USER'S MANUAL FOR

SHAKE91

A Computer Program for Conducting Equivalent Linear
Seismic Response Analyses of Horizontally Layered Soil Deposits

Program Modified based on the Original ***SHAKE*** program published in
December 1972 by Schnabel, Lysmer & Seed

Modifications by

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I. M Idriss[1] and Joseph I. Sun[2]

INTRODUCTION

The computer program **SHAKE** was written in 1970-71 by Dr. Per Schnabel and Professor John Lysmer and was published in December 1972 by Dr. Per Schnabel and Professors John Lysmer and H. Bolton Seed in report No. UCB/EERC 72/12, issued by the Earthquake Engineering Research Center at the University of California in Berkeley. This has been by far the most widely used program for computing the seismic response of horizontally layered soil deposits.

The program computes the response of a semi-infinite horizontally layered soil deposit overlying a uniform half-space subjected to vertically propagating shear waves. The analysis is done in the frequency domain, and, therefore, for any set of properties it is a linear analysis. An iterative procedure is used to account for the nonlinear behavior of the soils as summarized below.

The object motion (ie, the motion that is considered to be known) can be specified at the top of any sublayer within the soil profile or at the corresponding outcrop.

The program **SHAKE** was originally written for a main frame computer. It was converted for use on a personal computer by Dr. S. S. Lai in 1985; almost everything else remained identical to the original computer program. While there have been many modifications and several editions of the program **SHAKE** have been referenced in recent publications, the version included herein constitutes the most extensive modifications to

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the original program. The intent of the modifications was to make the program more convenient for use with a personal computer.

MODIFICATIONS IMPLEMENTED IN SHAKE91

The main modifications incorporated in *SHAKE91* include the following:

- The number of sublayers was increased from 20 to 50; this should permit a more accurate representation of deeper and/or softer soil deposits.

- Removed all built-in modulus reduction and damping relationships. These relationships are now specified by the user; up to 13 different relations of modulus reduction, G/G_{max}, versus shear strain and damping ratio, λ, versus shear strain can be specified as part of the input file. A number of published variations of G/G_{max} and λ with shear strain are available in the literature (eg, Hardin and Drnevich, 1970; Seed and Idriss, 1970; Seed et al, 1986; Sun et al, 1988; Vucetic and Dobry, 1991).

- The maximum shear velocity or the maximum modulus are now specified for each sublayer; again these are part of the input and therefore the program no longer calculates modulus values as a function of either confining pressure or shear strength. The user specifies the maximum values, which are derived by the user.

- Object motion is now read from a separate file; the number of header lines and format are specified by the user.

- Other clean-up included: renumbering of options, elimination of infrequently used options, user specified periods for calculating spectral ordinates ... etc.

DESCRIPTION OF THE PROGRAM

The soil profile is idealized as a system of homogeneous, visco-elastic sublayers of infinite horizontal extent; the idealized soil profile is shown in Fig. 1. The response of this system is calculated considering vertically propagating shear waves. The algorithm in the original program **SHAKE** (Schnabel et al, 1972) is based on the continuous solution to the wave equation (Kanai, 1951; Matthiesen et al, 1964; Roesset and Whitman, 1969; Lysmer et al 1971), which was adapted for transient motions using the Fast Fourier Transform techniques of Cooley and Tukey (1965). The program *SHAKE91* retains this feature of the original program. Details pertinent to the derivation of the applicable equations of motion and solution of these equations are summarized in the original **SHAKE** manual, in the aforementioned references and in most textbooks on wave propagation.

An equivalent linear procedure (Idriss and Seed, 1968; Seed and Idriss, 1970) is used to account for the nonlinearity of the soil using an iterative procedure to obtain values for modulus and damping that are compatible with the equivalent uniform strain induced in each sublayer. Thus, at the outset, a set of properties (shear modulus, damping and total unit weight) is assigned to each sublayer of the soil deposit. The analysis is conducted using these properties and the shear strains induced in each sublayer is calculated. The shear modulus and the damping ratio for each sublayer are then modified based on the applicable relationship relating these two properties to shear strain. The analysis is repeated until strain-compatible modulus and damping values are arrived at. Starting with the maximum shear modulus for each sublayer and a low value of damping, essentially (ie, difference less than one percent) strain-compatible properties are obtained in 5 to 8 iterations for most soil profiles.

The following assumptions are incorporated in the analysis (Schnabel et al, 1972):

- Each sublayer, m, is completely defined by its shear modulus, G_m, damping ratio, λ_m, total unit weight, γ_{tm} (or corresponding mass density, ρ_m) and thickness, h_m; these properties are independent of frequency.

- The responses in the soil profile are caused by the upward propagation of shear waves from the underlying rock half-space.

- The shear waves are specified as acceleration ordinates at equally spaced time intervals. (Cyclic repetition of the acceleration time history is implied in the solution).

- The strain dependence of the shear modulus and damping in each sublayer is accounted for by an equivalent linear procedure based on an equivalent uniform strain computed in that sublayer. The ratio of this equivalent uniform shear strain divided by the calculated maximum strain is specified by the user (see Option 5 below) and is assumed to be the same for all sublayers.

Available Options

The options incorporated into *SHAKE91* are as follows:

Option Number	Description
1	dynamic soil properties
2	data for soil profile
3	input (object) motion
4	assignment of object motion to the top of a specified sublayer
5	number of iterations specified & ratio of uniform strain to max strain
6	sublayers at top of which peak accelerations & time histories are computed and saved

7	sublayer at top of which time history of shear stress or strain is computed and saved
8	save time history of object motion
9	compute response spectrum
10	compute amplification spectrum
11	compute Fourier amplitudes

Note that the original program **SHAKE** included 16 options and that the modified program includes only 11; the five options eliminated pertain mostly to plotting and to adjusting the time increment all of which can best be done in auxiliary programs.

INPUT DATA

The input data are provided in an input file that is specified directly from the key board at the time of program execution; a sample input is presented in Table 1. As can be noted in the table, each option starts with the following two lines:

Line No. 1 (Format: A80)

columns 1 - 80 Identification information for this option (this line cannot be blank)

Line No. 2 (Format: I5)

column 1 - 5 Option Number

The specific inputs for each option are presented below.

Option 1 -- Dynamic Soil Properties

- first line after option number (Format: I5)

column 1 - 5 Number of materials included (maximum is 13)

then, for each material, the following input should be supplied:

first line (Format: I5, 11A6)

column 1 - 5 number of strain values to be read (maximum is 20)
column 6 - 71 identification for this set of modulus reduction values

second & consecutive lines (Format: 8F10.0)

column 1 - 80	strain values, in percent, beginning with the lowest value. Eight entries per line (maximum is 20)

consecutive lines (Format: 8F10.0)

column 1 - 80	values of modulus reduction (G/G_{max}) each corresponding to the shear strain provided in the previous lines; these values should be in decimal not in percent.

the second set for the same material will consist of identical information except that values of damping (in percent) are provided as illustrated in Table 1.

After the last set is completed, the following information is to be provided (Format: 16I5):

column 1 - 5	number, N, of materials to be used in this analysis
column 6 - 10	first material number which will be used
column 11 - 15	second material number to be used
column 16 - 20	third material number to be used
.	....
.	....
.	etc until all N materials are identified.

Values of G/G_{max} and λ versus strain for these N materials will then be saved in output file No. 1 (see section on OUTPUT below) so that only the material properties used in this analysis are saved in this file. This feature was added for the convenience of the user who can include up to 13 sets of material properties in the input file but for any one analysis uses fewer than 13. This feature also provides a check that the intended material properties were utilized in the analysis.

Option 2 -- Soil Profile

- first line after option number (Format: 2I5, 5X, 6A6)

column 1 - 5	soil deposit number; may be left blank
column 11 - 10	number of sublayers, including the half-space
column 16 - 51	identification for soil profile

- second and subsequent lines; one line for each sublayer, including the half-space (Format: 2I5, 5X, 5F10.0)

column 1 - 5	sublayer number
column 11 - 10	soil type (corresponding to numbers assigned to each material in Option 1). [Note that if this material type is given as 0 (zero) for *all* sublayers, then the calculations are conducted for only one iteration using the

	properties (modulus, or shear wave velocity, and damping) specified in this input].
column 16 - 25	thickness of sublayer, in feet
column 26 - 35	maximum shear modulus for the sublayer, in ksf (leave blank if maximum shear wave velocity for the sublayer is given)
column 36 - 45	initial estimate of damping (decimal)
column 46 - 55	total unit weight, in ksf
column 56 - 65	maximum shear wave velocity for the sublayer, in ft/sec (leave blank if maximum shear modulus for the sublayer is given)

For the half-space, leave columns 16 to 25 blank; ie, no thickness should be specified for the half-space.

__Option 3 -- Input (Object) Motion__

- first line after option number (Format: 2I5, F10.3, A30, A12)

column 1 - 5	number, NV, of acceleration values to be read for input motion
column 6 - 10	number, MA, of values for use in Fourier Transform; MA should be a power of 2 (typically, this number is 1024, 2048 or 4096). Note that MA should always be greater than NV. The following may be used as a guide: for NV ≤ 800, MA can be 1024, for NV ≤ 1800, MA can be 2048 and for NV ≤ 3800, MA can be 4096. The current program is limited to a maximum value of 4096 for MA. For those rare occasions when MA = 8196 is needed, the size of the COMMON block and the length of the variable MAMAX in the MAIN Module (see Appendix A) should be changed to 51220 and 8196, respectively.
8192 ?	
column 11 - 20	time interval between acceleration values, in seconds
column 21 - 50	name of file for input (object) motion
column 51 - 62	format for reading acceleration values

- second line after option number (Format: 3F10.0, 2I5)

column 1 - 10	multiplication factor for adjusting acceleration values; use only if columns 11 - 20 are left blank
column 11 - 20	maximum acceleration to be used, in g's; the acceleration values read-in will be scaled to provide the maximum acceleration specified in these columns; leave columns 11 - 20 blank if a multiplication factor is specified in columns 1 - 10.
? column 21 - 30	maximum frequency (ie, frequency cut-off) to be used in the analysis
column 31 - 35	number of header lines in file containing object motion
column 36 - 40	number of acceleration values per line in file containing object motion

Option 4 -- Assignment of Object Motion to a Specific Sublayer

- first line after option number (Format: 2I5)

column 1 - 5	number of sublayer at the top of which the object motion is assigned
column 11 - 10	use 0 (zero) if the object motion is to be assigned as outcrop motion, otherwise use 1 (one) if the object motion is applied within the soil profile at the top of the assigned sublayer

Option 5 -- Number of Iterations & Ratio of Equivalent Uniform Strain to Maximum Strain

- first line after option number (Format: 2I5, F10.0)

column 1 - 5	parameter used to specify whether the strain-compatible soil properties are saved after the final iteration; set = 1 if these properties are to be saved; otherwise leave columns 1 - 5 blank
column 1 - 10	number of iterations
column 11 - 20	ratio of equivalent uniform strain divided by maximum strain; typically this ratio ranges from 0.4 to 0.75 depending on the input motion and which magnitude earthquake it is intended to represent. The following equation may be used to estimate this ratio: [ratio = (M - 1)/10] in which M is the magnitude of the earthquake. Thus, for M = 5, the ratio would be 0.4, for M = 7.5, the ratio would be 0.65 ... etc.

7

Option 6 -- Computation of Acceleration at Top of Specified Sublayers

can specify a maximum of fifteen sublayers; if accelerations for more than 15 sublayers are desired, then repeat Option 6 as many times as needed

- first line after option number (Format: 15I5)

column 1 - 75	array indicating the numbers of the sublayers at the top of which the acceleration is to be calculated

- second line after option number (Format: 15I5)

column 1 - 75	array specifying types of above sublayer: 0 (zero) for outcropping or 1 (one) for within the soil profile

- third line after option number (Format: 15I5)

column 1 - 75	array to specify the mode of output for the computed accelerations: 0 (zero) if only maximum acceleration is desired or 1 (one) if both the maximum acceleration and the time history of acceleration are to be calculated and saved

Option 7 – Computation of Shear Stress or Strain Time History at Top of Specified Sublayers

can specify a maximum of two sublayers; if stress or strain time histories for more than two sublayers are desired, then repeat Option 7 as many times as needed

- first line after option number (Format: 5I5, F10.0, 5A6)

column 1 - 5	number of sublayer
column 11 - 10	set equal to 0 (zero) for strain or 1 (one) for stress
column 11 - 15	set equal to one to save time history of strain or stress
column 16 - 20	leave blank
column 21 - 25	number of values to be saved; typically this should be equal to the number NV (see Option 3 above)
column 26 - 35	leave blank
column 36 - 65	identification information

- second line after option number (Format: 5I5, F10.0, 5A6)

same as the above line for the second sublayer

Note that the time histories of shear stresses or strains are calculated at the top of the specified sublayer. Thus, if the time history is needed at a specific depth within the soil profile, that depth should be made the top of a sublayer. The time history of stresses or strains is saved in second Output file.

This options should be specified after Option 6 as shown in Table 1 and in Table B-1.

Option 8 – Save Time History of Object Motion

Although this option was retained, its purpose is most easily accomplished in Option 6.

Option 9 – Response Spectrum

- first line after option number (Format: 2I5)

column 1 - 5	sublayer number
column 6 - 10	set equal to 0 (zero) for outcropping or equal to 1 (one) for within

- second line after option number (Format: 2I5, F10.0)

column 1 - 5	number of damping ratios to be used
column 6 - 10	set equal to 0 (zero)
column 11 -20	acceleration of gravity

- third line after option number (Format: 6F10.0)

column 1 - 60	array for damping ratios (in decimal)

Option 10 -- Amplification Spectrum

- first line after option number (Format: 4I5, F10.0, 8A6)

column 1 - 5	number of first sublayer
column 6 - 10	set equal to 0 (zero) for outcropping or equal to 1 (one) for within
column 11 -15	number of second sublayer
column 16 - 20	set equal to 0 (zero) for outcropping or equal to 1 (one) for within
column 21 - 30	frequency step (in cycles per second); the amplification spectrum is calculated for 200 frequencies using this frequency step and starting with 0
column 31 - 78	identification information

[The amplification spectrum is the ratio of the amplitude of motion at the top of the second sublayer divided by that at the top of the first sublayer].

If the amplification spectrum is desired for two other sublayers, Option 10 can be repeated as many times as needed.

Option 11 -- Fourier Spectrum

- first line after option number (Format: 5I5)

column 1 - 5	number of the sublayer
column 6 - 10	set equal to 0 (zero) for outcropping or equal to 1 (one) for within
column 11 -15	set equal to 2 (two) if spectrum is to be saved to file
column 16 - 20	number of times the spectrum is to be smoothed
column 21 - 25	number of values to be saved

The following expression (Schnabel et al, 1972) is used to smooth the Fourier spectrum:

$$A_i = \frac{A_{i-1} + 2A_i + A_{i+1}}{4}$$

in which A_i is the amplitude of the spectrum for the i^{th} frequency.

A second line is always needed when using Option 11. Thus, either provide a second line for another sublayer or repeat the information provided in the first line in a second line.

It may be noted that calculation of Fourier amplitudes for a specific accelerogram is best accomplished in an auxiliary program.

__Program Termination__

For program termination, provide a line that contains information that execution will terminate when the number is encountered as an option number; the line following this information should have 0 (zero) with a format of I5. Execution will then terminate.

OUTPUT

The output of the program is contained in two files. The first file echoes much of the input information and contains the results of each iteration, the listing of calculated maximum shear stresses and strains, maximum acceleration, response spectrum, Fourier spectrum and amplification spectrum, as appropriate. The second file contains all the time histories requested. The name of each file is specified by the user at the time of program execution directly from the key-board.

COMPUTER LISTING

The FORTRAN listing of program *SHAKE91* is given in Appendix A.

SAMPLE PROBLEM

The results for a sample problem are given in Appendix B.

CONCLUDING REMARKS

The computer program SHAKE has been widely used throughout the United States and in many parts of the world for conducting ground response studies. Its use in recent studies involving recordings obtained at several sites from the 1989 Loma Prieta earthquake (eg, Idriss, 1990; Dickenson et al, 1991; Idriss, 1991; Rollins et al, 1992; Yokel, 1992) have indicated that the calculated surface motions are in reasonably good agreement with the recorded values when the appropriate soil properties and input rock motions are used. Therefore, this program remains a convenient tool for conducting such analyses at many sites and for a variety of applications.

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Table 1
Sample Input

```
option 1 - dynamic soil properties - (max is thirteen):
    1
    3
   11      #1 modulus reduction for clay (Sun et al, 1988) upper range
0.0001     0.0003     0.001      0.003      0.01       0.03       0.1        0.3
1.         3.         10.
1.000      1.000      1.000      0.981      0.941      0.847      0.656      0.438
0.238      0.144      0.110
   11      damping for clay (Idriss 1990) -
0.0001     0.0003     0.001      0.003      0.01       0.03       0.1        0.3
1.         3.16       10.
0.24       0.42       0.8        1.4        2.8         5.1        9.8       15.5
21.        25.        28.
   11      #2 modulus reduction for sand (seed & idriss 1970) - upper Range
0.0001     0.0003     0.001      0.003      0.01       0.03       0.1        0.3
1.         3.         10.
1.000      1.000      0.990      0.960      0.850      0.640      0.370      0.180
0.080      0.050      0.035
   11      damping for sand (Idriss 1990) - (LRng from seed & idriss) 1970)
0.0001     0.0003     0.001      0.003      0.01       0.03       0.1        0.3
1.         3.         10.
0.24       0.42       0.8        1.4        2.8         5.1        9.8       15.5
21.        25.        28.
    8      #3 modulus for rock half space (Schnabel et al, 1972)
 .0001      0.0003     0.001      0.003      0.01       0.03       0.1      1.0
 1.000      1.000      0.9875     0.9525     0.900      0.810      0.725    0.550
    5      Damping in Rock (Schnabel et al, 1972)
 .0001      0.001      0.01       0.1        1.
  0.4       0.8        1.5        3.0        4.6
    2    1    3
option 2 -- soil profile:
    2
    1    9            EXAMPLE SITE
    1    1             7.00  1500.      0.05       0.120
    2    1            13.00  1000.      0.05       0.100
    3    1            10.00  1800.      0.05       0.100
    4    1            12.00  2000.      0.05       0.100
    5    1            20.00  2500.      0.05       0.125
    6    1            18.00  3000.      0.05       0.125
    7    1            20.00  4000.      0.05       0.125
    8    1            20.00  5000.      0.05       0.125
    9    3                              0.01       0.150      3000.
option 3 -- input motion:
    3
  800 2048   .02    PAS.acc                          (8f9.6)
             .1      25.        1    8
option 4 -- sublayer where input motion is applied (within or outcropping):
    4
    9    0
option 5 -- number of iterations & ratio of avg. strain to max strain:
    5
    1    7    0.65
option 6 -- sublayers for which accn. time histories are to computed & saved:
    6
    1    2    3    4    5    6    7    8    9    9
    1    1    1    1    1    1    1    1    1    0
    1    0    0    0    0    0    0    0    1    0

option 7 -- sublayer for which shear stresses or strains are computed & saved:
    7
    4    1    1      809            -- stress in level 4
```

Table 1
Sample Input

```
    4    0    1       809           -- strain in level 4
option 9 -- compute & save response spectrum:
    9
    1    0
    1    0     981.0
   0.05
option 10 -- compute & save amplification spectrum:
   10
    9    0    1    0    0.125
option 11 -- compute & save Fourier spectrum:
   11
    1    0    1    1 1000
    1    0    1    3 1000
execution will stop when program encounters 0
    0
```

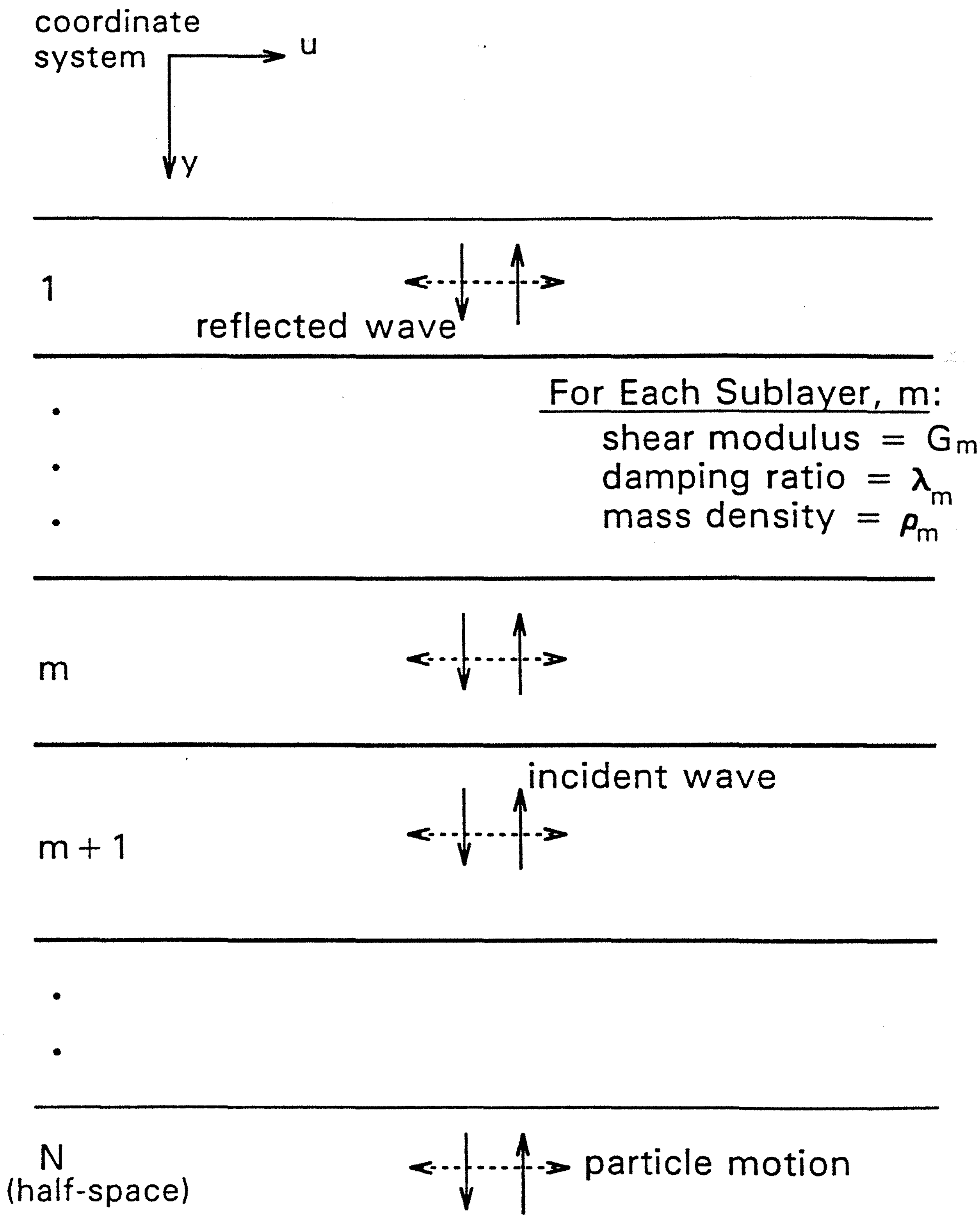


Fig. 1 One-Dimensional Idealization of a Horizontally-Layered Soil Deposit Over a Uniform Half-Space

APPENDIX B

SAMPLE PROBLEM

A 150-ft soil profile consisting of clay and sand overlying a half-space was used for this sample problem; the input is summarized in Table B-1. The response was calculated using as object (or input) motion the earthquake time history which had been recorded at Diamond Heights (EW component) during the 1989 Loma Prieta earthquake as an outcrop to the half-space underlying the soil profile. This motion was normalized to a peak acceleration of 0.1g.

The maximum shear wave velocities used for this sample problem are shown in Fig. B-1. The modulus reduction and the damping values as functions of strain are presented in Fig. B-2. The time history of the object motion, normalized to a peak acceleration of 0.1 g, and its response spectrum are shown in Fig. B-3.

The results for this sample problem are presented in Table B-2 and in Figs. B-3 through B-8. Table B-2 includes the properties used, the strain-compatible damping and modulus values obtained for each sublayer, the maximum strains, maximum shear stresses and maximum accelerations calculated throughout the soil profile. Also presented in Table B-2 are the spectral ordinates for the motions calculated at the ground surface of the soil profile and the amplification spectrum (ground surface/rock outcrop).

The calculated maximum shear strains and the strain-compatible damping and shear wave velocities obtained for this soil profile are shown in Fig. B-4. The calculated maximum accelerations and the maximum shear stresses are plotted in Fig. B-5. Figure B-6 shows the acceleration time history and spectral ordinates for the motion computed at the ground surface. The amplification spectrum (for frequencies up to 25 Hz) is presented in Fig. B-7. Time histories of shear strains and stresses calculated at depths of 20 and 60 ft are presented in Fig. B-8.

Table B-1
Input Data for Sample Problem

```
          option 1 - dynamic soil properties - (max is thirteen):
              1
              3
             11        #1 modulus for clay (seed & sun 1989) upper range
Strain  {  0.0001 1    0.0003 2  0.001 3   0.003 4   0.01 5    0.03 6    0.1 7     0.3 8
        {  1.     9    3.     10 10.   11
G/Gmax  {  1.000       1.000     1.000     0.981     0.941     0.847     0.656     0.438
        {  0.238       0.144     0.110
             11          damping for clay (Idriss 1990) -
Strain  {  0.0001      0.0003    0.001     0.003     0.01      0.03      0.1       0.3
        {  1.          3.16      10.
Damping {  0.24        0.42      0.8       1.4       2.8        5.1       9.8      15.5
        {  21.         25.       28.
             11        #2 modulus for sand (seed & idriss 1970) - upper Range
           0.0001      0.0003    0.001     0.003     0.01      0.03      0.1       0.3
           1.          3.        10.
           1.000       1.000     0.990     0.960     0.850     0.640     0.370     0.180
           0.080       0.050     0.035
             11          damping for sand (Idriss 1990) - (about LRng from SI 1970)
           0.0001      0.0003    0.001     0.003     0.01      0.03      0.1       0.3
           1.          3.        10.
           0.24        0.42      0.8       1.4       2.8        5.1       9.8      15.5
           21.         25.       28.
              8          #3 ATTENUATION OF  ROCK  AVERAGE
            .0001        0.0003    0.001      0.003     0.01      0.03       0.1     1.0
            1.000        1.000     0.9875    0.9525    0.900     0.810     0.725    0.550
              5          DAMPING IN ROCK
            .0001        0.001     0.01       0.1       1.
             0.4         0.8       1.5        3.0       4.6
              3     1    2    3
           Option 2 -- Soil Profile
              2     Soil Type       Thickness (ft)
Layer         1    17        Example -- 150-ft layer; input:Diam @ .1g
              1     2             5.00   Thickness   .050 Max    .125 Initial 1000.  Total
              2     2             5.00   (ft)        .050 Shear  .125 Damping  900.  Unit
              3     2            10.00               .050 Mod    .125 Est      900.  weight
              4     2            10.00               .050 (Ksf)  .125          950.  (Ksf)
              5     1            10.00               .050        .125         1000.
              6     1            10.00               .050        .125         1000.
              7     1            10.00               .050        .125         1100.
              8     1            10.00               .050        .125         1100.
              9     2            10.00               .050        .130         1300.  Max
             10     2            10.00               .050        .130         1300.  Shear
             11     2            10.00               .050        .130         1400.  Wave
             12     2            10.00               .050        .130         1400.
             13     2            10.00               .050        .130         1500.  Velocity
             14     2            10.00               .050        .130         1500.
             15     2            10.00               .050        .130         1600.  (ft/sec)
             16     2            10.00               .050        .130         1800.
             17     3                                .010        .140         4000.
           Option 3 -- input motion:
              3
            1900 4096    .02       diam.acc                          (8f10.6)
                         .10       25.         3    8
           Option 4 -- sublayer for input motion (within (1) or outcropping (0):
              4
             17     0
```

Table B-1
Input Data for Sample Problem

```
Option 5 -- number of iterations & ratio of avg strain to max strain
    5
    0    8     0.50
Option 6 -- sublayers for which accn time histories are computed & saved:
    6
    1    2    3    4    5    6    7    8    9   10   11   12   13   14   15
    0    1    1    1    1    1    1    1    1    1    1    1    1    1    1
    1    0    0    0    0    0    0    0    0    0    0    0    0    0    0
Option 6 -- sublayers for which accn time histories are computed & saved:
    6
   16   17   17
    1    1    0
    0    1    0
option 7 -- sublayer for which shear stress or strain are computed & saved:
    7
    4    1    1    0 1800           -- stress in level 4
    4    0    1    0 1800           -- strain in level 4
option 7 -- sublayer for which shear stress or strain are computed & saved:
    7
    8    1    1    0 1800           -- stress in level 8
    8    0    1    0 1800           -- strain in level 8
option 9 -- compute & save response spectrum:
    9
    1    0
    1    0      981.0
   0.05
option 10 -- compute & save amplification spectrum:
   10
   17    0    1    0       0.125      - surface/rock outcrop
execution will stop when program encounters 0
    0
```

