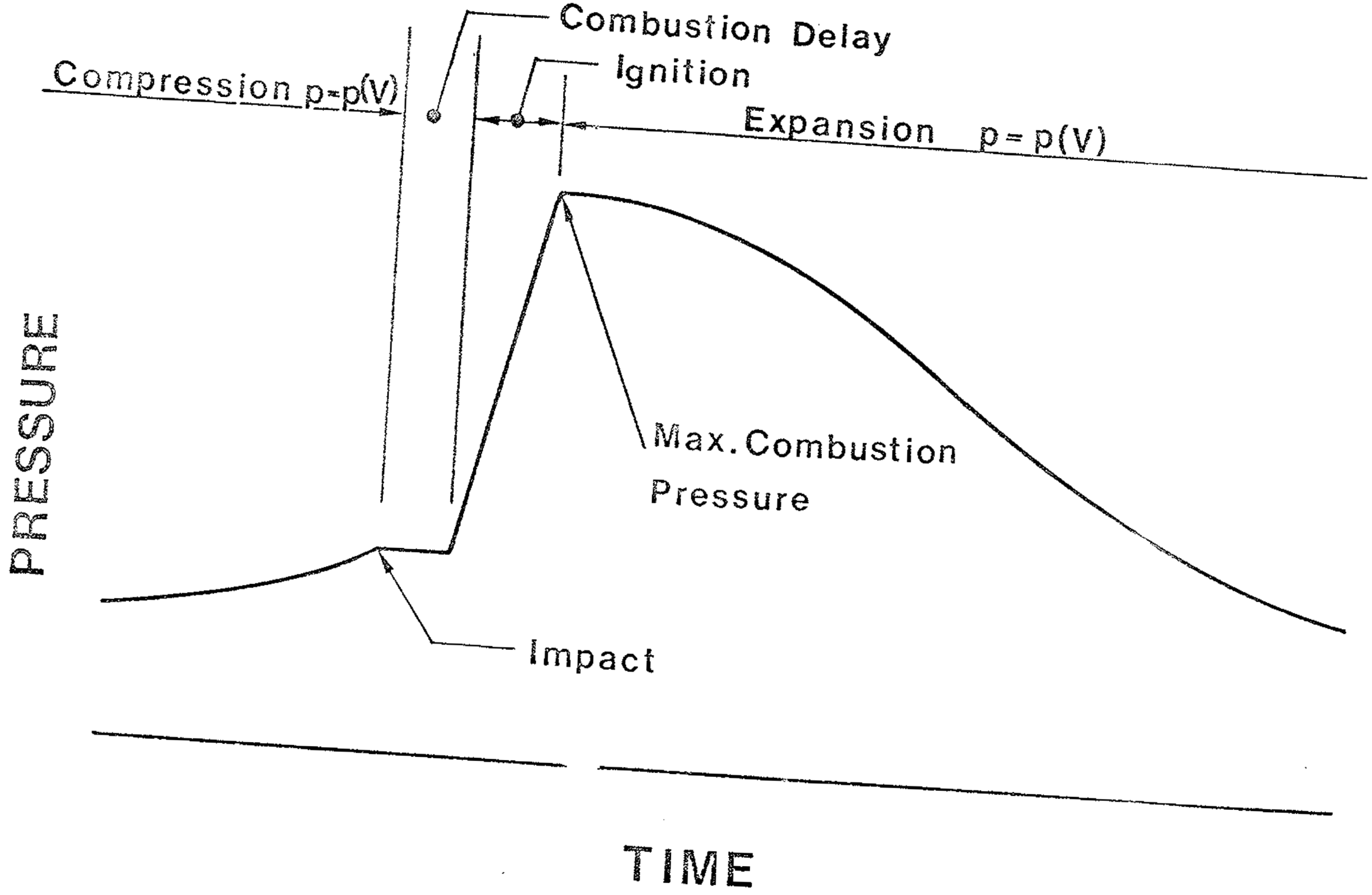

FIGURE 2-5: THE FOUR PHASES OF THE THERMODYNAMIC MODEL

$$V_{R,E} = \sqrt{2g(\mathrm{STROKE} - \mathrm{DEPIB})} \qquad (3\text{-}9)$$

where STROKE is the ram fall height and DEPIB is the distance between the exhaust ports and the impact block (or anvil). The initial volume of air is

$$\mathrm{VIN} = \mathrm{DEPIB}\ (\mathrm{ARAM}) + \mathrm{VCHAM} \qquad (3\text{-}10)$$

where ARAM is the cross sectional area of the cylinder and VCHAM is the remaining volume at impact. If during compression the position of the ram is DPOS (measured from the anvil) then the pressure below the ram is

$$P = \left(\frac{\mathrm{VIN}}{(\mathrm{DPOS})\ (\mathrm{ARAM})}\right)^{\mathrm{EXPP}} (\mathrm{PATM}) \qquad (3\text{-}11)$$

Here, EXPP is a parameter depending on the specific heats of the gas in the cylinder and PATM is the atmospheric pressure (14.7 psi or 1.01 bar). For adiabatic compression of air EXPP is 1.4. Since the process is not completely adiabatic EXPP should be chosen less than 1.4. Results of actual measurements were used to determine the correct value (see Appendix A).

With regard to combustion either analytical, experimental or combined approaches can be chosen. The truly analytical approach can only be as good as the available information on many hammer parameters. Actually, there are limits as to the accuracy of the analytical approach since effects of cooling, scavenging, fuel atomization and others can only be estimated. It should be added that efforts were actually made to predict combustion pressures. Appendix A contains a sample calculation and a discussion of such results.

The truly experimental approach can only be as good as the measurements are. In particular it is important to obtain representative data. On the other hand, limitations on the number of independent variables considered will always have to be imposed. For the present program the most important limitations on the independent variables are:

(a) Normal ambient temperature (approximately 68°F (20°C)).

(b) Normal atmospheric pressure (14.7 psi (1.01 bar)).

(c) Normal hammer performance and condition (compression, temperature, lubrication, fuel injection).

(d) Normal fuel type.

A hammer tested under these conditions, i.e. measurements of pressure stroke and pile top force and acceleration, provides sufficient information. The parameters to be extracted would be time of ignition and magnitude of pressure. Effects of variable stroke on the pressure behavior should be studied. The records should be obtained under normal conditions.

Since it is too difficult to obtain pressure-volume data for most diesel hammers the pressure must be computed in the program after ignition using an appropriate model. An expansion modeled according to Equation (3-11) was found to be sufficiently accurate. This model can be considered a combined experimental and analytical approach.

The validity of the model of Figure 3-5 is shown in Figure 3-6. The solid curve in Figure 3-6 is a pressure record[*] obtained on a DELMAG D-12 hammer under "normal" conditions. The record exhibits first a gradual increase

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[*] Courtesy of the Foundation Equipment Corporation, Newcomerstown, Ohio.

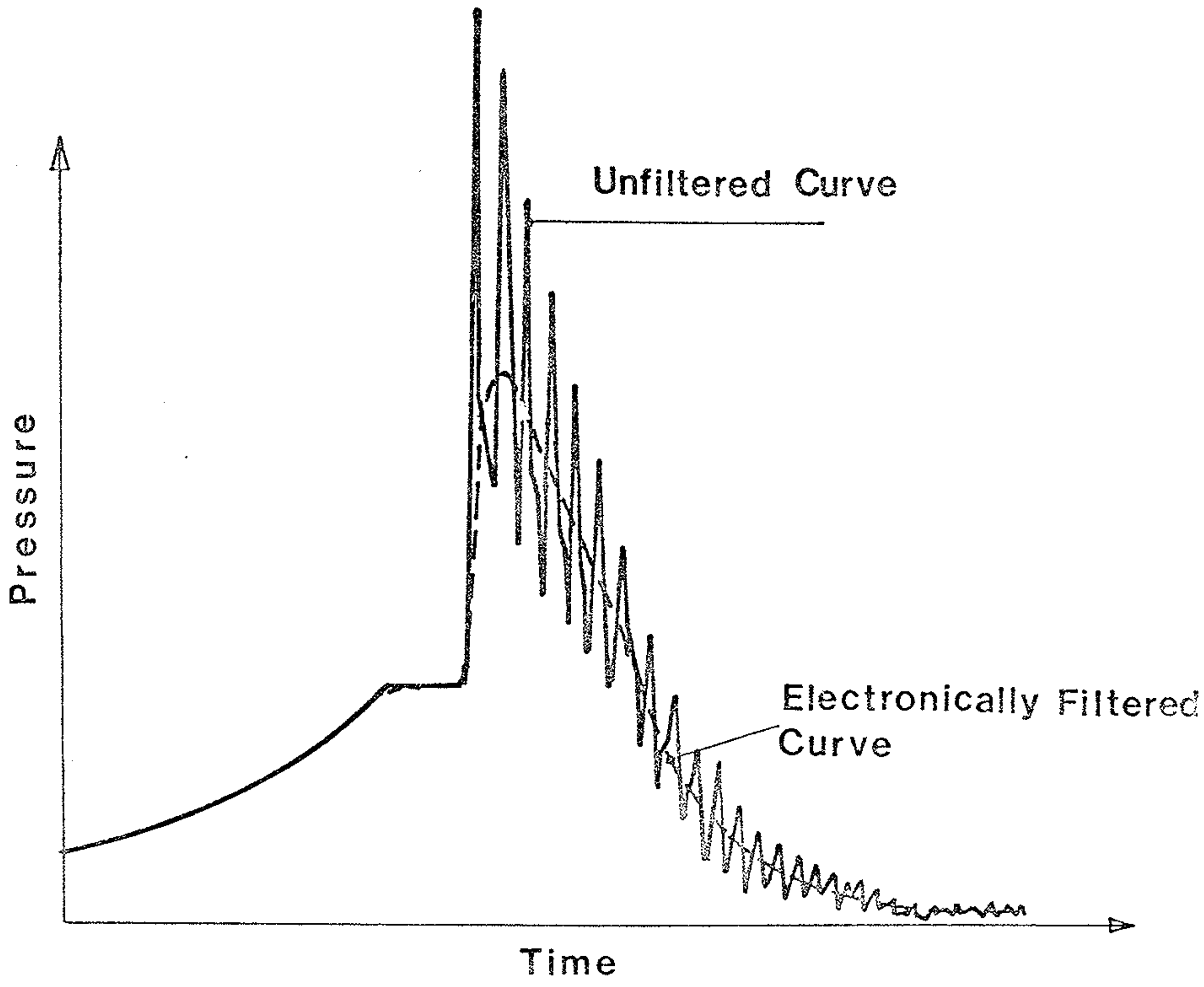

FIGURE 3-6: MEASURED COMBUSTION CHAMBER PRESSURE

during precompression; then it stays constant for a short time period which is the time between impact and combustion and is called the combustion delay; next, it displays a very rapid increase (ignition) and very high magnitude, high frequency variations which gradually decay.

While the timing information on this record is accurate, it is very hard to determine the average or effective maximum pressure. For this reason a low pass, 1 kHz filter was employed which produced the dashed curve of Figure 3-6. The rise of pressure is slower in the filtered than in the unfiltered curve, the maximum pressure value, however, can easily be determined.

Further conclusions for the pressure record are:

(a) The high frequency components of the record are caused by pressure waves in the chamber and are of little significance to the hammer behavior. This phenomenon has also been reported in measurements made on internal combustion engines.

(b) The expansion process can only be judged in connection with actual pressure-volume data. It was found by simulation and comparison with measured data that the records represented Otto rather than Diesel cycles and that the expansion model can be rather simple.

In summary, the following values are used in the model:

(a) The expansion coefficient, EXPP, for the compression phase was set at 1.35.

(b) The duration of the combustion delay can vary but was taken at 0.002 seconds.

(c) The maximum combustion pressure depends on measurements.

(d) The duration of the ignition phase was set to 0.5 milliseconds.

(e) The expansion coefficient, EXPF, for the expansion phase was set to 1.30.

Certain modifications of this model are necessary when a hammer using atomized fuel injection is considered. In this case the combustion delay has to be computed from the start of the fuel injection and the duration of the ignition should be increased to cover the duration of the injection.

For cases where manufacturer's data were not available, both a delay and duration of 10 milliseconds was used with the restriction that ignition occurs at least at impact. It should be mentioned that accurate timing information for atomized injection may be very important.

3.2.4 Working Principle of the Closed End Diesel Hammer

The closed end hammer works very much like the open ended one. In principle the main change consists of a closed cylinder top. Figure 3-7 shows two of these hammer types. When the ram moves upward, air is being compressed at the top of the ram which causes a shorter stroke and, therefore, higher blow rate.

The bounce chamber has ports such that atmospheric pressure exists as long as the ram top is below these ports. As the ram moves toward the cylinder top it creates a pressure which increases until it is just in balance with the weight of the cylinder itself. Further compression is not possible and if the ram still has an upwards velocity uplift of the cylinder will result. This uplifting cannot be tolerated as it can lead both to an unstable driving condition and to the destruction of the hammer. For this reason the fuel amount and, hence maximum combustion chamber pressure, has

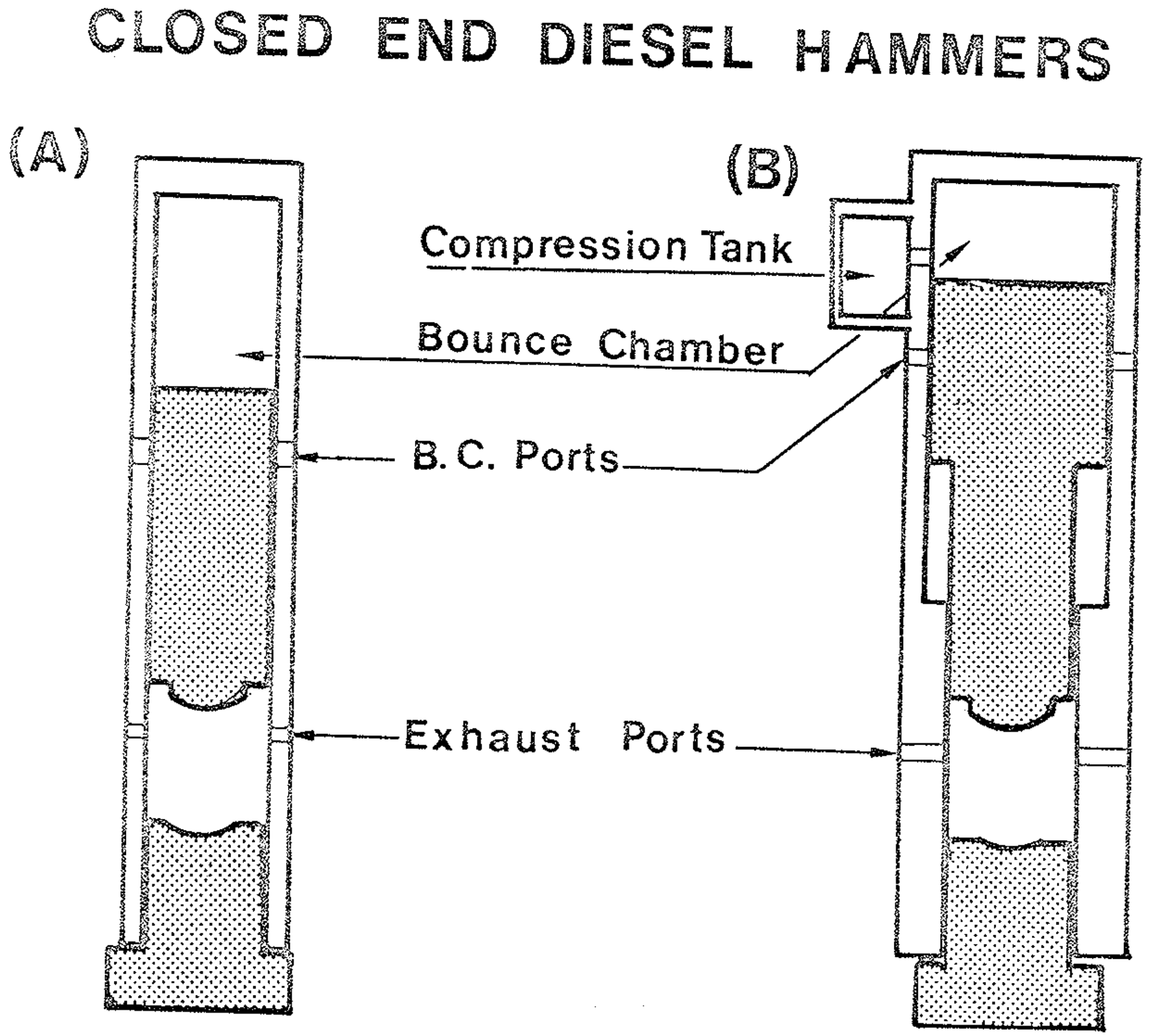

FIGURE 3-7: SCHEMATICS OF CLOSED END DIESEL HAMMERS
(A) UNIFORM (B) NON-UNIFORM RAM

to be reduced such that there is only a very slight lift off or none at all.

Uplift occurs only when the soil resistance forces are sufficiently high. For low resistance forces the stroke will be less than the one for which uplift is imminent.

Another feature of a few closed end hammers (Linkbelt) is an improved scavenging system. This design uses both intake and exhaust ports and an air tank which provides a horizontal air flow through the cylinder when the ram moves downward. It can be expected that the relative amount of unscavenged combustion products present during combustion is smaller than in other hammers.

Another closed end hammer type (BSP) should be discussed. This hammer type employs a vacuum chamber below its ram to increase its operating speed. Two phases of this hammer's operation are shown in Figure 3-8. As can be seen, the hammer is not really closed at the top (although a protective cover is usually present). However, the stroke is limited by the vacuum action under the upper portion of the ram such that it does not become visible during operation. In addition to being faster than an open end hammer this type has the advantage of not lifting off during operation since the vacuum force is always less than the cylinder weight.

3.2.4.1 Hammers with Uniform Rams

The design of these hammers is not very different from the open end hammers. The principal difference is that the ram on its upward travel

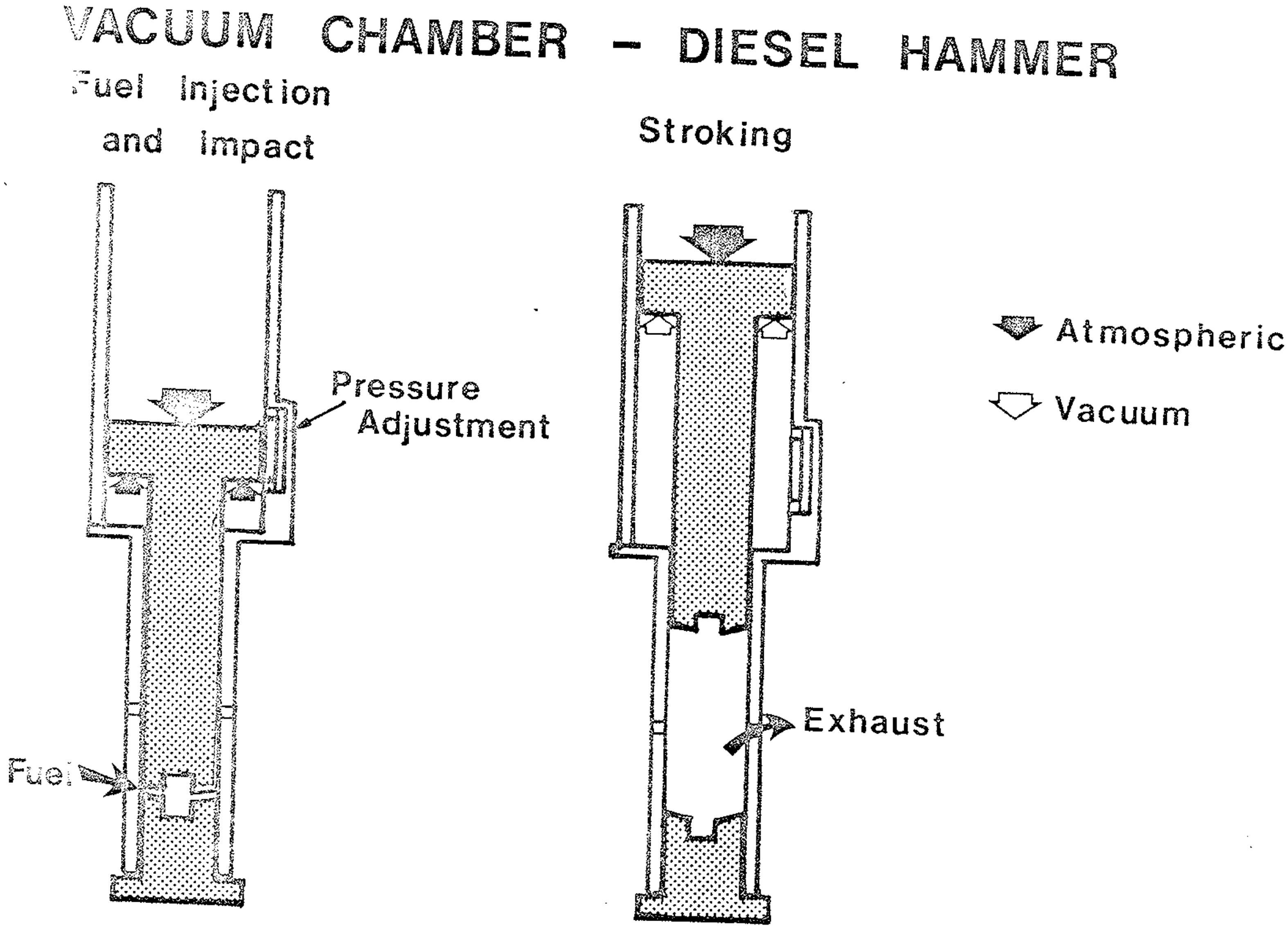

FIGURE 3-8: SCHEMATIC OF A VACUUM CHAMBER DIESEL HAMMER

closes the bounce chamber exhaust ports and, since the cylinder is closed at the top, compresses the air above the ram (Figure 3-7a). Since the bounce chamber is filled with air, compression occurs adiabatically to a chamber pressure:

$$PB = PATM \left(\frac{DEPBB}{DPOS}\right)^{1.4} \tag{3-12}$$

where DEPBB is the distance from exhaust ports and DPOS is the distance from the ram top to the bounce chamber top. Of course, for DPOS being greater than DEPBB

$$PB = PATM\,. \tag{3-13}$$

There exists a value of DPOS at which the pressure becomes so large that the cylinder starts to lift up. If the weight of the hammer excluding ram and driving system is given by RWH, then this limiting pressure is given by

$$PLIM = \frac{RWH}{ARAM} + PATM\,. \tag{3-14}$$

From Equation (3-12) one finds the maximum stroke is

$$STRMAX = DBCIB + DEPBB\left(1 - \left(\frac{PATM}{PLIM}\right)^{\frac{1}{1.4}}\right). \tag{3-15}$$

DBCIB is the distance that the ram travels upward before it closes the bounce chamber ports.

3.2.4.2 Hammers with nonuniform rams and compression tanks

Sometimes the top of the ram has a larger cross section (ART) than the bottom in order to reduce the precompression force for better hammer performance in easy driving. Also, a compression tank may be attached to the bounce chamber. In this way the bounce chamber volume is relatively large until the ram closes the ports of this tank. The remaining volume in the cylinder is called a safety volume. As the ram progresses into it the pressures increase very rapidly and hammer lift off will soon occur.

Because of the existence of a pressure tank of volume VCT, Equation (3-12) has to be revised. The bounce chamber pressure is then:

$$PB = PATM \left(\frac{(DEPBB)(ART) + VCT}{(DPOS)(ART)}\right)^{1.4} \qquad (3\text{-}16)$$

which is valid for DPOS $\geq$ DSF. (DSF is the distance from the pressure tank port to the bounce chamber top).

The maximum pressure in the compression tank, PCT, is given by substituting DSF for DPOS in Equation (3-16). Defining

$$VBIN = (DEPBB)(ART) \qquad (3\text{-}17a)$$

and

$$VSF = (DSF)(ART) \qquad (3\text{-}17b)$$

one obtains

$$PCT = PATM \left(\frac{VBIN + VCT}{VSF}\right)^{1.4} \qquad (3\text{-}18)$$

and for DPOS $<$ DSF one can now find

$$PB = PCT \left(\frac{DSF}{DPOS}\right)^{1.4} \qquad (3\text{-}19)$$

or

$$\text{STRMAX} = \text{DBIB} + \text{DEFBB} - \text{DSF}\left(\frac{\text{PCT}}{\text{PLIM}}\right)^{1/1.4} \qquad (3\text{-}20a)$$

If the maximum stroke occurs for DPOS > DSF then

$$\text{STRMAX} = \text{DBCIB} + \frac{\text{VBIN}+\text{VCT}}{\text{ART}}\left(\frac{\text{PATM}}{\text{PLIM}}\right)^{1/1.4} \qquad (3\text{-}20b)$$

3.2.5 The Vacuum Chamber Hammer

This hammer type utilizes a vacuum rather than compressed air as for other closed end hammers to reduce its stroke and, therefore, increase its blow rate. The essential components and phases of operation are shown in Figure 3-8. Since the vacuum force is limited (maximum: atmospheric pressure, PATM, times the difference in area between ram top and bottom, DELA) uplift cannot occur as long as the cylinder weight exceeds this value. The hammer can therefore be treated as an open ended hammer type as long as the vacuum force is properly considered.

If the distance of the ram above the anvil is DBC, and the pressure in the vacuum chamber starts to decrease when the ram is at a distance DSTART and if DIN = VIN/DELA (with VIN = the volume in the chamber at DBC = DSTART) then the net force, F, on the ram in downward direction is

$$F = \text{PATM}\ (\text{DELA})\left(1 - \left(\frac{\text{DIN}}{\text{DBC} - \text{DSTART} + \text{DIN}}\right)^{1.4}\right). \qquad (3\text{-}21)$$

Of course, if DBC is less than DSTART (anvil has moved downward) then no vacuum force exists. It should be noted that the cylinder position, DCYL, is considered in the program but not included here for the sake of clarity.

In order to be able to treat the hammer like an open ended one a formula must be derived for the ram velocity at the ports, VFALL.

$$VFALL = \sqrt{2\ \frac{G}{W}\ ((STROKE - DEPIB)(W + PATM(DELA)) + DP)} \qquad (3\text{-}22)$$

where $DP = PATM\ (DELA)\ \frac{DIN^{1.4}}{0.4}\ (DB^{-0.4} - DE^{-0.4})$,

$DE = DEPIB - DSTART + DIN$,

$DB = STROKE - DSTART + DIN$

and W and G are ram weight and gravitational acceleration, respectively.

3.2.6 The Air/Steam Hammer Model

The Air/Steam Hammer is much simpler to model than diesel hammers, first, because it has an external power supply and, second, because it has only a few simple hammer components. The ram usually consists of a compact block with a so-called ram point attached to its bottom. The ram point strikes against the capblock. For this reason, the impact is cushioned by a soft material. This in turn allows the ram flexibility to be neglected.

The ram is raised by externally produced air or steam pressure (Figure 3-9b) acting against a piston, housed in the hammer cylinder, which in turn is connected to the ram by a rod. Once the ram is raised a certain distance a valve is activated and the pressure in the chamber is released. At that time the ram has some upward velocity. Therefore it "coasts" up to the maximum height (stroke) and then falls free to impact on the capblock (Figure 3-9a). Upon impact pressure enters again the cylinder. The hammer described

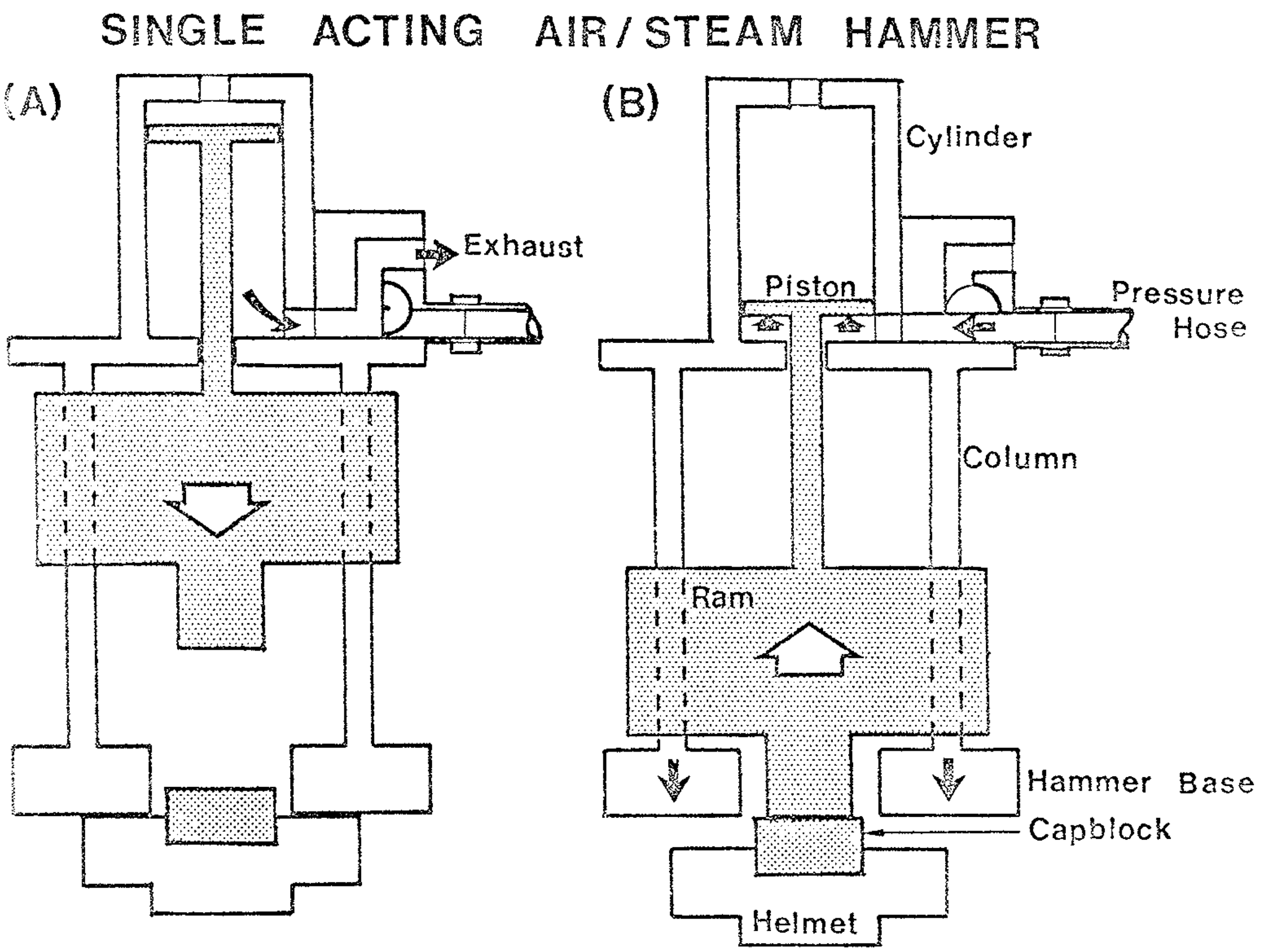

FIGURE 3-9: SIMPLE ACTING AIR/STEAM HAMMER
(A) DURING FALL (B) AFTER IMPACT

above is known as the single acting air/steam hammer.

A double acting hammer is one in which the ram is accelerated during its fall by pressure in addition to gravity. The working principle of one type of double acting hammer, the differential hammer, is illustrated in Figure 3-10.

The pressure applied at the top of the piston acts against the top of the cylinder similar to the bounce chamber pressure in a closed end diesel hammer. Of course, the pressure could lift the hammer assembly, of weight WA to which the cylinder is connected. Thus, maximum hammer output will be achieved when the pressure is kept at its upper limit (PLIM, here gage pressure) at which assembly lift off is incipient.

The maximum energy of a differential acting hammer is

$$\mathrm{EMAX} = (\mathrm{W} + \mathrm{PLIM}(\mathrm{A}))\ \mathrm{STRM} \qquad (3\text{-}23a)$$

where W is the weight of the ram, A is the effective cylinder area, and STRM is the maximum stroke of the hammer. (Note that the effective cylinder area is equal to that of the smaller (lower) piston). Since

$$\mathrm{A} = \mathrm{WA}/\mathrm{PLIM} \qquad (3\text{-}23b)$$

the potential energy of a hammer driven by an actual pressure PSTEAM is

$$\mathrm{E} = (\mathrm{W} + \mathrm{PSTEAM}\ \frac{\mathrm{WA}}{\mathrm{PLIM}})\ \mathrm{STRM}\,. \qquad (3\text{-}23c)$$

From this relation an effective stroke, STROKE, is derived that a weight W,

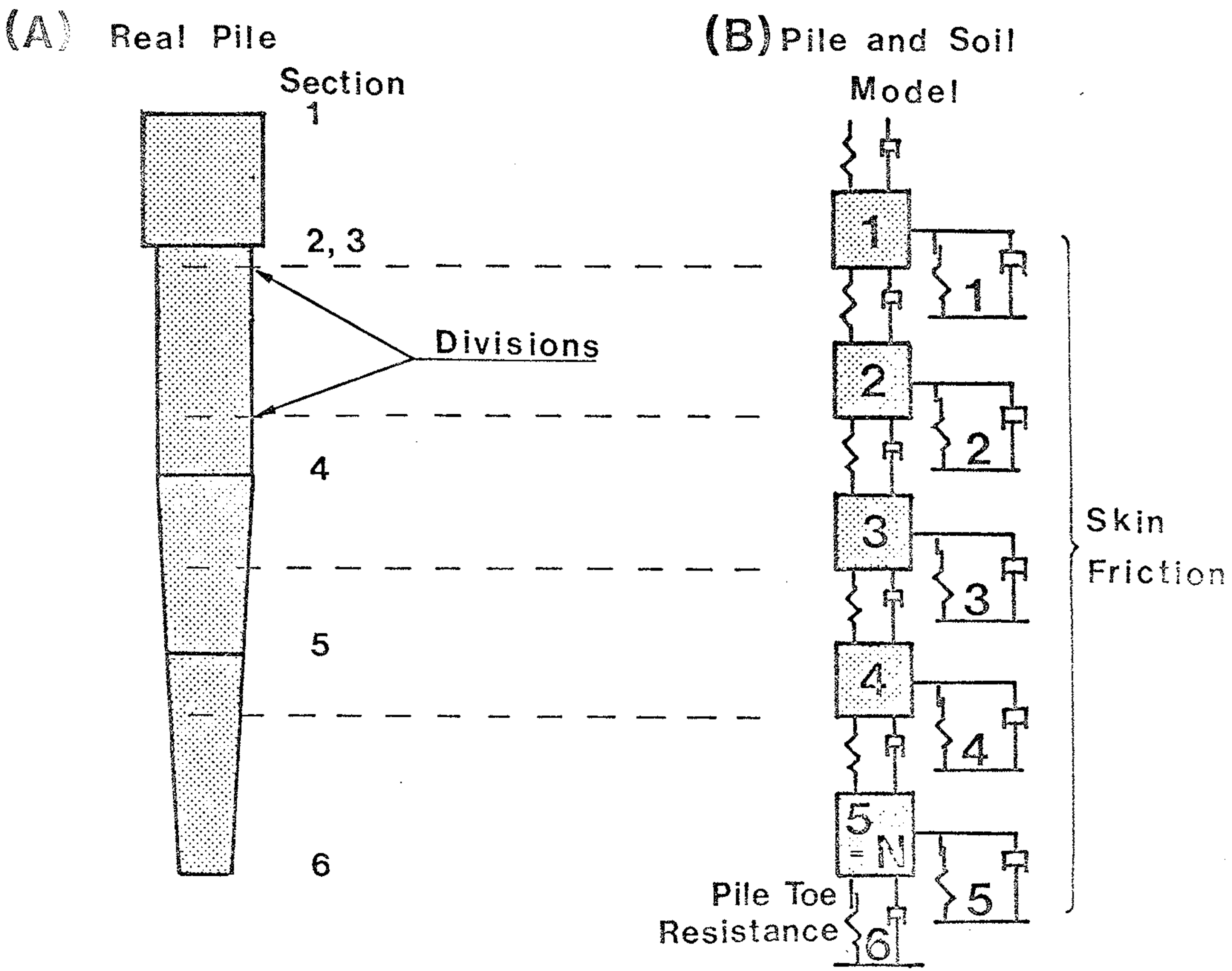

FIGURE 3-1 : (A) SCHEMATIC REPRESENTATION OF PILE AND (B) PILE AND SOIL MODEL with $\overline{RP}$ being the average mass density of the pile and $\overline{AP}$ the average cross sectional area of the pile. The averages are taken over DL.

Similarly the segment stiffnesses are

$$STP(I) = \frac{\overline{EP}\ (\overline{AP})}{DL} \tag{3-29}$$

where $\overline{EP}$ is the average elastic modulus over the element length. Obviously, multi-material piles can be treated in this fashion.

A third parameter, the <u>pile</u> damping value can be specified for the pile. Since little is known about the correct structural damping model and since this type of damping produces relatively small forces compared to soil damping, an elaborate model does not seem justified. Thus, viscous damping was assumed with parameters:

$$CDP(I) = \frac{2}{100}\ IBD\ \sqrt{STP(I)\ PM(I)} \tag{3-30}$$

with IBD being the damping constant in percent of critical. Note that Equation 3-30 is based on the definition of critical damping of the one degree of freedom oscillator.

The damping force between two segments is then

$$PD(I) = CDP(I)\ (VP(I-1) - VP(I)) \tag{3-31}$$

where VP(I) is the velocity of the I-th segment.

The damping constants IBD are not related to pile length. Thus, if for a particular pile a different number of elements are used with the same damping parameters, then the total damping force is different. This approach is not quite satisfactory and is only tolerated in light of the small effects of pile damping and the limited knowledge of material damping. Further efforts in this area are encouraged.

3.4 Soil

The soil model used offers as an option some differences from the one usually employed. It basically consists of a spring and dashpot (Figure 3-12). The elastic spring yields at a pile segment displacement QS(I) (quake) such that there is no further increase in static resistance with increased displacement (RS(I) = SU(I), SU being the ultimate static resistance at that element). Unloading, i.e. when the pile segment has an upward velocity, follows at a spring rate that is in the usual case equal to that in the loading path.

An option was built into this model allowing the use of a coefficient of restitution, ESOIL, which is employed such that

$$\overline{\mathrm{SOK(I)}} = \frac{\mathrm{SOK(I)}}{\mathrm{ESOIL}^2} \qquad (3\text{-}32)$$

where SOK(I) indicates the soil stiffness at the I-th pile element and where the barred quantity indicates unloading. Note that ESOIL is the same for all pile elements.

In the usual case where the pile experiences an appreciable net set the energy consumption by the use of a coefficient of restitution is negligible. However, for the very hard driving cases (blow count greater than 120 blows per foot) an energy loss due to an ESOIL - value will improve the validity of the soil model.

The damping model can be chosen according to Smith

$$\mathrm{DAM} = \mathrm{J(I)\ VP(I)\ RS(I)} \qquad (3\text{-}33)$$

where DAM is a damping force in kips (N) and J(I), VP(I) and RS(I) are the damping factor in sec/ft (sec/m), the pile velocity in ft/sec (m/sec) and the static resistance force in kips (N), respectively; all taken at the same pile segment I.

The second choice is a non-dimensionalized viscous damping for which

$$\mathrm{DAM} = \mathrm{JC(I)\ VP(I)}\ \sqrt{\mathrm{STP(I)\ PM(I)}}. \qquad (3\text{-}34)$$

Here JC(I) is the Case (Institute of Technology) damping factor of unit dimension. Note that

$$\sqrt{\mathrm{STP(I)\ PM(I)}} = \mathrm{EA}/c \qquad (3\text{-}35)$$

(this is also called pile impedance; Young's modulus, E, times cross sectional area, A, divided by wave speed, c; all in the pile). The use of the expression on the left of Equation 3-35 is preferred as it reflects the average properties at an element. Recalling that viscous damping is defined as

$$\mathrm{DAM} = \mathrm{JV(I)VP(I)} \qquad (3\text{-}36)$$

with JV(I) being the viscous damping constant it is apparent that

$$JC(I) = \frac{JV(I)}{\sqrt{STP(I)\ PM(I)}} = \frac{JV(I)}{EA/c} \qquad (3\text{-}37)$$

while Smith's damping factor becomes

$$J(I) = \frac{JV(I)}{RS(I)} \qquad (3\text{-}38)$$

The distribution of damping is handled in the following way: For Smith's damping a constant factor is used along the pile skin and another factor is used at the toe. This actually means that the corresponding viscous damping factor varies proportionally to the static resistance distribution along the skin. In order to have a similar situation for the Case damping approach the input consists here also of skin and toe damping factors which are converted to viscous damping factors by virtue of Equation 3-37. The skin damping factor is then distributed to the segments in proportion to the static resistance.

3.5 Numerical Treatment

There are two aspects in the numerical treatment of the analysis that differ substantially from the TTI or Smith's approach. First the integration equations involve also the acceleration terms, and second a so-called predictor-corrector approach is used.

The integration equations are simply (note that subscripts indicating element numbers are omitted if not necessary for clarity):

$$VN = \frac{1}{2} (AO + AN)\ DT + VO \qquad (3\text{-}39)$$

and

$$DN = \frac{1}{6} (2AO + AN)\ DT^2 + VO(DT) + DO. \qquad (3\text{-}40)$$

In these equations A stands for acceleration, V for velocity, D for displacement, O (old) for the beginning and N (new) for the end of the current time increment, DT.

Starting with the hammer and continuing with the pile a prediction of the values DN and VN is made by integrating according the Equations 3-39 and 3-40. Since AN is not known it is set to AO. Then the top (FO) and bottom (FU) spring forces at the I-th element can be computed:

$$FO = (DN(I-1) - DN(I))\ ST(I) \qquad (3\text{-}41a)$$

and

$$FU = (DN(I+1) - DN(I))\ ST(I+1) \qquad (3\text{-}41b)$$

(an H or P after DN and ST would indicate hammer or pile, respectively). Force contributions due to pile damping at the I-th segment are:

$$FDO = (VNP(I-1) - VNP(I)) * CDP\ (I) \qquad (3\text{-}42a)$$

and

$$FDU = (VNP(I+1) - VNP(I)) \cdot CDP(I+1). \qquad (3\text{-}42b)$$

Static resistance forces, RES, are computed using the soil stiffness SOK

$$RESN = RESO + (DN-DO)\ SOK \qquad (3\text{-}43a)$$

with

$$|RESN| \leq SU(I) \qquad (3\text{-}43b)$$

and for the toe

$$0 \leq RESN \leq SU(N+1) \qquad (3\text{-}43c)$$

Due to damping resistance

$$DA = (SJ)(VNP) \qquad (3\text{-}44a)$$

for Case and

$$DA = (SJ)(VNP)(RESN) \qquad (3\text{-}44b)$$

for Smith's damping.

Including the gravitational acceleration, G, the new acceleration value can now be found:

$$AN = G + (FO + FU + FDO + FDU - RESN - DA)/PM \qquad (3\text{-}45)$$

(For ram bottom and anvil this equation contains, of course, the gas pressure force too). Integration of AN leads to new VN and DN values.

Once all VN and DN values are corrected the change from the previous quantities is determined and the process is repeated, computing again for all elements the various quantities starting with Equation 3-41a. This process is repeated until both the pile top force and bottom velocity converge. An input directed maximum number of cycles (ITER) is observed.

CHAPTER 4

PROGRAM INPUT INFORMATION

4.1 Introduction

In this chapter the program input information will be described briefly. The input structure was designed so as to minimize the effort required of the engineer in the preparation of data. Therefore, as much routine computation as possible is performed internally. However, in some cases the flexibility of very detailed engineer input is desirable, so options are available which control the form of the input required by the program.

In one particular case, the hammer, it is usually unnecessary for the user to prepare detailed data to describe the hammer since there is a limited number of available hammers. The TTI program has required that each user obtain the hammer details from manufacturers or dealers. A great danger exists that incorrect information is input. In the WEAP program hammer information has been obtained from the manufacturers. Where questions arose the manufacturer was contacted and clarification obtained.

4.2 Open End Diesel Hammer

To call a hammer the user needs only to specify the hammer number (IHAMR) from a list of hammers in the file. There exists an option (IHAMR = 0) that allows the input of all hammer parameters. These parameters are in order:

NAME	an alphanumeric string of up to eight characters.
HM(I)	weight of the I-th ram segment in kips for all I(I=1,M).
STH(I) ...	stiffness of the I-th ram segment in kips/inch for I = 1, M-1.

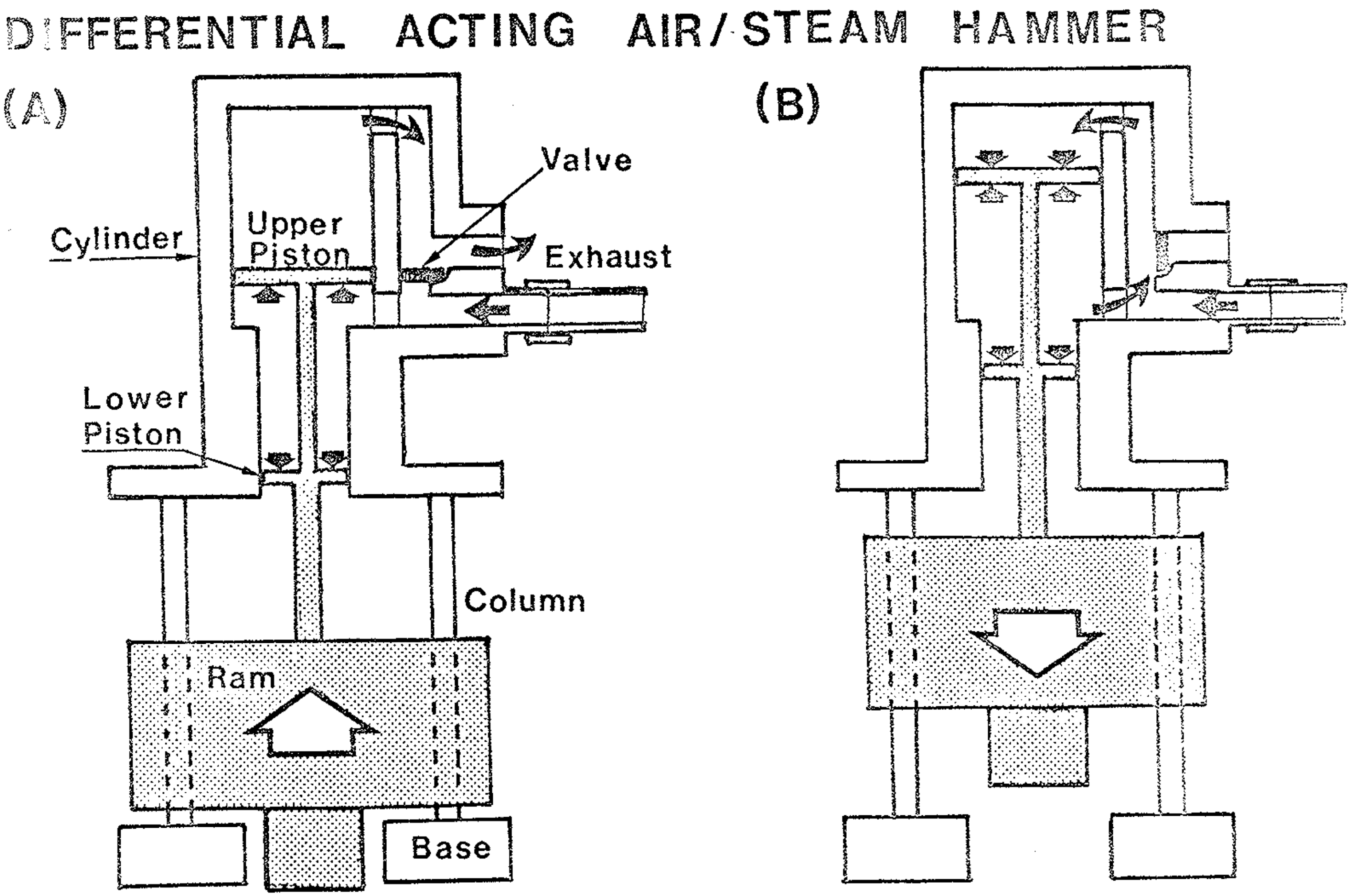

FIGURE 3-10: DIFFERENTIAL ACTING AIR/STEAM HAMMER
(A) AFTER IMPACT (B) DURING FALL

should fall in order to provide a kinetic energy equal to E:

$$\text{STROKE} = \text{STRM}\ (1 + \frac{\text{PSTEAM}}{\text{PLIM}}\ \frac{\text{WA}}{\text{W}}). \qquad (3\text{-}24)$$

Unfortunately, the quantities STRM and PSTEAM are often lower than specified since the ram might not rise high enough or pressure losses occur and other losses might occur during the fall. For this reason it is common to multiply the effective stroke of both single and double acting hammers by an efficiency, EFFICY, which is a number less than or equal to one. The ram impact velocity then becomes:

$$\text{VFALL} = \sqrt{(\text{STROKE})\ (\text{EFFICY})2\text{G}} \qquad (3\text{-}25)$$

(G is the gravitational acceleration).

The mechanical model of the air/steam hammer (Figure 3-11) includes M masses and M-1 stiffnesses to represent the ram. Mass M+1 is the cap mass (capblock plus helmet) and the stiffness M is assigned to the capblock stiffness. In most cases an air/steam hammer is modeled with only one ram mass and no ram stiffness (M = 1). Coefficients of restitution and "DS-values" (see Section 3.2.2) are applicable to the cap cushion, the pile top cushion (if present) and the pile top.

As an addition to this active hammer portion a passive one is considered consisting of MA masses and stiffnesses that represent the hammer assembly. This assembly is assumed to rest on the helmet before impact and to fall freely after impact until an impact of assembly with cap occurs.

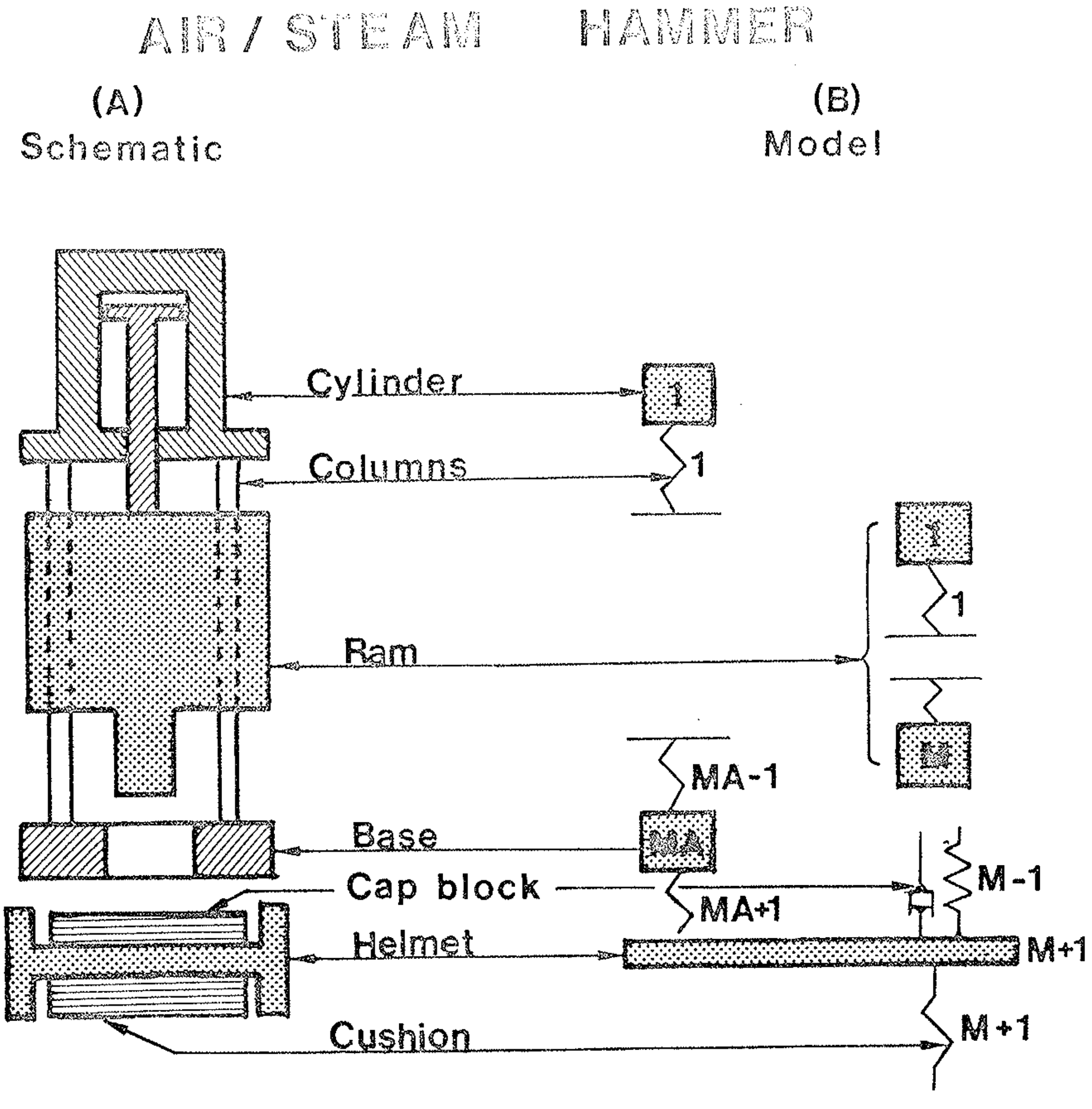

FIGURE 3-11: AIR/STEAM HAMMER (A) SCHEMATIC AND (B) WEAP MODEL

According to Figure 3-11 the model of the assembly will consist of MA masses and MA stiffnesses. Usually, MA equals two. Then the weights correspond to cylinder and base weights and the two stiffnesses should be derived from that of the ram guide bars. Since the impact of the assembly is uncushioned it is recommended that for both springs in this system the same value be used, namely, twice that of all assembly columns. In this way the overall flexibility of the assembly is correctly represented without much sacrifice in accuracy. The flexibilities of both the helmet and lower assembly mass are extremely small and can hardly be modeled as elastic bodies. A coefficient of restitution and a "DS-value" are used in the program to model this assembly drop as realistically as possible.

3.3 Pile

The pile model consists of springs, masses and dashpots (see Figure 3-12). The pile is divided in N segments whose lengths are given by

$$DL = ALPH(I) \quad (XPT) \tag{3-26}$$

where XPT is the total pile length and ALPH(I) is a multiplier which is normalized (by the program) such that:

$$\sum_{I=1}^{N} (ALPH(I)) = 1.0 \tag{3-27}$$

The mass of the I-th segment is

$$PM(I) = \overline{RP} \quad \overline{(AP)} \quad DL \tag{3-28}$$

M	the number of ram masses. It can be determined by dividing the ram length by 2.5. M should be greater than or equal to two for all Diesel hammers.
HM(M+1) ...	weight of anvil in kips
STH(M) ...	stiffness of last ram element and anvil combined in kips/inch (see Equation 3-4).
TDEL	combustion delay in seconds (values between 0.001 and 0.0025 seconds are normal for regular injection).
VFIN	final volume or combustion chamber volume in cubic inches.
DEPIB	distance between exhaust ports and impact block (anvil) in inches.
ARAM	cross sectional area of cylinder in square inches.
P1, P2,...., P5	combustion pressures for up to five fuel settings in pounds per square inch. Note that only P1 must be given. Default of P1 causes the use of P1 = 1000 psi.
EFFICY ...	a hammer efficiency as defined for the air/steam hammer.
STRM	maximum stroke in inches as specified by the manufacturer. This value will be used as a convergence criterion on the stroke. It is assumed that the stroke cannot exceed this value.
EXPP	exponent for the expanding, combusted gases. A value between 1.2 and 1.4 is reasonable.
POWSCAV ..	should be set to 1 if the scavenging is independent of stroke.
DINJ	distance between ram location at which atomized fuel is injected and anvil in feet. DINJ = 0.0 for regular fuel injection.
TS	the divation of atomized fuel injection or the divation of ignition in general.
ITYPH	hammer type: here=1.001 for open end diesel.

4.3 Closed End Diesel Hammers

The data needed for the complete description of a closed end or a vacuum chamber (VCH) hammer are (in addition to those for open end hammers) as follows:

ART	the cross sectional area of bounce chamber in square feet.
DEPBB	the distance between the combustion chamber ports and the top of the combustion chamber in feet (not for VCH).
DSP	the distance between the pressure tank ports (only if present) and the top of the bounce chamber in feet. For VCH this is the distance that the ram travels upward before the vacuum chamber pressure starts to decrease.
DBBT	the distance between the anvil and the top of the combustion chamber minus the ram length in feet (not for VCH). Note that DBBT - DEPBB = DBCIB as used in Equation 3-15.
RWH	the hammer assembly weight, i.e. that force which cannot be exceeded by the bounce chamber (gage) pressure times ART (not for VCH).
EXPB	the exponent used for calculation of the bounce chamber pressure (usually 1.4).
VCT	the volume of the compression tank in cubic feet. For VCH this is the initial vacuum chamber volume (at the time when the pressure starts to decrease).

Note that ITYPH is to be given as 2.001 for all closed end diesel hammers except vacuum chamber hammers which are type ITYPH = 1.001. Note also that STRM is disregarded for ITYPH = 2.001.

4.4 Air Steam Hammers

These hammer types require the following input values:

(a) As for diesel hammers:

NAME

HM(I), I = 1, M

STH(I), I = 1, M-1

M

P1 (Here, maximum (gage) pressure for which uplift just occurs in psi; for double acting air-steam hammers only).

EFFICY

STRM which is here the regular working stroke in inches.

RWH (for double acting hammers only).

ITYPH (here equal to 3.001, i.e. air-steam hammer).

(b) In addition to this data, hammer assembly information is necessary if its effect is to be studied:

AM(I) .... the assembly weights in kips for I = 1, MA.

STA(I) ... the assembly stiffnesses in kips/inch for I = 1, MA.

MA .... the number of assembly stiffness values. Note that MA = 0 causes the assembly analysis to be ignored.

4.5 Other Hammer Related Input Information

This data is required (often at option) even if the program stored hammer information is used.

IOSTR .... (Ignored for air/steam hammers).

If set equal to 1 it will cause one stroke (either specified or unspecified) to be analyzed. Thus, no iteration on stroke will result. If equal to 1, the stroke specified in STROKE (see below) or the program assumed stroke (5.0 feet for open end and STRMAX for closed end hammers) is analyzed and iteration on maximum fuel pressure is performed.

If 0 (or not specified) then the maximum fuel pressure (P1, ..., P5 as specified by IFUEL) is kept constant and iteration on stroke is performed.

Generally speaking, hammers that are operated at a fixed fuel setting should be analyzed with an iteration on stroke. There are hammers, however, (e.g. BSP) which do not have a fixed setting and which, therefore, should be analyzed by assuming a stroke iterating on fuel setting (combustion pressures).

The engineer must be aware that the fixed stroke option may provide unreasonable answers. For example, a stroke specified relatively high together with a low soil resistance may not be achieved in the field.

IFUEL .... (Ignored for air/steam hammers).

If set to 1, 2, ---, 5 the corresponding pressures P1, P2, ---, P5 will be used. Thus, IFUEL amounts to a fuel setting. If the corresponding pressure is zero P1 will be used; if P1 is zero 1000 psi is assumed.

IFUEL may or may not correspond physically to fuel settings at the hammer. Measurements of combustion pressures at reduced fuel settings are only available for a DELMAG D-30 Hammer. Using the results from this test as a guide proportional pressure reductions were determined for other hammers. Use of the IFUEL value should be restricted to parameter studies. In general, it is advisable to determine first the maximum stroke using IFUEL = 0 or 1. If it is necessary to limit stroke (e.g. stress limitations) then a fixed stroke (IOSTR = -1) analysis can be made for a similar stroke.

It is then, when hammers with variable fuel pumps are used, an easy task to adjust the fuel pressure in the field such that the analyzed stroke is actually obtained.

TDEL ..... Is the combustion delay in seconds. It overrides the value set in the diesel hammer data. If negative (hammers with fuel injection have only positive time delays since here TDEL is the delay after injection) preignition will result. As discussed earlier 0.001 to 0.0025 seconds is reasonable.

STROKE ... For diesel hammers: Is a starting value for the ram stroke in feet if IOSTR = 0. It is the stroke analyzed for IOSTR = 1 or -1.

For air/steam hammers this value overrides the hammer information (both program or user supplied).

EFFICY .... Overrides the efficiency supplied in the hammer information (applicable to all hammer types).

PSTEAM .... The actual air/steam pressure used. To be supplied for differential acting hammers only. If not given PSTEAM will be set to P1, i.e. the maximum value.

RWH .... Overrides the hammer assembly weight supplied in the hammer information. Ignored for open end diesels or single acting air/steam hammers.

4.6 Driving Accessories

The term "Driving Accessories" refers to the capblock, the helmet and a possible pile cushion. There are a variety of such accessories available and standardization is hardly possible. The User's Manual contains data for a few frequently encountered systems.

In the case of no capblock the anvil stiffness will be doubled and an equal stiffness assumed between helmet and anvil. This assumption seems justified in light of the uncertainties involved in metal to metal impact. The data to be specified for the accessories is then:

HM(M+2).......Weight of cap (helmet plus capblock including any pile top adapter) in kips.

STH(M+1) ... Stiffness of capblock in kips per inch.

STH(M+2) ... Stiffness of pile cushion in kips per inch.

In addition to the weight and stiffness values, coefficients of restitution should be specified for all non-elastic materials and/or impact interfaces.

Four values are required:

EANV	Coefficient of restitution (C.O.R.) of anvil in the case of diesels or that of the capblock for air/steam hammers.
ECAP	C.O.R. of capblock (diesel) or assembly (air/steam).
EPT	C.O.R. of pile top.
ECUS	C.O.R. of pile cushion.

Default (i.e. input not specified) results in all coefficients to be set to 0.85 with the exception that ECUS would be set to 1 if no cushion is present. The User's Manuel contains suggested values. Other recommendations are: for the anvil and for steel pile tops 0.85, for pile tops of concrete 0.7 and timber, 0.5. If a pile cushion is used with ECUS < 1 then greater EPT values should be chosen. Note: actually, EANV is a hammer property and should be stated with the hammer. However, since this value is hardly measurable and can only be judged by comparing analysis results with measurements, some flexibility is given here by providing the opportunity for change.

4.7 Pile

There are several options which govern the input of the pile properties. The two option parameters to be considered are:

NCROSS ... = 0 means uniform pile

>0 means non-uniform pile

and

IPEL ..... = 0 means automatic generation of pile segment parameters

EP(I) .... elastic modulus in kips per square inch at XP(I)

WP(I) .... specific weight in pounds per cubic feet at XP(I)

As a last set of values those of the pile bottom XP(I) = XPT must be given.

The extended input, i.e. the input of STP(I) (pile segment stiffness), PM(I) (pile segment weight) and ALPH(I) (relative segment length values) is described in the User's Manual. Computation of stiffnesses and weights should be done according to Equations 3-28 and 3-29. Note that RP = WP/G with G being the gravitational acceleration (32.2 ft/sec^2 or 9.81 m/sec^2).

Another input allows the specification of maximum tension force, SPLICE(I), in any one pile spring. Note that the pile top has a spring that cannot transmit tension. This means that SPLICE(1) is always set to zero. All other spring tension forces are set to -5000 kips. If at certain elements other values are requested then ISPL should be set to the number of springs involved and for each spring a pair of values:

J, SPLICE(J) ... element number, maximum tension force in kips (tension is negative) be specified.

SPLICE(I) can also be specified as a "slack" value in feet. Slack is a distance which a spring can extend without exhibiting any tension force. If SPLICE(I) is given between -0.5 and 0.0 then it is assumed to indicate a slack. More information regarding this input can be found in the User's Manual.

Finally, the pile material damping parameter IBEDAM (IBD in Section 3.3) should be specified as 1 (1% of critical) for steel, 3 for concrete and 5 for timber.

= 1 means automatic generation of pile segment parameters except that the relative element lengths (ALPH(I)) are to be specified.

= 2 means that all parameters are specified as input including the relative element lengths.

N, the number of pile elements to be analyzed must be given for IPEL > 0. (For IPEL = 0, N is determined for a segment length of approximately 5 feet).

For uniform piles (NCROSS = 0) the following data is sufficient:

XPT ...... the total pile length in feet

AP(1) .... the pile top cross sectional area in square inches

EP(1) .... the pile top elastic modulus in kips per square inch

WP(1) .... the pile top specific weight in pounds per cubic feet.

Material properties are contained in the User's Manual.

For non-uniform piles the cross section and the material values must be completely defined. As it is necessary for the computer to interpolate between neighboring defined cross section values this means that discontinuities (sudden changes) have to be defined with two equal depth values the first of which specifies the quantities above the change, and the second one, those below the change. Examples are given in the User's Manual. The program accepts up to nineteen (19) cross sectional values. These are:

XP(I) .... depth at which values are specified in feet

AP(I) .... cross sectional area in square inches at XP(I)

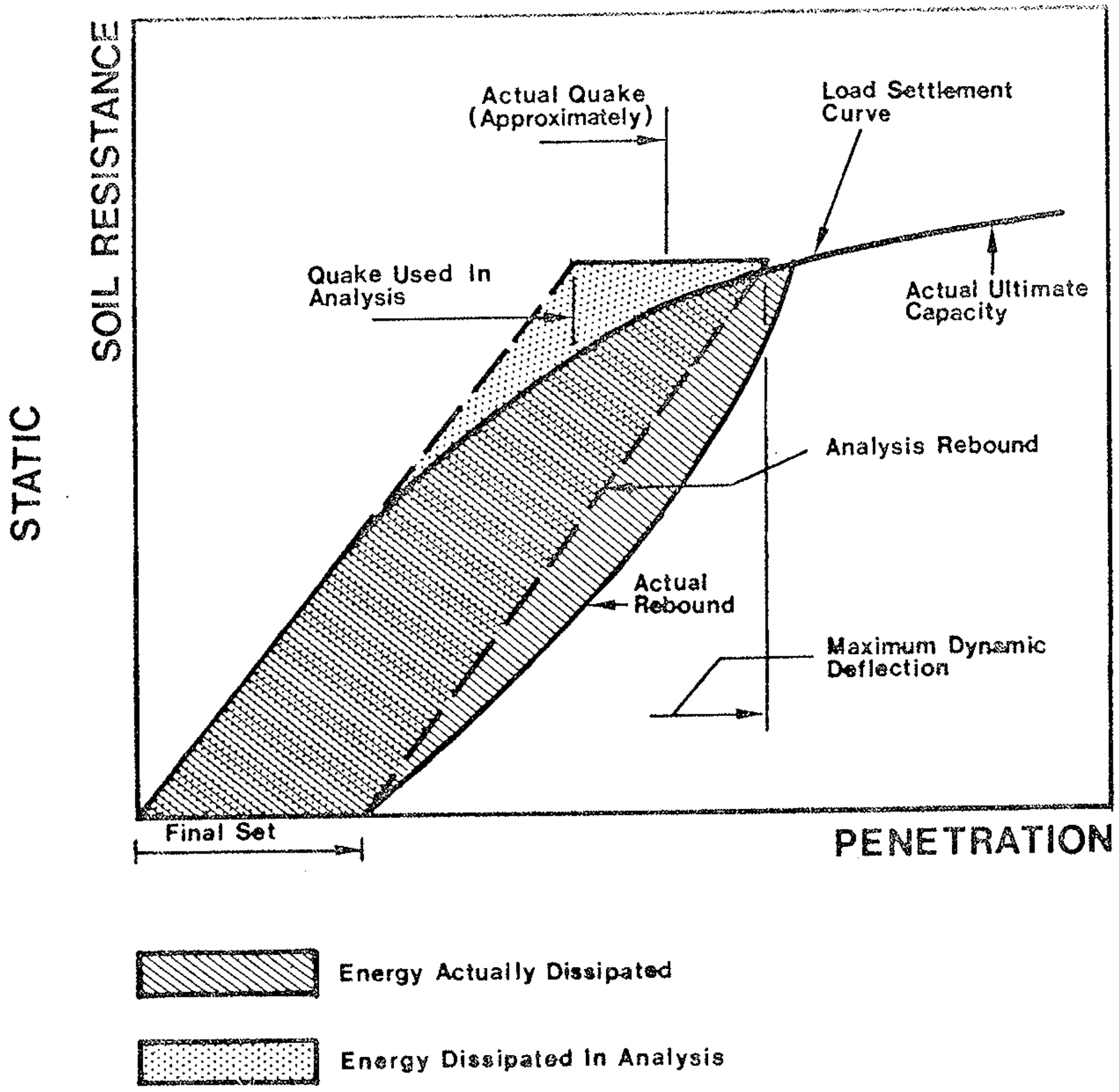

FIGURE 4-1: REAL LOAD DEFLECTION CURVE AND ITS MODEL. IN A CORRECT ANALYSIS QUAKES SMALLER THAN REAL MUST BE USED.

4.8 Soil

Soil data consists of:

quakes,

damping values,

ultimate resistance (optional),

coefficient of restitution of soil and resistance distribution.

Required values are:

QS(1) .... quake at skin in inches (default: 0.1 inches)

QS(N+1) .. quake at pile bottom (default: 0.1 inches)

Quake values were proposed in the literature between 0.1 and 0.5 inches (7). They are usually based on static load test evaluations. However, it should be noted that the assumed elasto-plastic soil resistance law is only an approximation and should allow the pile to obtain a permanent set under a realistic energy consumption (see Figure 4-1 for an example of a reasonable approximation). The questions arising from these approximations together with those of the damping model are the most serious ones with regard to wave equation applications.

Because of these questions it seems unreasonable to use the static quake values as proposed by Coyle et. al. (7). It is more likely that values between 0.1 and 0.15 inches give satisfactory results. Note that values that are too small produce a soil stiffness that can cause numerical problems.

Damping values impose a much greater problem than quake values because they affect the blow count result to a much larger degree. Recommendations are given in the User's Manual. Smith's damping values were relatively well proven during several years of use. It is for this reason that Smith's damping should be used whenever no experience with Case Damping exists.

The required damping values are:

SJ(1) .... skin damping constant in s/ft for Smith (ISMITH = 1) damping and dimensionless for Case damping.

SJ(N+1) .. toe damping constant with dimensions as before.

As for pile quantities, all soil parameters QS(I), SJ(I) and SU(I) can be specified for <u>each</u> segment in order to override the automatic conditions. The values are read when the ITYS value is negative.

The total ultimate static resistance value can be specified in three ways:

(a) RULT > 0 in tons leads to the analysis for the one RULT value specified.

(b) RULT = 0 (or blank) causes the computer to determine ultimate resistance values based on the pile impedance (EA/c) and an assumed fraction of impact velocity. There will be at most ten (10) analyses performed. If a blow count has exceeded 1200 blows/foot (100 blows/inch - 40 blows/cm) then the analysis will be halted and the results printed.

(c) RULT < 0 will cause a set of ultimate resistance values (at most 10) to be read and analyzed. These values should be given in an increasing order as the starting values of the stroke are based on this assumption. Also, the termination condition of (b) hold, again assuming an increasing order of the RULT values.

ESOIL ... is the coefficient of restitution of the soil (default 1.0). If the stroke does not converge for reason of too little energy consumption by the soil (a condition that becomes an unfortunate reality in some cases) then a lower value might be tried. However, values lower than one-half (0.5) should not be taken because of numerical stability.

The distribution of resistance foces, SU(I) can either be taken from a list of ten (10) types which are built into the program (ITYS) or, if this value is 0 or blank, it should be specified as a series of depth and relative magnitude values:

XP(I), DIS(I) ... I-th depth in feet and I-th magnitude (non-dimensional). As in the case of the pile description, discontinuities in the distribution have to be described with two identical XP(I) values. The last XP(I) value must be equal to the pile length, the first one equal to zero.

The proportion of skin to total resistance has to be specified by IPERCS ... the percentage of skin friction of total RULT. This value can also be specified as a negative number. In this case the skin friction force will be determined from the first RULT value (-IPERCS (RULT)) and will be kept at the same level for further RULT analysis. This means that only a gain of toe bearing is assumed.

4.9 Other Program Options

Other input parameters not yet described must be specified in order to obtain the desired

(a) Output type and quantity

(b) Analysis type

Output type can be obtained in printed and plotted form. Basically, the higher the IOUT (card 2.000) parameter is specified, the more output is obtained. The IOUT = 0 option causes minimum output which is recommended if more than one RULT value is analyzed (typical production run). IOUT > 9 causes plots to be produced. The use of these options as well as the more extensive print is discussed in detail in the User's Manual.

It should be noted that the program performs several analyses for one RULT value. For this reason all output quantities have to be temporarily stored until it is known that the stroke or maximum combustion pressure has converged. In order to keep the program small enough for implementation on a variety of computers, the output must be limited to certain types (forces or velocities etc.) and to a maximum number of values (number of pile segments, number of time increments).

The magnitude of the time increments has to be chosen less than critical. This critical time increment is the minimum of:

$$\mathrm{DTCR} = \sqrt{\mathrm{PM(I)/STP(I)}} \qquad (4\text{-}1)$$

for all I, or it is the time that the stress wave needs to travel through the shortest element IM

$$\mathrm{DTCR} = \mathrm{ALPH(IM)\ (XPT)}/c \qquad (4\text{-}2)$$

(if only one material is considered) and the actual time increment either for hammer or pile has to be

$$DT \leq DTCR \tag{4-3}$$

In order to accomplish this a percentage value IPHI (%) can be specified which is defined as

$$IPHI = (DTCR/DT)100 \tag{4-4}$$

This IPHI should be always greater or equal to 100. Default or if IPHI was accidentally set to less than 100 results in IPHI = 140 for diesel and 160 for air/steam hammers. It is reasonable to specify IPHI as large as 200. It should be mentioned here that the program involves checks on DTCR which go beyond Equations 4-1 or 4-2. These checks include the magnitude of damping and static soil resistance.

CHAPTER 5

PROGRAM FLOW

Only a small part of the program is actually a wave equation program. It consists of approximately one-third each input and output coding, one-sixth dynamic analysis and the other sixth, in the case of diesel hammers, of "pseudo-dynamic" and simplified dynamic analyses and general control.

By pseudo-dynamic analysis is meant that the total system is not strictly analyzed. This can be done for the rebound portion once the ram has risen a sufficient distance from the impact block. A simplified dynamic analysis is also used for the precompression period.

The following steps are performed by the program for the open end hammer, standard run,(i.e. fixed fuel, variable stroke).

(a) Read input information

(b) Assemble hammer data

(c) Determine pile segment parameters

(d) Determine soil model parameters

(e) Find stroke (either input or assumed)

(f) Determine ram velocity at exhaust ports

(g) Find initial values just before impact using a simplified dynamic analysis.

(h) Perform a wave analysis until pile rebounds and ram has risen sufficiently.

(i) Find velocity (and therefore stroke) at exhaust ports

(j) For a stroke which is less than 10% different from the assumed one repeat process (h) using the new stroke and modified initial values; for greater differences go to (g). If the stroke was within 5% of the assumed value, print and plot the required output and continue with (h).

(k) If a new ultimate resistance value is to be analyzed, determine new stroke based on previous one and continue at (f).

As an alternative (fixed stroke, variable fuel) step (j) is modified in the following manner: For a rebound stroke that is more than 5% (3% for closed end hammer) different from the assumed stroke the maximum combustion pressure value is changed and the process is continued at step (h). Of course, in step (k) no new stroke is assumed. A block diagram indicating the program flow is shown in Figure 5-1.

The steps taken for the closed end hammer (standard run) differ somewhat from those just discussed. Because of the limitations on the stroke in a closed end hammer and since the throttle setting is reduced when uplift occurs, the process is directed such that, if no other stroke is specified, the maximum stroke (Equations 15 or 20) is used for a first analysis together with the maximum fuel setting. If the soil resistance is relatively small, then a rebound stroke will result. In this case iteration is performed on stroke. For higher rebound strokes uplift would occur and, therefore, the fuel setting has to be reduced. Since the question of fuel con-

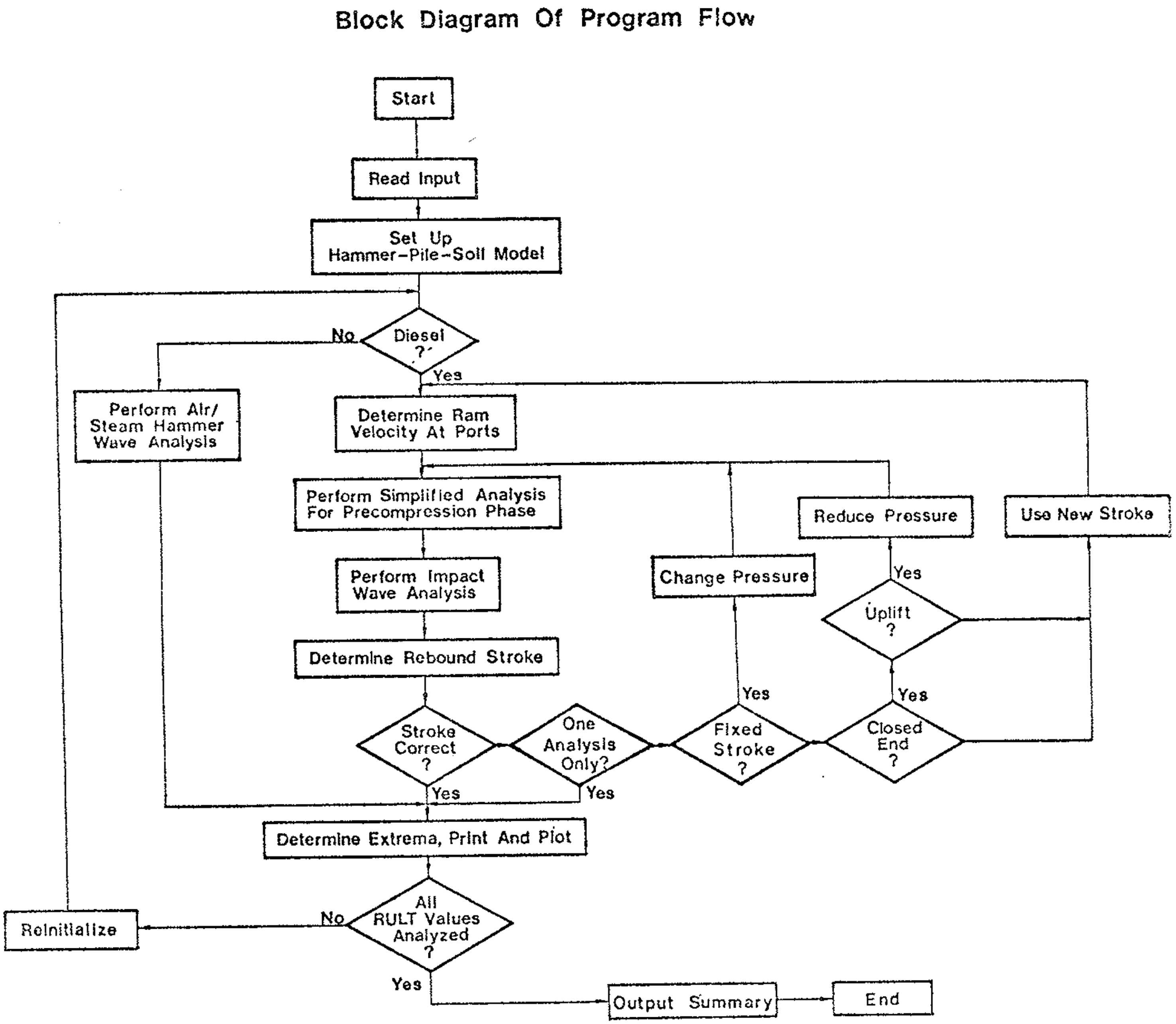

FIGURE 5-1: BLOCK DIAGRAM OF PROGRAM FLOW

sumption is not of importance and since the injection pumps usually employ continuous rather than discrete settings, an arbitrary reduction of 10% of maximum combustion pressure is used. This process is also repeated iteratively.

For closed end hammers (standard run) the program control always causes a decrease in hammer energy supplied and an increase in blow count. In one case this occurs due to a reduced effectiveness of the hammer blow (smaller impact velocity) and in the other case due to a reduced combustion pressure. As the latter effect is probably relatively small, the step size of 10% in pressure reduction seems to be sufficiently small.

In the open end program, iterating on stroke, the initial value for stroke is either as given by the user or taken as five feet. If a second RULT (ultimate resistance) value is used (greater than the previous one), then a stroke 20% higher than the previous result is tried. For a third or further RULT value, an extrapolation over the earlier strokes is employed. If the iterations are done on combustion pressure then the pressure from the previous analysis is starting value for the new RULT value.

A similar process is used for the closed end program except in a case where the previous result was the maximum stroke at a reduced fuel setting. In this case the maximum stroke is again assumed together with a throttle setting that is increased by one step. It should be noted that the program thereafter does not increase fuel settings. Thus, RULT values specified in decreasing order could lead to erroneous results.

The program flow of the air/steam hammer analysis is straight forward. Initial values need not to be determined and the stroke is assumed fixed. A greater energy output for higher soil resistance values has been observed, but no attempt was made here to include the effect of variable stroke.

CHAPTER 6

PROGRAM PERFORMANCE

6.1 Introduction

Both the program and the hammer data were extensively tested against measurements. Measurements consisted of pile-top force and velocity and, in two cases, combustion-chamber pressure records. In addition, blow count and stroke was recorded in many cases. The program testing often proved to be difficult since all of the relevant information was not always available. The information required consisted of three different groups.

(1) Driving system data (cap weight, capblock and cushion stiffness plus all four coefficients of restitution). While the cap weight was usually accurately known, stiffness and coefficient of restitution was either guessed or chosen from a large range of possible values.

(2) Thermodynamic data (combustion delay, combustion pressure, expansion coefficient). The combustion delay was fixed at two milli-seconds for all hammers with regular fuel injection. It was determined for atomized injection by parameter studies. Combustion pressures were measured in some cases and determined from stroke and/or force measurements in other cases. In order to do this properly, the expansion coefficient was fixed at 1.3.

(3) Soil data (skin and toe quake, skin and toe damping and the distribution of the resistance forces). The quakes were mostly chosen as 0.1 inches. However, there were a few exceptional cases where larger values had to be used to achieve satisfactory agreement between computed and measured

values. Damping values were difficult to determine in that they directly affected the stroke and, therefore, the pile top stress and velocity at impact and the blow count. The distribution of the resistance forces affected the shape of force and velocity curves.

Counting the resistance distribution as only one unknown (although it involves all elements) the above list indicates that often as many as 14 different parameters had to be determined for each test case.

Parameter studies performed by the TTI researchers (6) were basically aimed at matching the predicted with the observed blow count. In the current study, however, the attempt was also made to match force, velocity, pressure and stroke. The parameters given in the literature were often found to be insufficient. The current results shed some light on the quality of the predictions of pile force as well as blow count that may be achieved. Since the information regarding hammer performance in the field was often limited, the answers obtained give an idea of the accuracy which can be expected when the program is used. Thus, the comparisons discussed below can be regarded as an assessment of expected program performance. Many of the problems which have been reported for wave equation programs may be partially the result of excessive expectations.

6.2 Data Selection

A vast amount of dynamic and static data was gathered during the course of the Case Western Reserve University piling research projects. In addition, the consulting activity of the authors and the work of other agencies which also use the Case Method of pile testing have contributed to the data that was available for pile testing.

The results of 16 different pile analyses are presented in this report. The attempt was made to cover a large number of different hammers and pile types. Names of test piles, references and other basic information are given in Table 1.

There are a relatively large number of DELMAG hammers among the hammer types tested. The reason is that a substantial amount of testing, including combustion pressure and stroke measurements, was conducted on these hammers. Stroke is an especially important quantity in this work and it must be emphasized in program testing.

Only one concrete pile is represented in the data. No timber pile data was included. Both concrete and timber introduce additional uncertainties into the evaluation of the program, mainly because of the unknown conditions at the pile top (pile cushion of conrete piles and pile top quality of timber piles).

6.3 Representation of Results

Figures 6-1 through 6-16 contain comparisons of computed with measured forces, velocities and combustion pressures all as a function of time. Velocity comparisons of this kind are certainly a first in Wave Equation test runs, and the large amount of force vs. time curve comparisons is unequalled. For plotting, the curves were shifted in time such that the impact time was in agreement. In addition, the measured forces were shifted vertically such

TABLE 1: DESCRIPTION OF TEST DATA

Pile No.	Name	Source	Type	Length feet	Hammer	Type
1	FEC 72	C[1]	HBP	40	Delmag D12	OED
2	FEC 72	C	HBP	75	Delmag D12	OED
3	FEC 75	C	HBP	40	Delmag D12	OED
4	Purdue	(10)[2]	HBP	50	Delmag D12	OED
5	DTP 3	(11)	18x18 PC	60	Delmag D22	OED
6	FEC 71	C	HBP	70	Delmag D30	OED
7	Bismark	C	HBP	160	Kobe K22	OED
8	GRTP1	C	HBP	60	Kobe K22	OED
9	K25 VP	(12)	HBP	30	Kobe K25	OED
10	Georgia	(15)	Pipe	40	MKT DE30	OED
11	B-N	S[3]	HBP	119	MKT DA35B	CED
12	CR 4	(13)	Pipe	90	LB 440	CED
13	DTP 33	C	Pipe	41	LB 660	CED
14	Phila 78	(14)	Pipe	43	Vulcan 01	A/S
15	V08VP	(12)	HBP	30	Vulcan 08	A/S
16	V08VP	(12)	HBP	30	Vulcan 08	A/S
17	LaV016	S[4]	Pipe	200	Vulcan 016	A/S

[1] Records from author's consulting practice.
[2] Numbers in parentheses pertain to references at end of text.
[3] Special records, were obtained from New York Department of Transportation
[4] Special records, were obtained from Soil Exploration Company.

that the computed and measured precompression forces agreed. This shift was necessary since the precompression force was often subtracted from the measured force curves because of its static nature.

Almost all figures contain two time scales, milliseconds and L/c units. The L/c units are often helpful in recognizing characteristic effects in the stress waves. One figure (6-16) is also included which shows the automatically plotted three dimensional representation of force vs. pile length and time. These plots are instructive where wave propagation considerations are concerned but of less use in the program testing effort.

The figures always show that portion of the record that was analyzed by the accurate analysis portion (excluding the simplified precompression and expansion phases). This produces plots which are spread over time such that the higher frequency components of the curves become apparent.

6.4 Results

Table 2 contains both observed and computed values of the program results, RULT (total static pile bearing capacity) in tons, blow count in blows per foot and stroke (or an equivalent quantity for closed end hammers). In fact, RULT was determined using either the Case Method (1), the CAse Pile Wave Analysis Program (1), or a static load test. Unfortunately, the static load test was usually not performed when stroke measurements were taken. However, it is felt that so many test cases were solved that sufficient confidence in the program is obtained.

TABLE 2: COMPARISON OF COMPUTED WITH OBSERVED QUANTITIES FOR TESTED DATA

		Measured		Predicted	
Pile No.	Bearing Capacity tons	Blow Count bl/ft	Stroke ft	Blow Count bl/ft	Stroke ft
1	16[C]	6	4.0±.2	9	4.0
2	70[A]	27	6.0±.3	28	5.6
3	60[C]	24	5.4±.1	26	5.4
4	83[L]	40	5.5±.1	36	5.6
5	10[A]	12	4.0±.1	8	4.1
6	125[A]	N/A	N/A	21	5.5
7	200[L]	500	7 (1 plug)	102(150)	6.6(5.5[P])
8	120[A]	41	6 (1 plug)	37	5.5[P]
9	300[C]	120	8.0±.3	151	8.0
10	130[L]	107	N/A	114	8.7
11	31[A]	25	N/A	19	4.0
12	180[L]	R*	Maximum	R	Maximum
13	350[A]	R	Maximum	R	Maximum
14	75[L]	43	Normal	44	---
15	8[L]	6	Normal	7	---
16	260[C]	184	Normal	R	---
17	275[A]	55	Normal	50	---

[P] Using Preignition and reduced fuel pressure

[C] Case Method

[A] CAPWAP Analysis

[L] Load Test

*Refusal ... no noticeable set

Pile No. 1

This pile was driven for a hammer performance test. Combustion chamber pressures and stroke were measured in addition to both pile top acceleration and force. Using the Case Method static capacity prediction as the RULT value a WEAP run was made. The resulting pile top force and combustion pressure are shown together with the measured quantities in Figure 6-1. Maximum force is underpredicted by about 8%. The curve behavior follows the measured curve closedly except that it is somewhat smoother. It should be mentioned that the record portion after time 2L/c after impact is mainly governed by the soil model and is only, to a smaller degree, influenced by the hammer model.

The pressure curves show basically the same behavior except that the measured one is somewhat higher in the beginning and lower later on. Note, however, that the plot is a pressure vs. time plot and that minute changes in ram position appreciably alter the pressure behavior. Since the stroke was determined correctly one can consider the overall pressure behavior to be sufficiently accurate. The force effect on the pile from pressure differences is rather small (100 psi pressure correspond to about 10 kips force).

Pile No. 2

This pile was tested under similar conditions to Pile No. 1. The difference was that a heavy plate was added at the toe. This additional mass accounts for the third force peak (Figure 6-2). This force curve was very well predicted by the program. (Better than 5% agreement for the maximum).

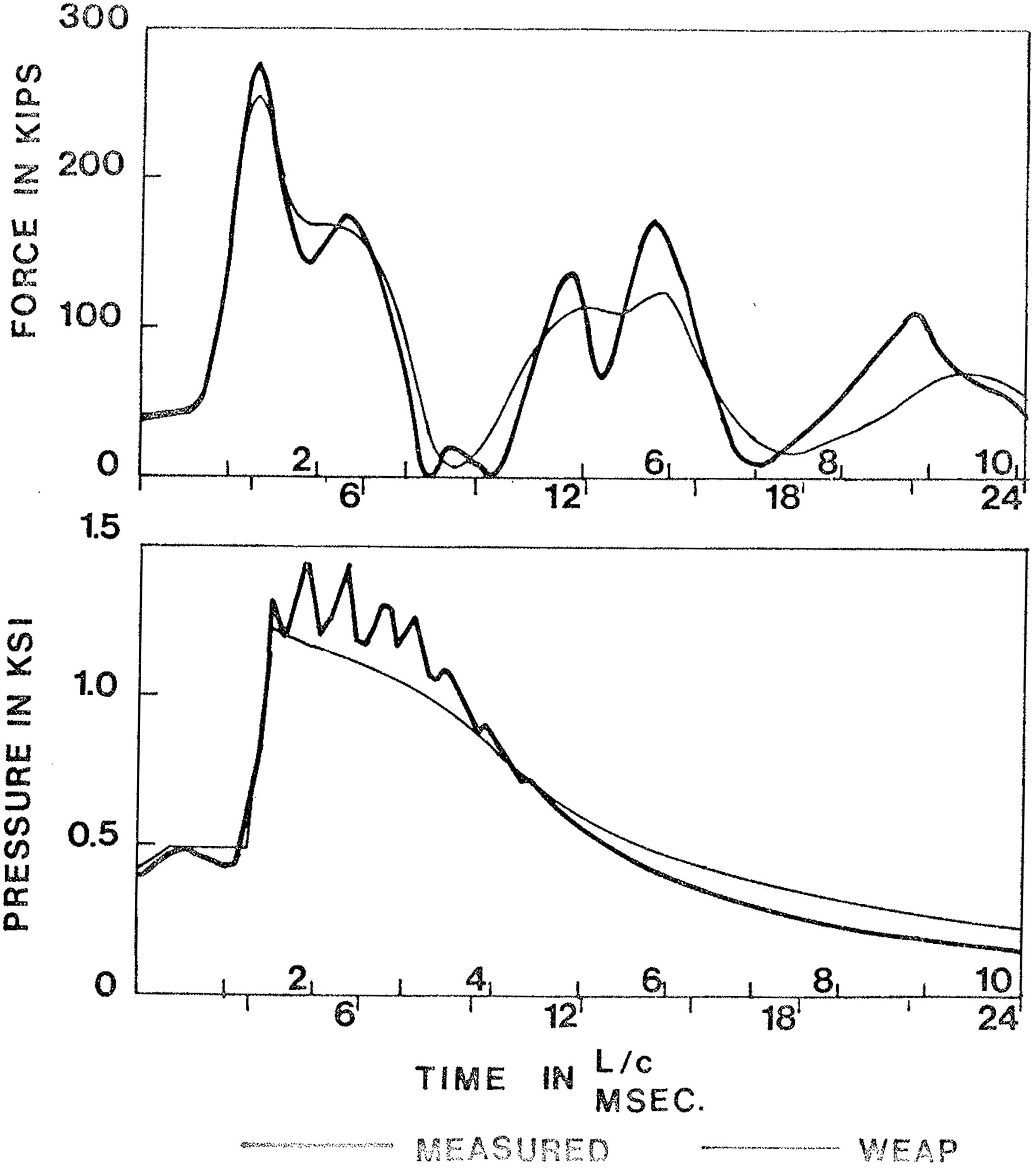

FIGURE 6-1: COMPARISON OF PREDICTED WITH MEASURED PILE TOP FORCES AND COMBUSTION PRESSURES FOR PILE NO.1.

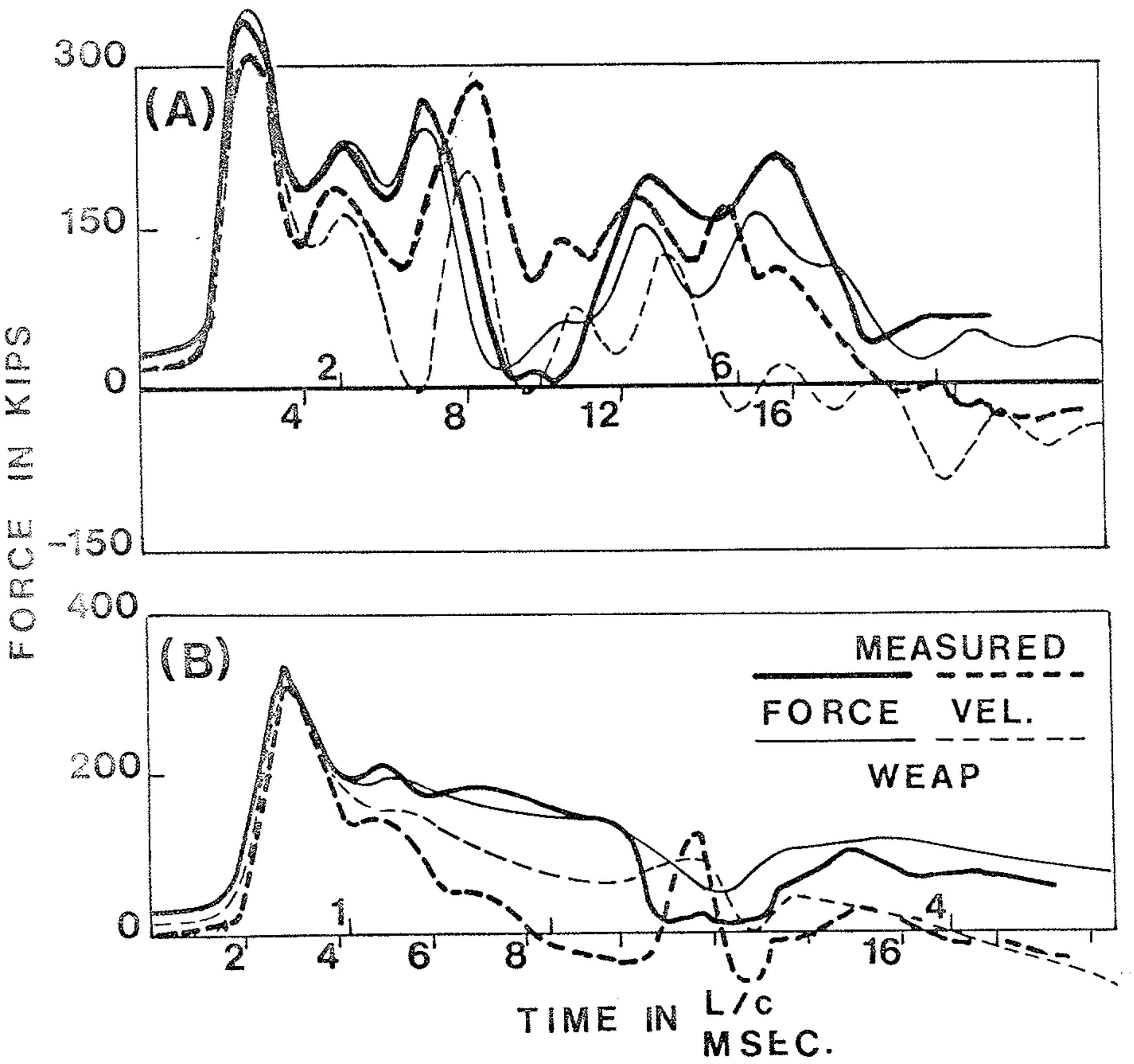

FIGURE 6-2: COMPARISON OF PREDICTED WITH MEASURED PILE TOP FORCE AND VELOCITY FOR (A) PILE NO. 2 AND (B) PILE NO. 3

The velocity curve (note that velocity curves are plotted after multiplication by the proportionality factor EP(AP)/c) however, though similar in character, deviates before time 2L/c after impact. This deviation is not considered critical since the blow count was determined rather accurately. Also, the calculated stroke was found to be in good agreement with the measured one.

Pile No. 3

This pile was an extension of Pile No. 1. Again force, (Figure 6-2b) stroke and blow count agreement is very good. It is interesting to note that the force shows a rather smooth behavior while the velocity displays a peak at the time of the wave return (10 milliseconds). The maximum force predicted showed an agreement within 5%.

Pile No. 4

Another well-controlled hammer test was performed on the campus of Purdue University on the occasion of the ASCE Specialty Conference in 1972 (see Reference 10). The force and velocity match of Figure 6-3 is quite good (especially at the time of wave return). The maximum force was overpredicted by 11% and the blow count was underpredicted (36 vs. 40 measured). It may be that a force transducer reduced the force peak to some degree. This transducer was inserted between hammer and pile top and utilized steel plates at top and bottom for attachment. The weight of these plates was not modeled and the additional contact area was not considered in the analysis.

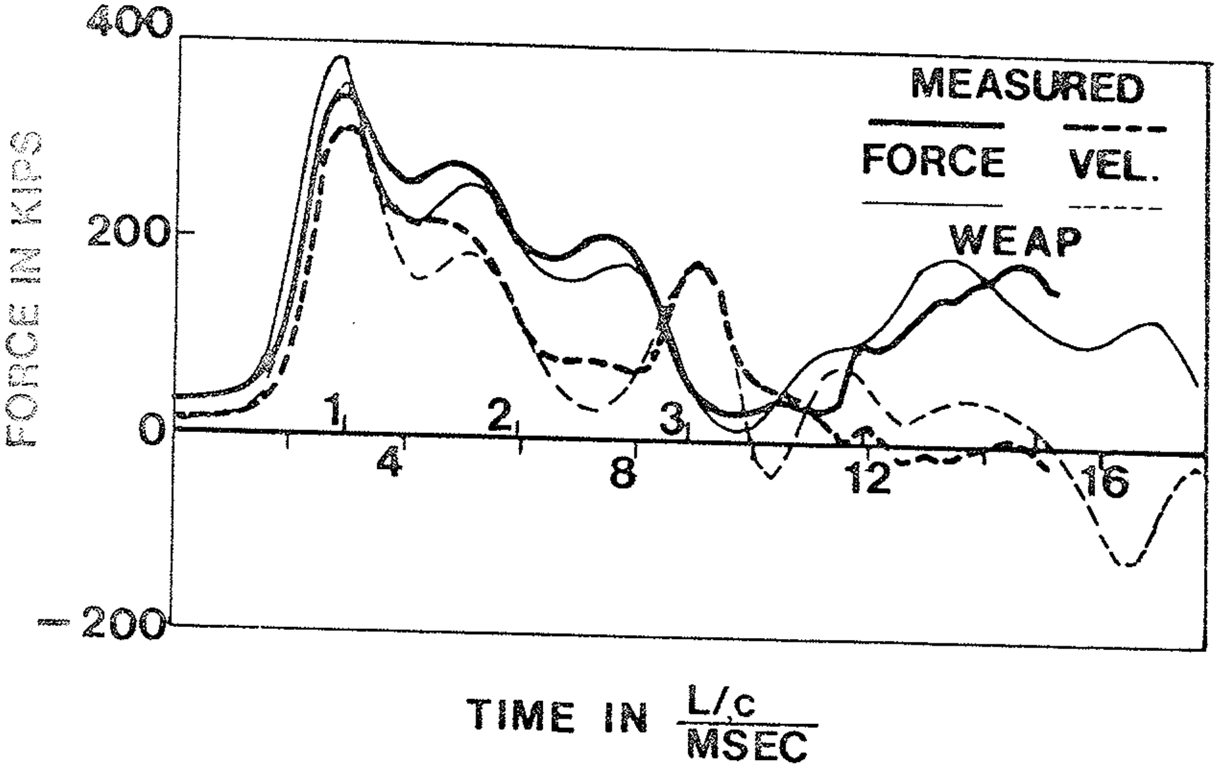

FIGURE 6-3: FORCE AND VELOCITY MATCH FOR PILE NO. 4 (PURDUE)

Under these circumstances the results cannot be expected to be extremely accurate.

Pile No. 5

This pile was of concrete and was tested within a special research project of Case Western Reserve University (11). In order to evaluate Whether or not the "easy driving case" can be modeled correctly, an early record was selected with a resistance approximately equal the hammer plus pile weight. This case represents the worst condition regarding tensile stresses. Figure 6-4 shows a very good agreement for the force (8%) considering the uncertainties of cushion properties. The measured velocity shows a higher peak at the time of the wave return which is, perhaps, due to an improper damping assumption. However, for soil resistance values as low as the one used here, a much better agreement seems to be a matter of luck.

Pile No. 6

Another special hammer performance test, this time a DELMAG D-30 hammer, was used for comparison. As can be seen in Figure 6-5 all quantities agree very well, with a maximum force difference that is negligibly small. The computed pressures are somewhat low but for the reasons given for Pile No. 1. These differences are of relatively little concern.

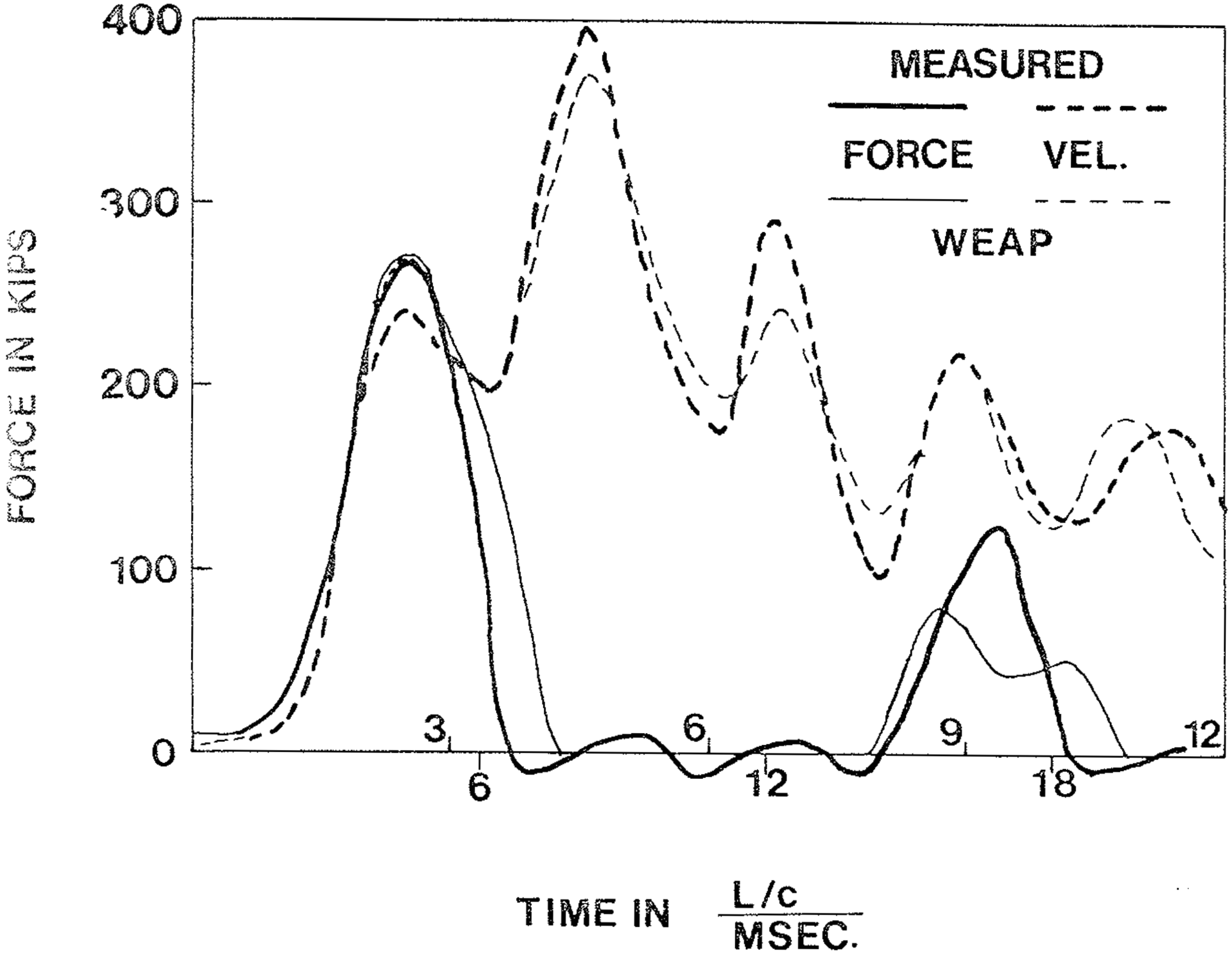

FIGURE 6-4: FORCE AND VELOCITY MATCH FOR PILE NO. 5
(MIAMI DTP 3)

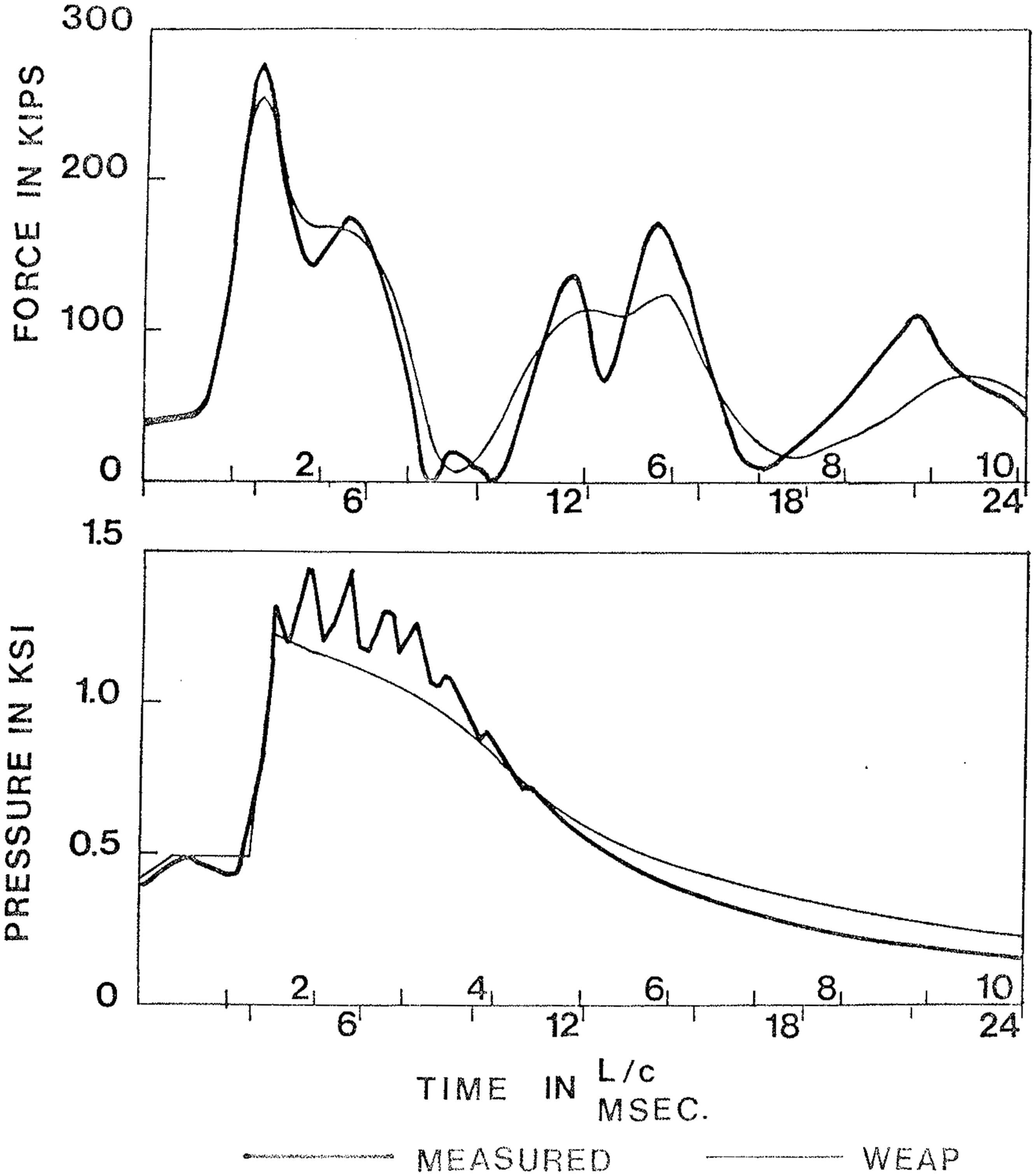

FIGURE 6-5: FORCE, VELOCITY AND PRESSURE MATCH FOR PILE NO. 6

Pile No. 7

This case was selected for two reasons. First, it was a pile driven by a Kobe K22 hammer and second, an exhaust plug was installed into the hammer in order to increase the stroke. The plug produces slower exhausting and, therefore, adds to the pressure in the cylinder after the ram has cleared the ports.

The results shown in Figure 6-6a were produced by a "regular" analysis, i.e. assuming normal hammer performance. It can be seen that the stroke was slightly underpredicted while the force was too high by 18%. Also, the blow count was much smaller than recorded (102 vs. approximately 500). It can also be observed that the measured force increased during impact at a much lower rate.

It was concluded that the hammer both preignited and had a reduced combustion pressure due to poor scavenging. Reanalyzing with a time delay of -0.001 (1 millisecond preignition) and reduced fuel setting (IFUEL = 3) produced the force match of Figure 6-6b. This match is vastly improved and so is the blow count. Since the condition of a plug in the ports cannot be modeled by the program, it is not surprising that the stroke was now smaller than observed (5.5 feet). It can be argued that the effective stroke was indeed about 5.5 feet which indicates a hammer efficiency of 79%.

It is interesting to note that a second plug increased the actual stroke by another 1.5 feet.

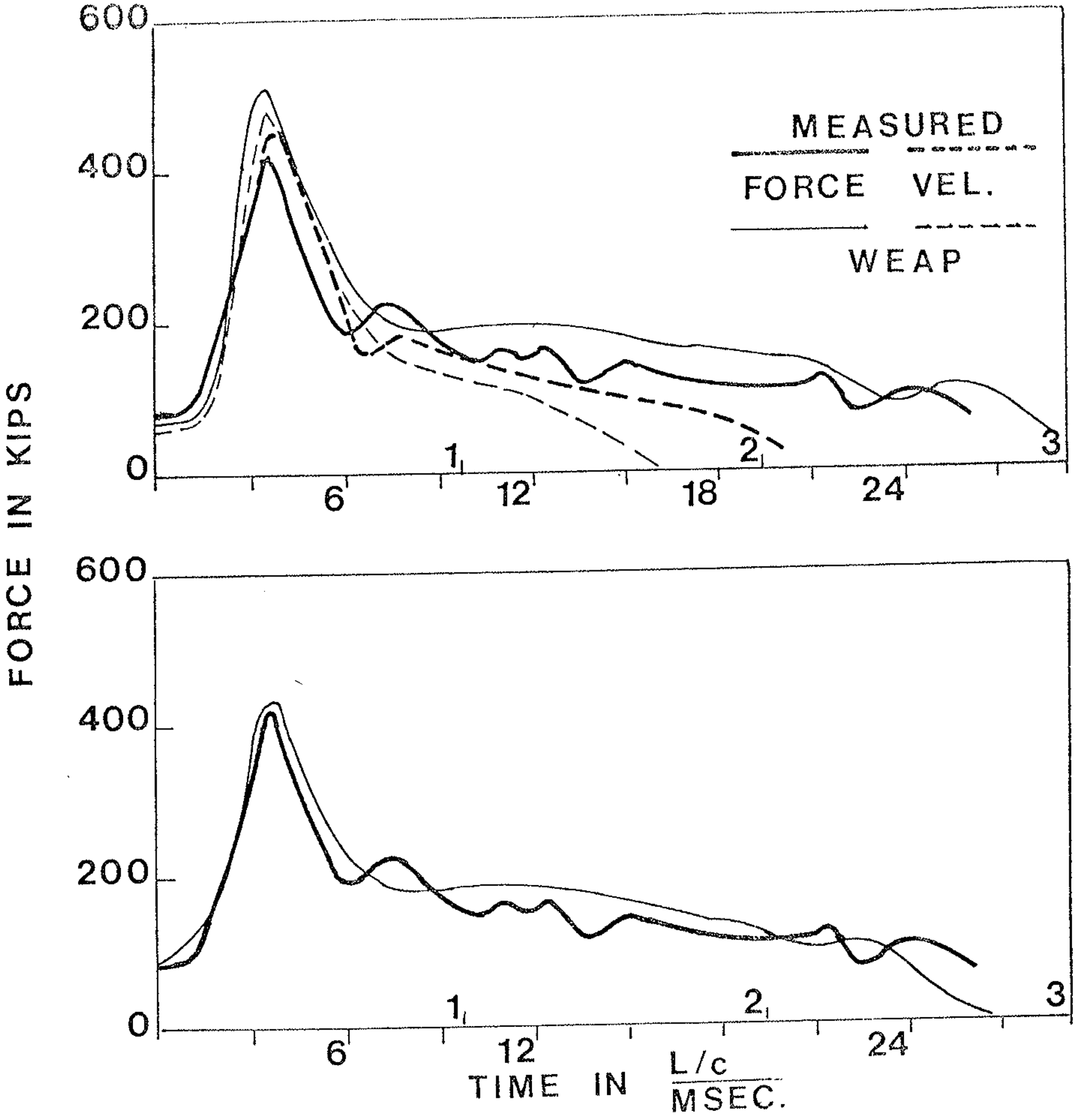

FIGURE 6-6: FORCE AND VELOCITY MATCH FOR PILE NO. 7
(A) NORMAL PROGRAM PERFORMANCE, (B)
USING PREIGNITION AND REDUCED FUEL SETTING

Pile No. 8

The data on this pile was used for testing to check a second time on the performance of the K22 with one exhaust port plugged. Using practically the same assumptions as for Pile No. 6 the match of Figure 6-7 was obtained.

The match shows a 9% overprediction in force and a deviation in behavior after the wave returns. Note that the velocity did correlate very well at impact. The later deviation in force and velocity is probably due to an incorrect soil quake (the full resistance acts too early). However, in light of the assumptions necessary to model this hammer, the agreement can be considered sufficient.

Pile No. 9

The match of force and velocity shown in Figure 6-8 was obtained for an H pile driven by a Kobe K25 hammer to rock. Agreement is very good considering that yielding occurred and the pile actually buckled at the pile top.

The measured forces appear to be higher by 17%. However, since strains in the pile were measured, these forces were actually lower and should not have been computed by using a constant elastic modulus throughout the record. The program properly determined that yielding occurred. Blow count and stroke results are very good.

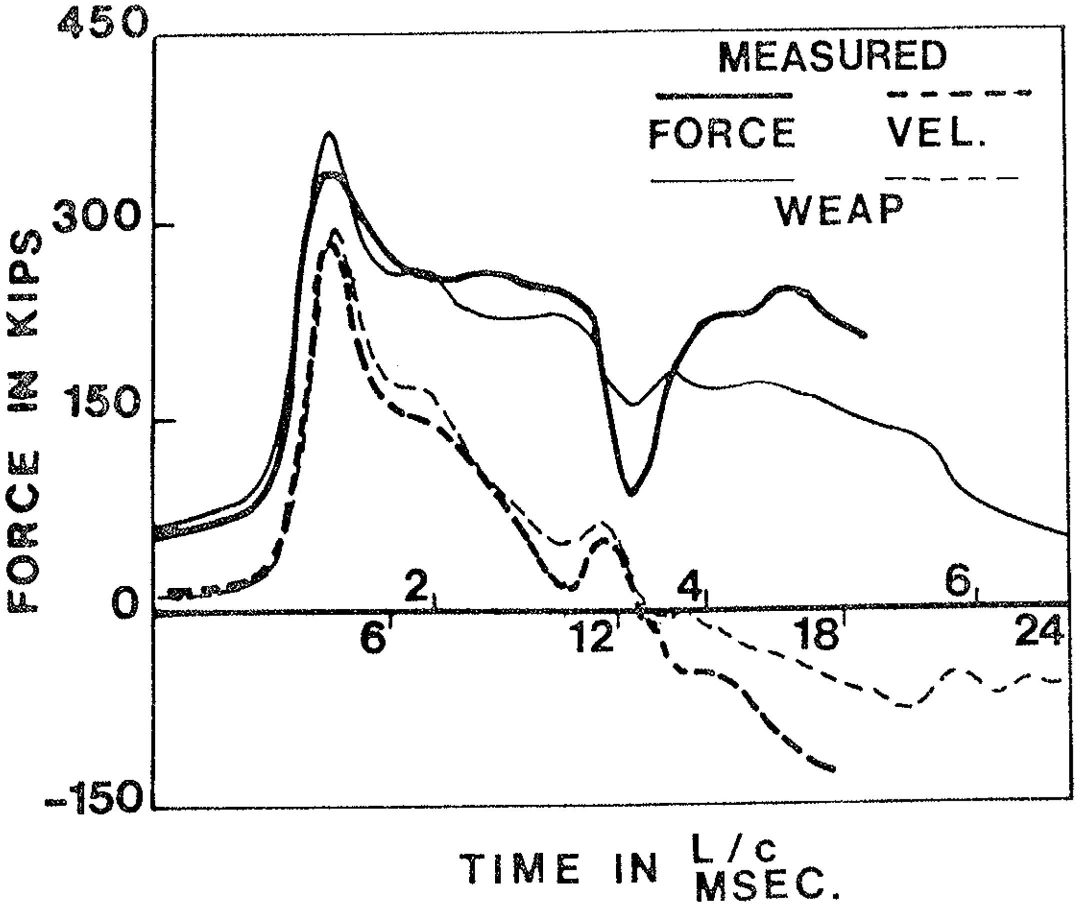

FIGURE 6-7: FORCE AND VELOCITY MATCH FOR PILE NO. 8
USING PREIGNITION AND REDUCED FUEL SETTING

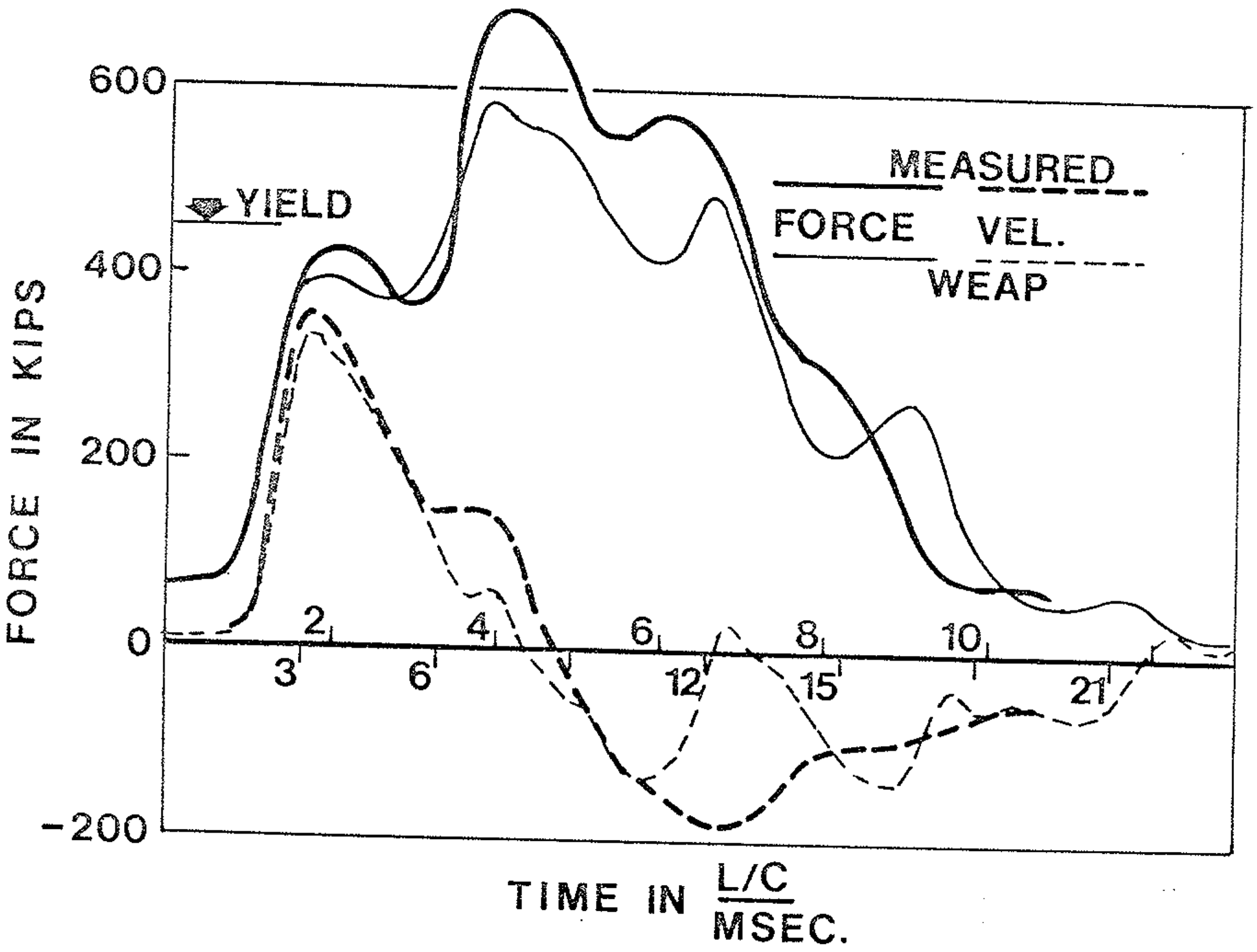

FIGURE 6-8: FORCE AND VELOCITY MATCH FOR PILE NO. 9

Pile No. 10

This pile was driven and tested as a part of the Case Western Reserve University research project (15). It was selected for analysis because it represented an open end MKT hammer (DE30). Although stroke measurements were not undertaken, it is felt that the results indicate a good agreement (blow count 114 predicted vs. 130 measured).

Figure 6-9 shows the match. The maximum force value was determined very accurately. The deviation of force after the impact peak must be due to some resistance near the top since it does not have an equivalent in the velocity curve.

The velocity match is poor at the time of wave return in a manner similarly observed for earlier piles (e.g. No's 3 and 4). This effect is not fully understood and strangely enough, it only occurs if the force valley at time 2L/c after impact is properly matched (Figure 6-6). The authors believe that this high velocity return is due to an improper model of the soil below the pile tip. This problem of a proper soil model has not been solved and should receive attention in further research activities.

