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**Seismic Signal Location Program
for the Los Alamos Scientific Laboratory's
Dry Hot Rock Geothermal Project**

by

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SEISMIC SIGNAL LOCATION PROGRAM FOR THE LOS ALAMOS SCIENTIFIC LABORATORY'S

DRY HOT ROCK GEOTHERMAL PROJECT

by

P. R. Kintzinger

ABSTRACT

During hydraulic fracturing, seismic signals produced as the fracture grows may be used to determine orientation, size, and shape of the fracture. This seismic signal location program has been written to utilize such signals, along with an experimentally determined seismic velocity model to help determine the fracture orientation, size, and shape.

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INTRODUCTION

The Los Alamos Scientific Laboratory (LASL) is investigating methods of extracting geothermal energy from dry hot rock in the crust of the earth. A system presently being investigated is for use in hot formations that have a low permeability. The system is based on the creation of a pressurized-water circulation loop by drilling two holes from the surface and connecting them by means of a large crack system produced by hydraulic fracturing.^{1,2}

One procedure may be to drill one hole, hydraulically fracture at the desired depth, determine the orientation of the large hydraulic fracture, and then drill the second hole to intersect the hydraulic fracture. It is very important that techniques be developed for determination of the orientation, size, and shape of hydraulic fractures that have been produced.

The method described herein utilizes an array of surface seismic stations to locate seismic events that are caused by the hydraulic fracturing process.

The project area is 3 km (2 miles) west of the peripheral ring fault zone associated with the collapse of the Valles Caldera in the Jemez Mountains in New Mexico. The geothermal site location is NE 1/4, Section 13, T19N, R2E NMPM. Land surface elevation is 2648.7 m (8690 ft).

Geothermal Test Hole No. 2 (GT-2) was drilled in 1974 to a total depth of 2932 m (9619 ft). In

1975, the first borehole of the energy extraction system (EE-1) was drilled to a depth of 3064 m (10 053 ft). Pettitt has summarized in detail the GT-2 drilling operation,^{3,4} and a synopsis of the drilling of EE-1 will be published at a later date.

During hydraulic fracturing no usable signals have been received at the surface seismic stations. It is hoped that as larger fractures are produced, as surface station instrumentation is upgraded, and as analysis techniques are improved, usable signals will be obtained.

GEOLOGY

GT-2 penetrated 137 m (449 ft) of volcanics, 238 m (780 ft) of Permian red beds and 355 m (1165 ft) of Pennsylvanian-Mississippian shales and limestones, before encountering granite at 732 m (2402 ft).⁵ The crystalline Precambrian rocks include granites, granodiorites, monzonites, biotite schist, and amphibolite. The textures range from fine- to coarse-grained and the colors from pink to black.⁶

SURFACE SEISMIC STATIONS

Seismic stations have been set up around GT-2 and EE-1 to monitor natural seismic signals and to measure signals produced during hydraulic fracturing in GT-2 and EE-1. Figure 1 shows the location of seismometers with the "Q" designation, denoting seismometers emplaced by the Geothermal Energy Group,

Fig. 1. Map of seismometer locations near LASL geothermal site.

Q-22, and the "J" designation, denoting seismometers emplaced by J-Division. The Q-22 seismometers are Teledyne Geotech S-13 short-period seismometers and J-Division seismometers are Teledyne Geotech S-13 or other short-period seismometers.⁷

SEISMIC LOCATION PROGRAM

Program MEHYPO is designed to locate seismic signal sources in a flat earth, using initial arrivals which have followed refracted ray paths starting upwards. The methods used are common to most least-squares hypocenter determination programs. Techniques used for computation of distances and travel times and derivatives have been appropriately modified for a horizontally layered, flat earth. Other arrivals such as the S-wave arrivals could be used for source location provided that the appropriate seismic velocity model is available.

This program is a modification of programs that have been developed by Teledyne Geotech of Garland, Texas. G. E. Clawson and J. L. Johnson of Teledyne Geotech modified and adapted the program for use on the Los Alamos Scientific Laboratory's geothermal project.

Input for seismic velocity models has been provided by the sonic travel-time logs of GT-2⁶ and by the seismic velocity calibration study in the area around GT-2.⁸

The following material presents information and data needed for use of program MEHYPO on the LASL Control Data Corporation 6600 computer and the KRONOS operating system. Included are operating procedures (batch and remote), input and output data formats, program listings, site coordinates, and earth model data for GT-2.

Program MEHYPO consists of eight modules as follows.

- HYCNTL - control program
- MEHYPO - hypocenter determination routine
- TTIM - travel time and derivative routine
- ELVCOR - station elevation and velocity correction
- DELETS - station data deletion routine
- STAIN - station constants input routine
- MODIN - earth model input routine
- DATIN - hypocenter and arrival data input routine

There are some basic oscillation problems inherent in the use of iterative least-squares techniques for estimating hypocenters in a layered earth with significant velocity contrasts across layer boundaries. Because of this, MEHYPO includes coding specifically designed to detect such problems and permit or force convergence, or at least provide useful results when they do occur.

PROGRAM OPERATION

Batch Operation

For batch operations, the MEHYPO program modules are followed by a card deck of all station constants. This is followed by an earth-model card deck behind which are any desired number of event and associated station-arrival groups. Different earth models, each followed by event and station groups, can be specified as desired. Use of an event name of FINA immediately followed by an earth-model name of FINA terminates MEHYPO (see Fig. 2).

Remote Operation

MEHYPO source program modules are called from permanent disk storage in the central computer system for remote terminal operation under KRONOS. In addition, station-constant, earth-model, and arrival time data files are created, modified, and defined

Fig. 2. MEHYPO program and data card deck (batch operation).

for MEHYPO access by use of KRONOS on the remote terminal. Input files are defined as follows.

Tape 1 - Station Constants File (SCF) name.

Tape 2 - Earth Model File (MODF) name. (Note: The last model in each file must be named "FINA.")

Tape 3 - Arrival Time Data File (ATDF) name. (It is suggested the ATDF name correspond to the event name for the arrival time data.)

File names must consist only of alphanumeric characters because KRONOS may interpret other characters (such as -, ?s, .s, etc.) as delimiters.

Figure 3 shows required actions and sequences for remote terminal operation of MEHYPO. Examples of file creation and modification are given in Tables I and II. File data must follow card format specifications as shown in Fig. 4 and detailed in the section on data formats.

Fig. 3. MEHYPO program KRONOS remote terminal operation.

TABLE I
EXAMPLE FILE CREATION

KRONOS Output	Manual Input	Remarks
BEGIN TEXT EDITING	EDIT,FILNAME	Defines file name
? ENTER TEXT	A	Add data
? ? ? ? ? ?	/DATA RECORD 1 DATA RECORD 2 DATA RECORD 3 DATA RECORD N/	Add data between /'s
READY ? ?	R L;*	Reset line counter to 1. List entire file.
DATA RECORD 1 DATA RECORD 2 DATA RECORD 3 DATA RECORD N -END OF FILE- ? END TEXT EDITING. READY.	END	Text editing complete.
READY.	SAVE,FILNAME	Save new file.

