VULCAN IRON WORKS INC.
GENERAL OFFICES & FACTORY
2909 Riverside Drive
P.O. Box 5402
Chattanooga, Tennessee 37406
Telephone: 615-698-1581
Telex: 55-8412
Telecopier: 615-698-1587

ZWAVE Instruction Manual

Version 1.0 -- 02/22/1988

Vulcan Iron Works Inc.
P.O. Box 5402
Chattanooga, TN 37406
(800)742-6637/(615)698-1581

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P.O. Box 5402
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General Introduction

This manual details the installation and use of the ZWAVE wave equation pile driving analysis program, Version 1.0. ZWAVE is a finite difference program to analyze the stresses and penetration of piling during driving. It is designed only for use with external combustion hammers (ECH), and not with diesel hammers. Such hammers it can use would include air/steam and hydraulic hammers, both cushioned and cushionless.

ZWAVE is designed to be both simple to install and operate and advanced in its features. This manual is divided into two parts; one, a description of the theory and a comparison with actual driving results; two, a detailed description of the use and operation of the program.

I. THEORY AND COMPARISON

Introduction

For nearly thirty years now the finite difference wave equation analysis, as pioneered by Smith (1964), has been the state of the art in the analysis of the penetration resistance and dynamic stresses of pile driving by impact hammers. Although finite element routines such as Smith and Chow (1984) describe are now beginning to be used, the finite difference programs remain by far the predominant method of pile driving analysis, both for the prediction of pile behaviour during impact and analysis after driving. This is especially true in the wake of the development of microcomputers, for finite element analysis with these at present can be very consuming of both computer time and memory.

ZWAVE, developed at Vulcan Iron Works, is a new finite difference wave equation analysis program, designed to analyze the hammer/pile system behaviour of systems driven with external combustion hammers. By this, we mean hammers with the combustion of the motive fuel separate from the workings of the hammer itself, as opposed to internal combustion units such as the diesel hammers. This would include not only the air/steam hammers manufactured for a century by Vulcan and others, but also include the hydraulic hammers manufactured by such makers as Menck, Hydroblok, IHC, Udcomb, etc..

The development of the source for ZWAVE was begun by converting the TTI wave equation program as modified by Holloway (1975) to Microsoft Basica on an IBM PC-XT computer and compatibles; further details on the TTI program are given by Hirsch et.al. (1968,1976). The development of the program then proceeded using the Microsoft QuickBasic compiler, which both increased the speed of computation greatly and produced a stand-alone run file for ease of use and distribution. As a result of its origins and development, ZWAVE is similar in both basic theory and many details to existing wave equation programs. Thus, it would be redundant to describe here the basics of wave equation theory here; in addition to the TTI material referenced above, the documentation of WEAP/WEAP86 by Goble et.al. (1976,1986) is also relevant background for ZWAVE. What follows will describe only the improvements made in the development of ZWAVE will be described above.

Features

Numerical Method

In order to integrate the wave equation, both the Smith and TTI wave equation routines used a modified, first-order Euler method. This was doubtless a necessity in view of the computing speed available when these programs were developed. Later routines use higher order methods; predictor-corrector methods (WEAP86 -- Goble et.al. (1986)), Crank-Nicholson techniques (Levacher (1986)), fourth-order Runge-Kutta integration (BATLAB--Bossard and Corte (1984)), to say nothing about the use ofimpedance methods (ADIG -- Meunier (1984)). With a problem as non-linear in nature as this one, it would seem that, given the capabilities of current digital computers, at least a second order method be necessary for proper integration.

For ZWAVE, it was initially decided to use a Heun method with a single corrector, as described in Chapra and Canale (1985); however, problems were experienced with excessive deflections and velocities, generally originating at the slack in the pile head. Problems like this one are not unique to ZWAVE; other programs, such as WEAP86, deal with excessive deflections and stresses by introducing small amounts of dampening into the system. While any engineering material has some dampening in it, if possible this should not be used to correct problems with the numerical integration scheme.

At the most basic level, the problem is twofold. First, any time a continuous medium is divided up into finite segments, the fineness of the results will be adversely affected; this is demonstrated by Meirovitch (1975). Second, it is necessary at all times and all places in the system to maintain both conservation of momentum and energy. In the integration from acceleration to velocity, conservation of momentum is preserved because the integration equations are essentially those of momentum conservation. However, when the second stage of integration is reached (from velocity to displacement), in most methods the change in displacement is simply computed by multiplying the time by the velocity in some fashion. Thus in this step there is no guarantee that the conservation of energy be preserved. With higher, say fourth-order methods, the precision of the method will probably take care of this but for lower order methods this is not necessarily the case.

ZWAVE solves the second problem by modifying the Heun method and directly integrating both the velocity and the displacement from the acceleration, thus both reducing numerical error and insuring conservation of energy. ZWAVE also works to reduce integration error through double precision accumulation of sums and maintaining the time step as one half of the shortest spring-mass period found in the system.

Hammer Modeling

ZWAVE models pile hammers in one of two ways. For hammers with a hammer cushion but no anvil (not a pile accessory "anvil", but an anvil as is found on diesel hammers) are modeled with a rigid ram and a cushion spring. This will cover most air/steam hammers, such as the Vulcan hammers. For all other hammers, the user divides the ram into segments with masses and springs, as is done with piles.

Segment Generation

ZWAVE uses automatic segment property generation throughout the program. For pile and cushionless hammer segments, the user inputs the length, cross-sectional area, and material; the program computes the spring and mass values. A similar algorithm is used for hammer and pile cushions. Contrary to much current practice, ZWAVE concentrates the mass in the centre of the segment, as is done in the model of Van Weele and Kay (1984). Strictly speaking, this is the correct practice for any finite difference method. The only really serious side effect of this is to create a massless node at the pile toe; this is dealt with with positional averaging techniques.

Plastic Cushions

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Virtually all pile and hammer cushions are plastic to some degree. The amount of plasticity of a cushion is expressed by the coefficient of restitution, which is in fact the square of the ratio of the energy put into the cushion during compression to the energy gotten back from the cushion during relaxation.

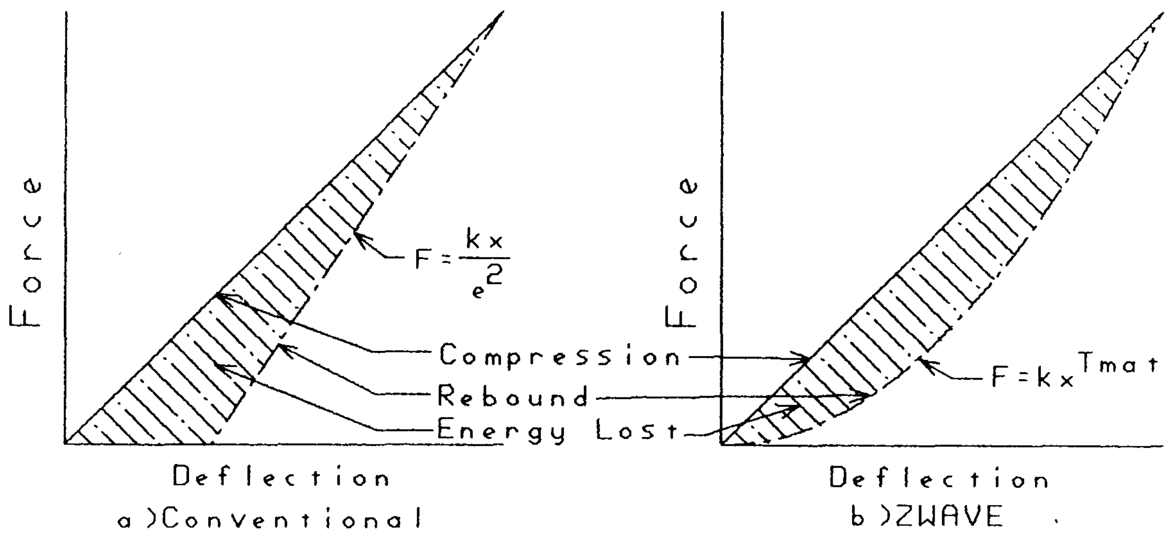

Figure 1 Cushion Models for Plastic Cushions

Most wave equation analyses handle the compression and relaxation as shown in Figure 1a, using straight line compression and relaxation functions. The most serious problem with this is that the cushion completely unloads before the absolute compression of the cushion spring reaches zero, forcing some elaborate algorithms to deal with the resulting gap. While this gap exists with real cushions, it is a serious problem only while the cushion is being "run in" and not when it has been in use for a while.

To simplify matters, ZWAVE retains the linear compression function, but uses an exponential relaxation function, as shown in Figure 1b, which results in zero force at zero absolute compression for both compression and relaxation and some cushion force for any given cushion compression. The exponent is called Tmat; it is computed directly from the coefficient of restitution by

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$$Tmat = 2/e.-1, \quad 0<e<=1 \qquad (1)$$

and is computed so that the energy loss ratio in the cushion from compression and relaxation is identical to both that used previously in wave equation analyses and taken experimentally in cushion tests such as that described in the standard of the Deep Foundations Institute (1986).

Shaft Resistance

The shaft resistance model in ZWAVE is somewhat different in two respects from many previous wave equation analysis programs.

First, as is the case with WEAP86, a truly viscous soil model is used for the dampening component. To arrive at this dampening coefficient, when conventional Smith values are used, the Smith dampening Js is multiplied by the local resistance. (This is also the case with the toe.)

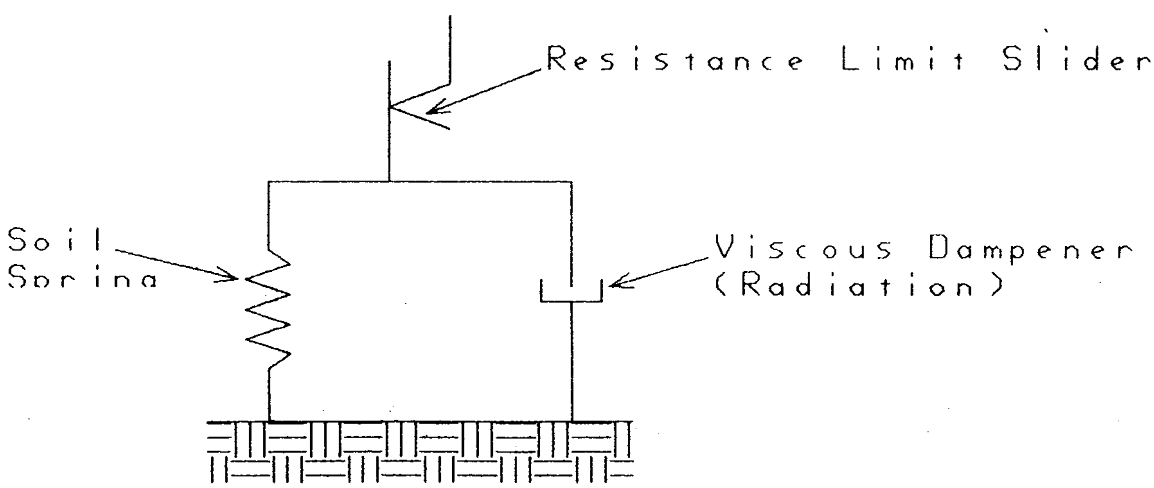

Figure 2 Soil Model for ZWAVE

Second, the soil model is as diagrammed in Figure 2. This is taken primarily from the work of Corte and Lepert (1986), and additionally from Randolph and Simons (1986). The major practical result of this is that at no time in the analysis of a pile does the dynamic exceed the static

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resistance; this tends to give the shaft friction effect like that of a rigid-plastic soil model. In view of this, ZWAVE follows the recommendation of Corte and Lepert (1986) that traditionally used dampening values be multiplied by 7.5.