Pile No. 11

The measurements on this pile were obtained by the New York Department of Transportation and are the only ones available for a closed end MKT hammer. The match shown in Figure 6-10 is good with regard to both impact and the time of wave return. Between these two times, however, the predicted force and velocity are both higher than measured. This error can

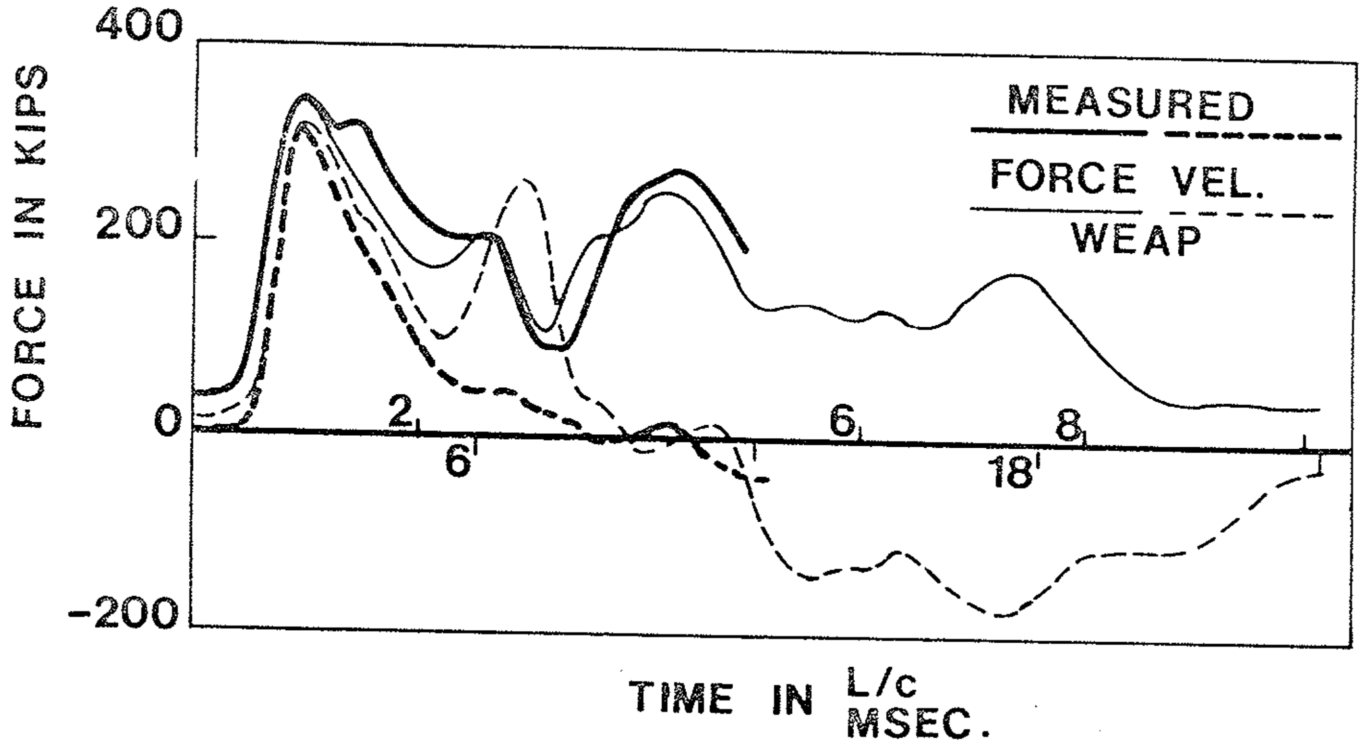

FIGURE 6-9: FORCE AND VELOCITY MATCH FOR PILE NO. 10 (GEORGIA)

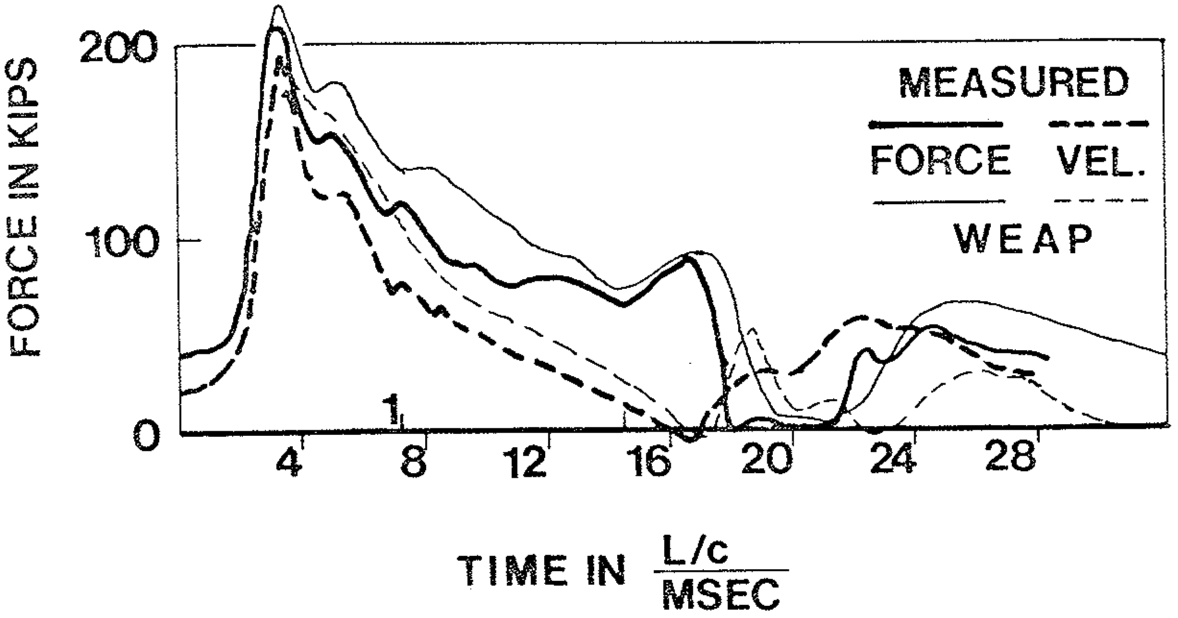

FIGURE 6-10: FORCE AND VELOCITY MATCH FOR PILE NO. 11

be due to a low combustion pressure. (Perhaps because it was in early driving and the hammer did not ignite properly). The fact that the blow was actually higher (25) than computed (19) supports this explanation.

Pile No. 12

This load test pile was restruck, after a waiting period, by a Link Belt 440 hammer. The hammer lifted off and no penetration of the pile was achieved. Both observations were correctly predicted by the program. The maximum stress prediction was within 5%. The velocity match (Figure 6-11) is in this case somewhat better than the force match. Both matches are poor, probably because of inaccurate skin resistance distribution and ignition timing. The latter event is not as well defined for atomized fuel injection as for those hammers which use the impact for atomization.

Pile No. 13

A Link Belt 660 hammer record is shown in Figure 6-12. The match is very good. (Maximum force match within 8%). As in the case of Pile No. 12, no set was observed and the hammer had to be throttled back in order to avoid lift-off.

Pile No. 14

A rather poor match (21% error in maximum force prediction) is shown in Figure 6-13 for a load test pile from the Case research program (14). The hammer was a Vulcan No. 1, powered by compressed air. Unfortunately, capblock

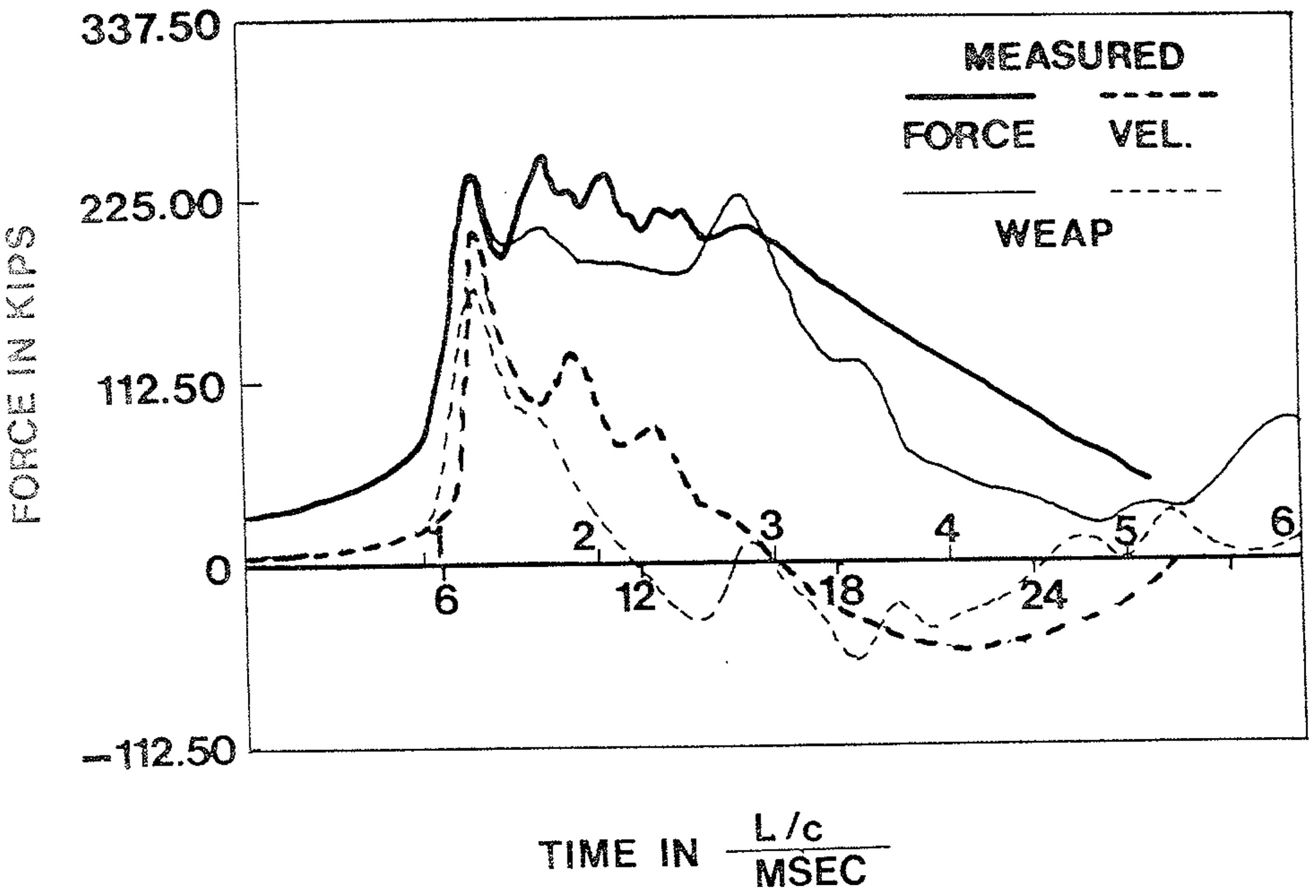

FIGURE 6-11: FORCE AND VELOCITY MATCH FOR PILE NO. 12
(CUYAHOGA RIVER)

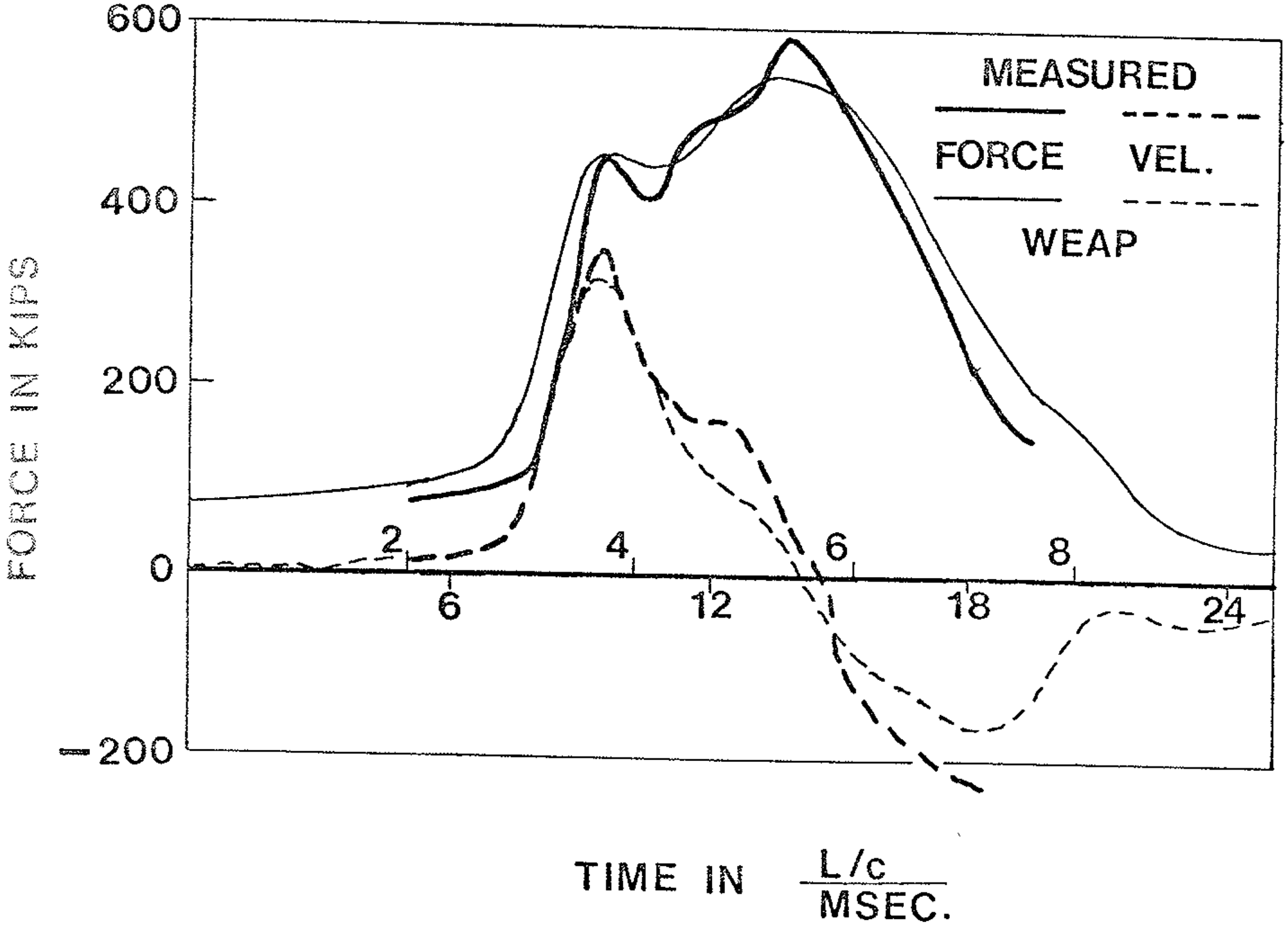

FIGURE 6-1 : FORCE AND VELOCITY MATCH FOR PILE NO. 13

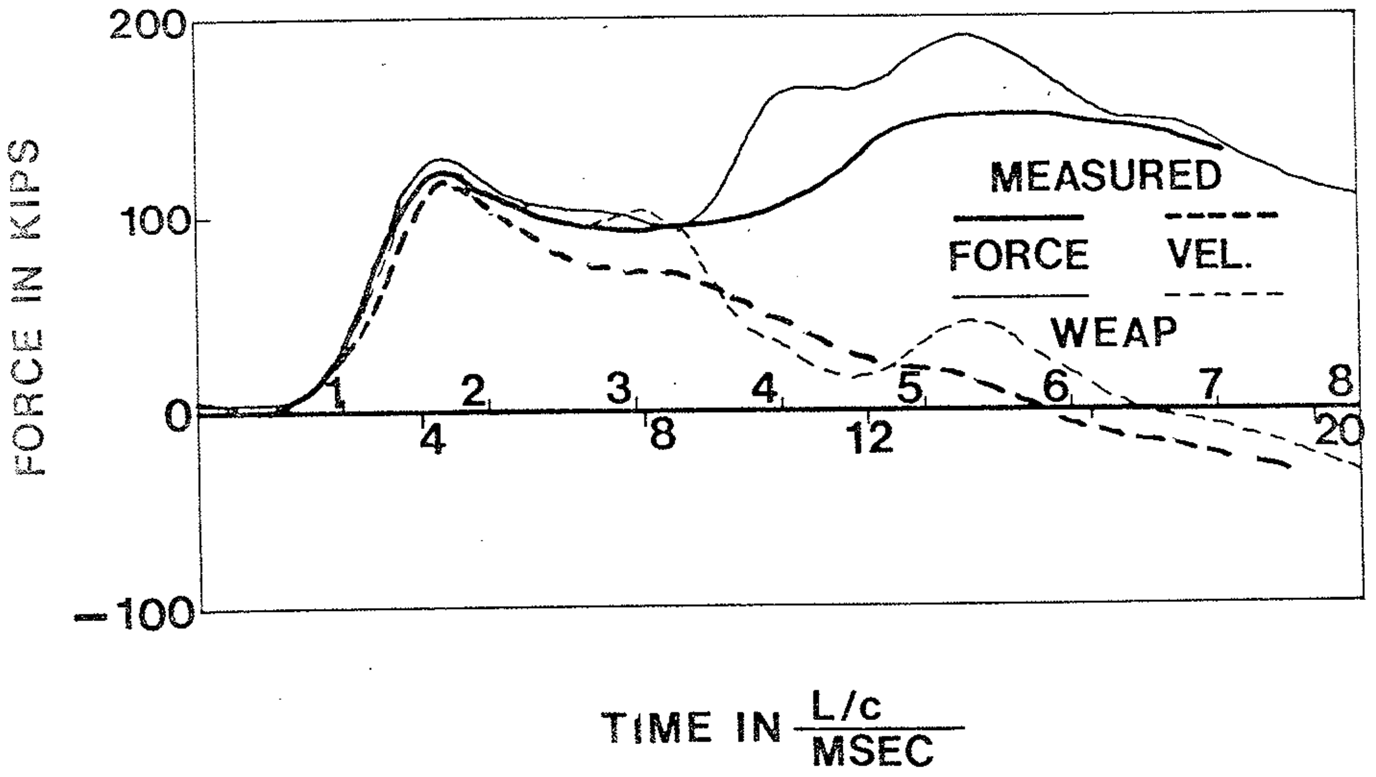

FIGURE 6-13: FORCE AND VELOCITY MATCH FOR PILE NO. 14 (PHILADELPHIA)

and helmet properties were not recorded. The blow count was predicted very accurately.

Piles No. 15 and 16

Both records (Figures 6-14 and 6-15) were actually recorded on the same pile using an air powered Vulcan 08 hammer. The pile was driven at the same site as Pile No. 9, Reference 12.

Both Figure 6-14 which was recorded in easy driving (the capacity of the pile was determined by a pull out test) and Figure 6-15 (which was one of the first records after the pile hit rock) show a very good match. The blow count was accurately determined for the easy driving case; refusal was indicated for hard driving. Note that the measured blow count of 184 is essentially refusal.

Pile No. 17

This was a rather long pile driven by a Vulcan 016 hammer and analysis shows that the assembly drop effect can be predicted rather accurately. Figure 6-16 contains two plots that were obtained on this WEAP run. The lower one is a three dimensional plot of force vs. pile length and time.

Note that the assembly drop creates a wave similar to the impact wave although of lower magnitude.

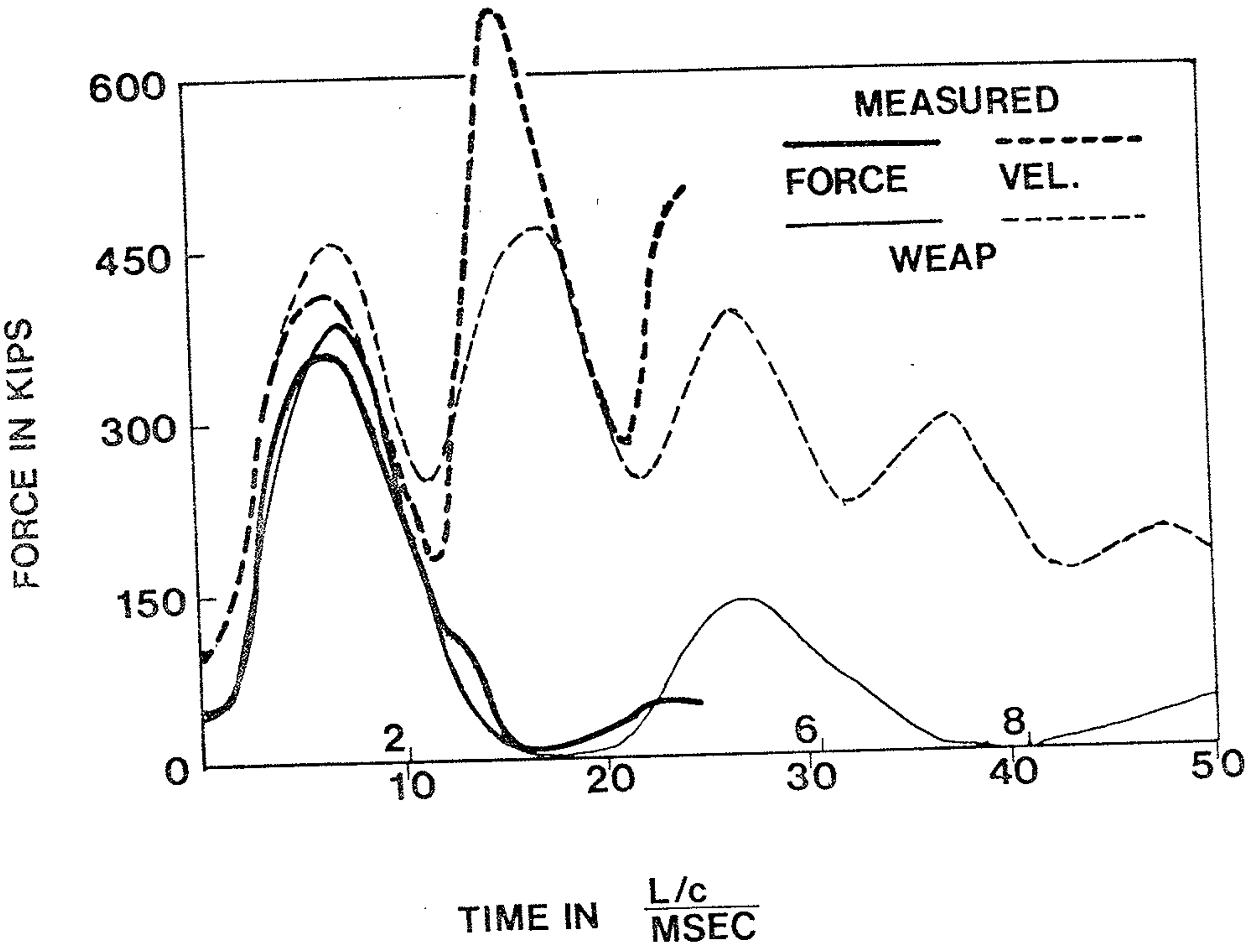

FIGURE 6-14: FORCE AND VELOCITY MATCH FOR PILE NO. 15

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

The foregoing results and the experience obtained with the program to date support the following conclusions:

(1) The program can be used very easily for most of commonly encountered dynamic pile analyses.

(2) Stress predictions will be good (less than 10% error) if the components of the driving system are well-modeled and if the hammer performs normally. The extensive study of program performance versus actual measurements has proven this point. However, it is only when measurements are available that one can be confident of the modeling if the system is at all unusual.

(3) Blow count (or bearing capacity) predictions were within 10% for most of the cases tested. Exceptions were Piles No. 7, 9, and 16 which had blow counts greater than 120 blows per foot. Blow counts becoming greater than this value result in a very small increase in capacity and are often referred to as "at refusal".

It should be mentioned that small penetrations, less than 0.1 inch per blow, may be associated with higher capacities than predicted by the wave equation. This fault lies in the assumption of an elasto-plastic static soil resistance. The ultimate resistance is not activated but a final set is obtained because of the nonlinear soil behavior.

(4) Stress and blow count are both dependent on stroke. The stroke,

on the other hand, was well-determined by the program for all those cases in which the hammer performed properly. Improper conditions were found with a hammer whose exhaust ports were partially plugged. Other problems that may be encountered are preignition or low fuel throttle settings.

Since low fuel throttle settings produce low strokes, their effect is readily recognized in the field. Preignition, on the other hand, produces an ineffective blow at a high stroke and is, therefore, dangerous. It can only be recognized by the examination of field measurements.

The use of the program can help in construction control to avoid problems resulting from such abnormal hammer conditions. The engineer has to evaluate pile driving performance using all analysis results (stroke or bounce chamber pressure, blow count and stresses) simultaneously.

(5) The program is well-suited to solve the driveability problem since it uses the actual hammer potential for a given soil condition. Of course, the program does not solve the principal problem of determination of soil bearing capacity.

(6) The program can be used to establish driving criteria in the conventional way except that it will provide a certain stroke value together with stress and blow count. The stroke should be verified in the field.

(7) The program can be used in the investigation of tension stresses in a pile. These stresses can be predicted accurately by the program if the soil resistance distribution and the driving system properties are accurately known. Further work is required to understand dynamic soil performance.

APPENDIX A

COMBUSTION CALCULATIONS USING COMBUSTION CHARTS

A.1 General Remarks

A variety of combustion charts exist which simplify combustion calculations. Among the charts are those of Hotel, Williams and Satterstield (8), and Newhall and Starkman (9). Unfortunately, these charts are usually devised for four cycle engines or they only consider the combustion of isooctane. Thus, some errors are made in using these charts. However, the uncertainties in basic assumptions usually introduce greater errors than those caused by the use of the charts.

One important question is the degree to which scavenging occurs. Suppose, that the stroke is five times the distance from the exhaust ports to the impact block. Now if the piston has reached the top dead center the gases in the cylinder consist in the worst case of 20% burned products and 80% fresh air. Depending on the geometry of the exhaust ports the down stroke of the piston might either cause all fresh air, all burned products or a fraction of air and fresh products to be exhausted. Thus, the ratio of burned products to fresh air, f, might be anywhere between 0 and 100%.

For the following sample calculation the charts of (9) were used. These charts were set up for isooctane combustion but since the H/C ratio of this fuel is similar to that of diesel fuel, the results should not be affected seriously.

"The Unburned Compression Chart" i.e. the charts that are valid for the compression phase, in (9) were prepared assuming an air-fuel mixture. In the case of diesel hammers, however, pure air (or a mixture of air and combustion products) is compressed. For this reason the unburned charts are not used but rather the results from measurements.

The burned product to fresh air ratio, f, will be assumed at 20% (a very high value compared with the usual engine cycles) together with a constant volume combustion. The latter assumption is justified because the combustion occurs at a very high rate (as evidenced by Figure 6) and because the volume is at the minimum during combustion. This is also apparent from the measurements as the precompression force stays constant during the combustion delay.

Another error is introduced by using the chemical energy value, U_c, as given in (8). This effect can be considered negligible, too.

A.2 Sample Calculation

As an example, consider a DELMAG D-12 hammer with a compression ratio, C.R., of 1:13.5, a fuel charge of 0.00463 lbs. (2.1 grams) per blow and an initial volume of 1308 cubic inches (2.14 cubic decimeters) of air. Assuming an initial temperature of 537°R (25°C) the volume of one pound of air (454 grams) is 13.53 cubic feet (383.1 cubic decimeter). The air to fuel ratio is, therefore

$$A/F = \frac{\frac{1308}{1728(13.53)}}{0.00463} = 12.1$$

The chemically correct mixture has an air/fuel ratio of 15.0 for Diesel fuel (based on the combustion of 1 mol $C_{12}H_{26}$ with 18.50 mols of O_2 and (18.5)(3.773) moles of N_2).

Thus the mixture is $100\,\frac{15-12.1}{12.1} = 24\%$ fuel rich. The charts for a 20% fuel rich mixture will be used.

(a) Compression cycle

The measured pressure at impact was on the average 500 psi (34.5 bar). Assuming the pressure volume relation to follow

$$p = p_{atm}\,(\frac{V_{atm}}{V})^{exp} = p_{atm}\,(C.R.)^{exp}$$

with p_{atm} and V_{atm} being the atmospheric pressure and the corresponding volume respectively, one obtains for the unknown exponent

$$exp = \frac{p}{p_{atm}} \; \frac{1}{C.R.} = \frac{500}{14.7} \; \frac{1}{13.5} = 1.36$$

(instead of 1.4 as for the adiabatic and pure air process).

The precompression temperature can then be determined from

$$T = 537(\frac{500}{14.7})^{1 - \frac{1}{1.36}} = 1366 \quad °R$$

$$(T = 759\ °K)$$

The internal energy for this temperature is taken from Chart 6. Thus, using the $\phi = 1.2$ curve, one obtains approximately

$$U_2 = 185 \text{ BTU } (195 \text{ kilo Joule})$$

(b) Combustion

Going to Chart 3 and using f = 0.2 the chemical energy becomes

$$U_c = 0.8\ (-60.88) + 0.2\ (-1379) = -324 \text{ BTU } (-341 \text{ kJ})$$

Thus

$$U_3 = 185 - 324 = -139 \text{ BTU } (-146 \text{ kJ})$$

The volume V_3 is the compressed volume which according to the legend of Chart 5 and using $K_{\phi = 1.2} = 0.3778$ becomes

$$V_3 = 0.3778\ \frac{1366}{500} = 1.03 \text{ ft}^3$$

$$(29.17 \text{ dm}^3)$$

and from Chart 3, approximately:

$$p_3 = 1800 \text{ psi } (124 \text{ bar})$$

$$T_3 = 4750\ °R\ (2639\ °K)$$

$$S_3 = 2.205 \text{ BTU/°R } (4.19 \text{ kJ/°c})$$

(c) Expansion

The final volume of expansion is

$$V_4 = 1.03\ (13.5) = 13.9 \text{ ft}^3\ (393 \text{ dm}^3)$$

and with $S_4 = 2.205$ BTU/°R (4.19 kJ/°c)

one obtains

$$p_4 = 70 \text{ psi } (4.83 \text{ bar})$$

$$T_4 = 2420 \text{ °R } (1344 \text{ °K})$$

$$U_4 = -830 \text{ BTU } (788 \text{ kJ})$$

(d) Work

Expansion:

$$W_e = U_3 - U_4 = -139 - (-830)$$

$$W_e = 691 \text{ BTU } (729 \text{ kJ})$$

Compression:

$$W_c = U_2 - U_1 = 185 - 0$$

$$W_c = 185 \text{ BTU } (195 \text{ kJ})$$

Net Work:

$$W_n = 691 - 185 = 506 \text{ BTU } (534 \text{ kJ})$$

Thermal Efficiency

$$\eta_{th} = \frac{W_n}{(\text{LHV})(\text{Fuel weight})} = \frac{506}{(19{,}240)(0.056)} = 47\%$$

(Using the weight of diesel fuel per cycle).

A.3 Discussion

The fuel energy per blow converted to work is theoretically

$$W_t = 0.47\ (19240)(0.00463) =$$

$$41.9 \text{ BTU } (44 \text{ kJ})$$

or

$$W_t = 41.9\ (0.778) = 32.6 \text{ k-ft}$$

Note that this corresponds to a stroke of

$$\text{Stroke} = \frac{32.6}{2.75} = 11.9 \text{ ft } (3.63 \text{ m})$$

and that the hammer is rated at 22.5 k-ft. (30.5 kJ) for an 8.2 ft (2.50 m) stroke. Such a stroke is more than the maximum possible one of 10.8 ft (3.30 m), e.c.since in general very little combustion energy is consumed through energy losses and, therefore, all of it produces stroke. It can be said that the computed energies are approximately 50% too high. This argument is confirmed by the fact that the combustion pressure was computed much higher than measured.

For this reason it was decided to use the measured combustion pressure as a starting value for the expansion process which was then modeled isentropically using an expansion exponent that is given by the combustion chart. In the current case (D-12, 20% fuel rich) one obtains:

$$\exp = \frac{1800}{70} \quad \frac{1}{\text{C.R.}} = 1.25$$

in order to account for some additional losses during the expansion process, the exponent was chosen as 1.3. As a further argument against pressure calculations based on combustion theory it should be mentioned that the strokes predicted by the present wave analysis, using the model just described are in very good agreement with those observed. A limited pressure diesel cycle with measured pressures but a theoretical pressure volume relation would also produce a much larger net work and cannot be considered a satisfactory approach (see also Figure A1 for a comparison of computed with measured work).

Calculations were also performed in which the combustion product to air ratio, f, was determined assuming a maximum combustion pressure of 1600 psi. The result was $f = 0.48$.

The reason for the differences between theory and measurement probably lie in the inefficient way fuel is mixed with the air. The atomized injection hammers are actually using much lower fuel/air ratios.

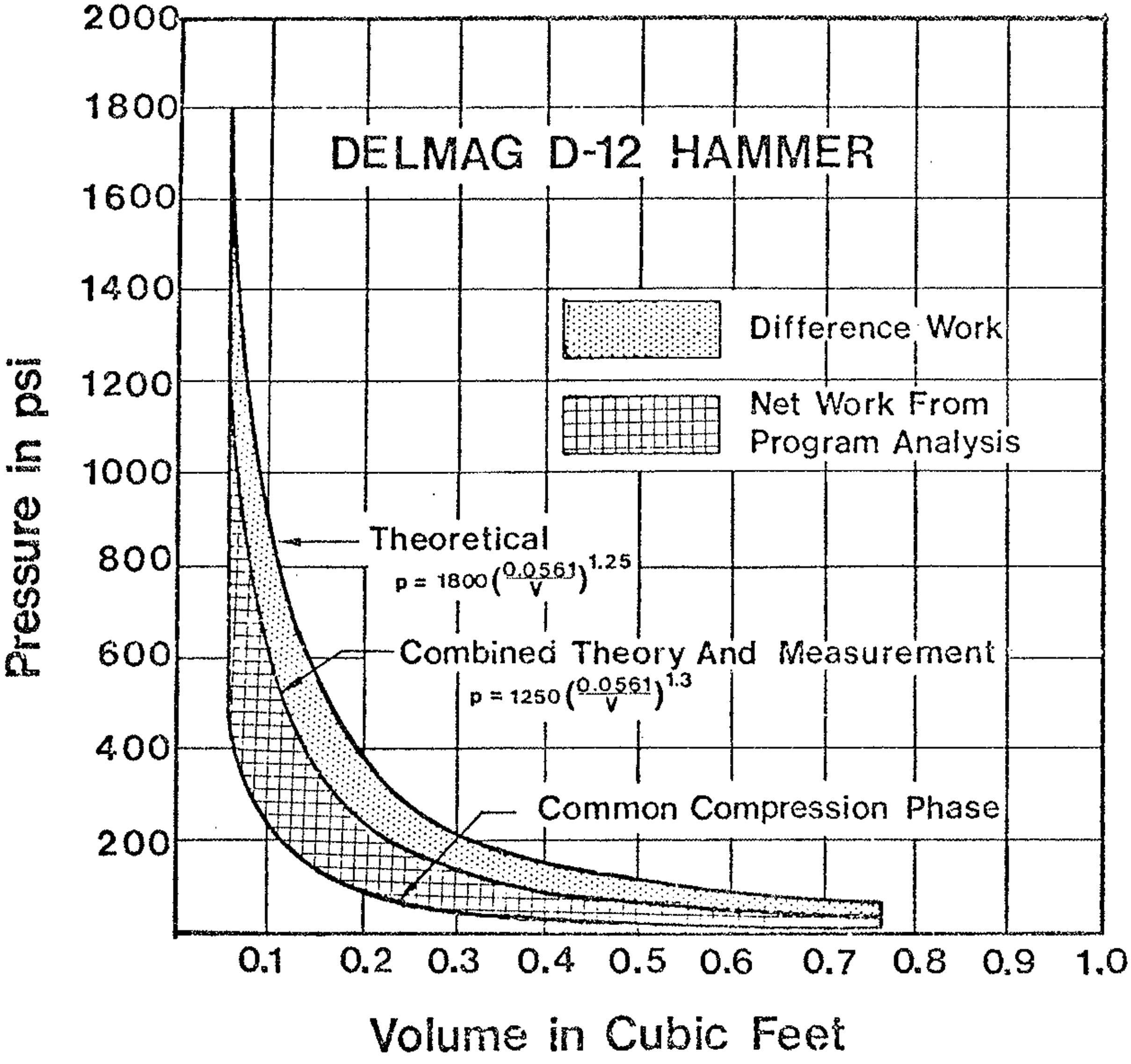

FIGURE A1: COMPARISON OF COMPUTER WITH MEASURED COMBUSTION AND EXPANSION CYCLE.

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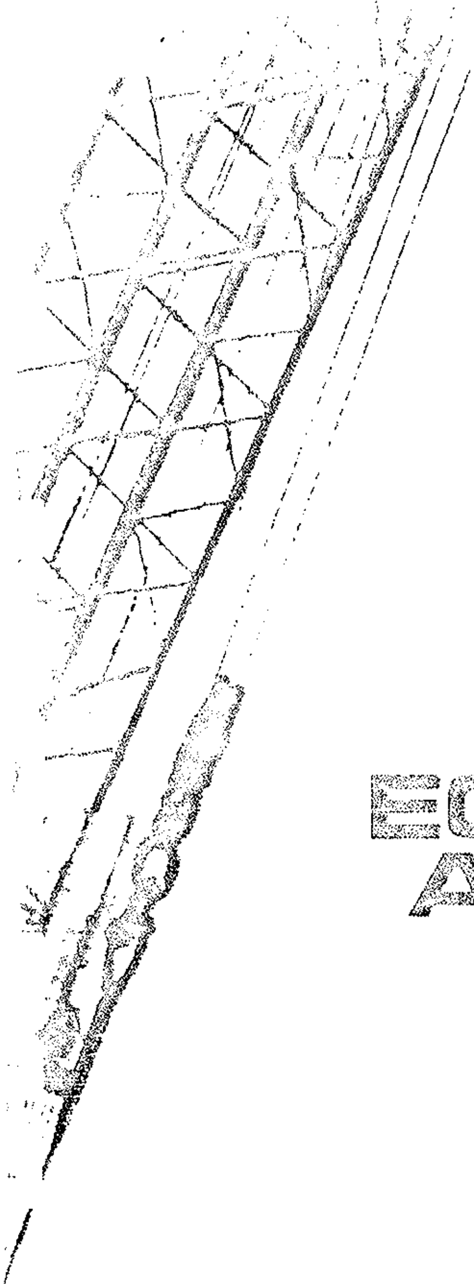
15. Goble, G. G., and Likins, G. E., Jr., "Predicting the Bearing Capacity of a Pile from Dynamic Measurements in Tarver, Georgia", Department of Solid Mechanics, Structures and Mechanical Design, Case Western Reserve University, Cleveland, Ohio, February 1974.

METRIC CONVERSION FACTORS

To Convert	To	Multiply By
pounds (lbm)	kilograms (kg)	0.4535924
pounds force (lb)	newtons (N)	4.4482219
kips (1000lb)	kilonewtons (kN)	4.4482219
inches (in.)	centimeters (cm)	2.54
feet (ft)	meters (m)	0.3048
feet per second (fps)	meters per second (m/sec)	0.3048
foot-pounds (ft-lb)	newton-meters (N·m)	0.355818
foot-pounds (ft-lb)	joules (J)	1.355818
Pounds per foot (lb/ft)	kilograms per meter (kg/m)	1.488164
Acceleration of gravity (g)	meters per second squared (m/s^2)	9.806650
Acceleration of gravity (g)	feet per second squared (ft/sec^2)	32.17405
kip-inches (kip-in.)	newton-meters (N m)	112.9848
degrees Centigrade	degrees Fahrenheit	1.8 and add 32



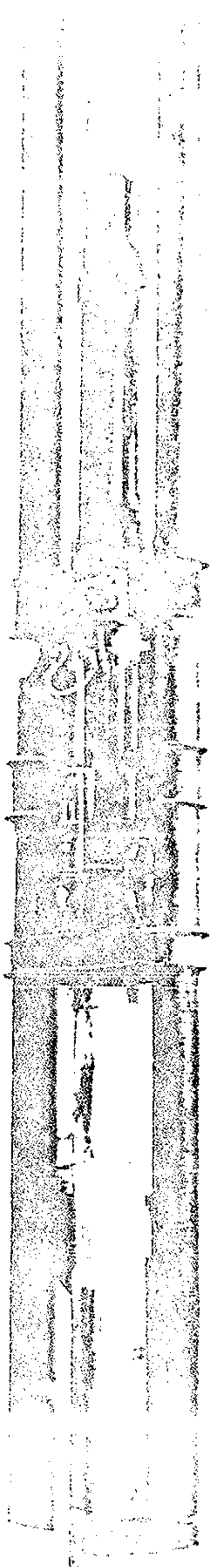
76-14.2

Implementation Package

WAVE EQUATION ANALYSIS OF PILE DRIVING

[illegible]
[illegible]
PROGRAM

Volume II – User's Manual



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16. Abstract

A computer program was written and tested that performs a realistic Wave Equation Analysis of Piles driven by any type of impact hammer. Conventional pile and soil models were used in addition to both a thermodynamic model for diesels and refined mechanical hammer models.

The program development was aimed at providing a simple input and both a flexible and extensive output that includes automatic plotting capabilities. Pile Driving Hammer data were prepared and stored in a file for most of the commonly encountered models. The computer language is FORTRAN IV.

The program was extensively tested against measured pile top force and velocity data and against measured diesel combustion pressure and stroke.

This volume is the second in a series. The others in the series are:

Vol. No.	FHWA No.	Short Title	NTIS (PB) No.
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3	IP-76-14	Program Documentation	
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WEAP

WAVE EQUATION ANALYSIS OF PILES

USER'S MANUAL

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CHAPTER 1

INTRODUCTION

WEAP is a computer program written in FORTRAN IV code which performs a Wave Equation Analysis for Piles. This program was developed between July 1975 and July 1976 under a contract with the Federal Highway Administration, Offices of Research and Development. In addition to the program code and this User's Manual, the following publications were prepared:

1. Wave Equation Analysis of Pile Driving, Background
2. Wave Equation Analysis of Pile Driving, Program Documentation
3. Wave Equation Analysis of Pile Driving, Narrative

This User's Manual is intended to provide first, a very basic outline of the various program functions; second, a definition of the input quantities; third, a description of the output and finally, sample problems. The Manual does not give an introduction into the wave equation approach for solving pile driving problems. Also, it does not provide, except for examples, input quantities of pile-soil parameters. The user who is not familiar with the concept of wave equation analyses for piles should, therefore, familiarize himself with such ideas by reading at least Chapter 1 of the Background report and some of the publications referenced there. Other chapters of the Background report should be read when questions regarding the basic approach of the program exist.

The program documentation contains details of the program flow and gives recommendations on the program installation in a computer system. The "narrative" contains text and illustrations of a tape/slide show.

The use of a discrete pile model, i.e. a string of springs and masses, to analyze the pile driving problem was first proposed by E. A. L. Smith in 1955. Smith himself wrote a program that performed the necessary computations on a digital computer. The apparent advantages of his method prompted various other investigators to expand the concept and to test the idea. As a result, several other program versions were written. The most widely distributed version was prepared by the Texas Transportation Institute (TTI).

The TTI program proved to be a valuable tool both for the design engineer and for construction control. However, as it was developed primarily for air/steam or drop hammers, shortcomings were found when diesel hammer analyses were attempted.

The authors of WEAP intended to contribute to the art in the following ways:

(a) Provide for a realistic diesel hammer analysis.

(b) Improve the air/steam hammer analysis by also considering the very heavy assembly of such hammers.

(c) Test the wave equation analysis results by comparison with force and velocity records, measured at the pile top.

(d) Make the input as simple as possible by the elimination of "computed input" and by the provision of a data file that contains the data of commonly used pile driving hammers.

(e) Provide improved output by utilizing automatic plotting capabilities in addition to a very flexible printout, capable of giving the user many variables versus time in a very instructive manner.

The usual production run that a user must make in order to analyze an actual problem is generally specified with only a few parameters describing pile and soil. Such a run can therefore be coded by using the so-called "Short Input". In unusual cases, i.e. when the user wants to specify quantities which cannot be computed by the program, or when a hammer is to be used that is not contained in the hammer data file, the "Complete Input" has to be utilized.

After a brief discussion of the program flow (which does not replace the corresponding section of the background report) in Chapter 2, Chapter 3 and 4 deal with the description of the Short and Complete Input, respectively. Chapter 5 gives examples that relate to a few selected, frequently encountered input problems. Chapter 6 describes the computer output and Chapter 7 demonstrates first, three basic examples utilizing the short input and second, two hypothetical cases which require the complete input. Forms for both short and complete input are added in the Appendix.

CHAPTER 2

THE BASIC PROGRAM FLOW

In order to facilitate the understanding of the following chapters a few of the ideas behind the program are mentioned. However, this chapter cannot replace the more detailed discussions in the report.

2.1 Input

Input was programmed such that the actual known parameter such as pile length, skin friction distribution, etc. can be used directly. Since hammers require specification of a large number of data, input has been prepared and stored on a file for most of the commonly encountered types.

The program converts the input data to the standard Wave Equation parameters. It is because of this automated data preparation that many of the names that appear in the Texas Transportation Institute (TTI) program are not found in this manual. Also it was intended to make a standard computer run simple while providing for unusual cases. For this reason the input was divided in two parts: Short and Complete Input. In the short input terms known from the TTI work are used as much as possible to identify input quantities. Thus, standard cases can be solved using WEAP by people used to the TTI program without much preparation.

2.1.1 Input of Soil Damping

One parameter should be discussed a little further. It is the skin and toe damping value, usually referred to as J-values. Since the soil damping force in Smith's approach is equal to the product of J times segment velocity times static soil resistance force, damping is automatically distributed like the static skin resistance. In fact, even though a toe damping parameter may have been specified the toe damping force would be zero if skin friction was 100 percent.

WEAP also allows the use of damping parameters which are independent of the static soil resistance. This type is referred to as viscous damping. The viscous damping force is calculated as damping parameter times segment velocity (the damping constant, therefore, has dimensions kips per foot per second).

In order to make the input comparable for the two damping types, skin and toe damping are again specified. The skin damping parameter for viscous damping is the sum of all segment-skin-damping values. The program apportions this sum according to the skin friction distribution specified (and would be present even for zero skin friction).

To further facilitate the input of the viscous damping parameters, non-dimensionalized skin and toe damping constants are used (so-called Case damping). Non-dimensionalization is accomplished by division by the pile's impedance: EA/c = Young's Modulus times cross sectional area divided by the wave speed. This impedance has the dimensions of a viscous damping parameter. Thus, the input values for Case (or viscous damping) are truly dimensionless.

To clarify further the actual computer program, steps are now listed for the two damping types:

(a) Smith:	Input	Set each segment's skin damping parameter to the input skin damping parameter. Set toe segment's damping parameter to the corresponding input constant.
	Analysis	Damping force at a segment equals damping parameter times static resistance force times velocity, all for the same segment.
(b) Viscous (Case):	Input	Apportion input skin damping parameter to all segments according to their static skin friction (still non-dimensional). Multiply each skin damping parameter by the EA/c value of the corresponding segment. Multiply input toe damping parameter by the EA/c value of the toe segment.
	Analysis	Damping force equals damping parameter times velocity for the same element.

In this context it should be mentioned that the corresponding viscous damping parameters of Smith's approach can become very large (especially at the toe). Since the corresponding viscous parameter is the product of Smith's constant times the static resistance it can vary from analysis to analysis, proportional to the static resistance force. (E.g., 80% toe resistance, J_{toe} = 0.15 s/ft, RULT = 50, 100, 150, 200 tons. In the first analysis the corresponding viscous damping constant is 2 x 50 x 0.8 x 0.15 = 12 kips/ft/sec. In the last analysis it is 48 - this is almost four times the impedance of a twelve inch pile with .178 inch wall).

WEAP reduces the analysis time increment when the damping constant at any one segment becomes large relative to the pile's impedance (EA/c). Thus, a Smith's damping value that is large at an element which has also a high static resistance force may produce a long and, therefore, costly computer run.

Damping parameters affect the blow count result to a considerable degree. Therefore, it is advisable to use the rather well-documented Smith-values whenever doubts exist as to the proper Case damping values.

2.2 Analysis Cycle

2.2.1 Open End Diesel Hammers

Open end diesel hammers are usually started by assuming a five foot stroke (if the user did not specify another one); a dynamic analysis is then performed and the return stroke is determined. If this return stroke is different by more than five percent from the first assumption, then a new analysis is performed and again a check is made on the convergence of the stroke.

Up to four iterations are usually allowed except for cases where the stroke converges in an alternating mode. Then six trials are permitted.

After the last stroke is analyzed, the extreme values found are printed together with other optional output.

A new ultimate resistance is then analyzed starting with a new stroke. This new stroke is based on previous results assuming an increase in resistance. Of course, iterations are again performed.

This process is continued until all ultimate resistance values are analyzed or until no more permanent set occur. Then a summary of all results is printed and the program is ready to analyze a completely new data set.

An exception to this "standard run" is the "constant stroke" analysis (IOSTR = -1). This option causes the change of combustion pressures until the return stroke equals the input stroke. The use of this option is recommended for hammers that have a variable fuel pump and/or for cases where reduced strokes are to be used. The program does not check on any fuel energy limits when this option is used. Thus, strokes may be accidentally specified which are too large and cannot possibly be obtained in the field (e.g. when the soil resistance is low).

2.2.2 Closed End Diesel Hammer

For this hammer type, a start is made at the maximum stroke at which uplift is just imminent, if the user did not specify another value. Depending on the soil resistance, the stroke will either become smaller or fuel reductions will be necessary to avoid uplift. Again, the program iterates until the proper stroke or fuel setting is found. A maximum of four cycles is allowed.

Fuel setting or stroke are again used as a starting point for further RULT values analyzed and a summary is printed.

The "constant stroke analysis" can also be performed for closed end hammers. Table 1 was provided to facilitate the stroke input for a given

MKTDA35B		MKTDA55B		LB 180		LB 440		LB 520		LB 660	
STROKE,	B.C.P.	STROKE,	B.C.P.	STROKE,	B.C.P.	STROKE,	B.C.P.	STROKE,	B.C.P.	STROKE,	B.C.P.
1.27	-.00	1.41	-.00	.69	2.36	1.35	5.26	.92	2.87	1.64	5.16
1.37	.12	1.51	.40	.79	2.82	1.45	5.82	1.02	3.28	1.74	5.61
1.47	.54	1.61	.85	.89	3.29	1.55	6.39	1.12	3.70	1.84	6.08
1.57	.99	1.71	1.32	.99	3.79	1.65	7.00	1.22	4.15	1.94	6.56
1.67	1.46	1.81	1.81	1.09	4.32	1.75	7.64	1.32	4.61	2.04	7.07
1.77	1.95	1.91	2.34	1.19	4.86	1.85	8.30	1.42	5.09	2.14	7.59
1.87	2.47	2.01	2.89	1.29	5.44	1.95	9.01	1.52	5.60	2.24	8.14
1.97	3.02	2.11	3.47	1.39	6.04	2.05	9.75	1.62	6.12	2.34	8.71
2.07	3.60	2.21	4.09	1.49	6.68	2.15	10.53	1.72	6.67	2.44	9.31
2.17	4.21	2.31	4.75	1.59	7.35	2.25	11.36	1.82	7.25	2.54	9.93
2.27	4.86	2.41	5.44	1.69	8.06	2.35	12.23	1.92	7.85	2.64	10.58
2.37	5.55	2.51	6.18	1.79	8.81	2.45	13.16	2.02	8.48	2.74	11.26
2.47	6.28	2.61	6.97	1.89	9.60	2.55	14.14	2.12	9.14	2.84	11.98
2.57	7.05	2.71	7.80	1.99	10.44	2.65	15.18	2.22	9.84	2.94	12.72
2.67	7.88	2.81	8.70	2.09	11.33	2.75	16.29	2.32	10.57	3.04	13.51
2.77	8.76	2.91	9.66	2.19	12.28	2.85	17.47	2.42	11.34	3.14	14.33
2.87	9.70	3.01	10.69	2.29	13.28	2.95	18.74	2.52	12.15	3.24	15.20
2.97	10.71	3.11	11.79	2.39	14.35	3.05	20.08	2.62	13.00	3.34	16.11
3.07	11.80	3.21	12.98	2.49	15.49	3.15	20.46	2.72	13.90	3.44	17.07
3.17	12.96	3.31	14.26	2.59	16.72			2.82	14.86	3.54	18.08
3.27	14.22	3.41	15.65	2.69	18.03			2.92	15.87	3.64	19.15
3.37	15.57	3.51	17.16	2.79	19.43			3.02	16.94	3.74	20.28
3.47	17.04	3.61	18.80	2.89	20.95			3.12	18.07	3.84	24.29
3.57	18.64	3.71	20.59	2.99	22.58			3.22	19.28		
3.67	20.38	3.81	22.55	3.09	24.35			3.32	20.56		
3.77	22.28	3.91	24.71	3.19	26.13			3.42	21.93		
3.87	24.36	4.01	27.09					3.52	23.40		
3.97	26.66	4.11	29.72					3.62	24.74		
4.07	29.19	4.21	32.66								
4.17	32.01	4.31	35.94								
4.27	35.14	4.41	39.64								
4.37	38.66	4.51	43.82								
4.47	42.63	4.61	48.59								
4.57	47.12	4.71	54.06								
4.67	52.26	4.81	60.40								
4.77	58.18	4.91	67.80								
4.87	65.06	5.01	76.56								
4.97	73.13	5.11	80.11								
5.07	82.70										
5.17	89.35										

TABLE 1: STROKES AND CORRESPONDING BOUNCE CHAMBER PRESSURE FOR CLOSED END HAMMERS
STROKE IS IN FEET; B.C.P. IS IN PSI, GAUGE PRESSURE

bounce chamber pressure. This table lists strokes and corresponding bounce chamber pressures for all closed end hammers which are contained in the hammer file.

2.2.3 Air Steam Hammers

This hammer type is simply analyzed for the stroke and efficiency specified. In contrast to other programs, the motion and impact of the assembly is also modeled. This feature does not influence the overall program flow and no further discussion seems necessary.

2.3 Analysis Details (Diesel Hammers Only)

For a better understanding of the program output a few details of the diesel hammer analysis should be known. The analysis is divided into three parts:

(a) Precompression

(b) Impact Analysis

(c) Ram Rebound

Whenever this manual refers to "the analysis", part (b) is usually meant. It starts approximately one millisecond before either impact or before ignition and lasts until one of the following two conditions is met:

(a) TEMAX as specified by the user is exceeded.

(b) ((2L/c* have at least passed (no impact)) or (2.3 L/c have at least passed since impact)) and ((ram has risen at least 20% of distance to ports and toe has rebounded at least 2%) or (ram has risen at least 10% of distance to ports and toe has rebounded at least 20%)).

---

* Twice the time that the stress wave needs to travel along the pile of length L.

Output values are collected and extrema are determined at intervals between time increments which depend on the total expected analysis time. The check for stress minima (tension stresses) is limited to a time 3L/c after impact. The minimum stress is at least zero.

A further discussion of the analysis is given in Chapters 3, 4 and 5 of the research report.

2.4 Output

Output is made for each RULT analysis and at the end of the job. Variables, like forces, as a function of time have to be stored temporarily since it is not known a priori if the current analysis is for the correct stroke. To keep the program size limited, output is restricted and is given for, at most, two hundred time steps. To cover a sufficiently long time period, the output values stored and later printed are usually not consecutive ones.

When plots are made, the time curves sometimes appear not well rounded. This appearance is caused by the skipping of intermediate values and the plotter's linear interpolation.

CHAPTER 3

SHORT INPUT

The short input consists of the following information: Title, Options and Selections, Cap and Cushion Information, Coefficients of Restitution, Pile Description and Soil Description. Note that an unlimited number of problems can be solved in one run by submitting several input data sets at one time.

The following terminology will be used:

Default:	A value was not specified (left blank). Usually the program inserts a standard value automatically.
Blank or Unspecified:	A data field is left without input.
Integer:	An integer number. Input of integers has to be always right justified within their field, i.e., they may have leading but not trailing blanks.
Real:	A number <u>containing always a decimal point</u> (integer plus fraction). Reals can be input anywhere in their field. Thus, the location of the decimal point is not restricted.
Field:	A number of consecutive spaces in which several characters all belonging to one quantity can be filled.

3.1 Title
(Card No. 1.000)

A string of up to 40 alphanumeric characters identifying the problem.

3.2 Options and Selections
(Card No. 2.000)

Integers in fields of four spaces, right justified.

The following options are available:

(a)	IOUT	Used to specify which output level is chosen. = 0 minimum output consisting of hammer and pile model plus the extreme values found for each RULT. A summary is also printed. = 1 in addition to the output of the 0 option two forces in the hammer and as many as 13 in the pile are printed as a function of time for each RULT. = 2 As for 1 but with velocities instead of forces. = 3 As for 1 but with stresses instead of forces. = 4 As for 1 but with accelerations instead of forces. = 5 As for 1 but with displacements instead of forces. = 6 As for 1 but with selected properties like combustion pressure, sum of resistance forces and force, velocity and displacement being printed at three different pile locations. If 10 is added to the above option numbers then plots of the corresponding printouts are made. The plots obtained will include one plot of the specified quantities vs. time for each RULT and a summary of resistance, stroke and both maximum and minimum stress vs. blow count. If 20 is added then in addition to the +10 option output a three-dimensional plot of the printed quantities is made (this is not true for option 26). This plot features quantity vs. pile length and time. If IOUT $>$ 9 card No.s 7.000 and 8.000 have to be supplied (Sections 3.8, 4.13, 4.14).
(b)	IJJ	This is an option which if equal to 1 requests additional input on Card No. 9.101 (Section 4.15). This input then defines the element numbers whose quantities are printed under output level 1 through 5 (or 11 through 15 or 21 through 25). IJJ = 0 causes these element numbers to be automatically determined.
(c)	IHAMR	This quantity selects the hammer to be used. It is keyed to Table 2. Accordingly, IHAMR can be any value between 1 and 100. If IHAMR = 0 then input providing various hammer properties has to be provided. (Card No.s 5.201 through 5.205, Sections 4.4 through 4.8).

TABLE 2: HAMMER IDENTIFIER

Identifier	Hammer Name	Identifier	Hammer Name	Identifier	Hammer Name	Identifier	Hammer Name
1	Delmag D-5	26	Kobe KC-25	51	Vulcan 2	76	Vulcan 540
2	Delmag D-12	27	Kobe K-35	52	Vulcan 1	77	Vulcan 360
3	Delmag D-15	28	Kobe KC-35	53	Vulcan 06	78	Vulcan 560
4	Delmag D-22	29	Kobe K-45	54	Vulcan-106 LR	79	Vulcan 3100
5	Delmag D-22-02	30	Kobe KB-60	55	Vulcan-106 HR	80	Vulcan 5100
6	Delmag D-30	31	Kobe K-150	56	Vulcan 08	81	Vulcan 140C-off
7	Delmag D-30-02	32	BSP 15	57	Vulcan 010-on	82	Vulcan 200C-off
8	Delmag D-36	33	BSP 25	58	Vulcan 014-on	83	Vulcan 400C
9	Delmag D-36-02	34	BSP 35	59	Vulcan 016-on	84	Vulcan 600C
10	Delmag D-44	35	BSP 45	60	Vulcan 020-on	85	
11	Delmag D-46	36	Linkbelt 180	61	Vulcan 030-on	86	MKT S-5
12	Delmag D-46-02	37	Linkbelt 440	62	Vulcan 30C	87	MKT S-8
13	Dalmag D-55	38	Linkbelt 520	63	Vulcan 50C	88	MKT S-10
14	MKT DE-10	39	Linkbelt 660	64	Vulcan 65C	89	MKT S-14
15	MKT DE-20	40		65	Vulcan 80C	90	MKT S-20
16	MKT DE-30	41		66	Vulcan 85C	91	MKT No. 7
17	MKT DE-40	42		67	Vulcan 100C	92	MKT 9B3
18	MKT DE-30B	43		68	Vulcan 140C-on	93	MKT 10B3
19	MKT DE-50B	44		69	Vulcan 200C-on	94	MKT 11B3
20	MKT DE-70B	45		70	Vulcan 010-off	95	MKT C-5
21	MKT DA-35B	46		71	Vulcan 014-off	96	MKT C-826
22	MKT DA-55B	47		72	Vulcan 016-off	97	
23	Kobe K-13	48		73	Vulcan 020-off	98	
24	Kobe K-22	49		74	Vulcan 030-off	99	
25	Kobe K-25	50		75	Vulcan 340	100	

(d)	IOSTR	If equal to 0, normal program operation, i.e. iteration on stroke (fixed fuel). If equal to 1, no iteration. If equal to -1, iteration on fuel (fixed stroke). For IOSTR = -1 a stroke should be input in Card No. 6.000. (See also Chapters 4 and 5 of the research report.)
(e)	IFUEL	If equal to 0 or 1, normal operation. If equal to 2 through 5 other fuel settings corresponding to the P2 through P5 pressures in the hammer data (Section 4.6) will be used. For a discussion of this input see also Chapters 4 and 5 of the research report.
(f)	IPEL	Defines how one arrives at the pile segment parameters: = 0: automatic determination of pile segments. = 1: automatic determination but with the relative segment lengths (ALPH(I)) being input Card No.s 2.101,..., Section 4.3. = 2: pile masses and stiffnesses are input (Card No.s 2.101,... and 2.201,..., Sections 4.1, 4.2). Corresponding ALPH(I) values are also required (Card No.s 2.301,..., Section 4.3).
(g)	N	Number of pile segments (maximum 98). If $N = 0$ or 1: automatic determination based on an element length of approximately 5 feet. Note that IPEL $\neq 0$ requires the input of $N > 1$.
(h)	ISPL	The number of springs which can transfer only limited tension forces or for which a slack (extension without tension force) is to be specified. If ISPL is greater than zero, additional input is required (Card No.s 6.501,...., Section 4.12).
(i)	NCROSS	If set to 0 it will be assumed that the pile is uniform and Card No. 5.000, Section 3.5 suffices for pile description. If NCROSS is greater than 0 (usually = 1) then data describing both the variation of pile cross sectional area and pile material vs. depth is required (Card No.s 5.010, ..., Section 3.5-b).

(j)	IBEDAM	The pile internal damping value in percent of pile critical damping. Recommended values are for steel 1, concrete 3 and timber 5. These values are usually of minor importance and sufficient information for their choice is not yet available. Default: 1. For 0 pile damping set IBEDAM = -1.
(k)	IPERCS	Percent skin friction (between 0 and 100). This value can also be input as a negative number which causes the skin friction as determined for the first analysis (see RULT on Card No. 6.000, Section 3.6) to be kept constant for all further analyses. For example: IPERCS = -60 and RULT (the total static pile bearing capacity) = 50, 100, 125 tons will produce three analyses with the skin friction always at 30 tons and, therefore, the toe resistance only increasing (20, 70 and 95 tons).
(l)	ISMITH	= 1: The damping parameters are assumed to be of the Smith type, i.e., dimension sec/ft. = 0: The damping parameters are assumed to be of the viscous type but non-dimensionalized by division through EA/c (Section 3.6). This type is also called Case damping.
(m)	ITYS	Type of skin friction distribution. If between 1 and 10 a corresponding distribution will be chosen from Figure 1. If 0 or -1 a description of the distribution (on Card No.s 6.401,..., Section 3.7) has to be input. If <-1 QS, SJ and SU must be given for all elements plus the pile point as additional input (Card No.s 6.101,..., 6.201,..., 6.301,...). If equal to -1 only the damping parameters are read on Card No.s 6.201,... (See Sections 4.9 through 4.11).
(n)	IPHI	Sets the ratio of time increment to critical time increment. It is in percent. Thus, 100 should be the smallest value provided. If left unspecified the IPHI will be set to 140 ($\Delta t/\Delta t_{cr} = 1.4$) for diesel and 160 for air/steam hammers. Normally this value is not specified.

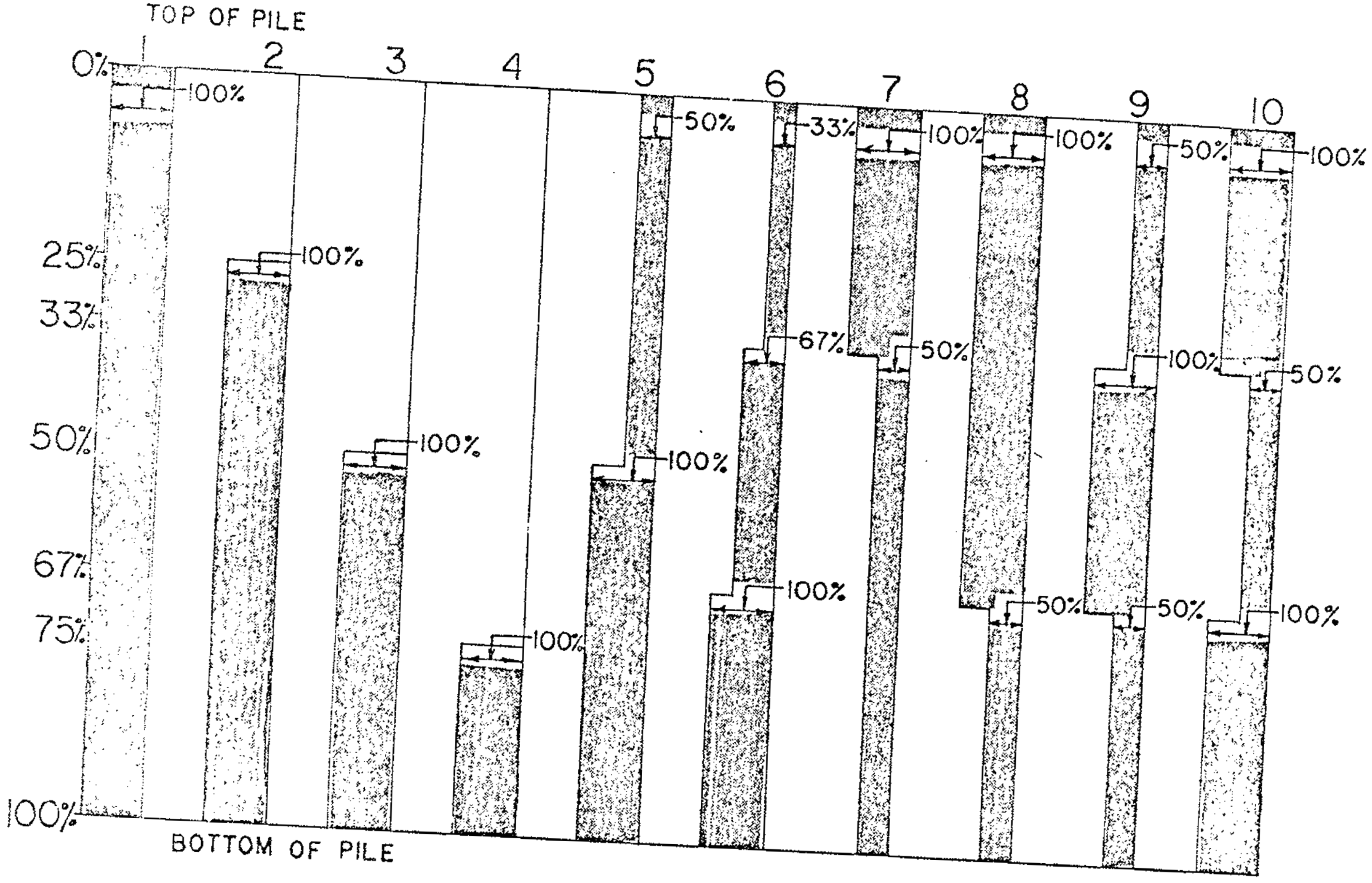


FIGURE 1: PROGRAM BUILT-IN SOIL RESISTANCE DISTRIBUTIONS

In all of the following input, real numbers are required containing a decimal point - each in a field of eight spaces.

3.3 Cap Weight, Cap Stiffness, Cushion Stiffness (Card No. 3.000)

For the definition of "CAP" see Figure 2. Weight of cap in kips, stiffness of capblock in kips per inch and the stiffness of the pile cushion in kips per inch. If either of the two cushions is not present its stiffness should be 0.0 (or blank). A list of typical capblock and cushion properties is given in Table 3.

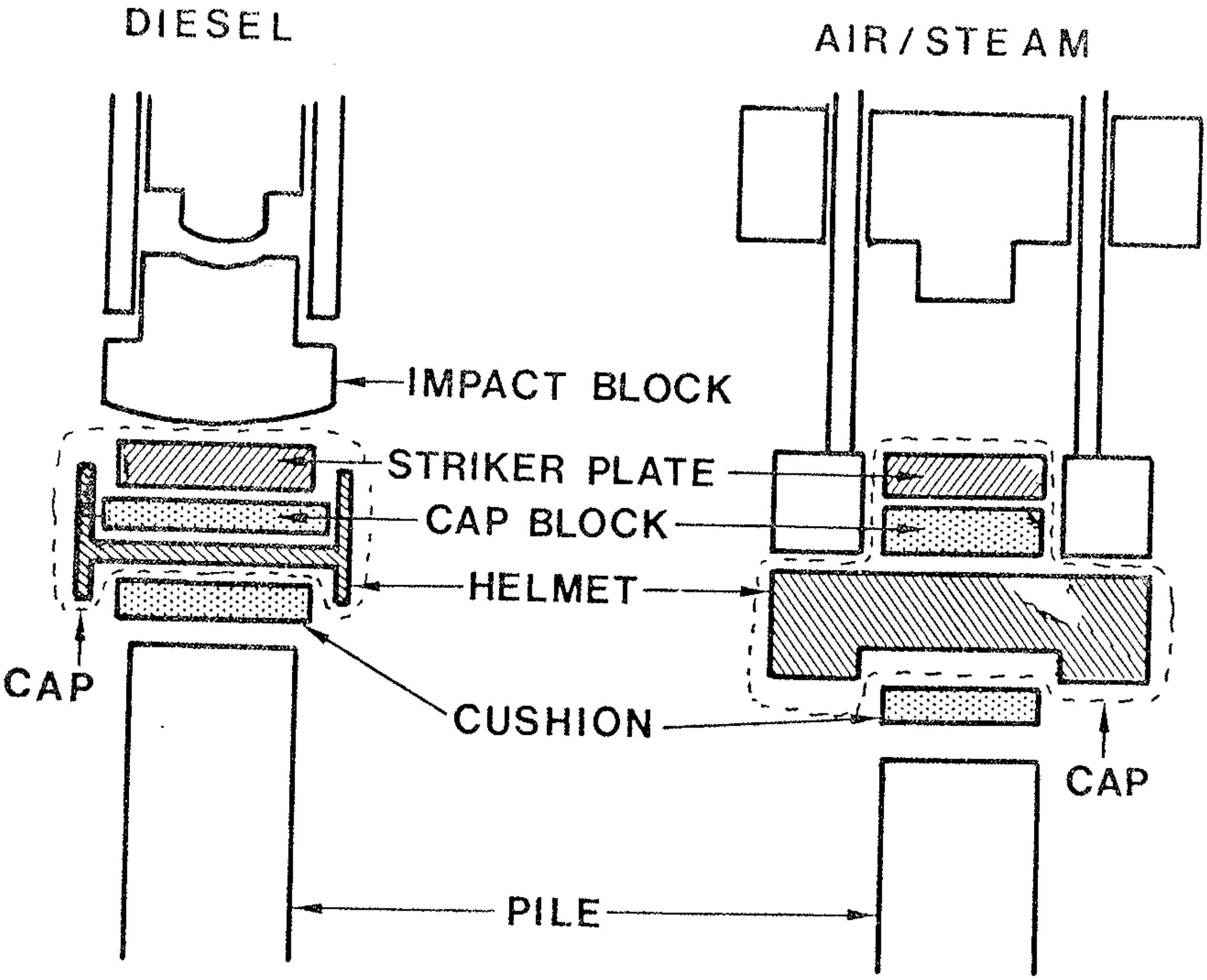
3.4 Coefficients of Restitution

TDEL
TEMAX
(Card No. 4.000)

Four coefficients of restitution have to be specified for Anvil, Cap, Pile Top and Pile Cushion for diesel hammers or Cap, Assembly, Pile Top and Pile Cushion for air/steam hammers. If they are not specified a value of 0.85 will be assumed except for ECUS when no cushion is present. Then ECUS will be set to 1.0 no matter how it was specified. It is recommended to use 0.85 for steel to steel impact and lower values should be used where cushioning material is present. Table 3 contains some of these values.

TDEL is the combustion delay after impact or atomized fuel injection in seconds. Specifying TDEL here overrides the data file value or the value specified on Card No. 5.202. It can be specified as a negative value which would cause preignition except for atomized fuel injection where the time delay is always positive and depends on the time of injection. Small positive values can also cause preignition in the case of atomized fuel injection. Usually TDEL is left blank.

TEMAX is the maximum time up to which the analysis is to be carried out (in milliseconds). Note that TEMAX is usually determined by the program such that the stroke is found with sufficient accuracy. Thus, specification of TEMAX might lead to wrong results.



NOTE: THE TERM CAP (CARDS NO. 3.000 AND 4.000) INCLUDES STRIKER PLATE, CAP BLOCK AND HELMET.

FOR STIFFNESS OF CAP USUALLY ONLY THE CAP BLOCK NEEDS TO BE CONSIDERED.

WEIGHT OF CUSHION IS EITHER NEGLECTED OR CAN BE ADDED TO THE CAP.

FIGURE 2: TERMINOLOGY USED FOR DRIVE SYSTEM.

TABLE 3: CAPBLOCK AND CUSHION PROPERTIES AND A FEW HELMET WEIGHTS

TABLE 3(A): BASIC DATA OF CUSHION MATERIALS

Material	Elastic Modulus E (ksi)	Coefficient of Restitution e
Asbestos (1)	45	0.5
Conbest (2)	560	0.80
Forbon (2)	800	0.85 (est.)
Micarta (1)	450	0.80
Micarta + Aluminum (1)	700	0.80
Oak (⊥ grain)	40-100	0.50
Oak (// grain)	1000-2000	0.50
Plywood	25-100	0.5
Urethane (3)	350	0.72

TABLE 3(B): WEIGHTS AND STIFFNESSES FOR FEC(4) DRIVE CAPS

	OAK		CONBEST	
Size	Weight(7) kips	Stiffness(5) kips/in	Weight(7) kips	Stiffness(6) kips/in
12"x12"	0.91	28000	0.95	21000
14"x14"	0.96	38000	1.00	28000
16"x16"	1.48	48000	1.53	36000
18"x18"	1.67	60000	1.72	45000
20"x20"	N/A	N/A	2.44	45000
22"x22"	N/A	N/A	2.22	45000
24"x24"	N/A	N/A	2.36	45000

TABLE 3: cont'd

TABLE 3(C): STIFFNESS OF CUSHION USING FOSTERLON AS SPECIFIED BY L.B. FOSTER CO. (8)

Hammer	Size (Nominal)	Thickness in.	Stiffness kips/in
Kobe K13, K22 K25	17"	3.5	62,000
Kobe K32, K42, K35 K45	24"	3.5	126,000
Vulcan 1, 06, 106 50C, 65C	11.5" dia.	6.5	12,200
Vulcan 2, 30C	10.5" dia.	6.5	10,200
Vulcan 0, OR, 08, 010, 80C	14.0" dia.	8.5	14,000
Vulcan 014, 016, 140C	17.5" dia.	7.0	26,700
Vulcan 020, 200C	19.75" dia.	7.5	31,900
MKT DE30, DA35	19" dia.	2.5	88,400
MKT DE40	23" dia.	2.5	130,000

TABLE 3(D): OAK CUSHIONS AS RECOMMENDED FOR KOBE HAMMERS (9)

Hammer	K13	K25	KC25	K35	KC35	K45	KB60	K150
Thickness (in)	4	6	6	6	6	8	8	11
Stiffness (kips/in)	102,000	100000	100000	141000	141000	138000	183000	242000

TABLE 3: FOOTNOTES

(1) Taken from Table A p. 14 of Manual of TTI, 1973.

(2) As specified by manufacturer.

(3) Determined by New York DOT

(4) FEC ... Foundation Equipment Co., Newcomerstown, Ohio. Distributor of DELMAG hammers; manufacturer of pile driving accessories.

(5) Based on an E = 1000 ksi (load parallel to grain).

(6) Based on an E = 560 ksi as specified by manufacturer.

(7) Does not include adaptors.

(8) L.B. Foster Company, Pittsburgh, Pa.,
Data taken from L.B. Foster Brochure.

(9) Taken from Specifications as supplied by the L. B. Foster Co., using E_{oak} = 1420 ksi.

3.5 (a) Pile Description
(Card No. 5.000)
L pile, A pile top
E pile top, W pile top

(For pile material data see Table 4.) i.e. Pile length, and for the pile top cross-sectional area, elastic modulus and specific weight, respectively. In the simpliest case which is a uniform pile these four quantities are sufficient to describe the pile.

Table 4: Pile Material Properties

Material	Elastic Modulus EP ksi	Specified Weight RP lbs/ft^3	Wave Speed c ft/msec
Steel	29,500-31,000	492	16.7-17.0
Concrete	3,000-7,000	150	9.6-14.7
Timber	1,300-2,500	40-70	Dependent on Ep and Rp

(b) For NCROSS $>$ 0:
Card No.s 5.101,...
XP (I), AP(I), EP(I), WP(I)

i.e. depth, cross sectional area, elastic modulus and specific weight, the latter three at the XP(I) depth. The program interpolates properties linearly between consecutive XP(I) values. Stepwise changes of cross section (or changes of material) have to be identified by two cards with identical XP(I) values first giving the pile properties just above the change and second just below that section.

Any combination of linear with straight sections and with any type of material is possible.

The program recognizes the last set of input values by comparing XP(I) with Lpile. It is, therefore, imperative that the last set of XP(I), AP(I), ..., specifications starts with an XP(I) value that is greater than or equal to Lpile.

Example 1: A steel pile (EP = 30000 ksi, WP = 492 lbs/ft^3) consists of 45 feet of uniform pipe with a cross sectional area of 10 square inches.

Below is added a tapered 45 foot pipe that decreases from 10 to 7.5 in^2, linearly. The input would be as in Figure 3(a).

Example 2: A concrete pile (EP = 5000 ksi, WP = 150 lbs/ft^3) 14 by 14 inches square is 60 feet long and has a steel tip of 15 feet length and 15.5 square inch cross section. The data for this case is given in Figure 3(b).

3.6 Soil Information Hammer Optional Input (Card No. 6.000)

The necessary soil information is basically supplied in terms of the commonly known wave equation parameters. The following need to be specified (for soil damping values see Table 5).

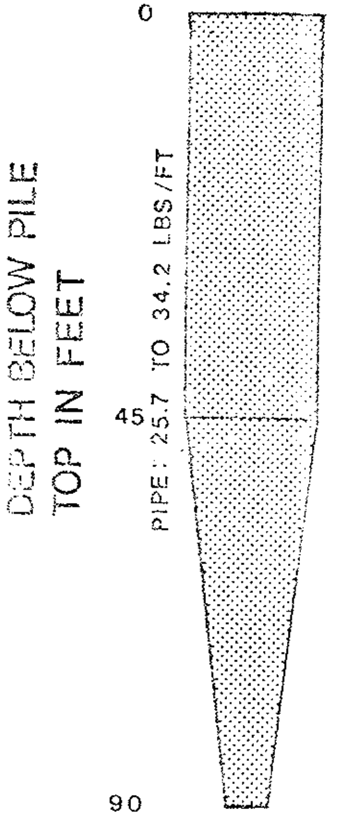
Table 5: Recommended Damping Values

	Smith*		Case	
	Skin	Toe	Skin	Toe
Gravel	0.05	0.05-0.1	0.1-0.2	0.1
Sand	0.05	0.1-0.2	0.2-0.4	0.1-0.2
Silt	0.10-0.15**	0.1-0.5**	0.5-1.5	0.4-0.8
Clay	0.2	0.01-1.0**	1.0-2.0	0.5-0.8

*These values are based on the usually employed distribution of static resistance forces.

** The TTI recommendations are the lower bound values.

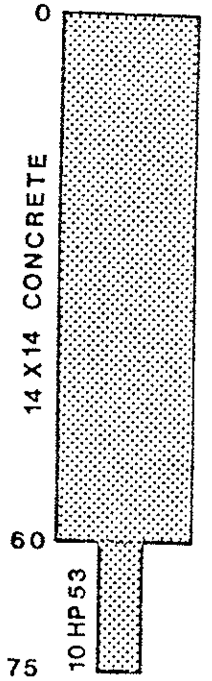
(A)



DATA

XP	AP	EP	WP.
FT	IN^2	KSI	LBS/FT^3
0.0	10.0	3000.0	492.0
45.0	10.0		
90.0	7.5		

(B)



DATA

XP	AP	EP	WP
FT	IN^2	KSI	LBS/FT^3
0.0	196.0	5000.0	150.0
60.0	196.0		
60.0	15.5	30000.0	492.0
75.0	15.5		

FIGURE 3: (A) EXAMPLE 1 (B) EXAMPLE 2 FOR NON-UNIFORM PILE DATA INPUT

Quake Skin, Quake Toe, Damping Skin, Damping Toe, RULT ESOIL

Quakes are to be specified in inches (usually 0.1). Damping parameters can be given in either of two ways. *If ISMITH (Card No. 2.000)* was chosen as 1, meaning that Smith damping is to be employed, the damping values have the usual s/ft dimension. If ISMITH was equal to zero then the damping values are considered dimensionless (for a conversion from Smith to viscous damping see the report). RULT is the total static capacity in tons for which an analysis is to be performed. If RULT is zero (or not specified) various values (at most 10) will be assumed by the computer and all analyses will be performed unless the blow count exceeds 1200 blows/ft.
If RULT is given as a negative value (e.g. -1.0) an additional card (No. 9.000, Section 3.9) with up to 10 RULT values, (in tons), must be supplied.

ESOIL is a coefficient of restitution that is applied to all static soil resistance calculations. ESOIL left blank will cause the computer to use 1.0 (usual case).

Stroke, Efficiency Steam Pressure and Reaction Weight

The Stroke value (in feet) is used as a starting value in a diesel hammer analysis (if IOSTR = 1 or = -1 then only this stroke will be analyzed). For air/steam hammer it replaces the -usual- stroke value either program or user supplied.

The Efficiency can be left blank which causes the use of a hammer efficiency of 0.95 for diesel hammers or the one specified in the hammer data for air/steam hammers.

The Steam Pressure (in psi) is disregarded for all except differential acting steam hammers. If it is chosen greater than the maximum allowed by the manufacturer, it is ignored. If not supplied, the maximum value specified by the manufacturer is used.

The Reaction Weight (in kips) is only used for closed end diesel or differential acting air/steam hammers. It replaces - if specified - the values supplied by the data file or user.

3.7 Skin Friction Distribution (Card No.s 5.401, ...)

For skin friction distributions that do not conform to Table 2, i.e., when ITYS = 0, the following cards - at most 20 - can be used. These specifications consist of pairs of values.

XP(I), DIS(I)

XP(I) is the depth in feet (in increasing order) and DIS(I) is a relative, dimensionless quantity. Only the skin friction is affected by the distribution choice. The amount of skin friction is a certain percentage of the total ultimate resistance RULT and was specified by IPERCS. As for the pile data on Card No.s 5.101, ..., it is imperative that the last depth value, XP(I), be greater than or equal to Lpile.

Example 1: The data for a triangular distribution over the bottom half of a 60 foot pile is given in Figure 4(a). Note that DIS(3) could have been given as any other value (it is only relative). Also, as in the case of pile specifications (Card No. 5.101, ...) the end of distribution specifications is recognized by the appearance of an XP value which is equal to or greater than Lpile.

Example 2: For the pile of Example 1 the soil resistance is of rectangular shape from 20 to 30 feet and then starting with one-half of the value above increasing linearly to twice that value at 50 feet. It is to be zero below that point. The required data is given in Figure 4(b). Note that 20 is the maximum number of pairs of values (or cards).

An additional example showing the computations performed by the computer to derive the SU(I) values from DIS(I) is shown in Figure 5.

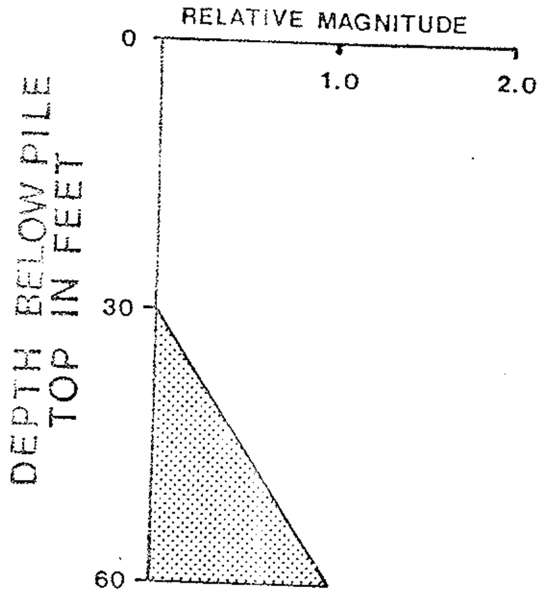
3.8 Plotter Information (Card No.s 7.000 and 8.000)

Two cards specifying the scale and the quantities to be plotted are to be given if IOUT $>$ 9. A discussion of this data is given in Sections 4.13 and 4.15. The most important plotter output is provided and a scale is automatically chosen, if the two cards are left blank.

3.9 RULT Values (Card No. 9.000)

For RULT $<$ 0 on Card No. 6.000 up to 10 RESULT (I) values can be specified.

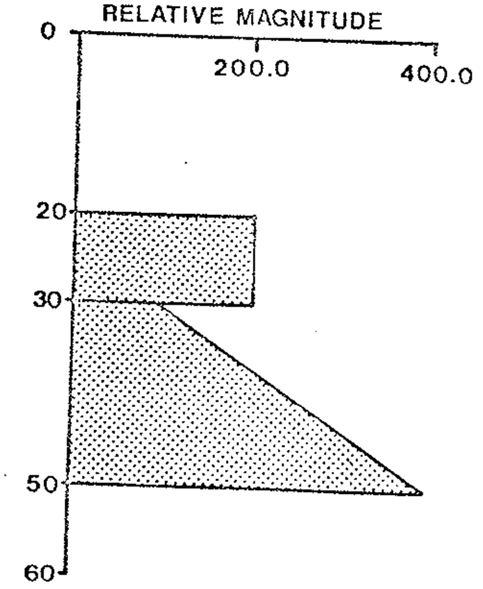
(A)



DATA

XP	DIS
FT	
0.0	0.0
30.0	0.0
60.0	1.0

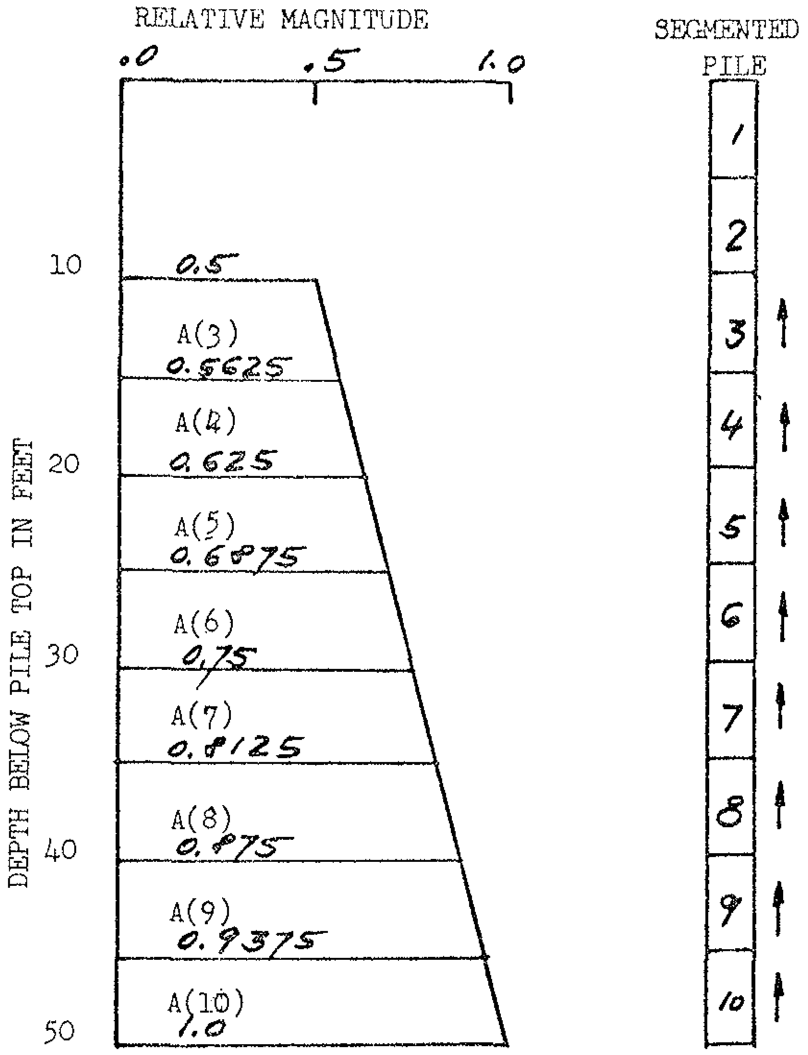
(B)



DATA

XP	DIS
FT	
0.0	0.0
20.0	0.0
20.0	200.0
30.0	200.0
30.0	100.0
50.0	400.0
50.0	0.0
60.0	0.0

FIGURE 4: (A) EXAMPLE 1 (B) EXAMPLE 2 FOR INPUT OF SKIN FRICTION DISTRIBUTION



A(I) (feet)	FRACTION OF RULT* ("1")	SU(I) (tons)
2.656	0.035	4.43
2.969	0.040	4.95
3.281	0.044	5.47
3.594	0.048	5.99
3.906	0.052	6.51
4.219	0.056	7.03
4.531	0.060	7.55
4.844	0.064	8.07
30.000 (A_{tot})	0.40 (IPERCS)	50.00 (R_{skin})

$$^{*}\text{FRACTION OF RULT} = \frac{A(I)}{A_{tot}}\ \frac{(IPERCS)}{100} \qquad SU(I) = (\text{FRACTION OF RULT}) \times (\text{RULT})$$

EXAMPLE FOR THE COMPUTATION OF ELEMENT RESISTANCE FORCES:

IPERCS = 40 (%), RULT = 125 (tons)
N = 10 XPT = 50 (feet)
Segments are of equal length (5 feet)

Total Skin Resistance = 125 (40)/ 100 = 50 (tons)
Total Area under resistance curve = $(0.5 + 1.0)\frac{1}{2}(50 - 10) = 30.0$ (feet)
Toe Resistance = SU(11) = (100 - 40)(125)/ 100 = 75 (tons)

FIGURE 5: EXAMPLE COMPUTATION FOR THE DISTRIBUTION OF SKIN RESISTANCE FORCES. (THIS COMPUTATION IS USUALLY PERFORMED BY THE COMPUTER)

RESULT (1), RESULT (2), ...	RESULT(I) is the I-th ultimate resistance (RULT) in tons. The values should be given in increasing order. The first occurrence of a zero (or blank field) terminates the search for further RULT values. Also, no additional analysis is performed if the blow count of the last RULT value has exceeded 1200 blows/foot.

CHAPTER 4

COMPLETE INPUT

The following data can be specified in addition to the short input. The following cards have to be inserted according to card number sequence - see also complete input form. All values are real numbers (with decimal points) inserted in fields of 8 spaces except in Card No.s 6.501,..., 8.000 and 8.101.

4.1	For IPEL = 2: STP(I), I = 1, N Card No.s 2.101,...		Pile segment stiffnesses in kips per inch for all N elements. Since 10 values are read per card there might be up to 10 cards. (N = 98 = maximum) if the I-th value is the same as the (I-1) - th, it can be left blank. The first value must be given.
4.2	For IPEL = 2: PM(I), I = 1, N Card No.s 2.201,...		Pile segment weights in kips for all N elements. Otherwise as for STP(I).
4.3	For IPEL ≠ 0: ALPH(I), I = 1, N Card No.s 2.301,...		Relative segment lengths (any relative - real - numbers). Otherwise as for STP(I). (Note, ALPH(I) has to be provided even though STP(I) and PM(I) are given since it is needed to determine the spacing in the 3-dimensional plot).
4.4	For IHAMR = 0 Card No. 5.201	NAME	8 alphanumeric characters describing the hammer.
		HM(1), STH(1)	consecutive pairs of hammer weights in kips and stiffnesses in kips per inch.
		. . .	
		HM(5)	If there are less than 5 values to be specified then the others are left blank.
4.5	For IHAMR = 0 Card No. 5.202	STH(5), HM(6) STH(6), HM(7)	Continuation of ram weights and stiffnesses. Note, that there will be always one stiffness less than weights.

	M	The number of ram segments to be used (given as a real number, e.g., 3.0). $M \geq 3$ for Diesels.
	HM(M+1)	Anvil weight in kips (diesel only).
	STH(M)	Combined anvil and last ram spring stiffness (diesel only).
	TDEL	Combustion delay in seconds (diesel hammers only). For a description of this value see 3.4.
	TS	The duration of fuel injection or ignition in seconds. For atomized injection ($DINJ > 0$ on Card No. 5.204) TS should correspond to the duration of injection. For regular injection 0.001 sec. is a reasonable value.
4.6 For IHAMR = 0 Card No. 5.230	VFIN	Combustion chamber volume in cubic inches. (Diesel hammers)
	DEPIB	Distance between exhaust ports and anvil top in inches. (Diesel hammers)
	ARAM	Inside cross section of cylinder in square inches. (Diesel hammers)
	P1, P2, . . ., P5	Up to five maximum combustion pressures as measured. (Diesel and double acting air/steam hammers). For diesel hammers IFUEL = 1, 2, ..., 5 will cause these pressures to be used as maxima. For Double Acting air/steam hammers P1 is the pressure at which hammer is rated.
	EFFICY	Hammer efficiency. (All hammers) (Default 0.95). Will be overridden by the value on Card 6.000.
	STRM	Maximum stroke (diesel) or stroke to be used (air/steam) in inches.
4.7 For IHAMR = 0 Card No. 5.204	EXPP	Exponent for the expansion process (diesel hammers).
	ART	Bounce chamber cross sectional area in square feet (closed end diesel hammers).

	DEPBB	Distance between bounce chamber exhaust ports and cylinder top in feet (closed end diesel hammers).
	DSF	Distance between compression tank ports and cylinder top in feet. (Closed end diesel hammer with compression tank). For vacuum chamber hammers DSF is the distance between ram bottom and anvil at which the pressure in the vacuum hammer starts to decrease.
	DBBT	Distance between anvil and cylinder top minus ram length in feet (closed end diesel hammers).
	POWSCA	0.0 most cases. 1.0 where power scavenging is employed (e.g. Linkbelt) (diesel hammers).
	RWH	Reaction weight of closed end diesel or air/steam hammer in kips. Will be overridden by the value of Card 6.000.
	EXPB	Exponent for bounce chamber expansion - compression (usually 1.4) for closed end diesel hammers.
	DINJ	Distance of ram bottom from anvil at which atomized fuel is injected in feet. Should be zero for non-atomized fuel (diesel hammers).
	VCT	Volume of compression tank in cubic feet (closed end diesel hammers). For vacuum chamber hammers it is the volume of the chamber when pressure starts to decrease.
	RAM	For vacuum chamber hammers only the ram weight in kips (serves as identifier for this hammer type).
For IHAMR = 0: Card No. 5.205	AM(I), STA(I)	Assembly segment weights (kips) and stiffnesses (kips/inch) for up to three assembly segments. (Air/steam hammers only).
	MA	Number of assembly segments (MA = 2 or 3) given as a real number, e.g., 2.0. (Air/steam hammers only).

		ITYPH	Hammer type 1.01 open end diesel hammer 2.01 closed end diesel hammer 3.01 air/steam hammer
4.9	For ITYS < -1: Card No.s 6.101,...	QS(I), I = 1, N+1	Soil quake in inches for all elements plus pile point, up to 99 values may be required. (Otherwise as for 2.101).
4.10	For ITYS < 0: Card No. 6.201,...	SJ(I), I = 1, N+1	Soil damping parameters. For ISMITH = 1 in s/ft, the usual values as given in Table 5 can be used. For ISMITH = 0 as a fraction of the EA/c value of the corresponding segment. Otherwise as for 6.101. If a zero value is to be specified and the previous values were non-zero a 0.0002 should be given. Note that Case damping values are not related to static soil resistance. Therefore, they can be specified even though the static resistance is zero. However, the values recommended in Table 5 represent the sum of all skin damping parameters. Input on Card No. 6.201 represents the constant for each individual element. For example: For N = 15, a 0.2 Case skin damping factor corresponds to 0.2/15 = 0.0133 for each element if a uniform damping distribution is desired.
4.11	For ITYS < -1: Card No. 6.301, ...	SU(I) I = 1, N+1	Relative magnitudes of ultimate static soil resistance values. Note that this input overrides IPERCS, i.e., the point resistance is determined using SU(N+1). The program normalizes the SU(I) values. Therefore, only relative magnitudes need to be given. As in 6.201 a blank field indicates that the previous value is to be used. Thus, zero input should be made as 0.0002. At least one value should be greater than zero.
4.12	For ISPL > 0: Card No. 6.501,...	J, SPLICE (J)	The number of cards to be provided is equal to ISPL. On each card the element number J (a right justified integer in a field of 4 spaces) and the corresponding splice value SPLICE(J) (a real number with 8 space field). SPLICE(J) is the largest tension force (negative) that spring J can transmit, if SPLICE(J) = 0.0 or < -0.5 (kips). SPLICE(J) specified between -0.5 and 0.0 (feet) means a slack value (0 tension force within an extension of SPLICE(J) feet). See Example 5.7.

The following two cards are always required when plots are desired; they both may be blank.

4.13 For IOUT > 9 Card No. 7.000	YMAX	The maximum value to which the positive axis in the plotter routine should be drawn. For example, if YMAX = 100.0 and if forces were plotted then the positive axis would extend to 100 kips (often four inches). There would be no problem if YMAX would be slightly smaller than the actually occurring maximum value. However, if YMAX was accidentally set too small by a full order of magnitude or more the program would automatically change this scale. Note that YMAX is dimensional and should correspond to the output variables selected by IOUT. Thus, the dimensions for YMAX are kips for IOUT = 11 or 21 ft/s for IOUT = 12 or 22 ksi for IOUT = 13 or 23 g's for IOUT = 14 or 24 inches for IOUT = 15 or 25 psi for IOUT = 16 or 26 and ISEG(1) = 0 kips for IOUT = 16 or 26 and ISEG(1) = 1 ft/s for IOUT = 16 or 26 and ISEG(1) = 2 kips for IOUT = 16 or 26 and ISEG(1) = 3 (ISEG(I) is specified on the next card). If YMAX is not specified then the scale is automatically selected.
4.14 For IOUT > 9: Card No. 8.000	ISEG(I), I = 1, 15	Integers in fields of 4 spaces. Selects pile segments to be plotted as a function of time. If ISEG(I) is specified equal to J then the J=1 corresponds to ram bottom J=2 corresponds to anvil and J=3 through J=15 correspond either to the pile segments specified by INP(1) through INP(13) (next card) or to the automatically selected INP(I) values. An example will be given below. If IOUT = 16 or 26 then the variable vs. time plot would be combustion pressure for ISEG(1) = 0, pile top force and pile bottom force, for

ISEG(1) = 1, pile top and bottom velocity for ISEG(1) = 2, and pile top force plus the proportional pile top velocity (multiplied by EA/c) for ISEG(1) = 3. If ISEG(2) through ISEG(4) are also specified all of these plots can be obtained.

Viz ISEG(1) = 0, ISEG(2) = 1,
ISEG(3) = 2, ISEG(4) = 3
plots all four combinations. Note that ISEG(5) through ISEG(15) are ignored if IOUT = 16 or 26. If all ISEG(I) values are zero then the ISEG(3), i.e., the pile top quantity in the usual case will be selected for plotting except for IOUT = 16 or 26 where combustion pressure would be selected. Examples will be given below.

4.15 For IJJ = 1 and IOUT ≠ 6, 16 or 26:
INP(I), I = 1, 13
Card No. 9.101

Integers in fields of 4 spaces.
At most 15 variables can be printed due to the width limitations of the paper. Since two hammer variables are usually included a selection of variables has to be made if N > 13. This is conveniently done automatically (IJJ = 0). If the user wants to specify certain elements, he can do this by specifying the 13 pile segments for which he desires output. For example, if N = 40 a uniform spacing would be given using the following string of numbers:

1, 4, 7, 10, 13, 16, 20, 24, 27, 30, 33, 36, 40
which would include the pile top (1) and bottom (40).

Examples: (a) IOUT = 3, N = 10, IJJ = 1

Since no plot is desired, YMAX and ISEG(I) would not be read. Because of IJJ = 1 INP(I) would have to be specified which would be: 1, 2, 3,..., 9, 10 and three blank fields. The output would be stresses in the ram, anvil and in all pile elements. The INP(I) values thus specified would be the same as the automatically selected ones.

(b) IOUT = 15, N = 10, IJJ = 0

YMAX may be left blank and ISEG(I) may be chosen as 3, 12, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, in which case all 10 pile displacements plus the two hammer displacements would be printed and a plot vs. time be constructed showing the pile top and pile bottom displacement as a function of time.

(c) IOUT = 16, N = 50, IJJ = 0

YMAX and ISEG(I) may be left blank. In addition, INP(I) is not read and IOUT = 16 calls for output of a variety of variables. The result would be a plot of combustion pressure vs. time.

(d) A pile is 120 feet long and N is given to be 16. A plot and print of stresses at pile top, middle and bottom are desired with the fixed scale of 50 ksi = maximum. Set IJJ = 1, IOUT = 13 (or 23 which would also provide a three dimensional plot of stresses), YMAX = 50.0 and ISEG(I) = 3, 10, 15, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, (I = 1, 15) INP(I) = 1, 2, 4, 5, 6, 7, 8, 9, 10, 12, 14, 15, 16 (I = 1, 13). This would produce a print of stresses in ram and anvil in addition to those in pile springs identified by INP(I). The stress vs. time plot would contain the stresses in pile spring No. 1, 9 and 16.

CHAPTER 5

ADDITIONAL INPUT EXAMPLES

5.1 Specifying a Soil Plug

Suppose it is intended to describe a steel pipe pile (A_S, E_S, W_S) which was driven open ended and within which a soil plug has been formed. A plug exists when the soil does not move relative to the pile. It may be assumed that the soil has a negligible stiffness compared to the pile. Thus, the pile area and modulus specified must yield the pile stiffness and, therefore, only WP is affected. This value can be calculated as follows:

$$WP = W_{soil} \frac{A_{plug}}{A_S} + W_S$$

where WP is the unit weight of steel plus soil combined, W_{soil} is the unit weight of the plug and A_{plug} is the cross sectional area of the plug.

For a 24 inch outside diameter pipe with 60 feet length, 1 inch wall and 5 foot plug, one would obtain

$$A_S = 23\ (1) \quad = 72.27 \quad in^2$$

$$W_S = 492 \quad \#/cu\ ft$$

$$E_S = 30{,}000 \quad ksi$$

$$W_{soil} = 110 \quad \#/cu\ ft \quad (assumed)$$

$$A_{plug} = 22^2 \quad /4 = 380.13 \quad in^2$$

and therefore

$$WP = 110(380.13)/72.27 + 492 = 1071 \quad lb/cu\ ft$$

The input would be:

Card #	Lpile/XP	AP	EP	WP
5.000	60.	72.26	3000.0	492.0
5.001	55.	72.26		
5.002	55.	72.26		1071.0
5.003	60.	72.26		1071.0

5.2 Specifying a Pile Point

Suppose the input is to be given for a 10HP42 ($AP = 42/3.42 = 12.28\ in^2$) pile of 40 feet length with a 75 pound pile point that extends 3 inches below the bottom of the H-pile. Since the effective cross sectional area of the pile point, A_{point}, is not known it is sufficiently accurate to find

$$A_{point} = \frac{1728\ WT_{point}}{(W_{point})\ (T_{point})} \qquad \frac{(in^3\ /ft^3)(lbs)}{(lbs/ft^3)(in)}$$

with WT_{point} being the total weight, W_{point} the unit weight, T_{point} the maximum thickness of the pile point.

In the given example one obtains:

$$A_{point} = 1728(75)/(492(3)) = 87.80\ \ in^2$$

The input would be

Card #	Lpile/XP	AP	EP	WP
5.000	40.25	12.28	30000.	492.
5.001	40.0	12.28		
5.002	40.0	87.8		
5.003	40.25	87.8		

5.3 Specifying a Single Acting Air/Steam Hammer

This is the simplest hammer to specify and, incidentally, a drop hammer would be specified in the same manner.

As an example, consider a hammer with 5.000 kips ram weight, efficiency 0.8, normal stroke 36.0 inches. The assembly is to be disregarded.

Since the air/steam ram is very compact its stiffness is extremely high and can be neglected. Thus, the necessary input is as follows:

Card #	
5.201	NAME = AIRSTEAM, HM(1) = 5.0
5.202	M = 1.0
5.203	EFFICY = 0.8, STRM = 36.0
5.204	blank
5.205	ITYPH = 3.001

Should the assembly be considered the following must be determined: Weight of the assembly top (supported by columns), weight of hammer base, stiffness of all columns. Suppose the assembly top weighs 3.0 kips and the base 2.0 kips. There are four columns of 4-1/2 inch diameter and 90 inch length. Therefore, the assembly stiffness is

$$\mathrm{STA} = 4(4.5^2)\,\pi/4 \quad (30000)/90 = \frac{21206}{\text{Kips/inch}}$$

The two assembly springs have twice this stiffness. Thus, the following data is to be given on card 5.205: AM(1) = 3.0, STA(1) = 42212., AM(2) = 2.0, STA(2) = 42212., MA = 2.0, ITYPH = 3.01.

5.4 Specifying an Open End Diesel Hammer

In this example a hammer is considered having the following properties:

	Ram	Anvil	
Weight:	2,750	810	lbs
Length:	95	19	inch
Diameter:	12.5	12.5	inch

Compression ratio 12:1
Chamber volume 120 cu in
Combustion delay approximately 2 Msec.
Maximum combustion pressure on full throttle 1150 psi
(Values for other throttle settings not known).
Maximum stroke 102 inch
Expansion exponent not determined, assume 1.3
No power scavenging
No atomized fuel injection

The ram cross sectional area is

$$\mathrm{ARAM} = \frac{\pi}{4} \; 12.5^2 = 122.7 \quad \mathrm{in}^2$$

The volume displaced by the ram is

$$\mathrm{VR} = 12(120) - 120 = 1320 \quad \mathrm{cu.in}$$

The distance between exhaust ports and anvil is therefore (assuming cylinder area equal ram cross section):

$$\mathrm{DEPIB} = \frac{1320}{122.7} = 10.76 \quad \mathrm{in}$$

Choosing three ram elements (equal length) their weights are

$$\mathrm{HM(I)} = \frac{2.75}{3} = 0.917 \quad \mathrm{kips,\ I = 1,\ 2,\ 3}$$

The segment stiffnesses are (E = 30000 ksi):

$$\mathrm{STH(I)} = 3\,\frac{30000(122.7)}{95} = 116000 \ \mathrm{kips/inch,\ I = 1,\ 2}$$

The anvil's stiffness is

$$STA = \frac{30000\ (122.7)}{19} = 194000 \text{ kips/inch}$$

Combining STA with the ram bottom stiffness one obtains (M = 3):

$$STH(3) = \frac{194000\ (116000)}{194000 + 116000} = 72600 \text{ kips/inch}$$

The corresponding input is:

Card #

```
5.201:    NAME = HYPOTHET, HM(1) = 0.917 = HM(2) = HM(3), STH(1) = 116000. = STH(2)
5.202:    M = 3.0, HM(M+1) = 0.81, STH(M) = 72600., TDEL = 0.002
5.203:    VFIN = 120., DEPIP = 10.76, ARAM = 122.72, P1 = 1150.0, STRM = 102.0
5.204:    EXPP = 1.3
5.205:    ITYPH = 1.01
```

A computer run demonstrating the use of this hammer data is discussed in Example 7.4.

5.5 Additional Specifications for a Double Acting Air/Steam Hammer

If the hammer of Section 5.3 were double acting the following additional specifications would be needed:

> P1 (maximum operating pressure, i.e., at lift-off)
> RWH (hammer reaction weight)

Note that these two values are related by the effective cylinder area, Ae, during downstroke (P1 = RWH/Ae). For example, if the maximum rated energy for the hammer of Section 5.3 was given as 27,000 ft-lbs then 12,000 ft-lbs would be from the pressure on the downward stroke. The reaction weight is equal to the maximum pressure force (at rated pressure):

$$\text{Pressure force} = \text{Energy/stroke} = 12/3 = 4 \text{ kips}$$

The equation used for calculating reduced equivalent strokes in the program assumes that uplift occurs at the rated pressure force. If $Ae = 50 \text{ in}^2$

$$RWH = 4.0 \text{ kips}$$

$$P1 = (4.0/50)\ 1000 = 80 \text{ psi}$$

Note, assembly weights and reaction weight need not agree numerically.

5.6 Additional Specifications for Closed End Diesel Hammers

Suppose that the hammer of Section 5.4 had a closed cylinder top with the following known data:

> Ram top starts to compress bounce chamber when the ram has moved 5 inches up from the anvil. The ram is uniform and there is a distance of 4-1/4 feet that the ram can move upward from the time the bounce chamber compression begins before it hits the top. No compression tank and, therefore, safety chamber exists.

Thus the following can be determined:

$$ART = ARAM = 122.72/144 = 0.8522 \ \ ft^2$$

$$DEPBB = 4.5 \ \ ft$$

$$DBBT = DEPBB + 5 \ \ inch$$

$$= 4.5 + 5/12 = 4.9167 \ \ ft$$

(Of course the maximum stroke would be smaller than in Section 5.4).

Assuming an adiabatic bounce chamber compression/expansion (EXPB = 1.4) all of the additional data to be given on Card 5.204 is found. On Card 5.205 the hammer type is to be changed to 2.01.

5.7 Specifying Slack or Splice

Suppose that a 100 foot pile had two different splices. First, 32 feet above the pile bottom a connection was made which cannot transmit more than 100 kips tension force. 66 feet above the toe a second connection allows a two inch (0.167 feet) extension before it can transmit tension.

In order to properly assign JSPLICE values, N should be specified, say N = 20. Then the sixth spring would correspond to the upper and the 13-th spring to the lower splice.

The input would be

Card No.	Element J	SPLICE(J)
6.501:	6	-0.167
6.502:	13	-100.

CHAPTER 6

OUTPUT DESCRIPTION

In this section a discussion will be given in input check print and headings used in the printed output. Also a discussion of possible message printout will be given.

6.1 Input Check

The first page always contains listings of important input values. After the job name the pile description is printed as it was given on Cards 5.000 and 5.101, ...

For air/steam hammers the following is added: The stroke actually used, efficiency and derived impact velocity, for double acting air/steam hammers also the maximum and actual pressure and ram and reaction weights. Next, the hammer model including cap and cushion are printed. The headings are self-explanatory.

Under the heading "PILE PROPERTIES" follows a summarized description of the pile and its material (pile top properties). Then for each pile segment the following values are given:

Weight	...	the weight of the segment in kips
Stiffness	...	the stiffness of each spring kips/inch
Pdamp	...	the damping constant for each pile dashpot in kips/ft/sec
Splice	...	the minimum force value (compression is positive) which can be transferred by the springs in kips.
Soil-S	...	the static soil resistance force acting at an element as a fraction of the total static capacity (RULT)

Soil-D ... the soil damping parameters either in kips/ft/sec (Case damping) or in sec/ft (Smith's damping)

Quake ... the quake of each elasto-plastic soil spring in inches

L.B.T. ... the length below the top to which the bottom of a segment extends

After the print out for all N elements the three soil properties Soil-S, Soil-D and Quake for the pile toe and the soil's coefficient of restitution are printed. For a negative IPERCS a message is then printed indicating that the skin friction is to be kept at a constant value. Next follows a recap of options and specifications:

PHI ... the ratio of the critical to the time increment used

S-Damping ... whether Smith's or whether viscous damping was used

P-Damping ... the pile damping parameter in percent of critical

J SKIN ... the soil skin damping parameter (dimensions as in the pile table under Soil-D)

J TOE ... the soil toe damping parameter (dimensions as for J SKIN)

TEMAX ... the maximum analysis time allowed in milliseconds (input value)

IFUEL, i.e., the fuel setting

IOUT, i.e., the output option

Soil Dist. No., i.e., ITYS

IOSTR, i.e., stroke option

RWT (kips), i.e., the hammer reaction weight actually used

TDEL (sec), i.e., the combustion delay (input value)

EFFICIENCY; i.e., the efficiency used in the case of diesel hammers

TIME INCR. (MS) the analysis time increment

6.2 Output

After the input recap a heading is given indicating the total static soil resistance analyzed and the portion acting at the bottom. For print options which are not 0, 10 or 20 selected variables are then printed vs. time. The selection of variables was discussed in the input information. The headings used indicate the type of variable and its dimension (except for the 6, 16, 26 option), the hammer variables (RAM M means the ram bottom), and the pile variables. TOP stands for the first segment while the following numbers refer to the corresponding pile segments.

JP is a time counter and TIME is in milliseconds. TIME is usually started one millisecond before impact.

For the 6, 16, 26 option the following headings are used:

JP ... Time counter

TIME ... Time in milliseconds

P ... Combustion pressure for diesel hammers

SEA ... Distance between assembly and cap for air/steam hammers

D ... Indicating displacement for RAM, ANV (anvil), TOP (pile top), MID (at midlength) and TOE (pile bottom segment)

V ... Indicating velocity with subscripts TOP, MID and TOE

F	...	Indicating forces in the pile with subscript TOP, MID and TOE (for the first, middle and last pile spring, respectively)
SUM ST	...	Is the sum of all activated static soil resistance
SUM DP	...	Is the sum of all activated dynamic soil resistance
RT TOE	...	Is the activated static toe resistance

In all cases a table follows with extreme values for each pile element and their time of occurrence. Time of occurrence is given in terms of JP (JP time the time increment is the time since the start of the analysis).

The headings in this table are ELEM for element or segment, FMAX and FMIN for maximum and minimum pile force, respectively; MINSTR and MAXSTR for minimum and maximum pile stress, respectively; VELMX AND DISMX for maximum pile velocity and displacement. The table contains the extreme values followed by the time counter in parentheses. Appended to these tables is the maximum energy transferred to the pile and the strokes analyzed. Note that the last stroke listed is the rebound stroke. Also for the fixed stroke run, the total change of maximum combustion pressure is given as necessitated for stroke convergence.

If more than one RULT value is analyzed further output starting with the new total and toe static resistance is given. After the last analysis and its respective table of extreme values a summary table is then printed containing the analysis No., RULT value, Blow Count, Stroke and the minimum and maximum (of all elements) stress. For all diesel hammers the blow rate (blows per minute) is also given. For all closed end hammers a number in parentheses is appended to stroke indicating how many fuel reductions had to be taken and the maximum bounce chamber pressure is given.

6.3 Messages

A number of messages may or may not be printed during the execution of the program. Four different types of them exist.

P	...	Regular output giving certain indications about the program's performance.
S	...	Stop messages. Program termination message.
I	...	Interrupt message. An unexpected condition causes the program to skip to the next RULT or next data set.
W	...	Warning. The program's performance is not affected, however, the user is cautioned about the results.

Message No.	Message Type Subroutine	Message Text and Explanation
1	I Main	Damping grtr. critical, T.I. required lss .01 msec. (xxx) The damping parameter became so large that an analysis would have become infeasible. Damping should either be spread over more elements or reduced.
2	I Main	Analysis was terminated as no permanent set resulted. The condition encountered was no permanent set (infinite blow count) and no increase in stroke in the case of diesel hammers. Therefore, no additional RULT values were analyzed since they are assumed to be even larger.
3	P IPTN	Insufficient plotter information, therefore values are assumed. YMAX and/or ISEG were not specified (Card

		numbers 7.000 and 8.000) although IOUT was greater than 9. Zero input was automatically assumed.
4	P STARTC	Hammer will not run. For the given parameters no impact occurred or the ram did not get sufficiently close to the anvil for a reasonable analysis. The current analysis is, therefore, skipped and a higher RULT value is analyzed if RULT was specified $\leq$ 0 in Card No. 6.000. Otherwise the next set of data is read.
5	P Main	Fuel setting reduced by ten percent. Message given for closed end hammers that reach lift off and, therefore, require a reduced fuel setting.
6	P Main	No Fuel Conversion. After four fuel reductions lift off was still imminent. No new fuel reduction is analyzed. Results are in general acceptable.
7	P Main	No Stroke Conversion. After four analyses the rebound stroke was still different from the input stroke. No new stroke is analyzed. Depending on the last rebound stroke it should be decided whether an additional analysis would be necessary using the last stroke value as an input.
8	P Main	Large Damping Requires New Time Increment = xxx Msec. The damping parameters had become greater than critical. To avoid numerical instability time increments were reduced.
9	W Main	***Caution Ram Might Blow Out*** For open end diesel hammers if the stroke exceeds the maximum stroke specified by the manufacturer. Note that at most the maximum stroke will be analyzed.
10	S VACHAM	Negative Volume in Vac Chamber. Similarly to message No. 18, this was caused by improper vacuum hammer specifications.

11	S IPTN	Masses and Stiffnesses for First Elements are not Specified. Extended input requires at least the first segment specifications to be greater than zero.
12	S IPTN	Pile Properties at Bottom of Pile not Specified. During the specification of AP, EP and RP an XP value had been encountered that was less than earlier ones. This is interpreted as out of range or as a later input card. Thus, pile bottom specifications were not found.
13	S IPTN	Pile Masses or Stiffnesses Too Small, Check Input Info. At least one of the pile stiffnesses or masses were less than 100 kips/in or 10^{-7} kips/ft/sec^2, respectively. Either the pile specifications or the extended input were in error.
14	S HAEL	Insufficient Hammer Info. IHAMR = xxx. The number of ram segments specified was less than one. Either the hammer data file, or the user supplied data cards were in error, or the user has specified a hammer identifier corresponding to an empty file.
15	S STARTC	Negative Velocity in Start. Due to some abnormal condition the ram velocity was upwards at the exhaust ports. Check hammer data.
16	S IPTN	Unknown Hammer Type, Sorry. IHAMR was specified greater than the available number of hammers on file.
17	S IPTN	***N was not set, extended input not possible*** If IPEL is given greater than zero, N has to be specified to match pile segment specifications.

18	S VACHAM	Improper Condition Met When Determining Ram Velocity at Ports, VFALL = xxx. Geometric properties were such for the vacuum chamber hammer that a complex impact velocity resulted.
19	S IPTN	Hammer or Pile T.I. Equal to Zero, Check Input. Critical time increments were not sufficiently large. Probably input error.
20	S UP	Ram Still Moves Downward at End of Blow. End of blow is here defined as the end of the impact analysis. Causes may be insufficient combustion pressure, extremely low soil resistance or incorrect hammer or pile data. It may also indicate that the hammer does not run under the given conditions.
21	S IPTN	Data Error. Message was probably caused by improper data format.

CHAPTER 7

WAVE EQUATION EXAMPLES

7.1 Open End Diesel Hammer - Determination of Bearing Graph

7.1.1 Situation

A 45 ton (design) pile is to be driven through a soft compressible layer into a dense, coarse sand with gravel. The contractor wants to use 10HP53 profiles and a D-12 hammer. He uses a standard 12x12 inch cap with 4-1/2 inches of conbest.

7.1.2 Problem

Determine the blow count/bearing capacity relation.

7.1.3 Approach

Using a safety factor of two (2) the pile has to be driven to an ultimate capacity of 90 tons. A curve can be constructed for the desired range if capacities of 30, 60, 90 and 120 tons are analyzed.

7.1.4 Solution

The short input form is sufficient for solving this problem.

Card No. 1.000			Inserting a proper title
Card No. 2.000			IOUT = 10 for a printed and plotted summary only.
	IJJ	...	leave it blank (no output vs. time)
	IHAMR=2	...	for DELMAG D12 (see Table 2)
	IOSTR	...	leave it blank (stroke iteration allowed)
	IFUEL	...	leave it blank (full combustion pressure)
	IPEL	...	leave it blank (computer determines pile elements)

	N	leave it blank (automatically determined)
	ISPL	leave it blank (no splices or slacks)
	NCROSS	leave it blank (uniform pile, neglect the existence of an endplate)
	IBEDAM	leave it blank (steel)
	IPERCS	leave it blank (endbearing only)
	ISMITH	leave it blank for Case damping input.
	ITYS-6	for skin resistance distribution type 6 of Figure 1. (Note that since toe bearing only was assumed this distribution will pertain to the viscous damping parameters).
	IPHI	leave it blank (normal)
Card No. 3.000	Weight of cap	.95 kips (Table 3B - Conbest)
	Stiffness of cap	21,000 kips/inch (Table 3B - Conbest)
	Stiffness of Cushion	leave it blank (no cushion)
Card No. 4.000	C.O.R. Cap	0.80 (Table 3A)
	C.O.R. Anvil	0.80 (a little more conservative than the usual 0.85)
	C.O.R. Pile Top	0.80
	C.O.R. Cushion	leave it blank (no cushion)
	TEMAX	leave it blank (normal)
	TDEL	leave it blank (normal)

Card No. 5.000	L PILE ...	40.0 ft
	A PILE ...	$53 \frac{144}{492} = 15.5$ inch^2
	E PILE ...	30000 ksi (Table 4)
	W PILE ...	492 lbs/ft^3 (Table 4)
Card No. 5.101,...		Do not use, since NCROSS = 0.
Card No. 6.000	Quake Skin ..	0.1 inch (standard)
	Quake Toe ...	0.1 inch (standard)
	Damping Skin..	0.3 (Table 5 - Case Damping, assume sand governs)
	Damping Toe..	0.15 (Table 5 - Case Damping, assume sand governs)
	RULT ...	-1.0 (more than one value is to be input)
	Coeff. of Rest. of Soil.	leave it blank (means 1.0)
	Stroke ...	leave it blank (uses 5.0 feet as a starting value)
	Hammer Efficiency ..	leave it blank (normal)
	Steam Pressure ...	leave it blank (for A/S hammers only)
	Reaction Weight ...	leave it blank (for closed diesel or double acting A/S hammers only)
Card No. 6.401, ...		Do not insert (ITYS = 6)
Card No. 7.000	YMAX ...	leave it blank (no plots vs. time)
Card No. 8.000	ISEG ...	leave it blank (no plots vs. time)
Card No. 9.000	Ultimate Resistance...	30.0, 60.0, 90.0, 120.0

The input form is shown in Form 1. The output is shown in Figure 6 and Form 2.

7.1.5 Discussion of Results

It can be concluded that a design load of 45 tons (90 tons with FS = 2) requires a blow count of 40 blows/ft. The stroke should at this time be 5.7 feet. Then the maximum compressive stress would be 23.4 ksi.

7.2 Closed End Hammer - Driveability Study

7.2.1 Situation

A step tapered pipe pile (20.4 feet of 14 inch O.D., .203 inch wall, 23 feet of 11.5 inch OD, .219 inch wall, rest 10 inch OD, .219 inch wall) of 79 feet length with an additional 11 inch diameter toe plate of 1 inch thickness is to be driven to a depth of 74 feet. The soil consists of silt with some sand.

The soils expert has determined that the pile would be able to transfer as much as 160 tons load to the soil, mainly (70%) in skin friction. However, he expects a loss of 25% of this capacity during driving due to dynamic effects (the "static" capacity during driving would, therefore, be only 120 tons). He recommends to use high soil damping parameters as are appropriate for clays.