Outcropping

Max & time History

max # of sublayers

w/in soil profile

only maximum

stress

strain

# of damping ratios

array of damping ratios

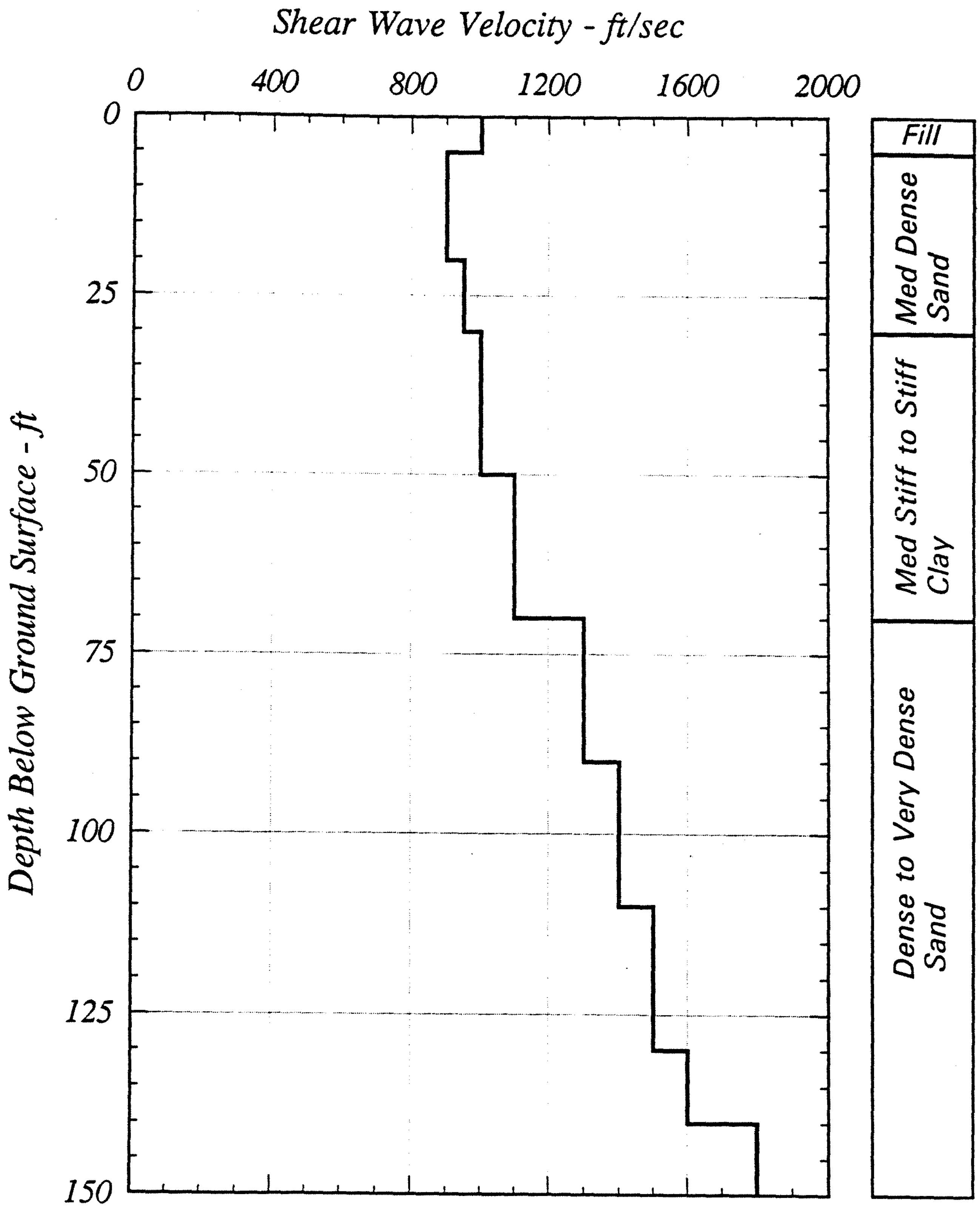


Fig. B-1 Shear Wave Velocities Used for Sample Problem

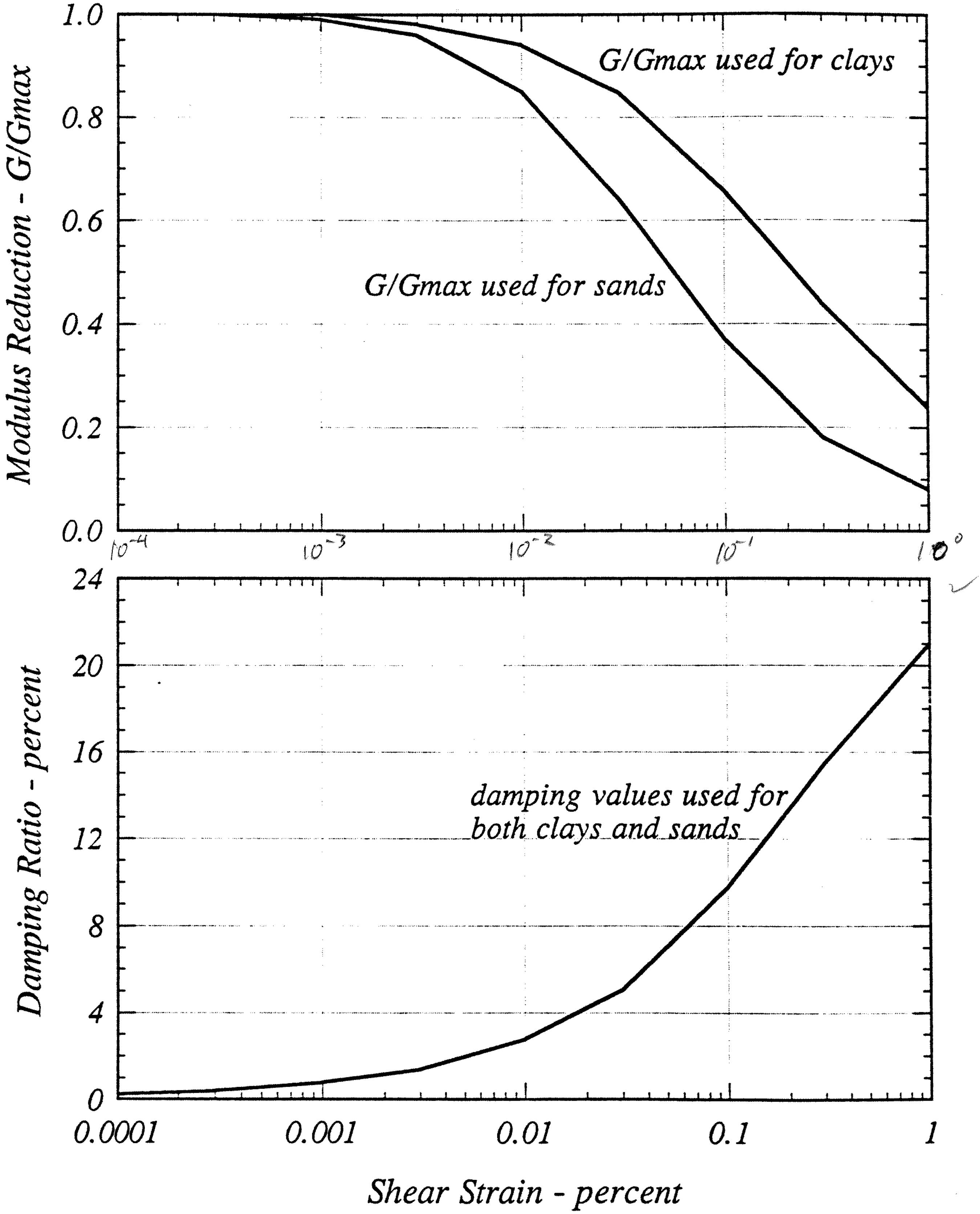


Fig. B-2 Moduius Reduction and Damping Values Used for Sample Problem

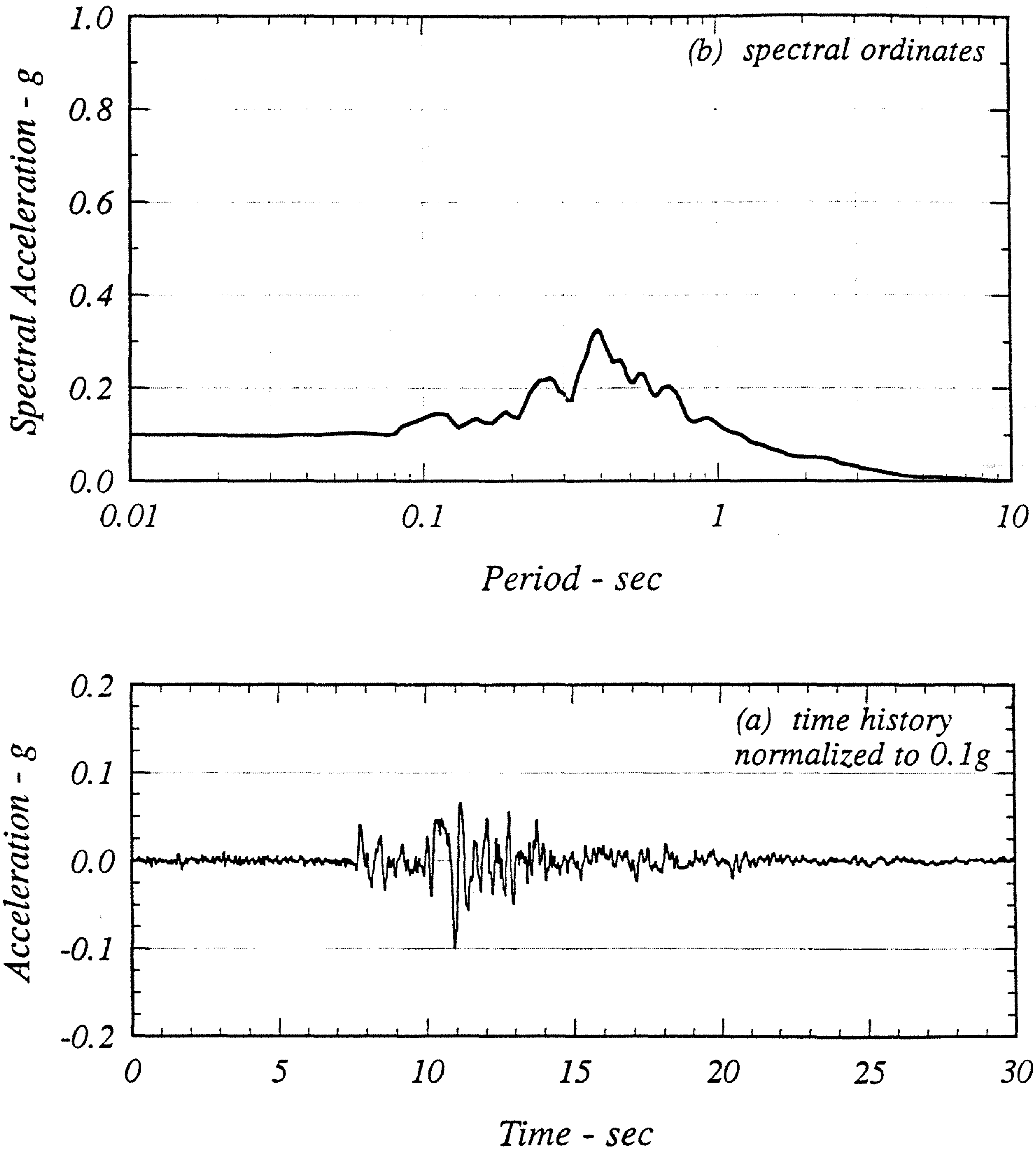


Fig. B-3 Acceleration Time History and Spectral Ordinates for EW Component Recorded at Diamond Heights

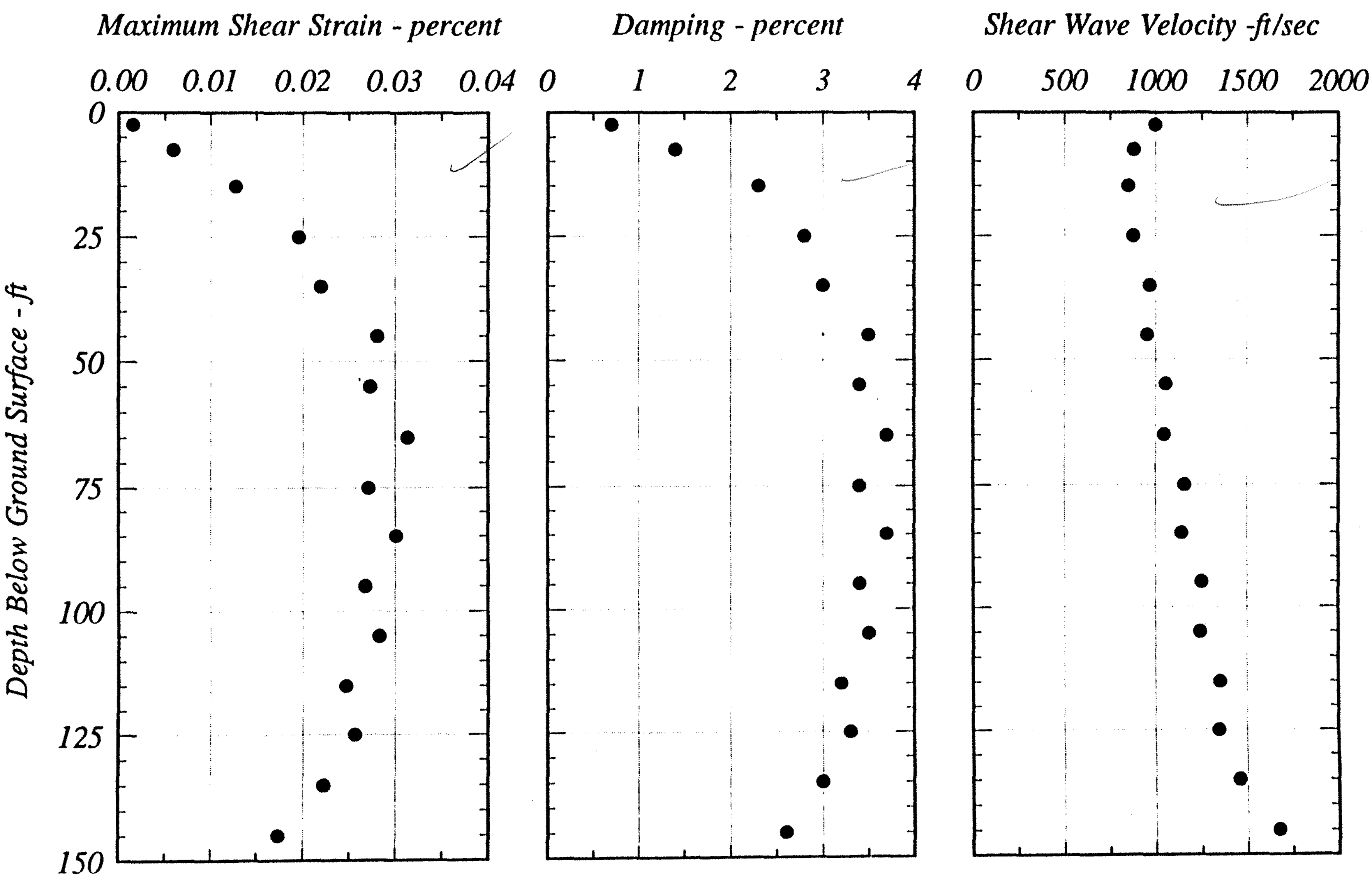


Fig. B-4 Calculated Shear Strains and Strain-Compatible Damping and Shear Wave Velocities for Sample Problem Using Diamond Heights Record as Input Motion

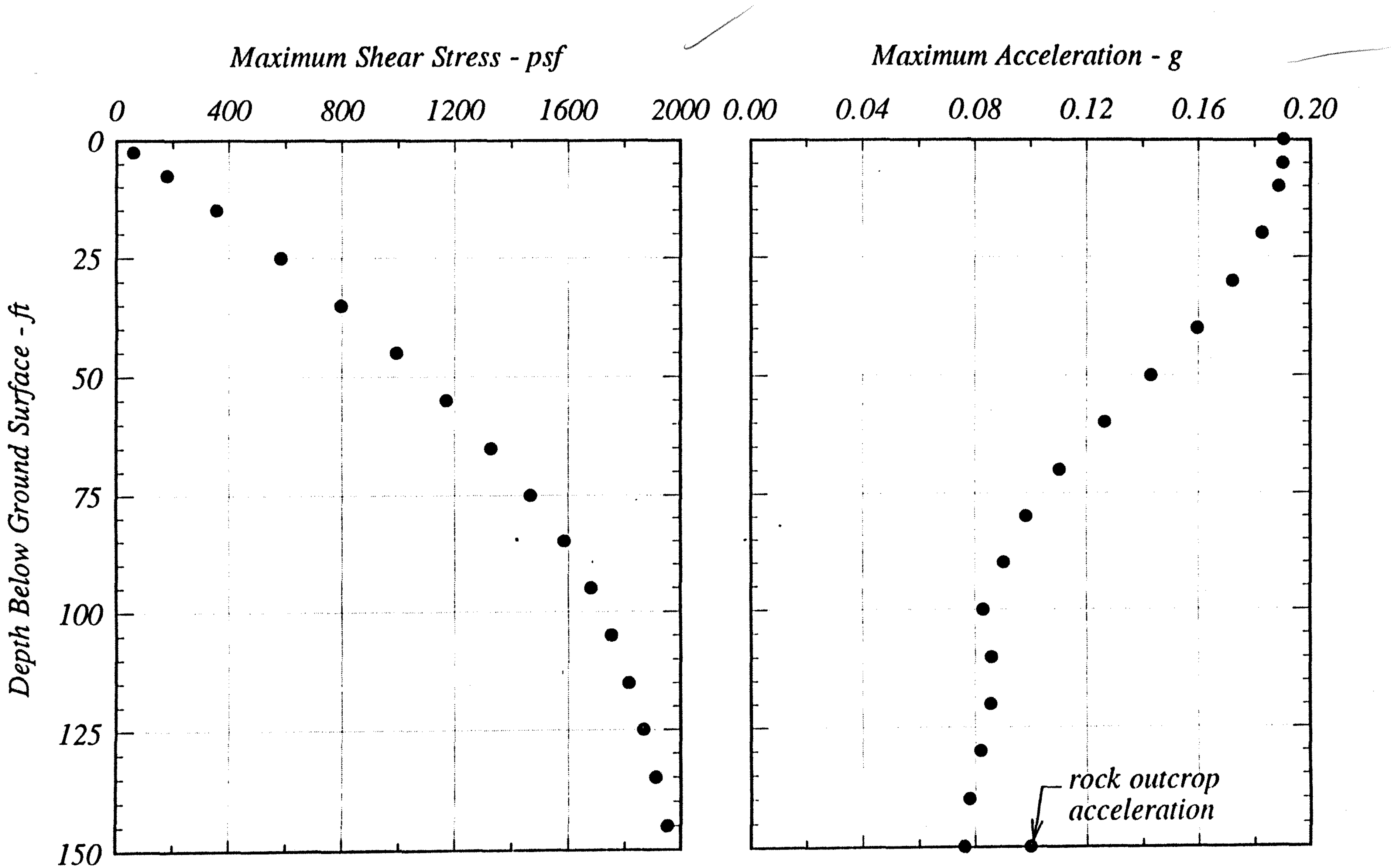
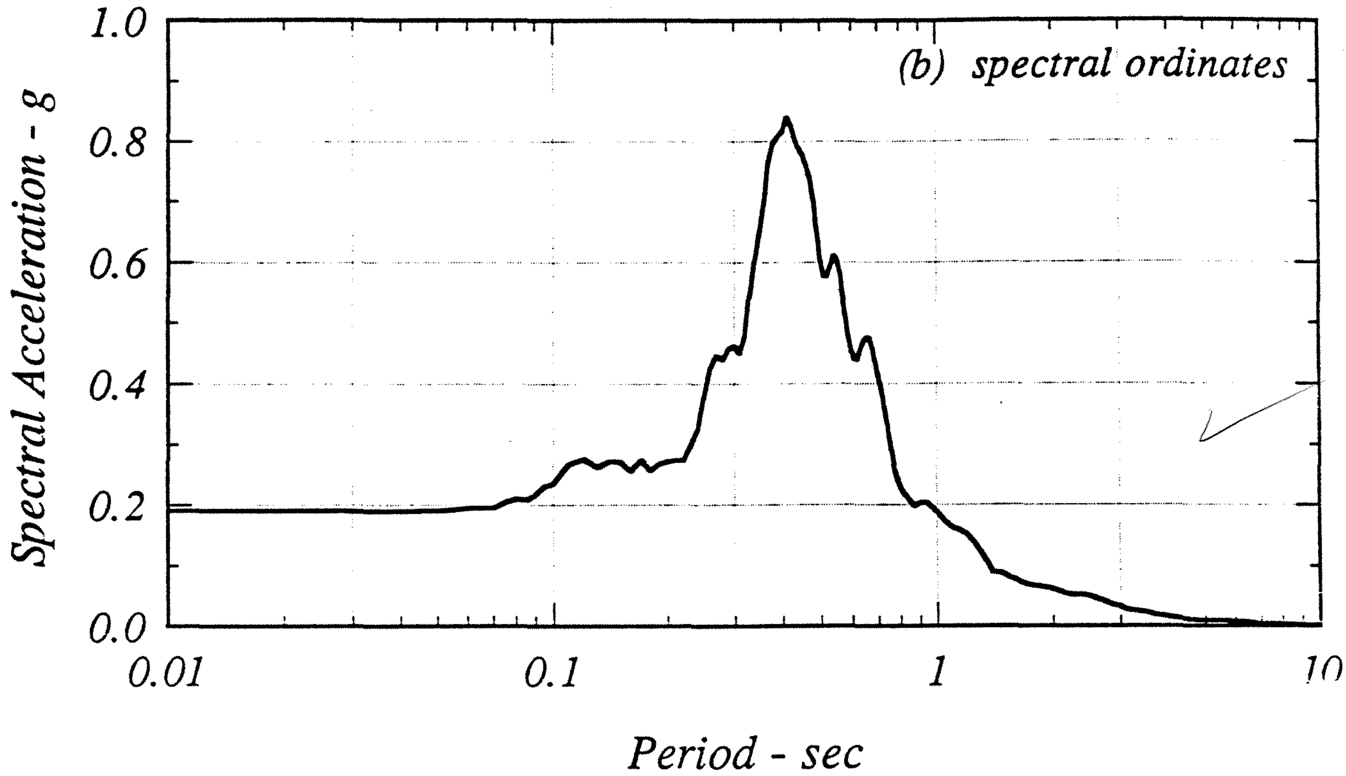


Fig. B-5 Calculated Shear Stresses and Accelerations for Sample Problem Using Diamond Heights Record as Input Motion



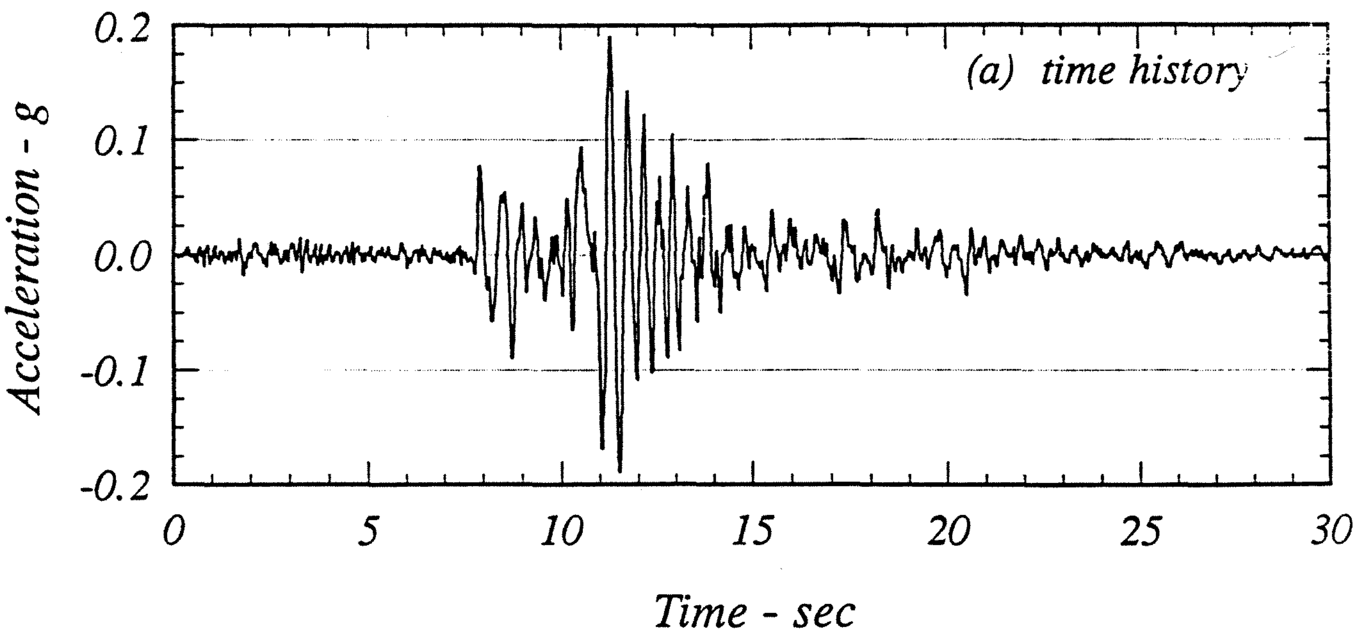


Fig. B-6 Acceleration Time History and Spectral Ordinates for Computed Motion at the Ground Surface Using Diamond Heights Record as Input Motion

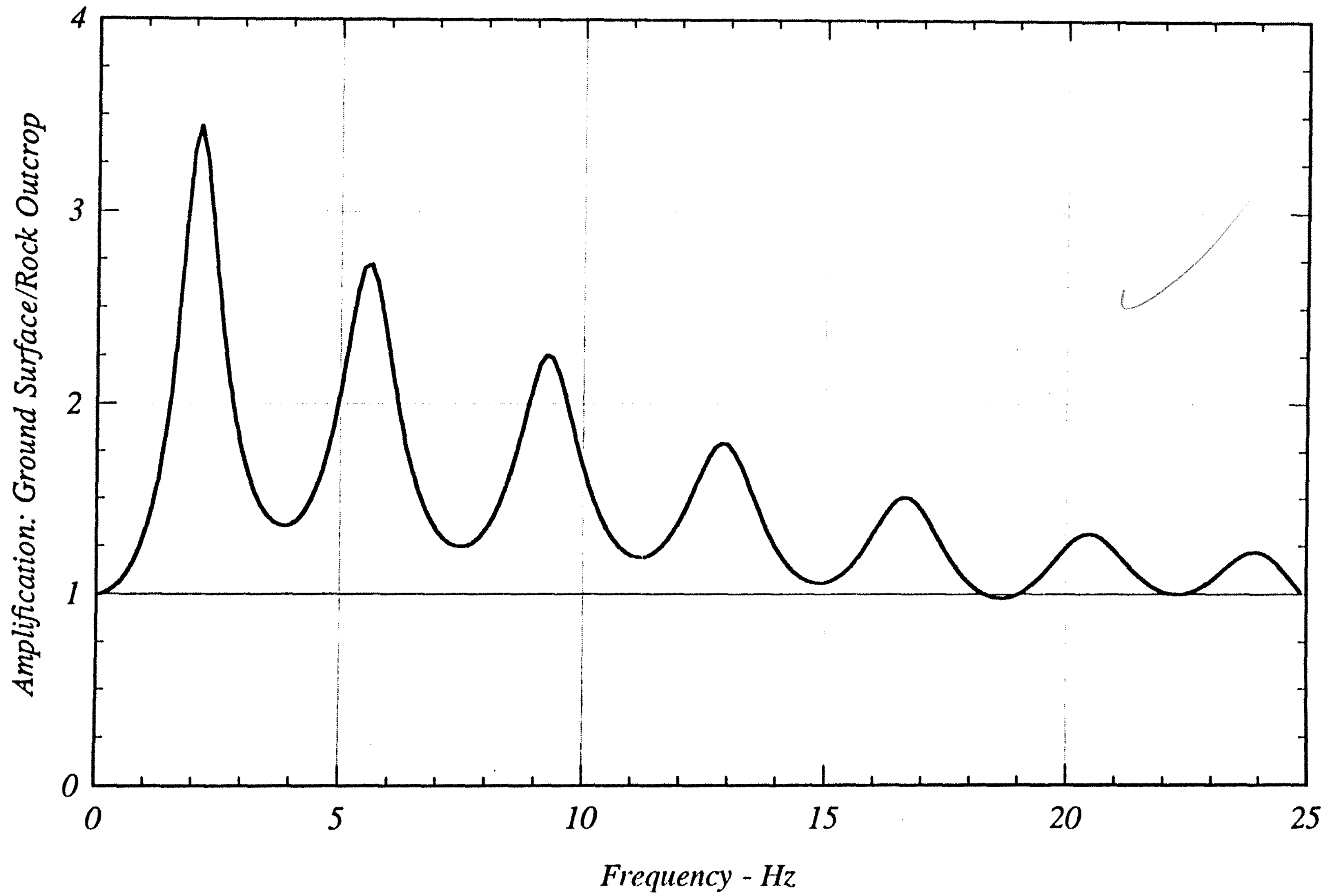


Fig. B-7 Calculated Amplification Spectrum for Sample Problem Using Diamond Heights Record as Input Motion

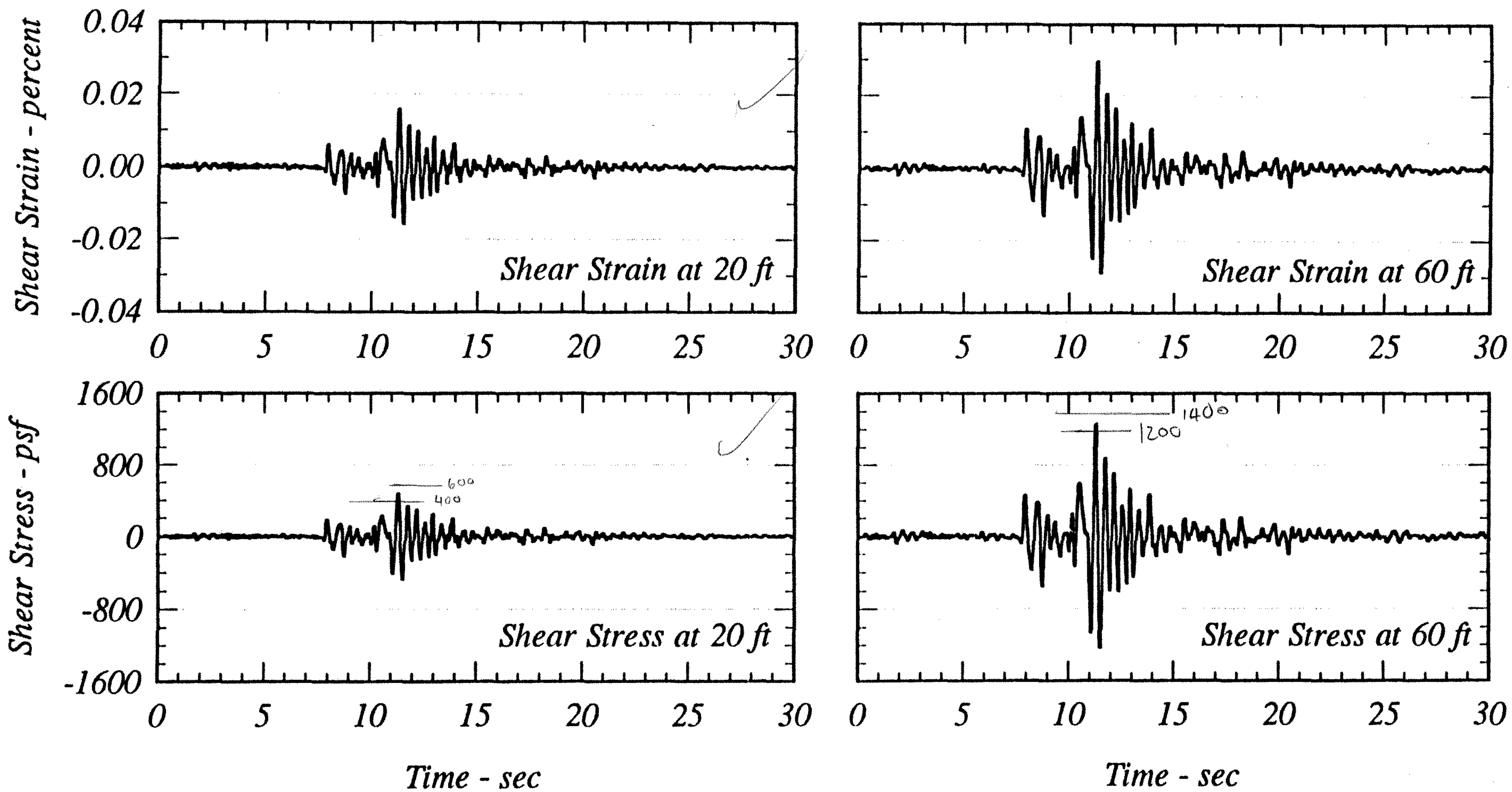


Fig. B-8 Time Histories of Shear Strains and Stresses Calculated at Depths of 20 and 60 ft for Sample Problem Using Diamond Heights Record as Input Motion

USER'S MANUAL
FOR

SHAKE91

A Computer Program for Conducting Equivalent Linear
Seismic Response Analyses of Horizontally Layered Soil Deposits

Program Modified based on the Original ***SHAKE*** program published in
December 1972 by Schnabel, Lysmer & Seed

Modifications by

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Sponsored by

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November 1992

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USER'S MANUAL FOR

SHAKE91

A Computer Program for Conducting Equivalent Linear Seismic Response Analyses of Horizontally Layered Soil Deposits

Program Modified based on the Original ***SHAKE*** program published in December 1972 by Schnabel, Lysmer & Seed

Modifications by

I. M Idriss[1] and Joseph I. Sun[2]

INTRODUCTION

The computer program **SHAKE** was written in 1970-71 by Dr. Per Schnabel and Professor John Lysmer and was published in December 1972 by Dr. Per Schnabel and Professors John Lysmer and H. Bolton Seed in report No. UCB/EERC 72/12, issued by the Earthquake Engineering Research Center at the University of California in Berkeley. This has been by far the most widely used program for computing the seismic response of horizontally layered soil deposits.

The program computes the response of a semi-infinite horizontally layered soil deposit overlying a uniform half-space subjected to vertically propagating shear waves. The analysis is done in the frequency domain, and, therefore, for any set of properties it is a linear analysis. An iterative procedure is used to account for the nonlinear behavior of the soils as summarized below.

The object motion (ie, the motion that is considered to be known) can be specified at the top of any sublayer within the soil profile or at the corresponding outcrop.

The program **SHAKE** was originally written for a main frame computer. It was converted for use on a personal computer by Dr. S. S. Lai in 1985; almost everything else remained identical to the original computer program. While there have been many modifications and several editions of the program **SHAKE** have been referenced in recent publications, the version included herein constitutes the most extensive modifications to

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the original program. The intent of the modifications was to make the program more convenient for use with a personal computer.