Advanced Soil Model

The same research used in the development of ZWAVE's shaft resistance model sets forth the procedure for the computation of soil properties such as soil spring constant and soil dampening from basic soil properties. ZWAVE makes provision for the user to take advantage of this recent work and, for single cases where the shaft and toe resistance per unit area of pile surface is known, to compute the soil spring constant, quake, and dampening. If we define the quantities of first soil shear wave velocity

$$c = .(G/p) \quad (2)$$

and of soil relative impedance

$$IO = p.c \quad (3)$$

we can compute the shaft spring constant for an element by the equation

$$Ksh = ..G.L \quad (4)$$

and the toe spring constant as

$$Kt = 2.D.G/(1-ü) \quad (5)$$

while the shaft dampening (or more accurately the shaft soil impedance) is

$$Csh = ..D.L.IO \quad (6)$$

and the toe soil impedance/dampening is

$$Ct = 1.08.A.IO/(1-ü) \quad (7)$$

To utilize these equations, in addition to the resistance values, the user needs only input the soil shear modulus of elasticity, soil density, and soil Poisson's Ratio. Two especially important items should be noted; first, the soil "dampening" is in reality a recognition that the soil is a continuum (more or less) of distributed mass and elasticity, and second, that the true "viscous dampening" of the soil is neglected.

Although this type of soil modeling has a great deal of promise, both in improving the accuracy of the analysis and in estimating soil dynamic properties from simple soil physical constants, much more work needs to be done in the practical integration of the wave equation with these properties.

Input Format

Most of the currently used wave equation programs started out (and are still used in many installations) as batch FORTRAN programs on a mainframe or minicomputer with card input of data. Some have been converted for use on microcomputers, but the legacy of card input is still strong in the way the input is done.

ZWAVE was designed from the start for microcomputers, and specifically the IBM PC-XT and its compatibles; thus, an entirely new input format, independent of card input considerations, was chosen. Having loaded the program and commenced execution, the computer asks the user a series of questions about the hammer/pile system he or she wants to analyse. In the course of the input, the program makes decisions as to the type and number of questions it will need to ask in order to allow complete input of data. Also, to speed input, default values for certain variables are offered, and many variables (such as spring and mass variables) are automatically computed.

Rebound and Plastic Soil Deformation

ZWAVE, in common with other wave equation programs, computes the pile set by subtracting from the maximum deflection of the tip the total soil quake, which is a weighted average of the different soil quakes around the pile, computed in the same way as Goble et.al. (1986). In addition to this, to provide additional data on soil deformation, ZWAVE computes the amount of energy the system expends in plastically deforming the soil. This energy is computed as the sum of the products of the individual element soil plastic deflections and the element resistances. Theoretically, at least, one could compute the set of the pile as

$$s = Wfp/R \quad (8)$$

as shown by Kümmel (1984) and Warrington (1987). This result does not always agree with the conventionally computed figure; this is probably the result of several factors such as the lack of residual stress analysis (RSA) capability with ZWAVE or deficient soil properties.

Example Problem and Comparison with Actual Driving

To demonstrate both the workings of ZWAVE and at the same time a comparison of ZWAVE's output with the actual results, we will consider the case of a test pile programme commissioned by the Jacksonville Electric Authority at the site of their Blount Island coal loading terminal on the St. John's River in Jacksonville, FL. The piles were a mixture of both 14" and 20" square concrete piles and 16" and 24" diameter, 1/2" wall thickness steel pipe piles. These were driven during April and May of 1987 into a variety of fine sands. The piling were first driven, then, during the restrike, data concerning the pile's behaviour were taken using a Pile Driving Analyser; subsequently, the data was analyzed with the CAPWAPC computer program. Static load tests were also performed on the piling, following ASTM D-1143 for the compressive tests and ASTM D-3689 for the tension tests. The pile driving contractor was S.K. Whitty and Co, Inc. of New Orleans, LA, who used a Vulcan 510 for most of the driving and all of the restrikes. It is interesting to note that, in addition to this being the first job where ZWAVE was used for data comparison, it was also the first job for a Vulcan 510 to be used for pile driving. Geotechnical supervision was provided by Law Engineering. Further details of this jobsite and the results are described by Kett and McDaniel (1987).

Data from ten piles were made available; unfortunately, load tests to failure following the Davisson criterion were valid for only five of the piles. Despite this, ZWAVE was run to compare with the actual results for all the piles, using the following procedure to develop the comparison:

1)Using manufacturer's data for the hammer and standard data for the cushion properties, the 510 hammer was modeled. To show this, and to show ZWAVE's input format, a sample of the hammer data input screen is shown in Figure 3.

2)Pile data was developed both from the driving log data and the CAPWAPC results, especially with the element division of the piles, which was made to be as close to the ones generated by CAPWAPC as possible.

3)Soil data was taken from the CAPWAPC, which included the soil resistance distribution, CAPWAPC's own estimate of the pile capacity, and soil quake and dampening properties.

4)Since no direct measurement of the hammer's mechanical efficiency was made, for each pile ZWAVE was run with the data from Steps (1-3) in increments of 5% until the closest match was made between CAPWAPC's and ZWAVE's maximum pile head enthru. Using this method, efficiency estimates ranged from 35-55%, which is probably explained by the fact that the number of blows during the restrike were relatively few, not affording the hammer's operator the chance to bring the ram up to full stroke before measurements were taken.

5)Using all the data above except CAPWAPC's total bearing capacity data, a survey run was made for each pile. The actual restrike blow-count from the driving logs was taken and corresponding pile capacity estimates from ZWAVE were then interpolated.

The results of this procedure are summarized in Table 1. Piles A-E have the load test data. while Piles F-J do not. All piles returned a comparison for maximum tension and compression stresses. In general, the compressive stress correlation came out well, just slightly low in general, while the tension stress correlation was not as

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satisfactory, but in general was high. As for the bearing capacity/blow-count comparison, in general when CAPWAPC's capacity estimate was used, ZWAVE's blow-count came back lower than that of the driving logs, but when the survey interpolation was performed, ZWAVE's estimate improved for four of the five piles with a refusal load test, and on these four piles (A,B,C, and D) the capacity estimates are at least on par with and sometimes better than that of CAPWAPC.

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Table 1
Results of Data Comparison

Pile	Pile Type	Maximum Stress, ksi Compressive		Tensile		Pile Bearing Capacity, kips			Blow Count, BPF		% Capacity Shaft Friction
Data Source>>>		C	Z	C	Z	C	Z	LT	DL	Z	C
A	2	2.08	1.67	-.21	-.25	361	456-320	360	84-41	50	61
B	2	2.47	1.87	-.37	-.22	474	608-542	576	156-107	72	64
C	1	2.83	2.96	-.36	-.44	477	442	344	160	235	92
D	2	1.56	1.62	-.24	-.07	457	530	600	432	204	83
E	2	2.41	2.07	-.30	-.48	436	650	280	120	54	82
F	1	3.15	3.30	-.75	-.51	521	560-477		180-96	126	14
G	4	18.68	16.34	-2.08	-6.60	303	528-387		72-36	24	96
H	4	19.60	18.78	-2.26	-1.12	878	997		592	176	72
I	4	20.19	18.56	-1.16	-4.50	910	909		576	540	44
J	3	21.92	22.36	-1.24	-1.26	491	575		.	259	70

Notes to Table 1:

1)Pile Types: 1 = 14" Square Concrete
2 = 20" Square Concrete
3 = 16" Diameter Steel Pipe
4 = 24" Diameter Steel Pipe

2)Data Sources: C = CAPWAPC
Z = ZWAVE
LT = Load Tests, Davisson Criteria
DL = Driving Logs

3)ZWAVE Pile Capacities interpolated from survey runs and driving log blow-counts.

4)When two values for ZWAVE Load Capacity/Driving Log blow counts are encountered, this results from blow-count variations during restrike.

One additional item of note concerns the shaft friction. As Table 1 shows, the percentage of shaft friction varied widely. There is no apparent effect of the proportion of shaft friction to total friction in the comparisons. Whether the new shaft soil model produces superior results in and of itself is hard to tell with this data, and the advanced soil model was not invoked in this study; however, there is no evident degradation of the results with this model.

II. OPERATION

Installation

ZWAVE is simple to install and run; however, before the user starts he or she needs to give some attention to the hardware the program is to be used on. The following computer setup is <u>necessary</u> to run ZWAVE:

1)IBM PC-XT or compatible--DOS 2.0 or higher
2)256K of RAM Memory
3)One (1) 360K 5.5" or 720K 3.5" floppy disk drive.
4)IBM CGA, EGA, or VGA Graphics Monitor or Equivalent, Monochrome or Colour
5)Printer (EPSON compatible dot matrix is preferable)

To set ZWAVE up on either hard or floppy disk, the disk must be bootable, and the COMMAND.COM in the same directory as ZWAVE. There is only one file necessary for ZWAVE, namely ZWAVE.EXE, and this can be copied from the original disk to the working disk before use begins. Once this module is on the disk in the default drive, all that is necessary is to type ZWAVE and the Return key.

Input

Once ZWAVE is started, the screen will display the title block in its centre, which will show the time, date, copyright notice, and manufacturer. From there, the program will ask you a series of questions about options and various input data for the program. Since the data required for a successful wave equation analysis is dependent upon the options you choose, you will not be asked the same set of data questions for each case and situation. Most inputs require typing in a number and pressing "Enter" or "Return"; however, many inputs are a single character or number; once you have pressed the key, the program will take the input and proceed to the next step without you having to press "Enter" or "Return".

Many of the questions that you are asked have "default" values, namely those which are assigned to the variable in question when you respond to the question by simply pressing the "Enter" or "Return" key. These default values are given in this manual. This is a time saving feature to allow the user easy access to the more likely choices in the program; it is <u>not</u> a technical endorsement of these choices, and not an attempt on ZWAVE's part to second guess

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your hammer/pile/soil system.

The input is divided into four groups, each of which is input as a group before the screen clears itself and accepts new data. Should you make an error in input during a given screen, simply press "Enter" or "Return" or whatever is necessary until the program asks you "Accept this screen y/n?", at which time you enter "n" and the program will start the screen all over again. These "screens" are as follows:

1)Opening screen (title block and output file location).
2)Hammer Data.
3)Pile Data.
4)Soil Data.