7.2.2 Problem

The contractor who must drive the pile to penetration wants to use an LB 520 hammer. He is not sure, however, whether this hammer will do the job

WAVE EQUATION ANALYSIS for PILES

Short Input Form, page 1

1.000 Title (40 characters): EXAMPLE 7.1 OPEN END DIESEL HAMMER

2.000

IOUT	IJJ	IHAMR	IOSTR	IFUEL	IPEL	N	ISPL No. of Splices	NCROSS 0 = Uniform	IBEDAM	IPERCS	ISMITH 1=Smith	ITYS	IPHI
10		2										6	

3.000 Cap and Cushion

Wt. Cap (kips)	Stiff. Cap (K/in)	Stiff. Cushion (K/in)
.75	21000.	

4.000

Coefficients of Restitution: Anvil (Diesel) Cap(Air/Steam)	Coefficients of Restitution: Cap (Diesel) Assembly(A/S)	Coefficients of Restitution: Pile Top	Coefficients of Restitution: Cushion	TEMAX (msec.)	TDEL (sec.)
.8	.8	.8			

5.000

L Pile (ft)	A Pile Top (in^2)	E Pile Top (ksi)	W Pile Top (lbs/ft^3)
40.	15.5	30000.	492.

If NCROSS = 1 and IPEL ≠ 2 only

	LP_i (ft)	AP_i (ft)	EP_i (ksi)	WP_i (lbs/ft^3)
5.101				
5.102				
.				
.				
.				
5.119				

FORM 1: INPUT, EXAMPLE 7.1

WAVE EQUATION ANALYSIS for PILES

Short Input Form, page 2

6.000

Quake Skin (in)	Quake Toe (in)	Damping Skin*	Damping Toe*	RULT (tons)	Coeff. of Rest. Of Soil	Stroke (ft)	Hammer Efficiency	Steam Pressure (psi)	Reaction wt. (kips)
.1	.1	.3	.15	-1.0					

*Damping Parameters - sec/ft for Smith; Dimensionless for Case

If ITTS = 0 or -1 only

6.401
6.402
.
.
.
6.420

XPi (ft)	% Soil Res.

If IOUT > 9

7.000

TMAX

Plotter Scale

If IOUT > 9 only
ISEQ(I), I = 1,2,...,15 (Plotted Variables)

8.000

If RULT < 0 only:

Ultimate Resistance - tons (at most 10 values)

9.000

30.	60.	90.	120.

1 2 3 4 5 6 7 8 9 10 1 2 3 4 5 6 7 8 9 20 1 2 3 4 5 6 7 8 9 30 1 2 3 4 5 6 7 8 9 40 1 2 3 4 5 6 7 8 9 50 1 2 3 4 5 6 7 8 9 60 1 2 3 4 5 6 7 8 9 70 1 2 3 4 5 6 7 8 9 80

FORM 1: CONTINUED

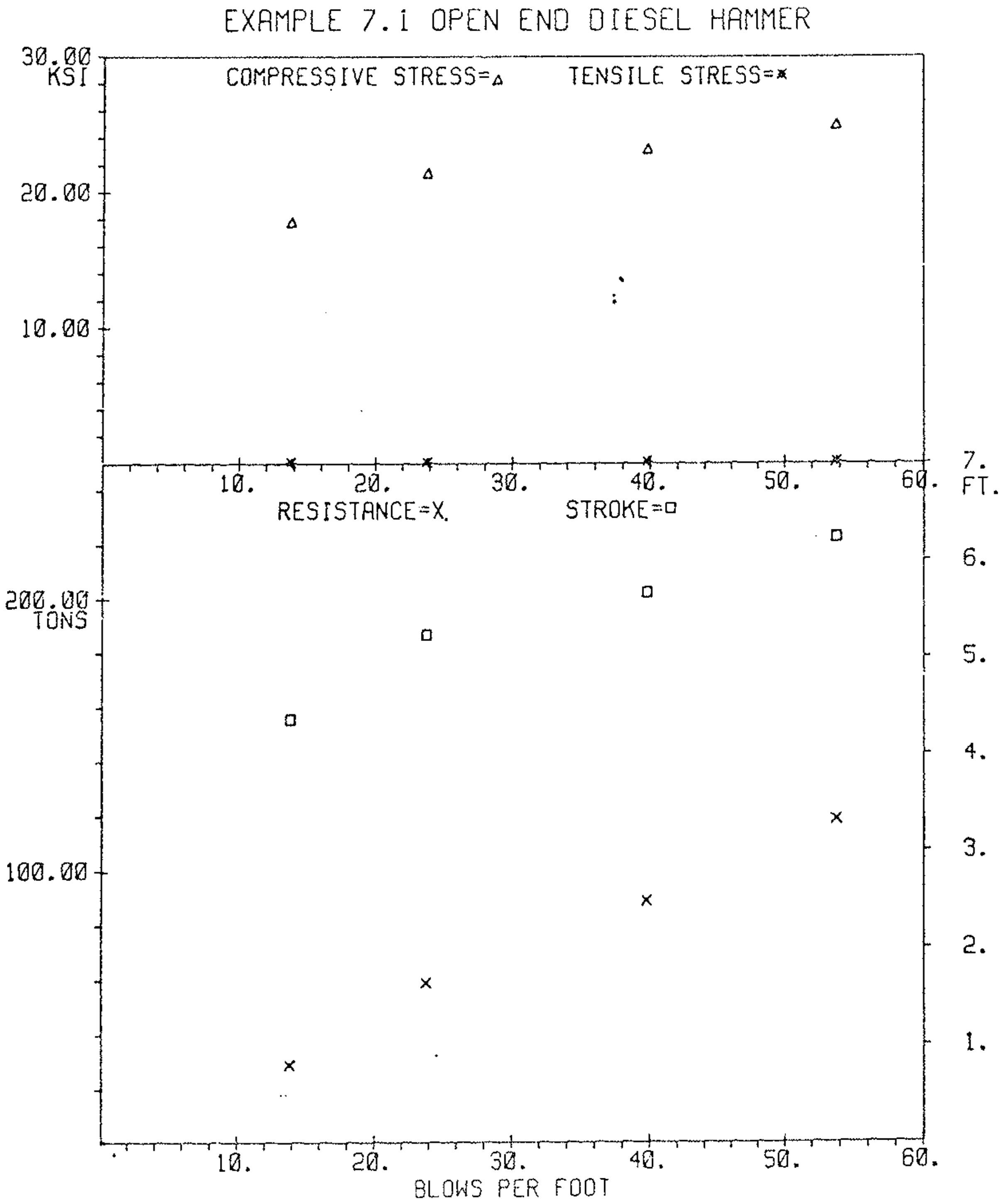


FIGURE 6: BEARING GRAPH AS OBTAINED FOR EXAMPLE 7.1

```
                        W E A P  -  WAVE EQUATION ANALYSIS FOR PILES

              THIS PROGRAM WAS PREPARED FOR THE FEDERAL HIGHWAY ADMINISTRATION
                        BY GOBLE & ASSOCIATES, CLEVELAND, OHIO

          EXAMPLE 7.1 OPEN END DIESEL HAMMER
                      PILE DESCRIPTION

X BEL. TOP (FT)        .0     40.0
A (SQ. IN.)          15.5     15.5
E (KSI)            30000.   30000.
GAMMA (LB/CU FT)    492.0    492.0


              HAMMER MODEL DEL.D-12
   ELEMENT       WEIGHT  STIFFNESS     COEFF.
   NUMBER        (KIPS)    (K/IN)    RESTITUTION
      1           .688
      2           .688  121250.0
      3           .688  121250.0
      4           .688  121250.0
   ANVIL          .810   66833.3        .800
    CAP           .950   21000.0        .800
   CUSHION                    .0       1.000
  PILE TOP                              .800
```

FORM 2: OUTPUT, EXAMPLE 7.1

```
                              PILE PROPERTIES


PILE LENGTH=  40. FT., AREA(AT TOP)=  15.5 S-IN
E. MODUL(AT TOP)=30000. KSI., SPEC. WT.(AT TOP)= 492. LBS/CU FT


       WEIGHT STIFFN.  PDAMP.  SPLICE  SOIL-S  SOIL-D   QUAKE  L.B.T.
NO.    (KIPS)  (K/IN) (KS/FT)  (KIPS)  (PCT.) (KS/FT)   (IN.)   (FT.)
  1     .235   8719.     .55       0.    .000    .516    .100     4.4
  2     .235   8719.     .55   -5000.    .000    .516    .100     8.9
  3     .235   8719.     .55   -5000.    .000    .516    .100    13.3
  4     .235   8719.     .55   -5000.    .000   1.032    .100    17.8
  5     .235   8719.     .55   -5000.    .000   1.032    .100    22.2
  6     .235   8719.     .55   -5000.    .000   1.032    .100    26.7
  7     .235   8719.     .55   -5000.    .000   1.547    .100    31.1
  8     .235   8719.     .55   -5000.    .000   1.547    .100    35.6
  9     .235   8719.     .55   -5000.    .000   1.547    .100    40.0
TOE                                     1.000   4.150    .100

COEFFICIENT OF RESTITUTION OF SOIL    1.000

                  OPTIONS AND SPECIFICATIONS
PHI    1.40       S-DAMPING     VISCOUS    RWT (KIPS)          .00
IOUT     10       P-DAMPING           1    SOIL DIST. NO.        6
IFUEL     1       J SKIN            .30    TDEL (SEC.)       .0000
IOSTR     0       J TOE             .15    TEMAX (MS)          .00
                  EFFICIENCY       .950
                  TIME INCR. (MS)  .087
```

FORM 2: CONTINUED

```
                    RULT=   30.0, AT TOE=   30.0 TONS
                    --------------------------------

        TABLE OF EXTREME VALUES FOR PILE AND TIME OF OCCURRENCE
ELEM.    FMAX         FMIN        MINSTR       MAXSTR        VELMX        DISMX
 NO.     KIPS         KIPS          KSI          KSI          FT/S         INCH
  1    280.7( 36)     .0(  0)     .0(  0)    18.1( 36)     9.14( 37)    .989(285)
  2    279.0( 39)     .0(  0)     .0(  0)    18.0( 39)     9.05( 40)    .983(286)
  3    278.5( 42)     .0(  0)     .0(  0)    18.0( 42)     8.92( 43)    .977(293)
  4    279.0( 45)     .0(  0)     .0(  0)    18.0( 45)     8.74( 46)    .971(297)
  5    275.1( 48)     .0(  0)     .0(  0)    17.8( 48)     9.51( 78)    .966(299)
  6    271.7( 51)     .0(  0)     .0(  0)    17.5( 51)     9.22( 77)    .960(301)
  7    265.7( 54)     .0(  0)     .0(  0)    17.1( 54)     8.51( 57)    .954(304)
  8    240.4( 57)     .0(  0)     .0(  0)    15.5( 57)    10.10( 63)    .948(306)
  9    187.5( 58)     .0(  0)     .0(  0)    12.1( 58)    11.99( 64)    .942(308)

        THE MAXIMUM TRANSFERRED ENERGY (ENTHRU) WAS   9.6 K-FT

        STROKES ANALYZED AND LAST RETURN (FT)   5.0   4.4   4.4
```

FORM 2: CONTINUED

```
                              RULT=   60.0, AT TOE=   60.0 TONS
                              ---------------------------------


           TABLE OF EXTREME VALUES FOR PILE AND TIME OF OCCURRENCE
ELEM.      FMAX          FMIN         MINSTR        MAXSTR        VELMX         DISMX
 NO.       KIPS          KIPS           KSI           KSI          FT/S          INCH
   1     336.7( 33)      .0(  0)      .0(  0)     21.7( 33)     11.00( 34)    .692(176)
   2     335.6( 36)      .0(  0)      .0(  0)     21.6( 36)     10.87( 38)    .682(181)
   3     334.8( 39)      .0(  0)      .0(  0)     21.6( 39)     10.71( 41)    .674(186)
   4     336.0( 43)      .0(  0)      .0(  0)     21.7( 43)     10.49( 44)    .665(187)
   5     332.3( 46)      .0(  0)      .0(  0)     21.4( 46)     10.24( 47)    .655(188)
   6     329.1( 49)      .0(  0)      .0(  0)     21.2( 49)      9.96( 50)    .644(189)
   7     324.0( 52)      .0(  0)      .0(  0)     20.9( 52)      9.96( 54)    .632(192)
   8     299.4( 55)      .0(  0)      .0(  0)     19.3( 55)     10.92( 58)    .620(197)
   9     250.4( 57)      .0(  0)      .0(  0)     16.2( 57)     12.91( 61)    .608(198)

           THE MAXIMUM TRANSFERRED ENERGY (ENTHRU) WAS   9.7 K-FT

           STROKES ANALYZED AND LAST RETURN (FT)   5.2   5.1
```

FORM 2: CONTINUED

```
                    RULT=   90.0, AT TOE=   90.0 TONS
                    ---------------------------------


          TABLE OF EXTREME VALUES FOR PILE AND TIME OF OCCURRENCE
ELEM.     FMAX          FMIN         MINSTR        MAXSTR        VELMX          DISMX
 NO.      KIPS          KIPS          KSI           KSI           FT/S           INCH
   1    362.3( 32)      .0(  0)      .0(  0)      23.4( 32)    11.86( 33)     .555(139)
   2    361.6( 35)      .0(  0)      .0(  0)      23.3( 35)    11.73( 36)     .537(141)
   3    361.8( 38)      .0(  0)      .0(  0)      23.3( 38)    11.53( 39)     .518(141)
   4    363.2( 41)      .0(  0)      .0(  0)      23.4( 41)    11.25( 42)     .498(136)
   5    358.6( 44)      .0(  0)      .0(  0)      23.1( 44)    10.96( 46)     .478(135)
   6    355.5( 48)      .0(  0)      .0(  0)      22.9( 48)    10.67( 49)     .458(153)
   7    351.4( 51)      .0(  0)      .0(  0)      22.7( 51)    10.55( 52)     .439(152)
   8    329.4( 53)      .0(  0)      .0(  0)      21.3( 53)    11.15( 56)     .419(149)
   9    291.0( 56)      .0(  0)      .0(  0)      18.8( 56)    12.34( 60)     .400(120)

          THE MAXIMUM TRANSFERRED ENERGY (ENTHRU) WAS   9.3 K-FT

          STROKES ANALYZED AND LAST RETURN (FT)   5.7   5.8
```

FORM 2: CONTINUED

```
                         RULT=  120.0, AT TOE=  120.0 TONS
                         ---------------------------------


          TABLE OF EXTREME VALUES FOR PILE AND TIME OF OCCURRENCE
ELEM.     FMAX             FMIN         MINSTR         MAXSTR         VELMX          DISMX
 NO.      KIPS             KIPS           KSI            KSI          FT/S           INCH
   1     392.0( 30)        .0(  0)       .0(  0)      25.3( 30)     12.82( 31)     .504(118)
   2     391.1( 33)        .0(  0)       .0(  0)      25.2( 33)     12.65( 34)     .484(116)
   3     390.6( 36)        .0(  0)       .0(  0)      25.2( 36)     12.44( 38)     .461(115)
   4     391.9( 40)        .0(  0)       .0(  0)      25.3( 40)     12.17( 41)     .443(106)
   5     388.0( 43)        .0(  0)       .0(  0)      25.0( 43)     11.86( 44)     .424(106)
   6     384.6( 46)        .0(  0)       .0(  0)      24.8( 46)     11.50( 47)     .400(106)
   7     380.7( 49)        .0(  0)       .0(  0)      24.6( 49)     11.29( 51)     .375(105)
   8     361.8( 52)        .0(  0)       .0(  0)      23.3( 52)     11.56( 54)     .349(100)
   9     335.4( 56)        .0(  0)       .0(  0)      21.6( 56)     11.88( 58)     .323( 98)

          THE MAXIMUM TRANSFERRED ENERGY (ENTHRU) WAS   9.6 K-FT

          STROKES ANALYZED AND LAST RETURN (FT)   5.9   6.2   6.2
```

FORM 2: CONTINUED

```
        EXAMPLE 7.1 OPEN END DIESEL HAMMER

                     SUMMARY

NO     R ULT    BLOW CT    STROKE  MIN STR   MAX  STR    BLOWS/
       TONS      1/FT        FT      KSI        KSI      MINUTE
 1      30.0      14.       4.35      .00      18.11      56.3
 2      60.0      24.       5.22      .00      21.72      51.4
 3      90.0      40.       5.66      .00      23.43      49.5
 4     120.0      54.       6.23      .00      25.29      47.2
```

FORM 2: CONTINUED

and is worried about the driving stresses in this relatively thin walled pile. He would also like to know if an interruption would affect the driveability. (The contractor supplied the following data: helmet (cap) weight = 450 lbs., stiffness 10,000 kips/inch.)

7.2.3 Solution

First, a sketch of the pile geometry is made on page 1 of the short input form. Similarly a sketch is made of an assumed skin friction distribution (for both adhesion and friction) on page 2 of the short input form.

Card No. 2.000	It was decided to print forces as a function of time (IOUT = 1); IHAMR was found in Table 2 as 38 and NCROSS was set to 1 (non-uniform pile). IPERCS was set to 70. No other data were needed on Card No. 2.000.
Card No. 3.000	The cap parameters were inserted as given by the contractor. No cushion is present.
Card No. 4.000	Standard coefficients of restitution were chosen (blank card).
Card No. 5.000	The pile length includes the toe plate. A pile top was computed from wall thickness and diameter E pile top (as for the rest of the pile) was set at the pipe manufacturers value of 29000 ksi. Standard steel weight was inserted for W Pile Top.
Card No. 5.101,...	There were three points of discontinuity which had to be described at depths of 20.4, 43.4 and 79.0 feet. Also the cross sectional area of the end plate had to be given at the pile bottom. Thus, seven cards were necessary. Note that EP and WP were not repeated.

Card No. 6.000	Of interest on this card are only the damping values. Since Case damping parameters were chosen (ISMITH blank) value from the right part of Table 5 are chosen. Since the recommendation was to use high values (in order to investigate the worst case) values of 2.0 and .8 for skin and toe, respectively, were chosen. (It is interesting to make a comparison of the Case damping values with the corresponding Smith parameters). The average pile impedance (EA/c) is about 14 kips/ft/sec (using 8 inch^2 as an average steel area). Thus the total skin viscous damping constant is 14x2 = 28 kips/ft/sec. The static skin resistance at 120 tons is 0.7x240 = 168 kips. Thus, the corresponding Smith damping parameter is 28/168 = 0.167 (somewhat less than the usually recommended 0.2). The toe damping constant used here corresponds to about 0.17. This latter value seems rather small, however, it is actually a large damping value since 30% end bearing were used more than could usually be expected in clay).
Cards No. 6.401,...	A trapezoidal distribution was chosen assuming that the pile top was 5 feet above grade and that the skin friction would be twice as high at the bottom as it was at 10 feet below the pile top.
Card No. 9.000	The capacities to be investigated are 120 and 160 tons.

The two pages of input are shown in Form 3. The output is reproduced in Form 4.

7.2.4 Discussion of Results

The important results can be found in the summary, the last page of Form 4. It is found there that the blow count for RULT = 120 is 221 more than 18 blows per inch. The stroke (see also B.C.P. = Bounce Chamber Pressure) is at the maximum and in order to avoid lift-off, the fuel setting

WAVE EQUATION ANALYSIS for PILES

Short Input Form, page 1

1 2 3 4 5 6 7 8 9 10 1 2 3 4 5 6 7 8 9 20 1 2 3 4 5 6 7 8 9 30 1 2 3 4 5 6 7 8 9 40 1 2 3 4 5 6 7 8 9 50 1 2 3 4 5 6 7 8 9 60

1.000 Title (40 characters): EXAMPLE 7.2 DRIVEABILITY STUDY LB 520

2.000 IOUT: 1 | IJJ: | IHAMR: 35 | IOSTR: | IFUEL: | IPEL: | N: | ISPL No. of Splices: | NCROSS 0 = Uniform: 1 | IBEDAM: | IPERCS: 70 | ISMITH 1=Smith: | ITYS: | IPHI:

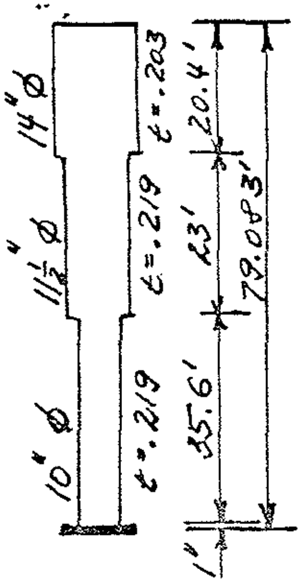
3.000 Wt. Cap (kips): .45 | Cap and Cushion Stiff. Cap (K/in): 10000. | Stiff. Cushion (K/in):

4.000 Coefficients of Restitution: Anvil (Diesel) Cap(Air/Steam): | Cap (Diesel). Assembly(A/S): | Pile Top: | Cushion: | TEMAX (msec.): | TDEL (sec.):

5.000 L Pile (ft): 79.083 | A Pile Top (in^2): 8.80 | E Pile Top (ksi): 29000. | W Pile Top (lbs/ft^3): 492.

If NCROSS = 1 and IPEL ≠ 2 only

	ZP_i (ft)	AP_i (ft)	EP_i (ksi)	WP_i (lbs/ft^3)
5.101	20.4	8.8		
5.102	20.4	8.4		
.	43.4	8.4		
.	43.4	7.4		
.	79.0	7.4		
5.119	79.0	95.0		
	79.083	95.0		



FORM 3: EXAMPLE 7.2

WAVE EQUATION ANALYSIS for PILES

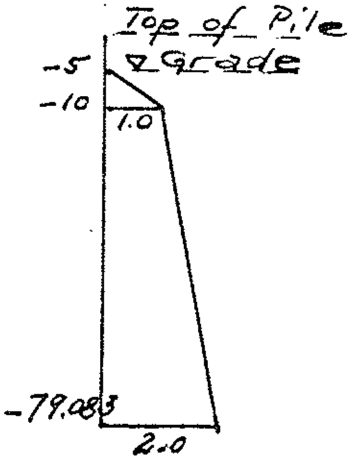
Short Input Form, page 2

	Quake Skin (in)	Quake Toe (in)	Damping Skin*	Damping Toe*	RULT (tons)	Coeff. of Rest. Of Soil	Stroke (ft)	Hammer Efficiency	Steam Pressure (psi)	Reaction wt. (kips)
6.000	.1	.1	2.0	.8	-1.0					

*Damping Parameters - sec/ft for Smith; Dimensionless for Case

If ITTS = 0 or -1 only

	XPi (ft)	% Soil Res.
6.401	0.0	0.0
6.402	5.0	0.0
	10.0	1.0
	79.083	2.0
6.420	.	. .



If IOUT > 9

7.000 TMAX ______ Plotter Scale

If IOUT > 9 only
ISEG(I), I = 1,2,...,15 (Plotted Variables)

8.000 ______

If RULT < 0 only:

Ultimate Resistance - tons (at most 10 values)

9.000 120. 160.

1 2 3 4 5 6 7 8 9 10 1 2 3 4 5 6 7 8 9 20 1 2 3 4 5 6 7 8 9 30 1 2 3 4 5 6 7 8 9 40 1 2 3 4 5 6 7 8 9 50 1 2 3 4 5 6 7 8 9 60 1 2 3 4 5 6 7 8 9 70 1 2 3 4 5 6 7 8 9 80

FORM 3: CONTINUED

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                 W E A P  -  WAVE EQUATION ANALYSIS FOR PILES

         THIS PROGRAM WAS PREPARED FOR THE FEDERAL HIGHWAY ADMINISTRATION
                      BY GOBLE & ASSOCIATES, CLEVELAND, OHIO

          EXAMPLE 7.2 DRIVEABILITY CHECK LB 520
                       PILE DESCRIPTION

X BEL. TOP (FT)        .0     20.4     20.4     43.4     43.4     79.0     79.0     79.1
A (SQ. IN.)           8.8      8.8      8.4      8.4      7.4      7.4     95.0     95.0
E (KSI)            29000.   29000.   29000.   29000.   29000.   29000.   29000.   29000.
GAMMA (LB/CU FT)    492.0    492.0    492.0    492.0    492.0    492.0    492.0    492.0


                HAMMER MODEL LB   520
      ELEMENT      WEIGHT  STIFFNESS    COEFF.
      NUMBER       (KIPS)   (K/IN)   RESTITUTION
         1          1.753
         2          1.692  247000.0
         3          1.600  239000.0
       ANVIL        2.058   81000.0        .850
        CAP          .450   10000.0        .850
       CUSHION                   .0       1.000
     PILE TOP                              .850
```

FORM 4: OUTPUT, EXAMPLE 7.2

```
                         PILE PROPERTIES

PILE LENGTH=  79. FT., AREA(AT TOP)=   8.8 S-IN
E. MODUL(AT TOP)=29000. KSI., SPEC. WT.(AT TOP)= 492. LBS/CU FT

      WEIGHT STIFFN.  PDAMP.  SPLICE  SOIL-S  SOIL-D   QUAKE  L.B.T.
NO.   (KIPS)  (K/IN) (KS/FT)  (KIPS)  (PCT.) (KS/FT)   (IN.)  (FT.)
 1     .149    4303.     .31      0.    .000    .000    .100     4.9
 2     .149    4303.     .31  -5000.    .016    .695    .100     9.9
 3     .149    4303.     .31  -5000.    .034   1.487    .100    14.8
 4     .149    4303.     .31  -5000.    .036   1.591    .100    19.8
 5     .143    4131.     .30  -5000.    .038   1.626    .100    24.7
 6     .142    4107.     .29  -5000.    .041   1.715    .100    29.7
 7     .142    4107.     .29  -5000.    .043   1.813    .100    34.6
 8     .142    4107.     .29  -5000.    .045   1.911    .100    39.5
 9     .138    3989.     .29  -5000.    .048   1.954    .100    44.5
10     .125    3618.     .26  -5000.    .050   1.857    .100    49.4
11     .125    3618.     .26  -5000.    .052   1.943    .100    54.4
12     .125    3618.     .26  -5000.    .055   2.030    .100    59.3
13     .125    3618.     .26  -5000.    .057   2.117    .100    64.3
14     .125    3618.     .26  -5000.    .059   2.203    .100    69.2
15     .125    3618.     .26  -5000.    .062   2.290    .100    74.1
16     .150    3675.     .29  -5000.    .064   2.622    .100    79.1
TOE                                     .300  11.464    .100

COEFFICIENT OF RESTITUTION OF SOIL    1.000

                OPTIONS AND SPECIFICATIONS
PHI    1.40     S-DAMPING     VISCOUS    RWT (KIPS)        6.30
IOUT      1     P-DAMPING           1    SOIL DIST. NO.       0
IFUEL     1     J SKIN           2.00    TDEL (SEC.)      .0000
IOSTR     0     J TOE             .80    TEMAX (MS)         .00
                EFFICIENCY       .950
                TIME INCR. (MS)  .094
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FORM 4: CONTINUED

```
                        RULT=  120.0, AT TOE=   36.0 TONS
                        -----------------------------------

                                          HAMMER AND PILE FORCES(KIPS)
 JP  TIME     HAMMER                                  PILE ELEMENTS
     (MS)  RAM M    ANVIL     TOP      2        3        4        6        7        8       10       11       13       14       15       16
  3    .3    96.5   126.5    79.7     78.1     71.8     61.5     44.3     37.3     31.2     21.4     17.7     12.0      9.8      8.1      6.7
  6    .6    30.1   133.3    83.3     81.7     75.3     64.4     46.3     38.9     32.5     22.3     18.4     12.4     10.2      8.4      6.9
  9    .8   149.5   140.2    87.1     85.4     78.9     67.5     48.4     40.7     34.0     23.2     19.2     12.9     10.6      8.7      7.2
 12   1.1   100.2   148.1    91.1     89.4     82.7     70.9     50.7     42.6     35.6     24.3     20.0     13.5     11.0      9.0      7.5
 15   1.4    67.9   158.0    95.3     93.5     86.6     74.5     53.3     44.7     37.3     25.4     20.9     14.0     11.5      9.4      7.8
 18   1.7   138.6   168.1    99.7     97.7     90.6     78.5     56.0     46.9     39.1     26.6     21.9     14.7     12.0      9.8      8.1
 21   2.0   184.6   287.7   104.6    102.1     94.9     82.5     58.9     49.4     41.1     27.9     22.9     15.4     12.5     10.3      8.4
 24   2.3   274.5   459.6   110.4    107.1     99.5     86.7     62.1     52.0     43.2     29.3     24.0     16.1     13.1     10.7      8.8
 27   2.5   448.7   574.4   118.5    113.2    104.4     91.0     65.5     54.8     45.6     30.8     25.2     16.9     13.8     11.2      9.2
 30   2.8   412.1   577.3   131.2    121.5    110.4     95.8     69.1     57.8     48.0     32.4     26.6     17.7     14.4     11.8      9.7
 33   3.1   276.9   448.6   150.5    134.0    118.5    101.7     73.1     61.0     50.7     34.2     28.0     18.6     15.2     12.4     10.1
 36   3.4   197.6   271.3   176.3    153.1    130.7    109.6     77.6     64.6     53.5     36.0     29.5     19.6     15.9     13.0     10.6
 39   3.7   101.5   189.0   204.8    178.8    149.1    121.0     83.1     68.6     56.7     38.1     31.1     20.7     16.8     13.7     11.2
 42   4.0   104.7   188.6   229.0    207.7    174.0    138.0     90.3     73.5     60.2     40.2     32.9     21.8     17.7     14.4     11.8
 45   4.2   166.5   185.2   243.8    233.3    202.5    161.3    100.4     80.1     64.6     42.6     34.8     23.0     18.7     15.2     12.4
 48   4.5   115.2   182.1   249.1    249.6    228.4    188.3    114.9     89.6     70.4     45.3     36.8     24.3     19.8     16.0     13.1
 51   4.8    98.9   178.8   248.6    256.1    246.0    213.4    134.9    103.5     78.9     48.6     39.2     25.8     20.9     17.0     13.8
 54   5.1   154.0   175.4   246.6    256.3    253.4    231.0    158.8    122.2     91.4     53.0     42.1     27.3     22.1     17.9     14.6
 57   5.4   109.4   172.3   246.1    254.2    253.7    239.1    182.3    144.4    108.8     59.4     46.0     29.1     23.5     19.0     15.5
 60   5.6    95.7   169.2   248.2    253.1    251.5    240.4    200.2    166.7    129.8     68.7     51.6     31.3     25.0     20.2     16.4
 63   5.9   143.6   166.3   251.9    254.4    250.4    239.0    210.2    184.7    150.8     81.8     59.9     34.3     26.9     21.5     17.4
 66   6.2   103.9   163.6   255.8    257.9    251.8    238.3    213.1    195.0    167.9     98.3     71.4     38.6     29.5     23.2     18.6
 69   6.5    87.9   161.1   259.0    262.1    255.4    239.7    212.5    198.1    178.5    116.7     86.0     45.0     33.3     25.5     20.1
 72   6.8   132.2   158.8   261.4    265.6    259.6    243.2    211.8    197.7    182.3    133.5    102.3     53.8     38.9     28.8     22.1
 75   7.1   109.4   156.7   262.4    267.8    263.1    247.4    212.7    197.1    182.0    145.0    118.0     65.2     46.7     33.7     25.1
 78   7.3    78.5   154.7   262.6    268.7    265.3    250.8    215.6    198.0    181.8    150.5    130.2     78.0     56.7     40.6     29.6
 81   7.6   124.8   152.9   262.3    268.7    266.1    252.8    219.4    200.9    183.6    152.8    136.6     90.5     68.0     49.5     35.9
 84   7.9   108.9   151.3   261.7    268.0    265.7    253.6    223.0    205.3    187.2    154.2    138.8    100.6     79.1     59.7     44.1
 87   8.2    79.4   149.8   261.0    266.8    264.7    253.6    226.1    209.8    191.7    156.1    140.5    107.8     88.4     69.8     53.3
 90   8.5   112.6   148.5   260.0    265.5    263.6    253.0    228.2    213.3    196.6    159.6    143.1    112.2     94.9     78.3     62.4
 93   8.7   112.3   147.3   258.7    264.3    262.5    252.4    229.5    215.8    200.5    164.6    146.6    114.7     99.0     84.0     69.6
 96   9.0    79.1   146.3   257.2    263.0    261.5    252.1    230.2    217.5    203.0    169.4    151.3    117.1    102.0     87.2     74.1
 99   9.3   109.7   145.4   255.5    261.5    260.7    251.9    230.7    218.4    204.7    173.5    156.7    122.3    105.0     89.1     76.3
102   9.6   109.7   144.7   253.7    260.0    259.8    251.4    230.9    218.9    206.2    177.2    161.4    126.4    108.5     91.2     77.4
105   9.9    79.3   144.0   251.8    258.4    258.5    250.7    230.9    219.5    207.2    180.1    164.8    131.2    112.6     94.5     78.9
108  10.2   102.5   143.5   250.0    256.5    256.8    249.7    231.0    220.1    208.1    182.1    167.8    135.2    117.1     98.9     81.8
111  10.4   110.6   143.0   248.2    254.4    254.8    248.2    231.0    220.5    209.2    183.7    170.2    138.6    121.4    103.7     85.8
114  10.7    84.2   142.7   246.5    252.3    252.7    246.5    230.6    220.9    210.1    185.3    171.6    141.5    125.3    108.2     90.1
117  11.0   102.2   142.4   244.5    250.2    250.5    244.7    230.0    221.0    210.6    186.4    172.6    143.8    128.4    111.8     94.2
120  11.3   106.5   140.8   242.3    248.0    248.4    243.0    229.3    220.7    210.7    187.0    173.9    145.9    130.8    114.7     97.6
123  11.6    84.6   139.3   240.1    245.6    246.4    241.3    228.2    219.9    210.6    187.6    175.2    147.6    132.6    116.8    100.2
126  11.9    97.2   137.8   237.7    243.3    244.3    239.6    226.9    218.9    209.8    188.3    176.1    148.9    134.1    118.5    102.3
129  12.1   100.3   136.3   235.5    241.0    242.0    237.8    225.5    217.7    208.7    188.6    176.8    150.0    135.4    119.9    103.7
132  12.4    86.4   135.1   233.3    238.6    239.7    235.6    223.9    216.2    207.8    188.5    177.1    150.9    136.4    120.9    103.9
135  12.7    93.2   133.8   230.8    236.1    237.2    233.2    222.1    214.9    207.0    188.1    176.9    151.4    136.9    121.1    103.7
138  13.0    97.8   132.7   228.0    233.3    234.5    230.8    220.2    213.6    205.9    187.4    176.4    151.4    136.8    120.6    103.5
141  13.3    84.4   131.6   225.0    230.2    231.5    228.1    218.3    212.1    204.6    186.4    175.7    150.7    135.9    119.9    103.2
144  13.5    87.9   130.6   221.7    226.7    228.2    225.3    216.4    210.2    203.0    185.4    174.7    149.4    134.7    119.2    102.7
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FORM 4: CONTINUED

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147  13.8    93.8   129.7   218.3   223.0   224.7   222.4   214.2   208.2   201.2   184.1   173.3   147.7   133.5   118.3   102.0
150  14.1    84.8   128.9   214.8   219.2   221.1   219.4   211.7   206.1   199.2   182.3   171.4   146.1   132.2   117.1   101.1
153  14.4    84.8   128.1   211.1   215.5   217.5   216.1   209.1   203.7   197.1   180.0   169.2   144.5   130.7   115.9   100.1
156  14.7    92.1   127.4   207.3   211.6   213.7   212.5   206.3   201.1   194.6   177.4   166.8   142.8   129.1   114.5    99.0
159  15.0    85.1   126.7   203.4   207.4   209.6   208.8   203.2   198.2   191.8   174.7   164.5   140.9   127.5   113.1    97.8
162  15.2    82.8   126.0   199.3   203.0   205.2   205.0   199.8   195.0   188.6   172.2   162.1   138.9   125.8   111.7    96.7
165  15.5    89.9   125.4   195.0   198.2   200.6   200.8   196.3   191.5   185.4   169.7   159.7   136.9   124.0   110.2    95.4
168  15.8    85.1   124.8   190.3   193.3   195.8   196.3   192.4   187.9   182.3   167.1   157.3   134.8   122.2   108.7    94.2
171  16.1    81.5   124.2   185.3   188.1   190.6   191.6   188.4   184.5   179.2   164.5   155.0   132.7   120.3   107.0    92.8
174  16.4    87.7   123.7   180.1   182.6   185.2   186.6   184.3   181.0   176.1   162.0   152.7   130.8   118.5   105.3    91.4
177  16.6    85.0   123.1   174.7   176.6   179.4   181.3   180.3   177.4   173.0   159.5   150.4   128.9   116.7   103.7    89.9
180  16.9    80.5   122.6   169.0   170.5   173.3   175.9   176.3   173.8   169.8   157.1   148.2   127.1   115.0   102.1    88.5
183  17.2    85.6   122.0   163.0   164.2   167.2   170.6   172.1   170.1   166.6   154.7   146.1   125.3   113.4   100.6    87.2
186  17.5    84.5   121.4   156.6   157.7   161.2   165.2   167.9   166.5   163.4   152.3   144.1   123.7   111.9    99.3    85.9
189  17.8    79.7   120.8   150.2   151.2   155.1   159.8   163.6   162.8   160.2   149.9   142.0   122.1   110.5    98.0    84.9
192  18.1    83.4   120.2   143.7   144.7   148.9   154.3   159.4   159.1   157.0   147.5   140.0   120.6   109.2    97.0    84.3
195  18.3    83.7   119.5   137.3   138.0   142.5   148.7   155.1   155.4   153.8   145.2   138.0   119.2   108.1    96.3    83.9
198  18.6    78.7   118.7   131.0   131.4   136.1   143.1   150.9   151.7   150.6   142.9   136.0   117.9   107.3    95.8    83.4
201  18.9    80.6   117.9   124.7   124.8   129.8   137.4   146.6   148.0   147.4   140.5   134.1   116.8   106.6    95.2    82.6
204  19.2    82.1   117.1   118.6   118.5   123.6   131.8   142.3   144.3   144.2   138.2   132.2   115.8   105.8    94.3    81.7
207  19.5    77.6   116.1   112.5   112.2   117.5   126.3   137.9   140.5   141.0   136.0   130.5   114.8   104.7    93.2    80.7
210  19.8    78.1   115.1   106.6   106.1   111.6   120.9   133.6   136.7   137.8   133.9   128.8   113.5   103.4    92.1    79.7
213  20.0    79.9   114.1   101.0   100.1   105.8   115.7   129.4   133.0   134.6   131.9   127.2   112.0   102.1    90.9    78.7
216  20.3    76.0   112.9    95.5    94.4   100.0   110.6   125.3   129.4   131.6   129.8   125.3   110.5   100.8    89.8    77.7
219  20.6    75.4   111.7    90.2    89.2    94.4   105.6   121.4   126.0   128.6   127.6   123.3   108.9    99.4    88.6    76.7
222  20.9    77.2   110.3    85.2    84.0    89.0   100.6   117.7   122.8   125.8   125.1   121.1   107.4    98.1    87.5    75.8
225  21.2    73.9   109.0    80.5    79.0    84.0    95.8   114.1   119.7   123.0   122.7   119.0   105.8    96.8    86.4    74.9
228  21.4    72.4   107.5    76.0    74.4    79.4    90.9   110.5   116.6   120.2   120.3   116.9   104.3    95.6    85.4    74.0
231  21.7    73.9   106.0    71.7    70.3    75.1    86.3   106.9   113.4   117.2   118.0   114.8   102.8    94.3    84.4    73.2
234  22.0    71.3   104.4    67.8    66.5    70.9    82.0   103.2   110.0   114.3   115.8   112.9   101.4    93.1    83.4    72.3
237  22.3    69.1   102.7    64.2    62.6    67.1    78.0    99.4   106.7   111.4   113.7   111.1   100.0    91.9    82.4    71.5
240  22.6    70.2   101.0    60.9    59.0    63.5    74.3    95.7   103.4   108.6   111.7   109.4    98.7    90.8    81.4    70.7
243  22.9    68.2    99.2    57.8    55.9    60.1    70.5    92.0   100.2   105.8   109.7   107.8    97.5    89.8    80.5    69.9
246  23.1    66.6    97.4    54.9    53.1    56.9    66.8    88.5    97.1   103.1   107.7   106.1    96.4    88.8    79.7    69.2
249  23.4    68.4    95.5    52.3    50.3    53.8    63.4    85.2    94.1   100.5   105.8   104.5    95.3    87.9    78.9    68.5
252  23.7    64.1    93.7    49.8    47.5    50.9    60.4    81.9    91.3    98.0   104.0   103.0    94.2    87.0    78.2    67.9
255  24.0    63.2    91.7    47.5    44.9    48.2    57.7    78.7    88.6    95.7   102.2   101.4    93.2    86.2    77.5    67.3
258  24.3    64.0    89.8    45.3    42.8    46.0    55.3    75.9    85.9    93.4   100.5   100.0    92.1    85.3    76.7    66.7
261  24.6    60.4    87.9    43.1    41.0    44.1    53.1    73.4    83.5    91.2    98.9    98.6    91.1    84.4    76.0    66.1
264  24.8    59.3    85.9    41.2    39.3    42.5    51.2    71.0    81.4    89.2    97.3    97.2    90.1    83.5    75.2    65.5
267  25.1    59.8    84.0    39.5    37.6    40.8    49.5    68.7    79.4    87.4    95.8    96.0    89.1    82.7    74.5    64.9
270  25.4    56.6    82.0    38.1    36.1    39.2    47.8    66.8    77.6    85.8    94.4    94.7    88.2    81.9    73.9    64.3
273  25.7    55.3    80.1    36.8    34.7    37.7    46.2    65.3    75.8    84.3    93.2    93.5    87.3    81.1    73.2    63.8
276  26.0    55.7    78.2    35.6    33.6    36.5    44.8    63.9    74.2    82.8    92.1    92.5    86.5    80.4    72.6    63.3
279  26.2    52.8    76.3    34.5    32.6    35.4    43.7    62.5    72.8    81.6    91.1    91.7    85.7    79.8    72.1    62.8


            TABLE OF EXTREME VALUES FOR PILE AND TIME OF OCCURRENCE
   ELEM.     FMAX          FMIN        MINSTR         MAXSTR          VELMX         DISMX
    NO.      KIPS          KIPS          KSI            KSI            FT/S          INCH
     1     262.6( 78)      .0(  0)      .0(  0)      29.8( 78)      9.83( 48)     .826(135)
     2     268.7( 78)      .0(  0)      .0(  0)      30.5( 78)      9.38( 51)     .771(138)
     3     266.1( 81)      .0(  0)      .0(  0)      30.2( 81)      8.92( 54)     .717(141)
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FORM 4: CONTINUED

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 4   253.6( 84)      .0(   0)     .0(   0)    28.8( 84)    8.45( 57)    .664(141)
 5   241.7( 96)      .0(   0)     .0(   0)    28.6( 96)    7.91( 60)    .610(144)
 6   231.0(108)      .0(   0)     .0(   0)    27.5(108)    7.38( 63)    .557(147)
 7   221.0(117)      .0(   0)     .0(   0)    26.3(117)    6.90( 69)    .506(147)
 8   210.7(120)      .0(   0)     .0(   0)    25.1(120)    6.47( 72)    .458(150)
 9   199.7(120)      .0(   0)     .0(   0)    24.4(120)    5.99( 75)    .410(153)
10   188.6(129)      .0(   0)     .0(   0)    25.5(129)    5.43( 78)    .361(159)
11   177.1(132)      .0(   0)     .0(   0)    23.9(132)    4.85( 81)    .316(165)
12   164.6(135)      .0(   0)     .0(   0)    22.2(135)    4.21( 84)    .275(168)
13   151.4(138)      .0(   0)     .0(   0)    20.5(138)    3.61( 87)    .238(174)
14   136.9(135)      .0(   0)     .0(   0)    18.5(135)    3.04( 90)    .206(180)
15   121.1(135)      .0(   0)     .0(   0)    16.4(135)    2.53( 93)    .178(183)
16   103.9(132)      .0(   0)     .0(   0)    11.7(132)    2.14( 96)    .154(186)

         THE MAXIMUM TRANSFERRED ENERGY (ENTHRU) WAS  13.5 K-FT
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FORM 4: CONTINUED

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                           RULT=  160.0, AT TOE=   48.0 TONS
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                                                 HAMMER AND PILE FORCES(KIPS)
 JP   TIME     HAMMER                                 PILE ELEMENTS
      (MS)   RAM M    ANVIL    TOP      2      3      4      6      7      8     10     11     13     14     15     16
  3     .3    97.9    128.3    81.2   79.7   72.4   60.9   42.1   34.7   28.4   18.5   14.9    9.6    7.7    6.3    5.1
  6     .6    30.5    135.1    85.1   83.6   76.0   63.9   44.1   36.3   29.7   19.4   15.6   10.0    8.1    6.5    5.3
  9     .8   151.5    142.1    89.3   87.6   79.9   67.1   46.3   38.1   31.1   20.3   16.3   10.5    8.4    6.8    5.6
 12    1.1   101.5    149.9    93.6   91.8   84.0   70.5   48.6   40.0   32.7   21.3   17.1   11.0    8.8    7.1    5.8
 15    1.4    68.1    159.0    98.0   96.3   88.4   74.2   51.1   42.0   34.3   22.3   17.9   11.5    9.2    7.4    6.1
 18    1.7   140.8    193.4   102.8  101.0   92.9   78.1   53.8   44.2   36.1   23.4   18.8   12.0    9.6    7.8    6.3
 21    2.0   228.6    343.0   108.1  105.9   97.5   82.4   56.7   46.6   38.0   24.6   19.7   12.6   10.1    8.1    6.6
 24    2.3   327.0    513.3   114.7  111.2  102.3   87.1   59.7   49.1   40.0   25.9   20.8   13.3   10.6    8.5    7.0
 27    2.5   457.9    597.8   124.4  117.8  107.7   91.9   63.0   51.7   42.1   27.3   21.9   13.9   11.2    9.0    7.3
 30    2.8   390.7    553.7   139.4  127.6  114.4   97.2   66.6   54.6   44.5   28.7   23.0   14.7   11.7    9.4    7.7
 33    3.1   245.6    393.6   161.6  142.7  124.0  103.6   70.5   57.7   46.9   30.3   24.3   15.5   12.3    9.9    8.1
 36    3.4   151.5    224.2   189.7  164.7  138.4  112.6   75.0   61.2   49.6   32.0   25.6   16.3   13.0   10.4    8.5
 39    3.7    96.5    181.4   218.5  192.7  159.5  126.2   80.6   65.1   52.6   33.8   27.0   17.2   13.7   11.0    8.9
 42    4.0   121.7    178.4   240.5  221.9  186.8  146.1   88.5   70.1   56.1   35.8   28.6   18.1   14.5   11.6    9.4
 45    4.2   141.4    174.8   251.8  245.6  216.1  171.7  100.4   77.0   60.4   37.9   30.2   19.2   15.3   12.2    9.9
 48    4.5    99.5    171.4   254.2  258.7  240.5  199.3  117.6   87.6   66.5   40.5   32.1   20.3   16.1   12.9   10.5
 51    4.8   115.6    168.0   252.1  262.2  254.7  223.0  139.9  103.1   75.8   43.6   34.3   21.4   17.1   13.6   11.0
 54    5.1   130.0    164.6   249.9  260.3  258.8  237.9  164.6  124.0   89.5   48.1   37.0   22.8   18.1   14.4   11.7
 57    5.4    97.1    161.5   249.9  257.6  257.1  243.2  187.4  147.9  108.0   54.9   40.9   24.4   19.2   15.3   12.3
 60    5.6   107.5    158.6   252.3  257.0  254.5  242.3  203.6  169.9  130.1   64.9   46.8   26.4   20.5   16.3   13.1
 63    5.9   123.8    155.8   255.8  259.0  253.8  240.2  211.0  185.6  151.6   78.6   55.6   29.3   22.3   17.4   13.9
 66    6.2    89.1    153.4   259.3  262.5  255.7  240.0  211.7  193.8  167.3   95.1   67.5   33.7   24.8   18.9   14.9
 69    6.5   101.1    151.1   262.2  266.0  259.4  242.2  210.4  195.3  175.1  112.5   82.0   40.3   28.6   21.1   16.3
 72    6.8   118.9    149.0   263.8  269.0  263.3  245.7  210.2  193.8  177.4  128.0   97.2   49.4   34.3   24.4   18.2
 75    7.1    89.4    147.2   264.0  270.8  266.2  249.4  211.7  193.4  177.0  138.7  110.8   60.4   42.2   29.4   21.3
 78    7.3    89.5    145.5   263.8  271.0  267.6  252.3  214.7  195.4  176.7  143.1  121.2   72.1   51.8   36.3   25.8
 81    7.6   117.1    144.0   263.3  270.1  267.8  254.0  218.7  198.9  179.1  144.0  127.1   82.5   62.0   44.9   32.2
 84    7.9    89.1    142.7   262.5  269.0  266.9  254.2  222.2  203.0  183.7  145.7  129.0   90.1   71.2   54.0   40.0
 87    8.2    86.4    141.6   261.4  267.9  265.5  253.6  224.7  207.5  188.5  148.8  129.9   94.8   78.1   62.4   48.3
 90    8.5   110.3    140.6   260.2  266.5  264.3  252.9  226.5  211.0  192.6  152.7  133.2   97.6   82.2   68.5   55.6
 93    8.7    93.2    139.8   259.0  264.9  263.2  252.3  227.7  212.9  196.4  157.4  138.1  100.2   84.3   71.9   60.6
 96    9.0    86.2    139.2   257.3  263.5  262.1  251.9  228.1  214.1  198.9  162.7  142.8  103.7   86.1   73.3   63.1
 99    9.3   104.5    138.6   255.4  262.2  261.1  251.6  228.2  215.0  200.2  166.9  147.6  108.3   88.6   74.0   63.6
102    9.6    93.6    138.3   253.5  260.5  260.1  251.1  228.6  215.4  201.2  169.8  152.4  113.3   92.4   75.3   63.6
105    9.9    85.5    138.0   251.7  258.5  258.8  250.2  228.8  215.8  202.5  172.4  156.1  117.8   97.0   78.0   64.5
108   10.2   101.2    137.9   249.9  256.7  256.8  248.9  228.5  216.6  203.5  174.8  158.5  121.7  101.4   81.8   66.7
111   10.4    95.7    137.9   248.2  254.7  254.6  247.4  228.3  217.1  204.2  176.2  160.2  124.9  105.2   85.6   69.8
114   10.7    90.3    137.9   246.4  252.5  252.6  245.6  228.1  217.1  205.2  177.2  161.5  127.3  108.6   88.8   72.8
117   11.0    99.6    138.1   244.3  250.3  250.5  243.8  227.4  217.0  205.8  178.1  162.6  129.1  111.2   91.4   75.0
120   11.3    96.2    137.3   242.1  248.1  248.3  242.1  226.2  216.8  205.5  178.8  163.5  130.7  112.6   93.4   76.7
123   11.6    89.2    136.5   239.9  245.8  246.2  240.5  225.2  215.9  204.8  179.1  164.4  131.8  113.6   94.7   78.0
126   11.9    97.8    135.7   237.8  243.4  244.1  238.6  224.0  214.3  203.9  179.3  165.0  132.3  114.4   95.5   79.0
129   12.1    93.8    135.1   235.4  241.1  241.8  236.6  222.2  212.9  202.8  179.1  165.0  132.7  115.0   96.3   79.6
132   12.4    84.6    134.5   233.1  238.7  239.4  234.5  220.3  211.6  201.6  178.5  164.5  132.9  115.4   97.0   80.0
135   12.7    96.0    134.1   230.6  235.9  236.8  232.0  218.4  210.0  200.3  177.4  163.7  132.8  115.6   97.4   80.4
138   13.0    93.2    133.7   228.0  232.9  233.8  229.3  216.5  208.2  198.9  176.0  162.6  132.3  115.6   97.5   80.6
141   13.3    88.3    133.4   225.0  229.6  230.3  226.4  214.4  206.4  197.1  174.6  161.3  131.7  115.1   97.5   80.5
144   13.5    92.6    133.1   221.5  225.9  226.7  223.5  212.2  204.4  195.1  173.1  160.1  130.8  114.5   97.1   80.2
```

FORM 4: CONTINUED

```
147  13.8    91.1   132.9   217.6   221.6   223.1   220.3   209.8   202.1   193.1   171.6   158.8   129.7   113.6    96.3    79.7
150  14.1    88.5   132.8   213.5   217.2   219.0   216.8   207.1   199.7   191.1   170.0   157.4   128.5   112.5    95.3    78.9
153  14.4    91.9   132.7   209.0   212.7   214.3   212.9   204.1   197.3   189.0   168.4   155.9   127.4   111.3    94.2    78.0
156  14.7    91.7   132.6   204.4   207.7   209.5   208.6   201.0   194.7   186.9   166.8   154.5   126.1   110.2    93.2    77.4
159  15.0    88.6   132.6   199.5   202.2   204.3   203.9   197.8   192.0   184.6   165.1   153.0   124.8   109.1    92.4    76.8
162  15.2    90.7   132.5   194.1   196.4   198.7   199.1   194.3   189.1   182.1   163.4   151.5   123.7   108.2    91.8    76.0
165  15.5    91.6   132.5   188.3   190.4   192.8   194.1   190.6   186.0   179.5   161.5   149.9   122.7   107.5    91.1    75.2
168  15.8    88.9   132.5   182.0   183.9   186.8   188.9   186.8   182.7   176.8   159.5   148.3   121.9   106.7    90.1    74.2
171  16.1    90.2   132.4   175.5   177.1   180.6   183.5   182.8   179.2   173.8   157.6   146.8   120.9   105.8    89.2    73.3
174  16.4    91.5   132.3   168.9   170.2   173.9   177.9   178.6   175.7   170.7   155.6   145.3   119.8   104.7    88.3    72.4
177  16.6    89.1   132.2   162.1   163.1   167.1   171.9   174.3   172.0   167.7   153.6   143.7   118.5   103.6    87.3    71.6
180  16.9    89.6   132.0   155.3   155.9   160.2   165.8   169.8   168.2   164.6   151.5   141.9   117.2   102.5    86.4    70.8
183  17.2    91.0   131.7   148.4   148.6   153.3   159.6   165.3   164.5   161.5   149.3   140.0   115.9   101.4    85.5    70.1
186  17.5    88.9   131.4   141.4   141.4   146.2   153.5   160.6   160.7   158.3   147.0   138.0   114.5   100.3    84.6    69.4
189  17.8    88.7   130.9   134.4   134.1   139.3   147.3   156.0   156.8   155.1   144.6   136.0   113.1    99.2    83.8    68.7
192  18.1    89.9   130.3   127.5   126.8   132.4   141.2   151.5   152.8   151.6   142.2   134.0   111.8    98.2    83.0    68.2
195  18.3    88.1   129.6   120.6   119.7   125.6   135.4   147.0   148.8   148.0   139.7   132.0   110.6    97.2    82.2    67.6
198  18.6    87.1   128.8   113.9   112.8   119.0   129.6   142.5   144.8   144.6   137.3   130.1   109.3    96.2    81.4    67.0
201  18.9    88.0   127.8   107.4   106.1   112.6   123.9   138.0   140.9   141.3   134.9   128.1   108.1    95.3    80.7    66.4
204  19.2    86.4   126.7   101.1    99.8   106.2   118.2   133.6   137.1   138.1   132.6   126.2   106.9    94.4    80.0    65.9
207  19.5    84.8   125.4    95.2    93.8    99.8   112.7   129.4   133.5   135.0   130.5   124.4   105.7    93.4    79.3    65.3
210  19.8    85.3   124.0    89.6    88.0    93.6   107.1   125.3   130.0   132.0   128.4   122.6   104.5    92.4    78.5    64.7
213  20.0    83.8   122.5    84.3    82.2    87.9   101.6   121.4   126.7   129.2   126.4   121.0   103.3    91.5    77.7    64.0
216  20.3    81.8   120.8    79.3    77.0    82.7    96.2   117.6   123.5   126.5   124.5   119.4   102.2    90.5    76.9    63.3
219  20.6    81.7   119.0    74.5    72.5    77.9    91.0   113.8   120.4   123.9   122.7   117.9   101.1    89.5    76.0    62.6
222  20.9    80.3   117.1    70.0    68.3    73.4    86.3   110.1   117.3   121.4   120.9   116.4   100.1    88.6    75.3    62.0
225  21.2    78.0   115.1    66.1    64.1    69.3    82.0   106.5   114.2   118.9   119.2   115.0    99.1    87.8    74.5    61.3
228  21.4    77.4   112.9    62.5    60.2    65.4    78.1   103.2   111.3   116.3   117.5   113.6    98.1    87.0    73.9    60.7
231  21.7    76.0   110.7    59.2    56.8    61.8    74.6   100.0   108.5   113.8   115.8   112.2    97.2    86.2    73.2    60.1
234  22.0    73.6   108.4    56.2    54.0    58.8    71.2    96.8   105.8   111.5   114.1   110.8    96.3    85.4    72.5    59.6
237  22.3    74.7   106.0    53.5    51.5    56.2    68.1    93.8   103.2   109.3   112.4   109.5    95.4    84.7    71.9    59.0
240  22.6    72.5   103.6    51.1    49.1    53.7    65.4    91.0   100.7   107.2   110.9   108.1    94.5    84.0    71.3    58.5
243  22.9    68.6   101.1    49.0    46.8    51.3    62.9    88.5    98.4   105.2   109.4   106.8    93.5    83.2    70.7    58.0
246  23.1    69.5    98.6    47.2    44.8    49.1    60.5    86.1    96.3   103.3   108.0   105.6    92.6    82.5    70.1    57.5
249  23.4    67.4    96.1    45.6    43.1    47.2    58.3    83.8    94.4   101.6   106.7   104.5    91.8    81.7    69.5    57.1
252  23.7    63.7    93.6    44.1    41.7    45.6    56.6    81.6    92.5   100.0   105.4   103.4    91.0    81.1    69.0    56.6
255  24.0    64.3    91.1    42.7    40.4    44.4    55.2    79.6    90.8    98.5   104.3   102.4    90.3    80.5    68.4    56.2
258  24.3    62.2    88.7    41.5    39.4    43.4    53.9    77.9    89.2    97.1   103.3   101.5    89.7    79.9    68.0    55.8
261  24.6    58.9    86.2    40.5    38.5    42.4    52.9    76.4    87.8    95.8   102.4   100.8    89.1    79.5    67.6    55.5
264  24.8    59.1    83.8    39.6    37.8    41.6    51.9    75.1    86.6    94.7   101.5   100.1    88.6    79.0    67.2    55.1
267  25.1    57.2    81.4    38.9    37.0    40.8    51.1    74.1    85.6    93.8   100.7    99.4    88.1    78.6    66.9    54.9
270  25.4    54.2    79.1    38.4    36.4    40.2    50.3    73.2    84.9    93.1   100.1    98.9    87.8    78.3    66.6    54.6
273  25.7    54.2    76.9    37.9    36.0    39.7    49.7    72.4    84.2    92.6    99.6    98.4    87.4    78.0    66.3    54.3
276  26.0    52.5    74.6    37.5    35.7    39.3    49.2    71.8    83.7    92.2    99.3    98.1    87.1    77.7    66.0    54.1
279  26.2    49.8    72.5    37.1    35.5    39.2    48.9    71.3    83.3    91.8    99.0    97.8    86.8    77.5    65.8    53.9
282  26.5    49.7    70.4    36.8    35.3    39.0    48.8    71.0    83.0    91.5    98.9    97.7    86.6    77.3    65.6    53.7
285  26.8    48.2    68.3    36.6    35.2    39.0    48.7    70.8    82.8    91.4    98.8    97.6    86.5    77.1    65.5    53.6


                TABLE OF EXTREME VALUES FOR PILE AND TIME OF OCCURRENCE
      ELEM.     FMAX           FMIN       MINSTR         MAXSTR          VELMX          DISMX
       NO.      KIPS           KIPS         KSI            KSI            FT/S           INCH
        1     264.0( 75)        .0(  0)       .0(  0)     30.0( 75)      9.68( 48)      .745(126)
```

FORM 4: CONTINUED

```
  2   271.0( 78)        .0(   0)        .0(   0)      30.8( 78)      9.21( 51)       .688(126)
  3   267.8( 81)        .0(   0)        .0(   0)      30.4( 81)      8.75( 54)       .632(129)
  4   254.2( 84)        .0(   0)        .0(   0)      28.9( 84)      8.25( 57)       .577(129)
  5   240.7( 99)        .0(   0)        .0(   0)      28.5( 99)      7.70( 60)       .521(132)
  6   228.8(105)        .0(   0)        .0(   0)      27.2(105)      7.14( 63)       .467(132)
  7   217.1(111)        .0(   0)        .0(   0)      25.8(111)      6.58( 66)       .416(132)
  8   205.8(117)        .0(   0)        .0(   0)      24.5(117)      6.10( 69)       .367(135)
  9   192.7(120)        .0(   0)        .0(   0)      23.6(120)      5.57( 72)       .320(135)
 10   179.3(126)        .0(   0)        .0(   0)      24.2(126)      4.84( 78)       .271(138)
 11   165.0(129)        .0(   0)        .0(   0)      22.3(129)      4.17( 78)       .226(141)
 12   149.5(129)        .0(   0)        .0(   0)      20.2(129)      3.56( 81)       .185(141)
 13   132.9(132)        .0(   0)        .0(   0)      18.0(132)      3.02( 84)       .149(144)
 14   115.6(135)        .0(   0)        .0(   0)      15.6(135)      2.49( 87)       .117(144)
 15    97.5(138)        .0(   0)        .0(   0)      13.2(138)      2.00( 90)       .091(147)
 16    80.6(138)        .0(   0)        .0(   0)       9.1(138)      1.60( 93)       .069(150)

           THE MAXIMUM TRANSFERRED ENERGY (ENTHRU) WAS  12.2 K-FT
ANALYSIS WAS TERMINATED AS NO PERMAMENT SET RESULTED
```

FORM 4: CONTINUED

```
          EXAMPLE 7.2 DRIVEABILITY CHECK LB 520

                               SUMMARY

NO      R ULT   BLOW CT     STROKE   MIN STR   MAX  STR     BLOWS/  B.C. PR.
        TONS     1/FT         FT       KSI        KSI       MINUTE       PSI
 1      120.0     221.      3.60(1)     .00      30.54       73.9       24.7
 2      160.0  9999999.     3.60(2)     .00      30.80       73.9       24.7
```

FORM 4: CONTINUED

was once reduced (a computational process that is not related to a physical process).

For RULT = 160 no permanent set resulted.

It must be concluded that even if driving is not interrupted and therefore no set up occurs during the driving process, the blow count is already too high to be economical. Note that it is not very easy to keep the stroke exactly at maximum thus it can be expected that driving is even harder. The maximum stresses were about 31 ksi and occurred at the top (see list of maxima for individual elements in Form 4). Thus, the danger of yield, which will be greatest at the points of cross sectional change, is only limited. A recommendation based on these results is to increase the wall thickness rather than the hammer size. (Stiffer piles drive better).

7.3 Tension Stress Check

7.3.1 Situation

Using a Vulcan 80 C hammer a 14x14 inch prestressed concrete pile is to be driven through very soft material. The pile length is 50 feet. The soil engineer has estimated that there will be only 10 tons of skin resistance (no tip resistance) in the early stages of driving (20 feet penetration) and that skin damping (Smith) is equal to 0.2.

7.3.2 Problem

It is expected that tension stresses will develop in the pile during the early driving stages. These tension stresses should at no point exceed 1.0 ksi (prestress). How many sheets of 3/4 inch plywood should be put on the pile top to sufficiently protect the pile? The plywood sheets are to be reused. Capblock properties are given as: weight = 1.5 kips, stiffness = 10,000 kips/inch and coefficient of restitution = 0.8.

7.3.3 Solution

The following input was made solving first the case of a cushion consisting of 3 plywood sheets.

Card No. 2.000
IOUT = 3 for a print of stresses
IHAMR = 65 from Table 2
IPERCS = 100 no toe resistance
ISMITH = 1 for Smith's damping
IBEDAM = 3 for concrete

Card No. 3.000
Wt. Cap = 1.5 kips
Stiff. Cap = 10000. kips/inch
Stiff. Cushion = 3360.; This value was derived from AE/L with -
$A = 196$ inch^2 (equal to the pile cross sectional area)
$E = 30$ ksi (estimated for plywood)
$L = 3 \times 0.58$ inch (assuming that the plywood was compressed to one and three-quarter inches during use)

Card No. 4.000
C.O.R. of Cap = 0.8, of pile top = 1.0, of Cushion = 0.5, of assembly = blank (normal).

Card No. 5.000
L Pile = 50. feet
A Pile Top = 196. square inch
E Pile Top = 5000. ksi (assumed)
W Pile Top = 150. lbs. per cu. ft. (standard)

Card No. 6.000
Quakes = 0.1 inch
Skin Damping = 0.2 sec/ft

	Toe Damping	Not specified since there is no toe resistance force.
	RULT = 10.0	tons All other data are left blank for standard performance.
Card No. 6.401,...	From 0 to 30 feet below the pile top no skin friction. From 30 to 50 feet uniform skin friction.	

The filled-in input form is shown in Form 5. The corresponding output is reproduced in Form 6.

7.3.4 Discussion of Results

The output shows that the tension stresses are greater than 1.0 ksi at several segments (note that the output gives tension as a negative stress). Driving the pile with only 3 cushion sheets is therefore not advisable.

7.3.5 Additional Computer Analysis

It is concluded that more cushion sheets should be used and a second computer run is made for six cushion sheets. Thus the cushion stiffness on Card No. 3.000 is merely divided by 2. The first and last page of the output is reproduced in Form 7. Obviously the maximum tension stress was reduced such that tension cracks are less likely to occur. Driving with reduced pressures in the early phases of driving is recommended for a better and more effective means of getting the pile safely into the ground. The program could have equally well been used to find PSTEAM which would also limit tension in easy driving.

WAVE EQUATION ANALYSIS for PILES

Short Input Form, page 1

1234567890123456789012345678901234567890123456789012345678901234567890

1.000 Title (40 characters): EXAMPLE 7.3 TENSION STRESS CHECK 3-PLY

2.000

IOUT	IJJ	IHAMR	IOSTR	IFUEL	IPEL	N	ISPL No. of Splices	NCROSS 0 = Uniform	IBEDAM	IPERCS	ISMITH 1=Smith	ITYS	IPHI
	3	65							3	100	1		

3.000 Cap and Cushion

Wt. Cap (kips)	Stiff. Cap (K/in)	Stiff. Cushion (K/in)
1.5	10000.	3360.

For 6 plywood sheets, cushion stiffness is 1,680 k/in

4.000

Coefficients of Restitution: Anvil (Diesel) Cap(Air/Steam)	Coefficients of Restitution: Cap (Diesel) Assembly(A/S)	Coefficients of Restitution: Pile Top	Coefficients of Restitution: Cushion	TEMAX (msec.)	TDEL (sec.)
.8		1.0	.5		

5.000

L Pile (ft)	A Pile Top (in^2)	E Pile Top (ksi)	W Pile Top (lbs/ft^3)
50.	196.	5000.	150.

If NCROSS = 1 and IPEL ≠ 2 only

	LP_i (ft)	AP_i (ft)	EP_i (ksi)	WP_i (lbs/ft^3)
5.101				
5.102				
.				
.				
.				
5.119				

FORM 5: INPUT, EXAMPLE 7.3

WAVE EQUATION ANALYSIS for PILES

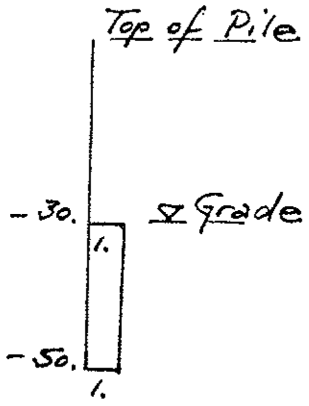
Short Input Form, page 2

	Quake Skin (in)	Quake Toe (in)	Damping Skin*	Damping Toe*	RULT (tons)	Coeff. of Rest. Of Soil	Stroke (ft)	Hammer Efficiency	Steam Pressure (psi)	Reaction wt. (kips)
6.000	.1	.1	.2		10.					

*Damping Parameters - sec/ft for Smith; Dimensionless for Case

If ITYS = 0 or -1 only

	XPi (ft)	% Soil Res.
6.401	0.	0.
6.402	30.	0.
.	30.	1.
.	50.	1.
.		
6.420		



If IOUT > 9

YMAX

7.000 Plotter Scale

If IOUT > 9 only
ISPG(I), I = 1,2,...,15 (Plotted Variables)

8.000

If RULT < 0 only:

Ultimate Resistance - tons (at most 10 values)

9.000

1 2 3 4 5 6 7 8 9 10 1 2 3 4 5 6 7 8 9 20 1 2 3 4 5 6 7 8 9 30 1 2 3 4 5 6 7 8 9 40 1 2 3 4 5 6 7 8 9 50 1 2 3 4 5 6 7 8 9 60 1 2 3 4 5 6 7 8 9 70 1 2 3 4 5 6 7 8 9 80

FORM 5: CONTINUED

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                 W E A P  -  WAVE EQUATION ANALYSIS FOR PILES

        THIS PROGRAM WAS PREPARED FOR THE FEDERAL HIGHWAY ADMINISTRATION
                   BY GOBLE & ASSOCIATES, CLEVELAND, OHIO

        EXAMPLE 7.3 TENSION STRESS CHECK  3-PLY
                   PILE DESCRIPTION

X BEL. TOP (FT)       .0    50.0
A (SQ. IN.)        196.0   196.0
E (KSI)            5000.   5000.
GAMMA (LB/CU FT)   150.0   150.0
STROKE (EQUIV.) 3.1 FT, EFFICIENCY  .80 , IMPACT VELOCITY 12.5 FT/S
ACTUAL/ MAX. PRESSURE 120.0/ 120.0 PSI, REACT./RAM WEIGHT   9.8/   8.0 KIPS


               HAMMER MODEL VULC.80C
   ELEMENT       WEIGHT  STIFFNESS    COEFF.
   NUMBER        (KIPS)   (K/IN)   RESTITUTION
     1           8.000
    CAP          1.500   10000.0       .800
   CUSHION                3360.0       .500
  PILE TOP                            1.000
```

FORM 6: OUTPUT, EXAMPLE 7.3, 3-PLY

```
                     PILE PROPERTIES

PILE LENGTH=  50. FT., AREA(AT TOP)= 196.0 S-IN
E. MODUL(AT TOP)= 5000. KSI., SPEC. WT.(AT TOP)= 150. LBS/CU FT


     WEIGHT STIFFN.  PDAMP.  SPLICE  SOIL-S  SOIL-D   QUAKE  L.B.T.
NO.  (KIPS)  (K/IN) (KS/FT)  (KIPS)  (PCT.)  (S/FT)   (IN.)  (FT.)
  1    .928  17967.    4.73      0.    .000    .200    .100    4.5
  2    .928  17967.    4.73  -5000.    .000    .200    .100    9.1
  3    .928  17967.    4.73  -5000.    .000    .200    .100   13.6
  4    .928  17967.    4.73  -5000.    .000    .200    .100   18.2
  5    .928  17967.    4.73  -5000.    .000    .200    .100   22.7
  6    .928  17967.    4.73  -5000.    .000    .200    .100   27.3
  7    .928  17967.    4.73  -5000.    .091    .200    .100   31.8
  8    .928  17967.    4.73  -5000.    .227    .200    .100   36.4
  9    .928  17967.    4.73  -5000.    .227    .200    .100   40.9
 10    .928  17967.    4.73  -5000.    .227    .200    .100   45.5
 11    .928  17967.    4.73  -5000.    .227    .200    .100   50.0
TOE                                    .000    .000    .100

COEFFICIENT OF RESTITUTION OF SOIL     1.000

                 OPTIONS AND SPECIFICATIONS
PHI    1.60      S-DAMPING     SMITH       RWT (KIPS)        9.78
IOUT      3      P-DAMPING         3       SOIL DIST. NO.       0
IFUEL     1      J SKIN          .20       TDEL (SEC.)      .0000
IOSTR     0      J TOE           .00       TEMAX (MS)         .00
                 TIME INCR. (MS) .184
```

FORM 6: CONTINUED

```
                          RULT=   10.0, AT TOE=     .0 TONS
                          ---------------------------------

                                               HAMMER AND PILE STRESSES (KSI)
 JP  TIME     HAMMER                                    PILE ELEMENTS
     (MS)  RAM M   ANVIL    TOP      2      3      4      5      6      7      8      9     10     11
  1    .2    .00     .00    .06    .06    .06    .06    .06    .05    .05    .04    .03    .03    .02
  2    .4    .00     .00    .06    .06    .06    .06    .06    .05    .05    .04    .03    .03    .02
  3    .6    .00     .00    .06    .06    .06    .06    .06    .05    .05    .04    .03    .03    .01
  4    .7    .00     .00    .06    .06    .06    .06    .05    .05    .05    .04    .03    .02    .01
  5    .9    .00     .00    .06    .06    .06    .06    .05    .05    .04    .04    .03    .02    .01
  6   1.1    .00     .00    .06    .05    .05    .05    .05    .05    .04    .04    .03    .02    .01
  7   1.3    .00     .00    .06    .05    .05    .05    .05    .05    .04    .04    .03    .01    .01
  8   1.5    .00     .00    .06    .05    .05    .05    .05    .05    .04    .03    .02    .01    .01
  9   1.7    .00     .00    .06    .05    .05    .05    .05    .04    .04    .03    .02    .01    .01
 10   1.8    .00     .00    .06    .05    .05    .04    .04    .04    .03    .03    .02    .01    .01
 11   2.0    .00    1.23    .06    .05    .05    .04    .04    .04    .03    .02    .01    .01    .01
 12   2.2    .00    3.09    .06    .05    .05    .04    .04    .03    .03    .02    .01    .01    .00
 13   2.4    .00    5.38    .07    .06    .05    .04    .03    .03    .02    .02    .01    .01    .00
 14   2.6    .00    7.85    .08    .07    .05    .04    .03    .02    .02    .01    .01    .01    .00
 15   2.8    .00   10.28    .10    .09    .05    .04    .03    .02    .01    .01    .01    .01    .00
 16   2.9    .00   12.39    .14    .13    .07    .04    .02    .01    .01    .01    .01    .01    .00
 17   3.1    .00   13.97    .21    .18    .09    .04    .02    .01    .01    .01    .01    .00    .00
 18   3.3    .00   14.89    .31    .26    .12    .05    .02    .01    .01    .01    .00    .00    .00
 19   3.5    .00   15.13    .45    .35    .18    .08    .03    .01    .01    .00    .00    .00    .00
 20   3.7    .00   14.51    .65    .49    .25    .11    .04    .02    .01    .00    .00    .00    .00
 21   3.9    .00   13.16    .90    .66    .35    .17    .07    .03    .01    .00    .00   -.00   -.00
 22   4.0    .00   11.33   1.20    .87    .48    .24    .11    .04    .02    .01    .00   -.00   -.00
 23   4.2    .00    9.33   1.52   1.12    .65    .35    .17    .07    .03    .01    .00   -.00   -.00
 24   4.4    .00    7.46   1.84   1.41    .86    .48    .24    .11    .04    .02    .00   -.00   -.00
 25   4.6    .00    5.93   2.12   1.71   1.11    .65    .35    .17    .07    .03    .01    .00   -.00
 26   4.8    .00    4.83   2.34   2.01   1.40    .86    .48    .25    .11    .04    .02    .00    .00
 27   5.0    .00    4.15   2.51   2.26   1.70   1.11    .66    .35    .17    .07    .03    .01    .00
 28   5.1    .00    3.86   2.62   2.46   1.99   1.39    .87    .49    .25    .12    .05    .02    .01
 29   5.3    .00    3.90   2.66   2.59   2.24   1.68   1.11    .66    .36    .18    .08    .03    .01
 30   5.5    .00    4.19   2.66   2.66   2.45   1.97   1.39    .87    .50    .26    .12    .05    .02
 31   5.7    .00    4.76   2.56   2.67   2.59   2.23   1.67   1.11    .67    .37    .18    .08    .03
 32   5.9    .00    5.61   2.40   2.63   2.66   2.44   1.96   1.38    .88    .51    .26    .12    .05
 33   6.1    .00    6.74   2.19   2.52   2.67   2.58   2.22   1.67   1.12    .68    .37    .18    .07
 34   6.2    .00    8.09   1.99   2.36   2.62   2.65   2.43   1.95   1.39    .89    .51    .26    .11
 35   6.4    .00    9.59   1.80   2.16   2.51   2.66   2.57   2.21   1.67   1.12    .68    .37    .15
 36   6.6    .00   11.13   1.65   1.95   2.36   2.61   2.65   2.42   1.95   1.38    .88    .49    .22
 37   6.8    .00   12.56   1.55   1.76   2.17   2.51   2.66   2.57   2.20   1.66   1.11    .65    .29
 38   7.0    .00   13.78   1.49   1.61   1.96   2.36   2.61   2.65   2.42   1.93   1.35    .83    .38
 39   7.2    .00   14.66   1.48   1.52   1.77   2.18   2.51   2.67   2.57   2.18   1.61   1.02    .49
 40   7.3    .00   15.15   1.50   1.48   1.62   1.98   2.37   2.62   2.65   2.38   1.86   1.23    .60
 41   7.5    .00   15.24   1.54   1.48   1.52   1.80   2.19   2.52   2.67   2.52   2.07   1.43    .72
 42   7.7    .00   14.82   1.60   1.52   1.48   1.64   2.00   2.37   2.62   2.60   2.23   1.61    .83
 43   7.9    .00   13.97   1.68   1.58   1.49   1.54   1.82   2.20   2.50   2.59   2.33   1.75    .93
 44   8.1    .00   12.79   1.77   1.65   1.53   1.49   1.66   2.01   2.34   2.50   2.34   1.82    .99
 45   8.3    .00   11.44   1.86   1.74   1.59   1.49   1.55   1.81   2.14   2.35   2.26   1.81   1.01
 46   8.4    .00   10.07   1.94   1.83   1.66   1.53   1.49   1.64   1.92   2.13   2.09   1.71    .97
 47   8.6    .00    8.79   2.00   1.92   1.75   1.59   1.47   1.50   1.69   1.86   1.84   1.53    .88
 48   8.8    .00    7.71   2.05   1.99   1.83   1.66   1.49   1.40   1.46   1.55   1.52   1.27    .73
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FORM 6: CONTINUED

49	9.0	.00	6.86	2.07	2.04	1.91	1.73	1.53	1.33	1.24	1.23	1.15	.94	.54
50	9.2	.00	6.24	2.06	2.07	1.98	1.79	1.56	1.29	1.05	.90	.75	.57	.31
51	9.4	.00	5.86	2.01	2.07	2.02	1.84	1.59	1.25	.88	.58	.35	.19	.08
52	9.5	.00	5.69	1.91	2.03	2.03	1.87	1.59	1.21	.74	.29	-.03	-.18	-.15
53	9.7	.00	5.67	1.79	1.96	2.00	1.87	1.57	1.14	.60	.04	-.37	-.49	-.34
54	9.9	.00	5.76	1.65	1.84	1.93	1.82	1.51	1.05	.46	-.16	-.62	-.73	-.48
55	10.1	.00	5.93	1.50	1.69	1.81	1.72	1.42	.92	.32	-.31	-.79	-.88	-.57
56	10.3	.00	6.14	1.35	1.50	1.63	1.57	1.27	.77	.18	-.41	-.86	-.93	-.59
57	10.5	.00	6.37	1.22	1.31	1.41	1.36	1.08	.60	.05	-.47	-.84	-.87	-.55
58	10.6	.00	6.59	1.09	1.10	1.15	1.09	.84	.41	-.07	-.47	-.73	-.73	-.46
59	10.8	.00	6.76	.97	.89	.87	.78	.55	.21	-.16	-.43	-.57	-.53	-.32
60	11.0	.00	6.86	.87	.69	.56	.43	.24	.00	-.22	-.35	-.36	-.28	-.16
61	11.2	.00	6.86	.77	.48	.26	.08	-.08	-.20	-.25	-.22	-.13	-.03	.01
62	11.4	.00	6.73	.68	.29	-.03	-.27	-.38	-.38	-.25	-.08	.09	.20	.16
63	11.6	.00	6.46	.58	.09	-.30	-.58	-.66	-.53	-.24	.08	.30	.39	.28
64	11.7	.00	6.03	.49	-.09	-.54	-.84	-.88	-.64	-.21	.21	.47	.53	.36
65	11.9	.00	5.48	.40	-.25	-.74	-1.04	-1.03	-.70	-.18	.32	.59	.61	.39
66	12.1	.00	4.81	.30	-.39	-.89	-1.16	-1.10	-.72	-.15	.37	.64	.63	.38
67	12.3	.00	4.06	.20	-.50	-.98	-1.19	-1.09	-.69	-.12	.38	.63	.59	.34
68	12.5	.00	3.27	.10	-.58	-1.00	-1.15	-1.01	-.62	-.11	.33	.54	.50	.28
69	12.7	.00	2.48	.02	-.59	-.96	-1.04	-.87	-.52	-.10	.24	.40	.37	.20
70	12.8	.00	1.72	.00	-.54	-.84	-.86	-.68	-.41	-.11	.11	.21	.20	.12
71	13.0	.00	1.04	.00	-.43	-.65	-.64	-.48	-.29	-.13	-.04	-.00	.02	.02
72	13.2	.00	.48	.00	-.27	-.41	-.38	-.27	-.18	-.16	-.19	-.21	-.16	-.08
73	13.4	.00	.07	.00	-.09	-.13	-.10	-.06	-.09	-.20	-.33	-.40	-.34	-.18
74	13.6	.00	.00	.00	.11	.17	.18	.12	-.02	-.23	-.45	-.55	-.48	-.27
75	13.8	.00	.00	.00	.29	.45	.43	.29	.03	-.26	-.53	-.66	-.59	-.35
76	13.9	.00	.00	.00	.44	.68	.66	.42	.08	-.28	-.56	-.72	-.66	-.40
77	14.1	.00	.00	.00	.53	.85	.82	.53	.12	-.27	-.56	-.72	-.67	-.41
78	14.3	.00	.00	.00	.58	.93	.92	.61	.17	-.23	-.51	-.67	-.63	-.39
79	14.5	.00	.00	.00	.56	.92	.95	.66	.23	-.15	-.43	-.57	-.55	-.33
80	14.7	.00	.00	.00	.50	.84	.89	.67	.30	-.05	-.30	-.43	-.41	-.24
81	14.9	.00	.00	.00	.40	.68	.77	.65	.37	.09	-.13	-.26	-.25	-.14
82	15.0	.00	.00	.00	.27	.48	.60	.59	.44	.25	.06	-.05	-.06	-.03
83	15.2	.00	.00	.00	.13	.26	.40	.49	.50	.41	.28	.18	.14	.08
84	15.4	.00	.00	.00	-.01	.04	.19	.38	.53	.57	.52	.43	.33	.18
85	15.6	.00	.00	.00	-.13	-.15	-.01	.26	.53	.71	.75	.66	.51	.28
86	15.8	.00	.00	.00	-.22	-.30	-.17	.14	.52	.82	.95	.88	.66	.36
87	16.0	.00	.00	.00	-.28	-.40	-.29	.04	.48	.90	1.11	1.06	.80	.42
88	16.2	.00	.00	.00	-.30	-.44	-.35	-.03	.44	.93	1.21	1.18	.90	.48
89	16.3	.00	.00	.00	-.28	-.42	-.36	-.06	.41	.92	1.24	1.24	.96	.52
90	16.5	.00	.00	.00	-.23	-.35	-.31	-.05	.38	.86	1.20	1.23	.99	.54
91	16.7	.00	.00	.00	-.15	-.24	-.21	.00	.37	.78	1.09	1.16	.96	.53
92	16.9	.00	.00	.00	-.06	-.10	-.06	.10	.37	.68	.94	1.02	.87	.50
93	17.1	.00	.00	.00	.03	.06	.11	.21	.38	.57	.75	.82	.73	.44
94	17.3	.00	.00	.00	.12	.22	.29	.35	.40	.47	.55	.59	.55	.34
95	17.4	.00	.00	.00	.21	.38	.47	.47	.42	.37	.34	.34	.32	.21
96	17.6	.00	.00	.00	.29	.51	.62	.59	.44	.28	.16	.09	.08	.06
97	17.8	.00	.00	.00	.34	.62	.74	.67	.46	.21	-.01	-.14	-.16	-.10
98	18.0	.00	.00	.00	.39	.68	.81	.72	.47	.15	-.14	-.35	-.38	-.24
99	18.2	.00	.00	.00	.40	.71	.82	.72	.46	.10	-.25	-.50	-.55	-.36
100	18.4	.00	.00	.00	.40	.68	.78	.69	.43	.06	-.32	-.61	-.66	-.43
101	18.5	.00	.00	.00	.36	.61	.70	.61	.37	.02	-.36	-.65	-.70	-.45
102	18.7	.00	.00	.00	.30	.50	.57	.49	.29	-.02	-.36	-.63	-.66	-.42

FORM 6: CONTINUED

103	18.9	.00	.00	.00	.21	.36	.40	.35	.18	-.06	-.34	-.56	-.56	-.35
104	19.1	.00	.00	.00	.11	.19	.22	.17	.06	-.11	-.30	-.43	-.41	-.25
105	19.3	.00	.00	.00	.01	.01	.01	-.02	-.08	-.16	-.23	-.27	-.23	-.12
106	19.5	.00	.00	.00	-.10	-.17	-.20	-.21	-.22	-.19	-.14	-.09	-.03	.00
107	19.6	.00	.00	.00	-.20	-.34	-.40	-.41	-.35	-.22	-.05	.09	.15	.12
108	19.8	.00	.00	.00	-.28	-.49	-.59	-.58	-.46	-.23	.04	.24	.31	.21
109	20.0	.00	.00	.00	-.34	-.61	-.75	-.73	-.54	-.22	.13	.37	.42	.27
110	20.2	.00	.00	.00	-.39	-.70	-.87	-.83	-.59	-.20	.19	.44	.48	.31
111	20.4	.00	.00	.00	-.41	-.75	-.93	-.88	-.60	-.17	.23	.47	.49	.31
112	20.6	.00	.00	.00	-.42	-.77	-.94	-.87	-.58	-.15	.23	.44	.45	.28
113	20.7	.00	.00	.00	-.41	-.73	-.89	-.81	-.52	-.13	.20	.36	.36	.22
114	20.9	.00	.00	.00	-.37	-.66	-.78	-.70	-.44	-.12	.14	.25	.24	.15
115	21.1	.00	.00	.00	-.32	-.54	-.62	-.54	-.35	-.12	.04	.11	.10	.06
116	21.3	.00	.00	.00	-.24	-.39	-.43	-.36	-.24	-.13	-.06	-.05	-.04	-.03
117	21.5	.00	.00	.00	-.14	-.21	-.21	-.17	-.14	-.15	-.17	-.20	-.19	-.11
118	21.7	.00	.00	.00	-.02	-.01	.02	.02	-.05	-.16	-.27	-.34	-.31	-.19
119	21.8	.00	.00	.00	.10	.19	.23	.19	.03	-.17	-.36	-.46	-.41	-.24
120	22.0	.00	.00	.00	.22	.38	.42	.33	.10	-.17	-.41	-.53	-.48	-.28
121	22.2	.00	.00	.00	.32	.53	.58	.44	.16	-.16	-.42	-.56	-.51	-.30
122	22.4	.00	.00	.00	.39	.65	.68	.51	.21	-.12	-.40	-.55	-.50	-.29
123	22.6	.00	.00	.00	.43	.71	.74	.55	.25	-.07	-.34	-.48	-.45	-.27
124	22.8	.00	.00	.00	.44	.71	.74	.57	.29	.00	-.24	-.38	-.37	-.22
125	22.9	.00	.00	.00	.40	.65	.69	.55	.32	.09	-.10	-.23	-.25	-.16
126	23.1	.00	.00	.00	.32	.54	.60	.52	.36	.19	.05	-.06	-.10	-.08
127	23.3	.00	.00	.00	.22	.39	.47	.46	.39	.31	.22	.12	.05	.02
128	23.5	.00	.00	.00	.11	.23	.32	.39	.42	.43	.39	.31	.22	.11
129	23.7	.00	.00	.00	.00	.06	.17	.31	.44	.54	.56	.50	.38	.20
130	23.9	.00	.00	.00	-.09	-.09	.03	.23	.46	.64	.72	.67	.52	.29
131	24.0	.00	.00	.00	-.16	-.21	-.09	.16	.46	.72	.85	.81	.64	.36
132	24.2	.00	.00	.00	-.21	-.29	-.18	.10	.45	.77	.94	.92	.73	.41
133	24.4	.00	.00	.00	-.22	-.32	-.22	.06	.44	.79	.99	.98	.79	.44
134	24.6	.00	.00	.00	-.20	-.30	-.22	.04	.41	.78	1.00	1.00	.80	.44
135	24.8	.00	.00	.00	-.16	-.24	-.17	.05	.39	.74	.96	.97	.78	.43
136	25.0	.00	.00	.00	-.10	-.14	-.09	.09	.37	.67	.88	.89	.72	.40
137	25.1	.00	.00	.00	-.02	-.02	.03	.15	.36	.59	.76	.77	.62	.34
138	25.3	.00	.00	.00	.06	.11	.16	.24	.35	.50	.61	.60	.49	.27
139	25.5	.00	.00	.00	.13	.24	.30	.32	.35	.40	.44	.42	.34	.19
140	25.7	.00	.00	.00	.20	.36	.42	.41	.36	.30	.26	.22	.17	.10
141	25.9	.00	.00	.00	.26	.45	.53	.49	.36	.22	.10	.02	.00	.00
142	26.1	.00	.00	.00	.30	.52	.60	.54	.36	.14	-.05	-.16	-.16	-.09
143	26.2	.00	.00	.00	.32	.55	.64	.56	.35	.08	-.16	-.31	-.31	-.18
144	26.4	.00	.00	.00	.32	.55	.64	.55	.33	.03	-.25	-.42	-.42	-.25
145	26.6	.00	.00	.00	.29	.51	.59	.51	.28	-.01	-.30	-.49	-.49	-.30
146	26.8	.00	.00	.00	.25	.44	.50	.43	.22	-.04	-.31	-.50	-.51	-.32
147	27.0	.00	.00	.00	.19	.34	.38	.31	.15	-.07	-.30	-.48	-.49	-.31
148	27.2	.00	.00	.00	.12	.21	.23	.18	.06	-.10	-.27	-.41	-.41	-.26
149	27.3	.00	.00	.00	.04	.07	.07	.03	-.04	-.12	-.22	-.31	-.31	-.19
150	27.5	.00	.00	.00	-.04	-.08	-.11	-.13	-.14	-.14	-.16	-.19	-.17	-.10
151	27.7	.00	.00	.00	-.12	-.22	-.28	-.28	-.24	-.16	-.10	-.06	-.03	-.01
152	27.9	.00	.00	.00	-.20	-.35	-.43	-.42	-.33	-.18	-.03	.07	.11	.08
153	28.1	.00	.00	.00	-.26	-.46	-.56	-.54	-.40	-.19	.03	.18	.23	.16
154	28.3	.00	.00	.00	-.31	-.55	-.66	-.63	-.46	-.19	.08	.26	.31	.21
155	28.4	.00	.00	.00	-.34	-.60	-.72	-.68	-.49	-.19	.12	.32	.36	.24
156	28.6	.00	.00	.00	-.35	-.62	-.75	-.70	-.49	-.18	.14	.33	.37	.24

FORM 6: CONTINUED

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157  28.8    .00    .00    .00   -.34   -.60   -.72   -.68   -.47   -.16    .13    .30    .33    .21
158  29.0    .00    .00    .00   -.31   -.55   -.66   -.61   -.42   -.15    .10    .24    .26    .16
159  29.2    .00    .00    .00   -.26   -.47   -.56   -.52   -.35   -.13    .06    .15    .16    .10
160  29.4    .00    .00    .00   -.20   -.36   -.42   -.39   -.27   -.12   -.00    .04    .05    .03
161  29.5    .00    .00    .00   -.13   -.22   -.26   -.25   -.18   -.11   -.08   -.07   -.07   -.04
162  29.7    .00    .00    .00   -.05   -.08   -.09   -.09   -.09   -.11   -.15   -.19   -.18   -.11
163  29.9    .00    .00    .00    .04    .07    .08    .06   -.01   -.10   -.21   -.29   -.27   -.16
164  30.1    .00    .00    .00    .12    .21    .25    .20    .07   -.10   -.26   -.36   -.34   -.20
165  30.3    .00    .00    .00    .19    .34    .39    .32    .14   -.08   -.29   -.41   -.38   -.23
166  30.5    .00    .00    .00    .26    .44    .50    .41    .20   -.06   -.28   -.41   -.39   -.23
167  30.6    .00    .00    .00    .30    .51    .57    .47    .25   -.02   -.25   -.38   -.36   -.22
168  30.8    .00    .00    .00    .32    .54    .61    .50    .28    .03   -.18   -.31   -.31   -.19
169  31.0    .00    .00    .00    .32    .54    .60    .51    .31    .10   -.09   -.21   -.22   -.14
170  31.2    .00    .00    .00    .29    .49    .55    .48    .34    .17    .03   -.09   -.12   -.08
171  31.4    .00    .00    .00    .24    .41    .47    .44    .36    .26    .16    .06    .01   -.01
172  31.6    .00    .00    .00    .18    .31    .37    .39    .37    .35    .30    .21    .14    .07
173  31.8    .00    .00    .00    .10    .19    .26    .33    .39    .44    .44    .37    .27    .14
174  31.9    .00    .00    .00    .02    .07    .15    .27    .40    .52    .56    .51    .39    .21
175  32.1    .00    .00    .00   -.05   -.04    .05    .21    .41    .58    .67    .63    .50    .27
176  32.3    .00    .00    .00   -.11   -.13   -.04    .16    .41    .63    .76    .73    .58    .32
177  32.5    .00    .00    .00   -.14   -.19   -.09    .13    .41    .66    .81    .80    .64    .35
178  32.7    .00    .00    .00   -.15   -.21   -.12    .11    .40    .67    .83    .82    .66    .37
179  32.9    .00    .00    .00   -.14   -.20   -.11    .10    .39    .66    .82    .81    .65    .36
180  33.0    .00    .00    .00   -.11   -.15   -.07    .12    .37    .62    .77    .76    .61    .34
181  33.2    .00    .00    .00   -.06   -.07   -.01    .15    .35    .56    .69    .68    .54    .30
182  33.4    .00    .00    .00    .00    .02    .08    .19    .34    .49    .59    .57    .45    .25
183  33.6    .00    .00    .00    .07    .12    .18    .24    .32    .41    .46    .43    .34    .18
184  33.8    .00    .00    .00    .13    .22    .28    .30    .31    .33    .33    .28    .21    .11
185  34.0    .00    .00    .00    .18    .31    .37    .35    .30    .24    .19    .13    .08    .04
186  34.1    .00    .00    .00    .22    .38    .44    .39    .29    .16    .06   -.02   -.05   -.04
187  34.3    .00    .00    .00    .25    .42    .48    .42    .27    .09   -.06   -.16   -.17   -.10
188  34.5    .00    .00    .00    .25    .44    .50    .42    .25    .04   -.15   -.27   -.26   -.16
189  34.7    .00    .00    .00    .24    .42    .48    .40    .21   -.01   -.22   -.34   -.33   -.20
190  34.9    .00    .00    .00    .22    .37    .42    .35    .17   -.05   -.26   -.39   -.37   -.22
191  35.1    .00    .00    .00    .18    .30    .34    .28    .12   -.08   -.27   -.39   -.38   -.23
192  35.2    .00    .00    .00    .12    .21    .23    .18    .06   -.10   -.26   -.37   -.35   -.21
193  35.4    .00    .00    .00    .07    .10    .10    .06   -.02   -.12   -.23   -.31   -.30   -.18
194  35.6    .00    .00    .00    .00   -.01   -.03   -.06   -.09   -.13   -.18   -.23   -.22   -.13
195  35.8    .00    .00    .00   -.06   -.13   -.17   -.18   -.17   -.14   -.13   -.14   -.12   -.07
196  36.0    .00    .00    .00   -.12   -.23   -.30   -.30   -.24   -.15   -.07   -.04   -.02   -.01
197  36.2    .00    .00    .00   -.18   -.33   -.41   -.40   -.31   -.16   -.02    .05    .08    .05
198  36.3    .00    .00    .00   -.23   -.41   -.50   -.48   -.36   -.16    .02    .13    .16    .11
199  36.5    .00    .00    .00   -.26   -.46   -.56   -.53   -.39   -.16    .06    .19    .22    .15
200  36.7    .00    .00    .00   -.28   -.49   -.59   -.56   -.40   -.16    .07    .22    .26    .17


             TABLE OF EXTREME VALUES FOR PILE AND TIME OF OCCURRENCE
     ELEM.     FMAX          FMIN        MINSTR         MAXSTR        VELMX         DISMX
      NO.      KIPS          KIPS         KSI            KSI          FT/S          INCH
        1    522.3( 29)      .0(  0)      .0(  0)       2.7( 29)    11.56( 73)    3.426(272)
        2    524.2( 31)  -115.4( 69)     -.6( 69)       2.7( 31)    10.58( 73)    3.425(272)
        3    522.4( 33)  -196.7( 68)    -1.0( 68)       2.7( 33)     9.21( 78)    3.424(272)
        4    521.9( 35)  -234.0( 67)    -1.2( 67)       2.7( 35)     9.89( 82)    3.423(272)
```

FORM 6: CONTINUED

```
  5   522.1( 37)  -215.6( 66)    -1.1( 66)      2.7( 37)   10.34( 83)    3.421(272)
  6   523.0( 39)  -140.6( 66)     -.7( 66)      2.7( 39)   11.04( 61)    3.418(272)
  7   523.1( 41)   -54.1( 76)     -.3( 76)      2.7( 41)   11.13( 61)    3.415(272)
  8   508.8( 42)  -110.7( 76)     -.6( 76)      2.6( 42)   10.60( 59)    3.412(272)
  9   458.3( 44)  -168.4( 56)     -.9( 56)      2.3( 44)    9.85( 56)    3.408(272)
 10   356.0( 44)  -181.7( 56)     -.9( 56)      1.8( 44)   11.40( 51)    3.406(272)
 11   197.9( 45)  -115.3( 56)     -.6( 56)      1.0( 45)   12.55( 51)    3.405(272)
       THE MAXIMUM TRANSFERRED ENERGY (ENTHRU) WAS  14.2 K-FT
```

```
      EXAMPLE 7.3 TENSION STRESS CHECK  3-PLY

                          SUMMARY

NO     R ULT   BLOW CT     STROKE  MIN STR    MAX  STR
       TONS     1/FT         FT      KSI        KSI
 1     10.0        4.      3.06     -1.19      2.67
```

FORM 6: CONTINUED

```
                W E A P  -  WAVE EQUATION ANALYSIS FOR PILES

          THIS PROGRAM WAS PREPARED FOR THE FEDERAL HIGHWAY ADMINISTRATION
                    BY GOBLE & ASSOCIATES, CLEVELAND, OHIO

          EXAMPLE 7.3 TENSION STRESS CHECK 6-PLY
                      PILE DESCRIPTION

 X BEL. TOP (FT)        .0     50.0
 A (SQ. IN.)         196.0    196.0
 E (KSI)             5000.    5000.
 GAMMA (LB/CU FT)    150.0    150.0
 STROKE (EQUIV.) 3.1 FT, EFFICIENCY  .80 , IMPACT VELOCITY 12.5 FT/S
 ACTUAL/ MAX. PRESSURE 120.0/ 120.0 PSI, REACT./RAM WEIGHT   9.8/   8.0 KIPS


                 HAMMER MODEL VULC.80C
      ELEMENT      WEIGHT  STIFFNESS    COEFF.
      NUMBER       (KIPS)   (K/IN)    RESTITUTION
        1          8.000
       CAP         1.500   10000.0        .800
      CUSHION               1680.0        .500
     PILE TOP                            1.000




             EXAMPLE 7.3 TENSION STRESS CHECK 6-PLY

                               SUMMARY

   NO      R ULT    BLOW CT     STROKE   MIN STR    MAX  STR
           TONS      1/FT         FT       KSI         KSI
    1      10.0         4.       3.06      -.62        2.10
```

FORM 7: OUTPUT, EXAMPLE 7.3; 6-PLY
(ONLY FIRST AND LAST PAGE ARE INCLUDED)

7.4 Hypothetical Hammer Input

7.4.1 Situation

A contractor has decided to build his own hammer. He supplied the data as used in Input Sample 5.4. A pile with 12 3/4 inch OD pipe with 1/4 inch wall thichness has to be driven to 90 ton ultimate capacity. The length of the pile is 60 feet including a one inch toe plate.

7.4.2 Problem

Determine whether this new hammer will drive the pile assuming that the 90 ton resistance will be reached at a depth of 50 feet where the otherwise loose sand becomes dense.

7.4.3 Solution

Since the hammer being analyzed is not contained in the data file the Complete Input Form must be used. A sketch is made of the assumed skin friction distribution on Page 3 of the input form

Card No. 2.000	IOUT = 0 for minimum output IHAMR = 0, hammer data to be input NCROSS = 1 nonuniform pile (toe plate) IPERCS = 10 (loose sand on skin, dense sand at toe)
Card No. 3.000	Wt. Cap = .95 kips Stiff. Cap = 21000 kips/inch Stiff. Cushion = leave blank (no cushion)
Card No. 4.000	C.O.R. of Anvil = 0.8 of Cap = 0.8 of Pile Top = 0.8

Card No. 5.000	L Pile = 60.0 feet A Pile Top = $9.82 = (12.75-0.25)\pi(0.25)$ inch^2 E Pile Top = 30000 ksi W Pile Top = 492 lbs/cu.ft.
Card No. 5.101,...	The pile is uniform until the end plate, so only three cards are required to specify the discontinuity and cross sectional area of the end plate ($12.75^2\pi/4 = 127.7$ inch^2).
Card No. 5.201 through 5.205	Since IHAMR was set to 0, the next 5 cards must be input. The data is as in 5.4
Card No. 6.000	Quakes = 0.1 Skin Damping = 0.3 Toe Damping = 0.15 RULT = 90 tons Stroke = 6.0 feet - assumed stroke is input as a starting value.
Card No. 6.401,...	The skin resistance distribution was based on SPT values of 2, between grade and 20 feet depth, 4 between 30 and 40 feet depth, and values increasing to 6 just above the dense sand. Note that these SPT readings could have been inserted directly in the % Soil Res. column with no difference in the resulting resistance distribution. The input is listed in Form 8. The corresponding output is reproduced in Form 9.

7.4.4 Discussion of Results

The summary found on the last page of the output shows all the important information. With RULT = 90, the blowcount is 28, or 2.3 blows per inch. The stroke is 6.0 feet as assumed. The maximum stress is almost 27 ksi. The hammer is running at a speed of 48 blows per minute, driving the pile at a rate of 1.7 feet per minute. It can be concluded that this hammer would be a reasonable choice for driving the pile.

WAVE EQUATION ANALYSIS for PILES Complete Input Form, page 1

12345678901234567890123456789012345678901234567890123456789012345678901234567890

Title (40 characters)

1.000 EXAMPLE 7.4 HYPOTHETICAL HAMMER IMPCT

	IOUT	IJJ	IHAMR	IOSTR	IFUEL	IPEL	N	ISPL No. of Splices	NCROSS 0 = Uniform	IBEDAM	IPERCS	ISMITH 1=Smith	ITYS	IPHI
2.000									1		10			

If IPEL = 2
ST(I), I = 1,2,...,N (Pile Segment Stiffnesses - k/in)

2.101
.
.
2.110

If IPEL = 2
P(I), I= 1,2,...,N (Pile Segment Weights - kips)

2.201
.
.
2.210

If IPEL > 0
ALPH(I), I = 1,2,...,N (Relative Lengths of Pile Segments)

2.301
.
.
2.310

	Wt. Cap (kips)	Cap and Cushion Stiff. Cap (K/in)	Stiff. Cushion (K/in)
3.000	.95	21000.	

Coefficients of Restitution

	Anvil (Diesel) Cap (Air/Steam)	Cap (Diesel) Assembly(A/S)	Pile Top	Cushion	TEMAX (msec.)	TDEL (sec.)
4.000	.8	.8	.8			

FORM 8: INPUT EXAMPLE 7.4

WAVE EQUATION ANALYSIS for PILES Complete Input Form, page 2

	L pile (ft)	A pile top (in²)	E pile top (ksi)	W pile top (lbs/ft³)
5.000	60.	9.82	30000.	492.

If NCROSS = 1 and IPEL ≠ 2 only

	XPi (ft)	APi (ft)	EPi (ksi)	WPi (lbs/ft³)
5.101	59.92	9.82		
5.102	59.92	127.7		
.	60.	127.7		
.				
.				
5.119				

Hammer Information (if IHAMR = 0 only)

	NAME	HM(1) (kips)	STH(1) (k/in)	HM(2) (kips)	STH(2) (k/in)	HM(3) (kips)	STH(3) (k/in)	HM(4) (kips)	STH(4) (k/in)	HM(5) (kips)
5.201	HYPOTHET	.917	116000.	.917	116000.	.917				

Hammer Information (if IHAMR = 0 only)

	STH(5) (k/in)	HM(6) (kips)	STH(6) (k/in)	HM(7) (kips)	M	HM(M+1)(kips)	STH(M) (k/in)	TDEL (sec)
5.202					3.001	.81	72700.	.002

Hammer Information (if IHAMR = 0 only)

	VFIN (in³)	DEPIB (in)	ARAM (in²)	P1 (psi)	P2 (psi)	P3 (psi)	P4 (psi)	P5 (psi)	EFFICY	STRM (in)
5.203	120.	10.76	122.72	1150.						102.

Hammer Information (if IHAMR = 0 only)

	EXPP	ART (ft²)	DEPPB (ft)	DSP (ft)	DBBT (ft)	POWSCA (1)	RWH (kips)	EXPB	DINJ (ft)	VCT (ft³)
5.204	1.3									

Hammer Information (if IHAMR = 0 only)

	RAM (kips)	AM(1) (kips)	STA(1) (k/in)	AM(2) (kips)	STA(2) (k/in)	AM(3) (kips)	STA(3) (k/in)	MA	ITTPH
5.205									1.001

	Quake Skin (in)	Quake Toe (in)	Damping Skin*	Damping Toe*	RULT (tons)	Coeff. of Rest. of Soil	Stroke (ft)	Hammer Efficiency	Steam Pressure (psi)	Reaction wt. (kips)
6.000	.1	.1	.3	.15	90.		6.			

*Damping Parameters - sec/ft for Smith; Dimensionless for Case

FORM 8: CONTINUED

WAVE EQUATION ANALYSIS for PILES Complete Input Form, page 3

If ITYS <-1
Q'(I), I = 1,2,...,N+1 (Quakes - in.)

6.101
.
.
6.110

If ITYS < 0
SJ(I) , I = 1,2,...,N+1 (Damping Parameters - sec/ft for Smith; Dimensionless for Case)

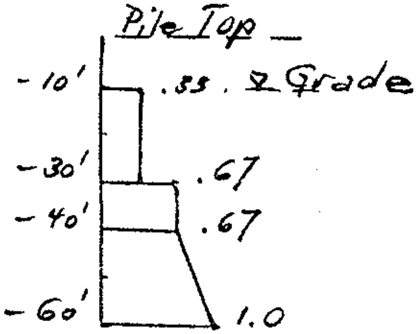
6.201
.
.
6.210

If ITYS < -1
SU(I), I = 1,2,...,N+1 (Relative Ultimate Soil Resistances)

6.301
.
.
6.310

If ITYS = 0 or -1 only

	XPi (ft)	% Soil Res.
6.401	0.	0.
6.402	10.	0.
.	10.	0.33
.	30.	0.33
.	30.	0.6
6.420	40.	0.6
	60.	1.0



If ISPL > 0 only
No. J SPLICE(J)(kips) or Slack in feet

6.501
.
.
6.598

Note: Splice force = 0.0 kips or less than -0.5 kips.
Slack between -0.5 and 0.0 feet.
Both Splice and Slack are to be given as negative numbers.

FORM 8: CONTINUED

WAVE EQUATION ANALYSIS for PILES Complete Input Form, page 4

If IOUT > 9
Plotter Scale
YMAX

7.000 For dimension of scale see Input Information

If IOUT > 9 only
ISPG(I), I = 1,2,...,15 (Plotted Variables)

8.000

If RULT < 0 only:
Ultimate Resistance - tons (at most 10 values)

9.000

If IJJ > 0
INP(J), I = 1,2,...,13 (Printed Variables)

9.101

1 2 3 4 5 6 7 8 9 10 1 2 3 4 5 6 7 8 9 20 1 2 3 4 5 6 7 8 9 30 1 2 3 4 5 6 7 8 9 40 1 2 3 4 5 6 7 8 9 50 1 2 3 4 5 6 7 8 9 60 1 2 3 4 5 6 7 8 9 70 1 2 3 4 5 6 7 8 9 80

FORM 8: CONTINUED

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                    W E A P  -  WAVE EQUATION ANALYSIS FOR PILES

              THIS PROGRAM WAS PREPARED FOR THE FEDERAL HIGHWAY ADMINISTRATION
                    BY GOBLE & ASSOCIATES, CLEVELAND, OHIO

              EXAMPLE 7.4 HYPOTHETICAL HAMMER INPUT
                    PILE DESCRIPTION

         X BEL. TOP (FT)        .0     59.9     59.9     60.0
         A (SQ. IN.)           9.8      9.8    127.7    127.7
         E (KSI)            30000.   30000.   30000.   30000.
         GAMMA (LB/CU FT)    492.0    492.0    492.0    492.0


                  HAMMER MODEL HYPOTHET
            ELEMENT      WEIGHT  STIFFNESS     COEFF.
            NUMBER       (KIPS)   (K/IN)    RESTITUTION
               1          .917
               2          .917  116000.0
               3          .917  116000.0
            ANVIL         .810   72700.0       .800
             CAP          .950   21000.0       .800
            CUSHION                   .0      1.000
           PILE TOP                            .800
```

FORM 9: OUTPUT, EXAMPLE 7.4

```
                       PILE PROPERTIES

PILE LENGTH=  60. FT., AREA(AT TOP)=   9.8 S-IN
E. MODUL(AT TOP)=30000. KSI., SPEC. WT.(AT TOp)= 492. LBS/CU FT

     WEIGHT STIFFN.  PDAMP.  SPLICE  SOIL-S  SOIL-D   QUAKE  L.B.T.
NO.  (KIPS)  (K/IN) (KS/FT)  (KIPS)  (PCT.) (KS/FT)   (IN.)  (FT.)
  1    .155   5319.     .35      0.    .000    .000    .100    4.6
  2    .155   5319.     .35  -5000.    .000    .000    .100    9.2
  3    .155   5319.     .35  -5000.    .004    .222    .100   13.8
  4    .155   5319.     .35  -5000.    .005    .267    .100   18.5
  5    .155   5319.     .35  -5000.    .005    .267    .100   23.1
  6    .155   5319.     .35  -5000.    .005    .267    .100   27.7
  7    .155   5319.     .35  -5000.    .008    .405    .100   32.3
  8    .155   5319.     .35  -5000.    .010    .542    .100   36.9
  9    .155   5319.     .35  -5000.    .010    .545    .100   41.5
 10    .155   5319.     .35  -5000.    .011    .593    .100   46.2
 11    .155   5319.     .35  -5000.    .012    .655    .100   50.8
 12    .155   5319.     .35  -5000.    .014    .717    .100   55.4
 13    .187   5406.     .39  -5000.    .015    .862    .100   60.0
TOE                                    .900   2.913    .100

COEFFICIENT OF RESTITUTION OF SOIL    1.000

                OPTIONS AND SPECIFICATIONS
PHI    1.40     S-DAMPING     VIScOUS    RWT (KIPS)          .00
IOUT     0      P-DAMPING           1    SOIL DIST. NO.        0
IFUEL    1      J SKIN            .30    TDEL (SEC.)       .0000
IOSTR    0      J TOE             .15    TEMAX (MS)          .00
                EFFICIENCY       .950
                TIME INCR. (MS)  .102
```

FORM 9: CONTINUED

```
                         RULT=   90.0, AT TOE=   81.0 TONS
                         --------------------------------



        TABLE OF EXTREME VALUES FOR PILE AND TIME OF OCCURRENCE
ELEM.   FMAX          FMIN       MINSTR        MAXSTR        VELMX        DISMX
 NO.    KIPS          KIPS         KSI           KSI          FT/S         INCH
   1   258.3( 26)      .0(  0)      .0(  0)     26.3( 26)    13.39( 28)   .861(130)
   2   258.6( 28)      .0(  0)      .0(  0)     26.3( 28)    13.44( 30)   .836(130)
   3   263.7( 32)      .0(  0)      .0(  0)     26.9( 32)    13.18( 32)   .810(130)
   4   262.5( 34)      .0(  0)      .0(  0)     26.7( 34)    13.23( 36)   .782(132)
   5   261.3( 38)      .0(  0)      .0(  0)     26.6( 38)    13.02( 38)   .755(136)
   6   261.1( 40)      .0(  0)      .0(  0)     26.6( 40)    12.84( 42)   .730(138)
   7   259.3( 44)      .0(  0)      .0(  0)     26.4( 44)    12.63( 44)   .703(140)
   8   259.7( 46)      .0(  0)      .0(  0)     26.4( 46)    12.22( 48)   .675(142)
   9   254.3( 48)      .0(  0)      .0(  0)     25.9( 48)    12.03( 50)   .645(144)
  10   253.4( 52)      .0(  0)      .0(  0)     25.8( 52)    11.61( 52)   .613(146)
  11   250.0( 54)      .0(  0)      .0(  0)     25.5( 54)    11.30( 56)   .586(132)
  12   243.0( 58)      .0(  0)      .0(  0)     24.7( 58)    11.18( 58)   .557(134)
  13   235.1( 60)      .0(  0)      .0(  0)     19.8( 60)    11.70( 62)   .528(134)

        THE MAXIMUM TRANSFERRED ENERGY (ENTHRU) WAS  11.9 K-FT

        STROKES ANALYZED AND LAST RETURN (FT)   6.0   6.0
```

FORM 9: CONTINUED

```
          EXAMPLE 7.4 HYPOTHETICAL HAMMER INpUT

                          SUMMARY

NO      R ULT   BLOW CT     STROKE  MIN STR   MAX   STR    BLOWS/
        TONS     1/FT         FT       KSI         KSI    MINUTE
 1       90.0       28.      6.00        .00     26.85      48.0
```

FORM 9: CONTINUED

7.5 Pile Segment and Damping Input

7.5.1 Situation

A timber pile, (See also Figure 7 for details) has to be driven through a soil of stratified clay and sand to a dense gravel layer. The timber pile has a length of 36 feet and 2 inch. Its cross sectional area varies from 128.7 at the top to 56.2 (square inches) at the bottom. It has to be driven by a Link Belt 440 hammer.

A soils investigation resulted in the following data: At a depth of 25 feet and 8 inches the pile point will have penetrated into the gravel such that a total ultimate bearing of 75 tons (90% at the toe) is obtained. The Smith damping factors are 0.15 sec/ft in the sand and in the gravel (toe) and 0.20 sec/ft in the clay .

7.5.2 Problem

The hammer should be run at a bounce chamber pressure of 15 psi (gauge) to avoid pile damage. To what blow count must the pile be driven to insure the 75 ton bearing capacity?

7.5.3 Solution

The Complete Input Form must be used since the damping factors are different along the pile skin. For the purpose of demonstration only, the element masses and stiffnesses are also calculated and input in the Complete Form. They can be determined automatically in this case.

Form 10 lists the input parameters. They are:

WAVE EQUATION ANALYSIS for PILES Complete Input Form, page 1

12345678901234567890123456789012345678901234567890123456789012345678901234567890

Title (40 characters)

1.000 EXAMPLE 7.5 PILE SEGMENT+ DAMPING INPUT

	IOUT	IJJ	IHAMR	IOSTR	IFUEL	IPEL	N	ISPL No. of Splices	NCROSS 0 = Uniform	IBEDAM	IPERCS	ISMITH 1=Smith	ITYS	IPHI
2.000			37	-1		2	12		1	5	10	1	-1	

If IPEL = 2
ST(I), I = 1,2,...,N (Pile Segment Stiffnesses - k/in)

2.101	6592.	6557.	6176.	5800.	5445.	5100.	4764.	4440.	4128.	3823.
.	3534.	3257.								
.										
2.110										

If IPEL = 2
PW(I), I= 1,2,...,N (Pile Segment Weights - kips)

2.201	.142	.126	.118	.111	.104	.098	.091	.085	.079	.073
.	.068	.065								
.										
2.210										

If IPEL > 0
ALFH(I), I = 1,2,...,N (Relative Lengths of Pile Segments)

2.301	3.176	3.0	3.	3.	3.	3.	3.	3.	3.	3.
.	3.	3.0								
.										
2.310										

Cap and Cushion

	Wt. Cap (kips)	Stiff. Cap (K/in)	Stiff. Cushion (K/in)
3.000	.7	30000.	

Coefficients of Restitution

	Anvil (Diesel) Cap (Air/Steam)	Cap (Diesel) Assembly(A/S)	Pile Top	Cushion	TEMAX (msec.)	TDEL (sec.)
4.000		.8	.5			

FORM 10: INPUT; EXAMPLE 7.5

WAVE EQUATION ANALYSIS for PILES Complete Input Form, page 2

	L pile (ft)	A pile top (in²)	E pile top (ksi)	W pile top (lbs/ft³)
5.000	36.167	128.67	2000.	51.

If NCROSS = 1 and IPEL ≠ 2 only

	XP₁ (ft)	AP₁ (ft)	EP₁ (ksi)	WP₁ (lbs/ft³)
5.101	.167	128.67		
5.102	7.	112.65		
.	14.	97.33		
.	21.	83.13		
.	28.	70.04		
5.119	36.167	56.2		

Hammer Information (if IHAMR = 0 only)

	RATE	AM(1) (kips)	STH(1) (k/in)	HM(2) (kips)	STH(2) (k/in)	HM(3) (kips)	STH(3) (k/in)	HM(4) (kips)	STH(4) (k/in)	HM(5) (kips)
5.201										

Hammer Information (if IHAMR = 0 only)

	STH(5) (k/in)	HM(6) (kips)	STH(6) (k/in)	HM(7) (kips)	M	HM(M+1)(kips)	STH(M) (k/in)	TDEL (sec)
5.202								

Hammer Information (if IHAMR = 0 only)

	VRAM (in³)	DEPIP (in)	ARAM (in²)	P1 (psi)	P2 (psi)	P3 (psi)	P4 (psi)	P5 (psi)	EFFICY	STRM (in)
5.203										

Hammer Information (if IHAMR = 0 only)

	EXPP	ART (ft²)	DEPPB (ft)	DSP (ft)	DBBT (ft)	POWSCA (1)	RWH (kips)	EXPB	DINJ (ft)	VCT (ft³)
5.204										

Hammer Information (if IHAMR = 0 only)

	RAM (kips)	AM(1) (kips)	STA(1) (k/in)	AM(2) (kips)	STA(2) (k/in)	AM(3) (kips)	STA(3) (k/in)	MA	ITYPH
5.205									

	Quake Skin (in)	Quake Toe (in)	Damping Skin*	Damping Toe*	RULT (tons)	Coeff. of Rest. of Soil	Stroke (ft)	Hammer Efficiency	Steam Pressure (psi)	Reaction wt. (kips)
6.000	.1	.1			75.		2.65			

*Damping Parameters - sec/ft for Smith; Dimensionless for Case

FORM 10: CONTINUED

WAVE EQUATION ANALYSIS for PILES Complete Input Form, page 3

If ITYS <-1
Q(I), I = 1,2,...,N+1 (Quakes - in.)

6.101
.
.
6.110

If ITYS < 0
SJ(I) , I = 1,2,...,N+1 (Damping Parameters - sec/ft for Smith; Dimensionless for Case)

6.201	0.	0.	0.	.05	.2	.2	.05	.2	.2	.05
	.05	.05	0.05							
.										
.										
6.210										

If ITYS <-1
SU(I), I = 1,2,...,N+1 (Relative Ultimate Soil Resistances)

6.301
.
.
6.310

If ITYS = 0 or -1 only

	XP_i (ft)	% Soil Res.
6.401	0.	0.
6.402	10.5	0.
.	10.5	1.
.	36.167	1.
.		
6.420		

If ISPL > 0 only
SPLICE(J)(kips) or
No. J Slack in feet

6.501
.
.
6.598

Note: Splice force = 0.0 kips or less than -0.5 kips.
Slack between -0.5 and 0.0 feet.
Both Splice and Slack are to be given as negative numbers.

FORM 10: CONTINUED

WAVE EQUATION ANALYSIS for PILES Complete Input Form, page 4

If IOUT > 9
Plotter Scale
YMAX

7.000 ☐☐☐☐☐☐☐☐ For dimension of scale see Input Information

If IOUT > 9 only
ISEG(I), I = 1,21...,15 (Plotted Variables)

8.000

If RULT < 0 only:
Ultimate Resistance - tons (at most 10 values)

9.000

If IJJ > 0
INP(I), I = 1,2,...,13 (Printed Variables)

9.101

1 2 3 4 5 6 7 8 9 10 1 2 3 4 5 6 7 8 9 20 1 2 3 4 5 6 7 8 9 30 1 2 3 4 5 6 7 8 9 40 1 2 3 4 5 6 7 8 9 50 1 2 3 4 5 6 7 8 9 60 1 2 3 4 5 6 7 8 9 70 1 2 3 4 5 6 7 8 9 80

FORM 10: CONTINUED

Card No. 1.000 A Title

Card No. 2.000

IOUT = 0 for minimum output
IHAMR = 37 according to Table 2
IOSTR = -1 to effect a constant stroke analysis
IPEL = 2 to allow the input of element masses and stiffnesses
N = 12 Because of IPEL ≠ 0 a choice of the number of elements had to be made. N = 12 results in segments of approximately 3 feet length which is a length much smaller than necessary
NCROSS = 1 The pile is non-uniform
IBEDAM = 5 Pile Damping for Timber
IPERCS = 10 According to the soil investigation
ISMITH = 1 As specified in 7.5.1
ITYS = -1 To allow the input of damping parameters. for individual elements.

Cards No. 2.101, 2.102 Pile Segment stiffnesses, STP(I), for I = 1, ... ,12. They are computed using the formula

$$STP(I) = \frac{\overline{AP}(I)\ \overline{EP}(I)}{ALPH(I)\ (L)}$$

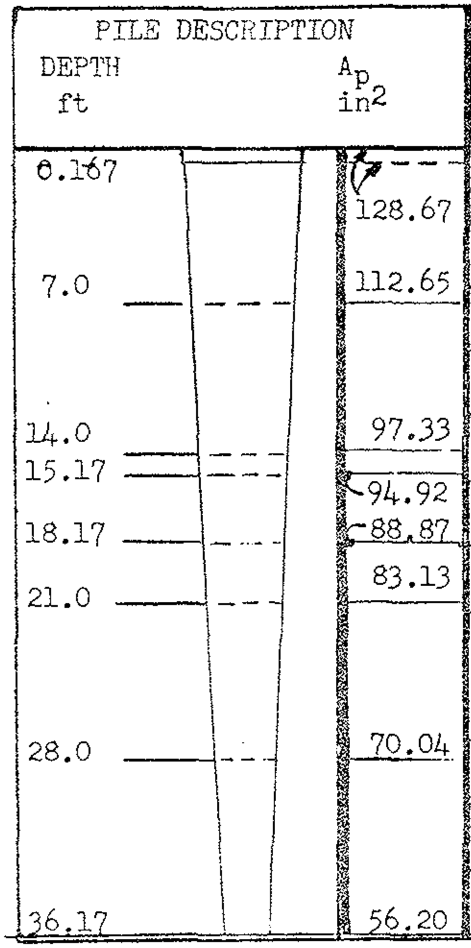
where $\overline{AP}(I)$ is the average pile cross sectional area, $\overline{EP}(I)$ is the average elastic modulus, both averages are to be taken over the element length ALPH(I) (L); ALPH(I) is the normalized, relative element length of the I-th segment and L is the total pile length. (See Figure 7 for a sample calculation).

