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INST OF GEOPHYSICS HONOLULU L N FRAZER ET AL. SEP 85  
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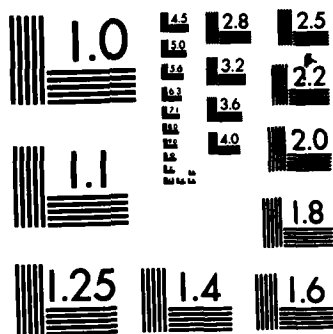
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plotting protocols. A brief outline of the theory and a program listing with examples are included.

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# Generation of Vertically Incident Seismograms

**By L. NEIL FRAZER, DAVID L. BATES, and ALBERT J. RUDMAN**

**DEPARTMENT OF NATURAL RESOURCES  
GEOLOGICAL SURVEY OCCASIONAL PAPER 49**



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# Generation of Vertically Incident Seismograms

*By* L. NEIL FRAZER, DAVID L. BATES, *and* ALBERT J. RUDMAN

GEOPHYSICAL COMPUTER PROGRAM 10

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DEPARTMENT OF NATURAL RESOURCES  
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# Generation of Vertically Incident Seismograms

By L. NEIL FRAZER, DAVID L. BATES, and ALBERT J. RUDMAN

## Abstract

An algorithm for synthetic seismograms following the method of Kennett (1981) has been implemented in FORTRAN 77. Computations proceed in the frequency domain and then are Fourier inverted. Reflections of normally incident waves and their multiples are plotted on a Versatec plotter. The algorithm allows easy adjustment to other plotting protocols. A brief outline of the theory and a program listing with examples are included.

## Introduction

This report concerns the generation of synthetic seismograms for vertically incident waves on a multilayered horizontal medium. Superposition of plane waves allows the simulation of a localized source. Computa-

tions proceed in the frequency domain to permit inclusion of attenuation by a complex velocity. The plane-wave components are related to reflection and transmission within the layers by a standard filter theory approach following the method of Kennett (1981). An expansion of the response into a power series permits the user to choose a complete-response seismogram or to designate the number of multiples to be used. The final seismogram is constructed by Fourier inversion.

The algorithm presented here, Program VISIP, is modified from Kennett for the case of horizontally layered media bounded on top and bottom by half spaces. This code does not include a free surface, and therefore the ringing effect of surface multiples is not included.

## Theory

In wave propagation in the presence of absorption, solution to the wave equation leads to a complex velocity  $V(w)$  that

depends on the  $Q$  of the medium. The absorption model is an exponential decay with distance

$$A = A_0 e^{-az} \quad (1)$$

where  $a$  is related to frequency  $w$  and  $Q$

$$a \approx \frac{|w|}{2cQ} \quad (2)$$

and  $c$  is the phase velocity.

A plane compressional wave normally incident on two semi-infinite layers generates a reflected and transmitted wave. Continuity

of displacement and stress determines the amplitudes of the waves in terms of the reflection and transmission coefficients  $R$  and  $T$

$$R = \frac{P_j v_j - P_{j+1} v_{j+1}}{P_j v_j + P_{j+1} v_{j+1}} \quad T = \frac{2 P_j v_j}{P_j v_j + P_{j+1} v_{j+1}} \quad (3)$$

where  $\rho_j$  is the density of layer  $j$  and  $v_j$  is the compressional velocity.

For  $n$  layers sandwiched between two half

spaces, a matrix representation of the upgoing and downgoing wave fields  $U$  and  $D$  is given by

$$\begin{pmatrix} U_1 \\ D_1 \end{pmatrix} = Q_1 Q_2 \dots Q_n \begin{pmatrix} U_{n+1} \\ D_{n+1} \end{pmatrix} \quad (4)$$

$Q$  is a wave propagator related to a matrix of the total reflection and transmission coefficient

coefficients  $R$  and  $T$  (Kennett, 1981, equation 3.81)

$$Q = \left( \begin{array}{c|c} T_U - R_D T_D^{-1} R_U & R_D T_D^{-1} \\ \hline -T_D R_U & T_D^{-1} \end{array} \right) \quad (5)$$

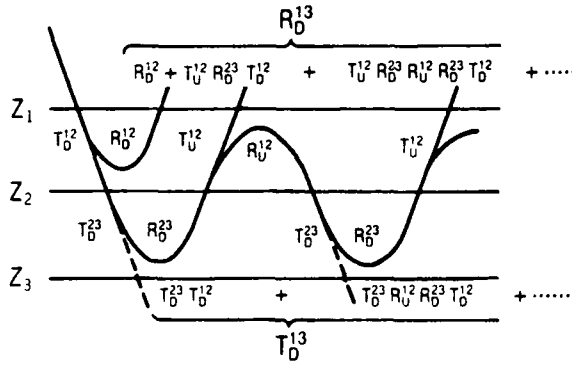


Figure 1. Graphic representation showing the first few terms of equation 9 for reflection and transmission matrices of superposed media and showing schematically the interactions undergone by the waves with the regions  $z_1 < z < z_2$  and  $z_3 < z < z_2$ . From Kennett (1981).

where the subscripts  $U$  and  $D$  refer to computations for upgoing and downgoing waves.

To illustrate the significance of the total reflection and transmission coefficient, first consider two layers sandwiched between half spaces (fig. 1). Then the overall response in terms of reflection and transmission properties is

$$\begin{aligned} R_D^{13} &= \bar{R}_D^{12} + \bar{T}_U^{12} \bar{R}_D^{23} & [I - \bar{R}_U^{12} \bar{R}_D^{23}]^{-1} \bar{T}_D^{12} \\ T_D^{13} &= \bar{T}_D^{23} & [I - \bar{R}_U^{12} \bar{R}_D^{23}]^{-1} \bar{T}_D^{12} \\ R_U^{13} &= \bar{R}_U^{23} + \bar{T}_D^{23} \bar{R}_U^{12} & [I - \bar{R}_D^{23} \bar{R}_U^{12}]^{-1} \bar{T}_U^{23} \\ T_U^{13} &= \bar{T}_U^{12} & [I - \bar{R}_D^{23} \bar{R}_U^{12}]^{-1} \bar{T}_U^{23} \end{aligned}$$

```

COMMON / CHAR / ITIME, IDATE, IOBT, TITLE
WRITE(6, '(1X, "VISP OCEAN CRUST MODELING PROGRAM", 8X,
+      A10, 2X, A10//)') ITIME, IDATE
WRITE(6, '( " EPS = ", F6.4, " SIGMA = ", F5.2, 3X, "Y SIDE=", F5.2,
+ 3X, "TLNTH = ", F5.2, /)') EPS, SIGMA, YSIDE, TLNTH
WRITE(6, '( " LAYER#", 1X, "VELOCITY", 4X, "Q", 5X, "DENSITY", 1X,
+ "THICKNESS", 7X, "DEPTH", /, 9X, "KM/SEC", 2X, "KM/SEC", 3X, "GRM/SEC",
+ 5X, "M", 13X, "M")')
WRITE(6, '( "      1 ", F8.2, F9.1, F8.2)') CL(1), QL(1), RHO(1)
TTOT = 0.0
DO 40 I=2, NL-1
  WRITE(6, '(1X, I4, 1X, F8.2, F9.1, F8.2, 1X, F9.2, F10.2,
+ " TO", 1X, F7.2)') I, CL(I), QL(I), RHO(I), T(I), TTOT, TTOT+T(I)
  TTOT = TTOT+T(I)
40 CONTINUE
WRITE(6, '(1X, I4, 1X, F8.2, F9.1, F8.2, F20.2,
+ " TO INFINITY")') NL, CL(NL), QL(NL), RHO(NL), TTOT
RETURN
END

```

```

C-----
C
C      SUBROUTINE PLTARM1
C
C-----

```

```

SUBROUTINE PLTARM1
COMMON / NUM / CL(200), QL(200), RHO(200), T(200), EPS, SIGMA,
+      CRUST, NL, NTRACE, LOBS, NW, TSEC, TSC, ASC, NMULT,
+      TLAG, YSIDE, TLNTH
COMMON / CHAR / ITIME, IDATE, IOBT, TITLE
COMMON / FILTDT / F1(10), IDB(10), IFILTYP(10), NFILT, MPHASE,
+ FF1(10)
COMMON / AR / IAGC, WINDOW
LOGICAL MPHASE
CHARACTER*80 TITLE
CHARACTER*10 ITIME, IDATE, LINE
CHARACTER*1 IOBT
NFILT = 0
READ(1, '(A2)') WWW
READ(1, *) NTRACE, NW, TSEC, TSC, ASC, NMULT, IAGC,
+ WINDOW
WRITE(6, 101)
101 FORMAT(/, 1X, "NTRACE", 1X, "# FREQS", 1X, "T(MSECS)", 1X, "IN/MSECS",
+ 1X, "AMP-SCL", 1X, "MULTPL", 1X, "AGC", 1X, "WINDOW")
WRITE(6, 102) NTRACE, NW, TSEC, TSC, ASC, NMULT, IAGC, WINDOW
102 FORMAT(3X, I2, 4X, I4, 3X, F6.0, 4X, F4.3, 6X, F4.1, 4X, I2, 3X,
+ I3, 2X, F4.0)
  IF (NTRACE .GT. 10.0) CALL TERMIN(27, 0)
  IF ((NW.NE.16) .AND. (NW.NE.32) .AND. (NW.NE.64) .AND. (NW.NE.128)
+ .AND. (NW.NE.256) .AND. (NW.NE.512)) CALL TERMIN(23, NW)
  IF (TSEC .LT. 1.0) CALL TERMIN(25, NINT(TSEC))
  IF ((TSC.EQ.0.0) .OR. (TSC*TSEC.GT.YSIDE)) THEN
    TSC = YSIDE/TSEC
  
```

```

      IF (NINTLAY+1 .GT. NL) CALL TERMIN(4,MLNR)
      TINTLAY = RHO(I)
      IF (TINTLAY .LT. 0) THEN
        TINTLAY = -TINTLAY-CRUST
        IF (TINTLAY .LT. 0) CALL TERMIN(5,MLNR)
      ENDIF
      CRUST = CRUST+TINTLAY
      INCRCL = (CL(I+NINTLAY)-CL(I-1))/(NINTLAY+1)
      INCRQL = (QL(I+NINTLAY)-QL(I-1))/(NINTLAY+1)
      IF (RHO(I+NINTLAY).EQ. -1) RHO(I+NINTLAY)=(CL(I+NINTLAY)+1.5)/3
      INCRRHO = (RHO(I+NINTLAY)-RHO(I-1))/(NINTLAY+1)
      DO 25 J=1,NINTLAY
        CL(J+I-1) = CL(I-1) + J*INCRCL
        QL(J+I-1) = QL(I-1) + J*INCRQL
        RHO(J+I-1) = RHO(I-1) + J*INCRHO
        T(J+I-1) = TINTLAY/NINTLAY
25    CONTINUE
      I = I+NINTLAY
    ELSE
      IF (RHO(I) .EQ. -1) RHO(I)=(CL(I)+1.5)/3
      IF (T(I) .LT. 0) THEN
        T(I) = -T(I)-CRUST
        IF (T(I) .LT. 0) CALL TERMIN(5,MLNR)
      ENDIF
      IF (I .LT. NL) THEN
        CRUST = CRUST+T(I)
      ELSE
        T(I) = 10000
      ENDIF
      I = I+1
    ENDIF
    IF (I.LT.NL)GO TO 20
    IF (RHO(I).EQ. -1) RHO(I) = (CL(I)+1.5)/3
    DO 30 I=2,NL
      IF ((CL(I).LE.0) .OR. (CL(I).GE.10)) CALL TERMIN(11,I)
      IF (QL(I) .LT. 0) CALL TERMIN(12,I)
      IF (((RHO(I).LE.0).AND.(RHO(I).NE.-1)).OR.(RHO(I).GE.10))
      * CALL TERMIN(15,I)
30    CONTINUE
    END

```

```

C-----
C
C      SUBROUTINE PRTMLDA
C
C-----

```

```

SUBROUTINE PRTMLDA
CHARACTER*80 TITLE
CHARACTER*10 ITIME, IDATE
CHARACTER*1 IOBT
COMMON / NUM / CL(200),QL(200),RHO(200),T(200),EPS,SIGMA,
+          GRUST,NL,NTRACE,LOBS,NW,TSEC,TSC,ASC,NMULT,
+          TLAG,YSIDE,TLNTH

```

END

```

C-----
C
C          SUBROUTINE MDLINCH
C-----

```

```

      SUBROUTINE MDLINCH
      CHARACTER*80 TITLE
      CHARACTER*10 ITIME, IDATE
      CHARACTER*1 IOBT
      COMMON / NUM / CL(200), QL(200), RHO(200), T(200), EPS, SIGMA,
+          CRUST, NL, NTRACE, LOBS, NW, TSEC, TSC, ASC, NMULT,
+          TLAG, YSIDE, TLNTH
      COMMON / CHAR / ITIME, IDATE, IOBT, TITLE
      REAL      INCRCL, INCRQL, INCRHO, TINTLAY
      TINTLAY=0.0
      ILNR=0

C
C      READ IN TITLE AND WRITE IT
C
      READ(1,100)TITLE
100  FORMAT(A)
      WRITE(6,200)TITLE
200  FORMAT(///,1X,A)
      NL=-1
      ILNR = ILNR+1
      DO 10 I=1,200
          NL = NL+1
          IF (NL .EQ. 0) THEN
              READ(1,'(A2)')WWW
              READ(1,*) EPS,SIGMA,YSIDE,TLNTH
              READ(1,'(A2)')WWW
          ELSE
              READ(1,*) CL(NL),QL(NL),RHO(NL),T(NL)
              IF(CL(NL).EQ.9999)GO TO 15
          ... INTERPOLATED LAYERS
              IF (CL(NL) .EQ. 0) NL=NL+NINT(QL(NL))-1
              IF (NL .GT. 200) CALL TERMIN(1,ILNR)
          ENDIF
10    CONTINUE
15    IF ((CL(1) .EQ. 0) .OR. (T(1) .LT. 0)) CALL TERMIN(3,1)
      NL = NL-1
      CRUST = 0
      MLNR=1
      I=2

C
C      ...EXPAND INTERPOLATED LAYERS AND CONVERT ABSOLUTE DEPTHS TO THICKNESS.
C
20    MLNR = MLNR+1
      IF (CL(I) .EQ. 0) THEN
          NINTLAY = NINT(QL(I))

```

```

C -----
C
C
C THE CODE HAS A MAIN PROGRAM THAT CALLS 6 SUBROUTINES. THESE
C SUBROUTINES, IN TURN, CALL 6 OTHER SUBROUTINES. OUTPUT CONSISTS
C OF A BRIEF LINE PRINTER SUMMARY OF THE INPUT PARAMETERS AND A
C PLOT OF THE SYNTHETIC SEISMOGRAM AND LAYER PARAMETERS (VELOCITY,
C Q AND DENSITY).
C
C ACTION OF PROGRAM:
C -----
C
C THE PROGRAM READS AND CHECKS THE MODEL PARAMETERS. IN ALL CASES IT THEN
C PLOTS THE PARAMETER VALUES AS THEY VARY WITH DEPTH. THEY ARE PLOTTED ON
C THE SAME GRAPH, WITH VALUES OF Q REDUCED BY 1000. THE Y AXIS FILLS THE
C PAPER WIDTH AND HAS VALUES 0 - MAX PARAMETER VALUE. THE LENGTH OF THE X
C AXIS IS DEPENDENT ON BOTH THE TOTAL THICKNESS AND THE NUMBER OF LAYERS
C REQUESTED IN THE MODEL.
C
C THE MODEL USES THE THEORY OF B.L.N.KENNETT (ADVANCES IN APPLIED
C MECHANICS, VOLUME 21, PP.79-167, ACADEMIC PRESS, 1981) TO COMPUTE
C RESPONSE OF MODEL FOR SELECTED FREQUENCIES (SUBROUTINE EXEMODL)
C  $2\pi/TSEC, \dots, NW*2\pi/TSEC$ . THE RESPONSE VALUES ARE THEN
C FOURIER TRANSFORMED TO THE TIME DOMAIN AND PLOTTED.
C IF NO TIME SCALE FACTOR IS SPECIFIED (OR IF THE ONE GIVEN IS
C INAPPROPRIATE), A VALUE OF 1 MSEC PER INCH OR LESS, IF NECESSARY, IS USED.
C TRACES ARE SPACED 0.65 INCHES APART AND ARE SCALED TO A MAXIMUM MAGNITUDE
C OF 0.5 INCHES, UNLESS AN ASC VALUE IS DESIGNATED (OTHER THAN 1). IN THAT
C CASE, PEAKS ARE TRUNCATED AT 0.5 INCHES.
C
C -----
C -----
C
C MAIN PROGRAM
C -----
C
C PROGRAM TEST(OUTPUT,TAPE6=OUTPUT)
C CHARACTER*80 TITLE
C CHARACTER*10 DATE,TIME,ITIME,IDATE
C CHARACTER*1 IOBT
C COMMON / NUM / CL(200),QL(200),RHO(200),T(200),EPS,SIGMA,
C + CRUST,NL,NTRACE,LOBS,NW,TSEC,TSC,ASC,NMULT,
C + TLAG,YSIDE,TLNTH
C COMMON / CHAR / ITIME,IDATE,IOBT,TITLE
C COMMON /AR/IAGC,WINDOW
C OPEN(UNIT=1,STATUS='OLD',FILE='MDL')
C ITIME=TIME()
C IDATE=DATE()
C CALL MDLINCH
C CALL PRTMLDA
C CALL PLTARMI
C CALL EXEMODL
C IF(IAGC.EQ.1)CALL AGCFREQ
C CALL WRTPLT

```

AMPLIFY ALL EVENTS AND CREATE A RINGING EFFECT. TOO LARGE  
A WINDOW EFFECTIVELY CANCELS THE AGCACTION.

8) CAPTIONS (NOT READ BY THE COMPUTER)

9) PARAMETERS SELECTING DETECTOR AND LAYER TO PUT IT  
LINE, LOBS

WHERE

LINE - IS EITHER "REFLECTION", "VERTICAL" OR "PRESSURE"  
DEPENDING ON RECEIVER TYPE DESIRED

LOBS - IS LAYER NUMBER TO PLACE RECEIVER (NUMBER MUST  
BE IN COL 28)

IF THE RECEIVER CHOICE IS THE REFLECTION COEFFICIENT  
ONLY LAYER 1 MAY BE DESIGNATED. THE CALCULATION IS  
MADE AT THE BASE OF THE HALF SPACE. IF THE RECEIVER IS  
DESIGNATED AS VERTICAL(DISPLACEMENT) OR PRESSURE, THE  
RECEIVER IS AN OBS OR BOREHOLE INSTRUMENT AND MUST BE  
PLACED IN LAYER 2 OR GREATER (NOT LAYER 1). THE OBS  
IS AT THE TOP OF THE LAYER SPECIFIED, BUT WITHIN THE  
LAYER. FOR EXAMPLE, AN OBS IN LAYER 2 IS AT THE TOP  
OF LAYER 2, ESSENTIALLY ACROSS THE INTERFACE FROM THE  
STANDARD REFLECTION COEFFICIENT CALCULATION IN  
LAYER 1.

10) CAPTIONS (NOT READ BY COMPUTER)

11) IF THE PLOT IS TO BE FILTERED, THE FILTER PHASE IS GIVEN  
IPHASE

IPHASE - IF "0" THE FOLLOWING FILTER(S) IS ZERO PHASE,  
IF "1" THE FILTER(S) ARE MINIMUM PHASE

12) SUBSEQUENT DATA LINES (UP TO 10) ARE FILTER DEFINITIONS  
IFILTYP, IDB, FF1

WHERE:

IFILTYP - 1 = HIGH CUT (LOW PASS) BUTTERWORTH  
2 = LOW CUT (HIGH PASS) BUTTERWORTH  
3 = NOTCH FILTER

IDB - DECIBEL REDUCTION WHERE POLES =  $DB/6 + 1$

FF1 - CUT-OFF FREQUENCY IN HZ

IF A BAND PASS FILTER IS DESIRED, TWO DATA LINES ARE  
READ IN CONSECUTIVELY: ONE GIVING THE HIGH CUT VALUES  
THE OTHER THE LOW-CUT.

IF A NOTCH FILTER IS DESIRED, INPUT IS SIMILAR TO  
BAND PASS (SEE ABOVE), EXCEPT IFILTYP = 3 FOR  
BOTH INPUT LINES

USING THE PROGRAM:

TO ZERO. THE FINAL LAYER IS THE BOTTOM HALF-SPACE AND IS IDENTIFIED BY A THICKNESS T SET EQUAL TO ZERO. A FLAG OF 4 CONSECUTIVE 9999'S CLOSES OFF THE LAYER PARAMETER INPUT.

FOR EACH LAYER, OTHER THAN THE FIRST, IF RHO IS GIVEN AS A -1, A DEFAULT VALUE OF  $(CL+1.5)/3$  IS TAKEN.

