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Coal-seismic, desk-top computer program in BASIC; part 3: compute, tabulate, and plot normal moveout times

by

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ABSTRACT

Data taken with the U.S. Geological Survey's coal-seismic system are processed on a desk-top, stand-alone computer. Programs for this computer are written in an extended BASIC language specially augmented for acceptance by the Tektronix 4051 Graphic System[1/]. This report presents a computer program to compute, tabulate, and plot first-approximation normal moveout (NMO) times for the multi-layered, zero-dip case. A choice is offered between computing with a constant root-mean-square (RMS) velocity within a selected coincident-ray reflection-time interval or with a given variable RMS velocity function, such as would be determined from a downhole velocity survey.

INTRODUCTION

Normal moveout (NMO) is the difference between reflection arrival times due to the difference in shotpoint-detector distances. The particular NMO computed in this program is the one for the horizontal multi-layer case in which it is assumed that use of a root-mean-square (RMS) velocity function will produce sufficiently accurate first-approximation results. Those familiar with NMO, for whom this report is intended, will recognize that the normal moveout velocity (VNMO) may be redefined so as to approximate NMO's for the horizontal single-layer case (VNMO set equal to the interval velocity), the dipping single-layer case (VNMO set equal to the interval velocity divided by the cosine of the dip), and the dipping parallel multilayer case (VNMO set equal to the RMS velocity divided by the cosine of the dip). These

1/ Use of brand names in this report is for descriptive purposes only and does not constitute endorsement by the U.S. Geological Survey.

modifications to the VMNO's are easily accomplished by changing them before they are entered.

One principal use of NMO plots is to guide the picking of reflections. Because it takes only a few minutes to produce a screen display of a set of NMO curves, one can work interactively with the desk-top computer as the seismic records are being picked so as to gain some feeling for the velocity condition.

The program to compute first-approximation NMO with the U.S. Geological Survey's coal-seismic system is written for use on a desk-top, stand-alone computer. The language is an extended BASIC specially augmented by Tektronix, Inc. for use on their 4051 Graphic System. In addition to the Tektronix 4051 Graphic System, a Tektronix 4662 Interactive Digital Plotter is called for by the program. To copy the screen display, a Tektronix 4631 Hard Copy unit can be used.

Extensive knowledge about the operation of the 4051 Graphic System is not required to use the program of this report. To get started, the following operations need to be known:

1. Entering a program from the keyboard.
2. Storing and retreiving a program from a magnetic tape, and
3. Entering information from the keyboard.

These tasks are well documented in the computer's operator's manuals.

Two sample problems are included in this report. In the first, a set of NMO curves is computed using a constant RMS velocity. In the second, a set of NMO curves is computed using an RMS velocity function obtained from results of a downhole velocity survey at a water well located in the southwest corner of the Denver Federal Center. This survey was run by Bruce A. Kososki and Roberto J. Martinez, of the U.S. Geological Survey. Table 1 lists the results of the downhole velocity survey.

Table 1

Detector Depth	Vertical Time	Average Velocity	RMS Velocity
16.4	13.26	1.24	1.24
31.7	19.03	1.67	1.79
46.9	26.46	1.77	1.86
62.1	34.17	1.82	1.89
77.4	40.65	1.90	1.97
92.6	47.94	1.93	1.99
107.9	53.18	2.03	2.10
123.1	60.32	2.04	2.10
138.4	69.41	1.99	2.05
153.6	74.52	2.06	2.13
168.8	80.60	2.09	2.16
184.1	84.68	2.17	2.26
199.3	93.72	2.13	2.21
214.5	100.76	2.13	2.21

The computer program is self-prompting; that is, one does not have to remember what to do next--the program tells you. In tracing through the sample problems, you will notice that the program will cause questions to be printed across the screen and that these questions will terminate with a flashing question mark. The computer then waits for you to supply an answer. Replies that you will need to enter from the keyboard are given in the examples--to make these responses more easily recognized, they are enclosed in boxes on the figures.

The program is listed with a printer that cannot print an underscore. This deficiency presents a problem in the display of control characters. Four display control characters are used in the program: <u>G</u> (rings bell), <u>K</u> (moves cursor up one line), <u>L</u> (erases screen and moves cursor to the HOME position), and _ (moves cursor to the left margin and down one line). In the print of the program listing, these control characters are shown as G_, K_, L_, and _ _.

EXAMPLE WITH CONSTANT RMS VELOCITY

In this sample problem, NMO values are computed, tabulated, and plotted under the assumption that the RMS velocity within a specified reflection-time interval is a constant. Figure 1 is a copy of the screen display showing the first page of information required by the NMO program. You are first asked to enter the spread information, distances in meters, and then asked if you want to compute with a constant RMS velocity. Upon receiving the information that you want to compute with a constant RMS velocity, the program then asks you to enter the constant average and RMS velocities (in m/msec) and the reflection time intervals over which they are to be applied (in msec from the datum). Specification of the incremental vertical reflection time, in this case 20 msec, tells the program how many curves you want. Finally you are asked if you want to have the results tabulated.

Figure 2 is a copy of the screen display showing the results of the MNO calculations. The numbers across the top of the columns are the numbers of curves and vertical reflection times respectively. The body of the listing gives the NMO times, in msec, for each of the 12 spread distances. Thus, for a vertical reflection time (the reflection time of 0 spread distance) of 100 msec, the NMO time at a spread distance of 48 m would be 5.00 msec when the RMS velocity is 1.5 m/msec.

