UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

HYPOCENTER LOCATION PROGRAM

HYPOINVERSE

Part 1: Users Guide to Versions 1, 2, 3, and 4

Open-file Report 78–694
This report is preliminary and has not been edited or reviewed for conformity with Geological Survey standards and nomenclature

Menlo Park, California

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Hypocenter Location Program
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by
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CONTENTS

INTRODUCTION

Purpose and Scope

The hypocenter inversion program HYPOINVERSE is a general purpose earthquake location program designed for minicomputer use and specifically the Data General Eclipse. It is file oriented in that it reads data and control files and writes output on user selectable disk files or peripheral devices. The program will locate one or any number of events without any interaction required at the console, but the selection of input files can easily be changed. It is therefore useful in both interactive and batch situations. Version 1 of the program accepts a crustal model with homogeneous layers. Version 3 uses a travel time table for a model with linear velocity gradients within layers and may include a low velocity zone.

Versions 1 and 3 of the program require about 28,000 16-bit words of core, but can easily be shortened by reducing the permissable number of stations and arrival times. Versions 2 and 4 are smaller equivalents of Versions 1 and 3, and require about 22,000 words of core. Execution time on the Eclipse for Version 1 ranges between 5 and 10 seconds per event, depending on the amount of input and output. Version 3 runs about 30% faster. Coding uses standard Fortran as much as possible, and information useful in adapting the program to other computers is in the appendix.

Computationally, the program uses a generalized inverse method, specifically the singular value decomposition (SVD) technique. The eigenvalues, eigenvectors, covariance matrix, and error ellipsoid of the inversion are available as outputs. The SVD approach also permits eigenvalue truncation, which prevents hypocenter adjustments in poorly constrained directions. Additionally the program permits some flexibility in modeling crustal layers, station delays, arrival time weighting, hypocenter convergence criteria, and error calculation. It also produces a file of arrival time and other station data for each event. This file could then be read and the events relocated under different program conditions, or read by a post-location program to plot first motion data, tabulate residual statistics, or some other operation not part of the location process.

Most options are defined by parameters read by the program from input files. Other parameters are defined in a BLOCK DATA subprogram, and normally are unchanged once processing for a given network or project is set up. Changing these parameters involves recompiling the short BLOCK DATA routine and reloading the program.

The program builds upon and uses many computational features of earlier earthquake location programs, namely a generalized inverse location program (Carl Johnson, unpublished), a real-time location program (Sam Stewart, unpublished) HYPOELLIPSE (Lahr, et al., unpublished), HYPO71 (Lee and Lahr, 1972), a version of HYPO71 modified to accept multilayer velocity-gradient crustal models (Christoph Gelbke, University of Karlsruhe, unpublished), and HYPOLAYR (Eaton, 1969).

This guide assumes that the user can introduce and manipulate files on the Eclipse, but an otherwise minimal knowledge of programming is assumed. The symbol "$_\Delta$" as used in this guide stands for a blank space or character. When it makes a difference, the convention in this guide is to use Ø for zero and O for "oh", but association with a decimal point also indicates a zero character.

The format of phase and station data required by this program is compatible with previous standard formats, except for the instruction card in some cases. A new user should read the input sections carefully to be sure that he is specifying everything necessary.

Simplified Outline of Program Capabilities

Details can be found in the user's guide section.

Input

The program reads input/output file names and output control parameters from the short file HYPINST. Station list, crustal model and phase (arrival time) data are input from three separate files. The program defines constants relating to convergence, weighting, error calculation and coda magnitude calculation. These are generally fixed for a given network, and can easily be reset by recompiling only the BLOCK DATA subprogram.

Important Note: If your data are from cards and read into the Eclipse using XFER, col. 80 must contain some non-blank character. If your data are from another source, col. 80 must contain some valid ASCII character which can be blank. This is true for station and phase data inputs. Alternatively, if card data is input to the Eclipse using the program RCARD, the requirement of a punch in col. 80 is relaxed. RCARD pads out blanks as necessary to represent card images internally as 80 columns.

Crustal Model

Version 1 of the program accepts up to 3 crustal models, each of which may have up to 12 homogeneous layers including halfspace. A particular station always uses the same crustal model. Version 3 uses a travel time table which needs to be set up only once using the program TTGEN or by some other means. TTGEN calculates travel times for layered models with linear velocity gradients within layers. One imbedded low velocity zone is permitted. Homogeneous layers with zero gradient are permitted, but velocity discontinuities are not.

Station List Input

Versions 1 and 3 accept up to 300 stations in the network available for earthquake locations (70 stations in Versions 2 and 4). The network may straddle the equator, international date line, or prime meridian. The station card format follows that of HYPO71, with a few exceptions. Check the user's guide carefully before running the program.

Phase List Input

Versions 1 and 3 of the program accept data from up to 160 different stations, with up to 240 arrival times (P or S) for each event. These limits for Versions 2 and 4 are 50 and 60 respectively. Each event is terminated by a normally blank line, which may contain trial hypocenter information. The phase cards are compatible with the standard HYPO71/HYPOELLIPSE format, but the terminating card is consistent only if it is entirely blank, or blank except for an instruction parameter in col's 18-19.

Arrival time weighting

The actual weight given an arrival is the product of several factors: 1) station weight, to give a station zero weight for the entire run; 2) S weight, to zero-weight all S arrivals; 3) assigned weight, to reflect different qualities of readings; 4) distance weight, to decrease weight of distant stations and 5) residual weight, to decrease weight of arrivals with large residuals. Distance and residual weights are decreasing functions of distance and residual. They use a cosine taper for smoothness.

Delay models

Two delay models may be specified, and one, the other or a combination of both can be used in computing station delays. When both are used, the choice of which delay model to use depends only on epicentral position relative to a dividing line drawn through the array. A transition zone of variable width along the dividing line smooths the discontinuity between delay models for epicenters near the dividing line.

Iteration and convergence criteria

The depth is held fixed at the trial depth until the epicenter begins to converge. Depth may be held fixed for any or all events. Several parameters are available to damp any iterations which become unstable. One can, for example, avoid taking iterative steps in directions poorly constrained by the data which correspond to directions of small eigenvalues and large errors. Iteration stops when the iteration limit is reached or when either the hypocenter adjustment or the change in the root-mean-square traveltime residual (RMS) becomes small.

Error calculations

The program calculates the full 4 x 4 covariance matrix of the solution, and derives from it the error ellipsoid and the horizontal and vertical errors. The error calculation requires an estimate of the variance in the arrival time data, calculated here as $SIGMA^2 = RDERR^2 + ERCOF \cdot RMS^2$. RDERR is the estimated reading error and RMS the root-mean-square traveltime residual. RDERR and ERCOF are user definable constants.

Amplitude (local) magnitudes

Amplitudes from Wood-Anderson, NCER short period, or 1 other type of seismogram may be read, and the program computes an equivalent Wood-Anderson local magnitude.

Duration or coda magnitudes

The program uses a bilinear relation between magnitude and log duration or F-P time. Two equations of the form

$$FMAG = C_A + C_B \cdot \log (duration) + C_D \cdot distance + C_Z \cdot depth$$

can be used over two different duration ranges.

This makes 9 constants which may be specified.

Program outputs

The quantity of printed output produced is under the control of the parameter KPRINT (see section on the input/output control file HYPINST). The program can produce the following items in sequence on the print output file: 1) hypocenter data, 1 line per iteration; 2) eigenvalue, eigenvector, covariance and error ellipse data; 3) final hypocenter in 2 lines; 4) station list for the event. The station list includes a new parameter, the importance of the arrival time to the final solution. Output also includes a file of station data in condensed format for archiving and later processing such as plotting first motions on the focal sphere. One line per event of summary data can be written in any, all or none of 3 formats to 3 different files. The formats are HYPO71, HYPOELLIPSE, and HYPOINVERSE, which is identical to HYPOELLIPSE with additional data out to col. 90.