EXTRAPOLATION - IT MAY BE DESIRED TO HAVE LAYER PARAMETERS CHANGE SMOOTHLY FOR A CERTAIN REGION. TO AVOID HAVING TO HAND CALCULATE AND INPUT VALUES FOR SUCH A REGION DIVIDED INTO A DISCRETE NUMBER OF LAYERS, IT IS POSSIBLE TO REQUEST THAT BETWEEN THE PRIOR AND NEXT FULLY DESCRIBED LAYERS THERE WILL BE N LAYERS OF EQUAL THICKNESS AND WITH PARAMETERS COMPUTED BY LINEAR EXTRAPOLATION BETWEEN THE VALUES FOR THE PRIOR AND NEXT LAYERS. THIS OPTION IS REQUESTED BY ENTERING A LINE OF THE FORMAT 0,N,T WHERE THE 0 IS AN ESCAPE VALUE FOR THE NORMALLY EXPECTED CL, N IS THE NOS OF LAYERS TO BE INSERTED, T IS THE TOTAL THICKNESS OF THOSE LAYERS, AND THE "1" IS A DUMMY. FOR EXAMPLE, THE VALUE OF CL FOR THE 2ND INTERPOLATED LAYER WILL BE:

$$CL(PRIOR) + 2*(CL(NEXT) - CL(PRIOR))/(N+1)$$

AS A USEFUL GUIDE, IF YOU WANT EACH LAYER 1/4 WAVELENGTH THICK (AT THE HIGHEST FREQUENCY TO BE USED), CHOOSE  $N = T*NW*4/(CL*TSEC)$

ABSOLUTE DEPTH - NORMALLY T SHOULD BE A POSITIVE VALUE SPECIFYING THE THICKNESS OF THE LAYER. IF, HOWEVER, IT IS PREFERRED TO SPECIFY THE DEPTH BELOW THE HALF SPACE TO WHICH THE LAYER WILL EXTEND (ITS STARTING POINT WILL OF COURSE BE IMMEDIATELY BELOW THE PREVIOUSLY DESCRIBED LAYER), A NEGATIVE VALUE CAN BE GIVEN, WHOSE MAGNITUDE WILL INDICATE THAT ABSOLUTE DEPTH. THIS OPTION CAN ALSO BE BE USED WITH EXTRAPOLATED LAYERS.

#### 6) CAPTIONS (NOT READ BY COMPUTER)

#### 7) INPUT PARAMETERS FOR COMPUTATIONAL PURPOSES IN FREE FORMAT ARE: NTRACE, NW, TSEC, TSC, ASC, NMULT, IAGC, WINDOW

WHERE:

NTRACE - NUMBER OF TRACES PLOTTED AS DUPLICATES ON THE SYNTHETIC  
NW - NOS OF FREQUENCIES ( $\pm 16$ , POWER OF 2) TO BE USED IN FOURIER TRANSFORM TO TIME DOMAIN.

TSEC - MSECS OF TIME SERIES (STARTS AT -1, -5 OR -10 MSECS DEPENDING ON THE VALUE OF TSEC). TSEC SHOULD BE MORE THAN TIME FOR 1-3 REFLECTIONS FROM BOTTOM INTERFACE, DEPENDING ON WHETHER YOU ARE REQUESTING PRIMARIES ONLY OR FULL RESPONSE.

TSC - TIME SCALING FACTOR (IN/MSEC). IF  $TSEC * TSC \neq YSIDE$ , THEN IF TSC IS POSITIVE, A VALUE OF TSC IS COMPUTED =  $YSIDE/TSEC$ , WHILE IF TSC IS NEGATIVE, PLOT IS TRUNCATED AT  $YSIDE/TSC$  MILLISECONDS

ASC - AMPL SCALE FACTOR (DEFAULT =  $\pm 1.0$ ). IF  $\neq 1$ , SIGNAL IS AMPLIFIED, BUT THE PLOT IS CLIPPED AT 0.5 INCHES AMPLITUDE.

NMULT - NOS OF MULTIPLE REFLECTIONS TO BE COMPUTED.

VALUE  $\neq 0$  IMPLIES FULL RESPONSE REQUIRED (BY MATRIX INVERSION).

IAGC - SET = TO 1 IF AUTOMATIC GAIN CONTROL IS DESIRED

WINDOW - LENGTH OF AGC WINDOW IN MSECS. A SMALL WINDOW (RELATIVE TO EXPECTED TIME INTERVALS OF REFLECTIONS) WILL

[illegible]

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## (VERTICAL INCIDENT SEISMOGRAM PROGRAM)

**USES I/O STREAMS AS FOLLOWS:**

- ### FORMATS AND DESCRIPTIONS OF INPUT FILE:

- WHERE :**

5) CL, QL, RHO, T

WHERE :

ALL SUBSEQUENT DATA LINES ARE READ AS DESCRIPTIONS OF CONSECUTIVE LAYERS OF THE MODEL (UP TO 200). THE FIRST LAYER IS THE UPPER HALF-SPACE (CORRESPONDING TO AN OCEAN LAYER) WITH THICKNESS SET

|         |                                                                          |
|---------|--------------------------------------------------------------------------|
| RVRB2EW | RVRB2*EWIGH* $TU$                                                        |
| SC      | FFT variable                                                             |
| SIGMA   | Parameter used in computing variation of velocities with $W$             |
| SIGNI   | FFT variable                                                             |
| SQREFT  | Square of amplitude                                                      |
| SQREFW  | Frequency equivalent of SQREFT                                           |
| T       | Array of thickness (in meters), one for each layer                       |
| TD      | Downward transmission coefficients for current interface                 |
| TD0N    | Downward transmission coefficients from ocean bottom to lower half space |
| TD0NP   | New value of TD0N                                                        |
| TD0R    | Downward transmission coefficients from ocean bottom to receiver         |
| TEMP    | Temporary variable for truncation                                        |
| TEST    | Temporary variable                                                       |
| TINTLAY | Thickness of each interpolated layer                                     |
| TITLE   | String used for plotting                                                 |
| TLAG    | Time plots will begin at -TLAG msec                                      |
| TLNTH   | Fixed length of parameter plot (in inches)                               |
| TSC     | Time-scaling factor in inches/msec                                       |
| TSEC    | Number of msec of time series                                            |
| TTOT    | Total thickness (in meters)                                              |
| TU      | Upward transmission matrix for current interface                         |
| TUN0    | Upwards transmission matrix from lower half space                        |
| TUN0P   | New value of TUN0                                                        |
| UNIT    | CMPLX (1.0, 0.0)                                                         |
| W       | Current frequency in KHz                                                 |
| WARNED  | Logical variable                                                         |
| WIGH    | Phase lag associated with propagation through vertical distance          |
| WINDOW  | AGC window length in msec                                                |
| WW      | AGC filter                                                               |
| WWW     | Ruse to read past a card                                                 |
| Y       | Common factor used in routine REFL                                       |
| YSIDE   | Max length of plot (in inches)                                           |

|         |                                                                             |
|---------|-----------------------------------------------------------------------------|
| ISTEP   | FFT variable                                                                |
| ITIME   | Current time                                                                |
| ITW2    | Number of points in AGC filter                                              |
| IW      | Frequency loop counter                                                      |
| J       | Miscellaneous loop counter                                                  |
| L       | FFT variable                                                                |
| LINE    | String to hold lines read from input file (allows free format). (See IOBT.) |
| LOBS    | Layer in which OBS located (1 if no OBS)                                    |
| LX      | FFT variable                                                                |
| M       | FFT variable                                                                |
| MAXABSV | Filter variable                                                             |
| MD      | (See Kennett, 1981, p. 106, equation 3.38.)                                 |
| MPHASE  | Flag: If set, Minimum-phase filter required; otherwise, Zero phase          |
| MLNR    | Counter of model file input lines, used in error messages                   |
| MU      | (See Kennett, 1981, p. 106, equation 3.38.)                                 |
| NINTLAY | Number of interpolated layers requested                                     |
| NFILT   | Number of filters requested                                                 |
| NL      | Total number of layers in model including bounding half spaces              |
| NMULT   | Number of multiple reflections to be calculated                             |
| NT      | Number of time steps (= NW*2)                                               |
| NTRACE  | Number of traces to be plotted on the seismogram                            |
| NW      | Number of frequencies to be calculated                                      |
| PI      | 3.141592653                                                                 |
| POLES   | Filter variable                                                             |
| PR      | Value of pressure recorded at OBS                                           |
| PRESSFA | Pressure related variable for given layer                                   |
| QL      | Array of P-wave Q values, one for each layer                                |
| R       | Filter variable                                                             |
| RCOEFF  | Reflection coefficient or OBS response for current frequency W and slowness |
| RD      | Downward reflection matrix for current interface                            |
| RD0N    | Downward reflection matrix from ocean bottom to lower half space            |
| RD0NP   | New value of RD0N                                                           |
| REFT    | Reflection coefficient (or OBS response) in time domain                     |
| REFW    | Reflection coefficient (or OBS response) in frequency domain                |
| RHO     | Array of densities, one for each layer                                      |
| RHO1    | Density of layer above the current interface                                |
| RHO2    | Density of layer below the current interface                                |
| RTB1    | Temporary variable                                                          |
| RTB2    | Temporary variable                                                          |
| RTB3    | Variable in computation of RCOEFF                                           |
| RU      | Upward reflection coefficients for current interface                        |
| RUN0    | Upward reflection coefficients from lower half space to ocean bottom        |
| RUN0P   | New value of RUN0                                                           |
| RUR0    | Upward reflection coefficients from receiver to ocean bottom                |
| RVRB1   | Effect on downward waves of all multiples in current layer                  |
| RVRB1EW | RVRB1*EWIGH*TD0N                                                            |
| RVRB2   | Effect on upward waves of all multiples in current layer                    |

## Appendix 2. Glossary of Variables Used in Program VISP

(Variables in the plotting Program PLTVISP are not listed here)

|         |                                                                  |
|---------|------------------------------------------------------------------|
| A       | Dummy argument in multiple computation                           |
| AA      | FFT variable                                                     |
| AL1     | P-wave slowness of the layer above the current interface         |
| AL2     | P-wave slowness of the layer below the current interface         |
| ASC     | Amplitude scaling factor for traces                              |
| B       | Dummy argument in multiple computation                           |
| BB      | AGC filter variable                                              |
| BEX     | Numbers smaller than exp (-BEX) taken to be zero                 |
| CO      | CMPLX (0.0,0.0)                                                  |
| C1      | CMPLX (1.0,0.0)                                                  |
| CL      | Array of P-wave velocities, one per layer                        |
| CRUST   | Total thickness of layers, excluding first and last              |
| CTEMP   | FFT variable                                                     |
| CW      | FFT variable                                                     |
| CX      | FFT variable                                                     |
| CURRMIN | AGC filter variable                                              |
| DELFREQ | Frequency increment in filtering                                 |
| DELTAT  | Time increment                                                   |
| DET     | Temporary variable in multiple computation                       |
| EIW     | CMPLX(EPS,-W)**SIGMA                                             |
| EPS     | Parameter governing variation of velocities with frequency W     |
| EWIGH   | EXP(WIGH)                                                        |
| EWRD    | EWIGH*RD                                                         |
| EWRUN0  | EWIGH*RUN0                                                       |
| F1      | Cut off frequency in Khz                                         |
| FF1     | Cut off frequency in Hz                                          |
| FACTOR  | Filter variable                                                  |
| FILT    | Digitized filter                                                 |
| FILT1   | Second copy of filter                                            |
| FRSTTIM | Logical variable                                                 |
| GL      | Z-comp of P-slowness vector                                      |
| GL1     | Z-comp of P-slowness vector in layer above current interface     |
| GL2     | Z-comp of P-slowness vector in layer below current interface     |
| I       | Miscellaneous loop counter                                       |
| IAGC    | Flag for AGC filter                                              |
| IDATE   | Current date                                                     |
| IDB     | DB reduction for notch filter, or =6*POLES-1 for Butterworth     |
| IFILTYP | Type of each filter requested                                    |
| IL      | Layer loop counter                                               |
| INCRCL  | Incremental value of CL through interpolated layers              |
| INCRQL  | Incremental value of QL through interpolated layers              |
| INCRHO  | Incremental value of RHO through interpolated layers             |
| INDEX1  | Filter variable                                                  |
| INDEX2  | Filter variable                                                  |
| IOBT    | Character for type of OBS response: reflection/vertical/pressure |
| IPHASE  | Flag: 0 for zero phase and 1 for minimum phase                   |

## Appendix 1. Generalized Description Diagram of Programs VISP and PLTVISP

## Program VISP

| Subroutine | Comments                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1. MAIN    | Calls six subroutines listed below.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| 2. MDLINCH | Reads model parameters and interpolates layer parameters. Calls TERMIN for error stop.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| 3. PRTMLDA | Writes model parameters.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| 4. PLTARMI | Reads and writes computational parameters, user options, and filter specifications. Calls TERMIN for error stop.                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| 5. EXEMODL | Main computation subroutine for a given frequency: Computes reflection coefficient for all layers (for user-designated number of multiples). Options for pressure or vertical displacement. Repeats for all frequencies and then filters. Finally, transforms to time domain.<br><br>The above computations involve calls to five subroutines: PARMGEN (computes vertical slowness), REFL (computes reflection coefficient for a single interface at a single frequency), REVERB (selects multiple computations), FILTER (filters amplitudes), and FFT (fast Fourier transform). |
| 6. AGCFREQ | Simulates automatic gain control in frequency domain for specified window. Calls FFT.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| 7. WRTPLT  | Writes header and seismogram amplitudes on file for plotting by Program PLTVISP. (See table below.)                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |

## Program PLTVISP

| Subroutine | Comments                                                                           |
|------------|------------------------------------------------------------------------------------|
| 1. MAIN    | Calls four subroutines listed below.                                               |
| 2. READINP | Reads data generated by Program VISP.                                              |
| 3. INITPLT | Plots major headings.                                                              |
| 4. PARMPLT | Initializes plot parameters and plots axes and model parameters.                   |
| 5. RSPMDL  | Writes filter, AGC, and multiple specifications. Plots seismogram traces and axes. |

# LITERATURE CITED

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typical field records. As a demonstration, a model that simulates a continuous velocity log with 123 layers was used to create Test 1 (fig. 2). A CDC Cyber 170/855 computer at the Indiana University Wrubel Computing Center generated the output data in 13.6 seconds with a 71300 octal field length. Table 1 lists the input data used to generate figure 2.

Appendix 4 lists the input data and output

plots for 12 other test cases used to demonstrate the user options.

## Literature Cited

Kennett, B. L. N.

1981 - Elastic wave propagation in stratified media, in *Advances in applied mechanics*: New York, Academic Press, Inc., v. 21, p. 79-167.

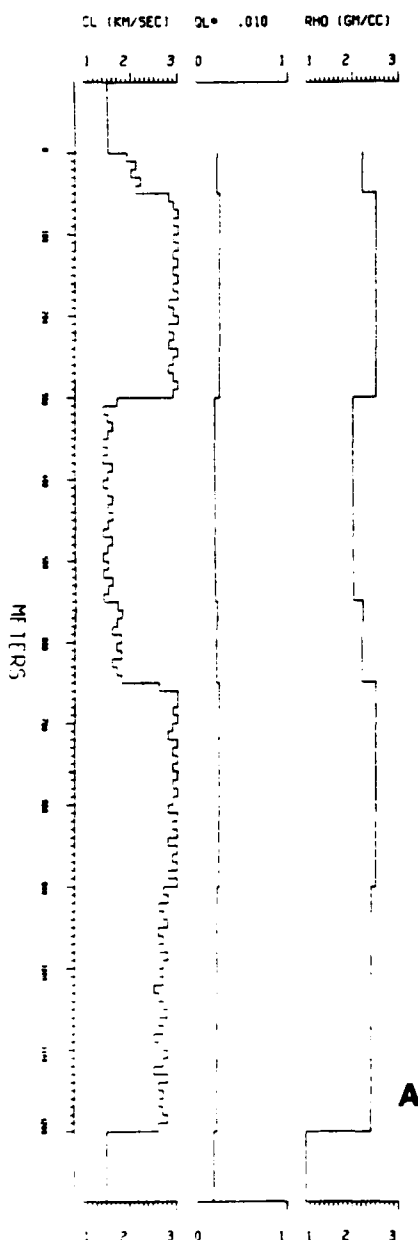
Table 1. Input data used to generate a typical synthetic seismogram (fig. 2)

| TEST 1 - DSYN. SYNTHETIC SEISMOGRAM. |       |                   |           |                   |       |     |        |
|--------------------------------------|-------|-------------------|-----------|-------------------|-------|-----|--------|
| EPS                                  | SIGMA | YSIDE             | XSIDE     |                   |       |     |        |
| 0.001                                | 0.1   | 40.               | 12.0      |                   |       |     |        |
| CL                                   | QL    | RHO               | THICKNESS |                   |       |     |        |
| 1.5                                  | 2000. | 1.1               | 0.        |                   |       |     |        |
| 1.9                                  | 22.   | 2.2               | 10.       |                   |       |     |        |
| 2.1                                  | 22.   | 2.2               | 10        |                   |       |     |        |
| 2.0                                  | 22.   | 2.2               | 10        |                   |       |     |        |
| 2.2                                  | 22.   | 2.2               | 10        |                   |       |     |        |
| 2.1                                  | 22.   | 2.2               | 10        |                   |       |     |        |
| 2.8                                  | 25.   | 2.5               | 10        |                   |       |     |        |
| 2.9                                  | 25.   | 2.5               | 10        |                   |       |     |        |
| .                                    | .     | .                 | .         |                   |       |     |        |
| .                                    | .     | .                 | .         |                   |       |     |        |
| .                                    | .     | .                 | .         |                   |       |     |        |
| .                                    | .     | .                 | .         |                   |       |     |        |
| 2.7                                  | 23    | 2.4               | 10        |                   |       |     |        |
| 2.6                                  | 23    | 2.4               | 10        |                   |       |     |        |
| 2.7                                  | 23    | 2.4               | 10        |                   |       |     |        |
| 2.8                                  | 23    | 2.4               | 10        |                   |       |     |        |
| 2.6                                  | 23    | 2.4               | 10        |                   |       |     |        |
| 1.5                                  | 20    | 2.2               | 0.        |                   |       |     |        |
| 9999                                 | 9999  | 9999              | 9999      |                   |       |     |        |
| #TRC                                 | #FREQ | T(MSEC)           | IN/MSEC   | AMP-SCALE         | MLTPL | AGC | WINDOW |
| 5                                    | 512   | 2000.             | .006      | 1.0               | -1    | 1   | 400    |
| DETECTOR TYPE                        |       | DETECTOR LOCATION |           |                   |       |     |        |
| REFLECTION                           |       | LAYER 1           |           |                   |       |     |        |
| FILTER PHASE                         |       |                   |           |                   |       |     |        |
| 1 (MINIMUM PHASE)                    |       |                   |           |                   |       |     |        |
| FILTER-TYPE                          |       | DB                | SLOPE     | CUT-OFF FREQUENCY |       |     |        |
| 1                                    |       |                   | 72        | 70                |       |     |        |
| 2                                    |       |                   | 72        | 30                |       |     |        |

## GENERATION OF VERTICALLY INCIDENT SEISMOGRAMS

## VISP: PLOTS OF PARAMETERS

TEST 1 - DSYN. SYNTHETIC SEISMOGRAM.



TEST 1 - DSYN. SYNTHETIC SEISMOGRAM.  
 REFLECTION COEFFICIENT  
 AT OBS IN LAYER 1 AT .0 M DEPTH  
 FREQ(MHZ) = 512 \* (MSECS) = 2000  
 MIN = .50 HZ MAX = 256.00 HZ  
 FULL RESPONSE (ALL MULTIPLES)  
 AGC WINDOW = 400.MSECS

---FILTERS = MINIMUM PHASE---  
 HIGH CUT AT 70. HZ:72 DB SLOPE  
 LOW CUT AT 30. HZ:72 DB SLOPE

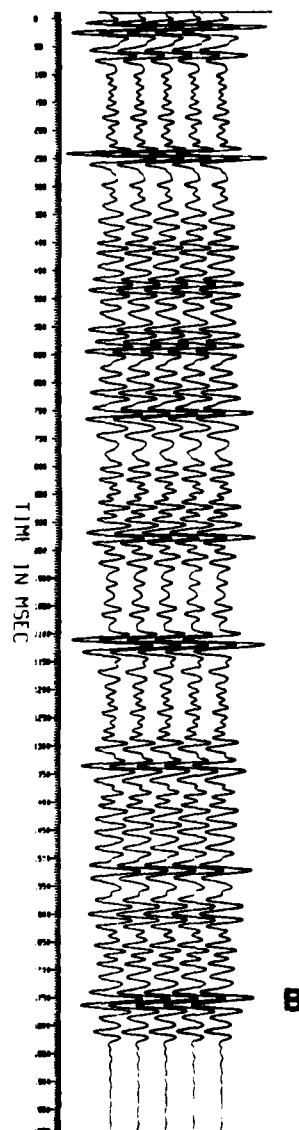


Figure 2. (Test 1) Output plots generated by Program VISP. A, input data: velocity (CL), Q (QL), and density (RHO); B, synthetic seismogram generated from input data. Significant parameters are listed above the seismogram.

## SUMMARY

where, for example, the coefficients  $\bar{R}_D^{12}$  are for the interface at  $Z_2$ , and the coefficients  $\bar{R}_D^{23}$  are for the interface at  $Z_3$ , but are

$$\bar{R}_D^{23} = E R_D^{23} E \quad \bar{R}_U^{23} = E R_U^{23} E \quad \bar{T}_D^{23} = E T_D^{23} \quad \bar{T}_U^{23} = E T_U^{23} \quad (7)$$

Kennett (1981) pointed out that the bracketed quantity may be expanded as a

adjusted for travel through the layer by  $E = e^{i\omega d/c}$ , where  $d$  is layer thickness. Hence

power series

$$[I - A]^{-1} = I + A + A^2 + \dots \quad (8)$$

Therefore,

$$R_D^{13} = R_D^{12} + T_U^{12} R_D^{23} T_D^{12} + T_U^{12} R_D^{23} R_U^{12} R_D^{23} T_D^{12} + \dots \quad (9)$$

which is represented schematically in figure 1.  $R_D^{12}$  is the reflection from the upper region. Reading from right to left,  $T_U^{12} R_D^{23} T_D^{12}$  represents a transmission back up through the upper zone.  $T_U^{12} R_D^{23} R_U^{12} R_D^{23} T_D^{12}$  represents a reverberation within the layer.

The total response (equation 6) includes all internal reverberations, and the bracketed quantity is termed the reverberation operator. Note that the reflection-transmission coefficient may be calculated iteratively by adding a layer at each stage, beginning at the top or the bottom of the stack of layers. Computation of the response of the model proceeds for selected frequencies and is finally Fourier transformed to the time domain and plotted.