Operating under KRONOS, MEHYPO is called and tape files are defined by the following command.

```
/GET,TAPE1=SCF,TAPE2=MODF,TAPE3=ATDF,MEHYPO.
```

where SCF, MODF, and ATDF are file names.

Compilation and running of MEHYPO is then initiated by the following command.

```
/FUN,G,I=MEHYPO.
```

As shown in Fig. 3, MEHYPO then reads the SCF, reads and prints the MODF, and requests a trial hypocenter by printing the following.

```
INPUT HYPOCENTER ESTIMATE.
```

The operator must then enter trial hypocenter data as shown in Fig. 4; however, the data may be in free format (see section on data formats) of the following form.

```
(EVENTNAME),ORIGINTIME,YCOORDINATE,XCOORDINATE,  
DEPTH,DEPTHCONTROL,PRINTCONTROL.
```

Operation of the program then proceeds as shown in Fig. 3. Use of an event name of FINA immediately followed by an earth model name of FINA terminates MEHYPO.

DATA FORMATS

General

MEHYPO input data formats are shown in Fig. 4 and detailed in the following sections.

Station Constants

A list of site coordinates (station constants) for the LASL Dry Hot Rock Geothermal Energy Project is given in Appendix A.

Program MEHYPO is dimensioned for constants for a maximum 50 stations.

Constants

Card Cols.	Format	Description
1-4	A4	station or site designator
5-12	F8.5	y-coordinate in km
13-20	F8.5	x-coordinate in km
21-28	F8.5	station model elevation in km
29-36	F8.5	station model velocity in km/sec

Termination. The station constants file is terminated by a blank station designator.

Earth Model

Earth-model data for Fenton Hill, obtained from the drilling and logging of exploratory hole GT-2, are given in Appendix B.

TABLE II

EXAMPLE FILE MODIFICATION

<u>KRONOS Output</u>	<u>Manual Input</u>	<u>Remarks</u>
BEGIN TEXT EDITING.	GET,FILNAME	
?	EDIT,FILNAME	
DATA RECORD 1	L;*	List entire file.
DATA RECORD 2		
DATA RECORD 3		
... ..		
... ..		
DATA RECORD N		
-END OF FILE-		
?	F:/DATA RECORD 3/	Find data in /'s.
DATA RECORD 3		
?	A	Add (=insert) data
ENTER TEXT.		
?	/DATA RECORD 4/	Add data in /'s.
READY.		
?	R	Reset line counter to 1.
?	F:/DATA RECORD N/	Find data in /'s.
DATA RECORD N		
?	C	Change data
ENTER TEXT.		
?	/DATA RECORD LAST/	Change to data in /'s.
READY.		
?	R	Reset line counter to 1.
?	L;*	List entire file.
DATA RECORD 1		
DATA RECORD 2		
DATA RECORD 3		
DATA RECORD 4		
... ..		
... ..		
DATA RECORD LAST		
-END OF FILE-		
?	END	Text editing complete.
END TEXT EDITING.		
READY.	REPLACE,FILNAME	Save modified file.
READY.		

Program MEHYPO is dimensioned for an earth model consisting of a maximum of 20 layers.

Model Name

Card Cols.	Format	Description
1-30	3A10	name of the earth model

Model Layers

Card Cols.	Format	Description
1-10	F10.2	layer thickness in km
11-20	F10.2	layer velocity in km/sec

Termination

(a) The earth model is terminated by a layer of zero thickness.

(b) An earth-model name of FINA in card cols. 1-4 terminates program MEHYPO.

Trial Hypocenter

Trial hypocenter data input is accomplished in free format as discussed in the section on remote operation. Alpha information must be contained within brackets and the field must be terminated with a comma [viz: (ABC),]. Numeric information should be of the correct mode (real or integer) and the field must be terminated with a comma. Basic card formats as shown in Fig. 4 are given as follows.

Hypocenter Estimate

Card Cols.	Format	Description
1-4	A4	event name or designation

[illegible]

Termination. The hypocenter estimate is normally followed by station arrival-time data; however, if the event name is FINA, the program will expect a new earth model.

Station Arrival-Time Data

Arrival-Time Data

Card	Cols.	Format	Description
1-4	A4		station code
5-12	F8.2		refracted-wave arrival time in sec

Termination. Arrival-time data for an event is terminated by a blank station code.

RESULTS

General

In summary, MEHYPO results are as follows. The current model is printed. This is followed by results for each hypocenter and associated arrival-data set processed for the model. Normally, the input hypocenter and arrival data are printed followed by the final computed station and hypocenter results. If the iterative output option was selected, station and hypocenter results are also printed at the end of each iteration. Example results from program MEHYPO are shown in Fig. 5 for a depth-free run with iterative output.

A variety of error and processing-problem messages are printed as appropriate concerning failure to provide station constants, deletion of station data, possible singular normal equation matrix, oscillation, and ray paths which reach critical angles. The value of variable IBACK, printed as part of the final solution, is also used to indicate the status of the solution achieved at termination.

Results are described in detail in the following sections.

Earth Model

The name of the model and the number, thickness (km), and velocity (km/sec) are printed for each layer.

Trial Hypocenter

The event name, input origin time (sec), and input y, x, and depth coordinates (km) are printed.

Station Arrival Data

The station number, code, and arrival time (sec) of each station are printed, sequenced by epicentral distance.

Iteration Output

Station Data. The code, distance (km), travel-time (sec), travel-time residual (sec), and distance and depth derivatives (sec/km) are printed for each station used in the iteration, sequenced by epicentral distance.

Hypocenter Data. The iteration number, the changes to the origin time (sec), y, x, and depth coordinates (km), and the resulting standard deviation and average for the travel-time residuals (sec) are printed followed by the new origin time (sec) and new y, x, and depth coordinates (km).

Solution

The event name and the final solution or terminal values for the origin-time (sec), y, x, and depth coordinates (km), and the standard deviation and average residual (sec) are printed. In addition, the total number of iterations used and the value of the variable IBACK are printed. Values of IBACK indicate the following conditions.

- 0 - Normal return; solution valid.
- 1 - Iteration limit reached; solution may not be valid.
- 2 - Calculated depth less than zero or greater than model; solution may not be valid.
- 3 - Singular solution to normal equation matrix; solution may not be valid.
- 4 - Too few stations because of critical-angle-of-incidence problem; solution not valid.
- 5 - Too few stations because of deletions by three-standard-deviation problem; solution not valid.
- 6 - Depth oscillation; solution may not be valid.

Diagnostics

No Station Constants. If the card deck of station constants is omitted, the error message NO STATION CONSTANTS FOUND is printed and processing is terminated.

Unknown Station. If the station code for an arrival time cannot be found in the list of station constants, the error message AAAA (station code) XXX.XX (arrival time) SKIPPED is printed. Processing continues if possible.