Cards No. 2.201, 2.202 Pile Segment Weights, PM(I), for I = 1, ... ,12. They are computed using the formula

$$PM(I) = \overline{AP}(I)\ \overline{WP}(I)\ ALPH(I)\ \ (L)$$

where $\overline{WP}(I)$ is the average specific weight of the pile material over the segment length (See Figure 7 for a sample calculation).

Cards No. 2.301, 2.302 Relative Length values of pile segments, ALPH(I) for I = 1, ... ,12. It was convenient to use the



STIFFN. kips/in	PILE MODEL WEIGHT kips	SEGMT. No.	DEPTH below top feet		SOIL PROFILE	DAMPING J sec/ft	STATIC % Soil Res.
6592	.142	1	3.167			0.0	
6557	.126	2	6.167			0.0	
6176	.118	3	9.167	10.5	GRADE	0.0	1.0
5800	.111	4	12.17	13.0	SAND	0.05	
5445	.104	5	15.17		CLAY	0.20	
5100	.098	6	18.17	18.2		0.20	
4764	.091	7	21.17	21.2	SAND	0.05	
4440	.085	8	24.17		CLAY	0.20	
4128	.079	9	27.17	27.2		0.20	
3823	.073	10	30.17		SAND	0.05	
3534	.068	11	33.17			0.05	
3257	.065	12	36.16	36.2		0.05	1.0
					TOE:	0.05	

EXAMPLE CALCULATION: $STP(6) = \frac{2000(94.92+88.87)}{2\ (3.0)\ 12} = 5100$ kips/inch

$$PM(6) = \frac{94.92 + 88.87}{2\ (144)\ 1000}\ 51\ (3.0) = .098 \text{ kips}$$

FIGURE 7: DETAILS OF EXAMPLE 7.5

actual element lengths. (Note that the input could have been simplified, since equal and consecutive values need not be repeated).

Card No. 3.000	Weight of Cap = .7 kips (assumed) Stiffness of Cap = 30000 kips/inch (assumed) Cushion Stiffness = blank (no cushion)
Card No. 4.000	Coefficients of restitution Cap = 0.8 Pile Top = 0.5 (timber) Other C.O.R.'s are left blank for computer determination.
Card No. 5.000	L Pile = 36.167 feet A Pile Top = 128.67 inch^2 E Pile Top = 2000 ksi W Pile Top = 51 lbs/ft^3 Note, these values have to be provided although the element masses and stiffnesses are specified. The program utilizes these values for printing and for stress calculations.
Card No. 5.101, and 5.102, ...	The pile geometry is input on these cards according to Figure 7. The note of card 5.000 is applicable.
Card No. 6.000	Quakes = 0.1 inch Skin and Toe damping values are left blank (Damping has to be specified on cards No. 6.201 and 6.202). RULT = 75 tons Stroke = 2.63 feet (for 15.0 psi bounce chamber pressure, see Table 1).
Cards No. 6.201, and 6.202	N+1 = 13 damping parameters are given as shown in figure 7. The 13th value is the toe damping factor.
Card No. 6.401, and 6.402, ...	A uniform skin friction distribution is specified as shown in Figure 7.

The output is reproduced in Form 11.

```
                  W E A P  -  WAVE EQUATION ANALYSIS FOR PILES

        THIS PROGRAM WAS PREPARED FOR THE FEDERAL HIGHWAY ADMINISTRATION
                      BY GOBLE & ASSOCIATES, CLEVELAND, OHIO

        EXAMPLE 7.5 PILE SEGMENT + DAMPING INPUT
                    PILE DESCRIPTION

X BEL. TOP (FT)       .0       .2      7.0     14.0     21.0     28.0     36.2
A (SQ. IN.)        128.7    128.7    112.6     97.3     83.1     70.0     56.2
E (KSI)            2000.    2000.    2000.    2000.    2000.    2000.    2000.
GAMMA (LB/CU FT)    51.0     51.0     51.0     51.0     51.0     51.0     51.0


               HAMMER MODEL LB   440
      ELEMENT     WEIGHT  STIFFNESS    COEFF.
      NUMBER      (KIPS)   (K/IN)   RESTITUTION
         1         2.106
         2          .987  235000.0
         3          .943  111000.0
       ANVIL       1.160   70000.0        .850
        CAP         .700   30000.0        .800
       CUSHION                  .0       1.000
      PILE TOP                            .500
```

FORM 11: OUTPUT, EXAMPLE 7.5

```
                        PILE PROPERTIES

 PILE LENGTH=  36. FT., AREA(AT TOP)= 128.7 S-IN
 E. MODUL(AT TOP)= 2000. KSI., SPEC. WT.(AT TOP)=  51. LBS/CU FT

      WEIGHT STIFFN.  PDAMP.  SPLICE  SOIL-S  SOIL-D   QUAKE  L.B.T.
 NO.  (KIPS)  (K/IN) (KS/FT)  (KIPS)  (PCT.)  (S/FT)   (IN.)   (FT.)
   1    .142   6592.    1.87      0.    .000    .000    .100     3.2
   2    .126   6557.    1.76  -5000.    .000    .000    .100     6.2
   3    .118   6176.    1.65  -5000.    .000    .000    .100     9.2
   4    .111   5800.    1.55  -5000.    .006    .050    .100    12.2
   5    .104   5445.    1.45  -5000.    .012    .200    .100    15.2
   6    .098   5100.    1.37  -5000.    .012    .200    .100    18.2
   7    .091   4764.    1.27  -5000.    .012    .050    .100    21.2
   8    .085   4440.    1.19  -5000.    .012    .200    .100    24.2
   9    .079   4128.    1.10  -5000.    .012    .200    .100    27.2
  10    .073   3823.    1.02  -5000.    .012    .050    .100    30.2
  11    .068   3534.     .95  -5000.    .012    .050    .100    33.2
  12    .065   3257.     .89  -5000.    .012    .050    .100    36.2
 TOE                                    .900    .050    .100

 COEFFICIENT OF RESTITUTION OF SOIL    1.000

                OPTIONS AND SPECIFICATIONS
PHI    1.40   S-DAMPING     SMITH    RWT (KIPS)        5.21
IOUT      0   P-DAMPING         5    SOIL DIST. NO.       0
IFUEL     1   J SKIN          .00    TDEL (SEC.)      .0000
IOSTR    -1   J TOE           .15    TEMAX (MS)         .00
              EFFICIENCY     .950
              TIME INCR. (MS) .075
```

FORM 11: CONTINUED

```
                    RULT=   75.0, AT TOE=   67.5 TONS
                    ------------------------------


          TABLE OF EXTREME VALUES FOR PILE AND TIME OF OCCURRENCE
ELEM.     FMAX          FMIN          MINSTR        MAXSTR        VELMX         DISMX
 NO.      KIPS          KIPS           KSI           KSI          FT/S          INCH
   1    153.6(242)       .0(   0)       .0(   0)     1.2(242)     6.26(164)     .581(268)
   2    154.8(246)       .0(   0)       .0(   0)     1.2(246)     6.26(168)     .560(270)
   3    155.7(248)       .0(   0)       .0(   0)     1.2(248)     6.26(170)     .538(272)
   4    155.9(250)       .0(   0)       .0(   0)     1.4(250)     6.21(172)     .513(274)
   5    157.9(220)       .0(   0)       .0(   0)     1.4(220)     6.17(176)     .487(276)
   6    162.4(216)       .0(   0)       .0(   0)     1.7(216)     6.09(178)     .459(278)
   7    165.3(214)       .0(   0)       .0(   0)     1.7(214)     6.01(182)     .429(282)
   8    164.9(212)       .0(   0)       .0(   0)     2.0(212)     5.86(184)     .398(284)
   9    160.9(212)       .0(   0)       .0(   0)     1.9(212)     5.58(186)     .364(288)
  10    158.9(220)       .0(   0)       .0(   0)     1.9(220)     5.08(188)     .328(290)
  11    157.7(200)       .0(   0)       .0(   0)     2.3(200)     4.20(190)     .289(292)
  12    159.4(198)       .0(   0)       .0(   0)     2.3(198)     3.12(200)     .248(296)

          THE MAXIMUM TRANSFERRED ENERGY (ENTHRU) WAS   4.8 K-FT

          RETURNED STROKES AND STROKE ANALYZED, (FT)   3.1   2.7   2.6   2.6
           TOTAL PRESSURE CHANGE -22.6 %
```

FORM 11: CONTINUED

```
          EXAMPLE 7.5 PILE SEGMENT + DAMPING INPUT

                         SUMMARY

 NO     R ULT    BLOW CT     STROKE  MIN STR    MAX  STR     BLOWS/  B.C. PR.
        TONS      1/FT         FT      KSI          KSI      MINUTE      PSI
  1      75.0       81.       2.63(2)    .00         2.28       82.6      14.7
```

FORM 11: CONTINUED

7.5.4 Discussion of Results

The relatively complicated input should be checked by comparing Figure 7 with the pile model table on the second page of the output. The skin and toe damping parameters in the "Options and Specifications" output are zero since they were not specified on Card No. 6.000.

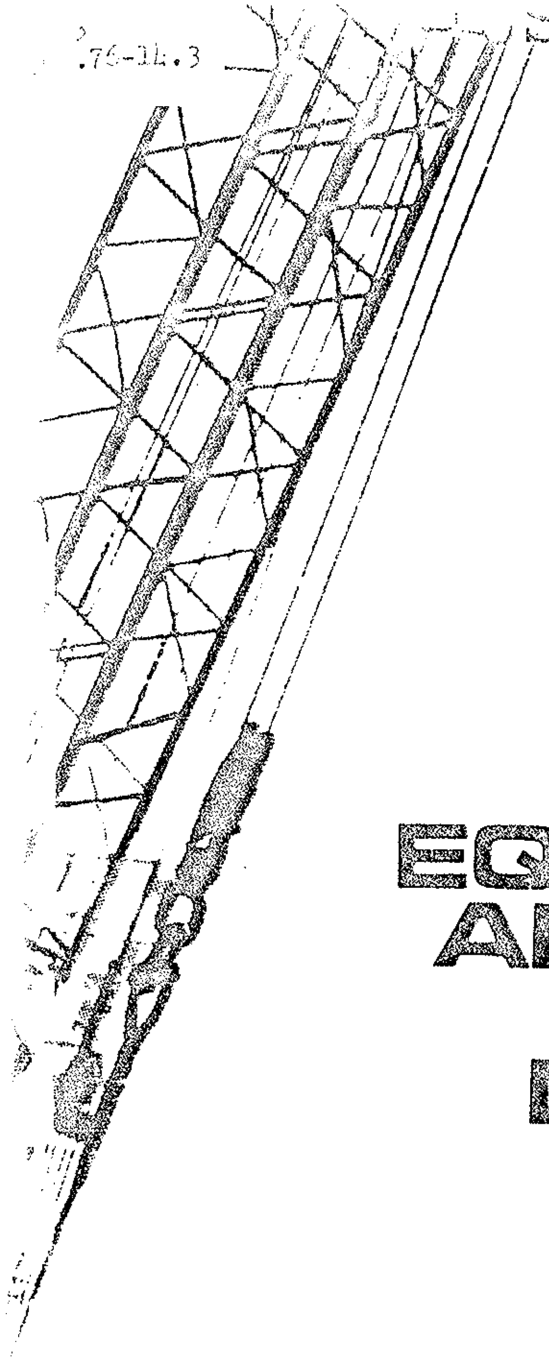
The summary output shows that a blow count of 83 blows per foot will drive the pile to 75 tons capacity if the hammer runs at 15 psi bounce chamber pressure. The summary lists B.C.P. as 14.2 psi which was the bounce chamber pressure on the last return stroke. The corresponding stroke was considered sufficiently accurate and no additional analysis was performed to obtain better agreement.

The concentrated toe resistance resulted in a relatively high stress of 2.3 ksi. Actually this stress is higher yet however, the area of the bottom element was only roughly approximated by the area specification just above the bottom (70.04 inch^2). A better job of stress computation is done by the computer if element masses and stiffnesses are automatically determined. The reader is encouraged to rerun this problem with IPEL = 0 and correspondingly no input on Cards No. 2.101 to 2.302.

METRIC CONVERSION FACTORS

To Convert	To	Multiply By
pounds (lbm)	kilograms (kg)	0.4535924
pounds force (lb)	newtons (N)	4.4482219
kips (1000lb)	kilonewtons (kN)	4.4482219
inches (in.)	centimeters (cm)	2.54
feet (ft)	meters (m)	0.3048
feet per second (fps)	meters per second (m/sec)	0.3048
foot-pounds (ft-lb)	newton-meters (N'm)	0.355818
foot-pounds (ft-lb)	joules (J)	1.355818
Pounds per foot (lb/ft)	kilograms per meter (kg/m)	1.488164
Acceleration of gravity (g)	meters per second squared (m/s^2)	9.806650
Acceleration of gravity (g)	feet per second squared (ft/sec^2)	32.17405
kip-inches (kip-in.)	newton-meters (N m)	112.9848
degrees Centigrade	degrees Fahrenheit	1.8 and aaa 32

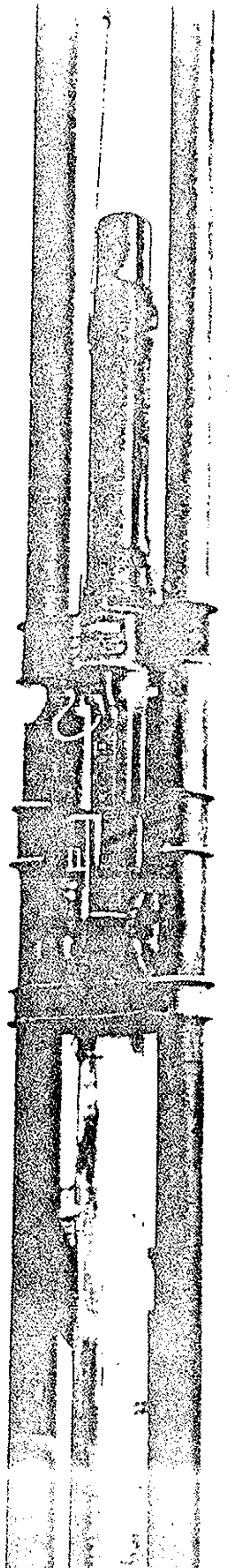
*U.S. GOVERNMENT PRINTING OFFICE : 1978 0-734-754 [illegible]



76-14.3

Implementation Package

WAVE EQUATION ANALYSIS OF PILE DRIVING



WEAP PROGRAM

Volume III — Program Documentation

U.S. DEPARTMENT OF TRANSPORTATION
Federal Highway Administration
Offices of Research and Development
Implementation Division
Washington, D.C. 20590

NOTICE

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16. Abstract

A computer program was written and tested that performs a realistic Wave Equation Analysis of Piles driven by any type of impact hammer. Conventional pile and soil models were used in addition to both a thermodynamic model for diesels and refined mechanical hammer models.

The program development was aimed at providing a simple input and both a flexible and extensive output that includes automatic plotting capabilities. Pile Driving Hammer data were prepared and stored in a file for most of the commonly encountered models. The computer language is FORTRAN IV.

The program was extensively tested against measured pile top force and velocity data and against measured diesel combustion pressure and stroke.

This volume is the third in a series. The others in the series are:

Vol. No.	FHWA No.	Short Title	NTIS (PB) No.
1	IP-76-14	Background	
2	IP-76-14	User's Manual	
4	IP-76-14	Narrative Presentation	

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FOREWARD

This program documentation is one of four volumes of the description of WEAP, Wave Equation Analysis of Piles. The other three volumes contain:

1. Background
2. User's Manual
3. A Narrative Report (tape/slide show).

The WEAP program was written under contract with the Federal Highway Administration. It performs a dynamic analysis of impact driven piles. The results of the analysis consist, among others, of pile stresses, velocities and penetrations and are provided by the program in printed and plotted form. The program is used in foundation design, construction control and pile driving preparation. Potential users include soil and foundation engineers, construction supervisors and pile driving contractors.

WEAP
WAVE EQUATION ANALYSIS FOR PILES
PROGRAM DOCUMENTATION

TABLE OF CONTENTS

1. GENERAL INSTRUCTIONS

1.1 Program

There are a few changes that usually have to be made in the program before it can be compiled and loaded into a machine. The changes pertain to the I/O device numbers that are referenced in the program.

The following I/O devices are used:

a) Card Reader

b) Line Printer

c) Sequentially Reading Tape or Disc File

It is easily possible to convert the program for use with a terminal type I/O device having only 80 print columns.

The following program changes have to be made in any case:

a) In SUBROUTINE IPTN set IW to the card reader's or terminal's device number.

b) In SUBROUTINE IPTN set IR to the line printer's or terminal's device number.

c) For terminal use set ICOL = 0 in IPTN (ICOL = 132 otherwise).

d) In SUBROUTINE HAEL set IF to the tape or disc file's device number.

If a plotter is to be used, additional work will have to be done to adjust the SUBROUTINE OUTPUT to the particular software of the machine to be used. Since plotter routines are not standardized advice cannot be given here. For no plotter use the calls to OUTPUT should be removed from the main program. Conversion routines are available for standard CALCOMP software.

1.2 File

Two steps are involved when loading the hammer data file.

(i) Run the initialization program provided. It initializes the file in the proper format. Note that IF has to be set in this program to the proper file device number before compilation.

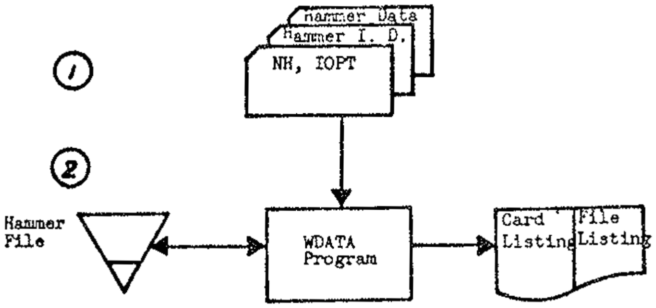
(ii) Run the file update program with the data provided. Before compiling it IW, IR and IF have to be set (as in 1.1). Any change of data can be accomplished by running this program with the new hammer data sets. The new hammer data sets have to be supplied with their respective identifier number and in ascending order of identifier number. Also the total number of hammers to be loaded has to be given as a first input (a print option can be set on this card too). This input data is also explained on the file loading form.

2. OPERATOR'S FLOW CHART

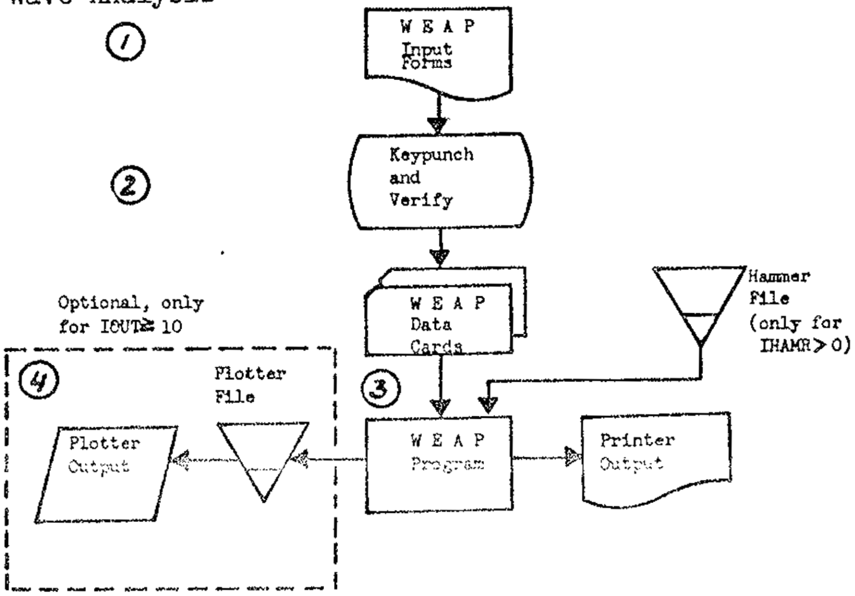
2.1 Graphic

2.1.1 Initialize Hammer Data File

2.1.2 Load Hammer Data File



2.1.3 Perform Wave Analysis



2.2 Narrative

2.2.1 INITIALIZE HAMMER FILE

1. Initialize file (either tape, disc or drum) using program WINIT. This program loads zeroes and blanks in the proper format in the file.

2.2.2 LOAD HAMMER DATA

1. Obtain hammer data cards from engineering department consisting of:

   First card: NH, IOPT ... number of hammers to be loaded,
   print option (2I4).

   and NH times

   1 card: IHAMR ... hammer number (I4)

   5 data cards: ... as per input forms. (Total number of cards 6 (NH) + 1).

2. Process using WDATA program which replaces data on file with corresponding card data. Input cards from step 1 and hammer file. Output to hammer file and printer. Printed output is the card data and, if IOPT was greater than 0, the total file contents (non-zero data).

2.2.3 WAVE ANALYSIS

1. Obtain input forms from engineering department.

2. Punch and verify input cards with format as indicated in forms.

3. Process WEAP program.

   Input: data cards from step 2; hammer file - only if IHAMR $>$ 0 (card No. 2.000, cc 9-12).

   Output: Printed Results

   Plotter Data if IOUT $>$ 9 (card No. 2.000 cc 1-4).

4. Plot Plotter Data from Step 3.

3. DESCRIPTION OF SUBROUTINES

Subroutine Name	Subroutine primary function and calls
IPTN	Read input from cards. Assemble and initialize data; calls HAEL, PIEL, SOILN, OUTIN, JJNP, VACHAM.
HAEL	Supply hammer information and determine hammer critical time increment.
PIEL	Determine pile segment properties.
SOILN	Determine distribution of static soil resistance; reads from cards.
OUTIN	Determine input information.
JJNP	Determine output segment numbers.
DOWN	Determine maximum stroke and velocity at exhaust ports for closed end diesel hammers; calls FTR.
FTR	Determine force on ram top.
STARTC	Using stroke determine initial values; calls FTR, VACHAM.
VACHAM	Determine velocity of ram at ports or vacuum force if vacuum chamber hammer is analyzed.
DIESEL	Carry out the analysis of a diesel hammer; calls PILEAN, FILL, FILL2, INTEGR, STIFF.
PILEAN	Analyze the pile for a certain pile increment; calls INTEGR, SRESN.
INTEGR	Integrate assuming linear acceleration to obtain displacement.
STIFF	Find stiffness of a spring with quadratic force-deflection relation.
SRESN	Find static soil resistance.

UP	Find rebound stroke from pressure and ram velocity; calls FTR, VACHAM.
OUT2	Print segment variables as function of time and extreme values for each pile element.
OUTPUT	Plot segment variables vs. time, vs. time and pile length and plot summary. Calls FPLOT, FMOVE, FCHAR, FSCHAR, FSCALE; writes to plotter file.
FILL	Fills up to output arrays depending on output option.
FILL2	Fills up output arrays for options 6, 16, 26.
FPLOT[*]	Plots to a point.
FMOVE[*]	Moves to a point
FCHAR[*]	Plots a character or string of characters.
FSCHAR[*]	Plots a special character.
FSCALE[*]	Sets up origin and scale.

[*] Only contained in certain program versions; may be computer library routines. The F ... routines call standard CALCOMP routines like NEWPEN, NUMBER, PLOT, PLOTS, QPLOT, SYMBOL.

4. FLOW CHARTS

NOTES ON SUBROUTINE GRAPHS:

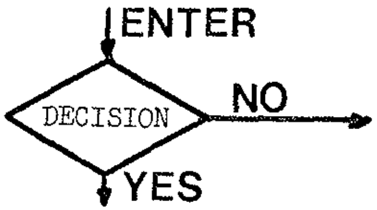
(i) The programs and subroutines are listed in order of occurence in the program flow.

(ii) The flow charts contain three different symbols.

a.

A process may involve arithmetic, input/output or any other data manipulation.

b.



Decisions lead the program in either of two branches. The rule used in the following branches was always

YES = downwards
NO = sidewise

The text in the decision diamond may or may not be identical with the corresponding IF statement in the program code. In general, it was attempted to provide a text that explains the action taken rather than a copy of the actual code.

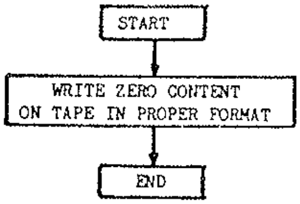
c.

If the program flow chart is interrupted by an end of page then flow lines are terminated and restarted by the off-page connector using corresponding numbers.

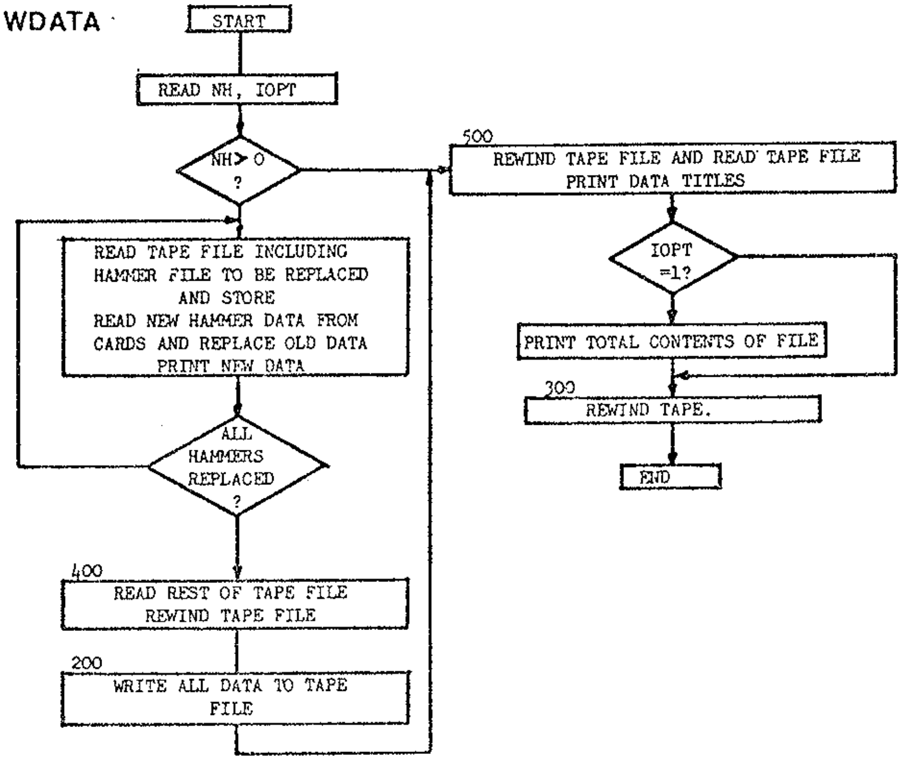
(iii) Statement numbers were added to the flow charts whereever possible.

(iv) The reference to tape file includes tape simulated discs or tape simulated drums.

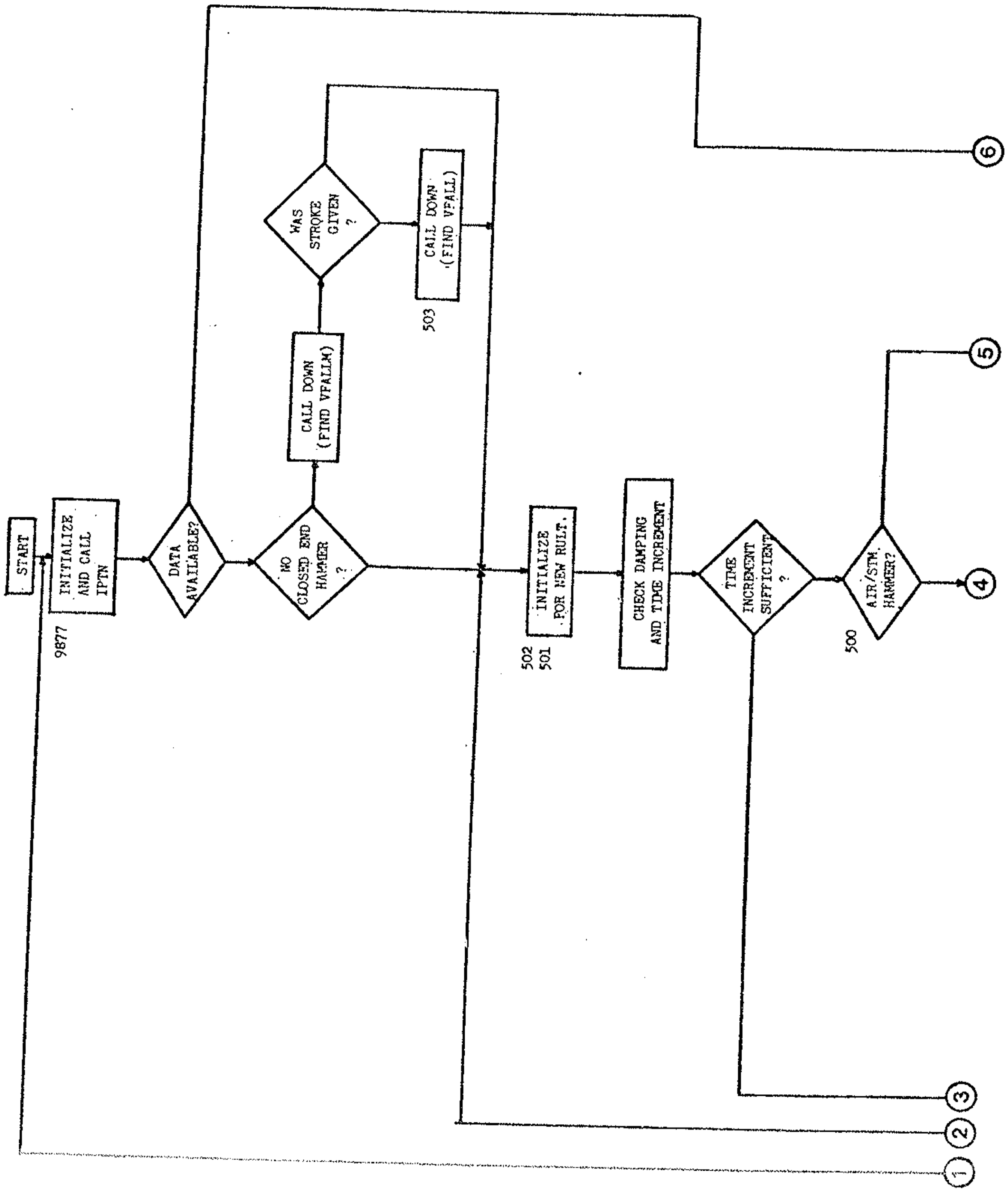
PROGRAM WINIT



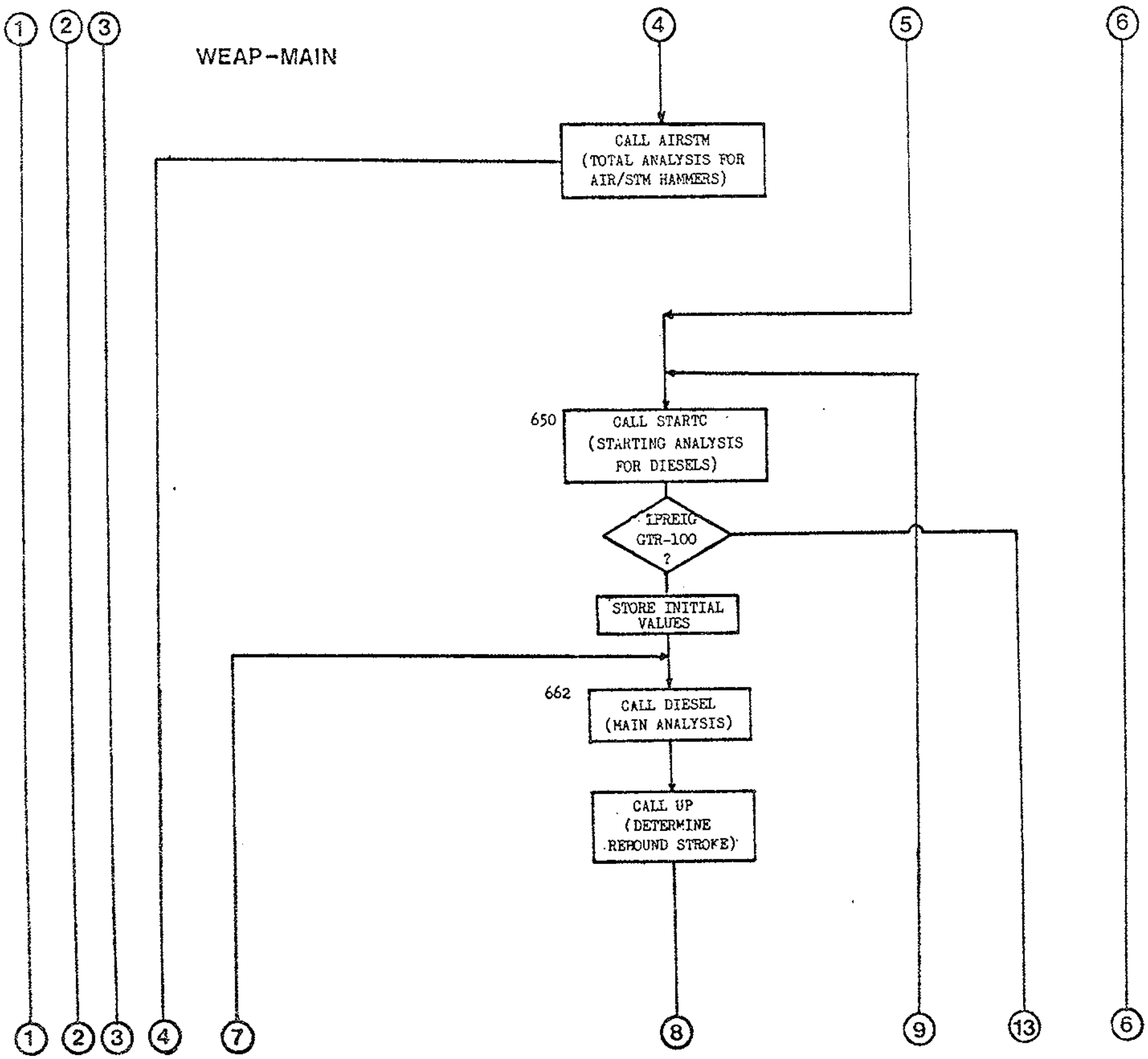
PROGRAM WDATA



WEAP-MAIN

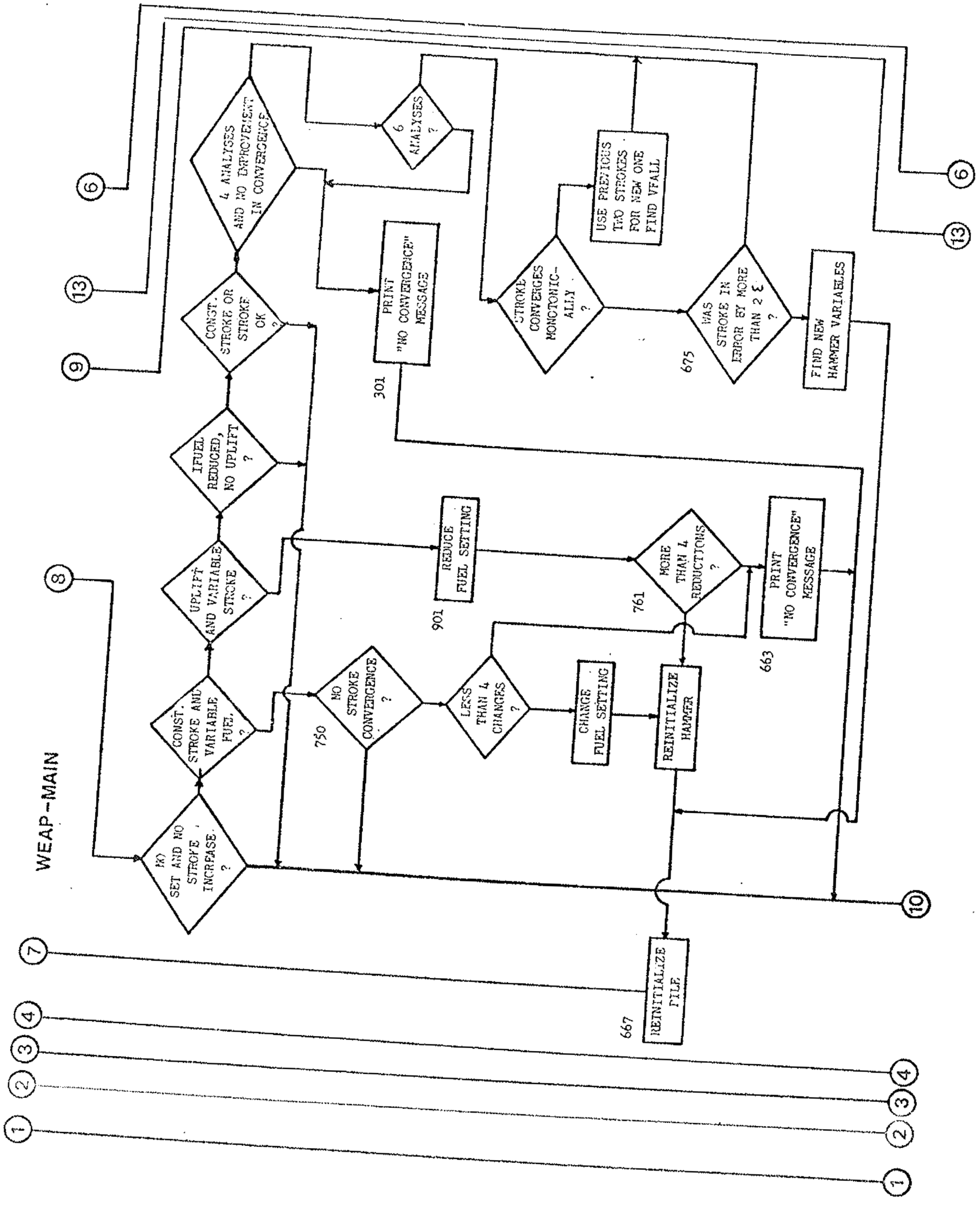

START
INITIALIZE AND CALL IPTN
9877
DATA AVAILABLE?
NO CLOSED END HAMMER ?
CALL DOWN (FIND VFALLM)
WAS STROKE GIVEN ?
CALL DOWN (FIND VFALL)
503
INITIALIZE FOR NEW RULT.
502
501
CHECK DAMPING AND TIME INCREMENT
TIME INCREMENT SUFFICIENT ?
AIR/STM. HAMMER?
500
①
②
③
④
⑤
⑥

WEAP-MAIN



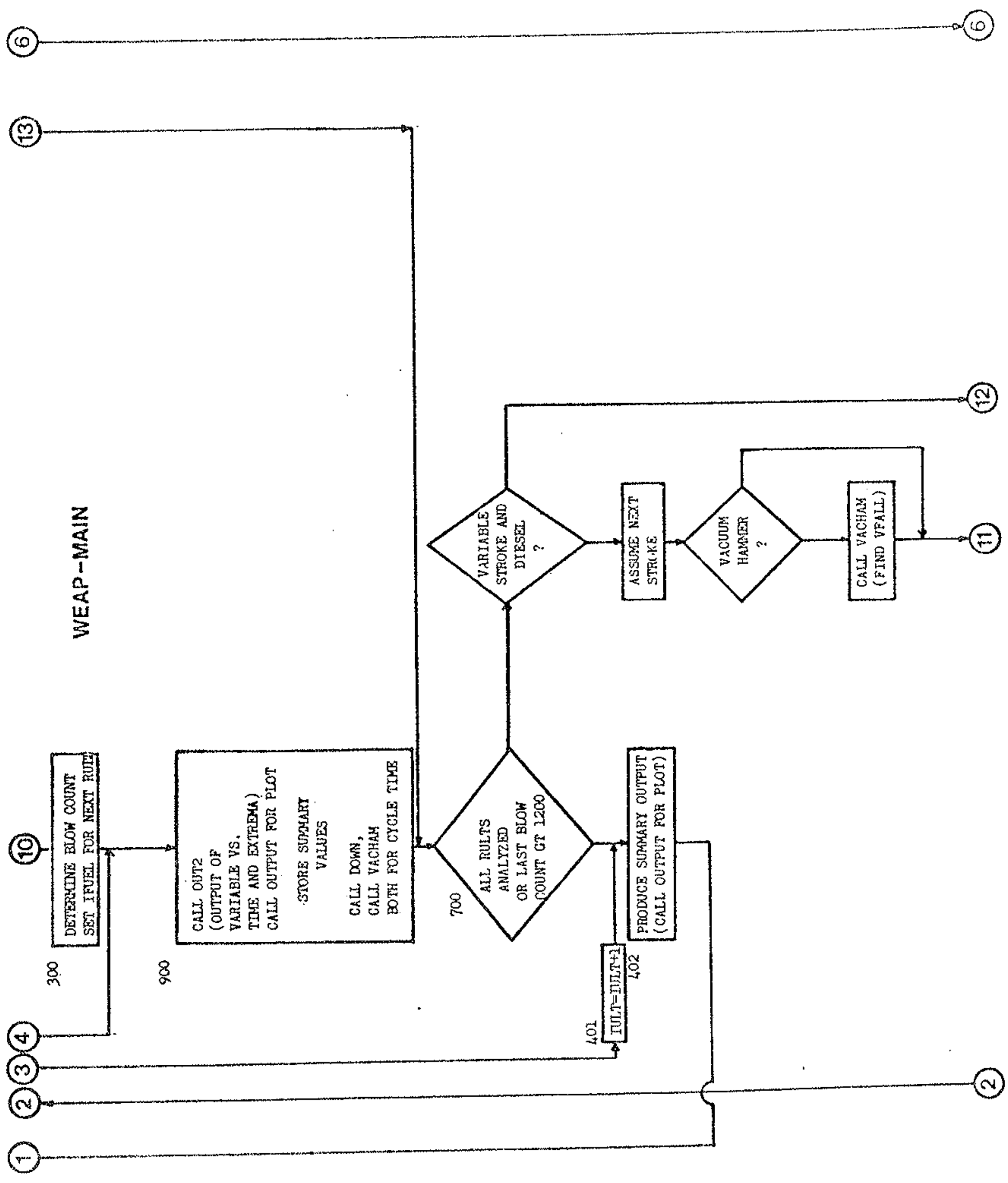
1
2
3
4
5
6
CALL AIRSTM (TOTAL ANALYSIS FOR AIR/STM HAMMERS)
650
CALL STARTC (STARTING ANALYSIS FOR DIESELS)
IPREIG GTR-100 ?
STORE INITIAL VALUES
662
CALL DIESEL (MAIN ANALYSIS)
CALL UP (DETERMINE REBOUND STROKE)
1
2
3
4
7
8
9
13
6

WEAP-MAIN

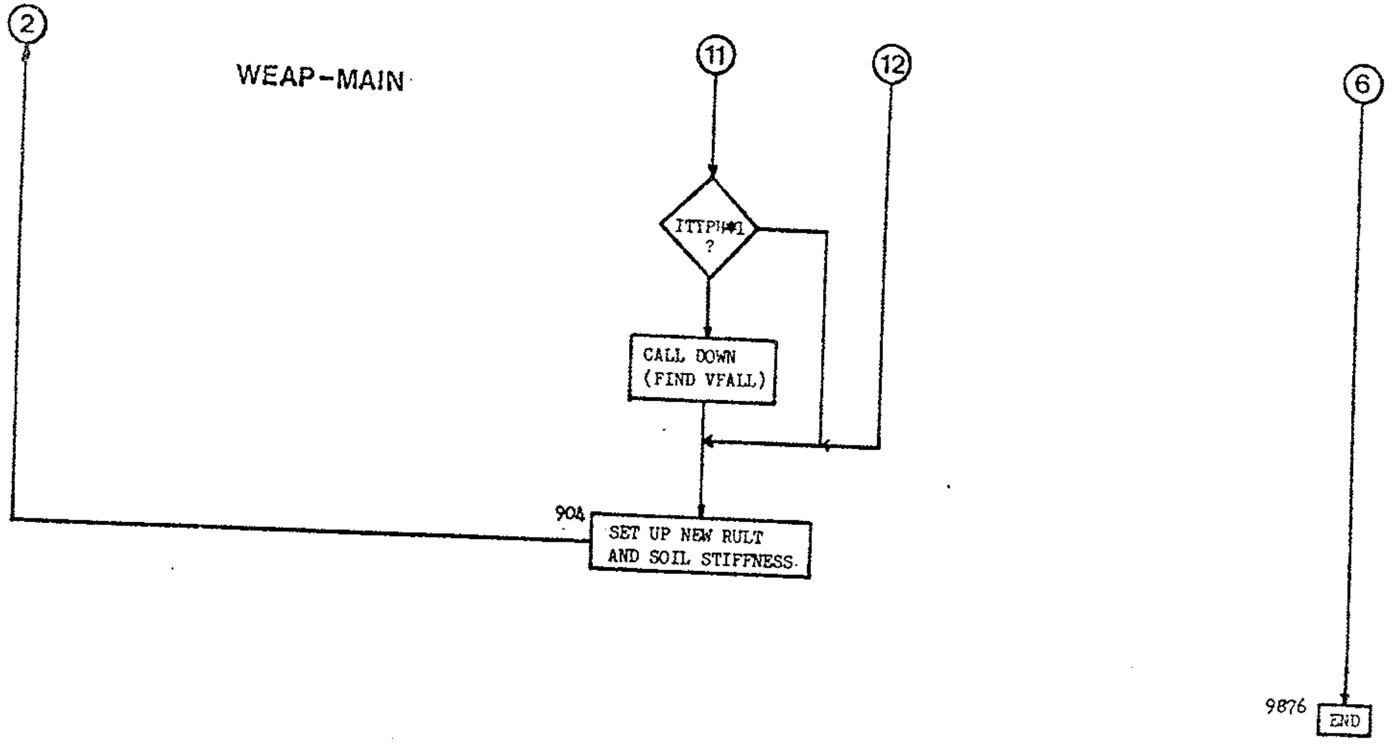


NO SET AND NO STROKE INCREASE ?
CONST. STROKE AND VARIABLE FUEL ?
UPLIFT AND VARIABLE STROKE ?
IFUEL REDUCED, NO UPLIFT ?
CONST. STROKE OR STROKE OK ?
4 ANALYSES AND NO IMPROVEMENT IN CONVERGENCE ?
6 ANALYSES ?
750
NO STROKE CONVERGENCE ?
LESS THAN 4 CHANGES ?
CHANGE FUEL SETTING
REINITIALIZE HAMMER
901
REDUCE FUEL SETTING
761
MORE THAN 4 REDUCTIONS ?
663
PRINT "NO CONVERGENCE" MESSAGE
301
PRINT "NO CONVERGENCE" MESSAGE
STROKE CONVERGES MONOTONIC-ALLY ?
USE PREVIOUS TWO STROKES FOR NEW ONE FIND VFALL
675
WAS STROKE IN ERROR BY MORE THAN 2 ε ?
FIND NEW HAMMER VARIABLES
667
REINITIALIZE FILE
①
②
③
④
⑦
⑧
⑨
⑬
⑥
⑩
⑥
⑬
④
③
②
①

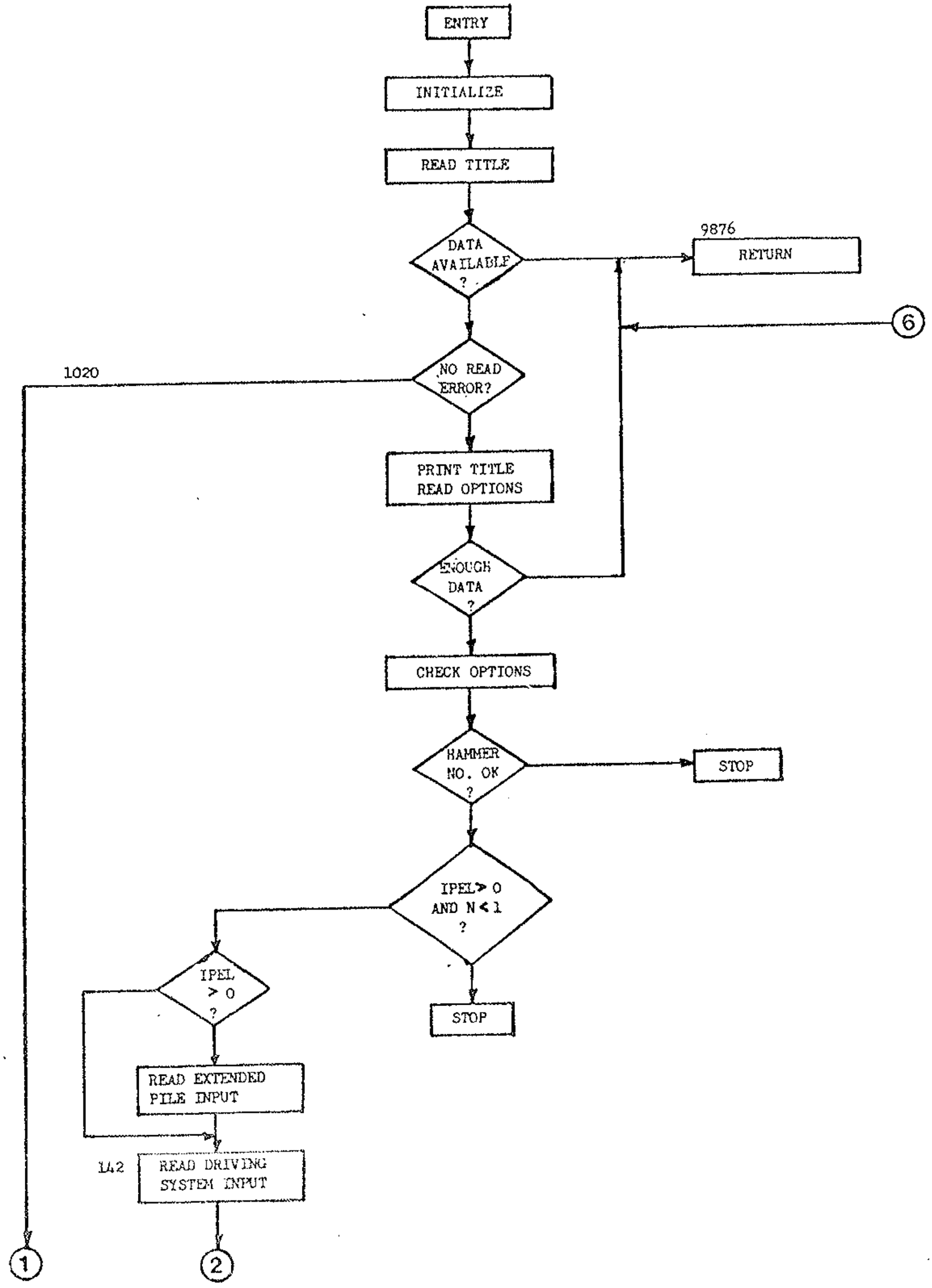
WEAP-MAIN



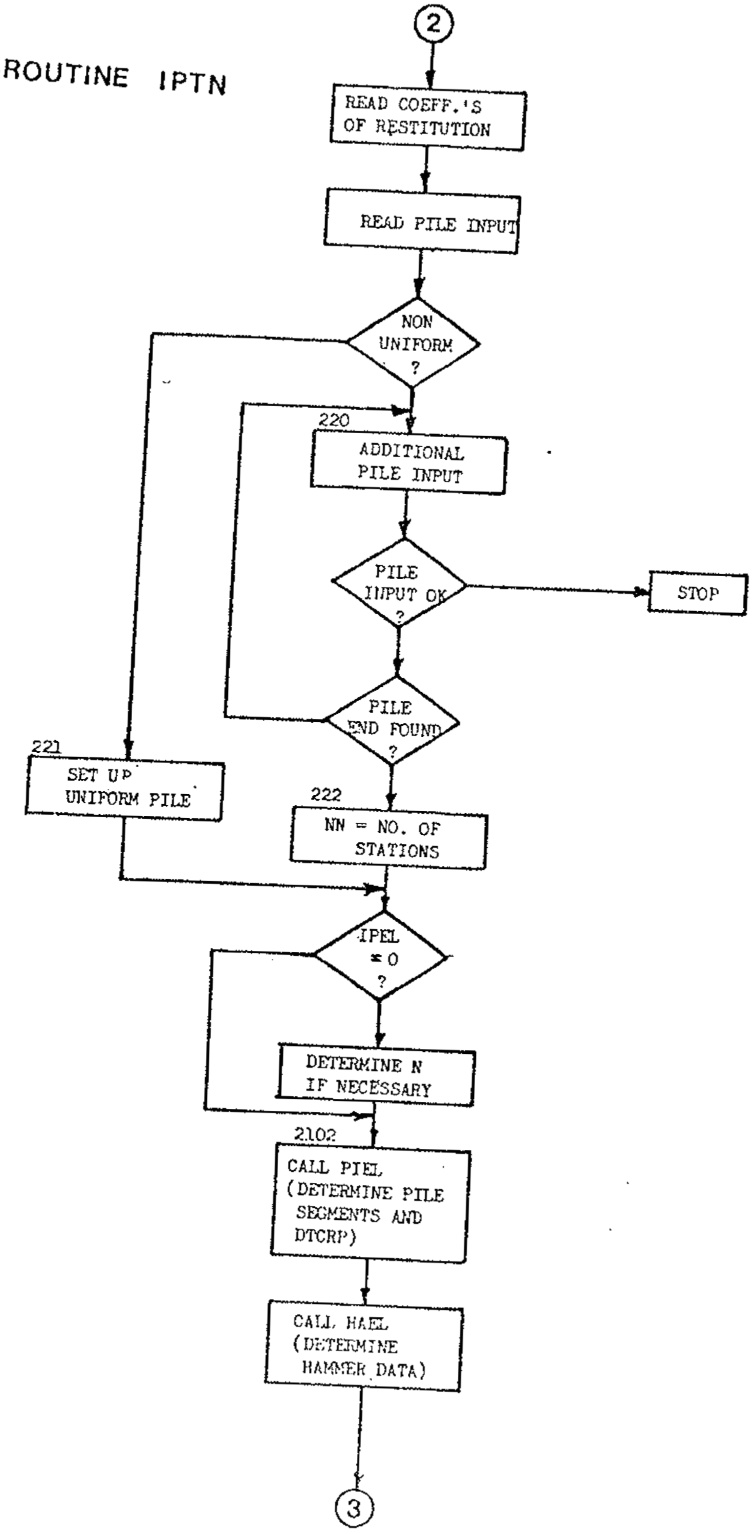
⑥
⑬
⑩
300
DETERMINE BLOW COUNT
SET IFUEL FOR NEXT RUN
④
900
CALL OUT2
(OUTPUT OF
VARIABLE VS.
TIME AND EXTREMA)
CALL OUTPUT FOR PLOT
STORE SUMMARY
VALUES
CALL DOWN,
CALL VACHAM
BOTH FOR CYCLE TIME
③
②
①
700
ALL RULTS
ANALYZED
OR LAST BLOW
COUNT GT 1200
401
IULT=IULT+1
402
PRODUCE SUMMARY OUTPUT
(CALL OUTPUT FOR PLOT)
VARIABLE
STROKE AND
DIESEL
?
⑫
ASSUME NEXT
STROKE
VACUUM
HAMMER
?
CALL VACHAM
(FIND VFALL)
⑪
②
⑥


WEAP-MAIN
2
11
12
6
ITTPH≠1
?
CALL DOWN
(FIND VFALL)
904
SET UP NEW RULT
AND SOIL STIFFNESS.
9876
END

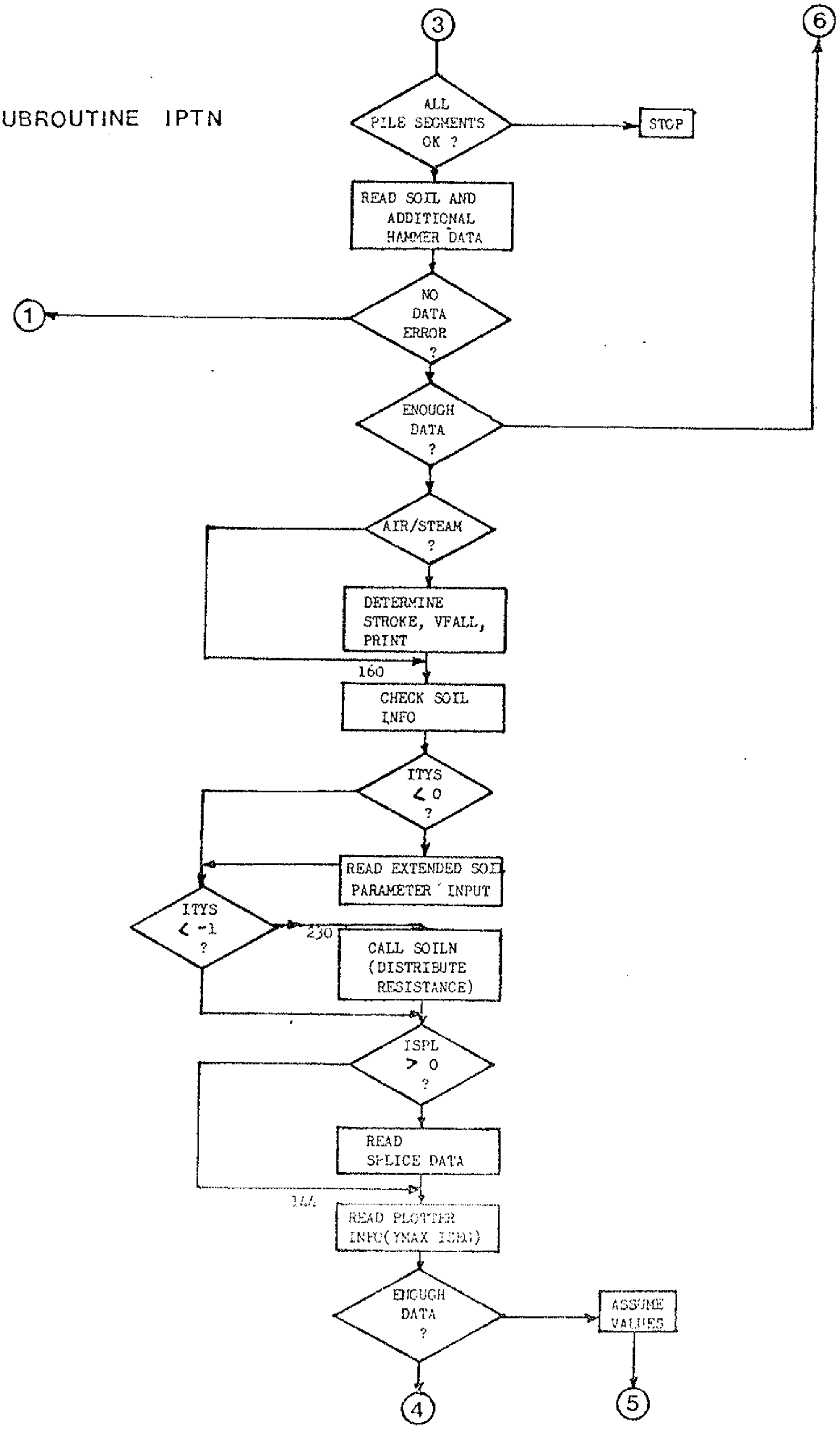
SUBROUTINE IPTN



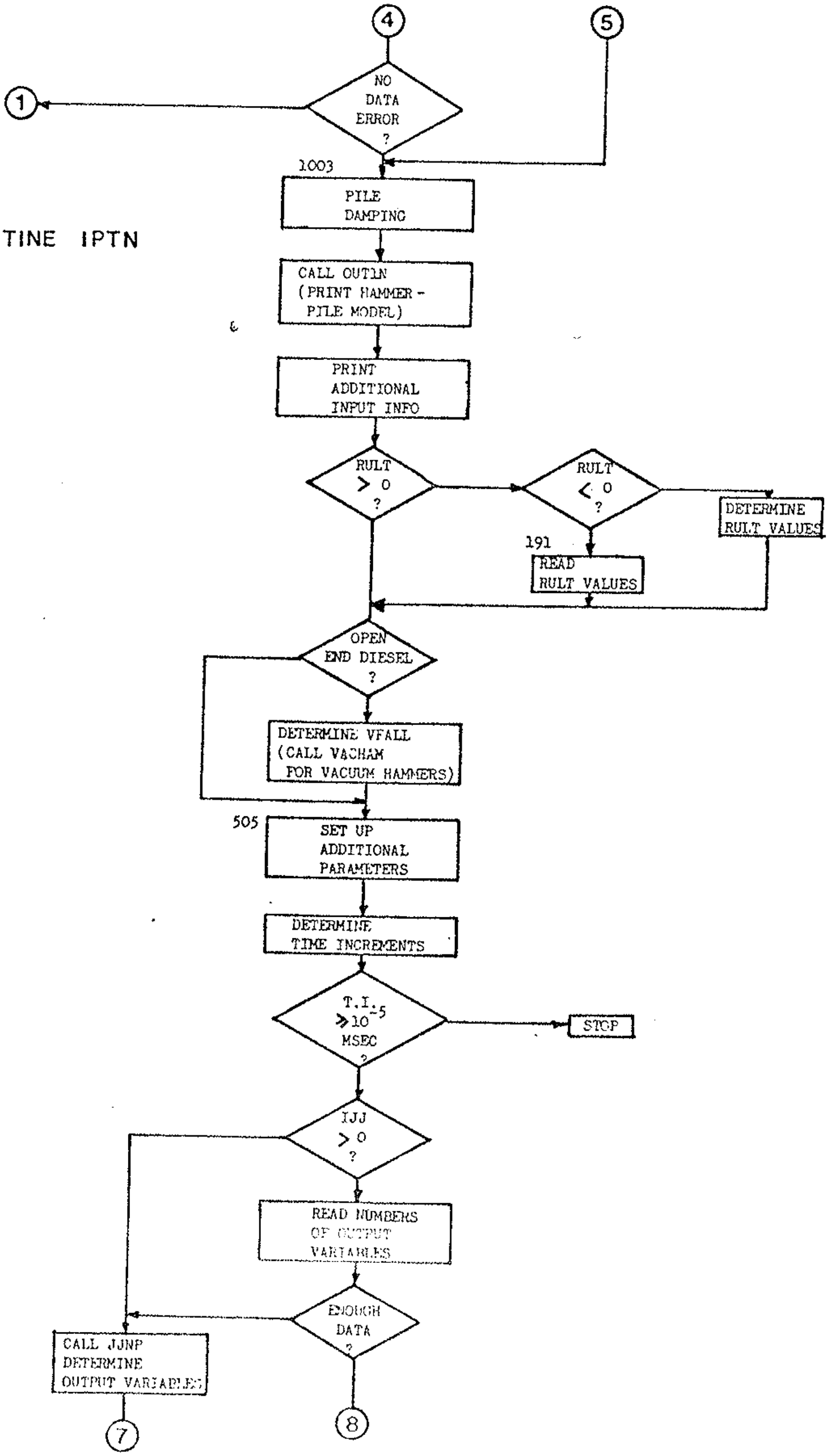
SUBROUTINE IPTN



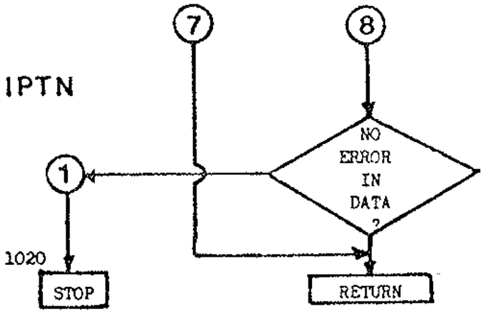
SUBROUTINE IPTN



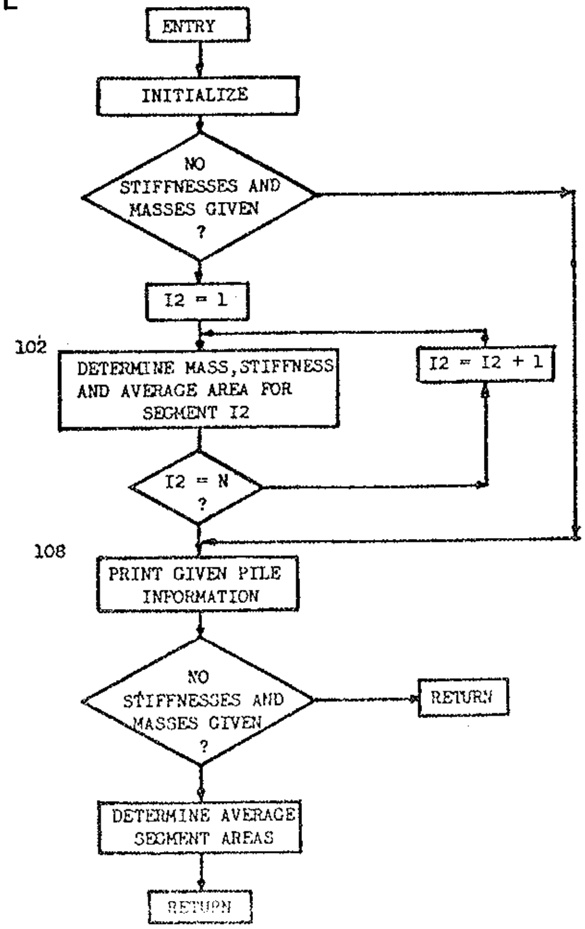
SUBROUTINE IPTN



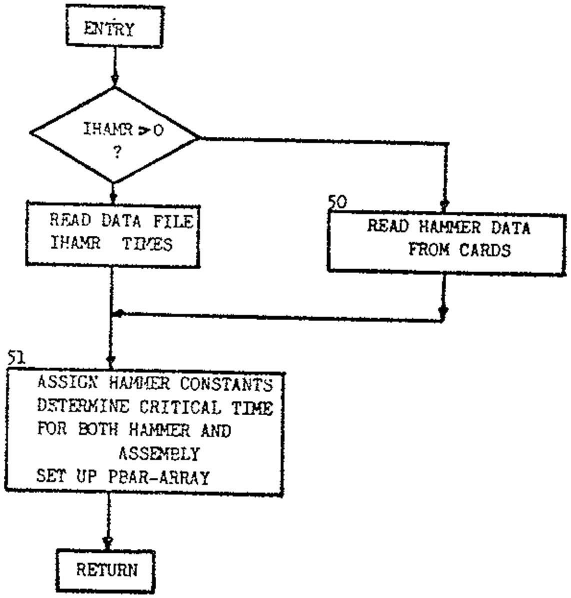
SUBROUTINE IPTN



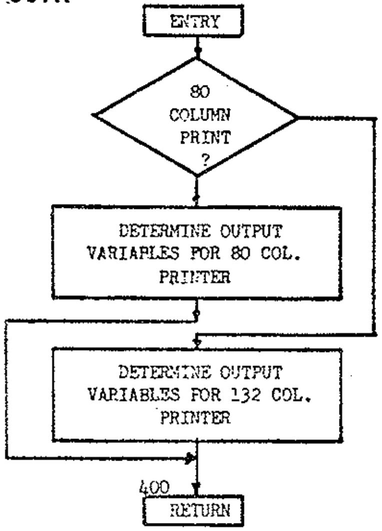
SUBROUTINE PIEL



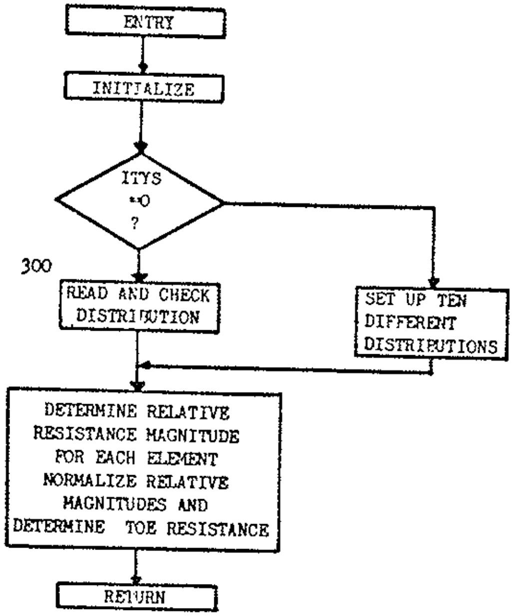
HAEL



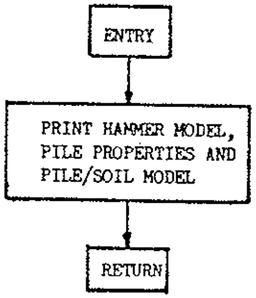
JJNP



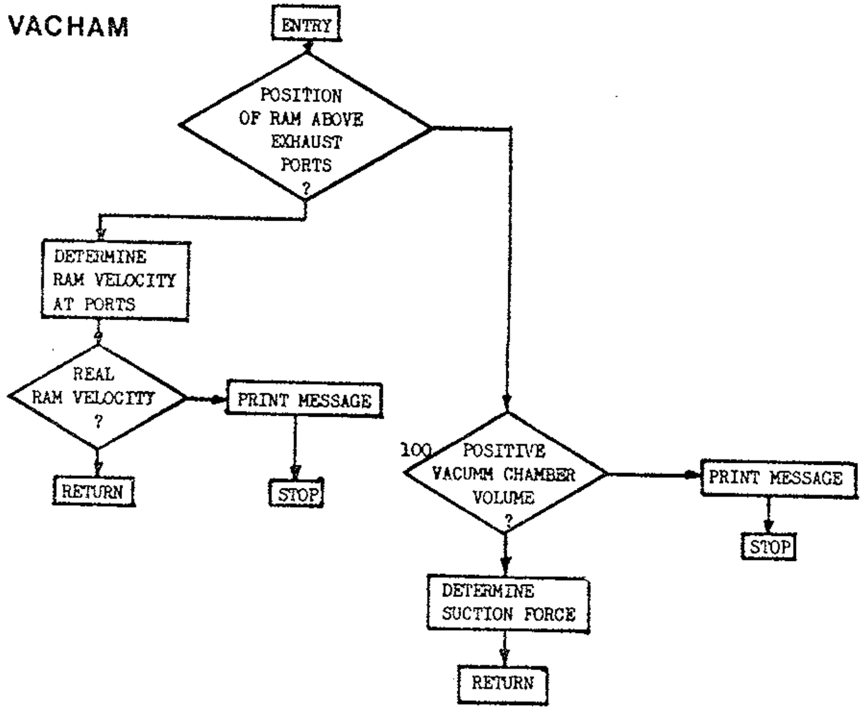
SOILN



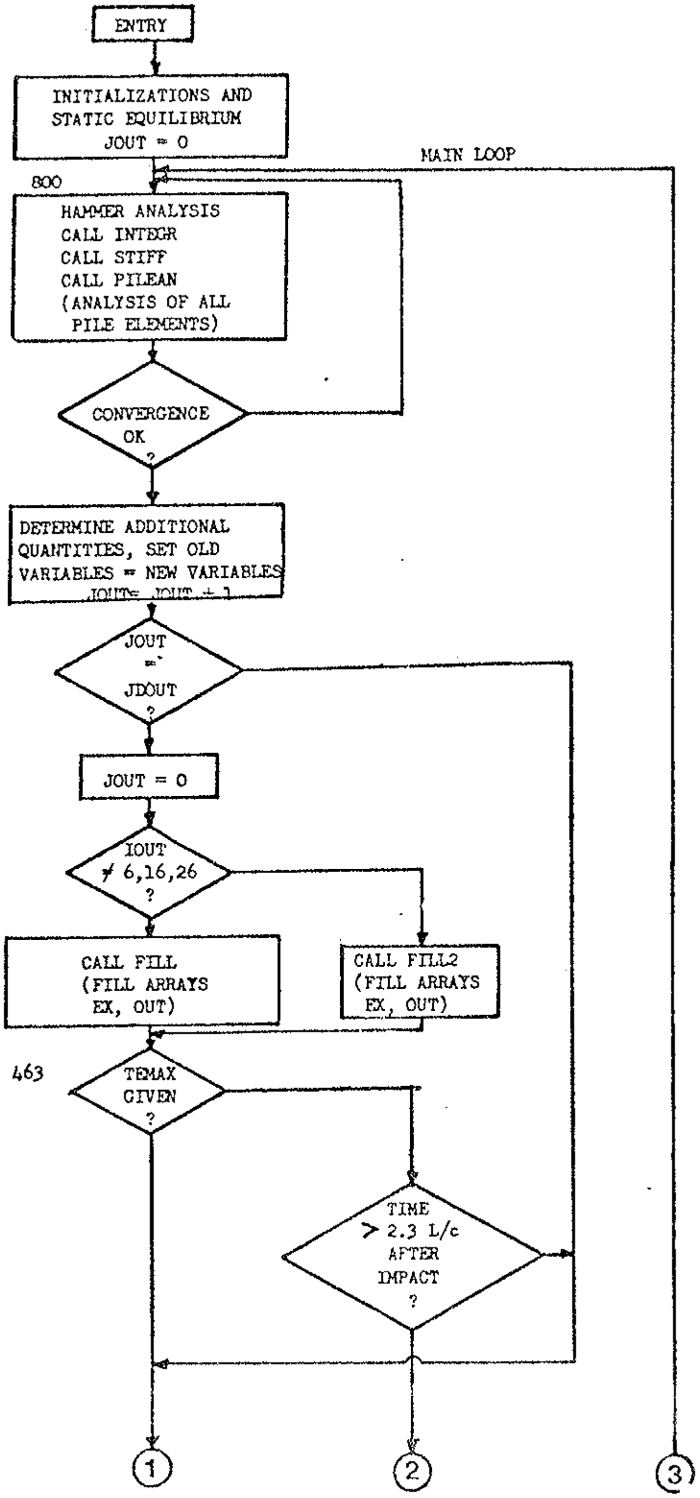
OUT1N



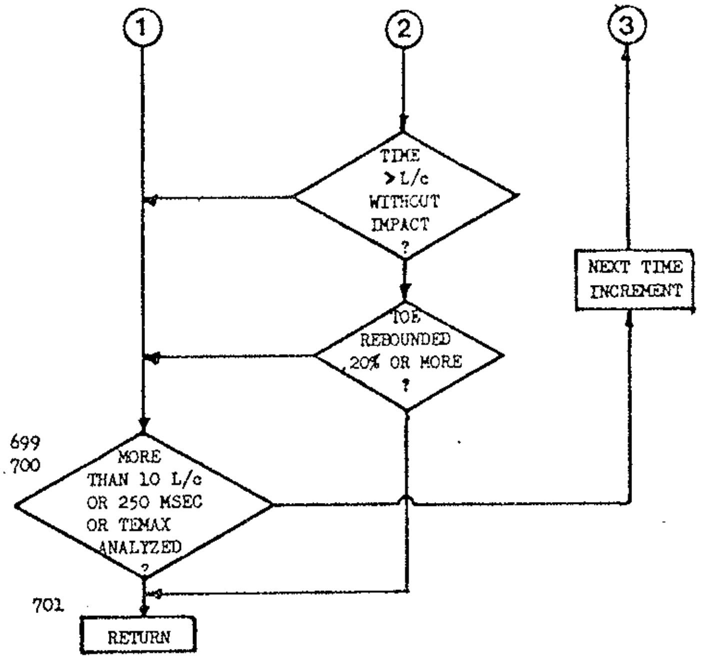
VACHAM


ENTRY
POSITION OF RAM ABOVE EXHAUST PORTS ?
DETERMINE RAM VELOCITY AT PORTS
REAL RAM VELOCITY ?
PRINT MESSAGE
STOP
RETURN
100
POSITIVE VACUMM CHAMBER VOLUME ?
PRINT MESSAGE
STOP
DETERMINE SUCTION FORCE
RETURN

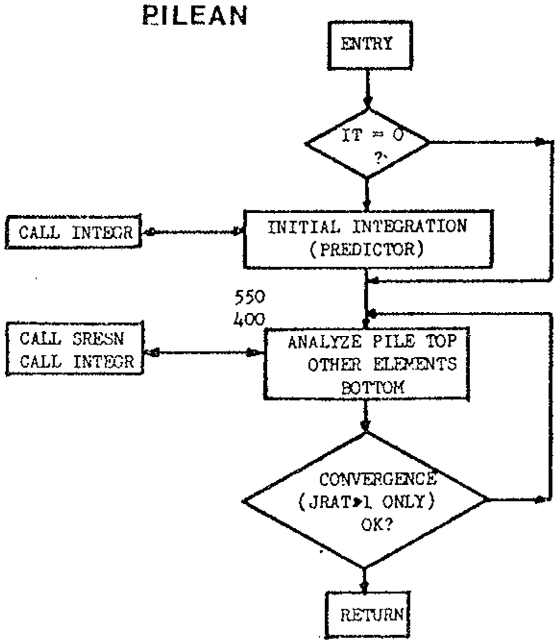
SUBROUTINE AIRSTM



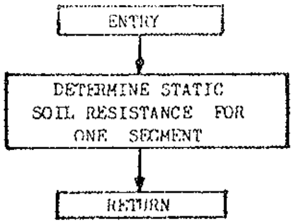
AIRSTM



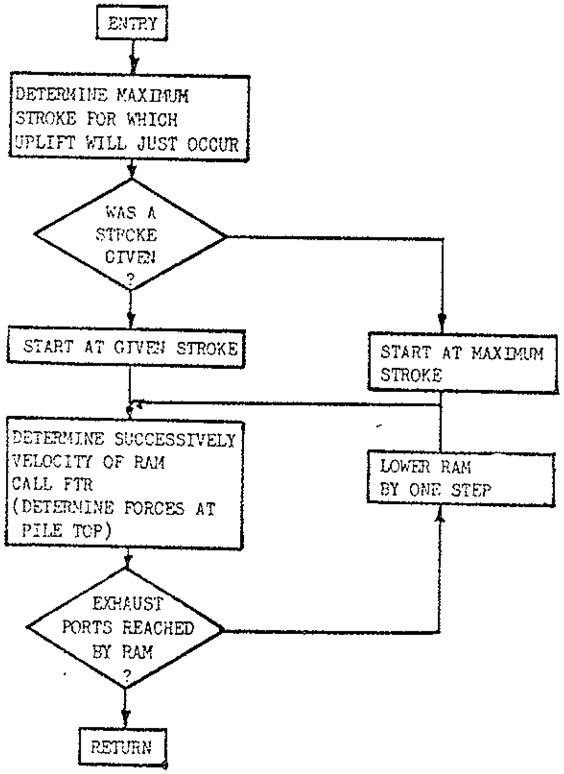
PILEAN



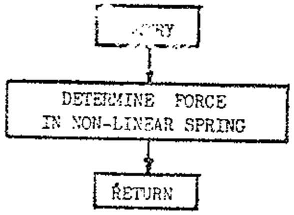
SRESN



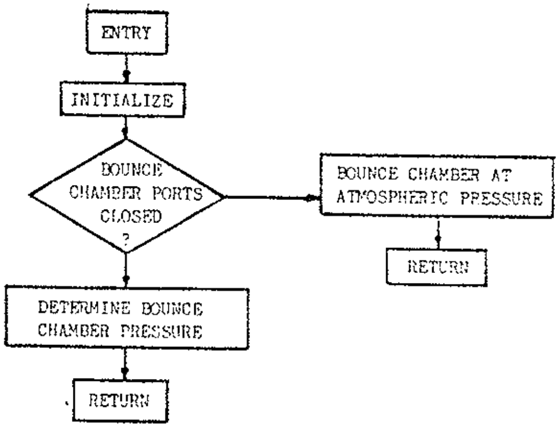
DOWN



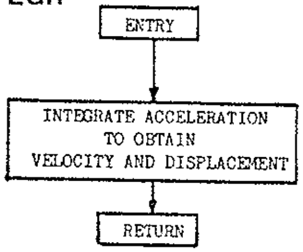
STIFF



FTR

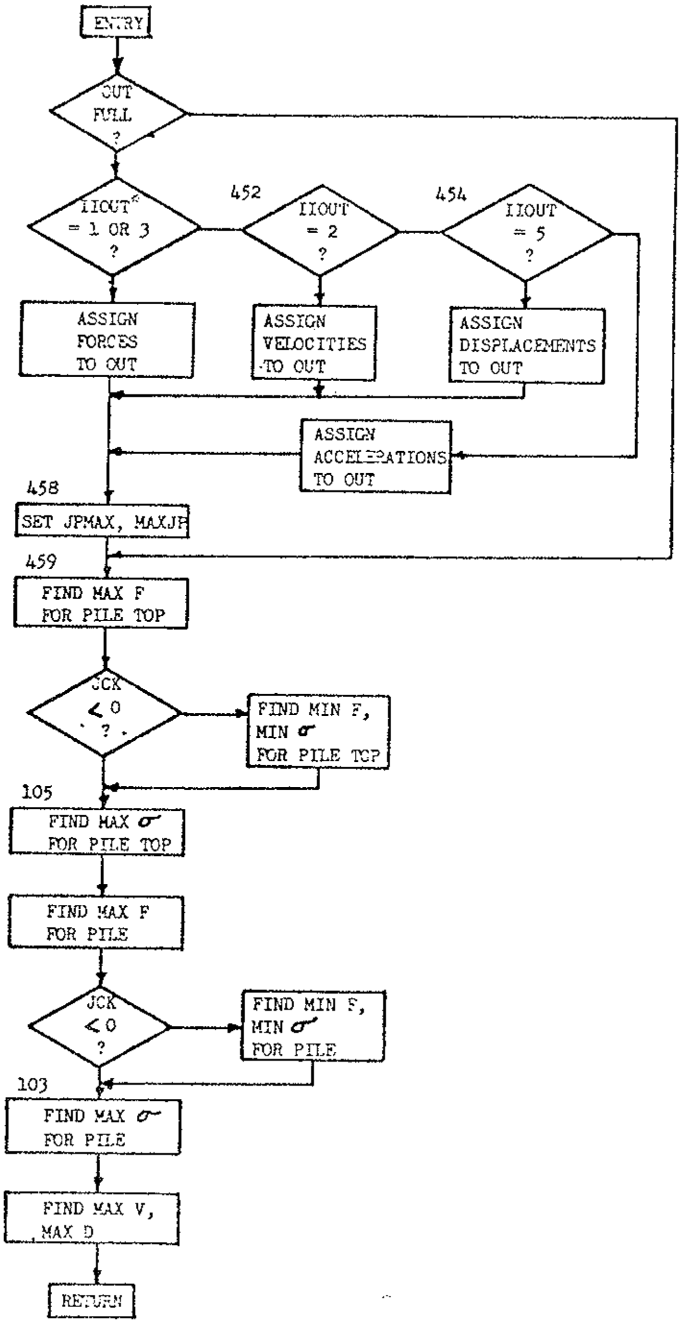


INTEGR

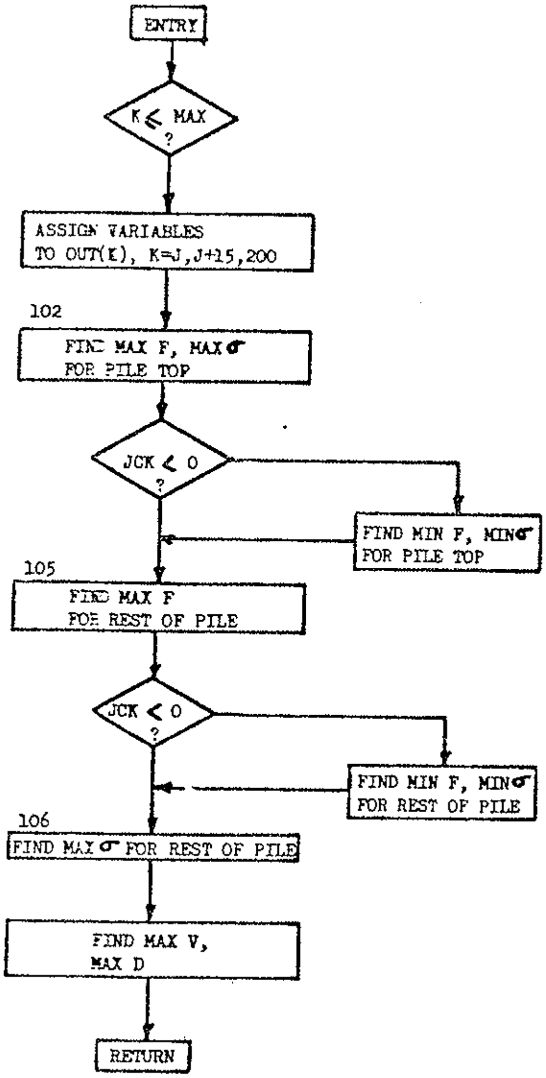


FILL

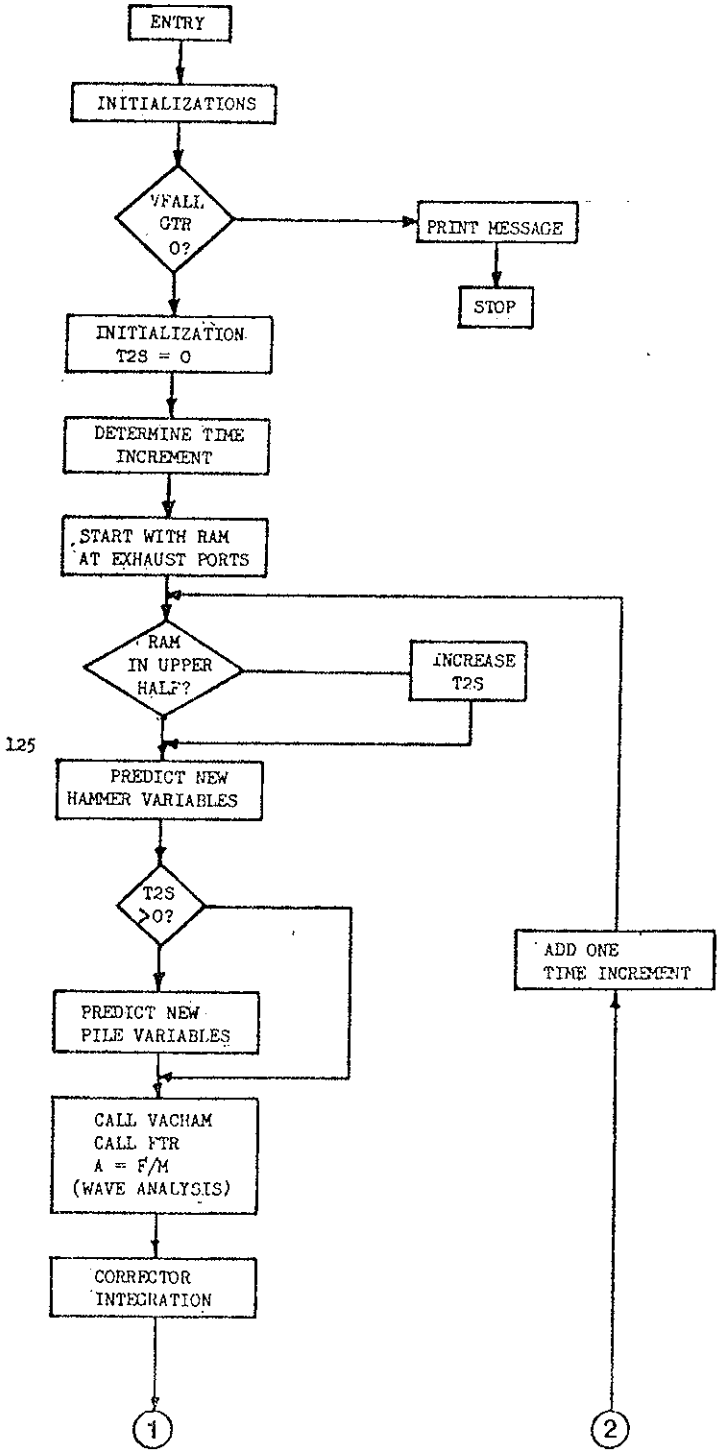
*
IIOUT
= IOUT - 10 FOR $9 < \text{IOUT} \leq 19$
= IOUT - 20 FOR $19 < \text{IOUT}$



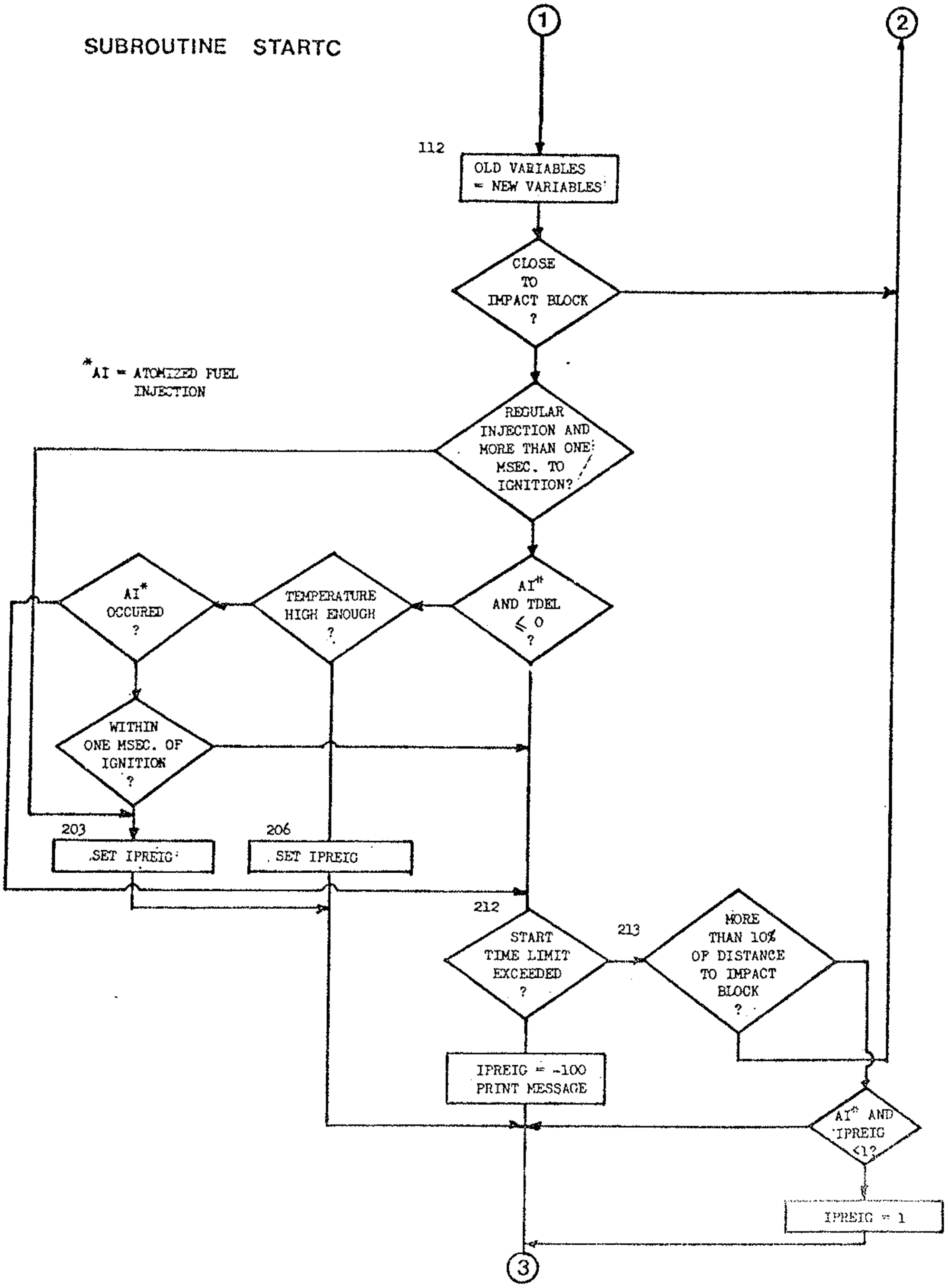
FILL2


ENTRY
K ≤ MAX ?
ASSIGN VARIABLES TO OUT(K), K=J,J+15,200
102
FIND MAX F, MAX σ FOR PILE TOP
JCK < 0 ?
FIND MIN F, MIN σ FOR PILE TOP
105
FIND MAX F FOR REST OF PILE
JCK < 0 ?
FIND MIN F, MIN σ FOR REST OF PILE
106
FIND MAX σ FOR REST OF PILE
FIND MAX V, MAX D
RETURN

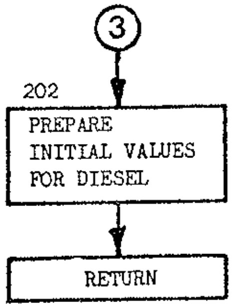
SUBROUTINE STARTC



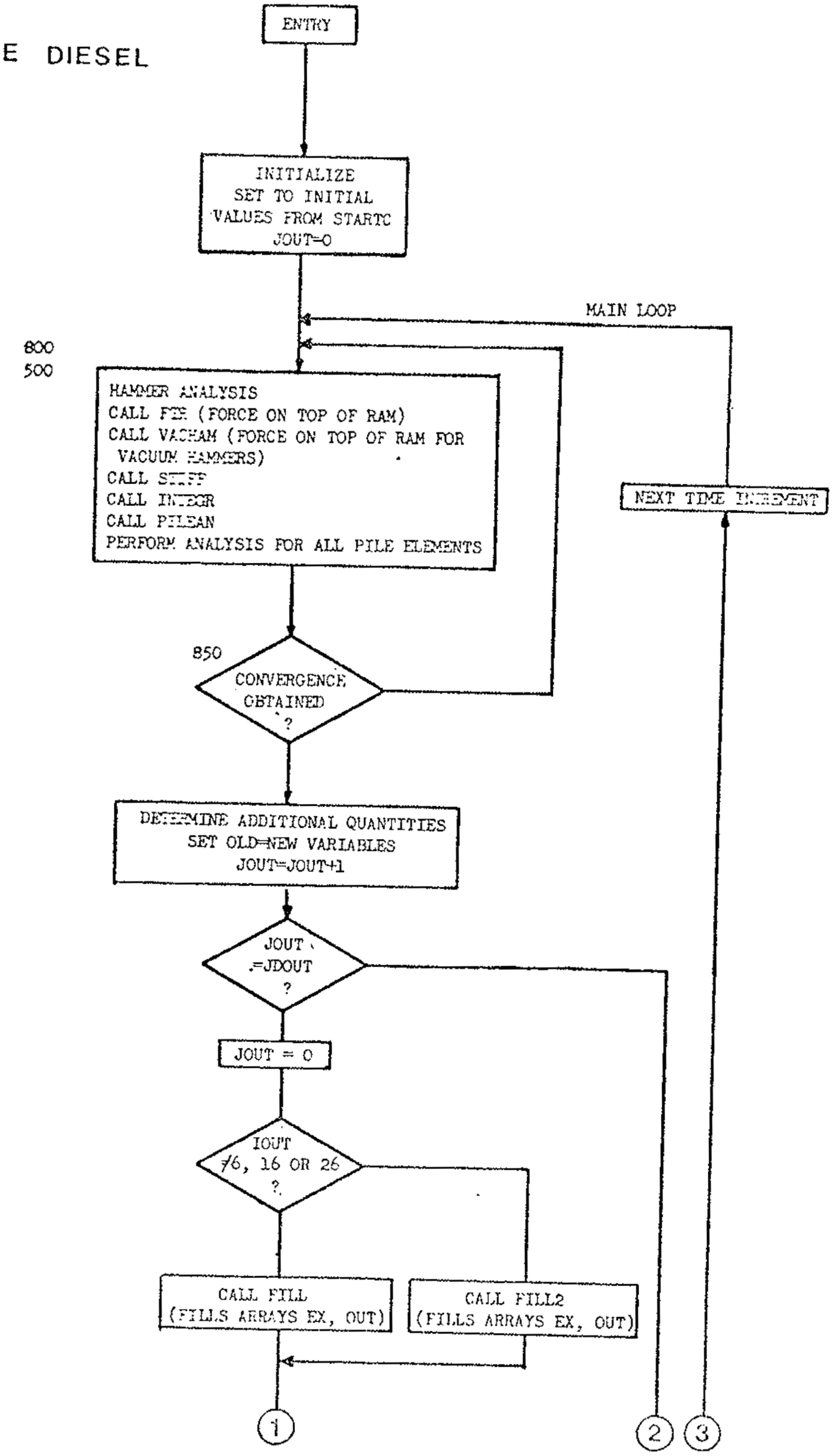
SUBROUTINE STARTC



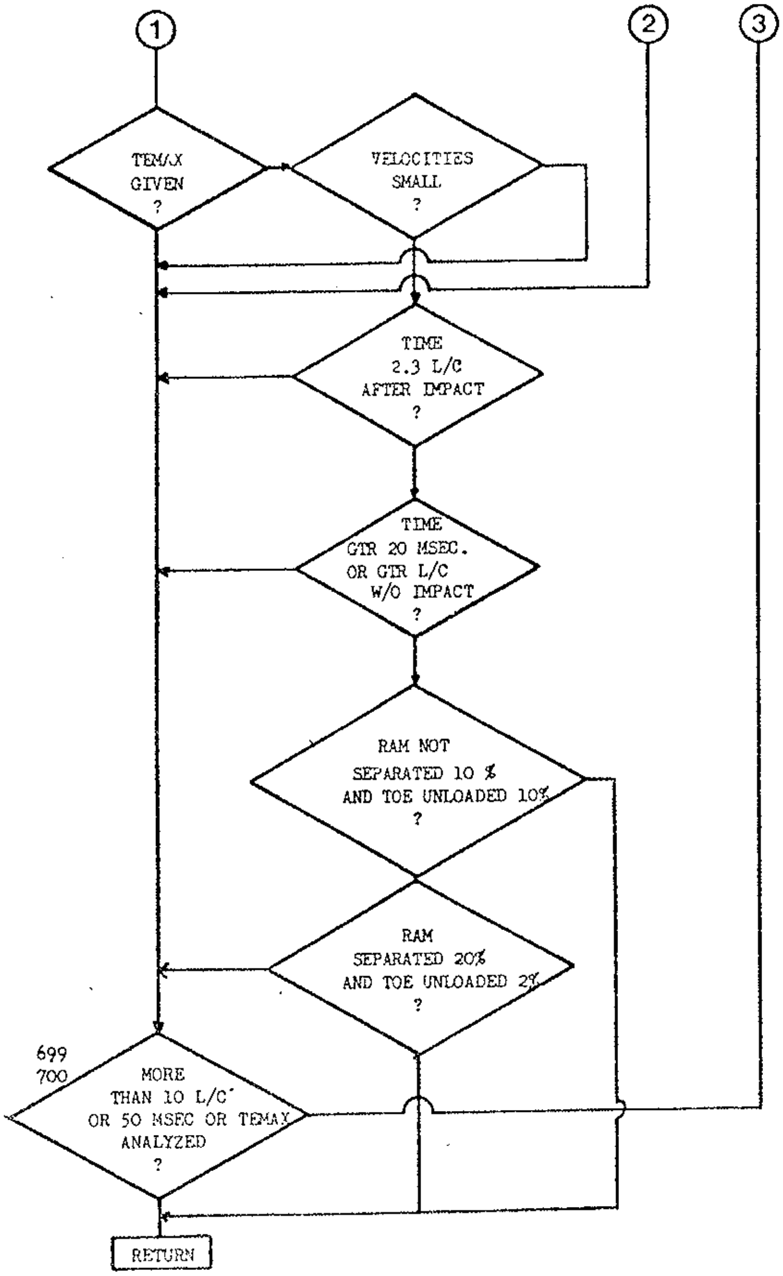
SUBROUTINE STARTC

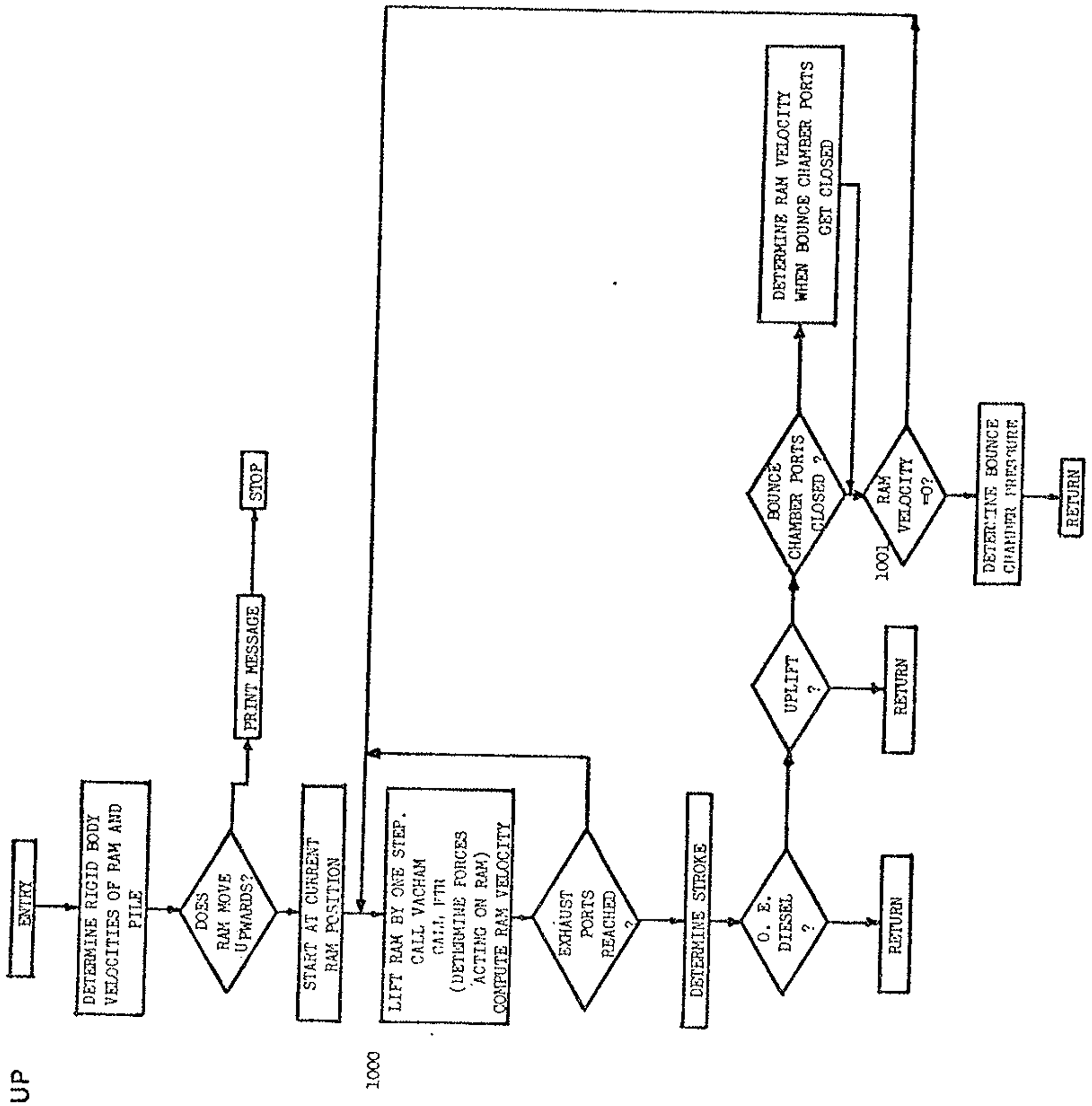


SUBROUTINE DIESEL

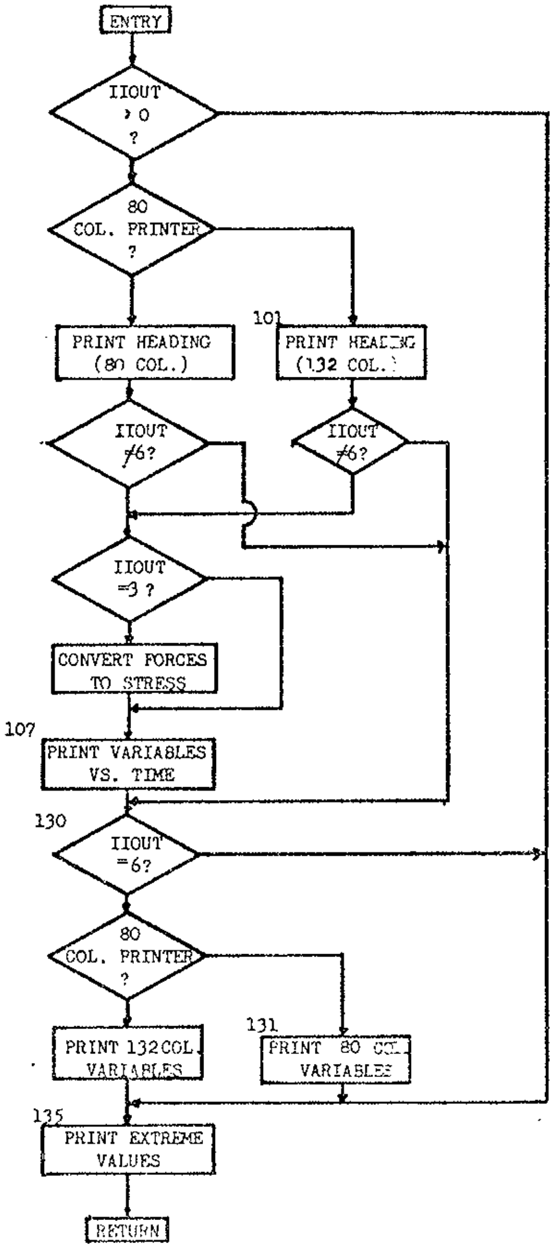


DIESEL

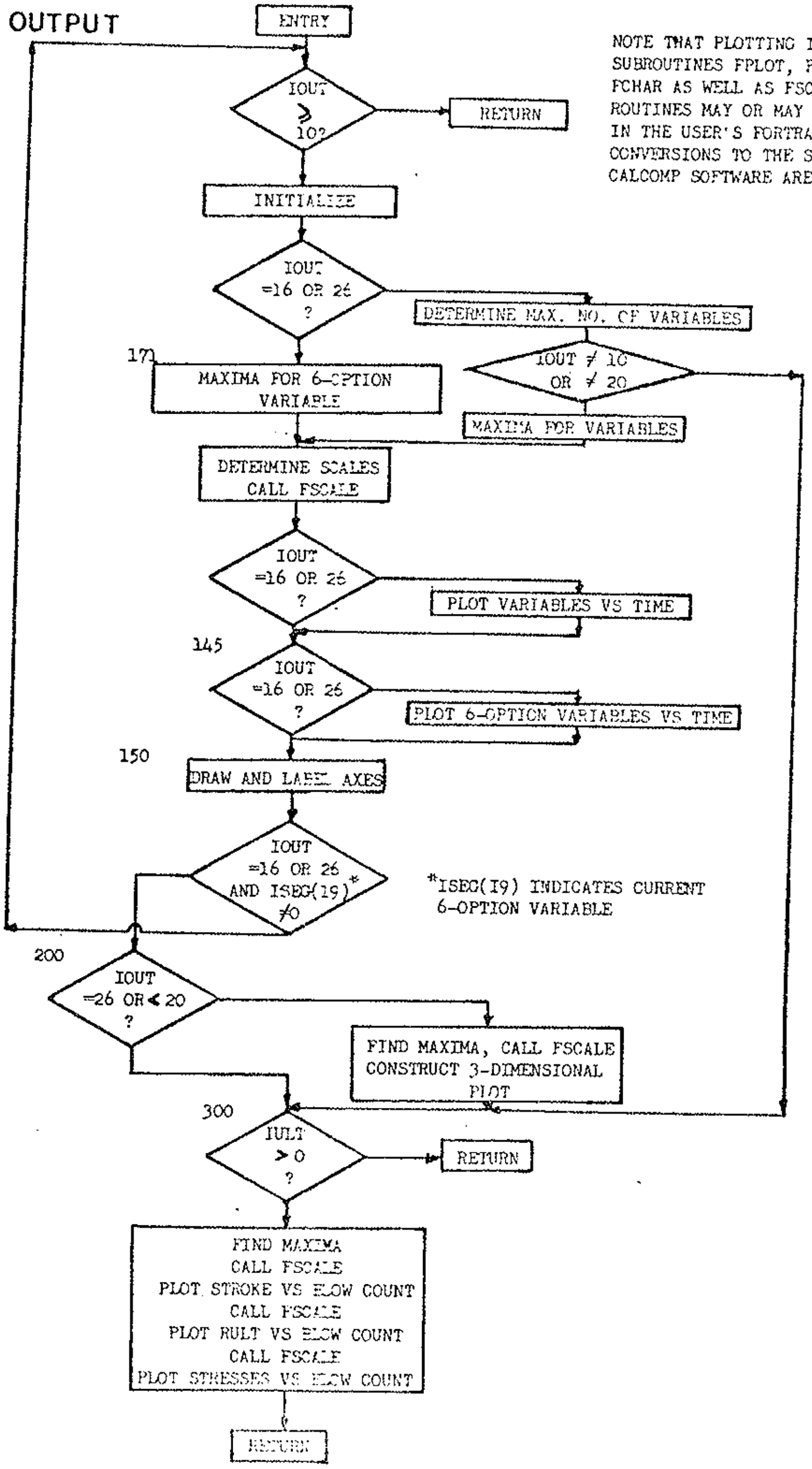

①
②
③
TEMAX GIVEN ?
VELOCITIES SMALL ?
TIME 2.3 L/C AFTER IMPACT ?
TIME GTR 20 MSEC. OR GTR L/C W/O IMPACT ?
RAM NOT SEPARATED 10 % AND TOE UNLOADED 10% ?
RAM SEPARATED 20% AND TOE UNLOADED 2% ?
699
700
MORE THAN 10 L/C OR 50 MSEC OR TEMAX ANALYZED ?
RETURN


UP
ENTRY
DETERMINE RIGID BODY VELOCITIES OF RAM AND PILE
DOES RAM MOVE UPWARDS?
PRINT MESSAGE
STOP
START AT CURRENT RAM POSITION
1000
LIFT RAM BY ONE STEP. CALL VACHAM CALL FTR (DETERMINE FORCES ACTING ON RAM) COMPUTE RAM VELOCITY
EXHAUST PORTS REACHED ?
DETERMINE STROKE
O. E. DIESEL ?
RETURN
UPLIFT ?
RETURN
BOUNCE CHAMBER PORTS CLOSED ?
DETERMINE RAM VELOCITY WHEN BOUNCE CHAMBER PORTS GET CLOSED
1001
RAM VELOCITY =0?
DETERMINE BOUNCE CHAMBER PRESSURE
RETURN

OUT2


ENTRY
IIOUT > 0 ?
80 COL. PRINTER ?
101
PRINT HEADING (80 COL.)
PRINT HEADING (132 COL.)
IIOUT ≠6?
IIOUT ≠6?
IIOUT =3 ?
CONVERT FORCES TO STRESS
107
PRINT VARIABLES VS. TIME
130
IIOUT =6?
80 COL. PRINTER ?
131
PRINT 132 COL. VARIABLES
PRINT 80 COL. VARIABLES
135
PRINT EXTREME VALUES
RETURN

OUTPUT



NOTE THAT PLOTTING INVOLVES CALLS TO SUBROUTINES FPLOT, FMOVE, FSCHAR, FCHAR AS WELL AS FSCALE. THESE ROUTINES MAY OR MAY NOT BE AVAILABLE IN THE USER'S FORTRAN LIBRARY. CONVERSIONS TO THE STANDARD CALCOMP SOFTWARE ARE AVAILABLE.

*ISEG(19) INDICATES CURRENT 6-OPTION VARIABLE

5. LIST OF COMMON VARIABLES

Major variables used in WEAP are stored in COMMON. The following variables appear in order:

Item No.	Name	Type Dimension	Description
1	VINH	Real 10	Initial velocity of hammer components just prior to impact; loaded in STARTC, MAIN.
2	DINH	Real 10	Initial displacement of hammer components; otherwise as in VINH.
3	AOH, VOH DOH	Real 10	Acceleration, velocity and displacement of hammer components at the end of previous time increment. Temporarily used in STARTC, DIESEL, AND AIRSTM.
4	ANH, VNH DNH	Real 10	As in 3 but for current time increment.
5	STH	Real 10	Stiffness of hammer segments; loaded in HAEL and IPTN.
6	HM	Real 10	Mass of hammer segments, otherwise as in 5.
7	AM	Real 10	Assembly masses; loaded in HAEL.
8	STA	Real 10	Assembly stiffnesses; loaded in HAEL.
9	MA	Integer	Number of assembly segments.
10	ESOIL	Real	The soil's coefficient of restitution, squared; loaded in IPTN; used in SRESN.
11	AOP, ANP	Real 99	Acceleration of pile segments at end of previous and at end of current time increment, respectively; loaded in STARTC, PILEAN, DIESEL and AIRSTM.
12	DOP, DNP	Real 99	As in 11 but for pile displacement.

Item No.	Name	Type Dimension	Description
13	VOP, VNP	Real 99	As in 11 but for pile velocities.
14	STP	Real 99	As in 5 but for pile stiffnesses.
15	PM	Real 99	As in 6 but for pile masses.
16	CDP	Real 99	Pile damping parameters; loaded in IPTN.
17	RES, RESO	Real 99	Static soil resistance for end of current and end of previous time increment, respectively. Initialized in AIRSTM, DIESEL, SRESN.
18	SJ	Real 99	Soil damping parameter.
19	SOK	Real 99	Static soil stiffness; loaded in IPTN and MAIN.
20	QS	Real 99	Soil quake; loaded in IPTN.
21	SU	Real 99	Ultimate static resistance. Initialized in SOILN: reloaded in IPTN and MAIN.
22	SPLICE	Real 99	Splice force or slack displacement. Loaded in IPTN.
23	DEPIB	Real	Distance between exhaust ports and impact block. Loaded in HAEL.
24	ARAM	Real	Cross sectional area of ram (bottom); loaded in HAEL.
25	ECUS, ECAP, EPT, EANV	Real	Coefficients of restitution (squared) of pile cushion, capblock, pile top and impact block; loaded in IPTN.
26	VFALL	Real	Ram velocity at time of port closure (diesel) or impact (air/steam). Loaded in IPTN, DOWN, VACHAM, MAIN.
27	VCHAM	Real	Volume of combustion chamber; loaded in HAEL.

Item No.	Name	Type Dimension	Description
28	XPT	Real	Total pile length; loaded in IPTN.
29	SJJJ	Real	Ignition duration; loaded in HAEL or IPTN.
30	EMP	Real	Elastic modulus at pile top; loaded in IPTN.
31	RHO	Real	Mass density at pile top; loaded in IPTN.
32	DTH, DTP	Real	Time increments for hammer and pile, respectively; loaded in IPTN.
33	N, M	Integer	Number of pile, ram segments, respectively; loaded in IPTN and HAEL, respectively.
34	JRAT	Integer	Ratio of pile to hammer time increment; loaded in IPTN.
35	IULT	Integer	RULT - analysis counter; loaded in IPTN as total number of analyses, reloaded in MAIN as counter.
36	RULT	Real	Ultimate capacity; loaded in IPTN; reloaded in MAIN.
37	SOILM	Real	Soil mass; added to pile bottom element; use restricted.
38	DSACP	Real 4	Rounding displacements for impact zones; loaded in IPTN.
39	FPTO	Real	Force at pile top at end of last time increment; loaded in STARTC, DIESEL, AIRSTM.
40	IW	Integer	Write unit number; loaded in IPTN.
41	PCOM	Real	Pressure multiplier; loaded in IPTN.
42	TDEL	Real	Combustion delay; loaded in HAEL.
43	IOUT	Integer	Output option; loaded in IPTN.

Item No.	Name	Type Dimension	Description
44	OUT	Real 3200	Output storage for variables vs. time, loaded in FILL for 1 through 5 and FILL2 for 6 option; contains variables at increments of 200 locations for same time; used in OUT2 and OUTPUT.
45	EXPP	Real	Combustion exponent; loaded in HAEL.
46	TEMI, TEMO	Real	Gas temperature; initial value and value at end of previous time increment; loaded in STARTC.
47	INP	Integer 13	Contains segment numbers of up to 13 pile segments for which output is desired; loaded in IPTN or JJNP.
48	STROKO	Real	Stroke at beginning of analysis; loaded in IPTN and MAIN.
49	STROKN	Real	Rebound stroke; loaded in UP and MAIN.
50	VO	Real	Chamber volume at end of previous time increment; loaded in STARTC and DIESEL.
51	PO	Real	As in 50 but for pressure.
52	DFIN	Real	Final set; loaded in DIESEL, AIRSTM.
53	JDOUT	Integer	Number of time increments which are skipped between output values minus 1; loaded in AIRSTM, DIESEL.
54	JPMAX	Integer	Maximum time counter of values stored in OUT; loaded in FILL or FILL2.
55	EX	Real 600	Stores extreme values obtained in an analysis. Loaded in FILL or FILL2.
56	ICOL	Integer	Printer column indicator (0 = 80 columns, > 0 = 132 columns). Loaded in IPTN.
57	FINTMX	Real	Stores both maximum interaction force and cycle time. Loaded in AIRSTM, DIESEL, STARTC.

Item No.	Name	Type Dimension	Description
58	TEMAX	Real	Maximum analysis time; loaded in IPTN.
59	RESULT	Real 100	Contains summary results from all analyses; subscript 1-10 = RULT 11-20 = Blow Count 21-30 = Stroke 31-40 = Min. Stress 41-50 = Max. Stress 51-60 = Blow Rate 61-70 = Fuel Setting 71-80 = Bounce Chamber Pressure 81-100 = Not used; loaded in MAIN.
60	ISMITH	Integer	Damping option; loaded in IPTN.
61	ITER	Integer	Iteration counter; loaded in IPTN.
62	ITYPH	Integer	Hammer type; loaded in HAEL.
63	IPREIG	Integer	Preignition indicator; loaded in STARTC.
64	VFALLM	Real	Velocity at which uplift occurs; loaded in DOWN.
65	STRMAX	Real	Stroke at which uplift occurs; loaded in DOWN.
66	DCYL	Real	Displacement of cylinder; loaded in DIESEL, UP.
67	PBAR	Real 20	Array containing the following hammer properties in order: (for variable description see the User's Manual, Chapter 4) ART, DSF, not used, EXPB, VCT, DEPBB, DBBT, RWH, DINJ, STRM, P1, P2, P3, P4, P5, EFFICY, Mass of ram (kips sec^2/ft), RWH (Air/Steam), POWSCA, RAM; Loaded in HAEL and IPTN.
68	AREA	Real 99	Cross sectional areas of pile segments; loaded in PIEL.
69	JEX	Integer 600	Time counter values corresponding to EX array; loaded in FILL or FILL2.