## Summary

The algorithm for Program VISP and Program PLTVISP (appendix 1) presumes an incident plane wave originating at the base of, but within, the upper half space. The two programs are written in FORTRAN 77, and the codes are listed in appendix 3. Only one input file is required to run Program VISP. One output file is generated for plotting. Program PLTVISP plots the output on a Versatec plotter by using standard calcomp calls. A glossary of constants and variables is in appendix 2. The comment cards at the

beginning of Program VISP detail, card by card, the input data required to generate an output.

User's options include an output plot (seismogram) of the reflection coefficient (pressure of the reflected wave divided by the pressure of the incident wave), pressure, or vertical displacement. The receiver may be at the top of any of the layers except when a reflection coefficient is requested; then the receiver is just above the first interface. Seismograms may be filtered by using a Butterworth-type high-pass, low-pass, or band-pass filter. The filter slopes and the phase characteristics (minimum or zero) are specified in the input. The user may uniformly amplify the signal (ASC) or optionally select a simulated automatic gain control (AGC). The final seismogram may display primary reflections only, primaries and a selected number of multiples, or a complete response.

Besides computational parameters, the user must read in the following model parameters for each layer and the top and the bottom half space: velocity,  $Q$ , density, and thickness. If a negative one is read in for the density, a default value of  $(\text{velocity} + 1.5)/3$  is calculated. Program VISP successfully generates synthetic seismograms that simulate

```

      ELSEIF (TSC.LT.0.0) THEN
C
C      ...IN THIS CASE DONT PLOT ALL.
C
      TSC = -TSC
    ENDIF
    IF (ASC .EQ. 0.0) ASC=1.0
    IF ((ASC .LT. 1.0) .OR. (ASC .GT. 100)) CALL TERMIN(29,0)
C
C      LOOK FOR OBS OPTIONS
C      -----
C
      READ(1,'(A2)')WWW
      READ(1,'(A11,16X,I1)')LINE,LOBS
      WRITE(6,103)LINE,LOBS
103  FORMAT(/,1X,"DETECTOR TYPE IS ",A," IN LAYER #",I3)
      IOBT=LINE(1:1)
      IF ((IOBT.EQ.'V') .OR. (IOBT.EQ.'P')) THEN
        IF ((LOBS.LT.2) .OR. (LOBS.GT.NL)) CALL TERMIN(31,0)
      ELSE
      ENDIF
C
C      NOW READ FILTER PARAMETERS
C      -----
C
      READ(1,'(A2)')WWW
      READ(1,*) IPHASE
      IF(IPHASE.EQ.0)THEN
        WRITE(6,'(1X,"FILTER-PHASE")')
        WRITE(6,'(1X,I1,"(ZERO PHASE)")')IPHASE
        MPHASE=.FALSE.
      ELSEIF(IPHASE.EQ.1)THEN
        WRITE(6,'(1X,"FILTER-PHASE")')
        WRITE(6,'(1X,I1,"(MINIMUM PHASE)")')IPHASE
        MPHASE=.TRUE.
      ELSEIF(IPHASE.NE.0.AND. IPHASE.NE.1)THEN
        WRITE(6,'(1X,"NO FILTERS")')
        GO TO 15
      ELSE
      END IF
      WRITE(6,'(//,1X,"FILTER TYPE",2X,"DB SLOPE",2X,
+      "CUT-OFF FREQUENCY")')
      READ(1,'(A2)')WWW
      DO 10 I=1,15
        READ(1,*,END=15) IFILTYP(I),IDB(I),FF1(I)
        IF(IFILTYP(I).EQ.1)GO TO 11
        IF(IFILTYP(I).EQ.3)GO TO 41
        GO TO 21
11      WRITE(6,104)IFILTYP(I),IDB(I),FF1(I)
104      FORMAT(1X,I1,"(LOW PASS)",4X,I3,10X,F4.0)
        GO TO 31
21      WRITE(6,105)IFILTYP(I),IDB(I),FF1(I)
105      FORMAT(1X,I1,"(HIGH PASS)",3X,I3,10X,F4.0)
        GO TO 31
41      WRITE(6,106)IFILTYP(I),IDB(I),FF1(I)

```

```

106      FORMAT(1X,I1,"(NOTCH FILTER)",3X,I3,10X,F4.0,3X,F4.0)
31       NFILT=NFILT+1
        F1(NFILT) = FF1(NFILT)*.001
10       CONTINUE
15      IF (NFILT .GT. 10) CALL TERMIN(30,NFILT)
        CLOSE(UNIT=1)
        RETURN
        END

```

```

C-----
C
C          SUBROUTINE EXEMODL
C-----
C
C          SUBROUTINE EXEMODL
COMMON / NUM / CL(200),QL(200),RHO(200),T(200),EPS,SIGMA,
+        CRUST,NL,NTRACE,LOBS,NW,TSEC,TSC,ASC,NMULT,
+        TLAG,YSIDE,TLNTH
COMMON / CHAR / ITIME,IDATE,IOBT,TITLE
COMMON / FILTDT/ F1(10),IDB(10),IFILTYP(10),NFILT,MPHASE,
+ FF1(10)
CHARACTER*1 IOBT
CHARACTER*10 ITIME,IDATE
CHARACTER*80 TITLE
COMPLEX GL1,GL2
COMPLEX EIW,WIGH,RCOEFF,C0,C1,AL1,AL2
COMPLEX EWIGH,RVRB1,RVRB2
COMPLEX EWRUN0,EWRD,RVRB1EW,RVRB2EW
COMPLEX RTB1,RTB2,RTB3,TI9NP,TUN0P
COMPLEX RDGNP,RUN0P,RD0N,RUN0
COMPLEX TD0N,TUN0,RD,RU,TD,TU
COMPLEX MU,MD,RUR0,TD0R
COMPLEX PRESSFA,PR,UNIT,REFW(1024)
COMMON /TS/ REFT(1024)
DATA     PI/3.141592653/
DATA     BEX/-20.0/
DATA     C0/(0.0,0.0)/, C1/(1.0,0.0)/
C
C          INITIALIZE BEGINNING OF PLOT
C-----
C
NT = 2*NW
IF (TSEC .GT. 150.0) THEN
    TLAG = 10.0
ELSEIF (TSEC .GT. 90.0) THEN
    TLAG = 5.0
ELSE
    TLAG = 1.0
ENDIF
UNIT = C1
C
C          LOOP OVER ALL FREQUENCIES
C-----

```

```

C
DO 10 IW=1, NW-1
  W = IW*PI*2/TSEC
  EIW = CMPLX(EPS, -W)**SIGMA
  AL1 = CMPLX(1.0/CL(1), 0.0)*(CMPLX(0.5/QL(1), 0.0)/EIW+C1)
  RHO1 = RHO(1)
  CALL PARMGEN(AL1, GL1)

C
C
C      LOOP OVER ALL LAYERS
C      -----
C
DO 15 IL=1, NL-1
  AL2 = CMPLX(1.0/CL(IL+1), 0.0) *
+      (CMPLX(0.5/QL(IL+1), 0.0)/EIW + C1)
  RHO2 = RHO(IL+1)
  CALL PARMGEN(AL2, GL2)
  CALL REFL(RHO1, RHO2, GL1, GL2, RU, RD, TU, TD)
  IF (IL .EQ. 1) THEN
    RDON=RD
    RUNO=RU
    TDON=TD
    TUNO=TU
    MD = C0
    MU = C0
  ELSE
    WIGH = CMPLX(0.0, W*T(IL))*GL1
    IF (REAL(WIGH) .GT. BEX) THEN
      EWIGH = CEXP(WIGH)
    ELSE
      EWIGH = C0
    ENDIF
    EWRD=EWIGH*RD
    EWRUNO=EWIGH*RUNO
    RTB1=EWRUNO*EWRD
    IF (NMULT .LT. 0) THEN
      ...COMPUTE ALL MULTIPLES RVRB2=1+EWIGH*RD*RVRB1*EWIGH*RUNO.

      CALL REVERB(RTB1, RVRB1)
      RTB1=RVRB1*EWRUNO
      RTB2=EWRD*RTB1
      RVRB2=UNIT+RTB2
    ELSE
      ...VALUE FOR NO MULTIPLES.

      RVRB1=UNIT
      RVRB2=UNIT
      IF (NMULT .GT. 0) THEN
        ...COMPUTE FINITE NUMBER OF MULTIPLES.

        DO 20 I=1, NMULT
          RTB2=RVRB1*RTB1

```

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## GENERATION OF VERTICALLY INCIDENT SEISMOGRAMS

20

```

      RVRB1=UNIT+RTB2
      CONTINUE
      RTB1=EWRD*EWRUN0
      DO 25 I=1, NMULT
        RTB2=RVRB2*RTB1
        RVRB2=UNIT+RTB2

```

25

```

      CONTINUE
      ENDIF
      ENDIF
      RTB1=EWIGH*TD0N
      RVRB1EW=RVRB1*RTB1

```

C  
C  
C

```

      ...TD0N=TD*RVRB1*EWIGH*TD0N.

```

```

      TD0NP=TD*RVRB1EW
      RTB1=EWIGH*TD0N
      RVRB2EW=RVRB2*RTB1

```

C  
C  
C

```

      ...TUN0=TUN0*RVRB2*EWIGH*TD0N.

```

```

      TUN0P=TUN0*RVRB2EW
      RTB1=EWRD*RVRB1EW

```

C  
C  
C

```

      ...RD0N=RD0N+TUN0*EWIGH*RD*RVRB1*EWIGH*TD0N.

```

```

      RTB2=TUN0*RTB1
      RD0NP=RD0N+RTB2
      RTB1=EWRUN0*RVRB2EW

```

C  
C  
C

```

      ...RUN0=RU+TD*EWIGH*RUN0*RVRB2*EWIGH*TD0N.

```

```

      RTB2=TD*RTB1
      RUN0P=RU+RTB2
      TD0N=TD0NP
      TUN0=TUN0P
      RD0N=RD0NP
      RUN0=RUN0P

```

```

      ENDIF
      TEST = CABS(TD0N)

```

C  
C  
C

```

      ...EXIT LAYER LOOP

```

```

      IF((TEST.EQ.0.0).OR.(ALOG10(TEST).LT.-8))GO TO 30
      IF (IL.EQ. LOBS-1) THEN

```

```

        RUN0=RUN0
        TD0R=TD0N
        TD0N=UNIT
        TUN0=UNIT
        RUN0 = C0
        RD0N = C0
        PRESSFA = RHO(LOBS)*(1.0-(4.0/3.0))

```

C  
C  
C

```

      ...THE OBS. SITS IN THE UPPERMOST PART.

```

```

      MU = -GL2

```

```

      MD = GL2
      ENDIF
      AL1 = AL2
      RHO1 = RHO2
      GL1 = GL2
C
C      ...END OF THE LAYER LOOP.
C
15  CONTINUE
30  CONTINUE
      IF (LOBS .GT. 1) THEN
C
C      ...IF AN OBS MOTION IS ASKED FOR THE INCIDENT PRESSURE WAVE
C      ...IS A DERIVATIVE OF A DELTA FUNCTION. IF AN OBS PRESSURE
C      ...IS ASKED FOR, THE INCIDENT PRESSURE WAVE IS ASSUMED TO BE
C      ...A DELTA FUNCTION.
C
      RTB1=RUR0*RD0N
      IF(NMULT.LT.0) THEN
        CALL REVERB(RTB1,RTB2)
      ELSE
        RTB2=UNIT
        IF(NMULT.GT.0) THEN
          DO 40 I=1,NMULT
            RTB2=UNIT+RTB1*RTB2
40      CONTINUE
          ENDIF
        ENDIF
C
      RTB1=RTB2*TD0R
      RTB2=RD0N*RTB1
      PR=PRESSFA*(RTB2+RTB1)
      RTB2=MU*RD0N
      RTB2=MD+RTB2
      RTB3=RTB2*RTB1
C
C      ADJUST FOR RECEIVER TYPE
C      -----
C
      IF(IOBT.EQ.'V')THEN
        RCOEFF = RTB3/RHO(1)
      ELSE
C
C      ...PRESSURE.
C
        RCOEFF = PR/RHO(1)
      ENDIF
      ELSE
        RCOEFF = RD0N
      ENDIF
      RCOEFF = RCOEFF * CMPLX(50.*(1+COS(PI*IW/NW)),0.) *
+      CEXP(CMPLX(0.0,W*TLAG))
      REFW(IW+1) = RCOEFF
C
C      ... NEGATIVE FREQUENCIES ARE COMPLEX CONJ.

```

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## GENERATION OF VERTICALLY INCIDENT SEISMOGRAMS

```

C      REFW(NT-1W+1) = CONJG(RCOEFF)
C
C      ...END FREQUENCY LOOP
C
10  CONTINUE
C
C      ...DC AND NYQUIST FREQUENCY SET = TO 0
C
C      REFW(1) = C0
C      REFW(NW+1) = REFW(1)
C      CALL FILTER(REFW,NW,TSEC)
C
C      ...TRANSFORM TO TIME DOMAIN
C
C      CALL FFT(NT,REFW,-1.)
C      DO 35 I=1, NT
C          REFT(I) = REAL(REFW(I))
35  CONTINUE
C      RETURN
C      END

```

```

C-----
C
C      SUBROUTINE PARMGEN
C
C-----

```

```

SUBROUTINE PARMGEN(AL,GL)
COMPLEX AL,GL
GL = CSQRT(AL*AL)
IF (AIMAG(GL).LT.0.0) GL=-GL
RETURN
END

```

```

C-----
C
C      SUBROUTINE REFL
C
C-----

```

```

SUBROUTINE REFL(RHO1,RHO2,GL1,GL2,RU,RD,TU,TD)

```

```

C      ...COMPUTES REFLECTION COEFFICIENT RU,RD,TU & TD FOR GIVEN LAYER
C      ...INTERFACE PARAMETERS. THE REFLECTION/TRANSMISSION COEFFICIENTS ARE
C      ...RATIOS OF DISPLACEMENT POTENTIALS. IN THE KTH LAYER, THE DISPLACEMENT
C      ...VECTOR U(K) IS GIVEN BY:
C          U(K) = GRAD(PHIU(K)+PHID(K))/(1*W) +
C                  CURL CURL(ZHAT(PSIU(K)+PSID(K))) / (W*W*P)
C      ...IN WHICH PHIU AND PHID ARE THE POTENTIALS ASSOCIATED WITH THE UP AND
C      ...DOWN GOING P-WAVES RESPECTIVELY. ZHAT IS A UNIT VECTOR
C      ...POINTING IN THE POSITIVE Z DIRECTION, I.E. DOWNWARDS.
C      ...THEN, FOR EXAMPLE, THE DOWNWARD TRANSMISSION COEFFICIENT FOR P WAVES

```

```

C      ...FROM LAYER 1 TO LAYER 2 IS  TPP12 = PHID(2)/PHID(1).
C
C      COMPLEX GL1, GL2
C      COMPLEX RU, RD, TU, TD, C0
C      COMPLEX Y
C
C      ...NOTE THAT:  GL=1/ALPHA
C
C      DATA C0/(0.0,0.0)/
C      Y = RHO1*GL2 + RHO2*GL1
C      TD = 2.0*RHO1*GL1/Y
C      RD = (RHO2*GL1 - RHO1*GL2)/Y
C      TU = 2.0*RHO2*GL2/Y
C      RU = -RD
C      RETURN
C      END

```

```

C-----
C
C      SUBROUTINE REVERB
C
C-----

```

```

C      SUBROUTINE REVERB(A,B)
C      COMPLEX A,B,X,Y,DET,C0,C1
C      LOGICAL WARNED
C      DATA C0/(0.0,0.0)/,C1/(1.0,0.0)/,WARNED/.FALSE./
C      IF (ABS(REAL(A))+ABS(AIMAG(A)).LT. 1.0E-12)THEN
C        IF (.NOT. WARNED)THEN
C          WRITE(6, '( /, "***MULTIPLES IGNORED WHERE MAGNITUDE < E-12" )')
C          WARNED = .TRUE.
C        ENDIF
C
C      ...IGNORE MULTIPLES, TO AVOID UNDERFLOW PROBLEMS
C
C      B = C1
C      ELSE
C      X = 1.0 - A
C      Y = 1.0
C      DET = X*Y
C      B = Y/DET
C      ENDIF
C      RETURN
C      END

```

```

C-----
C
C      SUBROUTINE FILTER
C
C-----

```

```

SUBROUTINE FILTER(REFW,NW,TSEC)
LOGICAL MPHASE
COMMON /FILTDT/ F1(10),IDB(10),IFILTP(10),NFILT,MPHASE,
+ FF1(10)
REAL      MAXABSV
LOGICAL    FRSTTIM
COMPLEX    FILT(1024), F1LT(1024), REFW(1024)
DATA      PI/3.141592/
DATA      FRSTTIM/.TRUE./
IF (NFILT .EQ. 0) RETURN

C
C      .....GENERATE FILTER.....
C
IF (FRSTTIM) THEN
C
C      ...INITIATE FILTER IN POSITIVE FREQUENCY DOMAIN. NEGATIVE
C      ...FREQUENCIES BECOME COMPLEX CONJUGATES OF POSITIVE FREQUENCIES
C      ...AND CAN BE COMPUTED WHEN NECESSARY.
C
      DO 10 I=1, NW+1
        F1LT(I) = CMPLX(1.0, 0.0)
10      CONTINUE
C
C      ...SMEARING RANGE
C
      DELFREQ = 0.0
      IF (MPHASE) DELFREQ=2*PI/TSEC
      DO 15 I=1, NFILT
        IF (IFILTP(I) .EQ. 1) THEN
C
C          ...LOW PASS BUTTERWORTH FILTER
C
          POLES = FLOAT(IDB(I))/6 + 1
          R = 1/((F1(I)-DELFREQ)*TSEC)
          DO 20 J=1, NW+1
            F1LT(J) = F1LT(J)/SQRT(1+((J-1)*R)**POLES)
20          CONTINUE
          ELSEIF (IFILTP(I) .EQ. 2) THEN
C
C          ...HIGH PASS BUTTERWORTH FILTER
C
          POLES = FLOAT(IDB(I))/6 + 1
          FACTOR = 1/((F1(I)+DELFREQ)*TSEC)
          DO 25 J=1, NW+1
            R = ((J-1)*FACTOR)**POLES
            F1LT(J) = F1LT(J)*SQRT(R/(1+R))
25          CONTINUE
          ELSE
C
C          ...NOTCH FILTER
C
            IF (I.EQ.2) GO TO 26
            INDEX1 = IFIX((F1(I)-DELFREQ)*TSEC) + 1
            GO TO 27
26          INDEX2 = IFIX((F1(I)+DELFREQ)*TSEC) + 2
27          GO TO 27
          ENDIF
        ENDIF
      END DO
    
```

```

      IF (INDEX2-INDEX1 .LT. 16) THEN
        WRITE(6,(' " *** F1(1) TOO CLOSE TO F1(2) IN NOTCH - NO "
          +      "FILTERING DONE ***"'))
        RETURN
      ENDIF

C      ...IDB REDUCTION
C
C      GO TO 29
27      R = 1 - 10**(-(FLOAT(IDB(1))/20))
C
C      ...NEILS DESIGN
C      IF(1.EQ.1)GO TO 28
C
29      DO 30 J=INDEX1, INDEX2
        FILT(J) = FILT(J)*
          +      (1 + R*(COS(2*PI*(J-INDEX1)/(INDEX2-INDEX1))-1)/2)
30      CONTINUE
28      ENDIF
15      CONTINUE
      IF (MPHASE) THEN
C
C      ...SET A(W) = LN F(W)
C
      DO 35 I=1, NW+1
        IF (REAL(FILT(I)) .EQ. 0.0) THEN
          FILT(I) = CMPLX(-30.0, 0.0)
        ELSE
          FILT(I) = CMPLX(ALOG(REAL(FILT(I))), 0.0)
        ENDIF
35      CONTINUE
C
C      ... NEGATIVE NEEDED FOR FFT
C
      DO 40 I=NW+2, NW*2
        FILT(I) = CONJG(FILT(NW*2-I+2))
40      CONTINUE
C
C      ...A(T) = INVERSE FFT A(W)
C
      CALL FFT(NW*2,FILT,-1.0)
C      ... B(T) = A(T)*G(T)
      DO 45 I=2, NW+1
C      ... G(T)
        R = (1+COS(PI*(I-1)/NW)) / 2
C      ... NW+1 VALUE = 0
        FILT(I) = R*FILT(I)
C      ...1 ST VALUE UNCHANGED
        FILT(NW*2+2-I) = R*FILT(NW*2+2-I)
C      ...2 & NW*2 VALUE NEARLY = 0
45      CONTINUE
C      ...NW+1 VAL = 0 IS USED HERE
      DO 50 I=1, NW
        FILT1(I) = FILT(I)
50      CONTINUE

```

```

C      ... C(T) HAS INVERTED 2 HALF
DO 55 I=NW+1, NW*2
    FILT1(I) = -CONJG(FILT(I))
55    CONTINUE
C      ... B(W) = FT B(T), C(W) = FT C(T)
    CALL FFT(NW*2,FILT,1.0)
    CALL FFT(NW*2,FILT1,1.0)
    MAXABSV = 0.0
C      ... F'(W) = EXP(B(W)+C(W))
DO 60 I=1, NW+1
    FILT(I)=CEXP(FILT(I) + FILT1(I))
    MAXABSV = AMAX1(CABS(FILT(I)),MAXABSV)
60    CONTINUE
DO 65 I=1, NW+1
C      ...NORMALIZE
    FILT(I) = FILT(I)/MAXABSV
65    CONTINUE
    ENDIF
    FRSTTIM = .FALSE.
ENDIF
C
C      .....ACTUAL FILTERING FOLLOWS.....
C
C      ...MULTIPLY BY POSITIVE FREQ FILTER
C
DO 70 I=1, NW+1
    REFW(I) = REFW(I) * FILT(I)
70    CONTINUE
C
C      ... NEGATIVE FREQUENCY ARE CONJUGATES
C
DO 75 I=NW+2, NW*2
    REFW(I) = CONJG(REFW(NW*2-I+2))
75    CONTINUE
    RETURN
    END