MODIFICATIONS IMPLEMENTED IN SHAKE91

The main modifications incorporated in ***SHAKE91*** include the following:

- The number of sublayers was increased from 20 to 50; this should permit a more accurate representation of deeper and/or softer soil deposits.

- All built-in modulus reduction and damping relationships were removed. These relationships are now specified by the user; up to 13 different relations of modulus reduction, G/G_{max}, versus shear strain and damping ratio, λ, versus shear strain can be specified as part of the input file. A number of published variations of G/G_{max} and λ with shear strain are available in the literature (eg, Hardin and Drnevich, 1970; Seed and Idriss, 1970; Seed et al, 1986; Sun et al, 1988; Vucetic and Dobry, 1991).

- The maximum shear velocity or the maximum modulus are now specified for each sublayer; again these are part of the input and therefore the program no longer calculates modulus values as a function of either confining pressure or shear strength. The user specifies the maximum values, which are derived by the user.

- Object motion is now read from a separate file; the number of header lines and format are specified by the user.

- Other clean-up include: renumbering of options, elimination of infrequently used options, user specified periods for calculating spectral ordinates ... etc.

DESCRIPTION OF THE PROGRAM

The soil profile is idealized as a system of homogeneous, visco-elastic sublayers of infinite horizontal extent; the idealized soil profile is shown in Fig. 1. The response of this system is calculated considering vertically propagating shear waves. The algorithm in the original program **SHAKE** (Schnabel et al, 1972) is based on the continuous solution to the wave equation (Kanai, 1951; Matthiesen et al, 1964; Roesset and Whitman, 1969; Lysmer et al 1971), which was adapted for transient motions using the Fast Fourier Transform techniques of Cooley and Tukey (1965). The program ***SHAKE91*** retains this feature of the original program. Details pertinent to the derivation of the applicable equations of motion and solution of these equations are summarized in the original **SHAKE** manual, in the aforementioned references and in most textbooks on wave propagation. Therefore, they are not repeated in this user's manual.

An equivalent linear procedure (Idriss and Seed, 1968; Seed and Idriss, 1970) is used to account for the nonlinearity of the soil using an iterative procedure to obtain values for modulus and damping that are compatible with the equivalent uniform strain induced in each sublayer. Thus, at the outset, a set of properties (shear modulus, damping and total unit weight) is assigned to each sublayer of the soil deposit. The analysis is conducted using these properties and the shear strains induced in each sublayer is calculated. The shear modulus and the damping ratio for each sublayer are then modified based on the applicable relationship relating these two properties to shear strain. The analysis is repeated until strain-compatible modulus and damping values are arrived at. Starting with the maximum shear modulus for each sublayer and a low value of damping, essentially strain-compatible properties (ie, difference less than about one percent) are obtained in 5 to 8 iterations for most soil profiles.

The following assumptions are incorporated in the analysis (Schnabel et al, 1972):

- Each sublayer, m, is completely defined by its shear modulus, G_m, damping ratio, λ_m, total unit weight, γ_{tm} (or corresponding mass density, ρ_m) and thickness, h_m; these properties are independent of frequency.

- The responses in the soil profile are caused by the upward propagation of shear waves from the underlying rock half-space.

- The shear waves are specified as acceleration ordinates at equally spaced time intervals. (Cyclic repetition of the acceleration time history is implied in the solution).

- The strain dependence of the shear modulus and damping in each sublayer is accounted for by an equivalent linear procedure based on an equivalent uniform strain computed in that sublayer. The ratio of this equivalent uniform shear strain divided by the calculated maximum strain is specified by the user (see Option 5 below); the same value of this ratio is used for all sublayers.

Available Options

The options incorporated into ***SHAKE91*** are as follows:

Option Number	Description
1	dynamic soil properties
2	data for soil profile
3	input (object) motion
4	assignment of object motion to the top of a specified sublayer or to the corresponding outcrop
5	number of iterations specified & ratio of uniform strain to maximum strain

6	sublayers at top of which peak accelerations & time histories are computed and saved
7	sublayer at top of which time history of shear stress or strain is computed and saved
8	time history of object motion
9	response spectrum
10	amplification spectrum
11	Fourier amplitudes

Note that the original program **SHAKE** included 16 options and that the modified program includes only 11; the five options eliminated pertain mostly to plotting and to adjusting the time increment. Such operations can best be done in auxiliary programs.

INPUT DATA

The input data are provided in an input file; the name and location of this input file is specified directly from the key board at the time of program execution. A sample input is presented in Table 1. As can be noted in the table, each option starts with the following two lines:

Line No. 1 (Format: A80)

columns 1 - 80 Identification information for this option (this line cannot be blank)

Line No. 2 (Format: I5)

columns 1 - 5 Option Number

The specific inputs for each option are presented below.

Option 1 -- Dynamic Soil Properties

- first line after option number (Format: I5)

columns 1 - 5 Number of materials included (maximum is 13)

then, for each material, the following input should be supplied:

first line (Format: I5, 11A6)

columns 1 - 5 number of strain values to be read (maximum is 20)

columns 6 - 71	identification for this set of modulus reduction values

second & consecutive lines (Format: 8F10.0)

columns 1 - 80	strain values, in percent, beginning with the lowest value. Eight entries per line using 8F10.0 Format (maximum is 20)

consecutive lines (Format: 8F10.0)

columns 1 - 80	values of modulus reduction (G/G_{max}) each corresponding to the shear strain provided in the previous lines; these values should be in decimal not in percent.

the second set for the same material will consist of identical information except that values of damping (in percent) are provided as illustrated in Table 1.

After the last set is completed, the following information is to be provided (Format: 16I5):

columns 1 - 5	number, N, of materials to be used in this analysis
columns 6 - 10	first material number which will be used
columns 11 - 15	second material number to be used
columns 16 - 20	third material number to be used
.	....
.	....
.	etc until all N materials are identified.

Values of G/G_{max} and λ versus strain for these N materials will then be saved in output file No. 1 (see section on OUTPUT below) so that only the material properties used in this analysis are saved in this file. This feature was added for the convenience of the user who can include up to 13 sets of material properties in the input file but for any one analysis uses fewer than 13. This feature also provides a check that the intended material properties were utilized in the analysis.

Option 2 – Soil Profile

- first line after option number (Format: 2I5, 5X, 6A6)

columns 1 - 5	soil deposit number; may be left blank
columns 11 - 10	number of sublayers, including the half-space
columns 16 - 51	identification for soil profile

- second and subsequent lines; one line for each sublayer, including the half-space (Format: 2I5, 5X, 5F10.0)

columns 1 - 5	sublayer number
columns 11 - 10	soil type (corresponding to numbers assigned to each material in Option 1). [Note that if this material type is given as 0 (zero) for ***all*** sublayers, then the calculations are conducted for only one iteration using the properties (modulus, or shear wave velocity, and damping) specified in this input].
columns 16 - 25	thickness of sublayer, in feet
columns 26 - 35	maximum shear modulus for the sublayer, in ksf (leave blank if maximum shear wave velocity for the sublayer is given)
columns 36 - 45	initial estimate of damping (decimal)
columns 46 - 55	total unit weight, in ksf
columns 56 - 65	maximum shear wave velocity for the sublayer, in ft/sec (leave blank if maximum shear modulus for the sublayer is given)

For the half-space, leave columns 16 to 25 blank; ie, no thickness should be specified for the half-space.

<u>Option 3 -- Input (Object) Motion</u>

- first line after option number (Format: 2I5, F10.3, A30, A12)

columns 1 - 5	number, NV, of acceleration values to be read for input motion
columns 6 - 10	number, MA, of values for use in Fourier Transform; MA should be a power of 2 (typically, this number is 1024, 2048 or 4096). Note that MA should always be greater than NV. The following may be used as a guide: for NV $\leq$ 800, MA can be 1024, for NV $\leq$ 1800, MA can be 2048 and for NV $\leq$ 3800, MA can be 4096. The current program is limited to a maximum value of 4096 for MA.
columns 11 - 20	time interval between acceleration values, in seconds
columns 21 - 50	name of file for input (object) motion
columns 51 - 62	format for reading acceleration values

- second line after option number (Format: 3F10.0, 2I5)

columns 1 - 10	multiplication factor for adjusting acceleration values; use only if columns 11 - 20 are left blank
columns 11 - 20	maximum acceleration to be used, in g's; the acceleration values read-in will be scaled to provide the maximum acceleration specified in these columns; leave columns 11 - 20 blank if a multiplication factor is specified in columns 1 - 10.
columns 21 - 30	maximum frequency (ie, frequency cut-off) to be used in the analysis

columns 31 - 35	number of header lines in file containing object motion
columns 36 - 40	number of acceleration values per line in file containing object motion

<u>Option 4 -- Assignment of Object Motion to a Specific Sublayer</u>

- first line after option number (Format: 2I5)

columns 1 - 5	number of sublayer at the top of which the object motion is assigned
columns 11 - 10	use 0 (zero) if the object motion is to be assigned as outcrop motion, otherwise use 1 (one) if the object motion is applied within the soil profile at the top of the assigned sublayer

<u>Option 5 -- Number of Iterations & Ratio of Equivalent Uniform Strain to Maximum Strain</u>

- first line after option number (Format: 2I5, F10.0)

columns 1 - 5	parameter used to specify whether the strain-compatible soil properties are saved after the final iteration; set = 1 if these properties are to be saved; otherwise leave columns 1 - 5 blank
columns 1 - 10	number of iterations
columns 11 - 20	ratio of equivalent uniform strain divided by maximum strain; typically this ratio ranges from 0.4 to 0.75 depending on the input motion and which magnitude earthquake it is intended to represent. The following equation may be used to estimate this ratio: [ratio = (M - 1)/10] in which M is the magnitude of the earthquake. Thus, for M = 5, the ratio would be 0.4, for M = 7.5, the ratio would be 0.65 ... etc.

<u>Option 6 -- Computation of Acceleration at Top of Specified Sublayers</u>

(Note that a maximum of fifteen sublayers can be specified at a time; if accelerations for more than 15 sublayers are desired, then Option 6 can be repeated as many times as needed).

- first line after option number (Format: 15I5)

columns 1 - 75	array to indicate the numbers of the sublayers at the top of which the acceleration is to be calculated

- second line after option number (Format: 15I5)

columns 1 - 75	array to specify type of each sublayer: 0 (zero) for outcropping or 1 (one) for within the soil profile

- third line after option number (Format: 15I5)

columns 1 - 75	array to specify the mode of output for the computed accelerations: 0 (zero) if only maximum acceleration is desired or 1 (one) if both the maximum acceleration and the time history of acceleration are to be calculated and saved

Option 7 -- Computation of Shear Stress or Strain Time History at Top of Specified Sublayers

(Note that a maximum of two sublayers can be specified; if stress or strain time histories for more than two sublayers are desired, then Option 7 can be repeated as many times as needed).

- first line after option number (Format: 5I5, F10.0, 5A6)

columns 1 - 5	number of sublayer
columns 11 - 10	set equal to 0 (zero) for strain or 1 (one) for stress
columns 11 - 15	set equal to one to save time history of strain or stress
columns 16 - 20	leave blank
columns 21 - 25	number of values to be saved; typically this should be equal to the number NV (see Option 3 above)
columns 26 - 35	leave blank
columns 36 - 65	identification information

- second line after option number (Format: 5I5, F10.0, 5A6)

same as the above line for the second sublayer

Note that the time histories of shear stresses or strains are calculated at the top of the specified sublayer. Thus, if the time history is needed at a specific depth within the soil profile, that depth should be made the top of a sublayer. The time history of stresses or strains is saved in the second Output file.

This options should be specified after Option 6 as shown in Table 1 and in Table B-1.

Option 8 -- Time History of Object Motion

Although this option was retained, its purpose is most easily accomplished in Option 6.

Option 9 -- Response Spectrum

- first line after option number (Format: 2I5)

columns 1 - 5	sublayer number
columns 6 - 10	set equal to 0 (zero) for outcropping or equal to 1 (one) for within

- second line after option number (Format: 2I5, F10.0)

columns 1 - 5	number of damping ratios to be used
columns 6 - 10	set equal to 0 (zero)
columns 11 -20	acceleration of gravity

- third line after option number (Format: 6F10.0)

columns 1 - 60	array for damping ratios (in decimal)

Option 10 -- Amplification Spectrum

- first line after option number (Format: 4I5, F10.0, 8A6)

columns 1 - 5	number of first sublayer
columns 6 - 10	set equal to 0 (zero) for outcropping or equal to 1 (one) for within
columns 11 -15	number of second sublayer
columns 16 - 20	set equal to 0 (zero) for outcropping or equal to 1 (one) for within
columns 21 - 30	frequency step (in cycles per second); the amplification spectrum is calculated for 200 frequencies using this frequency step and starting with 0
columns 31 - 78	identification information

[The amplification spectrum is the ratio of the amplitude of motion at the top of the second sublayer divided by that at the top of the first sublayer].

If the amplification spectrum is desired for two other sublayers, Option 10 can be repeated as many times as needed.

Option 11 -- Fourier Spectrum

- first line after option number (Format: 5I5)

columns 1 - 5	number of the sublayer
columns 6 - 10	set equal to 0 (zero) for outcropping or equal to 1 (one) for within
columns 11 -15	set equal to 2 (two) if spectrum is to be saved to file
columns 16 - 20	number of times the spectrum is to be smoothed
columns 21 - 25	number of values to be saved

The following expression (Schnabel et al, 1972) is used to smooth the Fourier spectrum:

$$A_i = \frac{A_{i-1} + 2A_i + A_{i+1}}{4}$$

in which A_i is the amplitude of the spectrum for the i^{th} frequency.

A second line is always needed when using Option 11. Thus, the user should either provide a second line for another sublayer or repeat the information provided in the first line in a second line.

It may be noted that calculation of Fourier amplitudes for a specific accelerogram is best accomplished in an auxiliary program.

Program Termination

For program termination, the user should provide a line that contains information that execution will terminate when the number is encountered as an option number; the line following this information should have 0 (zero) with a format of I5. Execution will then terminate.

OUTPUT

The output of the program is contained in two files. The first file echoes much of the input information and contains the results of each iteration, the listing of calculated maximum shear stresses and strains, maximum acceleration, response spectrum, Fourier spectrum and amplification spectrum, as appropriate. The second file contains all the time histories requested. The name of each file is specified by the user at the time of program execution directly from the key-board.

COMPUTER LISTING

The FORTRAN listing of program ***SHAKE91*** is given in Appendix A.

SAMPLE PROBLEM

The results for a sample problem are given in Appendix B.

CONCLUDING REMARKS

The computer program SHAKE has been widely used throughout the United States and in many parts of the world for conducting ground response studies. Its use in recent studies involving recordings obtained at several sites from the 1989 Loma Prieta earthquake (eg, Idriss, 1990; Dickenson et al, 1991; Idriss, 1991; Rollins et al, 1992; Yokel, 1992) have indicated that the calculated surface motions are in reasonably good agreement with the recorded values when the appropriate soil properties and input rock motions are used.

Therefore, this program remains a convenient tool for conducting such analyses at many sites and for a variety of applications.

ACKNOWLEDGMENTS

The modification of the original SHAKE program was completed as part of a research study regarding earthquake ground motions being completed at the University of California at Davis. The study is being supported by a research grant from the National Institute of Standards and Technology (NIST); Dr. Felix Y. Yokel of NIST is the Contract monitor for this study. The writers gratefully acknowledge the support of NIST and thank Dr. Yokel for his timely input and support during this study.

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Table 1
Sample Input

```
option 1 - dynamic soil properties - (max is thirteen):
    1
    3
   11      #1 modulus reduction for clay (Sun et al, 1988) upper range
0.0001     0.0003    0.001     0.003     0.01      0.03      0.1       0.3
1.         3.        10.
1.000      1.000     1.000     0.981     0.941     0.847     0.656     0.438
0.238      0.144     0.110
   11      damping for clay (Idriss 1990) -
0.0001     0.0003    0.001     0.003     0.01      0.03      0.1       0.3
1.         3.16      10.
0.24       0.42      0.8       1.4       2.8        5.1       9.8      15.5
21.        25.       28.
   11      #2 modulus reduction for sand (seed & idriss 1970) - upper Range
0.0001     0.0003    0.001     0.003     0.01      0.03      0.1       0.3
1.         3.        10.
1.000      1.000     0.990     0.960     0.850     0.640     0.370     0.180
0.080      0.050     0.035
   11      damping for sand (Idriss 1990) - (LRng from seed & idriss) 1970)
0.0001     0.0003    0.001     0.003     0.01      0.03      0.1       0.3
1.         3.        10.
0.24       0.42      0.8       1.4       2.8        5.1       9.8      15.5
21.        25.       28.
    8      #3 modulus for rock half space (Schnabel et al, 1972)
 .0001      0.0003    0.001        0.003     0.01      0.03        0.1     1.0
 1.000      1.000     0.9875    0.9525    0.900     0.810     0.725     0.550
    5      Damping in Rock (Schnabel et al, 1972)
 .0001      0.001     0.01         0.1       1.
  0.4       0.8       1.5          3.0       4.6
    2    1    3
option 2 -- soil profile:
    2
    1    9          EXAMPLE SITE
    1    1           7.00  1500.      0.05      0.120
    2    1          13.00  1000.      0.05      0.100
    3    1          10.00  1800.      0.05      0.100
    4    1          12.00  2000.      0.05      0.100
    5    1          20.00  2500.      0.05      0.125
    6    1          18.00  3000.      0.05      0.125
    7    1          20.00  4000.      0.05      0.125
    8    1          20.00  5000.      0.05      0.125
    9    3                            0.01      0.150     3000.
option 3 -- input motion:
    3
  800 2048    .02    PAS.acc                          (8f9.6)
              .1      25.         1    8
option 4 -- sublayer where input motion is applied (within or outcropping):
    4
    9    0
option 5 -- number of iterations & ratio of avg. strain to max strain:
    5
    1    7     0.65
option 6 -- sublayers for which accn. time histories are to computed & saved:
    6
    1    2    3    4    5    6    7    8    9    9
    1    1    1    1    1    1    1    1    1    0
    1    0    0    0    0    0    0    0    1    0
```

Table 1
Sample Input

```
option 7 -- sublayer for which shear stresses or strains are computed & saved:
    7
    4    1    1       809            -- stress in level 4
    4    0    1       809            -- strain in level 4
option 9 -- compute & save response spectrum:
    9
    1    0
    1    0     981.0
   0.05
option 10 -- compute & save amplification spectrum:
   10
    9    0    1    0    0.125
option 11 -- compute & save Fourier spectrum:
   11
    1    0    1    1 1000
    1    0    1    3 1000
execution will stop when program encounters 0
    0
```

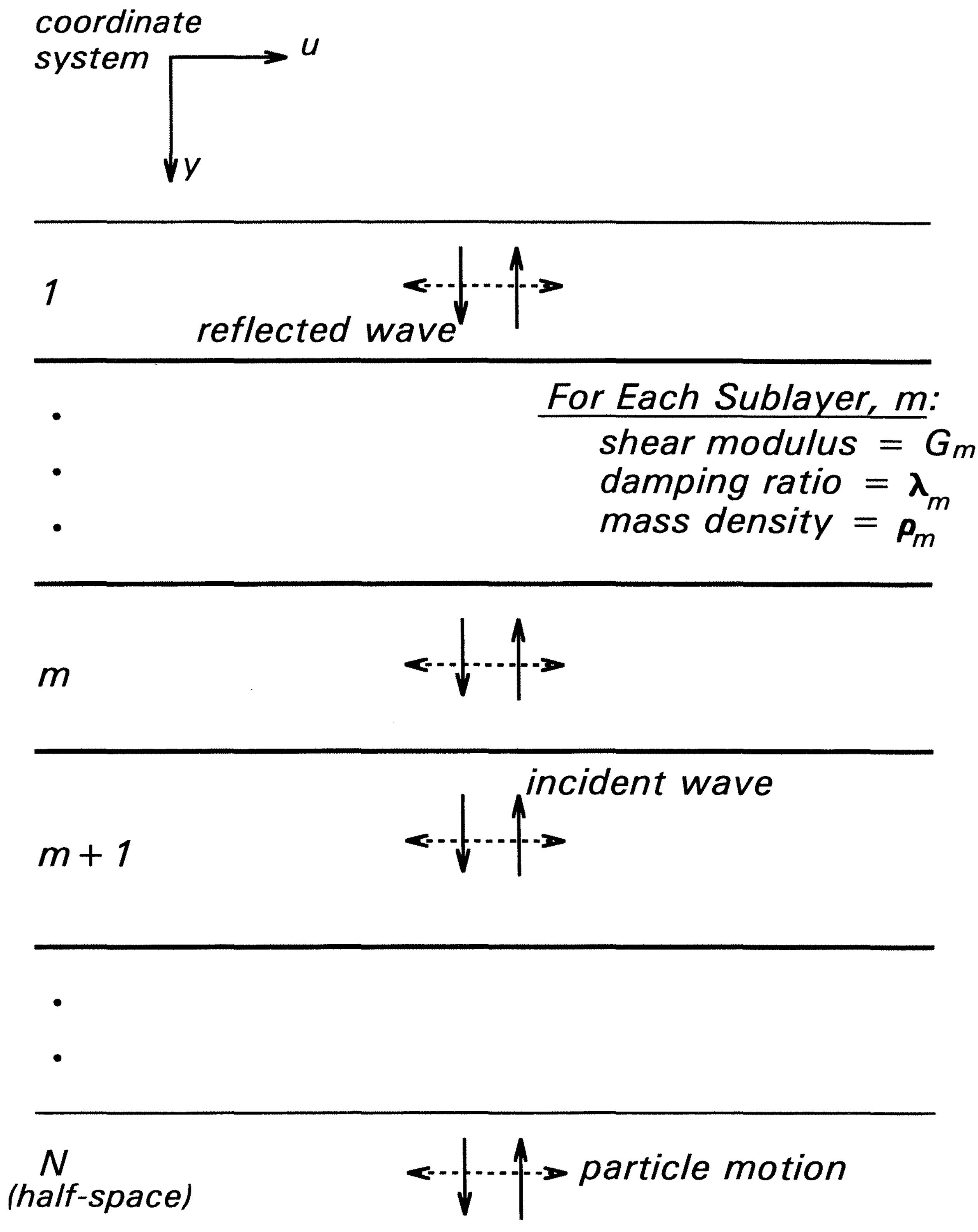

Fig. 1 One-Dimensional Idealization of a Horizontally-Layered Soil Deposit Over a Uniform Half-Space

APPENDIX A

COMPUTER LISTING

SHAKE91

A Computer Program for Conducting Equivalent Linear
Seismic Response Analyses of Horizontally Layered Soil Deposits

Program Modified based on the Original ***SHAKE*** program published in
December 1972 by Schnabel, Lysmer & Seed

Modifications by

I. M Idriss and Joseph I. Sun

November 1992

APPENDIX A

COMPUTER LISTING

The FORTRAN listing of the program ***SHAKE91*** is included in this Appendix. The program consists of the following four modules:

- MAIN
- A1
- B1
- C1

Each module contains several subroutines as follows:

MODULE	SUBROUTINE
MAIN	EARTHQ
A-1	CURVEG
	STEPG
	RESP
	DRCTSP
	CMPMAX
	FFT
	RFFT
	RFSN
	XMX
B-1	AMP
	UTPR
	REDUCE
	INCR
	MOTION
	CXSOIL
	STRAIN
C-1	SHAKIT
	STRT
	SOILIN
	CG

The program has been compiled in DOS using FORTRAN 5.1 and under Windows 3.1; the latter offers the opportunity to run the program concurrently with other applications if desired.