Opening Screen

Once the title block is displayed, the first screen of data asks for one piece of information, namely where the output of the program is to be directed. There are two options, namely 1)to the printer (the default option), and 2)to a disk, hard or floppy. Should the latter be chosen, the pathname\filename of the file is asked. ZWAVE does support pathnames; however, should you not input the pathname, the output will appear in the same disk drive and directory and/or subdirectory you have ZWAVE located in.

This completes the first screen of data. The screen now clears itself and begins afresh with the hammer system data.

Hammer Data

Rated Striking Energy of the Hammer, ft-kips.

Hammer Mechanical Efficiency, Percent:This takes into account the losses in the drop of the ram from the stroke implied above to the impact point. It doesn't include losses in the cushion--these are dealt with separately.

Hammer Anvil:This allows you to account for a hammer anvil. There is some confusion as to terminology with anvils. For the purposes of this program, an anvil is a block below the ram but integral to the hammer, as with most diesel hammers (although this program is not suitable for diesel hammers). The drive cap is the adapter block between the hammer and the pile. All pile driving systems in this program must have drive caps but anvils are optional. Default for this option is no anvil.

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Cushion Material: You are asked whether the hammer has any cushioning between the ram and the cap, or between the anvil and the cap. Most air/steam hammers have cushioning, while many of the hydraulic hammers do not. Default for this option is yes, there is cushion material.

At this point the next data input depends upon the previous two inputs.

Hammers with cushion but no anvil: The following sequence of inputs comes up:

1) Ram Weight, lbs.
2) Cushion Pot Diameter, in. (if not round, take the area and convert to equivalent diameter for same area.)
3) Cushion Pot Length, in. (Depth of cushion stack).
4) Cushion Pot Tangent Modulus of Elasticity, ksi.
5) Cushion Pot Coefficient of Restitution.

All Other Hammer Types:

Before we get into the input of the ram data there is a little explanation necessary of how to go about setting up the ram in the program.

For rams with a cushion and no anvil, ZWAVE models these as a rigid ram with cushion pot having all the flexibility; however, in all other cases ZWAVE requires dividing the ram into discrete elements with springs and masses. For these cases, ZWAVE is set up to afford the user simple ram data input without a large number of manual calculations; however, the setting up of the ram elements takes a little forethought. ZWAVE simplifies input by allowing the user to input segments or parts of a ram where there is uniform cross-sectional area, material, etc. From here the user specifies the number of discrete elements necessary for analysis. The program then numbers the elements and computes the masses and spring constants (remember always that the spring matched with the element is the spring below the element!). Each time a change in the cross sectional area or material of the ram takes place, the user must specify a new configuration. In the element division of a ram, the user should keep in mind that, when smaller elements are used, the time step to advance the integration is shortened, thus lengthening run time and increasing the possibility of round-off error.

With all this in mind, we then proceed to input the ram data:

Number of Ram Configurations: This allows the user to input the number of different ram materials and cross sectional area that he or she has in the total ram train. (Default is one.) From here, for each configuration or segment the program asks for the following information:

Average Cross-Sectional Area, sq. in. (No Default)
Step Length, in. (No Default)
Number of Step Elements. (Default is One)
Material Code. This is an integer code which then calls on ZWAVE's data base of material properties. The available materials and codes are as follows: (Default is Steel, 1):

1) Steel
2) Cast Iron
3) Lead
4) Water
5) Aluminum
6) Bronze
7) Concrete
8) Wood

When you press one of these numbers, the program will respond by spelling out the material you have chosen. If you choose concrete -- an unlikely choice for rams and anvils, but not for piles -- you will additionally be asked the elastic modulus of the concrete, as this varies considerably amongst different types of concrete. Default value is 4250 ksi.

Hammers with neither cushion nor anvil proceed directly to the input of drive cap weight at this point. The other proceed with inputs as follows:

Anvil Cross Sectional Area, sq.in. (No default)
Anvil Length, in. (No default)
Anvil Material Code (Default is Steel--same input format as with rams)
Cushion Pot Diameter, in. (No default)

Hammers with an anvil but no cushion drop out of the input sequence and proceed directly to the input of the drive cap weight at this point. Hammers with both an anvil and cushion proceed with inputs as follows:

Cushion Pot Length, in. (Default is internally computed)
Cushion Pot Tangent Modulus of Elasticity, ksi (Default is 250 ksi)
Cushion Pot Coefficient of Restitution, dimensionless

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(Default is 1)

No matter what options you have chosen for the above, the program returns to a uniform input sequence.

Drive Cap Weight, lbs. (No default) This is mandatory for all runs.

Pile Cushion Thickness, in. (Default is no pile cushion.) If there is one, enter the thickness here. The program will then ask you for a)Pile cushion tangent modulus of elasticity, ksi and b)pile cushion coefficient of restitution.

This completes the second screen.

Pile Data

The third screen now appears for the pile data, but before we get into this there is a little explanation necessary of how to go about setting up your pile in the program.

ZWAVE is set up to afford the user simple pile data input without a large number of manual calculations; however, the setting up of the pile elements takes a little forethought. Like most wave equation programs, ZWAVE divides up the pile into discrete elements, but in order to simplify input it also allows the user to input segments or parts of a pile where one has uniform cross sectional area, material, etc. From here the user divides up the segment into the discrete elements necessary for analysis. The program then numbers the elements and computes the masses and spring constants (remember always that the spring matched with the element is the spring below the element!). In setting up the element structure of the pile, the user must make sure that the element boundaries fall where all of the following occur along the length of the pile:

1)Splices, to allow the insertion of slack.
2)Ground Surface, as ZWAVE is not really equipped to handle an element partially in the earth and partially out.
3)End of soil plug, in open ended pile piles.
4)Change in material or cross sectional area.

Elements should be no shorter than 10'. Although most wave equation programs advise against it, non-uniform section lengths are no problem with ZWAVE, but the user should realize that, when smaller elements are used, the time step to advance the integration is shortened, thus lengthening run time and increasing the possibility of round-off error.

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With all this in mind, we then proceed to input the pile data:

Number of Pile Configurations: This allows the user to input the number of different types of piles he or she has in the total pile train. The user may also take this opportunity to split the pile for taper (variable area), splits for ground or splice, or change in element length. Default is one (1) pile configuration. From here, for each configuration or segment the program asks for the following information:

Slack Entry Option: Slack in the system takes place where there is some kind of joint in the pile, such as in section connectors. Slack also takes place between ram and cap or cap and pile, but this slack is automatically entered by the program. The option you choose here will allow you to enter joint slack between elements in the pile. Default for this option is no slack entry.

The input will then cycle through the number of pile configurations you have specified, asking for each the following:

Average Cross-Sectional Area, sq. in.
Pile Diameter, in. For round piles, this is obvious; for pile that are not round, take the total length around the edge of the pile cross-section and divide by pi for the equivalent diameter.
Configuration Length, ft. The total configuration length for the segment.
Number of Segments. The program suggests a minimum number of segments based on a maximum segment length of 10'. This is the default value.
Material Code. The material code is the same code as used with the cushionless rams. (Default is Steel (1).)
Element Slack, in. If you have called for manual input of element slacks, the program will then ask for the element slack for each element in the pile configuration.

ZWAVE then takes the configuration and divides it up into even length elements and does all the computations of weight and spring constant for you.

One thing to watch for here is the number of pile elements you end up with. ZWAVE has capacity for only 51 elements, and, in addition to the hammer and cap elements, the pile tip requires one element. The program will inform you when you specify too many elements but by this time it is

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usually too late to do anything about it.

Once the pile configuration data is input, ZWAVE will want to know about two important pile parameters:

Open or Closed Ended Pile: ZWAVE will ask you whether your pile is on the one hand open ended or solid or on the other hand closed ended. For open ended piling, ZWAVE calculates the area as the cross sectional area of the lowest pile configuration. For closed ended piling, ZWAVE will take the diameter of the lowest pile configuration and compute the area=0.785*Diameter squared. This area is especially important when advanced soil input is being used and careful attention to its computation is needed in these cases.

Batter or Plumb Pile:This allows you to specify whether the pile is batter of plumb. Default is plumb. If the user has told ZWAVE that it is driving a batter pile, ZWAVE asks for the pile batter in the customary 1:X format.

This completes the pile input.

Soil Input

The screen now clears itself and asks you to input the data for the soil data for this case. The input required here is as follows:

Tip Elevation. ZWAVE defines tip elevation as the distance from the very tip of the pile to where soil resistance begins.

Basic or Advanced Soil Input. Input "b" or "a". Basic soil input is the classical, Smith type input for soil quake and dampening. Advanced soil input uses a new method of computing these values, detailed by Randolph and Simons (1986).

The next series of inputs depends upon whether you are using basic or advanced soil input.

Basic Soil Input:
Tip Quake, in. (Default is 0.1")
Side Quake, in. (Default is 0.1")
Tip Smith Damping Constant, sec/ft (Default is 0.15 sec/ft)
Side Smith Damping Constant, sec/ft (Default is 0.05 sec/ft)

Skin Friction Distribution, whether it is uniform,

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triangular, or manually input. For uniform or triangular input, the skin friction is proportioned to the length of the pile.
Total Pile Capacity, in kips. If you desire a survey of the different pile capacities versus blow count resistance, enter zero.
Detailed Output, whether you would like a detailed output showing certain important parameters for each run.

Percentage of Total Pile Capacity Developed at Tip, Percent (Uniform and Triangular Distributions Only--No Default).

Percentage of Capacity for Each Element, Percent (Manual Distribution Only--No Default). For manual distribution, the program will ask for the capacity percentage of the total capacity for each element, including the tip.

Advanced Soil Input:

Soil Shear Modulus of Elasticity, psi
Soil Specific Gravity, dimensionless (default is 2.65)
Soil Poissons's Ratio, dimensionless (default is 0.33)
Plug Length, ft. (Open Ended Pile Only--No Default)
Average Skin Friction, psi.
Tip Resistance, psi.
Detailed Output, same as basic input. Soil surveys are not allowed with the advanced input as the soil properties are too interdependent to make the results meaningful.

And that concludes the input for ZWAVE. Should you need to terminate a run during computation, you can press any key; ZWAVE will ask you whether you would like a new run, without exiting its environment. At the end of a problem, the program will ask you if there are any more problems to be solved. If there are, simply press the "y" key; if not, press the "n" or "return" key.

For problem entry after the first problem, the input is the same as above, except that, before each section of input (except for the basic input, which is always entered) the program will ask whether you want that section of input or not. For example, before the hammer input screen comes up, it will ask you the question

New hammer input y/n?".

If you desire to use the same hammer, press "n" and Return or just Return; if a new hammer is needed, then press "y" and return. The same type of routine applies to pile and soil input.

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Because of its internal structure, ZWAVE cannot accept every new/old combination you can give to it. For instance, ZWAVE will not accept a new pile and the old soil model because of the possibility that the pile will be of different length and thus confuse its resistance structure--also, a change of length or pile size will probably occasion a change in soil conditions anyway. ZWAVE is set up to deal with this by simply bringing up the necessary screen to insure that the proper input it made. Nevertheless, this feature will save time by eliminating repetitive input.