After the results are tabulated, you are asked if you want to have the NMO values plotted, and on which plotter. If an N is entered in response to the bottom question of figure 3, then the plot will be made on the CRT screen of the 4051 Graphic System. As shown on figure 3, you are also asked to enter the tickmark interval for the NMO values (in this case, 1 msec) and for the shotpoint-detector distance, 3 m.

```
YOU HAVE SELECTED PROGRAM TO COMPUTE,TABULATE,AND PLOT NORMAL MOVEOUTS

ENTER SPREAD INFORMATION

    Distance to near seismometer = 30
   Interval between seismometers = 3
Number of seismometers on spread = 12

DO YOU WANT TO COMPUTE USING A CONSTANT RMS VELOCITY WITHIN
   A SELECTED INCIDENT-REFLECTION TIME INTERVAL? (Y OR N) Y

ENTER CONSTANT-VELOCITY-COMPUTATION PARAMETERS
            Assumed constant average velocity = 1.5
                Assumed constant RMS velocity = 1.5
Incident reflection time at start of interval = 100
        Incremental vertical reflection times = 20
  Incident reflection time at end of interval = 200

DO YOU WANT TO TABULATE NMO VALUES? (Y OR N) Y
```

Figure 1. Copy of screen display showing first page of information required by the NMO program. The replies to be entered from the keyboard in order to trace through the constant RMS velocity sample problem have been emphasized by enclosing the responses in boxes.

TABLE OF NMO'S FOR FIRST 7 HORIZONS WITH RMS VELOCITY = 1.5 m/msec

	1	2	3	4	5	6	7
	100	120	140	160	180	200	0
X							
30	1.98	1.66	1.42	1.25	1.11	1.00	0.00
33	2.39	2.00	1.72	1.51	1.34	1.21	0.00
36	2.84	2.38	2.04	1.79	1.59	1.43	0.00
39	3.32	2.78	2.39	2.10	1.87	1.68	0.00
42	3.85	3.22	2.77	2.43	2.16	1.95	0.00
45	4.40	3.69	3.18	2.79	2.48	2.24	0.00
48	5.00	4.19	3.61	3.17	2.82	2.54	0.00
51	5.62	4.72	4.07	3.57	3.18	2.87	0.00
54	6.28	5.28	4.55	4.00	3.56	3.21	0.00
57	6.98	5.87	5.07	4.45	3.97	3.58	0.00
60	7.70	6.49	5.60	4.92	4.39	3.96	0.00
63	8.46	7.14	6.16	5.42	4.84	4.36	0.00

Figure 2. Tabulation of results for the constant RMS velocity sample problem.

```
DO YOU WANT TO PLOT NMO VALUES? <Y OR N> [Y]

TICKMARK INTERVALS ON PLOT
     NMO Tickmark interval = [1]
Distance tickmark interval = [3]

DO YOU WANT TO PLOT ON 4662 PLOTTER? <Y OR N> [N]
```

Figure 3. Copy of screen display showing questions and replies (boxed) for instructing the NMO program to produce the family of NMO curves shown on figure 4.

Figure 4 is a copy of the screen display showing the family of NMO curves specified by the entries made on figure 1. The labels at the right termination of the curves give the vertical reflection time and depth respectively.

EXAMPLE WITH VARIABLE RMS VELOCITY

After an N reply is entered in response to the question on the nature of the RMS velocity function, (fig. 5), the program asks you to supply information about the location at which the function applies. It then asks, as shown on figure 6, that you enter data for each NMO curve desired. In general, the information derived from a downhole survey (table 1) will not give the vertical one-way times as integers. In using an NMO chart, however, it is easier to use these displays if the vertical reflection times are given as integers. The program thus asks you to enter the one-way integar times that you want for each curve, and then asks you to enter both the one-way times and velocity values that bracket the desired integer values. An example of how these data are entered is shown in figure 6.

Figure 7 shows the interpolated values for the seven curves of the variable RMS velocity function. Note that the range in velocity within the bracketing limits is relatively small, (fig. 6); therefore, a linear interpolator is sufficiently precise for these NMO calculations.

Results computed for the variable RMS velocity sample problems are shown in figure 8. In this tabulation, X is the source-to-detector distance ranging from 30 to 63 m, and V.TIME is the vertical reflection time in msec.

Figure 9 is a copy of the screen display showing the information that was entered in order to produce the NMO plots shown on figure 10. If the user had elected to plot the results on the interactive digital plotter (Y answer entered to the last question on fig. 9), then the display shown on figure 11 would have been produced.