Listings of the above modules are included in the remaining pages of this Appendix.

```
$NOFLOATCALLS
$NODEBUG
C ..................................................................
      PROGRAM SHAKE91
      CHARACTER*32 FIN,FOUT,PUNCH
      COMMON X(25620)
      COMMON /TIME/ T(9)
      COMMON /WGK/  WW, GT, SKO
C ..................................................................
      WRITE(*,100)
  100 FORMAT(2X,'*****************************************************'/
     + 2X,'* SHAKE  --    A COMPUTER PROGRAM FOR EARTHQUAKE RESPONSE  *'/
     + 2X,'*              ANALYSIS OF HORIZONTALLY LAYERED SITES      *'/
     + 2X,'*              by: Per B. Schnabel & John Lysmer -- 1970   *'/
     + 2X,'* ------------------------------------------------------- *'/
     + 2X,'* shake85      IBM-PC version of SHAKE                     *'/
     + 2X,'*              by: S.S. (Willie) Lai, January 1985         *'/
     + 2X,'* ------------------------------------------------------- *'/
     + 2X,'* shake88    : New modulus reduction curves for clays added*'/
     + 2X,'*              using results from Sun et al (1988)         *'/
     + 2X,'*              by: J. I. Sun & Ramin Golesorkhi            *'/
     + 2X,'*              February 26, 1988                           *'/
     + 2X,'* ------------------------------------------------------- *'/
     + 2X,'* SHAKE90/91: Adjust last iteration; Input now is either  *'/
     + 2X,'*              Gmax or max Vs; up to 13 material types can *'/
     + 2X,'*              be specified by user; up to 50 Layers can   *'/
     + 2X,'*              be specified; object motion can be read in  *'/
     + 2X,'*              from a separate file and can have user      *'/
     + 2X,'*              specified format; Different periods for     *'/
     + 2X,'*              response spectral calculations; options     *'/
     + 2X,'*              are renumbered; and general cleanup         *'/
     + 2X,'*              by: J. I. Sun, I. M. Idriss & P. Dirrim     *'/
     + 2X,'*              June 1990 - February 1991                   *'/
     + 2X,'* ------------------------------------------------------- *'/
     + 2X,'* SHAKE91    : General cleanup and finalization of input/  *'/
     + 2X,'*              output format ... etc                       *'/
     + 2X,'*              by: I. M. Idriss                            *'/
     + 2X,'*              December 1991                               *'/
     + 2X,'*****************************************************')
C
      WRITE(*,200)
  200 FORMAT(4X,'Name of Input File ='\)
      READ(*,10) FIN
C
      WRITE(*,300)
  300 FORMAT(4X,'Name of Output File #1 (input, peak values .. etc) ='\)
      READ(*,10) FOUT
C
      WRITE(*,400)
  400 FORMAT(4X,'Name of Output File #2 (time histories .. etc) ='\)
      READ(*,10) PUNCH
C
   10 FORMAT(A32)
C
      OPEN(5,FILE=FIN,STATUS='OLD')
      OPEN(6,FILE=FOUT,STATUS='NEW')
      OPEN(7,FILE=PUNCH,STATUS='NEW')
C
      WRITE(6,100)
      WW = .0624
      GT = 32.2
      MAMAX=4096
C ..................................................................
C
      NAX = MAMAX + 5
      NAA = NAX + 3*(MAMAX + 4)
      NS = NAA + 2*MAMAX
      NINV = NS + NAX/8 + 1
      NTOT = NINV + NAX/8 + 1
      IF (SKO .LT. .000001)   SKO = .45
      WRITE(6,2000) MAMAX, NTOT
C
      CALL SHAKIT(X(1), X(NAX), X(NAA), X(NS), X(NINV))
C
      STOP
C ***************************************************
 1000 FORMAT(I5, F10.0)
 2000 FORMAT( 45H  MAX. NUMBER OF TERMS IN FOURIER TRANSFORM =   I10/
     1        45H  NECESSARY LENGTH OF BLANK COMMON X          =   I10)
      END
C*****************************************************************
      SUBROUTINE EARTHQ(X,AX,S,INV)
C******************************************************************
C
C   THIS ROUTINE  READS THE MOTION IN THE TIME DOMAIN, ADDS TRAILING
C   ZEROS, SCALES THE VALUES, FIND MAXIMUM VALUE AND VARIOUS PARAMETERS
C   AND TRANSFER THE MOTION INTO THE FREQUENCY DOMAIN.
C
C   CODED BY PBS SEPT. 1970
C
C        X       = INPUT MOTION
C        AX      = TEMPORARY STORAGE OF X
C        TITLE   = IDENTIFICATION FOR MOTION
C        DT      = TIME STEP BETWEEN VALUES IN TIME DOMAIN
C        NV      = NUMBER OF ACC. VALUES TO BE READ
C        MA      = LENGTH OF MOTION INCLUDING TRAILING ZEROS
C        MMA     = LENGTH OF SIGNIFICANT PART OF MOTION
C        XF      = MULTIPLICATION FACTOR FOR ACCELERATION VALUES
C        DF      = FREQUENCY STEPS IN FREQ. DOMAIN
C
C******************************************************************
C
      CHARACTER*6 TITLE
      CHARACTER*30 FINPEQ
      CHARACTER*80 HEAD
      CHARACTER*12 FMAT
      COMPLEX X, AX
      DIMENSION XR(8),X(300),AX(3,270),S(70),INV(70)
      COMMON /EQ/ MFOLD,MA2,TITLE(5),DT, MA , MMA, DF, MX
      COMMON/FRCUT/ NCUT,NZERO
      COMMON /JISCK/ JIS,FINPEQ
C
      PI2 = 6.283185307
      READ(5,1001) NV, MA, DT, FINPEQ, FMAT
      READ(5,1004) XF,XMAX,FMAX,NHEAD, NPL
      IF (FMAX.LT. .001) FMAX = 100000.
      IF (FMAT .EQ. '            ') FMAT = '(8F9.6,I7)'
      MA2=2
    2 IF(MA2.GE.MA) GO TO 3
      MA2=MA2*2
      GO TO 2
    3 MA=MA2
```

```
C ...................................................................
      WRITE(6,2012) FINPEQ, NV, MA, NHEAD, NPL, DT, FMAT
      WRITE (*,2026) FINPEQ,FMAT
      OPEN(8,FILE=FINPEQ,STATUS='OLD')
      WRITE (6,2021)
      DO 4 I=1,NHEAD
      READ(8,2022) HEAD
    4 WRITE(6,2022) HEAD
      MMA = NV + NV/10
      IF (MMA.GT.MA) MMA=MA
      MA2 = MA + 2
      MFOLD = MA2/2
      MFOLD = MFOLD + 1
      DF = 1./(MA*DT)
      FMA = FLOAT(MA)
      MX = (ALOG10(FMA)/ALOG10(2.))- 1
    1 NMX = 2**(MX+1)
      IF (MA  .LE. NMX) GO TO 11
      MX = MX + 1
      GO TO 1
   11 NCARDS = (NV-1)/NPL + 1
      JL=NPL*NCARDS-NV
      NV = NV + 1
      N = 0
      LC = 0
      WRITE(6,2024)
      DO 31 I = 1,NCARDS
      LC = LC + 1
      READ(8,FMAT) (XR(J), J=1,NPL)
      IF(I.NE.NCARDS) GO TO 6
      IF(JL.EQ.0) GO TO 6
      JL=NPL+1-JL
      DO 5  J=JL,NPL
    5 XR(J)=0.
C---------------------------------------------------------------
    6 ICHECK = NCARDS - I
      IF (I .LE. 5 .OR. ICHECK .LT. 5) WRITE(6,2008) I,(XR(J), J=1,NPL)
        IF (I .EQ. 10) WRITE (6,2009)
 2009 FORMAT(3X,'........ INPUT MOTION READ NOT ECHOED...........')
C     ENDIF
C
C   FIND MAX. INPUT ACC. (XMAX)
C
  311 DO 31 J = 1,NPL,2
      N = N + 1
      X(N) = CMPLX(XR(J),XR(J+1))
   31 CONTINUE
      CLOSE (8)
      N = N + 1
      DO 32 I = N,MFOLD
   32 X(I) = 0.
      CALL XMX(X,MA,XM,NXMAX)
      IF (XMAX.LT. .000001) GO TO 300
      XF = XMAX/XM
  300 DO 30 I = 1,N
   30 X(I) = X(I)*XF
      XMAX = XM*XF
      TMAX = FLOAT(NXMAX-1)*DT
      WRITE(6,2014) XM,TMAX,XF,XMAX
C
      CALL RFFT(X,MX,INV,S,IFERR,1)
C
C   REMOVE FREQUENCIES ABOVE FMAX AND FIND MAX. ACC. OF NEW MOTION
C
      FREQ = 0.
      SXX = 0.
      SFX = 0.
      NCUT=0
      DO 33 I = 1,MFOLD
      IF(FREQ.LE.FMAX) GO TO 34
      NCUT=NCUT+1
      X(I)=0.0
   34 CONTINUE
      XA = CABS(X(I))
      SXX= SXX + XA*XA
      SFX = SFX + FREQ*XA*XA
      AX(1,I) = X(I)
      FREQ = FREQ + DF
   33 CONTINUE
      SFX = SFX/SXX
      NCUT=MFOLD-NCUT
      NZERO=NCUT+1
      WRITE(6,2005) SFX
      IF (FMAX.GT.FREQ) RETURN
      CALL RFSN(X,MX,INV,S,IFERR,-2)
      CALL XMX(X,MA,XM,NXMAX)
      DO 72 I = 1,MFOLD
   72 X(I) = AX(1,I)
      WRITE(6,2001) XM,FMAX
C
 1001 FORMAT(2I5,  F10.3, A30, A12)
 1002 FORMAT(8F9.5,I7)
 1003 FORMAT(8F10.0)
 1004 FORMAT(3F10.0,2I5)
 2001 FORMAT(21H  MAX ACCELERATION =  F10.5, 22H FOR FREQUENCIES REMOV
     19HED ABOVE F10.2, 7H C/SEC.)
 2003 FORMAT(17H   ACC. CARD NO. I4,16H OUT OF SEQUENCE  )
 2005 FORMAT(25H MEAN SQUARE FREQUENCY =  F10.2, 7H C/SEC. )
C2008 FORMAT(2X, I5, 5X, 8F15.6)
 2008 FORMAT(1X,I5,1X, 8F9.6)
 2012 FORMAT(/1X, ' FILE NAME FOR INPUT MOTION = ', A30,/
     +         1X, '   NO. OF INPUT ACC. POINTS = ',I5,/
     +         1X, '  NO. OF POINTS USED IN FFT = ',I5/
     +         1X, '        NO. OF HEADING LINES = ',I5/
     +         1X, '     NO. OF POINTS PER LINE = ',I5/
     +         1X, ' TIME STEP FOR INPUT MOTION = ',F6.4/
     +         1X, ' FORMAT FOR OF TIME HISTORY = ', A12, /)
 2014 FORMAT(/23H MAXIMUM ACCELERATION =  F9.5/
     1        23H AT TIME              =  F6.2, 4H SEC/
     1 44H THE VALUES WILL BE MULTIPLIED BY A FACTOR = F7.3/
     3 44H TO GIVE NEW MAXIMUM ACCELERATION          = F9.5 )
 2021 FORMAT (/1X,'***** H E A D E R  ')
 2022 FORMAT (A80)
 2023 FORMAT (1X,'**************************************************'
     1        ,'*****************')
 2024 FORMAT (' **  FIRST & LAST 5 LINES OF INPUT MOTION *****'/)
 2025 FORMAT (' ****************************************************'/)
 2026 FORMAT(/,1X, ' READING INPUT MOTION FROM ----> ',A30/
     +         1X, ' FORMAT OF INPUT MOTION USED --> ',A12)
      RETURN
      END
```

```
$NOFLOATCALLS
$NODEBUG
C***********************************************************************
      SUBROUTINE  CURVEG(NC, NV, K1, A, B, NN, TSTEP, NT, T,V,X,Y,NSTEP)
C***********************************************************************
C   THE PROGRAM GENERATES NEW POINTS ON A CURVE BY LINEAR INTERPOLATION
C   USING AN ARITHMETIC OR A HALFLOGARITHMIC SCALE
C
C        NV(I)      =    NUMBER OF VALUES ON CURVE I
C        NC         =    NUMBER OF CURVES
C        K1         =    SWITCH     K1 = 1  ARITHMETIC SCALE
C                                   K1 = 2  HALFLOGARITHMIC SCALE
C        A,B        =    PARAMETERS FOR CALCULATING NEW VALUES
C                        Y = A*X + B
C        X,Y        =    KNOWN POINTS ON CURVE
C        T          =    VALUES ON ABSISSA WHERE NEW POINTS ARE GENERATED
C        V          =    NEW ORDINATE VALUES
C
C        ARITHMETIC SCALE  K1 = 1
C        NN         =    NUMBER OF INTERVALS
C        TSTEP      =    LARGEST VALUE IN EACH INTERVAL
C        NT         =    NUMBER OF STEPS IN EACH INTERVAL
C
C        HALFLOGARITHMIC SCALE
C        NN         =    NUMBER OF VALUES IN EACH LOG10
C
C   CODED BY PER B SCHNABEL SEPT 1970
C
C***********************************************************************
C
      DIMENSION X(27,20),Y(27,20),A(27,20),B(27,20),NV(27),TSTEP(27)
      DIMENSION NT(27), T(200), V(27,200)
C
      XMIN = 100000000.
      XMAX = 0.
      DO 1 L= 1,NC
      M = NV(L)
      IF (XMAX .LT. X(L,M))    XMAX = X(L,M)
      IF (XMIN .GT. X(L,1)) XMIN = X(L,1)
      M = M - 1
      DO 1 I = 1,M
      X1 = X(L,I)
      X2 = X(L,I+1)
      IF (K1 .EQ. 2)  X1 = ALOG10(X1)
      IF (K1 .EQ. 2)  X2 = ALOG10(X2)
      X(L,I) = X(L,I+1)
      A(L,I) = (Y(L,I+1) - Y(L,I))/(X2 - X1)
    1 B(L,I) = -A(L,I)*X1 + Y(L,I)
C
      CALL STEPG(K1, NN, TSTEP, NT, XMIN, XMAX, T, NSTEP)
C
      DO 2 L = 1,NC
      M = NV(L) - 1
      DO 2 I = 1,NSTEP
      DO 3 J = 1,M
      IF (T(I) .LT. X(L,J))  GO TO  31
    3 CONTINUE
      J = M
   31 TT = T(I)
      IF (K1 .EQ. 2) TT = ALOG10(TT)
    2 V(L,I) = A(L,J)*TT  + B(L,J)
      RETURN
      END
C***********************************************************************
      SUBROUTINE STEPG(KK, NN, TSTEP, NT, T1, TN, T, NSTEP)
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C   THE ROUTINE GENERATES STEPS IN LINEAR OR LOGARITHMIC INCREMENT
C
C        KK       = SWITCH     KK = 1     STEP INCREASE OF VALUES
C                              KK = 2     LOGARITHMIC INCREASE OF VALUES
C        NN       = NUMBER OF STEPS   OR NUMBER OF VALUES IN EACH 10
C        TSTEP    = LARGEST VALUE IN EACH STEP
C        NT       = NUMBER OF VALUES IN EACH STEP
C        T1       = FIRST VALUE IN LOG-STEP
C        TN       = LAST  VALUE IN LOG-STEP
C        T        = VALUES GENERATED
C        NSTEP    = NUMBER OF VALUES
C
C   CODED PER B SCHNABEL SEPT. 1970
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      DIMENSION T(200), TSTEP(27), NT(27)
C
      GO TO (1, 2), KK
    1 K = 1
      T(K) = 0.
      SAVE = 0.
      DO 11 N = 1,NN
      M = NT(N)
      STEP = (TSTEP(N) - SAVE)/FLOAT(M)
      SAVE = TSTEP(N)
      DO 11 I = 1,M
      K = K + 1
   11 T(K) = T(K-1) + STEP
      NSTEP = K
      RETURN
    2 NST = ALOG10(T1)
      IF (T1.LT. 1.) NST = NST - 1
      STEP = 1./NN
      K = 1
      TA = 10.**FLOAT(NST)
      T(1) = TA
      DO 22 J = 2,NN
      K = K + 1
      T(K) = TA*10.**(STEP*FLOAT(J))
      IF (T(K) .GT. T1) GO TO 221
   22 CONTINUE
  221 TA = T(K-1)
      K = 0
  211 DO 21 J = 1,NN
      K = K + 1
      T(K) = TA*10.**(STEP*FLOAT(J))
      IF (T(K).GT.TN)  GO TO 212
   21 CONTINUE
      TA = TA*10.
      GO TO 211
  212 NSTEP = K
      RETURN
      END
C***********************************************************
      SUBROUTINE RESP(LN,LS,NN,X,AX,A,S,INV)
```

```
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C   THIS PROGRAM READS DATA FOR RESPONSE SPECTRUM ANALYSIS
C   NECESSARY SUBROUTINES     DRCTSP,  CMPMAX
C
C        NN       = RESPONSE SPECTRUM NUMBER
C        ND       = NUMBER OF DAMPING VALUES
C        X        = FOURIER TRANSFORM OF OBJECT MOTION
C        AX       = FOURIER TRANSFORM OF COMPUTED MOTIONS
C        T        = PERIODS FOR WHICH RESPONSE IS TO BE COMPUTED
C
C   CODED PER B SCHNABEL DEC. 1970
C   New Sets of Periods -- included in February 1991
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      CHARACTER*6 TITLE,ID,IBLANK,IDNT
      CHARACTER*60 ABSIS
      CHARACTER*32 FPERIOD
      CHARACTER*80 headerd
      COMPLEX X, AX
C
      DIMENSION X(64), AX(3,64),A(2,64), S(10),INV(10)
      DIMENSION ID(27,11)
C
      COMMON /SOILA/ IDNT(6),BL(51),GL(51),FACT(51),H(51),R(51),BF(51)
      COMMON /EQ/ MFOLD,MA2,TITLE(5),DT, MA , MMA, DF,MX
      COMMON /RVAL/ NND(27), ZLD(6),T(200), SA(5,200),SV(5,200)
C
      IBLANK = '      '
      ABSIS = ' PERIOD IN SEC.'
C
      READ(5,4) ND, KPER, GGT
    4 FORMAT(2I5,F10.2)
      READ(5,5) (ZLD(I), I = 1,ND)
    5 FORMAT(6F10.3)
      WRITE(6,9001) LN, (ZLD(I), I = 1,ND)
C ----------------------------------------------------------------
C   IF KPER = 0; Periods from 0.03 to 10 sec are included in data block
C                in this subroutine
C    otherwise, periods are specified by user (maximum is 200 periods)
C ----------------------------------------------------------------
      IF (KPER.EQ. 0) GO TO 99
        READ(5,'(A32)') FPERIOD
        WRITE(6,60) FPERIOD
   60   FORMAT(' File from which periods were read: ' A32)
        OPEN(8,FILE=FPERIOD,STATUS='OLD')
        READ (8,4) NLINES, NNM
        DO 10 I = 1, NLINES
        READ(8,*) headerd
        WRITE(6,*) headerd
   10   CONTINUE
        READ(8,*) (T(I), I=1, NNM)
        CLOSE(8)
        GO TO 101
C -------------------------------------------------------------------
C  default periods for calculating response spectra
C -------------------------------------------------------------------
   99   NNM=152
      T(1) = .01
      data (t(i), i=2,152)/
     1     0.03,     0.04,     0.05,     0.06,     0.07,     0.08,     0.09,
     2     0.10,     0.11,     0.12,     0.13,     0.14,     0.15,     0.16,
     3     0.17,     0.18,     0.19,     0.20,     0.21,     0.22,     0.23,
     4     0.24,     0.25,     0.26,     0.27,     0.28,     0.29,     0.30,
     5     0.31,     0.32,     0.33,     0.34,     0.35,     0.36,     0.37,
     6     0.38,     0.39,     0.40,     0.41,     0.42,     0.43,     0.44,
     7     0.45,     0.46,     0.47,     0.48,     0.49,     0.50,     0.51,
     8     0.52,     0.53,     0.54,     0.55,     0.56,     0.57,     0.58,
     9     0.60,     0.62,     0.64,     0.66,     0.68,     0.70,     0.72,
     T     0.74,     0.76,     0.78,     0.80,     0.82,     0.84,     0.86,
     1     0.88,     0.90,     0.92,     0.94,     0.96,     0.98,     1.00,
     2     1.05,     1.10,     1.15,     1.20,     1.25,     1.30,     1.35,
     3     1.40,     1.45,     1.50,     1.55,     1.60,     1.65,     1.70,
     4     1.75,     1.80,     1.85,     1.90,     1.95,     2.00,     2.05,
     5     2.10,     2.15,     2.20,     2.25,     2.30,     2.35,     2.40,
     6     2.50,     2.60,     2.70,     2.80,     2.90,     3.00,     3.10,
     7     3.20,     3.30,     3.40,     3.50,     3.60,     3.70,     3.80,
     8     3.90,     4.00,     4.10,     4.20,     4.30,     4.40,     4.50,
     9     4.60,     4.70,     4.80,     4.90,     5.00,     5.10,     5.20,
     T     5.40,     5.60,     5.80,     6.00,     6.20,     6.40,     6.60,
     1     6.80,     7.00,     7.20,     7.40,     7.60,     7.80,     8.00,
     2     8.50,     9.00,     9.50,    10.00/
C ---------------------------------------------------------------------
C   SAVE VALUES OF X IN AA
  101 DO 11 I = 1,MFOLD
      A(1,I) = REAL(X(I))
      A(2,I) = AIMAG(X(I))
      IF (LS.EQ.0) GO TO 11
      X(I) = AX(LS,I)
   11 CONTINUE
C
C   TRANSFORM VALUES IN X OR AX INTO THE TIME DOMAIN
      CALL RFSN(X,MX,INV,S,IFERR,-2)
      DO 13 L = 1,ND
      IF (NN.GE.5)  NN= 0
      NN = NN + 1
      DO 131 I = 1,5
  131 ID(NN,I) = TITLE(I)
      DO 132 I = 6,11
      ID(NN,I) = IDNT(I-5)
      IF (LS.EQ.0) ID(NN,I) = IBLANK
  132 CONTINUE
C
C   COMPUTE RESPONSE FOR ACCELERATION VALUES IN AA(1, )FOR THE PERIODS
C   GIVEN IN T( )
      CALL  DRCTSP(NN,MMA, DT, GGT, ID, ZLD(L),NNM,X)
   13 CONTINUE
C
C   GIVE X BACK ORIGINAL VALUES
      DO 12 I = 1,MFOLD
   12 X(I) = CMPLX(A(1,I),A(2,I))
C     ==========================================================
  134 NN = 0
      RETURN
 1000 FORMAT(10I5)
 9000 FORMAT( 8F10.3)
 9001 FORMAT( 50H  RESPONSE SPECTRUM ANALYSIS FOR LAYER NUMBER      I4
     1/26H CALCULATED FOR DAMPING     8F10.3)
      END
C*********************************************************************
      SUBROUTINE DRCTSP(NN, KG, DT, GGT, ID, D, M, A)
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
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C   THIS ROUTINE COMPUTES RESPONSE SPECTRA BY THE STEP BY STEP METHOD
C
C       NN       = RESPONSE SPECTRUM CURVE NUMBER  USED (Canceled)
C       KG       = NUMBER OF ACCELERATION VALUES
C       DT       = TIME STEP BETWEEN EACH ACCELERATION VALUE
C       M        = NUMBER OF PERIODS FOR WHICH RESPONSE IS TO BE COMPUTED
C       T        = ARRAY WITH THE PERIODS
C       A        = ACCELERATION VALUES
C       D        = CRITICAL DAMPING RATIO
C       ID       = IDENTIFICATION
C       GGT      = Acceleration of gravity - cm/sec/sec, or in/sec/sec
C                   or ft/sec/sec
C
C   CODED BY I. M. IDRISS 1967
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      CHARACTER*6 ID
      DIMENSION A(1)
      COMMON /RVAL/ NND(27), ZLD(6),T(200), SA(5,200),SV(5,200)
      DIMENSION PRV(200), PAA(200), RD(200)
      DIMENSION ID(27,11)
C ....................................................................
      zmax =0
      DO 10 K = 1, KG
      IF(zmax .GT. ABS(A(K))) GO TO 9
      zmax = ABS(A(K))
    9 A(K) = GGT*A(K)
   10 CONTINUE
      PIW = 6.283185307
      SV(NN,1) = zmax*GGT*T(1)/PIW
      SA(NN,1) = zmax
      KUG = KG-1
      RD(1) = zmax*GGT*T(1)*T(1)/(PIW*PIW)
      PRV(1) = zmax*GGT*T(1)/PIW
      PAA(1) = zmax
      WRITE(6,112) D
      N = 1
      YY = SQRT(1.-D*D)
      DO 200 LOOP = 2, M
      W = 6.283185307/T(N)
      WD = YY*W
      W2 = W*W
      W3 = W2*W
      CALL CMPMAX(KUG,T(N),W,W2,W3,WD,D,DT,ZD,ZV,ZA,A)
      SV(NN,N) = ZV
      SA(NN,N) = ZA/GGT
       RD(N) = ZD
      PRV(N) = W*ZD
      PAA(N) = W2*ZD/GGT
  200 N = N + 1
      WRITE(6,312) GGT, (ID(NN,I), I = 1,10),D
      SUMSV = 0.
      SUMSA = 0.
      SUMT  = 0.
      SVMAX = 0.
      SAMAX = 0.
      TT1 = .1
      TT2 = 0.
      DO 320 N = 1, M
      FREKV = 1./T(N)
      IF (T(N) .LT. .0999 .OR. TT2.GT.2.4999)  GO TO 320
      TT2 = (T(N+1) + T(N))/2.
      IF (TT2.GT.2.5)  TT2 = 2.5
      TT = TT2 - TT1
      SUMSA = SA(NN,N)*TT + SUMSA
      SUMSV = SV(NN,N)*TT + SUMSV
      SUMT = SUMT + TT
      TT1 = TT2
      IF (SVMAX.LT.SV(NN,N))  SVMAX = SV(NN,N)
      IF (SAMAX.LT.SA(NN,N))  SAMAX = SA(NN,N)
  320 WRITE(6,322) N,T(N),RD(N),SV(NN,N),PRV(N),SA(NN,N),PAA(N),FREKV
      WRITE(6,2002) SUMSA,SUMSV,SAMAX,SVMAX
      DO 11 K = 1,KG
   11 A(K) = A(K)/GGT
      RETURN
C
  112 FORMAT(/5X,41HTIMES AT WHICH MAX. SPECTRAL VALUES OCCUR /
     1 10X,33HTD = TIME FOR MAX. RELATIVE DISP. /
     2 10X,33HTV = TIME FOR MAX. RELATIVE VEL.  /
     3 10X,33HTA = TIME FOR MAX. ABSOLUTE ACC.    /
     4 5X, 15HDAMPING RATIO =  F5.2)
  312 FORMAT(5X,' SPECTRAL VALUES --'/
     15X,' [Acceleration of gravity used =' F8.2 ']'/
     210A6,2X,15HDAMPING RATIO =
     3 F5.2/5X,3HNO.,4X,6HPERIOD,5X,10HREL. DISP.,6X,9HREL. VEL.,3X,
     4 12HPSU.REL.VEL.,6X,9HABS. ACC.,3X,12HPSU.ABS.ACC. 5X,5HFREQ.)
  322 FORMAT(I8,F10.2,5F15.5,F10.2)
  402 FORMAT(8F9.5)
  412 FORMAT(I5,25H ACC. RESPONSE VALUES FOR   , 8A6)
  413 FORMAT(I5,25H VEL. RESPONSE VALUES FOR   , 8A6)
 2002 FORMAT(10X,40HVALUES IN PERIOD RANGE .1 TO 2.5 SEC.         /
     115X35HAREA OF ACC. RESPONSE SPECTRUM    =  F10.3/
     215X35HAREA OF VEL. RESPONSE SPECTRUM    =  F10.3/
     315X35HMAX. ACCELERATION RESPONSE VALUE =   F10.3/
     415X35HMAX. VELOCITY      RESPONSE VALUE =   F10.3)
      END
C *******************************************************************
      SUBROUTINE CMPMAX (KUG,PR,W,W2,W3,WD,D,DT,ZD,ZV,ZA, UG)
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C   THIS ROUTINE COMPUTES RESPONSE VALUES FOR ONE SINGLE DEGREE OF
C   FREEDOM SYSTEM USING STEP BY STEP METHOD
C
C   EXPLANATIOS TO PARAMETERS GIVEN IN DRCTSP
C
C   CODED BY I. M. IDRISS  1967
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      DIMENSION XD(2), XV(2), T(3)
      DIMENSION UG(1)
C
      ZA = 0.
      ZD = 0.
      ZV = 0.
      XD(1) = 0.
      XV(1) = 0.
      F1 = 2.*D/(W3*DT)
      F2 = 1./W2
      F3 = D*W
      F4 = 1./WD
      F5 = F3*F4
      F6 = 2.*F3
```

```
      E = EXP(-F3*DT)
      S = SIN(WD*DT)
      C= COS(WD*DT)
     G1 = E*S
     G2 = E*C
     H1 = WD*G2 - F3*G1
     H2 = WD*G1 + F3*G2
     DO 100 K = 1, KUG
      Y = K-1
     DUG = UG(K+1) - UG(K)
     Z1 = F2*DUG
     Z2 = F2*UG(K)
     Z3 = F1*DUG
     Z4 = Z1/DT
      B = XD(1) + Z2 -Z3
      A = F4*XV(1) + F5*B + F4*Z4
     XD(2) = A*G1 + B*G2 + Z3 - Z2 - Z1
     XV(2) = A*H1 - B*H2 - Z4
     XD(1) = XD(2)
     XV(1) = XV(2)
     AA = -F6*XV(1) - W2*XD(1)
      F = ABS(XD(1))
      G = ABS(XV(1))
      H = ABS(AA)
     IF(F .LE. ZD) GO TO 75
     T(1) = Y
      ZD = F
   75 IF(G .LE. ZV) GO TO 85
     T(2) = Y
      ZV = G
   85 IF(H .LE. ZA) GO TO 100
     T(3) = Y
      ZA = H
  100 CONTINUE
     DO 110 L = 1, 3
  110 T(L) = DT*T(L)
     WRITE(6,112) PR, (T(L),L=1,3)
  112 FORMAT(5X,5HPER = F5.2,5X,19HTIMES FOR MAXIMA -- ,3X,
    14HTD = F8.4,3X,4HTV = F8.4,3X,4HTA = F8.4)
     RETURN
     END
C    ****************************************
     SUBROUTINE FFT (A,M,INV,S,IFSET,IFERR)
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
     DIMENSION A(1),INV(1),S(1),N(3),M(3),NP(3),W(2),W2(2),W3(2)
     EQUIVALENCE (N1,N(1)), (N2,N(2)), (N3,N(3))
C
     M1=M(1)
     M2=M(2)
     M3=M(3)
     MTT=M1-2
     MT=MAX0(2,MTT)
     NT=2**MT
10   IF (IABS(IFSET)-1) 610,610,20
610  MT=MAX0(M(1),M(2),M(3))-2
     MT=MAX0(2,MT)
     IF (MT-20) 630,630,620
620  IFERR=1
     GO TO 600
630  IFERR=0
     NT=2**MT
     NTV2=NT/2
     THETA=.7853981634
     JSTEP=NT
     JDIF=NTV2
     S(JDIF)=SIN(THETA)
     DO 660 L=2,MT
     THETA=THETA/2.
     JSTEP2=JSTEP
     JSTEP=JDIF
     JDIF=JSTEP/2
     S(JDIF)=SIN(THETA)
     JC1=NT-JDIF
     S(JC1)=COS(THETA)
     JLAST=NT-JSTEP2
     IF (JLAST-JSTEP) 660,640,640
640  DO 650 J=JSTEP,JLAST,JSTEP
     JC=NT-J
     JD=J+JDIF
650  S(JD)=S(J)*S(JC1)+S(JDIF)*S(JC)
660  CONTINUE
C
C    SET UP INV(J) TABLE
     MTLEXP=NTV2
     LM1EXP=1
     INV(1)=0
     DO 680 L=1,MT
     INV(LM1EXP+1)=MTLEXP
     DO 670 J=2,LM1EXP
     JJ=J+LM1EXP
670  INV(JJ)=INV(J)+MTLEXP
     MTLEXP=MTLEXP/2
680  LM1EXP=LM1EXP*2
     IF (IFSET) 20,600,20
20   MTT=MAX0(M(1),M(2),M(3))-2
     ROOT2=SQRT(2.)
     IF (MTT-MT) 40,40,30
30   IFERR=1
     WRITE(6,1000)
     STOP
1000 FORMAT(31H --- ERROR IN FOURIER TRANSFORM  )
40   IFERR=0
C    M1=M(1)
C    M2=M(2)
C    M3=M(3)
     N1=2**M1
     N2=2**M2
     N3=2**M3
     IF (IFSET) 50,50,70
50   NX=N1*N2*N3
     FN=NX
     DO 60 I=1,NX
     A(2*I-1)=A(2*I-1)/FN
60   A(2*I)=-A(2*I)/FN
70   NP(1)=N1*2
     NP(2)=NP(1)*N2
     NP(3)=NP(2)*N3
     DO 330 ID=1,3
     IL=NP(3)-NP(ID)
     IL1=IL+1
     MI=M(ID)
     IF (MI) 330,330,80
```

```
80     IDIF=NP(ID)
       KBIT=NP(ID)
       MEV=2*(MI/2)
       IF (MI-MEV) 120,120,90
90     KBIT=KBIT/2
       KL=KBIT-2
       DO 100 I=1,IL1,IDIF
       KLAST=KL+I
       DO 100 K=I,KLAST,2
       KD=K+KBIT
       T=A(KD)
       A(KD)=A(K)-T
       A(K)=A(K)+T
       T=A(KD+1)
       A(KD+1)=A(K+1)-T
100    A(K+1)=A(K+1)+T
       IF (MI-1) 330,330,110
110    LFIRST=3
       JLAST=1
       GO TO 130
120    LFIRST=2
       JLAST=0
130    DO 320 L=LFIRST,MI,2
       JJDIF=KBIT
       KBIT=KBIT/4
       KL=KBIT-2
       DO 140 I=1,IL1,IDIF
       KLAST=I+KL
       DO 140 K=I,KLAST,2
       K1=K+KBIT
       K2=K1+KBIT
       K3=K2+KBIT
       T=A(K2)
       A(K2)=A(K)-T
       A(K)=A(K)+T
       T=A(K2+1)
       A(K2+1)=A(K+1)-T
       A(K+1)=A(K+1)+T
       T=A(K3)
       A(K3)=A(K1)-T
       A(K1)=A(K1)+T
       T=A(K3+1)
       A(K3+1)=A(K1+1)-T
       A(K1+1)=A(K1+1)+T
       T=A(K1)
       A(K1)=A(K)-T
       A(K)=A(K)+T
       T=A(K1+1)
       A(K1+1)=A(K+1)-T
       A(K+1)=A(K+1)+T
       R=-A(K3+1)
       T=A(K3)
       A(K3)=A(K2)-R
       A(K2)=A(K2)+R
       A(K3+1)=A(K2+1)-T
140    A(K2+1)=A(K2+1)+T
       IF (JLAST) 310,310,150
150    JJ=JJDIF+1
       ILAST=IL+JJ
       DO 160 I=JJ,ILAST,IDIF
       KLAST=KL+I
       DO 160 K=I,KLAST,2
       K1=K+KBIT
       K2=K1+KBIT
       K3=K2+KBIT
       R=-A(K2+1)
       T=A(K2)
       A(K2)=A(K)-R
       A(K)=A(K)+R
       A(K2+1)=A(K+1)-T
       A(K+1)=A(K+1)+T
       AWR = A(K1)-A(K1+1)
       AWI=A(K1+1)+A(K1)
       R=-A(K3)-A(K3+1)
       T=A(K3)-A(K3+1)
       A(K3)=(AWR-R)/ROOT2
       A(K3+1)=(AWI-T)/ROOT2
       A(K1)=(AWR+R)/ROOT2
       A(K1+1)=(AWI+T)/ROOT2
       T=A(K1)
       A(K1)=A(K)-T
       A(K)=A(K)+T
       T=A(K1+1)
       A(K1+1)=A(K+1)-T
       A(K+1)=A(K+1)+T
       R=-A(K3+1)
       T=A(K3)
       A(K3)=A(K2)-R
       A(K2)=A(K2)+R
       A(K3+1)=A(K2+1)-T
160    A(K2+1)=A(K2+1)+T
       IF (JLAST-1) 310,310,170
170    JJ=JJ+JJDIF
       DO 300 J=2,JLAST
       I=INV(J+1)