Excessive Residual Deletion. On the third or more iteration, if a station's time residual exceeds the standard deviation of all residuals by a factor of 3 or more, the message AAAA (station code) DELETED BECAUSE OF EXCESSIVE RESIDUAL is printed. Processing continues if possible.

```

MODEL NEVADA BR 3
LAYER THICKNESS(KM) VELOCITY(KM/S)

1      1.00      3.30
2      2.00      4.70
3      16.50     6.00
4      1000.00   8.50

INPUT HYPOCENTER ESTIMATE
(1-ST),105.5,1.5,2.5,3.6,2.1
      EV      DTIM      YLOC      XLOC      HLOC
MEHYPO INPUT  1-ST      105.500      1.500      2.500      3.600

1  A      101.903
2  B      101.718
3  C      101.559
4  D      101.172

STA      DIST      TT      RES      PTD      PTH
D      1.591      1.046     -5.374     .088     .142
B      4.301      1.385     -5.167     .156     .060
A      7.106      1.837     -5.434     .165     .025
C      7.778      1.947     -5.888     .165     .021

1  CHANGES=     -5.3131     -1.5972     -2.4710      0.0000      .304     -5.466
    NEW LOCATION=    100.1869      -.0972      .0290      3.6000

STA      DIST      TT      RES      PTD      PTH
D      1.465      1.037     -.052     .082     .145
C      4.940      1.485     -.113     .160     .047
B      6.039      1.662     -.131     .163     .033
A      7.382      1.882     -.166     .165     .023

2  CHANGES=     -.1153      .0977     -.0850      0.0000      .047     -.115
    NEW LOCATION=    100.0716      .0005     -.0559      3.6000

STA      DIST      TT      RES      PTD      PTH
D      1.454      1.037      .064     .082     .145
C      4.967      1.489     -.002     .160     .047
B      6.138      1.678     -.032     .164     .032
A      7.264      1.863     -.031     .165     .024

3  CHANGES=     -.0484      .0209      .0661      .8102      .045      .000
    NEW LOCATION=    100.0229      .0289      .0017      4.4102

STA      DIST      TT      RES      PTD      PTH
D      1.393      1.156     -.007     .062     .155
C      5.024      1.555     -.019     .146     .030
B      6.086      1.712     -.017     .154     .064
A      7.253      1.893     -.013     .159     .051

4  CHANGES=     -.0222     -.0285     -.0010      .0872      .000     -.014
    NEW LOCATION=    100.0008      .0004      .0006      4.4974

STA      DIST      TT      RES      PTD      PTH
D      1.413      1.171     -.000     .062     .155
C      5.001      1.559     -.001     .145     .033
B      6.082      1.718     -.000     .153     .067
A      7.280      1.903     -.000     .158     .053

      EV      DTIM      YLOC      XLOC      HLOC  NIT  IEACK  SDEV      AVG
MEHYPO OUTPUT 1-ST      100.001      .000      .001      4.497  5    0    .000     -.000

```

Fig. 5. Example MEHYPO results (depth-free run).

Critical Angle of Incidence. If the refracted ray path from the trial hypocenter towards a station reaches or exceeds the critical angle of incidence (causes reflection) or is diffracted, the message CRITICAL OR 90 DEG ANGLE OF INCIDENCE REACHED FOR AAAA (station code) at XXX.XXX (distance) is printed. The station's arrival is deleted for that run of the event. Processing continues if possible.

Singular Matrix. If the determinant of the normal equation matrix becomes less than 1.0×10^{-8} , the message POSSIBLE SINGULAR MATRIX WITH DETERMINANT OR X.XXE-XX is printed. Processing continues.

Oscillation. If a satisfactory solution is not obtained for the hypocenter because of depth oscillation, hypocenter results will be printed at 1-km-depth increments from a depth of 1 km to the bottom of the model.

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APPENDIX A

SITE COORDINATES FOR THE LOS ALAMOS SCIENTIFIC LABORATORY'S

DRY HOT ROCK GEOTHERMAL PROJECT

Site Code	y-Coord. (km)	x-Coord. (km)	Model Elev. (km)	Velocity (km/sec)	Site Elev. (km)
T-1	539.89266	115.31549	-0.00790	2.0	2.64078
T-2	539.39144	115.78955	-0.00488	2.0	2.64380
T-3	540.37431	112.95938	-0.02332	2.0	2.62536
T-4	541.77323	112.77835	-0.03874	2.0	2.60994
T-5	542.16963	113.86302	+0.00313	2.0	2.65181
T-6	542.78444	115.43212	+0.02774	2.0	2.67642
T-7	541.44741	113.83300	-0.00145	2.0	2.64723
T136	541.02370	116.99522	-0.30571	2.3	2.34287
W136	541.48790	114.44356	+0.00190	2.0	2.65049
J-1	541.41868	114.26251	+0.00460	2.0	2.65328
J-2	541.91855	114.74745	+0.01100	2.0	2.65968
J-3	542.57631	115.00074	+0.01436	2.0	2.66304
J-4	541.91550	115.58930	-0.15176	2.1	2.49692
J-5	540.15528	115.21989	-0.02953	2.0	2.61915
J-6	540.96544	114.30396	-0.01338	2.0	2.63530
J-7	540.09554	113.42888	-0.05270	2.0	2.59598
J-8	540.49361	113.06282	-0.02527	2.0	2.62341
J-9	540.00593	112.77509	-0.04477	2.0	2.60391
J-10	540.82615	112.72876	-0.03411	2.0	2.61457
J-11	541.62655	112.96894	-0.14292	2.1	2.50576
J-12	542.89879	114.11864	+0.01161	2.0	2.66029
J-13	540.97245	115.01445	-0.08348	2.0	2.56520
Q-1	542.14746	114.32987	+0.00948	2.0	2.65816
Q-2	541.54060	114.88156	-0.04996	2.0	2.59872
Q-3	540.67527	114.60206	-0.01887	2.0	2.62981
Q-4	540.69783	113.63584	-0.01429	2.0	2.63439
Q-5	541.12820	113.43803	-0.01673	2.0	2.63195
Q-6	541.42996	114.18570	+0.00582	2.0	2.65450
Q-7	541.36625	114.08237	+0.00125	2.0	2.64993
Q-8	541.34857	114.16375	+0.00064	2.0	2.64932
RGCT	541.30160	114.14797	0.00000	2.0	2.64868
GT-2	541.30139	114.14864	+0.00002	2.0	2.64870
PP	541.41758	114.15997	+0.00567	2.0	2.65435

APPENDIX B

MODEL DATA, GT-2 BOREHOLE

Detailed Structure							LASL GT2A Model			
Layer No.	Depth (ft)	Thick-ness (ft)	Velocity (ft/sec)	Depth (km)	Thick-ness (km)	Velocity (km/sec)	Layer No.	Depth (km)	Thick-ness (km)	Velocity (km/sec)
	0			0				0.0		
1	350	350	?	0.107	0.107	?	1	0.1	0.1	2.0
2	475	125	7000	0.145	0.038	2.134				
3	550	75	8500	0.168	0.023	2.591				
4	750	200	9900	0.229	0.061	3.018				
5	1000	250	7700	0.305	0.076	2.347	2		0.3	2.5
6	1150	150	8900	0.351	0.046	2.713				
7	1250	100	7000	0.381	0.030	2.134				
8	1375	125	12800	0.419	0.038	3.901		0.4		
9	1600	225	9700	0.488	0.069	2.957				
10	1750	150	12000	0.533	0.045	3.658	3		0.3	3.2
11	1810	60	10000	0.552	0.019	3.048				
12	2575	765	?	0.785	0.233	?		0.7		
13	2800	225	19900	0.853	0.068	6.066				
14	3000	200	21100	0.914	0.061	6.431	4		0.3	6.1
15	3300	300	19000	1.006	0.092	5.791	5	1.0	0.2	6.3
16	4200	900	20700	1.280	0.274	6.309	6	1.2	0.3	6.2
17	5375	1175	20300	1.638	0.358	6.187		1.5		
18	6000	625	20000	1.829	0.191	6.096	7		0.4	6.1
19	6300	300	19000	1.920	0.091	5.791	8	1.9	1.1	6.0
							9	3.0	7.0	6.5