Output

Now that you have loaded the data into ZWAVE, some results should come out. This section looks at the output with a sample run.

Input:A Vulcan 560 hammer is required to drive a 200' long steel pipe, 72" in diameter. The pipe has two wall thicknesses; the top 100' has a 2" wall thickness (Area=439.82 sq. in.), the lower 100' has a 3" wall thickness (Area=650.31 sq. in.). The tip elevation is 100'. The soil has standard (default) quake and damping properties. We don't know the actual capacity, so we'll run a survey to start with, but we think that the skin friction is uniformly distributed. The pile is being driven closed ended, and 25% of the capacity/resistance is at the tip.

The 560 has a rated striking energy of 312.5 ft-kips and a ram weight of 62.5 kips. We assume a plumb efficiency of 70%. The cushion pot of a 560 with an integral ring pot is 31 1/4" in diameter and 7 1/2" deep (we ignore the top plate). We are using a hypothetical cushion material with a tangent modulus of elasticity of 250 ksi (the maximum permitted in a standard Vulcan cushion pot) and a coefficient of restitution of 0.8. The pipe cap weighs 32.055 kips.

The pile we are driving is batter pile, 1:5 batter. Using an element length of 10', we will have 10 elements for the 2" wall thickness section and 10 likewise for the 3" section. There are no joints and no manual slack input is needed.

The results print out as on the following pages:

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ZWAVE, the Wave Equation Analyzer from Vulcan Iron Works Inc.

Case Manual Sample and Problem 1

Analysis Done 01-18-1988 and the Options Chosen at 18:04:25 are:

Automatic Entry of Slack Values
Basic Soil Input
Multiple Calculations of Ru vs. BPF
Uniform Side Distribution of Skin Friction
Batter Pile, 1: 5
Cushioned Hammer Without Anvil
No Pile Cushion

General Parameters Used

Rated Striking Energy of Hammer, ft-kips	312.500
Ram Weight, kips	62.500
Hammer Mechanical Efficiency, Percent	70.000
Net Striking Velocity, ft/sec	15.013
Ultimate Pile Load Capacity, kips	2383.725
Pile Weight, kips	367.592
Tip Elevation of Pile, ft.	100.000
Maximum Number of Time Steps	281.000
Number of Time Steps Per Second	4697.452
Element Determining Time Step	22.000
System Length, in.	0.453
Maximum Pile Elastic Compression, in.	0.457
Dist. of Wave Travel in TPM per Time Step, ft.	3.537
Force Coefficient	0.568
VIWI Formula Pile Force, kips	6528.100
VIWI Formula Pile Stress, psi	14842.661

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GENERAL OFFICES & FACTORY
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Element Data for Case Manual Sample and Problem 1

M	Area	Z'	W	K	COR	K'	Quake	C/Z	Ru%	Slack	Diameter
1	766.6	1.000	62500	25553	0.800	0	0.000	0.0000	0.00	1000.0	31.250
2	439.8	1.000	32055	211929	1.000	0	0.000	0.0000	0.00	1000.0	72.000
3	439.8	0.992	14831	105965	1.000	0	0.000	0.0000	0.00	0.0	72.000
4	439.8	0.992	14831	105965	1.000	0	0.000	0.0000	0.00	0.0	72.000
5	439.8	0.992	14831	105965	1.000	0	0.000	0.0000	0.00	0.0	72.000
6	439.8	0.992	14831	105965	1.000	0	0.000	0.0000	0.00	0.0	72.000
7	439.8	0.992	14831	105965	1.000	0	0.000	0.0000	0.00	0.0	72.000
8	439.8	0.992	14831	105965	1.000	0	0.000	0.0000	0.00	0.0	72.000
9	439.8	0.992	14831	105965	1.000	0	0.000	0.0000	0.00	0.0	72.000
10	439.8	0.992	14831	105965	1.000	0	0.000	0.0000	0.00	0.0	72.000
11	439.8	0.992	14831	105965	1.000	0	0.000	0.0000	0.00	0.0	72.000
12	439.8	0.992	14831	126425	1.000	0	0.000	0.0000	0.00	0.0	72.000
13	650.3	1.467	21928	156677	1.000	1788	0.100	0.0592	7.50	0.0	72.000
14	650.3	1.467	21928	156677	1.000	1788	0.100	0.0592	7.50	0.0	72.000
15	650.3	1.467	21928	156677	1.000	1788	0.100	0.0592	7.50	0.0	72.000
16	650.3	1.467	21928	156677	1.000	1788	0.100	0.0592	7.50	0.0	72.000
17	650.3	1.467	21928	156677	1.000	1788	0.100	0.0592	7.50	0.0	72.000
18	650.3	1.467	21928	156677	1.000	1788	0.100	0.0592	7.50	0.0	72.000
19	650.3	1.467	21928	156677	1.000	1788	0.100	0.0592	7.50	0.0	72.000
20	650.3	1.467	21928	156677	1.000	1788	0.100	0.0592	7.50	0.0	72.000
21	650.3	1.467	21928	156677	1.000	1788	0.100	0.0592	7.50	0.0	72.000
22	650.3	1.467	21928	313355	1.000	1788	0.100	0.0592	7.50	1000.0	72.000
23	4069.4	9.178	0	0	1.000	5959	0.100	0.0126	25.00	0.0	72.000

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Pile Capacity Survey for Case Manual Sample and Problem 1

Vul/BPF	/Act	RuTotal	TipForce	#	Max C-Str	#	Max T-Str	#	Enthru	Wfp
16.3	20.9	2384	1709	75	+18323	12	-11512	11	186.3	107.4
30.2	32.5	3371	2255	75	+18463	12	-9159	11	186.3	101.5
48.7	38.5	4129	2617	75	+18575	12	-7511	11	186.3	103.6
76.7	44.6	4767	2889	75	+18671	12	-6187	11	186.3	102.3
126.0	51.2	5330	3109	74	+18757	12	-5003	11	186.3	100.4
239.8	58.3	5839	3294	74	+18836	12	-4171	11	186.3	98.4
806.6	66.2	6307	3452	74	+18908	12	-3599	11	186.3	96.4
0.0	75.1	6742	3572	75	+18976	12	-3199	11	186.3	94.1
0.0	85.2	7151	3690	75	+19039	12	-2909	11	186.3	91.8
0.0	96.9	7538	3785	75	+19099	12	-2961	12	186.3	89.2
0.0	110.7	7906	3857	75	+19156	12	-3078	12	186.3	86.8
0.0	126.9	8257	3919	75	+19211	12	-3175	12	186.3	84.2
0.0	146.5	8595	3935	76	+19267	12	-3257	12	186.3	81.6
0.0	171.0	8919	3980	76	+19322	12	-3328	12	186.3	79.0
0.0	201.1	9232	3982	76	+19374	12	-3390	12	186.3	76.4
0.0	240.7	9535	3940	76	+19424	12	-3443	12	186.3	73.8
0.0	294.7	9828	3953	77	+19472	12	-3486	12	186.3	71.2
0.0	367.7	10113	3899	77	+19518	12	-3520	12	186.3	68.6
0.0	480.3	10390	3842	77	+19564	12	-3548	12	186.3	66.0
0.0	661.0	10660	3783	77	+19608	12	-3572	12	186.3	63.4

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The End of ZWAVE Analysis, Case Manual Sample, Completed 01-18-1988 at 18:17:32

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The first page shows three main groups of items: 1) Title and time, 2) a list of options chosen, and 3) some of the basic parameters of the program. These are explained as follows:

Options Chosen

Slack Value Entry: Whether it was automatic or manual.
Soil Input Type: Whether it was basic or advanced.
Resistance Format: Whether it was for a single case or multiple (survey) case. For the latter, the program generates its own set of resistances, based on its own estimate of what the maximum potential penetrable resistance might be.
Side Friction Distribution: Whether this is uniform, triangular, or manual (basic soil input only).
Pile Inclination: Whether the pile is a batter pile (no output here for plumb piles), and what the batter is.
Cushion and Anvil Options: What combination of cushion and anvil a hammer has.
Pile Cushion Option: Whether a pile cushion is being used.

General Parameters

Rated Striking Energy: The ideal kinetic, mechanical output of a hammer, without taking into account losses due to mechanical and cushion losses.
Ram Weight: The weight of the striking parts of the hammer.
Hammer Mechanical Efficiency: The percentage of the rated energy of the hammer that actually constitutes the kinetic, impacting energy of the hammer.
Net Striking Velocity: The velocity used by ZWAVE as the initial velocity of the ram. All other initial velocities of anvil, cap, and pile are zero.
Ultimate Pile Load Capacity: For single cases, the input (Basic Soil) or computed (Advanced Soil) ultimate capacity of the pile. For surveys, the first ultimate load capacity generated by the program--the full series of values are given in the results table.
Pile Weight: The weight of the pile.
Tip Elevation of Pile: The distance from the toe of the pile to the surface of the soil, or at least the soil that is generating significant resistance.
Maximum Number of Time Steps: The maximum number of time steps that ZWAVE will execute during any single complete cycle. ZWAVE is set up to have cycles last for no more

than four traverses from one end of the system (not just the pile) to the other.
Number of Time Steps Per Second: ZWAVE searches the system and computes the natural frequency of each adjacent spring-mass combination. The time step is half of the smallest natural frequency it finds. The number is the inverse of this time step.
Element Determining Time Step: The mass element at which this smallest time step was found.
System Length: A quantity describing the driving capability of a hammer, detailed by Warrington (1987).
Maximum Pile Elastic Compression: The estimated elastic compression of the pile top when it is struck by the hammer, without consideration of the movement of the pile in the soil. The computation of this is described by Gonin (1985).
Distance of Wave Travel in Top Pile Material (TPM) per Time Step: The hammer-pile system generates a force-time curve that travels down the pile. This distance shows how far each point in that wave travels with each time step, in the pile material found in the top of the pile.
Force Coefficient: The ratio of the actual estimated maximum force to the maximum theoretical force in the pile with the existing system, as detailed by Warrington (1987).
VIWI Formula Pile Force: The estimated maximum force the hammer has on the pile, again as shown by Warrington (1987)
VIWI Formula Pile Stress: The force divided by the area of the pile top.

The second page shows details for the elements. The data, from left to right are as follows:

1) Element number.
2) Element cross sectional area, sq. in.
3) Impedance ratio, (Element Impedance)/(Hammer Impedance)
4) Element weight, lbs.
5) Element stiffness, kips/in. Remember that the spring referred to by this stiffness is the spring under the element and not above.
6) Coefficient of Restitution for Element.
7) Spring constant for the soil, kips/in.
8) Soil quake, in.
9) C/Z, dimensionless. Whether for basic or advanced soil input, ZWAVE uses pure viscous soil damping, and does all the necessary conversions from either Smith or advanced inputs to arrive at the correct, corresponding values. (For some details on this conversion process, along with a description of ZWAVE's skin friction model, see Corte and Lepert (1986)). Since soil damping and impedance are in the same units, the quantity in the program is the ratio of

the two, and is in fact the Case damping coefficient for the element in question.
10)Percentage of element resistance to total resistance.
11)Element slack, in. For breaks in the system such as the cap-pile and pile-tip interface, a slack of 1000" is used.
12)Element Diameter, in.