       IC=NT-I
       W(1)=S(IC)
       W(2)=S(I)
       I2=2*I
       I2C=NT-I2
       IF (I2C) 200,190,180
180    W2(1)=S(I2C)
       W2(2)=S(I2)
       GO TO 210
190    W2(1)=0.
       W2(2)=1.
       GO TO 210
200    I2CC=I2C+NT
       I2C=-I2C
       W2(1)=-S(I2C)
       W2(2)=S(I2CC)
210    I3=I+I2
       I3C=NT-I3
       IF (I3C) 240,230,220
220    W3(1)=S(I3C)
       W3(2)=S(I3)
       GO TO 280
230    W3(1)=0.
       W3(2)=1.
       GO TO 280
240    I3CC=I3C+NT
       IF (I3CC) 270,260,250
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250   I3C=-I3C
      W3(1)=-S(I3C)
      W3(2)=S(I3CC)
      GO TO 280
260   W3(1)=-1.
      W3(2)=0.
      GO TO 280
270   I3CCC=NT+I3CC
      I3CC=-I3CC
      W3(1)=-S(I3CCC)
      W3(2)=-S(I3CC)
280   ILAST=IL+JJ
      DO 290 I=JJ,ILAST,IDIF
      KLAST=KL+I
      DO 290 K=I,KLAST,2
      K1=K+KBIT
      K2=K1+KBIT
      K3=K2+KBIT
      R=A(K2)*W2(1)-A(K2+1)*W2(2)
      T=A(K2)*W2(2)+A(K2+1)*W2(1)
      A(K2)=A(K)-R
      A(K)=A(K)+R
      A(K2+1)=A(K+1)-T
      A(K+1)=A(K+1)+T
      R=A(K3)*W3(1)-A(K3+1)*W3(2)
      T=A(K3)*W3(2)+A(K3+1)*W3(1)
      AWR=A(K1)*W(1)-A(K1+1)*W(2)
      AWI=A(K1)*W(2)+A(K1+1)*W(1)
      A(K3)=AWR-R
      A(K3+1)=AWI-T
      A(K1)=AWR+R
      A(K1+1)=AWI+T
      T=A(K1)
      A(K1)=A(K)-T
      A(K)=A(K)+T
      T=A(K1+1)
      A(K1+1)=A(K+1)-T
      A(K+1)=A(K+1)+T
      R=-A(K3+1)
      T=A(K3)
      A(K3)=A(K2)-R
      A(K2)=A(K2)+R
      A(K3+1)=A(K2+1)-T
290   A(K2+1)=A(K2+1)+T
300   JJ=JJDIF+JJ
310   JLAST=4*JLAST+3
320   CONTINUE
330   CONTINUE
      NTSQ=NT*NT
      M3MT=M3-MT
      IF (M3MT) 350,340,340
340   IGO3=1
      N3VNT=N3/NT
      MINN3=NT
      GO TO 360
350   IGO3=2
      N3VNT=1
      NTVN3=NT/N3
      MINN3=N3
360   JJD3=NTSQ/N3
      M2MT=M2-MT
      IF (M2MT) 380,370,370
370   IGO2=1
      N2VNT=N2/NT
      MINN2=NT
      GO TO 390
380   IGO2=2
      N2VNT=1
      NTVN2=NT/N2
      MINN2=N2
390   JJD2=NTSQ/N2
      M1MT=M1-MT
      IF (M1MT) 410,400,400
400   IGO1=1
      N1VNT=N1/NT
      MINN1=NT
      GO TO 420
410   IGO1=2
      N1VNT=1
      NTVN1=NT/N1
      MINN1=N1
420   JJD1=NTSQ/N1
      JJ3=1
      J=1
      DO 570 JPP3=1,N3VNT
      IPP3=INV(JJ3)
      DO 560 JP3=1,MINN3
      GO TO (430,440), IGO3
430   IP3=INV(JP3)*N3VNT
      GO TO 450
440   IP3=INV(JP3)/NTVN3
450   I3=(IPP3+IP3)*N2
      JJ2=1
      DO 560 JPP2=1,N2VNT
      IPP2=INV(JJ2)+I3
      DO 550 JP2=1,MINN2
      GO TO (460,470), IGO2
460   IP2=INV(JP2)*N2VNT
      GO TO 480
470   IP2=INV(JP2)/NTVN2
480   I2=(IPP2+IP2)*N1
      JJ1=1
      DO 550 JPP1=1,N1VNT
      IPP1=INV(JJ1)+I2
      DO 540 JP1=1,MINN1
      GO TO (490,500), IGO1
490   IP1=INV(JP1)*N1VNT
      GO TO 510
500   IP1=INV(JP1)/NTVN1
510   I=2*(IPP1+IP1)+1
      IF (J-I) 520,530,530
520   T=A(I)
      A(I)=A(J)
      A(J)=T
      T=A(I+1)
      A(I+1)=A(J+1)
      A(J+1)=T
530   CONTINUE
540   J=J+2
550   JJ1=JJ1+JJD1
560   JJ2=JJ2+JJD2
570   JJ3=JJ3+JJD3
```

```
      IF (IFSET) 580,600,600
580   DO 590 I=1,NX
590   A(2*I)=-A(2*I)
600   RETURN
      END
C*********************************************
      SUBROUTINE RFFT (A,M,INV,S,IFERR,IFSET)
C* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      DIMENSION A(1), L(3), INV(1), S(1)
C
C     IFSET=1
      L(1)=M
      L(2)=0
      L(3)=0
      NTOT=2**M
      NTOT2=2*NTOT
      FN=NTOT
      DO 10 I=2,NTOT2,2
10    A(I)=-A(I)
      DO 20 I=1,NTOT2
20    A(I)=A(I)/FN
      CALL FFT (A,L,INV,S,IFSET,IFERR)
C
C     MOVE LAST HALF OF A(J)S DOWN ONE SLOT AND ADD A(N) AT BOTTOM TO
C     GIVE ARRAY FOR A1PRIME AND A2PRIME CALCULATION
C
      DO 30 I=1,NTOT,2
      J0=NTOT2+2-I
      A(J0)=A(J0-2)
30    A(J0+1)=A(J0-1)
      A(NTOT2+3)=A(1)
      A(NTOT2+4)=A(2)
C
C     CALCULATE A1PRIMES AND STORE IN FIRST N SLOTS
C     CALCULATE A2PRIMES AND STORE IN SECOND N SLOTS IN REVERSE ORDER
C
      K0=NTOT+1
      DO 40 I=1,K0,2
      K1=NTOT2-I+4
      AP1RE=.5*(A(I)+A(K1))
      AP2RE=-.5*(A(I+1)+A(K1+1))
      AP1IM=.5*(-A(I+1)+A(K1+1))
      AP2IM=-.5*(A(I)-A(K1))
      A(I)=AP1RE
      A(I+1)=AP1IM
      A(K1)=AP2RE
40    A(K1+1)=AP2IM
      NTO=NTOT/2
      NT=NTO+1
      DEL=3.1415927/FLOAT(NTOT)
      SS=SIN(DEL)
      SC=COS(DEL)
      SI=0.0
      CO=1.0
C
C     COMPUTE C(J)S FOR J=0 THRU J=N
      DO 50 I=1,NT
      K6=NTOT2-2*I+5
      AP2RE=A(K6)*CO+A(K6+1)*SI
      AP2IM=-A(K6)*SI+A(K6+1)*CO
      CIRE=.5*(A(2*I-1)+AP2RE)
      CIIM=.5*(A(2*I)+AP2IM)
      CNIRE=.5*(A(2*I-1)-AP2RE)
      CNIIM=.5*(A(2*I)-AP2IM)
      A(2*I-1)=CIRE
      A(2*I)=CIIM
      A(K6)=CNIRE
      A(K6+1)=-CNIIM
      SIS=SI
      SI=SI*SC+CO*SS
50    CO=CO*SC-SIS*SS
C
C     SHIFT C(J)S FOR J=N/2+1 TO J=N UP ONE SLOT
      DO 60 I=1,NTOT,2
      K8=NTOT+4+I
      A(K8-2)=A(K8)
60    A(K8-1)=A(K8+1)
      DO 70 I=3,NTOT2,2
      A(I)=2.*A(I)
70    A(I+1)= 2.*A(I+1)
      RETURN
      END
C*****************************************
      SUBROUTINE RFSN (A,M,INV,S,IFERR,IFSET)
C****************************************************************
      DIMENSION A(1),L(3),INV(1),S(1)
C
      L(1)=M
      L(2)=0
      L(3)=0
      NTOT=2**M
C     IFSET=-1
      NTOT2=NTOT+NTOT
      NN=NTOT2+2
      A(NN+2)=A(NN)
      A(NN+1)=A(NN-1)
      FN=NTOT
      NTOT3=NTOT2+4
      DO 70 I=3,NTOT2,2
      A(I)=0.5* A(I)
   70 A(I+1)= .5*A(I+1)
      DO 60 I=1,NTOT,2
      K8=NTOT2+2-I
      A(K8)= A(K8-2)
   60 A(K8+1)=A(K8-1)
      NTO=NTOT/ 2
      NT=NTO+1
      DEL=3.141592654/FN
      SS= SIN(DEL)
      SC= COS(DEL)
      SI=0.
      CO =1.0
      DO 50 I=1,NT
      K6=NTOT2-2*I+5
      CIRE= A(2*I-1) + A(K6)
      CIIM=A(2*I)-A(K6+1)
      CNIRE=(-SI*(A(2*I)+A(K6+1))+CO*(A(2*I-1)-A(K6)))
      IF(SI)62,61,62
   62 CNIIM=(A(2*I-1)-A(K6)-CO*CNIRE)/SI
      GO TO 63
   61 CNIIM=0.
   63 A(2*I-1)=CIRE
```

```
      A(2*I)=CIIM
      A(K6)=CNIRE
      A(K6+1)=CNIIM
      SIS=SI
      SI=SI*SC+CO*SS
   50 CO=CO*SC-SIS*SS
      KO=NTOT+1
      DO 40 I=1,KO,2
      K1=NTOT2-I+4
      AP1RE=A(I)-A(K1+1)
      AP2RE=-(A(I+1)+A(K1))
      AP1IM=A(I)+A(K1+1)
      AP2IM=A(I+1)-A(K1)
      A(I)=AP1RE
      A(I+1)=AP2RE
      A(K1)=AP1IM
   40 A(K1+1)=AP2IM
      NTOP=NTOT2+2
      NT00=NTOT+1
      A(1)=A(NTOT2+3)
      A(2)=A(NTOT2+4)
   21 DO 52 I=NT00,NTOP,2
      A(I)=A(I+2)
   52 A(I+1)=A(I+3)
      CALL  FFT(A,L,INV,S,IFSET,IFERR)
      DO 20 I=1,NTOT2
   20 A(I)=A(I)*FN
      DO 10 I=2,NTOT2,2
   10 A(I)=-A(I)
      RETURN
      END
C*************************************
      SUBROUTINE XMX(X,MX,XMAX,NXMAX)
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C   THIS ROUTINE FIND MAX. VALUE, XMAX, AND NUMBER OF MAX. VALUE, NXMAX.
C   OF ARRAY X WITH MX NUMBER OF VALUES
C
C   CODED PER B SCHNABEL OCT. 1971
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      DIMENSION X(1)
      XMAX = 0.
      DO 1 I = 1,MX
      XA = ABS(X(I))
      IF (XMAX.GT.XA) GO TO 1
      NXMAX = I
      XMAX = XA
    1 CONTINUE
      RETURN
      END
```

```
$NOFLOATCALLS
$NODEBUG
C************************************
      SUBROUTINE AMP( N1,IN,INT,LL,LT,KPL,IDAMP,NA,DF)
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C   THIS ROUTINE COMPUTES THE AMPLIFICATION SPECTRUM BETWEEN ANY TWO
C   LAYERS
C
C      N1      = NUMBER OF SOIL LAYERS EXCLUDING ROCK
C      IN      = NUMBER OF SUBLAYER FROM WHICH AMPLIFICATION IS COMP.
C      INT     = SUBLAYER TYPE
C                     0 - OUTCROPPING LAYER
C                     1 - LAYER WITHIN PROFILE
C      LL      = NUMBER OF SUBLAYER TO WHICH AMPLIFICATION IS COMP.
C      LT      = SUBLAYER TYPE
C                     0 - OUTCROPPING LAYER
C                     1 - LAYER WITHIN PROFILE
C      DF      = FREQUENCY STEPS IN AMP. FUNCTION
C      NA      = CURVE NUMBER IN PLOTTING
C      IDAMP   = IDENTIFICATION
C
C   CODED PER B SCHNABEL  FEB. 1971
C   modified to increase number of sublayers to 50
C   February 1991
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      COMPLEX G, V, PLUS, MINUS
      COMPLEX E, F, EE, FF, A, EX, AIN, IPI2,AA
      CHARACTER*60 ABSIS
      CHARACTER*6 ID,IDNT,IDAMP
C
      DIMENSION IDAMP (27,11),T(200)
      COMMON /JOE4/ ST(27,200)
      COMMON /SOILA/ IDNT(6),BL(51),GL(51),FACT(51),H(51),R(51),BF(51)
      COMMON /CSOIL/ G(51), V(51), PLUS(51), MINUS(51)
      COMMON /CCG/ ID(27,11)
C
      ABSIS = ' CYCLES/SEC. '
C
      IPI2 = CMPLX(0., 6.283185307)
      FREQ = 0.
      ST(NA,1) = 1.
      DO 19 I = 2,200
      E = 1.
      FF = 1.
      FREQ = FREQ + DF
      A = FREQ*IPI2
      DO 191 K = 1,N1
      IF (K.NE.IN) GO TO 192
      AIN = E + FF
      IF (INT.EQ.0) AIN = 2.*E
  192 IF (K.NE.LL) GO TO 11
      AA    = E + FF
      IF (LT.EQ.0) AA = 2.*E
   11 EX = CEXP(H(K)*A/V(K))
      EE = E*EX
      F = FF/EX
      E = EE*PLUS(K) + MINUS(K)*F
      FF = PLUS(K)*F + MINUS(K)*EE
  191 CONTINUE
      IF (IN.NE.N1+1) GO TO 193
      AIN = E + FF
      IF (INT.EQ.0) AIN = 2.*E
  193 IF (LL   .NE.N1+1) GO TO 21
      AA    = E + FF
      IF (LT.EQ.0)  AA = 2.*E
   21 ST(NA,I) = CABS(AA/AIN)
   19 CONTINUE
      DO 23 I = 1,200
   23 T(I) = DF*FLOAT(I-1)
      AMAX = 0.
      WRITE(6,2)
      DO 22 I = 1,200
      IF (KPL .GE. 2) WRITE(6,1) T(I), ST(NA,I)
      IF (ST(NA,I) .LT.  AMAX) GO TO 22
      TMAX = T(I)
      AMAX = ST(NA,I)
   22 CONTINUE
      IF (NA.LT.9) NA=NA+1
      PERIOD = 1./TMAX
      IF (TMAX.LT. .0001)  WRITE(6,1001) AMAX, TMAX
      IF (TMAX.GT. .0001)  WRITE(6,1001) AMAX, TMAX,PERIOD
      IF (KPL.EQ.0) RETURN
      WRITE(6,1000)
      N = NA-1
      NA = 1
      RETURN
    1 FORMAT(1X,F10.4, 3X, F10.4)
    2 FORMAT(/2X,'FREQUENCY    AMPLITUDE')
 1000 FORMAT(33H1  PLOT OF AMPLIFICATION SPECTRA  /)
 1001 FORMAT(25H MAXIMUM AMPLIFICATION =   F6.2/
     1 25H FOR FREQUENCY          = F6.2, 7H C/SEC. /
     1 25H     PERIOD             =  F6.2, 5H SEC. )
      END
C*****************************************
      SUBROUTINE UTPR(KK,DPTH,LS,K2,LH,LT,X,AX,S,INV)
C**********************************************************************
C
C   THIS ROUTINE TRANSFERS THE VALUES IN AX(LH, ) INTO THE TIME DOMAIN
C   IN X( ), TRANSFERS RESULTS TO OUTPUT FILE
C
C        KK       = 5 TABULATE MAX. ACC.
C                   6 PRINT MAX ACC. SEPARATELY
C        DPTH     = DEPTH OF LAYER
C        X( )     = OBJECT MOTION
C        AX(LS, )= COMPUTED MOTION
C        LS       = COMPUTED MOTION NUMBER
C                   0 IF OBJECT MOTION
C        LH       = SUBLAYER NUMBER
C        LT       = SUBLAYER TYPE
C                   0 - OUTCROPPING
C                   1 - INSIDE
C        S,INV  SCRATCH ARRAYS
C
C   CODED  PER B SCHNABEL  OCT. 1970
C   MODIFIED PBS AUG. 1971
C   modified to increase number of layers to 50
C**********************************************************************
      CHARACTER*6 TITLE,IDNT
      COMPLEX SAVE
      COMPLEX X, AX
C
```

```
      DIMENSION XR(8)
      DIMENSION X(300),AX(3,270),S(70),INV(70)
      COMMON /SOILA/ IDNT(6),BL(51),GL(51),FACT(51),H(51),R(51),BF(51)
      COMMON /EQ/ MFOLD,MA2,TITLE(5),DT, MA , MMA, DF,MX
C
      FREQ = 0.
      SFX = 0.
      SXX = 0.
C   TRANSFORM VALUES IN X OR IN AX INTO THE TIME DOMAIN
      DO 24  I = 1,MFOLD
      IF (LS.EQ.0) GO TO 241
      SAVE = X(I)
      X(I) = AX(LS,I)
      AX(LS,I) = SAVE
  241 XA = CABS(X(I))
      SXX= SXX + XA*XA
      SFX = SFX + XA*FREQ*XA
      FREQ = FREQ + DF
   24 CONTINUE
      SFX = SFX/SXX
C
      CALL RFSN(X,MX,INV,S,IFERR,-2)
C
      CALL XMX(X,MA,XMAX,NMAX)
      TMAX = DT*FLOAT(NMAX-1)
      XEND = 0.
      N = MA/20
      NN = 9*N
      N = 8*N
      DO 25 I = N,NN
      XABS = REAL(X(I))
      XABS = ABS(XABS)
      IF (XABS.GT.XEND) XEND = XABS
      XABS = AIMAG(X(I))
      XABS = ABS(XABS)
      IF (XABS.GT.XEND) XEND = XABS
   25 CONTINUE
      XEND = XEND/XMAX
C
C   SAVE OUTPUT
      N = 1
      NN = 4
      NCARDS=MA/8
      NC = NCARDS
      IF (K2.EQ.0) NC = 0
C     IF (KK.EQ.5) GO TO 252
      IF (KK.EQ.6) GO TO 252
      IF (LT.EQ.0)  WRITE(6,2000) LH, (IDNT(I),I=1,6)
      IF (LT.EQ.1)  WRITE(6,2002) LH, (IDNT(I),I=1,6)
      WRITE(6, 2005) SFX
      WRITE(6,2003) XMAX, TMAX
  252 IF (KK.EQ.6.AND.LT.EQ.0)  WRITE(6,2001) DPTH,XMAX,TMAX,SFX,XEND,NC
      IF (KK.EQ.6.AND.LT.EQ.1) WRITE(6,2010) DPTH,XMAX,TMAX,SFX, XEND,NC
      IF (K2.EQ.0) GO TO 262
      WRITE(7,2006) XMAX, (TITLE(I),I=1,5)
      IF (LT.EQ.1)  WRITE(7,2002) LH, (IDNT(I),I=1,6)
      IF (LT.EQ.0)  WRITE(7,2000) LH, (IDNT(I),I=1,6)
      DO 26 I = 1,NCARDS
      K = 0
      DO 261 J = N,NN
      K = K+ 1
      XR(K) = REAL(X(J))
      K = K + 1
      XR(K) = AIMAG(X(J))
  261 CONTINUE
      WRITE(7,2009) (XR(J),J=1,8),I
      IF (K2 .EQ. 2) WRITE(6,2019) (XR(J), J = 1,8), I
      NN = 4 + NN
      N = N + 4
   26 CONTINUE
  262 CALL RFFT(X,MX,INV,S,IFERR,2)
      IF (LS.EQ.0)   RETURN
      DO 27 I = 1,MFOLD
      SAVE = AX(LS,I)
      AX(LS,I) = X(I)
   27 X(I) = SAVE
      RETURN
C
 2000 FORMAT(43H  ACCELERATION VALUES AT OUTCROPPING LAYER I3,3H - 6A6)
 2001 FORMAT(5X,6HOUTCR. F15.1,F15.5,2F15.2,F20.3,I20)
 2010 FORMAT(5X,6HWITHIN F15.1,F15.5,2F15.2,F20.3,I20)
 2002 FORMAT(42H  ACCELERATION VALUES AT THE TOP OF LAYER I3,3H - 6A6)
 2003 FORMAT(/15H  MAX. ACC. =  F9.6,11H AT TIME = F6.3, 5H SEC. /)
 2005 FORMAT(/26H   MEAN SQUARE FREQUENCY = F10.2/)
 2006 FORMAT(21X,6HXMAX= F7.4,5A6)
 2008 FORMAT(2X, I5, 5X, 8F15.6)
 2009 FORMAT(8F9.6,I7)
 2019 FORMAT(8F14.6,I10)
      END
C*************************************
      SUBROUTINE REDUCE(IFR,X,AX,LL)
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C   THIS ROUTINE INCREASES TIME INTERVAL AND REDUCES NUMBER OF VALUES
C
C        IFR    =    DIVIDING FACTOR ON LENGTH OF RECORD
C                    MULTIPLICATION FACTOR ON TIME STEP
C                    MUST BE A POWER OF 2.
C        DT     =    TIMESTEP IN SEC.
C        DF     =    FREQUENCY STEP IN C/SEC.
C        MA     =    NUMBER OF POINTS USED IN FOURIER TRANSFORM
C        X      =    FOURIER TRANSFORM OF OBJECT MOTION
C        AX     =    FOURIER TRANSFORM OF COMPUTED MOTIONS
C
C
C   CODED BY PER B. SCHNABEL DEC. 1970.
C   MODIFIED SEPT. 1971
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      CHARACTER*6 TITLE
      COMPLEX X, AX
C
      DIMENSION X( 68), AX(3, 64), LL(3)
      COMMON /EQ/ MFOLD,MA2,TITLE(5),DT, MA , MMA, DF,MX
      COMMON/FRCUT/ NCUT,NZERO
C
      F1 = .5/DT
      FR = FLOAT(IFR)
      DT = DT*FR
      MA = MA/IFR
      MMA = MMA/IFR
      MA2 = MA + 2
      MFOLD = MA2/2
```

```
      N = MFOLD + 1
      DO 12 I = MFOLD,N
      X(I) = 0.
C
      DO 12 L = 1,3
      IF (LL(L).LE.0) GO TO 12
      AX(L,I) = 0.
   12 CONTINUE
      MFOLD = MFOLD + 1
      F2 = .5/DT
      WRITE(6,1000) F1,F2,DT, MA
      FMA = FLOAT(MA)
      MX = (ALOG10(FMA)/ALOG10(2.))-1.
      IF (MA.GT.2**(MX+1)) MX=MX+1
      IF(NCUT.LE.MFOLD) GO TO 15
      NCUT=MFOLD
   15 CONTINUE
 1000 FORMAT( 20H  FREQUENCIES FROM  F6.2, 3H TO F6.2,14H C/SEC ARE REM
     1SHOVED /
     216H NEW TIMESTEP = F5.4/19H NUMBER OF VALUES = I5)
      RETURN
      END
C*****************************
      SUBROUTINE INCR(IFR,X,AX)
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C   THIS ROUTINE INCREASES NUMBER OF POINTS IN THE RECORD
C   BY DECREASING TIMESTEP
C
C        IFR   =   MULTIPLYING FACTOR ON LENGTH OF RECORD
C                  MUST BE A POWER OF 2.
C        DT    =   TIMESTEP IN SEC.
C        DF    =   FREQUENCY STEP IN C/SEC.
C        MA    =   NUMBER OF POINTS USED IN FOURIER TRANSFORM
C        X     =   FOURIER TRANSFORM OF OBJECT MOTION
C        AX    =   FOURIER TRANSFORM OF COMPUTED MOTIONS
C
C
C   CODED BY PER B. SCHNABEL DEC. 1970.
C   MODIFIED OCT.  1971
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      COMPLEX X, AX
      CHARACTER*6 TITLE
C
      DIMENSION X( 68), AX(3, 64)
      COMMON /EQ/ MFOLD,MA2,TITLE(5),DT, MA , MMA, DF,MX
C
      F1 = .5/DT
      FR = FLOAT(IFR)
      DT = DT/FR
      N = MFOLD- 1
      MA = MA*IFR
      MMA = MMA*IFR
      MA2 = MA + 2
      MFOLD = MA2/2
      MFOLD = MFOLD + 1
      DO 10 I = N, MFOLD
      X(I) = 0.
      DO 10 L = 1,3
   10 AX(L,I) = 0.
      F2 = .5/DT
      WRITE(6,1000) F1,F2,DT, MA
      FMA = FLOAT(MA)
      MX = (ALOG10(FMA)/ALOG10(2.))-1.
      IF (MA.GT.2**(MX+1)) MX=MX+1
 1000 FORMAT(27H    FREQUENCIES ADDED FROM  F6.2,3H TO F6.2/
     216H NEW TIME STEP = F5.4/19H NUMBER OF VALUES = I5/)
      RETURN
      END
C***********************************************************
      SUBROUTINE MOTION(N1,IN,INT,LL,LT, X,AX)
***********************************************************
C   THIS ROUTINE CALCULATES THE MOTION IN ANY TWO SOIL LAYERS OR IN
C   ROCK FROM MOTION GIVEN IN ANY LAYER OR IN ROCK
C
C        N1      = NUMBER OF SOIL LAYERS EXCLUDING ROCK
C        IN      = NUMBER OF LAYER WHERE OBJECT MOTION IS GIVEN
C        INT     = MOTION TYPE
C                  IF EQUEL 0      OUTCROPPING LAYER
C        LL()    = NUMBER OF LAYERS WHERE OUTPUT MOTION IS WANTED
C                  MAX  3 LAYERS
C        LT()    = MOTION TYPE
C                  0 - OUTCROPPING LAYER
C                  1 - LAYER WITHIN PROFILE
C        X()     = OBJECT MOTION
C        AX()    = OUTPUT MOTION
C
C   CODED BY PER B SCHNABEL  OCT 1970
C   modified to increase the number of layers to 50
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      INTEGER LL(3), LT(3)
      CHARACTER*6 TITLE,IDNT
      COMPLEX AA(3)
      COMPLEX X, AX
      COMPLEX G, V, PLUS, MINUS
      COMPLEX E, F, EE, FF, A, EX, AIN, IPI2
C
      DIMENSION X(300),AX(3,270),S(70)
      COMMON /EQ/ MFOLD,MA2,TITLE(5),DT, MA , MMA, DF,MX
      COMMON /SOILA/ IDNT(6),BL(51),GL(51),FACT(51),H(51),R(51),BF(51)
      COMMON /CSOIL/ G(51), V(51), PLUS(51), MINUS(51)
      COMMON/FRCUT/ NCUT,NZERO
C
      IPI2 = CMPLX(0., 6.283185307)
      DO 20 L = 1,3
      IF (LL(L) .GT. 0) AX(L,1) = X(1)
      IF(NCUT.EQ.MFOLD) GO TO 20
      DO 30 I=NZERO,MFOLD
      AX(L,I)=CMPLX(0.,0.)
   30 CONTINUE
   20 CONTINUE
      FREQ = 0.
      DO 19 I=2,NCUT
      E = 1.
      FF = 1.
      FREQ = FREQ + DF
      A = FREQ*IPI2
      DO 191 K = 1,N1
      IF (K.NE.IN) GO TO 192
      AIN = E + FF
      IF (INT.EQ.0) AIN = 2.*E
C   FIND SUBLAYER WHERE MOTION IS WANTED
```

```
  192 DO 11 L = 1,3
      IF (K.NE.LL(L)) GO TO 11
C   AMPLIFICATION FACTOR FOR SUBLAYER WITHIN PROFILE
      AA(L) = E + FF
C   AMPLIFICATION FACTOR FOR OUTCROPPING SUBLAYER
      IF (LT(L).EQ.0)  AA(L) = 2.*E
   11 CONTINUE
      EX = CEXP(H(K)*A/V(K))
      EE = E*EX
      F = FF/EX
      E  = EE*PLUS(K) + MINUS(K)*F
      FF = PLUS(K)*F + MINUS(K)*EE
  191 CONTINUE
      IF (IN.NE.N1+1) GO TO 193
      AIN = E + FF
      IF (INT.EQ.0) AIN = 2.*E
  193 DO 21 L = 1,3
      IF (LL(L).NE.N1+1) GO TO 21
      AA(L) = E + FF
      IF (LT(L).EQ.0) AA(L) = 2.*E
   21 CONTINUE
      DO 23 L = 1,3
      IF (LL(L) .GT. 0) AX(L,I) = X(I)*AA(L)/AIN
   23 CONTINUE
   19 CONTINUE
      RETURN
      END
C**************************************************
      SUBROUTINE CXSOIL(N1)
C***********************************************************************
C
C   THIS ROUTINE CALCULATES THE COMPLEX SOIL PROPERTIES AND TRANSFER
C   FUNCTIONS FOR THE LAYERS
C
C        N1       = NUMBER OF SOIL LAYERS
C        BL       = RATIO OF CRITICAL DAMPING
C        GL       = SHEAR MODULUS
C        R        = DENSITY
C        G        = COMPLEX SHEAR MODULUS
C        V        = COMPLEX SHEAR WAVE VELOCITY
C        PLUS     = COMPLEX TRANSFER FUNCTION
C        MINUS    = COMPLEX TRANSFER FUNCTION
C
C   CODED BY PER B SCHNABEL OCT 1971
C
C***********************************************************************
C
      COMPLEX G, V, PLUS, MINUS, MU
      CHARACTER*6 IDNT
      COMMON /SOILA/ IDNT(6),BL(51),GL(51),FACT(51),H(51),R(51),BF(51)
      COMMON /CSOIL/ G(51), V(51), PLUS(51), MINUS(51)
C
      N = N1 + 1
      DO 1 I = 1,N
      GIMAG=2.*BL(I)*GL(I)*SQRT(1.-BL(I)*BL(I))
      GREAL=GL(I)*(1.-2.*BL(I)*BL(I))
      G(I)=CMPLX(GREAL,GIMAG)
      V(I) = CSQRT(G(I)/R(I))
    1 CONTINUE
      DO 2 I = 1,N1
      J = I + 1
      MU = CSQRT(R(I)/R(J)*G(I)/G(J))
      PLUS(I) = (1. + MU)/2.
      MINUS(I)= (1. - MU)/2.
    2 CONTINUE
      RETURN
      END
C**********************************************
      SUBROUTINE STRAIN( LL, LGS, LPCH, LPL,LNV,X,AX,AA,N1,S,INV)
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C   THIS SUBROUTINE COMPUTES STRAIN AND/OR STRESS TIME-HISTORY AT THE
C   TOP OF ANY LAYER FOR ACCELERATION HISTORY KNOWN IN ANY LAYER
C   TWO RESPONSE HISTORIES ARE COMPUTED IN ONE RUN
C
C        LL      =   SUBLAYER NUMBER WHERE RESPONSE IS TO BE COMPUTED
C        LGS     =   SWITCH FOR STRESS OR STRAIN
C        LPCH    =   SWITCH FOR SAVING OUTPUT
C        LPL     =   SWITCH FOR PLOT
C        X       =   FOURIER TRANSFORM OF OBJECT MOTION
C        AX(1, )     FOURIER TRANSFORM OF SURFACE MOTION
C        AX(2, )     FOURIER TRANSFORM OF FIRST COMPUTED RESPONSE
C        AX(3, )     FOURIER TRANSFORM OF SECOND RESPONSE
C        AA(1, )     TIME HISTORY OF FIRST RESPONSE
C        AA(2, )     TIME HISTORY OF SECOND RESPONSE
C
C   CODED BY PER B. SCHNABEL  JULY 1971
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      INTEGER TP
      CHARACTER*6 TITLE,IDNT,ID
      CHARACTER*60 ABSIS
      COMPLEX X, AX
      COMPLEX G, V, PLUS, MINUS
      COMPLEX E,F,EE, A,AH,IPI2, AE,AF,EX,AI
C
      DIMENSION AE(2), AF(2)
      DIMENSION X(1),  AX(3,1), AA(2,1), S(1),  INV(1)
      DIMENSION LL(2), LGS(2),  LPCH(2), LPL(2), LNV(2)
C
      COMMON /SOILA/ IDNT(6),BL(51),GL(51),FACT(51),H(51),R(51),BF(51)
      COMMON /SOILB/ FAC(51), WL(51), TP(51), DEPTH(51), WEIGHT(51)
      COMMON /CSOIL/ G(51), V(51), PLUS(51), MINUS(51)
      COMMON /EQ/ MFOLD,MA2,TITLE(5),DT, MA , MMA, DF,MX
      COMMON /CCG/ ID(27,11)
      COMMON /FRCUT/ NCUT,NZERO
      COMMON /TIME/ T(9)
C
      ABSIS = ' TIME IN SEC '
      IPI2 = CMPLX(0.,6.283185307)
      GT = 32.2
      AX(2,1) = 0.
      AX(3,1) = 0.
      FREQ = 0.
      AI = GT/IPI2
C
C  STARTING AT THE SURFACE THE STRAIN IS COMPUTED SUCCESSIVELY DOWNWARDS
C   FOR EACH FREQUENCY
      DO 1 I=2,NCUT
      E = AX(1,I)/2.
      F = E
```

```
      FREQ = FREQ + DF
      AH = AI/FREQ
      A = FREQ*IPI2
      DO 11  K = 1,N1
      DO 12 L = 1,2
      IF (K.NE.LL(L)) GO TO 12
      AE(L) = E/V(K)
      AF(L) = F/V(K)
   12 CONTINUE
      EX = CEXP(H(K)*A/V(K))
      E = E*EX
      F = F/EX
      EE = E*PLUS(K) + MINUS(K)*F
      F  = F*PLUS(K) + MINUS(K)*E
      E = EE
   11 CONTINUE
      DO 13 L = 1,2
      IF (LL(L).NE.N1+1) GO TO 13
      AE(L) = E/V(N1+1)
      AF(L) = F/V(N1+1)
   13 CONTINUE
      DO 14 L = 1,2
      IF (LL(L).GT.0) AX(L+1,I) = (AE(L) -AF(L))*AH
   14 CONTINUE
    1 CONTINUE
      DO 2 I = 1,MFOLD
    2 AX(1,I) = X(I)
      DO 3 L = 1,2
      IF (LL(L).EQ.0) GO TO 3
      X(1) = 0.
      DO 31 I=2,NCUT
   31 X(I) = AX(L+1,I)
      IF(NCUT.EQ.MFOLD) GO TO 33
      DO 34 II=NZERO,MFOLD
      X(II)=CMPLX(0.,0.)
   34 CONTINUE
   33 CONTINUE
      CALL RFSN(X,MX,INV,S,IFERR,-2)
      DO 32 I =1,MFOLD
      AA(L,2*I-1) =REAL(X(I))*100.
   32 AA(L,2*I) = AIMAG(X(I))*100.
    3 CONTINUE
C
      DO 4 I = 1,MFOLD
    4 X(I) = AX(1,I)
C   COMPUTE STRESS IF WANTED AND SAVE COMPUTED RESPONSES
      DO 5 L = 1,2
      IF (LL(L) .EQ. 0) GO TO 5
      NVAL = LNV(L)
      IF (NVAL.LE.0) NVAL = MMA
      IF (NVAL.GT.MA)  NVAL = MA
      IF (NVAL.GT.2049) NVAL = 2049
      DO 51 I = 1,5
   51 ID(L,I) = TITLE(I)
      N = LL(L)
      ID(L,6) = 'STRAIN'
      IF (LGS(L) .EQ.0) GO TO 53
      ID(L,6) = 'STRESS'
      DO 52 I = 1,NVAL
   52 AA(L,I) = GL(N)*AA(L,I)/100.
   53 IF (LPCH(L).EQ.0) GO TO 54
      WRITE(7,2000) (ID(L,I), I=1,11),N
      N = 1
      NCARDS = NVAL/8
      DO 55 K = 1,NCARDS
      NN = N + 7
      WRITE(7,2001) (AA(L,I), I = N,NN), K
   55 N = N + 8
   54 IF (LPL(L).EQ.0) GO TO 5
      N = 0
      NSKIP = 1
      DO 56 I = 1,NVAL,NSKIP
      N = N + 1
      IF (NSKIP.GT.1) AA(L,N) = AA(L,I)
   56 T(N) = DT*FLOAT(I-1)
      IF  (LGS(L).EQ.0)  WRITE(6,2002)
      IF (LGS(L).EQ.1)  WRITE(6,2003)
      IF (LPL(L).EQ.0) GO TO 5
      IF (LPL(2).EQ.2) GO TO 5
      IF (L.EQ.1)  GO TO  58
      DO 57 I = 1,N
   57 AA(1,I) = AA(2,I)
      DO 50 I = 1,11
   50 ID(1,I) = ID(2,I)
   58 CONTINUE
      GO TO 5
    5 CONTINUE
 2000 FORMAT(11A6,5HLAYER I5)
 2001 FORMAT(8F9.6,I7)
 2002 FORMAT(41H1  TIME HISTORY OF STRAIN IN PERCENT          )
 2003 FORMAT(41H1  TIME HISTORY OF STRESS IN KSF              )
      RETURN
      END
```

```
$NOFLOATCALLS
$NODEBUG
C ......................................................................
      SUBROUTINE SHAKIT(X,AX,AA,S,INV)
C ......................................................................
      INTEGER TP
      CHARACTER*6 TITLE,ID,IDNT,IDAMP,IBLANK
      CHARACTER*60 ABSIS, ABSPR,ABSCL
      CHARACTER*80 OPHEAD
      CHARACTER*30 FINPEQ
      COMPLEX X, AX
      COMPLEX G, V, PLUS, MINUS
C
      DIMENSION LL(3), LT(3),LNSW(3)
      DIMENSION LLL(2), LLGS(2),LLPCH(2),LLPL(2),LNV(2),SK(2)
      DIMENSION X(300),AX(3,270),AA(2,550),S(70),INV(70)
      DIMENSION LL5(15), LT5(15), LP5(15),LP(3)
      DIMENSION IDAMP(27,11),MMM(3)
C
      COMMON /EQ/ MFOLD,MA2,TITLE(5),DT, MA , MMA, DF,MX
      COMMON /SOILA/ IDNT(6),BL(51),GL(51),FACT(51),H(51),R(51),BF(51)
      COMMON /SOILB/ FAC(51), WL(51), TP(51), DEPTH(51), WEIGHT(51)
      COMMON /SOILC/ MSOIL,MWL
      COMMON /CSOIL/ G(51), V(51), PLUS(51), MINUS(51)
      COMMON /CCG/ ID(27,11)
      COMMON /JISCK/ JIS,FINPEQ
      COMMON/FRCUT/ NCUT,NZERO
      COMMON /TIME/ T(9)
C     originallly coded by Per Schnabel in 1970-71
C     modified by Sun, Dirrim & Idriss in 1990-91 to
C     increase number of layers to 50;
C     renumber the Options & other cleanup
C
      IBLANK = '      '
      ABSIS = ' TIME IN SECONDS  '
      ABSCL = '  CYCLES/SEC'
      ABSPR = ' PERIOD IN SEC.   '
c
C * * * * * * * * * *
C
      DO 102 I = 1,3
      LL(I) = 0
  102 LT(I) = 0
      DO 103 L = 1,9
      DO 103 I = 1,11
      ID(L,I) = IBLANK
  103 IDAMP(L,I) = IBLANK
      NF = 0
      NR=0
      NP=0
      NA = 1
C
C * * * * * * * * * *
      KK = -1
C .................................
  101 READ (5,1700) OPHEAD
 1700 FORMAT(A80)
C
      IF(KK.GE.1.AND.KK.LE.11) WRITE(*,24) KK
      READ(5,1000,END=999) KK
      IF (KK .EQ. 0) STOP
      WRITE(*,23) KK
C ******************* Options ***************
      IF (KK .EQ. 1) GO TO 8
      IF (KK .EQ. 2) GO TO 2
      IF (KK .EQ. 3) GO TO 1
      IF (KK .EQ. 4) GO TO 3
      IF (KK .EQ. 5) GO TO 4