EXAMPLE OF MODEL LISTING

PROGRAM GT2A

[LASL GT-2A]

0.1 2.0
0.3 2.5
0.3 3.2
0.3 5.0
0.2 5.6
0.3 6.2
0.4 6.1
1.1 6.0
7.0 6.5
0

FINA

The first column is layer thickness (km) and the second is velocity (km/sec).

APPENDIX C
PROGRAM MEHYPO LISTING

```

PROGRAM    MEHYPO

      PROGRAM HYCNTRL (INPUT,OUTPUT,TAPE1,TAPE2,TAPE3)
C *** THIS ROUTINE IS THE CONTROL PROGRAM FOR MEHYPO.
C
C *** MODEL STRUCTURE COMMON
COMMON TL(20),VL(20),NL,HMAX
C *** HYPOCENTER INFORMATION COMMON
COMMON IDE,OTIM,YLOC,XLOC,HLOC,NIT,IBACK,SDVEV,AVRES
C *** STATION LOCATION COMMON
COMMON IDSC(50),STAY(50),STAX(50),STAE(50),STAV(50),NSTA
C *** STATION ARRIVAL INFORMATION COMMON
COMMON IDX(50),ATIM(50),DIST(50),NA
C   IHCNT=DEPTH CONTROL(0=FREE,1=RESTRAINED,2=RESTRAINED AND FREE)
C   KPFLG=PRINT CONTROL(0=SOLUTION,1=ITERATIVE,2=DEPTH INCREMENTS)
C
      NSTA=0
C   INPUT STATION COORDINATES
      CALL STAIN
      IF(NSTA.NE.0) GO TO 10
      PRINT 1000
1000  FORMAT (1H1,1X,27HNO STATION CONSTANTS FOUND.)
      GO TO 999
C   INPUT EARTH MODEL.
10  CALL MODIN
      IF(NL.EQ.0) GO TO 999
C   INPUT TRIAL HYPOCENTER AND/OR STATION ARRIVAL DATA.
20  CALL DATIN(IHCNT,KPFLG)
      NACON=NA
      IF(NA.EQ.0) GO TO 10
      NRUN=IHCNT+1
      IF(NRUN.EQ.1) NRUN=2
25  NRUN=NRUN-1
      IF(NRUN.EQ.0) GO TO 20
      IDEPT=IHCNT
      IF(IDEPT.EQ.2) IDEPT=1
      IHCNT=0
      IORBIT=0
30  NIT=15
      NA=NACON
      NETKS=NA
      SMTV=0.1E-07
      CALL MEHYPO (NETKS,IDEPT,KPFLG,SMTV)
      IF(IBACK.EQ.0) GO TO 150
      IF(IBACK.EQ.1) GO TO 100
      IF(IBACK.NE.2) GO TO 40
      IF(IORBIT.NE.0) GO TO 100
      IORBIT=IORBIT+1
      GO TO 30
40  IF(IBACK.EQ.6) GO TO 100
50  GO TO 150
C   RUN AT ALL POSSIBLE DEPTHS
100 IDEPT=1
      KTEMP=KPFLG
      KPFLG=2
      DHMAX=HMAX-1000.0
      HINDX=1.0
      HLDC=1.0
      PRINT 125
125  FORMAT(1H1,2X,5HEVENT,5X,4HOTIM,5X,4HYLOC,5X,4HXLOC,5X,4HHLOC,6X,
     C3HNIT,4X,5HIBACK,4X,5HSTDEV,4X,5HAVRES,/)
130  NIT =10
      NA=NACON
      NETKS=NA
      SMTV=0.1E-07

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      CALL MEHYPO (NETKS,IDEPT,KPFLG,SMTV)
      PRINT 145,IDE,OTIM,YLOC,XLOC,HLOC,NIT,IBACK,SDVEV,AVRES
145  FORMAT (4X,A4,4F9.3,2(5X,I4),2F9.3)
      HLOC=HLOC+HINDX
      IF (HLOC.LT.DHMAX) GO TO 130
      KPFLG=KTEMP
150  GO TO 25
999  RETURN
      END

      SUBROUTINE MEHYPO (NETKS,IDEPT,KPFLG,SMTV)
C
C *** PURPOSE - TO DETERMINE THE HYPOCENTER OF A MICROSEISMIC EVENT
C               USING ARRIVAL TIMES AT FOUR OR MORE LOCATIONS NEAR ENOUGH THE
C               EXPECTED HYPOCENTER TO FIT A MULTIPLE LAYERED FLAT EARTH MODEL.
C   NETKS - NUMBER OF ARRIVALS IN STATION NETWORK.
C   IDEPT - INDICATOR OF DEPTH COMPUTATION (0=FREE, 1=RESTRAINED)
C   KPFLG - PRINT CONTROL(0=SOLUTION,1=ITERATIVE,2=DEPTH INCREMENTS)
C   SMTV - SINGULAR MATRIX TEST VALUE
C
C *** MODEL STRUCTURE COMMON
C   COMMON TL(20),VL(20),NL,HMAX
C *** HYPOCENTER INFORMATION COMMON
C   COMMON IDE,OTIM,YLOC,XLOC,HLOC,NIT,IBACK,SDVEV,AVRES
C       OTIM - INPUT AS ESTIMATED AND OUTPUT AS COMPUTED
C               HYPOCENTER ORIGIN TIME (IN SECONDS).
C       XLOC,YLOC,HLOC - INPUT AS ESTIMATED AND OUTPUT AS
C               COMPUTED LOCATION OF THE HYPOCENTER
C               (IN KILOMETERS).
C       NIT - INPUT AS NUMBER OF ITERATIONS ALLOWED, OUTPUT AS
C               NUMBER OF ITERATIONS TAKEN TO COMPLETE
C               CONVERGENCE OR REJECT EVENT.
C       IBACK - INDICATOR FOR CONDITION OF RETURNED SOLUTION
C               0 - NORMAL RETURN
C               1 - ITERATION LIMIT EXCEEDED
C               2 - CALCULATED DEPTH EITHER LESS THAN 0 KM
C                   OR GREATER THAN DEFINED MODEL
C               3 - SINGULAR SOLUTION TO MATRIX
C               4 - TOO FEW STATIONS BECAUSE OF
C                   ANGLE OF INCIDENCE PROBLEM
C               5 - TOO MANY STATIONS DELETED
C                   BECAUSE OF 3 SIGMA RESIDUAL
C               6 - EVENT OSCILLATED IN DEPTH
C       SDVEV - STANDARD DEVIATION OF RESIDUALS
C       AVRES - AVERAGE OF THE RESIDUALS
C *** STATION LOCATION COMMON