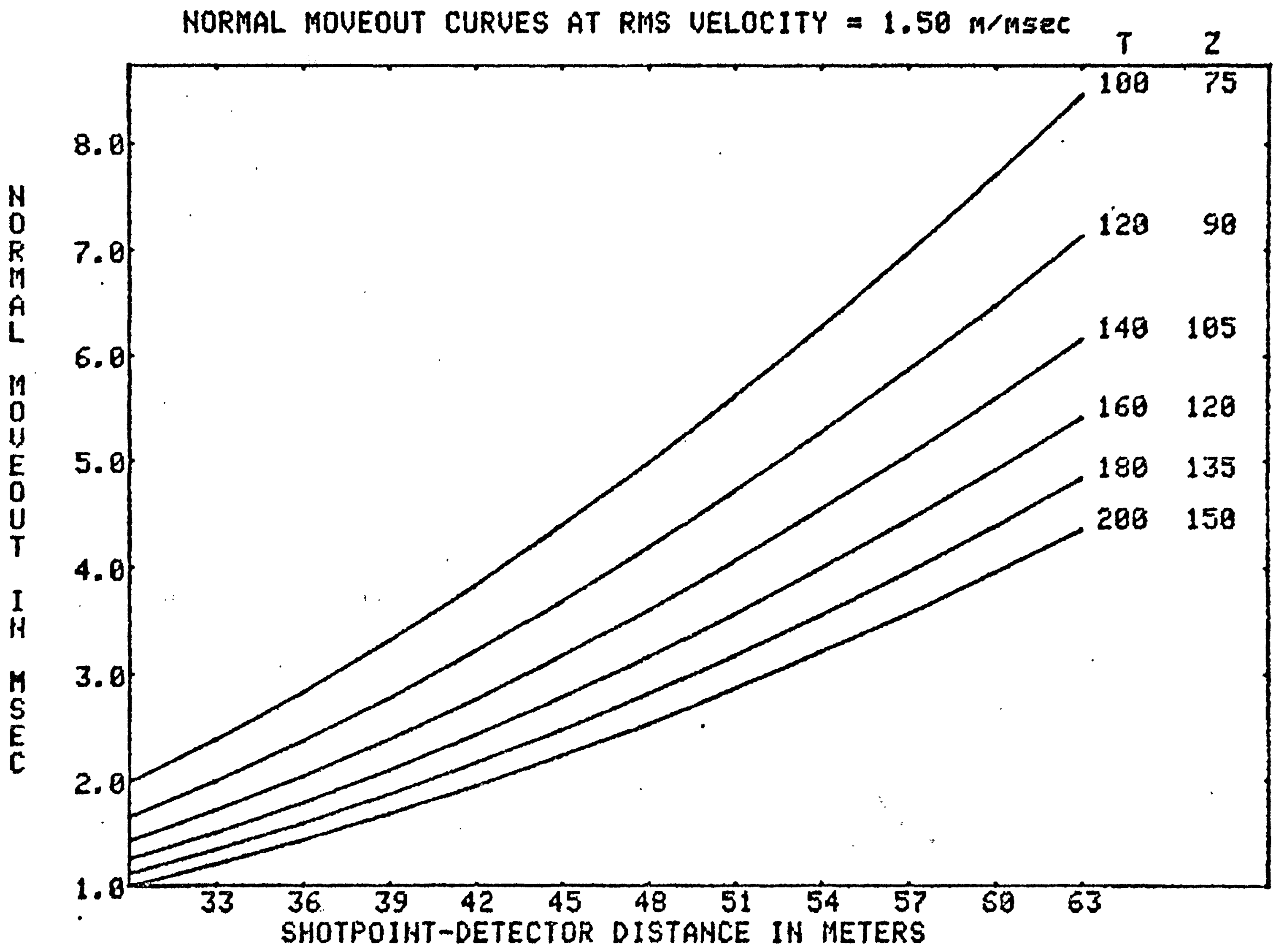

Figure 4. Copy of screen display showing family of curves plotted by the NMO program for the constant RMS velocity sample problem. The vertical reflection time T and the depth Z are referenced to datum.

```
YOU HAVE SELECTED PROGRAM TO COMPUTE,TABULATE,AND PLOT NORMAL MOVEOUTS

ENTER SPREAD INFORMATION

    Distance to near seismometer = [30]
   Interval between seismometers = [3]
Number of seismometers on spread = [12]

DO YOU WANT TO COMPUTE USING A CONSTANT RMS VELOCITY WITHIN
   A SELECTED INCIDENT-REFLECTION TIME INTERVAL? (Y OR N)[N]

YOU HAVE SELECTED TO ENTER DATA FROM A DOWNHOLE SURVEY

    Survey area (20 characters,max) : Denver Fed. Center

Hole designation (7 characters,max) : DFC W-1

      Data date (12 characters,max) : Sept.13,1979

             Number of NMO curves = 7
```

Figure 5. Copy of screen display showing first page of information required by the NMO program. The replies to be entered from the keyboard in order to trace through the variable RMS velocity sample problem have been emphasized by enclosing them in boxes.

ENTER THE FOLLOWING FOR EACH NMO CURVE TO BE COMPUTED AND PLOTTED

1. One-way time for curve to be computed = T0,
2. Observed one-way time less than T0 = T5,
3. Observed one-way time greater than T0 = T6,
4. Average velocity at T5 = V5,
5. Average velocity at T6 = V6,
6. RMS velocity at T5 = V7, and
7. RMS velocity at T6 = V8

CURVE NO.	1-WAY TIME,T0	BRACKETING TIMES T5	T6	BRACKETING VELOCITES V5	V6	V7	V8
1	20	19.03	26.46	1.67	1.77	1.79	1.86
2	30	26.46	34.17	1.77	1.82	1.86	1.89
3	40	34.17	40.65	1.82	1.99	1.89	1.97
4	50	47.94	53.18	1.93	2.03	1.99	2.10
5	60	53.18	60.32	2.03	2.04	2.10	2.10
6	80	74.52	80.60	2.06	2.09	2.13	2.16
7	100	93.72	100.76	2.13	2.13	2.21	2.21

Figure 6. Copy of screen display showing second page of information required by the NMO program when used to run the variable RMS velocity sample problem. Entered responses are enclosed in the box.

INTERPOLATED VELOCITIES AND DEPTH VS. VERTICAL REFLECTION TIME

CURVE NO.	REFLECTION TIME	AVG. VELOCITY	RMS VELOCITY	DEPTH
1	40.0	1.68	1.80	33.7
2	60.0	1.79	1.87	53.8
3	80.0	1.97	1.96	78.9
4	100.0	1.97	2.03	98.5
5	120.0	2.04	2.10	122.4
6	160.0	2.09	2.16	167.0
7	200.0	2.13	2.21	213.0

Figure 7. Interpolated values for the curves of the variable RMS velocity sample problem.