For surveys, items (7) and (9) are unique to the first resistance of the survey, the rest are valid for all. In the case of a single run, all items are good for that run.

Once the input is done and the initial output is also complete, the program will begin to cycle through. You will see some graphical output on the screen. This tracks two displacements, 1)displacement of pile top and 2)displacement of pile toe. The displacements are plotted on the y-axis against the time on the x-axis. The origin is in the lower left hand corner of the screen, and for positive (downward) displacement, the graph proceeds upward, and rightward for advancing time. The maximum time (right edge of screen) is the maximum time permitted, and the maximum graphed displacement (top edge of the screen) is twice the estimated elastic compression of the pile. Although the two plots are not labeled on the screen, the pile top normally displaces first and advances rapidly toward the top of the screen, and the tip follows afterward. In the case of a survey, all of the survey's cycles are plotted on the same screen.

For the 560 case, our first problem is a survey, thus we get the survey results table on the next page. Again from left to right, the results are as follows:

1)VIWI formula BPF of resistance.
2)ZWAVE computation of BPF of resistance.
3)Total pipe capacity/resistance, kips.
4)Maximum tip resistance during driving, kips.
5)Time step for (4).
6)Maximum compressive stress in pile, psi.
7)Element for (6)
8)Maximum tensile stress in pile, psi.
9)Element for (8)
10)Maximum enthru of hammer system into pile, ft-kips.
11)Energy the system actually exerts to plastically deform the soil and thus make penetration possible (hereafter referred to as Wfp), ft-kips.

Now we have completed the survey. Our second problem for this concerns a specific case. This time, we input a specific load capacity, namely 5000 kips, and we also

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change the skin friction distribution to triangular. The first two pages are the same for single run as with as survey. We have chosen a detailed run, so as ZWAVE runs it outputs certain information. The program's output is as on the following pages:

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ZWAVE, the Wave Equation Analyzer from Vulcan Iron Works Inc.

Case Manual Sample and Problem 2

Analysis Done 01-18-1988 and the Options Chosen at 18:19:01 are:

Automatic Entry of Slack Values
Basic Soil Input
Detailed Output During Analysis
Single Calculation of Ru vs. BPF
Triangular Side Distribution of Skin Friction
Batter Pile, 1: 5
Cushioned Hammer Without Anvil
No Pile Cushion

General Parameters Used

Rated Striking Energy of Hammer, ft-kips	312.500
Ram Weight, kips	62.500
Hammer Mechanical Efficiency, Percent	70.000
Net Striking Velocity, ft/sec	15.013
Ultimate Pile Load Capacity, kips	5000.000
Pile Weight, kips	367.592
Tip Elevation of Pile, ft.	100.000
Maximum Number of Time Steps	281.000
Number of Time Steps Per Second	4697.452
Element Determining Time Step	2.000
System Length, in.	0.453
Maximum Pile Elastic Compression, in.	0.457
Dist. of Wave Travel in TPM per Time Step, ft.	3.537
Force Coefficient	0.568
VIWI Formula Pile Force, kips	6528.100
VIWI Formula Pile Stress, psi	14842.661

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Element Data for Case Manual Sample and Problem 2

M	Area	Z'	W	K	COR	K'	Quake	C/Z	Ru%	Slack	Diameter
1	766.6	1.000	62500	25553	0.800	0	0.000	0.0000	0.00	1000.0	31.250
2	439.8	1.000	32055	211929	1.000	0	0.000	0.0000	0.00	1000.0	72.000
3	439.8	0.992	14831	105965	1.000	0	0.000	0.0000	0.00	0.0	72.000
4	439.8	0.992	14831	105965	1.000	0	0.000	0.0000	0.00	0.0	72.000
5	439.8	0.992	14831	105965	1.000	0	0.000	0.0000	0.00	0.0	72.000
6	439.8	0.992	14831	105965	1.000	0	0.000	0.0000	0.00	0.0	72.000
7	439.8	0.992	14831	105965	1.000	0	0.000	0.0000	0.00	0.0	72.000
8	439.8	0.992	14831	105965	1.000	0	0.000	0.0000	0.00	0.0	72.000
9	439.8	0.992	14831	105965	1.000	0	0.000	0.0000	0.00	0.0	72.000
10	439.8	0.992	14831	105965	1.000	0	0.000	0.0000	0.00	0.0	72.000
11	439.8	0.992	14831	105965	1.000	0	0.000	0.0000	0.00	0.0	72.000
12	439.8	0.992	14831	126425	1.000	0	0.000	0.0000	0.00	0.0	72.000
13	650.3	1.467	21928	156677	1.000	375	0.100	0.0124	0.75	0.0	72.000
14	650.3	1.467	21928	156677	1.000	1125	0.100	0.0373	2.25	0.0	72.000
15	650.3	1.467	21928	156677	1.000	1875	0.100	0.0621	3.75	0.0	72.000
16	650.3	1.467	21928	156677	1.000	2625	0.100	0.0870	5.25	0.0	72.000
17	650.3	1.467	21928	156677	1.000	3375	0.100	0.1118	6.75	0.0	72.000
18	650.3	1.467	21928	156677	1.000	4125	0.100	0.1367	8.25	0.0	72.000
19	650.3	1.467	21928	156677	1.000	4875	0.100	0.1616	9.75	0.0	72.000
20	650.3	1.467	21928	156677	1.000	5625	0.100	0.1864	11.25	0.0	72.000
21	650.3	1.467	21928	156677	1.000	6375	0.100	0.2113	12.75	0.0	72.000
22	650.3	1.467	21928	313355	1.000	7125	0.100	0.2361	14.25	1000.0	72.000
23	4069.4	9.178	0	0	1.000	12500	0.100	0.0265	25.00	0.0	72.000

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Telex: 55-8412
Telecopier: 615-698-1587

Detailed Output for Case Manual Sample and Problem 2

N	Dram	Vram	Fram	Dpt	Vpt	Fpt	Dtip	Ftip	D'tip
1	+0.046	+14.97	490.0	+0.008	+0.01	0.000	+0.008	0.072	+0.000
2	+0.084	+14.81	1459.7	+0.008	+0.04	0.009	+0.007	0.067	+0.000
3	+0.122	+14.56	2399.4	+0.008	+0.16	0.040	+0.007	0.062	+0.000
4	+0.158	+14.20	3292.0	+0.009	+0.45	0.100	+0.007	0.058	+0.000
5	+0.194	+13.76	4124.2	+0.011	+0.94	0.183	+0.007	0.055	+0.000
6	+0.229	+13.23	4886.0	+0.014	+1.61	0.278	+0.007	0.052	+0.000
7	+0.262	+12.62	5569.9	+0.019	+2.40	0.373	+0.006	0.051	+0.000
8	+0.293	+11.95	6170.1	+0.026	+3.23	0.458	+0.006	0.049	+0.000
9	+0.323	+11.23	6681.7	+0.036	+4.00	0.531	+0.006	0.048	+0.000
10	+0.350	+10.46	7100.7	+0.047	+4.69	0.598	+0.006	0.046	+0.000
11	+0.376	+9.65	7424.2	+0.059	+5.30	0.666	+0.006	0.044	+0.000
12	+0.400	+8.82	7651.5	+0.074	+5.87	0.738	+0.005	0.043	+0.000
13	+0.421	+7.97	7784.5	+0.089	+6.45	0.813	+0.005	0.041	+0.000
14	+0.440	+7.12	7827.2	+0.107	+7.04	0.885	+0.005	0.040	+0.000
15	+0.457	+6.27	7761.6	+0.125	+7.62	0.944	+0.005	0.039	+0.000
16	+0.472	+5.45	7510.3	+0.145	+8.13	0.985	+0.005	0.038	+0.000
17	+0.485	+4.68	7123.6	+0.167	+8.50	1.003	+0.005	0.037	+0.000
18	+0.496	+3.96	6632.3	+0.189	+8.70	1.001	+0.004	0.037	+0.000
19	+0.506	+3.30	6068.4	+0.211	+8.72	0.984	+0.004	0.036	+0.000
20	+0.513	+2.71	5463.1	+0.233	+8.59	0.961	+0.004	0.035	+0.000
21	+0.520	+2.18	4845.3	+0.255	+8.36	0.934	+0.004	0.035	+0.000
22	+0.525	+1.73	4240.0	+0.276	+8.09	0.905	+0.004	0.035	+0.000
23	+0.528	+1.33	3666.9	+0.296	+7.80	0.868	+0.004	0.034	+0.000
24	+0.531	+0.99	3139.8	+0.316	+7.48	0.822	+0.004	0.034	+0.000
25	+0.534	+0.71	2665.9	+0.334	+7.10	0.763	+0.004	0.034	+0.000
26	+0.535	+0.47	2247.2	+0.352	+6.64	0.695	+0.004	0.035	+0.000
27	+0.536	+0.27	1881.9	+0.368	+6.11	0.625	+0.004	0.035	+0.000
28	+0.536	+0.10	1566.3	+0.383	+5.54	0.561	+0.004	0.035	+0.000
29	+0.537	-0.03	1295.8	+0.396	+4.99	0.507	+0.004	0.035	+0.000
30	+0.536	-0.14	1066.2	+0.408	+4.50	0.464	+0.004	0.036	+0.000
31	+0.536	-0.23	873.3	+0.419	+4.09	0.427	+0.004	0.036	+0.000
32	+0.535	-0.30	712.7	+0.429	+3.76	0.391	+0.004	0.037	+0.000
33	+0.534	-0.36	580.3	+0.439	+3.46	0.350	+0.004	0.038	+0.000
34	+0.533	-0.41	471.6	+0.447	+3.15	0.304	+0.004	0.038	+0.000
35	+0.532	-0.44	382.3	+0.455	+2.81	0.258	+0.004	0.039	+0.000
36	+0.531	-0.47	308.9	+0.461	+2.45	0.217	+0.004	0.039	+0.000
37	+0.530	-0.49	248.2	+0.467	+2.11	0.187	+0.004	0.040	+0.000
38	+0.529	-0.50	198.1	+0.472	+1.82	0.169	+0.004	0.041	+0.000
39	+0.527	-0.51	156.9	+0.477	+1.62	0.159	+0.004	0.041	+0.000
40	+0.526	-0.52	123.3	+0.481	+1.50	0.150	+0.004	0.042	+0.000
41	+0.525	-0.53	96.3	+0.484	+1.41	0.137	+0.004	0.043	+0.000
42	+0.523	-0.53	74.7	+0.488	+1.33	0.118	+0.004	0.043	+0.000
43	+0.522	-0.53	57.4	+0.491	+1.20	0.094	+0.004	0.044	+0.000