```

```

C-----
C
C      SUBROUTINE FFT
C
C-----

```

```

SUBROUTINE FFT(LX,CX,SIGNI)
COMPLEX CX(LX),CTEMP,CW
J = 1
SC = SQRT(1./FLOAT(LX))
DO 3 I=1,LX
    IF(I.GT.J) GO TO 1
    CTEMP = CX(J)*SC
    CX(J) = CX(I)*SC
    CX(I) = CTEMP
1    M = LX/2
2    IF(J.LE.M) GO TO 3

```

```

      J = J - M
      M = M/2
      IF(M.GE.1) GO TO 2
3     J = J + M
      L = 1
4     ISTEP = 2*L
      DO 5 M=1,L
      AA = 314159265358979.D-14*SIGNI*(M-1)/L
      CW = CMPLX(COS(AA),SIN(AA))
      DO 5 I=M,LX,ISTEP
      CTEMP = CW*CX(I+L)
      CX(I+L) = CX(I) - CTEMP
5     CX(I) = CX(I) + CTEMP
      L = ISTEP
      IF(L.LT.LX) GO TO 4
      RETURN
      END

```

```

C-----
C
C      SUBROUTINE WRTPLT
C
C-----

```

```

      SUBROUTINE WRTPLT
      COMMON / NUM / CL(200),QL(200),RHO(200),T(200),EPS,SIGMA,
+          CRUST,NL,NTRACE,LOBS,NW,TSEC,TSC,ASC,NMULT,
+          TLAG,YSIDE,TLNTH
      COMMON /TS/ REFT(1024)
      COMMON/AR/IAGC,WINDOW
      COMMON /FILTDT/ F1(16),IDB(10),IFILTYP(10),NFILT,MPHASE,
+      FF1(10)
      COMMON / CHAR /ITIME,IDATE,IOBT,TITLE
      CHARACTER*1 IOBT
      CHARACTER*10 ITIME,IDATE
      CHARACTER*80 TITLE
      OPEN(UNIT=4,FILE='PLTIN',STATUS='NEW')
      IF(IOBT.EQ.'P')THEN
          INUM=1
      ELSE IF(IOBT.EQ.'V')THEN
          INUM=2
      ELSE
          INUM=3
      END IF
      NT=2*NW
      WRITE(4,1001)TITLE
1001  FORMAT(A)
      WRITE(4,999)NTRACE,YSIDE,NW,TLNTH,NL,NFILT,MPHASE
999   FORMAT("NTRACE=",I4,"",YSIDE="F5.2,"",NW="I5,"",TLNTH="
+      F5.2,"",NL="I3,"",NFILT="I3,"",MPHASE="L2)
      WRITE(4,989)TSEC,TSC,TLAG,ASC
989   FORMAT("TSEC="F10.0,"",TSC="F10.5,"",TLAG="F10.0,"",ASC="F10.5)
      DO 5 I=1,NFILT

```

```

      WRITE(4,995) IFILTY(1),IDB(1),FF1(1)
995  FORMAT("FILTER TYPE=",I2,1X,"DB-SLOPE=",I3,1X,
+ "CUT-OFF FREQUENCY=",F5.1)
5  CONTINUE
      WRITE(4,987) INUM, LOBS, NMULT, CRUST, IAGC, WINDOW
987  FORMAT(1X, "IOBT=", I1, " , LOBS=", I3, " , NMULT=", I5, " , CRUST=", F10.5
+ , " , IAGC=", I3, " , WINDOW", F7.2)
      DO 6 I=1, NL
          WRITE(4, '(1X, "CL=", F5.2, " , QL=", F6.0, " , RHO=", F5.2, " , T=", F6.1)')
+ CL(I), QL(I), RHO(I), T(I)
6  CONTINUE
      DO 10 I=1, NT
          WRITE(4, '( "REFT=", 1X, F20.14)') REFT(I)
10  CONTINUE
      RETURN
      END

```

```

C-----
C
C      SUBROUTINE AGCFREQ
C-----
C
      SUBROUTINE AGCFREQ
      DIMENSION SQREFT(1024), BB(2)
      COMPLEX SQREFW(1024), WW(1024)
      COMMON / NUM / CL(200), QL(200), RHO(200), T(200), EPS, SIGMA,
+          CRUST, NL, NTRACE, LOBS, NW, TSEC, TSC, ASC, NMULT,
+          TLAG, YSIDE, TLNTH
      COMMON / CHAR / ITIME, IDATE, IOBT, TITLE
      COMMON /TS/ REFT(1024)
      COMMON /AR/ IAGC, WINDOW
      DATA PI/3.141592653/
C
C      .... SQUARE TRACE AMPLITUDES AND MAKE COMPLEX
C      .... INITIALIZE FILTER TO COMPLEX ZERO
C
      SUMSQ=0.0
      NT = NW*2
      DO 330 I = 1, NT
          SQREFT(I) = REFT(I)*REFT(I)
          SUMSQ=SUMSQ+SQREFT(I)
          SQREFW(I) = CMPLX(SQREFT(I), 0.0)
          WW(I) = CMPLX(0.0, 0.0)
330  CONTINUE
C
C      CONDITION THE INPUT TIME SERIES
C
      AVSQ=SUMSQ/NT
      BOOST=1.0/AVSQ
      DO 331 I=1, NT
          SQREFW(I) = SQREFW(I)*BOOST
331  CONTINUE

```

```

C
C      ....CONSTRUCT AGC FILTER IN TIME DOMAIN
C      ...."WINDOW" (READ IN BY USER) IS FILTER LENGTH IN MSECS
C
      DELTAT = TSEC/NT
      ITW2 = NINT((WINDOW/DELTAT)/2.0)
      DO 340 I = 1, ITW2+1
        WW(I) = CMPLX(0.5*(1.0+COS(PI*(I-1)/ITW2)), 0.0)
        J = NT+1-I
        WW(J) = WW(I)
340  CONTINUE
C
C      CONDITION THE FILTER
C
      SUMFIL=0.0
      DO 341 I=1,NT
        SUMFIL=SUMFIL + WW(I)
341  CONTINUE
      BOST = NT/SUMFIL
      DO 342 I=1,NT
        WW(I)=WW(I)*BOST
342  CONTINUE
C
C      ...TRANSFORM TO FREQUENCY DOMAIN AND FILTER
C
      CALL FFT(NT, SQREFW, +1.0)
      CALL FFT(NT, WW, +1.0)
      DO 350 I = 1, NT
        SQREFW(I) = SQREFW(I)*WW(I)
350  CONTINUE
C
C      ...TRUNCATE DC COMPONENT TO 5 SIGNIFICANT FIGURES
C
      TEMP=REAL(SQREFW(1))
      ENCODE(14, 345, BB)TEMP
      DECODE(14, 345, BB)TEMP1
345  FORMAT(1E14.5)
      SQREFW(1) = CMPLX(TEMP1, 0.0)
C
C      ...RETURN TO TIME DOMAIN
C
      CALL FFT(NT, SQREFW, -1.0)
C
C      RESTORE TIME SERIES
C
      SUMSQF = 0.0
      DO 346 I=1,NT
        SUMSQF = SUMSQF + SQREFW(I)**2
346  CONTINUE
      AVSQF = SUMSQF/NT
      BOOST = AVSQF/AVSQF
      DO 347 I=1,NT
        SQREFW(I) = SQREFW(I)*BOOST
347  CONTINUE
C

```

30

## GENERATION OF VERTICALLY INCIDENT SEISMOGRAMS

C  
C

APPLY AGC

```

CURRMIN = REAL(SQREFW(1))
DO 360 I= 2,NT
    CURRMIN = AMIN1(CURRMIN,REAL(SQREFW(I)))
360 CONTINUE
DO 380 I = 1,NT
    IF (CURRMIN.LT.0.0) THEN
        REFT(I) = REFT(I)/SQRT(REAL(SQREFW(I)) + ABS(CURRMIN*2.0))
    ELSE
        REFT(I) = REFT(I)/SQRT(REAL(SQREFW(I)))
    ENDIF
380 CONTINUE
RETURN
END

```

C-----  
C  
C  
C  
C-----

SUBROUTINE TERMIN

SUBROUTINE TERMIN(NERR, LNR)

```

COMMON / NUM / CL(200),QL(200),RHO(200),T(200),EPS,SIGMA,
+ CRUST,NL,NTRACE,LOBS,NW,TSEC,TSC,ASC,NMULT,
+ TLAG,YSIDE,TLNTH
COMMON / CHAR / ITIME,IDATE,IOBT,TITLE

IF (NERR .LT. 10) THEN
    WRITE(6,('(/" *** ERROR IN MODEL FILE LAYER: ",I4)') LNR
ELSEIF (NERR .LT. 20) THEN
    CALL PRTMLDA
    WRITE(6,('(/" *** ERROR IN PROCESSED LAYER: ",I4)') LNR
ENDIF

IF (NERR .EQ. 1) THEN
    WRITE(6,('(" TOO MANY LAYERS IN MODEL: ",I6," , MAX=200")') NL
ELSEIF (NERR .EQ. 3) THEN
    WRITE(6,('("CL CANNOT BE 0 AND H CANNOT BE -VE FOR FIRST
+LAYER")')
ELSEIF (NERR .EQ. 4) THEN
    WRITE(6,('("LAST LAYER CANNOT BE AN INTERPOLATED LAYER")')
ELSEIF (NERR .EQ. 5) THEN
    WRITE(6,('("ABSOLUTE DEPTH GIVEN IS LESS THAN THE CURRENT DEPTH")')

ELSEIF (NERR .EQ. 11) THEN
    WRITE(6,('("CL NOT IN RANGE 0 ‡ CL ‡ 10")')
ELSEIF (NERR .EQ. 12) THEN
    WRITE(6,('("QL ‡ 100")')
ELSEIF (NERR .EQ. 15) THEN
    WRITE(6,('("RHO NOT IN RANGE 0 ‡ RHO ‡ 10")')
ELSEIF (NERR .EQ. 21) THEN
    WRITE(6,('(/" *** TOO FEW (OR TOO MANY) VALUES ON ONE LINE "
+ "OF MODEL FILE -"/" CHECK FOR / AT END OF INTERPOLATED LAYER ",

```

## Test 3. Multiples

Two layers, 75 and 100 m thick, are sandwiched between half spaces (fig. 3B).  $Q = 200$  and density = 1.1 for all units. The 100-meter-thick layer has a velocity of 3.0 km/sec; the other units have a velocity of 1.5 km/sec. The seismogram consisted of the time-domain reflection coefficient plotted without filtering.

A series of tests were run with options beginning with "primaries only" to options for a selected number of "multiples" and finally a "complete-response" seismogram (fig. 5). R1 and R2 identify the reflections from the top of the two reflectors. M1

through M4 identify the "peg-leg" multiples. Figure 5A demonstrates the complete-response option; the clipping occurs because of a large amplification option ( $ASC = 100$ ). Figure 5B shows the seismogram for the same model but for a user option of only one multiple. Note that no reflections are observed beyond the first multiple arrival at 234 ms. Arrival times, amplitudes, and polarity in figure 5 are consistent with those predicted by hand calculations based on reflection-transmission coefficients. Table 3 summarizes the results.

Table 3. Arrival times of reflections and multiples for a two-layer model (fig. 5)

| Reflector index | Primary only | One multiple | Two multiples | Full response |
|-----------------|--------------|--------------|---------------|---------------|
| R1              | 100 ms       | 100 ms       | 100 ms        | 100 ms        |
| R2              | 167 ms       | 167 ms       | 167 ms        | 167 ms        |
| M1              | —            | 234 ms       | 234 ms        | 234 ms        |
| M2              | —            | —            | 300 ms        | 300 ms        |
| M3              | —            | —            | —             | 367 ms        |
| M4              | —            | —            | —             | 434 ms        |

Table 4. Input data used to test a full response (fig. 5A)

```

TEST 3 - D2L.  FULL RESPONSE OPTION.
EPS      SIGMA      YSIDE      XSIDE
0.001    0.1        40.        6.
CL       QL        RHO      THICKNESS
1.50     200.      1.1        0.
1.50     200.      1.1        75.
3.00     200.      1.1        100.
1.5      200.      1.1        0.
9999     9999      9999      9999
#TRC  #FREQ  T(MSEC)  IN/MSEC  AMP-SCALE  MLTPL  AGC  WINDOW
5      512   1000.   .006    100.0    -1    0    0
DETECTOR TYPE      DETECTOR LOCATION
REFLECTION          LAYER 1
FILTER PHASE
2 (NO FILTERS)
FILTER-TYPE  DB SLOPE  CUT-OFF FREQUENCY

```

TEST 2 - D1L. HIGH Q (=1500)  
 REFLECTION COEFFICIENT  
 AT OBS IN LAYER 1 AT .0 M DEPTH  
 FREQ(NW)= 512 T(MSECS)=2000  
 MIN = .50 HZ MAX =256.00 HZ  
 PRIMARIES ONLY  
 NO AGC. ASC = 1.  
 NO FILTERS

TEST 2 - D1L. LOW Q (=5)  
 REFLECTION COEFFICIENT  
 AT OBS IN LAYER 1 AT .0 M DEPTH  
 FREQ(NW)= 512 T(MSECS)=2000  
 MIN = .50 HZ MAX =256.00 HZ  
 PRIMARIES ONLY  
 NO AGC. ASC = 1.  
 NO FILTERS

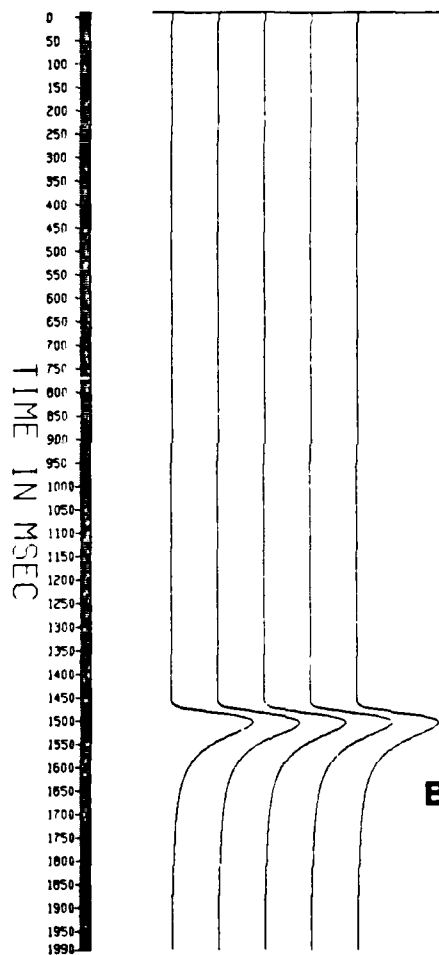
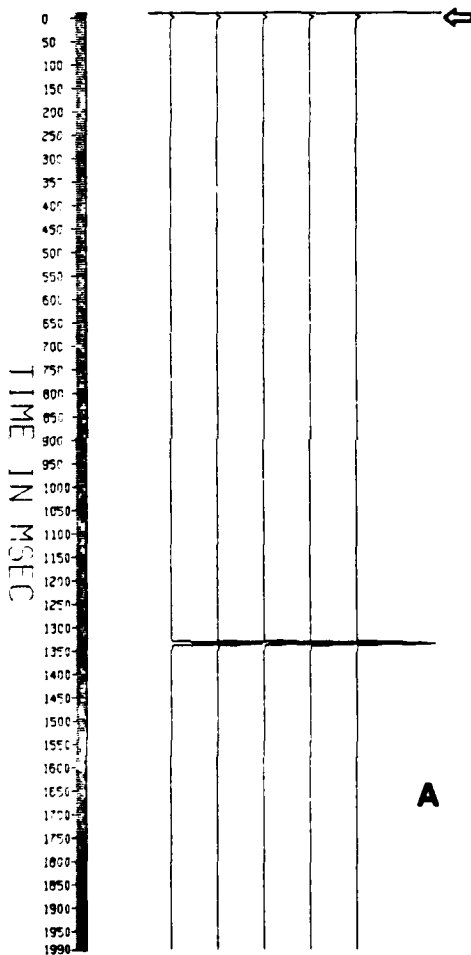


Figure 4. (Test 2) Reflection from a single layer (fig. 3A) for A,  $Q = 1500$  and B,  $Q = 5$ . Arrow identifies reflection from change in  $Q$  at upper half space.

## Test 2. Attenuation Factor Q

A layer 1000 m thick was overlain by a half space with an identical velocity (1.5 km/sec) and underlain by a half space with a velocity of 3.0 km/sec (fig. 3A). All units had a constant density of 1.1 gm/cc. No filter was applied. The seismograms consisted of a plot of reflection coefficients for primary arrivals only. A wide frequency range of 1-512 hz was invoked to study the waveforms better.

The Q of rocks for seismic energy is of the order 50, although poorly consolidated materials may be lower. In this test Q was varied from 5 to 2000. For Q values above 50, the response was essentially a spike with a width of less than 10 msec. Figure 4A illustrates a Q of 1500. For Q values of 20 or less, the pulse width of the response increased

to 20 msec, with a width of about 150 msec for a Q of 5 (fig. 4B). As expected, low Q emphasized lower frequencies.

A change of Q from 15 in the top half space to 1500 in a layer 1,000 m thick (but with no change in the user-specified velocity between these two regions) yielded a small pulse at zero time. (See arrow in fig. 4A.) This is consistent with our algorithm, which brings in attenuation changes through a complex velocity.

The following records (table 2) were used as input to Program VISP to generate figure 4A. The same records were used to generate figure 4B, except that QL values were all set equal to five.

Table 2. Input data used to test high Q (fig. 4A)

|                |       |                   |                   |           |       |     |        |
|----------------|-------|-------------------|-------------------|-----------|-------|-----|--------|
| TEST 2 - D1L.  |       | HIGH Q (=1500)    |                   |           |       |     |        |
| EPS            | SIGMA | YSIDE             | XSIDE             |           |       |     |        |
| 0.001          | 0.1   | 40.               | 6.0               |           |       |     |        |
| CL             | QL    | RHO               | THICKNESS         |           |       |     |        |
| 1.5            | 15.   | 1.1               | 0.                |           |       |     |        |
| 1.5            | 1500. | 1.1               | 1000.             |           |       |     |        |
| 3.0            | 1500. | 1.1               | 0.                |           |       |     |        |
| 9999           | 9999  | 9999              | 9999              |           |       |     |        |
| #TRC           | #FREQ | T(MSEC)           | IN/MSEC           | AMP-SCALE | MLTPL | AGC | WINDOW |
| 5              | 512   | 2000.             | .003              | 1.0       | 0     | 0   | 0      |
| DETECTOR TYPE  |       | DETECTOR LOCATION |                   |           |       |     |        |
| REFLECTION     |       | LAYER 1           |                   |           |       |     |        |
| FILTER PHASE   |       |                   |                   |           |       |     |        |
| 2 (NO FILTERS) |       |                   |                   |           |       |     |        |
| FILTER-TYPE    |       | DB SLOPE          | CUT-OFF FREQUENCY |           |       |     |        |

## Appendix 4. Input Records and Output Plots for 12 Tests

Thirteen tests were run to demonstrate the reliability of the options available to the user of Program VISIP. Test 1 consisted of a model simulating a standard field record (fig. 2). In the remaining 12 tests, three basic models were used: (1) one-layer, (2) two-layer, and (3) six-layer (figs. 3A-3C). Each of the

following test cases is related to one of these three models, although the velocity,  $Q$ , and (or) density may be varied. Program VISIP has detailed comment cards at the beginning that explain the various user options tested in this appendix.