TABLE OF NMO'S IN GROUPS OF 7 DEPTHS ON THE VELOCITY FUNCTION

DEPTH=	34	54	79	98	122	167	213
V.TIME=	40.0	60.0	80.0	100.0	120.0	160.0	200.0
X							
30	3.34	2.10	1.45	1.08	0.85	0.60	0.46
33	4.00	2.53	1.75	1.31	1.02	0.73	0.56
36	4.73	3.00	2.08	1.56	1.22	0.87	0.66
39	5.50	3.51	2.43	1.82	1.43	1.02	0.78
42	6.31	4.05	2.81	2.11	1.66	1.18	0.90
45	7.18	4.63	3.22	2.42	1.90	1.35	1.03
48	8.08	5.24	3.66	2.75	2.16	1.54	1.18
51	9.03	5.88	4.12	3.10	2.43	1.74	1.33
54	10.01	6.56	4.60	3.47	2.72	1.95	1.49
57	11.03	7.27	5.11	3.86	3.03	2.17	1.66
60	12.08	8.01	5.65	4.26	3.35	2.40	1.83
63	13.16	8.78	6.20	4.69	3.69	2.64	2.02

Figure 8. Tabulation of results for the variable RMS velocity sample problem.

```
DO YOU WANT TO PLOT NMO VALUES? (Y OR N) Y

TICKMARK INTERVALS ON PLOT
     NMO Tickmark interval = 1
Distance tickmark interval = 6

DO YOU WANT TO PLOT ON 4662 PLOTTER? (Y OR N) N
```

Figure 9. Copy of screen display showing information to be entered to produce the cunes of figure 10.

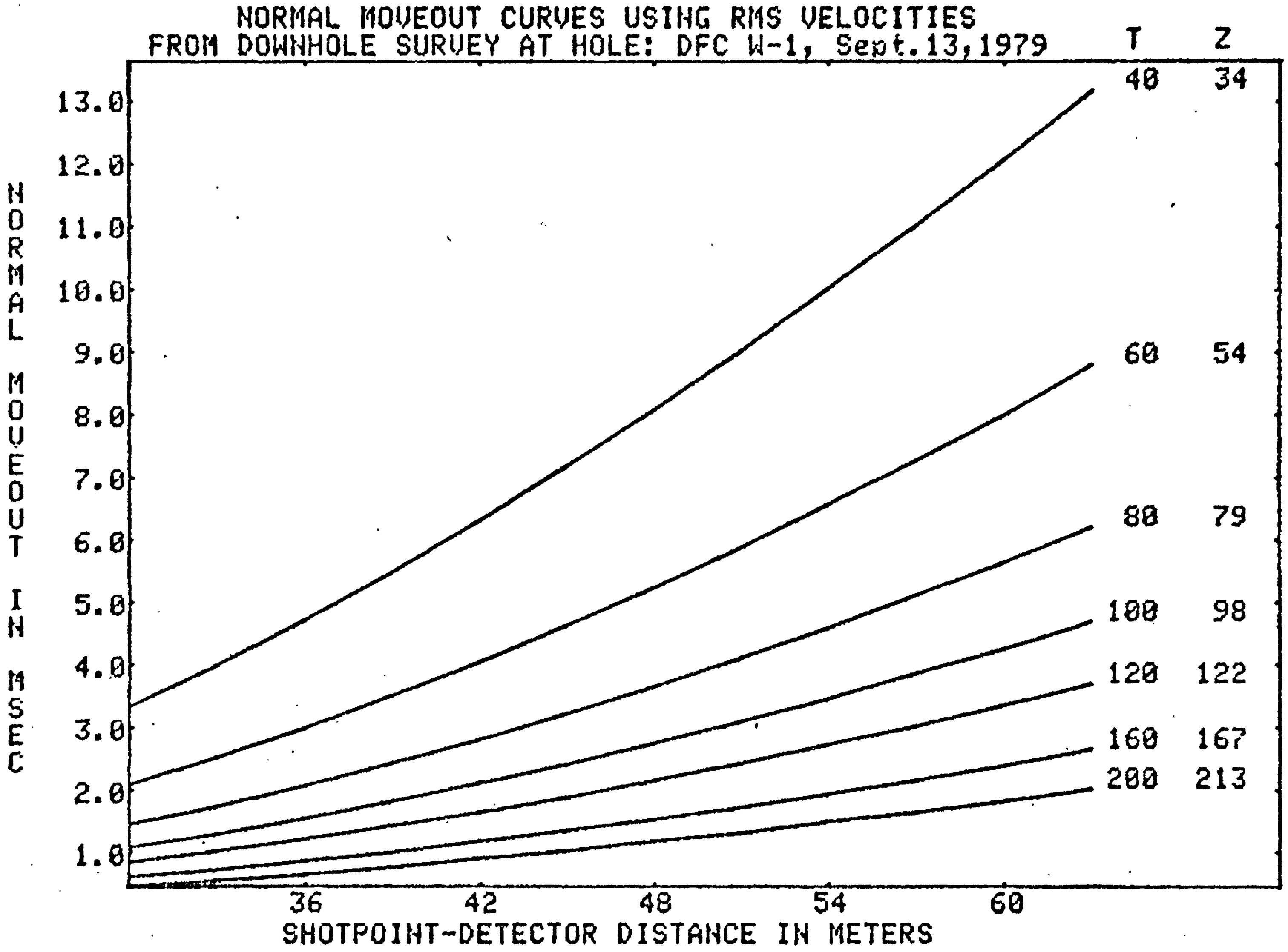

Figure 10. Copy of screen display showing family of curves plotted by the NMO program for the variable RMS. velocity sample problem. The vertical reflection time T and the depth Z are referenced to datum.