APPENDIX A

PROGRAM LISTING

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CHI/OS  22 JUN 76:        RUN 2       GOBLE H  (134600,8)                             14:55:26         DATE: 22 JUN 76

  SEQ. NO. 3901649



AF ASG PCF=CED,134600,8,                                          LENGTH  232.   LAST WRITTEN 18 JUN 76 AT 14:02:24


Δ CUR
CUR OF MARCH 3, 1976                                              TUESDAY, JUNE 22, 1976 AT 14:55:27
  1.  LIST IPTN
         IPTN                     SYMBOLIC FORTRAN  18 JUN 76  14:01:37   72   76    5   00226255    2465
           1              SUBROUTINE IPTN (JSELEC,ISEG,YMAX,ALPH,TITLE,IOSTR,STRM)                 32     76      000004 0
           2              COMMON VINH,DINH,AOH,VOH,DOH,ANH,VNH,DNH,STH,HM,AM,STA,MA,ESOIL,          1     76      000016 5
           3             1 AOP,ANP,DOP,DNP,VOP,VNP,STP,PM,CDP,RES,RESO,SJ,SOK,QS,SU,                1     76      000033 0
           4             2 SPLICE,DEPIB,ARAM,ECUS,ECAP,EPT,EANV,VFALL,VCHAM,XPT,SJJJ,               1     76      000046 2
           5             3 EMP,RHO,DTH,DTP,N,M,JRAT,IULT,RULT,SOILM,DSACP,                          1     76      000061 5
           6             4 FPTO,IW,PCOM,TDEL,IOUT,OUT,EXPP,TEMI,TEMO,INP,STROKO,STROKN,VO,PO        1     76      000073 2
           7             5 ,DFIN,JDOUT,JPMAX,EX,ICOL,FINTMX, TEMAX,RESULT,ISMITH,ITER               1     76      000110 0
           8             6 ,ITYPH,IPREIG,VFALLM,STRMAX,DCYL,PBAR,AREA,JEX                          53     76      000123 3
           9              COMMON/SLAK/OPEN(99)                                                     74     76      000134 5
          10              DIMENSION VINH(10),DINH(10),AOH(10),VOH(10),DOH(10),ANH(10),              1     76      000141 2
          11             1 VNH(10),DNH(10),STH(10),HM(10), VNP(99),                                 1     76      080154 5
          12             2 AOP(99),ANP(99),DOP(99),DNP(99),VOP(99),STP(99),PM(99),CDP(99),          1     76      000165 1
          13             3 RES(99),RESO(99),SJ(99),SOK(99),QS(99),SU(99),SPLICE(99),                1     76      000201 3
          14             4DSACP(3),OUT(3200),INP(13),EX(600),RESULT(100),JEX(600)                  53     76      000214 5
          15             1 ,AP(20),XP(20),TITLE(10),EE(4),SMITH(2),VISCOU(2),DTYP(2)                1     76      000227 4
          16             2 ,AM(10),STA(10),RP(20),EP(20),ALPH(99),HNAME(2),JSELEC(13),              9     76      000243 0
          17             3 ISEG(15),PBAR(20),AREA(99)                                              52     76      000256 4
          18        C                                                                              70     76      000264 4
          19        C     INITIALIZE                                                               70     76      000265 5
          20        C                                                                              70     76      000271 0
          21              DATA  SMITH,VISCOU  /4H SMI,4HTH   ,4H VIS,4HCOUS /                       1     76      000272 1
          22              IW=6                                                                     43     76      000303 4
          23              ICOL=132                                                                 46     76      000305 3
          24              IR=5                                                                     43     76      000310 0
          25              NHAMR = 100                                                              60     76      000311 5
          26              PELE=5.0                                                                 43     76      000314 5
          27              NLIM=98                                                                  43     76      000317 2
          28              MLIM=10                                                                  43     76      000321 4
          29              DO 30 I=1,3                                                              43     76      000324 0
          30          30  DSACP(I)=.01                                                             43     76      000327 0
          31              CDP(1)=0.0                                                               43     76      000332 4
          32              SPLICE(1)=0.                                                             43     76      000335 3
          33              DO 40 I=2,99                                                             43     76      000340 4
          34              SPLICE(I)=-5000.0                                                        43     76      000343 5
          35          40  CDP(I)=0.0                                                               43     76      000347 5
          36              EXPP=1.3                                                                 43     76      000353 1
          37              TEMI=25.0                                                                43     76      000355 4
          38              SOILM=0.0                                                                43     76      000360 2
          39              SJJJ=0.0                                                                 43     76      000363 0
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      DULT=0.0                                                              43   76   000365 3
      DO 146 I=1,13                                                         27   76   000370 0
  146 JSELEC(I)=0                                                           27   76   000373 2
C                                                                           70   76   000377 0
C     START TO READ DATA                                                    70   76   000400 1
C     READ AND PRINT TITLE                                                  70   76   000404 4
C     IF NO MORE DATA - QUIT                                                70   76   000411 3
C                                                                           70   76   000416 4
 1    FORMAT (20I4)                                                          1   76   000417 5
 2    FORMAT (10F8.2)                                                        1   76   000423 4
 4    FORMAT (1H1,19X,44HW E A P  -  WAVE EQUATION ANALYSIS FOR PILES//     72   76   000427 5
     110X,64HTHIS PROGRAM WAS PREPARED FOR THE FEDERAL HIGHWAY ADMINISTR    69   76   000444 3
     2ATION/22X,38HBY GOBLE & ASSOCIATES, CLEVELAND, OHIO//10X,10A4)        71   76   000461 1
      READ (IR,5,END=9876,ERR=1020) TITLE                                   70   76   000475 1
      GO TO 9877                                                            61   76   000504 2
 9876 IW =-1000                                                             61   76   000507 1
      RETURN                                                                61   76   000512 4
 9877 CONTINUE                                                              61   76   000514 5
      ALPH(1) = 1.0                                                         67   76   000520 1
 5    FORMAT (10A4)                                                         70   76   000523 3
      WRITE (IW,4) TITLE                                                    70   76   000527 2
C                                                                           70   76   000533 3
C     READ OPTIONS AND SPECS.                                               70   76   000534 4
C                                                                           70   76   000542 0
      READ (IR,1,END=9876,ERR=1020) IOUT,IJJ,IHAMR,IOSTR,IFUEL,IPEL,N,      70   76   000543 1
     1 ISPL,NCROSS,IBEDAM,IPERCS,ISMITH,ITYS,MAXJRT,IPHI,ITER,IDAHA         70   76   000557 2
C                                                                           70   76   000573 1
C     CHECK AND/OR CORRECT OPTIONS                                          70   76   000574 2
C                                                                           70   76   000602 4
      II=IABS(IOUT)                                                         43   76   000603 5
      PM(99) = 0.0                                                          62   76   000607 1
      IF (IDAHA.EQ.0) PM(99) = 2.0                                          69   76   000612 2
      IF (IDAHA.GT.0) PM(99) = IDAHA                                        62   76   000620 2
      CDP(99) = 0.0                                                         58   76   000626 4
      IF (IPERCS.LT.0.0) CDP(99) = 1.0                                      58   76   000632 0
      IPERCS = IABS(IPERCS)                                                 70   76   000640 4
      IF (IBEDAM.EQ.0) IBEDAM = 1                                           64   76   000645 2
      IF (IBEDAM.LT.0) IBEDAM = 0                                           64   76   000653 0
      IF (II.GE.20) II=II-20                                                43   76   000660 4
      IF (II.GE.10) II=II-10                                                43   76   000665 3
      IF (II.GT.6) IOUT=0                                                   43   76   000672 2
      IF (IFUEL.LT.1.OR.IFUEL.GT.5) IFUEL=1                                 41   76   000676 4
      IF (ITER.EQ.0) ITER=2                                                 60   76   000706 1
      IF (ITER.LT.0) ITER=0                                                 60   76   000712 5
      IF (MAXJRT.LE.0) MAXJRT=1                                             21   76   000717 3
      IF (IHAMR.GT.NHAMR) WRITE (IW,3)                                       1   76   000724 5
      IF (IHAMR.LT.0) IHAMR=0                                               60   76   000733 3
      IF (II.EQ.6) IJJ = 0                                                  67   76   000740 3
 3    FORMAT (27H UNKNOWN HAMMER TYPE, SORRY)                                1   76   000745 0
      IF (IHAMR.GT.NHAMR) STOP                                               1   76   000755 2
   10 FORMAT (48H ***N WAS NOT SET,EXTENDED INPUT NOT POSSIBLE***)          25   76   000762 3
      IF (N.LE.1.AND.IPEL.GT.0) WRITE (IW,10)                               67   76   000776 3
      IF (N.LE.1.AND.IPEL.GT.0) STOP                                        67   76   001006 2
C                                                                           70   76   001014 4
```

```
 C      EXTENDED PILE INPUT                                              70    76    001015 5
 C                                                                       70    76    001022 3
        IF (IPEL.EQ.2) READ (IR,2) (STP(I),I=1,N)                        25    76    001023 4
        IF (IPEL.EQ.2) READ (IR,2) (PM(I),I=1,N)                         25    76    001033 5
        IF (IPEL.GE.1) READ (IR,2) (ALPH(I),I=1,N)                        1    76    001043 5
        IF (IPEL.LT.2) GO TO 142                                         13    76    001054 1
      9 FORMAT (50H MASSES AND STIFFNESSES FOR FIRST ELEMENT ARE NOT     21    76    001061 2
       *9HSPECIFIED)                                                     21    76    001075 3
        IF (PM(1).LT.10.E-8.OR.STP(1).LT.10.E-8) WRITE (IW,9)            21    76    001100 5
        IF (PM(1).LT.10.E-8.OR.STP(1).LT.10.E-8) STOP                    21    76    001113 0
        DO 143 I=1,N                                                     13    76    001123 5
        STP(I)=STP(I)*12.0                                               53    76    001127 0
        PM(I)=PM(I)/32.17                                                53    76    001133 1
        IF (STP(I).LT.0.0001) STP(I)=STP(I-1)                            53    76    001137 1
    143 IF (PM(I).LT.10.E-8) PM(I)=PM(I-1)                               53    76    001146 4
    142 CONTINUE                                                         13    76    001156 2
        DO 600 I=2,99                                                    66    76    001161 3
    600 IF (ALPH(I).LT.0.0001) ALPH(I)=ALPH(I-1)                         21    76    001164 5
        M1=8                                                              1    76    001175 3
        M2=9                                                              1    76    001177 2
 C                                                                       70    76    001201 1
 C      DRIVING SYSTEM INPUT                                             70    76    001202 2
 C                                                                       70    76    001207 1
        READ (IR,2) HM(M2),STH(M1),STH(M2)                                9    76    001210 2
        HM(M2)=HM(M2)/32.17                                               9    76    001217 2
        STH(M2) = STH(M2)*12.                                             1    76    001223 4
        STH(M1) = STH(M1)*12.                                             1    76    001230 2
        READ(IR,2) (EE(I),I=1,4),TEMAX,B,A,C                             54    76    001235 0
        IF (STH(M2).LT.1.0) EE(4) = 1.0                                  60    76    001244 2
        DO 141 I=1,4                                                      1    76    001252 5
        IF (EE(I).LT.0.00001.OR.EE(I).GT.1.0) EE(I) = 0.85               64    76    001256 0
    141 EE(I)=EE(I)**2                                                    1    76    001267 4
        EANV=EE(1)                                                        1    76    001273 5
        ECAP=EE(2)                                                        1    76    001276 4
        EPT=EE(3)                                                         1    76    001301 3
        ECUS=EE(4)                                                        1    76    001304 1
 C                                                                        1    76    001307 0
 C      NCROSS EQL 0 MEANS UNIFORM                                        1    76    001310 1
 C                                                                       70    76    001316 0
 C      START PILE INPUT                                                 70    76    001317 1
 C                                                                       70    76    001323 2
        NN=2                                                              1    76    001324 3
        XP(1) = 0.0                                                       1    76    001326 2
        READ (IR,2) XPT,AP(1),EP(1),RP(1),SOILM,TDORGA,A1,B1,C1          69    76    001331 2
        ATP = AP(1)/144.0                                                38    76    001344 0
        IF (EP(1).LT.0.1) EP(1) = 29000.                                 60    76    001350 0
        IF (RP(1).LT.0.1) RP(1) = 492.                                   60    76    001356 4
        EMP=EP(1)*144.                                                   13    76    001365 0
        RHO=RP(1)/32170.                                                 13    76    001370 3
        IF (NCROSS.LT.1) GO TO 221                                       21    76    001374 2
        I=2                                                               1    76    001401 5
 C      FOR NONUNIFORM PILES                                             70    76    001403 3
    220 READ (IR,2) XP(I),AP(I),EP(I),RP(I)                               1    76    001410 2
        NN=I                                                              1    76    001420 1
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              IF (EP(I).LT.0.1) EP(I) = EP(I-1)                                       60     76     001422 0
              IF (RP(I).LT.0.1) RP(I)=RP(I-1)                                          1     76     001430 5
              I = I+1                                                                  1     76     001437 2
          12  FORMAT (48H PILE PROPERTIES AT BOTTOM OF PILE NOT SPECIFIED)            37     76     001441 4
              IF (XP(I-1).LT.XP(I-2)) WRITE (IW,12)                                   37     76     001455 4
              IF (XP(I-1).LT.XP(I-2)) STOP                                            37     76     001465 1
              IF (XP(I-1).LT.XPT) GO TO 220                                            1     76     001473 1
              GO TO 222                                                                1     76     001501 2
         221  CONTINUE                                                                 1     76     001504 0
              AP(2)=AP(1)                                                              1     76     001507 2
              XP(2)=XPT                                                               16     76     001512 2
              EP(2)=EP(1)                                                              1     76     001515 0
              RP(2)=RP(1)                                                              1     76     001520 0
         222  CONTINUE                                                                 1     76     001523 0
   C          DETERMINE NO. OF STATIONS SPECIFIED                                     70     76     001526 1
              DO 2100 I=1,20                                                           1     76     001535 4
              IF (XP(I).GE.XPT-10E-8) GO TO 2101                                       1     76     001541 1
        2100  CONTINUE                                                                 1     76     001550 1
        2101  NN=I                                                                     1     76     001553 3
              IF (IPEL.NE.0) GO TO 2102                                                1     76     001556 1
              N1=XPT/PELE+1                                                            7     76     001563 3
              IF (N.LE.1) N=N1                                                         7     76     001566 5
              IF (N.GT.NLIM) N=NLIM                                                    1     76     001572 4
   C                                                                                  70     76     001577 2
   C          DETERMINE PILE SEGMENTS                                                 70     76     001600 3
   C                                                                                  70     76     001605 5
        2102  CALL PIEL(NN,N,XP,AP,EP,RP,STP,PM,ALPH,IOUT,IW,ICOL,IPEL,               60     76     001607 0
             1 AREA)                                                                  52     76     001622 5
   C                                                                                  70     76     001625 1
   C          OBTAIN HAMMER DATA                                                      70     76     001626 2
   C                                                                                  70     76     001632 5
              CALL HAEL(IHAMR,DTCRH,DTCRA,HNAME,IR)                                   40     76     001634 0
              IF (ABS(TDORGA).GT.10.E-8) SJJJ = TDORGA                                69     76     001643 3
              STRM = PBAR(10)                                                         39     76     001653 3
   C                                                                                  70     76     001657 1
   C          CHECK ON SELF-GENERATED PILE DATA                                       70     76     001660 2
   C                                                                                  70     76     001667 3
              DO 150 I=1,N                                                            41     76     001670 4
              IF (STP(I).GT.100.0.AND.PM(I).GT.10E-8) GO TO 150                       42     76     001673 5
           7  FORMAT (54H PILE MASSES OR STIFFNESSES TOO SMALL,CHECK INPUT INFO)      41     76     001705 2
              WRITE (IW,7)                                                            41     76     001722 1
              STOP                                                                    41     76     001725 2
         150  CONTINUE                                                                41     76     001727 1
   C          FUEL PRESSURE AND PRESSURE MULTIPLIER FOR DIESELS                       70     76     001732 2
              PSPEC=PBAR(10+IFUEL)                                                    41     76     001744 1
              IF (PSPEC.LT.0.01.AND.IFUEL.GT.1) PSPEC=1000.0                          41     76     001750 4
              IF (VCHAM.GT.10.E-8) PCOM=PSPEC/(14.7*(1.+DEPIB*ARAM/VCHAM)**1.35)      57     76     001761 4
              NM1=N-1                                                                  1     76     001776 1
              N1=N+1                                                                  18     76     002000 3
              IF (A.GT.0.1) PCOM = A                                                  17     76     002002 4
              SOILM=SOILM/32.17                                                       41     76     002007 3
              IF (A1.GT.10.E-8) DSACP(1)=A1                                           41     76     002013 3
              IF (B1.GT.10.E-8) DSACP(2)=B1                                           41     76     002021 4
              IF (C1.GT.10.E-8) DSACP(3)=C1                                           41     76     002027 5
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       IF (C.GT.0.1) EXPP = C                                          17   76   002036 0
       IF (ABS(B).GT.10.E-8) TDEL=B                                    58   76   002042 5
 C                                                                     70   76   002050 5
 C     READ SOIL AND ADDITIONAL HAMMER DATA                            70   76   002052 0
 C                                                                     70   76   002061 4
       READ (IR,2,END=9876,ERR=1020) QS(1),QS(N+1),SJ(1),SJ(N+1),RULT, 70   76   002062 5
      1 ESOIL,STROKE,EFFICY,PSTEAM,RWT                                 70   76   002076 5
       SJS=SJ(1)                                                       55   76   002105 3
       SJT=SJ(N+1)                                                     55   76   002110 1
       IF (EFFICY.GT.0.001) PBAR(16)=EFFICY                            49   76   002113 1
       IF (RWT.GT.0.0.AND.ITYPH.NE.3) PBAR(8)=RWT                      50   76   002122 3
       IF (ITYPH.NE.3) GO TO 160                                       49   76   002132 5
 C                                                                     70   76   002140 1
 C     FOR A/S HAMMERS OVERRIDE FILE DATA                              70   76   002141 2
 C                                                                     70   76   002150 4
       IF (STROKE.GT.0.001) PBAR(10)=STROKE                            49   76   002151 5
       IF (STROKE.LT.0.01) STROKE=STRM                                 52   76   002161 1
       IF (RWT.GT.0.0) PBAR(18)=RWT                                    50   76   002167 4
       IF (PSTEAM.GT.PBAR(11)) PSTEAM=PBAR(11)                         49   76   002175 4
       IF (PSTEAM.LT.0.001) PSTEAM=PBAR(11)                            49   76   002205 3
 C     DOUBLE ACTING AIR/STEAM STROKE (EQUIVALENT)                     70   76   002214 5
       IF (PBAR(11).GT.10.0) STROKE=PBAR(10)*(1.0+(PSTEAM*PBAR(18))/(  66   76   002225 4
      1 PBAR(11)*PBAR(17)))                                            66   76   002241 3
       VFALL=SQRT(STROKE*64.34*PBAR(16))                               49   76   002246 1
       WRITE (IW,161) STROKE,PBAR(16),VFALL                            49   76   002255 0
   161 FORMAT (16H STROKE (EQUIV.) ,F4.1,4H FT, ,11H EFFICIENCY ,      49   76   002264 2
      1 F5.2,18H , IMPACT VELOCITY ,F5.1,5H FT/S )                     49   76   002300 1
                                                                       49   76   002310 5
       IF (PBAR(11).GT.10.0) WRITE (IW,162) PSTEAM,PBAR(11),PBAR(18),  49   76   002311 4
      1 PBAR(17)                                                       49   76   002325 3
   162 FORMAT (22H ACTUAL/ MAX. PRESSURE ,F6.1,1H/,F6.1,23H PSI, REACT./R 54   76   002330 2
      1AM WEIGHT,F6.1,1H/,F6.1,5H KIPS )                               49   76   002345 3
       DO 164 I=21,30                                                  69   76   002354 3
   164 RESULT(I) = STROKE                                              69   76   002360 0
   160 CONTINUE                                                        49   76   002365 0
 C                                                                     70   76   002370 1
 C     DETERMINE ULTIMATE CAPACITY TO BE ANALYZED                      70   76   002371 2
 C                                                                     70   76   002402 0
       RULT=2.*RULT                                                    25   76   002403 1
       RMAX=RULT                                                       60   76   002406 2
       IF (ESOIL.LT.10.E-4.OR.ESOIL.GT.1.0) ESOIL=1.0                  50   76   002411 0
       ESOIL=ESOIL**2.                                                  7   76   002422 0
       DO 114 I=2,N                                                    64   76   002425 4
       SJ(I)=SJ(1)                                                      1   76   002430 5
   114 QS(I)=QS(1)                                                      1   76   002433 5
 C                                                                     70   76   002437 4
 C     READ EXTENDED SOIL INPUT                                        70   76   002440 5
 C                                                                     70   76   002446 2
       IF (ITYS.LT.-1) READ(IR,2) (QS(I),I=1,NI)                       58   76   002447 3
       IF (ITYS.LT.0) READ (IR,2) (SJ(I),I=1,NI)                       25   76   002457 4
       IF (ITYS.LT.-1) READ(IR,2) (SU(I),I=1,NI)                       58   76   002467 5
       IF (ITYS.GE.0) GO TO 230                                        58   76   002500 0
       DO 200 I=2,NI                                                   25   76   002505 1
       IF (QS(I).LT.0.0001) QS(I)=QS(I-1)                              25   76   002510 3
```

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      IF (SJ(I).LT.0.0001) SJ(I)=SJ(I-1)                                        25    76    002517 3
      IF (ITYS.LT.-1.AND.SU(I).LT.0.0001) SU(I)=SU(I-1)                         64    76    002526 3
  200 CONTINUE                                                                  26    76    002540 0
  230 CONTINUE                                                                  58    76    002543 2
C                                                                               70    76    002546 4
C     DISTRIBUTE RESISTANCE                                                     70    76    002547 5
C                                                                               70    76    002554 5
      IF (ITYS.GE.-1) CALL SOILN (ITYS,IPERCS,N,XPT,SU,IR,ALPH)                 58    76    002556 0
      SUS=0.                                                                    21    76    002571 0
      DO 184 I=1,N1                                                             21    76    002573 1
  184 SUS=SUS+SU(I)                                                             21    76    002576 3
      SUJ = SUS - SU(N1)                                                        25    76    002602 3
C                                                                               70    76    002606 4
C     DISTRIBUTE CASE DAMPING                                                   70    76    002607 5
C                                                                               70    76    002615 1
      DO 185 I=1,N1                                                             21    76    002616 2
      IF (ISMITH.GT.0.OR.I.EQ.N1) GO TO 187                                     64    76    002621 4
      IF(ITYS.LT.0)GO TO 1187                                                   74    76    002631 1
      IF (SUJ.LT.10.E-10) SJ(I)=SJ(I)/FLOAT(N)                                  64    76    002636 1
      IF (SUJ.GE.10E-10) SJ(I)=SJ(I)*SU(I)/SUJ                                  64    76    002646 1
 1187 CONTINUE                                                                  74    76    002656 1
      SJ(I)=SJ(I)*SQRT(STP(I)*PM(I))                                            64    76    002661 3
  187 CONTINUE                                                                  64    76    002667 5
      QS(I)=QS(I)/12.                                                           21    76    002673 1
      SU(I)=SU(I)/SUS                                                           21    76    002676 5
C                                                                               70    76    002702 3
C     CHECK QUAKES                                                              70    76    002703 4
C                                                                               70    76    002707 1
  185 IF (QS(I).LT.0.0001) QS(I)=.08333                                         21    76    002710 2
      IF (ISMITH.LT.1) SJ(N1)=SJ(N1)*SQRT(STP(N)*PM(N))                         28    76    002717 5
6     FORMAT(I4,2F8.2)                                                          74    76    002735 3
      DO 301 I=1,99                                                             76    76    002741 4
301   OPEN(I)=0.0                                                               74    76    002745 0
      IF (ISPL.LT.1) GO TO 144                                                  15    76    002750 4
C                                                                               70    76    002755 5
C     READ SPLICE AND PLOTTER INFO.                                             70    76    002757 0
C                                                                               70    76    002765 3
      DO 300 I=1,ISPL                                                            8    76    002766 4
      READ(IR,6,END=9876,ERR=1020),J,SPLICE(J),OPEN(J)                          74    76    003000 0
300   CONTINUE                                                                  74    76    003011 2
      DO 302 I=2,N                                                              75    76    003017 4
302   OPEN(I)=OPEN(I)+OPEN(I-1)                                                 74    76    003022 5
  144 CONTINUE                                                                  15    76    003030 5
      IF (IABS(IOUT).GT.9) READ (IR,2,END=1000,ERR=1020) YMAX                   70    76    003034 0
      IF (IABS(IOUT).GT.9) READ (IR,I,END=1000,ERR=1020) (ISEG(I),I=I,15        71    76    003046 4
     1)                                                                         36    76    003063 1
      GO TO 1003                                                                36    76    003064 4
 1000 CONTINUE                                                                  36    76    003067 3
 1001 FORMAT (51H INSUFFICIENT PLOTTER INFORMATION,THEREFORE VALUES ,           37    76    003072 5
     *11HARE ASSUMED)                                                           36    76    003107 4
      YMAX = 0.0                                                                71    76    003113 3
      DO 1004 I=1,15                                                            71    76    003116 2
 1004 ISEG(I) = 0                                                               71    76    003121 5
      WRITE (IW,1001)                                                           36    76    003125 4
```

```
 1003 CONTINUE                                                              36  76  003131 2
C     DETERMINE PILE DAMPING                                                24  76  003134 4
      DFAC=FLOAT(IBEDAM)/50.                                                24  76  003141 5
      DO 145 I=1,N                                                          24  76  003146 4
  145 CDP(I)=DFAC*SQRT(PM(I)*STP(I))                                        41  76  003151 5
C                                                                           70  76  003160 5
C     PRINT INPUT INFO                                                      70  76  003162 0
C                                                                           70  76  003166 1
      CALL OUTIN(SU,SJ,QS,STH,STP,HM,PM,IHAMR,EE,N,M,IW,XPT,ISMITH,          1  76  003167 2
     1HNAME,ESOIL,AP(1),EMP,RHO,SPLICE,CDP,ALPH,ITYPH)                      48  76  003203 0
      DO 876 I=1,2                                                           1  76  003214 3
      DTYP(I) = VISCOU(I)                                                    1  76  003217 4
      IF (ISMITH.EQ.1) DTYP(I)=SMITH(I)                                      1  76  003224 0
  876 CONTINUE                                                               1  76  003232 5
      IF (IPHI.LT.100.AND.ITYPH.LT.3) IPHI=140                              60  76  003236 1
      IF (IPHI.LT.100.AND.ITYPH.EQ.3) IPHI = 160                            60  76  003246 1
      PHI = FLOAT(IPHI)/100.                                                 1  76  003256 3
      PFAC = 1./PHI                                                         60  76  003263 2
    8 FORMAT (/15X,26HOPTIONS AND SPECIFICATIONS/                           64  76  003266 4
     1 4H PHI,F7.2,4X,12HS-DAMPING   ,2A4,4X,10HRWT (KIPS),F10.2/           62  76  003277 4
     2 5H IOUT,I6,4X,10HP-DAMPING ,I10,4X,14HSOIL DIST. NO.,I6/             62  76  003313 0
     3 6H IFUEL,I5,4X,6HJ SKIN,F14.2,4X,11HTDEL (SEC.),F9.4/                64  76  003326 1
     4 6H IOSTR,I5,4X,5HJ TOE,F15.2,4X,10HTEMAX (MS),F10.2)                 64  76  003340 5
      DO 188 I=2,N                                                          64  76  003353 1
      IF (SPLICE(I).GT.0.0) SPLICE(I) = -SPLICE(I)                          64  76  003356 2
      IF (ABS(SPLICE(I)).LT.10.E-8) SPLICE(I) = 10.E-8                      73  76  003367 0
      IF (SPLICE(I).LT.0.0.AND.SPLICE(I).GE.-.5)                            67  76  003400 2
     * WRITE (IW,189) I,SPLICE(I)                                           64  76  003410 4
  189 FORMAT (10H AT SEGMT.,I2,11H SLACK (FT),F10.5)                        73  76  003430 1
  188 CONTINUE                                                              65  76  003442 0
   47 FORMAT (7H SOILM=,F5.2,5H KIPS,8H DS ANV=,F5.3,                       70  76  003445 2
     1 8H DS CAP=,F5.3,9H DS PTOP=,F5.3)                                    43  76  003457 1
      IS = ITYS                                                             47  76  003466 2
      IF (IS.EQ.11) IS = 0                                                  47  76  003471 0
      WRITE (IW,8) PHI,DTYP,PBAR(8),IOUT,IBEDAM,IS,IFUEL,SJS,B,IOSTR,       62  76  003475 3
     1 SJT,TEMAX                                                            62  76  003511 3
  506 FORMAT (15X,10HEFFICIENCY,F10.3)                                      76  76  003514 3
      IF (ITYPH.LT.3.AND.PBAR(16).GT.0.001) WRITE (IW,506) PBAR(16)         76  76  003524 0
      IF (SOILM.GT.0.0.OR.A1.GT.0.0.OR.B1.GT.0.0.OR.C1.                     70  76  003537 4
     1 GT.0.0) WRITE (IW,47) SOILM,A1,B1,C1                                 70  76  003551 1
      IULT = 0                                                               1  76  003560 5
      IF (RULT.GT.10.E-4) GO TO 502                                         36  76  003563 2
      IF (RULT.LT.0.) GO TO 191                                             21  76  003571 3
C                                                                           70  76  003576 5
C     GENERATE RULT VALUES                                                  70  76  003600 0
C                                                                           70  76  003604 5
      RULT = SQRT(EMP*RHO)*ATP*3.0                                          38  76  003606 0
      I = RULT*0.05 + 0.5                                                   47  76  003614 0
      IF (I.LT.1) I = 1                                                     47  76  003620 2
      RULT = I * 20.0                                                       47  76  003624 2
      IF (EMP.LT.3000000.) RULT=RULT/2.0                                     1  76  003630 0
      RMAX=RULT*5.0                                                         60  76  003637 0
      IULT=10                                                               11  76  003642 2
      GO TO 502                                                             21  76  003644 4
```

```
   191  CONTINUE                                                           1     76     003647 2
C                                                                         70     76     003652 4
C       READ RULT VALUES                                                  70     76     003653 5
C                                                                         70     76     003660 0
        READ (IR,2) (RESULT(I),I=1,10)                                    21     76     003661 1
        DO 500 I=1,10                                                     21     76     003667 3
        IF (RESULT(I).LT.0.001) GO TO 501                                 70     76     003672 5
   500  CONTINUE                                                          70     76     003701 4
    501 CONTINUE                                                          21     76     003705 0
        RMAX=RESULT(I-1)*2.0                                              60     76     003710 1
        IULT = I-1                                                        38     76     003714 4
C                                                                         70     76     003717 3
C       CONVERT FIRST RULT TO KIPS                                        70     76     003720 4
C                                                                         70     76     003726 3
        RULT=RESULT(1)*2.0                                                54     76     003727 4
    502 CONTINUE                                                          21     76     003733 5
        IF (ITYPH.NE.1) GO TO 505                                         42     76     003737 0
        DFFALL=STROKE-DEPIB                                                1     76     003744 2
        IF (DFFALL.GT.0.001) GO TO 106                                     1     76     003750 4
C       STROKE FOR VACCUUM HAMMER                                         70     76     003757 0
        STROKE = 5.                                                        1     76     003764 4
        IF (PBAR(20).GT.10.E-8) STROKE=3.0                                58     76     003767 4
        DCYL =0.0                                                         58     76     003776 4
        DFFALL = STROKE-DEPIB                                              1     76     004001 2
   106  CONTINUE                                                           1     76     004006 0
C                                                                         70     76     004011 2
C       DETERMINE RAM VELOCITY AT PORTS                                   70     76     004012 3
C                                                                         70     76     004021 2
        IF (DFFALL.GT.0.0) VFALL=SQRT(64.34*DFFALL)                       59     76     004022 3
        IF (PBAR(20).GT.10.E-8) CALL VACHAM(PBAR,ARAM,DEPIB,DCYL,STROKE,  58     76     004033 0
       1 FSUCK,VFALL,IOUT,IW)                                             58     76     004047 1
    505 CONTINUE                                                          50     76     004054 0
C       SOIL STIFFNESS                                                    70     76     004057 1
        DO 115 I=1,N1                                                     15     76     004063 0
        SU(I)=SU(I)*RULT                                                   1     76     004066 2
        SOK(I) = SU(I) / QS(I)                                             1     76     004072 1
   115  CONTINUE                                                           1     76     004077 0
C       CHECK TIME INCREMENT INCLUDING SOIL STIFFNESS                     70     76     004102 2
        RRAT = RMAX/RULT                                                  60     76     004113 3
        IF (CDP(99).GT.0.5) RRAT = 1                                      61     76     004117 2
        STCR = STP(N)+SOK(N)+SOK(N1)                                      62     76     004125 2
        DTCRP = PM(N)/(STCR*RRAT)                                         62     76     004133 2
        IF (CDP(99).GT.0.5) DTCRP=PM(N)/(STP(N)+SOK(N)+(RMAX-RULT)/QS(N1))61     76     004140 4
        NM1=N-1                                                           60     76     004155 1
        DO 1010 I=1,NM1                                                   60     76     004157 3
        ST = STP(I+1)                                                     60     76     004163 1
        IF (STP(I).GT.ST) ST=STP(I)                                       60     76     004166 3
        ST=ST+SOK(I)*RRAT                                                 60     76     004174 1
        DTM=PM(I)/ST                                                      60     76     004200 1
        IF (DTM.LT.DTCRP) DTCRP=DTM                                       60     76     004203 2
   1010 CONTINUE                                                          60     76     004211 0
        DTCRP=SQRT(DTCRP)                                                 60     76     004214 2
C       CUSHION DAMPER                                                    70     76     004220 2
        PM(99) = PM(99)*SQRT(STH(M)*HM(M))/50.0                           69     76     004224 1
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C       DETERMINE TIME INCREMENTS FOR HAMMER AND PILE GTR CRITICAL          1    76    004234 0
        DTP=PFAC*DTCRP                                                      1    76    004247 3
        DTH=PFAC*DTCRH                                                      1    76    004253 0
C       CHECK TIME INCREMENTS                                              70    76    004256 3
        IF (DTH.LT.10.E-6.OR.DTP.LT.10.E-6) WRITE (IW,119)                 55    76    004263 3
        IF (DTH.LT.10.E-6.OR.DTP.LT.10.E-6) STOP                           55    76    004275 1
    119 FORMAT (47H HAMMER OR PILE T.I. EQUAL TO ZERO, CHECK INPUT )       55    76    004305 1
        IF (DTCRA.LT.DTCRH) DTH=PFAC*DTCRA                                  1    76    004321 2
        IF (DTH.GT.DTP) GO TO 33                                           41    76    004330 2
        DO 118 JRAT=1,20                                                   41    76    004335 3
        IF (FLOAT(JRAT+1)*DTH.GT.DTP) GO TO 117                            41    76    004341 2
    118 CONTINUE                                                           41    76    004351 1
C                                                                          70    76    004354 2
C       DETERMINE TIME INCREMENTS IF HAMMER INCREMENTS SMALLER THAN PILE   70    76    004355 3
C       T.I.                                                               70    76    004372 0
C                                                                          70    76    004374 1
    117 IF (MAXJRT.LT.1) MAXJRT=1                                          41    76    004375 2
        IF (JRAT.GT.MAXJRT) JRAT=MAXJRT                                    41    76    004403 3
        DTP=DTH*FLOAT(JRAT)                                                41    76    004412 0
        GO TO 22                                                           41    76    004416 2
     33 DTH=DTP                                                            41    76    004420 5
        JRAT=1                                                             41    76    004423 4
     22 CONTINUE                                                           41    76    004425 5
   21   FORMAT (15X,15HTIME INCR. (MS),F5.3)                               62    76    004430 5
        DTPM=DTP*1000.                                                      1    76    004440 5
C                                                                          70    76    004444 2
C       SET UP LOADING STIFFNESSES                                         70    76    004445 3
C                                                                          70    76    004453 2
        IF (ITYPH.EQ.3) STH(M1)=STH(M1)*ECUS                               54    76    004454 3
        IF (ITYPH.LT.3) STH(M1)=STH(M1)*ECAP                               54    76    004463 5
        IF (MA.GT.0) STA(MA)=STA(MA)*ECAP                                  54    76    004473 1
        STH(M2) = STH(M2)*ECUS                                              1    76    004502 0
        STP(1) = STP(1)*EPT                                                 1    76    004506 5
        STH(M) = STH(M)*EANV                                                1    76    004513 1
        WRITE (IW,21) DTPM                                                 62    76    004517 4
        STROKO = STROKE                                                     1    76    004523 5
C       SET UP OUTPUT VARIABLES                                            70    76    004527 3
        IF (IJJ.EQ.1) READ (IR,1,END=1005,ERR=1020) (INP(I),I=1,13)        70    76    004534 5
        GO TO 1006                                                         36    76    004550 1
   1005 IJJ=0                                                              36    76    004553 0
   1006 CONTINUE                                                           36    76    004555 5
        IF (IJJ.NE.1) CALL JJNP (ICOL,N,INP,JMAX)                          11    76    004561 1
C   ... JMAX=NO. OF PILE VARIABLES THAT CAN BE PRINTED (JMAX.LE.N)         11    76    004571 2
C       NOT USED HERE, RECOMPUTED IN ANALYSIS                              11    76    004605 3
        RETURN                                                              1    76    004615 2
   1020 CONTINUE                                                           70    76    004617 3
   1021 FORMAT (11H DATA ERROR)                                            70    76    004622 5
        WRITE (IW,1021)                                                    70    76    004630 5
        STOP                                                               70    76    004634 3
        END                                                                 1    76    004636 2
                                                   .9760 CRU

END OF RUN:     2 CRU    ACCOUNT: 134600,8    CARDS:    4 IN    0 OUT    PAGES:   10    CORE USAGE:      25.0K MAX.      20.8K AVERAGE
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PIEL                SYMBOLIC FORTRAN  07 JUN 76  12:31:33   20   24    5   00132516      522
             SUBROUTINE PIEL (MP,N,XP,AP,EP,RP,STP,PM,ALPH,IOUT,IW,ICOL,          16   24   000004 0
           1 IPEL,AREA)                                                            14   24   000017 2
             DIMENSION XP(20),AP(20),EP(20),RP(20),STP(99),PM(99),ALPH(99)         1   24   000022 3
           1 ,AREA(99)                                                             14   24   000036 1
             SALPH=0.0                                                              1   24   000046 2
             DO 101 I1=1,N                                                          1   24   000051 0
         101 SALPH=SALPH+ALPH(I1)                                                   1   24   000054 2
      C                                                                            18   24   000061 3
      C      ELEMENT COUNTER I2, CROSS SECTION INDEX I3                            18   24   000062 4
      C                                                                            18   24   000073 2
             IF (IPEL.EQ.2) GO TO 108                                              24   24   000074 3
             I2=1                                                                   1   24   000101 4
             I3=2                                                                   1   24   000103 3
             IJ=I3-1                                                                1   24   000105 2
             XT=0.0                                                                 1   24   000107 4
             XB=(XP(MP)*ALPH(I2))/SALPH                                             1   24   000111 5
             DX = XB                                                               22   24   000117 2
             AT=AP(1)                                                               1   24   000121 4
             RPT=RP(1)                                                              7   24   000124 1
             EPT=EP(1)                                                              7   24   000126 5
             GO TO 110                                                              1   24   000131 3
      C                                                                            18   24   000134 1
      C      REPEAT 102 LOOP FOR EVERY SEGMENT I2                                  18   24   000135 2
      C                                                                            18   24   000145 0
         102 XT=XB                                                                  1   24   000146 1
             DX = (XP(MP)*ALPH(I2))/SALPH                                          18   24   000150 5
             XB = XT + DX                                                          19   24   000156 5
        110  STP(I2)=10.E12                                                        21   24   000166 3
             PM(I2)=0.0                                                             1   24   000172 5
             AREA(I2)=0.0                                                          14   24   000175 4
      C                                                                            18   24   000200 5
      C      REPEAT 103 LOOP UNTIL NEXT CROSS SECTION DEPTH IS BELOW SEGMENT       18   24   000202 0
      C                                                                            18   24   000216 2
         103 IF (XB.LT.XP(I3)) GO TO 107                                            1   24   000217 3
             X1=XP(I3)-XT                                                           1   24   000226 0
             XT=XP(I3)                                                              1   24   000231 1
             AA0=(AT+AP(I3))/2.                                                    15   24   000233 5
             AT=AP(I3+1)                                                            1   24   000240 0
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      RPO=(RPT+RP(I3))/2.                                  7   24   000243 0
      RPT=RP(I3+1)                                         7   24   000247 2
      EPO=(EPT+EP(I3))/2.                                  7   24   000252 3
      EPT=EP(I3+1)                                         7   24   000256 5
      IF (X1.LT.10.E-8) GO TO 105                         18   24   000262 0
      AREA(I2) = AREA(I2)+ AAO*X1                         18   24   000267 4
      SUMM=RPO*X1*AAO/(144000.0*32,17)                     7   24   000275 2
      SUMK=AAO*EPO/X1                                      7   24   000304 0
      PM(I2)=SUMM+PM(I2)                                   1   24   000307 4
      STP(I2)=(SUMK*STP(I2))/(SUMK+STP(I2))                1   24   000313 5
  105 I3=I3+1                                             10   24   000323 2
      IF (I3.GT.MP) GO TO 118                             10   24   000326 2
      IJ=I3-1                                             10   24   000333 2
      GO TO 103                                            1   24   000335 4
  107 X1=XB-XT                                             1   24   000340 2
C                                                         18   24   000343 3
C     FOR BOTTOM PORTION OF SEGMENT                       18   24   000344 4
C                                                         18   24   000353 1
      XX = XP(I3) - XP(IJ)                                18   24   000354 2
      XF = 1.0                                            18   24   000360 5
      IF (XX.GT.0.0) XF = (XB-XP(IJ))/XX                  18   24   000363 2
      AAU =AP(IJ)+(AP(I3)-AP(IJ))*XF                      18   24   000372 2
      AAO=(AT+AAU)/2.                                     15   24   000400 4
      AT=AAU                                               1   24   000404 2
      RPU = RP(IJ)+(RP(I3)-RP(IJ))*XF                     18   24   000406 3
      RPO=(RPT+RPU)/2.                                     8   24   000415 0
      RPT=RPU                                              8   24   000420 5
      EPU = EP(IJ)+(EP(I3)-EP(IJ))*XF                     18   24   000423 1
      EPO=(EPU+EPT)/2.                                     8   24   000431 4
      EPT=EPU                                              8   24   000435 3
      IF (X1.LT.10.E-8) GO TO 118                         18   24   000437 5
      AREA(I2) = AREA(I2)+AAO*X1                          18   24   000445 3
      SUMM=RPO*X1*AAO/(144000.0*32,17)                     8   24   000453 0
      SUMK=AAO*EPO/X1                                      8   24   000461 4
      STP(I2)=(SUMK*STP(I2))/(SUMK+STP(I2))                1   24   000465 2
      PM(I2)=SUMM+PM(I2)                                   1   24   000474 5
  118 AREA(I2) = AREA(I2)/DX                              20   24   000501 0
      IF (I2.EQ.N) GO TO 108                              20   24   000506 4
      I2=I2+1                                              1   24   000513 3
C                                                         18   24   000515 5
C     NEXT SEGMENT                                        18   24   000517 0
C                                                         18   24   000522 3
      GO TO 102                                            1   24   000523 4
  108 CONTINUE                                            16   24   000526 2
C                                                         18   24   000531 4
C     PRINT GIVEN INFORMATION                             18   24   000532 5
C                                                         18   24   000540 1
  111 FORMAT (20X,16HPILE DESCRIPTION/)                    7   24   000541 2
  112 FORMAT (16H X BEL. TOP (FT),13F8.1)                  1   24   000550 5
  113 FORMAT (16H A (SQ. IN.)     ,13F8.1)                 1   24   000560 4
  114 FORMAT (16H E (KSI)         ,13F8.0)                 1   24   000570 0
  115 FORMAT (17H GAMMA (LB/CU FT) ,F7.1,12F8.1)           7   24   000576 4
      WRITE (IW,111)                                       1   24   000607 4
      MAX=6                                                1   24   000613 1
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 93              IF (ICOL.EQ.132) MAX=13                                          1    24    000615 1
 94              I4=1                                                             6    24    000622 1
 95              I5=MAX                                                           1    24    000624 0
 96              IF (I5.GT.MP) I5=MP                                              6    24    000626 1
 97         116  WRITE (IW,112) (XP(I),I=I4,I5)                                   1    24    000632 3
 98              WRITE (IW,113) (AP(I),I=I4,I5)                                   1    24    000641 3
 99              WRITE (IW,114) (EP(I),I=I4,I5)                                   1    24    000647 5
100              WRITE (IW,115) (RP(I),I=I4,I5)                                   1    24    000656 1
101              IF (I5.GE.MP) GO TO 117                                          6    24    000664 3
102              I4=I5+1                                                          6    24    000671 3
103              I5=I4+MAX                                                        6    24    000673 5
104              IF (I5.GT.MP) I5=MP                                              6    24    000676 3
105              GO TO 116                                                        1    24    000702 5
106         117  CONTINUE                                                        16    24    000705 3
107              IF (IPEL.NE.2) RETURN                                           15    24    000710 5
108       C                                                                      18    24    000715 3
109       C      DETERMINE AVERAGE AREAS FOR THE CASE WHERE MASSES AND           18    24    000716 4
110       C      STIFFNESSES WERE GIVEN                                          18    24    000731 1
111       C                                                                      18    24    000736 2
112              DL = 0.0                                                        15    24    000737 3
113              DO 145 I=1,N                                                    15    24    000742 0
114              DO 146 J=2,MP                                                   23    24    000750 3
115              IF (XP(J).GT.DL) GO TO 147                                      15    24    000753 5
116         146  CONTINUE                                                        15    24    000761 2
117         147  AREA(I)=AP(J-1)                                                 15    24    000764 4
118         145  DL = DL + ALPH(I)*XP(MP)/SALPH                                  24    24    000776 3
119              RETURN                                                           4    24    001005 4
120              END                                                              1    24    001007 5
  1              SUBROUTINE DIESEL                                                1    37    000004 0
  2              COMMON VINH,DINH,AOH,VOH,DOH,ANH,VNH,DNH,STH,HM,AM,STA,MA,ESOIL, 1    37    000010 0
  3             1 AOP,ANP,DOP,DNP,VOP,VNP,STP,PM,CDP,RES,RESO,SJ,SOK,QS,SU,       1    37    000024 1
  4             2 SPLICE,DEPIB,ARAM,ECUS,ECAP,EPT,EANV,VFALL,VCHAM,XPT,SJJJ,      1    37    000037 3
  5             3 EMP,RHO,DTH,DTP,N,M,JRAT,IULT,RULT,SOILM,DSACP,                 1    37    000053 0
  6             4 FPTO,IW,PCOM,TDEL,IOUT,OUT,EXPP,TEMI,TEMO,INP,STROKO,STROKN,VO,PO 1  37    000064 3
  7             5 ,DFIN,JDOUT,JPMAX,EX,ICOL,FINTMX, TEMAX,RESULT,ISMITH,ITER      1    37    000101 1
  8             6 ,ITYPH,IPREIG,VFALLM,STRMAX,DCYL,PBAR,AREA,JEX                 25    37    000114 4
  9              DIMENSION VINH(10),DINH(10),AOH(10),VOH(10),DOH(10),ANH(10),     1    37    000126 0
 10             1 VNH(10),DNH(10),STH(10),HM(10), VNP(99),                        1    37    000141 3
 11             2 AOP(99),ANP(99),DOP(99),DNP(99),VOP(99),STP(99),PM(99),CDP(99), 1    37    000151 5
 12             3 RES(99),RESO(99),SJ(99),SOK(99),QS(99),SU(99),SPLICE(99),       1    37    000166 1
 13             4DSACP(3),OUT(3200),INP(13),EX(600),RESULT(100),JEX(600)         25    37    000201 3
 14             5 ,AOAH(99),VOAH(99),DOAH(99),AREA(99),DELAH(99),STA(10),AM(10)   1    37    000214 2
 15             6 ,PBAR(20)                                                       4    37    000230 2
 16              KLIM = 200                                                       1    37    000233 2
 17       C       KLIM ... MAX NO. OF VALUES OF ONE VARIABLE IN OUTPUT,           1    37    000236 1
 18       C      KLIM*15=DIM(OUT)                                                 1    37    000250 4
 19              EXPT = 1.-1./EXPP                                                1    37    000254 5
 20              CDH = PM(99)                                                    30    37    000260 5
 21       C                                                                      35    37    000264 0
 22       C      SET UP OUTPUT VARIABLES                                         35    37    000265 1
 23       C                                                                      35    37    000272 3
 24              IIOUT = IABS(IOUT)                                              36    37    000277 2
 25              IF (IIOUT.GE.20) IIOUT=IIOUT-20                                 10    37    000303 3
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      IF (IIOUT.GE.10) IIOUT=IIOUT-10                                      10   37   000312 0
      SCJ = 0.0                                                            34   37   000320 3
      IAI = 0.0                                                            34   37   000323 1
      JOUT=0                                                               10   37   000325 5
      JDOUT = 6.0*XPT/(SQRT(EMP/RHO)*DTP)                                   1   37   000330 0
      JDOUT = JDOUT / 100                                                   1   37   000337 1
      TJD = FLOAT(JDOUT)*DTP*1000.                                          1   37   000343 3
      IF (TJD.GT.0.5) JDOUT = (0.0005/DTP) + 0.5                            1   37   000351 3
      IF (JDOUT.LT.1) JDOUT=1                                               1   37   000361 5
      IF (IIOUT.EQ.6) JDOUT = JDOUT + 1                                     5   37   000366 5
C     JMAX ... NUMBER OF OUTPUT TIME TO ANALYSIS PILE TIME INCREMENT        1   37   000375 4
      JMAX = 6                                                              1   37   000411 5
      IF (ICOL.GT.0) JMAX=13                                                1   37   000414 2
      IF (JMAX.GT.N) JMAX=N                                                 1   37   000421 1
C     JMAX ... NUMBER OF PILE VARIABLES PRINTED (DEPENDENT ON FORM          1   37   000425 5
C     SIZE)                                                                 1   37   000441 4
C                                                                          35   37   000444 0
C     INITIALIZE                                                           35   37   000445 1
C                                                                          35   37   000450 2
      FINTMX=0.5                                                            7   37   000451 3
      TS = 0.0005                                                           9   37   000454 2
      IF (PBAR(9).GT.0.0) TS = SJJJ                                        33   37   000457 2
      IF (PBAR(9).GT.0.0.AND.TS.LT.10.E-8) TS = 0.01                       33   37   000465 3
      RED=0.90                                                              8   37   000476 3
      IF (EMP.LT.3000000.) RED = 0.0                                       14   37   000501 0
      KK=0                                                                  1   37   000507 2
      N1=N+1                                                                1   37   000511 1
      NM1=N-1                                                               1   37   000513 2
      FTPO = FPTO                                                           1   37   000515 4
      FTIT = FPTO                                                           1   37   000520 4
      FTPOA =FTPO                                                           1   37   000523 4
      TLIM = 0.0                                                           31   37   000526 4
      FANVOA = 0.0                                                          1   37   000531 3
      FCUOA = VO                                                           20   37   000534 4
      VNPIT = VOP(N)                                                        1   37   000537 3
      VNHIT = VINH(M)                                                       1   37   000543 0
      VO = VCHAM + (DINH(M+1)-DINH(M))*ARAM                                 1   37   000546 4
      TIMP = 0.0                                                            1   37   000556 1
      TT=0.0                                                                7   37   000561 0
      TI=0.0                                                                7   37   000563 1
      TBLOW = -1.0                                                          9   37   000565 2
      RIMP = 1.                                                             1   37   000570 3
      RIDEL = 1.                                                            1   37   000573 1
      PCOMR = PCOM                                                          1   37   000576 0
      IF (PBAR(19).GT.0.0) GO TO 801                                       22   37   000601 1
      PCOMF = 0.5*(STROKO-DEPIB)/DEPIB                                      1   37   000607 3
C     REDUCTION DUE TO POOR SCAVENGING                                      1   37   000616 1
      IF (PCOMF.GT.1.0) PCOMF = 1.0                                         1   37   000625 1
      IF (PCOMF.LT.0.5) PCOMF = 0.5                                         5   37   000633 2
      PCOM=1.0+(PCOM-1.0)*PCOMF                                            22   37   000641 3
  801 CONTINUE                                                             22   37   000646 5
      PCOM1=PCOM                                                           17   37   000652 0
      IFIRST=0                                                              1   37   000654 5
      IREM = 0                                                              1   37   000657 2
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  80             V1PMAX = 0.0                                                                  9    37    000661 5
  81             DNPMAX = 0.0                                                                  1    37    000665 0
  82             MM1=M-1                                                                       1    37    000670 1
  83             M1=M+1                                                                        1    37    000672 3
  84             M2=M+2                                                                        1    37    000674 4
  85             G=32.17                                                                       1    37    000676 5
  86             ENTHRU = 0.0                                                                  1    37    000701 1
  87             EMAX = 0.0                                                                    1    37    000704 2
  88             T2LC = 2000.*XPT*SQRT(RHO/EMP)                                                1    37    000707 1
  89     C       LIMIT OF MAIN LOOP                                                           35    37    000740 0
  90             NT = 0.005*T2LC/DTP                                                           1    37    000744 3
  91             JCK = NT                                                                     29    37    000750 5
  92             IF (FLOAT(NT)*DTP.LT.0.050) NT = 0.050/DTP                                   35    37    000763 4
  93             IF (TEMAX.GT.1.0) NT=TEMAX/(1000.0*DTP)                                       8    37    000774 0
  94     C                                                                                    35    37    001003 5
  95     C       LOADING AND REBOUND STIFFNESSES FOR PILE TOP,ANVIL, AND CAPBLOCK             35    37    001005 0
  96     C                                                                                    35    37    001021 3
  97             STPT1 = STH(M2)*STP(1)/(STH(M2)+STP(1))                                       1    37    001022 4
  98             STPT2 = (STH(M2)/ECUS)*(STP(1)/EPT)/((STH(M2)/ECUS)+STP(1)/EPT)               1    37    001032 3
  99             STAL = STH(M)                                                                 1    37    001046 3
 100             STAR = STAL/EANV                                                              1    37    001051 5
 101             STCL = STH(M1)                                                                1    37    001055 4
 102             STCR = STCL/ECAP                                                              1    37    001061 1
 103     C       HAMMER VARIABLES TO INITIAL VALUES                                           35    37    001065 0
 104             DO 100 I=1,M2                                                                 1    37    001074 2
 105             VOH(I)=VINH(I)                                                               18    37    001077 4
 106             DOH(I)=DINH(I)                                                               18    37    001103 1
 107             VOAH(I)=VINH(I)                                                               1    37    001106 4
 108             DOAH(I)=DINH(I)                                                               1    37    001112 2
 109             DELAH(I) = 0.0                                                                1    37    001116 0
 110             AOAH(I)=G                                                                     1    37    001121 3
 111       100   CONTINUE                                                                      1    37    001124 1
 112     C       CONVERGENCE CRITERIA                                                         35    37    001127 3
 113             EPSV = 0.02                                                                   1    37    001134 2
 114             EPSF = 1.0                                                                    1    37    001137 2
 115             DO 97 I=1,N1                                                                  1    37    001142 1
 116        97   AOP(I) = G                                                                    1    37    001145 2
 117             DO 450 I=1,3200                                                              26    37    001150 5
 118        450  OUT(I)=0.0                                                                    1    37    001154 3
 119     C       EXTREMUM ARRAY                                                               35    37    001160 0
 120             DO 460 J=1,6                                                                  1    37    001163 5
 121             DO 460 I=1,N                                                                  1    37    001167 0
 122             IJ=N*(J-1)+I                                                                  1    37    001172 1
 123             EX(IJ) = 0.0                                                                  1    37    001175 2
 124             JEX(IJ) = 0                                                                  31    37    001200 3
 125       460   CONTINUE                                                                     29    37    001203 3
 126             ACYL = G                                                                     19    37    001206 5
 127             PBR = 0.144*14.7*PBAR(1)                                                     19    37    001211 2
 128             IF (PBAR(1).LT.10.E-8) PBR = 2.117*ARAM                                      27    37    001216 3
 129             DELP = 0.0                                                                   27    37    001226 2
 130             IF (PBAR(1).GT.ARAM) DELP = 2.117*(PBAR(1)-ARAM)                             27    37    001231 1
 131             IF (PBAR(20).GT.0.0) PBR = 0.0                                               26    37    001242 3
 132     C       CYLINDER VARIABLES                                                           35    37    001250 5
 133             CYLM=PBAR(8)/G                                                               23    37    001255 2
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      DCYL = DOH(M1)                                                      19   37   001260 5
      VCYL = VOH(M1)                                                      19   37   001264 2
C     IGNITION VARIABLES                                                  35   37   001267 5
      TSLOW = 1.0                                                         16   37   001274 2
      TSA=1.0/PCOM                                                        17   37   001277 2
      TSB=(1.0-TSA)/TS                                                    17   37   001302 3
C     CONTACT AREA VARIABLES                                              35   37   001306 2
      AFA=(3.-FINTMX)/2.                                                   7   37   001313 3
      AFB=(1.-FINTMX)/(2.*DSACP(1))                                        7   37   001317 4
      EXP = 1.35                                                           5   37   001325 5
      IF (IOUT.LT.0) WRITE (IW,653)                                        1   37   001330 4
C                                                                         29   37   001336 5
C     START MAIN LOOP                                                     29   37   001340 0
C                                                                         29   37   001344 0
      DO 700 J=1,NT                                                        1   37   001345 1
      IF (J.GT.JCK) JCK=-1                                                26   37   001350 3
      IF (V1PMAX.LT.VNP(1)) V1PMAX = VNP(1)                                9   37   001355 0
      IF (RED.LT.0.01) GO TO 103                                           9   37   001364 3
      IF (VNP(1).GT.0.9*V1PMAX.OR.V1PMAX.LT.5.0) GO TO 103                17   37   001372 0
      STPT1 = STPT2 * RED                                                 14   37   001404 0
      RED = 0.0                                                            9   37   001410 2
  103 CONTINUE                                                             8   37   001413 0
      DPOS = DOH(M)-DCYL                                                  20   37   001416 1
C     FORCE ON TOP OF RAM FOR REGULAR CLOSED END OR VAC HAMMER            35   37   001422 2
      PTR = FTR(DPOS,PBAR,IWT)                                            19   37   001435 3
      DBC = -DOH(M)                                                       26   37   001442 4
      IF (PBAR(20).GT.0.0) CALL VACHAM(PBAR,ARAM,DEPIB,DCYL,DBC,PTR,      26   37   001446 0
     1 VFALL,IOUT,IW)                                                     26   37   001461 5
      IF (PBAR(8).GT.0.0) ACYL=G+(PBR-PTR)/CYLM                           23   37   001465 4
      IF (PBAR(20).GT.0.0) PTR=PTR+ARAM*2.117                             27   37   001475 5
      IF (PBAR(20).LT.10.E-8) PTR = PTR-DELP                              27   37   001505 4
      DCYL = DCYL + VCYL * DTP                                            19   37   001515 2
      VCYL = VCYL + ACYL * DTP                                            19   37   001522 3
      IF (DCYL.GT.DOH(M1)) VCYL = VOH(M1)                                 19   37   001527 4
      IF (DCYL.GT.DOH(M1)) DCYL = DOH(M1)                                 19   37   001536 5
      TT=TT+DTP*1000.0                                                     7   37   001546 0
C     ABSOLUTE TIME COUNTER (MILLISEC.)                                   35   37   001551 5
C     TIME AFTER IMPACT (TIMP)                                            35   37   001561 0
C     RIMP = 0.0 MEANS FIRST IMPACT HASS OCCURED                          35   37   001566 3
      IF (RIMP.GT.0.5) TIMP=(DOH(M)-DOH(M1))/VOH(M)                       17   37   001577 1
      IF (RIMP.LT.0.5) TIMP=TIMP+DTP                                      17   37   001610 0
      TI=TI+DTP*(1.0-PCOM/PCOM1)                                          17   37   001616 2
C     IGNITION START FOR ATOMIZED FUEL                                    32   37   001623 5
      IF (PBAR(9).GT.0.0.AND.RIMP.LT.0.5) RIDEL = 0.0                     32   37   001632 5
      IF (TIMP.GE.TDEL.AND.IPREIG.EQ.0) RIDEL = 0.0                       16   37   001644 0
      IF (J.GT.0.AND.J.EQ.IPREIG) RIDEL = 0.0                             16   37   001654 5
      IF (RIDEL.GT.0.5.OR.PCOM.LT.0.01) GO TO 470                          7   37   001664 4
      TEMO=TEMO*PCOM                                                       7   37   001675 1
      PO=PO*PCOM                                                           7   37   001700 4
      EXP = EXPP                                                           5   37   001703 3
      PCOM = 0.0                                                           5   37   001706 2
  470 CONTINUE                                                             5   37   001711 1
      IF (TT.LT.50.) GO TO 471                                             9   37   001714 3
      IF (DDC.LT.12.*DEPIB) GO TO 471                                      9   37   001721 4
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C       FOR RAM REACHING PORTS
        IF (TbLOW.LT.0.) PBLOW = (PN-2.12)*100.*DTP                            35     37     001730 1
        TbLOW = 1.0                                                             9     37     001735 2
        PN = PN - PBLOW                                                         9     37     001745 5
        IF (PN.LT.2.117) PN = 2.117                                             9     37     001750 5
        PO = PN                                                                 9     37     001754 3
   471  CONTINUE                                                               30     37     001762 1
        IT=0                                                                    9     37     001764 3
C                                                                               1     37     001767 5
C       OVERALL LOOP STARTS                                                    35     37     001771 4
C                                                                              35     37     001772 5
   800  CONTINUE                                                               35     37     001777 3
        FCUO = FCUOA                                                            1     37     002000 4
        FTPO = FTPOA                                                            1     37     002004 0
        FANVO = FANVOA                                                          1     37*    002007 1
        DO 99 I=1,M2                                                            1     37     002012 2
        VOH(I)=VOAH(I)                                                          1     37     002015 5
        AOH(I)=AOAH(I)                                                          1     37     002021 0
    99  DOH(I)=DOAH(I)                                                          1     37     002024 3
C                                                                               1     37     002030 0
C       HAMMER ANALYSIS                                                         1     37     002034 1
C                                                                               1     37     002035 2
        DO 600 JH=1,JRAT                                                        1     37     002041 2
        ITH=0                                                                   1     37     002042 3
C       PREDICTION                                                              1     37     002046 2
        DO 585 I=1,M2                                                           1     37     002050 2
        IF (IT.EQ.0) ANH(I)=AOH(I)                                              1     37     002053 3
        IF (IT.GT.0) ANH(I)=AOH(I)+FLOAT(JH)*DELAH(I)                           1     37     002056 5
   585  CONTINUE                                                                1     37     002064 2
        DO 101 I=1,M2                                                           1     37     002075 1
   101  CALL INTEGR(DTH,AOH,ANH,VOH,DOH,VNH,DNH,I)                              1     37     002100 3
C                                                                               1     37     002103 5
C       HAMMER CYCLE STARTS                                                    35     37     002115 0
C                                                                              35     37     002116 1
   500  CONTINUE                                                               35     37     002122 5
        I=1                                                                     1     37     002124 0
        ANH(1)=G+((DNH(2)-DNH(1))*STH(1)+PTR)/HM(1)                             1     37     002127 2
        CALL INTEGR (DTH,AOH,ANH,VOH,DOH,VNH,DNH,I)                            21     37     002131 0
        DO 102 I=2,MM1                                                          1     37     002141 3
        I1=I+1                                                                  1     37     002152 0
        IM1=I-1                                                                 1     37     002155 3
        ANH(I)=G+((DNH(I1)-DNH(I))*STH(I)+(DNH(IM1)-DNH(I))*STH(IM1))/HM(I      1     37     002157 4
     1)                                                                         1     37     002162 0
        CALL INTEGR(DTH,AOH,ANH,VOH,DOH,VNH,DNH,I)                              1     37     002176 3
   102  CONTINUE                                                                1     37     002200 0
C       NOW CHECK DISPLACEMENT OF RAM AND IMPACT BLOCK                          1     37     002210 2
        V = VCHAM + ARAM*(DNH(M1)-DNH(M))                                       1     37     002213 4
        IF (V.LT.VCHAM) V = VCHAM                                               1     37     002225 0
        PN = PO*(VO/V)**EXP                                                     1     37     002233 5
        TEMN = TEMO*(PN/PO)**EXPT                                               5     37     002241 1
C       LAST RAM ELEMENT                                                        1     37     002245 3
        DDIS = DNH(M1)-DNH(M)                                                   1     37     002252 5
        IF (PCOM.LT.0.1) TSLOW=TSA+TSB*TI                                       1     37     002257 0
        IF (TSLOW.GT.1.0) TSLOW = 1.0                                          17     37     002263 4
                                                                                5     37     002272 3
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       PE = PN*TSLOW                                            5   37   002300 4
       AFAC = 1.0                                               5   37   002304 0
       IF (DDIS.LT.-DSACP(1)) AFAC=AFA+AFB*DDIS                 7   37   002306 5
       IF (DDIS.LT.-3.*DSACP(1)) AFAC=FINTMX                    7   37   002316 5
       FP = PE*ARAM*AFAC                                        5   37   002326 2
       FANV = 0.0                                               1   37   002332 2
       IF (DDIS.GT.0.0) GO TO 811                               1   37   002335 1
       DVEL = VNH(M1) - VNH(M)                                  1   37   002342 4
       DSAC = DSACP(1)                                          1   37   002347 4
       DDISO = DOH(M1)-DOH(M)                                   1   37   002353 2
       DDD = DDIS - DDISO                                       1   37   002360 1
C      ANVIL SPRING FORCE ALWAYS TENSION= +                     1   37   002364 2
       CALL STIFF (DDIS,DVEL,STAL,STAR,FANVO,FANV,DSAC,DDD)     1   37   002374 0
       IF (FANV.GT.0.0) FANV = 0.0                              1   37   002406 0
   811 FINTAC = -FP+FANV                                        1   37   002413 4
       DDC=DDIS*12.0                                            1   37   002420 3
       IF (DDIS.GT.0.0) IREM = 0                                1   37   002423 5
       IF (DDIS.LT.0.0) RIMP = 0.0                              1   37   002431 1
       IF (DDIS.LT.0.0.AND.IREM.NE.1) IFIRST = 1                1   37   002436 5
C      IFIRST = 1 MEANS IMPACT HAS OCCURED THE FIRST TIME      35   37   002447 0
       IF (IFIRST.NE.1) GO TO 675                               1   37   002461 0
       TIMP=0.0                                                29   37   002466 3
       JCK=0.0015*T2LC/DTP                                     29   37   002471 0
       TTI = TT                                                 1   37   002475 2
       IREM = 1                                                 1   37   002477 5
       TLIM = TT + 1.15*T2LC                                    1   37   002502 2
       IF (TLIM.LT.10.) TLIM = 10.                              1   37   002507 0
   675 CONTINUE                                                 1   37   002514 4
       ANH(M) = G + ((DNH(MM1)-DNH(M))*STH(MM1)+FINTAC)/HM(M)   1   37   002520 0
       CALL INTEGR(DTH,AOH,ANH,VOH,DOH,VNH,DNH,M)               1   37   002532 2
C      ANVIL                                                    1   37   002542 4
       FINTAC = -FINTAC                                         1   37   002545 0
       DHA = 0.0                                               30   37   002550 5
       DDIS = DNH(M2)-DNH(M1)                                   1   37   002553 3
       FCU = 0.0                                                1   37   002560 2
       IF (DDIS.GT.0.0) GO TO 812                               1   37   002563 0
       DVEL = VNH(M2)-VNH(M1)                                   1   37   002570 3
       DHA = DVEL*CDH                                          30   37   002575 2
       DSAC = DSACP(2)                                          1   37   002600 5
       DDISO = DOH(M2)-DOH(M1)                                  1   37   002604 3
       DDD = DDIS - DDISO                                       1   37   002611 3
       FCUO = -FCUO                                             1   37   002615 4
       CALL STIFF (DDIS,DVEL,STCL,STCR,FCUO,FCU,DSAC,DDD)       1   37   002620 5
       IF (FCU.GT.0.0) FCU=0.0                                  1   37   002632 3
       FCUO = -FCUO                                             1   37   002637 3
   812 CONTINUE                                                 1   37   002642 4
       ANH(M1) = G+(FINTAC+FCU+DHA)/HM(M1)                     30   37   002646 0
       CALL INTEGR(DTH,AOH,ANH,VOH,DOH,VNH,DNH,M1)              1   37   002655 1
C      CAP                                                      1   37   002665 4
       DT1 = FLOAT(JH)*DTH                                      1   37   002667 4
       I = 1                                                    1   37   002674 0
       DNP1 = DOP(1)+(DT1/DTP)*(DNP(1)-DOP(1))                  1   37   002676 0
       VNP1 = VOP(1) + (DT1/DTP)*(VNP(1)-VOP(1))                1   37   002705 5
       IF (IT.GT.0) GO TO 575                                   1   37   002716 0
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      CALL INTEGR(DT1,AOP,AOP,VOP,DOP,VNP,DNP,I)                         1    37    002722 5
      DNP1 = DNP(1)                                                      1    37    002733 1
      VNP1 = VNP(1)                                                      1    37    002736 3
575   CONTINUE                                                           1    37    002741 5
      DDIS = DNP1-DNH(M2)                                                1    37    002745 1
      VCAP = 0.0                                                        30    37    002751 3
      PTD = 0.0                                                         30    37    002754 2
      DVEL = 0.0                                                        30    37    002757 0
      FTP = 0.0                                                          1    37    002761 5
      IF (DDIS.GT.0.0) GO TO 813                                         1    37    002764 3
      DVEL = VNP1-VNH(M2)                                                1    37    002772 0
      VCAP = VNH(M2)                                                    30    37    002776 2
      DSAC = DSACP(3)                                                    1    37    003001 5
      DDISO = DOP(1)-DOH(M2)                                             1    37    003005 3
      DDD = DDIS-DDISO                                                   1    37    003012 2
      FTPO = -FTPO                                                       1    37    003016 1
      CALL STIFF (DDIS,DVEL,STPT1,STPT2,FTPO,FTP,DSAC,DDD)               1    37    003021 2
      IF (FTP.GT.-SPLICE(1)) FTP = -SPLICE(1)                            1    37    003033 2
      FTPO = -FTPO                                                       1    37    003043 1
813   FCU = -FCU                                                         1    37    003046 2
      ANH(M2) = G+(FCU+FTP+DVEL*CDP(1)-DHA)/HM(M2)                      30    37    003052 0
      CALL INTEGR(DTH,AOH,ANH,VOH,DOH,VNH,DNH,M2)                        1    37    003062 4
      ITH = ITH +1                                                       1    37    003073 1
      FTP = -FTP                                                         1    37    003076 2
C                                                                       35    37    003101 1
C     IF DTH EQ DTP (JRAT=1) THE FOLLOWING IS SKIPPED (ONE TIME         35    37    003102 2
C     INCREMENT)                                                        35    37    003115 4
C                                                                       35    37    003120 5
      IF (JRAT.EQ.1) GO TO 650                                           1    37    003122 0
      IF (ITH.GT.ITER) GO TO 650                                         1    37    003127 1
      ERR = ABS(VNHIT-VNH(M))                                            1    37    003134 4
      VNHIT = VNH(M)                                                     1    37    003141 4
      IF (ERR.GT.EPSV) GO TO 500                                         1    37    003145 1
650   CONTINUE                                                           1    37    003152 4
      DO 501 I=1,M2                                                      1    37    003156 0
      DELAH(I) = AOH(I)+(ANH(I)-AOH(I))/FLOAT(JRAT)                      1    37    003161 2
      AOH(I)=ANH(I)                                                      1    37    003172 1
      VOH(I)=VNH(I)                                                      1    37    003175 3
501   DOH(I)=DNH(I)                                                      1    37    003200 5
      TEMO = TEMN                                                        1    37    003205 0
      PO = PN                                                            1    37    003210 0
      VO = V                                                             1    37    003212 2
      FANVO = FANV                                                       1    37    003214 3
      FTPO = FTP                                                         1    37    003217 4
      FCUO = FCU                                                         1    37    003222 3
600   CONTINUE                                                           1    37    003231 5
C                                                                       35    37    003236 2
C     PILE ANALYSIS                                                     35    37    003237 3
C                                                                       35    37    003243 1
      CALL PILEAN (IPT,AOP,VOP,DOP,ANP,VNP,DNP,STP,PM,SPLICE,SJ,CDP,RES,  1    37    003246 2
     1 RESO,SU,SOK,VNPIT,VCAP,SOILM,SCJ,DTP,N,IT,ISMITH,EPSV,IAI,ESOIL, 34    37    003277 3
     2 FTP,JRAT,ITER)                                                    1    37    003314 0
C                                                                       35    37    003317 5
C     CHECK FOR CONVERGENCE                                             35    37    003321 0
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C                                                                                35   37   003326 0
      IT = IT + 1                                                                 1   37   003327 1
      IF (IT.GT.ITER) GO TO 850                                                   1   37   003332 1
      ERRV = ABS(VNPIT-VNP(N))                                                    1   37   003337 3
      IF (JRAT.EQ.1) VNPIT = VNP(N)                                               1   37   003344 4
      IF (JRAT.EQ.1.AND.ERRV.GT.EPSV) GO TO 800                                   1   37   003352 5
      ERR = ABS(FTIT-FTP)                                                         1   37   003363 0
      FTIT = FTP                                                                  1   37   003367 2
      IF (ERR.GT.EPSF) GO TO 800                                                  1   37   003372 1
  850 CONTINUE                                                                    1   37   003377 4
C     PREPARE OUTPUT FOR CURRENT                                                 35   37   003403 0
C     TIME INCREMENT AND                                                         35   37   003410 5
C     SET UP STARTING VALUES                                                     35   37   003415 2
C     FOR NEXT STEP                                                              35   37   003422 3
      RSUM = 0.0                                                                  1   37   003426 1
      DSUM=SJ(N1)*VNP(N)                                                          1   37   003431 0
      IF (ISMITH.EQ.1) DSUM=RES(N1)*DSUM                                          1   37   003435 1
      IF (DSUM.LT.0.0) DSUM = 0.0                                                 1   37   003444 1
      VMAXP = 0.0                                                                35   37   003451 5
      DO 401 I=1,N1                                                               1   37   003454 5
      RESO(I) = RES(I)                                                            1   37   003460 1
      AOP(I) = ANP(I)                                                             1   37   003464 0
      VOP(I)=VNP(I)                                                               1   37   003467 4
      RSUM = RSUM + RES(I)                                                        1   37   003473 0
      DDAM=SJ(I)*VNP(I)                                                           1   37   003477 3
      IF (ISMITH.EQ.1) DDAM=DDAM*RES(I)                                           1   37   003503 3
      IF (I.NE.N1) DSUM = DSUM + DDAM                                             1   37   003512 2
      IF (ABS(VOP(I)).GT.VMAXP) VMAXP = ABS(VOP(I))                              35   37   003520 5
  401 DOP(I)=DNP(I)                                                               1   37   003531 4
      IF (DNP(N).GT.DNPMAX) DNPMAX = DNP(N)                                       1   37   003535 5
      FANVOA = FANVO                                                              1   37   003545 2
      FCUOA = FCUO                                                                1   37   003550 5
      FTPOA = FTPO                                                                1   37   003554 0
      DO 402 I=1,M2                                                               1   37   003557 1
      AOAH(I)=ANH(I)                                                              1   37   003562 3
      VOAH(I)=VNH(I)                                                              1   37   003566 0
  402 DOAH(I)=DNH(I)                                                              1   37   003571 3
      DOPINC = DOP(1)*12.                                                         1   37   003575 5
      DEN = VOP(1)*DTP*FTP                                                        1   37   003602 1
C     TRANSFERRED ENERGY                                                         35   37   003606 4
      ENTHRU = ENTHRU + DEN                                                       1   37   003613 1
      IF (ENTHRU.GT.EMAX) EMAX = ENTHRU                                           1   37   003617 5
      JOUT = JOUT + 1                                                             1   37   003626 4
      FTPO = FTP                                                                 37   37   003632 2
      IF (JOUT.NE.JDOUT) GO TO 699                                                1   37   003635 1
      JOUT = 0                                                                    1   37   003643 1
      PT=PTR/PBAR(1)                                                             22   37   003645 4
      NO2 = N/2                                                                   1   37   003653 4
      NO21 = NO2+1                                                                1   37   003656 2
      PG = PE/0.144                                                               5   37   003661 3
  652 FORMAT (1H,I4,4I2,F6.1,F8.3,2F6.1,2F8.1,2F6.1,2(F6.1,F8.1),3F8.1,           1   37   003664 5
     1 F7.3,F6.0)                                                                 1   37   003701 5
      DO 686 I=NO2,NM1                                                           31   37   003705 0
      I1 = I+1                                                                   31   37   003710 5
```

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 404              COM = DNP(I)-DNP(I1)                                                      31     37     003713 2
 405              F = COM*STP(I1)                                                           31     37     003717 5
 406              IF (F.LT.SPLICE(I1)) F = SPLICE(I1)                                       31     37     003723 3
 407              IF (F.GT.0.0.OR.SPLICE(I1).LT.-.5) GO TO 685                              31     37     003732 4
 408              F = 0.0                                                                   31     37     003743 2
 409              IF (COM.LT.SPLICE(I1)) F = (COM-SPLICE(I1))*STP(I1)                       31     37     003745 4
 410       685    FOPN = F                                                                  31     37     003757 3
 411              IF (I.EQ.NO2) FOP5 = F                                                    31     37     003762 5
 412       686    CONTINUE                                                                  31     37     003767 4
 413     C        DEBUG OUTPUT                                                              35     37     003773 0
 414       653    FORMAT                                                                     1     37     003776 3
 415             1     (132H   JP F T H P  TIME    DCHAM    VRU     VAN      FINT      FPT    1     37     004001 3
 416             A  V1     EN     V5        F5     VN        FN       CP       RS       DA      1     37     004013 4
 417             B   D    T   )                                                              1     37     004023 0
 418              IF (IOUT.LT.0) WRITE (IW,652)                                              1     37     004025 5
 419             A   J,IFIRST,IT,ITH,IPI,TT,DDC  ,VNH(M),VNH(M1),FINTAC,FTP,VOP(1),          1     37     004034 0
 420             1 ENTHRU,VOP(NO2),FOP5,VOP(N),FOPN,PQ,RSUM,DSUM,DOPINC,PT                  22     37     004050 1
 421              IF (IIOUT.LT.6) CALL FILL(KK,KLIM,OUT,JMAX,IIOUT,DNH,STH,                  1     37     004067 3
 422             1FINTAC,FTP,INP,DNP,STP,SPLICE,VNH,VNP,ANH,ANP,JPMAX,MAXJP,EX,AREA,        25     37     004102 3
 423             2 J,M,N,JEX,JCK)                                                           26     37     004117 1
 424     C        JPMAX IS THE LATEST J                                                      1     37     004123 0
 425     C        FILLS IN THE OUTPUT ARRAY OUT(KLIM*15)                                     1     37     004130 0
 426     C        MAXJP IS THE MAXIMUM NUMBER OF VALUES STORED OF ONE VARIABLE               1     37     004140 0
 427     C        MAXJP EQUALS APPROX. JPMAX/JDOUT                                           1     37     004153 5
 428              IF (IIOUT.EQ.6) CALL FILL2(N,M,OUT,PQ,DNH,FTP,VNP,DNP,FOP5,SJ,             1     37     004162 5
 429             1RSUM,DSUM,RES,FOPN,KK,ICOL,TT,ISMITH,J,MAXJP,JPMAX,STP,AREA,               1     37     004176 4
 430             2 SPLICE,EX,JEX,J,JCK)                                                     26     37     004212 2
 431     C        CHECK WHETHER ANALYSIS WAS CARRIED OUT SUFFICIENTLY LONG                  35     37     004217 1
 432              IF (TEMAX.GT.1.0) GO TO 699                                               31     37     004232 2
 433              IF (V1PMAX*0.20.LT.VMAXP) GO TO 699                                       37     37     004247 1
 434              IF (TT.LT.TLIM) GO TO 699                                                  1     37     004256 2
 435              IF (TT.LT.T2LC.OR.TT.LT.20.0) GO TO 699                                   37     37     004300 5
 436              IF ((DNH(M1)-DNH(M)).GT..1*DEPIB.AND.DNP(N).LT.DNPMAX*0.9) GO TO           5     37     004310 4
 437             1 701                                                                       1     37     004324 5
 438              IF ((DNH(M1)-DNH(M)).GT..2*DEPIB.AND.DNP(N).LT.0.98*DNPMAX) GO TO          5     37     004326 5
 439             1 701                                                                       5     37     004343 1
 440       699    IFIRST = 0                                                                 1     37     004345 1
 441       700    CONTINUE                                                                   1     37     004350 5
 442       701    CONTINUE                                                                   1     37     004354 1
 443              FINTMX = FLOAT(J)*DTP                                                     28     37     004357 3
 444              DFIN = (DNPMAX-QS(N))*12.                                                  1     37     004364 1
 445              VNH(10)=VCYL                                                              19     37     004371 3
 446              DNH(10) = ACYL                                                            20     37     004374 4
 447              IF (IOUT.LT.0) WRITE (IW,654) ENTHRU,EMAX                                 31     37     004400 1
 448              ANP(99) = EMAX                                                            31     37     004410 2
 449       654    FORMAT (30H0TRANSFERRED ENERGY, FIN- MAX=,F6.1,2H -,F6.1,5H K-FT)          9     37     004413 5
 450              PCOM = PCOMR                                                               1     37     004431 0
 451              TEMO = TEMN                                                                1     37     004434 1
 452              RETURN                                                                     1     37     004437 1
 453              END                                                                        1     37     004441 2
                                                         1.1938 CRU

END OF RUN:      2 CRU     ACCOUNT: 134600,8     CARDS:     4 IN     0 OUT    PAGES:   12    CORE USAGE:      25.0K MAX.       21.3K AVERAGE
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OUT1N                 SYMBOLIC FORTRAN  30 APR 76  14:19:32   12   16    5   00155104   610
        SUBROUTINE OUT1N (SU,SJ,QS,STH,STP,HM,PM,IHAMR,EE,N,M,IW,XPT,      1   16   000004 0
       1ISMITH,HNAME,ESOIL,APO,EMP,RHO,SPLICE,CDP,ALPH,ITYPH)             13   16   000031 0
        DIMENSION HNAME(2),SU(99),SJ(99),QS(99),STH(10),HM(10),EE(4),      6   16   000043 2
       1STP(99),PM(99),CREE(4),SPLICE(99),CDP(99)                          6   16   000057 0
       2,ALPH(99)                                                         11   16   000067 2
      4 FORMAT (15X,14H HAMMER MODEL ,2A4)                                 1   16   000072 1
      5 FORMAT(6X,41H ELEMENT     WEIGHT  STIFFNESS    COEFF. )            1   16   000101 3
      6 FORMAT(6X,43H NUMBER      (KIPS)   (K/IN)   RESTITUTION )          1   16   000113 2
      7 FORMAT(6X,9H ANVIL   ,F10.3,F10.1,F10.3)                           1   16   000125 2
      8 FORMAT(6X,9H  CAP    ,F10.3,F10.1,F10.3)                           1   16   000135 2
  9     FORMAT (6X,9H CUSHION ,10X,F10.1,F10.3)                            1   16   000145 1
  10    FORMAT (6X,9HPILE TOP ,20X,F10.3)                                  1   16   000155 3
     12 FORMAT (2X,51H     WEIGHT STIFFN.  PDAMP.  SPLICE  SOIL-S  SOIL-D)  5   16   000165 0
     19 FORMAT (1H+,52X,16H   QUAKE  L.B.T.)                               8   16   000201 1
     13 FORMAT (2X,43HNO.  (KIPS)  (K/IN) (KS/FT)  (KIPS)  (PCT.))         5   16   000210 4
     20 FORMAT (1H+,45X,23H             (IN.)  (FT.))                      8   16   000224 0
   1302 FORMAT (1H+,45X,7H(KS/FT))                                        10   16   000233 2
   1301 FORMAT (1H+,46X,6H(S/FT))                                          8   16   000241 5
   1401 FORMAT (9X,I2,4X,F10.3,F10.1,3F10.3,F10.1)                         8   16   000250 1
     14 FORMAT (I5,F8.3,F8.0,F8.2,F8.0,3F8.3,F8.1)                         3   16   000261 2
     15 FORMAT (2X,3HTOE,32X,3F8.3)                                        3   16   000272 1
     16 FORMAT (/2X,35HCOEFFICIENT OF RESTITUTION OF SOIL    ,F8.3)        8   16   000300 3
     11 FORMAT (26X,17H PILE PROPERTIES //)                                3   16   000313 5
     17 FORMAT (2X,12HPILE LENGTH=,F5.0,5H FT.,,14H AREA(AT TOP)=,         8   16   000323 3
       *F6.1,5H S-IN)                                                     10   16   000337 1
     18 FORMAT (2X,17HE. MODUL(AT TOP)=,F6.0,6H KSI.,,                     8   16   000342 4
       *19H SPEC. WT.(AT TOP)=,F5.0,10H LBS/CU FT//)                       8   16   000354 1
   4711 FORMAT(1H )                                                        1   16   000365 0
        M1=M+1                                                             1   16   000370 5
        M2=M+2                                                             1   16   000373 0
        DO 4712 I=1,3                                                      1   16   000375 1
C                                                                         16   16   000400 3
C       OUTPUT HAMMER MODEL                                               16   16   000401 4
C                                                                         16   16   000406 2
   4712 WRITE (IW,4711)                                                    1   16   000407 3
        DO 100 I=1,4                                                       1   16   000414 0
    100 CREE(I) = SQRT(EE(I))                                              1   16   000417 1
        WRITE (IW,4) HNAME(1),HNAME(2)                                     1   16   000424 4
        WRITE (IW,5)                                                       1   16   000433 0
        WRITE (IW,6)                                                       1   16   000436 1
        WTH=HM(1)*32.17                                                    1   16   000441 2
        STFH=0.0                                                           1   16   000445 0
        I=1                                                                1   16   000447 3
        WRITE (IW,1401) I,WTH                                              8   16   000451 1
        IF (M.EQ.1) GO TO 104                                             13   16   000455 5
        DO 101 I=2,M                                                       1   16   000462 3
        STFH=STH(I-1)/12.0                                                 1   16   000465 4
        WTH=HM(I)*32.17                                                    1   16   000471 5
    101 WRITE (IW,1401) I,WTH,STFH                                         9   16   000475 3
    104 CONTINUE                                                          13   16   000503 5
        ANVWT=HM(M1)*32.17                                                 1   16   000507 0
        ANVSTF=STH(M)/12.0                                                 1   16   000513 1
        CAPWT=HM(M2)*32.17                                                 1   16   000517 2
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      CAPSTF=STH(M1)/12.0                                                   1    16    000523 3
      IF (ITYPH.EQ.3) CAPWT=HM(M1)*32.17                                   13    16    000536 4
      IF (ITYPH.EQ.3) CAPSTF=STH(M)/12.0                                   13    16    000545 4
      IF (ITYPH.NE.3) WRITE (IW,7) ANVWT,ANVSTF,CREE(1)                    13    16    000554 4
      EREP=CREE(2)                                                         14    16    000575 0
      IF (ITYPH.EQ.3) EREP=CREE(1)                                         14    16    000600 1
      WRITE (IW,8) CAPWT,CAPSTF,EREP                                       14    16    000606 1
      CSHSTF=STH(M2)/12.                                                    1    16    000614 3
      IF (ITYPH.EQ.3) CSHSTF=STH(M1)/12.0                                  14    16    000620 4
      IF (CSHSTF.GT.10.**9.) CSHSTF=0.                                      2    16    000627 5
      WRITE (IW,9) CSHSTF,CREE(4)                                           1    16    000636 3
      IF (CSHSTF.LT.0.00001) CSHSTF=10.**12                                 2    16    000644 1
      WRITE (IW,10) CREE(3)                                                 1    16    000653 4
C                                                                          16    16    000670 1
C     PRINT PILE PROPERTIES AND MODEL                                      16    16    000671 2
C                                                                          16    16    000700 1
 4713 FORMAT (1H1)                                                         16    16    000701 2
      WRITE (IW,4713)                                                      16    16    000705 2
      WRITE (IW,11)                                                         1    16    000711 0
      WRITE (IW,17) XPT,APO                                                 3    16    000714 2
      A1 = EMP/144.                                                        16    16    000727 5
      A2 = RHO*32170.                                                      16    16    000733 1
      WRITE (IW,18) A1,A2                                                  16    16    000736 5
      WRITE (IW,12)                                                         1    16    000743 1
      WRITE (IW,19)                                                         4    16    000746 3
      WRITE (IW,13)                                                         1    16    000751 5
      WRITE (IW,20)                                                         4    16    000755 1
      IF (ISMITH.EQ.1) WRITE (IW,1301)                                      6    16    000760 3
      IF (ISMITH.LT.1) WRITE(IW,1302)                                       6    16    000767 1
      SALPH=0.0                                                            11    16    000775 4
      DO 200 I1=1,N                                                        11    16    001000 2
  200 SALPH=SALPH+ALPH(I1)                                                 11    16    001003 4
      DD = 0.0                                                              1    16    001010 5
      DO 102 I=1,N                                                          1    16    001013 2
      PWT= PM(I)*32.17                                                      1    16    001016 3
      PSTF= STP(I)/12.0                                                     1    16    001022 2
      QSF=QS(I)*12.0                                                        1    16    001026 2
      DD=DD+XPT*ALPH(I)/SALPH                                              11    16    001031 5
  102 WRITE (IW,14) I,PWT,PSTF,CDP(I),SPLICE(I),SU(I),SJ(I),QSF,DD          3    16    001036 5
      A1 = QS(N+1)*12.0                                                    16    16    001063 2
      WRITE (IW,15) SU(N+1),SJ(N+1),A1                                     16    16    001067 2
 22   FORMAT (45H  SKIN FRICTION CONSTANT FOR ALL RULT VALUES )            15    16    001076 0
      IF (CDP(99).GT.0.5) WRITE (IW,22)                                    15    16    001111 3
      A1 = SQRT(ESOIL)                                                     16    16    001125 4
      WRITE (IW,16) A1                                                     16    16    001131 3
      RETURN                                                                1    16    001135 2
      END                                                                   1    16    001137 3
OUT2                  SYMBOLIC FORTRAN  11 MAY 76  12:19:22   14   18    5   00313614   992
      SUBROUTINE OUT2(OUT,JNP,STH,HM,STP,PM,EMP,RHO,ICOL,M,N,DTP,JPMAX,     1    18    000004 0
     1JDOUT,JEMAX,FINTMX,EX,JMAX,IW,IOUT,RESULT,AREA,JEX,ITYPH)            13    18    000020 2
      DIMENSION STH(10),HM(10),STP(99),PM(99),CONV(10),STSCNV(15),          1    18    000033 3
     1OUT(3200),JNP(13),EX(600),RESULT(99),AREA(99),JEX(600)                7    18    000047 0
      REAL IN                                                              15    18    000061 4
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      DATA P,PSI,SEA,IN/4H   P,4HPSI),4H SEA,4H IN)/                 14    18    000064 0
      H1 = P                                                          13    18    000074 4
      H2 = PSI                                                        13    18    000076 5
      IF (ITYPH.EQ.3) H1 = SEA                                        13    18    000101 2
      IF (ITYPH.EQ.3) H2 = IN  .                                      13    18    000106 3
    1 FORMAT (25X,30H HAMMER AND PILE FORCES(KIPS) )                   1    18    000113 3
    2 FORMAT (22X,36H HAMMER AND PILE VELOCITIES(FT/SEC) )             1    18    000125 0
    3 FORMAT (24X,32H HAMMER AND PILE STRESSES (KSI) )                 1    18    000137 3
    4 FORMAT (22X,36H HAMMER AND PILE ACCELERATIONS(G'S) )             1    18    000151 2
    5 FORMAT (20X,40H HAMMER AND PILE DISPLACEMENTS (INCHES) )         1    18    000163 5
    6 FORMAT (51X,30H HAMMER AND PILE FORCES(KIPS) )                   1    18    000177 1
    7 FORMAT (48X,36H HAMMER AND PILE VELOCITIES(FT/SEC) )             1    18    000210 4
    8 FORMAT (50X,32H HAMMER AND PILE STRESSES (KSI) )                 1    18    000223 1
    9 FORMAT (48X,36H HAMMER AND PILE ACCELERATIONS(G'S) )             1    18    000235 0
   10 FORMAT (46X,40H HAMMER AND PILE DISPLACEMENTS (INCHES) )         1    18    000247 3
   11 FORMAT (2X,25H JP  TIME     HAMMER     , 9X,15H PILE ELEMENTS )  1    18    000263 0
   12 FORMAT(6X,29H (MS)  RAM M    ANVIL    TOP ,I6,4I8)               1    18    000276 2
   13 FORMAT (2X,25H JP  TIME     HAMMER     ,30X,15H PILE ELEMENTS )  1    18    000307 5
   14 FORMAT (6X,29H (MS)  RAM M    ANVIL    TOP ,I6,11I8)             1    18    000323 1
   15 FORMAT (I5,F6.1,15F8.1)                                          1    18    000335 0
   16 FORMAT (I5,F6.1,15F8.3)                                          1    18    000342 4
   21 FORMAT(I5,F6.1,15F8.2)                                           7    18    000350 2
   31 FORMAT (15H    J   TIME   ,A4,5X,28HD RAM     ANV    FTOP   VTOP,   13    18    000355 4
     *62H    DTOP     FMID   VMID    DMID   SUM ST SUM DP RT TOE    FTOE,  3    18    000370 4
     *15H   VTOE     DTOE)                                             3    18    000403 2
   32 FORMAT (15H    J   TIME   ,A4,6X,27HFTOP   VTOP    DTOP    FTOE,  13    18    000407 2
     *15H   VTOE     DTOE)                                             3    18    000422 2
   33 FORMAT (8X,9H(MS)      (,A4,32H   (IN)     (IN)   (KIPS) (FT/S) ,  13    18    000426 2
     *61H  (IN)    (KIPS) (FT/S)   (IN)   (KIPS) (KIPS) (KIPS)   (KIPS),   3    18    000441 3
     *14H (FT/S)    (IN))                                              3    18    000455 0
   34 FORMAT (8X,9H(MS)      (,A4,32H   (KIPS) (FT/S)    (IN)   (KIPS),  13    18    000461 1
     *14H (FT/S)    (IN))                                              3    18    000474 3
   35 FORMAT (I5,F7.1,F9.1,2F8.3,2(F9.1,F6.1,F8.3),F9.1,2F7.1,F9.1,F6.1,   1    18    000500 4
     *F8.3)                                                            1    18    000515 4
   36 FORMAT (I5,F7.1,F9.1,2(F9.1,F6.1,F8.3))                          1    18    000517 5
      M1 = M+1                                                         1    18    000530 1
      KL1M = 200                                                       1    18    000532 4
      IMAX = (JMAX+2)*KLIM                                             1    18    000535 3
      K = 1                                                            1    18    000542 0
      KK = 1                                                           1    18    000544 0
      M2 = M+2                                                         1    18    000546 1
      EHMR = 31000.*144.                                               1    18    000550 4
      RHOHMR=0.492/32.17                                              10    18    000554 5
C     OUTPUT OPTION FOR PRINTING                                      17    18    000565 0
      IIOUT = IABS(IOUT)                                              17    18    000572 5
      IF (IIOUT.GE.20) IIOUT=IIOUT-20                                  6    18    000577 0
      IF (IIOUT.GE.10) IIOUT=IIOUT-10                                  6    18    000605 3
      IF (IIOUT.EQ.0) GO TO 135                                       12    18    000614 0
C     FOR IIOUT EQ 0 DO NOT PRINT VARIBLES VS TIME                    17    18    000621 2
      CONV(1) = 1.                                                     1    18    000632 2
      CONV(2) = 1.                                                     1    18    000635 3
      CONV(3)=1.0                                                      7    18    000640 4
      CONV(4) = 1./32.17                                               1    18    000643 4
      CONV(5) = 12.                                                    1    18    000647 5
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          IF (ICOL.GT.0) GO TO 101                              1    18    000653 1
      C   TITLE FOR 132 COLUMNS                                17    18    000660 2
          IF (IIOUT.EQ.1) WRITE (IW,1)                          1    18    000665 2
          IF (IIOUT.EQ.2) WRITE (IW,2)                          1    18    000673 2
          IF (IIOUT.EQ.3) WRITE (IW,3)                          1    18    000701 2
          IF (IIOUT.EQ.4) WRITE (IW,4)                          1    18    000707 2
          IF (IIOUT.EQ.5) WRITE (IW,5)                          1    18    000715 2
          IF (IIOUT.EQ.6) WRITE (IW,32) H1                     13    18    000723 2
          IF (IIOUT.EQ.6) WRITE (IW,34) H2                     13    18    000732 0
          IF (IIOUT.EQ.6) GO TO 130                             1    18    000740 4
          WRITE (IW,11)                                         1    18    000746 0
          WRITE (IW,12) (JNP(I),I=2,JMAX)                       1    18    000751 2
          GO TO 102                                             1    18    000757 5
      101 CONTINUE                                              1    18    000762 3
      C   TITLE FOR 80 COLUMNS                                 17    18    000765 5
          IF (IIOUT.EQ.1) WRITE (IW,6)                          1    18    000772 4
          IF (IIOUT.EQ.2) WRITE (IW,7)                          1    18    001000 4
          IF (IIOUT.EQ.3) WRITE (IW,8)                          1    18    001006 4
          IF (IIOUT.EQ.4) WRITE (IW,9)                          1    18    001014 4
          IF (IIOUT.EQ.5) WRITE (IW,10)                         1    18    001022 4
          IF (IIOUT.EQ.6) WRITE(IW,31)H1                       13    18    001030 5
          IF (IIOUT.EQ.6) WRITE (IW,33) H2                     13    18    001037 1
          IF (IIOUT.EQ.6) GO TO 130                             1    18    001045 5
          WRITE (IW,13)                                         1    18    001053 1
          WRITE (IW,14) (JNP(I),I=2,JMAX)                       1    18    001056 3
      102 CONTINUE                                              1    18    001065 0
          IF (IIOUT.NE.3) GO TO 107                             1    18    001070 2
      C                                                        17    18    001075 4
      C   STRESS CONVERSION FROM FORCES                        17    18    001076 5
      C                                                        17    18    001105 2
          CONST1 = 1./144.                                     16    18    001117 0
          IF (M.GT.1) CONST1 = SQRT(STH(M-1)*HM(M)/(EHMR*RHOHMR))
                                                               16    18    001122 5
          CONST2=SQRT(STH(M)*HM(M1)/(EHMR*RHOHMR))              1    18    001135 3
          CONST1=1.0/(CONST1*144.0)                            10    18    001145 3
          CONST2=1.0/(CONST2*144.0)                            10    18    001152 5
          DO 103 I=1,JMAX                                       1    18    001160 1
          K = JNP(I)                                            1    18    001163 5
      103 STSCNV(I)=1.0/AREA(K)                                 7    18    001166 4
          K = 1                                                 1    18    001174 0
          KK = 1                                                1    18    001176 0
          DO 106 I=1,IMAX                                       1    18    001200 1
          IF (I.GT.KLIM) GO TO 104                              1    18    001203 5
          OUT(I) = OUT(I)*CONST1                                1    18    001211 0
          GO TO 106                                             1    18    001215 5
      104 IF (I.GT.2*KLIM) GO TO 105                            1    18    001220 3
          OUT(I) = OUT(I)*CONST2                                1    18    001226 5
          GO TO 106                                             1    18    001233 4
      105 OUT(I) = OUT(I) * STSCNV(KK)                          1    18    001236 2
          K = K+1                                               1    18    001245 1
          IF (K.LE.KLIM) GO TO 106                              1    18    001247 3
          K = 1                                                 1    18    001254 4
          KK = KK + 1                                           1    18    001256 4
      106 CONTINUE                                              1    18    001261 4
      C                                                        17    18    001265 0
```

```
C       FOR ALL EXCEPT 6 OPTION                                                17    18    001266 1
C                                                                              17    18    001273 3
  107   DO 108 I=1,IMAX                                                         1    18    001274 4
  108   OUT(I) = OUT(I) * CONV(IIOUT)                                           1    18    001301 1
        JJ = 0                                                                  1    18    001310 1
  109   DO 110 JP = JDOUT,JPMAX,JDOUT                                          18    18    001320 3
        JJ = JJ+1                                                               1    18    001327 3
        JJMAX = (JMAX+1)*KLIM+JJ                                                1    18    001332 1
        TT = FLOAT(JP)*DTP*1000.                                                1    18    001337 2
        IF (IIOUT.EQ.1.OR.IIOUT.EQ.2.OR.IIOUT.EQ.4) WRITE (IW,15) JP,TT,        7    18    001344 3
       1(OUT(I),I=JJ,JJMAX,KLIM)                                                7    18    001360 4
        IF (IIOUT.EQ.3) WRITE (IW,21) JP,TT,(OUT(I),I=JJ,JJMAX,KLIM)            7    18    001366 0
        IF (IIOUT.EQ.5) WRITE (IW,16)JP,TT,(OUT(I),I=JJ,JJMAX,KLIM)             1    18    001401 3
  110   CONTINUE                                                                1    18    001414 5
C                                                                              17    18    001420 1
C       FOR 6 OPTION ONLY, FIRST 132 COLUMNS                                   17    18    001421 2
C                                                                              17    18    001431 0
  130   IF (IIOUT.NE.6) GO TO 135                                               1    18    001432 1
        IF (IIOUT.EQ.6.AND.ICOL.EQ.0) GO TO 131                                 1    18    001440 2
        KP=0                                                                   10    18    001450 1
        DO 132 JP = JDOUT,JPMAX,JDOUT                                          18    18    001457 0
        KP=KP+1                                                                10    18    001465 1
        KPMAX=15*KLIM+KP                                                       10    18    001467 3
    132 WRITE (IW,35) JP,(OUT(I),I=KP,KPMAX,KLIM)                              10    18    001473 2
        GO TO 135                                                               1    18    001504 1
C                                                                              17    18    001506 5
C       6 OPTION - 80 COLUMNS                                                  17    18    001510 0
C                                                                              17    18    001515 0
    131 KP=0                                                                   11    18    001516 1
        DO 134 JP = JDOUT,JPMAX,JDOUT                                          18    18    001525 4
        KP=KP+1                                                                10    18    001533 5
        KPMAX1=200+KP                                                           1    18    001536 1
        KP2 = 4*KLIM+KP                                                        16    18    001544 5
        KPMAX2=9*KLIM+KP                                                        9    18    001550 3
    134 WRITE (IW,36) JP,(OUT(I),I=KP,KPMAX1,KLIM),(OUT(I),I=KP2,KPMAX2,       10    18    001554 2
       1 KLIM)                                                                  7    18    001571 1
    135 CONTINUE                                                                1    18    001573 3
C                                                                              17    18    001576 4
C       FOR ALL OPTIONS EXTREME VALUE TABLES                                   17    18    001577 5
C                                                                              17    18    001607 3
     17 FORMAT(13X,56H TABLE OF EXTREME VALUES FOR PILE AND TIME OF OCCURR      7    18    001610 4
       1ENCE)                                                                   7    18    001625 4
     18 FORMAT (4X,79H ELEM.     FMAX           FMIN       MINSTR      MAXST    7    18    001627 5
       1R          VELMX          DISMX / 7X,76HNO.     KIPS           KIPS     7    18    001641 2
       1     KSI          KSI          FT/S          INCH)                      7    18    001651 1
     19 FORMAT (5X,I5,4(F8.1,1H(,I3,1H)),F8.2,1H(,I3,1H),F8.3,1H(,I3,1H))       7    18    001656 2
   20   FORMAT (1H )                                                            1    18    001673 1
        DO 115 I=1,3                                                            1    18    001677 0
  115    WRITE (IW,20)                                                          1    18    001702 1
        WRITE (IW,17)                                                           1    18    001706 2
        WRITE (IW,18)                                                           1    18    001711 4
        DO 120 I=1,N                                                            1    18    001715 0
        NN = 5*N + I                                                            1    18    001720 1
    120 WRITE (IW,19) I,(EX(J),JEX(J),J=I,NN,N)                                 7    18    001723 2
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           168            RETURN                                                          1     18     001733 5
           169            END                                                             1     18     001736 0
           IMPACTN                      SYMBOLIC FORTRAN  18 JUN 78  14:01:51   46   50    5   00241010      2371
000100      1.     C      **********  W E A P  WAVE EQUATION ANALYSIS FOR PILES  **********            000000
000100      2.     C      THIS PROGRAM WAS DEVELOPED FOR THE FEDERAL HIGHWAY ADMINISTRATION            000000
000100      3.     C      BY GOBLE, CONSULTING ENGINEERS                                               000000
000100      4.     C      FOR INFORMATION REGARDING THE PROGRAM CODING CONTACT                         000000
000100      5.     C                           GOBLE, CONSULTING ENGINEERS                             000000
000100      6.     C                           12434 CEDAR ROAD  #10                                   000000
000100      7.     C                           CLEVELAND HEIGHTS, OHIO  44106                          000000
000100      8.     C                           (216)-721-0220                                          000000
000100      9.     C                                                                                   000000
000100     10.     C                                                                                   000000
000100     11.     C      NOTE THAT THIS PROGRAM UTILIZES A DATA FILE WHICH CONTAINS                   000000
000100     12.     C      PROPRIETORY INFORMATION. THIS DATA, THEREFORE, MAY NOT BE                    000000
000100     13.     C      DUPLICATED IN ANY FORM WITHOUT THE EXPRESSED WRITTEN PERMISSION              000000
000100     14.     C      OF EITHER THE FHWA OR GOBLE CONSULTING ENGINEERS                             000000
000100     15.     C                                                                                   000000
000100     16.     C                                                                                   000000
000101     17.            COMMON VINH,DINH,AOH,VOH,DOH,ANH,VNH,DNH,STH,HM,AM,STA,MA,ESOIL,             000000
000101     18.           1 AOP,ANP,DOP,DNP,VOP,VNP,STP,PM,CDP,RES,RESO,SJ,SOK,QS,SU,                   000000
000101     19.           2 SPLICE,DEPIB,ARAM,ECUS,ECAP,EPT,EANV,VFALL,VCHAM,XPT,SJJJ,                  000000
000101     20.           3 EMP,RHO,DTH,DTP,N,M,JRAT,IULT,RULT,SOILM,DSACP,                             000000
000101     21.           4 FPTO,IW,PCOM,TDEL,IOUT,OUT,EXPP,TEMI,TEMO,INP,STROKO,STROKN,VO,PO           000000
000101     22.           5 ,DFIN,JDOUT,JPMAX,EX,ICOL,FINTMX, TEMAX,RESULT,ISMITH,ITER                  000000
000101     23.           6 ,ITYPH,IPREIG,VFALLM,STRMAX,DCYL,PBAR,AREA,JEX                              000000
000103     24.            DIMENSION VINH(10),DINH(10),AOH(10),VOH(10),DOH(10),ANH(10),                 000002
000103     25.           1 VNH(10),DNH(10),STH(10),HM(10), VNP(99),                                    000002
000103     26.           2 AOP(99),ANP(99),DOP(99),DNP(99),VOP(99),STP(99),PM(99),CDP(99),             000002
000103     27.           3 RES(99),RESO(99),SJ(99),SOK(99),QS(99),SU(99),SPLICE(99),                   000002
000103     28.           4DSACP(3),OUT(3200),INP(13),EX(600),RESULT(100),JEX(600)                      000002
000103     29.           5,AM(10),STA(10),ISEG(15),JSELEC(13),ALPH(99),TITLE(10)                       000002
000103     30.           6 ,PBAR(20),STINH(4,10),STINP(4,99),AREA(99),STRAR(10)                        000002
000104     31.      9877 CONTINUE                                                                      000002
000105     32.            STRMAX = 0.0                                                                 000002
000106     33.            CALL IPTN (JSELEC,ISEG,YMAX,ALPH,TITLE,IOSTR,STRM)                           000002
000107     34.            IF (IW.GT.-100) IWR = IW                                                     000002
000111     35.            IF (IW.LT.-100) GO TO 9876                                                   000013
000111     36.     C                                                                                   000022
000111     37.     C      IPTN READS ALL INPUT INFORMATION AND SETS UP HAMMER-PILE-SOIL-               000022
000111     38.     C      MODEL                                                                        000022
000111     39.     C      NOTE IPTN AUTOMATICALLY CALLS FOR THE RIGHT HAMMER AND SETS ITYPH            000022
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000111   C       FOR AIR STEAM HAMMERS STROKE AND VFALL ARE SET                           000022
000111   C                                                                                000022
000111   C       INITIALIZE FOR NEW PROBLEM                                               000022
000111   C                                                                                000022
000113           N1 = N+1                                                                 000030
000114           PCOMR = PCOM                                                             000033
000115           IIOUT = IOUT                                                             000035
000116           IF (IOUT.GT.9) IIOUT = IOUT-10                                           000040
000120           IF (IOUT.GT.19) IIOUT = IOUT-20                                          000050
000122           IFUEL = 0                                                                000062
000123           IWT = 0                                                                  000063
000124           DSTROK = 0.0                                                             000064
000125           INOW = 0                                                                 000065
000126           EPSSTR=0.05                                                              000066
000126   C       MAXIMUM QUAKE AT BOTTOM ELEMENT                                          000066
000127           Q = QS(N)                                                                000070
000130           IF (QS(N1).GT.Q) Q = QS(N1)                                              000073
000132           COLI=(XPT/SQRT(EMP/RHO))*1000.                                           000103
000133           NULT=IULT                                                                000115
000134           IF (NULT.EQ.0) NULT = 1                                                  000117
000136           IULT = 1                                                                 000123
000137           DULT=RULT*1.25                                                           000125
000140           IF (PBAR(1).LT.10.E-5) PBAR(1) = ARAM                                    000130
000142           IF (ITYPH.NE.2) GO TO 502                                                000137
000144           EPSSTR = 0.03                                                            000143
000144   C       FOR CLOSED END HAMMERS, DETERMINES VFALL FOR UPLIFT CONDITION            000143
000145           CALL DOWN(STRMAX,VFALLM,PBAR,HM,DEPIB,ARAM,IW,IOUT,DOWNT)                000145
000146           IF (STROKO.GT.0.1) GO TO 503                                             000160
000150           VFALL = VFALLM                                                           000165
000151           STROKO = STRMAX                                                          000167
000152           GO TO 502                                                                000171
000152   C       IF STROKE IS ASSIGNED FIND CORRESPONDING VFALL                           000171
000153       503 CALL DOWN(STROKO,VFALL,PBAR,HM,DEPIB,ARAM,IW,IOUT,DOWNT)                 000173
000154       502 CONTINUE                                                                 000206
000155       501 ISTR=0                                                                   000206
000155   C       INITIALIZE FOR NEW RULT                                                  000206
000156           IFA = 0                                                                  000206
000157           RTONS = RULT/2.0                                                         000207
000160           RTOE = SU(N1)*0.5                                                        000212
000161           WRITE (IW,9) RTONS,RTOE                                                  000216
000165         9 FORMAT (1H1,30X,5HRULT=,F7.1,9H, AT TOE=,F7.1,5H TONS/31X,33(1H-)/       000225
000165          1)                                                                        000225
000166           NM1=N-1                                                                  000225
000167           DTR = 1.0                                                                000236
000170           DTRM = 1.0                                                               000240
000171           DO 200 I=1,NM1                                                           000241
000171   C       CHECK DAMPING                                                            000241
000174           SDJ=SJ(I)                                                                000250
000175           IF (ISMITH.EQ.1) SDJ=SU(I)*SJ(I)                                         000251
000177           IF (SDJ.GT.10.E-8) DTR = PM(I)/SDJ                                       000256
000201           IF (DTR.LT.DTRM) DTRM = DTR                                              000266
000203       200 CONTINUE                                                                 000277
000205           SDJ = SJ(N) + SJ(N+1)                                                    000277
000206           IF (ISMITH.EQ.1) SDJ=SJ(N)*SU(N)+SJ(N1)*SU(N1)                           000303
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000210              IF (SDJ.GT.10.E-8) DTR = PM(N)/SDJ                          000315
000212              IF (DTR.LT.DTRM) DTRM = DTR                                 000326
000214              DTRM = DTRM*0.8                                             000335
000215              IF (DTRM.GE.DTP) GO TO 711                                  000340
000217              IF (DTRM.LT.0.00001) WRITE (IW,21) DTRM                     000344
000223              IF (DTRM.LT.0.00001) GO TO 401                              000363
000225              DTP = DTRM                                                  000365
000226              DTH = DTP/FLOAT(JRAT)                                       000367
000227              DTRM = DTRM*1000                                            000373
000230              WRITE (IW,18) DTRM                                          000376
000233         711  CONTINUE                                                    000405
000234         21   FORMAT (51H DAMPING GTR CRITICAL, T.I. REQUIRED LSS .01 MSEC.(,E10 000405
000234             1.5,1H))                                                     000405
000235         18   FORMAT (43H LARGE DAMPING REQUIRES NEW TIME INCREMENT=,F7.4, 000405
000235             1 6H MSEC.)                                                  000405
000236         500  CONTINUE                                                    000405
000237              JMAX = 6                                                    000405
000240              IF (ICOL.GT.0) JMAX = 13                                    000406
000242              IF (JMAX.GT.N) JMAX = N                                     000414
000244              IF (ITYPH.LT.3) GO TO 650                                   000423
000244        C     PERFORM AIR/STM HAMMER ANALYSIS AND GO TO OUTPUT (OUT2)     000423
000246              CALL AIRSTM                                                 000430
000247              IBLOW=-1                                                    000432
000250              DFIN = ((DFIN/12.0)+OS(N)-Q)*12.0                           000434
000251              IF (ABS(DFIN).GT.0.0) IBLOW=12.0/DFIN+0.5                   000443
000253              GO TO 900                                                   000456
000254         650  CONTINUE                                                    000460
000254        C     BEGIN ANALYSIS FOR ALL DIESEL HAMMERS                       000460
000255              VFR = VFALL                                                 000460
000256              CALL STARTC                                                 000461
000257              TSTART = FINTMX                                             000463
000260              M2=M+2                                                      000465
000260        C     STORE INITIAL VALUES FROM START ANALYSIS (MAY BE REUSED)    000465
000261              STINH(1,10)=VO                                              000470
000262              STINH(2,10)=FPTO                                            000472
000263              STINH(3,10)=FLOAT(IPREIG)+0.1                               000474
000264              STINH(4,10)=PO                                              000501
000265              DO 660 I=1,M2                                               000503
000270              STINH(1,I)=AOH(I)                                           000513
000271              STINH(2,I)=VINH(I)                                          000514
000272         660  STINH(3,I)=DINH(I)                                          000516
000274              DO 661 I=1,N1                                               000525
000277              STINP(1,I)=AOP(I)                                           000525
000300              STINP(2,I)=VOP(I)                                           000526
000301              STINP(3,I)=DOP(I)                                           000530
000302         661  STINP(4,I)=RESO(I)                                          000532
000304         662  IF (IPREIG.LT.-99) IBLOW=0                                  000536
000306              IF (IPREIG.LT.-99) GO TO 700                                000547
000310              CALL DIESEL                                                 000551
000311              TDIES = FINTMX                                              000553
000311        C     DETERMINE STROKE BY ANALYZING UPWARD MOTION                 000553
000312              CALL UP(PBAR,DNH,VNH,DNP,VNP,HM,PM,M,N,DCYL,DFIN,VFALL,VO,PO, 000555
000312             1 VFALLM,STROKN,DEPIR,ARAM,EXPP,IWT,IW,IOUT,PSI,TUP)         000555
000312        C     NO PENETRATION AND NO INCREASE OF STROKE MEANS QUIT (300)   000555
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000313          IF (DFIN.LT.0.0.AND.STROKN.LT.STROKO*1.025) GO TO 300                   000607
000315          IF (IOSTR.LT.0) GO TO 750                                               000625
000315   C      REDUCE FUEL FOR UPLIFT (901)                                            000625
000317          IF (IWT.EQ.1.AND.ITYPH.EQ.2.AND.IOSTR.NE.1) GO TO 901                   000631
000317   C      NO UPLIFT BUT PREVIOUS UPLIFT MEANS FUEL SUFFICIENTLY REDUCED(300)      000631
000321          IF (IFUEL.GT.0.AND.IOSTR.NE.1) GO TO 300                                000653
000323          IF (ITYPH.EQ.1.AND.STROKN.GT.STRM) WRITE (IW,20)                        000667
000326      20 FORMAT (35H *** CAUTION RAM MIGHT BLOW OUT ***)                          000711
000327          IF (ITYPH.EQ.1.AND.STROKN.GT.STRM) STROKN=STRM                          000711
000327   C      DETERMINE STROKE DIFFERENCE,STORE NEW STROKE                            000711
000331          DOSTR = DSTROK                                                          000730
000332          DSTROK = ABS(STROKN-STROKO)/STROKO                                      000732
000333          ISTR = ISTR + 1                                                         000737
000334          STRAR(ISTR) = STROKO                                                    000742
000335          IF (IOSTR.EQ.1.OR.DSTROK.LT.EPSSTR) GO TO 300                           000745
000337          STROKO = STROKN                                                         000761
000340          IF (ISTR.GT.4.AND.DSTROK.GT.(FLOAT(20-ISTR))*.05*DOSTR) GO TO 301       000763
000342          IF (ISTR.GT.6) GO TO 301                                                001006
000344          IF (ITYPH.GT.1.OR.ISTR.LT.2.OR.PBAR(20).GT.0.0) GO TO 675               001013
000346          IF (STRAR(ISTR).GT.STRAR(ISTR-1).AND.STROKN.GT.STRAR(ISTR)) GO TO       001040
000346         * 675                                                                    001040
000350          IF (STRAR(ISTR).LT.STRAR(ISTR-1).AND.STROKN.LT.STRAR(ISTR)) GO TO       001054
000350         * 675                                                                    001054
000350   C      FOR A NEW STROKE WHICH IS BETWEEN PREVIOUS VALUES                       001054
000352          STROKN = 0.5*(STRAR(ISTR)+STROKN)                                       001072
000353          VFALL = SQRT((STROKN-DEPIB)*64.34)                                      001076
000354          STROKO = STROKN                                                         001105
000354   C      AT 650 A NEW COMPLETE ANALYSIS STARTS                                   001105
000355          GO TO 650                                                               001107
000355   C      CHANGE FUEL SETTING                                                     001107
000356     750  ISTR = ISTR + 1                                                         001111
000357          IF (IWT.EQ.1) STROKN = STRMAX                                           001123
000361          DSTRF = (STROKN-STROKO)/STROKO                                          001127
000362          IF (IWT.EQ.1) DSTRF = DSTRF + (VFALL-VFALLM)/VFALLM                     001133
000364          IF (ABS(DSTRF).GT..2) DSTRF=.2*DSTRF/ABS(DSTRF)                         001142
000366          STRAR(ISTR) = STROKN                                                    001154
000367          STROKN = STROKO                                                         001157
000370          IF (ABS(DSTRF).LT.EPSSTR) GO TO 300                                     001161
000372          IF (ISTR.GT.4) GO TO 663                                                001166
000374      76  FORMAT (21H FUEL SETTING CHANGED,F6.3,7H PERCT.)                        001173
000375          IF (IWT.EQ.1.AND.DSTRF.LT.0.1.AND.ITYPH.EQ.2) DSTRF=DSTRF + 0.1         001173
000377          PCOM = PCOM*(1.0-DSTRF)                                                 001222
000400          IF (IOUT.LT.0) WRITE(IW,76) DSTRF                                       001226
000404          VFALL = VFR                                                             001240
000405          GO TO 761                                                               001242
000406     675  CONTINUE                                                                001244
000407          IF (DSTROK.GT.2.0*EPSSTR) GO TO 650                                     001244
000407   C      INITIAL VALUES ARE REUSED (AT 662)                                      001244
000411          DO 666 I=1,M2                                                           001251
000414          VINH(I)=STINH(2,I)                                                      001257
000415          IF (I.LE.M) VINH(I)=(VFALL/VFR)*VINH(I)                                 001261
000417          AOH(I)=STINH(1,I)                                                       001272
000420      666 DINH(I)=STINH(3,I)                                                      001274
000422          GO TO 667                                                               001300
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000423   202.     901  IFUEL = IFUEL + 1                                              001302
000424   203.          VFALL = VFALLM                                                 001304
000425   204.          PCOM = PCOMR*(1.0-FLOAT(IFUEL)/10.)                            001306
000426   205.     11   FORMAT (36H FUEL SETTING REDUCED BY TEN PERCENT)               001315
000427   206.          IF (IFUEL.GT.4) GO TO 663                                      001315
000431   207.          IF (IOUT.LT.0) WRITE (IW,11)                                   001321
000431   208.    C     REINITIALIZE                                                   001321
000434   209.     761  CONTINUE                                                       001333
000435   210.          DO 664 I=1,M2                                                  001333
000440   211.          AOH(I)=STINH(1,I)                                              001340
000441   212.          VINH(I)=STINH(2,I)                                             001341
000442   213.      664 DINH(I)=STINH(3,I)                                             001343
000444   214.      667 CONTINUE                                                       001347
000445   215.          DO 665 I=1,N1                                                  001347
000450   216.          AOP(I)=STINP(1,I)                                              001354
000451   217.          VOP(I)=STINP(2,I)                                              001355
000452   218.          DOP(I)=STINP(3,I)                                              001357
000453   219.      665 RESO(I)=STINP(4,I)                                             001361
000455   220.          VO=STINH(1,10)                                                 001364
000456   221.          FPTO=STINH(2,10)                                               001366
000457   222.          IPREIG=STINH(3,10)                                             001370
000460   223.          PO=STINH(4,10)                                                 001376
000461   224.          GO TO 662                                                      001400
000462   225.      663 WRITE (IW,12)                                                  001402
000464   226.          GO TO 300                                                      001406
000465   227.     12   FORMAT (20H NO FUEL CONVERSION )                               001410
000466   228.     301  WRITE (IW,8)                                                   001410
000470   229.     8    FORMAT (25H STROKE DOES NOT CONVERGE  )                        001415
000471   230.     300  CONTINUE                                                       001415
000471   231.    C                                                                    001415
000471   232.    C     ONE RULT HAS BEEN ANALYZED                                     001415
000471   233.    C                                                                    001415
000472   234.          IBLOW=-1                                                       001415
000473   235.          DFIN = ((DFIN/12.0)+QS(N)-Q)*12.0                              001416
000474   236.          IF (ABS(DFIN).GT.0.0) IBLOW=12./DFIN + 0.5                     001425
000476   237.          IF (IFUEL.EQ.5) IFUEL = 4                                      001440
000500   238.     900  CONTINUE                                                       001447
000500   239.    C     OUTPUT FOR ALL HAMMERS                                         001447
000501   240.          CALL OUT2(OUT,INP,STH,HM,STP,PM,EMP,RHO,ICOL,M,N,DTP,JPMAX,JDOUT,  001447
000501   241.         1 TEMAX,FINTMX,EX,JMAX,IW,IOUT,RESULT,AREA,JEX,ITYPH)          001447
000502   242.          WRITE (IW,51) ANP(99)                                          001500
000505   243.     51   FORMAT (1H0,13X,43HTHE MAXIMUM TRANSFERRED ENERGY (ENTHRU) WAS,  001506
000505   244.         1 F6.1,5H K-FT)                                                 001506
000506   245.     1    FORMAT (1H0,13X,37HSTROKES ANALYZED AND LAST RETURN (FT),7F6.1)  001506
000507   246.          IF (IOSTR.LT.0) GO TO 753                                      001506
000511   247.          IF (IFUEL.LT.1.AND.ITYPH.LT.3) WRITE (IW,1) (STRAR(I),I=1,ISTR),  001512
000511   248.         * STROKN                                                        001512
000522   249.     77   FORMAT (1H0,13X,42HRETURNED STROKES AND STROKE ANALYZED, (FT),  001547
000522   250.         1 7F6.1)                                                        001547
000523   251.          GO TO 754                                                      001547
000524   252.     753  WRITE (IW,77) (STRAR(I),I=1,ISTR),STROKO                       001551
000534   253.          PCOMC = (PCOM-PCOMR)/(PCOMR*0.01)                              001566
000535   254.     70   FORMAT (14X,22H TOTAL PRESSURE CHANGE,F6.1,2H %)               001574
000536   255.          WRITE (IW,70) PCOMC                                            001574
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000541        754  CONTINUE                                                            001603
000542             I1 = -IULT                                                          001603
000542        C    JDOUT  NO. OF TIME INCREMENTS BETWEEN OUTPUT VALUES + 1             001603
000542        C    JPMAX  MAXIMUM J IN OUTPUT                                          001603
000542        C    MAXJP  MAXIMUM NO. OF OUTPUT VALUES                                 001603
000543             MAXJP=(JPMAX/JDOUT)-1                                               001604
000544             STP1=STP(1)/EPT                                                     001611
000544        C                                                                        001611
000544        C    PLOT                                                                001611
000544        C                                                                        001611
000545             IF (IULT.LT.NULT) CALL OUTPUT(OUT,RESULT,INP,IOUT,DTP,JPMAX,JDOUT,  001616
000545            1 I1,N,MAXJP,ALPH,ISEG,JSELEC,YMAX,COLI,TITLE,STP1,PM(I))            001616
000545        C                                                                        001616
000545        C    DETERMINE OVERALL EXTREMA FOR SUMMARY                               001616
000545        C                                                                        001616
000547             SEXMIN = 10.**6                                                     001647
000550             SEXMAX = 0.0                                                        001651
000551             IF (CDP(99).LT.0.5) SU(N1)=SU(N1)/RULT                              001652
000553             DO 600 I=1,N                                                        001711
000556             IF (CDP(99).LT.0.5) SU(I)=SU(I)/RULT                                001711
000560             IF (SEXMAX.LT.EX(I+3*N)) SEXMAX=EX(I+3*N)                           001715
000562        600  IF (SEXMIN.GT.EX(I+2*N)) SEXMIN=EX(I+2*N)                           001724
000565             RESULT(IULT)=RULT*.5                                                001737
000566             RESULT(IULT+10) = IBLOW                                             001743
000567             IF (RESULT(IULT+10).LT.0.0) RESULT(IULT+10) = 9999999.              001746
000571             RESULT(IULT+20) = STROKO                                            001755
000572             RESULT(IULT+30) = SEXMIN                                            001760
000573             RESULT(IULT + 40) = SEXMAX                                          001762
000574             RESULT(IULT+60) = IFUEL                                             001764
000575             IF (IOSTR.LT.0) RESULT(IULT+60) = ISTR-1                            001767
000577             IF (ITYPH.EQ.3) GO TO 700                                           002001
000577        C                                                                        002001
000577        C    DETERMINE BLOWS/MINUTE FOR DIESELS                                  002001
000577        C                                                                        002001
000601             IF (ITYPH.EQ.1.AND.PBAR(20).GT.0.1) GO TO 680                       002005
000603             IF (ITYPH.EQ.2) GO TO 681                                           002022
000605             TDOWN = SQRT((STROKO-DEPIB)*0.06217)*2.0                            002026
000606             GO TO 682                                                           002037
000606        C    FOR CLOSED END HAMMERS FIND CYCLE TIME                              002037
000607        681  CALL DOWN(STROKO,VFALL,PBAR,HM,DEPIB,ARAM,IW,INOW,TDOWN)            002041
000610             TDOWN=TDOWN*2.0                                                     002053
000611             GO TO 682                                                           002056
000612        680  DCY = 0.0                                                           002060
000612        C    FOR VACUUM HAMMERS ONLY - DETERMINE TIME OF CYCLE                   002060
000613             CALL VACHAM(PBAR,ARAM,DEPIB,DCY,STROKO,FSTR,VFT,INOW,IW)            002060
000614             DD = DEPIB-0.001                                                    002073
000615             CALL VACHAM(PBAR,ARAM,DEPIB,DCY,DD,FSBO,VFB,IOUT,IW)                002076
000616             AC = 32.17*(1.0+0.5*(FSTR+FSBO)/PBAR(20))                           002111
000617             TDOWN = SQRT((STROKO-DEPIB)*2.0/AC)*2.0                             002120
000620        682  CONTINUE                                                            002133
000620        C    TOTAL CYCLE TIME                                                    002133
000621             TT = TDOWN + TSTART+TDIES+TUP                                       002133
000622             RESULT(IULT+50) = 60./TT                                            002137
000622        C    DETERMINE BOUNCE CHAMBER PRESSURE                                   002137
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000623   310.           IF (PBAR(1).GT.0.0) RESULT(IULT+70)=(PBAR(8)/PBAR(1))/0.144          002144
000625   311.           IF (IFUEL.EQ.0) RESULT(IULT+70) = PSI                                002155
000627   312.       700 IF (IULT.GE.NULT.OR.IBLOW.GT.1200.OR.IBLOW.LT.0) GO TO 402            002163
000627   313.     C                                                                        002163
000627   314.     C                                                                        002163
000627   315.     C     SET UP FOR NEXT RULT ANALYSIS                                        002163
000627   316.     C                                                                        002163
000631   317.           I = IULT                                                           002210
000632   318.           IF (ITYPH.EQ.3.OR.IOSTR.NE.0) GO TO 904                            002212
000632   319.     C     NEW STROKE (ASSUMED) FOR DIESELS                                     002212
000634   320.           STROKN = 1.2*STROKO                                                002224
000635   321.           IF (IULT.GT.1) STROKN = RESULT(IULT+20)*1.5-RESULT(IULT+19)*0.5    002230
000637   322.           IF (STROKN.GT.STRM) STROKN=STRM                                    002244
000637   323.     C     VELOCITY AT PORTS                                                    002244
000641   324.           IF (STROKN.GT.DEPIB) VFALL=SQRT(64.34*(STROKN-DEPIB))              002253
000643   325.           DCYL = 0.0                                                         002270
000644   326.           IF (PBAR(20).GT.0.0) CALL VACHAM(PBAR,ARAM,DEPIB,DCYL,STROKN,FSUCK 002271
000644   327.          1 ,VFALL,IOUT,IW)                                                   002271
000646   328.           IF (ITYPH.EQ.1) GO TO 904                                          002310
000650   329.           VFALL = VFALLM                                                     002314
000651   330.           IF (STROKN.LT.STRMAX)                                              002316
000651   331.          1CALL DOWN(STROKN,VFALL,PBAR,HM,DEPIB,ARAM,IW,IOUT,TDOWN)           002316
000653   332.           IF (STROKN.GT.STRMAX) STROKN = STRMAX                              002336
000655   333.           IF (IFUEL.GT.0) IFUEL = IFUEL - 1                                  002345
000657   334.           PCOM = PCOMR*(1.0-FLOAT(IFUEL)*0.1)                                002354
000660   335.       904 CONTINUE                                                           002364
000661   336.           IF (IOSTR.EQ.0) STROKO = STROKN                                    002364
000663   337.           IF (IOSTR.NE.0) VFALL = VFR                                        002367
000663   338.     C                                                                        002367
000663   339.     C     NEW STATIC SOIL RESISTANCE                                           002367
000663   340.     C                                                                        002367
000665   341.           IF (RESULT(I+1).GT.0.001) RULT=RESULT(I+1)*2.                      002404
000667   342.           IF (RESULT(I+1).GT.0.001) GO TO 399                                002412
000671   343.           RULT = RULT + DULT                                                 002414
000672   344.       399 IULT=IULT+1                                                        002420
000673   345.           IF (CDP(99).GT.0.5) GO TO 395                                      002422
000675   346.           DO 398 I=1,N1                                                      002427
000700   347.           SU(I) = SU(I)*RULT                                                 002434
000701   348.       398 SOK(I) = SU(I)/QS(I)                                               002436
000703   349.           GO TO 501                                                          002441
000704   350.       395 CONTINUE                                                           002443
000704   351.     C     FOR CONSTANT SKIN FRICTION                                           002443
000705   352.           SU(N1)=SU(N1)+RULT-RESULT(IULT-1)*2.0                              002443
000706   353.           SOK(N1) = SU(N1)/QS(N1)                                            002452
000707   354.           GO TO 501                                                          002454
000710   355.       401 IULT=IULT-1                                                        002456
000710   356.     C                                                                        002456
000710   357.     C     NOW ONE PROBLEM IS DONE                                              002456
000710   358.     C     OUTPUT SUMMARY AND                                                   002456
000710   359.     C     FINAL PLOT                                                           002456
000710   360.     C                                                                        002456
000711   361.       402 IF (QFIN.LE.0.0) WRITE (IW,23)                                     002461
000714   362.         4 FORMAT (1H1,12X,10A4/1H0,28X,7HSUMMARY)                            002471
000715   363.           WRITE (IW,4) TITLE                                                 002471
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000724   364.      23 FORMAT (53H ANALYSIS WAS TERMINATED AS NO PERMAMENT SET RESULTED )   002523
000725   365.         WRITE (IW,5)                                                          002523
000727   366.         IF (ITYPH.LT.3) WRITE(IW,40)                                          002530
000732   367.     40  FORMAT(1H+,57X,8H  BLOWS/)                                            002537
000733   368.         IF (ITYPH.EQ.2) WRITE (IW,30)                                         002537
000736   369.         WRITE (IW,6)                                                          002546
000740   370.         IF (ITYPH.EQ.2) WRITE (IW,31)                                         002553
000743   371.         IHP=50                                                                002562
000744   372.         IF (ITYPH.LT.3) IHP=60                                                002564
000746   373.         IF (ITYPH.LT.3) WRITE(IW,41)                                          002570
000751   374.     41  FORMAT (1H+,57X,8H  MINUTE)                                           002602
000752   375.         DO 800 I=1,IULT                                                       002602
000755   376.         WRITE (IW,7) I,(RESULT(J),J=I,IHP,10)                                 002607
000765   377.         IFF = RESULT(60+I)                                                    002623
000766   378.         IF (RESULT(I+10).LT.0.0) RESULT(I+10)=9999999.                        002630
000770   379.    800  IF (ITYPH.EQ.2) WRITE (IW,14) IFF,RESULT(I+70)                        002636
000776   380.     14  FORMAT (1H+,35X,1H(,I1,1H),27X,F10.1)                                 002653
000777   381.     30  FORMAT (1H+,67X,8HB.C. PR.)                                           002653
001000   382.     31  FORMAT (1H+,72X,3HPSI)                                                002653
001001   383.     5   FORMAT (1H0,55H    NO      R ULT    BLOW CT    STROKE  MIN STR   MAX   002653
001001   384.        1 STR  )                                                               002653
001002   385.     6   FORMAT (11X,44HTONS        1/FT         FT        KSI        KSI   )  002653
001003   386.     7   FORMAT (I6,F10.1,F10.0,3F10.2,F10.1)                                  002653
001004   387.         IF (MULT.EQ.1) IULT = 0                                               002653
001006   388.         CALL OUTPUT (OUT,RESULT,INP,IOUT,DTP,JPMAX,JDOUT,IULT,N,MAXJP,        002660
001006   389.        1 ALPH,ISEG,JSELEC,YMAX,COLI,TITLE,STP1,PM(1))                         002660
001007   390.    400  CONTINUE                                                              002704
001010   391.     10  FORMAT (1H1)                                                          002704
001010   392.   C                                                                           002704
001010   393.   C     GO TO READ NEW PROBLEM                                                002704
001010   394.   C                                                                           002704
001011   395.         GO TO 9877                                                            002704
001012   396.   9876  CONTINUE                                                              002706
001013   397.         WRITE (IWR,10)                                                        002706
001015   398.         END                                                                   002714