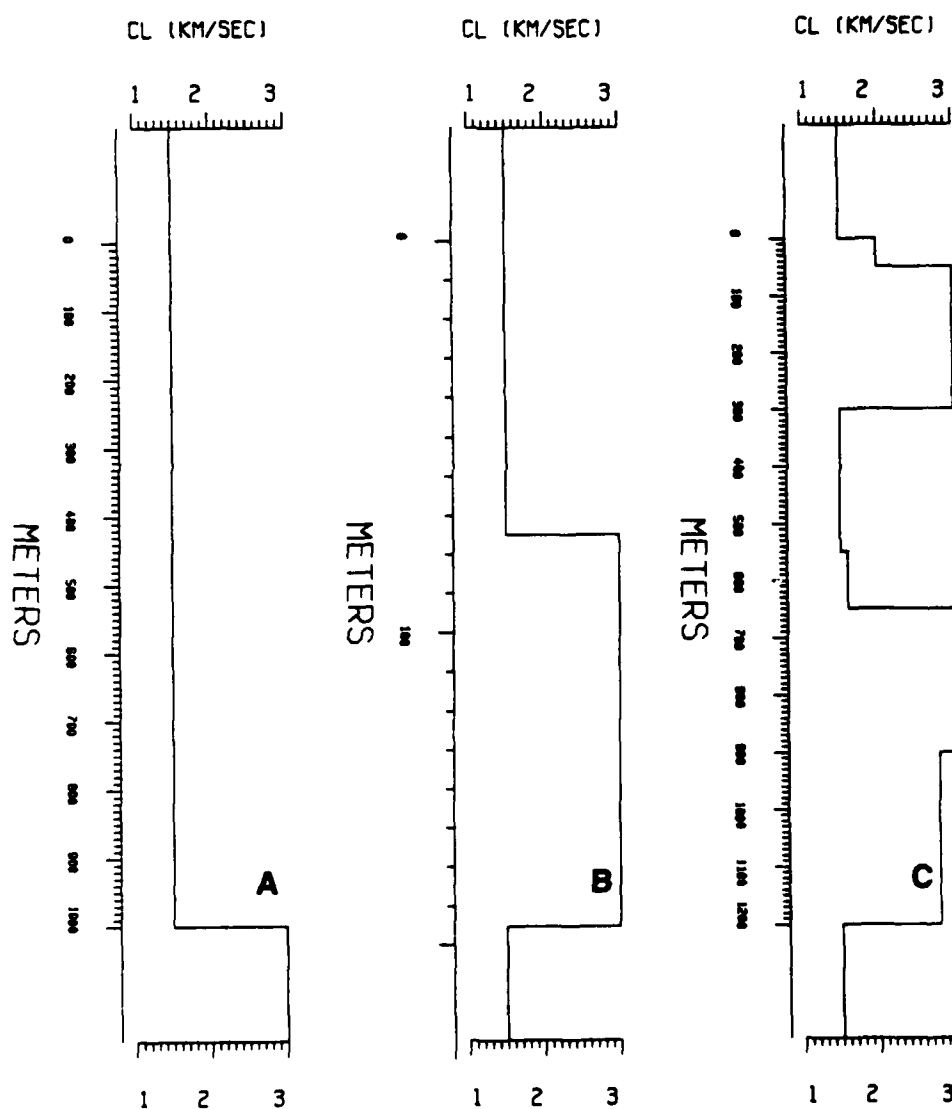


Figure 3. Velocity models for Tests 2-13 (appendix 4). A, one-layer; B, two-layer; C, six-layer.

```

      IF (MOD(IXRANGE,100) .EQ. 0)
+     CALL NUMBER(X-0.15,Y+YOFFSET,0.055,FLOAT(IXRANGE),0.0,-1)
      CALL PLOT(X,Y,INKOFF)
      CALL PLOT(X+0.75,Y,INKON)
      IF (I.EQ.0) CALL SYMBOL(X0+TLNTH/2-0.4,Y-0.7,0.16,
+     "METERS",0.0,6)

      Y = Y + 7.0 - 0.4
      X = X0

C
C
C
C
      PLOT MODEL PARAMETERS
      -----

DO 170 I=1,3
  IF (PMAX(I) .NE. PMIN(I))GO TO 55
  YSC = 0.0
  Y1 = YSTRIP/2
  GO TO 65
55  YSC = YSTRIP/(PMAX(I)-PMIN(I))
  Y1 = 0.0
65  YI = Y0 + 0.2 + (I-1)*(YSTRIP+0.2) + 0.1
  IF ((I.EQ.1) .OR. (I.EQ.5))
+  CALL PLOT(X0,YI+(PARM(1,I)-PMIN(I))*YSC+Y1,INKOFF)
  X = X0+0.75
  LIMIT=NL-1
  DO 180 J=1,LIMIT
    IF ((J.NE.1) .OR. ((I.LT.2) .OR. (I.GT.4)))GO TO 75
    CALL PLOT(X,YI+(PARM(2,I)-PMIN(I))*YSC+Y1,INKOFF)
    GO TO 85
75  CALL PLOT(X,YI+(PARM(J,I)-PMIN(I))*YSC+Y1,INKON)
    CALL PLOT(X,YI+(PARM(J+1,I)-PMIN(I))*YSC+Y1,INKON)
85  IF (J.LT.NL-1) X=X + T(J+1)*(TLNTH-1.5)/IXRANGE
180  CONTINUE
    X = X0+TLNTH
    CALL PLOT(X,YI+(PARM(NL,I)-PMIN(I))*YSC+Y1,INKON)
    IF(I.EQ.1)CALL SYMBOL(X0-0.6,Y0+(I-1)*(YSTRIP+.2)+.3,.1,
+ "CL (KM/SEC) ",90.,12)
    IF(I.EQ.2)CALL SYMBOL(X0-0.6,Y0+(I-1)*(YSTRIP+.2)+.3,.1,
+ "QL* ",90.,12)
    IF(I.EQ.3)CALL SYMBOL(X0-0.6,Y0+(I-1)*(YSTRIP+.2)+.3,.1,
+ "RHO (GM/CC) ",90.,12)
    CALL NUMBER(X0-0.6,Y0+1.96,0.10,PARMPY,90.0,3)
170  CONTINUE
    X0 = X0+TLNTH+2.5
    RETURN
  END

```

```

10      CALL PLOT(X,Y,INKOFF)
      IF(J.EQ.2)CALL PLOT(X+.1*(I*2-1),Y,INKON)
      CALL PLOT(X+0.1*(I*2-1),Y,INKON)
      CALL NUMBER(X+XOFFSET,Y,0.1,FLOAT(PMIN(J)),90.0,-1)
      CALL PLOT(X,Y,INKOFF)
      ISTART=PMIN(J)+1
      ISTOP=PMAX(J)
      DO 130 K=ISTART,ISTOP
        DO 140 L=1,10
          Y = Y + YSTRIP/((PMAX(J)-PMIN(J))*10)
          CALL PLOT(X,Y,INKON)
          IF(J.NE.2) CALL PLOT(X+0.05*(I*2-1),Y,INKON)
          CALL PLOT(X,Y,INKOFF)
140      CONTINUE
          CALL PLOT(X+0.1*(I*2-1),Y,INKON)
          IF(J.NE.2)
            CALL NUMBER(X+XOFFSET,Y-0.1,0.1,FLOAT(K),90.0,-1)
            IF(J.EQ.2.AND.K.EQ.PMAX(2))
              CALL NUMBER(X+XOFFSET,Y-0.1,0.1,FLOAT(K),90.0,-1)
            CALL PLOT(X,Y,INKOFF)
130      CONTINUE
20      Y = Y+0.1
120      CONTINUE
      X = X+TLNTH
      Y = Y0 + 0.2
110      CONTINUE
C
C      PLOT X AXIS
C      -----
      X = X0
      Y = Y0 + 0.2
      I = 0
      YOFFSET = -0.1+0.25*(I*2-1)
      CALL PLOT(X,Y,INKOFF)
      X = X+0.75
      CALL PLOT(X,Y,INKON)
      DO 160 N=1,IXRANGE,10
        J=N-1
        IF(MOD(J,100).NE.0)GO TO 30
        CALL PLOT(X,Y+0.1*(I*2-1),INKON)
        CALL NUMBER(X-0.05,Y+YOFFSET,0.055,FLOAT(J),0.0,-1)
        GO TO 40
30      CALL PLOT(X,Y+0.05*(I*2-1),INKON)
40      CALL PLOT(X,Y,INKOFF)
      X = X + (TLNTH-1.5)/IXRANGE*10
      CALL PLOT(X,Y,INKON)
160      CONTINUE
      CALL PLOT(X,Y+0.1*(I*2-1),INKON)

```

```

      INKON=2
      INKOFF=3
      Y0=0.5
      X0 = X0+2.0
      PARMAX = ABSPARM(1,2)
      DO 50 I= 2,NL
        PARMAX = AMAX1(PARMAX,ABSPARM(I,2))
50    CONTINUE
      IF(PARMAX.LT.100.0) PARMPY = 1.0
      IF(PARMAX.GE.100.0.AND.PARMAX.LT.1000.0) PARMPY = 0.1
      IF(PARMAX.GE.1000.0.AND.PARMAX.LT.10000.0) PARMPY = 0.01
      IF(PARMAX.GE.10000.0) PARMPY = 0.001
      DO 60 I=1,NL
        DO 70 J=1,3,2
          PARM(I,J) = ABSPARM(I,J)
70    CONTINUE
        PARM(I,2) = ABSPARM(I,2)*PARMPY
60    CONTINUE
      DO 80 I=1,3
        PMAX(I) = 0
        PMIN(I) = 1000
80    CONTINUE
      PMIN(1) = PARM(1,1)
      DO 90 I=2,NL
        DO 100 J=1,3
          PMAX(J) = MAX1(FLOAT(PMAX(J)),PARM(I,J)+0.999)
          PMIN(J) = MIN1(FLOAT(PMIN(J)),PARM(I,J))
100   CONTINUE
90    CONTINUE
      YSTRIP = 1.0
      IXRANGE = CRUST+0.99

      C
      C
      C
      C
      PLOT Y AXIS
      -----
      X = X0
      Y = Y0 + 0.2
      DO 110 M=1,2
        I=M-1
        XOFFSET = 0.12+0.3*(I*2-1)
        CALL PLOT(X,Y,INKOFF)
        DO 120 J=1,3
          Y = Y+0.1
          IF(PMIN(J).NE.PMAX(J))GO TO 10
          Y = Y + YSTRIP/2
          CALL PLOT(X,Y,INKOFF)
          CALL PLOT(X+0.1*(I*2-1),Y,INKON)
          CALL NUMBER(X+XOFFSET,Y,0.1,FLOAT(PMIN(J)),90.0,-1)
          Y = Y + YSTRIP/2
        GO TO 20

```

```

C      PLOT TIME SERIES
C      -----
C
      CURRMAX = ABS(REFT(1))
      NT=NW*2
      DO 290 I=2,NT
        CURRMAX = AMAX1(CURRMAX,ABS(REFT(I)))
290    CONTINUE
      X = X0
      Y = Y0 - 2.0
C
C      EFFECTIVELY A NULL TRACE (NOISE)
C
      IF (CURRMAX.LT.0.1) CURRMAX=-10.0
      DO 300 ITHETA=1,NTRACE
        AY = (ITHETA-0.5)*XSC
        CALL PLOT(X,Y+AY,INKOFF)
C
C      ALLOWS FOR TRUNCATED TIME SERIES (TSC ≠ 0)
C
      NPTS = NW*2*AMIN1(1.0,YSIDE/(TSEC*TSC))
      YSC = NPTS*TSEC*TSC/((NPTS-1)*NW*2)
      DO 310 I=1,NPTS
        IF(.NOT. ASC.EQ.1.0) GO TO 55
        XX(I) = X+(I-1)*YSC
        YY(I) = Y+AY+REFT(I)/(CURRMAX*2)
        CALL PLOT(XX(I),YY(I),INKON)
      GO TO 310
55    X1 = AMIN1(ABS(REFT(I))*ASC/(CURRMAX*2), 0.4)
      IF (REFT(I) .LT. 0.0) X1=-X1
      XX(I) = X+(I-1)*YSC
      YY(I) = Y+AY+X1
      CALL PLOT(XX(I),YY(I),INKON)
310  CONTINUE
300  CONTINUE
      RETURN
      END
C-----
C
C      SUBROUTINE PARMPLT
C-----
C
      SUBROUTINE PARMPLT
      COMMON/ PLTPAR /NTRACE,YSIDE,TSEC,TSC,TLAG,ASC,REFT(1024),NW
      *,IOBT,LOBS,NMULT,NL,CL(200),QL(200),RHO(200),T(200),TLNTH,X0
      *,CRUST,IAGC,WINDOW,NFILT
      COMMON/ FILTDT /IDB(10),IFILTYP(10),MPHASE,FF1(10)
      REAL      ABSPARM(200,3), PARM(200,3), TLNTH
      EQUIVALENCE (ABSPARM(1,1),CL(1))
      INTEGER  PMAX(3),PMIN(3)

```

C

```

X = X0
Y = Y0 - 2.4
I=0
XOFFSET = 0.07+0.3*(I*2-1)
CALL PLOT(X,Y,INKOFF)
DO 270 M=1,IYRANGE
  J=M-1
  IF(.NOT.MOD(J-1,MODF) .EQ. INT(TLAG)-1) GO TO 50
  CALL PLOT(X,Y+0.1*(I*2-1),INKON)

```

C

C CHANGE SIZE OF CHARACTER

C

```

IF(TSC.LT.(.01))GO TO 49
CALL NUMBER(X-0.07,Y+XOFFSET,0.055,FLOAT(J)-TLAG,0.,-1)
GO TO 50
49 CALL NUMBER(X+.03,(Y+XOFFSET)-.05,0.055,FLOAT(J)-TLAG,90.,-1)
50 IF(.NOT.MOD(J,(MODF-1)/10+1).EQ.0) GO TO 51
  CALL PLOT(X,Y+0.07*(I*2-1),INKON)
51 CALL PLOT(X,Y,INKOFF)
  IF(.NOT.IYRANGE.LE.20)GO TO 52
  DO 280 K=1,10
    X = X + TSC*0.1
    CALL PLOT(X,Y,INKON)
    CALL PLOT(X,Y+0.05*(I*2-1),INKON)
    CALL PLOT(X,Y,INKOFF)
280 CONTINUE
  GO TO 270
52 X = X+TSC
  CALL PLOT(X,Y,INKON)
270 CONTINUE
  CALL PLOT(X,Y+0.1*(I*2-1),INKON)
  IF(TSC.LT.(.01))GO TO 53
  CALL NUMBER(X-0.07,Y+XOFFSET,.055,FLOAT(IYRANGE)-TLAG,0.0,-1)
  GO TO 54
53 CALL NUMBER(X+.022,(Y+XOFFSET)-.05,.055,FLOAT(IYRANGE)-TLAG,
*90.,-1)
54 Y = Y0 - 1.4

X = X0+IYRANGE*TSC/2-1.5
CALL SYMBOL(X+.75,Y-1.5,.15,"TIME IN MSEC ",0.0,13)

```

C

C

C

C

PLOT X AXIS

-----

C

```

Y = Y0 - 2.0
CALL PLOT(X0,Y,INKOFF)
CALL PLOT(X0,Y+0.4+YS,INKON)

```

C

C

```

33 CALL SYMBOL(X0+1.8,6.5,.1,"---FILTERS = ZERO PHASE---",90.,26)
34 DO 101 I=1,NFILT
    IF(IFILTYP(I).NE.1)GO TO 35
    CALL NUMBER(X0+1.9+I*.15,7.5,.1,FF1(I),90.,0)
    CALL NUMBER(X0+1.9+I*.15,8.3,.1,FLOAT(IDB(I)),90.,-1)
    CALL SYMBOL(X0+1.9+I*.15,6.5,.1,
    *"HIGH CUT AT      HZ;      DB SLOPE",90.,33)
35 IF(IFILTYP(I).NE.2)GO TO 36
    CALL NUMBER(X0+1.9+I*.15,7.5,.1,FF1(I),90.,0)
    CALL NUMBER(X0+1.9+I*.15,8.3,.1,FLOAT(IDB(I)),90.,-1)
    CALL SYMBOL(X0+1.9+I*.15,6.5,.1,
    *"LOW CUT AT      HZ;      DB SLOPE",90.,33)
36 IF((IFILTYP(I).NE.1).AND.(IFILTYP(I).NE.2))GO TO 37
    GO TO 101
37 IF(I.EQ.2)GO TO 101
    CALL SYMBOL(X0+1.9+I*.15,6.5,.1,
    *"NOTCH      DB FREQUENCY RANGE      -      HZ",90.,95)
    CALL NUMBER(X0+1.9+I*.15,8.9,.1,FF1(1),90.,-1)
    CALL NUMBER(X0+1.9+I*.15,9.4,.1,FF1(2),90.,-1)
101 CONTINUE
31 IF(IACC.NE.1)GO TO 12
    CALL SYMBOL(X0+1.4,6.5,.1,"AGC WINDOW =      MSECS",90.,24)
    CALL NUMBER(X0+1.4,7.8,.1,WINDOW,90.,0)
    GO TO 30
12 CALL SYMBOL(X0+1.4,6.5,.1,"NO AGC. ASC =      ",90.,14)
    CALL NUMBER(X0+1.4,7.9,.1,ASC,90.,0)
30 X0 = X0+3.0
    XSC = 0.30

C
C   FOR TRUNCATED TIME SERIES
C
    IYRANGE = AMIN1(TSEC,YSIDE/TSC) - 0.01 + 1
C
C   (TSC  $\neq$  0)
C
    IF (IYRANGE .LE. 10) MODF=1
    IF (IYRANGE .LE. 20) MODF=2
    IF (IYRANGE .LE. 50) MODF=5
    IF (IYRANGE .LE. 100) MODF=10
    IF (IYRANGE .GT. 100) MODF=50
    YS = NTRACE*XSC

C
C   PLOT Y(TIME) AXES
C   -----

```

```

COMMON/ FILTDT /IDB(10),IFILTYP(10),MPHASE,FF1(10)
DIMENSION XX(1024),YY(1024)
LOGICAL MPHASE
INKON=2
INKOFF=3
R=0.0
Y0=9.0
X0=0.75
IF(IOBT.EQ.1)CALL SYMBOL(X0,6.5,.1,
+ "PRESSURE",90.,24)
IF(IOBT.EQ.2)CALL SYMBOL(X0,6.5,.1,
+ "VERTICAL DISPLACEMENT",90.,24)
IF(IOBT.NE.1.AND.IOBT.NE.2)CALL SYMBOL(X0,6.5,
+.1,"REFLECTION COEFFICIENT",90.,22)
IF(LOBS.NE.0)GO TO 10
GO TO 15
10 CALL SYMBOL(X0+.26,6.5,.1,
+ "AT OBS IN LAYER AT M DEPTH",90.,39)
CALL NUMBER(X0+.26,8.1,.1,FLOAT(LOBS),90.,-1)
CALL SYMBOL(X0+.52,6.5,.1,"FREQ(NW)",90.,9)
CALL NUMBER(X0+.52,7.4,.1,NW,90.,-1)
CALL SYMBOL(X0+.52,8.5,.1,"T(MSECS)",90.,9)
CALL NUMBER(X0+.52,9.3,.1,TSEC,90.,-1)
K=LOBS-1
IF(K.LT.2) GO TO 11
DO 20 I=2,K
R=R+T(I)
20 CONTINUE
11 CALL NUMBER(X0+.26,8.7,.1,R,90.,1)
15 CALL SYMBOL(X0+.8,6.4,.1," MIN = HZ",90.,17)
CALL NUMBER(X0+.8,7.2,.1,(1/TSEC)*1000.,90.,2)
CALL SYMBOL(X0+.8,8.1,.1,"MAX = HZ",90.,14)
CALL NUMBER(X0+.8,8.55,.1,(NW/TSEC)*1000.,90.,2)
IF(NMULT.LT.0)CALL SYMBOL(X0+1.1,6.5,.1,
+ "FULL RESPONSE (ALL MULTIPLES)",90.,29)
IF(NMULT.EQ.0)CALL SYMBOL(X0+1.1,6.5,.1,"PRIMARIES ONLY",
+90.,14)
IF(NMULT.GT.0)GO TO 25
GO TO 28
25 CALL SYMBOL(X0+1.1,6.5,.1,"NUMBER OF MULTIPLES =",90.,21)
CALL NUMBER(X0+1.1,8.7,0.1,FLOAT(NMULT),90.,-1)
28 IF(NFILT.GT.0)GO TO 27
CALL SYMBOL(2.5,6.5,.1,"NO FILTERS",90.,10)
GO TO 31
27 IF(.NOT.MPHASE)GO TO 33
CALL SYMBOL(X0+1.8,6.5,.1,"---FILTERS = MINIMUM PHASE---",90.,29)
GO TO 34

```

```

989  FORMAT(5X,F10.0,5X,F10.5,6X,F10.0,5X,F10.5)
      IF(NFILT.EQ.0)GO TO 985
      DO 15 I=1,NFILT
        READ(1,986)IFILTYP(I),IDB(I),FF1(I)
986   FORMAT(12X,I2,10X,I3,19X,F5.1)
15   CONTINUE
985   READ(1,987)IOBT,LOBS,NMULT,CRUST,IAGC,WINDOW
987   FORMAT(6X,I1,6X,I3,7X,I5,7X,F10.5,6X,I3,7X,F7.2)
      NT=2*NW
      DO 5 I=1,NL
        READ(1,102)CL(I),QL(I),RHO(I),T(I)
102   FORMAT(4X,F5.2,4X,F6.0,5X,F5.2,3X,F6.1)
5     CONTINUE
      DO 10 I=1,NT
        READ(1,101)REFT(I)
101   FORMAT(5X,F20.14)
10    CONTINUE
      RETURN
      END

```

```

C-----
C
C                                     SUBROUTINE INITPLT
C-----

```

```

SUBROUTINE INITPLT
COMMON/ CHAR /TITLE(8)
COMMON/ PLTPAR /NTRACE,YSIDE,TSEC,TSC,TLAG,ASC,REFT(1024),NW
+,IOBT,LOBS,NMULT,NL,CL(200),QL(200),RHO(200),T(200),TLNTH,X0
+,CRUST,IAGC,WINDOW,NFILT
COMMON/ FILTDT /IDB(10),IFILTYP(10),MPHASE,FF1(10)
CALL SYMBOL(.5,.5,0.15,"VISP; ",90.,6)
CALL SYMBOL(.5,.8,.15,"      PLOTS OF PARAMETERS      ",
+90.0,34)
CALL SYMBOL(1.5,.5,.1,TITLE,90.,80)
CALL SYMBOL(.5,6.5,.12,TITLE,90.,80)
X0=1.5
RETURN
END

```

```

C-----
C
C                                     SUBROUTINE RSPMDL
C-----

```

```

SUBROUTINE RSPMDL
COMMON/ PLTPAR /NTRACE,YSIDE,TSEC,TSC,TLAG,ASC,REFT(1024),NW
+,IOBT,LOBS,NMULT,NL,CL(200),QL(200),RHO(200),T(200),TLNTH,X0
+,CRUST,IAGC,WINDOW,NFILT

```

=====

## PROGRAM PLTVISP

(PLOTING ROUTINE FOR PROGRAM VISP)

MODIFIED FOR CDC 855 USE AT INDIANA UNIVERSITY  
 FROM PLOTTING CODE DEVELOPED BY FRAZER, BATES  
 AND RUDMAN AT THE HAWAII INSTITUTE OF GEOPHYSICS

INPUT FOR THIS PROGRAM IS GENERATED AS A FILE  
 ON TAPE 4 (AND DESIGNATED "PLTIN") BY PROGRAM  
 VISP (SEE SUBROUTINE WRTPLT).