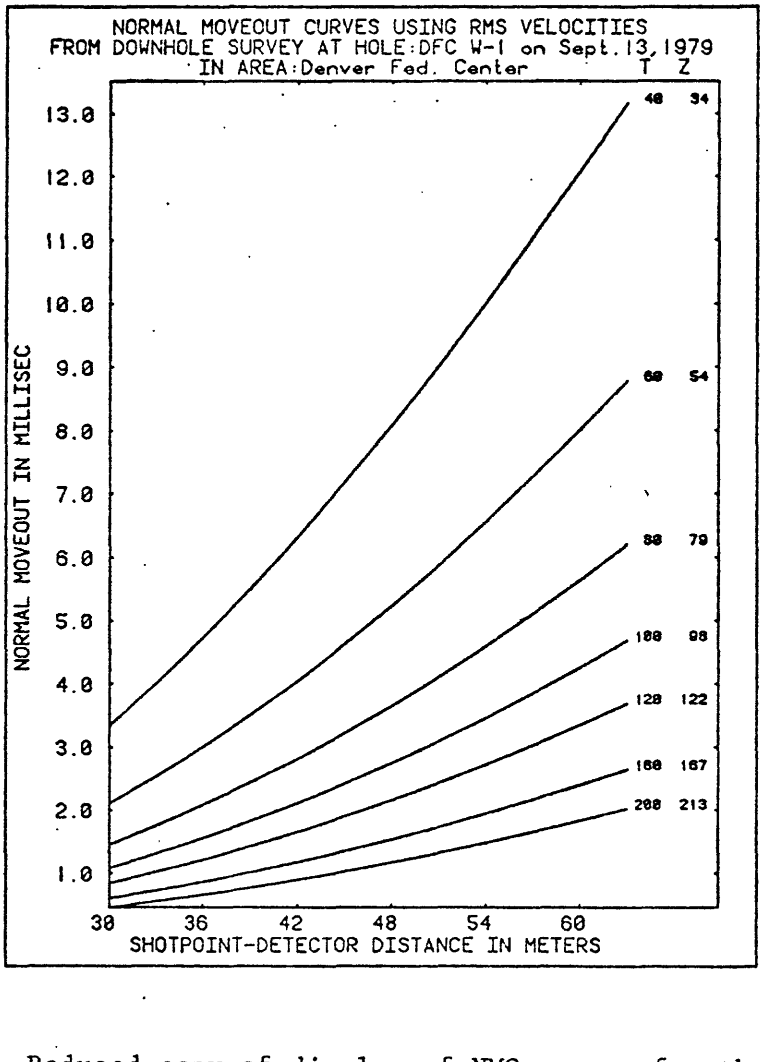

Figure 11. Reduced copy of display of NMO curves for the variable RMS velocity sample problem using the 4662 plotter. Original size of the outer border was 25.4 by 33.0 cm. Plot parameters are the same as those shown on figure 9.