C   COMMON IDSC(50),STAY(50),STAX(50),STAE(50),STAV(50),NSTA
C *** STATION ARRIVAL INFORMATION COMMON
C   COMMON IDX(50),ATIM(50),DIST(50),NA
C
C   DIMENSION TX(4),DH(4),EQN(4,5),RESHY(50),HCNG(6)
C
C   PRINT DATA INPUT TO MEHYPO.
C   IF (KPFLG.EQ.2) GO TO 35
C   20 PRINT 1000, IDE,OTIM,YLOC,XLOC,HLOC
1000  FORMAT (16X,42HEV      OTIM      YLOC      XLOC      HLOC,
C   1      /,1X,12HMEHYPO INPUT,3X,A4,2X,4F9.3,/)
C   DO 30 I=1,NA
C       K=IDX(I)
C       PRINT 2000,I,IDSC(K),ATIM(I)
2000  FORMAT(8X,I2,2X,A4,2X,F9.3)
C   30 CONTINUE
C   35 NOITR=NIT
C *** INITIALIZE
C   AVRES=0.0
C   SDVEV=0.0
C   NIT=0
C   ORIBIT FLAG
C   KORFLG=0
C   EXTRA ITERATION FLAG

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      IFLG=0
      DEPTH OSCILLATION FLAG
      JFLG=0
      KONFL=0
      IHRFLG=IDEPT
      TX(4)=0.0
      IF(IBACK.EQ.2) 40,50
40    IFLG=2
      KORFLG=1
C
C *** ITERATION LOOP.
      DO 70 I=1,5
      DO 70 J=1,6
      EQN(I,J)=0.0
      70 CONTINUE
      NIT=NIT+1
      SUMSQ=0.0
      IDEPT=IHRFLG
      IF(NIT.LE.2) IDEPT=1
C
C *** COMPUTE DISTANCES.
      DO 100 I=1,NETKS
      K=IDX(I)
      XDIST=XLOC-STAX(K)
      XDIST=XDIST+XDIST
      YDIST=YLOC-STAY(K)
      YDIST=YDIST+YDIST
      DIST(I)=SQRT(XDIST+YDIST)
      IF(I.EQ.1) GO TO 100
C      SORT ARRIVAL DATA BY INCREASING DISTANCES.
      K=I
      II=K-1
      DO 90 J=1,II
      IF(DIST(K).GE.DIST(J)) GO TO 90
C      SWAP ARRIVAL DATA (K AND J).
      IDXS=IDX(J)
      DISTS=DIST(J)
      ATIMS=ATIM(J)
      IDX(J)=IDX(K)
      DIST(J)=DIST(K)
      ATIM(J)=ATIM(K)
      IDX(K)=IDXS
      DIST(K)=DISTS
      ATIM(K)=ATIMS
      IF(J.NE.II) GO TO 80
      90 CONTINUE
      100 CONTINUE
C
      KALL=0
      KPRT=0
      IF(KPFLG.EQ.2) GO TO 130
      IF(KPFLG.EQ.1) GO TO 120
      IF(KONFL.NE.1) GO TO 130
      IF(NIT.LT.5) GO TO 130
      120 PRINT 3000
      3000 FORMAT(/,4X,49HSTA      DIST      TT      RES      PTD      PTH)
      KPRT=1
      130 I=0
      140 I=I+1
      K=IDX(I)
C**** COMPUTE TRAVEL TIMES AND DERIVATIVES
      CALL TTIM (KALL,I,TT,PTD,PTH)
      CALL ELVCOR (K,PTD,TT)
      IF(KALL.EQ.1) GO TO 145
      PRINT 3500,IDSC(K),DIST(I)
      3500 FORMAT (5X,/,5X,49HCritical OR 90 DEG ANGLE OF INCIDENCE REACHED F
10R,1X,A4,3H AT,F9.3,2HKM,/)
      CALL DELETS (I,NETKS)
      IF(NA.LT.3) GO TO 730
      IF(NA.EQ.3) IDEPT=1

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      KALL=0
      GO TO 130
C***** COMPUTE RESIDUAL
145 RESHY(I)= ATIM(I)-OTIM-I
      IF(KPRT.NE.1) GO TO 150
      PRINT 4000,IDSC(K),DIST(I),TT,RESHY(I),PTD,PTH
4000 FORMAT (4X,A4,5F9.3)
C***** COMPUTE NORMAL EQUATIONS
150 TEMP5=PTD*(XLOC-STAX(K))/DIST(I)
      TEMP6=PTD*(YLOC-STAY(K))/DIST(I)
      EQN(1,2)=EQN(1,2)+TEMP5
      EQN(1,3)=EQN(1,3)+TEMP6
      EQN(1,5)=EQN(1,5)+RESHY(I)
      EQN(2,2)=EQN(2,2)+TEMP5*TEMP5
      EQN(2,3)=EQN(2,3)+TEMP5*TEMP6
      EQN(2,5)=EQN(2,5)+RESHY(I)*TEMP5
      EQN(3,3)=EQN(3,3)+TEMP6*TEMP6
      EQN(3,5)=EQN(3,5)+RESHY(I)*TEMP6
      SUMSQ=SUMSQ+RESHY(I)*RESHY(I)
      IF(IDEPT)210,200,210
200 EQN(1,4)=EQN(1,4)+PTH
      EQN(2,4)=EQN(2,4)+TEMP5*PTH
      EQN(3,4)=EQN(3,4)+TEMP6*PTH
      EQN(4,4)=EQN(4,4)+PTH*PTH
      EQN(4,5)=EQN(4,5)+RESHY(I)*PTH
210 IF(I.LT.NETKS) GO TO 140
      STOR=NETKS-1
      IF(STOR)260,260,230
230 AVRES=EQN(1,5)/NETKS
      SDVEV=(SUMSQ-AVRES*EQN(1,5))/STOR
      IF(SDVEV.GE..0001) GO TO 235
      SDVEV=.000033
      GO TO 236
235 SDVEV=SQRT(SDVEV)
C      CHECK ALL STATIONS FOR RESIDUALS GREATER THAN OR EQUAL TO
C      THREE TIMES THE STANDARD DEVIATION
236 STOR=SDVEV+SDVEV+SDVEV
238 I=0
240 I=I+1
      IF(ABS(RESHY(I)-AVRES).LT.STOR) GO TO 250
      IF(ABS(RESHY(I)).LE.1.0) GO TO 250
      IF(NIT.LE.2) GO TO 250
      K=IDX(I)
      PRINT 4500, IDSC(K)
4500 FORMAT (5X,/,5X,7HSTATION,1X,A4,1X,37HDELETED BECAUSE OF EXCESSIVE
1 RESIDUAL,/)
      CALL DELET5 (I,NETKS)
      IF(NA.LT.3) GO TO 770
      IF(NA.EQ.3) IDEPT=1
      NIT=NIT-1
      GO TO 50
250 IF(I.LT.NETKS) GO TO 240
260 EQN(2,1)=EQN(1,2)
      EQN(3,1)=EQN(1,3)
      EQN(3,2)=EQN(2,3)
      EQN(4,1)=EQN(1,4)