      IF (KK .EQ. 6) GO TO 5
      IF (KK .EQ. 7) GO TO 16
      IF (KK .EQ. 8) GO TO 6
      IF (KK .EQ. 9) GO TO 9
      IF (KK .EQ. 10) GO TO 15
      IF (KK .EQ. 11) GO TO 13
C * * * * * * * * * *
C New Option 3 -- input motion
C.......................................................
    1 WRITE(6,1002) KK
      CALL EARTHQ(X,AX, S, INV)
      NSN = 0
      GO TO 101
C * * * * * * * * * *
C New Option 2 -- data for Soil Profile
C...........................................................
    2 WRITE(6,2002) KK
      CALL SOILIN(N1)
      NSN = 1
C
C   FIND FUNDAMENTAL PERIOD OF DEPOSIT FROM AVERAGE SHEAR WAVE VELOCITY
C   AND FROM THE PERIOD WHICH GIVE MAXIMUM AMPLIFICATION
      SH = 0.
      N = N1 + 1
      SHV = 0.
      DO 21 I = 1,N1
      SH = SH + H(I)
   21 SHV = SHV + H(I)*SQRT(GL(I)/R(I))
      VSAV = SHV/SH
      TT = 4.*SH/VSAV
      WRITE(6,4006) TT, VSAV
      DFA = .01/TT
      CALL AMP(N1,N ,1,1,0,0,IDAMP, 9, DFA)
      GO TO 101
C * * * * * * * * * *
C New Option 4 -- sublayer for input motion
C........................................................
    3 WRITE(6,3002) KK
      READ(5,1000) IN, INT
      IF (INT .EQ. 0) WRITE(6,3001) IN
      IF (INT .NE. 0) WRITE(6,3000) IN
      GO TO 101
C * * * * * * * * * *
C New Option 5 -- # of iterations & ratio of unif. strain/max strain
C..............................................................
    4 WRITE(6,4007) KK
      READ(5,4000) KS,ITMAX,PRMUL
      WRITE(6,4001) ITMAX,PRMUL
      LL(1) = 1
      LT(1) = 0
      JIS = 0
      WRITE(*,2029)
 2029 FORMAT(/)
      DO 41 L = 1,ITMAX
```

```
      WRITE(*,2028) L
 2028 FORMAT(1H+,12X,19H  ITERATION NUMBER  , I2)
      IF (IN.EQ.1) GO TO 412
      CALL MOTION(N1,IN, INT, LL, LT, X,AX)
      IF (L .EQ. ITMAX) JIS = 1
  412 CALL STRT( L, N1, DGMAX,PRMUL,X,AX,AA,S,INV)
C     IF (DGMAX.LT.ERR) GO TO 411
   41 CONTINUE
C
C   FIND FUNDAMENTAL PERIOD OF DEPOSIT FROM AVERAGE SHEAR WAVE VELOCITY
C   AND FROM THE PERIOD WHICH GIVE MAXIMUM AMPLIFICATION
  411 SH = 0.
      N = N1 + 1
      SHV = 0.
      DO 43 I = 1,N1
      SH = SH + H(I)
   43 SHV = SHV + H(I)*SQRT(GL(I)/R(I))
      VSAV = SHV/SH
      TT = 4.*SH/VSAV
      WRITE(6,4006) TT, VSAV
      DFA = .01/TT
      CALL AMP(N1,N ,1,1,0,0,IDAMP, 9, DFA)
C
      IF (KS .EQ. 0) GO TO 101
C   SAVE NEW SET OF SOIL DATA BASED ON NEW PROPERTIES
      WRITE(7,4003) MSOIL,N,MWL,(IDNT(I),I=1,6),(TITLE(I),I=1,4)
      DO 42 I = 1,N1
   42 WRITE(7,4004) I,TP(I), H(I), GL(I), BL(I), WL(I), FAC(I) ,BF(I)
      WRITE(7,4005) N,GL(N),BL(N),WL(N)
      GO TO 101
C * * * * * * * * * *
C New Option 6 -- sublayers for which acceleration TH are calculated
C.............................................................
    5 WRITE(6,5001) KK
      READ(5,1000) (LL5(L),L=1,15)
      READ(5,1000) (LT5(L),L=1,15)
      READ(5,1000) (LP5(L),L=1,15)
      WRITE(6,5002) FINPEQ,(IDNT(I),I=1,6)
      I = 0
      DO 51 LOOP = 1,5
      DO 511 L = 1,3
      I = I + 1
      LL(L) = LL5(I)
      LT(L) = LT5(I)
      LP(L) = LP5(I)
C
      IF (LL(1).EQ.0) GO TO 101
  511 CONTINUE
C
      CALL MOTION(N1,IN, INT, LL, LT, X,AX)
      DO 51  L = 1,3
      N = LL(L)
      K = L
      IF (N.EQ.0) GO TO 101
      IF (N.LE.N1)  DPTH = DEPTH(N) - H(N)/2.
      IF (N.GT.N1)  DPTH = DEPTH(N-1) + H(N-1)/2.
      CALL UTPR(KK,DPTH,K,LP(L),LL(L),LT(L),X,AX,S,INV)
   51 CONTINUE
      GO TO 101
C * * * * * * * * * *
C New Option 8 -- save time history of object motion
C.............................................................
    6 WRITE(6,6002) KK
      READ(5,1000) K2
      LS = 0
      LN = IN
      IF (K2.EQ.0)  WRITE(6,6000) LN
      IF (K2.EQ.1)  WRITE(6,6001) LN
   62 CALL UTPR(KK,DPTH,LS,K2,LN,INT   ,X,AX,S,INV)
      GO TO 101
C * * * * * * * * * *
C Option not used
C...................................................
    7 WRITE(6,7002) KK
      READ(5,7001) LL1,LT1,XF,DTNEW
      IF (DTNEW.LT..001) DTNEW=DT
      IF (LL1  .EQ.0) GO TO 71
C    CHECK IF MOTION IN SUBLAYER LL1 IS IN AX()
      DO 72 I = 1,3
      IF (LL1.NE.LL(I) .OR. LT1.NE.LT(I)) GO TO 72
      L = I
      GO TO 720
   72 CONTINUE
      LL(1) = LL1
      LT(1) = LT1
      L = 1
      CALL MOTION(N1,IN, INT, LL, LT, X,AX)
  720 DO 75 I = 1,MFOLD
   75 X(I) = AX(L,I)*XF
      NEW = LL(L)
      INT = LT(L)
      GO TO 73
   71 DO 74 I = 1,MFOLD
   74 X(I) = X(I)*XF
      NEW = IN
   73 IN = NEW
      WRITE(6,7000) NEW , XF,DT, DTNEW
      IF(IN.NE.1) GO TO 76
      DO 77 II=1,MFOLD
      AX(1,II)=X(II)
   77 CONTINUE
   76 CONTINUE
      DT = DTNEW
      DF = 1./(MA*DT)
      GO TO 101
C * * * * * * * * * *
C New Option 1 -- dynamic soil properties
C.............................................................
    8 WRITE(6,8001) KK
      CALL CG
      GO TO 101
C * * * * * * * * * *
C New Option 9 -- response spectrum
C.............................................................
    9 WRITE(6,9002) KK
      READ(5,1000) LL1, LT1
      IF (LL1.NE.0) GO TO 171
      WRITE(6,9001)
      LS = 0
      LN = IN
      GO TO 173
  171 DO 170 I = 1,3
```

```
      IF (LL1.NE.LL(I) .OR. LT1.NE.LT(I)) GO TO 170
      LS = I
      GO TO 172
  170 CONTINUE
      LS = 1
      LL(1) = LL1
      LT(1) = LT1
      CALL MOTION(N1,IN, INT, LL, LT, X,AX)
  172 LN = LL(LS)
C      WRITE(6,9000) LN
  173 CALL RESP(LN,LS,NR,X,AX,AA,S,INV)
      GO TO 101
C * * * * * * * * *
C Option Not used
C...................................................
   10 WRITE(6,1010) KK
      READ(5,1000) IFR
      CALL REDUCE(IFR,X,AX,LL)
      MMM(1)=MX
      MMM(2)=0
      MMM(3)=0
      CALL FFT(X,MMM,INV,S,0,IFERR)
      GO TO 101
C * * * * * * * * *
C Option not used
C.......................................................
   11 WRITE(6,1101) KK
      READ(5,1000) IFR
      CALL INCR(IFR,X,AX)
      MMM(1)=MX
      MMM(2)=0
      MMM(3)=0
      CALL FFT(X,MMM,INV,S,0,IFERR)
      GO TO 101
C * * * * * * * * *
C Option not used
C.........................................................
   12 WRITE(6,1203) KK
      READ(5,1000) K1, NSW, N
      IF (INT.EQ. 0) WRITE(6,1201) IN
      IF (INT.EQ. 1) WRITE(6,1202) IN
      NF = NF + 1
      IF (N.LE.0)  N= MFOLD - 1
      IF (N.GT.2049)   N=2049
      DO 120 I = 1,N
  120 AA(NF,I) = CABS(X(I))
      DO 121 I = 1,5
  121 ID(NF,I) = TITLE(I)
      DO 126 I = 6,11
  126 ID(NF,I) = IBLANK
      IF (NSW.EQ.0) GO TO 123
      M = N-1
      DO 124 LOOP = 1,NSW
      AA(NF,1) = (3.*AA(NF,1) + AA(NF,2))/4.
      AA(NF,N) = (3.*AA(NF,N) + AA(NF,N-1))/4.
      DO 124 I = 2,M
  124 AA(NF,I) = (AA(NF,I-1) + 2.*AA(NF,I) + AA(NF,I+1))/4.
  123 IF (K1.NE.1) GO TO 101
      DO 122 I = 1,N
      T(I ) = FLOAT(I-1)*DF
  122 CONTINUE
      WRITE(6,1200)
      NF = 0
      GO TO 101
C * * * * * * * * *
C New Option 11 -- Fourier Amplitudes
C..............................................................
   13 WRITE(6,1301) KK
      DO 180 I = 1,2
  180 READ(5,1000) LL(I), LT(I), LP(I), LNSW(I), LLL(I)
      CALL MOTION(N1, IN, INT, LL, LT, X, AX)
      NF = 0
      DO 184 L = 1,2
      IF (LL(L).EQ.0) GO TO 101
      IF (LT(L).EQ.0) WRITE(6,1201) LL(L)
      IF (LT(L).EQ.1) WRITE(6,1202) LL(L)
      N = LLL(L)
      IF (N.LE.0)   N = MFOLD - 1
      IF (N.GT.2049)   N = 2049
      NF = NF + 1
      IF (NF.LE.2)  GO TO 182
      WRITE(6,1800)
 1800 FORMAT(//  24H TOO MANY ARRAYS STORED   /)
      GO TO 101
  182 DO 188 I = 1,5
  188 ID(NF,I) = TITLE(I)
      DO 187 I = 6,11
  187 ID(NF,I) = IDNT(I-5)
      DO 185 I = 1,N
  185 AA(NF,I) = CABS(AX(L,I))
      NSW = LNSW(L)
      IF (NSW.EQ.0) GO TO 181
      M = N-1
      DO 186 LOOP = 1,NSW
      AA(NF,1) = (3.*AA(NF,1) + AA(NF,2))/4.
      AA(NF,N) = (3.*AA(NF,N) + AA(NF,N-1))/4.
      DO 186 I = 2,M
  186 AA(NF,I) = (AA(NF,I-1) + 2.*AA(NF,I) + AA(NF,I+1))/4.
      IF (LP(L).EQ.0) GO TO 184
  181 DO 183 I = 1,N
  183 T(I) = DF*FLOAT(I-1)
C     WRITE(6,1200)
  184 CONTINUE
      WRITE(6,1204)
 1204 FORMAT(1X,'        FREQ        FOURIER AMPLITUDES')
 1205 FORMAT(1X,F10.4,2F15.6)
      DO 133  I=1,N
  133 WRITE(6,1205)  T(I),(AA(NF,I), NF=1, 2)
      GO TO 101
C * * * * * * * * *
C Option not used
C.........................................................
   14 WRITE(6,1404) KK
      READ(5,1000) NSKIP, NN, NSW
      NP = NP + 1
      CALL RFSN(X,MX,INV,S,IFERR,-2)
      IF (NN.LE.0)  NN = MMA/NSKIP
      IF (NN.GT.2049)  NN = 2049
      NN =  NN*NSKIP
      N = 0
      DO 136 I=1, NN, NSKIP
      N = N + 1
```

```
      T(N) = FLOAT(I-1)*DT
  136 CONTINUE
      N = 0
      M = NN/2
      DO 130 I = 1,M
      N = N + 1
      AA(NP,N) = REAL(X(I))
      N = N + 1
      AA(NP,N) = AIMAG(X(I))
  130 CONTINUE
      IF  (NSKIP.EQ.1) GO TO 135
      N = 0
      DO 134 I = 1,NN ,NSKIP
      N = N + 1
      AA(NP,N) = AA(NP,I)
  134 CONTINUE
  135 CALL RFFT(X,MX,INV,S,IFERR,2)
      DO 131 I = 1,5
  131 ID(NP,I) = TITLE(I)
      DO 132 I = 6,11
      ID(NP,I) = IDNT(I-5)
      IF (NSN.EQ.0)  ID(NP,I)  = IBLANK
  132 CONTINUE
      IF (NSW.EQ.1) GO TO 101
      NP = 0
      GO TO 101
C * * * * * * * * * *
C New Option 10 -- amplification spectrum
C...........................................................
   15 WRITE(6,1502) KK
      READ(5,1400) LIN, LINT ,LOUT,LOTP,DFA,(IDAMP(NA,I),I=1,8)
      KP = 2
      WRITE(6,1401) LIN,LOUT
      IF  (LOTP.EQ.0) WRITE(6,1403)
      IF  (LINT.EQ.0) WRITE(6,1402)
      CALL AMP(N1, LIN, LINT, LOUT, LOTP, KP, IDAMP,NA, DFA)
      GO TO 101
C * * * * * * * * * *
C Option not used
C.............................................................
   16 WRITE(6,1601) KK
      DO 151 L = 1,2
      READ(5,1500) LLL(L),LLGS(L),LLPCH(L),LLPL(L),LNV(L),SK(L),
     1(ID(L,I),I=7,11)
      IF (LLL(L).GT.0) WRITE(6,1501) LLL(L),SK(L),(ID(L,I),I=7,11)
  151 CONTINUE
      DO 152 L = 1,3
  152 LT(L) = 0
      LL(3) = 0
      LL(2) = 0
      LL(1) = 1
      CALL MOTION(N1, IN, INT, LL, LT, X, AX)
      CALL STRAIN(LLL,LLGS,LLPCH,LLPL,LNV,X,AX,AA,N1,S,INV)
      DO 153 I = 1,3
  153 LL(I) = 0
      GO TO 101
C * * * * * * * * * *
C
   23 FORMAT(5X,'Option NO.',I5,'   is started.')
   24 FORMAT(5X,'Option NO.',I5,'   has been concluded.')
 1000 FORMAT(15I5)
 1002 FORMAT(/16H1******   OPTION  I3,
     1 58H  ***  READ INPUT MOTION                                 )
 2002 FORMAT(/16H1******   OPTION  I3,
     1 58H  ***  READ SOIL PROFILE                                 )
 3000 FORMAT(/32H  OBJECT MOTION IN LAYER NUMBER   I3/)
 3001 FORMAT(33H   OBJECT MOTION IN LAYER NUMBER I3,12H OUTCROPPING )
 3002 FORMAT(16H1******   OPTION  I3,
     1 58H  ***  READ WHERE OBJECT MOTION IS GIVEN                   )
 4000 FORMAT( 2I5, 7F10.0)
 4001 FORMAT(
     148H  MAXIMUM NUMBER OF ITERATIONS                =    I5/
     148H  FACTOR FOR UNIFORM STRAIN IN TIME DOMAIN    = F6.2/)
 4003 FORMAT(3I5,6A6, 4A6)
 4004 FORMAT(2I5,4X,1H1,F10.2,F10.0,2F10.3,10X,F10.3, F5.2)
 4005 FORMAT(I5,9X,1H110X,F10.0,2F10.3)
 4006 FORMAT(/10H  PERIOD = F5.2,' FROM AVERAGE SHEAR VELOCITY ='F8.0/)
 4007 FORMAT(/16H1******   OPTION  I3,
     1 58H  ***  OBTAIN STRAIN COMPATIBLE SOIL PROPERTIES            )
 5001 FORMAT(/16H1******   OPTION  I3,
     1 58H  ***  COMPUTE MOTION IN NEW SUBLAYERS                     )
 5002 FORMAT(/15H   EARTHQUAKE - A30/  17H  SOIL DEPOSIT -  6A6/
     15X, 6HLAYER
     1 10X,5HDEPTH 8X,9HMAX. ACC. 10X, 4HTIME 6X, 12HMEAN SQ. FR.
     1  9X, 10HACC. RATIO , 6X, 14H TH SAVED
     2/ 22X, 2HFT 12X, 1HG 16X, 4HSEC  9X, 5HC/SEC 13X,10HQUIET ZONE
     37X, 11HACC. RECORD   )
 6000 FORMAT(/37H  PRINT        ACCELERATION IN LAYER  I3)
 6001 FORMAT(/46H  PRINT AND PUNCH        ACCELERATION IN LAYER I3)
 6002 FORMAT(16H1******   OPTION  I3,
     1 58H  ***  PRINT OR PUNCH OBJECT MOTION                        )
 7000 FORMAT(/21H  SET MOTION IN LAYER  I3,17H AS OBJECT MOTION /
     141H MULTIPLICATION FACTOR FOR NEW MOTION =  F6.3/
     227H  TIMESTEP DT CHANGED FROM F6.3, 3H TO F6.3, 5H SEC./)
 7001 FORMAT(2I5, 5F10.0)
 7002 FORMAT(16H1******   OPTION   I3,
     1 58H  ***  CHANGE OBJECT MOTION                                 )
 8001 FORMAT(/16H1******   OPTION   I3,
     1 58H  ***  READ RELATION BETWEEN SOIL PROPERTIES AND STRAIN    )
 9000 FORMAT( 36H  COMPUTE RESPONSE SPECTRUM IN LAYER  I3)
 9001 FORMAT(43H COMPUTE RESPONSE SPECTRUM OF OBJECT MOTION )
 9002 FORMAT(/16H1******   OPTION  I3,
     1 58H  ***  COMPUTE RESPONSE SPECTRUM                            )
 1010 FORMAT(16H1******   OPTION    I3,
     1 58H  ***  INCREASE TIMESTEP                                  //)
 1101 FORMAT(16H1******   OPTION    I3,
     1 58H  ***  DECREASE TIMESTEP                                  //)
 1200 FORMAT(26H1 FOURIER SPECTRA         ')
 1201 FORMAT(15H  LAYER NUMBER I4,  12H OUTCROPPING /)
 1202 FORMAT(14H  LAYER NUMBER I4)
 1203 FORMAT(16H1******   OPTION    I3,
     1 58H  ***  PLOT OF FOURIER SPECTRUM OF OBJECT MOTION          )
 1301 FORMAT(16H1******   OPTION    I3,
     1 58H  ***       FOURIER SPECTRUM OF COMPUTED MOTION           )
 1400 FORMAT(4I5, F10.0, 8A6)
 1401 FORMAT(/41H    AMPLIFICATION SPECTRUM BETWEEN LAYER I4, 4H AND I4)
 1402 FORMAT(26H  INPUT LAYER OUTCROPPING )
 1403 FORMAT(26H  OUTPUT LAYER OUTCROPPING )
 1404 FORMAT(16H1******   OPTION  I3,
     1 58H  ***  PLOT TIME HISTORY OF OBJECT MOTION                 )
 1500 FORMAT(5I5,F10.0, 5A6)
 1501 FORMAT(/  49H  COMPUTE STRESS OR STRAIN HISTORY AT THE TOP OF
```

```
    1 6H LAYER  I5 /21H  SCALE FOR PLOTTING  F10.4/  15H IDENTIFICATION
    2 3H -     5A6,6X)
 1502 FORMAT(/16H1******    OPTION  I3,
    1 58H  ***  COMPUTE AMPLIFICATION FUNCTION                    )
 1601 FORMAT(/16H1******    OPTION  I3,
    1 58H  ***  COMPUTE STRESS/STRAIN HISTORY                     )
C
  999 STOP
      END
C**********************************************************************
      SUBROUTINE STRT( IT,N1,DGMAX,PRMUL,X,AX,AA,SF,INV)
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
C   THIS ROUTINE CALCULATES STRAIN IN THE MIDDLE OF EACH LAYER AND FIND
C   NEW SOIL PROPERTIES COMPATIBLE WITH THE STRAINS
C
C        IT      = ITERATION NUMBER
C        N1      = NUMBER OF LAYERS EXCLUDING ROCK
C        DGMAX   = MAX ERROR IN SOIL PARAMETERS B OR G IN PERCENT
C        X       = OBJECT MOTION
C        AX(1, ) = ACCELERATION VALUES AT THE SURFACE
C        AX(2, ) = INCIDENT WAVE-COMPONENT
C        AX(3, ) = REFLECTED WAVE-COMPONENT
C        PRMUL   = RATIO EFF. STRAIN/MAX. STRAIN
C
C   CODED PER B SCHNABEL OCT. 1970
C   MODIFIED PBS  SEPT. 1971
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      INTEGER TP
      CHARACTER*6 TITLE,IDNT
      CHARACTER*30 FINPEQ
      COMPLEX IPI2, EX, E, F, EE, FF
      COMPLEX X, AX
      COMPLEX G, V, PLUS, MINUS
C
      DIMENSION TMAX(51),EMAX(51),STR(51)
      DIMENSION X( 68), AX(3, 64), AA(2,128),SF(10), INV(10), ratio(51)
      COMMON /EQ/ MFOLD,MA2,TITLE(5),DT, MA , MMA, DF,MX
      COMMON /SOILA/ IDNT(6),BL(51),GL(51),FACT(51),H(51),R(51),BF(51)
      COMMON /SOILB/ FAC(51), WL(51), TP(51), DEPTH(51), WEIGHT(51)
      COMMON /SOILC/ MSOIL,MWL
      COMMON /SOILD/ GLMAX(51)
      COMMON /SOILDG/ S(27,20), AS(27,20), BS(27,20), NV(27)
      COMMON /CSOIL/ G(51), V(51), PLUS(51), MINUS(51)
      COMMON /JISCK/ JIS,FINPEQ
      COMMON/FRCUT/ NCUT,NZERO
C
      DO 43 I = 1,MFOLD
      AA(1,I) = REAL(X(I))
   43 AA(2,I) = AIMAG(X(I))
      DO 1  I = 1,MFOLD
      AX(2,I) = AX(1,I)/2.
    1 AX(3,I) = AX(2,I)
      PI2=6.283185307
      IPI2=CMPLX(0.,PI2)
      GT = 32.2
      DO 2 K = 1,N1
C     WRITE(*,2029) K
      FREQ = 0.
      X(1) = 0.
      FF = GT/(IPI2*V(K))
      EE = H(K)/2.*IPI2/V(K)
      DO 20 I=2,NCUT
      FREQ = FREQ + DF
      EX = CEXP(FREQ*EE)
      X(I) = (AX(2,I)*EX - AX(3,I)/EX)*FF/FREQ
      EX = EX*EX
      E = AX(2,I)*EX
      F = AX(3,I)/EX
      AX(2,I)= PLUS(K)*E + MINUS(K)*F
      AX(3,I)= PLUS(K)*F + MINUS(K)*E
   20 CONTINUE
      EMAX(K) = 0.
      IF(NCUT.EQ.MFOLD) GO TO 22
      DO 122 II=NZERO,MFOLD
      X(II)=CMPLX(0.,0.)
  122 CONTINUE
   22 CONTINUE
C
C   DETERMINE MAX. STRAIN BY INVERTING FOURIER TRANSFORM OF STRAIN
C   INTO THE TIME DOMAIN
C
      CALL RFSN(X,MX,INV,SF,IFERR,-2)
      CALL XMX(X,MA,XMAX,NXMAX)
C
      EMAX(K) = XMAX
      TMAX(K) = FLOAT(NXMAX-1)*DT
    2 CONTINUE
      IF (IT.GT.1) WRITE(6,2002)
      WRITE(6,2017) FINPEQ, (IDNT(I),I=1,6)
      WRITE(6,2027) IT
C     WRITE(6,2037) PRMUL
      WRITE(6,2000)
      DGMAX = 0.
      DO 23 I = 1,N1
      EM = EMAX(I)*PRMUL*100.
      EMAX(I) = EMAX(I)*100.
      IF (TP(I) .NE. 0)  GO TO 231
      STR(I) = EMAX(I)*GL(I)*10.
      WRITE(6,2107) I, TP(I), DEPTH(I), EM , BL(I), GL(I)
      GO TO 23
C
C   USE UNIFORM STRAIN AMPLITUDE (EM) TO GET NEW VALUES FOR DAMPING
C   AND SHEAR MODULUS
  231 IN = TP(I)*2 - 1
      SS= ABS(EM)
      SL = ALOG10(SS)
      LL = NV(IN)
      DO 31 L = 1,LL
      IF (SS.LE. S(IN,L)) GO TO 311
   31 CONTINUE
      L = LL
  311 GN =AS(IN,L)*SL +BS(IN,L)
      GG = GN*FACT(I)/1000.
      IN = IN + 1
      LL = NV(IN)
      DO 32 L = 1,LL
      IF (SS.LE. S(IN,L)) GO TO 321
   32 CONTINUE
      L = LL
  321 B  =AS(IN,L)*SL +BS(IN,L)
```

```
      B = B*BF(I)
C -----------------------------------------------------------------------
C  SHEAR STRESSES ARE COMPUTED USING CURRENT MODULI
C
      STR(I) = EMAX(I)*GL(I)*10.
      RATIO(I) = GL(I) / GLMAX(I)
C -----------------------------------------------------------------------
      B = B/100.
      DG = (GG - GL(I))*100./GG
      DB = ( B - BL(I))*100./B
      WRITE(6,2007) I, TP(I), DEPTH(I), EM, B, BL(I), DB, GG, GL(I), DG,
     + RATIO(I)
      IF (ABS(DG) .GT. DGMAX)  DGMAX = ABS(DG)
      IF (ABS(DB) .GT. DGMAX)  DGMAX = ABS(DB)
      IF (JIS .EQ. 1) GO TO 23
      BL(I) = B
      GL(I) = GG
   23 CONTINUE
      IF (JIS .NE. 1) GO TO 53
      WRITE(6,2011)
      WRITE(6,2001) (I,TP(I), H(I),DEPTH(I), EMAX(I), STR(I), TMAX(I),
     1 I = 1,N1)
   53 CALL CXSOIL(N1)
      DO 44 I = 1,MFOLD
   44 X(I) = CMPLX(AA(1,I),AA(2,I))
      RETURN
C
 2000 FORMAT(/23H  VALUES IN TIME DOMAIN //
     1,' NO TYPE DEPTH  UNIFRM. <---- DAMPING ---->   <---- SHEAR',
     2' MODULUS ----->    G/Go'/
     3'         (FT)   STRAIN  NEW    USED   ERROR      NEW       USED',
     4'    ERROR   RATIO'/
     5'--- ---- ----  ------- ----- ------  ------   -------   -------',
     6'   ------   -----')
 2002 FORMAT(1H1)
 2011 FORMAT(/23H  VALUES IN TIME DOMAIN //
     1 2X, 5HLAYER 2X,4HTYPE 6X, 9HTHICKNESS 10X, 5HDEPTH 5X, 10HMAX STR
     2AIN 5X, 10HMAX STRESS 10X, 4HTIME /
     323X, 2HFT 14X, 2HFT 9X, 5HPRCNT 12X, 3HPSF 13X, 3HSEC /)
 2001 FORMAT(2I6, 2F15.1, F15.5,2F15.2)
 2007 FORMAT(2I3, F7.1, F8.5,F6.3,1x,f6.3 F9.1, 1X,
     1 F9.1,1x,F9.1, F9.1, F8.3)
 2107 FORMAT(2I3,F8.1,F9.5,2F7.3,F8.1,2F10.1,F8.1,F7.3)
 2027 FORMAT(19H  ITERATION NUMBER   I2)
 2029 FORMAT(1H+,20X,'Processing layer no. ',I2)
 2030 FORMAT(1H+'                                                    ')
 2017 FORMAT(5X,15HEARTHQUAKE   -  A30/5X,15HSOIL PROFILE -   6A6/)
 2037 FORMAT(56H  THE CALCULATION HAS BEEN CARRIED OUT IN THE TIME DOMAI
     121HN WITH EFF. STRAIN = F3.2, 1H* 12H MAX. STRAIN )
      END
C*****************************************************************
      SUBROUTINE SOILIN(N1)
C*********************************************************************
C
C   THIS ROUTINE READS PROPERTIES OF A SOIL PROFILE, ASSIGNS VALUES TO
C   EACH LAYER, CALCULATES TOTAL PRESSURE AND DEPTH IN MIDDLE OF
C   EACH LAYER AND PRINTS THE RESULTS
C
C        IDNT     = IDENTIFIER FOR SOIL PROFILE
C        BL       = RATIO OF CRITICAL DAMPING
C        GL       = SHEAR MODULUS
C        FACT     = FACTOR FOR CALCULATING SHEAR MODULUS FROM STRAIN
C        H        = LAYER THICKNESS
C        R        = DENSITY
C        WL       = UNIT WEIGHT
C        TP       = SOIL TYPE
C        DEPTH    = DEPTH TO MIDDLE OF LAYER
C        WEIGTH   = TOTAL PRESSURE
C        ML       = NUMBER OF LAYERS INCLUDING HALFSPACE
C        N1       = NUMBER OF SUBLAYERS EXCLUDING HALFSPACE
C        NLN      = NUMBER OF SUBLAYERS IN EACH LAYER
C        W        = UNIT WEIGHT
C        VS       = SHEAR WAVE VELOCITY
C        BFAC     = FACTOR ON DAMPING
C        FACTOR   = FACTOR ON SHEAR MODULUS
C        HL       = THICKNESS OF LAYER
C        H        = THICKNESS OF SUBLAYER
C        GMOD     = SHEAR MODULUS
C        B        = CRITICAL DAMPING RATIO
C
C    CODED BY PER B SCHNABEL OCT. 1970
C    MODIFIED APRIL 1972
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
C
      INTEGER TP, TYPE
      CHARACTER*6 IDNT
      DIMENSION SMEAN(51)
C
      COMMON /SOILA/ IDNT(6),BL(51),GL(51),FACT(51),H(51),R(51),BF(51)
      COMMON /SOILB/ FAC(51), WL(51), TP(51), DEPTH(51), WEIGHT(51)
      COMMON /SOILC/ MSOIL,MWL
      COMMON /SOILD/ GLMAX(51)
      COMMON /WGK/  WW, GT, SKO
C
      READ(5,1003) MSOIL, ML, MWL, (IDNT(I),I=1,6)
      WRITE(6,2020) MSOIL, (IDNT(I),I=1,6)
C
C READ SOIL PROPERTIES FOR EACH LAYER AND ASSIGN VALUES TO EACH SUBLAYER
C
      J = 0
      DO 14 N =1, ML
      READ(5,1004) K, TYPE, NLN,   HL, GMOD, B , W, VS
      FACTOR = 1.
       BFAC = 1.
      IF (NLN.EQ. 0) NLN = 1
      IF (K .EQ. N) GO TO 141
      WRITE(6,2004) N
      STOP
C
C    COMPUTE MODULUS FROM SHEAR WAVE VELOCITY
C
  141 IF (GMOD .EQ. 0.) GMOD = VS*VS*W/GT
      DO 14 I = 1,NLN
      J = J+1
      BL(J) = B
      GL(J) = GMOD
      GLMAX(J) = GMOD
      FAC(J) = 1.
      FACT(J) =  1.
      BF(J) = 1.
      WL(J) = W
```

```
      H(J) = HL/NLN
      TP(J) = TYPE
   14 R(J) = W/GT
      N1 = J -1
C
C   CALCULATE AVERAGE DEPTH AND TOTAL PRESSURE IN EACH LAYER
C
      W1 = WL(1)
      IF (MWL .EQ. 1) W1 = WL(1) - WW
      DEPTH(1) = H(1)/2.
      WEIGHT(1) = H(1)*W1/2.
      SMEAN(1) = WEIGHT(1)*(1.+2.*SKO)/3.
      IF  (N1 .EQ. 1)  GO TO 151
      DO 15 I = 2,N1
      W2 = WL(I)
      IF (MWL .LT. I+1) W2 = WL(I) - WW
      DEPTH(I) = DEPTH(I-1) + H(I)/2. + H(I-1)/2.
      WEIGHT(I) = WEIGHT(I-1) + H(I)*W2/2. + H(I-1)*W1/2.
      SMEAN(I) = WEIGHT(I)*(1.+2.*SKO)/3.
   15 W1 = W2
  151 TD = DEPTH(N1) + H(N1)/2.
      IF (MWL .LT. N1+1)  WD = DEPTH(MWL)- H(MWL)/2.
      IF (MWL .EQ. N1+1)  WD = DEPTH(MWL-1) + H(MWL-1)/2.
C
C   CALCULATE FACTOR FOR SHEAR MODULUS
      DO 16 I = 1,N1
      IF (TP(I) .EQ. 0) GO TO 16
      IF (BF(I).LT..01) BF(I) = 2.53 - .45*ALOG10(WEIGHT(I)*1000.)
      NTP = TP(I)
C ----------------------------------------------------------------------
C  A total of 13 G/Gmax material types can be used
c-----------------------------------------------------------------------
      FAC(I) = FACT(I)
      FACT(I) = GL(I) * 1000. * FACT(I)
c-----------------------------------------------------------------------
   16 CONTINUE
  131 WRITE(6,2021) ML,TD
      WRITE(6,2015)
      DO 17 I = 1,N1
      VS = SQRT( GL(I)/R(I))
      WRITE(6,2005) I, TP(I), H(I),DEPTH(I)
     1,WEIGHT(I),GL(I),BL(I),WL(I),VS
   17 CONTINUE
      I = N1 + 1
      VS = SQRT(GL(I)/R(I))
      WRITE(6,2105) I, GL(I), BL(I), WL(I), VS
      CALL CXSOIL(N1)
 1003 FORMAT(3I5, 6A6)
 1004 FORMAT(3I5, 6F10.0,F5.0)
 2004 FORMAT(17H    SOIL CARD NO. I4,17H OUT OF SEQUENCE )
 2020 FORMAT(22H NEW SOIL PROFILE NO. I3,5X,17H IDENTIFICATION  6A6)
 2021 FORMAT(17H NUMBER OF LAYERS ,I20,10X,16HDEPTH TO BEDROCK,F14.2/)
 2015 FORMAT(  '  NO. TYPE  THICKNESS   DEPTH  ',
    1    'Tot. PRESS.  MODULUS  DAMPING   UNIT WT.  SHEAR VEL' /
    3    '                (ft)       (ft)       (ksf)         (ksf)',
    4    '                (kcf)      (fps)')
 2005 FORMAT(I4,I5,F10.2,F10.2,F10.2,F12.0,F8.3,F9.3,F10.1)
 2105 FORMAT(    I4, 3X, 4HBASE  25X, F15.0, F8.3, F9.3, F10.1)
      RETURN
      END
$NOFLOATCALLS
```

```
$NODEBUG
C*******************************************************
      SUBROUTINE CG
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *   * * *
C
C   THE SUBROUTINE READ POINTS ON A CURVE AND GENERATES NEW POINTS
C   BETWEEN THE GIVEN POINTS IN ARITHMETIC OR HALFLOGARITMIC SCALE
C   NECESSARY SUBROUTINES    CURVEG(),
C
C        NST     = NUMBER OF SOILTYPES
C        ABSIS   = TITLE ON ORDINATE FOR PLOTTING
C        NN      = NUMBER OF VALUES IN EACH 10 FOR SEMILOGPLOT
C        SC      = SCALE FOR PLOTTING
C        NC      = NUMBER OF CURVES
C        NV      = NUMBER OF VALUES WHERE STRAIN/PROPERTY-RELATION
C                  IS GIVEN
C        FPL     = MULTIPLICATION FACTOR FOR PLOTTING
C        ID      = IDENTIFICATION
C        X       = STRAIN VALUES
C        Y       = PROPERTY VALUES
C
C   CODED BY PER B SCHNABEL SEPT 1970
C
C * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *   * * *
C
      CHARACTER*6 ID
      CHARACTER*60 ABSIS
C
C     DIMENSION Y(27,20), TSTEP(27),NT(27),FPL(27),V(27,200),T(200)
      INTEGER ECHO(13)
      COMMON /JOE1/ Y(27,20), TSTEP(27),NT(27),FPL(27),V(27,200),T(200)
      COMMON /SOILDG/ S(27,20),AS(27,20),BS(27,20), NV(27)
      COMMON /CCG/ ID(27,11)
C
      ABSIS = ' STRAIN IN PERCENT '
C
      READ(5,*) NST
      NC = 2*NST
      DO 1 L = 1,NC
      READ(5,2001) NV(L), (ID(L,I), I=1,11)
      M = NV(L)
      READ(5,1002) (S(L,I), I = 1,M)
      READ(5,1002) (Y(L,I), I = 1,M)
    1 CONTINUE
C--------------------------------------------
C     ECHO INPUT DYNAMIC PROPERTY CURVES
C--------------------------------------------
      READ (5, 1007) NECHO,(ECHO(I), I=1,NECHO)
C      DO 10, I=1, NC, 2
      DO 10, K=1,NECHO
C      MTYPE=(I+1)/2
      MTYPE=ECHO(K)
      I=ECHO(K)*2-1
      WRITE(6,1003) MTYPE
      WRITE(6,1004) I, (ID(I,J), J=1,10), I+1, (ID(I+1,J),J=1,10)
      WRITE(6,1005) I,I+1
      M=MAX0(NV(I),NV(I+1))
   10 WRITE(6,1006) (S(I,J),Y(I,J),S(I+1,J),Y(I+1,J), J=1,M)
      CALL CURVEG( NC, NV,  2, AS, BS, 10, TSTEP, NT, T, V, S, Y, NSTEP)
C-------------------------
 1000 FORMAT(3I5,F10.0)
```

```
1001 FORMAT(/I5,F10.2, 11A6)
1002 FORMAT(8F10.3)
1003 FORMAT (/' **********************'/
    +       '  MATERIAL TYPE NO.',I2,/
    +       ' **********************')
1004 FORMAT(/2(1X,'CURVE NO. ',I2,': ', 10a6/)/)
1005 FORMAT(  '      CURVE NO.',I2,'             CURVE NO.',I2,'    '/
    1         '  ===================       ==================='/
    2         '    STRAIN    G/Gmax         STRAIN    DAMPING'/
    3         '  --------   -------        --------  --------')
1006 FORMAT(1X,F9.4,4X,F6.3,5X,1X,F9.4,4X,F6.2,5X)
1007 FORMAT(16I5)
2001 FORMAT(I5, 11A6)
2002 FORMAT( 12F10.4)
3000 FORMAT(53H  MODULUS AND DAMPING VALUES ARE SCALED FOR PLOTTING   )
3001 FORMAT(55H    CURVES FOR RELATION STRAIN VERSUS SHEAR MODULUS AND
    1 8H DAMPING /)
     RETURN
     END
```