## MAIN PROGRAM

```

PROGRAM TSTPLT(TAPE1,OUTPUT,TAPE4=OUTPUT,PLOT,TAPE7=PLOT)
COMMON/ CHAR /TITLE(8)
COMMON/ PLTPAR /NTRACE,YSIDE,TSEC,TSC,TLAG,ASC,REFT(1024),NW
+,IOBT,LOBS,NMULT,NL,CL(200),QL(200),RHO(200),T(200),TLNTH,X0
+,CRUST,IAGC,WINDOW,NFILT
COMMON/ FILTDT /IDB(10),IFILTYP(10),MPHASE,FF1(10)
CALL IDENT(7)
CALL READINP
CALL INITPLT
CALL PARMPLT
CALL RSPMDL
CALL PLOT(0.,0.,999)
STOP
END

```

## SUBROUTINE READINP

```

SUBROUTINE READINP
COMMON/ CHAR /TITLE(8)
COMMON/ PLTPAR /NTRACE,YSIDE,TSEC,TSC,TLAG,ASC,REFT(1024),NW
+,IOBT,LOBS,NMULT,NL,CL(200),QL(200),RHO(200),T(200),TLNTH,X0
+,CRUST,IAGC,WINDOW,NFILT
COMMON/ FILTDT /IDB(10),IFILTYP(10),MPHASE,FF1(10)
READ(1,1001)TITLE
1001 FORMAT(8A10)
READ(1,999)NTRACE,YSIDE,NW,TLNTH,NL,NFILT,MPHASE
999 FORMAT(7X,14,7X,F5.2,4X,15,7X,F5.2,4X,13,7X,13,8X,L2)
READ(1,989)TSEC,TSC,TLAG,ASC

```

## APPENDIX 3

+ "DECLARATION LINES")')

ELSEIF (NERR .EQ. 23) THEN  
 WRITE(6, '(/" \*\*\* ERROR - NFREQ ",14," MUST BE A POWER OF 2"  
 ", 16-512")') LNR

+ ELSEIF (NERR .EQ. 25) THEN  
 WRITE(6, '(/" \*\*\* ERROR - TIME ",14," TOO SHORT (MIN 1 MSEC)"  
 ')') LNR

ELSEIF (NERR .EQ. 27) THEN  
 WRITE(6, '(/" \*\*\* ERROR - NTRACE † 10")')

ELSEIF (NERR .EQ. 29) THEN  
 WRITE(6, '(/" \*\*\* ERROR - ASC † 1 OR † 100")')

ELSEIF (NERR .EQ. 30) THEN  
 WRITE(6, '(/" \*\*\* ERROR - † 10 FILTERS REQUESTED: ",14)')  
 LNR

+ ELSEIF (NERR .EQ. 31) THEN  
 WRITE(6, '(/" \*\*\* LAYER FOR OBS PLACEMENT † 2 OR † NUMBER",  
 " OF LAYERS")')

+ ELSE  
 WRITE(6, '(" \*\*\* UNKNOWN ERROR, NUMBER: ",14)') NERR  
 ENDIF  
 STOP  
 END

TEST 3 - D2L. FULL RESPONSE (ASC = 100).

REFLECTION COEFFICIENT

AT OBS IN LAYER 1 AT .0 M DEPTH

FREQ(NW)= 512 T(MSECS)= 1000

MIN = 1.00HZ MAX = 512.00 HZ

FULL RESPONSE (ALL MULTIPLES)

NO AGC. ASC = 100.

NO FILTERS

TEST 3 - DW2L. ONE-MULTIPLE OPTION.

REFLECTION COEFFICIENT

AT OBS IN LAYER 1 AT .0 M DEPTH

FREQ(NW)= 512 T(MSECS)= 1000

MIN = 1.00HZ MAX = 512.00 HZ

NUMBER OF MULTIPLES = 1

NO AGC. ASC = 100.

NO FILTERS

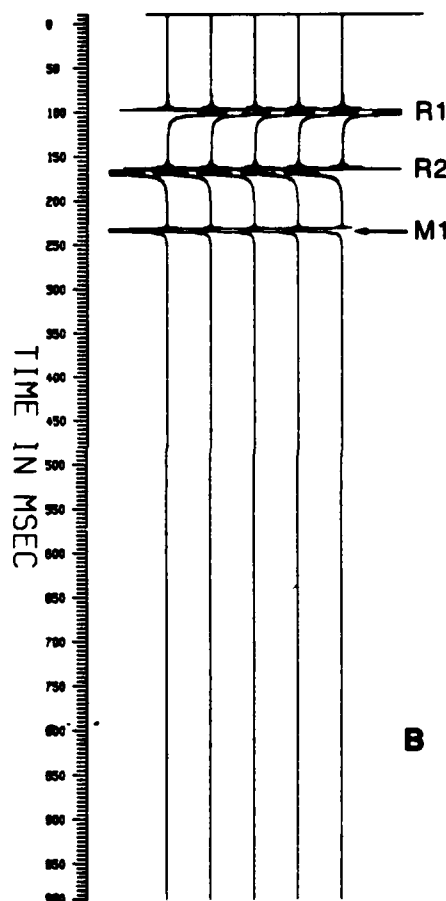
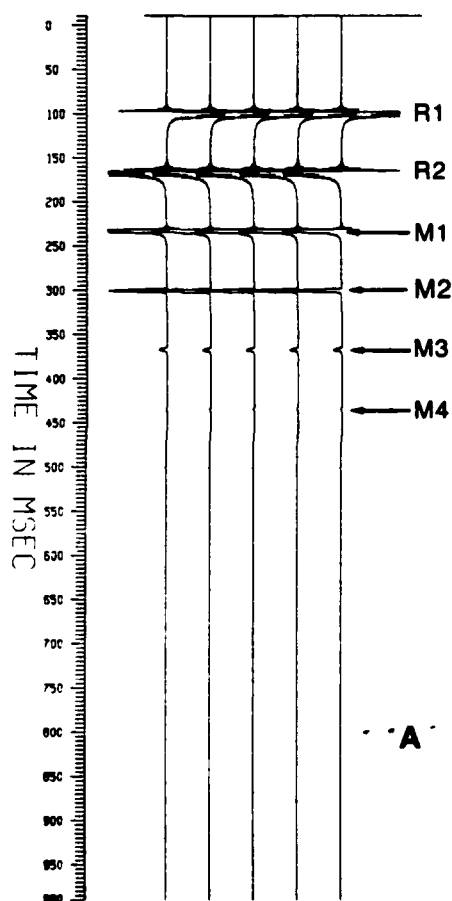


Figure 5. (Test 3) Reflections from a two-layer model (fig. 3B) for A, full-response option and B, one-multiple option. Reflections R and multiples M are identified in table 4.

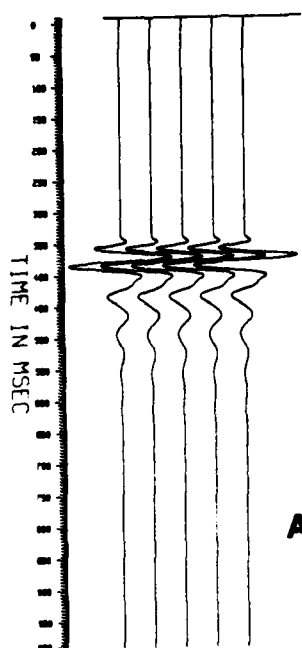
The following records (table 4) were used as input to Program VISF to generate all multiples shown in figure 5A. Figure 5B, a

test of one multiple only, has the same input records except MLTPL is changed from -1 to 1.

## GENERATION OF VERTICALLY INCIDENT SEISMOGRAMS

TEST 4 - DIL. BAND PASS (10-50 HZ)

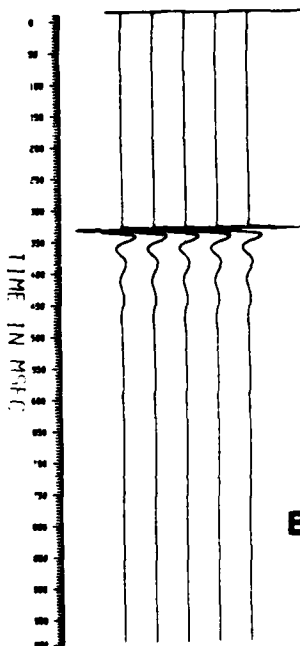
---FILTERS = MINIMUM PHASE---

HIGH CUT AT 50. HZ:96 DB SLOPE  
LOW CUT AT 10. HZ:96 DB SLOPE

A

TEST 4 - DWIL. BAND-PASS (10-500 HZ).

---FILTERS = MINIMUM PHASE---

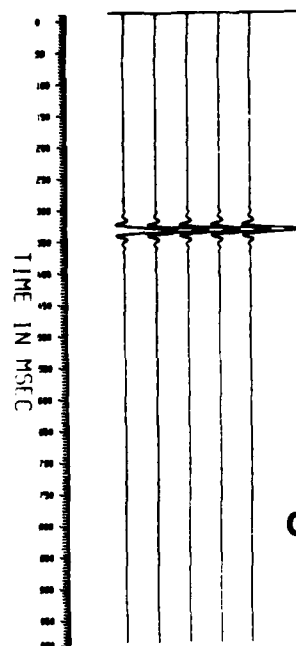
HIGH CUT AT 500. HZ:96 DB SLOPE  
LOW CUT AT 10. HZ:96 DB SLOPE

B

TEST 4 - DWIL. HIGH CUT (ZERO PHASE).

---FILTERS = ZERO PHASE---

HIGH CUT AT 75. HZ:96 DB SLOPE

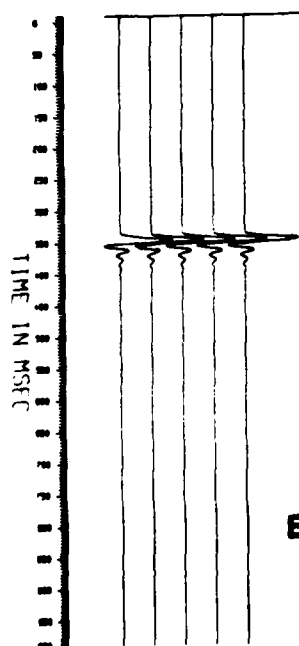


C

TEST 4 - DWIL. HIGH CUT (MINIMUM PHASE).

---FILTERS = MINIMUM PHASE---

HIGH CUT AT 75. HZ:96 DB SLOPE

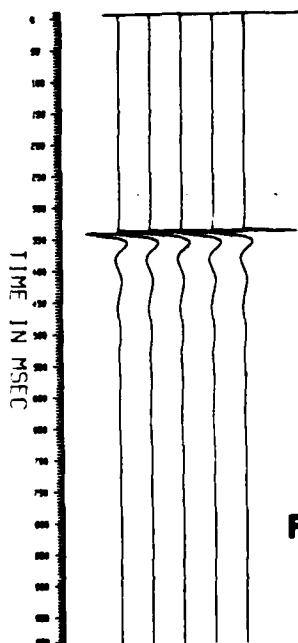


E

TEST 4 - DWIL. LOW CUT (MINIMUM PHASE).

---FILTERS = MINIMUM PHASE---

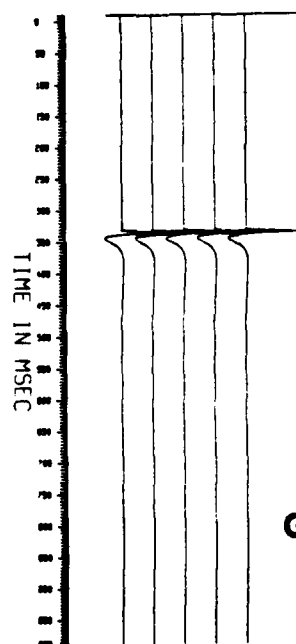
LOW CUT AT 5. HZ:96 DB SLOPE



F

TEST 4 - DIL. FILTER SLOPE (6 DB)

---FILTERS = MINIMUM PHASE---

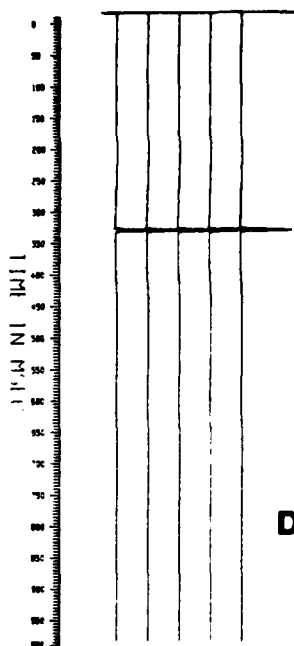
HIGH CUT AT 50. HZ:6 DB SLOPE  
LOW CUT AT 10. HZ:6 DB SLOPE

G

TEST 4 - DWIL. LOW CUT (ZERO PHASE)

---FILTERS = ZERO PHASE---

LOW CUT AT 5. HZ:96 DB SLOPE



```

REFLECTION COEFFICIENT
AT OBS IN LAYER      1  AT .0      M DEPTH
FREQ(NW)= 512          T(MSECS)= 1000
MIN = 1.00HZ          MAX = 512.00 HZ
PRIMARIES ONLY
NO AGC. ASC = 1.

```

**Figure 6. (Test 4) Reflections from a one-layer model (fig. 3A) used to display filter options. A, band pass of 10-50 hz; B, band pass of 10-500 hz; C, D, E, F, high and low cut with minimum and zero phase; G, band pass with 6-db slope versus 96-db slope used in A.**

## Test 4. Filters

A single layer 250 m thick is overlain by a half space with the same velocity (1.5 km/sec) and underlain by a half space with a velocity of 3.0 km/sec (fig. 3A). This one-layer model was used to test all filter options. Layer and half spaces have identical  $Q$  (200) and density (1.1). The single reflector permits a study of the waveform as a variety of filter parameters are changed (figs. 6A-6G).

**Band Pass.** Comparison of a minimum-phase band pass of 10-50 hz (fig. 6A) versus 10-500 hz (fig. 6B) shows high frequencies in the wider band pass (in the form of a spike). The dominant period on the 10-50 hz record is 30 msec (or 33 hz), about the center of the band pass. Band-pass slope was unchanged in figures 6A and 6B.

Table 5 is a copy of the input records used to generate a 10-50 hz band-pass filter (fig. 6A). To generate a 10-500 hz band-pass filter (fig. 6B), one needs only to change the cutoff frequency from 50 to 500.

**Notch Filter.** If a notch filter is desired, the input is similar to the band-pass option except that the "filter-type" is designated as 3 for both input lines. (See table 5.)

**High and Low Cut (zero phase).** A high-cut filter (low pass) set at 75 hz with 96-db slope and zero phase shows the reflection with a dominant period of 15 msec or 66 hz (fig. 6C).

A low-cut filter set at 5 Hz with 96-dB slope and zero phase shows the reflection characterized by a sharp spike (fig. 6D). Because the low-cut filter essentially passes all frequencies, we expect to see a spike. A zero-phase filter is noncausal; arrivals occur before the expected arrival times of 333 msec (two-way distance of 500 m at 1500 m/sec). Note that the dominant arrival (maximum amplitude) occurs at 333 msec.

Table 6 is a copy of the input records used to generate a high-cut filter (fig. 6C). To generate a low-cut filter (fig. 6D), change "filter-type" from 1 to 2 and change cutoff frequency from 75 to 5.

Table 5. Input data used to test a 10-50 hz band-pass filter (fig. 6A)

```

TEST 4 - D1L.  BAND-PASS (10-50 HZ).
EPS      SIGMA  YSIDE  XSIDE
0.001    0.1    40.    6.
CL       QL     RHO    THICKNESS
1.5      200.   1.1    0.
1.5      200.   1.1    250.
3.0      200.   1.1    0.
9999     9999   9999   9999
#TRC #FREQ T(MSEC)  IN/MSEC AMP-SCALE MLTPL AGC WINDOW
5     512  1000.   .006    1.0    0    0    0
DETECTOR TYPE      DETECTOR LOCATION
REFLECTION          LAYER 1
FILTER PHASE
1 (MINIMUM PHASE)
FILTER-TYPE DB SLOPE CUT-OFF FREQUENCY
1           96      50
2           96      10

```

Table 6. Input data used to test a high-cut filter with zero phase (fig. 6C)

```

TEST 4 - D1L.  HIGH CUT (ZERO PHASE).
EPS      SIGMA  YSIDE  XSIDE
0.001    0.1    40.    6.
CL       QL     RHO    THICKNESS
1.5      200.   1.1    0.
1.5      200.   1.1    250.
3.0      200.   1.1    0.
9999     9999   9999   9999
#TRC #FREQ T(MSEC)  IN/MSEC AMP-SCALE MLTPL AGC WINDOW
5     512  1000.   .006    1.0    0    0    0
DETECTOR TYPE      DETECTOR LOCATION
REFLECTION          LAYER 1
FILTER PHASE
0 (ZERO PHASE)
FILTER-TYPE DB SLOPE CUT-OFF FREQUENCY
1           96      75

```

*High and Low Cut (minimum phase).* The model used to study the zero-phase filter (above) was rerun with minimum-phase option. A high-cut filter set at 75 hz with 96-db slope and minimum phase (fig. 6E) displays a slightly different waveform than the zero-phase filter. Now instead of the amplitude maximum at 333 msec, the first motion occurs at that time.

A low-cut filter set at 5 hz with minimum phase (fig. 6F) also shows a sharp peak at 333

msec. This is consistent with the minimum-phase characteristics of high frequencies occurring at the front of the waveform. Note that the minimum-phase filter passes a tail of lower frequencies (fig. 6F), although the same zero-phase filter does not.

Table 6, used to generate the high-cut filter with zero phase, may also be used to generate the minimum-phase filter. The user only needs to change "filter-phase" from 1 to 0 to obtain figure 6E. To obtain the low-cut

minimum-phase seismogram of figure 6F, the user needs to also change the filter type from 1 to 2 and the cutoff frequency from 75 to 5.

**Filter Attenuation.** The user may select the filter-attenuation factor (slope in decibel per octave) for high- and low-cut filters. Note the slope in decibels in a Butterworth filter is related to the number of poles ( $= \text{DB}/6 + 1$ ). Variations in slope were tested on a minimum-phase 10-50 hz band-pass filter (fig. 6A). With a slope of 96 DB/octave, the 10-50 hz band pass is a boxcar-type filter yielding a reflection signal ringing at 33 hz, about the center frequency of the band pass. But the same filter with a slope of 6 DB/octave yields a reflection with a narrow spike (fig. 6G). The low slope passes a large range of frequencies to generate the spike. Figure 6G is generated with the input records shown in table 5 except for a change of slope from 96 to 6 db.

#### Test 5. Amplitude Scale

The user has available a simple amplitude multiplier (ASC). A two-layer model (fig. 3B), 75 m and 100 m thick, was used to test this option. For this model, reflections and multiples repeat at a 67-msec interval. For a full-response option, an  $\text{ASC} = 100$  displays six events (fig. 5A); for an  $\text{ASC} = 1$ , only three events are readily visible (fig. 7). Note that amplitudes greater than 0.5 inch are clipped. Table 4 with amplitude scale changed from 100 to 1 will generate figure 7.

TEST 5 - D2L. FULL RESPONSE ( $\text{ASC} = 1$ ).

REFLECTION COEFFICIENT

AT OBS IN LAYER 1 AT .0 M DEPTH

FREQ(NW)= 512 T(MSECS)= 1000

MIN = 1.00HZ MAX = 512.00 HZ

FULL RESPONSE (ALL MULTIPLES)

NO AGC.  $\text{ASC} = 1$ .

NO FILTERS

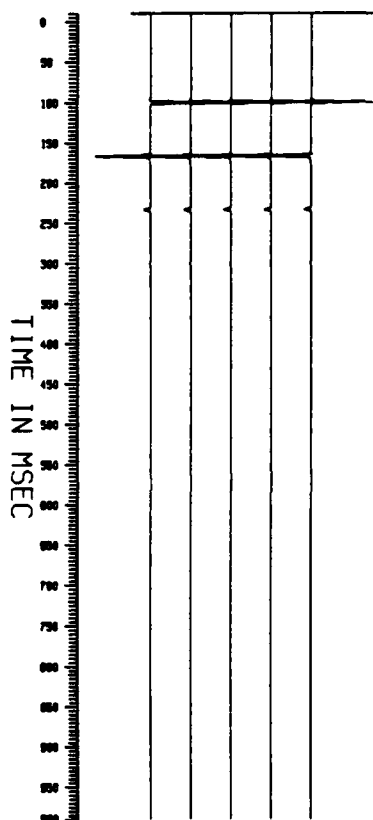
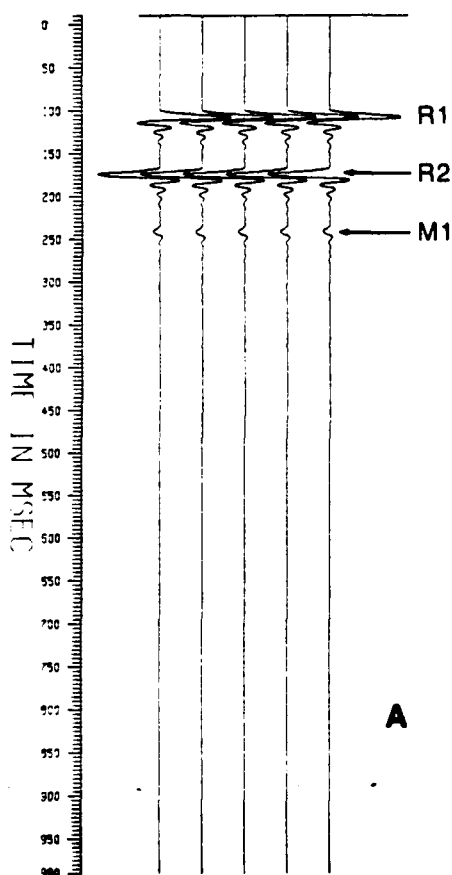


Figure 7. (Test 5) Reflections from a two-layer model (fig. 3B) with amplitude scale ( $\text{ASC}$ ) = 1. Compare with amplitude scale of 100 in figure 5A.