USER'S GUIDE TO HYPOCENTER INVERSION PROGRAM

INPUT

The input/output control file HYPINST.

The program reads this file first to get the file names and their attributes, and numerical parameters which govern how much output is produced. If the file HYPINST does not exist, default names and values will be used. If the file exists, all values will be taken as specified, and no defaults used. The defaults are given in parentheses ( ) following the explanations under "HYPINST format". The last column of each line in HYPINST must contain some non-blank character.

HYPINST format

Line	Col's	Format	Explanation
1	1-14	7A2	Name of file containing station list (DPØ:STATIONS).
1	15-16	A2	Attributes of station file. Must be 'RI'.
2	1-14	7A2	Name of file containing crustal model in Version 1, or name of the file containing the travel time table in Version 3 (DPØ:CRUST).
2	15-16	A2	Attributes of crustal file. Must be 'RI'.
3	1-14	7A2	Name of file containing phase (arrival) data (DPØ:PHASE).
3	15-16	A2	Attributes of phase file. Must be 'RI'.
4	1-14	7A2	Name of file or device to which printed output is directed (DPØ:HYPPRINT)
4	15-16	A2	Attributes of print output file. Should be: 'RP' if output is destined for the line printer; 'RO' is output is to begin a new or existing file or be output on a console, 'RA' is output is to be appended to the end of an existing file (RO).
5	1-14	7A2	Name of output file to contain station data which will be archived, read again as phase data, or read by another plotting or tabulation program (DPØ:HYPOUT).
5	15-16	A2	Attributes of station data output file. Should be either 'RO' or 'RA' (see above) (RO).
6	1-14	7A2	Name of file to contain summary data in HYPO71 format (DPØ:SUMM71).
6	15-16	A2	Attributes of HYPO71 summary file. Should be either 'RO' or 'RA' (see above) (RA).
7	1-14	7A2	Name of file to contain summary data in HYPOELLIPSE format (DPØ:SUMMEL).
7	15-16	A2	Attributes of NYPOELLIPSE summary file. Should be either 'RO' or 'RA' (see above) (RO).
8	1-14	7A2	Name of file to contain summary data in HYPOINVERSE format (DPØ:SUMMHI).
8	15-16	A2	Attributes of HYPOINVERSE summary file. Should be either 'RO' or 'RA' (see above) (RA).

9	1	I1	KSTCTL, the station list and crust model output control Set = 1 to get a station list, crust list, and brief list of test parameters on the print file. Set = Ø to omit a station list from the print file (1) .
9	2-3	I2	KPRINT controls how much information is output on the print file. Higher numbers add more output, and include all output generated by lower numbers (3 is recommended): -1 No printed output or station data output, but summary file(s) are written. Ø Final location only (2 lines). 1 Output station list (residuals, etc.) to both print and station data files. 2 Give the location, adjustment vector, and other data (1 line) for each iteration. 3 Give eigenvalues, eigenvectors, covariance matrix and error ellipse for the final solution. 5 Give eigenvalues, error ellipse, etc. for each iteration. 6 Give station list each iteration. (3)
9	4	I1	KS71 controls output of *summary data in* HYPO71 *format* (1).
9	5	I1	KSEL controls output of summary data in "HYPOELLIPSE". (Ø).
9	6	I1	KSHI controls output of summary data in "HYPOINVERSE" (1). Each of the above 3 control numbers act independently, so that any, all or none of the summary files can be written. Set = Ø to omit the file. Set = 1 to write summary data in that format.
9	7	A1	KEJCT, the page eject control. Use '1' to begin each event on a new page, and '△' to print event continuously (1).
9	8	I1	NOSDLY, the S delay control. Set = Ø to specify and use independent S delays (see section on station input). Set = 1 to use S delays dervied from P delays, and to treat the area reserved for S delays on the station card as a comment field. This comment field may contain any information such as calibration dates, which will appear on the printed listing (1).

<u>Examples of HYPINST control files:</u>

Example 1

```
STAS         RI
CRUST        RI
PHASES       RI
$LPT         RP
MTØ:Ø        RO
SUMM71       RA
SUMMEL       RA
SUMMHI       RA
1Ø31111Ø
```

A station list is read from the file STAS, a crustal model from the file CRUST and phase data from the file PHASES. Printed output is directed to the line printer (device code $LPT) and station list data is written to file Ø (the first) on tape unit Ø, over-writing any data on the tape. Summary data in the appropriate formats are written beginning at the ends of the files SUMM71, SUMMEL, and SUMMHI. Printed output includes a station and crustal list at the beginning, and error ellipse data for each event. S delays are specified on the station cards.

Example 2 is the default case if the file HYPINST does not exist:

```
DPØ:STATIONS  RI
DPØ:CRUST     RI
DPØ:PHASE     RI
DPØ:HYPRINT   RO
DPØ:HYPOUT    RO
DPØ:SUMM71    RA
DPØ:SUMMEL    RO
DPØ:SUMMHI    RA
1Ø31Ø111
```

Station, crustal and phase data are read from the disk files STATIONS, CRUST and PHASE. Printed output is written to file HYPPRINT, over-writing anything on the file, and including station and crustal lists. Station data are written to the file HYPOUT, and summary data in HYPO71 format are written to the end of the file SUMM71. S delays are obtained from P delays, and col's 68 to 80 of the station cards are transmitted as a comment field.

CRUSTAL MODEL - VERSION 1

Allowable models.

The crustal model must consist of flat homogeneous layers and velocity must increase with depth. Up to 12 layers (including the halfspace) are allowed in each model, and a maximum of 3 models is allowed. Which of the 3 crustal models to use in traveltime calculation is specified on the station card, and that model is always used for that station. Thus, different sub-arrays within a large network may use different models, or a vertical discontinuity may be crudely modeled. If only one model is needed, the space for the remaining models may be left blank on the input lines. Each model may have a different number of layers.

The crustal models described here are P velocity models. Traveltimes for S waves are calculated using the same model and multiplied by the P over S velocity ratio POS, which is set in the BLOCK DATA subprogram.

The crustal model input file.

The file must consist of from 1 to 12 lines, one line per layer. The first line specifies the velocity and depth of the top layer(s) of the model(s), and so on. The last velocity entry for each model is that of the halfspace. A model is terminated by either making the halfspace the last line of the file or by setting the velocity after the halfspace equal to Ø.

Note: each line (or card) in this file must have some non-blank character in col. 31.

Crustal Input Format
(one card per layer)

Col.	Format	Explanation
1-5	F5.2	Velocity (km/sec) of layer in first model
6-10	F5.2	Depth (km) to top of " " " "
11-15	F5.2	Velocity of layer in second model (optional)
16-20	F5.2	Depth to top of " " " " "
21-25	F5.2	Velocity of " " third " "
25-30	F5.2	Depth to top of " " " " "
31		Any non-blank character.

For example:

```
2.0  0.0 5.5  0.0
5.0  1.5 7.8 25.0
5.8  5.0 0.0  0.0
6.6  7.0
8.0 22.0
```

Specifies four layers over a halfspace in model 1 and one layer over a halfspace in model 2.

CRUSTAL MODEL - VERSION 3
Use of a travel time table

The program reads a travel time table generated independently of the location process, and calculates travel time, travel time derivatives, and emergence angles at the source by interpolation from the table. Three point (parabolic) interpolation is used within the table, and linear extrapolation is used beyond the table. The table itself is a condensed grid of travel times as a function of distance and depth. Two grid point spacings are permitted for each of distance and depth, so that travel times for shallow nearby sources may be accurately modeled without wasting space on deep or distant grid points where the travel time curve changes slowly. The user may generate his own travel time table empirically or with another program (see Appendix 2 for table format) or use the travel time generating program TTGEN to prepare a table from a given velocity-depth function.