      EQN(4,2)=EQN(2,4)
      EQN(4,3)=EQN(3,4)
      DO 270 I=1,4
      DO 270 J=1,5
      EQN(I,J)=EQN(I,J)/NETKS
270 CONTINUE
      EQN(1,1)=1.0
C***** SOLVE NORMAL EQUATIONS FOR CORRECTIONS
      IF(NIT.LT.5) GO TO 280
      IF(KONFL)760,280,760
280 L=4
      IF(IDEPT)290,300,290
290 L=5
300 DO 360 N=1,4

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      I=1
      J=2
      K=3
      IF(N-2)350,310,320
310  I=L
320  IF(N-3)350,330,340
330  J=L
      GO TO 350
340  K=L
350  DH(N)=EQN(1,I)+(EQN(2,J)+EQN(3,K)-EQN(3,J)+EQN(2,K))
      1      +EQN(2,I)+(EQN(3,J)+EQN(1,K)-EQN(1,J)+EQN(3,K))
      2      +EQN(3,I)+(EQN(1,J)+EQN(2,K)-EQN(2,J)+EQN(1,K))
360  CONTINUE
      IF(IDEPT)420,370,420
370  IF(L-5)380,390,420
380  STOR=DH(1)+EQN(4,4)-DH(2)+EQN(4,1)-DH(3)+EQN(4,2)-DH(4)+EQN(4,3)
      DOM=ABS(STOR)
      DUM=STOR
      NOW=1
      GO TO 425
390  DH(2)=DH(1)+EQN(4,5)-DH(2)+EQN(4,1)-DH(3)+EQN(4,2)-DH(4)+EQN(4,3)
      TX(4)=DH(2)/STOR
      DO 400 I=1,3
      EQN(I,6)=EQN(I,5)-(EQN(I,4)+TX(4))
400  CONTINUE
      L=6
      GO TO 300
C***** SINGULAR MATRIX
410  PRINT 4750, DUM
4750  FORMAT(5X,/,5X,44HPOSSIBLE SINGULAR MATRIX WITH DETERMINANT OF,
      1E10.2,/)
      IBACK=3
      IF(NIT,LT.7) GO TO 427
      IF(DOM-0.1E-10)780,427,427
420  DOM=ABS(DH(1))
      DUM=DH(1)
      NOW=2
425  IF(DOM-SMTV)410,427,427
427  GO TO(290,430,430),NOW
430  TX(1)=DH(2)/DH(1)
      TX(2)=DH(3)/DH(1)
      TX(3)=DH(4)/DH(1)
C      SAVE DEPTH CHANGES FOR LAST SIX ITERATIONS
      KNTR=NIT
432  KNTR=KNTR-6
      IF(KNTR)434,434,432
434  KNTR=KNTR+6
C      USE HALF OF THE DEPTH CORRECTION IF EXTRA ITERATION FLAG IS 2
      IF(IFLG-1)438,438,436
436  TX(4)=TX(4)/2.0
438  HCHG(KNTR)=TX(4)
      IF(KPFLG.NE.1) GO TO 450
      PRINT 5000,NIT,TX(1),TX(3),TX(2),TX(4),SDVEV,AVRES
5000  FORMAT(/,1X,I2,3X,8HCHANGES=,4F11.4,2F11.3)
C***** APPLY CORRECTIONS
450  IF(IDEPT)530,470,530
470  IF(HLOC+TX(4))480,520,490
480  STOR=HLOC
      HLOC=0.
      GO TO 510
490  IF(HLOC+TX(4).LE.HMAX) GO TO 520
      STOR=HMAX-HLOC
      HLOC=HMAX
510  STOR=(STOR+0.5)/TX(4)
      IFLG=2
      KORFLG=1
      TX(1)=TX(1)+STOR
      TX(2)=TX(2)+STOR
      TX(3)=TX(3)+STOR
      GO TO 530

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520 HLDC=HLDC+TX(4)
530 OTIM=OTIM+TX(1)
    XLDC=XLDC+TX(2)
    YLDC=YLDC+TX(3)
    IF(KPFLG.NE.1) GO TO 550
    PRINT 5000,OTIM,YLDC,XLDC,HLDC
6000 FORMAT (5X,13HNEW LOCATION=,4F11.4)
C**** CHECK FOR CONVERGENCE
650 IF(ABS(EQN(1,5)).GE.0.01) GO TO 720
    IF(ABS(TX(1)).GT.0.005) GO TO 720
    IF(ABS(TX(2)).GT.0.005) GO TO 720
    IF(ABS(TX(3)).GT.0.005) GO TO 720
    IF(IDEPT>710,700,710)
700 IF(ABS(TX(4)).GT.0.005) GO TO 720
710 KDNFL=1
    GO TO 50
C EXCESSIVE ITERATION CHECK
720 IF(NDITR.EQ.NIT)8000,50
8000 IF(IDEPT>750,8010,750)
8010 TEMP=HCNG(1)+HCNG(2)+HCNG(3)+HCNG(4)+HCNG(5)+HCNG(6)
    TEMP=ABS(TEMP)
    IF(TEMP.LE.0.5)8020,8040
C EVENT IS OSCILLATING
8020 IF(JFLG>772,8030,772)
8030 JFLG=1
    NDITR=NDITR+10
    IFLG=2
    GO TO 50
C EVENT NOT OSCILLATING BUT NOT CONVERGING EITHER
8040 IF(IFLG-1)8050,8060,750
8050 IFLG=1
    NDITR=NDITR+5
    GO TO 50
8060 IFLG=2
    NDITR=NDITR+5
    GO TO 50
C**** RETURN
730 IBACK=4
    GO TO 780
740 IBACK=2
    GO TO 780
750 IBACK=1
    IF(KDRFLG.EQ.1) GO TO 740
    GO TO 780
760 IBACK=0
    GO TO 780
770 IBACK=5
    GO TO 780
772 IBACK=6
C PRINT MEHYPO OUTPUT.
780 IF(KPFLG.EQ.2) GO TO 800
    PRINT 7000, IDE,OTIM,YLDC,XLDC,HLDC,NIT,IBACK,SDEV,AVRES
7000 FORMAT (/,15X,46HEV      OTIM      YLDC      XLDC      HLDC NIT,
    118H IBACK SDEV      AVG,/,1X,13HMEHYPO OUTPUT,1X,A4,1X,F9.3,
    2 2(1X,F8.3),1X,F9.3,I3,I4,2(1X,F7.3))
800 RETURN
    END

SUBROUTINE TTIM (KALL,I,TIME,PTD,PTH)
C *** ROUTINE TO COMPUTE THE TRAVEL TIME AND DISTANCE AND DEPTH
C DERIVATIVES FOR A DISTANCE OF DIST(I).
C
C *** CALLING PARAMETERS -
C KALL - INITIAL CALL IF ZERO ON INPUT, RETURNED AS 1 EXCEPT WHEN
C CRITICAL ANGLE OR ANGLE OF INCIDENCE OF 90 REACHED
C BEFORE REACHING THE DESIRED DISTANCE.
C I - INDEX TO DISTANCE ARRAY (DIST) FOR WHICH THE FOLLOWING
C PARAMETERS ARE DESIRED.