         1         SUBROUTINE FILL(KK,KLIM,OUT,JMAX,IIOUT,DNH,STH,FINTAC,FTP,INP,     2   8   000004 0
         2        1 DNP,STP,SPLICE,VNH,VNP,ANH,ANP,JPMAX,MAXJP,EX,AREA,J,M,N,JEX,JCK)  4   8   000017 5
         3         DIMENSION OUT(1),DNH(1),STH(1),INP(1),DNP(1),STP(1),               1   8   000034 3
         4        1SPLICE(1),VNH(1),VNP(1),ANH(1),ANP(1),EX(1),AREA(1),JEX(1)         3   8   000046 3
         5         KK = KK + 1                                                        1   8   000061 5
         6         M1 = M+1                                                           2   8   000064 5
         7         KKMAX = (JMAX+1)*KLIM + KK                                         1   8   000067 2
         8   C                                                                        7   8   000074 5
         9   C     CHECK IF OUT IS FULL                                               7   8   000076 0
        10   C                                                                        7   8   000102 5
        11         IF (KK.GT.KLIM) GO TO 459                                          1   8   000104 0
        12         K2 = KK + KLIM                                                     1   8   000111 2
        13         K3 = K2 + KLIM                                                     1   8   000114 5
        14         K4 = K3 + KLIM                                                     1   8   000120 2
        15         L = 1                                                              1   8   000123 5
        16         IF (IIOUT.NE.1.AND.IIOUT.NE.3) GO TO 452                           1   8   000125 5
        17   C                                                                        7   8   000135 5
        18   C     FORCE ASSIGNMENT                                                   7   8   000137 0
        19   C                                                                        7   8   000143 1
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             OUT(KK) = 0.0                                                    8    8    000153 5
             IF (M.GT.1) OUT(KK)=(DNH(M-1)-DNH(M))*STH(M-1)                   8    8    000157 1
             OUT(K2) = FINTAC                                                 1    8    000170 1
             OUT(K3) = FTP                                                    1    8    000174 0
             L = 2                                                            1    8    000177 2
             KK1 = INP(2)                                                     1    8    000201 2
             DO 451 I = K4,KKMAX,KLIM                                         1    8    000204 3
             KM1 = KK1-1                                                      1    8    000211 4
             COM = DNP(KM1)-DNP(KK1)                                          6    8    000224 1
             OUT(I) = COM*STP(KK1)                                            6    8    000231 1
             IF (OUT(I).LT.SPLICE(KK1)) OUT(I) = SPLICE(KK1)                  1    8    000235 5
             IF (OUT(I).GT.0.0.OR.SPLICE(KK1).LT.-.5) GO TO 686               6    8    000247 0
             OUT(I) = 0.0                                                     6    8    000260 4
             IF (COM.LT.SPLICE(KK1)) OUT(I) = (COM-SPLICE(KK1))*STP(KK1)      6    8    000263 5
             IF (OUT(I).LT.0.0.AND.OUT(I).GT.-.5) OUT(I) = 0.0                6    8    000277 1
       686   CONTINUE                                                         6    8    000310 4
             L = L+1                                                          1    8    000314 0
       451   KK1 = INP(L)                                                     1    8    000316 2
             GO TO 458                                                        1    8    000322 2
       452   IF (IIOUT.NE.2) GO TO 454                                        1    8    000325 0
     C                                                                        7    8    000333 1
     C       VELOCITY ASSIGNMENT                                              7    8    000334 2
     C                                                                        7    8    000341 0
             OUT(KK) = VNH(M)                                                 1    8    000342 1
             OUT(K2) = VNH(M1)                                                1    8    000346 0
             DO 453 I=K3,KKMAX,KLIM                                           1    8    000352 0
             KK1 = INP(L)                                                     1    8    000356 5
             OUT(I) = VNP(KK1)                                                1    8    000362 0
       453   L = L + 1                                                        1    8    000366 0
             GO TO 458                                                        1    8    000371 3
       454   IF (IIOUT.NE.5) GO TO 456                                        1    8    000374 1
     C                                                                        7    8    000402 2
     C       DISPLACEMENT ASSIGNMENT                                          7    8    000403 3
     C                                                                        7    8    000410 5
             OUT(KK) = DNH(M)                                                 1    8    000412 0
             OUT(K2) = DNH(M1)                                                1    8    000415 5
             DO 455 I=K3,KKMAX,KLIM                                           1    8    000421 5
             KK1 = INP(L)                                                     1    8    000426 4
             OUT(I) = DNP(KK1)                                                1    8    000431 5
       455   L = L+1                                                          1    8    000435 5
             GO TO 458                                                        1    8    000441 0
     C                                                                        7    8    000443 4
     C       ACCELERATION ASSIGNMENT                                          7    8    000444 5
     C                                                                        7    8    000452 1
       456   OUT(KK) = ANH(M)                                                 1    8    000453 2
             OUT(K2) = ANH(M1)                                                1    8    000460 0
             DO 457 I=K3,KKMAX,KLIM                                           1    8    000464 0
             KK1 = INP(L)                                                     1    8    000470 5
             OUT(I) = ANP(KK1)                                                1    8    000474 0
       457   L = L+1                                                          1    8    000500 0
       458   JPMAX = J                                                        1    8    000503 1
             MAXJP = KK                                                       1    8    000506 4
       459   CONTINUE                                                         1    8    000511 3
     C                                                                        1    8    000514 5
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C      CALCULATE THE EXTREMUM ARRAY EX(N*6)                         1    8    000516 0
C      FIRST FORCES AND STRESSES                                    7    8    000526 5
C                                                                   7    8    000534 3
       SEX1 = FTP/AREA(1)                                           4    8    000535 4
       IF (FTP.GT.EX(1)) JEX(1)=J                                   3    8    000541 5
       IF (FTP.GT.EX(1)) EX(1) = FTP                                1    8    000547 2
C                                                                   7    8    000555 3
C      JCK LESS 0 MEANS NO MINIMUM FORCE OR MINIMUM STRESS CHECK    7    8    000556 4
C                                                                   7    8    000572 0
       IF (JCK.LT.0) GO TO 105                                      4    8    000573 1
       IF (FTP.LT.EX(N+1)) JEX(N+1)=J                               3    8    000600 1
       IF (FTP.LT.EX(N+1))  EX(N+1) = FTP                           1    8    000606 3
       IF (SEX1.LT.EX(2*N+1)) JEX(2*N+1)=J                          5    8    000634 3
       IF (SEX1.LT.EX(2*N+1)) EX(2*N+1)=SEX1                        5    8    000643 4
   105 CONTINUE                                                     4    8    000653 1
       IF (SEX1.GT.EX(3*N+1)) JEX(3*N+1)=J                          5    8    000675 3
       IF (SEX1.GT.EX(3*N+1)) EX(N*3+1)=SEX1                        5    8    000704 4
       DO 461 I=2,N                                                 1    8    000714 1
       COM = DNP(I-1)-DNP(I)                                        6    8    000726 1
       FELP = COM*STP(I)                                            6    8    000732 5
       IF (FELP.LT.SPLICE(I)) FELP = SPLICE(I)                      1    8    000736 5
       IF (FELP.GT.0.0.OR.SPLICE(I).LT.-.5) GO TO 685               6    8    000746 4
       FELP = 0.0                                                   6    8    000757 4
       IF (COM.LT.SPLICE(I)) FELP = (COM-SPLICE(I))*STP(I)          6    8    000762 3
       IF (FELP.LT.0.0.AND.FELP.GT.-.5) FELP = 0.0                  6    8    000774 2
   685 CONTINUE                                                     6    8    001004 5
       SELP = FELP/AREA(I)                                          1    8    001010 1
       IF (FELP.GT.EX(I)) JEX(I)=J                                  3    8    001014 3
       IF (FELP.GT.EX(I))   EX(I) = FELP                            1    8    001022 1
       IF (JCK.LT.0) GO TO 103                                      4    8    001030 4
       IF (FELP.LT.EX(N+I)) JEX(N+I)=J                              3    8    001035 4
       IF (FELP.LT.EX(N+I)) EX(N+I) = FELP                          1    8    001044 1
       IF (SELP.LT.EX(2*N+I)) JEX(2*N+I)=J                          3    8    001053 2
       IF (SELP.LT.EX(2*N+I)) EX(2*N+I) = SELP                      1    8    001062 3
   103 CONTINUE                                                     4    8    001072 2
       IF (SELP.GT.EX(3*N+I)) JEX(3*N+I)=J                          3    8    001075 4
   461 IF (SELP.GT.EX(3*N+I)) EX(3*N+I) = SELP                      1    8    001104 5
C                                                                   7    8    001115 3
C      VELOCITY AND DISPLACEMENT EXTREMA                            7    8    001116 4
C                                                                   7    8    001125 5
       DO 462 I=1,N                                                 1    8    001127 0
       IF (VNP(I).GT.EX(4*N+I)) JEX(4*N+I)=J                        3    8    001132 1
       IF (VNP(I).GT.EX(4*N+I)) EX(4*N+I) = VNP(I)                  1    8    001141 4
       DISI = DNP(I) * 12.                                          1    8    001152 1
       IF (DISI.GT.EX(5*N+I)) JEX(5*N+I)=J                          3    8    001156 3
   462 IF (DISI.GT.EX(5*N+I))EX(5*N+I) = DISI                       1    8    001165 4
       RETURN                                                       1    8    001176 1
       END                                                          1    8    001200 2

       SUBROUTINE PILEAN (ITP,AOP,VOP,DOP,ANP,VNP,DNP,STP,PM,SPLICE,SJ,      1   10    000004 0
     1  COP,RES,RESO,SU,SOK,VNPIT,VCAP,SOILM,SJJJ,DTP,N,IT,ISMITH,EPSV,      1   10    000020 1
     2 IAI,ESOIL,FTP,JRAT,ITER)                                             2   10    000034 4
       DIMENSION AOP(99),VOP(99),DOP(99),ANP(99),DNP(99),PM(99),STP(99),     3   10    000042 1
     1 SPLICE(99),SJ(99),CDP(99),RES(99),RESO(99),SU(99),SOK(99),VNP(99)     1   10    000056 3
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      C                                                                                        8     10    000073 1
      C        THIS SUBPROGRAM PERFORMS A WAVE ANALYSIS FOR A PILE SUBJECT                      8     10    000074 2
      C        TO EITHER OF THE FOLLOWING THREE PILE TOP VARIABLES                              8     10    000110 0
      C        IAI EQUAL TO 0 , HAMMER FORCE USED IN PILEAN                                     1     10    000122 1
      C        IAI EQUAL TO 1, MEASURED FORCE USED IN PILEAN                                    1     10    000133 1
      C        IAI EQUAL TO 2, MEASURED ACCELERATION USED IN PILEAN                             1     10    000144 2
      C        START TO COMPUTE THE PILE VARIABLES                                              1     10    000156 4
      C                                                                                         1     10    000166 1
      C        SPLICE IS USUALLY AT THE STRUCTURAL LIMIT OF THE PILE MATERIAL (TENSION, T       1     10    000167 2
      C        HUS NEGATIV) EXCEPT WHERE SPLICES GIVE LOWER VALUE                               1     10    000205 3
      C        IF SPLICE IS BETWEEN 0 AND -0.5 FT IT IS A SLACK                                 8     10    000217 3
      C        IT IS THE ITERATION COUNTER (ASSIGNED OUTSIDE)                                   8     10    000231 1
      C        FU AND FO ARE FORCES AT AN ELEMENT DOWNWARDS POSITIVELY                          8     10    000242 3
      C                                                                                         8     10    000255 3
               NM1=N-1                                                                          1     10    000256 4
               ITP=0                                                                            1     10    000261 0
               IF (IT.GT.0) GO TO 550                                                           1     10    000263 0
               I1=1                                                                             1     10    000267 5
      C        PREDICTION                                                                       8     10    000271 4
               IF (IAI.LT.2) CALL INTEGR (DTP,AOP,AOP,VOP,DOP,VNP,DNP,I1)                       1     10    000274 5
               IF (IAI.EQ.2) CALL INTEGR (DTP,AOP,ANP,VOP,DOP,VNP,DNP,I1)                       1     10    000310 0
               G=32.170                                                                         1     10    000323 1
               DO 300 I=2,N                                                                     1     10    000325 4
               CALL INTEGR(DTP,AOP,AOP,VOP,DOP,VNP,DNP,I)                                       1     10    000330 5
          300  CONTINUE                                                                         1     10    000341 1
          550  CONTINUE                                                                         1     10    000344 3
      C                                                                                         8     10    000347 5
      C        WAVE ANALYSIS                                                                    8     10    000351 0
      C        FIRST PILE TOP                                                                   8     10    000354 4
      C                                                                                         8     10    000360 3
          400  FU = (DNP(2)-DNP(1))*STP(2)+(VNP(2)-VNP(1))*CDP(2)                               4     10    000361 4
               FOD = (VCAP-VNP(1))*CDP(1)                                                       4     10    000374 1
               IF (FOD+FTP.LT.SPLICE(1)) FOD = 0.0                                              4     10    000401 4
               IF (IAI.EQ.1) FOD = 0.0                                                          4     10    000410 5
               IF (FU.GT.-SPLICE(2)) FU = -SPLICE(2)                                            1     10    000415 5
               IF (SPLICE(2).LT.-0.5.OR.FU.LT.0.0) GO TO 175                                   10     10    000444 5
               EXT = DNP(2)-DNP(1)                                                              5     10    000455 4
               IF (EXT.LT.0.0) GO TO 175                                                        5     10    000462 0
               FU = 0.0                                                                         5     10    000467 2
               IF (EXT.LT.-SPLICE(2)) GO TO 175                                                 5     10    000471 5
               FU = (EXT+SPLICE(2))*STP(2)+(VNP(2)-VNP(1))*CDP(2)                               5     10    000500 3
          175  CONTINUE                                                                         5     10    000512 1
               I = 1                                                                            4     10    000515 3
               CALL SRESN (DNP,DOP,SU,SOK,I,RESO,RES,ESOIL)                                     1     10    000517 3
               DA = VNP(1)*SJ(I)                                                                1     10    000530 1
               IF (ISMITH.EQ.1) DA = DA * RES(1)                                                1     10    000534 1
               IF (IAI.NE.2) GO TO 200                                                          1     10    000543 0
               FTP = (ANP(1)-G)*PM(1)-FU-FOD+RES(1) + DA                                        4     10    000550 0
               GO TO 201                                                                        1     10    000560 1
          200  CONTINUE                                                                         4     10    000562 5
               ANP(1) = G + (FTP+FOD+FU-RES(1)-DA)/PM(1)                                        4     10    000566 1
               CALL INTEGR(DTP,AOP,ANP,VOP,DOP,VNP,DNP,I)                                       1     10    000576 2
      C                                                                                         8     10    000606 4
      C        ELEMENTS BETWEEN TOP AND TOE                                                     8     10    000607 5
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      C                                                                    8   10   000616 1
  201   DO 301 I=2,NM1                                                     1   10   000617 2
        I1=I+1                                                             1   10   000623 3
        IM1=I-1                                                            1   10   000625 4
        FO = -FU                                                           4   10   000630 0
        FU = (DNP(I1)-DNP(I))*STP(I1) + (VNP(I1)-VNP(I))*CDP(I1)           4   10   000632 3
        IF (FU.GT.-SPLICE(I1)) FU = -SPLICE(I1)                            1   10   000645 2
        IF (SPLICE(I1).LT.-0.5.OR.FU.LT.0.0) GO TO 176                     9   10   000672 4
        EXT = DNP(I1)-DNP(I)                                               5   10   000703 4
        IF (EXT.LT.0.0) GO TO 176                                          5   10   000710 1
        FU = 0.0                                                           5   10   000715 3
        IF (EXT.LT.-SPLICE(I1)) GO TO 176                                  7   10   000740 5
        FU=(EXT+SPLICE(I1))*STP(I1)+(VNP(I1)-VNP(I))*CDP(I1)               7   10   000747 4
  176   CONTINUE                                                           6   10   000761 4
        CALL SRESN (DNP,DOP,SU,SOK,I,RESO,RES,ESOIL)                       1   10   000765 0
        DA = VNP(I) * SJ(I)                                                1   10   000775 4
        IF (ISMITH.EQ.1) DA = DA * RES(I)                                  1   10   001002 0
        ANP(I) = G + (FO+FU-RES(I)-DA)/PM(I)                               4   10   001010 5
        CALL INTEGR(DTP,AOP,ANP,VOP,DOP,VNP,DNP,I)                         1   10   001020 1
  301   CONTINUE                                                           1   10   001030 3
      C                                                                    8   10   001033 5
      C START PILE TOE ANALYSIS                                            8   10   001035 0
      C                                                                    8   10   001042 2
        N1=N+1                                                             1   10   001043 3
        DNP(N1)=DNP(N)                                                     1   10   001045 4
        CALL SRESN (DNP,DOP,SU,SOK,N1,RESO,RES,ESOIL)                      1   10   001051 1
        IF (RES(N1).LT.0.0) RES(N1)=0.0                                    1   10   001062 0
        DAB=VNP(N)*SJ(N1)                                                  1   10   001070 3
        IF (ISMITH.EQ.1) DAB=DAB*RES(N1)                                   1   10   001074 3
        IF (DAB.LT.0.0) DAB=0.0                                            1   10   001103 1
        DCUBE = 0.                                                         4   10   001110 1
        IF (VNP(N).GT.0.0.AND.SJJJ.GT.0.) DCUBE = VNP(N)**3*SJJJ           4   10   001113 0
        CALL SRESN (DNP,DOP,SU,SOK,N,RESO,RES,ESOIL)                       1   10   001125 5
        DA = VNP(N) * SJ(N)                                                1   10   001136 3
        IF (ISMITH.EQ.1) DA = DA*RES(N)                                    1   10   001142 5
        FO = -FU                                                           4   10   001151 2
        ANP(N) = G + (FO-RES(N)-DA-RES(N1)-DAB-DCUBE)/(PM(N)+SOILM)        4   10   001153 5
        CALL INTEGR(DTP,AOP,ANP,VOP,DOP,VNP,DNP,N)                         1   10   001167 1
        ITP=ITP+1                                                          1   10   001177 3
        IF (JRAT.EQ.1) GO TO 750                                           1   10   001202 1
        IF (ITP.GT.ITER) GO TO 750                                         1   10   001207 2
      C CHECK CONVERGENCE (IF DTH NOT EQ DTP)                              8   10   001214 5
        ERR = ABS(VNPIT-VNP(N))                                            1   10   001224 4
        VNPIT = VNP(N)                                                     1   10   001231 4
      C FOR NO CONVERGENCE REPEAT ANALYSIS                                 8   10   001235 1
        IF (ERR.GT.EPSV) GO TO 400                                         1   10   001244 3
  750   CONTINUE                                                           1   10   001252 0
        RETURN                                                             1   10   001255 2
        END                                                                1   10   001257 3
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        SUBROUTINE STARTC                                                  1   43   000004 0
        COMMON VINH,DINH,AOH,VOH,DOH,ANH,VNH,DNH,STH,HM,AM,STA,MA,ESOIL,   1   43   000010 0
      1 AOP,ANP,DOP,DNP,VOP,VNP,STP,PM,CDP,RES,RESO,SJ,SOK,QS,SU,          1   43   000024 1
      2 SPLICE,DEPIB,ARAM,ECUS,ECAP,EPT,EANV,VFALL,VCHAM,XPT,SJJJ,         1   43   000037 3
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     3 EMP,RHO,DTH,DTP,N,M,JRAT,IULT,RULT,SOILM,DSACP,                      1     43     000053 0
     4 FPTO,IW,PCOM,TDEL,IOUT,OUT,EXPP,TEMI,TEMO,INP,STROKO,STROKN,VO,PO    1     43     000064 3
     5 ,DFIN,JDOUT,JPMAX,EX,ICOL,FINTMX, TEMAX,RESULT,ISMITH,ITER           1     43     000101 1
     6 ,ITYPH,IPREIG,VFALLM,STRMAX,DCYL,PBAR,AREA,JEX                      27     43     000114 4
      COMMON/SLAK/OPEN(99)                                                 42     43     000132 3
      DIMENSION VINH(10),DINH(10),AOH(10),VOH(10),DOH(10),ANH(10),          1     43     000137 0
     1 VNH(10),DNH(10),STH(10),HM(10), VNP(99),                             1     43     000152 3
     2 AOP(99),ANP(99),DOP(99),DNP(99),VOP(99),STP(99),PM(99),CDP(99),      1     43     000162 5
     3 RES(99),RESO(99),SJ(99),SOK(99),QS(99),SU(99),SPLICE(99),            1     43     000177 1
     4 DSACP(3),OUT(3200),INP(13),EX(600),RESULT(100),JEX(600)             27     43     000212 3
     5 ,AM(10),STA(10),PBAR(20),AREA(99)                                   26     43     000225 3
      IPREIG=0                                                             10     43     000234 4
      TCC=0.0                                                              10     43     000237 1
      TEMIK=272.0+TEMI                                                     10     43     000241 3
      EXP=1.35                                                             10     43     000245 2
      STTIME = 0.0                                                         31     43     000247 5
      EXPT=1.0-1.0/EXP                                                     10     43     000253 0
      PATM=14.7*.144                                                       10     43     000256 5
      TEMPC=0.0                                                            10     43     000262 2
      IF (TDEL.GT.1.0) TEMPC=TDEL                                          10     43     000265 0
      IF (VFALL.LT.0.0) WRITE (IW,5)                                       10     43     000272 4
    5 FORMAT (27H NEGATIVE VELOCITY IN START )                             10     43     000301 0
      IF (PBAR(16).GT.0.5) VFALL=VFALL*SQRT(PBAR(16))                      10     43     000311 2
      IF (VFALL.LT.0.0) STOP                                               10     43     000322 3
      M1=M+1                                                               10     43     000327 2
      M2=M+2                                                               10     43     000331 3
      N1=N+1                                                               10     43     000333 4
C                                                                          36     43     000335 5
C     INITIALIZE HAMMER AND PILE VARIABLES                                 36     43     000337 0
C                                                                          36     43     000346 4
      DCYL = 0.0                                                           29     43     000347 5
      DELP = 0.0                                                           30     43     000352 4
      IF (PBAR(I).GT.ARAM) DELP=(PBAR(I)-ARAM)*0.144*14.7                  30     43     000355 3
      FSUCK=0.0                                                            30     43     000367 2
      G=32.17                                                              10     43     000372 0
      RAM=0.0                                                              10     43     000374 2
      DO 100 I=1,M2                                                        10     43     000376 4
      IF (I.LT.M1) RAM = RAM + HM(I)                                       11     43     000402 0
      VOH(I)=0.0                                                           10     43     000410 2
      DOH(I)=0.0                                                           10     43     000413 1
      ANH(I) = 0.0                                                         25     43     000416 0
  100 AOH(I)=0.0                                                           10     43     000421 1
      DO 101 I=1,N1                                                        10     43     000424 4
      RES(I) = 0.0                                                         32     43     000430 0
      RESO(I)=0.0                                                          10     43     000433 1
      ANP(I) = 0.0                                                         25     43     000436 1
      VNP(I) = 0.0                                                         25     43     000441 2
      DNP(I) = 0.0                                                         25     43     000444 3
      VOP(I)=0.0                                                           10     43     000447 4
      DOP(I)=OPEN(I)                                                       42     43     000460 5
  101 AOP(I)=0.0                                                           10     43     000464 2
C                                                                          36     43     000467 5
C     DETERMINE TIME INCREMENT                                             36     43     000471 0
C                                                                          36     43     000476 3
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          STCL = STH(M1)*0.5                                          14   43   000477 4
          STP1=STH(M2)*STP(1)/(STH(M2)+STP(1))                        10   43   000503 5
          STP1 = STP1 * 0.5                                           14   43   000513 1
          DT1=HM(M1)/STCL                                             10   43   000517 1
          DT=HM(M2)/STP1                                              10   43   000522 5
          IF (DT.GT.DT1) DT=DT1                                       10   43   000526 2
          DT1=HM(M2)/STCL                                             10   43   000533 0
          IF (DT.GT.DT1) DT=DT1                                       10   43   000536 4
          DT1=PM(1)/STP1                                              10   43   000543 2
          IF (DT.GT.DT1) DT=DT1                                       10   43   000546 5
          DO 102 I=2,N                                                10   43   000553 3
          DT1=PM(I)/(STP(I)+SOK(I))                                   31   43   000556 4
          IF (I.EQ.N) DT1=PM(N)/(STP(N)+SOK(N)+SOK(N+1))              31   43   000564 0
      102 IF (DT.GT.DT1) DT=DT1                                       10   43   000575 0
          NM1 = N-1                                                   33   43   000602 2
          DAM = SJ(N) + SJ(N+1)                                       33   43   000605 0
          IF (ISMITH.EQ.1) DAM = SJ(N)*SU(N) + SJ(N1)*SU(N1)          33   43   000611 4
          DAM = DAM/SQRT(PM(N)*STP(N))                                33   43   000623 2
          DO 141 I = 1,N                                              33   43   000631 2
          DA = SJ(I)/SQRT(PM(I)*STP(I))                               33   43   000634 5
          IF (ISMITH.EQ.1) DA = DA*SU(I)                              33   43   000643 0
          IF (DA.GT.DAM) DAM = DA                                     33   43   000651 2
      141 CONTINUE                                                    33   43   000656 2
          DAM = DAM*1.2                                               40   43   000661 4
          IF (DAM.LT.2.) DAM = 2.                                     39   43   000665 0
          DT = SQRT(DT)/DAM                                           33   43   000672 0
          IF (DT.LT.0.00001) DT = 0.00001                             33   43   000676 0
          TLIM = 2.5*DEPIB/VFALL                                      16   43   000704 3
          DLIM = 0.25*DEPIB                                           16   43   000711 2
          IF (DLIM.LT.0.2) DLIM = 0.2                                 16   43   000716 2
C         PLACE RAM AT EXHAUST PORTS                                  36   43   000723 0
          DTOP=-DEPIB                                                 11   43   000730 5
          DOH(M)=-DEPIB                                               10   43   000733 5
          VOH(M)=VFALL                                                10   43   000737 1
          AOH(M)=G                                                    10   43   000742 2
          D0 = VCHAM/ARAM                                             16   43   000744 5
          DCU = PM(99)                                                35   43   000750 3
          DCT = 0.05*SQRT(STP1*HM(M2))                                16   43   000753 4
          DIN=DEPIB+VCHAM/ARAM                                        10   43   000761 4
          N5=N/2                                                      10   43   000766 1
          IN=0                                                        10   43   000770 2
          J=0                                                         10   43   000772 1
          T2S = 0.0                                                   12   43   000773 5
          FSLOW = 0.0                                                 12   43   000776 3
          D3LC = (3.0*XPT/SQRT(EMP/RHO))*VFALL                        36   43   001001 3
          DACRT = 0.5*DEPIB                                           35   43   001010 5
          IF (D3LC.GT.DACRT) DACRT = D3LC                             36   43   001014 5
C         DACRT IS DISTANCE AT WHICH PILE ANALYSIS STARTS             36   43   001023 2
          IF (IOUT.LT.0) WRITE (IW,1) DT,VFALL,DEPIB                  10   43   001034 5
        1 FORMAT (14H DT, V, DEPIB,F8.5,2F8.2)                        10   43   001045 1
    2     FORMAT(13X,102HFP           FC         FT      V RAM      V ANV      V TO   32   43   001054 5
         1P      V MID      V TOE      D CH      D TOP   TOE RES )    32   43   001066 0
          IF (IOUT.LT.0) WRITE (IW,2)                                 12   43   001075 5
      109 CONTINUE                                                    10   43   001103 3
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          STTIME = STTIME+DT                                                      31   43   001106 7
          IN=IN+1                                                                 10   43   001112 5
          J=J+1                                                                   10   43   001115 1
          FSLOW = FSLOW + 0.025                                                   33   43   001117 1
          IF (FSLOW.GT.1.) FSLOW = 1.0                                            12   43   001123 5
          IF (DOH(M).GT.-DACRT) T2S = T25 + 0.025                                 33   43   001131 5
          IF (T2S.GT.1.0) T2S = 1.0                                               12   43   001141 4
          IT = 1                                                                  18   43   001147 0
      125 CONTINUE                                                                18   43   001151 1
C         PREDICTOR INTEGRATION                                                   36   43   001154 2
          DO 103 I=M,M2                                                           10   43   001161 2
          VNH(I)=AOH(I)*DT+VOH(I)                                                 10   43   001164 4
      103 DNH(I)=VOH(I)*DT+DOH(I)                                                 16   43   001171 4
          IF (T2S.LT.10.E-8) GO TO 114                                            16   43   001177 2
          DO 104 I=1,N                                                            10   43   001205 2
          VNP(I)=AOP(I)*DT+VOP(I)                                                 10   43   001210 3
      104 DNP(I)=VOP(I)*DT+DOP(I)                                                 16   43   001215 3
      114 CONTINUE                                                                16   43   001223 1
          IF (IT.EQ.3) GO TO 112                                                  38   43   001316 0
C         START WAVE ANALYSIS                                                     36   43   001322 5
          DBC = -DNH(M)                                                           29   43   001327 3
          IF (PBAR(20).GT.0.0) CALL VACHAM(PBAR,ARAM,DEPIB,DCYL,DBC,FSUCK,        30   43   001332 5
         1 VFALL,IOUT,IW)                                                         30   43   001347 0
          FP=ARAM*PATM*((DIN/(D0+DNH(M1)-DNH(M)))**EXP)                           16   43   001352 5
          FP = FP-FSUCK+DELP                                                      29   43   001363 4
          FCU = (DNH(M2)-DNH(M1))*STCL+(VNH(M2)-VNH(M1))*DCU                      16   43   001367 5
          FPT = (DNP(1 )-DNH(M2))*STP1+(VNP(1 )-VNH(M2))*DCT                      16   43   001401 3
          DTOP=DNH(M)-DNH(M1)                                                     11   43   001413 1
          ANH(M) = G+(-FP+FTR(DTOP,PBAR,IWT))*FSLOW/RAM                           12   43   001417 3
          ANH(M1) = G + (FP*FSLOW+FCU)/HM(M1)                                     12   43   001430 2
          ANH(M2)=G+(-FCU+FPT)/HM(M2)                                             10   43   001437 3
          DO 305 I=M,M2                                                           39   43   001445 1
          VNH(I) = VOH(I) + ANH(I)*DT                                             39   43   001450 3
      305 DNH(I) = DOH(I) + (VOH(I) + VNH(I)) * 0.5 * DT                          39   43   001456 1
          IF (T2S.LT.10.E-8) GO TO 112                                            12   43   001470 0
          FO = -FPT*T2S                                                           12   43   001476 0
          DO 105 I=1,N                                                            10   43   001501 2
          FU = (DNP(I+1)-DNP(I))*STP(I+1)+(VNP(I+1)-VNP(I))*CDP(I+1)              16   43   001504 3
          RES(I)=RESO(I)+(DNP(I)-DOP(I))*SOK(I)                                   10   43   001517 4
          IF (RES(I).GT.SU(I)) RES(I)=SU(I)                                       10   43   001527 1
          DAM=SJ(I)*VNP(I)                                                        10   43   001536 0
          IF (ISMITH.EQ.1) DAM=DAM*RES(I)                                         10   43   001541 5
          IF (I.EQ.N) GO TO 106                                                   10   43   001550 2
          ANP(I)=G+(FO+FU-RES(I)-DAM)/PM(I)                                       10   43   001555 0
          VNP(I) = VOP(I) + ANP(I) * DT                                           39   43   001563 5
          DNP(I) = DOP(I) + (VNP(I) + VOP(I))*DT*0.5                              39   43   001572 0
      105 FO=-FU                                                                  10   43   001602 2
      106 RES(N1)=RESO(N1)+(DNP(N)-DOP(N))*SOK(N1)                                12   43   001605 1
          IF (RES(N1).GT.SU(N1)) RES(N1)=SU(N1)                                   10   43   001615 5
          DAT = SJ(N1)*VNP(N)                                                     12   43   001625 2
          IF (ISMITH.EQ.1) DAT=DAT*RES(N1)                                        10   43   001631 4
          ANP(N) = G+(FO-RES(N1)-RES(N)-DAT-DAM)/(PM(N)+SOILM)                    12   43   001640 2
          VNP(I) = VOP(I)                                                         39   43   001652 2
          VNP(N) = VOP(N) + ANP(N)*DT                                             39   43   001656 0
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           DNP(N) = DOP(N) + (VNP(N) + VOP(N))*0.5*DT                   39      43      001663 4
      112  CONTINUE                                                     12      43      001674 0
           VNP(N1) = VNP(N)                                             35      43      001702 2
           DNP(N1) = DNP(N)                                             35      43      001706 1
           DO 107 I=M,M2                                                10      43      001721 0
           AOH(I)=ANH(I)                                                10      43      001724 2
           VOH(I)=VNH(I)                                                10      43      001727 4
      107  DOH(I)=DNH(I)                                                10      43      001733 0
           IF (T2S.LT.10.E-8) GO TO 113                                 12      43      001737 0
           DO 108 I=1,N1                                                10      43      001745 0
           RESO(I)=RES(I)                                               10      43      001750 2
           AOP(I)=ANP(I)                                                10      43      001753 5
           VOP(I)=VNP(I)                                                10      43      001757 1
      108  DOP(I)=DNP(I)                                                10      43      001762 3
      113  CONTINUE                                                     12      43      001766 3
           D1=DOP(1)*12.                                                10      43      001771 5
           DCHAM=(DOH(M1)-DOH(M))*12.                                   10      43      001775 1
           IF (IOUT.LT.0.AND.IN.EQ.10) WRITE (IW,6) J,FP,FCU,FPT,VOH(M),10      43      002002 4
          1VOH(M1),VOP(1),VOP(N5),VOP(N),DCHAM,D1                       10      43      002016 2
          2 ,RESO(N1)                                                   32      43      002026 1
           IF (IN.EQ.10) IN=0                                           10      43      002031 1
        6  FORMAT (I5,11F10.3)                                          32      43      002035 2
 C         RAM CLOSE ENOUGH AT IMPACT BLOCK FOR IGNITION CHECK          36      43      002042 1
           IF (-DOH(M).GT.DLIM) GO TO 109                               16      43      002054 2
           PO = FP/ARAM                                                 16      43      002062 4
           TEMO = TEMIK*(PO/PATM)**EXPT                                 16      43      002065 5
           TIMP=1.0                                                     10      43      002073 5
           IF (VOH(M).GT.VOH(M1)) TIMP=(DOH(M1)-DOH(M))/(VOH(M)-VOH(M1))10      43      002076 2
 C                                                                      36      43      002112 0
 C         CHECK WHETHER IGNITION OR IMPACT IS ABOUT TO OCCUR           36      43      002113 1
 C                                                                      36      43      002125 1
           IF (-TDEL.GT.TIMP-0.001) GO TO 203                           10      43      002126 2
           IF (PBAR(9).GT.0.0.AND.TDEL.LT.10.E-8) GO TO 212             24      43      002135 2
           IF (TEMPC.GT.1.0.AND.TEMO.GT.TEMPC) GO TO 206                10      43      002146 4
           IF (-DOH(M).LT.PBAR(9).AND.PBAR(9).GT.0.0) TCC = TCC + DT    24      43      002157 3
           IF (TCC.GT.TDEL-0.001.AND.PBAR(9).GT.0.0) GO TO 203          24      43      002172 3
           GO TO 212                                                    10      43      002204 2
      203  IPREIG=0.001/DTP+0.5                                         10      43      002207 0
 C         IGNITION WILL OCCUR AFTER 1 MILLISEC.                        36      43      002214 1
           GO TO 202                                                    10      43      002224 0
      206   IPREIG = 0.00025/DTP + 0.5                                  13      43      002226 4
 C         TEMPERATURE IGNITION AFTER 1/4 MSEC.                         36      43      002235 0
           GO TO 202                                                    10      43      002244 4
      212  CONTINUE                                                     16      43      002247 2
           IF (FLOAT(J)*DT.LT.TLIM) GO TO 213                           16      43      002252 3
           WRITE (IW,9)                                                 16      43      002261 3
           IPREIG = -100                                                16      43      002264 4
           GO TO 202                                                    16      43      002270 0
      213  CONTINUE                                                     16      43      002272 4
        9  FORMAT (28H *** HAMMER WILL NOT RUN ***)                     10      43      002275 5
           IF (DNH(M1)-DNH(M).GT.0.01*DEPI8) GO TO 109                  13      43      002306 1
 C         FOR 0 TDEL AND ATOMIZED FUEL INJECTION                       36      43      002316 4
 C         (ASSUME AT IMPACT)                                           36      43      002326 4
           IF (TCC.GT.10.E-8) IPREIG = (TDEL-TCC)/DTP                   24      43      002333 1
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221          IF (TCC.GT.10.E-8.AND.IPREIG .LT.1) IPREIG = 1              24    43    002343 3
222      202 MM1=M-1                                                     10    43    002354 3
223          FPTO = -FPT                                                 24    43    002357 3
224          VO = -FCU                                                   24    43    002362 3
225          DO 111 I=M,M2                                               10    43    002365 1
226          DINH(I)=DOH(I)                                              10    43    002370 3
227      111 VINH(I)=VOH(I)                                              10    43    002374 0
228          DO 110 I1=1,MM1                                             10    43    002400 1
229          I=M-I1                                                      10    43    002403 5
230          VINH(I)=VOH(M)                                              10    43    002406 0
231      110 DINH(I) = DINH(I+1) + FP/STH(I)                             13    43    002411 3
232          FINTMX = STTIME                                             32    43    002420 4
233          RETURN                                                      10    43    002424 2
234          END                                                         10    43    002426 3
FILL2               SYMBOLIC FORTRAN  28 APR 76  15:09:57   9   13   5   00122703   519
  1           SUBROUTINE FILL2 (N,M,OUT,PQ,DNH,FTP,VNP,DNP,FN05,SJ,RSUM,DSUM,     1    13    000004 0
  2          1 RES,FTN,KK,ICOL,TT,ISMITH,J,MAXJP,JPMAX,STP,AREA,SPLICE,EX,JEX,    8    13    000020 0
  3          2 J1,JCK)                                                            8    13    000034 2
  4           DIMENSION OUT(3200),DNH(10),VNP(99),DNP(99),RES(99),SJ(99),         6    13    000037 0
  5          1 SPLICE(99),STP(99),AREA(99),EX(600),JEX(600)                       6    13    000052 2
  6           N1=N+1                                                              2    13    000063 2
  7           M1=M+1                                                              1    13    000065 3
  8           N05=N/2                                                             1    13    000067 4
  9           KK=KK+1                                                             3    13    000072 0
 10           KLIM=200                                                            6    13    000074 2
 11     C                                                                        13    13    000076 5
 12     C     CHECK IF OUT IS FULL                                               13    13    000100 0
 13     C                                                                        13    13    000104 5
 14           IF (KK.GT.KLIM) GO TO 102                                           3    13    000106 0
 15           K1=KK+KLIM                                                          3    13    000113 2
 16           K2=K1+KLIM                                                          3    13    000116 1
 17           K3=K2+KLIM                                                          3    13    000121 0
 18           K4=K3+KLIM                                                          3    13    000123 5
 19           K5=K4+KLIM                                                          3    13    000126 4
 20           K6=K5+KLIM                                                          3    13    000131 3
 21           K7=K6+KLIM                                                          3    13    000134 2
 22           K8=K7+KLIM                                                          3    13    000137 1
 23           K9=K8+KLIM                                                          3    13    000142 0
 24           K10=K9+KLIM                                                         3    13    000144 5
 25           K11=K10+KLIM                                                        3    13    000147 5
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          K12=K11+KLIM                                          3    13    000153 0
          K13=K12+KLIM                                          3    13    000156 1
          K14=K13+KLIM                                          3    13    000161 2
          K15=K14+KLIM                                          3    13    000164 3
    C                                                          13    13    000167 4
    C     ASSIGN VARIABLES TO OUT .                            13    13    000170 5
    C                                                          13    13    000176 1
          OUT(KK)=TT                                            3    13    000177 2
          OUT(K1)=PQ                                            3    13    000202 1
          OUT(K2)=DNH(M)*12.                                    3    13    000205 0
          OUT(K3)=DNH(M1)*12.                                   3    13    000211 1
          OUT(K4)=FTP                                           3    13    000215 3
          OUT(K5)=VNP(1)                                        3    13    000220 3
          OUT(K6)=DNP(1)*12.                                    3    13    000224 0
          OUT(K7)=FN05                                          3    13    000230 1
          OUT(K8)=VNP(N05)                                      3    13    000233 2
          OUT(K9)=DNP(N05)*12.                                  3    13    000237 1
          OUT(K10)=RSUM                                         3    13    000243 4
          OUT(K11)=DSUM                                         3    13    000247 0
          RTOE = SJ(N1)*VNP(N)                                 13    13    000256 4
          IF (RTOE.LT.0.0001) RTOE=0.                           1    13    000263 1
          IF (ISMITH.EQ.1) RTOE=RTOE*RES(N1)                    1    13    000270 5
          OUT(K12)=RES(N1)+RTOE                                 3    13    000277 5
          OUT(K13)=FTN                                          3    13    000304
          OUT(K14)=VNP(N)                                       3    13    000307 4
          OUT(K15)=DNP(N)*12.                                   3    13    000313 2
          IF (ICOL.NE.0) GO TO 101                              3    13    000317 4
          OUT(K7)=OUT(K13)                                      3    13    000324 5
          OUT(K8)=OUT(K14)                                      3    13    000[illegible]
          OUT(K9)=OUT(K15)                                      3    13    00033[illegible]
      101 JPMAX=J                                               3    13    000340
          MAXJP=KK                                              3    13    000343 2
    C     CALCULATE THE EXTREMUM ARRAY EX(N*6)                  4    13    000345 5
      102 CONTINUE                                              6    13    000355 3
          SEX1=FTP/AREA(1)                                      8    13    000360 4
          IF (FTP.GT.EX(1)) JEX(1)=J1                           6    13    000364 3
          IF (FTP.GT.EX(1)) EX(1)=FTP                           6    13    000372 1
    C                                                          13    13    000377 5
    C     JCK LESS 0 MEANS NO MINIMUM FORCE AND STRESS CHECK   13    13    000401 0
    C                                                          13    13    000413 0
          IF (JCK.LT.0) GO TO 105                               8    13    000414 1
          IF (FTP.LT.EX(N+1)) JEX(N+1)=J1                       6    13    000421 1
          IF (FTP.LT.EX(N+1)) EX(N+1)=FTP                       4    13    000427 4
          IF (SEX1.LT.EX(2*N+1)) JEX(2*N+1)=J1                  6    13    000436 1
          IF (SEX1.LT.EX(2*N+1)) EX(2*N+1)=SEX1                 4    13    000445 3
      105 CONTINUE                                              9    13    000455 0
          IF (SEX1.GT.EX(3*N+1)) JEX(3*N+1) = J1               10    13    000477 1
          IF (SEX1.GT.EX(3*N+1))  EX(3*N+1) = SEX1             10    13    000506 5
          DO 103 I=2,N                                          4    13    000516 4
          COM = DNP(I-1)-DNP(I)                                11    13    000530 0
          FELP = COM*STP(I)                                    11    13    000534 4
          IF (FELP.LT.SPLICE(I)) FELP=SPLICE(I)                 4    13    000540 4
          IF (FELP.GT.0.0.OR.SPLICE(I).LT.-.5) GO TO 685       11    13    000550 1
          FELP = 0.0                                           11    13    000561 1
```

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      IF (COM.LT.SPLICE(I)) FELP = (COM-SPLICE(I))*STP(I)              11      13      000564 0
      IF (FELP.LT.0.0.AND.FELP.GT.-0.5) FELP=0.0                       11      13      000575 5
  685 CONTINUE                                                         11      13      000606 1
      SELP=FELP/AREA(I)                                                 4      13      000630 1
      IF (FELP.GT.EX(I)) JEX(I)=J1                                      6      13      000634 1
      IF (FELP.GT.EX(I)) EX(I)=FELP                                     4      13      000642 1
      IF (JCK.LT.0) GO TO 106                                           8      13      000650 2
      IF (FELP.LT.EX(N+I)) JEX(N+I)=J1                                  6      13      000655 2
      IF (FELP.LT.EX(N+I))EX(N+I)=FELP                                  4      13      000664 0
      IF (SELP.LT.EX(2*N+I)) JEX(2*N+I)=J1                              6      13      000672 4
      IF (SELP.LT.EX(2*N+I)) EX(2*N+I)=SELP                             4      13      000702 0
  106 CONTINUE                                                          8      13      000711 3
      IF (SELP.GT.EX(3*N+I)) JEX(3*N+I)=J1                              6      13      000714 5
  103 IF (SELP.GT.EX(3*N+I)) EX(3*N+I)=SELP                             4      13      000724 1
      DO 104 I=1,N                                                      4      13      000734 2
      IF (VNP(I).GT.EX(4*N+I)) JEX(4*N+I)=J1                            6      13      000737 3
      IF (VNP(I).GT.EX(4*N+I)) EX(4*N+I)=VNP(I)                         4      13      000747 1
      DISI=DNP(I)*12.                                                   4      13      000757 2
      IF (DISI.GT.EX(5*N+I)) JEX(5*N+I)=J1                              6      13      000763 0
  104 IF (DISI.GT.EX(5*N+I)) EX(5*N+I)=DISI                             4      13      000772 2
      RETURN                                                            4      13      001002 3
      END                                                               1      13      001004
```

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000101          SUBROUTINE AIRSTM                                                      000000
000103          COMMON VINH,DINH,AOH,VOH,DOH,ANH,VNH,DNH,STH,HM,AM,STA,MA,ESOIL,       000000
000103         1 AOP,ANP,DOP,DNP,VOP,VNP,STP,PM,CDP,RES,RESO,SJ,SOK,QS,SU,             000000
000103         2 SPLICE,DEPIB,ARAM,ECUS,EASS,EPT,EANV,VFALL,VCHAM,XPT,SJJJ,            000000
000103         3 EMP,RHO,DTH,DTP,N,M,JRAT,IULT,RULT,SOILM,DSACP,                       000000
000103         4 FTPO,IW,PCOM,TDEL,IOUT,OUT,EXPP,TEMI,TEMO,INP,STROKO,STROKN,VO,PO     000000
000103         5 ,DFIN,JDOUT,JPMAX,EX,ICOL,FINTMX, TEMAX,RESULT,ISMITH,ITER            000000
000103         6 ,ITYPH,IPREIG,VFALLM,STRMAX,DCYL,PBAR,AREA,JEX                        000000
000104          DIMENSION VINH(10),DINH(10),AOH(10),VOH(10),DOH(10),ANH(10),           000000
000104         1 VNH(10),DNH(10),STH(10),HM(10),VNP(99),AM(10),STA(10),VOA(10),        000000
000104         2 DOA(10),AOA(10),VNA(10),DNA(10),ANA(10),DELAA(10),                    000000
000104         3 AOP(99),ANP(99),DOP(99),DNP(99),VOP(99),STP(99),PM(99),CDP(99),       000000
000104         4 RES(99),RESO(99),SJ(99),SOK(99),QS(99),SU(99),SPLICE(99),             000000
000104         4DSACP(3),OUT(3200),INP(13),EX(600),RESULT(100),JEX(600)                000000
000104         6 ,AOAH(99),VOAH(99),DOAH(99),AREA(99),DELAH(99)                        000000
000104         7 ,VOAA(10),AOAA(10),DOAA(10),PBAR(20)                                  000000
000105          KLIM = 200                                                             000000
000106          N1=N+1                                                                 000001
000107          NM1 = N-1                                                              000004
000110          M1 = M+1                                                               000007
000111          MAR = MA                                                               000012
000112          IF (MAR.LT.1) MAR = 1                                                  000014
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000114     23.           IAI = 0.0                                              000023
000115     24.           ML = MA                                                000024
000116     25.           CDH = PM(99)                                           000026
000117     26.           IF (M1.GT.ML) ML = M1                                  000030
000121     27.           TLIM = 0.0                                             000101
000122     28.           IIOUT = IABS(IOUT)                                     000102
000123     29.           TWOLOC=2.0*XPT/SQRT(EMP/RHO)                           000104
000124     30.           T2LC = TWOLOC*1000.                                    000116
000125     31.           IF (IIOUT.GT.19) IIOUT = IIOUT - 20                    000120
000127     32.           IF (IIOUT.GT. 9) IIOUT = IIOUT - 10                    000130
000131     33.           JDOUT = 3.0*TWOLOC/DTP                                 000140
000132     34.           JDOUT = JDOUT / 100                                    000147
000133     35.           TJD = FLOAT(JDOUT)*DTP*1000.                           000153
000133     36.     C     TJD IS TIME INCREMENT OF OUTPUT IN MILISECONDS         000153
000134     37.           IF (TJD.GT.0.5) JDOUT = (0.0005/DTP) + 0.5             000161
000136     38.           IF (JDOUT.LT.1) JDOUT=1                                000175
000140     39.           JMAX = 6                                               000204
000140     40.     C     6 COLUMS OF PILE OUTPUT IF ICOL =0  13 OTHERWISE IF NOT GTR N   000204
000141     41.           IF (ICOL.GT.0) JMAX=13                                 000206
000143     42.           IF (JMAX.GT.N) JMAX=N                                  000214
000145     43.           KK=0                                                   000223
000146     44.           RED = 0.9                                              000224
000147     45.           IF (EMP.LT.3000000.) RED = 0.0                         000226
000151     46.           SCJ = 0.0                                              000234
000152     47.           WRAM = 0.0                                             000235
000153     48.           G = 32.170                                             000236
000154     49.           DO 902 I=1,M                                           000243
000157     50.      902  WRAM = WRAM + HM(I)*G                                  000243
000161     51.           WASS=0.0                                               000247
000162     52.           DO 905 I=1,MAR                                         000253
000165     53.      905  WASS=WASS+AM(I)*G                                      000253
000167     54.           FAOA=WASS                                              000257
000170     55.           GAS = G*1.5                                            000260
000171     56.           IF (WASS.GT.0.0) GAS = (1.-SJJJ)*G*(1.+WRAM/WASS)      000263
000173     57.           GR = G                                                 000277
000174     58.           IF (MA.LT.1) FAOA = 0.0                                000301
000176     59.           FA = 0.0                                               000307
000177     60.           FAO = 0.0                                              000310
000200     61.           FTPO=WASS+HM(M1)*G                                     000311
000201     62.           FTIT = FTPO                                            000316
000202     63.           FTPOA =FTPO                                            000317
000203     64.           FANVOA = 0.0                                           000320
000204     65.           VNPIT = VOP(N)                                         000321
000205     66.           VNHIT = VINH(M)                                        000324
000206     67.           TBEF=0.002                                             000327
000207     68.           VFALLB=VFALL-G*TBEF                                    000331
000210     69.           VINH(M1) = 0.0                                         000334
000211     70.           DO 903 I=1,MAR                                         000340
000214     71.           DELAA(I) =0.0                                          000340
000215     72.           VOAA(I) =0.0                                           000340
000216     73.      903  AOAA(I) =0.0                                           000341
000220     74.           DNPMAX = 0.0                                           000343
000221     75.           MM1=M-1                                                000344
000222     76.           MAM1 = MA-1                                            000347
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000223          ENTHRU = 0.0                                           000352
000224          EMAX = 0.0                                             000353
000225          NT = 5.0*TWOLOC/DTP                                    000354
000226          JCK = 1.5*TWOLOC/DTP+0.003/DTP                         000364
000227          IF (FLOAT(NT)*DTP.LT.0.050) NT = 0.050/DTP             000377
000231          IF (TEMAX.GT.1.0) NT = TEMAX*0.001/DTP                 000415
000233          STPT1 = STH(M1)*STP(1)/(STH(M1)+STP(1))                000431
000234          STPT2 = (STH(M1)/ECUS)*(STP(1)/EPT)/((STH(M1)/ECUS)+STP(1)/EPT)  000440
000235          STAL = STH(M)                                          000446
000236          STAR = STAL/EANV                                       000451
000237          STASL = STA(MAR)                                       000453
000240          STASR = STASL/EASS                                     000456
000241          WP=0.0                                                 000460
000242          DO 51 I=1,NM1                                          000464
000245     51   WP=WP+PM(I)*G                                          000464
000247          DO 98 I=N,N1                                           000474
000252          DOP(I)=0.0                                             000474
000253          VOP(I)=0.0                                             000474
000254          AOP(I)=G                                               000475
000255     98   RESO(I)=0.0                                            000477
000257          DO 52 I=2,N                                            000504
000262          I1=N1-I                                                000504
000263          DOP(I1)=DOP(I1+1)+((FTPO+WP)/STP(I1+1))*FLOAT(I)/FLOAT(N)  000507
000264          VOP(I1)=0.0                                            000522
000265          AOP(I1)=G                                              000523
000266          RESO(I1)=0.0                                           000525
000267     52   WP=WP-PM(I1)*G                                         000526
000271          DINH(M1)=DOP(1)+SQRT(FTPO*DSACP(2)/STPT1)              000533
000272          MA1=MA+1                                               000545
000273          IF (MA.LT.1) GO TO 1906                                000550
000275          DOAA(MA)=DINH(M1)+SQRT(WASS*DSACP(3)/STA(MA))          000555
000276          W=WASS-AM(MA)*G                                        000567
000277          IF (MA.LT.2) GO TO 1906                                000573
000301          DO 906 I=2,MAM1                                        000600
000304          I1=MA1-I                                               000605
000305          DOAA(I1)=DOAA(I1+1)+W/STA(I1)                          000611
000306    906   W=W-AM(I1)*G                                           000615
000310   1906   CONTINUE                                               000624
000311          DO 901 I=1,M                                           000624
000314          VINH(I)=VFALLB                                         000657
000315    901   DINH(I)=-0.5*(VFALLB+VFALL)*TBEF+DINH(M1)              000660
000317          DO 100 I=1,M1                                          000667
000322          VOAH(I)=VINH(I)                                        000667
000323          DOAH(I)=DINH(I)                                        000670
000324          DELAH(I) = 0.0                                         000672
000325          AOAH(I)=G                                              000673
000326    100   CONTINUE                                               000676
000330          EPSV = 0.1                                             000676
000331          EPSF = 1.0                                             000700
000332          LIMOUT=KLIM*16                                         000702
000333          DO 450 I=1,LIMOUT                                      000705
000336    450   OUT(I)=0.0                                             000711
000340          DO 460 J=1,6                                           000715
000343          DO 460 I=1,N                                           000724
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000346    131.               IJ=N*(J-1)+I                                              000724
000347    132.               EX(IJ) = 0.0                                              000727
000350    133.               JEX(IJ) = 0                                               000731
000351    134.         460   CONTINUE                                                  000734
000354    135.               FINTMX=0.0                                                00073[illegible]
000355    136.               IF (IOUT.LT.0) WRITE (IW,653)                             000737
000360    137.               V1PMAX = 0.0                                              000750
000361    138.               JINC=(TBEF-0.001)/DTP                                     000751
000361    139.      C                                                                  000751
000361    140.      C        START MAIN LOOP                                           000751
000361    141.      C                                                                  000751
000362    142.               DO 700 J=1,NT                                             000767
000365    143.               IF (J.GT.JCK) JCK=-1                                      000767
000367    144.               TT = FLOAT(J)*DTP*1000.0                                  000776
000370    145.               IT=0                                                      001004
000371    146.               IF (V1PMAX.LT.VNP(1)) V1PMAX = VNP(1)                     001005
000373    147.               IF (RED.LT.0.01) GO TO 103                                001014
000375    148.               IF (VNP(1).GT.0.9*V1PMAX.OR.V1PMAX.LT.5.0) GO TO 103      001021
000377    149.               STPT1 = STPT2 * RED                                       001040
000400    150.               RED = 0.0                                                 001043
000401    151.         103   CONTINUE                                                  001045
000402    152.         800   CONTINUE                                                  001045
000403    153.               FAO = FAOA                                                001053
000404    154.               FTPO = FTPOA                                              001055
000405    155.               FANVO = FANVOA                                            001057
000406    156.               DO 99 I=1,ML                                              001067
000411    157.               VOA(I) =VOAA(I)                                           001067
000412    158.               AOA(I) = AOAA(I)                                          001070
000413    159.               DOA(I) = DOAA(I)                                          001072
000414    160.               VOH(I)=VOAH(I)                                            001074
000415    161.               AOH(I)=AOAH(I)                                            001076
000416    162.          99   DOH(I)=DOAH(I)                                            001100
000416    163.      C                                                                  001100
000416    164.      C        HAMMER ANALYSIS                                           001100
000416    165.      C                                                                  001100
000420    166.               DO 600 JH=1,JRAT                                          001106
000423    167.               ITH=0                                                     001106
000423    168.      C        PREDICTION                                                001106
000424    169.               DO 585 I=I,ML                                             001112
000427    170.               IF (IT.EQ.0) GO TO 909                                    001112
000431    171.               ANH(I) = AOH(I)+FLOAT(JH)*DELAH(I)                        001113
000432    172.               ANA(I) = AOA(I)+FLOAT(JH)*DELAA(I)                        001122
000433    173.               GO TO 585                                                 001126
000434    174.         909   CONTINUE                                                  001130
000435    175.               ANH(I) = AOH(I)                                           001130
000436    176.               ANA(I) = AOA(I)                                           001131
000437    177.         585   CONTINUE                                                  001135
000441    178.               DO 586 I=1,MAR                                            001135
000444    179.         586   CALL INTEGR(DTH,AOA,ANA,VOA,DOA,VNA,DNA,I)                001145
000446    180.               DO 101 I=1,M1                                             001164
000451    181.         101   CALL INTEGR(DTH,AOH,ANH,VOH,DOH,VNH,DNH,I)                001164
000453    182.         500   CONTINUE                                                  001201
000454    183.               I=1                                                       001206
000455    184.               IF (V1PMAX.GT.1.5) G=G*(-SJJJ)                            001211
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000457              IF (M.EQ.1) GO TO 904                                                    001216
000461              ANH(1)=G+(DNH(2)-DNH(1))*STH(1)/HM(1)                                    001222
000462              CALL INTEGR (DTH,AOH,ANH,VOH,DOH,VNH,DNH,I)                              001230
000463              IF (M.EQ.2) GO TO 904                                                    001242
000465              DO 102 I=2,MM1                                                           001246
000470              I1=I+1                                                                   001253
000471              IM1=I-1                                                                  001257
000472              ANH(I)=G+((DNH(I1)-DNH(I))*STH(I)+(DNH(IM1)-DNH(I))*STH(IM1))/HM(I       001263
000472            1)                                                                         001263
000473              CALL INTEGR(DTH,AOH,ANH,VOH,DOH,VNH,DNH,I)                               001275
000474         102  CONTINUE                                                                 001312
000476         904  CONTINUE                                                                 001312
000476      C       LAST RAM ELEMENT                                                         001312
000477              FANV = 0.0                                                               001313
000500              DANV = 0.0                                                               001314
000501              DDIS = DNH(M1)-DNH(M)                                                    001315
000502              IF (DDIS.GT.0.0) GO TO 811                                               001320
000504              DVEL = VNH(M1) - VNH(M)                                                  001323
000505              DANV = COH*DVEL                                                          001326
000506              DSAC = DSACP(1)                                                          001330
000507              DDISO = DOH(M1)-DOH(M)                                                   001332
000510              DDD = DDIS - DDISO                                                       001335
000510      C       ANVIL SPRING FORCE ALWAYS TENSION= +                                     001335
000511              CALL STIFF (DDIS,DVEL,STAL,STAR,FANVO,FANV,DSAC,DDD)                     001337
000512              IF (FANV.GT.0.0) FANV = 0.0                                              001351
000514         811  CONTINUE                                                                 001357
000515              FINTAC = FANV                                                            001357
000516              IF (TLIM.LT.0.0001.AND.FINTAC.LT.10.0) TLIM = TT+T2LC*1.15               001362
000520               FTR = 0.0                                                               001404
000521              IF (M.GT.1) FTR = (DNH(MM1)-DNH(M))*STH(MM1)                             001405
000523              ANH(M) = G + (FTR+FINTAC+DANV)/HM(M)                                     001417
000524              G = GR                                                                   001426
000525              CALL INTEGR(DTH,AOH,ANH,VOH,DOH,VNH,DNH,M)                               001430
000526              FINTAC = -FINTAC                                                         001442
000526      C       NOW CHECK TOTAL ASSEMBLY. THERE ARE AT LEAST TWO ASSEMBLY ELEMENTS       001442
000527              IF (MA.LT.1) GO TO 911                                                   001444
000531              IF (V1PMAX.GT.1.5) G = GAS                                               001451
000533              I = 1                                                                    001464
000534              ANA(1)=G+(DNA(2)-DNA(1))*STA(1)/AM(1)                                    001466
000535              CALL INTEGR (DTH,AOA,ANA,VOA,DOA,VNA,DNA,I)                              001474
000536              IF (MA.LT.3) GO TO 912                                                   001506
000540              DO 907 I=2,MAM1                                                          001513
000543              I1 = I+1                                                                 001520
000544               IM1 = I-1                                                               001524
000545              ANA(I)=G+((DNA(I1)-DNA(I))*STA(I)+(DNA(IM1)-DNA(I))*STA(IM1))/           001530
000545            1 AM(I)                                                                    001530
000546              CALL INTEGR(DTH,AOA,ANA,VOA,DOA,VNA,DNA,I)                               001542
000547         907  CONTINUE                                                                 001557
000551         912  CONTINUE                                                                 001557
000552              FA = 0.0                                                                 001560
000552      C       LAST ASSEMBLY ELEMENT                                                    001560
000553              DDIS = DNH(M1)-DNA(MA)                                                   001561
000554              IF (DDIS.GT.0.0) GO TO 908                                               001564
000556              DVEL=VNH(M1)-VNA(MA)                                                     001567
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000557    239.           DSAC = DSACP(3)                                        001572
000560    240.           DDISO = DOH(M1)-DOA(MA)                                001574
000561    241.           DDD = DDIS-DDISO                                       001577
000562    242.           FAO = -FAO                                             001601
000563    243.           CALL STIFF(DDIS,DVEL,STASL,STASR,FAO,FA,DSAC,DDD)      001603
000564    244.           IF (FA.GT.0.0) FA = 0.0                                001615
000566    245.           FAO = -FAO                                             001622
000567    246.      908  CONTINUE                                               001625
000570    247.           IF (MA.EQ.1) ANA(1)=G+FA/AM(1)                         001626
000572    248.           IF (MA.GT.1)                                           001636
000572    249.          1 ANA(MA)=G+((DNA(MAM1)-DNA(MA))*STA(MAM1)+FA)/AM(MA)   001636
000574    250.           CALL INTEGR(DTH,AOA,ANA,VOA,DOA,VNA,DNA,MA)            001653
000575    251.           FA = -FA                                               001665
000576    252.           G = GR                                                 001667
000577    253.      911  CONTINUE                                               001672
000577    254.     C     NOW ANALYZE CAP                                        001672
000600    255.           DT1=FLOAT(JH)*DTH                                      001676
000601    256.           I=1                                                    001703
000602    257.           DNP1=DOP(1)+(DT1/DTP)*(DNP(1)-DOP(1))                  001705
000603    258.           VNP1=VOP(1)+(DT1/DTP)*(VNP(1)-VOP(1))                  001713
000604    259.           IF (IT.GT.0) GO TO 575                                 001722
000606    260.           CALL INTEGR (DT1,AOP,AOP,VOP,DOP,VNP,DNP,I)            001723
000607    261.           DNP1 = DNP(1)                                          001735
000610    262.           VNP1 = VNP(1)                                          001737
000611    263.      575  CONTINUE                                               001742
000612    264.           FTP = 0.0                                              001742
000613    265.           DDIS = DNP1-DNH(M1)                                    001743
000614    266.           IF (DDIS.GT.0.0) GO TO 813                             001746
000616    267.           DVEL = VNP1-VNH(M1)                                    001751
000617    268.           DSAC = DSACP(2)                                        001754
000620    269.           DDISO = DOP(1)-DOH(M1)                                 001756
000621    270.           DDD = DDIS-DDISO                                       001761
000622    271.           FTPO = -FTPO                                           001763
000623    272.           CALL STIFF (DDIS,DVEL,STPT1,STPT2,FTPO,FTP,DSAC,DDD)   001765
000624    273.           IF (FTP.GT.-SPLICE(I)) FTP = -SPLICE(I)                001777
000626    274.           FTPO = -FTPO                                           002006
000627    275.      813  CONTINUE                                               002011
000630    276.           ANH(M1) = G+(FINTAC+FA+FTP-DANV)/HM(M1)                002011
000631    277.           CALL INTEGR(DTH,AOH,ANH,VOH,DOH,VNH,DNH,M1)            002020
000632    278.           ITH = ITH +1                                           002033
000633    279.           FTP = -FTP                                             002036
000633    280.     C     CHECK TO SEE IF HAMMER HAS CONVERGED                   002036
000634    281.           IF (JRAT.EQ.1) GO TO 650                               002040
000636    282.           IF (ITH.GT.ITER) GO TO 650                             002044
000640    283.           ERR = ABS(VNHIT-VNH(M))                                002050
000641    284.           VNHIT = VNH(M)                                         002054
000642    285.           IF (ERR.GT.EPSV) GO TO 500                             002056
000644    286.      650  CONTINUE                                               002063
000645    287.           DO 501 I=1,ML                                          002063
000650    288.           DELAA(I) = (ANA(I)-AOA(I))/FLOAT(JRAT)                 002074
000651    289.           AOA(I) = ANA(I)                                        002077
000652    290.           VOA(I) = VNA(I)                                        002101
000653    291.           DOA(I) = DNA(I)                                        002103
000654    292.           AOH(I)=ANH(I)                                          002105
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000655   293.          VOH(I)=VNH(I)                                                002107
000656   294.     501  DOH(I)=DNH(I)                                                002111
000660   295.          VCAP = VNH(M1)                                               002114
000661   296.          FANVO = FANV                                                 002117
000662   297.          FTPO = FTP                                                   002121
000663   298.          FAO = FA                                                     002123
000664   299.     600  CONTINUE                                                     002127
000664   300.   C                                                                   002127
000664   301.   C      PILE ANALYSIS                                                002127
000664   302.   C                                                                   002127
000666   303.          CALL PILEAN (IPT,AOP,VOP,DOP,ANP,VNP,DNP,STP,PM,SPLICE,SJ,CDP,RES,   002127
000666   304.         1 RESO,SU,SOK,VNPIT,VCAP,SOILM,SCJ,DTP,N,IT,ISMITH,EPSV,IAI,ESOIL,   002127
000666   305.         2 FTP,JRAT,ITER)                                              002127
000666   306.   C      CHECK TO SEE IF OVERALL CYCLE CONVERGED                      002127
000667   307.          IT = IT + 1                                                  002170
000670   308.          IF (IT.GT.ITER) GO TO 850                                    002173
000672   309.          ERRV = ABS(VNPIT - VNP(N))                                   002177
000673   310.          IF (JRAT.EQ.1) VNPIT = VNP(N)                                002204
000675   311.          IF (JRAT.EQ.1.AND.ERRV.GT.EPSV) GO TO 800                    002213
000677   312.          ERR = ABS(FTIT - FTP)                                        002230
000700   313.          FTIT = FTP                                                   002234
000701   314.          IF (ERR.GT.EPSF) GO TO 800                                   002236
000703   315.     850  CONTINUE                                                     002243
000703   316.   C                                                                   002243
000703   317.   C      GO TO 800 MEANS REPEAT                                       002243
000703   318.   C      GO TO 850 MEANS SUFFICIENTLY MANY ITERATIONS WERE PERFORMED  002243
000703   319.   C                                                                   002243
000704   320.          RSUM = 0.0                                                   002243
000705   321.          DSUM = SJ(N1)*VNP(N)                                         002243
000706   322.          IF (ISMITH.EQ.1) DSUM = RES(N1)*DSUM                         002247
000710   323.          IF (DSUM.LT.0.0) DSUM = 0.0                                  002263
000712   324.          VNPMAX = 0.0                                                 002302
000713   325.          DO 401 I=1,N1                                                002306
000716   326.          RESO(I)=RES(I)                                               002306
000717   327.          AOP(I)=ANP(I)                                                002310
000720   328.          VOP(I)=VNP(I)                                                002312
000721   329.          IF (ABS(VOP(I)).GT.VNPMAX) VNPMAX = ABS(VOP(I))              002314
000723   330.          RSUM = RSUM + RES(I)                                         002323
000724   331.          DDAM = SJ(I)*VNP(I)                                          002326
000725   332.          IF (ISMITH.EQ.1) DDAM = DDAM*RES(I)                          002331
000727   333.          IF (I.NE.N1) DSUM = DSUM + DDAM                              002336
000731   334.     401  DOP(I)=DNP(I)                                                002345
000733   335.          IF (DNP(N).GT.DNPMAX) DNPMAX = DNP(N)                        002351
000735   336.          FANVOA = FANVO                                               002361
000736   337.          FAOA = FAO                                                   002363
000737   338.          FTPOA = FTPO                                                 002365
000737   339.   C      SET OLD EQUAL NEW                                            002365
000740   340.          DO 402 I=1,ML                                                002372
000743   341.          AOAA(I) = ANA(I)                                             002372
000744   342.          VOAA(I) = VNA(I)                                             002373
000745   343.          DOAA(I) = DNA(I)                                             002375
000746   344.          AOAH(I)=ANH(I)                                               002377
000747   345.          VOAH(I)=VNH(I)                                               002401
000750   346.     402  DOAH(I)=DNH(I)                                               002403
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000752    347.              DOPINC = DOP(1)*12.                                            002406
000753    348.              DRA = (DNH(M1)-DNH(M))*12.0                                    002411
000754    349.              SEA = (DNH(M1)-DNA(MAR))*12.0                                  002417
000755    350.              DBO = DNP(N)                                                   002423
000756    351.              DEN = VOP(1)*DTP*FTP                                           002426
000757    352.              ENTHRU = ENTHRU + DEN                                          002432
000760    353.              IF (ENTHRU.GT.EMAX) EMAX = ENTHRU                              002434
000762    354.              JOUT = JOUT + 1                                                002443
000763    355.              IF (JOUT.NE.JDOUT) GO TO 699                                   002446
000765    356.              JOUT = 0                                                       002451
000766    357.              FTPO=FTP                                                       002452
000766    358.       C      OUTPUT FOR NEG. OPTION ONLY                                    002452
000767    359.              NO2 = N/2                                                      002454
000770    360.              NO21 = NO2+1                                                   002461
000771    361.         652  FORMAT (1H ,I4,I2,3I1,3F6.1,F6.2,2F7.0,2F6.1,2(F6.1,F8.1),3F8.1,  002470
000771    362.             1 2F6.1,F7.2)                                                   002470
000772    363.              DO 686 I=NO2,NM1                                               002470
000775    364.              I1 = I+1                                                       002470
000776    365.              COM = DNP(I)-DNP(I1)                                           002474
000777    366.              F = COM*STP(I1)                                                002477
001000    367.              IF (F.LT.SPLICE(I1)) F = SPLICE(I1)                            002502
001002    368.              IF (F.GT.0.0.OR.SPLICE(I1).LT.-.5) GO TO 685                   002512
001004    369.              F = 0.0                                                        002530
001005    370.              IF (COM.LT.SPLICE(I1)) F = (COM-SPLICE(I1))*STP(I1)            002531
001007    371.         685  FOPN = F                                                       002544
001010    372.              IF (I.EQ.NO2) FOP5 = F                                         002545
001012    373.         686  CONTINUE                                                       002555
001014    374.         653  FORMAT                                                         002555
001014    375.             1       (132H  JP   FIPH  TIME   VRU   VAN   SEP   FINT   FTP   VI   002555
001014    376.             A  EN      V5       F5     VN      FN      FA      RS     DA     D    002555
001014    377.             BDB   SEA  )                                                    002555
001015    378.              IF (IOUT.LT.0) WRITE (IW,652)                                  002555
001015    379.             A         J,IFIRST,IT,ITH,IPT,TT,VNH(M),VNH(M1),DRA,FINTAC,FTP,VOP(1  002555
001015    380.             1 ),ENTHRU,VOP(NO2),FOP5,VOP(N),FOPN,FA,RSUM,DSUM,DOPINC,DBO,SEA  002555
001047    381.          24  FORMAT (16F8.4)                                                002625
001047    382.       C      STORE OUTPUT                                                   002625
001050    383.              IF (IIOUT.LT.6) CALL FILL(KK,KLIM,OUT,JMAX,IIOUT,DNH,STH,FINTAC,  002625
001050    384.             1 FTP,INP,DNP,STP,SPLICE,VNH,VNP,ANH,ANP,JPMAX,MAXJP,EX,AREA,J,M,N,  002625
001050    385.             2 JEX,JCK)                                                      002625
001050    386.       C                                                                     002625
001050    387.       C      FILLS IN THE OUTPUT ARRAY OUT(KLIM*15)                         002625
001050    388.       C                                                                     002625
001052    389.              IF (IIOUT.EQ.6) JI = J                                         002666
001054    390.              IF (IIOUT.EQ.6) CALL FILL2 (N,M,OUT,SEA,DNH,FTP,VNP,           002674
001054    391.             1DNP,FOP5,SJ,RSUM,DSUM,RES,FOPN,KK,ICOL,TT,ISMITH,JI,MAXJP,JPMAX,  002674
001054    392.             2STP,AREA,SPLICE,EX,JEX,J,JCK)                                  002674
001056    393.              IF (IOUT.GE.0) GO TO 463                                       002736
001060    394.              IF (FINTAC.GT.FINTMX) FINTMX=FINTAC                            002742
001062    395.         463  CONTINUE                                                       002752
001063    396.              IF (TEMAX.GT.1.0) GO TO 699                                    002752
001065    397.              IF (TT.LT.TLIM) GO TO 699                                      002757
001067    398.              IF (TT.LT.0.5*T2LC) GO TO 700                                  002764
001071    399.              IF (DNP(N).LT.DNPMAX*0.8) GO TO 701                            002772
001073    400.         699  IFIRST = 0                                                     003001
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 001073    401.    C                                                                          003001
 001073    402.    C      END OF MAIN LOOP                                                    003001
 001073    403.    C                                                                          003001
 001074    404.      700  CONTINUE                                                            003004
 001076    405.      701  CONTINUE                                                            003004
 001077    406.           DFIN = (DNPMAX-QS(N))*12.                                           003004
 001100    407.           EFIN = ENTHRU                                                       003004
 001101    408.           IF (DFIN.GT.0.0) IBLCT =12./DFIN                                    003010
 001103    409.      654  FORMAT (1H0,10H  FIN SET= ,F8.4,21H INCHES   FIN ENTHRU= ,F6.1,     003012
 001103    410.          1 19H K-FT   MAX ENTHRU= ,F6.1,19H K-FT   BLOW COUNT= ,I5 )          003024
 001104    411.           IF (IOUT.LT.0) WRITE (IW,654) DFIN,EFIN,EMAX,IBLCT                  003024
 001113    412.           ANP(99) = EMAX                                                      003041
 001114    413.           RETURN                                                              003043
 001115    414.           END                                                                 003112

 000101      1.           SUBROUTINE VACHAM(PBAR,ARAM,DEPIB,DCYL,DBC,FSUCK,VFALL,IOUT,IW)     000000
 000103      2.           DIMENSION PBAR(1)                                                   000000
 000104      3.           ART = PBAR(1)                                                       000000
 000105      4.           EXPB = PBAR(4)                                                      000002
 000106      5.           DSTART = PBAR(2)                                                    000004
 000107      6.           EXP=EXPB                                                            000006
 000110      7.           VIN = PBAR(5)                                                       000007
 000110      8.    C      DSTART IS THE DISTANCE THAT THE RAM MOVES BEFORE IT CLOSES THE VAC  000007
 000110      9.    C      CHAMBER OFF.                                                        000007
 000111     10.           DELA = ART-ARAM                                                     000011
 000112     11.           DIN = VIN/DELA                                                      000013
 000113     12.           PATM = 0.144*14.7                                                   000015
 000114     13.           IF (DBC.LT.DEPIB) GO TO 100                                         000017
 000114     14.    C      DBC IS THE DISTANCE OF THE RAM FROM THE ANVIL ZERO POSITION OR IT   000017
 000114     15.    C      IS THE STROKE,I.E  DBC = DOH(M) FOR -DOH(M) LT DEPIB  DBC=STROKE    000017
 000114     16.    C      DBC LESS THAN DEPIB MEANS DBS IS NOT STROKE                         000017
 000116     17.           FAC = 1.0/(EXPB-1.0)                                                000024
 000117     18.           RAMW = PBAR(20)                                                     000030
 000117     19.    C      PBAR(20) IS THE RAM WEIGHT WHICH IS NOT NEEDED FOR OTHER THAN VAC   000030
 000117     20.    C      HAMMERS                                                             000030
 000120     21.           RMS = RAMW/32.17                                                    000032
 000121     22.           DB = DBC + DIN - DSTART                                             000034
 000122     23.           DE = DEPIB + DIN - DSTART                                           000037
 000123     24.           VFALL = DELA*PATM*(DIN**EXP)*FAC/RAMW                               000043
 000124     25.           VFALL = VFALL*(DB**(1.-EXP)-DE**(1.-EXP))                           000055
 000125     26.           VFALL = VFALL + (1.0+PATM*DELA/RAMW)*(DBC-DEPIB)*2.0*32.17          000074
 000126     27.           IF (VFALL.LT.0.0) WRITE (IW,2) VFALL                                000106
 000132     28.           IF (VFALL.LT.0.0) STOP                                              000123
 000134     29.        2  FORMAT (70H IMPROPER CONDITION MET WHEN DETERMINING RAM VELOCITY A  000127
 000134     30.          1T PORTS, VFALL=, E10.4)                                             000127
 000135     31.           VFALL = SQRT(VFALL)                                                 000127
 000136     32.           RETURN                                                              000133
 000137     33.      100  DVN = DCYL+DBC-DSTART+DIN                                           000136
 000140     34.           IF (DVN.GT.0.0) GO TO 101                                           000142
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000142    35.          WRITE(IW,1) DCYL,DBC,DSTART,DIN                                                    000145
000150    36.          STOP                                                                               000156
000151    37.    101   CONTINUE                                                                           000161
000152    38.          FSUCK = (DIN/DVN)**EXPB                                                            000161
000153    39.          IF (FSUCK.GT.1.0) FSUCK = 1.0                                                      000170
000155    40.          FSUCK = DELA*PATM*(1.0-FSUCK)                                                      000177
000156    41.      1   FORMAT (31H NEGATIVE VOLUME IN VAC CHAMBER,4F8.2)                                  000205
000157    42.          RETURN                                                                             000205
000160    43.          END                                                                                000254

   HAEL                    SYMBOLIC FORTRAN  28 APR 76  15:10:07   48    52     5   00131054      947
     1           SUBROUTINE HAEL (IHAMR,DTCRH,DTCRA,HNAME,IR)                                     18    52    000004 0
     2           COMMON VINH,DINH,AOH,VOH,DOH,ANH,VNH,DNH,STH,HM,AM,STA,MA,ESOIL,                  1    52    000014 4
     3          1 AOP,ANP,DOP,DNP,VOP,VNP,STP,PM,CDP,RES,RESO,SJ,SOK,QS,SU,                        1    52    000030 5
     4          2 SPLICE,DEPIB,ARAM,ECUS,ECAP,EPT,EANV,VFALL,VCHAM,XPT,SJJJ,                       1    52    000044 1
     5          3 EMP,RHO,DTH,DTP,N,M,JRAT,IULT,RULT,SOILM,DSACP,                                  1    52    000057 4
     6          4 FPTO,IW,PCOM,TDEL,IOUT,OUT,EXPP,TEMI,TEMO,INP,STROKO,STROKN,VO,PO                1    52    000071 1
     7          5 ,DFIN,JDOUT,JPMAX,EX,ICOL,FINTMX, TEMAX,RESULT,ISMITH,ITER                       1    52    000105 5
     8          6 ,ITYPH,IPREIG,VFALLM,STRMAX,DCYL,PBAR,AREA,JEX                                  36    52    000121 2
     9           DIMENSION VINH(10),DINH(10),AOH(10),VOH(10),DOH(10),ANH(10),                      4    52    000132 4
    10          1 VNH(10),DNH(10),STH(10),HM(10),VNP(99),                                          4    52    000146 1
    11          2 AOP(99),ANP(99),DOP(99),DNP(99),VOP(99),STP(99),PM(99),CDP(99),                  4    52    000156 2
    12          3 RES(99),RESO(99),SJ(99),SOK(99),QS(99),SU(99),SPLICE(99),                        4    52    000172 4
    13          4DSACP(3),OUT(3200),INP(13),EX(600),RESULT(100),JEX(600),                         37    52    000206 0
    14          ISTORE(1,26,2),STA(10),AM(10),HNAME(2),PBAR(20)                                   45    52    000221 0
    15        12 FORMAT (2A4,9F8.2)                                                               32    52    000232 1
    16         2 FORMAT (10F8.2)                                                                   1    52    000236 5
    17           IHAMRR = IHAMR                                                                   43    52    000242 5
    18           DO 107 I=1,20                                                                    49    52    000246 2
    19           AM(I) = 0.0                                                                      49    52    000251 4
    20       107 PBAR(I)=0.0                                                                      49    52    000254 4
    21           IF (IF.LT.1) IF = 7                                                              43    52    000260 3
    22           CONVS = 1.0                                                                      43    52    000264 5
    23           IF (IHAMR.EQ.0) GO TO 50                                                         43    52    000267 5
    24     C     FOR IHAMR = 0 READ FROM CARDS, OTHERWISE READ FROM FILE                          52    52    000275 0
    25           DO 52 I=1,IHAMR                                                                  43    52    000310 0
    26        52 READ (IF,54) ((STORE(1,J,K),K=1,2),J=1,26)                                       43    52    000313 4
    27        54 FORMAT (2A4/6(8E10.5/),2E10.5)                                                   43    52    000324 3
    28           REWIND IF                                                                        47    52    000333 2
    29           GO TO 51                                                                         43    52    000336 0
    30        50 CONTINUE                                                                         43    52    000340 3
    31           READ (IR,12) ((STORE(1,I,J),J=1,2),I=1,5),                                       43    52    000343 3
    32          1 STORE (1,6,1)                                                                   48    52    000353 5
    33           READ (IR,2) STORE(1,6,2), ((STORE(1,I,J),J=1,2),                                 48    52    000357 3
    34          1 I=7,25),STORE(1,26,1)                                                           43    52    000370 5
    35           CONVS = 12.                                                                      43    52    000375 5
    36        51 CONTINUE                                                                         43    52    000400 5
    37           IHAMRR = IHAMR                                                                   48    52    000403 5
    38           IHAMR = 1                                                                        43    52    000407 2
    39           ITYPH = STORE(1,26,1)                                                            43    52    000412 0
    40           MA = STORE(IHAMR,25,2)                                                           19    52    000416 4
    41           M=STORE(IHAMR,8,2)                                                               32    52    000423 3
    42           IF (M.LT.1) WRITE(IW,10) IHAMRR                                                  48    52    000427 4
    43     10    FORMAT (33H INSUFFICIENT HAMMER INFO. IHAMR=,I3)                                 18    52    000436 1
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      IF (M.LT.1) STOP                                          18    52     000450 1
      M1=M+1                                                     1    52     000454 0
      M2=M+2                                                     1    52     000456 1
      STH(M1)=STH(8)                                             1    52     000460 2
      STH(M2)=STH(9)                                             1    52     000463 5
      HM(M2)=HM(9)                                               1    52     000467 2
      DO 100 I1=1,2                                              1    52     000472 3
  100 HNAME(I1)=STORE(IHAMR,1,I1)                                1    52     000475 5
      HM(M1)=STORE(IHAMR,9,1)/32.17                              6    52     000504 2
      STH(M)=STORE (IHAMR,9,2)*CONVS                            38    52     000512 3
      IF (STH(M1).LT.0.1) STH(M)=2.0*STH(M)                      1    52     000520 5
      IF (STH(M1).LT.0.1) STH(M1)=STH(M)                         1    52     000530 2
      IF (STH(M2).LT..1) STH(M2)=10.0**12                        1    52     000537 2
      STOST=STH(M2)                                             12    52     000546 3
      STH(M2)=STOST*STP(1)/(STOST+STP(1))                       12    52     000551 5
      IF (ITYPH.EQ.3) HM(M1)=HM(M2)                             27    52     000561 0
      IF (ITYPH.EQ.3) STH(M)=STH(M1)                            27    52     000567 1
      IF (ITYPH.EQ.3) STH(M1)=STH(M2)                           27    52     000575 3
      IF (ITYPH.EQ.3) M2=M1                                     27    52     000604 0
      DO 102 I1=1,M2                                             1    52     000610 4
      I2=I1-1                                                    1    52     000614 1
      IF (I1.EQ.M) HM(I1)=STORE(IHAMR,I1+1,1)/32.17              9    52     000616 3
      IF (I1.GE.M) GO TO 101                                     1    52     000627 2
      HM(I1)=STORE(IHAMR,I1+1,1)/32.17                           6    52     000634 1
      STH(I1)=STORE (IHAMR,I1+1,2)*CONVS                        38    52     000642 5
  101 IF (I1.EQ.1) I2=1                                          1    52     000651 5
      DO 102 I3=I2,I1                                            1    52     000656 3
      TCRH=HM(I1)/STH(I3)                                        1    52     000662 1
      IF (I3.EQ.1) DTCRH=TCRH                                    1    52     000666 3
      IF (TCRH.LT.DTCRH) DTCRH=TCRH                              1    52     000673 3
  102 CONTINUE                                                   1    52     000701 4
      DTCRH=SQRT(DTCRH)                                          1    52     000704 5
      DTCRA=1000.0                                               1    52     000710 5
      STH(M2)=STOST                                             12    52     000714 0
      IF (MA.EQ.0) GO TO 105                                     1    52     000717 2
      DO 103 J1=1,MA                                             2    52     000724 1
      J2=J1-1                                                    1    52     000727 4
      IF (J1.EQ.1) J2=1                                          1    52     000732 0
      J3 = J1 + 21                                              18    52     000736 0
      AM(J1)=STORE(IHAMR,J3,1)/32.17                             6    52     000741 1
      STA(J1)=STORE(IHAMR,J3,2)                                 38    52     000747 3
      DO 103 J4=J2,J1                                            1    52     000754 5
      TCRA=AM(J1)/STA(J4)                                        1    52     000760 3
      IF (TCRA.LT.DTCRA) DTCRA=TCRA                              1    52     000764 5
  103 CONTINUE                                                   1    52     000773 0
      DTCRA=SQRT(DTCRA)                                          1    52     000776 1
  105 TDEL=STORE(IHAMR,10,1)                                     6    52     001002 1
      VIN=STORE(IHAMR,11,1)/1728.0                              20    52     001007 4
      VCHAM=STORE(IHAMR,11,2)/1728.0                            20    52     001015 4
      DEPIB=STORE(IHAMR,12,1)/12.                               20    52     001024 0
      ARAM=STORE(IHAMR,12,2)/144.0                              20    52     001031 4
      SJJJ = STORE(IHAMR,10,2)                                  51    52     001037 4
      DO 106 I=17,21                                            18    52     001044 5
      PBAR(I-16)=STORE(IHAMR,I,1)                               18    52     001050 2
```

```
 98     106  PBAR(I-11)=STORE(IHAMR,I,2)                                        18    52    001056 0
 99          PBAR(11)=STORE(IHAMR,13,1)                                         20    52    001064 3
100          PBAR(12)=STORE(IHAMR,13,2)                                         20    52    001072 0
101          PBAR(13)=STORE(IHAMR,14,1)                                         20    52    001077 3
102          PBAR(14)=STORE(IHAMR,14,2)                                         20    52    001105 0
103          PBAR(15)=STORE(IHAMR,15,1)                                         20    52    001112 3
104          PBAR(19)=STORE(IHAMR,19,1)                                         33    52    001120 0
105     C    PBAR(20) GTR 0 IDENTIFIES VACUUM CHAMBER HAMMER                    52    52    001125 3
106          PBAR(20)=STORE(IHAMR,21,2)                                         46    52    001137 0
107          STRM=STORE(IHAMR,16,1)/12.                                         16    52    001144 3
108          PBAR(10)=STRM                                                      23    52    001152 0
109          STRMAX = 0.0                                                       51    52    001155 2
110     C    PCOM IS PRESSURE FOR CORRESPONDING FUEL SETTING                    23    52    001160 3
111     C    PBAR(11) IS THE MAXIMUM DOWN PRESSURE ON A DOUBLE ACTING A/S       29    52    001172 0
112     C    HAMMER IDENTIFIER FOR SUCH HAMMERS                                 29    52    001205 5
113          EXPP=STORE(IHAMR,16,2)                                             13    52    001215 1
114          IF (EXPP.LT.0.1) EXPP=1.3                                          17    52    001222 0
115          IF (PBAR(1).LT.10.0E-8) PBAR(1) = ARAM                             49    52    001227 2
116          EFFICY=STORE(IHAMR,15,2)                                           29    52    001237 0
117          IF (EFFICY.LT.0.01) EFFICY=0.95                                    29    52    001244 1
118          RMWT=0.0                                                           20    52    001252 4
119          DO 220 I=1,M                                                       20    52    001255 1
120      220 RMWT=RMWT+HM(I)                                                    20    52    001260 2
121          PBAR(16)=EFFICY                                                    29    52    001272 1
122          PBAR(17)=RMWT*32.17                                                50    52    001335 1
123          PBAR(18)=STORE(IHAMR,19,2)                                         50    52    001341 3
124          RETURN                                                              1    52    001656 2
125          END                                                                 1    52    001660 3
```

```
000101      1.       SUBROUTINE UP(PBAR,DNH,VNH,DNP,VNP,HM,PM,M,N,DCYL,DFIN,VFALL,VO,           000023
000101      2.      1 PO,VFALLM,STROKE,DEPIB,ARAM,EXPP,IWT,IW,IOUT,RSI,T)                       000023
000103      3.       DIMENSION PBAR(1),DNH(1),VNH(1),DNP(1),VNP(1),HM(1),PM(1)                  000023
000103      4.    C                                                                             000023
000103      5.    C  THIS PROGRAM IS USED TO DETERMINE THE VELOCITY OF THE RAM OF               000023
000103      6.    C  CED'S AT THE EXHAUST PORTS.  THE ANALYSIS USES A RIGID BODY                000023
```

```
000103     C      PILE AND RAM ASSUMPTION FOR CLOSED END HAMMERS WHOSE UPWARD          000023
000103     C      VELOCITY WILL NOT CAUSE UPLIFT THE TOTAL STROKE IS DETERMINED        000023
000103     C                                                                           000023
000104            PATM = 14.7*0.144                                                    000023
000105            DFI = DFIN/12.                                                       000025
000106            T = 0.0                                                              000030
000107            VR = 0.0                                                             000031
000110            M1 = M+1                                                             000032
000111            M2=M+2                                                               000035
000112            VP=VNH(M1)*HM(M1)+VNH(M2)*HM(M2)                                     000040
000113            VCHAM = VO                                                           000056
000114            IF (DNH(M1).GT.DNH(M)) VCHAM = VO-(DNH(M1)-DNH(M))*ARAM              000060
000116            G = 32.17                                                            000101
000117            CYLM=PBAR(8)/G                                                       000103
000120            FATM = PATM*ARAM                                                     000106
000121            DELP = 0.0                                                           000111
000122            IF (PBAR(1).GT.0.0) DELP=(PBAR(1)-ARAM)*2.117                        000112
000124            IF (PBAR(1).GT.ARAM) FATM = PATM*PBAR(1)                             000122
000126            IF (PBAR(20).GT.0.0) FATM=0.0                                        000132
000130            ACYL=G                                                               000137
000131            IF (PBAR(8).GT.0.0) ACYL=DNH(10)                                     000141
000133            VCYL = VNH(10)                                                       000147
000134            PAM = 0.0                                                            000151
000135            IBLOW = 0                                                            000152
000136            RAM = 0.0                                                            000153
000137            IWT = 0                                                              000154
000140            TT=0.0                                                               000155
000141            IN=1                                                                 000156
000142          1 FORMAT (7X,83HTT         FP           FB        R VEL      R POS       V CYL   000160
000142           1     D CYL   .   V TOP      D TOP  )                                 000160
000143            IF (IOUT.LT.0) WRITE (IW,1)                                          000160
000143     C                                                                           000160
000143     C      DETERMINE RIGID RAM VELOCITY                                         000160
000143     C                                                                           000160
000146            DO 100 I=1,M                                                         000177
000151            RAM = RAM + HM(I)                                                    000177
000152      100   VR = VR + VNH(I)*HM(I)                                               000201
000152     C                                                                           000201
000152     C      DETERMINE RIGID PILE VELOCITY                                        000201
000152     C                                                                           000201
000154            DO 101 I=1,N                                                         000214
000157            PAM = PAM + PM(I)                                                    000214
000160      101   VP = VP + VNP(I)*PM(I)                                               000216
000162            VDR = VR/RAM                                                         000223
000163            VDP=VP/(PAM+HM(M1)+HM(M2))                                           000226
000164            IF (VDR.GT.-0.05) WRITE (IW,3)                                       000234
000167        3   FORMAT (41H RAM STILL MOVING DOWNWARD AT END OF BLOW)                000251
000170            IF (VDR.GT.-0.05) STOP                                               000251
000172            DDR=DNH(M)                                                           000255
000173            DDP=DNH(M1)                                                          000257
000174            DCDT=DCYL-DNH(M1)                                                    000262
000175            VCVT=VCYL-VNH(M1)                                                    000264
000176            VCYL=VDP+VCVT                                                        000270
000177            DCYL=DDP+DCDT                                                        000272
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```
000200          IF (DCYL.GT.DDP) VCYL=VDP                                   000274
000202          IF (DCYL.GT.DDP) DCYL=DDP                                   000303
000204          IUP = 0                                                     000312
000205          IF (VDP.LT.0.0) IUP =1                                      000313
000207          DPOS = DDR                                                  000321
000210          DRAIS = 0.01*DEPIB                                          000323
000210    C                                                                 000323
000210    C     START LOOP TO DETERMINE INCREMENTALLY THE RAM SPEED DURING  000323
000210    C     RAM UPWARDS MOTION                                          000323
000210    C                                                                 000323
000211     1000 DELT = ABS(DRAIS/VDR)                                       000327
000212          T=T+DELT*FLOAT(1-IBLOW)                                     000332
000213          TT=TT+DELT                                                  000341
000214          IN=IN+1                                                     000344
000215          IF (IOUT.LT.0.AND.IN.EQ.5) WRITE (IW,2) TT,FP,FB,VDR,DPOS,VCYL,   000347
000215         1 DCYL,VDP,DDP                                               000347
000231          IF (VCYL.LT.0.0.AND.VCYL.LT.VDP) VCYL=VDP                   000401
000233        2 FORMAT (9F10.4 )                                            000420
000234          IF (IN.EQ.5) IN=0                                           000420
000236          IF (IUP.EQ.1.AND.DDP.LT.DFI) VDP = 0.0                      000425
000240          IF (IUP.NE.1.AND.DDP.GT.DFI) VDP = 0.0                      000443
000242          DDP = DDP + VDP*DELT                                        000461
000243          VCYL = VCYL + ACYL * DELT                                   000465
000244          DCYL = DCYL + VCYL * DELT                                   000471
000245          IF (DCYL.GE.DDP) VCYL=VDP                                   000474
000247          IF (DCYL.GT.DDP) DCYL = DDP                                 000503
000251          DPOS = DPOS - DRAIS                                         000512
000252          V = VCHAM + (DDP-DPOS)*ARAM                                 000515
000253          FP = 2.117*ARAM                                             000521
000254          IF (IBLOW.EQ.0) FP =(PO*(VO/V)**EXPP)*ARAM                  000524
000256          DCYRA = DPOS-DCYL                                           000540
000257          DCB = -DPOS                                                 000543
000260          FB = FTR(DCYRA,PBAR,IWT)                                    000545
000261          IF (PBAR(20).GT.0.0) CALL VACHAM(PBAR,ARAM,DEPIB,DCYL,DCB,FB,VFALL   000553
000261         1 ,IOUT,IW)                                                  000553
000263          IF (PBAR(8).GT.0.0) ACYL=G+(FATM-FB)/CYLM                   000572
000265          IF (PBAR(20).GT.0.0) FB=FB+PATM*ARAM                        000603
000267          IF (PBAR(20).LT.10.E-8) FB=FB-DELP                          000613
000271          AC = G-(FP-FB)/RAM                                          000623
000272          VE = VDR + AC*DELT                                          000630
000273          VDR = VE                                                    000633
000274          VO = V                                                      000634
000275          PO = FP/ARAM                                                000636
000276          IF (DPOS.GT.-DEPIB+DCYL) GO TO 1000                         000641
000300          IF (IBLOW.EQ.1) GO TO 1001                                  000647
000300    C                                                                 000647
000300    C     IBLOW = 1 MEANS RAM HAS PASSED THE EXHAUST PORTS            000647
000300    C                                                                 000647
000302          IBLOW = 1                                                   000653
000303          VFALL = -VDR                                                000655
000303    C     FOR OPEN END HAMMERS                                        000655
000304          STROKE = VDR*VDR/64.34 + DEPIB                              000656
000305          DRAIS = 0.05                                                000662
000306          IF (PBAR(20).GT.0.0) GO TO 1001                             000664
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 000310     115.              IF (PBAR(6).LT.0.001) RETURN                                                   000670
 000312     116.              IF (VFALL.GT.VFALLM) IWT = 1                                                   000113
 000314     117.              IF (VFALL.GT.VFALLM) PSI=PBAR(8)/(PBAR(1)*0.144)                               000711
 000314     118.        C                                                                                    000711
 000314     119.        C     VFALL GT VFALLM MEANS UPLIFT                                                   000711
 000314     120.        C                                                                                    000711
 000316     121.              IF (VFALL.GT.VFALLM) RETURN                                                    000720
 000316     122.        C                                                                                    000720
 000316     123.        C     FOR HAMMERS WHOSE BOUNCE CHAMBER PORTS HAVE NOT YET BEEN CLOSED                000720
 000316     124.        C                                                                                    000720
 000320     125.              DEPS = PBAR(7)-PBAR(6)-DEPIB                                                   000115
 000321     126.              IF (DEPS.LT.0.0) GO TO 1001                                                    000730
 000323     127.              IF (VDR*VDR.LT.64.34*DEPS) GO TO 1001                                          000733
 000325     128.              VDR = SQRT(VDR*VDR-64.34*DEPS)                                                 000743
 000326     129.              DPOS = DPOS-DEPS                                                               000755
 000327     130.              VDR = -VDR                                                                     000760
 000330     131.         1001 IF (VDR.LT.0.0.AND.IWT.NE.1) GO TO 1000                                        000762
 000330     132.        C                                                                                    000762
 000330     133.        C     RAM REACHED UPMOST POINT                                                       000762
 000330     134.        C                                                                                    000762
 000332     135.              STROKE = -DPOS-DCYL                                                            000775
 000332     136.        C                                                                                    000775
 000332     137.        C     BOUNCE CHAMBER PRESSURE IN PSI (FOR VFALL LT VFALLM)                           000775
 000332     138.        C                                                                                    000775
 000333     139.              DPOS = -STROKE                                                                 001000
 000334     140.              FB = FTR(DPOS,PBAR,IWT)                                                        001001
 000335     141.              PSI=FB/(PBAR(1)*0.144)-14.7                                                    001007
 000336     142.              RETURN                                                                         001014
 000337     143.              END                                                                            001203