Allowable crustal models input to TTGEN

Crustal models consist of from 2 to 15 points at which the user specifies velocity and depth. Linear velocity gradients are assumed to connect the points. The last point fixes the velocity and depth of the homogeneous halfspace underlying the model. The halfspace velocity must be the greatest of any velocities specificed to insure that rays can be refracted along the top of the halfspace.

The use of linear gradients smooths out the discontinuities in travel time derivatives which result from homogeneous layer models, and gives a more realistic spread in emergence angles of downgoing rays than is possible with modeling rays as refracted from discontinunities.

One buried low velocity zone is permitted in the model. This means that velocity may not decrease with depth except for one group of adjacent velocity points. Hypocenters that occur within a low velocity zone may produce a shadow zone at the surface, and rays in this distance range are calculated as if refracted along the layer above the low velocity zone.

TTGEN can handle models with homogeneous layers, (zero gradients), but velocity discontinuities (infinite gradients) are not allowed. Velocity gradients should assume reasoable values such as 0.0 or between 0.02 and 8.0 km/sec/km in the interest of numerical stability.

TTGEN operates by shooting rays out from the source and calculating time, distance, and other parameters where (and if) they emerge at the surface. Layers with steep gradients (such as might be used to model a Moho transition) can produce reverse branches in the travel time curve, and such layers should be at least 0.3 km thick to insure that enough rays will bottom in the layer to define the travel time curve properly. Errors can be introduced in the final travel time table by undersampling a too complicated or irrigular velocity model with too few rays.

Using the program TTGEN

At depth intervals specified by the user, the program shoots rays with increasing ray parameter starting with vertically emergent rays, and calculates distance, travel time, and other parameters for each ray (see outputs of TTGEN section). At each depth, a printed listing of these results is produced, noting any reverse branches or rays lost to a low velocity waveguide. At the same time, a plot of reduced travel time versus distance is made showing all branches of the travel time curve. The program then produces the final travel time table by interpolating travel times at distance intervals specified by the user. Interpolation is done in the first arrival from among the various branches including refractions from the halfspace and top of a low velocity zone.

Input to TTGEN on the file TTMOD

All model parameters including depth, distance, and ray intervals at which computations are to be performed are input on the file TTMOD. The program uses reduced travel times for the table and for plotting to save space. One specifies the inverse of the reducing velocity REDV (in sec/km) to use in calculation and plotting. The reduced travel time is the absolute time minus distance times REDV. The values of reduced travel time passed to the location program with the table are limited to the range Ø to 32 seconds, and the user is responsible for choosing a suitable reducing velocity to stay within these limits. Using a reducing velocity equal to the halfspace velocity is a good choice.

The user specifies the amount by which the independent parameter Q is incremented to calculate distance and time for rays of various ray parameter and emergence angle. Ray parameter P and emergence angle PHI are functions of Q as follows:

$$PHI = 2 \cdot TAN^{-1}\left(\frac{Q}{ZH + 1/2}\right)$$

$$P = \frac{SIN\ (PHI)}{VH}$$

where ZH and VH are depth and velocity at the hypocenter, respecively. Q is a better independent parameter than either P or PHI since it gives a greater density of rays for deeper penetrations. This also gives the distant travel time points a distance spacing comparable to nearby points.

The parameter Q is incrimented as follows. It takes on the value 0.0 and NQ1 values at increments of DQ1, then NQ2 values at increments of DQ2. The largest value of Q is thus NQ1 · DQ1 + NQ2 · DQ2, and the greatest number of rays (maximum value of NQ1 + NQ2) is 200. Ray calculation stops when downgoing rays begin to penetrate the halfspace, and travel times approriate to a refracted ray are used beyond this point. Values of DQ1 = .08, NQ1 = 100, DQ2 = 0.4, and NQ2 = 100 are a good first try, and generally insure that the entire travel time curve can be adequately defined by less than 200 rays.

The grid points in distance and depth at which travel times are calculated for output to the final table are determined by eight parameters similar in concept to the Q parameters described above. Travel times are calculated at depths of 0.0 and NZ1 values at increments of DZ1, then NZ2 values at increments of DZ2. This permits a fine grid spacing for shallow depths and a coarse spacing at greater depths where the travel time curve will be smoother. Similarly, travel times are calculated at distances of 0.0, DD1, 2DD1, up to ND1 · DD1, and then at ND2 values in increments of DD2. Presently the maximum value of NZ1 + NZ2 is 27, and ND1 + ND2 may be as large as 41.

Velocity model input format (File TTMOD)

(Non-blank characters must be supplied out to the last used column of each line)

Line	Columns	Format	Explanation
1	1-8	4A2	Printed output filename. Use $LPT to print output directly on the printer.
1	9-16	4A2	Travel time table output filename. Should be the same as the name given in the file HYPINST.
1	17-22	F6.1	REDV, one over the reducing velocity used to condense the travel time plots and tables.
1	23	I1	Hard copy flag. Set equal to 1 to make a hard copy of the travel time curve plotted at each depth, and set equal to Ø otherwise.
1	24	I1	Pause flag. Set equal to 1 to start a computer pause after each plot to allow inspection or manual copying. Strike any key to resume the program.
2	1-5	F5.2	DQ1 Parameters for incrementing the
2	6-10	I5	NQ1 independent parameter Q governing ray
2	11-15	F5.2	DQ2 spacing (see Text).
2	16-20	I5	NQ2
3	1-5	F5.2	DZ1 Parameters for incrementing the grid
3	6-10	I5	NZ1 spacing in depth (see text).
3	11-15	F5.2	DZ2
3	16-20	I5	NZ2
4	1-5	F5.2	DD1 Parameters for incremenating the grid
4	6-10	I5	ND1 spacing in distance (see text).
4	11-15	F5.2	DD2
4	16-20	I5	ND2
5	1-5	F5.2	Length of distance axis of plots in km.
5	6-10	F5.2	Length of reduced travel time axis of plots in seconds.
6	1-20	10A2	Title to appear on travel time plots, TTGEN output, and earthquake location output.
6	21		Any non-blank character.
7	1-5	F5.2	Velocity of first point (km/sec).
7	6-10	F5.2	Depth of first point (km). This format is repeated for each velocity-depth point of the model, one line per point, up to a total of 15 points. The last point given sets the velocity and depth of the halfspace.

Outputs of TTGEN

At each depth point specified, a plot of reduced travel time versus distance is made including all branches of the travel time curve. The actual travel time used will be the first arrivals from various branches. All reversed branches are plotted, and zero-amplitude branches such as refractions from the halfspace or layer above a low velocity zone will be plotted as dashed lines. Each plot is labeled with a title and depth, and ticks appear on the axes every second and every kilometer. Normally a new plot will appear on the screen every few seconds, but the user can automatically make a hard copy of each plot or pause the program after each plot to allow inspection or manual copying. Strike any key to resume the program. All plotting is done in the subroutine TTPLT using the Tektronix plot-10 subroutines, and users of other computers can eliminate the plotting subroutine or write their own version.

The condensed travel time table contains all the information necessary to identify itself and be used by version 3 of HYPOINVERSE. Its filename in TTMOD should agree with the input name in HYPINST. The format of the table is transparent to the user, but is given in Appendix 2 for completeness.