TEST 6 - D2L. TEST OF AGC.  
 REFLECTION COEFFICIENT  
 AT OBS IN LAYER 1 AT .0 M DEPTH  
 FREQ(NW)= 512 T(MSECS)= 1000  
 MIN = 1.00HZ MAX = 512.00 HZ  
 FULL RESPONSE (ALL MULTIPLES)  
 NO AGC. ASC = 1.

---FILTERS = MINIMUM PHASE---  
 HIGH CUT AT 100. HZ:96 DB SLOPE



TEST 6 - D2L. TEST OF AGC.  
 REFLECTION COEFFICIENT  
 AT OBS IN LAYER 1 AT .0 M DEPTH  
 FREQ(NW)= 512 T(MSECS)= 1000  
 MIN = 1.00HZ MAX = 512.00 HZ  
 FULL RESPONSE (ALL MULTIPLES)  
 AGC WINDOW = 10. MSECS

---FILTERS = MINIMUM PHASE---  
 HIGH CUT AT 100. HZ:96 DB SLOPE

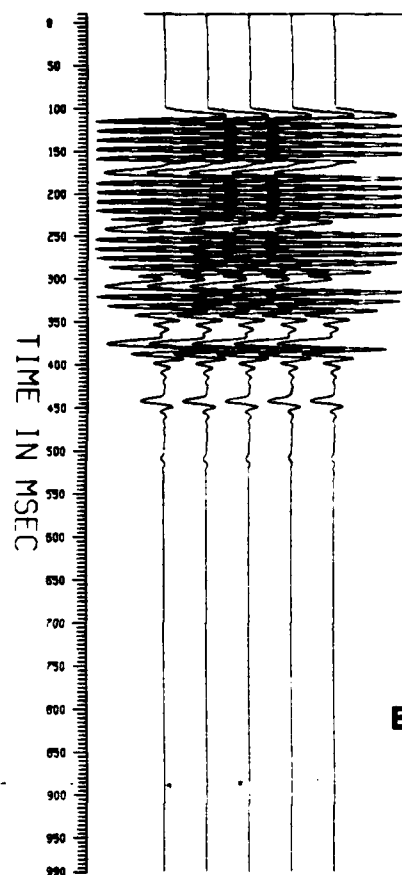


Figure 8. (Test 6) Full response from a two-layer model (fig. 3B) for A, no AGC; B, AGC with window = 10 msec; C, AGC with window = 60 msec; D, AGC with window = 500 msec. Reflections R1 and R2 and multiple M1 are identified in table 4.

## TEST 6 - D2L. TEST OF AGC.

REFLECTION COEFFICIENT

AT OBS IN LAYER 1 AT .0 M DEPTH

FREQ(NW)= 512 T(MSECS)=1000

MIN = 1.00HZ MAX =512.00 HZ

FULL RESPONSE (ALL MULTIPLES)

AGC WINDOW = 60. MSECS

---FILTERS = MINIMUM PHASE---

HIGH CUT AT 100. HZ:96 DB SLOPE

## TEST 6 - D2L. TEST OF AGC.

REFLECTION COEFFICIENT

AT OBS IN LAYER 1 AT .0 M DEPTH

FREQ(NW)= 512 T(MSECS)=1000

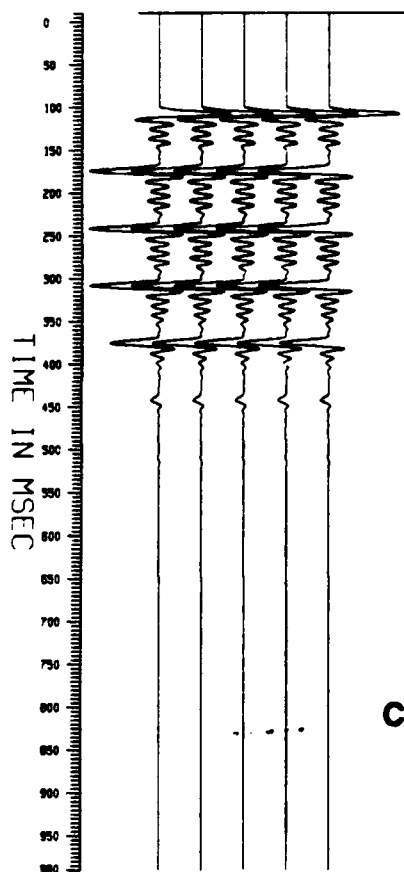
MIN = 1.00HZ MAX =512.00 HZ

FULL RESPONSE (ALL MULTIPLES)

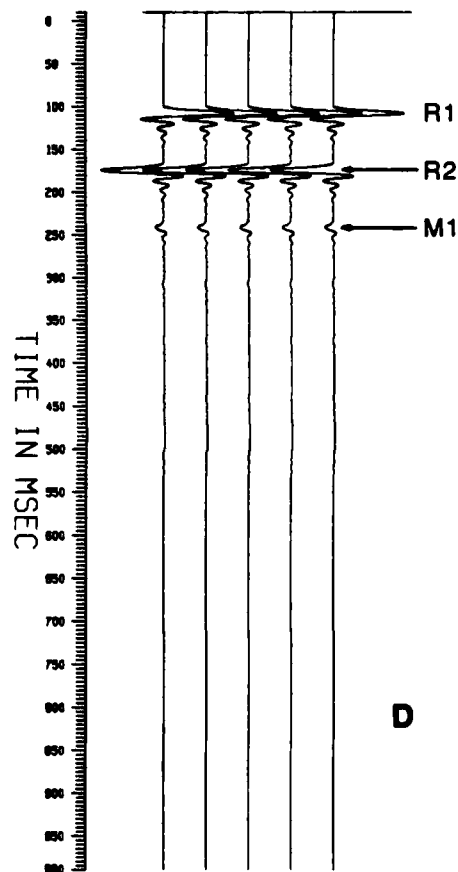
AGC WINDOW = 500.MSECS

---FILTERS = MINIMUM PHASE---

HIGH CUT AT 100. HZ:96 DB SLOPE



C



D

Figure 8 - Continued

## Test 6. Automatic Gain Control

*Theory.* Normally we perform automatic gain control (AGC) by dividing our time series by its own RMS value computed by using a

suitable window of fixed length. Therefore if  $f(t)$  is the input signal,  $f_c(t)$  is the AGC signal, and  $f_r(t)$  is the RMS signal, we have

$$f_r(t) = \left( \int f^2(\tau) W(t-\tau) d\tau \right)^{1/2} \quad (10)$$

and

$$f_c(t) = f(t) / f_r(t) \quad (11)$$

where

$$W(t) = (1 + \cos(2\pi |t| / TW)) / 2TW \quad (12)$$

is a window of length  $TW$  designated by the user. For convenience, Program VISIP carries out part of this computation in the frequency domain. Let  $F(f^2)$  denote the Fourier

transform of  $f^2(t)$  and  $F(W)$  the Fourier transform of  $W(t)$ .  $F^{-1}$  is the inverse Fourier transform. Then

$$f_c(t) = f(t) / \{F^{-1}[F(f^2)F(W)]\}^{1/2} \quad (13)$$

is the algorithm used.

*Window Size.* A two-layer model (fig. 3B), 75 and 100 m thick, was used to test the action of the AGC window size. Without AGC and  $ASC = 1$ , two reflectors (R1 and R2) and one multiple (M1) were observable (fig. 8A). The time interval between events is 67 msec. A small window (10 msec) yields a noisy (ringing) record that does not allow easy identification of the early events (fig. 8B). A window comparable to the expected time intervals (60 msec) still has some (ringing)

noise (fig. 8C). If the window (520 msec) is one-half or more of the time span of the entire record (1000 msec), a seismogram is obtained similar to the original record without AGC (fig. 8D). The ENCODE/DECODE statements in subroutine AGCFREQ were included to circumvent difficulties with significant figures. Users may have to adjust this part of the code for their computers.

Table 7 is a copy of the input records used to create figure 8C.

Table 7. Input data used to test automatic gain control (fig. 8C)

|                   |       |                   |           |                   |       |     |        |
|-------------------|-------|-------------------|-----------|-------------------|-------|-----|--------|
| TEST 6 - D2L.     |       | TEST OF AGC.      |           |                   |       |     |        |
| EPS               | SIGMA | Y SIDE            | X SIDE    |                   |       |     |        |
| 0.001             | 0.1   | 40.               | 6.0       |                   |       |     |        |
| CL                | QL    | RHO               | THICKNESS |                   |       |     |        |
| 1.50              | 200.  | 1.1               | 0.        |                   |       |     |        |
| 1.50              | 200.  | 1.1               | 75.       |                   |       |     |        |
| 3.00              | 200.  | 1.1               | 100.      |                   |       |     |        |
| 1.50              | 200.  | 1.1               | 0.        |                   |       |     |        |
| 9999              | 9999  | 9999              | 9999      |                   |       |     |        |
| #TRC              | #FREQ | T(MSEC)           | IN/MSEC   | AMP-SCALE         | MLTPL | AGC | WINDOW |
| 5                 | 512   | 1000.             | .006      | 1.0               | -1    | 1   | 60.    |
| DETECTOR TYPE     |       | DETECTOR LOCATION |           |                   |       |     |        |
| REFLECTION        |       | LAYER 1           |           |                   |       |     |        |
| FILTER PHASE      |       |                   |           |                   |       |     |        |
| 1 (MINIMUM PHASE) |       |                   |           |                   |       |     |        |
| FILTER-TYPE       |       | DB                | SLOPE     | CUT-OFF FREQUENCY |       |     |        |
| 1                 |       |                   | 96        | 100               |       |     |        |

## Test 7. Computational Frequency (NW)

A model with a single layer (fig. 3A) was used to test the importance of the user's choice of computational frequencies (NW) for a fixed record length of  $T = 1000$  msec. Figures 9A, 9B, and 9C show signal quality for computational frequencies of 16, 64, and 256 hz. A 10-50 hz minimum-phase band-pass filter was applied to the output. Comparison of NW = 16, 64, and 256 yielded seismograms that were subjectively evaluated, respectively,

as: not acceptable, poor, and excellent. Although not shown here, record quality for NW = 128 was good. For NW = 512 the record was identical to 256. On a CDC Cyber 170/855 the times, excluding compilation and plotting, varied from 0.088 sec for 16 hz, 0.196 sec for 64 hz, and 0.621 sec for 256 hz.

Table 8 is a copy of the input records used to create figure 9.

Table 8. Input data used to test computational frequencies (fig. 9C)

|                   |       |                           |           |                   |       |     |        |
|-------------------|-------|---------------------------|-----------|-------------------|-------|-----|--------|
| TEST 7 - D1L.     |       | ROLE OF FREQUENCIES (NW). |           |                   |       |     |        |
| EPS               | SIGMA | Y SIDE                    | X SIDE    |                   |       |     |        |
| 0.001             | 0.1   | 40.                       | 6.0       |                   |       |     |        |
| CL                | QL    | RHO                       | THICKNESS |                   |       |     |        |
| 1.5               | 200.  | 1.1                       | 0.        |                   |       |     |        |
| 1.5               | 200.  | 1.1                       | 250.      |                   |       |     |        |
| 3.0               | 200.  | 1.1                       | 0.        |                   |       |     |        |
| 9999              | 9999  | 9999                      | 9999      |                   |       |     |        |
| #TRC              | #FREQ | T(MSEC)                   | IN/MSEC   | AMP-SCALE         | MLTPL | AGC | WINDOW |
| 5                 | 256   | 1000.                     | .006      | 1.0               | 0     | 0   | 0      |
| DETECTOR TYPE     |       | DETECTOR LOCATION         |           |                   |       |     |        |
| REFLECTION        |       | LAYER 1                   |           |                   |       |     |        |
| FILTER PHASE      |       |                           |           |                   |       |     |        |
| 1 (MINIMUM PHASE) |       |                           |           |                   |       |     |        |
| FILTER-TYPE       |       | DB                        | SLOPE     | CUT-OFF FREQUENCY |       |     |        |
| 1                 |       |                           | 48        | 50                |       |     |        |
| 2                 |       |                           | 48        | 10                |       |     |        |

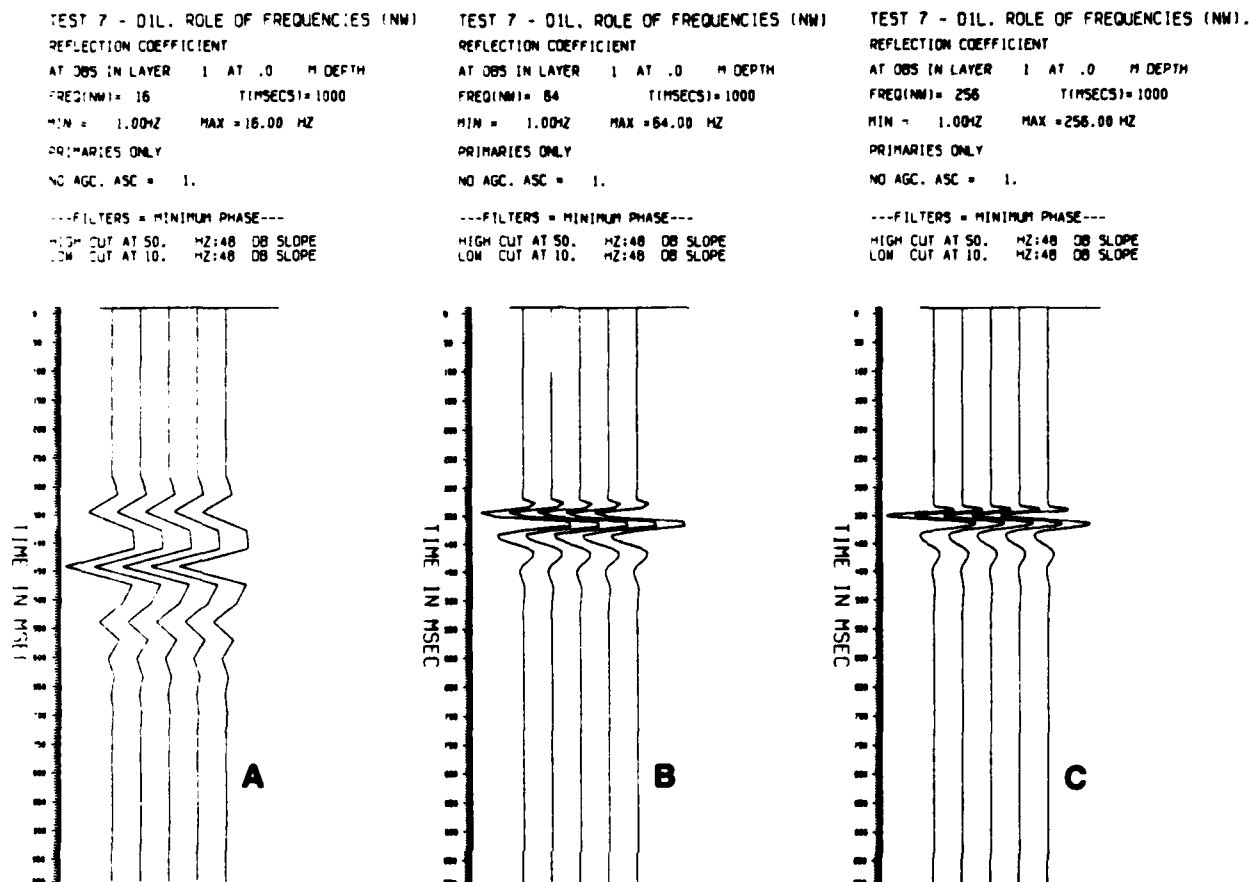


Figure 9. (Test 7) Variations of computational frequency (NW) for a single reflector model (fig. 3A) for A, NW = 16; B, NW = 64; C, NW = 256.

#### Test 8. Record Length (TSEC)

The interrelationship between the time span of the seismogram (TSEC) and computational frequency (NW) is examined with a six-layer model (fig. 3C). The record length (TSEC) was varied from 500 to 4000 msec in the presence of a fixed computational frequency NW = 512 hz. The minimum frequency is given by  $1/TSEC$ , and the maximum (Nyquist) frequency is given by  $NW/TSEC$ . The results shown in figure 10 demonstrate that the user's selection of time (TSEC) must influence the appearance of the seismogram. For example, reflector R3 of the six-layer model (fig. 3C) is at a depth of 300 m and has a predicted arrival time of 550 msec. (See table 10.) The choice of record length TSEC = 500 msec is too short, and R3 arrives as a wraparound event at 50 msec (fig.

10A). Therefore all the arrivals on figure 10A other than R0, R1, and R2 are wraparound events.

A record length of 2000 msec (fig. 10B) is sufficiently long that all events (R0 to R6) are observable at their proper arrival times. Excessive time length, however, reduces the frequency of content of the signal and may not be desirable. Note that a record length of TSEC = 2000 msec (fig. 10B) gives an  $f_{max}$  of only 256 hz versus 1024 hz for the seismogram with TSEC = 500 msec. One should first choose TSEC to avoid wrap-around and then choose frequency (NW) to obtain the desired (maximum) frequency content.

Table 9 is a copy of the input records used to generate figure 10B.

## TEST 8 - D6L. TEST OF TSEC (= 500)

REFLECTION COEFFICIENT

AT OBS IN LAYER 1 AT .0 M DEPTH

FREQ(NW)= 512 T(MSECS)=500

MIN = 2.00HZ MAX = 1024.00HZ

PRIMARIES ONLY

NO AGC. ASC = 1.

NO FILTERS

## TEST 8 - D6L. TEST OF TSEC (= 2000)

REFLECTION COEFFICIENT

AT OBS IN LAYER 1 AT .0 M DEPTH

FREQ(NW)= 512 T(MSECS)=2000

MIN = .50 HZ MAX = 256.00 HZ

PRIMARIES ONLY

NO AGC. ASC = 1.

NO FILTERS

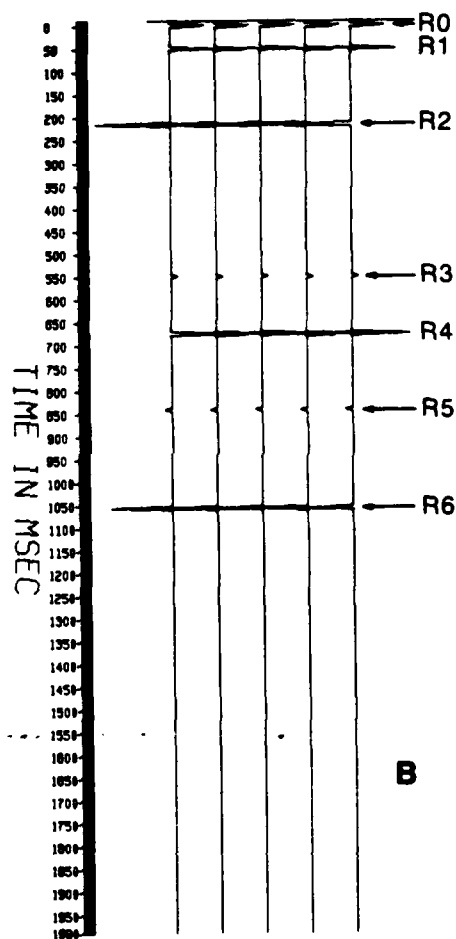
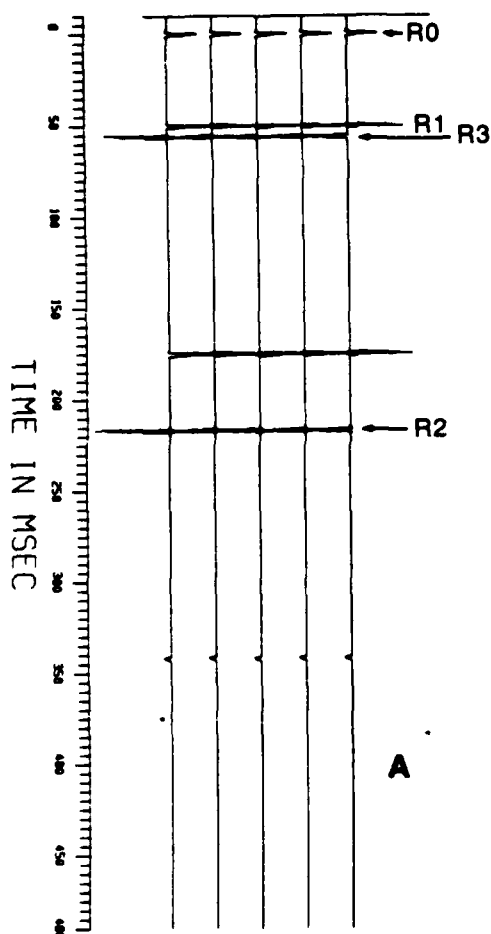


Figure 10. (Test 8) Variation of record length (TSEC) for a six-layer model (fig. 3C). A, TSEC = 500 and B, TSEC = 2000. Reflections R0 through R6 are identified in table 10.

Table 9. Input data used to test record length (fig. 10A)

```

TEST 8 - D6L.  TEST OF TSEC (= 2000)
EPS      SIGMA  YSIDE  XSIDE
0.001    0.1    40.    6.0
CL       QL     RHO    THICKNESS
1.5      10000. 1.1    0.
2.0      10000. 1.1    50.
3.0      10000. 1.1    250.
1.5      10000. 1.1    250.
1.6      10000. 1.1    100.
3.0      10000. 1.1    250.
2.8      10000. 1.1    300.
1.5      10000. 1.1    0.
9999     9999   9999   9999
#TRC #FREQ T(MSEC) IN/MSEC AMP-SCALE MLTPL AGC WINDOW
5     512  2000.  .003    1.0    0    0    0
DETECTOR TYPE      DETECTOR LOCATION
REFLECTION          LAYER 1
FILTER PHASE
2 (NO FILTERS)
FILTER-TYPE DB SLOPE CUT-OFF FREQUENCY

```

## Test 9. Arrival Times and Amplitudes

A six-layer model with constant  $Q = 10,000$  and  $p = 1.1$  (fig. 3C) was used to examine arrival times and amplitudes for the reflection-coefficient seismogram (fig. 11A). To generate a noise-free record, no multiples were included. A record length of  $T = 1200$  msec avoided wraparound problems. To avoid amplitude distortion, the seismograms were not filtered.