Program to compute, tabulate, and plot normal moveouts

```
100 PRINT "L_YOU HAVE SELECTED PROGRAM TO COMPUTE,TABULATE,AND PLOT";
110 PRINT " NORMAL MOVEOUTS"
120 INIT
130 Q=0
140 DIM A$(20),B$(22),D$(12),E$(40),F$(3),G$(1),H$(42),I$(29)
150 DIM J$(27),K$(26),U$(7)
170 PRINT "__ENTER SPREAD INFORMATION__"
180 PRINT "     Distance to near seismometer = ";
190 INPUT X3
200 PRINT "    Interval between seismometers = ";
210 INPUT S
220 PRINT "Number of seismometers on spread = ";
230 INPUT N2
240 DIM M0(7),X0(N2),Z1(7),M(7,N2)
250 M0=0
260 M=0
270 Z1=0
280 PRINT "__DO YOU WANT TO COMPUTE USING A CONSTANT RMS VELOCITY WITHIN"
290 PRINT "    A SELECTED INCIDENT-REFLECTION TIME INTERVAL? (Y OR N) ";
300 INPUT G$
310 IF G$="Y" THEN 340
320 GOSUB 3570
330 GO TO 590
340 Q=1
350 PRINT "__ENTER CONSTANT-VELOCITY-COMPUTATION PARAMETERS"
360 PRINT "                 Assumed constant average velocity = ";
370 INPUT V5
380 PRINT "                     Assumed constant RMS velocity = ";
390 INPUT V6
400 PRINT "Incident reflection time at start of interval = ";
410 INPUT T3
420 PRINT "          Incremental vertical reflection times = ";
430 INPUT T4
440 PRINT "  Incident reflection time at end of interval = ";
450 INPUT T6
460 N1=(T6-T3)/T4+1
470 DIM T0(N1+7),Z0(N1+7),T(N1+7,N2),V1(N1),V2(N1)
480 V1=V5
490 V2=V6
500 T0=0
510 T=0
520 Z0=0
530 T0(1)=T3
540 Z0(1)=T0(1)/2*V1(1)
550 FOR J=2 TO N1
560 T0(J)=T3+T4*(J-1)
570 Z0(J)=T0(J)/2*V1(1)
580 NEXT J
590 FOR J=1 TO N1
600 FOR K=1 TO N2
610 X0(K)=X3+S*(K-1)
620 T(J,K)=SQR(T0(J)*T0(J)+X0(K)/V2(J)*X0(K)/V2(J))-T0(J)
630 NEXT K
640 NEXT J
650 X4=X0(N2)
660 PRINT "__DO YOU WANT TO TABULATE NMO VALUES? (Y OR N) ";
670 INPUT G$
680 IF G$="N" THEN 830
690 PAGE
700 N3=INT(N1/7)+1
```

```
710 FOR K3=1 TO N3
720 K4=(K3-1)*7
730 FOR J=1 TO 7
740 M0(J)=T0(K4+J)
750 Z1(J)=Z0(K4+J)
760 FOR K=1 TO N2
770 M(J,K)=T(K4+J,K)
780 NEXT K
790 NEXT J
800 GOSUB 950
810 NEXT K3
820 PRINT
830 PRINT "__DO YOU WANT TO PLOT NMO VALUES? (Y OR N) ";
840 INPUT G$
850 IF G$="N" THEN 870
860 GOSUB 1170
870 IF Q>1 THEN 930
880 PRINT "__DO YOU WANT NMO'S WITH A DIFFERENT CONSTANT ";
890 PRINT "RMS VELOCITY? (Y OR N) ";
900 INPUT G$
910 IF G$="N" THEN 930
920 GO TO 350
930 PRINT "G_G_G___PROGRAM COMPLETED"
940 END
950 REM ** SUB: TABULATE NMO VALUES
960 IF Q=1 THEN 990
970 GOSUB 4230
980 GO TO 1100
990 IF K3=1 THEN 1020
1000 A$="NEXT"
1010 GO TO 1030
1020 A$="FIRST"
1030 PRINT "__  TABLE OF NMO'S FOR ";A$;" 7 HORIZONS";
1040 PRINT " WITH RMS VELOCITY = ";V6;" m/msec"
1050 IMAGE 3X,7(7X,2D)
1060 PRINT USING 1050:K4+1,K4+2,K4+3,K4+4,K4+5,K4+6,K4+7
1070 IMAGE 4X,7(5X,4D)
1080 PRINT USING 1070:M0(1),M0(2),M0(3),M0(4),M0(5),M0(6),M0(7)
1090 IMAGE 3D,X,7(3X,3D.2D)
1100 PRINT "  X"
1110 FOR K=1 TO N2
1120 PRI USI 1090:X0(K),M(1,K),M(2,K),M(3,K),M(4,K),M(5,K),M(6,K),M(7,K)
1130 NEXT K
1140 MOVE 0,0
1150 PRINT
1160 RETURN
1170 REM ** SUB: PLOT NMO VALUES
1180 PRINT "__TICKMARK INTERVALS ON PLOT"
1190 PRINT "      NMO Tickmark interval = ";
1200 INPUT M1
1210 PRINT "Distance tickmark interval = ";
1220 INPUT M2
1230 WINDOW 0,130,0,100
1240 VIEWPORT 0,130,0,100
1250 PRINT "__DO YOU WANT TO PLOT ON 4662 PLOTTER? (Y OR N) ";
1260 INPUT G$
1270 IF G$="Y" THEN 1320
1280 RESTORE 1290
1290 DATA 32,1.792,2.816,9,92,12,110,129
1300 READ P,K1,K2,B1,B2,B4,B5,B7
1310 GO TO 1400
```

```
1220 RESTORE 1330
1330 DATA 1,1.2,2,1.7,3,122,13,14,83,95
1340 READ P,K1,K2,K3,K4,B1,B2,B4,B5,B7
1350 MOVE @1:0,0
1360 RDRAW @1:0,100
1370 RDRAW @1:130,0
1380 RDRAW @1:0,-100
1390 RDRAW @1:-130,0
1400 B3=B2-B1
1410 B6=B5-B4
1420 B8=B7-B4
1430 B$="NORMAL MOVEOUT IN MSEC"
1440 J$="SHOTPOINT-DETECTOR DISTANCE IN METERS"
1450 K$="NORMAL MOVEOUT IN MILLISEC"