The printed output of TTGEN contains one tabulation for each depth grid point. One line is printed for each ray calculation until the deepening rays reach the halfspace. The tabulated data is as follows:

J	The ray index used to reference rays defining the endpoints of a shadow zone or reversed branches.
Q	The user-defined parameterizing variable (see CRUSTAL MODEL-VERSION 3 section). Equal increments of Q are designed to give a greater density of deeper rays where they are needed to define the travel time curve.
EM.ANG	Emergence angle of ray at the source, measured in degrees from zenith.
P	Ray parameter in sec/km.
DIST	Distance in km at which ray reaches the surface. If DIST = -1, then the ray is trapped in a waveguide and does not reach the surface.
TIME	Travel time in seconds.
REDUCED	Reduced travel time in seconds, given by TTIME - DIST · REDV, where REDV is one over the reducing velocity.
L.BOT	The layer in which downgoing rays bottom.
Z.BOT	The depth at which downgoing rays bottom.
V.BOT	The velocity at which downgoing rays bottom.
DDIF	Distance difference between this and the preceding ray. DDIF is negative on reverse branches.
BR	Branch number. It is incrimented by 1 each time a new forward branch is encountered.
AMP	Relative amplitude of the ray at the surface assuming an isotropic source and geometrical spreading. It is just the ratio of the area of a ring on a unit sphere surrounding the source to the corresponding area at which rays emerge at the earth's surface.

AMP*R**2 Amplitude times distance squared. Used to estimate the differences between actual and ideal inverse-square spreading.
REMK Remark such as RB (reversed branch) or WG (ray in wave guide).

STATION LIST INPUT

Versions 1 and 3 of the program accept up to 300 stations, and versions 2 and 4 allow 70 stations.

Array Center

The program uses a condensed station table to save space, and therefore the coordinates of some reference origin near the center of the array must be specified. The first station in the list must be called CNTR and have the coordinates of the reference origin. Station coordinates are stored in units of .02 minute (about 36 meters). This means that stations may be at most $\pm$ 10° 54' from the array center in both latitude and longitude. Distances from epicenter to stations are stored to the nearest 50 m and arrival times are kept to the nearest .01 sec. This means that the overall resolution of the program in time and space is about 50 m.

Station delays.

P delays are always taken from the station cards. Of course, leaving the P delay field blank will use a delay of 0.0 or no delay. S delays can be specified in one of two ways: 1) If the parameter NOSDLY equals 1 in the file HYPINST, S delays are assumed equal to V_p/V_s (the parameter POS), times the P delays for all stations; 2) If NOSDLY equals Ø, S delays must be specified independently of the P delays. In this case, the program looks for S delays in col's 71-80 of the station cards. (See sections on the HYPINST file and on station card format for details).

Two different delay models may be specified (two each for both P and S). The delay model used can be made to depend on which side of a line drawn through the array origin (station card CNTR) the epicenter lies. Once a delay model is chosen, it is used for all stations reporting that event. The parameters DLYAZ and DLYWD, and the coordinates of CNTR specify the boundary between the delay models (see the section on delay models for details).

To use two delay models simply specify both. To use one delay model, either 1) specify two identical models; or 2) specify only the first and set DLYAZ equal to 999.; or 3) specify only the second delay model and set DLYAZ equal to -999. Thus, the same set of station cards can be used to provide either of two independent delay models used for all epicentral positions, or a combination of the two delay models depending on epicentral position. Also note that if only the first delay model is specified and DLYAZ is, say equal to 90, then two models will be used with delays of 0.0 in the second model.

Sign of Coordinates

Latitude and longitude are given in degrees and (decimal) minutes. For south or east coordinates, use an E or S in the appropriate column. Use N or blank for north and W or blank for west. The program also handles networks which straddle the equator, international date line, or prime meridian.

Magnitude Corrections and Station Exclusion

Magnitude corrections may be specified for each station for both duration and amplitude (local) magnitudes. Normally, these corrections must be within the range ± 2.4, and all stations for which data are supplied will be used in computing the average amplitude or duration magnitudes. If you don't want a certain station's magnitude included in the average, use a correction of 5.0 plus the actual correction. Thus, a correction of 5.1 will apply a correction of +.1 in computing that station magnitude, which will not be included in the average, however.

The relationships used in handling arrival times are as follows:

TOBS = SEC + CCOR - OT and
RES = TOBS - TCAL - DLY where

SEC = observed arrival time
CCOR = clock correction
OT = origin time
TOBS = observed travel time
DLY = station delay
RES = traveltime residual

Station List Input Format

A plus (+) indicates a difference with the standard HYPO71 format.

First line - array origin (+)

Col	Format	Explanation
1-4	A4	Must be CNTR
6-7	F2.0	Latitude of reference origin, degrees.
9-13	F5.2	" " " " , minutes.
14	A1	N or blank for north latitude, S for south.
15-17	F3.0	Longitude of reference origin, degrees.
19-23	F5.2	" " " " , minutes.
24	A1	W or blank for west longitude, E for east.
36-40	F5.2	DLYAZ, the azimuth (in degrees east of north) of the line through the array origin (the point CNTR) which separates the 2 delay models. To use only delay model 1, set DLYAZ equal to 999. To use only delay model 2, set DLYAZ equal to -999.
42-46	F5.2	DLYWD, the half width in km of the transition zone between the 2 delay models. See the section on delay models for details.
80		Any non-blank character (card input) or any ASCII character (other input).

Second and later lines - one per station

Col	Format	Explanation
1-4	A4	Station name. The character in col. 1 may not be a number.
5	A1	Station weight for this run. Use an asterisk (*) to give no weight to readings from this station.
6-7	F2.0	Latitude of station, degrees.
9-13	F5.2	" " " , minutes.
14	A1	N or blank for north latitude, S for south.
15-17	F3.0	Longitude of station, degrees.
19-23	F5.2	" " " , minutes.
24	A1	W or blank for west longitude, E for east.
25-28	A4	Any remark, such as station elevation. It is listed with the stations available, but is otherwise unused (+).
29-31	F3.1	Period (in sec) at which maximum amplitude will be read for this station. Must be between the limits 0.1 and 1.9 inclusive (+).
34	I1	Crustal model to use in calculating all traveltimes to this station. Must be 1, 2, or 3.
36-40	F5.2	P delay in sec for delay model 1.

42-46	F5.2	" " " " " " " 2 (optional--see above).
48-52	F5.2	Amplitude magnitude correction (see above).
54-58	F5.2	Duration " " (" ").
60	I1	Instrument type code for this station used to select the appropriate response curve to derive an equivalent Wood-Anderson amplitude. Must be either Ø, 1 or 2: Ø: Standard Wood-Anderson torsion seismograph. 1: NCER standard (1 HZ velocity transducer with 0.7 critical damping). 2: Hawaii-type Sprengnether or HS-10 geophone with Develoco VCO.
61-66	F6.2	Calibration factor for amplitude magnitudes. This is equal to the peak to peak amplitude of a 10 microvolt RMS signal at 5 HZ applied to the VCO and measured in mm on the Develocorder film viewer (see section on amplitude magnitudes for details). For instrument types Ø and 2 (see below), this should generally be 1.0. A calibration factor of 0.0 for any instrument type signifies an unknown response and no amplitude magnitudes will be computed for this station. The calibration factor must be between 0.0 and 49.9 inclusive.
67-70	A4	Any remark. It is listed with the stations available but is otherwise unused (+).
71-80		If NOSDLY = 1 (see above), the format is 5A2, and col's 71-80 may contain any remark information, such as dates of installation or calibration. It is listed with the stations available, but is otherwise unused. If NOSDLY = Ø (see above) the format is 2F5.2. The first number is the S delay in sec for delay model 1, and the second is the S delay for model 2 (which is optional) (+).
80		If your data are input from cards, col. 80 must contain some valid non-blank ASCII character (such as Ø). If your data are from another source, col. 80 must contain some valid ASCII character, which can be a blank (+).