APPENDIX B

SAMPLE PROBLEM

SHAKE91

A Computer Program for Conducting Equivalent Linear Seismic Response Analyses of Horizontally Layered Soil Deposits

Program Modified based on the Original ***SHAKE*** program published in December 1972 by Schnabel, Lysmer & Seed

Modifications by

I. M Idriss and Joseph I. Sun

November 1992

APPENDIX B

SAMPLE PROBLEM

A 150-ft soil profile consisting of clay and sand overlying a half-space was used for this sample problem. The response was calculated using as object (or input) motion the earthquake time history which had been recorded at Diamond Heights (EW component) during the 1989 Loma Prieta earthquake. This motion was normalized to a peak acceleration of 0.1g.

The soil types considered for this profile and the maximum shear wave velocities used for this sample problem are shown in Fig. B-1. The modulus reduction and the damping values as functions of strain are presented in Fig. B-2.

The input data for this sample problem are listed in Table B-1. The time history of the object motion, normalized to a peak acceleration of 0.1 g, and its response spectrum are shown in Fig. B-3.

Selected results for this sample problem are presented in Table B-2 and in Figs. B-4 through B-8. Table B-2 includes the properties used, the strain-compatible damping and modulus values obtained for each sublayer, the maximum strains, maximum shear stresses and maximum accelerations calculated throughout the soil profile.

The calculated maximum shear strains and the strain-compatible damping and shear wave velocities obtained for this soil profile are shown in Fig. B-4. The calculated maximum accelerations and the maximum shear stresses are plotted in Fig. B-5. Figure B-6 shows the acceleration time history and spectral ordinates for the motion computed at the ground surface.

The amplification ratios (for frequencies up to 25 Hz) for the motions calculated at the ground surface divided by those at the base of the soil profile and by those at the rock outcrop are presented in Fig. B-7.

Time histories of shear strains and stresses calculated at depths of 20 and 60 ft are presented in Fig. B-8.

Table B-1

Input Data for Sample Problem Using Diamond Heights Record as Input Motion

```
option 1 - dynamic soil properties - (max is thirteen):
    1
    3
   11      #1 modulus for clay (seed & sun 1989) upper range
0.0001     0.0003     0.001      0.003      0.01       0.03       0.1        0.3
1.         3.         10.
1.000      1.000      1.000      0.981      0.941      0.847      0.656      0.438
0.238      0.144      0.110
   11        damping for clay (Idriss 1990) -
0.0001     0.0003     0.001      0.003      0.01       0.03       0.1        0.3
1.         3.16       10.
0.24       0.42       0.8        1.4        2.8         5.1        9.8       15.5
21.        25.        28.
   11      #2 modulus for sand (seed & idriss 1970) - upper Range
0.0001     0.0003     0.001      0.003      0.01       0.03       0.1        0.3
1.         3.         10.
1.000      1.000      0.990      0.960      0.850      0.640      0.370      0.180
0.080      0.050      0.035
   11        damping for sand (Idriss 1990) - (about LRng from SI 1970)
0.0001     0.0003     0.001      0.003      0.01       0.03       0.1        0.3
1.         3.         10.
0.24       0.42       0.8        1.4        2.8         5.1        9.8       15.5
21.        25.        28.
    8       #3 ATTENUATION OF  ROCK  AVERAGE
 .0001      0.0003     0.001       0.003      0.01       0.03        0.1       1.0
 1.000      1.000      0.9875     0.9525     0.900      0.810      0.725     0.550
    5       DAMPING IN ROCK
 .0001      0.001      0.01        0.1        1.
  0.4       0.8        1.5         3.0        4.6
    3    1    2    3
Option 2 -- Soil Profile
    2
    1   17       Example -- 150-ft layer; input:Diam @ .1g
    1    2           5.00                    .050       .125      1000.
    2    2           5.00                    .050       .125       900.
    3    2          10.00                    .050       .125       900.
    4    2          10.00                    .050       .125       950.
    5    1          10.00                    .050       .125      1000.
    6    1          10.00                    .050       .125      1000.
    7    1          10.00                    .050       .125      1100.
    8    1          10.00                    .050       .125      1100.
    9    2          10.00                    .050       .130      1300.
   10    2          10.00                    .050       .130      1300.
   11    2          10.00                    .050       .130      1400.
   12    2          10.00                    .050       .130      1400.
   13    2          10.00                    .050       .130      1500.
   14    2          10.00                    .050       .130      1500.
   15    2          10.00                    .050       .130      1600.
   16    2          10.00                    .050       .130      1800.
   17    3                                   .010       .140      4000.
Option 3 -- input motion:
    3
```

Table B-1

Input Data for Sample Problem Using Diamond Heights Record as Input Motion

```
 1900 4096    .02     diam.acc                          (8f10.6)
          .   .10      25.          3    8
Option 4 -- sublayer for input motion {within (1) or outcropping (0):
    4
   17    0
Option 5 -- number of iterations & ratio of avg strain to max strain
    5
    0    8    0.50
Option 6 -- sublayers for which accn time histories are computed & saved:
    6
    1    2    3    4    5    6    7    8    9   10   11   12   13   14   15
    0    1    1    1    1    1    1    1    1    1    1    1    1    1    1
    1    0    0    0    0    0    0    0    0    0    0    0    0    0    0
Option 6 -- sublayers for which accn time histories are computed & saved:
    6
   16   17   17
    1    1    0
    0    1    0
option 7 -- sublayer for which shear stress or strain are computed & saved:
    7
    4    1    1    0 1800           -- stress in level 4
    4    0    1    0 1800           -- strain in level 4
option 7 -- sublayer for which shear stress or strain are computed & saved:
    7
    8    1    1    0 1800           -- stress in level 8
    8    0    1    0 1800           -- strain in level 8
option 9 -- compute & save response spectrum:
    9
    1    0
    1    0     981.0
   0.05
option 10 -- compute & save amplification spectrum:
   10
   17    0    1    0       0.125      - surface/rock outcrop
execution will stop when program encounters 0
    0
```

Table B-2
Selected Results for Sample Problem Using Diamond Heights as Input Motion

```
1******   OPTION  1  ***  READ RELATION BETWEEN SOIL PROPERTIES AND STRAIN

 **********************
  MATERIAL TYPE NO. 1
 **********************

 CURVE NO.  1:      #1 modulus for clay (seed & sun 1989) upper range
 CURVE NO.  2:        damping for clay (Idriss 1990) -


      CURVE NO. 1               CURVE NO. 2
  ===================       ==================
    STRAIN    G/Gmax          STRAIN   DAMPING
  --------  -------         --------  --------
     .0001     1.000           .0001       .24
     .0003     1.000           .0003       .42
     .0010     1.000           .0010       .80
     .0030      .981           .0030      1.40
     .0100      .941           .0100      2.80
     .0300      .847           .0300      5.10
     .1000      .656           .1000      9.80
     .3000      .438           .3000     15.50
    1.0000      .238          1.0000     21.00
    3.0000      .144          3.1600     25.00
   10.0000      .110         10.0000     28.00

 **********************
  MATERIAL TYPE NO. 2
 **********************

 CURVE NO.  3:      #2 modulus for sand (seed & idriss 1970) - upper Range
 CURVE NO.  4:        damping for sand (Idriss 1990) - (about LRng from SI
```

Table B-2
Selected Results for Sample Problem Using Diamond Heights as Input Motion

CURVE NO. 3		CURVE NO. 4	
STRAIN	G/Gmax	STRAIN	DAMPING
.0001	1.000	.0001	.24
.0003	1.000	.0003	.42
.0010	.990	.0010	.80
.0030	.960	.0030	1.40
.0100	.850	.0100	2.80
.0300	.640	.0300	5.10
.1000	.370	.1000	9.80
.3000	.180	.3000	15.50
1.0000	.080	1.0000	21.00
3.0000	.050	3.0000	25.00
10.0000	.035	10.0000	28.00

```
**********************
MATERIAL TYPE NO. 5
**********************

CURVE NO.  9:       #5 ATTENUATION OF  ROCK  AVERAGE
CURVE NO. 10:       DAMPING IN ROCK
```

CURVE NO. 9		CURVE NO.10	
STRAIN	G/Gmax	STRAIN	DAMPING
.0001	1.000	.0001	.40
.0003	1.000	.0010	.80
.0010	.988	.0100	1.50
.0030	.952	.1000	3.00
.0100	.900	1.0000	4.60
.0300	.810	.0000	.00
.1000	.725	.0000	.00
1.0000	.550	.0000	.00

Table B-2
Selected Results for Sample Problem Using Diamond Heights as Input Motion

```
1******   OPTION  2  ***  READ SOIL PROFILE
 NEW SOIL PROFILE NO.   1      IDENTIFICATION   Example -- 150-ft layer; input:Diam
 NUMBER OF LAYERS                   17          DEPTH TO BEDROCK        150.00

  NO. TYPE  THICKNESS    DEPTH  Tot. PRESS.  MODULUS  DAMPING   UNIT WT.  SHEAR VEL
              (ft)        (ft)     (ksf)      (ksf)             (kcf)     (fps)
   1    2     5.00        2.50       .31      3882.     .050     .125    1000.0
   2    2     5.00        7.50       .78      3144.     .050     .125     900.0
   3    2    10.00       15.00      1.25      3144.     .050     .125     900.0
   4    2    10.00       25.00      1.88      3503.     .050     .125     950.0
   5    1    10.00       35.00      2.50      3882.     .050     .125    1000.0
   6    1    10.00       45.00      3.13      3882.     .050     .125    1000.0
   7    1    10.00       55.00      3.75      4697.     .050     .125    1100.0
   8    1    10.00       65.00      4.38      4697.     .050     .125    1100.0
   9    2    10.00       75.00      5.03      6823.     .050     .130    1300.0
  10    2    10.00       85.00      5.71      6823.     .050     .130    1300.0
  11    2    10.00       95.00      6.38      7913.     .050     .130    1400.0
  12    2    10.00      105.00      7.06      7913.     .050     .130    1400.0
  13    2    10.00      115.00      7.74      9084.     .050     .130    1500.0
  14    2    10.00      125.00      8.41      9084.     .050     .130    1500.0
  15    2    10.00      135.00      9.09     10335.     .050     .130    1600.0
  16    2    10.00      145.00      9.76     13081.     .050     .130    1800.0
  17   BASE                                  69565.     .010     .140    4000.0

  PERIOD =  .48 FROM AVERAGE SHEAR VELOCITY =   1253.


  FREQUENCY    AMPLITUDE
 MAXIMUM AMPLIFICATION =  13.80
 FOR FREQUENCY         =   2.32 C/SEC.
     PERIOD            =    .43 SEC.
```

Table B-2
Selected Results for Sample Problem Using Diamond Heights as Input Motion

```
1******   OPTION  3  ***  READ INPUT MOTION

  FILE NAME FOR INPUT MOTION =  diam.acc
    NO. OF INPUT ACC. POINTS =  1900
   NO. OF POINTS USED IN FFT =  4096
        NO. OF HEADING LINES =     3
      NO. OF POINTS PER LINE =     8
  TIME STEP FOR INPUT MOTION =  .0200
  FORMAT FOR OF TIME HISTORY = (8f10.6)

 ***** H E A D E R
"Loma P. Eqk","Diamond Hts","H1_90","init. vel:"," .307 c/s","disp: -0.016 cm"
"Total No. of Points :",2000,"@ DT =",.02
"Peak Acceleration (g) =",.1128945,"@ Time (sec) :",10.92
 **  FIRST & LAST 5 LINES OF INPUT MOTION *****
     1  -.001694 -.001668 -.000086 -.001356 -.000678  .000700 -.001209 -.000604
     2   .000730  .000737  .002496  .004583  .001644  .001377  .002408 -.000352
     3  -.001073 -.000359 -.000486  .000344  .000767 -.002507 -.003164 -.002890
     4  -.004086  .000143  .004340  .003943  .002350 -.001087 -.002345  .001716
     5  -.001943 -.007436 -.004493  .000827  .002915  .003241  .003055  .002658
   ........ INPUT MOTION READ NOT ECHOED..........
   234  -.000885 -.000806 -.001026 -.000795 -.001049 -.000340 -.000016 -.000647
   235  -.000515  .000588 -.000315 -.000794 -.001081 -.000293  .001415  .001959
   236   .000800 -.000751  .000743  .000708  .000867 -.000101 -.000805 -.001058
   237  -.001011 -.001037 -.001032 -.000992  .001206  .001623  .001755  .000918
   238  -.000949 -.000830 -.001072 -.000940  .000000  .000000  .000000  .000000
 MAXIMUM ACCELERATION =    .11289
 AT TIME              = 10.92 SEC
 THE VALUES WILL BE MULTIPLIED BY A FACTOR =    .886
 TO GIVE NEW MAXIMUM ACCELERATION          =    .10000
 MEAN SQUARE FREQUENCY =        2.52 C/SEC.
  MAX ACCELERATION =     .09997 FOR FREQUENCIES REMOVED ABOVE      25.00 C/SEC.
1******   OPTION  4  ***  READ WHERE OBJECT MOTION IS GIVEN
   OBJECT MOTION IN LAYER NUMBER  17 OUTCROPPING
```

Table B-2
Selected Results for Sample Problem Using Diamond Heights as Input Motion

```
1******   OPTION  5  ***  OBTAIN STRAIN COMPATIBLE SOIL PROPERTIES
  MAXIMUM NUMBER OF ITERATIONS                  =     8
  FACTOR FOR UNIFORM STRAIN IN TIME DOMAIN      =    .50

     EARTHQUAKE    -  diam.acc
     SOIL PROFILE -  Example -- 150-ft layer; input:Diam

  ITERATION NUMBER  8

  VALUES IN TIME DOMAIN
```

NO	TYPE	DEPTH (FT)	UNIFRM. STRAIN	DAMPING NEW	DAMPING USED	DAMPING ERROR	SHEAR MODULUS NEW	SHEAR MODULUS USED	SHEAR MODULUS ERROR	G/Go RATIO
1	2	2.5	.00077	.007	.007	.0	3851.5	3851.5	.0	.992
2	2	7.5	.00295	.014	.014	.0	3020.0	3020.0	.0	.960
3	2	15.0	.00634	.023	.023	.0	2803.8	2803.8	.0	.892
4	2	25.0	.00976	.028	.028	.0	2985.8	2985.8	.0	.852
5	1	35.0	.01099	.030	.030	.0	3621.7	3621.7	.0	.933
6	1	45.0	.01403	.035	.035	.0	3540.5	3540.5	.0	.912
7	1	55.0	.01362	.034	.034	.0	4296.0	4296.0	.0	.915
8	1	65.0	.01566	.037	.037	.0	4239.8	4239.8	.0	.903
9	2	75.0	.01356	.034	.034	.0	5402.8	5402.8	.0	.792
10	2	85.0	.01505	.037	.037	.0	5266.1	5266.2	.0	.772
11	2	95.0	.01336	.034	.034	.0	6288.3	6288.4	.0	.795
12	2	105.0	.01413	.035	.035	.0	6203.6	6203.6	.0	.784
13	2	115.0	.01233	.032	.032	.0	7357.0	7357.0	.0	.810
14	2	125.0	.01282	.033	.033	.0	7290.6	7290.6	.0	.803
15	2	135.0	.01115	.030	.030	.0	8570.2	8570.1	.0	.829
16	2	145.0	.00865	.026	.026	.0	11292.4	11292.4	.0	.863

Table B-2
Selected Results for Sample Problem Using Diamond Heights as Input Motion

VALUES IN TIME DOMAIN

LAYER	TYPE	THICKNESS FT	DEPTH FT	MAX STRAIN PRCNT	MAX STRESS PSF	TIME SEC
1	2	5.0	2.5	.00154	59.43	11.30
2	2	5.0	7.5	.00591	178.41	11.30
3	2	10.0	15.0	.01267	355.31	11.30
4	2	10.0	25.0	.01952	582.73	11.30
5	1	10.0	35.0	.02197	795.85	11.30
6	1	10.0	45.0	.02806	993.46	11.30
7	1	10.0	55.0	.02723	1169.83	11.30
8	1	10.0	65.0	.03132	1327.93	11.30
9	2	10.0	75.0	.02711	1464.73	11.30
10	2	10.0	85.0	.03011	1585.43	11.30
11	2	10.0	95.0	.02671	1679.79	11.30
12	2	10.0	105.0	.02825	1752.67	11.30
13	2	10.0	115.0	.02467	1814.84	11.52
14	2	10.0	125.0	.02563	1868.58	11.52
15	2	10.0	135.0	.02230	1911.02	11.52
16	2	10.0	145.0	.01729	1952.92	11.54

PERIOD = .52 FROM AVERAGE SHEAR VELOCITY = 1153.

FREQUENCY AMPLITUDE
MAXIMUM AMPLIFICATION = 20.47
FOR FREQUENCY = 2.11 C/SEC.
PERIOD = .47 SEC.