1460 E$="NORMAL MOVEOUT CURVES AT RMS VELOCITY = "
1470 H$="NORMAL MOVEOUT CURVES USING RMS VELOCITIES"
1480 I$="FROM DOWNHOLE SURVEY AT HOLE:"
1490 GOSUB 1620
1500 GOSUB 2070
1510 GOSUB 2220
1520 GOSUB 2320
1530 GOSUB 2570
1540 GOSUB 2830
1550 IF P=32 THEN 1570
1560 MOVE @1:130,100
1570 WINDOW 0,130,0,100
1580 VIEWPORT 0,130,0,100
1590 MOVE 0,0
1600 PRINT
1610 GO TO 870
1620 REM **.SUB: PRINT TITLE AND LABEL AXES
1630 IF P=1 THEN 1830
1640 IF Q=1 THEN 1700
1650 IMAGE "L_",13X,45A
1660 PRINT USING 1650:H$
1670 IMAGE 8X,30A,7A,",  "12A
1680 PRINT USING 1670:I$,U$,D$
1690 GO TO 1730
1700 IMAGE "L_",10X,40A,D.2D," m/msec"
1710 PRINT USING 1700:E$,V6
1720 IMAGE 40A,D.2D," m/msec"
1730 MOVE B5+2*K1,B2+4
1740 PRINT "T     Z"
1750 MOVE 0,(B1+B2+(LEN(B$)-1)*K2)/2
1760 FOR I=1 TO LEN(B$)
1770 F$=SEG(B$,I,1)
1780 PRINT F$
1790 NEXT I
1800 MOVE (B4+B5-K1*LEN(J$))/2,B1-6
1810 PRINT J$
1820 RETURN
1830 REM**TITLE AND LABELS ON 4662 PLOT
1840 PRINT @1,17:K3,K4
1850 PRINT @1,25:90
1860 IF Q=1 THEN 1960
1870 MOVE @1:3.6,14.5
1880 IMAGE 45A
1890 PRINT @1: USING 1880:H$
1900 MOVE @1:6.3,6
1910 IMAGE 29A,7A," on ",12A
1920 PRINT @1: USING 1910:I$,U$,D$
```

```
1930 MOVE @1:9,26
1940 PRINT @1:"IN AREA:";A$
1950 GO TO 1980
1960 MOVE @1:5,6.6
1970 PRINT @1: USING 1720:E$,V6
1980 MOVE @1:9,B5+0*K2
1990 PRINT @1:" T  Z"
2000 MOVE @1:128,(B4+B5-LEN(J$)*K3)/2
2010 PRINT @1:J$
2020 MOVE @1:(B1+B2+LEN(K$)*K3)/2,3
2030 PRINT @1,25:180
2040 PRINT @1:K$
2050 PRINT @1,25:90
2060 RETURN
2070 REM ** SUB: PLOT BORDERS
2080 IF P=1 THEN 2150
2090 MOVE B4,B1
2100 RDRAW 0,B3+3
2110 RDRAW B8,0
2120 RDRAW 0,-B3-3
2130 RDRAW -B8,0
2140 GO TO 2210
2150 MOVE @1:B2-3,B4
2160 B3=-B3
2170 RDRAW @1:0,B8
2180 RDRAW @1:B3+3,0
2190 RDRAW @1:0,-B8
2200 RDRAW @1:-B3-3,0
2210 RETURN
2220 REM ** SUB:DETERMINE MAX AND MIN NORMAL MOVEOUTS
2230 M3=1000
2240 M4=0
2250 FOR J=1 TO N1
2260 FOR K=1 TO N2
2270 M3=M3 MIN T(J,K)
2280 M4=M4 MAX T(J,K)
2290 NEXT K
2300 NEXT J
2310 RETURN
2320 REM ** SUB: PLOT AND LABEL NMO TICKMARKS
2330 C1=B3/(M4-M3)
2340 H1=M1*(INT(M3/M1)+1)
2350 G1=(H1-M3)*C1
2360 IF P=32 THEN 2390
2370 GOSUB 2970
2380 RETURN
2390 MOVE B4,B1
2400 RMOVE 0,G1
2410 GOSUB 2490
2420 FOR I=1 TO INT((M4-M3)/M1)
2430 RMOVE 0,M1*C1
2440 H1=H1+M1
2450 IF H1>M4 THEN 2480
2460 GOSUB 2490
2470 NEXT I
2480 RETURN
2490 REM ** SUB: TICKMARK PLOTTING
2500 RDRAW 0.2,0
2510 RMOVE B8-0.4,0
2520 RDRAW 0.2,0
2530 RMOVE -B8-5*K1,-K2/2
```

```
2540 PRINT USING "3D.D":H1
2550 RMOVE 5*K1,K2/2
2560 RETURN
2570 REM ** SUB: PLOT AND LABEL SP-DETECTOR DISTANCE TICKMARKS
2580 C1=B6/(X4-X3)
2590 H1=M2*(INT(X3/M2)+1)
2600 G1=(H1-X3)*C1
2610 IF P=32 THEN 2640
2620 GOSUB 3200
2630 RETURN
2640 MOVE B4,B1
2650 RMOVE G1,0
2660 GOSUB 2680
2670 GO TO 2760
2680 REM ** SUB: TICKMARK PLOTTING
2690 RDRAW 0,0.2
2700 RMOVE 0,B3+2.6
2710 RDRAW 0,0.2
2720 RMOVE -1.7*K1,-B3-K2-3
2730 PRINT @P: USING "3D":H1
2740 RMOVE 1.7*K1,K2
2750 RETURN
2760 FOR I=1 TO INT((X4-X3)/M2)
2770 H1=H1+M2
2780 IF H1>X4 THEN 2820
2790 RMOVE M2*C1,0
2800 GOSUB 2680
2810 NEXT I
2820 RETURN
2830 REM ** SUB: PLOT NMO'S
2840 IF P=32 THEN 2870
2850 GOSUB 3440
2860 RETURN
2870 WINDOW X3,X4,M3,M4
2880 VIEWPORT B4,B5,B1,B2
2890 FOR J=1 TO N1
2900 MOVE X3,T(J,1)
2910 FOR K=2 TO N2
2920 RDRAW X0(K)-X0(K-1),T(J,K)-T(J,K-1)
2930 NEXT K
2940 PRINT USING 3460:T0(J);Z0(J)
2950 NEXT J
2960 RETURN
2970 REM ** SUB: NMO TICKMARKS AND VALUES, 4662 PLOT
2980 MOVE @1:122,14
2990 K5=1.03
3000 K6=10.5
3010 K7=0.4
3020 RMOVE @1:-G1,0
3030 GOSUB 3110
3040 FOR I=1 TO INT((M4-M3)/M1)
3050 RMOVE @1:-M1*C1,0
3060 H1=H1+M1
3070 IF H1>M4 THEN 3100
3080 GOSUB 3110
3090 NEXT I
3100 RETURN
3110 REM ** SUB: TICKMARK PLOTTING
3120 RDRAW @1:0,K7
3130 RMOVE @1:0,B8-2*K7