PHASE DATA INPUT

Using phase data

All data from each station reporting an event are put on one line (or card). From 3 to 160 stations (in versions 1 and 3) may report each event with up to 240 total arrivals (P or S). These limits are 50 and 60, respectively, in Versions 2 and 4. The phase cards for each event are separated by a terminating line. The terminating line normally consists of 80 blanks, but may contain a trial hypocenter. Each station may report any or all of the following: P arrival time, S time, amplitude, or duration (for magnitude calculations).

An arrival time will not be recognized if the remark field (e.g. 'IP' or 'ES') is left blank. A phase card will be skipped if

1) the station is not on the list
2) it does not follow proper format
3) if the year, month and day do not agree with the first card of the event, or
4) if the arrival time differs by more than 4 minutes from the first card.

Important note: If your data are read into the Eclipse from cards, col. 80 must contain some non-blank character. If your data are from another source, col. 80 must be some valid ASCII character, which may be a blank. This is true for both phase cards and terminator cards. If your phase file was written by a previous execution of this program, this condition will be satisfied.

Phase data input format - one line per station

Col.	Format	Explanation
1-4	A4	Station name. Must be non-blank, and col. 1 may not be a numeric character.
5-6	A2	Remark such as 'IP'. Must be non-blank for P time to be accepted.
7	A1	P first motion code such as 'C' or 'D'. These are printed on output, and the non-blank entries are counted, but are otherwise unused by this program.
8	I1	Assigned weight code for P arrival as follows: ∅ or blank--full weight. 1-3/4 weight 2 - 1/2 weight 3 - 1/4 weight 4 to 9 - no weight
10-11	I2	Year Must be the same as first phase card of event.
12-13	I2	Month Must be the same as first phase card of event.
14-15	I2	Day Must be the same as first phase card of event.
16-17	I2	Hour Used for both P and S arrival.
18-19	I2	Minute Used for both P and S arrival.
20-24	F5.2	Second of P arrival.
32-36	F5.2	Second of S arrival.
37-38	A2	S remark such as 'ES'. Must be non-blank for S time to be accepted.
40	I1	Assigned weight code for S arrival (same codes as P)
45-47	I3	Peak to peak amplitude in millimeters on develocorder viewer screen or paper record.
63-65	A3	Optional remark. An event remark may be entered here. The first non-blank field on the series of phase cards will be used as an event remark <u>if</u> columns 1-4 and 70-72 of the terminator card are all blank.
66-70	F5.2	Clock correction, to be added to both P and S arrival times.
71	A1	Remark for this station such as 'D' (dead), 'L' (low frequency), 'N' (noisy) etc. Unused except on output.
72-75	I4	Coda duration (F-P time) in seconds.
80		Some non-blank character on card input, or some valid ASCII character otherwise.

Terminator card

One terminator line must follow each event. This line normally consists of 80 blanks, and if so, a standard trial hypocenter is used. The standard trial origin is 2 seconds before the first weighted P arrival, the trial epicenter is near the station with the earliest arrival, and the trial depth is the standard value (see section on convergence parameters). If any or all of depth, latitude, longitude, or origin time (as defined by hour, minute and second) are specified, the appropriate values are used instead of the standard trial values. Thus leaving all fields blank except trial depth will change only the trial depth, and for this event only. Either a HYPOELLIPSE or a HYPOINVERSE summary line may be used as a terminator. In fact, the terminators which are output by this program on the station data file are HYPOINVERSE summary lines. A terminator which is an old-style instruction card and is blank except for col's 18-19 is a valid terminator, but the instruction parameter will have no effect. To fix the depth for this event only, use a negative trial depth to fix depth at the positive value. To fix depth for all events, set the default trial depth (see section on convergence parameters) negative.

Terminator (trial hypocenter) format

Col's 1-4 must be blank, or col. 1 must contain a numeric character.

Col.	Format	Explanation	
7-8	I2	Trial hours	Optional, but if 1 is specified, all of hour, minute and second must be given
9-10	I2	Trial minute	
11-14	F4.2	Trial second	
15-16	F2.0	Trial latitude (deg.)	Optional, but if 1 is specified, both degrees and minutes must be.
17	A1	S for south latitude	
18-21	F4.2	Trial latitude (min)	
22-24	F3.0	Trial longitude (deg.)	Optional, but if 1 is specified, both degrees and minutes must be.
25	A1	E for east longitude	
26-29	F4.2	Trial longitude (min)	
30-34	F5.2	Trial depth (optional).	Set negative to fix depth at this value.
70-72	A3	Remark for this event such as 'BVL' or 'MER'. Unused except on output. If the terminator card is blank in the trial hypocenter and remark fields, the remark is taken from cols 63-65 of the first phase card on which that field is non-blank.	
80		Some non-blank character on card input, (such as a Ø), or some valid ASCII character such as blank otherwise.	

ARRIVAL TIME WEIGHTING

Weighting

The actual weight given an arrival is the product of several factors:

1) Station weight. Will zero-weight a given station for entire run. May be 0.0 or 1.0 (Set on station card).
2) S weight (S arrivals only). Will weight all S arrivals for entire run. Any value between 0.0 and 1.0 (set in BLOCK DATA).
3) Assigned weight. Designed to reflect individual arrival quality. May be 0.0, .25, .5, .75 or 1.0 (set on phase card).
4) Distance weight. Can be used to specify a decreasing weight with increasing distance. Will be between 0.0 and 1.0 (see below).
5) Residual weight. Can be used to specify a decreasing weight with increasing travel time residual. Will be between 0.0 and 1.0 (see below).

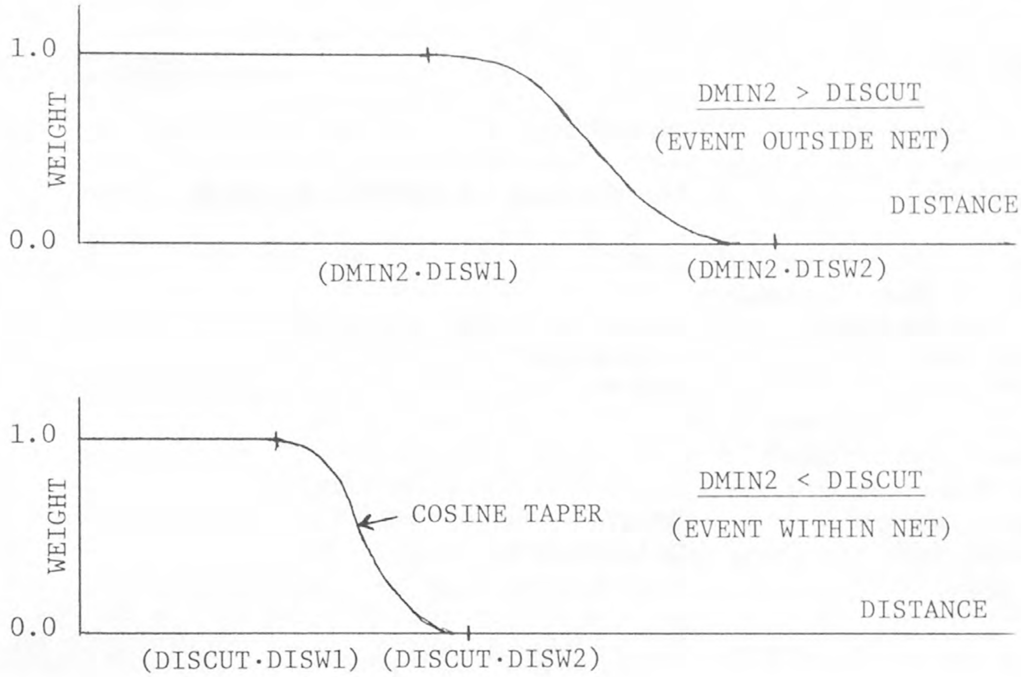


Figure 1 Distance weighting function. DMIN2 is the distance to the second closest station. DISCUT (Km), DISW1, DISW2 are user-defined constants.