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Chattanooga, Tennessee 37406
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44	+0.521	-0.52	43.5	+0.494	+1.03	0.071	+0.004	0.045	+0.000
45	+0.519	-0.52	32.2	+0.496	+0.85	0.055	+0.004	0.046	+0.000
46	+0.518	-0.52	23.2	+0.498	+0.69	0.049	+0.004	0.046	+0.000
47	+0.517	-0.51	16.0	+0.500	+0.59	0.052	+0.004	0.047	+0.000
48	+0.515	-0.51	10.5	+0.501	+0.56	0.057	+0.004	0.048	+0.000
49	+0.514	-0.50	6.5	+0.503	+0.58	0.059	+0.004	0.049	+0.000
50	+0.513	-0.49	3.6	+0.504	+0.60	0.054	+0.005	0.051	+0.000
51	+0.512	-0.49	1.8	+0.506	+0.58	0.042	+0.005	0.053	+0.000
52	+0.510	-0.48	0.7	+0.507	+0.50	0.027	+0.005	0.056	+0.000
53	+0.509	-0.47	0.1	+0.508	+0.38	0.015	+0.005	0.060	+0.000
54	+0.508	-0.47	0.0	+0.509	+0.25	0.013	+0.005	0.066	+0.000
55	+0.507	-0.46	0.0	+0.510	+0.16	0.020	+0.005	0.075	+0.000
56	+0.506	-0.45	0.0	+0.510	+0.12	0.033	+0.006	0.088	+0.000
57	+0.504	-0.45	0.0	+0.510	+0.13	0.046	+0.006	0.106	+0.000
58	+0.503	-0.44	0.0	+0.511	+0.15	0.053	+0.007	0.131	+0.000
59	+0.502	-0.43	0.0	+0.511	+0.14	0.053	+0.008	0.164	+0.000
60	+0.501	-0.43	0.0	+0.511	+0.05	0.049	+0.010	0.208	+0.000
61	+0.500	-0.42	0.0	+0.511	-0.11	0.047	+0.012	0.264	+0.000
62	+0.499	-0.41	0.0	+0.511	-0.31	0.053	+0.014	0.334	+0.000
63	+0.498	-0.41	0.0	+0.510	-0.50	0.070	+0.018	0.421	+0.000
64	+0.497	-0.40	0.0	+0.508	-0.65	0.095	+0.022	0.528	+0.000
65	+0.496	-0.39	0.0	+0.506	-0.75	0.122	+0.027	0.662	+0.000
66	+0.495	-0.39	0.0	+0.504	-0.82	0.144	+0.034	0.831	+0.000
67	+0.494	-0.38	0.0	+0.502	-0.91	0.156	+0.043	1.036	+0.000
68	+0.493	-0.37	0.0	+0.500	-1.06	0.158	+0.053	1.273	+0.000
69	+0.492	-0.37	0.0	+0.497	-1.26	0.154	+0.066	1.534	+0.000
70	+0.491	-0.36	0.0	+0.493	-1.51	0.150	+0.081	1.808	+0.000
71	+0.490	-0.35	0.0	+0.489	-1.76	0.150	+0.098	2.080	+0.003
72	+0.489	-0.35	0.0	+0.484	-1.96	0.154	+0.116	2.291	+0.016
73	+0.488	-0.34	0.4	+0.479	-2.10	0.157	+0.136	2.374	+0.036
74	+0.487	-0.33	2.6	+0.474	-2.18	0.154	+0.157	2.397	+0.057
75	+0.487	-0.33	8.2	+0.468	-2.23	0.140	+0.178	2.391	+0.078
76	+0.486	-0.32	18.3	+0.462	-2.31	0.116	+0.199	2.361	+0.099
77	+0.485	-0.32	34.0	+0.456	-2.43	0.085	+0.220	2.312	+0.120
78	+0.484	-0.32	56.1	+0.450	-2.59	0.055	+0.239	2.249	+0.139
79	+0.483	-0.32	84.8	+0.443	-2.74	0.034	+0.258	2.175	+0.158
80	+0.482	-0.33	120.1	+0.436	-2.84	0.023	+0.275	2.093	+0.175
81	+0.482	-0.34	162.0	+0.429	-2.85	0.021	+0.291	2.001	+0.191
82	+0.481	-0.36	210.0	+0.421	-2.78	0.020	+0.306	1.901	+0.206
83	+0.480	-0.38	263.8	+0.414	-2.65	0.016	+0.319	1.790	+0.219
84	+0.479	-0.41	322.4	+0.408	-2.52	0.005	+0.330	1.670	+0.230
85	+0.478	-0.44	384.7	+0.402	-2.38	0.000	+0.339	1.545	+0.239
86	+0.477	-0.48	448.9	+0.396	-2.25	0.000	+0.347	1.419	+0.247
87	+0.475	-0.53	513.7	+0.390	-2.14	0.000	+0.353	1.298	+0.253
88	+0.474	-0.59	577.3	+0.385	-2.05	0.000	+0.357	1.187	+0.257
89	+0.472	-0.65	637.9	+0.380	-1.98	0.000	+0.359	1.089	+0.259
90	+0.470	-0.72	693.8	+0.375	-1.93	0.000	+0.360	1.007	+0.260
91	+0.468	-0.80	743.2	+0.370	-1.89	0.000	+0.360	0.942	+0.260
92	+0.466	-0.88	784.6	+0.365	-1.85	0.000	+0.359	0.889	+0.260
93	+0.464	-0.96	816.4	+0.360	-1.83	0.000	+0.357	0.839	+0.260

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94	+0.461	-1.05	837.6	+0.356	-1.82	0.000	+0.355	0.790	+0.260
95	+0.459	-1.13	847.5	+0.351	-1.81	0.001	+0.352	0.741	+0.260
96	+0.456	-1.22	845.8	+0.346	-1.71	0.039	+0.349	0.691	+0.260
97	+0.452	-1.30	834.8	+0.342	-1.44	0.101	+0.346	0.641	+0.260
98	+0.449	-1.39	818.4	+0.339	-1.10	0.145	+0.342	0.593	+0.260
99	+0.445	-1.47	799.6	+0.337	-0.81	0.159	+0.338	0.548	+0.260
100	+0.442	-1.55	779.5	+0.335	-0.68	0.145	+0.334	0.507	+0.260
101	+0.437	-1.62	757.7	+0.333	-0.74	0.117	+0.331	0.471	+0.260
102	+0.433	-1.70	732.9	+0.331	-0.94	0.095	+0.327	0.440	+0.260
103	+0.429	-1.77	704.6	+0.328	-1.17	0.093	+0.323	0.412	+0.260
104	+0.424	-1.83	673.1	+0.325	-1.32	0.111	+0.320	0.386	+0.260
105	+0.419	-1.90	640.0	+0.322	-1.34	0.142	+0.316	0.361	+0.260
106	+0.415	-1.96	607.5	+0.318	-1.23	0.170	+0.313	0.337	+0.260
107	+0.409	-2.01	577.3	+0.315	-1.09	0.180	+0.310	0.312	+0.260
108	+0.404	-2.07	550.2	+0.313	-1.01	0.169	+0.307	0.288	+0.260
109	+0.399	-2.12	525.6	+0.310	-1.07	0.142	+0.304	0.266	+0.260
110	+0.393	-2.17	502.6	+0.307	-1.26	0.113	+0.301	0.245	+0.260
111	+0.388	-2.21	479.9	+0.304	-1.51	0.096	+0.298	0.228	+0.260
112	+0.382	-2.26	457.2	+0.299	-1.71	0.098	+0.296	0.213	+0.260
113	+0.376	-2.30	434.7	+0.295	-1.80	0.114	+0.294	0.201	+0.260
114	+0.370	-2.33	413.4	+0.290	-1.76	0.133	+0.291	0.191	+0.260
115	+0.364	-2.37	394.1	+0.286	-1.61	0.140	+0.289	0.182	+0.260
116	+0.358	-2.41	377.2	+0.282	-1.47	0.127	+0.288	0.174	+0.260
117	+0.352	-2.44	362.2	+0.279	-1.40	0.094	+0.286	0.166	+0.260
118	+0.346	-2.47	348.0	+0.275	-1.43	0.052	+0.285	0.159	+0.260
119	+0.339	-2.50	333.0	+0.271	-1.52	0.016	+0.283	0.153	+0.260
120	+0.333	-2.53	316.2	+0.267	-1.56	0.000	+0.282	0.149	+0.260
121	+0.327	-2.55	297.3	+0.263	-1.47	0.000	+0.281	0.146	+0.260
122	+0.320	-2.58	276.8	+0.260	-1.22	0.000	+0.280	0.144	+0.260
123	+0.313	-2.60	255.0	+0.257	-0.82	0.000	+0.279	0.143	+0.260
124	+0.307	-2.62	232.4	+0.256	-0.31	0.000	+0.278	0.143	+0.260
125	+0.300	-2.63	209.3	+0.256	+0.28	0.000	+0.278	0.140	+0.260
126	+0.293	-2.65	186.3	+0.257	+0.89	0.000	+0.277	0.137	+0.260
127	+0.287	-2.66	163.5	+0.260	+1.49	0.000	+0.276	0.130	+0.260
128	+0.280	-2.67	141.5	+0.265	+2.03	0.000	+0.276	0.121	+0.260
129	+0.273	-2.67	120.4	+0.271	+2.51	0.000	+0.275	0.110	+0.260
130	+0.266	-2.68	100.6	+0.278	+2.90	0.000	+0.275	0.096	+0.260
131	+0.259	-2.68	82.3	+0.285	+3.20	0.000	+0.274	0.080	+0.260
132	+0.252	-2.68	65.6	+0.294	+3.38	0.000	+0.273	0.061	+0.260
133	+0.246	-2.68	50.7	+0.302	+3.43	0.000	+0.272	0.041	+0.260
134	+0.239	-2.68	37.7	+0.311	+3.32	0.000	+0.270	0.018	+0.260
135	+0.232	-2.67	26.6	+0.319	+3.05	0.000	+0.269	0.003	+0.260
136	+0.225	-2.67	17.5	+0.326	+2.63	0.000	+0.267	0.000	+0.260
137	+0.218	-2.66	10.4	+0.332	+2.07	0.000	+0.266	0.000	+0.260
138	+0.211	-2.66	5.2	+0.337	+1.43	0.000	+0.264	0.000	+0.260
139	+0.205	-2.65	1.9	+0.340	+0.74	0.000	+0.262	0.000	+0.260
140	+0.198	-2.64	0.4	+0.341	+0.07	0.000	+0.259	0.000	+0.260
141	+0.191	-2.64	0.0	+0.340	-0.55	0.000	+0.257	0.000	+0.260
142	+0.184	-2.63	0.0	+0.338	-1.08	0.000	+0.255	0.000	+0.260
143	+0.178	-2.62	0.0	+0.335	-1.51	0.000	+0.253	0.000	+0.260