   NO DIAGNOSTICS.
                                                                       3.9710 SECONDS.
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DOWN                   SYMBOLIC FORTRAN  26 MAR 76  09:55:03   11   15    5   00061214    407
            SUBROUTINE DOWN(STRMAX,VFALLM,PBAR,HM,DEPIB,ARAM,IW,IOUT,T)     12    15    000114 3
            DIMENSION PBAR(1),HM(1)                                          2    15    000127 5
            T=0.0                                                           12    15    000134 5
            ART=PBAR(1)                                                     11    15    000136 5
            STR = STRMAX                                                     7    15    000141 5
            PATM=14.7*0.144                                                  8    15    000145 0
            PMAX=PATM+PBAR(8)/PBAR(1)                                        8    15    000150 4
            PRAT=(PATM/PMAX)**(1.0/PBAR(4))                                  8    15    000156 0
            VBIN = PBAR(6)*PBAR(1) + PBAR(5)                                 1    15    000164 3
            DUP=(VBIN/PBAR(1))*(1.0-PRAT)                                    8    15    000173 1
            DMAX=PBAR(6)-DUP                                                 8    15    000201 2
            DSF = PBAR(2)                                                   15    15    000207 3
      C     DUP = DISTANCE FROM BOUNCE CHAMBER VENTS                        15    15    000212 5
      C     DMAX = DISTANCE FROM TOP                                        15    15    000223 1
      C     DPOS = DISTANCE FROM ANVIL (NEGATIVE)                           15    15    000230 4
            IF (DMAX.GT.DSF) GO TO 202                                      15    15    000240 3
      C     MAX STROKE PENETRATES INTO SAFETY CHAMBER                       15    15    000246 0
            PRAT = (VBIN/(PBAR(5)+DSF*ART))**PBAR(4)                        15    15    000256 3
            PRAT = (PRAT*PATM/PMAX)**(1./PBAR(4))                           15    15    000266 3
            DMAX = DSF*PRAT                                                 15    15    000276 0
        202 CONTINUE                                                        15    15    000301 4
            DPOS = DMAX - PBAR(7)                                            1    15    000305 0
            RAM = 0.0                                                        2    15    000311 4
            DO 200 I=1,10                                                    3    15    000314 2
            IF (HM(I).LT.10E-8) GO TO 201                                    3    15    000317 4
        200 RAM = RAM + HM(I)                                                3    15    000325 5
        201 CONTINUE                                                         3    15    000332 4
            STRMAX = -DPOS                                                   1    15    000336 0
            IF (STR.GT.STRMAX) STR = STRMAX                                  7    15    000341 3
      C     START WITH RAM AT POSITION WHERE UPLIFT IS IMMINENT              1    15    000350 0
            TOTD = -DPOS-DEPIB                                               1    15    000362 1
            IF (STR.LT.0.1) GO TO 300                                       12    15    000402 4
            TOTD = STR-DEPIB                                                12    15    000410 0
            DPOS = -STR                                                     12    15    000413 5
            STRMAX = STR                                                    12    15    000416 5
        300 CONTINUE                                                        12    15    000422 0
            NST = TOTD/0.05                                                  1    15    000425 2
            DFALL = TOTD/FLOAT(NST)                                          1    15    000431 0
            G = 32.17                                                        1    15    000442 0
            AO = G                                                           1    15    000444 4
            VO = 0.0                                                         1    15    000446 5
            DO 100 I=1,NST                                                   1    15    000451 2
            A = G+(FTR(DPOS,PBAR,IWT)-PATM*ART)/RAM                         10    15    000454 5
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44          VA = VO/A                                                         4     15     000464 4
45          DELT = SQRT(VA*VA+2.*DFALL/A)-VA                                  4     15     000467 2
46          T = T+DELT                                                       12     15     000476 0
47          V = VO + 0.5*(A+AO)*DELT                                          1     15     000500 5
48          DPOS = DPOS + DFALL                                               1     15     000506 0
49          VO = V                                                            1     15     000512 2
50     100  AO = A                                                            1     15     000514 3
51          VFALLM = V                                                        6     15     000517 3
52          IF (STR.GT.0.1.AND.IOUT.LT.0  ) WRITE (IW,2) STR,V               13     15     000531 2
53     2    FORMAT (20H STROKE (LESS MAX.)=,F6.1,23H FT, VELOCITY AT PORTS=,  7     15     000543 0
54         1F6.1,5H FT/S )                                                    7     15     000557 4
55          IF (STR.GT.0.1) RETURN                                            7     15     000563 2
56          IF (IOUT.LT.0) WRITE (IW,1) STRMAX,VFALLM                         4     15     000570 1
57     1    FORMAT(28H MAXIMUM STROKE (NO UPLIFT)=,F6.2,30H FT MAXIMUM VELOCIT 5     15     000600 2
58         1Y AT PORTS=,F6.2,5H FT/S)                                         4     15     000615 2
59          RETURN                                                            1     15     000622 5
60          END                                                               1     15     000625 0
OUTPUT               SYMBOLIC FORTRAN  17 FEB 76  13:38:39   24   28    5   00042762   2237
 1          SUBROUTINE OUTPUT (OUT,RES,JNP,IOUT,DT,JPMAX,JDOUT,IULT,N,JDLIM,  1     28     000004 0
 2         1 ALPH,ISEG,JSELEC,YMAX,COLI,TITLE,STP1,PM1)                      12     28     000020 1
 3     C PLOT OUTPUT                                                          1     28     000030 5
 4          DIMENSION JSELEC(13),BIG(5),PLLY(5),PRJ(5),PUNIT(5)               1     28     000034 0
 5         2 ,OUT(3200),JNP(13),RES(100),ISEG(15),ALPH(99) ,                 23     28     000045 5
 6         1 JDUM(15),PYS(5),IUNIT(5),SALPH(99),TITLE(10)                     6     28     000057 2
 7         3 ,RCODE(2)                                                       27     28     000070 2
 8          I9=1                                                             13     28     000073 2
 9     112  JPM=JDLIM                                                         1     28     000075 1
10      1   FORMAT (20I4)                                                     1     28     000100 3
11      2   FORMAT (10F8.2)                                                   1     28     000104 2
12          YMAXR=YMAX                                                       10     28     000110 3
13          IF (IABS(IOUT).LT.10) RETURN                                      1     28     000113 2
14          DTP=DT*FLOAT(JDOUT)*1000.0                                        1     28     000121 2
15          DTPM=DTP*FLOAT(JDLIM)                                             1     28     000126 5
16      6   FORMAT (6H(RULT=,I4,1H))                                         27     28     000133 3
17          IRULT = RES(1)                                                   27     28     000141 1
18          IU = ABS(IULT)                                                   28     28     000153 0
19          IF (IULT.LT.0) IULT=0                                            28     28     000156 3
20          IF (IU.GT.1) IRULT = RES(IU)                                     28     28     000163 1
21          ENCODE(6,RCODE) IRULT                                            27     28     000171 1
22          YMIN=0.                                                           8     28     000175 5
23          PLENY=4.                                                          8     28     000200 1
24          PLENX=6.                                                          8     28     000202 4
25          YMAX=YMAX*.999                                                    8     28     000205 1
26          YMAXC=0.                                                          8     28     000210 4
27          IF (IABS(IOUT).EQ.16.OR.IABS(IOUT).EQ.26) GO TO 171              11     28     000213 1
28          DO 120 J=1,13                                                     1     28     000225 0
29          IF (JNP(J).EQ.0) GO TO 121                                        1     28     000230 2
30     120  JDUM(J)=J+2                                                       1     28     000235 5
31     121  JJNP=13                                                           1     28     000241 4
32          IF (J.NE.13) JJNP=J-1                                             1     28     000244 5
33          IF (J.EQ.13.AND.JNP(13).EQ.0) JJNP=12                             1     28     000251 3
34          JJNP2=JJNP+2                                                      1     28     000261 0
35          IF (IABS(IOUT).EQ.10.OR.IABS(IOUT).EQ.20) GO TO 300              22     28     000264 1
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      DO 100 ISEGNO = 3,JJNP2                                    7    28    000276 0
      DO 100 J=1,JPM                                             7    28    000303 0
      I = (ISEGNO-1)*200+J                                       7    28    000306 3
      IF (OUT(I).LT.YMIN) YMIN = OUT(I)                          7    28    000313 0
 100  IF (OUT(I).GT.YMAXC) YMAXC = OUT(I)                        7    28    000321 5
      GO TO 170                                                  8    28    000331 5
  171 I1=1                                                       8    28    000334 3
      EAOC=1.                                                    8    28    000337 0
      IF (ISEG(I9).EQ.0) KK=1                                   13    28    000341 2
      IF (ISEG(I9).EQ.1.OR.ISEG(I9).EQ.3) KK=4                  13    28    000346 2
      IF (ISEG(I9).EQ.2) KK=5                                   15    28    000356 2
  173 DO 172 I=1,JPM                                             8    28    000363 2
      IJ=KK*200+I                                               26    28    000372 3
      IF (KK.EQ.5.AND.I1.EQ.2) EAOC=SQRT(STP1*PM1)               8    28    000375 3
      IF (OUT(IJ)*EAOC.LT.YMIN) YMIN=OUT(IJ)*EAOC               13    28    000406 1
  172 IF (OUT(IJ)*EAOC.GT.YMAXC) YMAXC=OUT(IJ)*EAOC             14    28    000416 4
      I1=I1+1                                                    8    28    000430 1
      KK=KK+9                                                    8    28    000432 3
      IF (ISEG(I9).EQ.3) KK=5                                   13    28    000434 5
      IF (KK.EQ.10) GO TO 170                                   15    28    000441 5
      IF (I1.LT.3).GO TO 173                                    15    28    000446 5
  170 IF (YMAXC.GT.10.*YMAX) YMAX=YMAXC                         18    28    000453 4
      DEL=(YMAX-YMAXR)/YMAX                                     19    28    000463 1
 105  YM = YMAX                                                  7    28    000467 5
      DO 101 J=1,15                                              7    28    000473 2
      IF (YM.LT.1.) GO TO 102                                    7    28    000476 4
 101  YM = YM/10.                                                7    28    000503 4
 102  RJ = 10.**(J-2)*2.                                         7    28    000507 3
      I = YMAX/RJ+1.0                                            7    28    000514 3
      YMAX = RJ*FLOAT(I)                                         7    28    000520 1
      IF (ABS(DEL).LT.0.01) YMAX=YMAXR                          16    28    000524 2
      YMAXR=YMAX                                                18    28    000533 0
      IF (YMIN.LT.-YMAX*4.) YMAX = -YMIN                        22    28    000535 5
      YMI = -YMAX*3.                                            22    28    000544 5
      IF (YMIN.GT.-YMAX*0.75) YMI = -YMAX                       22    28    000550 2
      IF (YMIN.GT.-YMAX*0.5) YMI = -YMAX*1./3.                  22    28    000557 3
      IF (YMIN.GT.-YMAX*0.1667) YMI = 0.0                       22    28    000567 3
      YMIN = YMI                                                22    28    000576 4
      YS = (YMAX-YMIN) / PLENY                                   7    28    000601 3
      XS = DTPM/PLENX                                            7    28    000606 4
      K = DTPM/12.                                               7    28    000612 2
      XUNIT = K+1                                                7    28    000615 3
      CALL FSCALE(-3.0*XS,YMIN,XS,YS,YMAX,1H ,0.,0.)             7    28    000620 3
      IF (IABS(IOUT).EQ.16.OR.IABS(IOUT).EQ.26) GO TO 145        7    28    000631 3
      DO 103 I=1,15                                              7    28    000643 2
      IF (ISEG(I).EQ.0.AND.I.GT.1) GO TO 103                     7    28    000646 4
      ISEGNO = ISEG(I)                                           7    28    000656 2
      IF (ISEGNO.EQ.0) ISEGNO = 3                                7    28    000662 1
      DO 106 J = 1,JPM                                           7    28    000667 5
      II = (ISEGNO-1)*200 + J                                    7    28    000673 4
 106  CALL FPLOT(FLOAT(J)*DTP,OUT(II))                           7    28    000700 4
      CALL FMOVE(0.,0.)                                          7    28    000710 1
 103  CONTINUE                                                   7    28    000714 1
  145 IF (IABS(IOUT).NE.16.AND.IABS(IOUT).NE.26) GO TO 150      10    28    000717 3
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      IF (ISEG(I9).EQ.0) KK=1                                          13   28   000732 2
      IF (ISEG(I9).EQ.1.OR.ISEG(I9).EQ.3) KK=4                         13   28   000737 2
      IF (ISEG(I9).EQ.2) KK=5                                          13   28   000747 2
      DO 140 J=1,JPM                                                    6   28   000754 2
      II=KK*200+J                                                      26   28   000762 5
  140 CALL FPLOT (FLOAT(J)*DTP,OUT(II))                                 6   28   000765 5
      IF (KK.EQ.1) GO TO 150                                            6   28   000775 2
      KK=KK+9                                                           6   28   001002 1
      IF (ISEG(I9).EQ.3) KK=5                                          13   28   001004 3
      EAOC=1.                                                           6   28   001011 3
      IF (KK.EQ.5) EAOC=SQRT(STP1*PM1)                                  6   28   001013 5
      CALL FMOVE (0.,0.)                                                6   28   001022 3
      DO 141 J=1,JPM                                                    6   28   001026 4
      II=KK*200+J                                                      26   28   001035 1
  141 CALL FPLOT (FLOAT(J)*DTP,OUT(II)*EAOC,4HDASH)                     6   28   001040 1
      CALL FMOVE (4.*XS,3.5*YS)                                         6   28   001051 4
      IF (KK.EQ.13.OR.KK.EQ.5) CALL FCHAR (0.,.12,9,9HTOP FORCE)        6   28   001057 0
      IF (KK.EQ.14) CALL FCHAR (0.,.12,8,8HTOP VEL.)                    6   28   001072 1
      CALL FMOVE (5.*XS,3.56*YS)                                        6   28   001103 1
      CALL FPLOT (5.4*XS,3.56*YS)                                       6   28   001110 4
      CALL FMOVE (4.*XS,3.65*YS)                                        6   28   001116 2
      IF (KK.EQ.13) CALL FCHAR (0.,.12,9,9HTOE FORCE)                   6   28   001123 5
      IF (KK.EQ.14) CALL FCHAR (0.,.12,8,8HTOE VEL.)                    6   28   001135 0
      IF (KK.EQ.5) CALL FCHAR (0.,.12,9,9HVEL.*EA/C)                    6   28   001146 0
      CALL FMOVE (5.*XS,3.71*YS)                                        6   28   001157 0
      CALL FPLOT (5.4*XS,3.71*YS,4HDASH)                                6   28   001164 3
  150 CALL FMOVE (DTPM+.3*XS,-.12*YS)                                   6   28   001173 3
      CALL FCHAR(0.,.12,4,4HMSEC)                                       8   28   001202 4
      CALL FMOVE (DTPM+.3*XS,.05*YS)                                    6   28   001210 2
      CALL FCHAR (0.,.12,3,3HL/C)                                       6   28   001216 4
      CALL FMOVE (DTPM,0.)                                              1   28   001224 2
      L=DTPM/XUNIT                                                      1   28   001230 5
      DO 130 I=1,L                                                      1   28   001234 0
      XUSE=XUNIT*(L-I+1)                                                1   28   001237 1
      CALL FPLOT (XUSE,0.)                                              1   28   001243 2
      CALL FPLOT (XUSE,-.05*YS)                                         1   28   001247 5
      CALL FMOVE (XUSE-.25*XS,-.2*YS)                                  12   28   001255 1
    3 FORMAT (F4.0)                                                     1   28   001263 4
      ENCODE (3,PL) XUSE                                                1   28   001267 3
      CALL FCHAR (0.,.12,4,PL)                                          1   28   001273 4
      CALL FMOVE (XUSE,0.)                                              1   28   001300 5
  130 CONTINUE                                                          1   28   001305 2
      CALL FPLOT (0.,0.)                                                1   28   001310 3
      CALL FMOVE (2.8*XS,-.4*YS)                                        6   28   001314 4
      CALL FCHAR (0.,.12,4,4HTIME)                                      6   28   001322 1
      CALL FMOVE (DTPM,0.)                                              6   28   001330 1
      L=DTPM/COLI                                                      10   28   001334 4
      DO 146 I=1,L                                                      6   28   001337 4
      LI=L-I+1                                                          6   28   001342 5
      XUSE=COLI*LI                                                      6   28   001345 2
      CALL FPLOT (XUSE,0.)                                              6   28   001350 3
      CALL FPLOT (XUSE,0.05*YS)                                         6   28   001355 0
      CALL FMOVE (XUSE-.35*XS,.1*YS)                                   13   28   001362 2
      ENCODE (1,LC) LI                                                  6   28   001370 4
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144          CALL FCHAR (0.,.12,4,LC)                                    6    28    001374 3
145          CALL FMOVE (XUSE,0.)                                        9    28    001401 4
146      146 CONTINUE                                                    6    28    001406 1
147          CALL FMOVE (0.,YMIN)                                        1    28    001411 2
148          CALL FPLOT (-.05*XS,YMIN)                                  20    28    001415 5
149          CALL FMOVE (-.9*XS,YMIN-.06*YS)                            20    28    001423 1
150          ENCODE (2,PLY) YMIN                                        20    28    001431 4
151          CALL FCHAR (0.,.12,8,PLY)                                  20    28    001436 0
152          CALL FMOVE(0.,YMIN)                                        22    28    001443 2
153          M=PLENY+.001                                                1    28    001447 4
154          DO 131 I=1,M                                                1    28    001452 5
155          YUSE=YMIN+I*YS                                              1    28    001456 0
156          CALL FPLOT (0.,YUSE)                                        1    28    001461 3
157          CALL FPLOT (-.05*XS,YUSE)                                   1    28    001466 0
158          CALL FMOVE (-.9*XS,YUSE-.06*YS)                             1    28    001473 2
159          ENCODE (2,PLY) YUSE                                         1    28    001501 5
160          CALL FCHAR (0.,.12,8,PLY)                                   1    28    001506 1
161          CALL FMOVE (0.,YUSE)                                        1    28    001513 3
162      131 CONTINUE                                                    1    28    001520 0
163          CALL FMOVE (-XS,YMAX-3.0*YS)                                1    28    001523 1
164          IOUTS=IOUT                                                  1    28    001531 1
165          IF (IABS(IOUT).GT.20) IOUT=IABS(IOUT)-10                    1    28    001534 0
166          IF (ISEG(I9).EQ.1.AND.IABS(IOUT).EQ.16) IOUT=11            16    28    001544 0
167          IF (ISEG(I9).EQ.3.AND.IABS(IOUT).EQ.16) IOUT=11            16    28    001555 1
168          IF (ISEG(I9).EQ.2.AND.IABS(IOUT).EQ.16) IOUT=12            16    28    001566 2
169          IF (IABS(IOUT).EQ.11)CALL FCHAR (90.,.12,13,13HFORCE IN KIPS)         1    28    001577 3
170          IF (IABS(IOUT).EQ.12)CALL FCHAR (90.,.12,18,18HVELOCITY IN FT/SEC)    1    28    001613 1
171          IF (IABS(IOUT).EQ.13)CALL FCHAR (90.,.12,13,13HSTRESS IN KSI)         1    28    001627 4
172          IF (IABS(IOUT).EQ.14)CALL FCHAR (90.,.12,17,17HACCELERATION IN G)     1    28    001643 2
173          IF (IABS(IOUT).EQ.15) CALL FCHAR (90.,.12,15,15HDISPL IN INCHES)      1    28    001657 4
174          IF (IABS(IOUT).EQ.16) CALL FCHAR (90.,.12,15,15HPRESSURE IN PSI)      6    28    001673 5
175          IOUT=IOUTS                                                 16    28    001710 0
176          CALL FMOVE (0.0,4.1*YS)                                    27    28    001720 2
177          DO 160 I=1,10                                              10    28    001725 2
178      160 CALL FCHAR (0.,.15,4,TITLE(I))                             10    28    001730 4
179          CALL FMOVE (5.2*XS,4.1*YS)                                 27    28    001737 4
180          DO 161 I=1,2                                               27    28    001745 1
181      161 CALL FCHAR (0.,0.12,6,RCODE(I))                            27    28    001750 2
182          CALL FMOVE (0.,YMAX+3.5*YS)                                 6    28    001757 4
183          IF (IABS(IOUT).EQ.16.OR.IABS(IOUT).EQ.26) YMAX=0.0         19    28    001765 2
184          I9=I9+1                                                    13    28    001777 0
185          IF (IABS(IOUT).EQ.16.AND.ISEG(I9).NE.0) GO TO 112          16    28    002001 2
186          IF (IABS(IOUT).EQ.26.AND.ISEG(I9).NE.0) GO TO 112          16    28    002012 5
187      200 IF (IABS(IOUT).LT.20) RETURN                                1    28    002024 2
188          IF (IABS(IOUT).EQ.26) GO TO 300                             6    28    002033 0
189          PLENX=4.                                                    1    28    002041 3
190          PLENY=1.5                                                   1    28    002044 0
191          PLENMX=1.                                                   1    28    002046 4
192          PLENMY=2.5                                                  1    28    002051 2
193          YMAX=0.                                                     1    28    002054 1
194          DO 201 J=1,JPM                                              1    28    002056 3
195          DO 201 I=1,JJNP                                             1    28    002062 0
196          K=JSELEC(I)                                                 1    28    002065 4
197          IF (JSELEC(1).EQ.0) K=I+2                                   1    28    002070 4
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       IF (K.LE.2.OR.K.GT.15) GO TO 201                                1   28   002076 0
       K=(K-1)*200+J                                                   1   28   002104 4
       IF (OUT(K).GT.YMAX) YMAX=OUT(K)                                 1   28   002110 0
  201  CONTINUE                                                        1   28   002116 3
       YM=YMAX                                                         1   28   002121 5
       DO 202 J=1,15                                                   1   28   002124 1
       IF (YMAX.LT.1.) GO TO 203                                       1   28   002127 3
  202  YMAX=YMAX/10.                                                   1   28   002134 5
  203  RJ=10.**(J-2)*2.0                                               1   28   002141 0
       I=YM/RJ+1.                                                      1   28   002145 5
       YMAX=RJ*FLOAT(I)                                                1   28   002150 4
       XS=DTPM/PLENX                                                   1   28   002154 3
       YS=YMAX/PLENY                                                   1   28   002157 5
       CALL FSCALE (-3.*XS,-2.5*YS,XS,YS,YMAX,1H ,0.,0.)               1   28   002163 1
       NN=N                                                            1   28   002174 4
       IF (NN.GT.JNP(JJNP)) NN=JNP(JJNP)                               1   28   002176 3
       SALPH(1)=0.                                                     3   28   002205 2
       DO 206 I=2,JJNP                                                24   28   002210 2
       JEND=JNP(I)                                                    20   28   002214 0
       JBEG=JNP(I-1)+1                                                20   28   002217 0
       SALPH(I)=SALPH(I-1)                                            20   28   002222 4
       DO 206 J=JBEG,JEND                                             20   28   002227 0
   206 SALPH(I)=SALPH(I)+ALPH(J)                                      21   28   002233 1
       DO 204 J=1,JJNP                                                 1   28   002241 2
       I=JSELEC(J)                                                     1   28   002245 0
       IF (JSELEC(1).EQ.0) I=J+2                                      11   28   002250 0
       IF (I.LE.2.OR.I.GT.15) GO TO 204                                1   28   002255 2
       PMY=PLENMY*SALPH(J)/SALPH(JJNP)                                25   28   002272 1
       PMX=PMY*PLENMX/PLENMY                                           1   28   002300 4
       PMY=-PMY*YS                                                     1   28   002305 2
       PMX=-PMX*XS                                                     1   28   002310 2
       CALL FMOVE (PMX,PMY)                                            1   28   002313 2
       DO 205 K=1,JPM                                                  1   28   002317 5
       KK=(I-1)*200+K                                                  1   28   002323 2
   205 CALL FPLOT (PMX+FLOAT(K)*DTP,PMY+OUT(KK))                       4   28   002326 5
       CALL FPLOT (PMX+FLOAT(K)*DTP,PMY)                               4   28   002337 4
  204  CONTINUE                                                        3   28   002346 3
       CALL FPLOT (PMX,PMY)                                            4   28   002351 5
       CALL FMOVE (PMX+FLOAT(K)*DTP,PMY)                               4   28   002356 2
       CALL FPLOT (DTPM,0.)                                            3   28   002365 1
       CALL FMOVE (DTPM+XS*.3,0.)                                      3   28   002371 4
       CALL FCHAR (0.,.12,12,12HTIME IN MSEC)                          3   28   002377 1
       CALL FMOVE (DTPM,0.)                                            3   28   002406 5
       CALL FPLOT (DTPM,-.05*YS)                                       3   28   002413 2
       CALL FMOVE (DTPM-.12*XS,-.2*YS)                                 3   28   002420 4
       ENCODE (5,PLY) DTPM                                             3   28   002427 1
       CALL FCHAR (0.,.12,6,PLY)                                       3   28   002433 3
       CALL FMOVE (DTPM,0.)                                            3   28   002440 5
       CALL FPLOT (0.,0.,4HDASH)                                       6   28   002445 2
    5  FOKMAT (F6.2)                                                   3   28   002452 4
       CALL FPLOT (PMX,PMY)                                            3   28   002456 3
       CALL FMOVE (.55*PMX-.3*XS,.55*PMY+.1*YS)                        3   28   002463 0
       CALL FCHAR (67.5,.12,6,6HLENGTH)                                3   28   002473 0
       CALL FMOVE (-.3*XS,.25*YMAX)                                    6   28   002501 4
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      IF (IABS(IOUT).EQ.21) CALL FCHAR (90.,.12,5,5HFORCE)          3    28    002507 4
      IF (IABS(IOUT).EQ.22) CALL FCHAR (90.,.12,4,4HVEL.)           3    28    002521 4
      IF (IABS(IOUT).EQ.23) CALL FCHAR (90.,.12,6,6HSTRESS)         3    28    002533 3
      IF (IABS(IOUT).EQ.24) CALL FCHAR (90.,.12,4,4HACC.)           3    28    002545 4
      IF (IABS(IOUT).EQ.25) CALL FCHAR (90.,.12,6,6HDISPL.)         3    28    002557 3
      CALL FMOVE (-.9*XS,YMAX-.05*YS)                               3    28    002571 4
      ENCODE (2,PLY) YMAX                                           3    28    002600 1
      CALL FCHAR (0.,.12,8,PLY)                                     3    28    002604 3
      CALL FMOVE (0.,YMAX)                                          3    28    002611 5
      CALL FPLOT (-.05*XS,YMAX)                                     3    28    002616 2
      CALL FMOVE (0.,YMAX)                                          4    28    002623 4
      CALL FPLOT (0.,0.)                                            4    28    002630 1
      CALL FMOVE (0.0,1.6*YS)                                      27    28    002641 5
      DO 210 I=1,10                                                10    28    002646 5
  210 CALL FCHAR (0.,.15,4,TITLE(I))                               10    28    002652 1
      CALL FMOVE (5.2*XS,1.6*YS)                                   27    28    002661 1
      DO 162 I=1,2                                                 27    28    002666 4
  162 CALL FCHAR (0.0,.12,6,RCODE(I))                              27    28    002671 5
      CALL FMOVE (0.,YMAX+3.*YS)                                    6    28    002701 1
  300 IF (IULT.EQ.0) RETURN                                         1    28    002706 4
      DO 301 J=1,5                                                  1    28    002714 0
      BIG(J)=0.                                                     1    28    002717 1
      DO 302 I=1,IULT                                               1    28    002721 5
      K=(J-1)*10+I                                                  1    28    002725 3
  302 IF (ABS(RES(K)).GT.BIG(J)) BIG(J)=ABS(RES(K))                 1    28    002730 4
      BIG(J)=BIG(J)*1.1                                             6    28    002742 1
      YM=BIG(J)                                                     1    28    002746 1
      DO 303 I=1,15                                                 3    28    002750 5
      IF (YM.LT.1.) GO TO 304                                       1    28    002754 1
  303 YM=YM/10.                                                     1    28    002761 1
  304 PRJ(J)=10.**(I-2)                                             1    28    002764 3
      I=BIG(J)/PRJ(J)+1.                                            1    28    002771 1
  301 BIG(J)=PRJ(J)*FLOAT(I)                                        6    28    002775 2
      PLLY(1)=4.                                                    1    28    003002 5
      PLLY(2)=6.                                                    1    28    003005 4
      PLLY(3)=5.                                                    1    28    003010 3
      PLLY(4)=3.                                                    3    28    003013 2
      PLLY(5)=3.                                                    3    28    003016 1
      IF (BIG(5).GT.BIG(4)) PRJ(4)=PRJ(5)                           5    28    003021 0
      IF (BIG(4).GT.BIG(5)) PRJ(5)=PRJ(4)                           5    28    003030 1
      IF (BIG(5).GT.BIG(4)) BIG(4)=BIG(5)                           1    28    003037 2
      IF (BIG(4).GT.BIG(5)) BIG(5)=BIG(4)                           1    28    003046 3
      DO 305 J=1,5                                                  1    28    003055 4
      PYS(J)=BIG(J)/PLLY(J)                                         1    28    003060 5
      PUNIT(J)=PRJ(J)/5.                                            1    28    003065 3
  305 IUNIT(J)=BIG(J)/PRJ(J)+1.001                                  1    28    003071 4
      BIG(1)=BIG(1)*1.25                                            1    28    003100 2
      CALL FSCALE (-3.*PYS(2),0.,PYS(2),PYS(3),BIG(3),1H ,0.,0.)    1    28    003104 3
      I3=BIG(2)/PUNIT(2)                                            1    28    003117 4
      I2W=1                                                         1    28    003123 5
      DO 309 I=1,I3                                                 1    28    003125 5
      XUSE=PUNIT(2)*I                                               1    28    003131 1
      CALL FPLOT (XUSE,0.)                                          1    28    003134 5
      CALL FPLOT (XUSE,-.05*PYS(3))                                 1    28    003141 2
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      IF (I.NE.I2W*5) GO TO 309                                             1    28    003147 3
      I2W=I2W+1                                                             1    28    003154 5
      CALL FPLOT (XUSE,.05*PYS(3))                                          3    28    003157 3
      CALL FMOVE (XUSE-.25*PYS(2),-.2*PYS(3))                               1    28    003165 3
      ENCODE (3,PLX) XUSE                                                   1    28    003175 2
      CALL FCHAR (0.,.12,4,PLX)                                             1    28    003201 4
  309 CALL FMOVE (XUSE,0.)                                                  1    28    003207 0
      CALL FPLOT (BIG(2),0.)                                                1    28    003214 1
      IF (IUNIT(3).GT.BIG(3)) IUNIT(3)=IUNIT(3)/10.+1                       5    28    003221 0
      I2=BIG(3)/IUNIT(3)                                                    1    28    003232 1
      DO 308 I=1,I2                                                         1    28    003236 2
      YUSE=IUNIT(3)*I                                                       1    28    003241 4
      CALL FPLOT (BIG(2),YUSE)                                              1    28    003245 2
      CALL FPLOT (BIG(2)+.05*PYS(2),YUSE)                                   1    28    003252 3
      CALL FMOVE (BIG(2)+.1*PYS(2),YUSE-.06*PYS(3))                         1    28    003261 4
      ENCODE (3,PLY) YUSE                                                   1    28    003272 3
      CALL FCHAR (0.,.12,4,PLY)                                             1    28    003276 5
  308 CALL FMOVE (BIG(2),YUSE)                                              1    28    003304 1
      CALL FPLOT (BIG(2),BIG(3))                                            6    28    003312 1
      CALL FMOVE (BIG(2)+.3*PYS(2),YUSE-.25*PYS(3))                        12    28    003317 4
      CALL FCHAR (0.,.12,3,3HFT.)                                           6    28    003330 3
      DO 310 J=IULT,1,-1                                                    1    28    003336 1
      CALL FMOVE  (RES(J+10)-.06*PYS(2),RES(J+20)-.06*PYS(3))              14    28    003342 2
  310 CALL FSCHAR (0.,.12,62)                                               1    28    003354 5
      CALL FMOVE (0.,0.)                                                    1    28.   003362 3
      CALL FSCALE (-3.*PYS(2),0.,PYS(2),PYS(1),BIG(1),1H ,0.,0.)            1    28    003366 4
      I1=BIG(1)/PUNIT(1)                                                    1    28    003401 5
      I1W=1                                                                 6    28    003406 0
      DO 306 I=1,I1                                                         1    28    003410 0
      YUSE=PUNIT(1)*I                                                      10    28    003413 2
      CALL FPLOT (0.,YUSE)                                                  1    28    003417 0
      CALL FPLOT (-.05*PYS(2),YUSE)                                         1    28    003423 3
      IF (I.NE.I1W*5) GO TO 306                                            11    28    003431 4
      I1W=I1W+1                                                             6    28    003437 0
      CALL FPLOT (.05*PYS(2),YUSE)                                          3    28    003441 4
      CALL FMOVE (-.9*PYS(2),YUSE-.05*PYS(1))                               1    28    003447 4
      ENCODE (2,PLY) YUSE                                                   1    28    003457 3
      CALL FCHAR (0.,.12,8,PLY)                                             1    28    003463 5
  306 CALL FMOVE (0.,YUSE)                                                  1    28    003471 1
      CALL FPLOT (0.,BIG(1))                                               10    28    003476 2
      CALL FMOVE (-.5*PYS(2),(I1W-1)*PRJ(1)-.2*PYS(1))                     13    28    003503 1
      CALL FCHAR (0.,.12,4,4HTONS)                                          6    28    003514 3
      CALL FMOVE(1.3*PYS(2),4.6*PYS(1))                                    10    28    003522 3
      CALL FCHAR (0.,.12,12,12HRESISTANCE=X)                                6    28    003531 2
      CALL FMOVE (3.4*PYS(2),4.6*PYS(1))                                   10    28    003541 0
      CALL FCHAR (0.,.12,7,7HSTROKE=)                                       6    28    003550 0
      CALL FSCHAR (0.,.12,62)                                               6    28    003556 3
      DO 307 J=IULT,1,-1                                                    1    28    003563 3
      CALL FMOVE (RES(J+10)-.06*PYS(2),RES(J)-.06*PYS(1))                  13    28    003567 4
  307 CALL FSCHAR (0.,.12,93)                                               1    28    003601 3
      CALL FMOVE (2.3*PYS(2),-.4*PYS(1))                                   10    28    003607 1
      CALL FCHAR (0.,.12,14,14HBLOWS PER FOOT)                             13    28    003616 1
      CALL FMOVE (0.,5.*PYS(1))                                             3    28    003626 1
      CALL FSCALE (-3.*PYS(2),0.,PYS(2),PYS(4),BIG(4),1H ,0.,0.)            3    28    003633 3
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      I4=BIG(4)/PUNIT(4)                                                     3   28   003646 4
      DO 311 I=1,I4                                                          3   28   003652 5
      YUSE=PUNIT(4)*I                                                        6   28   003656 1
      CALL FPLOT (0.,YUSE)                                                   3   28   003661 5
      CALL FPLOT (-.05*PYS(2),YUSE)                                          3   28   003666 2
      DO 316 J=1,10                                                          3   28   003674 3
      XUSE=J*PRJ(4)                                                          3   28   003677 5
      IF (ABS(XUSE-YUSE).LT.0.001) GO TO 317                                 3   28   003703 1
  316 CONTINUE                                                               3   28   003712 5
      GO TO 311                                                              3   28   003716 0
  317 CALL FPLOT (.05*PYS(2),YUSE)                                           3   28   003720 4
      CALL FMOVE (-.9*PYS(2),YUSE-.05*PYS(4))                                3   28   003727 2
      ENCODE (2,PLY) YUSE                                                    3   28   003737 1
      CALL FCHAR (0.,.12,8,PLY)                                              3   28   003743 3
      FY=YUSE                                                               10   28   003750 5
  311 CALL FMOVE (0.,YUSE)                                                   3   28   003753 1
      CALL FPLOT (0.,BIG(4))                                                 6   28   003760 2
      CALL FMOVE (-.4*PYS(2),FY-.2*PYS(4))                                  11   28   003765 1
      CALL FCHAR (0.,.12,3,3HKSI)                                            6   28   003774 3
      CALL FMOVE (1.2*PYS(2),2.8*PYS(4))                                     6   28   004002 1
      CALL FMOVE (.9*PYS(2),2.8*PYS(4))                                     10   28   004011 1
      CALL FCHAR (0.,.12,19,19HCOMPRESSIVE STRESS=)                          6   28   004020 0
      CALL FSCHAR (0.,.12,4)                                                 6   28   004030 5
      CALL FMOVE (3.4*PYS(2),2.8*PYS(4))                                    10   28   004035 4
      CALL FCHAR (0.,.12,16,16HTENSILE STRESS=*)                             6   28   004044 4
      DO 313 J=IULT,1,-1                                                     6   28   004055 0
      CALL FMOVE (RES(J+10)-.06*PYS(2),ABS(RES(J+30))-.06*PYS(4))           13   28   004061 1
  313 CALL FSCHAR (0.,.12,40)                                                6   28   004074 3
      CALL FMOVE (0.,0.)                                                    10   28   004102 1
      I2W=1                                                                  6   28   004106 2
      DO 314 I=1,I3                                                          6   28   004110 2
      XUSE=PUNIT(2)*I                                                        6   28   004113 4
      CALL FPLOT (XUSE,0.)                                                   6   28   004117 2
      CALL FPLOT (XUSE,-.05*PYS(4))                                          6   28   004123 5
      IF (I.NE.I2W*5) GO TO 314                                              6   28   004132 0
      I2W=I2W+1                                                              6   28   004137 2
      CALL FPLOT (XUSE,.05*PYS(4))                                           6   28   004142 0
      CALL FMOVE (XUSE-.25*PYS(2),-.2*PYS(4))                                6   28   004150 0
      ENCODE (3,PLX) XUSE                                                    6   28   004157 5
      CALL FCHAR (0.,.12,4,PLX)                                              6   28   004164 1
  314 CALL FMOVE (XUSE,0.)                                                   6   28   004171 3
      CALL FPLOT (BIG(2),0.)                                                 6   28   004176 4
      CALL FPLOT (BIG(2),BIG(4))                                             6   28   004203 3
      CALL FPLOT (0.,BIG(4))                                                10   28   004211 0
      DO 315 J=1,IULT                                                        6   28   004215 5
      CALL FMOVE (RES(J+10)-.06*PYS(2),RES(J+40)-.06*PYS(4))                13   28   004221 3
  315 CALL FSCHAR (0.,.12,4)                                                 6   28   004233 5
      CALL FMOVE (.75*PYS(2),3.2*PYS(4))                                    10   28   004241 2
      DO 320 I=1,10                                                         10   28   004250 2
  320 CALL FCHAR (0.,.15,4,TITLE(I))                                        10   28   004253 4
      CALL FMOVE (0.,4.5*PYS(4))                                             6   28   004262 4
      RETURN                                                                 6   28   004270 1
      END                                                                    6   28   004272 2
```

```
SOILN                SYMBOLIC FORTRAN  30 APR 76  14:19:06    8   12    5   00147213      663
   1          SUBROUTINE SOILN (ITYS,IPERCS,N,XPT,SU,IR,ALPH)                          2     12     000004 0
   2                                                                                   1     12     000015 1
   3     C    THIS PROGRAM FINDS THE PERCENTAGE OF TOTAL PILE RESISTANCE THAT ACTS     1     12     000016 0
   4     C    AT INDIVIDUAL ELEMENTS                                                   1     12     000033 1
   5     C    NOTE THAT THIS PROGRAM ASSUMES THAT PILE ELEMENTS ARE OF EQUAL LENGTH    1     12     000040 2
   6     C    EXCEPT FOR TOP AND BOTTOM. THESE HAVE 1/2 THE LENGTH OF THE OTHERS.      1     12     000055 4
   7     C    DIS IS AN ARRAY THAT CONTAINS DISTRIBUTIONS OF STATIC SOIL RESISTANCE    1     12     000072 4
   8     C    FIRST INDEX = TYPE, SECOND INDEX 1=LOCATION 2=PERCENTAGE                 1     12     000110 0
   9     C    THIRD INDEX (MAX=6) FOR VALUES                                           1     12     000123 1
  10     C    BETWEEN GIVEN POINTS OF CHANGE OF DISTRIBUTION THE RESISTANCE IS         1     12     000131 5
  11     C    ASSUMED TO VARY LINEARLY                                                 1     12     000146 2
  12     C    XPT IS THE TOTAL PILE LENGTH                                             1     12     000153 5
  13     C    PERC* STANDS FOR PERCENTAGE OF TOTAL SKIN RESISTANCE AT *                1     12     000162 1
  14          DIMENSION SU(20),DIS(11,2,20),ALPH(99)                                   1     12     000175 3
  15          DO 201 I=1,11                                                            6     12     000205 1
```

```
 16            DO 201 J=1,2                                              1    12    000210 3
 17            DO 201 K=1,20                                             1    12    000213 4
 18            DIS(I,J,K)=0.0                                            1    12    000217 0
 19      201   CONTINUE                                                  1    12    000222 3
 20            IF (ITYS.LT.1) GO TO 300                                 11    12    000233 0
 21            DIS(1,2,1)=1.                                             1    12    000240 1
 22            DIS(5,2,1)=0.5                                            1    12    000243 3
 23            DIS(6,2,1)=1./3.                                          1    12    000247 0
 24            DIS(7,2,1)=1.                                             1    12    000252 5
 25            DIS(8,2,1)=1.                                             1    12    000256 1
 26            DIS(9,2,1)=0.5                                            1    12    000261 3
 27            DIS(10,2,1)=1.                                            1    12    000265 0
 28            DO 202 I=1,10                                             1    12    000270 3
 29            DO 202 J=1,2                                              1    12    000273 5
 30            DIS(I,J,2)=1.                                             1    12    000277 0
 31      202   CONTINUE                                                  1    12    000302 2
 32            DO 203 I=3,5                                              1    12    000305 4
 33            DO 203 J=1,2                                              1    12    000310 5
 34            DIS(I,J,2) = 0.5                                          1    12    000314 0
 35      203   CONTINUE                                                  1    12    000317 5
 36            DIS(2,1,2)=0.25                                           1    12    000323 1
 37            DIS(4,1,2)=0.75                                           1    12    000326 5
 38            DO 213 I=2,4                                              1    12    000332 3
 39      213   DIS(I,2,2) = 0.0                                          1    12    000335 4
 40            DIS(6,2,2)=1./3.                                          1    12    000342 2
 41            DIS(9,2,2)=0.5                                            1    12    000346 1
 42            DO 204 I=6,10                                             1    12    000351 4
 43            DIS(I,1,2)=1./3.                                          1    12    000355 0
 44      204   CONTINUE                                                  1    12    000360 5
 45            DIS(8,1,2)=2./3.                                          1    12    000364 1
 46            DO 205 I=2,5                                              1    12    000370 0
 47            DIS(I,2,3)=1.                                             1    12    000373 1
 48      205   CONTINUE                                                  1    12    000376 3
 49            DO 206 I=6,10                                             1    12    000401 5
 50      206   DIS(I,1,3)=1./3.                                          1    12    000405 1
 51            DO 207 I=7,10                                             1    12    000411 5
 52      207   DIS(I,2,3)=0.5                                            1    12    000415 1
 53            DIS(2,1,3)=0.25                                           1    12    000421 3
 54            DIS(3,1,3)=0.5                                            1    12    000425 1
 55            DIS(4,1,3)=0.75                                           1    12    000430 4
 56            DIS(5,1,3)=0.5                                            1    12    000434 2
 57            DIS(6,2,3)=2./3.                                          1    12    000437 5
 58            DIS(8,1,3)=2./3.                                          1    12    000443 4
 59            DIS(9,2,3)=1.                                             1    12    000447 3
 60            DO 208 I=1,9                                              1    12    000452 5
 61            DO 208 J=1,2                                              1    12    000456 0
 62      208   DIS(I,J,4)=1.                                             1    12    000461 1
 63            DIS(6,1,4)=2./3.                                          1    12    000465 2
 64            DIS(6,2,4)=2./3.                                          1    12    000471 1
 65            DIS(7,2,4)=0.5                                            1    12    000475 0
 66            DIS(8,2,4)=0.5                                            1    12    000500 3
 67            DIS(9,1,4)=2./3.                                          1    12    000504 0
 68            DIS(10,1,4) = 2./3.                                       1    12    000507 5
 69            DIS(10,2,4)=0.5                                           1    12    000514 1
```

```
      DO 209 I=6,10
  209 DIS(I,1,5)=2./3.                                                    1    12   000517 5
      DO 210 I=6,10                                                       1    12   000523 1
      DIS(I,2,5)=1.                                                       1    12   000527 5
  210 CONTINUE                                                            1    12   000533 1
      DIS(9,2,5)=0.5                                                      1    12   000536 3
      DO 211 I=6,10                                                       1    12   000541 5
      DO 211 J=1,2                                                        1    12   000545 2
      DIS(I,J,6)=1.                                                       1    12   000550 4
  211 CONTINUE                                                            1    12   000553 5
      DIS(9,2,6)=0.5                                                      1    12   000557 1
      GO TO 400                                                           1    12   000562 3
  500 CONTINUE                                                            1    12   000566 0
C                                                                         1    12   000570 4
C     FOR INPUT OF SOIL DISTRIBUION                                      12    12   000574 0
C                                                                        12    12   000575 1
  300 ITYS=11                                                            12    12   000603 4
    2 FORMAT (2F8.3)                                                      1    12   000604 5
      DO 306 I=1,20                                                       1    12   000607 5
      READ (IR,2) DIS(11,1,I),DIS(11,2,I)                                 1    12   000613 5
      I1=I                                                                1    12   000617 1
      IF (DIS(11,1,1).GT.0.0) I1=I1+1                                     6    12   000626 2
      DISX=DIS(11,1,I)                                                    6    12   000630 1
      DIS(11,1,I1)=DIS(11,1,I)/XPT                                        6    12   000636 4
      DIS(11,2,I1)=DIS(11,2,I)/100.                                       6    12   000642 3
      IF (DISX.GE.XPT-0.00001) GO TO 400                                  8    12   000650 3
  306 CONTINUE                                                            1    12   000656 4
  400 XU=0.0                                                              1    12   000665 4
      IF (DIS(11,1,1).GT.0.0) DIS(11,1,2)=0.0                             1    12   000670 5
      IF (DIS(11,1,1).GT.0.0) DIS(11,1,1)=0.0                             9    12   000713 2
      PERCS=IPERCS                                                        9    12   000723 1
      PERCS = PERCS*0.01                                                  1    12   000733 0
      IF (PERCS.LT.10.0E-8)  PERCS = 10.0E-8                              1    12   000736 1
      SUMT=0.0                                                           10    12   000742 2
      SALPH=0.0                                                           1    12   000751 5
      DO 110 I=1,N                                                        3    12   000754 2
  110 SALPH=SALPH+ALPH(I)                                                 3    12   000757 0
      DO 100 I=1,N                                                        3    12   000762 1
      XO=XU                                                               1    12   000767 1
      DL=ALPH(I)/SALPH                                                    1    12   000772 2
      XU=XO+DL                                                            3    12   000774 2
      SUM=0.0                                                             1    12   001000 1
      DO 101 J=2,20                                                       1    12   001002 4
      XXO = DIS(ITYS,1,J)                                                 5    12   001005 0
      IF (XXO.GT.XO) GO TO 102                                            1    12   001010 2
  101 CONTINUE                                                            1    12   001014 4
  102 CONTINUE                                                            1    12   001021 5
      J1=J-1                                                              1    12   001025 1
      XXO=XO                                                              1    12   001030 3
      PERCO=DIS(ITYS,2,J1)+ ((DIS(ITYS,2,J)-DIS(ITYS,2,J1))/(DIS(ITYS,     1    12   001032 4
     1 1,J) - DIS(ITYS,1,J1)))*(XO-DIS(ITYS,1,J1))                        1    12   001034 5
      DO 103 IJ = J,20                                                    1    12   001051 0
      XXU=DIS(ITYS,1,IJ)                                                  5    12   001061 5
      IF (XXU.GT.XU-10E-6) GO TO 104                                      1    12   001065 4
                                                                          5    12   001071 5
```

```
      PERCU=DIS(ITYS,2,IJ)                                              1    12    001100 1
      SUM = SUM + (PERCO+PERCU)*0.5*(XXU-XXO)                           1    12    001104 4
      XXO=XXU                                                           1    12    001114 3
      PERCO=PERCU                                                       1    12    001116 5
  103 CONTINUE                                                          1    12    001121 5
  104 CONTINUE                                                          1    12    001125 1
      XXU=XU                                                            1    12    001130 3
      J=IJ                                                              1    12    001132 4
      J1=IJ-1                                                           1    12    001134 3
      PERCU=DIS(ITYS,2,J1)+ ((DIS(ITYS,2,J)-DIS(ITYS,2,J1))/(DIS(ITYS,  1    12    001136 5
     1 1,J) - DIS(ITYS,1,J1)))*(XU-DIS(ITYS,1,J1))                      1    12    001153 0
      SUM = SUM + (PERCO+PERCU)*0.5*(XXU-XXO)                           1    12    001163 5
      SU(I) = SUM                                                       1    12    001173 4
      SUMT = SUMT +   IM                                                1    12    001176 4
  100 CONTINUE                                                          1    12    001202 4
      DO 105 I=1,N                                                      1    12    001206 0
  105 SU(I)=SU(I)*PERCS/SUMT                                            1    12    001211 1
      SU(N+1)=1.-PERCS                                                  4    12    001216 5
      RETURN                                                            1    12    001222 4
      END                                                               1    12    001224 5
SRESN                SYMBOLIC FORTRAN  02 JUL 75  15:54:44   1   1   5   00035127     60
      SUBROUTINE SRESN (DNP,DOP,SU,SOK,I,RESO,RESN,ESOIL)               1     1    000000 0
      DIMENSION DNP(20),DOP(20),SU(20),SOK(20),RESO(20),RESN(20)        1     1    000011 5
      SKE=SOK(I)                                                        1     1    000025 0
      IF (DNP(I).LT.DOP(I)) SKE=SKE/ESOIL                               1     1    000027 5
      DRES=(DNP(I)-DOP(I))*SKE                                          1     1    000037 0
      RESN(I)=RESO(I)+DRES                                              1     1    000044 1
      IF (RESN(I).LT.-SU(I)) RESN(I) = -SU(I)                           1     1    000050 4
      IF (RESN(I).GT.SU(I)) RESN(I)=SU(I)                               1     1    000060 3
      RETURN                                                            1     1    000067 4
      END                                                               1     1    000071 5
JJNP                 SYMBOLIC FORTRAN  02 MAR 76  16:50:40   1   4   5   00057663    283
      SUBROUTINE JJNP(ICOL,N,JNP,JMAX)                                  2     4    000011 5
      DIMENSION JNP(13)                                                 1     4    000020 3
      DO 100 I=1,13                                                     1     4    000024 3
  100 JNP(I)=0                                                          1     4    000027 5
      JNP(1)=1                                                          1     4    000033 0
      JNP(2)=2                                                          1     4    000035 3
      IF (ICOL.GT.0) GO TO 200                                          1     4    000040 0
      IF (N.GT.6) GO TO 107                                             1     4    000045 1
      DO 105 I=3,N                                                      1     4    000051 5
  105 JNP(I)=I                                                          1     4    000055 0
      JMAX=N                                                            1     4    000060 1
      GO TO 400                                                         1     4    000062 2
  107 CONTINUE                                                          2     4    000067 3
      JNP(6) = N                                                        2     4    000072 5
      JMAX = 6                                                          2     4    000075 4
      IF (N.GT.20) GO TO 301                                            2     4    000100 1
      II = 1                                                            2     4    000105 0
      DO 110 I=6,18,3                                                   1     4    000107 1
      IF (N.GT.I.AND.N.LE.I+2) GO TO 120                                1     4    000112 5
  110 II=II+1                                                           1     4    000121 5
```

```
      120 NCOUNT=II                                               1      4     000124 5
          DO 130 I=3,5                                            1      4     000130 1
      130 JNP(I)=JNP(I-1) + NCOUNT                                1      4     000133 2
          GO TO 400                                               1      4     000146 4
     301  JNP(3) = N/4                                            2      4     000151 2
          JNP(4) = N/2                                            2      4     000155 2
          JNP(5) = N*3/4                                          2      4     000160 3
          GO TO 400                                               2      4     000164 0
   C      FILLS IN THE INP ARRAY ONLY IF 132 COLUMNS IN PRINTOUT  1      4     000166 4
      200 IF (N.GT.13) GO TO 230                                  1      4     000201 2
          DO 220 I=1,N                                            1      4     000206 5
      220 JNP(I)=I                                                1      4     000212 0
          JMAX=N                                                  1      4     000215 1
          GO TO 400                                               1      4     000217 2
     230  JMAX = 13                                               1      4     000225 5
          JNP(13) = N                                             2      4     000231 2
          IF (N.GT.20) GO TO 302                                  3      4     000234 2
          DO 235 I=1,4                                            2      4     000241 1
          JNP(I) = I                                              2      4     000244 2
          J1 = 14 - I                                             1      4     000247 1
          J2 = (N+1) - I                                          1      4     000252 1
      235 JNP(J1)=J2                                              1      4     000255 4
          IF (N.EQ.17) JNP(5)=5                                   1      4     000261 1
          DO 240 I=5,9                                            1      4     000265 5
          IF (N.GE.14.AND.N.LE.16) JNP(I) = I+(I+2)/5             4      4     000300 1
          IF (N.EQ.17.AND.I.NE.5) JNP(I) = JNP(I-1) + 2           1      4     000310 4
          IF (N.GT.17) JNP(I) = JNP(I-1) + 2                      1      4     000321 3
     240  CONTINUE                                                1      4     000330 3
          GO TO 400                                               1      4     000336 1
     302  CONTINUE                                                2      4     000340 5
          NDEL = 0.1*FLOAT(N) + 0.5                               2      4     000344 1
          JNP(8) = N/2                                            2      4     000351 3
          JNP(7) = JNP(8)-1                                       2      4     000354 4
          DO 303 I=3,5                                            2      4     000360 4
     303  JNP(I) = 2 + (I-2)*NDEL                                 2      4     000363 5
          I2 = 0                                                  2      4     000371 4
          DO 304 I=10,12                                          2      4     000373 5
          I1 = 22-I                                               2      4     000377 2
          I2 = I2 + 1                                             2      4     000402 0
     304  JNP(I1) = N-I2*NDEL                                     2      4     000405 0
          JNP(9) = JNP(8) + NDEL                                  2      4     000412 1
          JNP(6) = JNP(7) - NDEL                                  2      4     000417 0
      400 CONTINUE                                                1      4     000423 5
          RETURN                                                  1      4     000427 0
          END                                                     1      4     000431 1
STIFF               SYMBOLIC FORTRAN  23 SEP 75  10:02:18    3    7    5    00035417      114
          SUBROUTINE STIFF (DDIS,DVEL,STL,STR,FO,FN,DSAC,DDD)     1      7     000004 0
          DLST = STR - STL                                        1      7     000015 5
          STI=STL+2.*DVEL*DLST                                    7      7     000027 5
          IF (STI.LT.STL) STI = STL                               1      7     000034 2
          IF (STI.GT.STR) STI = STR                               1      7     000041 4
          ST1=STI*DDD/(2.0*DSAC)                                  2      7     000056 1
          STQUAD=ST1*ST1-FO*STI/DSAC                              2      7     000063 0
```

```
  8            IF (STQUAD.LT.0) STQUAD=0                                        2     7     000070 3
  9            STIS=ABS(ST1)+SQRT(STQUAD)                                       4     7     000107 3
 10            IF (STIS.GT.STI) STIS = STI                                      1     7     000115 0
 11            IF (STIS.LT.0.0) STIS = 0.0                                      1     7     000122 4
 12            FN = FO + DDD*STIS                                               1     7     000130 2
 13      1     FORMAT (2F10.2,3F10.4,3F10.0,F10.4)                              5     7     000134 3
 14            RETURN                                                           1     7     000155 1
 15            END                                                              1     7     000157 2
INTEGR                 SYMBOLIC FORTRAN  04 SEP 74  11:58:39   1   1   5   00035056   41
  1            SUBROUTINE INTEGR(DT,XO,XN,XIO,XIIO,XIN,XIIN,I)                  1     1     000000 0
  2            DIMENSION XO(10),XN(10),XIO(10),XIIO(10),XIN(10),XIIN(10)        1     1     000011 1
  3            XIN(I)=XIO(I)+0.5*(XO(I)+XN(I))*DT                               1     1     000024 1
  4            XIIN(I)=XIIO(I)+XIO(I)*DT+(XO(I)*2.+XN(I))*DT*DT/6.              1     1     000033 1
  5            RETURN                                                           1     1     000045 0
  6            END                                                              1     1     000047 1
FTR                    SYMBOLIC FORTRAN  19 JAN 76  13:39:42   1   4   5   00036033   198
  1            FUNCTION FTR (DPOS,PBAR,IWT)                                     1     4     000003 0
  2            DIMENSION PBAR (20)                                              1     4     000011 0
  3            IWT=0                                                            1     4     000015 2
  4            PATM=14.7*0.144                                                  1     4     000017 2
  5            ART=PBAR(1)                                                      1     4     000023 0
  6            DSF=PBAR(2)                                                      1     4     000034 1
  7            EXPB=PBAR(4)                                                     1     4     000037 1
  8            VCT=PBAR(5)                                                      1     4     000042 2
  9            DEPBB=PBAR(6)                                                    1     4     000045 2
 10            DBBT=PBAR(7)                                                     1     4     000050 4
 11            RWH=PBAR(8)+PATM*ART                                             2     4     000056 5
 12            DBC=PBAR(7)+DPOS                                                 1     4     000063 2
 13            VBIN = DEPBB*ART + VCT                                           1     4     000067 1
 14            IF (DBC.GT.DEPBB.OR.DBBT.LT.0.1) FTR=PATM*ART                    1     4     000074 0
 15            IF (DBC.GT.DEPBB.OR.DBBT.LT.0.1) RETURN                          1     4     000104 5
 16            VBFIN=DBC*ART+VCT                                                1     4     000114 4
 17            VSF=DSF*ART                                                      1     4     000120 4
 18            IF (DBC.LT.DSF) VBFIN=VSF+VCT                                    1     4     000123 4
 19            FTR=PATM*ART*(VBIN/VBFIN)**EXPB                                  1     4     000131 5
 20            IF (DBC.LT.DSF) FTR=FTR*(VSF/(ART*DBC))**EXPB                    1     4     000140 2
 21            IF (FTR.GT.RWH) IWT=1                                            1     4     000151 1
 22            IF (FTR.GT.RWH) FTR=RWH                                          1     4     000155 5
 23            RETURN                                                           1     4     000162 5
 24      C     ART ... AREA AT TOP OF RAM                                       1     4     000165 0
 25      C     DSF ... DISTANCE OF SAFETY CHAMBER FROM TOP                      1     4     000172 5
 26      C     EXPB ... EXPONENT                                                1     4     000203 4
 27      C     VCT ... VOLUME OF COMPRESSION TANK                               1     4     000210 0
 28      C     DEPBB ... DISTANCE OF EXHAUST PORTS FROM TOP                     1     4     000217 2
 29      C     RWH ... WEIGHT OF CYLINDER ETC.                                  1     4     000230 2
 30      C     DBBT ... DISTANCE BETWEEN TOP AND BOTTOM - RAM LENGTH            1     4     000237 1
 31      C     VBIN ... INITIAL VOLUME OF BOUNCE CHAMBER                        1     4     000251 4
 32      C     VBFIN ... FINAL VOLUME OF BOUNCE CHAMBER                         1     4     000262 1
 33      C     DBC ... CURRENT POSITION ... DISTANCE FROM TOP                   1     4     000272 3
 34            END                                                              1     4     000303 5
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Δ FOR WINIT,WINIT
FOR OF JANUARY 20, 1976                                                 THURSDAY, FEBRUARY 12, 1976 AT 12:26:48
HIGHEST S.E. ADDRESS:    03110


   MAIN PROGRAM

   STORAGE USED (BLOCK, NAME, LENGTH)

         0001    CODE*    000053
         0000    DATA*    012135


   EXTERNAL REFERENCES (BLOCK, NAME)

         0002    NINTR$
         0003    NO$BFU
         0004    NIO1$
         0005    NIO2$
         0006    NSTOP$


   STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

    0001    000007 110G        0001    000010 113G        0001    000013 117G        0001    000032 126G        0001    000037 132G
    0001    000040 135G        0000    012125 5F          0000 R 012120 BLANK        0000 I 012122 I           0000 I 012121 IF
    0000 I 012123 IJ           0000 I 012124 KJ           0000 R 000000 STORE


000101      1.           DIMENSION STORE(100,2,26)                                                                  000000
000103      2.           DATA BLANK/4H    /                                                                         000001
000105      3.           IF = 7                                                                                     000001
000106      4.      5    FORMAT (2A4/6(8E10.5/),2E10.5)                                                             000010
000107      5.           DO 200 I=1,100                                                                             000010
000112      6.           DO 200 IJ=1,2                                                                              000010
000115      7.           STORE (I,IJ,1) = BLANK                                                                     000010
000116      8.           DO 200 KJ=2,26                                                                             000013
000121      9.    200    STORE (I,IJ,KJ) = 0.0                                                                      000013
000125     10.           DO 100 I=1,100                                                                             000032
000130     11.    100    WRITE (IF,5) ((STORE(I,IJ,KJ),IJ=1,2),KJ=1,26)                                             000032
000144     12.           END                                                                                        000052

 NO DIAGNOSTICS.
                                                                              1.8402 SECONDS.
```

```
000101      1.          DIMENSION STORE(100,2,26)                                                          000000
000103      2.          IF = 7                                                                             000001
000104      3.          IW = 6                                                                             000003
000105      4.          IR = 5                                                                             000005
000106      5.          MAX = 100                                                                          000007
000107      6.     3    FORMAT (20I4)                                                                      000011
000110      7.          READ (IR,3) NH,IOPT                                                                000011
000114      8.     5    FORMAT (2A4/6(8E10.5/),2E10.5)                                                     000020
000115      9.     8    FORMAT (2A4,9F8.2)                                                                 000020
000116     10.     9    FORMAT (10F8.2)                                                                    000020
000117     11.    10    FORMAT (1H ,2A4,4(F8.3,F8.0),F8.3)                                       *NEW      000020
000120     12.    11    FORMAT (1H ,2(F8.0,F8.3),2F8.3,F8.0,F8.4,2F8.2)                          *NEW      000020
000121     13.    12    FORMAT (1H ,F8.1,2F8.2,5F8.1,F8.3,F8.2)                                  *NEW      000020
000122     14.    13    FORMAT (1H ,10F8.3)                                                      *NEW      000020
000123     15.    14    FORMAT (1H ,F8.3,3(F8.3,F8.0),F8.2,2F8.3)                                *NEW      000020
000124     16.          IF (NH.LT.1) GO TO 500                                                   **-2      000020
000126     17.          IH0 = 1                                                                            000025
000127     18.          DO 100 I =1,NH                                                                     000027
000132     19.          READ (IR,3) IH                                                                     000040
000135     20.          DO 101 J=IH0,IH                                                                    000046
000140     21.   101    READ (IF,5) ((STORE(J,IJ,KJ),IJ=1,2),KJ=1,26)                                      000103
000154     22.          READ (IR,8) ((STORE(IH,IJ,KJ),IJ=1,2),KJ=1,5),STORE(IH,1,6)                        000121
000170     23.          READ (IR,9) STORE(IH,2,6),((STORE(IH,IJ,KJ),IJ=1,2),KJ=7,25),STORE                 000141
000170     24.         1 (IH,1,26)                                                                         000141
000205     25.          WRITE (IW,3) IH                                                                    000162
000210     26.          WRITE(IW,10)((STORE(IH,IJ,KJ),IJ=1,2),KJ=1,5),STORE(IH,1,6)                        000170
000224     27.          WRITE (IW,11) STORE(IH,2,6),((STORE(IH,IJ,KJ),IJ=1,2),KJ=7,10),          *NEW      000[illegible]
000224     28.         * STORE(IH,1,11)                                                          *NEW      000210
000241     29.          WRITE (IW,12) STORE(IH,2,11),((STORE(IH,IJ,KJ),IJ=1,2),KJ=12,15),        *NEW      000231
000241     30.         * STORE(IH,1,16)                                                          *NEW      000231
000256     31.          WRITE (IW,13) STORE(IH,2,16),((STORE(IH,IJ,KJ),IJ=1,2),KJ=17,20),        *NEW      000252
000256     32.         * STORE(IH,1,21)                                                          *NEW      000252
000273     33.          WRITE (IW,14) STORE(IH,2,21),((STORE(IH,IJ,KJ),IJ=1,2),KJ=22,25),        *NEW      000273
000273     34.         * STORE(IH,1,26)                                                          *NEW      000273
000310     35.          DO 103 IJ=2,7                                                            **-2      000320
000313     36.   103    STORE(IH,2,IJ)= STORE(IH,2,IJ)*12.0                                                000320
000315     37.          STORE(IH,2,9) = STORE(IH,2,9)*12.0                                                 000323
000316     38.          DO 104 IJ=22,24                                                                    000333
000321     39.   104    STORE(IH,2,IJ) = STORE(IH,2,IJ)*12.0                                               000333
000323     40.          IH0 = IH + 1                                                                       000336
000324     41.   100    CONTINUE                                                                           000342
000326     42.          DO 400 I=IH0,MAX                                                                   000342
000331     43.   400    READ (IF,5) ((STORE(I,IJ,KJ),IJ=1,2),KJ=1,26)                                      000351
000345     44.          REWIND IF                                                                          000367
000346     45.          DO 200 I=1,MAX                                                                     000375
000351     46.   200    WRITE (IF,5) ((STORE(I,IJ,KJ),IJ=1,2),KJ=1,26)                                     000375
000365     47.   500    CONTINUE                                                                           000414
000365     48.    C     CHECK IT                                                                           000414
000366     49.          REWIND IF                                                                          000414
000367     50.          DO 300 I=1,MAX                                                                     000416
000372     51.          READ (IF,5) ((STORE(I,IJ,KJ),IJ=1,2),KJ=1,26)                                      000424
000405     52.          IF (STORE(I,2,8).LT.1.0) GO TO 300                                                 000437
```

```
                               WDATA(2)                                              23 JAN 76  14:12:55   PAGE 3

 000407      53.            WRITE(IW,6)  I,(STORE(I,IJ,1),IJ=1,2),STORE(I,2,8),STORE(I,2,25),                    000444
 000407      54.            * STORE(I,1,26)                                                                      000444
 000422      55.            IF (IOPT.GT.0) WRITE(IW,10) ((STORE(I,IJ,KJ),IJ=1,2),KJ=1,5),STORE                   000467
 000422      56.            1 (I,1,6)                                                                            000467
 000437      57.            IF (IOPT.GT.0)WRITE (IW,11) STORE(I,2,6),((STORE(I,IJ,KJ),IJ=1,2),         *NEW      000526
 000437      58.            * KJ=7,10),STORE(I,1,11)                                                   *NEW      000526
 000455      59.            IF (IOPT.GT.0)WRITE (IW,12) STORE(I,2,11),((STORE(I,IJ,KJ),IJ=1,2)         *NEW      000566
 000455      60.            * ,KJ=12,15),STORE(I,1,16)                                                 *NEW      000566
 000473      61.            IF (IOPT.GT.0)WRITE (IW,13) STORE(I,2,16),((STORE(I,IJ,KJ),IJ=1,2)         *NEW      000626
 000473      62.            * ,KJ=17,20),STORE(I,1,21)                                                 *NEW      000626
 000511      63.            IF (IOPT.GT.0)WRITE (IW,14) STORE(I,2,21),((STORE(I,IJ,KJ),IJ=1,2)         *NEW      000670
 000511      64.            * ,KJ=22,25),STORE(I,1,26)                                                 *NEW      000670
 000527      65.      6     FORMAT (I5,4X,2A4,3F5.1)                                                   **-2      000737
 000530      66.    300     CONTINUE                                                                             000737
 000532      67.            REWIND IF                                                                            000737
 000533      68.            END                                                                                  000744