Table B-2

Selected Results for Sample Problem Using Diamond Heights as Input Motion

```
1******   OPTION  6  ***  COMPUTE MOTION IN NEW SUBLAYERS

   EARTHQUAKE - diam.acc
  SOIL DEPOSIT -  Example -- 150-ft layer; input:Diam
```

LAYER	DEPTH FT	MAX. ACC. G	TIME SEC	MEAN SQ. FR. C/SEC	ACC. RATIO QUIET ZONE	TH SAVED ACC. RECORD
OUTCR.	.0	.19037	11.28	2.42	.000	512
WITHIN	5.0	.19006	11.28	2.40	.000	0
WITHIN	10.0	.18876	11.28	2.35	.000	0
WITHIN	20.0	.18258	11.28	2.23	.000	0
WITHIN	30.0	.17208	11.28	2.19	.000	0
WITHIN	40.0	.15947	11.28	2.19	.000	0
WITHIN	50.0	.14288	11.28	2.17	.000	0
WITHIN	60.0	.12652	11.28	2.13	.000	0
WITHIN	70.0	.11050	11.52	2.12	.000	0
WITHIN	80.0	.09840	11.54	2.14	.000	0
WITHIN	90.0	.08999	11.56	2.19	.001	0
WITHIN	100.0	.08268	11.56	2.24	.001	0
WITHIN	110.0	.08559	10.94	2.32	.000	0
WITHIN	120.0	.08547	10.94	2.39	.001	0
WITHIN	130.0	.08198	10.94	2.45	.001	0

```
1******   OPTION  6  ***  COMPUTE MOTION IN NEW SUBLAYERS

   EARTHQUAKE - diam.acc
  SOIL DEPOSIT -  Example -- 150-ft layer; input:Diam
```

LAYER	DEPTH FT	MAX. ACC. G	TIME SEC	MEAN SQ. FR. C/SEC	ACC. RATIO QUIET ZONE	TH SAVED ACC. RECORD
WITHIN	140.0	.07769	10.92	2.48	.001	0
WITHIN	150.0	.07617	10.92	2.48	.001	512
OUTCR.	150.0	.10000	10.92	2.52	.000	0

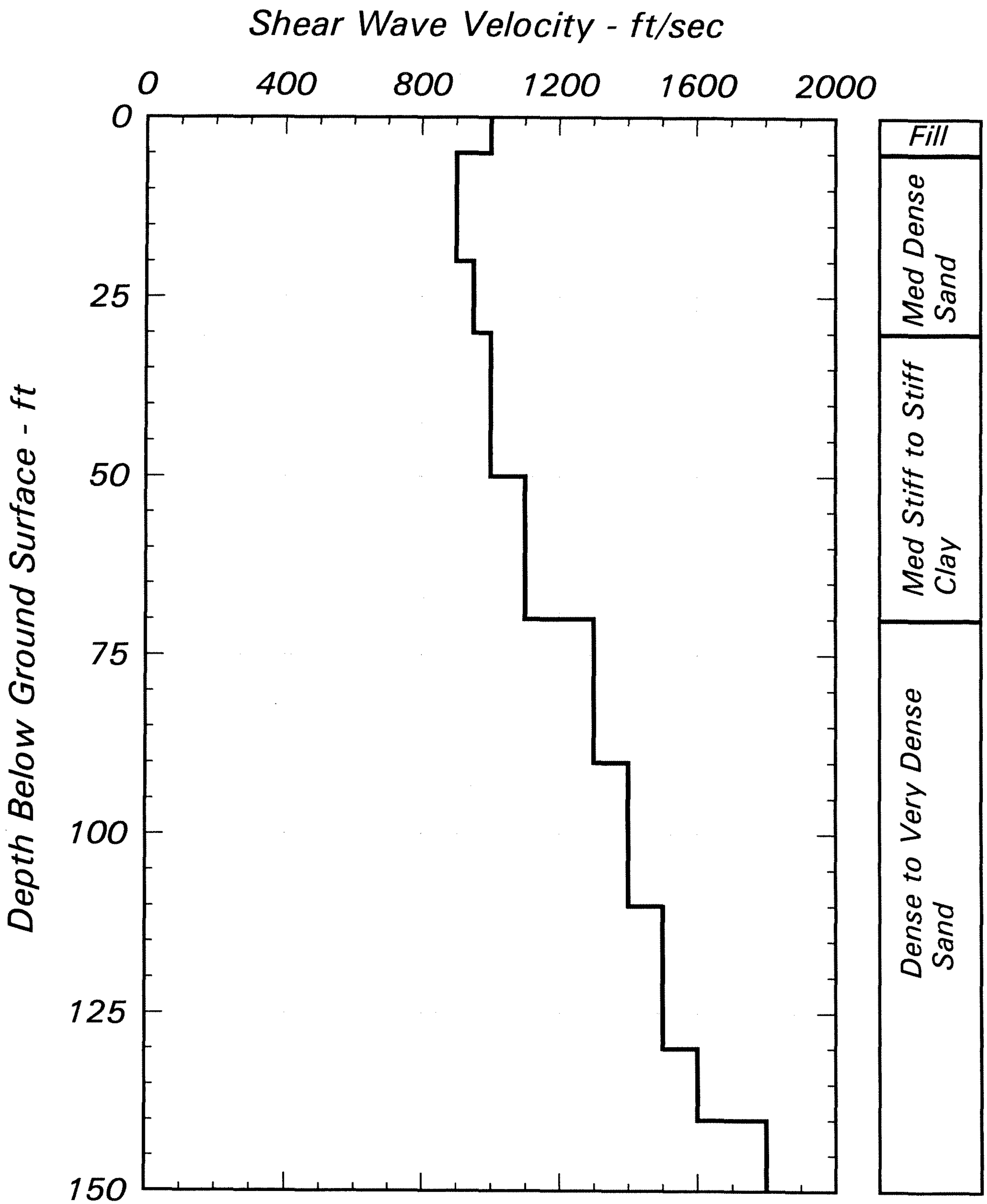


Fig. B-1 Shear Wave Velocities Used for Sample Problem

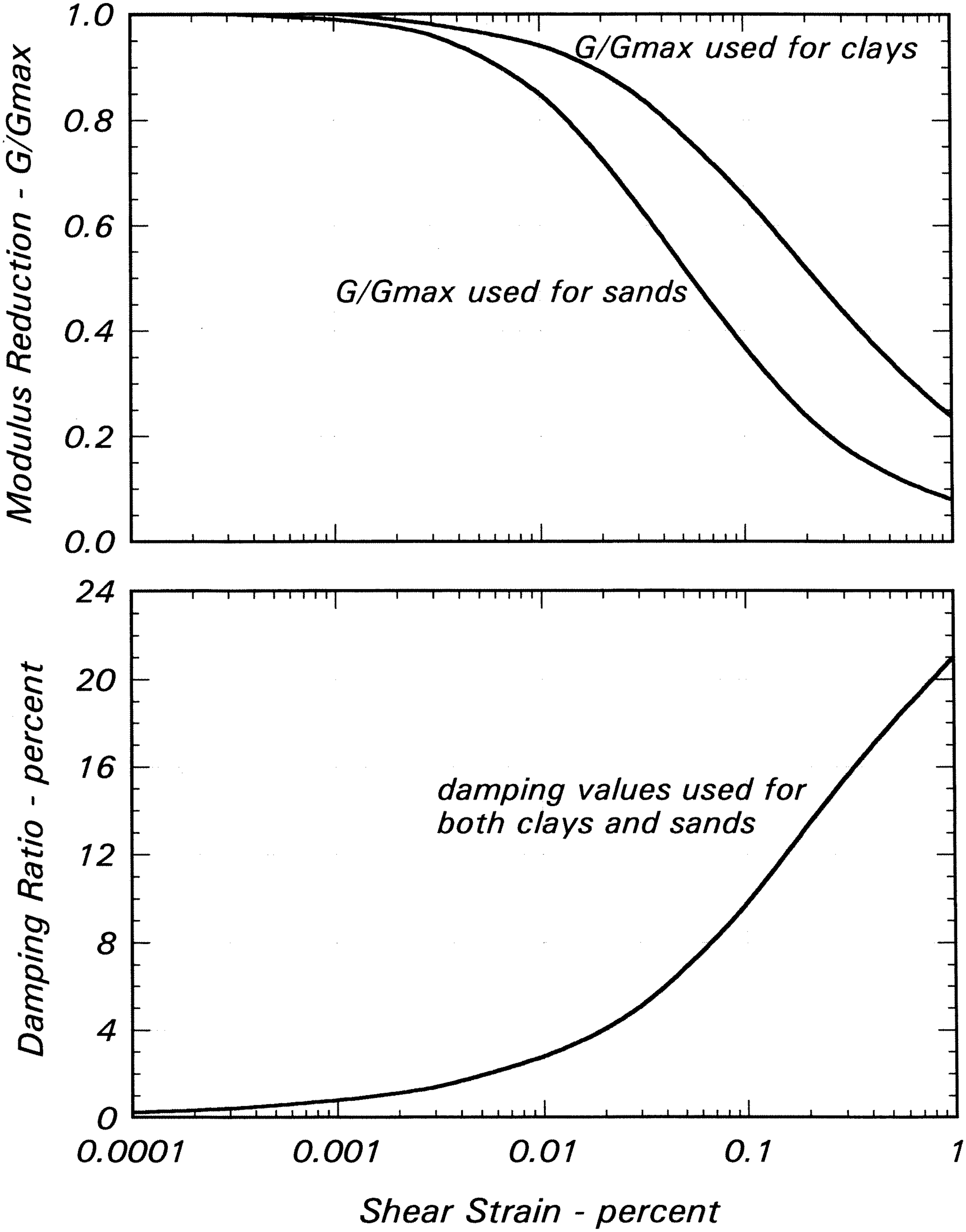
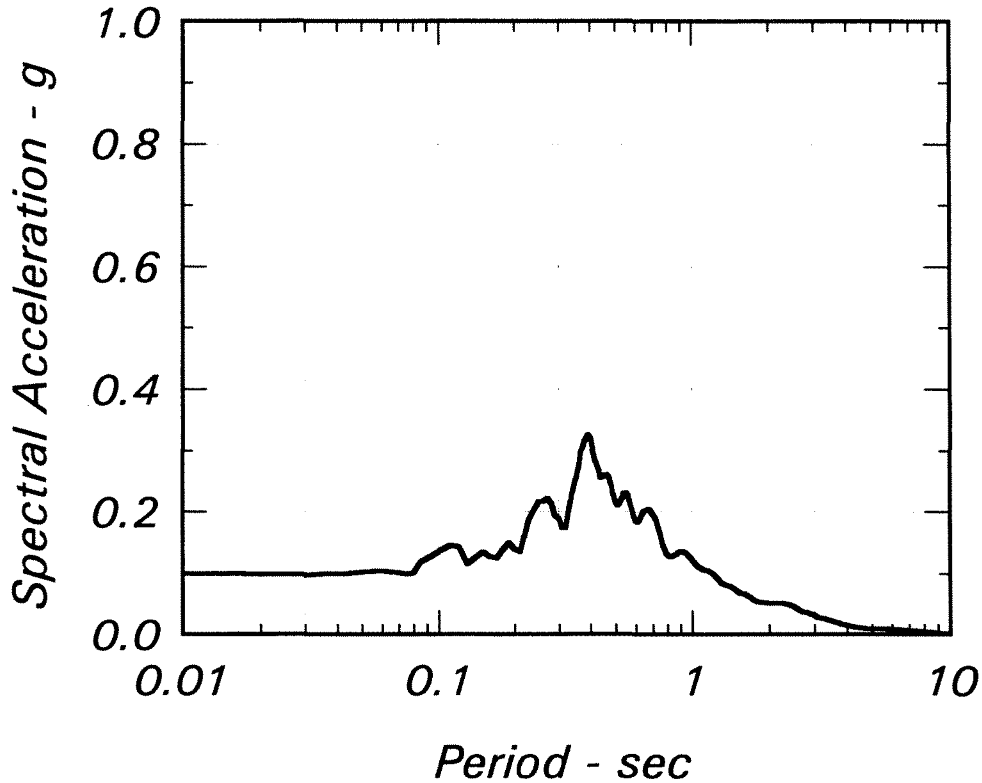


Fig. B-2 Modulus Reduction and Damping Values Used for Sample Problem



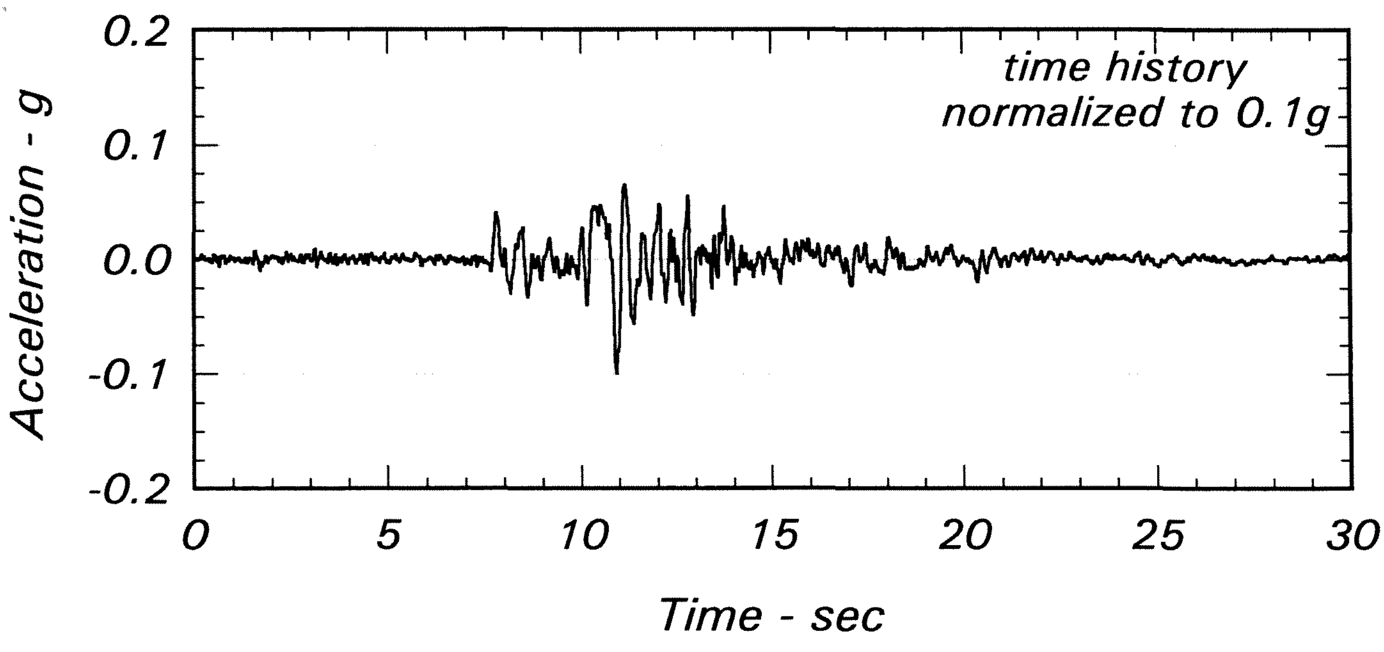


Fig. B-3 Acceleration Time History and Spectral Ordinates for EW Component Recorded at Diamond Heights

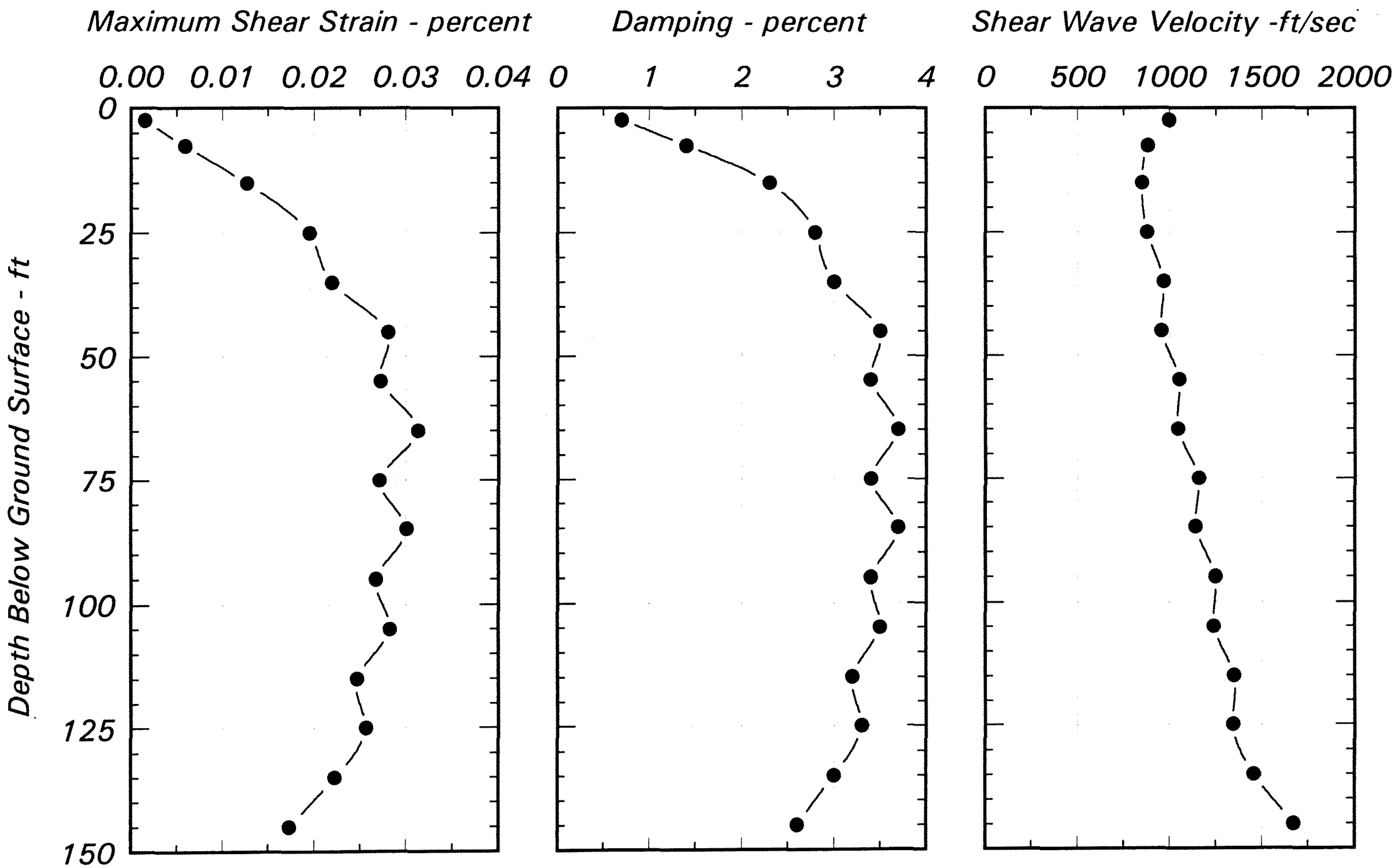


Fig. B-4 Calculated Shear Strains and Strain-Compatible Damping and Shear Wave Velocities for Sample Problem Using Diamond Heights Record as Input Motion

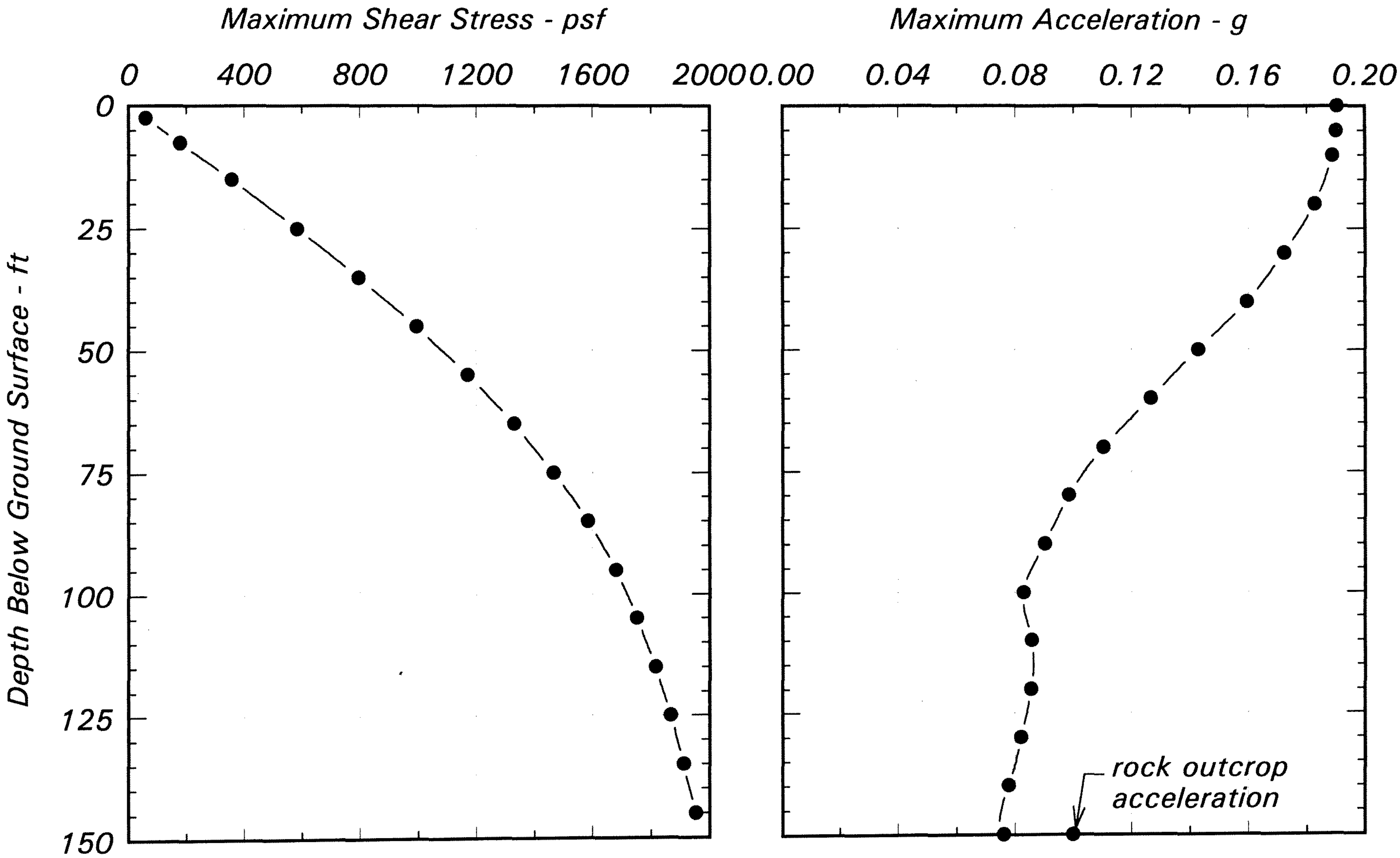
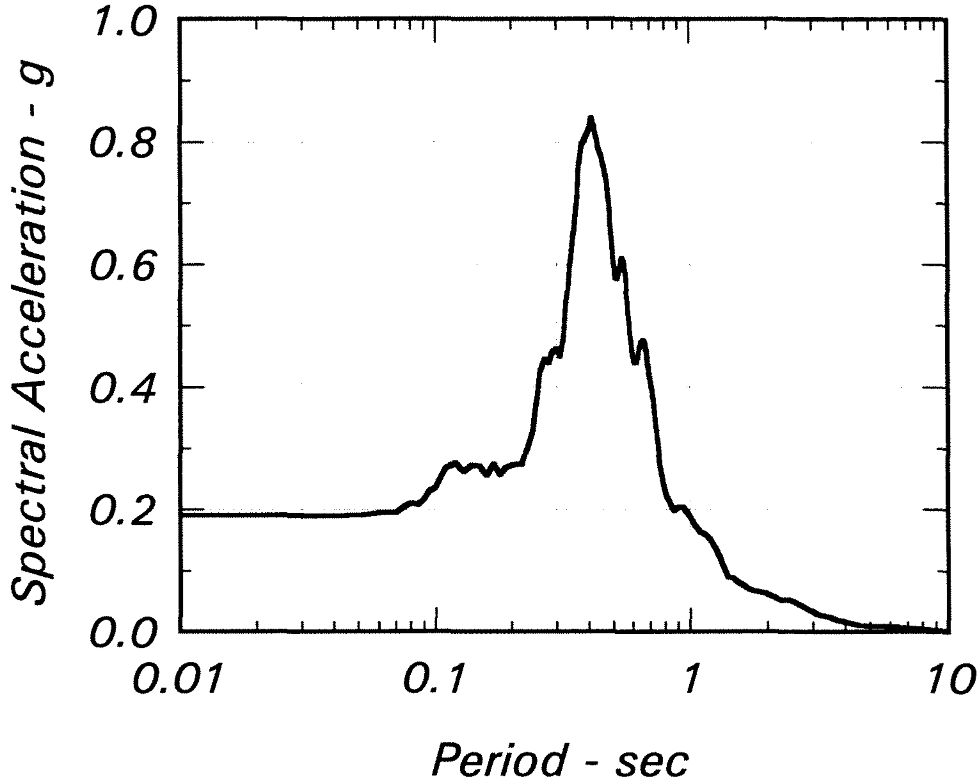


Fig. B-5 Calculated Shear Stresses and Accelerations for Sample Problem Using Diamond Heights Record as Input Motion



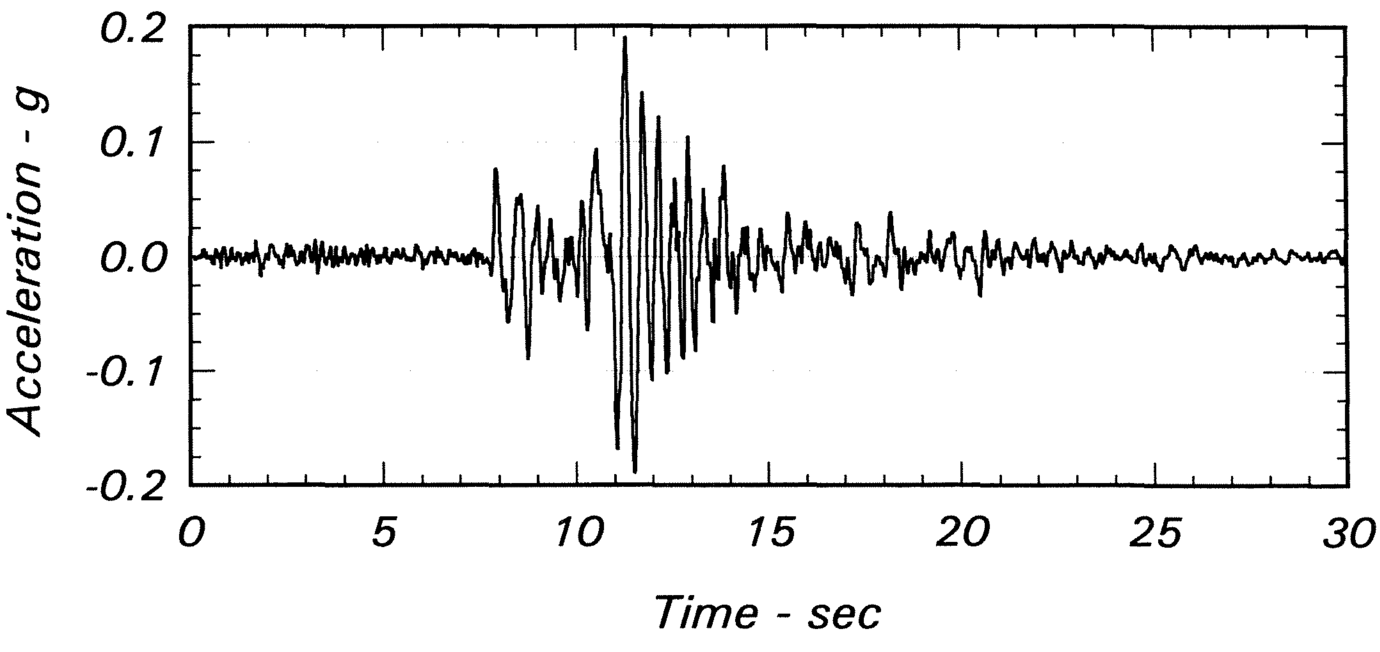


Fig. B-6 Acceleration Time History and Spectral Ordinates for Computed Motion at the Ground Surface Using Diamond Heights Record as Input Motion

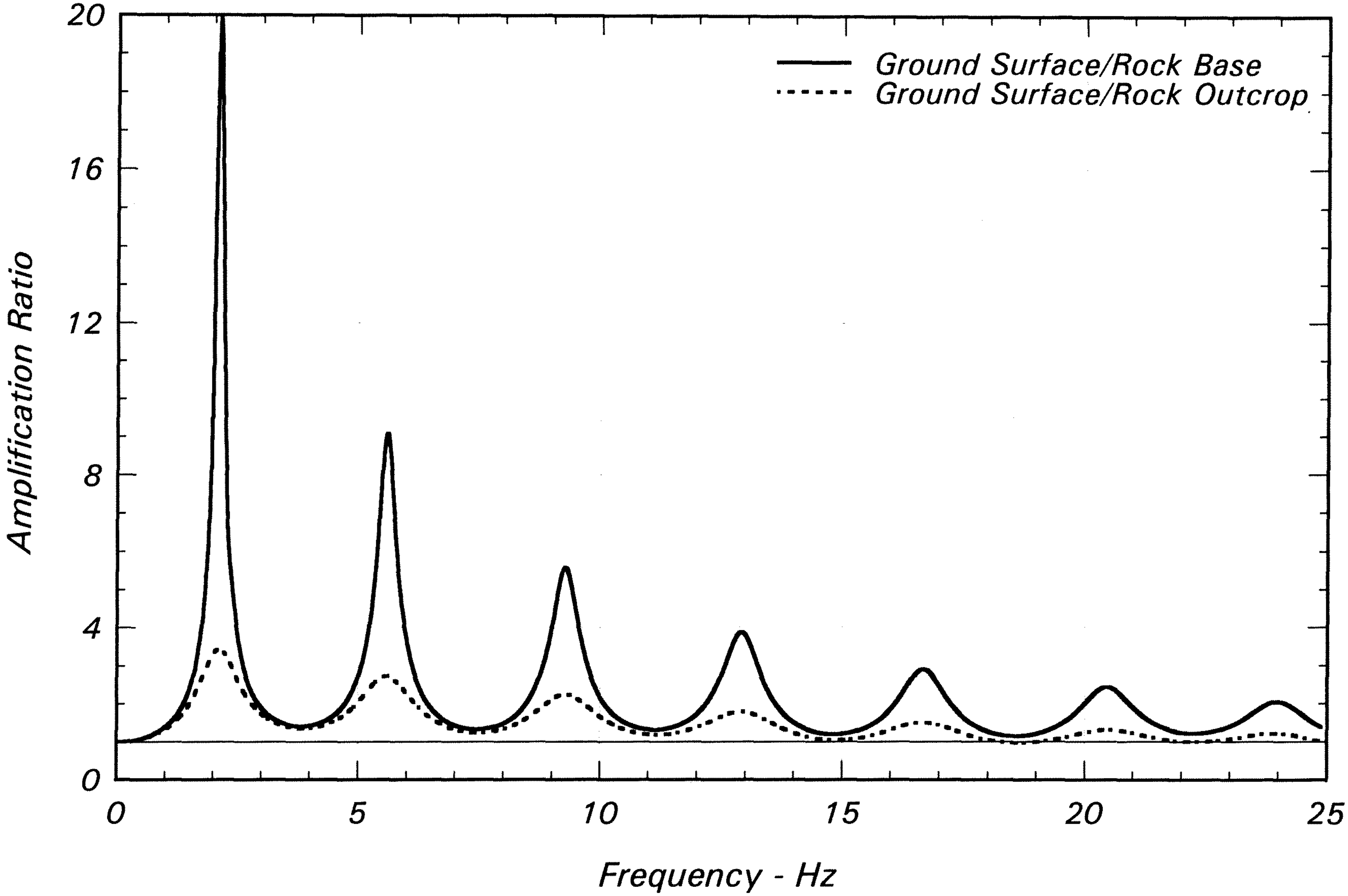


Fig. B-7 Calculated Amplification Spectra for Sample Problem Using Diamond Heights Record as Input Motion

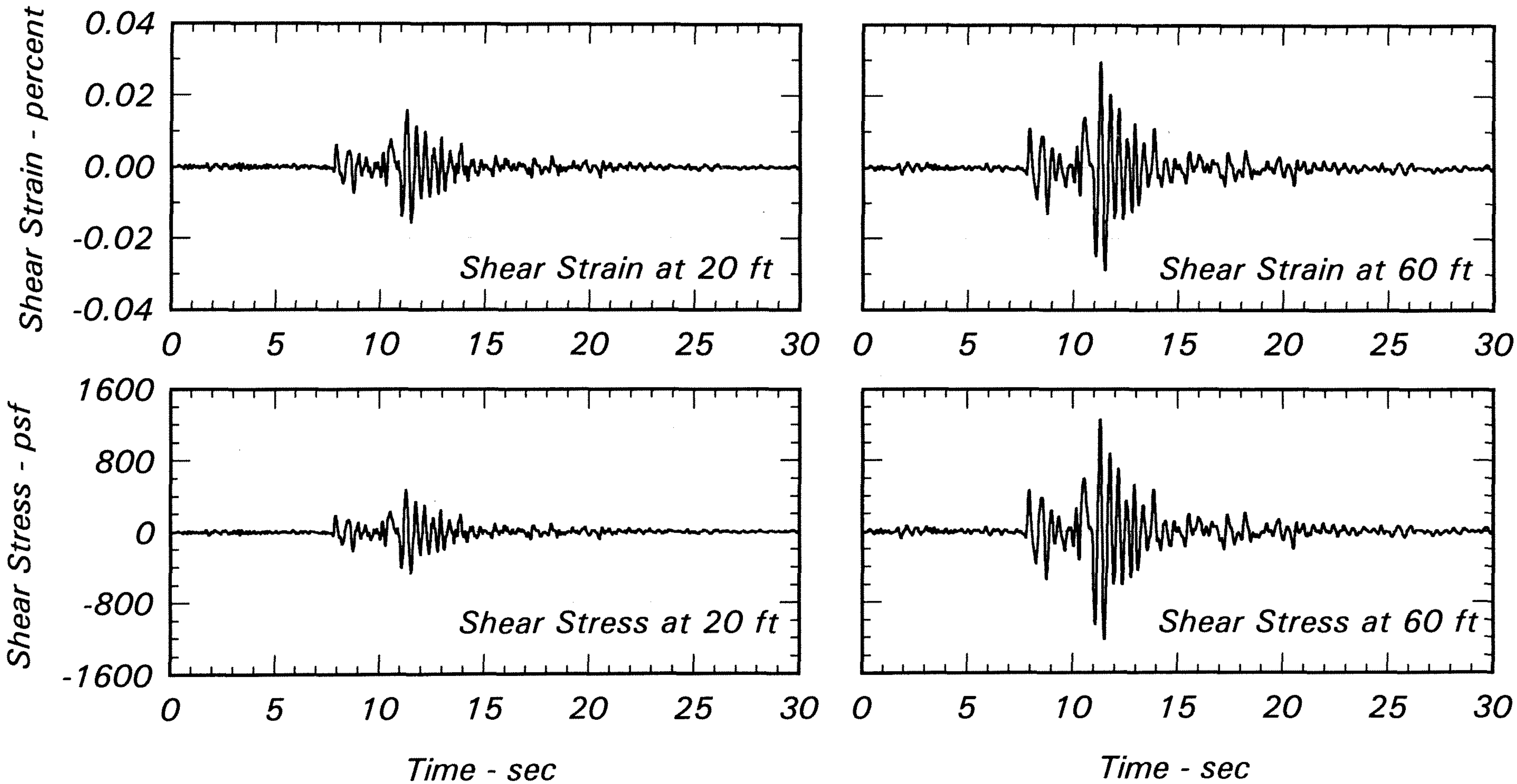


Fig. B-8 Time Histories of Shear Strains and Stresses Calculated at Depths of 20 and 60 ft for Sample Problem Using Diamond Heights Record as Input Motion