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144	+0.171	-2.62	0.0	+0.330	-1.84	0.000	+0.251	0.000	+0.260
145	+0.164	-2.61	0.0	+0.325	-2.09	0.000	+0.250	0.000	+0.260
146	+0.158	-2.60	0.0	+0.320	-2.26	0.000	+0.248	0.000	+0.260
147	+0.151	-2.60	0.0	+0.314	-2.38	0.000	+0.247	0.000	+0.260
148	+0.144	-2.59	0.0	+0.308	-2.45	0.000	+0.246	0.000	+0.260
149	+0.138	-2.58	0.0	+0.301	-2.50	0.000	+0.246	0.000	+0.260
150	+0.131	-2.58	0.0	+0.295	-2.51	0.000	+0.245	0.000	+0.260
151	+0.125	-2.57	0.0	+0.289	-2.50	0.000	+0.245	0.000	+0.260
152	+0.118	-2.56	0.0	+0.282	-2.46	0.000	+0.245	0.000	+0.260
153	+0.112	-2.56	0.0	+0.276	-2.40	0.000	+0.245	0.000	+0.260
154	+0.105	-2.55	0.0	+0.270	-2.30	0.000	+0.245	0.000	+0.260
155	+0.098	-2.54	0.0	+0.264	-2.18	0.000	+0.245	0.000	+0.260
156	+0.092	-2.54	0.0	+0.259	-2.05	0.000	+0.246	0.000	+0.260
157	+0.086	-2.53	0.0	+0.254	-1.90	0.000	+0.247	0.000	+0.260
158	+0.079	-2.52	0.0	+0.249	-1.76	0.000	+0.248	0.000	+0.260
159	+0.073	-2.52	0.0	+0.245	-1.63	0.000	+0.249	0.000	+0.260
160	+0.066	-2.51	0.0	+0.241	-1.51	0.000	+0.251	0.001	+0.260
161	+0.060	-2.50	0.0	+0.237	-1.40	0.000	+0.252	0.008	+0.260
162	+0.053	-2.50	0.0	+0.234	-1.30	0.000	+0.254	0.017	+0.260
163	+0.047	-2.49	0.0	+0.231	-1.19	0.000	+0.255	0.020	+0.260
164	+0.041	-2.48	0.0	+0.228	-1.06	0.000	+0.256	0.018	+0.260
165	+0.034	-2.48	0.0	+0.225	-0.90	0.000	+0.257	0.012	+0.260
166	+0.028	-2.47	0.0	+0.223	-0.72	0.000	+0.257	0.005	+0.260
167	+0.022	-2.46	0.0	+0.222	-0.54	0.000	+0.258	0.001	+0.260
168	+0.015	-2.46	0.0	+0.220	-0.35	0.000	+0.258	0.000	+0.260
169	+0.009	-2.45	0.0	+0.220	-0.19	0.000	+0.258	0.000	+0.260
170	+0.003	-2.44	0.0	+0.219	-0.07	0.000	+0.258	0.000	+0.260
171	-0.003	-2.44	0.0	+0.219	+0.03	0.000	+0.258	0.000	+0.260
172	-0.009	-2.43	0.0	+0.219	+0.09	0.000	+0.258	0.000	+0.260
173	-0.016	-2.42	0.0	+0.220	+0.15	0.000	+0.258	0.000	+0.260
174	-0.022	-2.42	0.0	+0.220	+0.20	0.000	+0.258	0.000	+0.260
175	-0.028	-2.41	0.0	+0.221	+0.27	0.000	+0.258	0.000	+0.260
176	-0.034	-2.40	0.0	+0.222	+0.36	0.000	+0.258	0.000	+0.260
177	-0.040	-2.40	0.0	+0.223	+0.46	0.000	+0.258	0.000	+0.260
178	-0.046	-2.39	0.0	+0.224	+0.55	0.000	+0.257	0.000	+0.260
179	-0.052	-2.38	0.0	+0.225	+0.62	0.000	+0.257	0.000	+0.260
180	-0.059	-2.37	0.0	+0.227	+0.65	0.000	+0.257	0.000	+0.260
181	-0.065	-2.37	0.0	+0.229	+0.64	0.000	+0.257	0.004	+0.260
182	-0.071	-2.36	0.0	+0.230	+0.58	0.000	+0.258	0.025	+0.260
183	-0.077	-2.35	0.0	+0.232	+0.48	0.000	+0.259	0.060	+0.260
184	-0.083	-2.35	0.0	+0.233	+0.37	0.000	+0.260	0.098	+0.260
185	-0.089	-2.34	0.0	+0.234	+0.25	0.000	+0.262	0.139	+0.260
186	-0.095	-2.33	0.0	+0.234	+0.15	0.000	+0.264	0.180	+0.260
187	-0.101	-2.33	0.0	+0.234	+0.06	0.000	+0.266	0.220	+0.260
188	-0.107	-2.32	0.0	+0.234	-0.00	0.000	+0.269	0.255	+0.260
189	-0.112	-2.31	0.0	+0.234	-0.06	0.000	+0.272	0.286	+0.260
190	-0.118	-2.31	0.0	+0.234	-0.10	0.000	+0.274	0.309	+0.260
191	-0.124	-2.30	0.0	+0.234	-0.13	0.000	+0.277	0.324	+0.260
192	-0.130	-2.29	0.0	+0.233	-0.14	0.000	+0.279	0.329	+0.260
193	-0.136	-2.29	0.0	+0.233	-0.14	0.000	+0.282	0.324	+0.260

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P.O. Box 5402
Chattanooga, Tennessee 37406
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Telex: 55-8412
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194	-0.142	-2.28	0.0	+0.233	-0.11	0.000	+0.283	0.308	+0.260
195	-0.148	-2.27	0.0	+0.233	-0.05	0.000	+0.284	0.282	+0.260
196	-0.153	-2.27	0.0	+0.233	+0.04	0.000	+0.285	0.246	+0.260
197	-0.159	-2.26	0.0	+0.233	+0.16	0.000	+0.285	0.205	+0.260
198	-0.165	-2.25	0.0	+0.233	+0.28	0.000	+0.284	0.159	+0.260
199	-0.171	-2.25	0.0	+0.234	+0.41	0.000	+0.282	0.112	+0.260
200	-0.176	-2.24	0.0	+0.236	+0.53	0.000	+0.280	0.067	+0.260
201	-0.182	-2.23	0.0	+0.237	+0.63	0.000	+0.278	0.027	+0.260
202	-0.188	-2.23	0.0	+0.239	+0.72	0.000	+0.275	0.005	+0.260
203	-0.194	-2.22	0.0	+0.241	+0.78	0.000	+0.273	0.000	+0.260
204	-0.199	-2.21	0.0	+0.243	+0.83	0.000	+0.270	0.000	+0.260
205	-0.205	-2.21	0.0	+0.245	+0.87	0.000	+0.267	0.000	+0.260
206	-0.210	-2.20	0.0	+0.247	+0.91	0.000	+0.265	0.000	+0.260
207	-0.216	-2.19	0.0	+0.250	+0.93	0.000	+0.262	0.000	+0.260
208	-0.222	-2.19	0.0	+0.252	+0.95	0.000	+0.260	0.000	+0.260
209	-0.227	-2.18	0.0	+0.254	+0.97	0.000	+0.258	0.000	+0.260
210	-0.233	-2.17	0.0	+0.257	+0.97	0.000	+0.256	0.000	+0.260
211	-0.238	-2.17	0.0	+0.259	+0.95	0.000	+0.254	0.000	+0.260
212	-0.244	-2.16	0.0	+0.262	+0.93	0.000	+0.253	0.000	+0.260
213	-0.249	-2.15	0.0	+0.264	+0.90	0.000	+0.252	0.000	+0.260
214	-0.255	-2.15	0.0	+0.266	+0.87	0.000	+0.251	0.000	+0.260
215	-0.260	-2.14	0.0	+0.268	+0.84	0.000	+0.251	0.000	+0.260
216	-0.266	-2.13	0.0	+0.271	+0.82	0.000	+0.250	0.000	+0.260
217	-0.271	-2.13	0.0	+0.273	+0.81	0.000	+0.250	0.000	+0.260
218	-0.277	-2.12	0.0	+0.275	+0.79	0.000	+0.249	0.000	+0.260
219	-0.282	-2.11	0.0	+0.277	+0.76	0.000	+0.249	0.000	+0.260
220	-0.287	-2.11	0.0	+0.279	+0.72	0.000	+0.249	0.000	+0.260
221	-0.293	-2.10	0.0	+0.280	+0.65	0.000	+0.249	0.000	+0.260
222	-0.298	-2.09	0.0	+0.282	+0.57	0.000	+0.250	0.000	+0.260
223	-0.304	-2.09	0.0	+0.283	+0.47	0.000	+0.250	0.000	+0.260
224	-0.309	-2.08	0.0	+0.284	+0.38	0.000	+0.251	0.000	+0.260
225	-0.314	-2.07	0.0	+0.285	+0.29	0.000	+0.252	0.000	+0.260
226	-0.319	-2.07	0.0	+0.286	+0.23	0.000	+0.253	0.000	+0.260
227	-0.325	-2.06	0.0	+0.286	+0.18	0.000	+0.254	0.001	+0.260
228	-0.330	-2.05	0.0	+0.287	+0.16	0.000	+0.255	0.007	+0.260
229	-0.335	-2.05	0.0	+0.287	+0.14	0.000	+0.256	0.018	+0.260
230	-0.340	-2.04	0.0	+0.288	+0.13	0.000	+0.257	0.030	+0.260
231	-0.346	-2.03	0.0	+0.288	+0.13	0.000	+0.258	0.043	+0.260
232	-0.351	-2.03	0.0	+0.288	+0.13	0.000	+0.259	0.057	+0.260
233	-0.356	-2.02	0.0	+0.289	+0.13	0.000	+0.260	0.070	+0.260
234	-0.361	-2.01	0.0	+0.289	+0.14	0.000	+0.261	0.081	+0.260
235	-0.366	-2.01	0.0	+0.289	+0.17	0.000	+0.262	0.090	+0.260
236	-0.371	-2.00	0.0	+0.290	+0.22	0.000	+0.263	0.095	+0.260
237	-0.376	-1.99	0.0	+0.290	+0.28	0.000	+0.264	0.099	+0.260
238	-0.382	-1.99	0.0	+0.291	+0.35	0.000	+0.265	0.101	+0.260
239	-0.387	-1.98	0.0	+0.292	+0.42	0.000	+0.266	0.103	+0.260
240	-0.392	-1.97	0.0	+0.293	+0.48	0.000	+0.267	0.105	+0.260
241	-0.397	-1.96	0.0	+0.295	+0.54	0.000	+0.267	0.107	+0.260
242	-0.402	-1.96	0.0	+0.296	+0.60	0.000	+0.268	0.109	+0.260
243	-0.407	-1.95	0.0	+0.298	+0.65	0.000	+0.268	0.111	+0.260