  NO DIAGNOSTICS.
                                                                   3.4896 SECONDS.
 DELETED:    WDATA                   SYMBOLIC FORTRAN   19 JAN 76   16:57:00    1    1    5   00165622     290
 DELETED:    WDATA       CODE        RELOCATABLE        19 JAN 76   16:57:00                  00166264     518    00167272    20
```

APPENDIX B

INPUT DATA FORMS

WAVE EQUATION ANALYSIS for PILES   Short Input Form, page 1

1 2 3 4 5 6 7 8 9 10 1 2 3 4 5 6 7 8 9 20 1 2 3 4 5 6 7 8 9 30 1 2 3 4 5 6 7 8 9 40 1 2 3 4 5 6 7 8 9 50 1 2 3 4 5 6 7 8 9 60

1.000 Title (40 characters)

2.000 IOUT IJJ IHAMR IOSTR IFUEL IPEL N ISPL No. of Splices NCROSS 0 = Uniform IBEDAM IPERCS ISMITH 1=Smith ITYS IPHI

3.000 Wt. Cap (kips) Stiff. Cap (K/in) Stiff. Cushion (K/in)

4.000 Coefficients of Restitution: Anvil (Diesel) Cap(Air/Steam) Cap (Diesel) Assembly(A/S) Pile Top Cushion TEMAX (msec.) TDEL (sec.)

5.000 L Pile (ft) A Pile Top (in^2) E Pile Top (ksi) W Pile Top (lbs/ft^3)

If NCROSS = 1

	XP_i (ft)	AP_i (in^2)	EP_i (ksi)	WP_i (lbs/ft^3)
5.101				
5.102				
.				
.				
.				
5.119				

WAVE EQUATION ANALYSIS for PILES

Short Input Form, page 2

6.000

Quake Skin (in)	Quake Toe (in)	Damping Skin*	Damping Toe*	RULT (tons)	Coeff. of Rest. Of Soil	Stroke (ft)	Hammer Efficiency	Steam Pressure (psi)	Reaction wt. (kips)

*Damping Parameters - sec/ft for Smith; Dimensionless for Case

If ITTS = 0 or -1 only

	XPi (ft)	% Soil Res.
6.401		
6.402		
.		
.		
.		
6.420		

If IOUT > 9

7.000 YMAX Plotter Scale

If IOUT > 9 only

ISPG(I), I = 1,2,...,15 (Plotted Variables)

8.000

If RULT < 0 only:

Ultimate Resistance - tons (at most 10 values)

9.000

1 2 3 4 5 6 7 8 9 10 1 2 3 4 5 6 7 8 9 20 1 2 3 4 5 6 7 8 9 30 1 2 3 4 5 6 7 8 9 40 1 2 3 4 5 6 7 8 9 50 1 2 3 4 5 6 7 8 9 60 1 2 3 4 5 6 7 8 9 70 1 2 3 4 5 6 7 8 9 80

WAVE EQUATION ANALYSIS for PILES   Complete Input Form, page 1

12345678901234567890123456789012345678901234567890123456789012345678901234567890

Title (40 characters)

1.000

IOUT	IJJ	THAMR	IOSTR	IFUEL	IPEL	N	ISPL No. of Splices	NCROSS 0 = Uniform	IBEDAM	IPERCS	ISMITH 1=Smith	ITYS	IPHI
2.000													

If IPEL = 2
STF(I), I = 1,2,...,N (Pile Segment Stiffnesses - k/in)

2.101
.
.
2.110

If IPEL = 2
PW(I), I= 1,2,...,N (Pile Segment Weights - kips)

2.201
.
.
2.210

If IPEL > 0
ALFH(I), I = 1,2,...,N (Relative Lengths of Pile Segments)

2.301
.
.
2.310

Wt. Cap (kips)	Stiff. Cap (K/in)	Stiff. Cushion (K/in)
3.000		

Coefficients of Restitution

Anvil (Diesel) Cap (Air/Steam)	Cap (Diesel) Assembly (A/S)	Pile Top	Cushion	TEMAX (msec.)	TDEL (sec.)
4.000					

WAVE EQUATION ANALYSIS for PILES Complete Input Form, page 2

5.000 L pile (ft) | A pile top (in^2) | E pile top (ksi) | W pile top (lbs/ft^3)

If NCROSS = 1

	XP_i (ft)	AP_i (in^2)	EP_i (ksi)	WP_i (lbs/ft^3)
5.101				
5.102				
.				
.				
.				
5.119				

Hammer Information (if IHAMR = 0 only)

5.201 NAME | HM(1) (kips) | STH(1) (k/in) | HM(2) (kips) | STH(2) (k/in) | HM(3) (kips) | STH(3) (k/in) | HM(4) (kips) | STH(4) (k/in) | HM(5) (kips)

Hammer Information (if IHAMR = 0 only)

5.202 STH(5) (k/in) | HM(6) (kips) | STH(6) (k/in) | HM(7) (kips) | M | HM(M+1)(kips) | STH(M) (k/in) | TDEL (sec) | TC1 (sec)

Hammer Information (if IHAMR = 0 only)

5.203 VFCH (in^3) | DEPIB (in) | APAM (in^2) | P1 (psi) | P2 (psi) | P3 (psi) | P4 (psi) | P5 (psi) | EFFICY | STRM (in)

Hammer Information (if IHAMR = 0 only)

5.204 EXPP | ART (ft^2) | DEPBB (ft) | DSF (ft) | DBHT (ft) | POWSCA (1) | RWH (kips) | EXPB | DINJ (ft) | VCT (ft^3)

Hammer Information (if IHAMR = 0 only)

5.205 RAM (kips) | AM(1) (kips) | STA(1) (k/in) | AM(2) (kips) | STA(2) (k/in) | AM(3) (kips) | STA(3) (k/in) | MA | ITYPH

6.000 Quake Skin (in) | Quake Toe (in) | Damping Skin* | Damping Toe* | RULT (tons) | Coeff. of Rest. of Soil | Stroke (ft) | Hammer Efficiency | Steam Pressure (psi) | Reaction wt. (kips)

*Damping Parameters - sec/ft for Smith; Dimensionless for Case

WAVE EQUATION ANALYSIS for PILES Complete Input Form, page 3

If ITYS <-1
QS(I), I = 1,2,...,N+1 (Quakes - in.)

6.101
.
.
6.110

If ITYS < 0
SJ(I) , I = 1,2,...,N+1 (Damping Parameters - sec/ft for Smith; Dimensionless for Case)

6.201
.
.
6.210

If ITYS < -1
SU(I), I = 1,2,...,N+1 (Relative Ultimate Soil Resistances)

6.301
.
.
6.310

If ITYS = 0 or -1 only

	XPi (ft)	% Soil Res.
6.401		
6.402		
.		
.		
.		
6.420		

If ISPL > 0 only

	No. J	SPLICE(J)(kips) or Slack in feet
6.501		
.		
.		

Note: Splice force = 0.0 kips or less than -0.5 kips.
Slack between -0.5 and 0.0 feet.
Both Splice and Slack are to be given as negative numbers.

WAVE EQUATION ANALYSIS for PILES Complete Input Form, page 4

If IOUT > 9
Plotter Scale
YMAX

7.000 For dimension of scale see Input Information

If IOUT ≥ 9 only
ISEG(I), I = 1,2,...,15 (Plotted Variables)

8.000

If RULT < 0 only:
Ultimate Resistance - tons (at most 10 values)

9.000

If IJJ > 0
INP(I), I = 1,2,...,13 (Printed Variables)

9.101

1 2 3 4 5 6 7 8 9 10 1 2 3 4 5 6 7 8 9 20 1 2 3 4 5 6 7 8 9 30 1 2 3 4 5 6 7 8 9 40 1 2 3 4 5 6 7 8 9 50 1 2 3 4 5 6 7 8 9 60 1 2 3 4 5 6 7 8 9 70 1 2 3 4 5 6 7 8 9 80

HAMMER DATA - FILE LOADING FORM

(Include as first card of run (2I4): Number of hammers to be loaded; print option: =0 minimum, =1 maximum)

Hammer I.D.
☐☐☐☐ (Hammer I.D.=Integer; all other data real numbers)

Name	HM(1) (kips)	STH(1) (k/in)	HM(2) (kips)	STH(2) (k/in)	HM(3) (kips)	STH(3) (k/in)	HM(4) (kips)	STH(4) (k/in)	HM(5) (kips)
							OED, CED, VCD,	OED CED VCD	
STH(5) (k/in)	HM(6) (kips)	STH(6) (k/in)	HM(7) (kips)	M	HM(M+1)(kips)	STH(M) (k/in)	TDEL (sec)	TGI (sec)	
← OED, CED, VCD →			OED VCD CED DAS	← OED, CED, VCD →					
VFIN (in^3)	DEPIB (in)	ARAM (in^2)	P1 (psi)	P2 (psi)	P3 (psi)	P4 (psi)	P5 (psi)	EFFICY	SIRM (in)
OED, CED, VCD	CED VCD	CED	CED VCD	CED	OED CED VCD	CED DAS } only	CED VCD	OED CED VCD	CED VCD
EXPP	ART (ft^2)	DEPBB (ft)	DSF (ft)	DBBT (ft)	POWSCA (1)	RWH (kips)	EX PB	DINJ (ft)	VCT (ft^3)
VCD only	← A/S, DAS →								
RAM (kips)	AM(1) (kips)	STA(1) (k/in)	AM(2) (kips)	STA(2) (k/in)	AM(3) (kips)	STA(3) (k/in)		MA	ITYPH

Hammer Types:	OED	Open End Diesel	ITYPH=1.001
	CED	Closed End Diesel	=2.001
	VCD	Vacuum Chamber Diesel	=1.001
	A/S	Single Acting Air/Steam	=3.001
	DAS	Double Acting Air/Steam	=3.001

If not otherwise noted information to be provided for all hammer types.

*U.S. GOVERNMENT PRINTING OFFICE : 1978 O-734-759/63

CATEGORY B

ELECTRONIC COMPUTER PROGRAM ABSTRACT

TITLE OF PROGRAM WESWEAP -- Wave Equation Analysis for Piles	**PROGRAM NO.** 741-F3-R0010

PREPARING AGENCY U. S. Army Engineer Waterways Experiment Station, Geotechnical Laboratory, P. O. Box 631, Vicksburg, MS 39180

AUTHOR(S)	**DATE PROGRAM COMPLETED**	**STATUS OF PROGRAM**	
		PHASE	**STAGE**
G. G. Goble and Frank Rausche WES Contact: Hugh M. Taylor, Jr.	July 1976	INIT	OP

A. PURPOSE OF PROGRAM

The program performs wave equation analysis of piles driven by a single blow of any type of impact hammer. Conventional pile and soil models were used in addition to both a thermodynamic model for diesels and refined mechanical hammer models. The program can be used to predict impact stresses in piles during driving and to estimate static soil resistance on piles at the time of driving.

B. PROGRAM SPECIFICATIONS

The program development was aimed at providing a simple input and both a flexible and extensive output that include automatic plotting capabilities. The computer language is FORTRAN IV.

C. METHODS

The pile and driving systems are represented by a series of discrete masses and springs. The soil is modeled by a spring and a dashpot attached to each mass. The soil resistance so represented are linear elastic plastic. The elastic resistances are linearly proportional to the element velocity for the velocity. By using Newton's Second Law, accelerations and displacements are calculated and the computation proceeds to the next time increment.

D. EQUIPMENT DETAILS

E. INPUT-OUTPUT

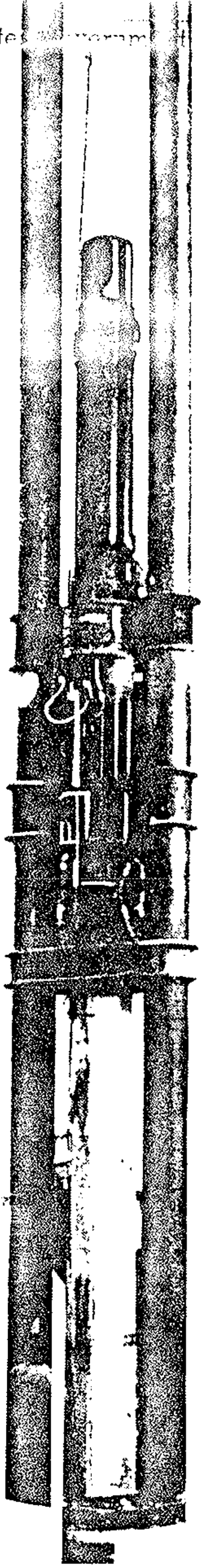
A short input and long or complete input forms are available. Common hammer property data are stored in a file. Input data is reprinted, options of printed and plotted parameters are available, and time plots are optional.

F. ADDITIONAL REMARKS

Manuals by the Federal Highway Administration that describe this program and its use are: Vol. I, Background, Report No. FHWA-IP-76-14.1; Vol. II, Users Manual, Report No. FHWA-IP-76-14.2, Vol. III, Program Documentation, Report No. FHWA-IP-76-14.3; and Vol. IV, Narrative Presentation, Report No. FHWA-IP-76-14.4.

76-14.4

Implementation Package



WAVE EQUATION ANALYSIS OF PILE DRIVING

WEAP PROGRAM

Volume IV – Narrative Presentation

U.S. DEPARTMENT OF TRANSPORTATION
Federal Highway Administration
Offices of Research and Development
Implementation Division
Washington, D.C. 20590

Technical Report Documentation Page

1. Report No. FHWA -IP-76-14.4	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Wave Equation Analysis of Pile Driving WEAP Program		5. Report Date July, 1976 6. Performing Organization Code 8. Performing Organization Report No.
7. Author(s) Goble, G. G., and Rausche, Frank		
9. Performing Organization Name and Address Goble & Associates 12434 Cedar Road Cleveland Heights, Ohio 44106		10. Work Unit No. (TRAIS) 11. Contract or Grant No. DOT-FH-11-8830
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Highway Administration Offices of Research and Development Washington, D.C. 20590		13. Type of Report and Period Covered Final Report Volume IV - Narrative Presentation 14. Sponsoring Agency Code

15. Supplementary Notes

FHWA Contract Manager: Chien-Tan Chang (HDV-22)

16. Abstract

A computer program was written and tested that performs a realistic Wave Equation Analysis of Piles driven by any type of impact hammer. Conventional pile and soil models were used in addition to both a thermodynamic model for diesels and refined mechanical hammer models.

The program development was aimed at providing a simple input and both a flexible and extensive output that includes automatic plotting capabilities. Pile Driving Hammer data were prepared and stored in a file for most of the commonly encountered models. The computer language is FORTRAN IV.

The program was extensively tested against measured pile tope force and velocity data and against measured diesel combustion pressure and stroke.

This volume is the fourth in a series. The others in the series are:

Vol No.	FHWA No.	Short Title	NTIS (PB) No.
1	IP-76-14.1	Background	
2	IP-76-14.2	User's Manual	
3	IP-76-14.3	Program Documentation	

17. Key Words COMBUSTION, COMPUTERS, DESIGN, DIESEL, DYNAMICS, FOUNDATIONS, IMPACT, PILE DRIVING, SOIL MECHANICS, WAVE EQUATION	18. Distribution Statement No restrictions. Copies of this volume are available from: National Technical Information Service Springfield, Virginia 22161

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 66	22. Price

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WAVE EQUATION ANALYSIS OF
PILE DRIVING

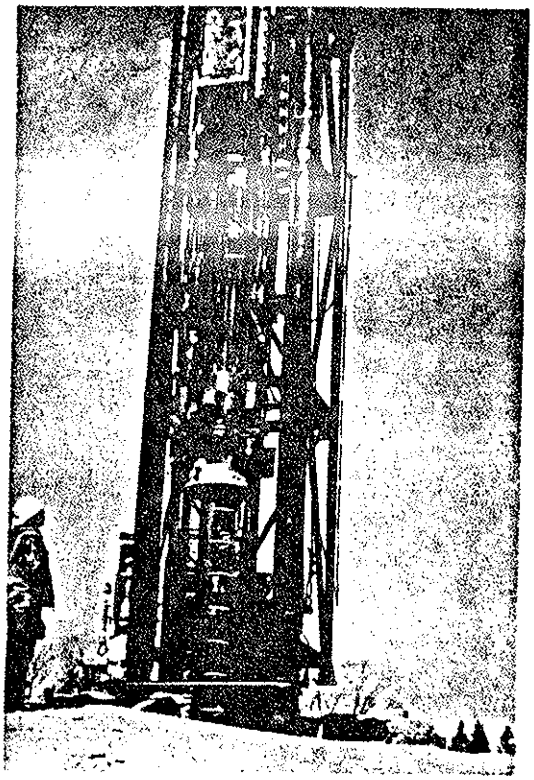
Narrative Presentation

Table of Contents

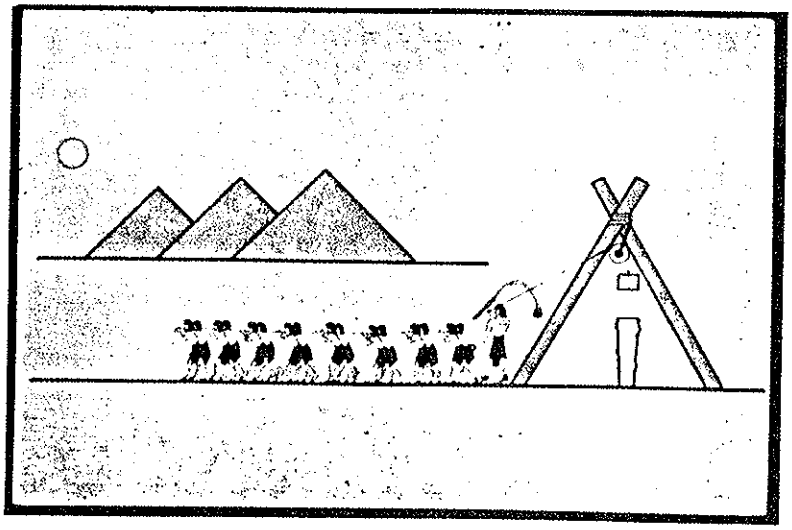
Part I

Background

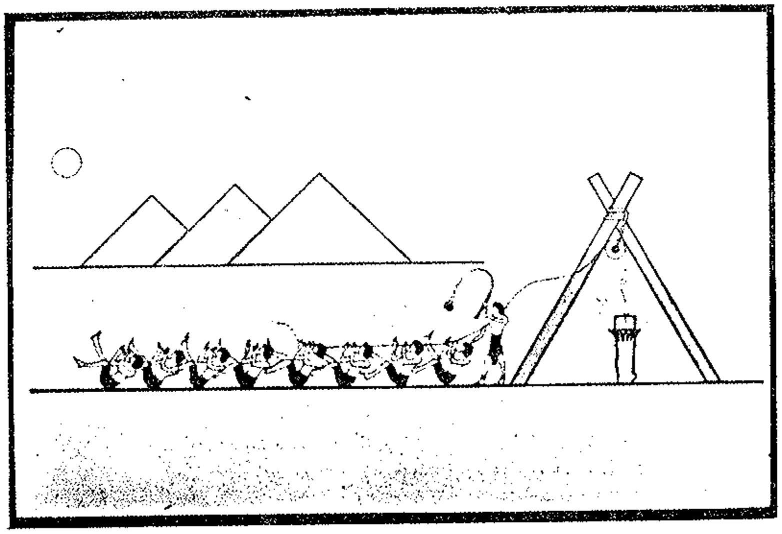
A1. When foundation engineers view pile driving and reflect on the fact that the driving operation induces failure in the pile-soil system, it is natural that they should attempt to use measurements made during driving to determine bearing capacity.

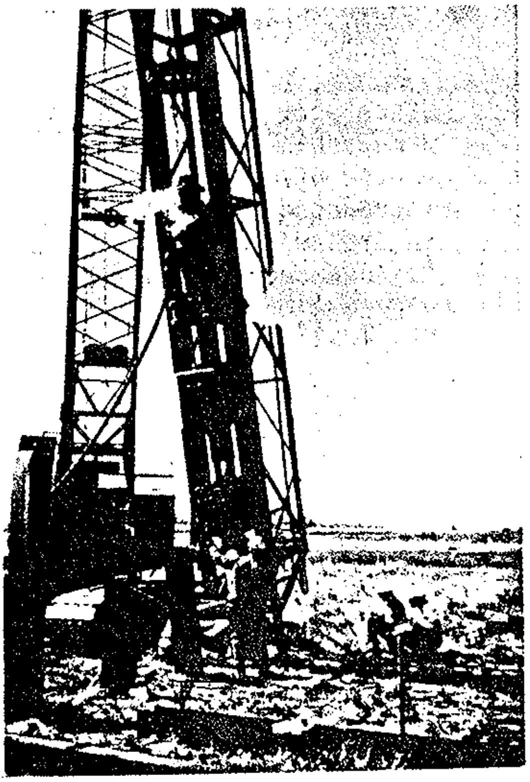


A2. Piles have been used as a foundation element since antiquity. They were driven with primitive equipment and were designed by a completely intuitive approach.



A3. Probably, failure of the pile or the driving operation was a common occurrence. During the last century pile usage increased with the development of the single acting steam hammer.





A4. Methods for predicting pile strength were proposed using dynamic data obtained during driving. Since the only realistic measurements at that time were ram stroke and pile set (or blow count)

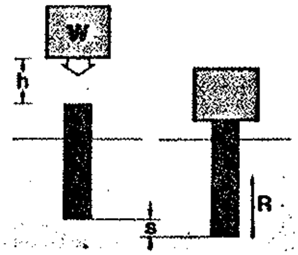
A5. it was natural that the engineer would turn to energy concepts, equating ram energy, Wh, to work done on the soil, Rs. Of course, rather gross assumptions were implied. The resistance of force, R, was assumed constant and the delivered energy was assumed to be the potential energy of the ram at the top of the stroke. The effects of cushions and helmets were neglected.

THE FUNDAMENTAL PILE DRIVING FORMULA

HAMMER ENERGY = WORK OF SOIL RESISTANCE

$$Wh = Rs$$

$$\boxed{R = \frac{Wh}{s}}$$



A6. Since poor results were achieved, a large factor of safety was introduced in order to insure against failure and the "losses" were estimated in terms of "lost" set.

ENGINEERING NEWS RECORD FORMULA

$$R = \frac{12\,W_{(kips)}\;h_{(feet)}}{S.F.\,(s_{(inch)} + \text{"lost" set}_{(inch)})}$$

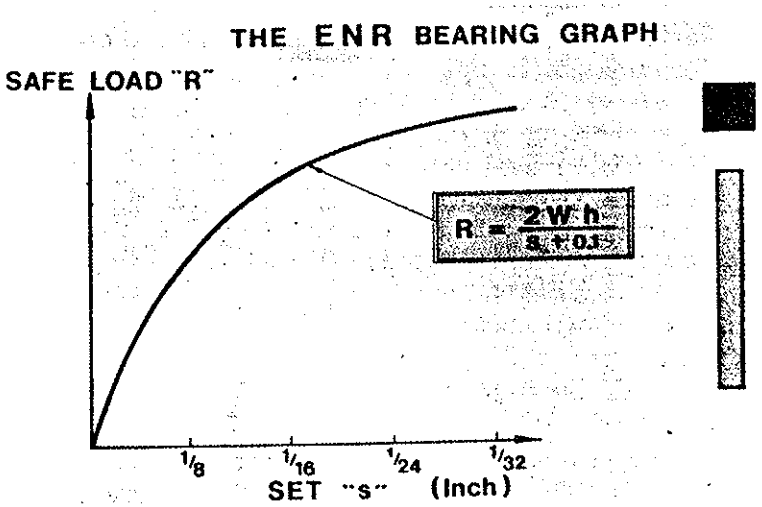
S.F. = 6 = SAFETY FACTOR

lost set = 0.1 inch

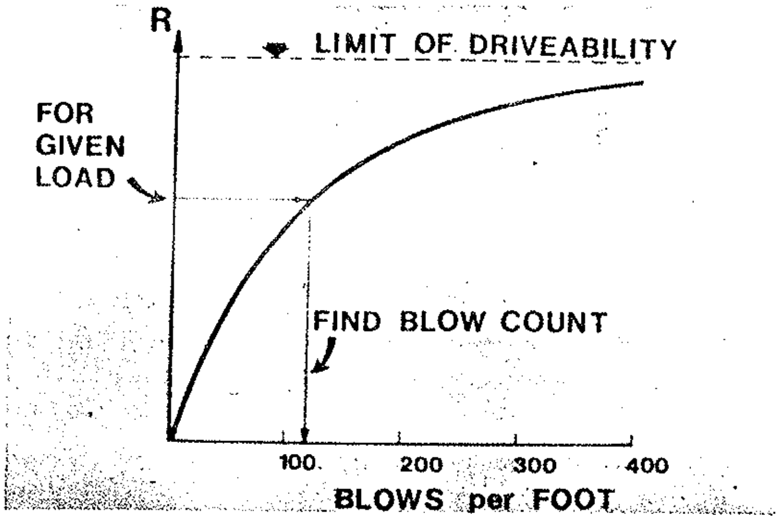
$$\boxed{R = \frac{2\,Wh}{s+0.1}}$$

A7. A large number of formulas appeared. While dynamic formulas have been generally discredited, they are still widely applied today because of their simplicity and the lack of a better, well-recognized approach.

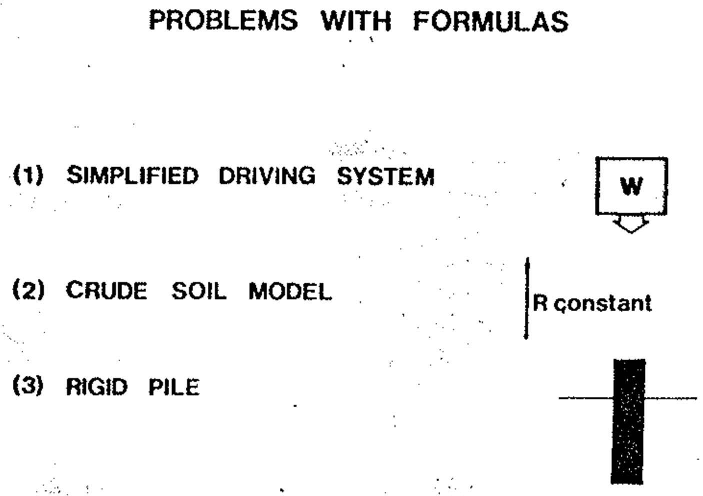
A8. It is interesting and instructive to examine a graphical representation of the ENR formula. Here pile capacity is plotted versus permanent set in a representation known as a bearing graph. Other formulas will have a similar shape. In application, a particular set or blow count (hammer blows per foot) is related to the pile design load.



A9. Alternatively, for a specified capacity the required blow count can be determined. Also, an equipment selection can be made. For example, a particular system can only overcome a certain maximum resistance. At the upper range of the curve, a large change in blow count does not indicate a comparable change in capacity.



A10. Now consider the causes for problems with the dynamic formulas. First, the derivation is not based on a realistic treatment of the driving system nor does it recognize the variability of equipment performance. Typical driving systems can include many elements in addition to the ram such as helmet, capblock, cushion, and anvil. Second, the soil resistance is very crudely treated. The assumption is made that the soil resistance is a constant force and this assumption neglect even the most obvious characteristics of real soil performance. Third, the pile is assumed to be rigid. This neglects compltely the real flexibility and the wide variations it can have.



PROBLEMS WITH FORMULAS

(1) SIMPLIFIED DRIVING SYSTEM

(2) CRUDE SOIL MODEL

(3) RIGID PILE

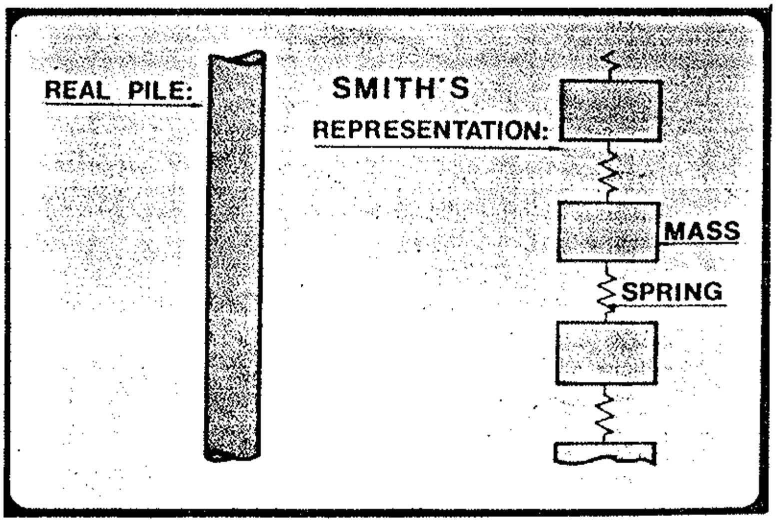
A11. As an alternative, the Wave Equation Analysis was proposed in the last century. The Wave Equation is actually a linear differential equation which was derived from Newton's Second Law. Since real pile driving problems are not easily solved by the Wave Equation.

THE WAVE EQUATION

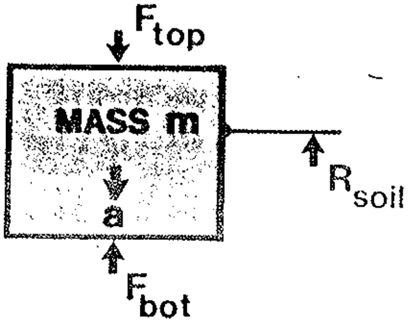
$$\boxed{\frac{\partial^2 u}{\partial t^2} = c^2 \frac{\partial^2 u}{\partial x^2}}$$

u	Displacement
c	Wave Speed
t, x	Time, Length Coordinates

A12. E.A.L. Smith proposed, in the 1950's, to divide the pile into relatively large segments (say a few feet each) and represent each of them by a discrete mass and a spring. The total pile and driving system is so represented and then the motion of the pile is analyzed by applying Newton's Second Law successively over very short time increments.



A13. The forces acting on a typical pile element are those due to the strain at its top and bottom and to the soil resistance. Thus, from Newton's Second Law, the elements' acceleration at a particular time is equal to the sum of F_{top} F_{bottom}, and R_{soil}, divided by the mass of the element.



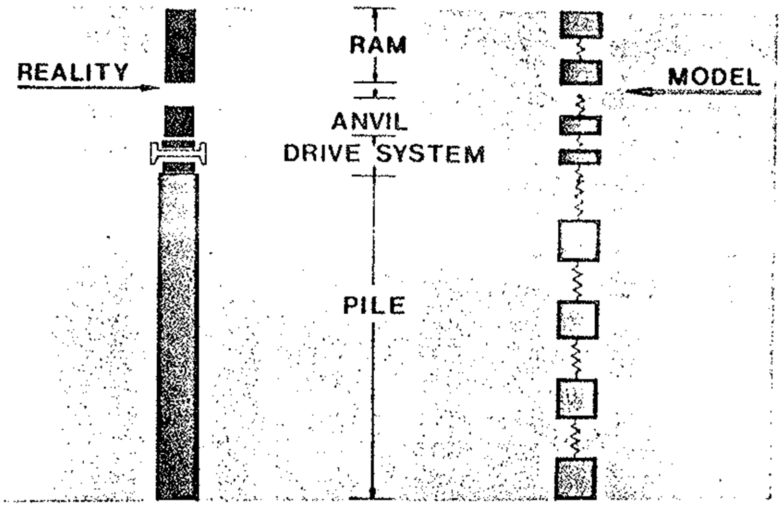
ACCELERATION: $\boxed{a = \frac{F_{top} - F_{bot} - R_{soil}}{m}}$

A14. Having determined the acceleration of the element, its velocity and displacement can be determined by integration. For this integration a small time increment is used during which the acceleration is assumed constant. The results of the integration becomes more accurate as the time increment is made shorter. Of course, as the time increment is made shorter the computational effort is increased. The cycle is completed by the determination of the compression in the spring between neighboring elements from the calculated element displacements. The compression then can be converted to forces acting on the elements and the computation repeated for the next time increment.

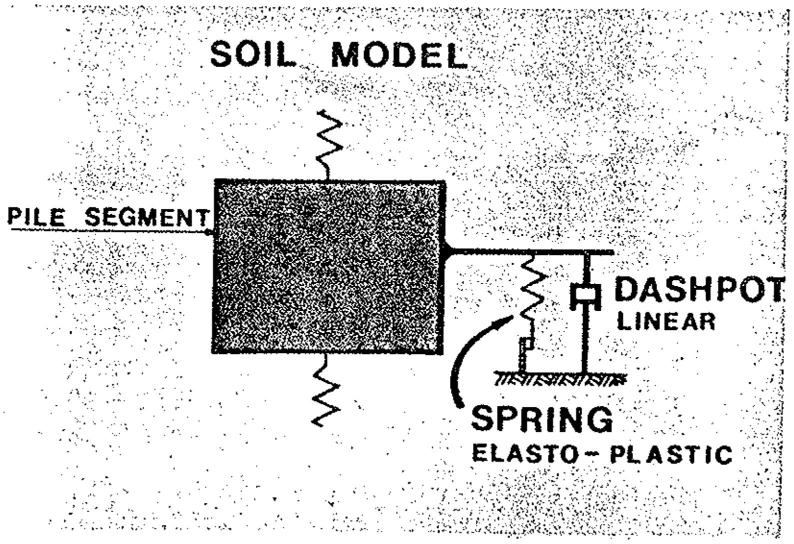
VELOCITY = ACCELERATION x TIME INCREMENT

DISPLACEMENT = VELOCITY x TIME INCREMENT

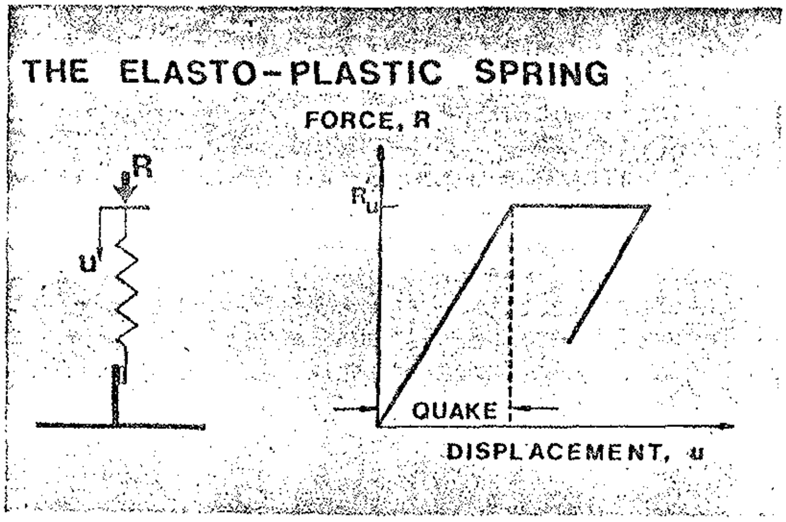
A15. In summary, the total pile driving system is represented by a series of masses and springs. It is analyzed by giving the ram an initial velocity determined by the manufacturer's stated characteristics and then analyzing the system using the force-inertia balance over the required time period consisting of a large number of time increments. The mass and spring characteristics can be calculated from the physical characteristics of the pile and the driving system.



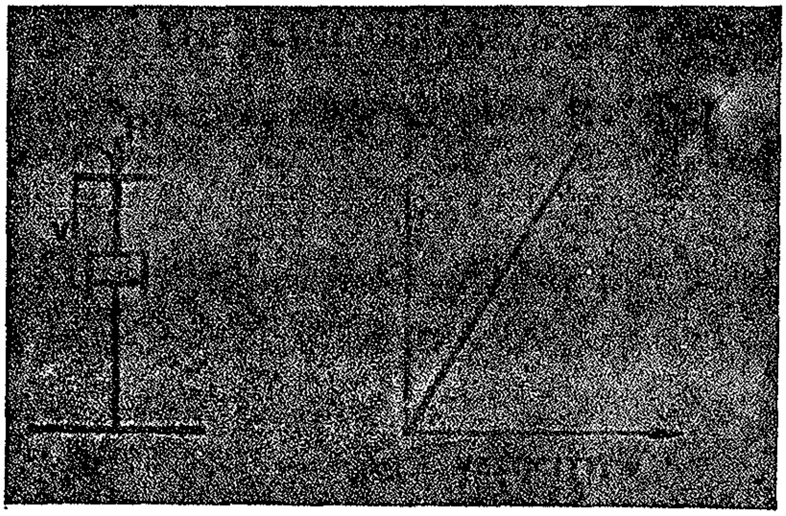
A16. But pile driving analysis must include more than just the pile and the driving system. A soil resistance force has been mentioned. Now consider some of the details of the description of this force. It is assumed to be composed of a static and a dynamic portion and it can be represented by a spring and a dashpot.



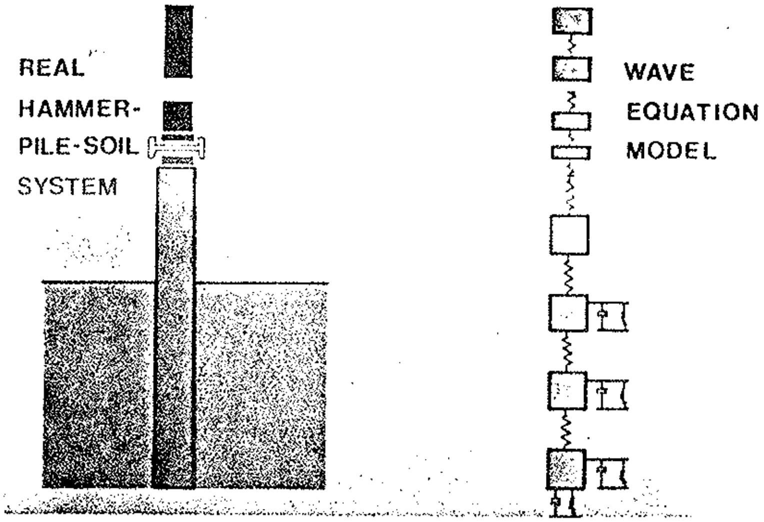
A17. The spring or static portion of the resistance relates the soil resistance to the pile element displacement. The soil resistance force is assumed to increase linearly with the displacement until a displacement called the quake is reached. With further displacement the force remains constant. Unloading occurs along a line parrallel to the loading line.



A18. The dynamic portion of the resistance is represented by a dashpot that assumes a linear relationship between the resistance force and the element velocity.

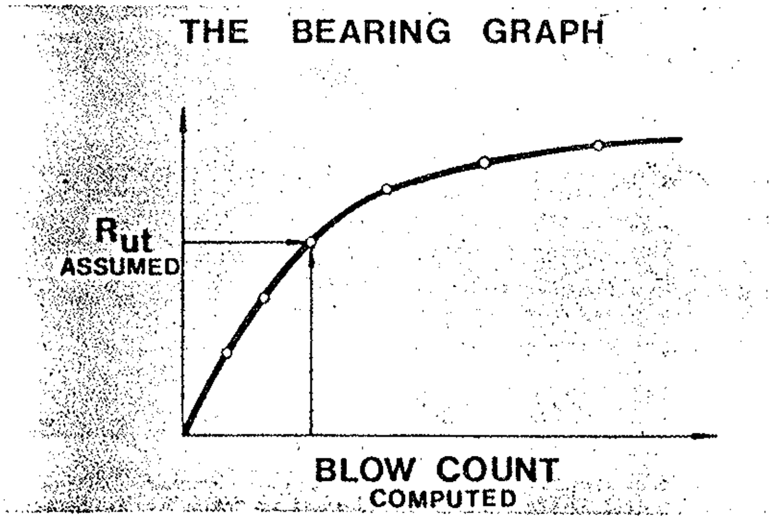


A19. So the total pile driving analysis problem is represented by the series of masses and springs representing the pile and the driving system with the soil resistance on the embedded portion modeled by elastic plastic springs and linear dashpots attached to the appropriate elements.

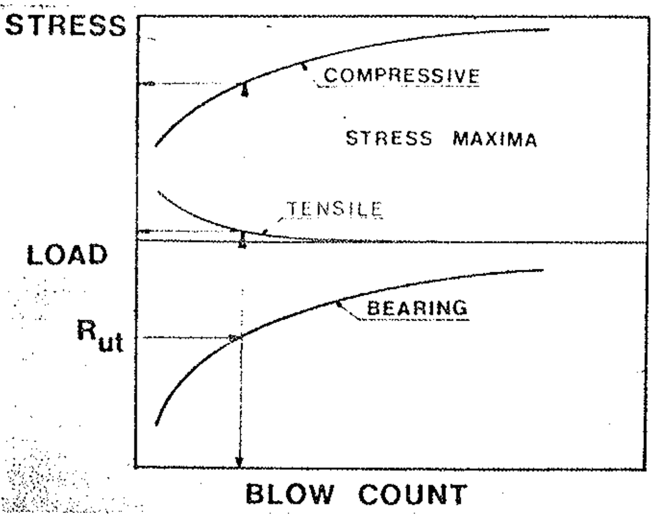


The engineer must supply all of the physical characteristics of the system including the soil. Computer programs have been prepared to perform the analysis and these programs have come to be known as Wave Equation programs. In this presentation the name wave equation will refer to computer programs of this general type.

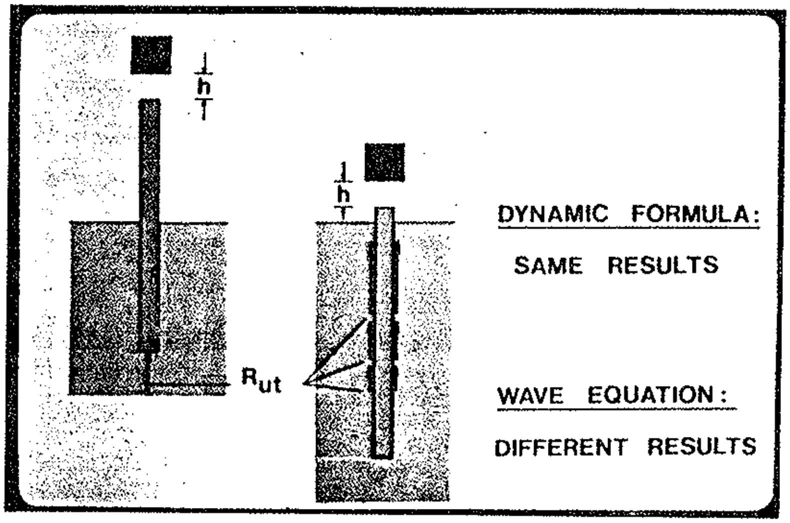
A20. The result of the wave equation analysis is a bearing graph of appearance similar to that produced by a dynamic formula. It is produced by assuming an R_u value and a damping constant to represent the soil acting on each element. The sum of all the R_u 's is the ultimate static capacity of the pile, R_{UT} . For a particular R_{UT} the wave equation analysis is performed and the permanent pile displacement is calculated. The bearing graph is constructed from a set (say 5 or 6) of these points by interpolation.



A20a. In addition to the bearing graph the critical stresses in the pile can also be determined since the forces in the pile at each element for every time increment were found during the analysis.



A21. It should be noted that a bearing graph is associated with a particular pile penetation. While it is similar in appearance to the graph generated by a dynamic formula, it represents something quite different. The dynamic formula has as its only variable, hammer energy with, perhaps, an estimate of losses. The wave equation includes pile flexibility, an estimate of soil performance, and driving system characteristics. In the case shown here the dynamic formula would give the same bearing graph in both cases while the wave equation bearing graph would be different.



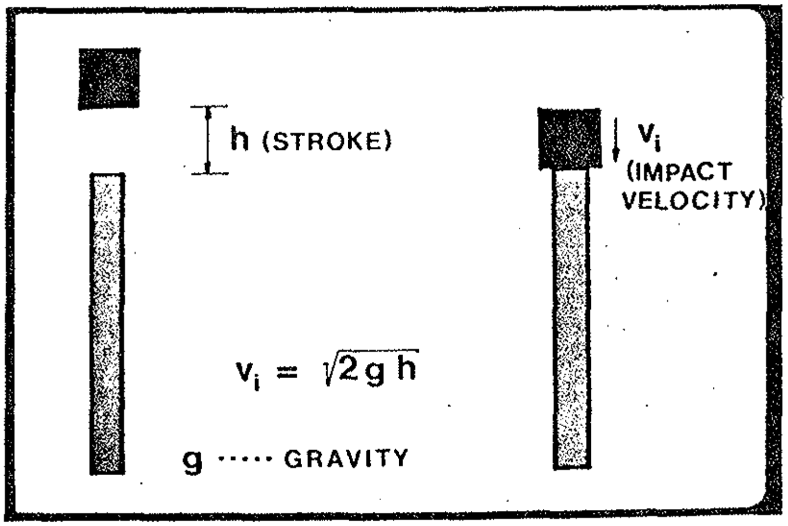
A22. Consider now a similar evaluation of the wave equation to that made previously for the dynamic formulas. First, the driving system treatment is improved. Accurate information on the dynamic performance of the driving system is required. Of course, if hammer performance is not up to its rated characteristics, that cannot be predicted by the wave equation. Second, the pile is accurately modeled. Third, the soil model, while crude, is clearly improved over that used in the dynamic formula. More accurate representations of the soil could be created but they are not justified due to the difficulty in determining the required parameters.

(1) DRIVING SYSTEM TREATMENT IMPROVED

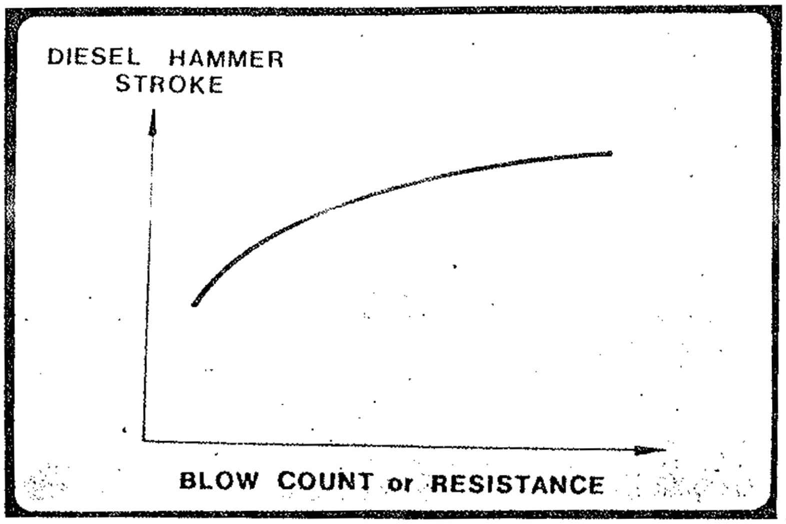
(2) PILE MODELED ACCURATELY

(3) SOIL MODEL CRUDE BUT IMPROVED

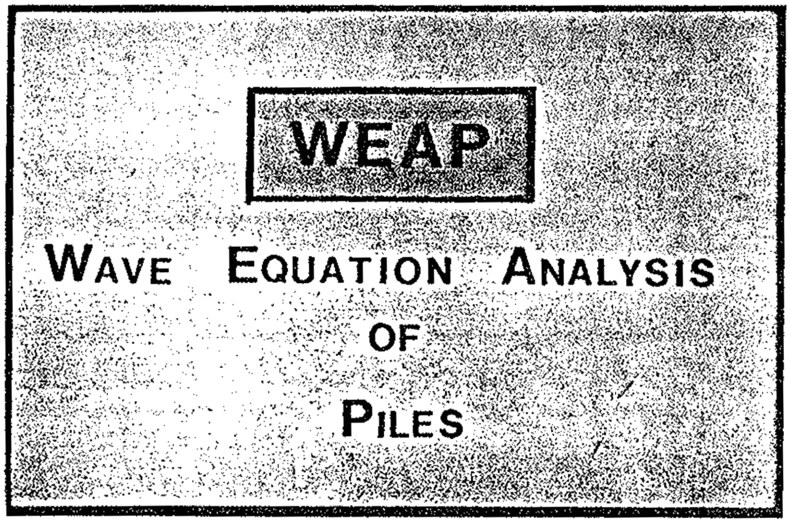
A23. The computer programs which have previously been available have used as basic input the ram impact velocity as computed from the stroke. This characteristic is particularly undesireable for application to diesel hammers



A24. where the stroke is dependent on driving resistance and is not known in advance. Difficulties have been encountered, particularly with the stress predictions obtained from these programs.



A24a. In order to find a solution to this problem, the Federal Highway Administration contracted with Goble & Associates to develop a wave equation program based on a more realistic model for pile driving hammers, particularly diesel hammers. Furthermore, the requirement was included to test the program against the large volume of force and velocity measurements made during the Case Western Reserve University Pile Driving Research Program. The result of this contract is a computer program called WEAP.

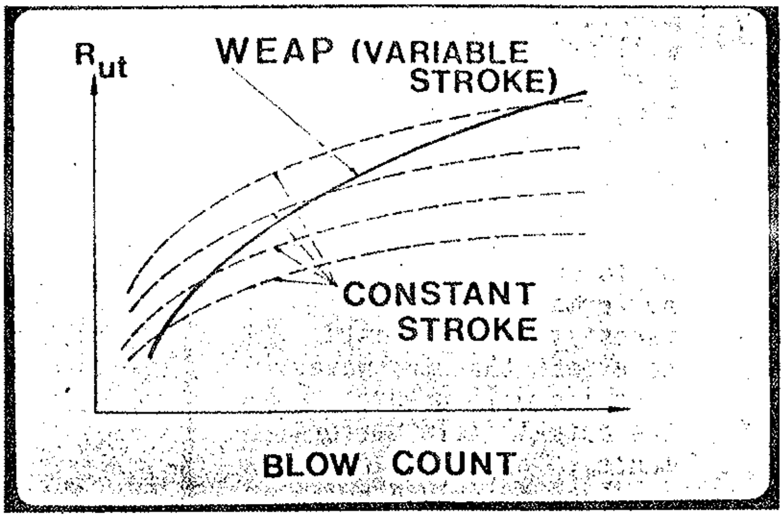


WEAP

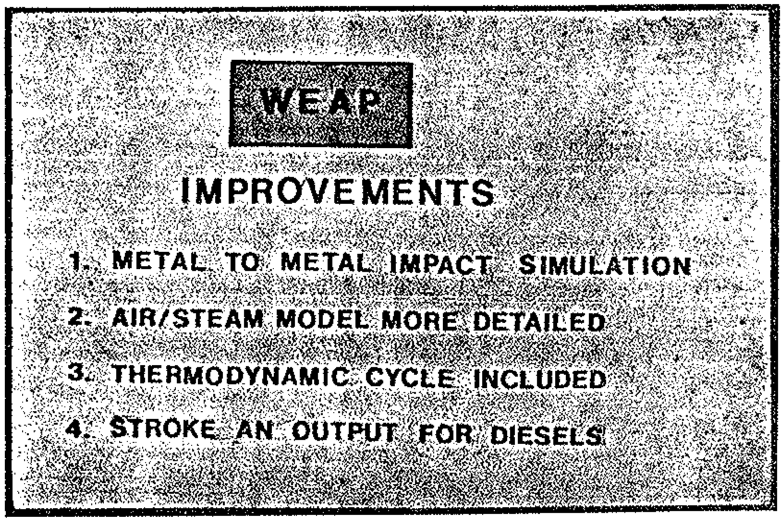
WAVE EQUATION ANALYSIS

OF

PILES



A25. The basic program is illustrated by the bearing graph shown here. If a separate bearing graph were obtained for each possible stroke, the family of curves shown dashed would be obtained. Now if the stroke were measured in the field together with the blow count, the appropriate curve could be used to determine the capacity. A series of strokes and related blow counts would produce the solid curve which is the actual bearing graph. Unfortunately, a driving system could not be evaluated prior to going to the field.



WEAP

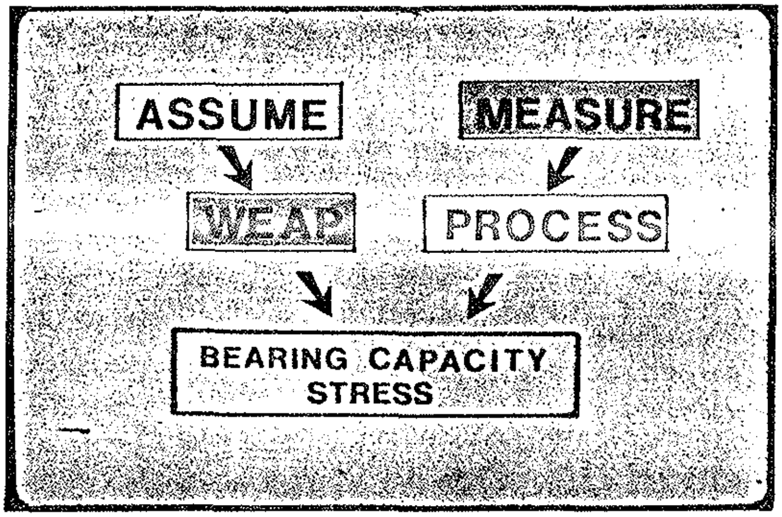
IMPROVEMENTS

1. METAL TO METAL IMPACT SIMULATION
2. AIR/STEAM MODEL MORE DETAILED
3. THERMODYNAMIC CYCLE INCLUDED
4. STROKE AN OUTPUT FOR DIESELS

A26. The WEAP Program provides an improved treatment of the combustion forces and a more accurate representation of air/steam hammers in addition to analyzing the total thermo-mechanical cycle of the diesel hammer and determining stroke (or bounce chamber pressure for closed end diesels) as an output quantity.

A good wave equation program which realistically

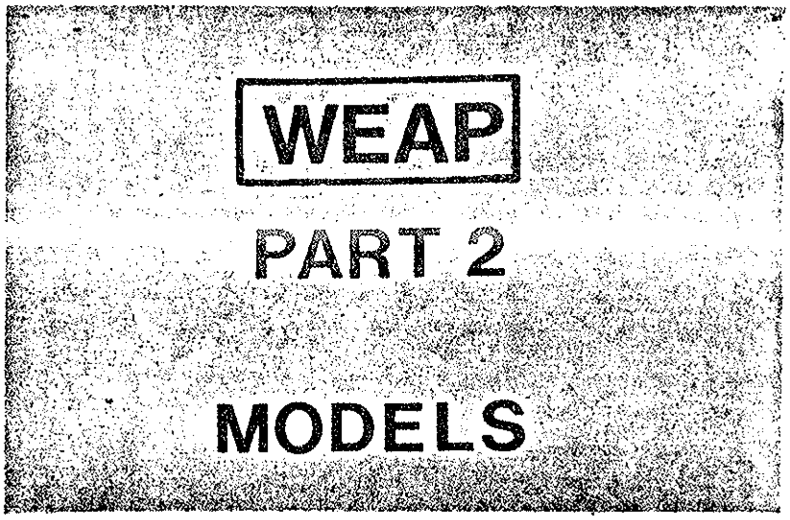
A27. models the total system will provide the best possible means of evaluating pile driving short of going to the field. In many cases it is impossible to provide the proper soil constants or to anticipate hammer performance. In such cases it is unrealistic to expect that the wave equation will predict the actual field performance. These problems can best be solved by field measurements using modern electronic devices which are now available.



Part II

Models

B1. In the previous section of this presentation the use of the wave equation program in the selection of equipment and driving criteria for pile foundations was discussed. Only very general considerations were covered. In this section a greater level of detail will be presented.



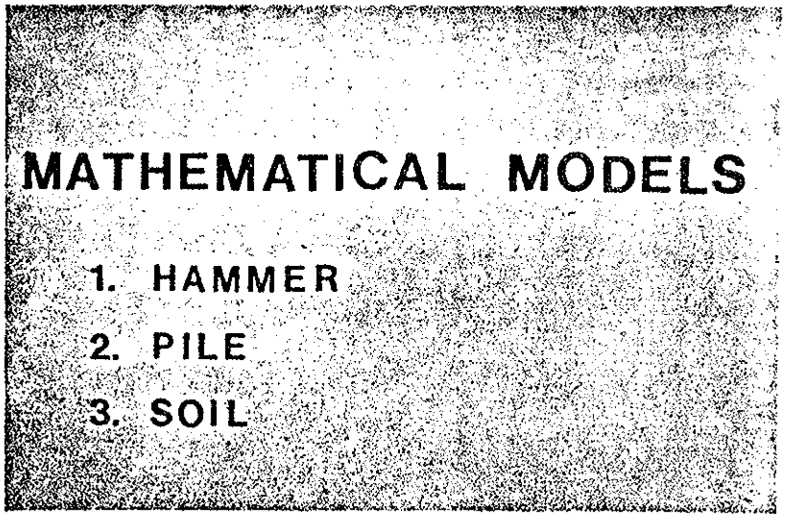
WEAP

PART 2

MODELS

B2. The operation of pile driving hammers and equipment will be discussed and the model used to represent the equipment, the pile and the soil will be described in detail.

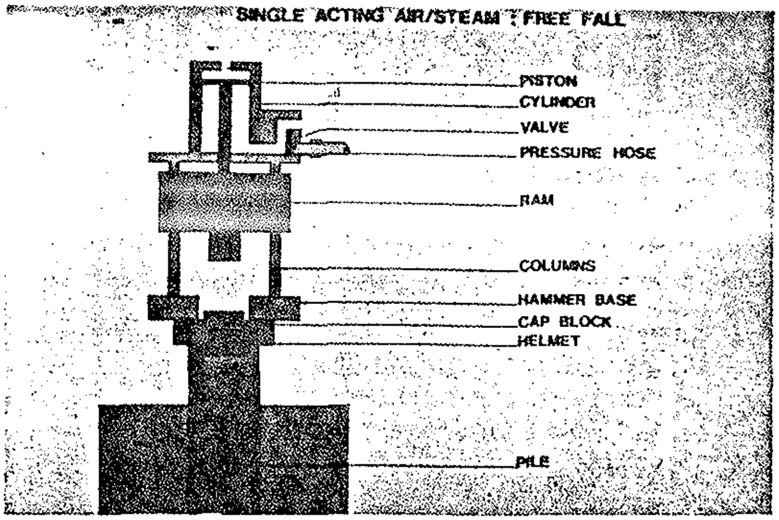
When creating a mathematical model of a pile driving hammer, it is necessary that the hammer operation be clearly understood. First, single acting air/steam hammers will be treated.



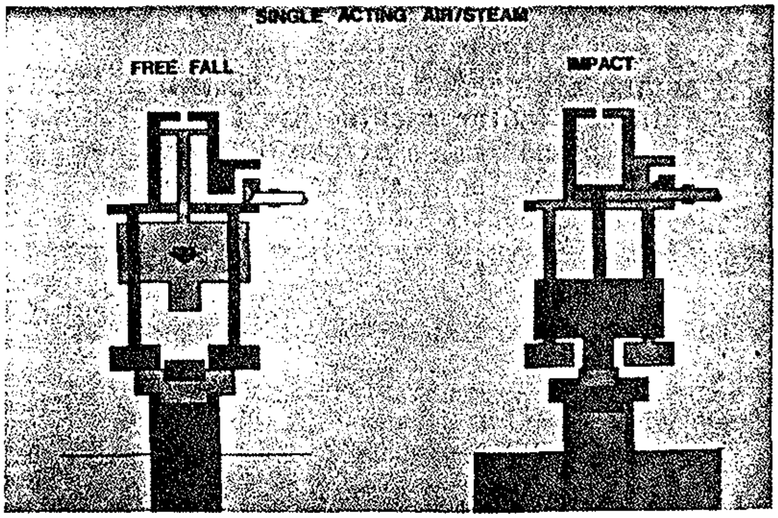
MATHEMATICAL MODELS

1. HAMMER
2. PILE
3. SOIL

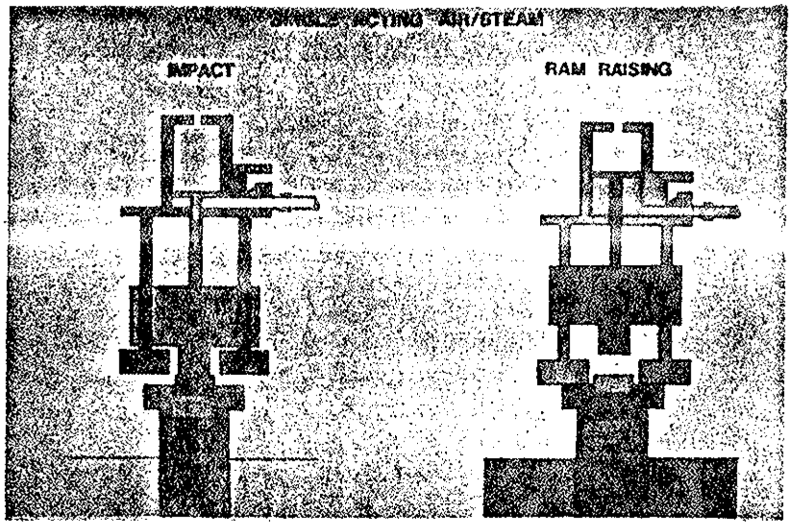
B3. The driving system consists of the hammer and a helmet holding the top of the pile in position and containing a capblock on which the ram impacts. For concrete piles a cushion is inserted between the pile top and the helmet. Assume that the cycle begins with the ram in the free fall down stroke sliding on the columns. The exhaust valve is open allowing the cylinder under the piston to exhaust directly to the atmosphere. At this time the hammer assembly consisting of the hammer base, columns, and cylinder are all resting on the helmet (and, hence, on the pile top).



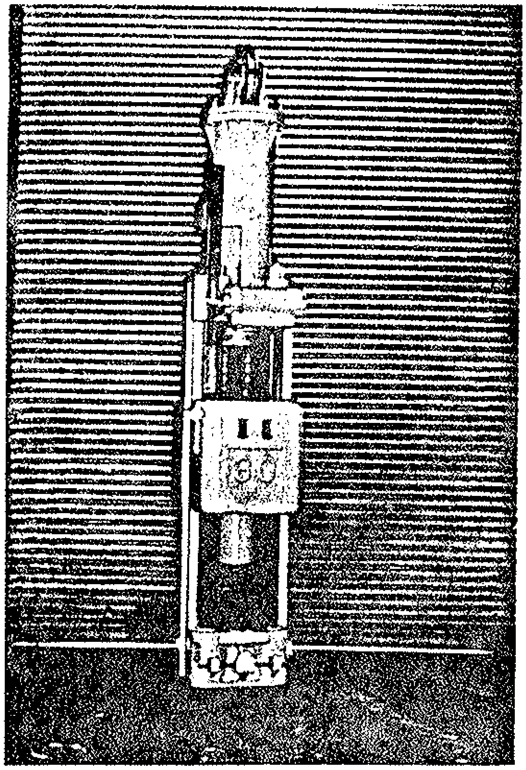
B4. At the bottom of the down stroke the ram impacts the capblock and drives it rapidly down together with the helmet and the pile top. The assembly is left up in the air falling under the action of gravity. Slightly before reaching the bottom of the stroke the intake valve is opened allowing the active gas (either compressed air or steam) to enter the cylinder. Therefore, since the gas pressure acts on the bottom of the cylinder it provides a force in addition to gravity which drives the assembly down.



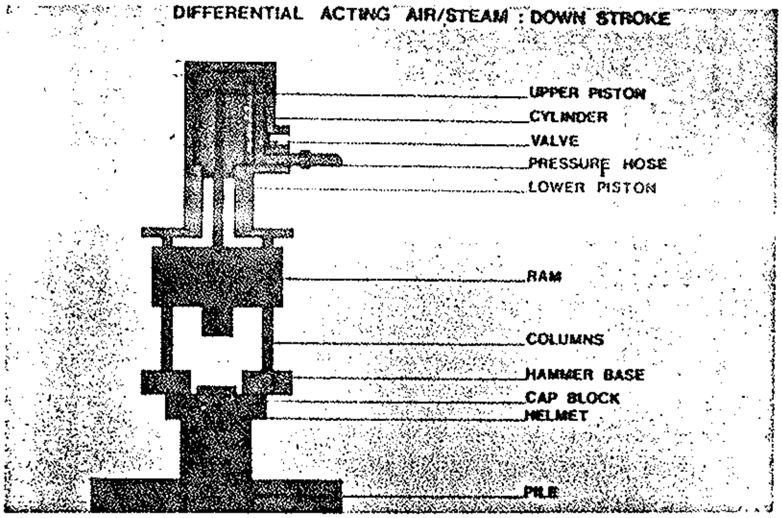
B5. The assembly impact with the helmet can be substantial since its weight is as great as the ram and the pile rebound velocity is often comparable to the ram impact velocity. The ram gains its upward velocity due to the pile rebound and the active gas pressure in the cylinder. At some point during the upstroke the exhaust valve opens and the ram "coasts" on up to the top of its stroke. Therefore, the stroke of an air/steam hammer is not necessarily constant.



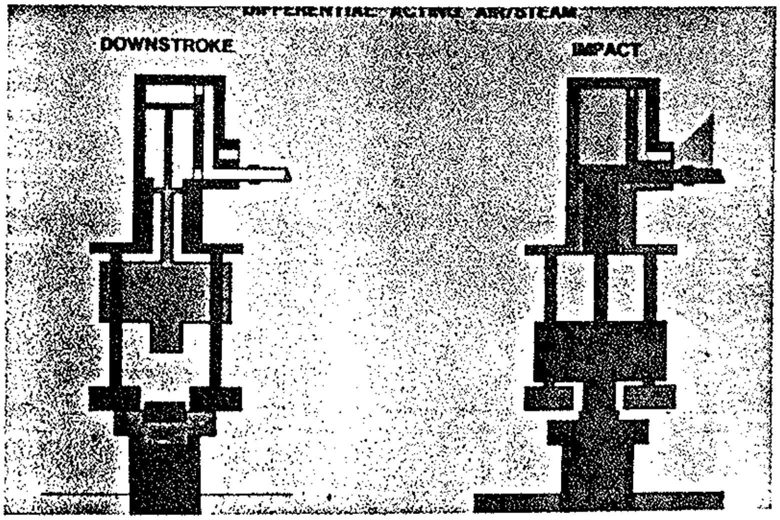
B6. In this slide a typical single acting air/steam hammer is shown. This particular machine has a 6,000 pound ram, a stroke of about three feet, and an operating speed of about 60 blows per minute.



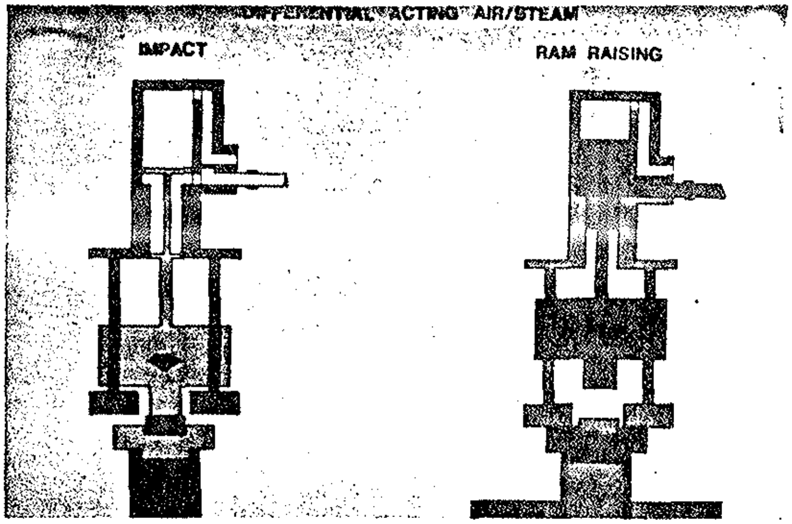
B7. The double acting air/steam hammer has a similar appearance but some important differences in operating characteristics. Of the various types of double acting air/steam hammers, the differential acting type will be described. The main components of this hammer are the same as the single acting machine. The differences are in the configuration of the cylinder. The piston has three surfaces which are subjected to gas pressure, the upper and lower surfaces of the upper piston and the upper surface of the much smaller, lower piston. Thus, since the same pressure acts on all surfaces there is a net down force on the piston which is reacted by the weight of the hammer assembly. The ram is acted on by both gravity and the applied force and is accelerated more quickly than for the single acting hammer. The upward acting force on the assembly must be limited so as not to lift the assembly off the helmet. This provides a limitation on the force which can be applied to the ram.



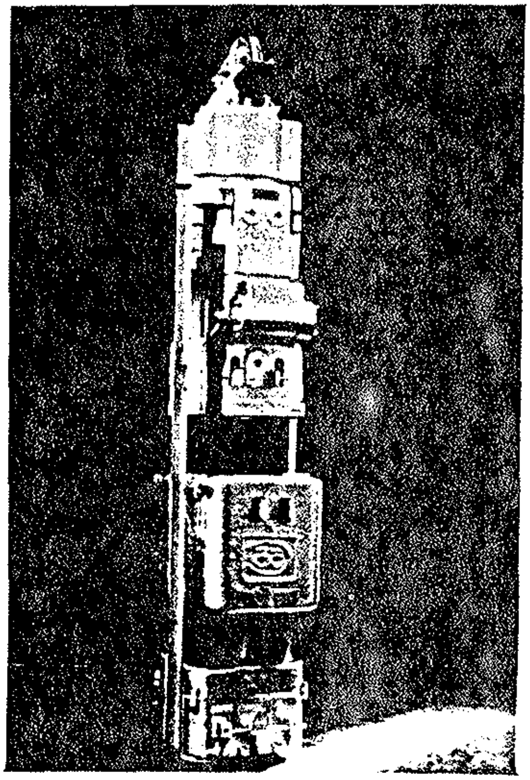
B8. When the ram impacts on the capblock the helmet is driven out from under the hammer assembly. The assembly then falls to the helmet for a second impact similar to the single acting hammer. Shortly before reaching the bottom of the stroke the valve changes so as to release all gas pressure from the upper chamber. Now with the upper chamber at ambient pressure the net force on the ram is up.



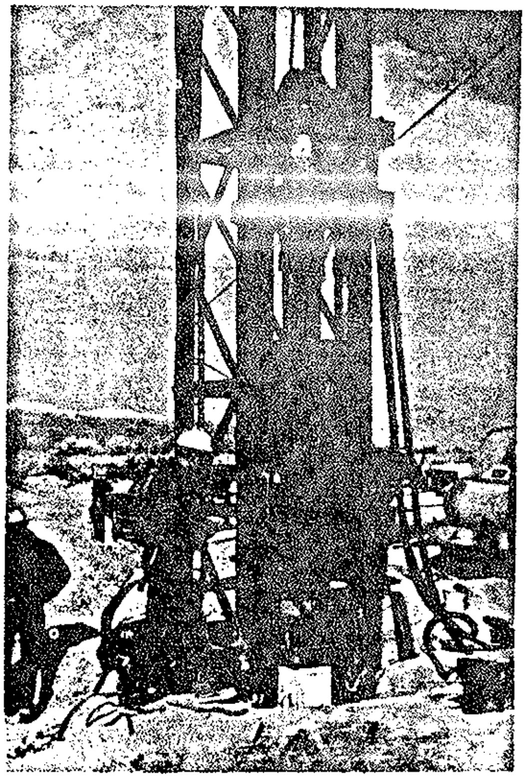
B9. The cycle is completed at the end of the up stroke when gas pressure is again applied in both the upper and lower chambers. The purpose of the double acting concept is to shorten the stroke and speed up the operation while maintaining about the same ram impact velocity. Typically, double acting hammers operate at about twice the speed of single acting hammers. As mentioned above, the differential acting hammer has been described. There are, of course, other types of double acting hammers.



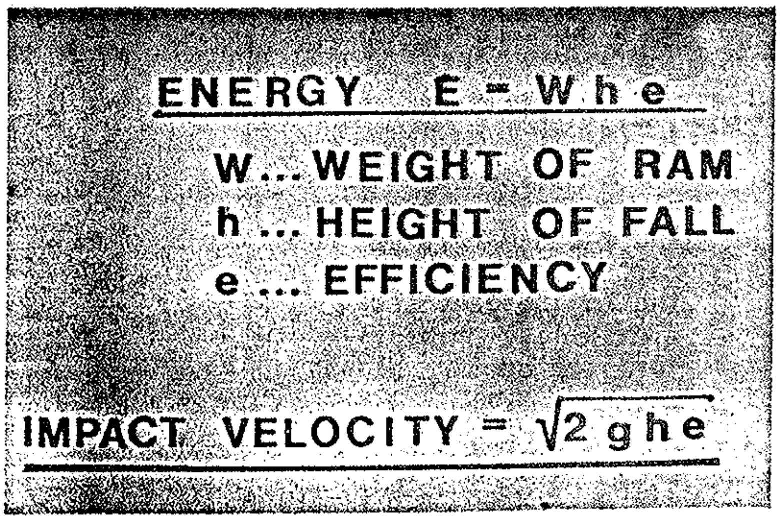
B10. The machine shown here is double acting and runs at about 110 blows per minute.



B11. This slide shows another example of the double acting hammer. This particular machine operates on hydraulic fluid supplied by a pump. The system is a closed one since the spent fluid is returned to the pump. The pump is equipped to allow the control of the fluid pressure.



B12. The rating of both the single and double acting hammer assumes a predictable and constant energy. To include any energy losses the impact velocity is usually calculated using a reduced energy obtained by multiplication with an efficiency factor which is less than one. From the reduced energy an impact velocity can be calculated for input to the Wave Equation. Both hammer types can be handled in the same computer model.



ENERGY $E = W h e$

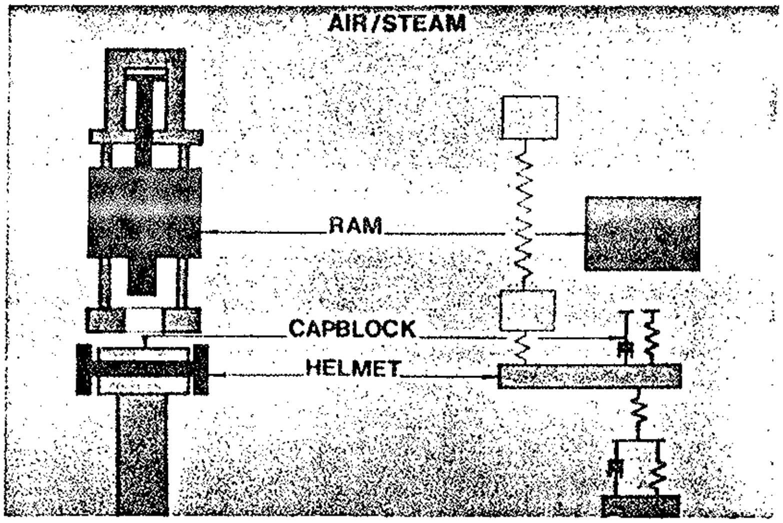
W... WEIGHT OF RAM

h ... HEIGHT OF FALL

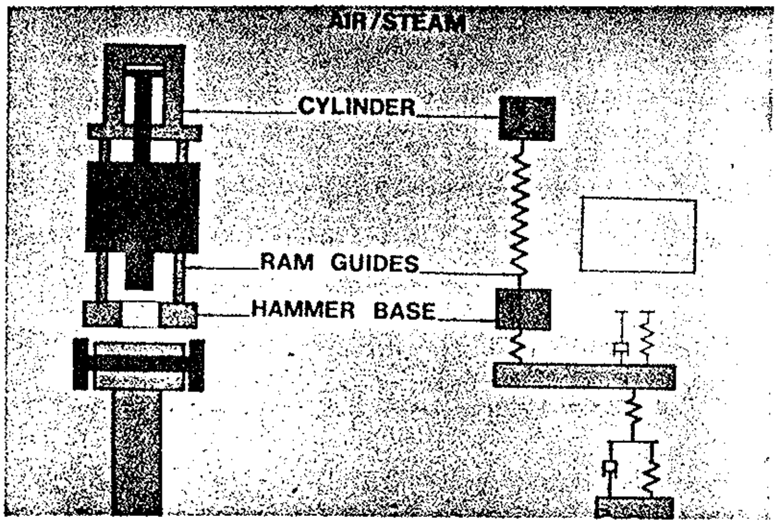
e ... EFFICIENCY

IMPACT VELOCITY = $\sqrt{2 g h e}$

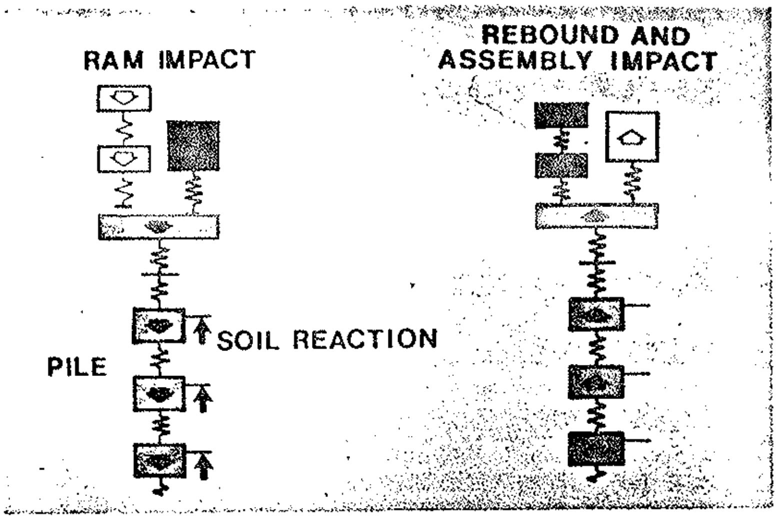
13a. The mathematical model used in the WEAP program is more detailed than that which has been used previously. The ram can be represented by a series of masses and springs. The spring shown connecting the bottom ram element and the helmet is capable of carrying compression only. For currently available air/steam hammers the rams are so stocky that they can be represented by a single mass element. The details of the modeling of the helmet-capblock assembly will be discussed later.



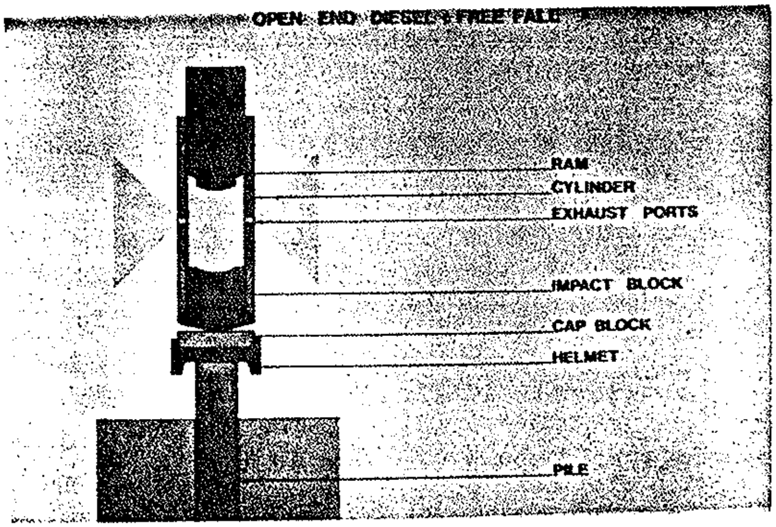
13b. The hammer assembly is also modeled by a series of masses and springs with the bottom spring at the interface of the assembly and the helmet also a compression-only spring. For the majority of currently available hammers, two masses are required; one representing the cylinder and the other, the hammer base. The connecting spring gets its flexibility primarily from the hammer columns.



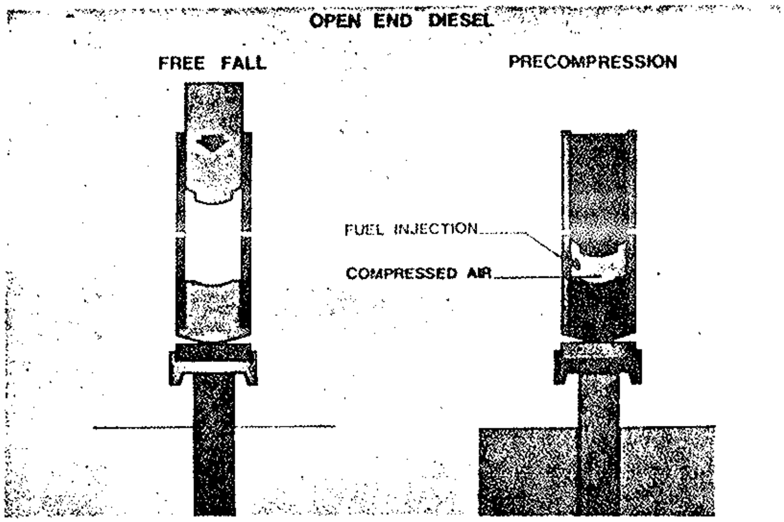
B14. The wave equation program begins by giving the ram element (or elements) the rated impact velocity. As impact occurs all segments of the wave equation model obtain a velocity and, therefore, move downward. The portions of the assembly segments are also continuously computed in their free fall. The motion of the pile segments causes the soil resistance forces to be activated. Once the pile has rebounded and all soil springs are elastic, computations are terminated.



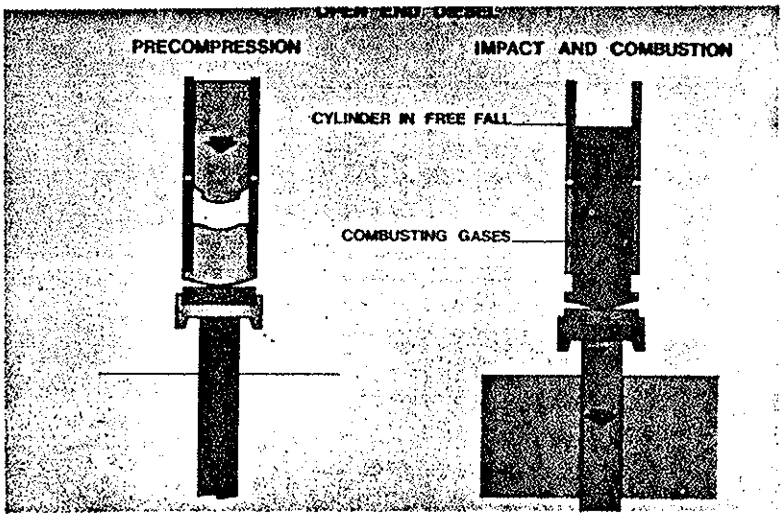
B15. Consider now the single acting or open end diesel hammer. It consists of three important elements: a ram, an impact block or anvil, and a cylinder all resting on a capblock and helmet similar to that used for air/steam hammers. To start the hammer the ram is lifted by the crane and dropped. Excess air is blown out of the exhaust ports or if this is a downstroke during operation combustion products and air are blown out.



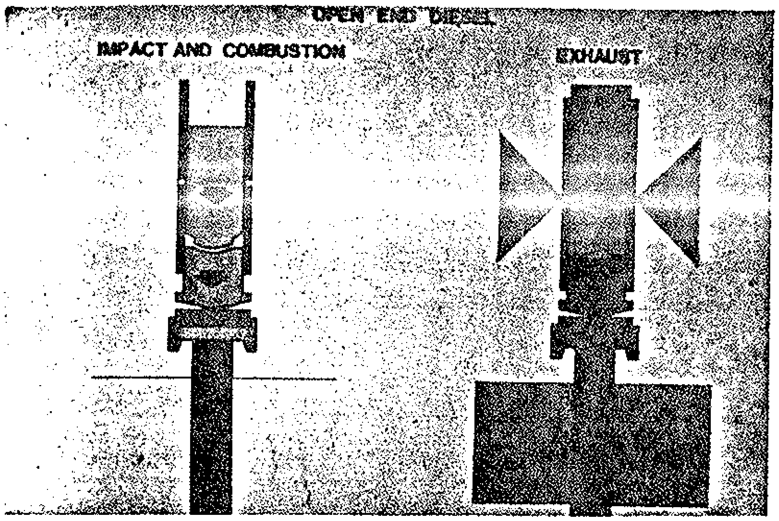
B16. When the ram falls past the exhaust ports they are blocked and the precompression phase begins. The falling ram activates a cam to inject fuel into the cylinder. This may be in liquid form falling onto the impact block or it may be atomized. In the latter case it is injected only shortly before impact.



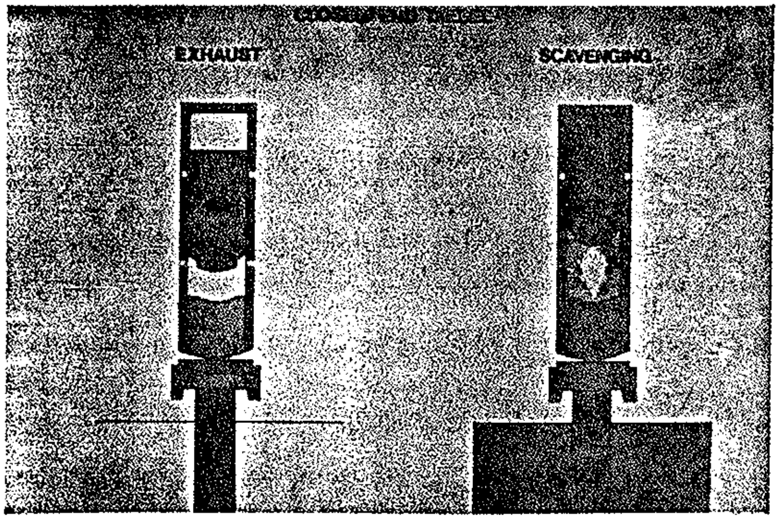
B17. The ram is shaped so that at impact a small combustion chamber remains with a high compression ratio. If the fuel is injected as a liquid it is atomized on impact. Combustion occurs causing a very rapid increase in pressure.



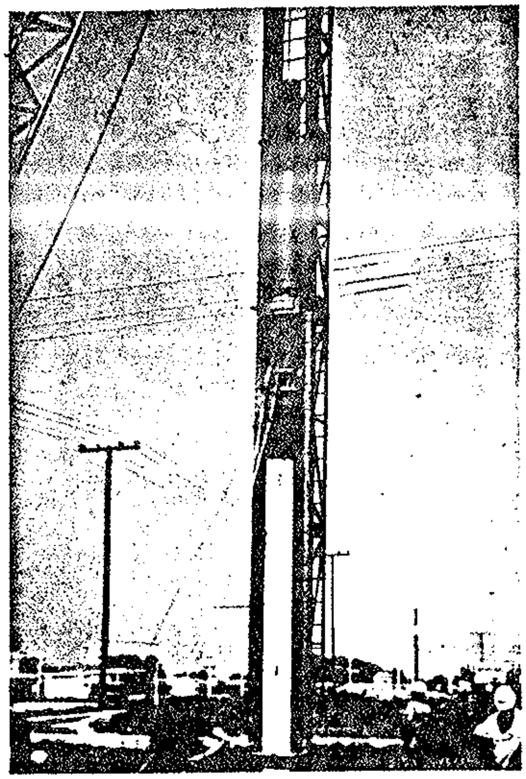
B18. As a result of the combined effect of the combustion chamber pressure and the pile rebound, the ram moves upward allowing an expansion of the combustion products. When it passes the exhaust ports the excess pressure is blown off.



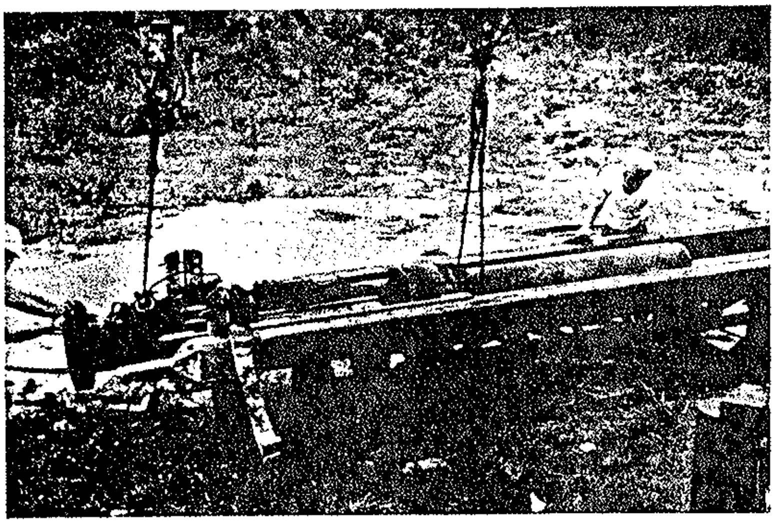
B19. However, the ram has an upward velocity so it continues upward in a free fall condition, in the process drawing in fresh air in a scavenging phase. The maximum height that the ram achieves depends on the pile rebound as well as the combustion effect. In normal operation the stroke can vary over a wide range depending on the pile rebound and stiffness. Strokes ranging between four feet and nine feet are not abnormal for various hammer types.



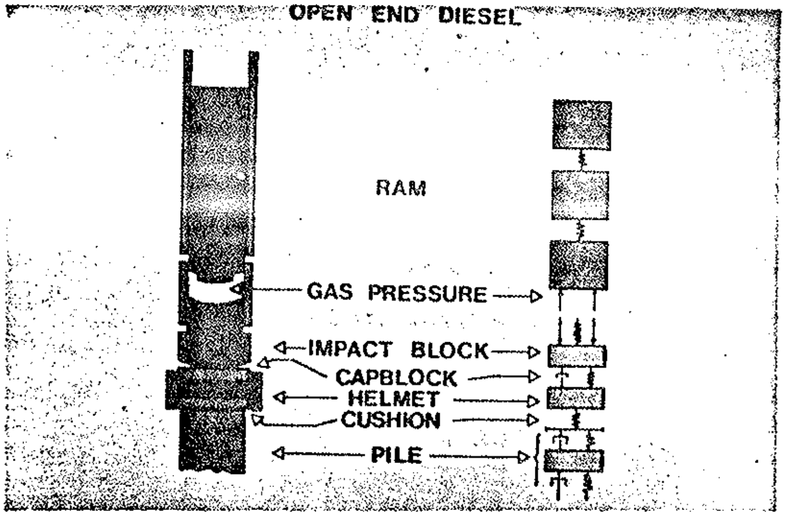
B20. An open end diesel hammer is shown here. The photograph was taken when the ram was near the top of the stroke and a large part of the ram extends beyond the top of the cylinder.



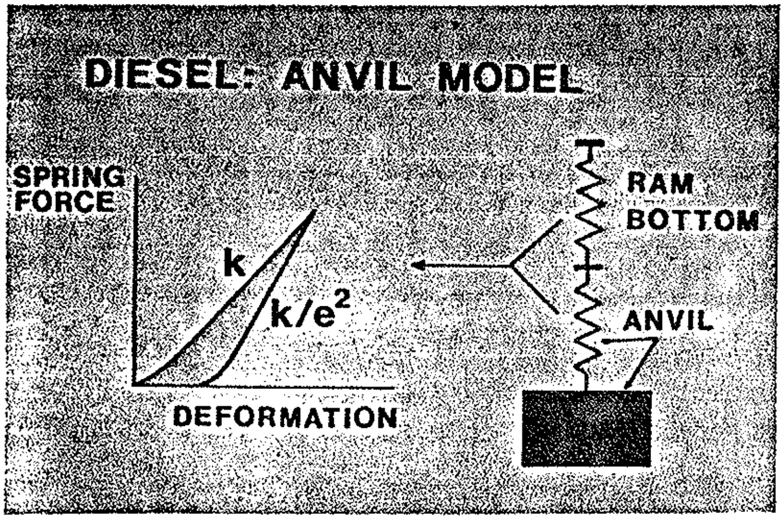
B21. In this photograph, another open end diesel hammer is shown. The impact block is partially extended and clearly visible at the bottom of the hammer.



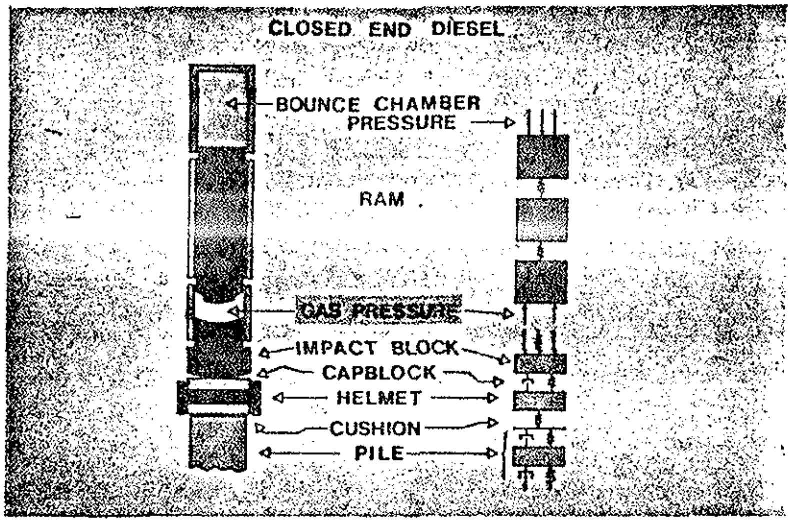
B22. The hammer is modeled in the WEAP program as shown here. The ram consists of a series of masses and springs. Since rams of diesel hammers are typically longer and more slender than is common for air/steam hammers, several elements are used. The impact block is represented by a single element.



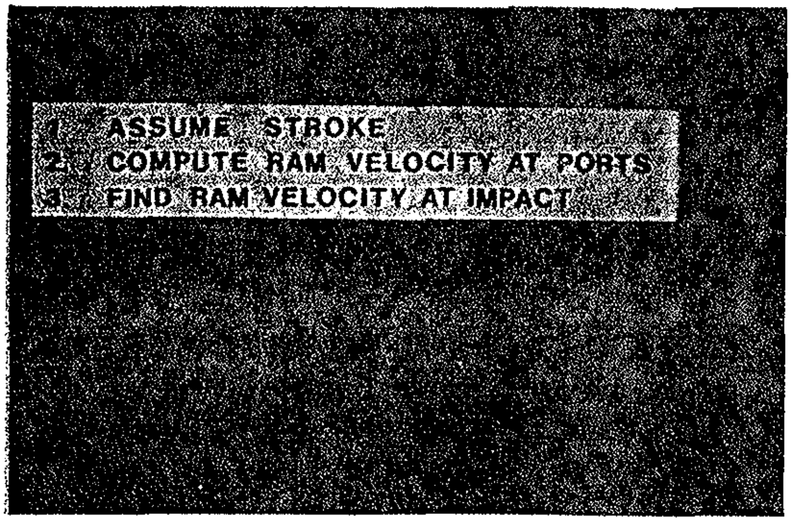
B23. The steel to steel impact of the ram on the impact block represents a particular problem and one which must be handled carefully. The research conducted during the development of the WEAP program leads to the use of an impact block spring which represents simply the combined stiffness of the last ram segment and the anvil. The spring is modeled with non-linear properties as are the springs of all cushion materials. The change of slope is identified by a coefficient of restitution, e. The model below the impact block is identical with that used for the air/steam hammer.



B24. The combustion chamber pressure must also be active between the ram and the impact block. The resulting forces can best be described by discussing the operation of the program as far as the hammer is concerned.

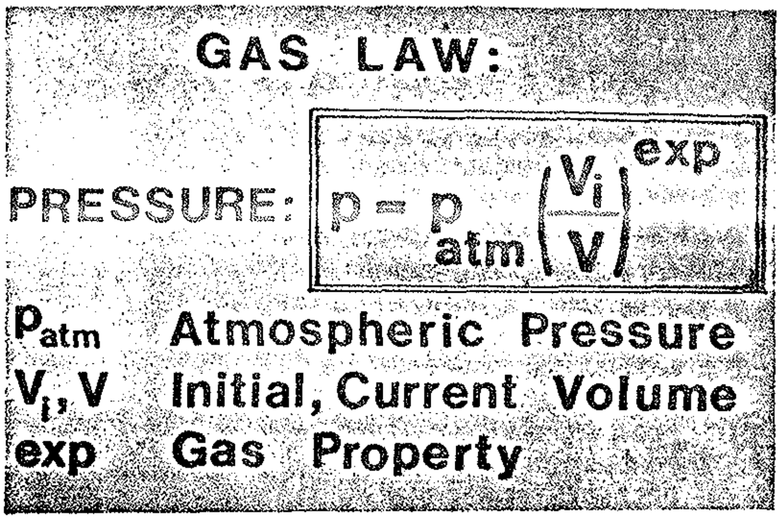


B25. The program begins with either an assumed or a user specified ram stroke. With a knowledge of the stroke the velocity of the ram as it falls past the exhaust ports can be calculated from elementary kinematics. When the exhaust ports are closed the combustion chamber pressure and ram velocity are determined using a rigid body assumption and step-wise calculating ram velocity resulting from the action of gravitational and combustion forces.



1. ASSUME STROKE
2. COMPUTE RAM VELOCITY AT PORTS
3. FIND RAM VELOCITY AT IMPACT

B26. As the ram moves down the combustion chamber pressure is calculated from the gas law. When the ram reaches the impact block the velocity is known and the wave analysis can be performed in a fashion similar to that described earlier.



GAS LAW:

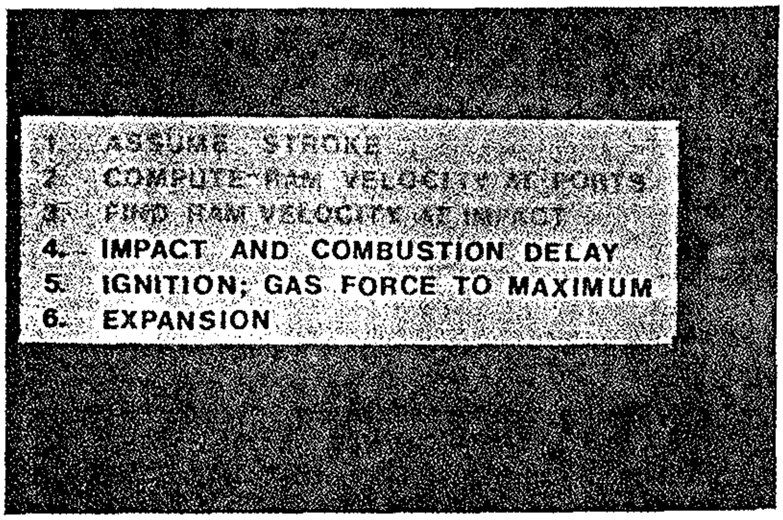
PRESSURE: $\boxed{p = p_{atm}\left(\frac{V_i}{V}\right)^{exp}}$

p_{atm} Atmospheric Pressure

V_i, V Initial, Current Volume

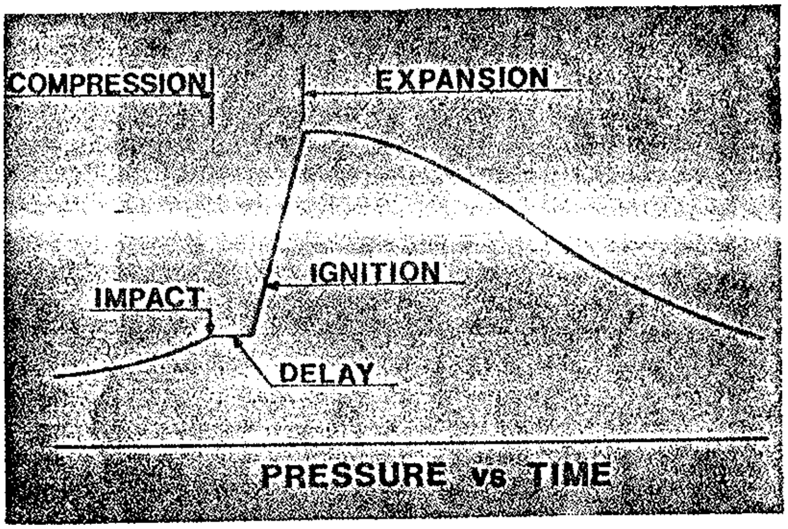
exp Gas Property

B27. Measurements of combustion chamber pressure have shown that there is normally a delay between ram impact and ignition. This delay time can vary depending on job conditions. It is usually about one or two milliseconds. During this time the impact induced wave is traveling down the pile and the combustion chamber pressure is about constant.

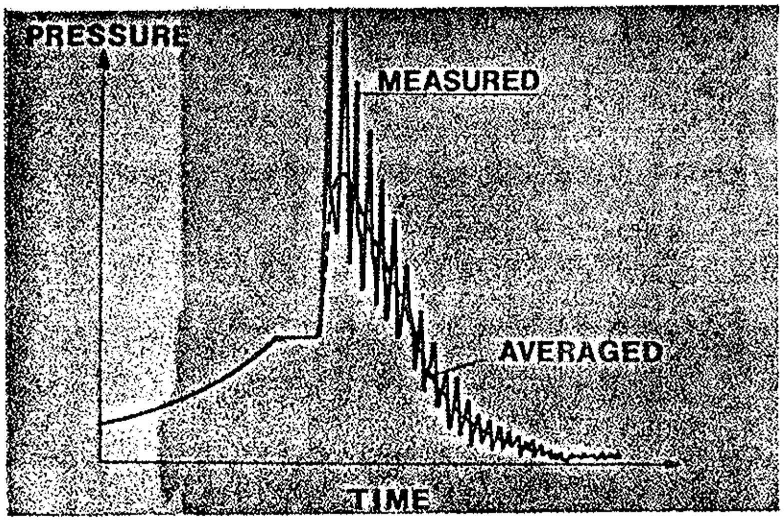


1. ASSUME STROKE
2. COMPUTE RAM VELOCITY AT PORTS
3. FIND RAM VELOCITY AT IMPACT
4. IMPACT AND COMBUSTION DELAY
5. IGNITION; GAS FORCE TO MAXIMUM
6. EXPANSION

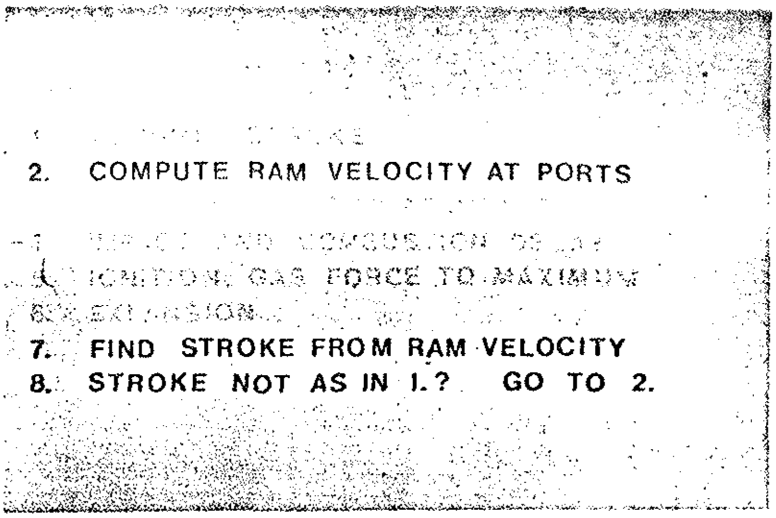
B28. When ignition occurs the pressure increases very rapidly to some maximum value. This pressure can be calculated from combustion laws. However, due to the imperfect nature of diesel hammer combustion the computed pressure is not reliable. Therefore, measured maximum pressures are used in the WEAP program. From this time on the combustion chamber pressure used in WEAP is determined by the volume of the chamber using the gas law.



B29. Actually, the pressure will have a high frequency fluctuation which is induced by ignition. However, this phenomenon cannot be realistically modeled and it has no significant effect on the pile dynamic performance.



B30. When the ram clears the exhaust ports the pressure is dropped to zero and the rigid body velocity calculated. The stroke can then be determined. If it agrees with the starting stroke, computation is stopped. Otherwise, a new calculation cycle is started using the rebound stroke as the beginning stroke. Convergence is usually rapid.



[illegible] STROKE

2. COMPUTE RAM VELOCITY AT PORTS

IMPACT AND COMBUSTION OF [illegible]

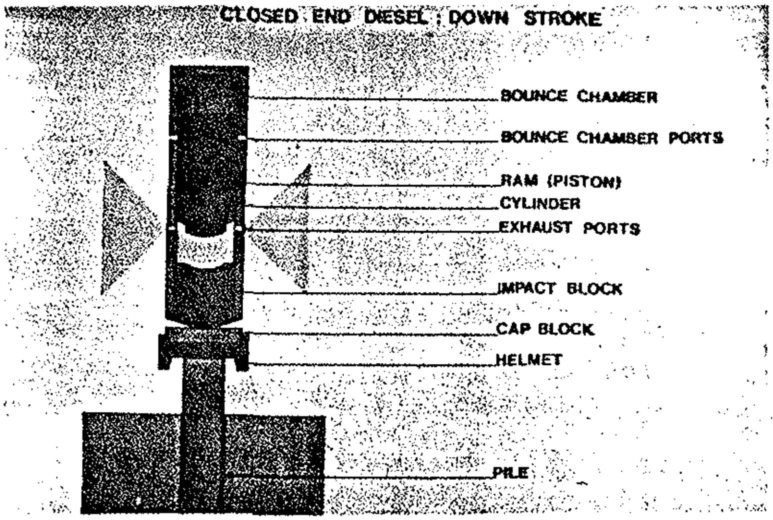
IGNITION, GAS FORCE TO MAXIMUM

EXPANSION

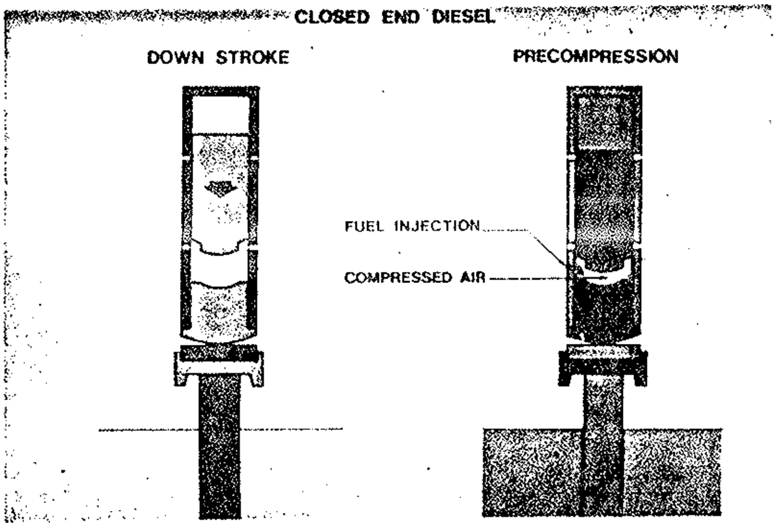
7. FIND STROKE FROM RAM VELOCITY

8. STROKE NOT AS IN 1.? GO TO 2.

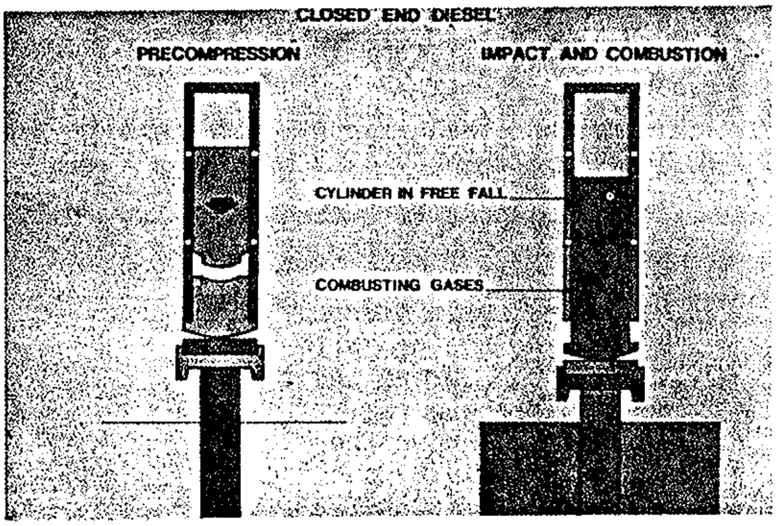
B31. The closed end diesel hammer is in some important ways different from the open end hammer. The top of the cylinder in this case is closed so that on the up stroke air is trapped in the resulting chamber, known as the bounce chmaber. The hammer is again started by lifting the ram with the crane. During the down stroke the ram accelerates under the action of gravity and the air pressure in the bounce chamber.



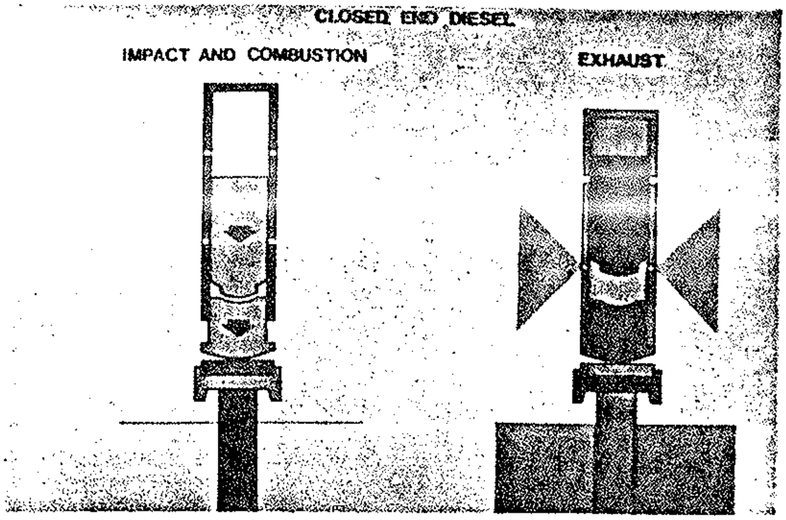
B32. Again when the ram passes the exhaust ports the gas in the combustion chamber is compressed.



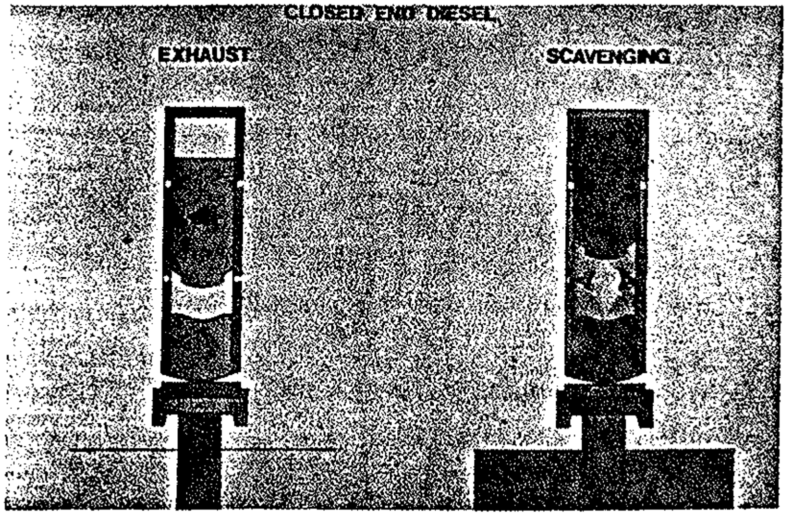
B33. At the bottom of the stroke the ram impacts with the anvil driving is and the pile top down. The bounce chamber ports are cleared and the bounce chamber pressure comes to atmospheric. Ignition occurs at about the same time. The ram then moves upward due to the action of both the pile rebound and the combustion chamber pressure.



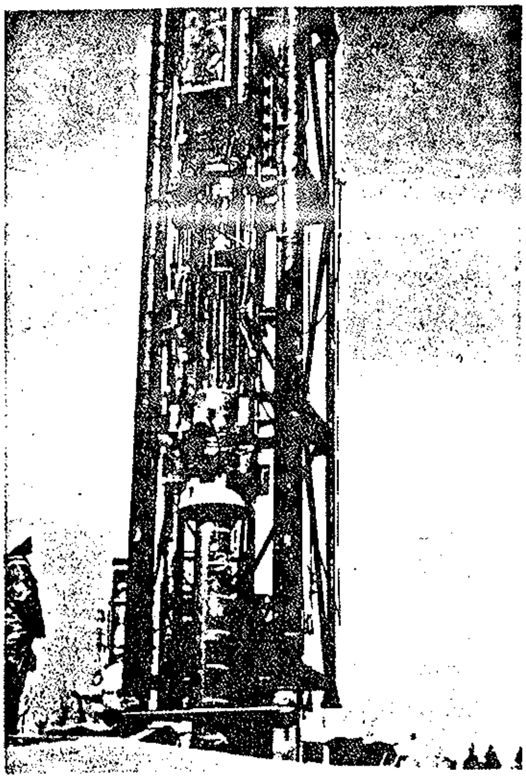
B34. When the exhaust ports are cleared the combustion chamber goes down to the ambient atmospheric pressure. Also, a pressure is built up in the bounce chamber slowing the ram down more quickly than would gravity alone.



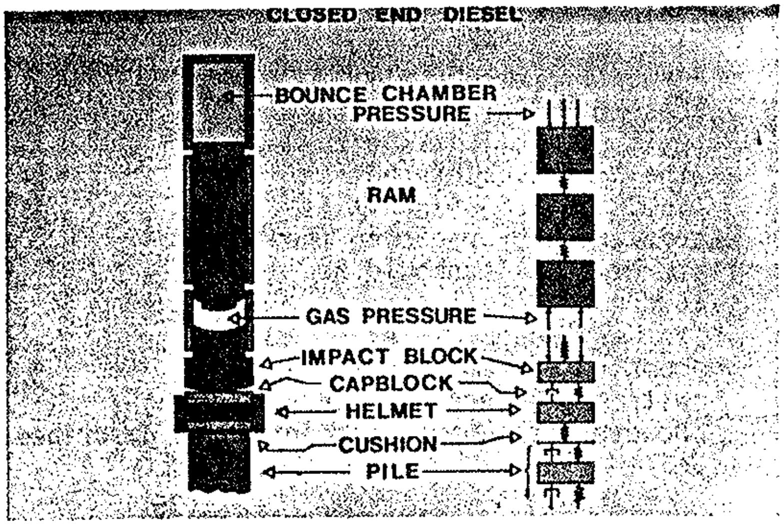
B35. As the ram continues on up fresh air is drawn into the combustion chamber and scavenging occurs. If the upward velocity of the ram is too great the bounce chamber pressure will become so large that the cylinder is lifted off the helmet. This action is undesirable and it is prevented by reducing the throttle. It should be understood that some hammers have a more complex system associated with the bounce chamber. However, the basic concept is as described.



B36. In this slide a double acting diesel hammer is shown. Characteristic for this particular hammer is a pressure tank at the top of the unit which provides for a larger bounce chamber.



B37. The model used to represent the hammer is shown here. It is similar to that used for the open end diesel except for the bounce chamber pressure. The resulting force acting on top of the hammer must be calculated from the gas law and included in the computation of ram motion.



CLOSED END DIESEL

BOUNCE CHAMBER PRESSURE

RAM

GAS PRESSURE

IMPACT BLOCK

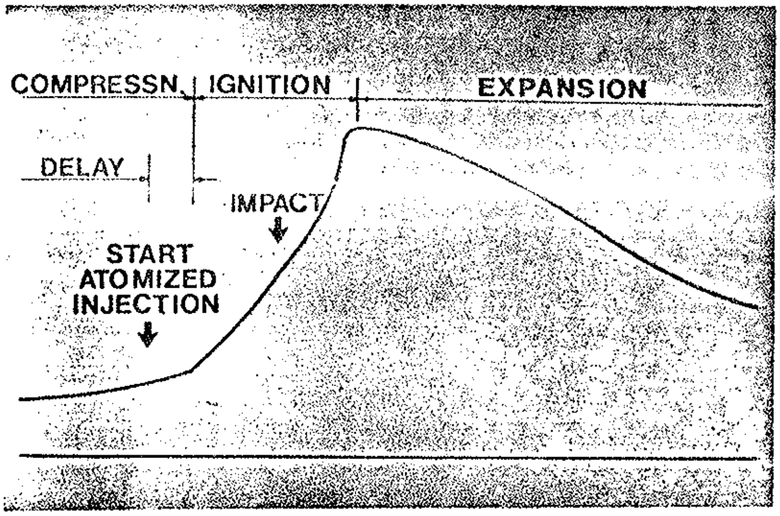
CAPBLOCK

HELMET

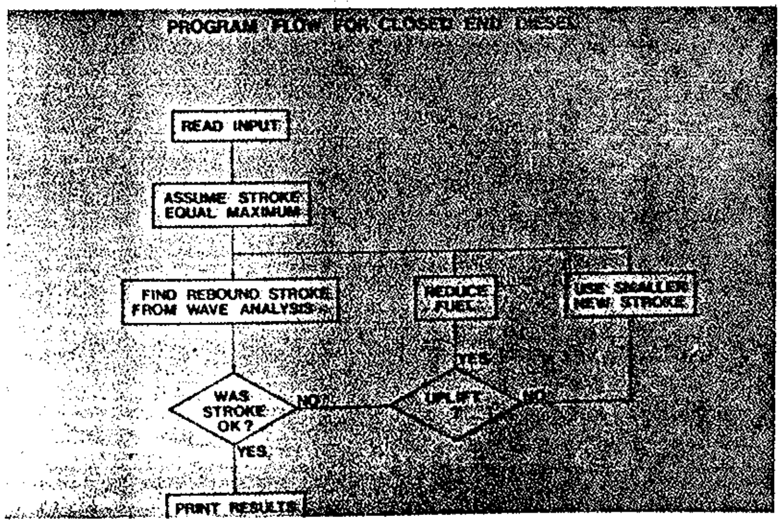
CUSHION

PILE

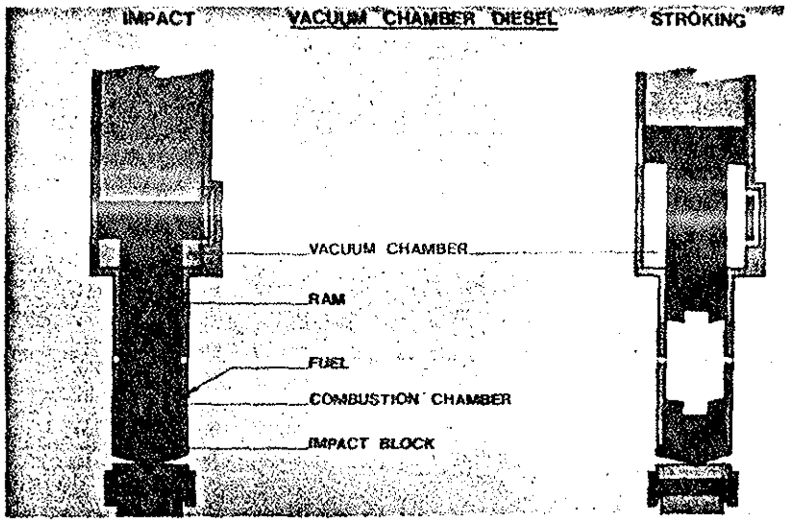
B38. Some hammers introduce the fuel in an atomized state. Thus, ignition occurs shortly after injection in a manner similar to the conventional diesel engine. Burning then takes place over a longer time depending on the rate of fuel injection.



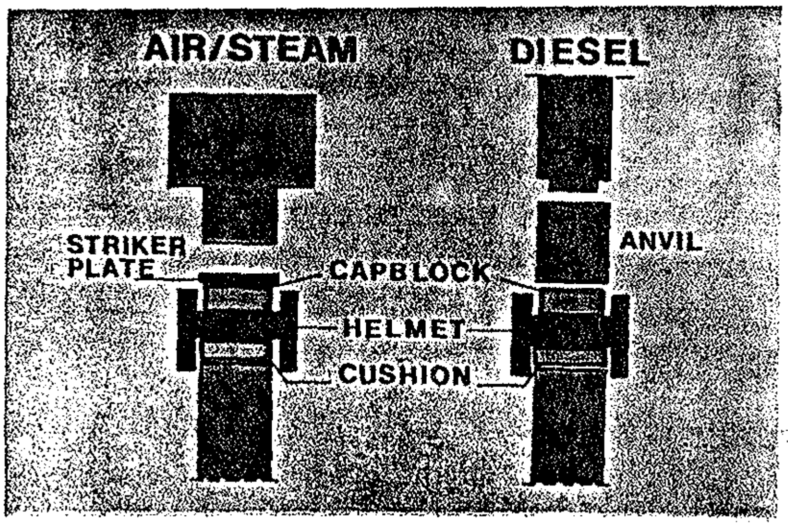
B39. The computer program for the closed end diesel hammer must operate somewhat differently than for open end hammers. If the open throttle stroke is such that lift off is induced then the combustion pressure, associated with a reduced throttle, must be found so that lift off is only incipient. On the other hand, if lift off does not occur then the computation is the same as for open end hammers where the stroke must converge.


PROGRAM FLOW FOR CLOSED END DIESEL

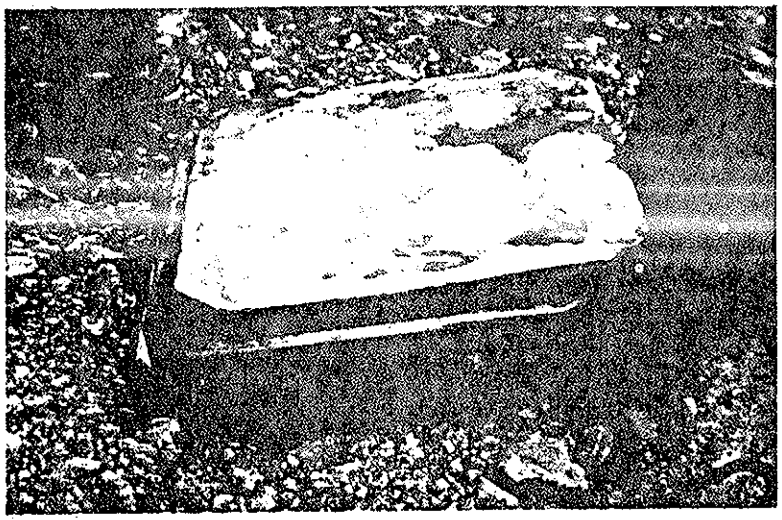
B40. An additional diesel hammer type known as the vacuum chamber diesel is also modeled in the program. The hammer is illustrated here schematically. This hammer is double acting in that on the up stroke a reduced pressure is induced in the vacuum chamber. This force increases rapidly to a near vacuum and then continues to increase only gradually. The stroke of the hammer is not limited by a hammer top so the computation convergence is only on stroke.



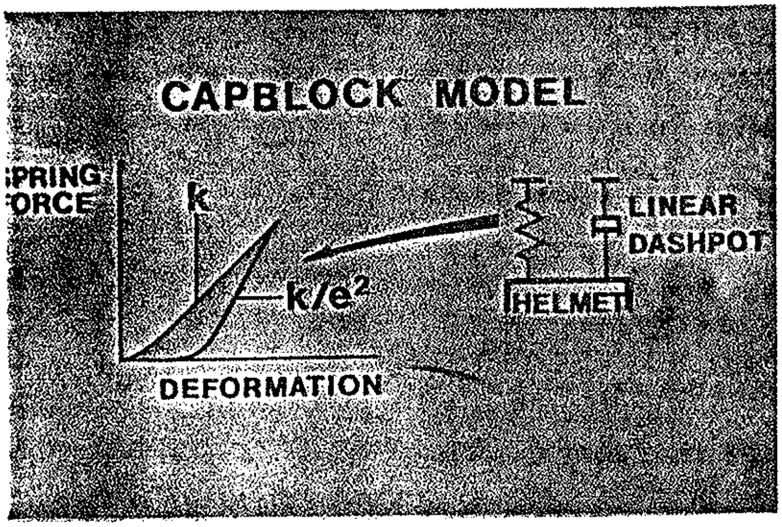
B41. So far only hammer models have been discussed. Now the next elements down in the driving system, the capblock, helmet, cushion model will be described. The capblock is that portion of the driving system which receives the impact force from the ram in the case of air/steam hammers or from the impact block from diesel hammers.



B42. Capblocks formerly consisted of hardwood or cable coils. Increasingly artificial composite materials are used. These newer materials have the advantage of offering more uniform and reproducible mechanical properties.

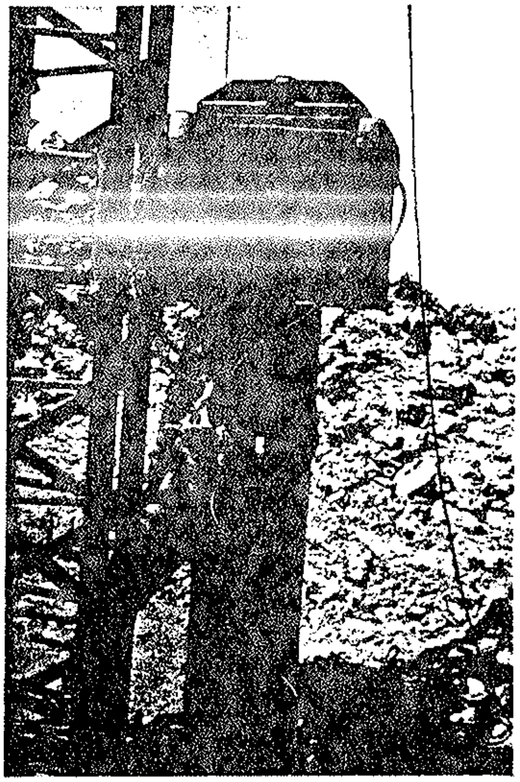


B43. The capblock is modeled as a spring with a steeper unloading portion to represent the coefficient of restitution. Also, a dashpot is used in its model. Comparison of measured with computed force and velocity curves proved this model to be valid.

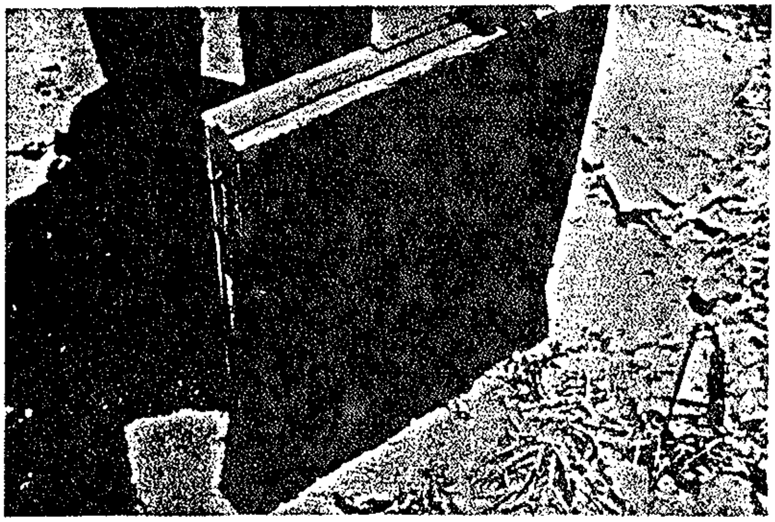


CAPBLOCK MODEL

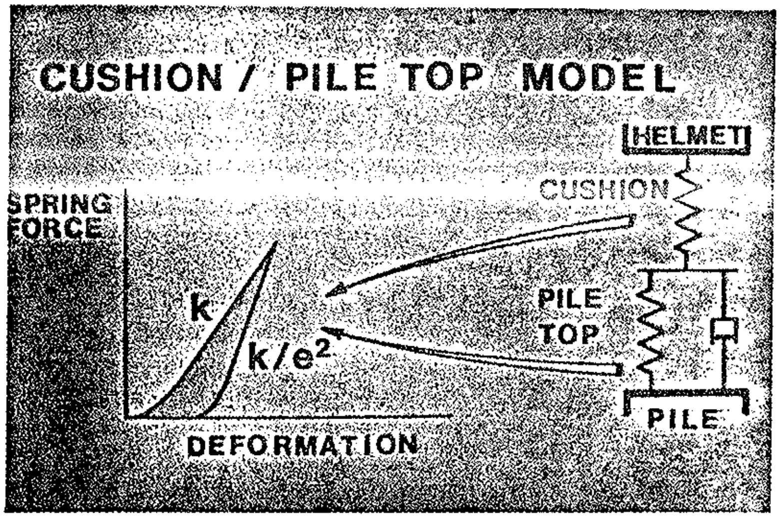
B44. The helmet is that steel element which contains the capblock on top and holds the pile in alignment with the appropriate recess in the bottom. It is modeled as a mass together with the mass of the capblock, strikerplates and pile adaptors, if present. If steel or timber piles are being driven the helmet fits directly on top of the pile.



B45. For concrete piles a softwood cushion is placed between the helmet and the pile. The thickness of this cushion may vary widely.

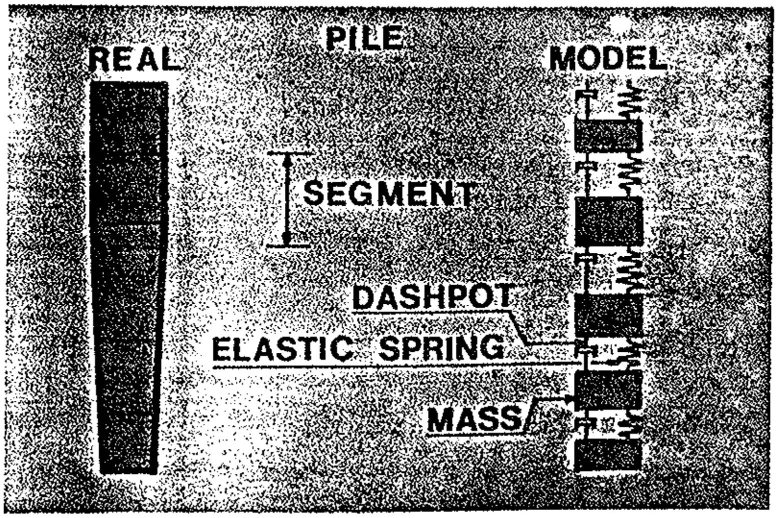


B46. It is modeled as a spring also with a coefficient of restitution. It is difficult to estimate the stiffness of the usual cushions since they are made of softwood struck across the grain and have substantially changing properties during driving.

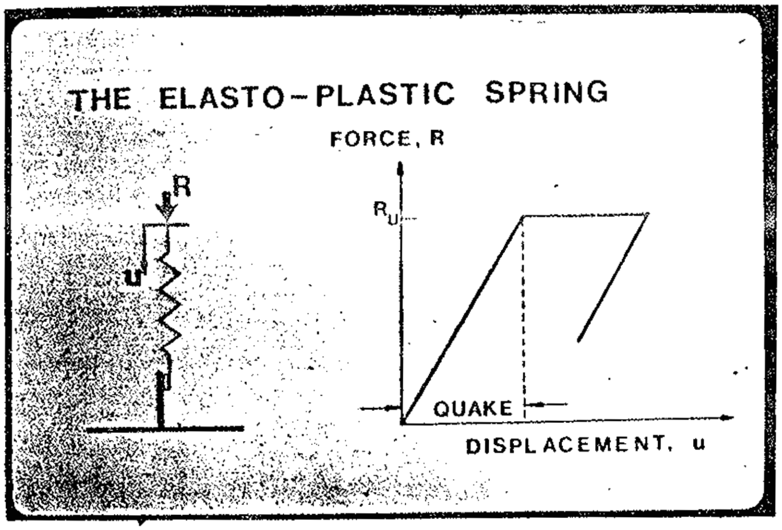


CUSHION / PILE TOP MODEL

B47. The pile is modeled as a series of masses, springs, and dashpots. The complete model of the pile is shown here. Probably the pile is the simplest element in the total Wave Equation Model. Dashpots have been included to account for some structural damping especially for pile materials like timber.

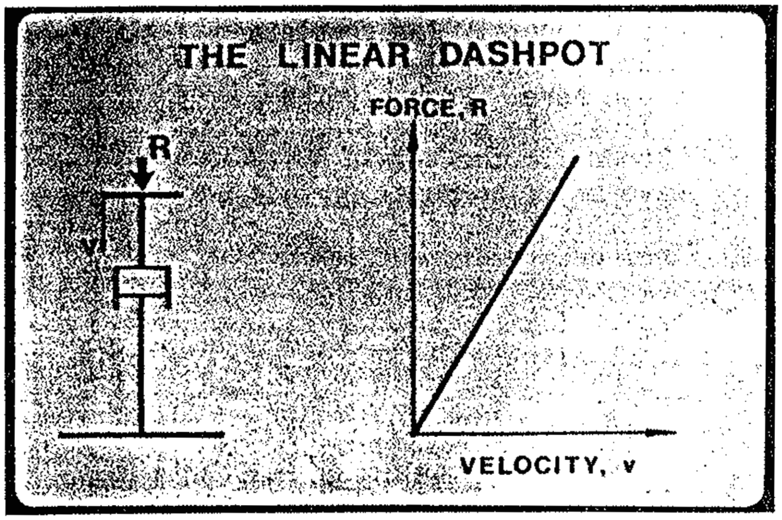


B48. The soil model was already introduced in the first section of this presentation. It consists of an elasto plastic spring which reaches an ultimate resistance force at a compression value called the quake.



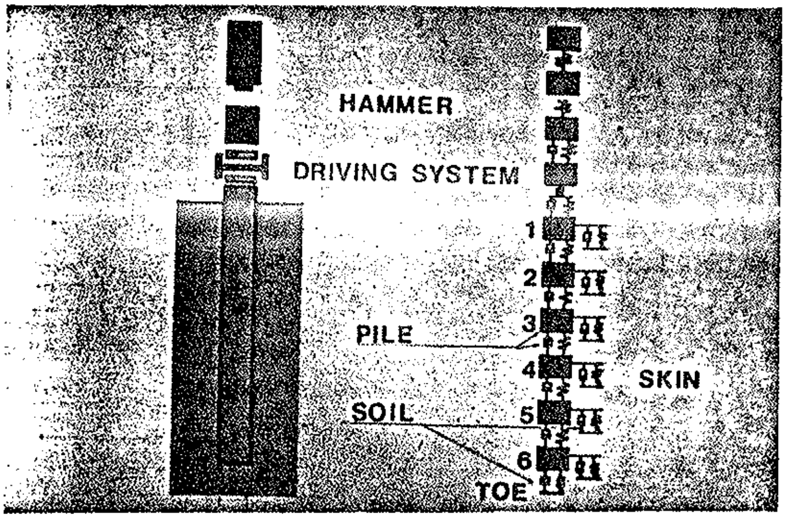
THE ELASTO-PLASTIC SPRING

B49. The soil model also includes a linear dashpot which produces a resistance force proportional to the pile velocity.



THE LINEAR DASHPOT

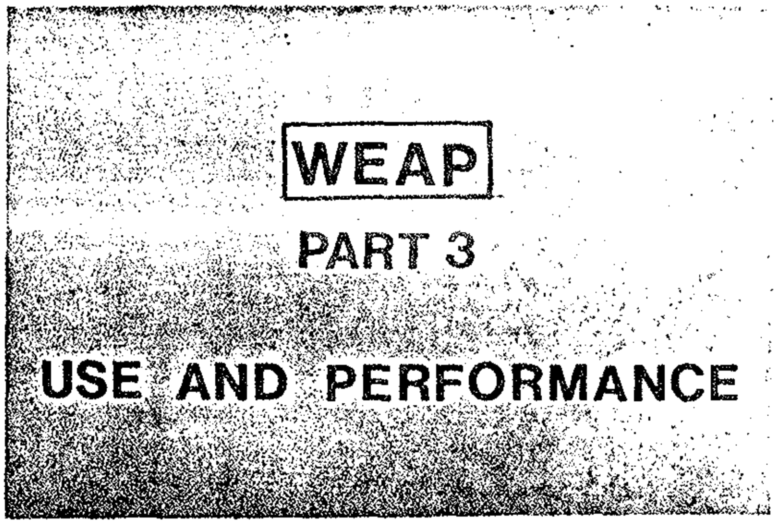
B50. The total wave equation model is shown here for the case of a diesel hammer driving a pile which is represented by six elements. A complete spring-dashpot soil model acts at each pile segment. An additional soil model unit acts at the toe to represent end bearing. The sum of the individual ultimate resistance forces acting at each pile segment, here six, is equal to the totoal ultimate skin resistance. Skin resistance plus end bearing equals the total pile resistance.



Part III

Program Use and Performance

C1. In this, the third section of this presentation, further details of the WEAP program will be presented. An example of data input will be described, three sample problems will be presented and some results of the correlation between measured and calculated force and velocity curves will be given. The total data input structure with all options is too lengthy to describe in detail. Rather, an example which can be run with minimal input data will be described.



WEAP

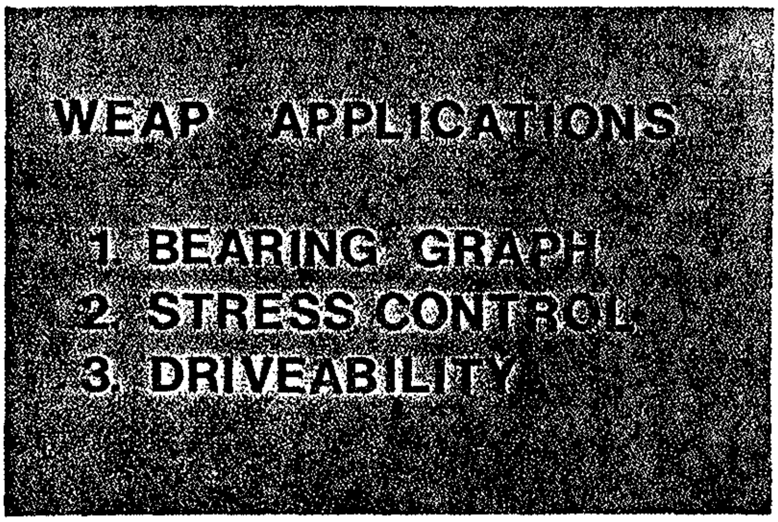
PART 3

USE AND PERFORMANCE

More detail is given in the User's Manual.

C2. There are three typical applications for a Wave Equation Program:

(a) The Construction of a Bearing Graph; (b) The Control of Stresses, in particular tension stresses in concrete and compression stresses in steel piles; and (c) The Analysis of driveability. By driveability we are referring to a check on a driving system, given a required pile bearing capacity.

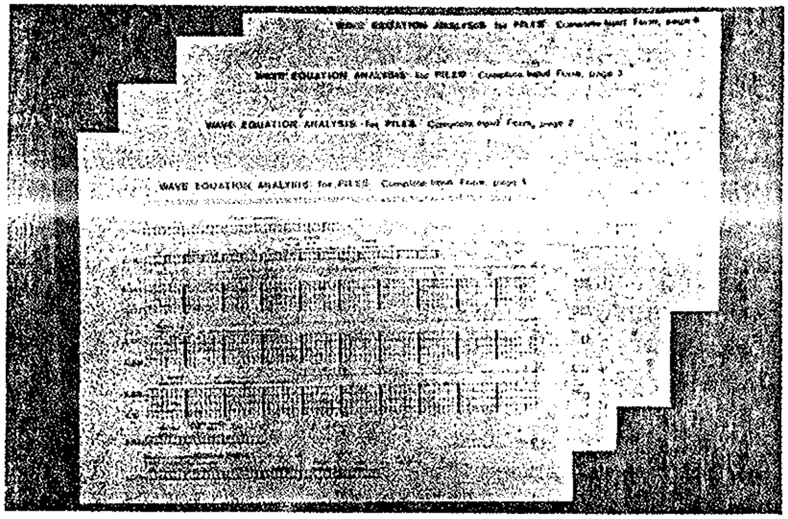


WEAP APPLICATIONS

1. BEARING GRAPH
2. STRESS CONTROL
3. DRIVEABILITY

For each of these three groups an example will be given.

C3. The construction of a bearing graph will be discussed in more detail to demonstrate the coding of input data. Two different input coding forms were prepared, a SHORT and a COMPLETE form;



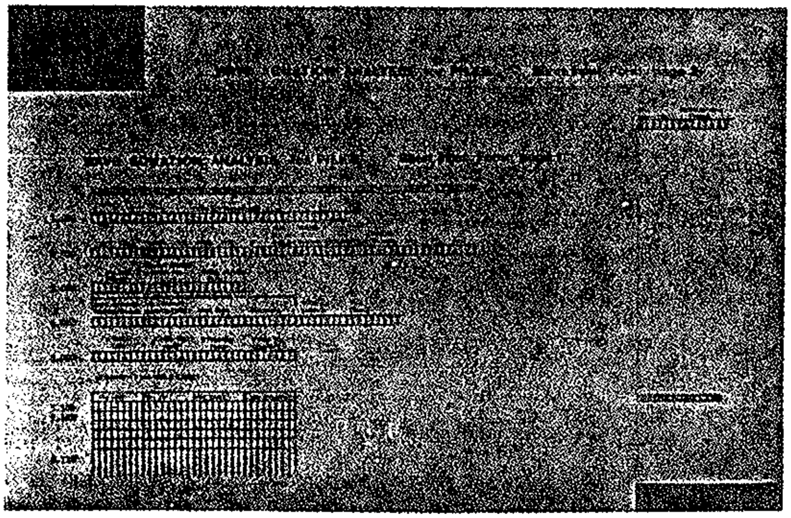
WAVE EQUATION ANALYSIS for PILES Complete Input Form, page 4

WAVE EQUATION ANALYSIS for PILES Complete Input Form, page 3

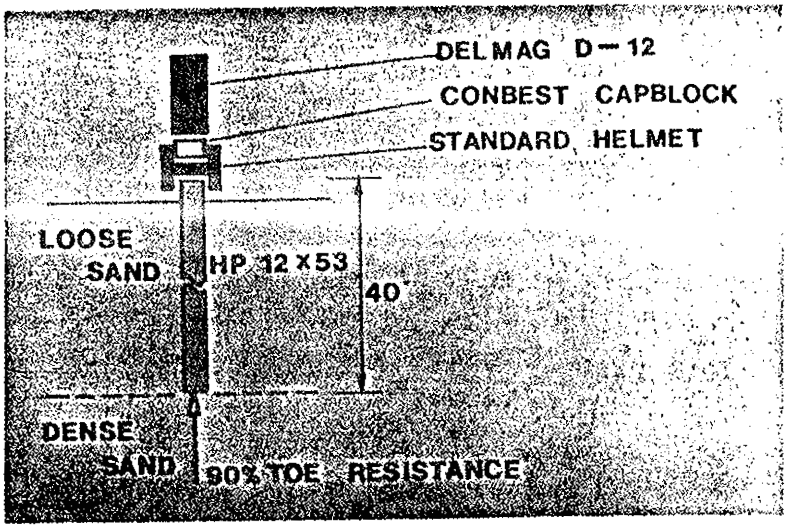
WAVE EQUATION ANALYSIS for PILES Complete Input Form, page 2

WAVE EQUATION ANALYSIS for PILES Complete Input Form, page 1

C4. only the short one is demonstrated here. The first problem can be stated as follows:

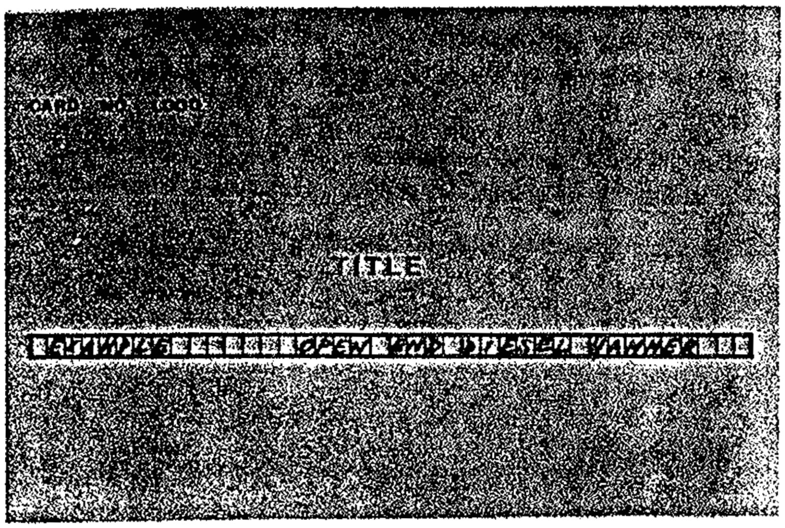


C5. An HP12 x 53 pile of 40 feet length is to be driven through loose into dense sand. A DELMAG D-12 which is an open end hammer is selected for pile driving. The contractor wants to use a standard conbest capblock and a twelve inch helmet. Because of the dense layer at 40 feet depth it is estimated that 90% of the total static capacity acts at the pile toe. The other 10% is assumed to be triangularly distributed along the side of the pile.

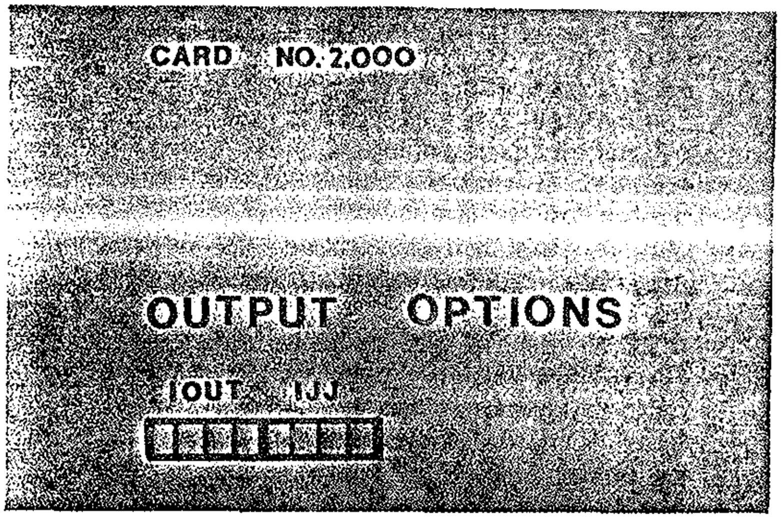


Input preparation is as follows:

C6. On card 1 a title is entered that identifies the problem.



C7. Card 2 allows the input of various options. The first two of these options deal with the type and the quantity of output. Leaving both data fields blank causes a small but sufficiently detailed output to be printed.

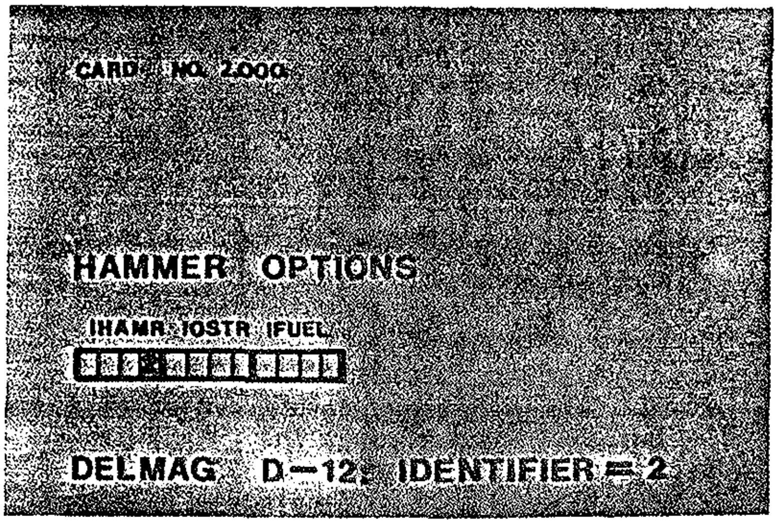


CARD NO. 2,000

OUTPUT OPTIONS

IOUT IJJ

C8. The next three fields of the option card are devoted to the hammer. IHAMR is the hammer identifier. A 2 is inserted here as given in the User's Manual for a D-12 hammer. Hammer information is stored on about 80 different hammers. Of course, all of the hammer information could be input, using data cards.



CARD NO. 2,000

HAMMER OPTIONS

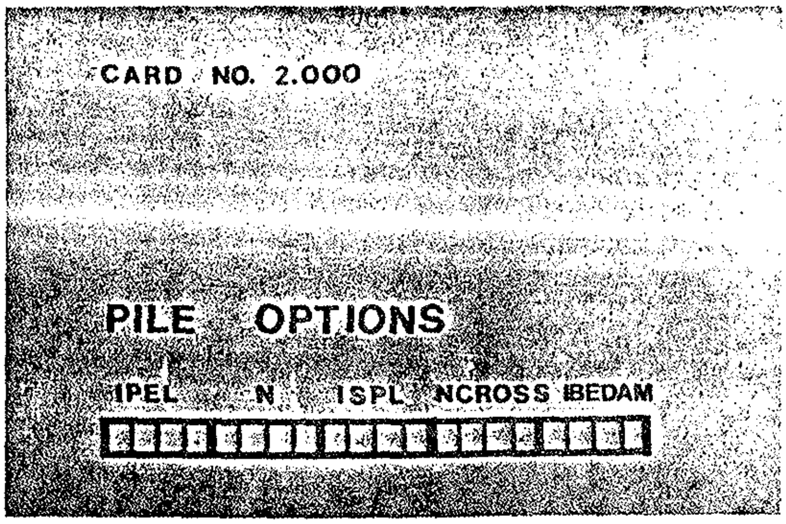
IHAMR IOSTR IFUEL

DELMAG D-12, IDENTIFIER = 2

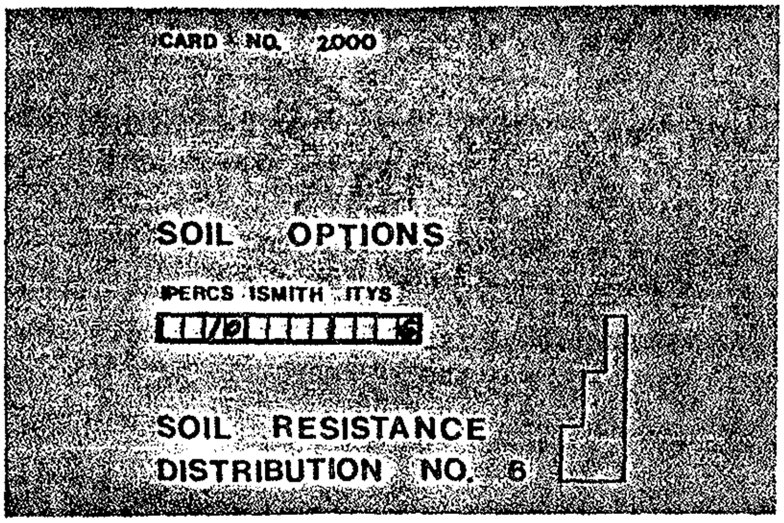
Leaving IOSTR blank causes the computer to find the proper hammer stroke. IOSTR set to -1 or 1 would produce an iteration with constant stroke or no iteration at all.

IFUEL determines where or not full combustion pressures are to be used. A blank field specifies normal operation.

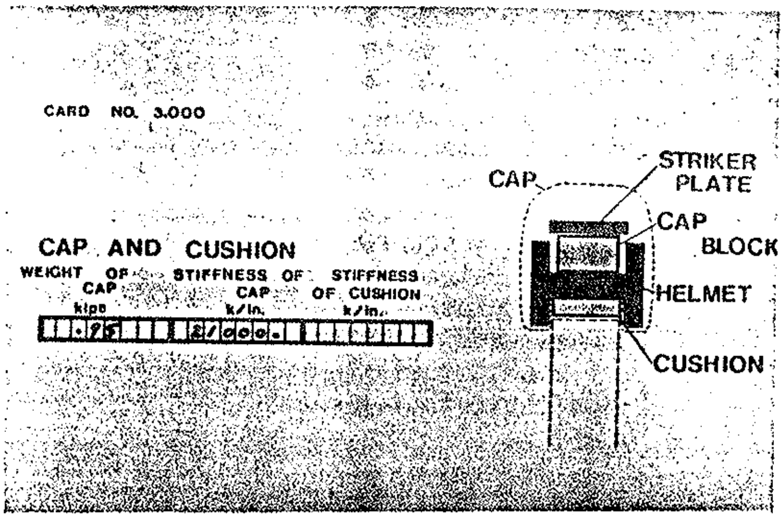
C9. The next five options deal with the pile input. Normally, segment stiffnesses and masses are determined by the program, and therefore, IPEL and N, the number of pile segments, can be left blank. There are no splices and the pile is uniform, thus ISPL and NCROSS are left blank. Finally, IBEDAM, the pile damping parameter, is left blank because a steel pile is being analyzed and its small damping is usually neglected.



C10. Three more parameters dealing with the soil are given on card no. 2. IPERCS is the percentage of skin friction, here 10. ISMITH is left blank since viscous rather than Smith's soil damping approach is chosen. During the course of the piling research project at Case Western Reserve University a different approach to the treatment of soil damping was developed. This model, referred to here as viscous, uses the pile impedance to nondimensionalize the damping constant. It has produced good results. Both methods are contained in the program. ITYS is set to 6 to distribute the resistance in a triangular manner. The resistance distributions which are available are given in the User's Manual.



C11. The driving system is identified on card no. 3. For this standard system one finds in the manual values of 0.95 kips for the helmet-capblock weight and 21,000 kips/inch for the conbest capblock stiffness. There is no cushion on top of the pile.

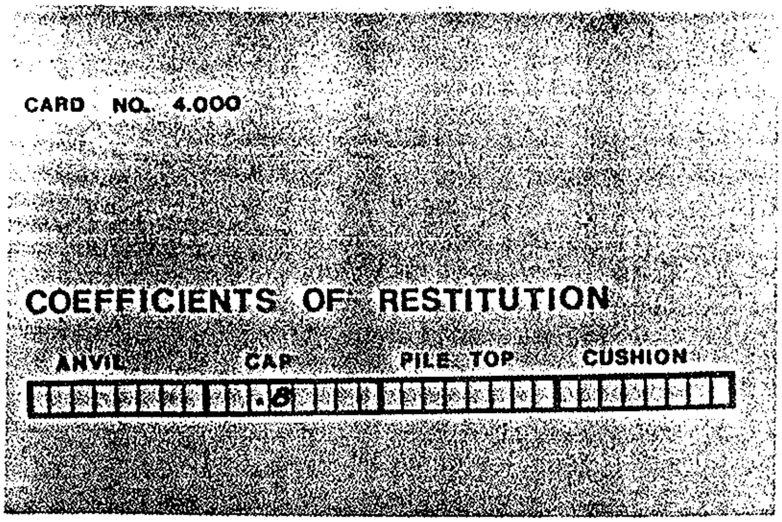


CARD NO. 3.000

CAP AND CUSHION

WEIGHT OF CAP kips	STIFFNESS OF CAP k/in.	STIFFNESS OF CUSHION k/in.
.95	21000.	

C12. Coefficients of restitution are left blank on card no. 4 except for the capblock where a 0.8 is inserted as appropriate for conbest. The computer will make a reasonable choice for all quantities that are left blank on this card.

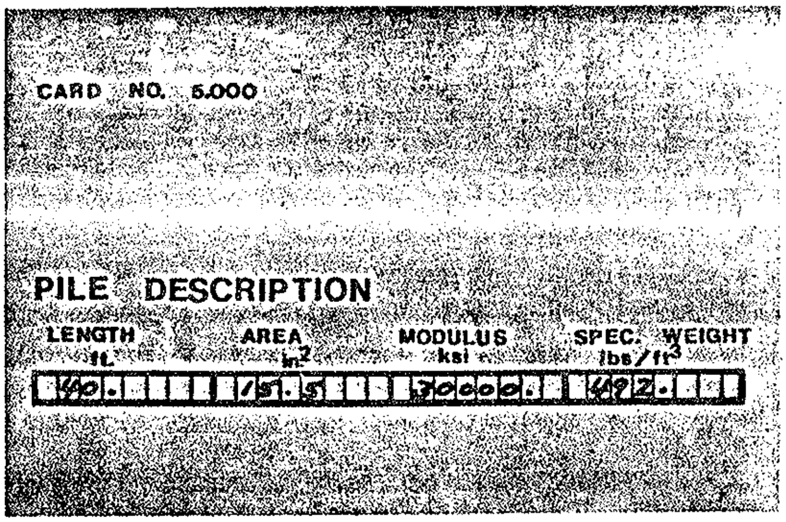


CARD NO. 4.000

COEFFICIENTS OF RESTITUTION

ANVIL	CAP	PILE TOP	CUSHION
	.8		

C13. The pile has to be described on card no. 5. For the uniform case the following input is sufficient: the length equal to 40 feet. the cross sectional area equal to 15.5 square inches, the steel's elastic modulus of 30,000 ksi and the steel's specific weight of 492 lbs/cubic foot.

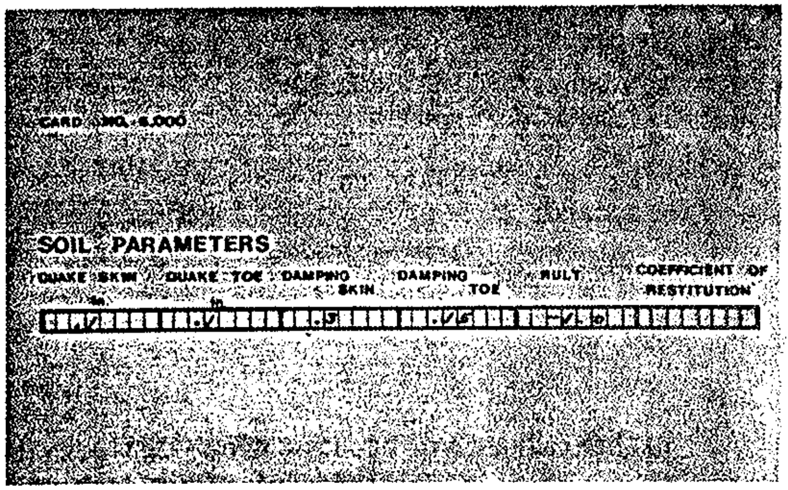


CARD NO. 5.000

PILE DESCRIPTION

LENGTH ft.	AREA in^2	MODULUS ksi	SPEC. WEIGHT lbs/ft^3
40.	15.5	30000.	492.

C14. Card no. 6 is used for soil parameter input. Quakes for both skin and toe bearing are set to 0.1 inches, soil damping was selected as 0.3 and 0.15 for the skin and toe, respectively. The ultimate soil bearing capacity was set to -1.0 since more than one value has to be analyzed. The soil's coefficient of restitution is left blank for normal operation.

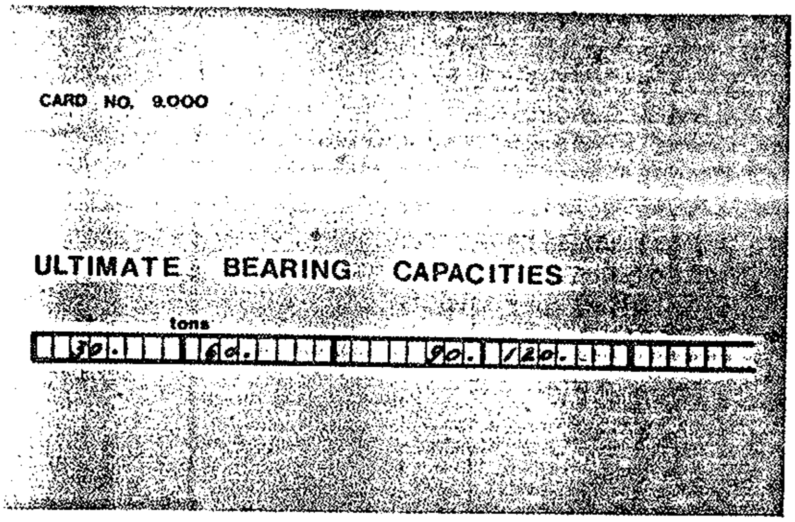


CARD NO. 6.000

SOIL PARAMETERS

QUAKE SKIN in.	QUAKE TOE in.	DAMPING SKIN	DAMPING TOE	RULT	COEFFICIENT OF RESTITUTION
.1	.1	.3	.15	-1.0	

C15. No other input except for card no. 9 is required. On this card four ultimate capacities; namely, 30, 60, 90, and 120 tons are specified. These four values are sufficient for the construction of a bearing graph.



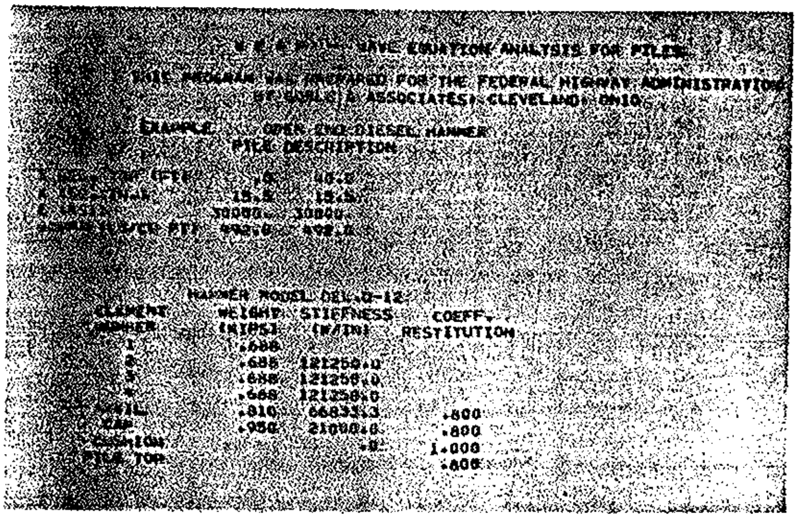
CARD NO. 9.000

ULTIMATE BEARING CAPACITIES

tons

30. 60. 90. 120.

C16. The output consists in this case of seven pages. There are two pages giving hammer, pile, soil, and option details. Four pages list the extrema of forces, stresses, velocities, and displacements for each element.



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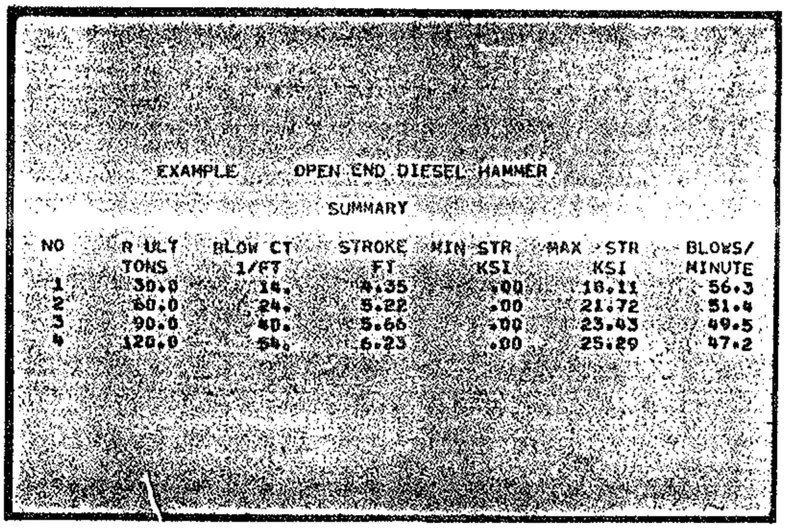
        W E A P [illegible] WAVE EQUATION ANALYSIS FOR PILES
    THIS PROGRAM WAS PREPARED FOR THE FEDERAL HIGHWAY ADMINISTRATION
             BY GOBLE & ASSOCIATES, CLEVELAND, OHIO

    EXAMPLE       OPEN END DIESEL HAMMER
                PILE DESCRIPTION

[illegible] (FT)           .0      40.0
A (SQ.IN.)             15.5      15.5
E (KSI)               30000.    30000.
[illegible] (LB/CU FT)   492.0     492.0


              HAMMER MODEL DEL.D-12
  ELEMENT       WEIGHT  STIFFNESS    COEFF.
  HAMMER        (KIPS)    (K/IN)   RESTITUTION
     1           .688
     2           .688  121250.0
     3           .688  121250.0
     4           .688  121250.0
   ANVIL         .810   66833.3       .800
    CAP          .950   21000.0       .800
  CUSHION                    .0      1.000
  PILE TOP                            .800
```

C17. On the last page a summary is printed containing the ultimate resistance, RULT, analyzed, and the corresponding blow count, stroke, minimum and maximum stresses and the speed of the hammer in blows per minute.



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                 EXAMPLE     OPEN END DIESEL HAMMER

                                SUMMARY

 NO     R ULT    BLOW CT     STROKE   MIN STR    MAX  STR     BLOWS/
        TONS      1/FT         FT       KSI         KSI       MINUTE
  1      30.0      14.        4.35       .00      18.11        56.3
  2      60.0      24.        5.22       .00      21.72        51.4
  3      90.0      40.        5.66       .00      23.43        49.5
  4     120.0      54.        6.23       .00      25.29        47.2
```
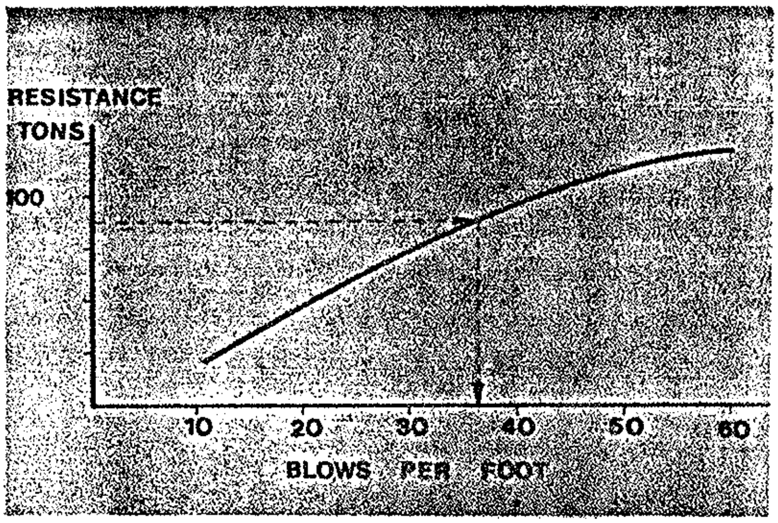
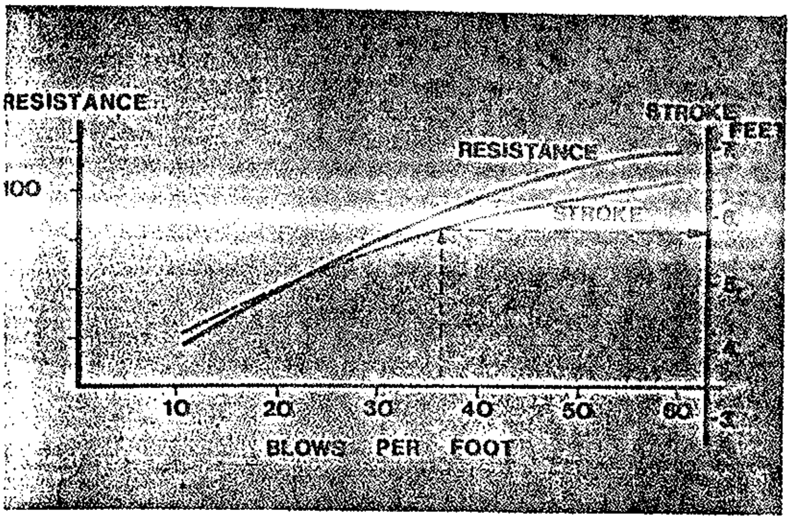
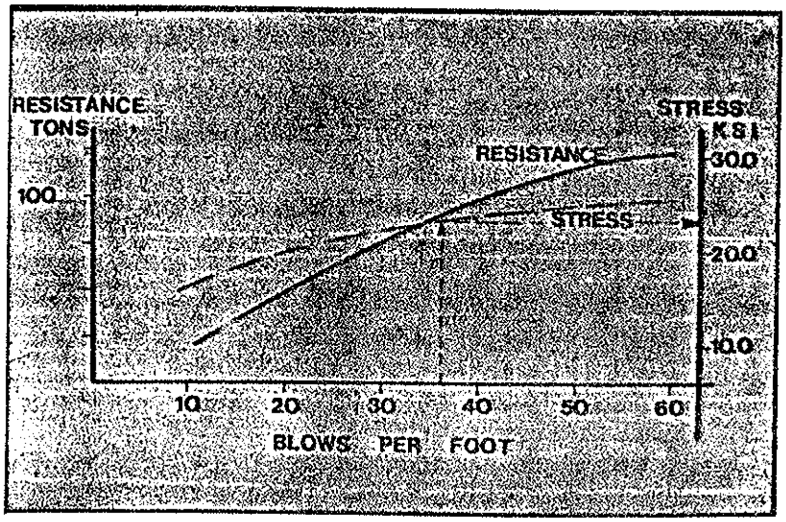

C18. The blow count results were used to construct a bearing graph as shown here. If an ultimate resistance of 90 tons was desired, then the blow count should be 36 blows per foot as indicated by the arrows.



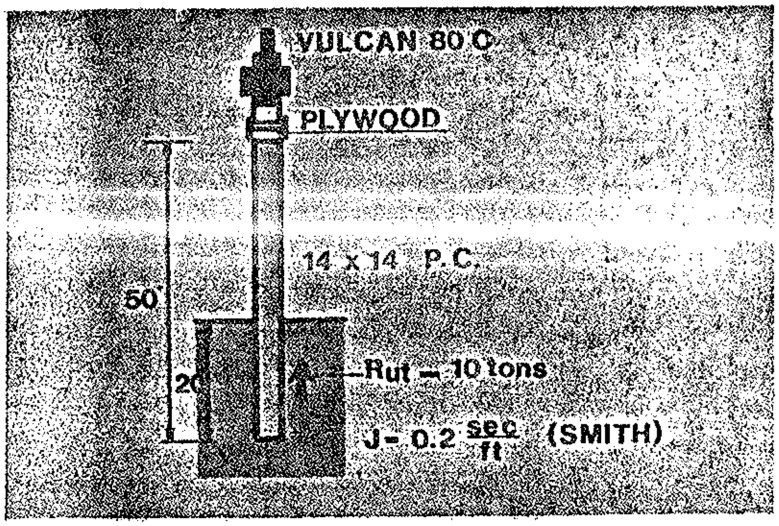
C19. Also plotted in this slide are the stroke results corresponding to the blow counts of the summary. The expected stroke for 90 ton resistance and 36 blows per foot is about 5.8 feet.



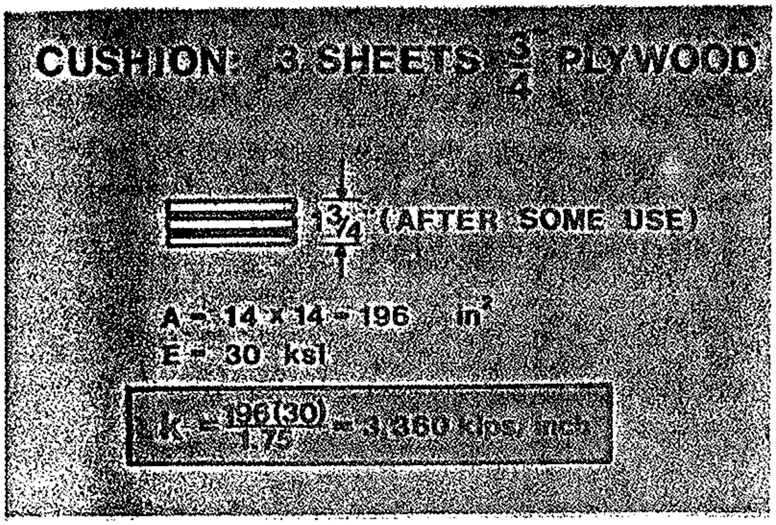
C20. In a similar manner the maximum compressive stresses are plotted and one finds a maximum stress of 24 ksi at 36 blows per foot driving resistance. It should be noted that the WEAP program produces the bearing graph automatically, if so desired.



C21. A second type of wave equation application is for the control of tension stresses in concrete piles. As an example consider a Vulcan 80C differential acting air/steam hammer driving a 50 foot long, 14 x 14 inch square, prestressed concrete pile. The soil overlaying the bearing strata is very soft and a situation is to be analyzed with only 10 tons skin resistance and a Smith skin damping value of 0.2 at a penetration of 20 feet. The cushion thickness is to be determined such that the tension stresses are less than 1.0 ksi.



C22. In a first run the cushion is assumed to consist of 3 sheets of 3/4 inch plywood, 14 x 14 cross section. Its elastic modulus--after some time of driving--is assumed to be 30 ksi and the three sheets are probably compressed to a total thickness of 1.75 inches. The resulting cushion stiffness is, therefore, 3360 kips/inch. The coeffient of restitution is 0.5.



CUSHION: 3 SHEETS $\frac{3}{4}$ PLYWOOD

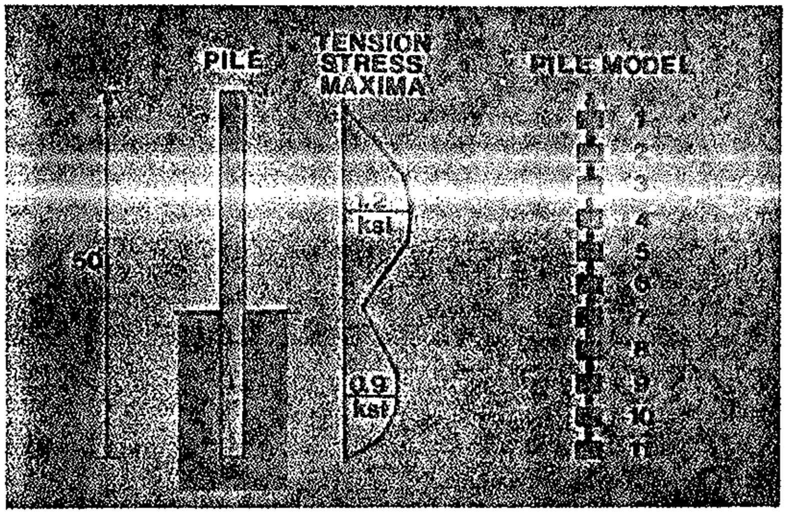
$1\frac{3}{4}$ (AFTER SOME USE)

A = 14 x 14 = 196 in^2

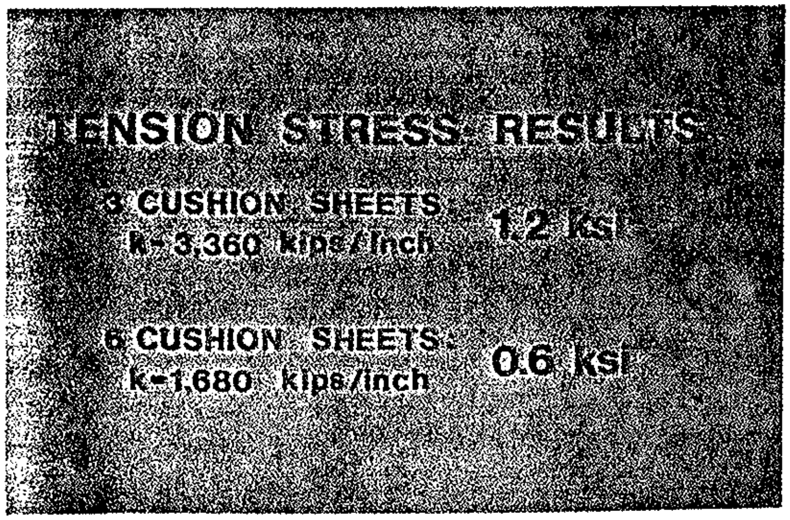
E = 30 ksi

$$k = \frac{196(30)}{1.75} = 3,360 \text{ kips/inch}$$

C23. In this slide the maximum tension stresses are plotted as determined by the computer for each element. The highest tension stress occurs at a depth of 18 feet and is 1.2 ksi.



C24. Thus the tension stresses are too high. A rerun of this problem with 6 cushion sheets and, therefore, a cushion stiffness which is only 1680 kips/inch, produces a tension stress of 0.6 ksi.

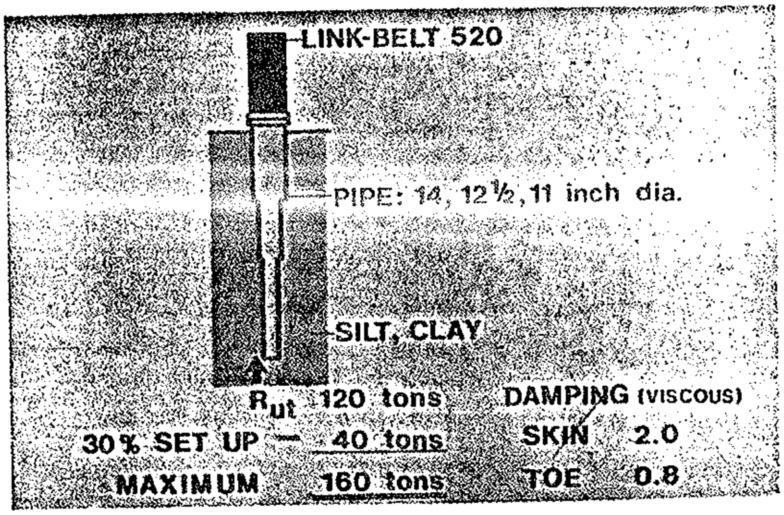


TENSION STRESS RESULTS

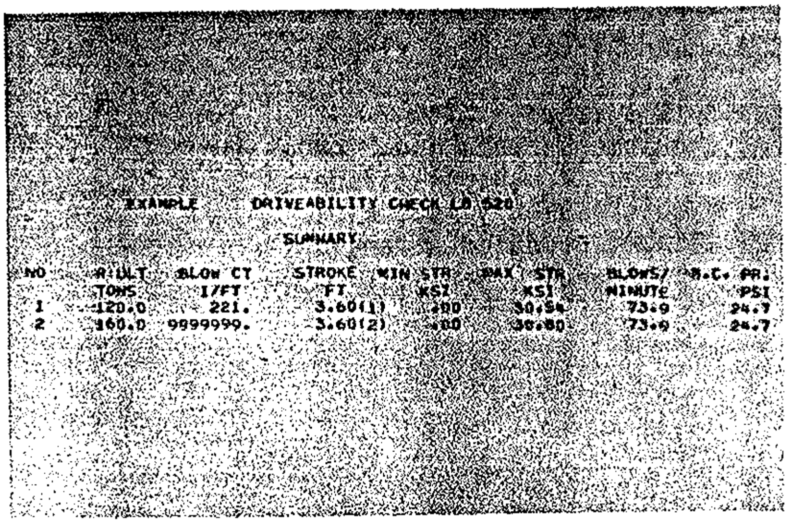
3 CUSHION SHEETS
k=3,360 kips/inch 1.2 ksi

6 CUSHION SHEETS
k=1,680 kips/inch 0.6 ksi

C25. The third problem to be demonstrated deals with driveability. A thin-walled pipe pile which is step tapered is to be driven by a Link-Belt 520 hammer. Estimates of bearing capacity in a cohesive silt and clay are 120 tons with 33% set up. This means that if driving is interrupted and the pile left at rest for an extended period of time, it would obtain a static capacity of 160 tons.

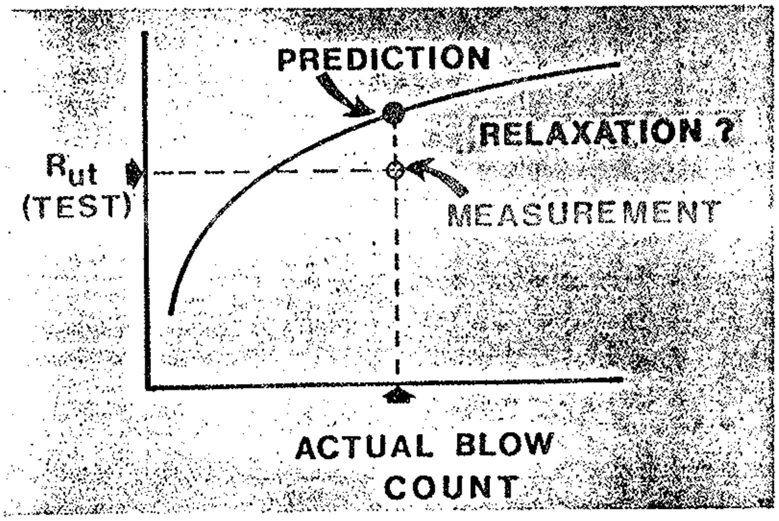


C26. A WEAP analysis with relatively high viscous damping factors of 2.0 and 0.8 for skin and toe, respectively, shows that the driving resistance would be 221 blows per foot at 120 tons resistance. It would be infinite, that is there would be no set, at the set up capacity of 160 tons. The conclusion is that the hammer/pile system would be insufficient if the pile had to be driven after a waiting period.

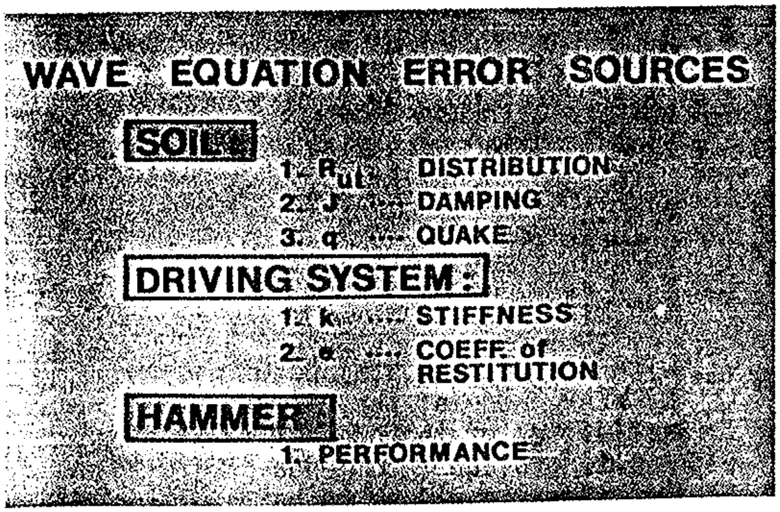


```
          EXAMPLE     DRIVEABILITY CHECK LB 520

                          SUMMARY

NO    R-ULT  BLOW CT    STROKE   MIN STR   MAX STR    BLOWS/   B.C. PR.
       TONS     1/FT       FT       KSI       KSI    MINUTE       PSI
 1    120.0     221.   3.60(1)      .00     30.54      73.9      24.7
 2    160.0 9999999.   3.60(2)      .00     30.80      73.9      24.7
```

C27. Previously developed wave equation programs have been tested by comparing the predicted pile capacity with the value obtained from static load tests. This comparison could be meaningless for a number of reasons. The pile may gain or lose strength between driving and load testing.



C28. The dynamic soil constants may be incorrectly estimated. The driving system constants may not be correctly known and the hammer performance may not be as expected. Thus, a very large number of constants can be adjusted to achieve a satisfactory correlation with capacity. The value of these constants are certainly not unique.



WAVE EQUATION ERROR SOURCES

SOIL:

1. R_{ut} ..... DISTRIBUTION
2. J ..... DAMPING
3. q ..... QUAKE

DRIVING SYSTEM:

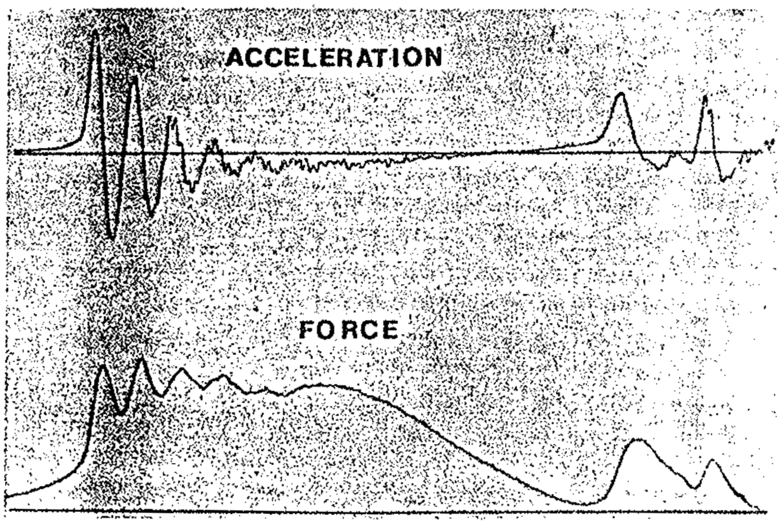
1. k ..... STIFFNESS
2. e ..... COEFF. of RESTITUTION

HAMMER:

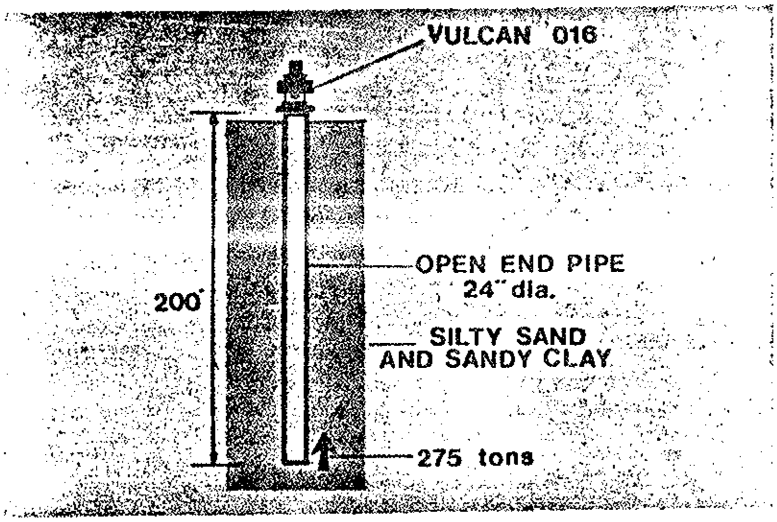
1. PERFORMANCE

C29. During the Piling Research Program at Case Western Reserve University a large volume of force and acceleration measurements were made at the pile top during driving.

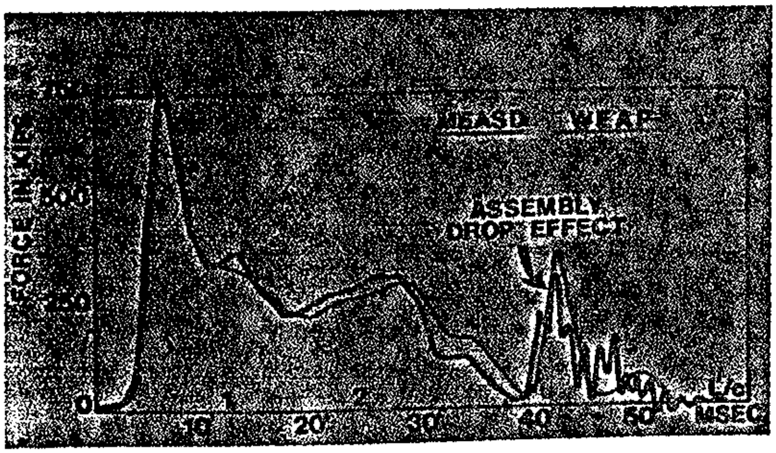
C30. This huge volume of data (several thousand hammer blows) was available to test the program. The available measurements consist of force and acceleration records at the pile top. These measurements were compared with the values obtained by WEAP. One of the major activities of the project was to provide recommendations on the values to be used for the hammer dynamic constants. Sixteen different jobs were so tested and the results are presented in the final report. Three of these examples will be shown here.



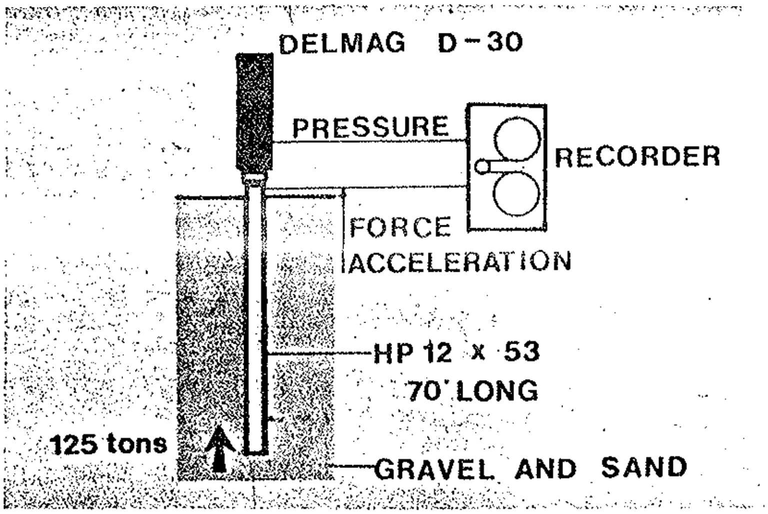
C31. The first case is an air/steam hammer driving a 200 foot long steel pipe pile. It was selected to test the assembly drop portion of the program.



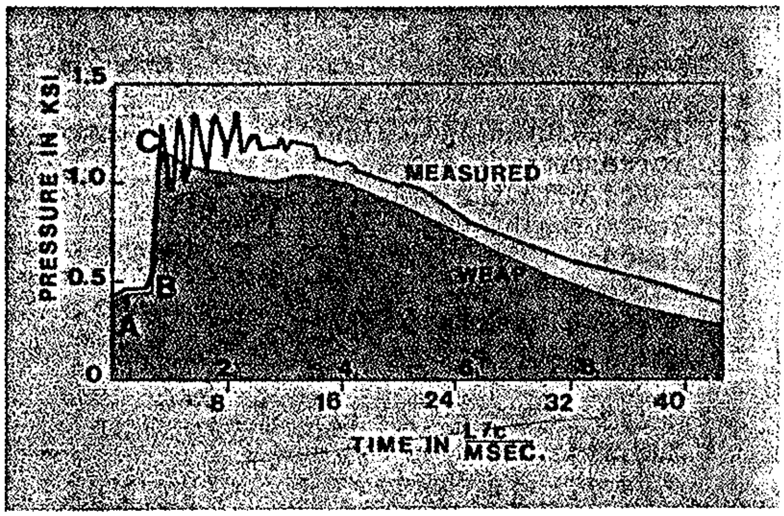
C32. The measured and calculated force records are shown here, with the measured force the heavy line. It is seen that the first maximum matches very well and the two curves agree well over their entire range. It should be noted that the time of the assembly drop was very accurately predicted.



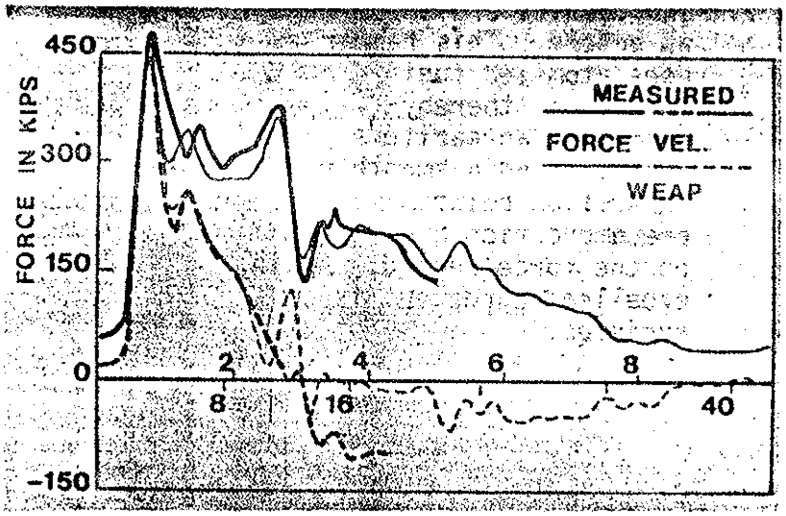
C33. The second test case was taken from a special test program on a DELMAG D-30 hammer. These tests were performed by Goble & Associates in 1971, for the Foundation Equipment Company of Newcomerstown, Ohio. In addition to force and velocity at the pile top the combustion chamber pressure was also measured.



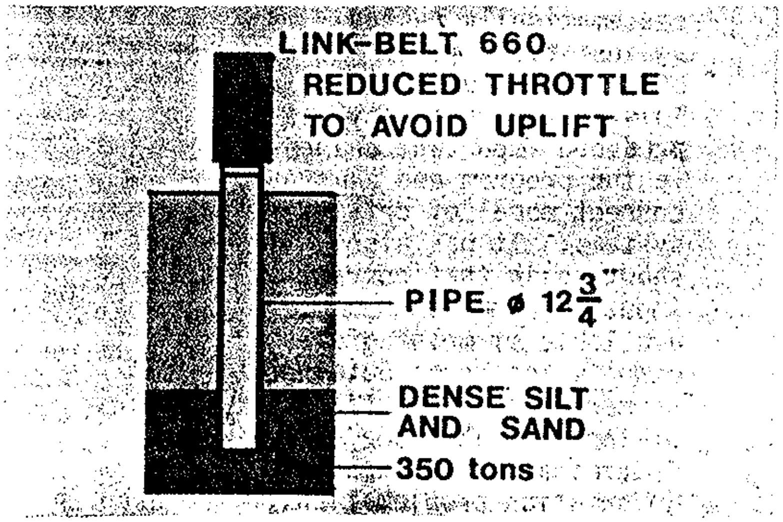
C34. The comparison of the pressure is shown here. Ram impact occurs at point A. Most of the precompression phase has not been included. The pressure remains constant for about 1 1/2 milliseconds until ignition begins at point B. Then it increases rapidly to point C. At ignition the measured record exhibits a high frequency oscillation characteristic of diesel engine ignition. Since this oscillation is unimportant for hammer performance no attempt is made to represent it. It can be seen that the pressure calculated by WEAP is similar but somewhat smaller than the measured value.



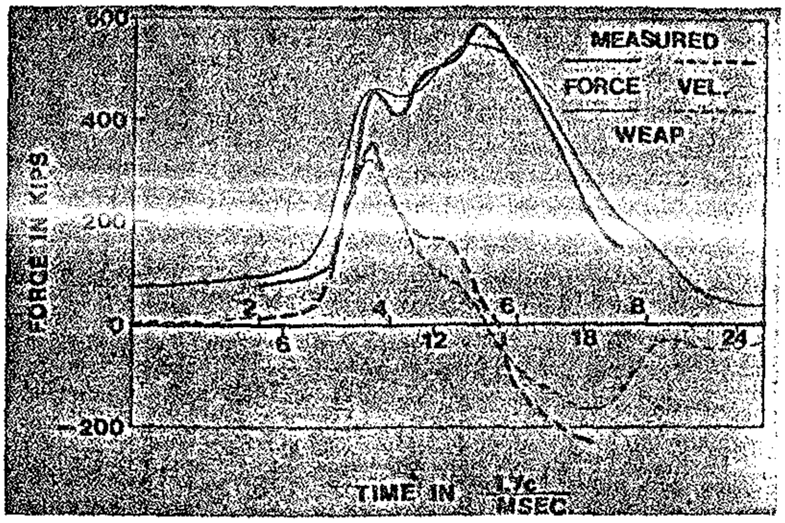
C35. A comparison of measured force and velocity for the top of this pile is shown here. The measured values are shown by the bold curves. The forces are solid lines and the velocity dashed. The agreement between these curves is quite good. In general, the velocity is a more sensitive quantity and, therefore, a better one to match. This sensitivity can be seen in this example at about 14 milliseconds where the measured and calculated velocities differ substantially.



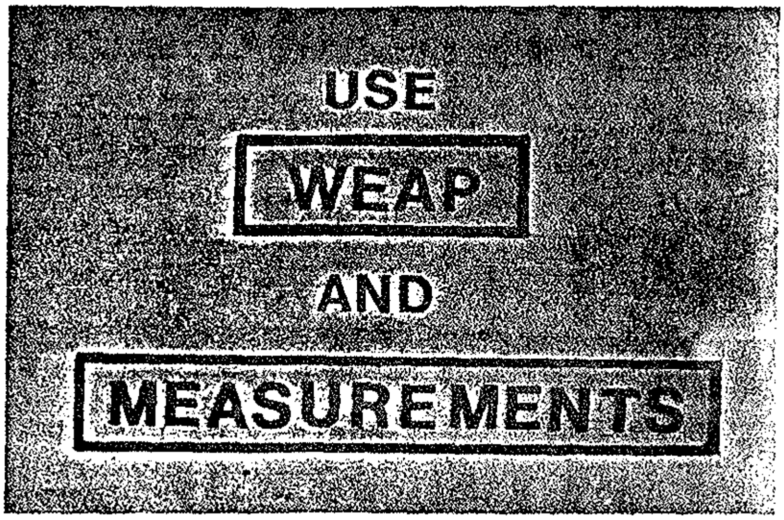
C36. As a third example consider a pile driven by a closed end diesel hammer, the Link-Belt 660. The pile was a 43 foot long pipe of 12-3/4 inch outside diameter. It was driven into very dense silt and sand.



C37. The results are shown here as before. This hammer uses atomized fuel injection, thereby producing an earlier ignition and a smoother transition between precompression and impact on the force record. Again, excellent agreement is achieved.



C38. The WEAP program is the first wave equation program to be extensively and systematically tested against field measurements of force and velocity. This testing activity has produced important changes in the program and a more correct model of driving systems. It has also shown again that correct input information must be available if meaningful results are to be obtained. In many cases the state-of-the-art makes the determination of input information problematical. The user should not be surprised if such cases produce results which differ from the field experience. The wave equation concept is another engineering tool, the results of which should be evaluated by a knowledgeable engineer. Happy Pile Driving!


USE

WEAP

AND

MEASUREMENTS