Arrival times for the seven reflectors (R0 to R6) were computed from the velocities and

thicknesses of the layers; R0 is from the top of layer 1, and R6 is from the top of the half space. Theoretical (predicted) amplitudes were also hand calculated for the model by using the usual relationships for reflection coefficients and two-way transmission coefficients. Study of the results (table 10) shows that the reflections arrived with correct amplitudes, polarities, and times.

Table 11 is a copy of the input records used to generate figure 11A.

Table 10. Observed and predicted times and amplitudes of reflection coefficients for a six-layer model (fig. 11A)

| Reflector index | Predicted times (msec) | Observed times (msec) | Predicted amplitudes (cm) (See fig. 11A) | Observed amplitudes (cm) (normalized) |
|-----------------|------------------------|-----------------------|------------------------------------------|---------------------------------------|
| R0              | 0                      | 0                     | +.14                                     | .14                                   |
| R1              | 50                     | 50                    | +.20                                     | .22                                   |
| R2              | 217                    | 215                   | -.31                                     | -.32                                  |
| R3              | 550                    | 550                   | +.03                                     | +.03                                  |
| R4              | 675                    | 675                   | +.25                                     | +.27                                  |
| R5              | 842                    | 840                   | -.03                                     | -.03                                  |
| R6              | 1056                   | 1050                  | -.22                                     | -.25                                  |

TEST 9 - D6L. ARRIVAL TIME TEST.  
 REFLECTION COEFFICIENT  
 AT OBS IN LAYER 1 AT .0 M DEPTH  
 FREQ(NM)= 512 TIMSECS)=1200  
 MIN = .83 HZ MAX = 426.67 HZ  
 PRIMARIES ONLY  
 NO AGC. ASC = 1.  
 NO FILTERS

TEST 10 - D6L. ARRIVAL TIME TEST.  
 VERTICAL DISPLACEMENT  
 AT OBS IN LAYER 2 AT .0 M DEPTH  
 FREQ(NM)= 512 TIMSECS)=1200  
 MIN = .83 HZ MAX = 426.67 HZ  
 PRIMARIES ONLY  
 NO AGC. ASC = 1.  
 NO FILTERS

TEST 10 - D6L. ARRIVAL TIME TEST.  
 PRESSURE  
 AT OBS IN LAYER 2 AT .0 M DEPTH  
 FREQ(NM)= 512 TIMSECS)=1200  
 MIN = .83 HZ MAX = 426.67 HZ  
 PRIMARIES ONLY  
 NO AGC. ASC = 1.  
 NO FILTERS

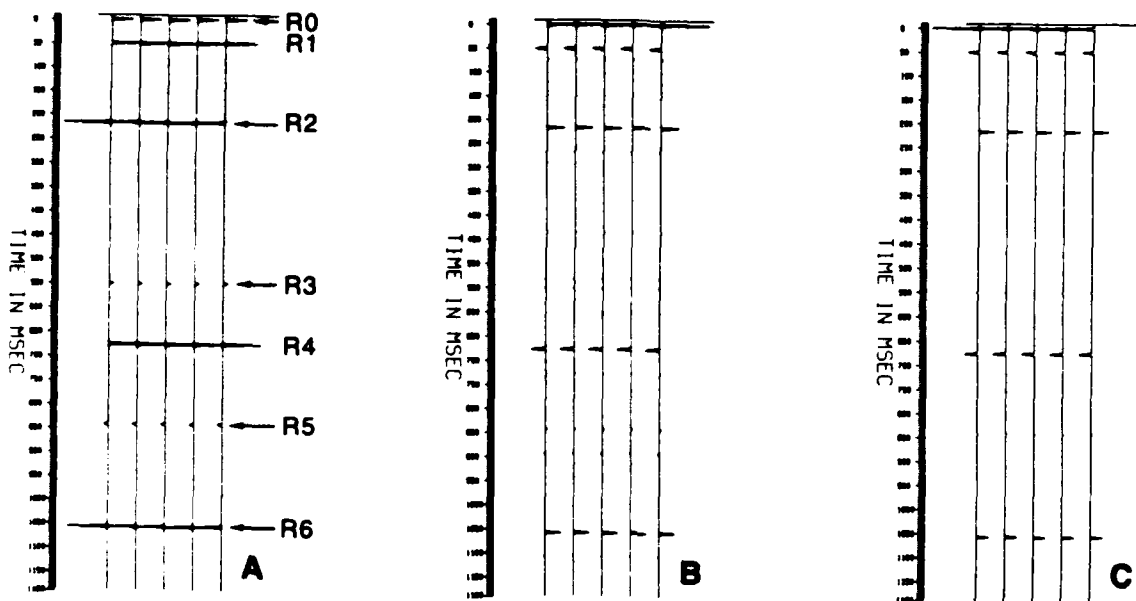


Figure 11. (Tests 9 and 10) Arrival times and amplitudes for a six-layer model (fig. 3C) for A, reflection coefficient; B, vertical displacement; C, pressure.

Table 11. Input data used to test times, amplitudes, and polarities of reflections (fig. 11A)

| TEST 9 - D6L.                          |        | ARRIVAL TIME TEST. |                                    |
|----------------------------------------|--------|--------------------|------------------------------------|
| EPS                                    | SIGMA  | YSIDE              | XSIDE                              |
| 0.001                                  | 0.1    | 40.                | 6.0                                |
| CL                                     | QL     | RHO                | THICKNESS                          |
| 1.5                                    | 10000. | 1.1                | 0.                                 |
| 2.0                                    | 10000. | 1.1                | 50.                                |
| 3.0                                    | 10000. | 1.1                | 250.                               |
| 1.5                                    | 10000. | 1.1                | 250.                               |
| 1.6                                    | 10000. | 1.1                | 100.                               |
| 3.0                                    | 10000. | 1.1                | 250.                               |
| 2.8                                    | 10000. | 1.1                | 300.                               |
| 1.5                                    | 10000. | 1.1                | 0.                                 |
| 9999                                   | 9999   | 9999               | 9999                               |
| #TRC                                   | #FREQ  | T(MSEC)            | IN/MSEC AMP-SCALE MLTPL AGC WINDOW |
| 5                                      | 512    | 1200.              | .003 1.0 0 0 0                     |
| DETECTOR TYPE                          |        | DETECTOR LOCATION  |                                    |
| REFLECTION                             |        | LAYER 1            |                                    |
| FILTER PHASE                           |        |                    |                                    |
| 2 (NO FILTERS)                         |        |                    |                                    |
| FILTER-TYPE DB SLOPE CUT-OFF FREQUENCY |        |                    |                                    |

## Test 10. Pressure and Vertical Displacement

The same six-layer model (fig. 3C) used to test arrival times and amplitudes for the reflection-coefficient seismogram (fig. 11A) was also used to test the waveforms and polarity of the options to plot vertical-displacement and pressure seismograms (figs. 11B and 11C). The algorithm for Program VISP is so designed that the vertical-displacement and pressure output may be activated only if the receiver is specified to be within one of the layers, not within the half space. The reflection-coefficient plot is obtained only when the receiver is at the bottom of the upper half space. Therefore, for computational purposes, the receivers for the three seismograms in figure 11 are located as follows: the reflection-coefficient output (fig. 11A) is from the receiver at the bottom of the half space (layer 1), and vertical displacement (fig. 11B) and pressure (fig. 11C) are from the

top of layer 2 (in effect at the same depth as the reflection-coefficient output but across the interface).

Comparison of the three outputs shows that vertical-displacement (fig. 11B) and pressure seismograms (fig. 11C) have the same polarity for reflectors R1-R6 but differ slightly in amplitude. Reflections R1-R6 on the reflection-coefficient seismogram (fig. 10A) have the opposite polarity. Because of the receiver location, noted above, the first arrival (R0) on the reflection-coefficient seismogram is a reflection, but the first arrival on the other two seismograms is a transmitted wave of opposite polarity.

Table 11 is a copy of the input records used to generate figure 11A. To generate figures 11B and 11C one needs only to change REFLECTION to either VERTICAL or PRESSURE and LAYER 1 to LAYER 2.

## Test 11. Receiver Depth

The user may place the receiver within any of the layers. The source is always within the half space, and zero time begins when the pulse encounters the top of layer 1. The six-layer model (fig. 3C), without multiples, was used to test this option. The receiver was placed at the top of layer 3 (fig. 12A), and vertical displacement was plotted. The reflection-coefficient option is not available within the layers but only at the bottom of the upper half space. Table 12 shows the computed and observed times for the primary reflections for vertical displacement (fig. 12B).

The seismogram (fig. 12B) shows the major reflectors arriving at the computed times with the appropriate polarities. Table 13 is a copy of the input records used to generate figure 12.

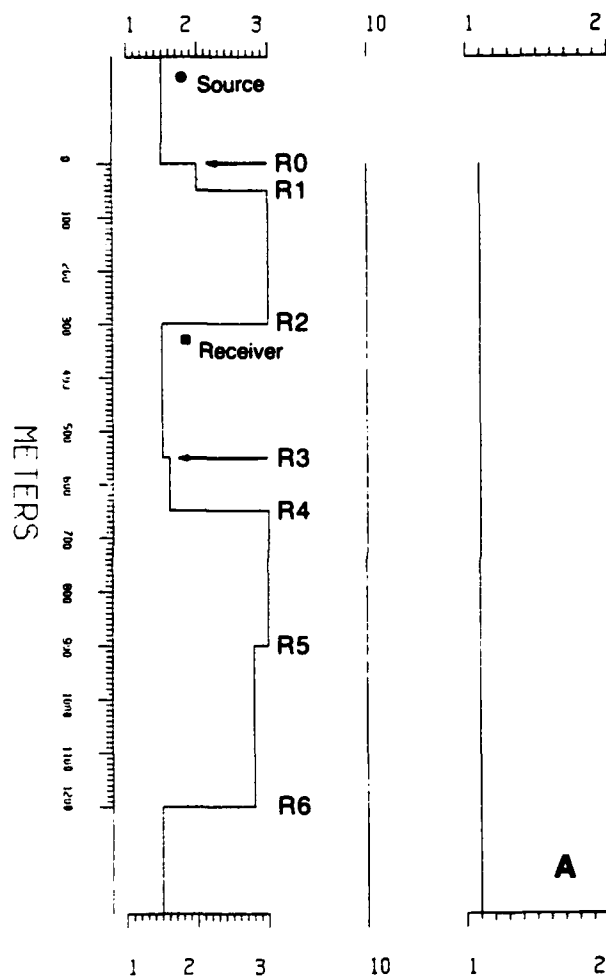
Table 12. Arrival times for a buried receiver (fig. 12)

| Reflections | Computed times (msec) | Observed times (msec) |
|-------------|-----------------------|-----------------------|
| Direct      | 108                   | 110                   |
| R3          | 442                   | 440                   |
| R4          | 567                   | 560                   |
| R5          | 733                   | 730                   |
| R6          | 947                   | 950                   |

## VISP; PLOTS OF PARAMETERS

TEST 11 - D6L. RECEIVER DEPTH.

CL (KM/SEC) CL\* .001 RHO (GM/CC)



TEST 11 - D6L. RECEIVER DEPTH.

VERTICAL DISPLACEMENT

AT OBS IN LAYER 4 AT 300.0 M DEPTH

FREQ(NW)= 512

T(MSECS)= 1200

MIN = .83 HZ

MAX = 426.67 HZ

PRIMARIES ONLY

NO AGC. ASC = 1.

NO FILTERS

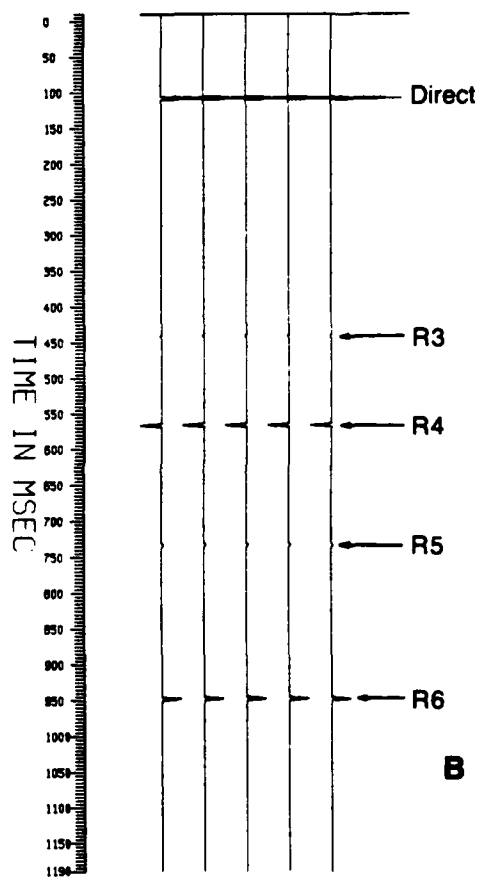


Figure 12. (Test 11) Primary reflections for a six-layer model (fig. 3C) for a receiver at the top of layer 4 (where the upper half space is termed layer 1).

Table 13. Input data used to test receiver depth (fig. 12)

```

TEST 11 - D6L.      RECEIVER DEPTH.
EPS      SIGMA      YSIDE      XSIDE
0.001    0.1        40.        6.0
CL       QL         RHO        THICKNESS
1.5      10000.     1.1        0.
2.0      10000.     1.1        50.
3.0      10000.     1.1        250.
1.5      10000.     1.1        250.
1.6      10000.     1.1        100.
3.0      10000.     1.1        250.
2.8      10000.     1.1        300.
1.5      10000.     1.1        0.
9999     9999       9999       9999
#TRC #FREQ T(MSEC)  IN/MSEC AMP-SCALE MLTPL AGC WINDOW
5      512  1200.   .005      1.0      0      0      0
DETECTOR TYPE      DETECTOR LOCATION
VERTICAL           LAYER 4
FILTER PHASE
2 (NO FILTERS)
FILTER-TYPE DB SLOPE CUT-OFF FREQUENCY

```

## Test 12. Interpolated Layers

It is possible to have layer velocities uniformly increase (or decrease) within specified depth intervals without hand calculating the values (fig. 13). The user enters a sequence of values within a sequence of

specified layers: O, N, T where O is the flag, N is the number of layers to be inserted, and T is the total thickness of the layers. Table 14 is a copy of the data used to generate figure 13.

Table 14. Input data used to interpolate layers (fig. 13)

```

TEST 12 -      INTERPOLATED LAYERS.
EPS      SIGMA      YSIDE      XSIDE
0.001    0.1        40.        6.0
CL       QL         RHO        THICKNESS
1.5      200.       1.1        0.
1.5      200.       1.1        75.
0.0      5          500        1
3.0      200.       1.1        100.
1.5      200.       1.1        0.
9999     9999       9999       9999
#TRC #FREQ T(MSEC)  IN/MSEC AMP-SCALE MLTPL AGC WINDOW
5      512  1000.   .006      1.0      0      0      0
DETECTOR TYPE      DETECTOR LOCATION
REFLECTION          LAYER 1
FILTER PHASE
1 (MINIMUM PHASE)
FILTER-TYPE DB SLOPE CUT-OFF FREQUENCY
1          96      100

```

## VISP: PLOTS OF PARAMETERS

TEST 12 - OIL. INTERPOLATED LAYERS.

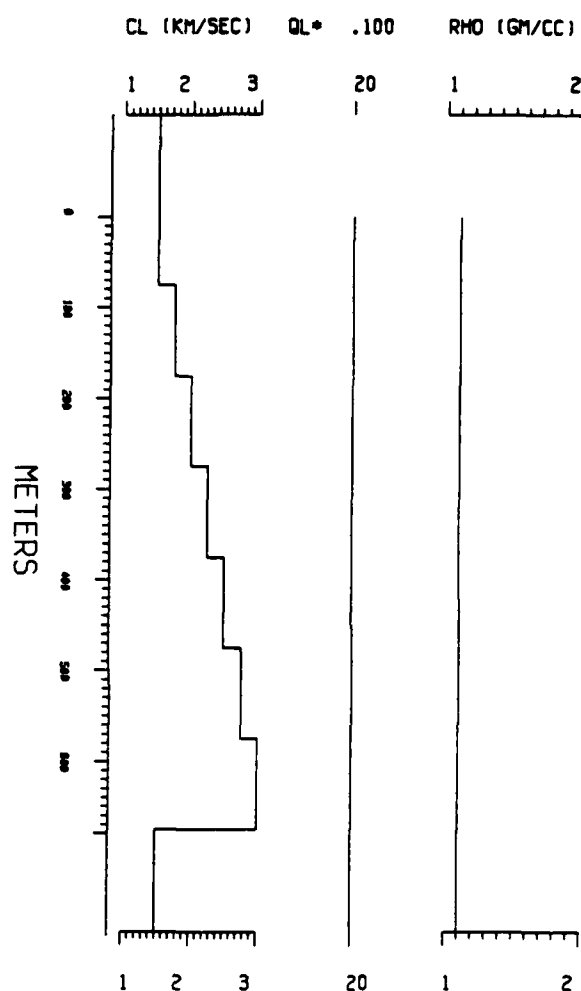


Figure 13. (Test 12) Generation of interpolated layers with uniformly increasing velocities.

## Test 13. Absolute Depth

The user may specify the absolute depth below the bottom of the upper half space instead of specifying the interval thickness of each layer. The absolute depths are entered as

negative values. Table 15 is a copy of the input that in effect generates the six-layer model (fig. 3C) used throughout this paper.

Table 15. Input data used to generate a six-layer model using absolute depths (fig. 3C)

|                |        |                       |           |                   |       |     |        |
|----------------|--------|-----------------------|-----------|-------------------|-------|-----|--------|
| TEST 13 - 1    |        | ABSOLUTE DEPTH INPUT. |           |                   |       |     |        |
| EPS            | SIGMA  | YSIDE                 | XSIDE     |                   |       |     |        |
| 0.001          | 0.1    | 40.                   | 6.0       |                   |       |     |        |
| CL             | QL     | RHO                   | THICKNESS |                   |       |     |        |
| 1.5            | 10000. | 1.1                   | 0.        |                   |       |     |        |
| 2.0            | 10000. | 1.1                   | -50.      |                   |       |     |        |
| 3.0            | 10000. | 1.1                   | -300.     |                   |       |     |        |
| 1.5            | 10000. | 1.1                   | -550.     |                   |       |     |        |
| 1.6            | 10000. | 1.1                   | -650.     |                   |       |     |        |
| 3.0            | 10000. | 1.1                   | -900.     |                   |       |     |        |
| 2.8            | 10000. | 1.1                   | -1200     |                   |       |     |        |
| 1.5            | 10000. | 1.1                   | 0.        |                   |       |     |        |
| 9999           | 9999   | 9999                  | 9999      |                   |       |     |        |
| #TRC           | #FREQ  | T(MSEC)               | IN/MSEC   | AMP-SCALE         | MLTPL | AGC | WINDOW |
| 5              | 512    | 1200.                 | .005      | 1.0               | 0     | 0   | 0      |
| DETECTOR TYPE  |        | DETECTOR LOCATION     |           |                   |       |     |        |
| VERTICAL       |        | LAYER 4               |           |                   |       |     |        |
| FILTER PHASE   |        |                       |           |                   |       |     |        |
| 2 (NO FILTERS) |        |                       |           |                   |       |     |        |
| FILTER-TYPE    |        | DB                    | SLOPE     | CUT-OFF FREQUENCY |       |     |        |

**INDIANA GEOLOGICAL SURVEY GEOPHYSICAL COMPUTER PROGRAMS  
ERRATA**

**Geophysical Computer Program 1 (Occasional Paper 10)**

Page 9, 19 lines from the bottom of the page:

Second line of R(M,N,4) now reads  $1+P(I+1,J+1)+P(I+1,J-1)+P(I-1,J+1)+P(I-1,J-1))/8.0$

Second line of R(M,N,4) should read  $1+P(I+1,J+2)+P(I+1,J-2)+P(I-1,J+2)+P(I-1,J-2))/8.0$

Page 9, 4 lines from the bottom of the page:

Second line of R(M,N,11) now reads  $1P(I-20,J-15)+P(I-15,J-15)+P(I+20,J+15)+P(I+15,J+20)$

Second line of R(M,N,11) should read  $1P(I-20,J-15)+P(I-15,J-20)+P(I+20,J+15)+P(I+15,J+20)$

Page 14, line 6, which reads C(6,12)=-0.04007, may be deleted.

**Geophysical Computer Program 2 (Occasional Paper 13)**

Page 11, line 18:

Now reads: (1,170)ITYPE,Z(I),XI(I)

Should read: (2,230)ITYPE,Z(I),XI(I)

Page 12, after line 18:

Insert: 230 FORMAT (I1,F4.0,F4.1)

**Geophysical Computer Program 3 (Occasional Paper 14)**

Page 12, line 11:

Now reads: 10 A(I+MN)-A(I)

Should read: 10 A(M+K-I)-A(N+K-I)

**Geophysical Computer Programs 4 and 5 (Occasional Papers 22 and 23)**

Geophysical Computer Programs 4 and 5 require many significant figures. Double precision may be needed on some computers. Indiana University computers use 60-bit words.

**Geophysical Computer Program 7 (Occasional Paper 29)**

Subroutine MYLINE2 has been removed from the program. Delete all references to this subroutine and read all references to "11 subroutines" as "10 subroutines."

Page 38:

Now reads: 30 × 27 km region

Should read: 31 × 27 km region

Page 39:

Now reads: 6 × 40 km region

Should read: 10 × 40 km region

Page 44:

Now reads: distance 200 km

Should read: distance 20 km

Page 52:

Now reads: as a function time

Should read: as a function of time

**Geophysical Computer Program 9 (Occasional Paper 40)**

Page 13, line 16:

Now reads: 110 THETA=PI/2.0

Should read: 110 THETA1=PI/2.0

**END**

**FILMED**

**11-85**

**DTIC**