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244	-0.412	-1.94	0.0	+0.299	+0.71	0.000	+0.269	0.111	+0.260
245	-0.417	-1.94	0.0	+0.301	+0.77	0.000	+0.269	0.108	+0.260
246	-0.422	-1.93	0.0	+0.303	+0.82	0.000	+0.269	0.104	+0.260
247	-0.426	-1.92	0.0	+0.305	+0.85	0.000	+0.270	0.098	+0.260
248	-0.431	-1.92	0.0	+0.308	+0.86	0.000	+0.270	0.092	+0.260
249	-0.436	-1.91	0.0	+0.310	+0.83	0.000	+0.269	0.086	+0.260
250	-0.441	-1.90	0.0	+0.312	+0.76	0.000	+0.269	0.083	+0.260
251	-0.446	-1.90	0.0	+0.314	+0.64	0.000	+0.269	0.083	+0.260
252	-0.451	-1.89	0.0	+0.315	+0.51	0.000	+0.269	0.085	+0.260
253	-0.456	-1.88	0.0	+0.316	+0.35	0.000	+0.269	0.089	+0.260
254	-0.460	-1.88	0.0	+0.317	+0.20	0.000	+0.269	0.095	+0.260
255	-0.465	-1.87	0.0	+0.317	+0.06	0.000	+0.269	0.101	+0.260
256	-0.470	-1.86	0.0	+0.317	-0.05	0.000	+0.269	0.108	+0.260
257	-0.475	-1.86	0.0	+0.317	-0.15	0.000	+0.270	0.114	+0.260
258	-0.480	-1.85	0.0	+0.317	-0.23	0.000	+0.270	0.121	+0.260
259	-0.484	-1.84	0.0	+0.316	-0.29	0.000	+0.270	0.127	+0.260
260	-0.489	-1.84	0.0	+0.315	-0.33	0.000	+0.271	0.134	+0.260
261	-0.494	-1.83	0.0	+0.314	-0.36	0.000	+0.271	0.140	+0.260
262	-0.498	-1.82	0.0	+0.313	-0.37	0.000	+0.272	0.146	+0.260
263	-0.503	-1.82	0.0	+0.312	-0.36	0.000	+0.272	0.152	+0.260
264	-0.508	-1.81	0.0	+0.311	-0.32	0.000	+0.273	0.157	+0.260
265	-0.512	-1.80	0.0	+0.311	-0.28	0.000	+0.273	0.162	+0.260
266	-0.517	-1.80	0.0	+0.310	-0.22	0.000	+0.274	0.165	+0.260
267	-0.521	-1.79	0.0	+0.310	-0.16	0.000	+0.274	0.168	+0.260
268	-0.526	-1.78	0.0	+0.309	-0.11	0.000	+0.275	0.170	+0.260
269	-0.531	-1.78	0.0	+0.309	-0.06	0.000	+0.275	0.171	+0.260
270	-0.535	-1.77	0.0	+0.309	-0.01	0.000	+0.275	0.171	+0.260
271	-0.540	-1.76	0.0	+0.309	+0.02	0.000	+0.276	0.171	+0.260
272	-0.544	-1.76	0.0	+0.309	+0.05	0.000	+0.276	0.170	+0.260
273	-0.549	-1.75	0.0	+0.309	+0.07	0.000	+0.276	0.169	+0.260
274	-0.553	-1.74	0.0	+0.309	+0.09	0.000	+0.276	0.168	+0.260
275	-0.557	-1.74	0.0	+0.310	+0.10	0.000	+0.276	0.167	+0.260
276	-0.562	-1.73	0.0	+0.310	+0.10	0.000	+0.276	0.165	+0.260
277	-0.566	-1.72	0.0	+0.310	+0.11	0.000	+0.276	0.164	+0.260
278	-0.571	-1.72	0.0	+0.310	+0.11	0.000	+0.276	0.162	+0.260
279	-0.575	-1.71	0.0	+0.311	+0.11	0.000	+0.276	0.159	+0.260
280	-0.579	-1.70	0.0	+0.311	+0.12	0.000	+0.276	0.155	+0.260
281	-0.584	-1.70	0.0	+0.311	+0.13	0.000	+0.276	0.149	+0.260

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P.O. Box 5402
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Telephone: 615-698-1581
Telex: 55-8412
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Final Results for Case Manual Sample and Problem 2

M	Ru	Max. Comp. #	Max. Comp. Stress	Max. Tens. #	Max. Tens. Stress	Displacement Max.,in.	Displacement Final,in.	Fin. Vel. ft/sec
1	0.0	14	+10210	0	+0	0.537	-0.584	-1.70
2	0.0	14	+17796	0	+0	0.513	-0.046	-0.20
3	0.0	21	+15003	126	-2974	0.511	0.311	0.13
4	0.0	24	+15029	127	-4579	0.507	0.311	0.14
5	0.0	24	+15029	127	-4579	0.502	0.311	0.06
6	0.0	27	+15003	125	-3997	0.493	0.311	0.05
7	0.0	30	+14978	123	-3145	0.481	0.310	-0.17
8	0.0	36	+14982	114	-3487	0.462	0.309	-0.27
9	0.0	39	+15188	113	-4334	0.438	0.308	-0.36
10	0.0	43	+16278	109	-4966	0.412	0.307	-0.49
11	0.0	45	+17589	107	-5406	0.394	0.305	-0.34
12	0.0	47	+18094	107	-5406	0.379	0.302	-0.12
13	37.5	50	+12360	105	-3042	0.367	0.297	0.04
14	112.5	52	+12437	98	-2310	0.357	0.293	0.13
15	187.5	55	+12457	95	-2726	0.356	0.289	0.16
16	262.5	55	+12457	92	-2909	0.355	0.285	0.05
17	337.5	58	+12408	92	-2909	0.357	0.283	0.03
18	412.5	61	+12292	87	-2947	0.361	0.281	-0.02
19	487.5	64	+12090	87	-2947	0.364	0.279	-0.12
20	562.5	66	+11729	85	-2129	0.367	0.278	-0.11
21	637.5	68	+10758	198	-1512	0.368	0.278	-0.11
22	712.5	70	+8289	198	-863	0.364	0.277	-0.09
23	1250.0	74	+0	0	+0	0.360	0.276	-0.09

Net Kinetic Striking Energy of Hammer, ft-kips	218.750
Maximum Pile Enthru, ft-kips	186.356
Final Pile Enthru, ft-kips	176.726
Energy Actually Moving Pile (Wfp), ft-kips	109.310
Ram Kinetic Rebound Energy, ft-kips	2.814
Energy Lost in Cushion/Drive Cap, ft-kips	39.210
Energy Dissipated in Soil, ft-kips	67.416
Maximum Pile Tensile Stress, psi	-5405.988
Element of Maximum Pile Tensile Stress	11.000
Maximum Pile Compressive Stress, psi	18094.350
Element of Maximum Pile Compressive Stress	12.000
Maximum Pile Tip Force, kips	2996.272
Averaged Quake for BPF, in.	0.100
Permanent Set of Pile, in.	0.260
Blows Per Foot of Penetration	46.151
VIWI Formula Blows Per Foot of Penetration	92.630
Total Cycles Actually Run	282.000

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GENERAL OFFICES & FACTORY
2909 Riverside Drive
P.O. Box 5402
Chattanooga, Tennessee 37406
Telephone: 615-698-1581
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ZWAVE Case Manual Sample and Problem 2 completed 01-18-1988 at 18:19:59

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The End of ZWAVE Analysis, Case Manual Sample, Completed 01-18-1988 at 18:19:59

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From left to right the information is as follows:

1)Time step.
2)Ram displacement, in.
3)Ram velocity, ft/sec.
4)Ram force, lbs.
5)Pile top displacement, in.
6)Pile top velocity, ft/sec
7)Pile top force ratio, dimensionless. This divides the actual pile top force by the VIWI maximum force.
8)Pile tip displacement, in.
9)Pile tip force ratio, dimensionless. This divides the actual pile tip force by the static tip resistance.
10)Pile tip soil displacement, in.

Once the program has decided to stop, the final results are given on another page. The tabular data is as follows:

1)Element number.
2)Element soil resistance, kips.
3)Time step for (4)
4)Maximum element compressive stress, psi.
5)Time step for (6)
6)Maximum element tensile stress, psi.
7)Maximum element displacement, in.
8)Final element displacement, in.
9)Final element velocity, ft/sec.

After the table some other final data is given. This is detailed as follows:

Net Kinetic Energy of Hammer, ft-kips:This is the kinetic energy of the ram at impact. From here, ZWAVE does what amounts to an energy balance of the system, starting with the energy input of the ram, and prints the following energies, all in ft-kips:
Maximum Pile Enthru:This is the quantity of energy entering the pile less the effects of rebound. Although it is not the actual energy entering the pile from the hammer system, it is the quantity used by most wave equation programs and pile analyzers to describe the enthru.
Final Pile Enthru:The actual enthru into the pile.
Energy Actually Moving Pile: This is the Wfp described above.
Ram Kinetic Rebound Energy:The energy returned to the ram

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by the system, assisting the ram in its upstroke.
Energy Lost in Cushion/Drive Cap:This energy is lost in the cushions through the plasticity of the hammer and/or the pile cushion. When both are employed (as with concrete pile), this can be substantial.
Energy Dissipated in Soil:This is energy lost in the soil through radiation dampening.

Maximum Pile Tensile Stress: The maximum tensile stress found in the pile, excluding any found in the hammer system. The program for each element keeps track of the tensile stresses in both springs connected to the element, and the maximum stresses reported here and in the table above are for that element. This enables you to clearly separate the stresses from one pile configuration to the other.
Element of Maximum Pile Tensile Stress:The element where this maximum stress was found.
Maximum Pile Compressive Stress:Same as tensile stress, only with compressive stresses.
Element of Maximum Pile Compressive Stress:Similar to compressive stresses.
Maximum Pile Tip Force: The maximum compressive force experienced by the tip.
Averaged Quake For BPF: Since frequently the toe quake varies widely from the shaft quake, and the set of the pile is determined by subtracting the actual tip penetration from the "quake", this quake is computed by taking a weighted average of the quakes based on capacity. This is described in more detail by Goble et. al. (1986).
Permanent Set of Pile:The set of pile computed as described previously.
Blows Per Foot of Penetration:The inverse of the previous quantity, converted into feet. The program will return a zero value for a negative set or a set less than 0.012".
VIWI Formula Blows Per Foot of Penetration:The BPF as computed by the formulae given by Warrington (1987).
Total Cycles Actually Run:The number of time steps the program actually went through before termination. In addition to the maximum number termination, ZWAVE can terminate after fulfilling a set of termination criteria which take into account ram contact, rebound of tip and residual pile energy.

Since this is the second and last problem, a tailsheet is produced and ZWAVE is finished with this case.

NOMENCLATURE

c Speed of Sound in a continuous medium, ft/sec

Csh	Shaft Dampening, slug/sec
Ct	Toe Dampening, slug/sec
e	Coefficient of Resitution, dimensionless
F	Cushion Force, lb
G	Shear Modulus of Elasticity, lbf/sq.ft.
IO	Relative Impedance of Material, slug/sec-sq.ft.
k	Cushion Spring Constant, lb/ft
Ksh	Shaft Soil Spring Constant, lb/ft
Kt	Toe Soil Spring Constant, lb/ft
p	Density, slug/cu.ft.
R	Ultimate Resistance of Soil, lb.
s	Set of Pile, ft.
Tmat	Exponent of Cushion Rebound, dimensionless
Wfp	Energy Lost in Plastic Deformation of Soil, ft-lb
x	Deformation of Cushion, ft
ü	Poisson's Ratio

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