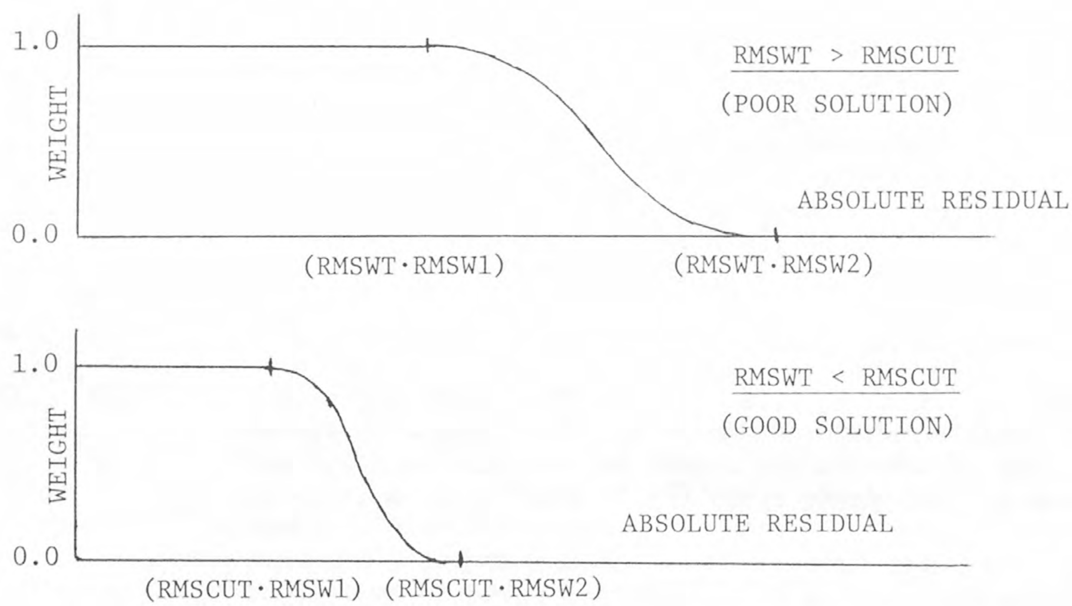


Figure 2. Residual weighting function. RMSWT is the root-mean-square traveltime residual. RMSCUT (sec), RMSW1 and RMSW2 are user-defined constants.

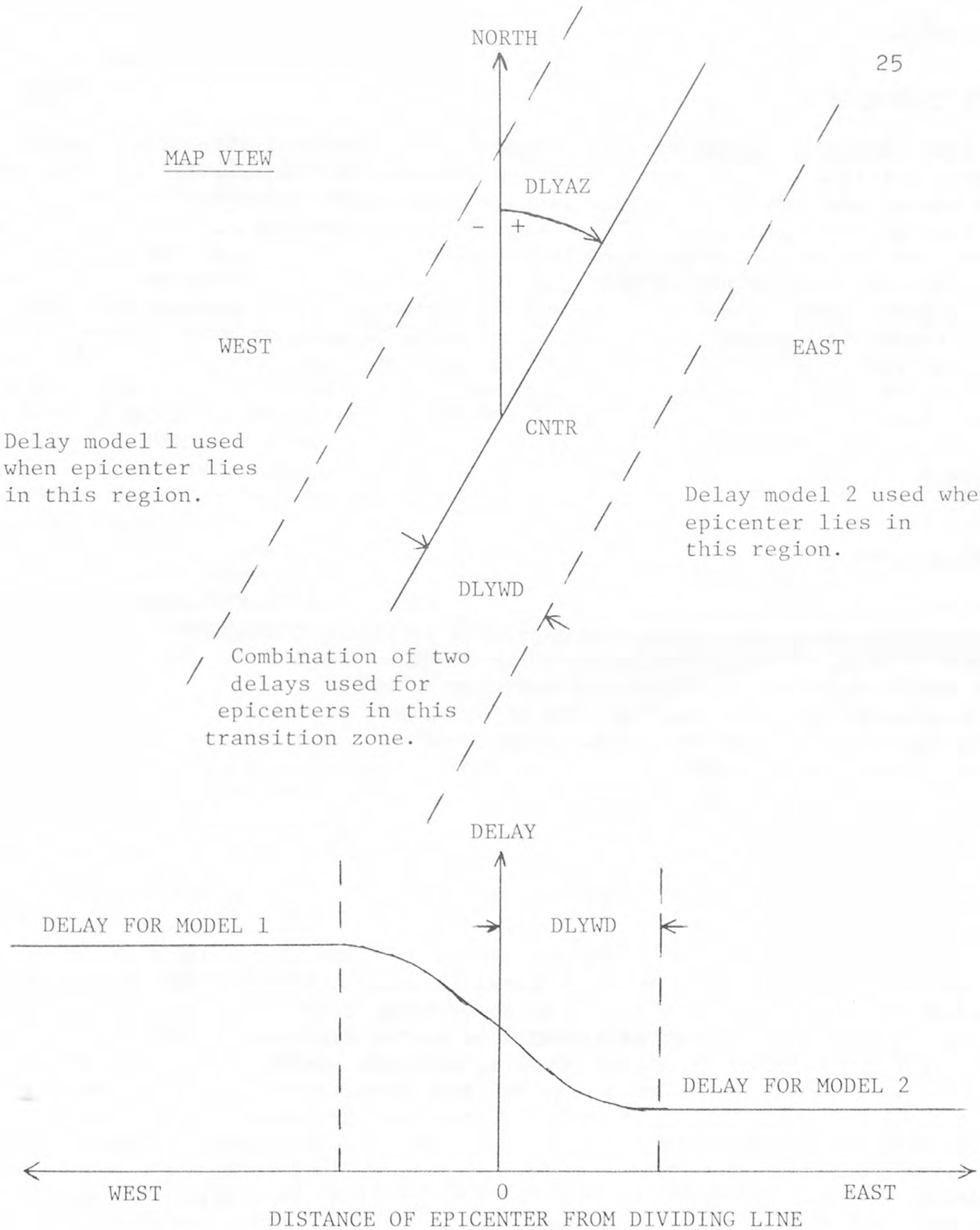


Figure 3. Map view showing delay model geometry. The delay model (or combination of delay models) depends only on the position of the epicenter relative to the dividing line. A cosine taper is used to smooth the transition between delay models.

Distance Weighting

An ideal distance weighting scheme should allow for both down-weighting of distant stations when an event is in the interior of the network, and maximum use of all stations when an event is outside the network. The distance weighting function is 1.0 for near stations, 0.0 for far stations, and follows a cosine taper in between. In this program the distance points at which weight tapering begin and end can be made to stretch out and scale with the distance to the second closest station for events outside the network, if desired. The three parameters which govern distance weighting are set in BLOCK DATA and are (with some sample values), DISCUT (50 km), DISW1 (1.) and DISW2 (3.). The distance at which the taper begins and ends scales with the second closest station distance when it is larger than DISCUT, and are fixed when it is less than DISCUT (see Figure 1). To keep the taper distance fixed at, for example, XNEAR and XFAR, set DISCUT = 1000, DISW1 = XNEAR/1000 and DISW2 = XFAR/1000.