3140 RDRAW @1:0,K7
```

```
3150 RMOVE @1:0,-B8
3160 RMOVE @1:K5,-K6
3170 PRINT @1: USING "3D.D":H1
3180 RMOVE @1:-K5,K6
3190 RETURN
3200 REM ** SUB: SP-SEIS DISTANCE TICKMARKS AND VALUES, 4662 PLOT
3210 K5=2.33*K3
3220 MOVE @1:125,B4-K5
3230 PRINT @1: USING "3D":X3
3240 MOVE @1:B2-3,B4
3250 K6=3
3260 RMOVE @1:0,G1
3270 GOSUB 3360
3280 FOR I=1 TO INT((X4-X3)/M2)
3290 RMOVE @1:0,M2*C1
3300 H1=H1+M2
3310 IF H1>X4 THEN 3350
3320 GOSUB 3360
3330 NEXT I
3340 PRINT @1,7:
3350 RETURN
3360 REM ** SUB: TICKMARK PLOTTING
3370 RDRAW @1:K7,0
3380 RMOVE @1:B3+3-2*K7,0
3390 RDRAW @1:K7,0
3400 RMOVE @1:K6,-K5
3410 PRINT @1: USING "3D":H1
3420 RMOVE @1:-B3-3-K6,K5
3430 RETURN
3440 REM ** SUB: PLOT NMO'S, 4662 PLOT
3450 PRINT @1,17:K1,K2
3460 IMAGE 4D,X,4D
3470 WINDOW M3,M4,X3,X4
3480 VIEWPORT B2,B1,B4,B5
3490 FOR J=1 TO N1
3500 MOVE @1:M4+M3-T(J,1),X3
3510 FOR K=2 TO N2
3520 RDRAW @1:T(J,K-1)-T(J,K),X0(K)-X0(K-1)
3530 NEXT K
3540 PRINT @1: USING 3460:T0(J),Z0(J)
3550 NEXT J
3560 RETURN
3570 REM ** SUB: COMPUTE NMO'S USING VELOCITY FUNCTION
3580 PRINT "__YOU HAVE SELECTED TO ENTER DATA FROM A DOWNHOLE SURVEY"
3590 PRINT "__     Survey area (20 characters,max) : ";
3600 INPUT A$
3610 PRINT "__Hole designation (7 characters,max) : ";
3620 INPUT U$
3630 PRINT "__       Data date (12 characters,max) : ";
3640 INPUT D$
3650 PRINT "__                  Number of NMO curves = ";
3660 INPUT N1
3670 DIM T0(N1+7),V1(N1),V2(N1),Z0(N1+7),T(N1+7,N2)
3680 T0=0
3690 V2=0
3700 Z0=0
3710 T=0
3720 MOVE 0,0
3730 PRINT
3740 PRINT "L_ENTER THE FOLLOWING FOR EACH NMO CURVE TO BE COMPUTED";
3750 PRINT " AND PLOTTED"
```

```
3760 PRINT "    1. One-way time for curve to be computed = T0,"
3770 PRINT "    2. Observed one-way time less than T0 = T5,"
3780 PRINT "    3. Observed one-way time greater than T0 = T6,"
3790 PRINT "    4. Average velocity at T5 = V5,"
3800 PRINT "    5. Average velocity at T6 = V6,"
3810 PRINT "    6. RMS velocity at T5 = V7, and"
3820 PRINT "    7. RMS velocity at T6 = V8"
3830 PRINT "__CURVE   1-WAY      BRACKETING TIMES";
3840 PRINT "          BRACKETING VELOCITES"
3850 PRINT " NO.    TIME,T0       T5          T6           V5      V6";
3860 PRINT "         V7     V8"
3870 FOR J=1 TO N1
3880 PRINT "  ";J;"       ";
3890 INPUT T0(J)
3900 PRINT "K_                    ";
3910 INPUT T5
3920 PRINT "K_                               ";
3930 INPUT T6
3940 K=(T0(J)-T5)/(T6-T5)
3950 PRINT "K_                                           ";
3960 INPUT V5
3970 PRINT "K_                                                   ";
3980 INPUT V6
3990 V1(J)=V5+K*(V6-V5)
4000 Z0(J)=V1(J)*T0(J)
4010 T0(J)=2*T0(J)
4020 PRINT "K_                                                         ";
4030 INPUT V7
4040 PRINT "K_                                                         ";
4050 PRINT "       ";
4060 INPUT V8
4070 V2(J)=V7+K*(V8-V7)
4080 NEXT J
4090 MOVE 0,0
4100 PRINT
4110 PRINT "L_INTERPOLATED VELOCITIES AND DEPTH VS. ";
4120 PRINT " VERTICAL REFLECTION TIME"
4130 PRINT "__CURVE   REFLECTION     AVG.           RMS         DEPTH"
4140 PRINT " NO.         TIME       VELOCITY     VELOCITY"
4150 IMAGE X,2D,7X,3D.D,8X,D.2D,9X,D.2D,,6X,4D.D
4160 FOR J=1 TO N1
4170 PRINT USING 4150:J,T0(J),V1(J),V2(J),Z0(J)
4180 NEXT J
4190 Q=2
4200 MOVE 0,0
4210 PRINT
4220 RETURN
4230 REM ** SUB: TABLE HEADING WHEN VELOCITY FUNCTION USED
4240 PRINT "__   TABLE OF NMO'S IN GROUPS OF 7 DEPTHS";
4250 PRINT " ON THE VELOCITY FUNCTION"
4260 PRINT "DEPTH=";
4270 IMAGE 3X,3D,6(6X,3D)
4280 PRINT USING 4270:Z1(1),Z1(2),Z1(3),Z1(4),Z1(5),Z1(6),Z1(7)
4290 PRINT "V. TIME=";
4300 IMAGE 4D.D,6(3X,4D.D)
4310 PRINT USING 4300:M0(1),M0(2),M0(3),M0(4),M0(5),M0(6),M0(7)
4320 RETURN
```