C TIME - TRAVEL TIME
C PTD - PARTIAL DERIVATIVE OF TIME WITH RESPECT TO DISTANCE

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C   PTH - PARTIAL DERIVATIVE OF TIME WITH RESPECT TO DEPTH
C
C   *** MODEL STRUCTURE COMMON
COMMON TL(20),VL(20),NL,HMAX
C   *** HYPOCENTER INFORMATION COMMON
COMMON IDE,OTIM,YLOC,XLOC,HLOC,NIT,IBACK,SDVEV,AYRES
C   *** STATION LOCATION COMMON
COMMON IDSC(50),STAY(50),STAX(50),STAE(50),STAV(50),NSTA
C   *** STATION ARRIVAL INFORMATION COMMON
COMMON IDX(50),ATIM(50),DIST(50),NA
C
C   IF(KALL.EQ.0) GO TO 5
C   IF KALL NE 0, USE PREVIOUS COMPUTATIONS ASSUMED UNCHANGED.
TL(L)=TL(L)-(H-DEPTH)
GO TO 50
5  D62RD= .0174532925
AGIMAX=1.570796325
C   FIND LAYER CONTAINING SOURCE DEPTH.
KZHFLG=0
L=0
H=0.
DEPTH=HLOC
IF(DEPTH.GT.0.) GO TO 10
KZHFLG=1
DEPTH=1.
IF(DEPTH.GT.TL(1)) DEPTH=TL(1)
10 L=L+1
H=H+TL(L)
IF(DEPTH.GT.H) GO TO 10
VLH5Q=VL(L)*VL(L)
TEMPTL=TL(L)
C   ADJUST THICKNESS OF LAST LAYER (USED).
TL(L)=TL(L)-(H-DEPTH)
AGI=0.
GO TO 30
20 AGI=AGI+D62RD
IF(AGI.LT.AGIMAX) GO TO 25
IF(D62RD.LT..000174) GO TO 60
AGI=AGI-D62RD
D62RD=D62RD*.1
GO TO 20
25 DP=D
TTP=TT
SINIP=SINI
30 SINI=SIN(AGI)
SQSI=SINI*SINI
N=L
D=0.
TT=0.
40 CON=VLH5Q-VL(N)*VL(N)+SQSI
IF(CON.LE.0.) GO TO 60
CONSQR=SQRT(CON)
DL=(TL(N)*VL(N)+SINI)/CONSQR
TTL=(TL(N)*VL(L))/(VL(N)*CONSQR)
D=D+DL
TT=TT+TTL
N=N-1
IF(N.GT.0) GO TO 40
IF(AGI.LE.D62RD) GO TO 20
C   CHECK TO SEE IF DISTANCE (DIST(I)) IS BETWEEN THIS DISTANCE (D)
C   AND THE PREVIOUS DISTANCE (DP).
50 IF(DIST(I).GT.D) GO TO 20
C   GET DISTANCE RATIO AND INTERPOLATE FOR TRAVEL TIME AND DERIVATIVES
IF(KZHFLG.NE.1) GO TO 55
TIME=(DIST(I)/VL(1))
PTD=1.0/VL(1)
GO TO 58
55 R=(DIST(I)-DP)/(D-DP)
TIME=TTP+R*(TT-TTP)
PTD=(SINIP+R*(SINI-SINIP))/VL(L)

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58 PTH=COS(AGI-DG2RD)
   PTH=(PTH+R*(COS(AGI)-PTH))/VL(L)
   KALL=1
   GO TO 70
C   ERROR RETURN
60 KALL=0
70 TL(L)=TEMPTL
   RETURN
   END

   SUBROUTINE ELVCOR (K,PTD,TT)
C
C   *** PURPOSE - CORRECTS COMPUTED TRAVEL-TIME FOR STATION ELEVATION
C   AND LOCAL VELOCITY ABOVE MODEL
C
C   *** MODEL STRUCTURE COMMON
C   COMMON TL(20),VL(20),NL,HMAX
C   *** HYPOCENTER INFORMATION COMMON
C   COMMON IDE,OTIM,YLOC,XLOC,HLOC,NIT,IBACK,SDVEV,AVRES
C   *** STATION LOCATION COMMON
C   COMMON IDSC(50),STAY(50),STAX(50),STAE(50),STAV(50),NSTA
C   *** STATION ARRIVAL INFORMATION COMMON
C   COMMON IDX(50),ATIM(50),DIST(50),NA
C
C   K - INDEX OF STATION IN CONSTANTS DATA ARRAYS
C   PTD - DISTANCE DERIVATIVE (SEC/KM)
C   TT - COMPUTED TRAVEL-TIME (SEC)
C
   IF(STAE(K).EQ.0.0)40,10
10  TEMP=(1-PTD*STAY(K)+PTD*STAY(K))
   IF(TEMP.LT.0.0)20,30
20  TEMP=0.0
30  STORE=SQRTF(TEMP)
   SEVC=(STAE(K)+STORE)/STAY(K)
   TT=TT+SEVC
40  RETURN
   END

   SUBROUTINE DELETS (I,NETKS)
C
C   **** PURPOSE - DELETS A STATIONS ARRIVAL DATA
C   BY PUTTING IT AT THE END, MOVING OTHERS UP,
C   AND REDUCING THE NUMBER OF ARRIVAL BY ONE.
C
C   I - INDEX OF STATION IN ARRIVAL DATA.
C   K - INDEX OF STATION IN CONSTANTS DATA.
C   NETKS - NUMBER OF ARRIVALS
C
C   **** MODEL STRUCTURE COMMON
C   COMMON TL(20), VL(20), NL, HMAX
C   **** HYPOCENTER INFORMATION COMMON
C   COMMON IDE,OTIM,YLOC,XLOC,HLOC,NIT,IBACK,SDVEV,AVRES
C   *** STATION LOCATION COMMON
C   COMMON IDSC(50),STAY(50),STAX(50),STAE(50),STAV(50),NSTA
C   *** STATION ARRIVAL COMMON
C   COMMON IDX(50),ATIM(50),DIST(50),NA
C
C
10  IDXT=IDX(I)
   ATIMT=ATIM(I)
   DISTT=DIST(I)
   NETKS=NETKS-1
   IF(I.GT.NETKS) GO TO 30
   DO 20 N=I,NETKS
     M=N+1
     IDX(M)=IDX(M)
     ATIM(M)=ATIM(M)
20  DIST(M)=DIST(M)
   IDX(NA)=IDXT
   ATIM(NA)=ATIMT

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        DIST(NA)=DISTT
30  NA=NA-1
40  RETURN
    END

    SUBROUTINE STAIN
C *** ROUTINE TO INPUT STATION COORDINATES.
C
C *** MODEL STRUCTURE COMMON
COMMON TL(20),VL(20),NL,HMAX
C *** HYPOCENTER INFORMATION COMMON
COMMON IDE,DTIM,YLOC,XLOC,HLOC,NIT,IBACK,SDVEV,AVRES
C *** STATION LOCATION COMMON
COMMON IDSC(50),STAY(50),STAX(50),STAE(50),STAV(50),NSTA
C *** STATION ARRIVAL INFORMATION COMMON
COMMON IDX(50),ATIM(50),DIST(50),NA
C