Residual weighting

The purpose of residual weighting is to down-weight arrivals with large residuals which may reflect large timing errors or travel paths for which the velocity model is very poor. The residual weighting function is 1.0 for small residuals, 0.0 for large residuals, and follows a cosine taper in between. In this program, the residual points at which weight tapering begin and end can be made to stretch out and scale with the root-mean-square residual (RMS).

The three parameters which govern residual weighting are set in BLOCK DATA and are (with sample values) RMSCUT (.10 sec), RMSW1 (1.), and RMSW2 (3.). The residuals at which the taper begins and ends scale with the RMS residual when it is larger than RMSCUT, and are fixed when it is less than RMSCUT (see Figure 2). Thus, most stations will be fully weighted when RMS is large, but as iteration and convergence proceed and RMS becomes smaller, large residuals will become down-weighted. RMSCUT prevents an inward spiral in which large residuals are discarded, which then lowers RMS, and which results in more large residuals being discarded, etc.

There are two distinct values of RMS used by the program. RMSWT is the RMS residual computed before residual weights are applied and on which residual weights are based. The output variable labeled RMS is the value of RMS computed after residual weights are applied, and is used for convergence tests (see below). Presently, residual weighting is applied twice, with RMSWT updated each time. This allows two large residuals to be weighted down, since the first value of RMSWT includes the effect of the largest residual and may be too large to have any effect on the second largest residual.

DELAY MODELS

The program in principle uses 2 sets of station delays. The delays are always subtracted from the observed arrival times. The parameter DLYAZ (see section on station list input for input formats) acts as a switch to always use delay model 1, always use delay model 2, or to use a combination of both for the entire run.

When both delay models are being used, the current location of the epicenter determines which model is actually used. The coordinates of the array origin (the station CNTR) and the paramter DLYAZ divide the planar network into two half-planes. The station CNTR will always lie on the dividing line. If the epicenter lies north or west of the dividing line, delay model 1 is used for all stations, and delay model 2 is used for epicenters on the other side (see Figure 3). A transition zone of half-width DLYWD is used to smoothly connect the two delay models about the diving line with a cosine function.

DLYAZ is in degrees east of north. If DLYAZ is 0. (north) then delay model 1 is on the west side, and if DLYAZ is positive but less than 180, delay model 1 is on the north side of the line. If DLYAZ is negative, model 1 is on the south side.

This configuration may be used to model a fault zone within a network of stations, so that fault zone delays will be expressed as higher delays for epicenters on the opposite side of the fault from the recording station. In this case DLYWD will be about 1 km. The two delay models can also model a long network, with different delays appropriate to each end. A large value of DLYWD provides a smoothly varying and gradual transition between the two regions.

ITERATION AND CONVERGENCE CRITERIA

Where to begin iterations

In absence of a specificed trial origin time, latitude, longitude, or depth on the terminator card, a standard trial hypocenter is assumed. Any one of the four trial hypocenter parameters may be specified independently, however. The trial origin time is two seconds before the first arrival, and the trial epicenter is near the station with the first arrival. Starting depth is at the trial depth ZTR (as specified in BLOCK DATA). During the early iterations (usually just the first), depth is held fixed until the horizontal adjustment is less than DXFIX (as specified in BLOCK DATA). If the trial depth ZTR is negative, all events in this run are held fixed at this depth (at the positive value), unless ZTR is temporarily overridden by a trial depth set for a particular event on its terminator card.

How iterative steps may be modified

Various parameters can be defined which damp the epicentral adjustments if the adjustment vector becomes large or unstable. DAMP is the damping factor by which all hypocenter adjustments are always multiplied before an iterative step is taken. Damping is automatically cut in half for the last 1/3 of the allowed number of iterations. Thus, if 15 iterations are allowed and convergence has not been reached after 10 iterations, the remaining 5 iterations will be heavily damped. Empirically this appears to improve convergence. If an iterative step would place the hypocenter in the air, the hypocenter is moved up to the fraction (1.-DZAIR) of its present depth. Thus the depth adjustment is -DZAIR * Z. The depth adjustment may be indepently damped if the adjustment is larger than DZMAX. If it is, the depth variation is damped by the factor DZMAX /(DZ + DZMAX) where DZ is the calculated depth adjustment.

If the value of RMS should increase by more than the amount RBACK from one iteration to the next, the hypocenter is moved back by the fraction BACFAC toward the previous hypocenter. This situation often occurs when a poorly constrained hypocenter iterates across a large velocity discontinuity in the crustal model.

The use of a generalized inverse scheme for finding the hypocenter adjustment for each iteration allows great control over the adjustments actually taken. For example we may choose not to make hypocenter adjustments in directions which are poorly constrained by the arrival time data and which are directions in which location errors are large. The parameter EIGTOL (set in BLOCK DATA) does exactly this, and serves as a cut-off below which eigenvalues of inversion are deemed unstable and are suppressed. A very brief description of the matrix equations of the inversion might aid in using this parameter.

Inversion scheme and use of eigenvalue cutoff.

If the solution to the earthquake location problem were linear and if we had exactly as many independent data (arrivals times) as hypocentral unknowns, the answer would be the solution of

$$T_{n} = A_{nxn} \cdot X_{n} + G_{n}$$

where T is the n-vector of arrival times, X is the n-vector of hypocenter coordinates and G is constant. A is the n by n partial derivative matrix

$$Aij = \frac{\partial Ti}{\partial Xj}$$

which may be directly calculated from an assumed velocity model. But since the earthquake problem is nonlinear (A is not constant), we must seek successive linearized solutions and iterate toward the true solution until we have converged to the desired accuracy. X and A must also be updated as iteration proceeds. If T_o and X_o are the arrival time and hypocenter vectors calculated at the previous step (or some initial guess on the first iteration) which satisfy

$$T_o = A \cdot X_o + G$$

then subtracting the equations yields

$$T - T_o = A \cdot (X - X_o) \text{ or } \underset{n}{R} = \underset{nxn}{A} \cdot \underset{n}{DX}$$

where R is the vector of travel time residuals (observed times minus those calculated from the model at the previous step) and DX is the hypocentral adjustment vector, given in this case by DX = A-1. R. The number of observations m for the earthquake problem is often in the range 8 to 40, but the number of unknowns is generally only 4. When m exceeds n, however, the true inverse A^{-1} does not exist. We seek the least squares solution which best solves

$$\underset{m}{R} = \underset{mxn}{A} \cdot \underset{n}{DX}$$

in the sense of minimizing

$$(R - A \cdot DX)^2$$

This is done by premultiplying by A^T to get the least-square condition

$$\underset{nxm}{A^T} \cdot \underset{m}{R} = \underset{nxn}{(A^TA)} \cdot \underset{n}{DX}$$

which now only requires inversion of the nxn symmetric matrix A^TA.

The solution can be sought in terms of the generalized inverse of A, and in particular the singular value decomposition (SVD) of A. This not only yields the usual least square solution, but permits manipulation of the eigenvalues of A^TA, calculation of the errors, and evaluation of the information content of the data. This program uses the SVD subroutine of Lawson and Hanson (1974) and forms the above matrices from elements of the decomposition.

The decomposition of A is given by

$$\underset{mxn}{A} = \underset{mxn}{U} \cdot \underset{nxn}{S} \cdot \underset{nxn}{V^T}$$

where U and V are eigenvector matrices and S is the diagonal matrix of eigenvalues of A^TA. Also $U^TU = I$, $V^TV = I$, and assuming that the number of linearly independent arrival time data exceeds the number of unknowns, $VV^T = I$. When the resolution matrix VV^T equals the identity matrix, the unknowns are perfectly resolved which is the usual case for the earthquake problem. Then the least-squares solution can be derived by substitution of A into the least-squares condition and is given by

$$\underset{n}{DX} = \underset{nxn}{V} \cdot \underset{nxn}{S^{-1}} \cdot \underset{nxm}{U^T} \cdot \underset{m}{R}$$

The covariance matrix of the solution DX is given by

$$\underset{n\times n}{C} = w^2 \underset{n\times n}{V} \cdot \underset{n\times n}{S^{-2}} \cdot \underset{n\times n}{V^T}$$

where w = constant.