C    FORMAT - STATION CODE (COL 1-4) READ A4
C            Y COORDINATE IN KM (COL 5-12), READ F8.3
C            X COORDINATE IN KM (COL 13-20), READ F8.3
C            ELEVATION IN KM (COL 21-28), READ F8.5
C            VELOCITY IN KM/SEC (COL 29-36), READ F8.5
C    STATION COORDINATES TERMINATE WITH A BLANK CARD.
C
    KBLNK=4H
    K=0
10  K=K+1
    READ (1,1000) IDSC(K),STAY(K),STAX(K),STAE(K),STAV(K)
1000 FORMAT (A4,4F8.5)
    IF(IDSC(K).NE.KBLNK) GO TO 10
    NSTA=K-1
    RETURN
    END

    SUBROUTINE MODIN
C *** ROUTINE TO INPUT EARTH MODEL.
C
C *** MODEL STRUCTURE COMMON
COMMON TL(20),VL(20),NL,HMAX
C *** HYPOCENTER INFORMATION COMMON
COMMON IDE,DTIM,YLOC,XLOC,HLOC,NIT,IBACK,SDVEV,AVRES
C *** STATION LOCATION COMMON
COMMON IDSC(50),STAY(50),STAX(50),STAE(50),STAV(50),NSTA
C *** STATION ARRIVAL INFORMATION COMMON
COMMON IDX(50),ATIM(50),DIST(50),NA
C
C    FORMAT FIRST CARD - (COL 1-12) MODEL NAME.
C    IF MODEL NAME IS FINA PROCESSING IS TERMINATED.
C    FORMAT OTHER CARDS - (COL 1-10) LAYER THICKNESS (KM) READ F10.2
C                        (COL 11-20) VELOCITY (KM/SEC) READ F10.2.
C    MODEL TERMINATES WITH A BLANK CARD.
C
    DIMENSION MNAME(3)
C
    KFINA=4HFINA
    NL=0
    READ (2,1000) (MNAME(K),K=1,3)
1000 FORMAT (3A10)
    IF(MNAME(1).EQ.KFINA) GO TO 30
10  NL=NL+1
    READ (2,2000) TL(NL),VL(NL)
2000 FORMAT (2F10.2)
    IF(NL.EQ.20) GO TO 15
    IF(TL(NL).NE.0.) GO TO 10
15  PRINT 3000,(MNAME(K),K=1,3)
3000 FORMAT(1H1,12X,5HMODEL,1X,3A10,/,5X,36H LAYER THICKNESS(KM) VELOCIT
1Y(KM/SEC)/)
C    ADD THICK LAYER TO MODEL.
    TL(NL)=1000.
    VL(NL)=8.5

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      HMAX=0.
      DO 20 K=1,NL
      HMAX=HMAX+TL(K)
      PRINT 4000,K,TL(K),VL(K)
4000  FORMAT (7X,I2,3X,F8.2,7X,F7.2)
      20 CONTINUE
      30 RETURN
      END

      SUBROUTINE DATIN (IHCONT,KPFLG)
C
C *** ROUTINE USED TO INPUT (OR COMPUTE) INITIAL HYPOCENTER ESTIMATE
C   AND TO INPUT ARRIVAL INFORMATION.
C
C *** MODEL STRUCTURE COMMON
      COMMON TL(20),VL(20),NL,HMAX
C *** HYPOCENTER INFORMATION COMMON
      COMMON IDE,OTIM,YLOC,XLOC,HLOC,NIT,IBACK,SIVEV,AVRES
C *** STATION LOCATION COMMON
      COMMON IDSC(50),STAY(50),STAX(50),STAE(50),STAV(50),NSTA
C *** STATION ARRIVAL INFORMATION COMMON
      COMMON IDX(50),ATIM(50),DIST(50),NA
C
C   EVENT FORMAT
C   COL 1-4 - EVENT ID, READ A4
C   COL 5-12 - ORIGIN TIME, READ F8.2
C   COL 13-18 - YCOORDINATE, READ F6.3
C   COL 19-24 - X COORDINATE, READ F6.3
C   COL 25-30 - H COORDINATE, READ F6.2
C   COL 31 DEPTH CONTROL(0=FREE,1=RESTRAINED,2=RESTRAINED AND FREE)
C   HYPOCENTER ESTIMATE IS COMPUTED FROM STATION ARRIVAL DATA.
C   PROCESSING TERMINATES IF EVENT ID IS FINA.
C   ARRIVAL FORMAT
C   COL 1-4 - STATION DESIGNATOR, READ A4
C   COL 5-12 - ARRIVAL TIME, READ F8.2
C   ARRIVAL INFORMATION TERMINATES WITH A BLANK CARD.
C
      KFINA=4HFINA
      KBLNK=4H
      NA=0
      PRINT 500
500  FORMAT (3X,25HINPUT HYPOCENTER ESTIMATE)
      INPUT,IDE,OTIM,YLOC,XLOC,HLOC,IHCONT,KPFLG
1000  FORMAT(A4,F8.2,2F6.3,F6.2,2I1)
      IF(IDE.EQ.KFINA) GO TO 70
      10 NA=NA+1
      20 READ (3,2000) IDSA,ATIM(NA)
2000  FORMAT (A4,F8.2)
      IF(IDSA.EQ.KBLNK) GO TO 50
C *** LOOK UP STATION CONSTANTS.
      DO 30 I=1,NSTA
      IF(IDSA.EQ.IDSC(I)) GO TO 40
      30 CONTINUE
C *** SKIP IT - DID NOT FIND.
      PRINT 3000,IDS,A,ATIM(NA)
3000  FORMAT (10X,A4,2X,F9.2,9H SKIPPED)
      GO TO 20
      40 IDX(NA)=I
      GO TO 10
C *** END OF ARRIVAL INPUT.
      50 NA=NA-1
      REWIND 3
      IF(NA.EQ.0) GO TO 70
      IF (OTIM.NE.0) GO TO 80
C *** COMPUTE HYPOCENTER ESTIMATES.
      J=1
      SX=0.
      SY=0.
      DO 60 I=1,NA
      K=IDX(I)

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      SX= SX+STAX(K)
      SY= SY+STAY(K)
      IF(ATIM(J).LE.ATIM(I)) GO TO 60
      J=I
60  CONTINUE
      FNA=NA
      XLDC= SX/FNA
      YLDC= SY/FNA
      K=IDX(J)
      D1=XLDC-STAX(K)
      D1=D1+D1
      D2=YLDC-STAY(K)
      D2=D2+D2
      OTIM=ATIM(J)-SQRT(D1+D2+HLDC+HLDC)/VL(1)
70  IF(IHCNT.NE.0) GO TO 80
      HLDC=0.5+TL(1)
80  RETURN
      END

```