We see at once that if one or more eigenvalues in S becomes small, both solution and error become large and unstable. Each eigenvalue corresponds to one of the mutually orthogonal principal directions of the solution, and if one eigenvalue becomes small, both the adjustment and standard error in that principal direction become large in proportion to one over that eigenvalue. The principal direction with the small eigenvalue will in general include components of origin time, latitude, longitude, and depth. Most often, however, the smallest eigenvalue has its largest component in depth. If an eigenvalue should become smaller than the parameter EIGTOL, no adjustment is taken in that principal direction for which the error is also large. The program does not add the term to DX originating from the small eigenvalue. In other words, solutions are prevented from becoming unstable and scattering out in the direction in which their error ellipsoids are very long.

In general, the largest eigenvalue is of order 5 (with its dominant component in origin time) and the spatial eigenvalues are of order 0.3 to 0.7. The difference is size between origin time and spatial enigenvalues arises because a change of several km in hypocenter location is required to produce the same change in an arrival time as a one second change in origin time. Unstable or very poorly constrained situations occur when the smallest eigenvalue becomes less than about .02. Looked at another way, instability occurs when the condition number (ratio of largest to smallest eigenvalue) exceeds about 200. The value of EIGTOL should be chosen after attempting to solve for the most marginal events one wishes to locate with a given network, and studying the eigenvalues and iteration history for these events.

When to stop iterating.

Iteration can stop in any of 3 ways: 1) when the number of iterations reaches the maximum allowed, ITRLIM (set in BLOCK DATA); 2) When the change in the RMS residual between iterations becomes less than DRQT sec (set in BLOCK DATA); 3) When the hypocenter adjustment vector is less than DQUIT km (set in BLOCK DATA). The last two tests are only applied after the depth has been freed from its trial value for at least one iteration.

ERROR CALCULATIONS

The covariance or error matrix

The covariance matrix is calculated from elements of the decomposition of the A matrix (see section on inversion scheme) as

$$\underset{n\times n}{C} = w^2 \underset{n\times n}{V} \cdot \underset{n\times n}{S^{-2}} \cdot \underset{n\times n}{V^T}$$

where S and V are matrices composed of eigenvalues and eigenvectors in the "solution space" of the hypocenter. w^2 is the variance (standard error squared) of the arrival time data. The program calculates w^2 as

$$w^2 = RDERR^2 + ERCOF \cdot RMS^2$$

where RDERR and ERCOF are parameters set in BLOCK DATA and RMS is the root mean square travel time residual. RDERR represents the estimated reading error in seconds of the arrival time data. ERCOF is just a weighting factor for including the effects of a poor solution in the error calculations. If you want the calculated errors in the hypocenter to reflect only errors introduced in reading the data, set ERCOF = Ø. This will give objective errors which include the effects of array geometry. If you want to include effects of poorly modeled travel times such as weaknesses in the crustal or delay models, then set ERCOF = 1. ERCOF can be set to any positive value or Ø.

The covariance matrix is a 4 x 4 symmetric matrix whose diagonal elements are the variances (standard errors squared) of origin time (in sec), and latitude, longitude and depth (all in km). The off-diagonal elements are the covariances between these quantities. This allows, for example, a quantitative estimate of origin time error and the tradeoff between origin time and depth. The error ellipsoid is specified by the 3 x 3 sub-matrix with origin time removed.

Error ellipsoid and vertical and horizontal errors.

The error ellipsoid is specificed by the 3 x 3 sub-matrix derived by removing origin time from the covariance matrix. The 3 x 3 covariance matrix must be rotated into the principal coordinates of the solution, whose axes are the major axes of the error ellipsoid. The three principal standard errors are calculated by taking square roots of the eigenvalues (diagonal elements in diagonal form) of the 3 x 3 covariance matrix. The earthquake then has a statistical probability of 32% of lying inside an ellipsoid of error whose major axes are given by the three principal standard errors. An error ellipsoid whose major axes are 2.4 times the standard errors calculated by this program has a 95% chance of containing the "true" hypocenter. The program also calculates the azimuths and dips of the principal axes of the error ellipsoid.

The vertical error ERZ and horizontal error ERH are simplified errors derived from the lengths and directions of the principal axes of the error ellipsoid. Each of the three principal axes (whose lengths are the standard errors) are projected onto a vertical line through the hypocenter, and the largest value is ERZ. ERH is simply the length of the longest of the principal axes when viewed from above (projected onto a horizontal plane).

AMPLITUDE (LOCAL) MAGNITUDES

The method for calculating local magnitudes assumes that maximum peak-to-peak amplitudes are read from a standard Wood-Anderson torsion seismograph. If amplitude is read from another instrument, it is corrected to an equivalent Wood-Anderson response (Eaton, 1970). Richter's original magnitude formula is

$$M_L = \log (A/2) - \log A_o + G$$

where A is the maximum peak-to-peak amplitude on a Wood-Anderson seismograph, $-\log A_o$ is a tabulated function of distance, and G is the station's magnitude correction. The term by term generalization of this formula as used in this program for a particular instrument is:

$$XMAG = \log \frac{AMP}{2 \cdot CAL \cdot R(PER)} + F(D^2) + XCOR$$

where

- AMP — is the peak-to-peak amplitude measured in mm on the seismogram or on the Develocorder viewer (or on an equivalent paper record).
- CAL — is the calibration factor of the instrument, defined as the peak-to-peak amplitude in mm of a 10 microvolt RMS signal at 5 HZ applied to the VCO. For a Wood-Anderson instrument, CAL should be input as 1.0.
- R(PER) — is the response of the instrument at standard gain as a function of period PER relative to the Wood-Anderson instrument. The program assumes that the relative response is completely specified by the product CAL·R(PER). For a Wood-Anderson instrument, the program uses R = 1.
- $F(D^2)$ — is Richter's distance term $-\log A_o$. It is approximated in the program as an algebraic function of D^2.
- XCOR — is the station correction.

The values of CAL, PER and XCOR are constants for the station specified on the station card. AMP is specified on the phase card. The function R(PER) is available for two instrument types beside the Wood-Anderson:

Type Code	Instrument
Ø	Wood-Anderson torsion seismograph
1	NCER standard (1 Hz velocity transducer with 0.7 critical damping).
2	Presently a Hawaii-type sprengnether or HS-10 geophone with Develoco VCO.

In the allowable period range (0.1 to 1.9 sec) R is approximately a linear function in the log-log sense.

For type 1: $\log (1/R) = -1.3 - .95 \log (0.2/PER)$
For type 2: $\log (1/R) = .41 + .56 \log (0.2/PER)$

The constants for type 2 are set in BLOCK DATA, and may easily be reset for another instrument type. Similarly, F is approximately a bilinear function of log (D^2):

For D smaller than 200 km: F = -.15 + .80 log (D2)
For D larger than 200 km: F = -3.38 + 1.5 log (D2)

These linear approximations introduce magnitude errors of less than .05 over their useful ranges.

If the calibration factor CAL is found equal to 0.0, no magnitude will be computed for that station. Its allowable range is 0.0 to 49.9 inclusive. The allowable range of PER is 0.1 to 1.9 sec inclusive. The useful range of XCOR is ± 2.4 inclusive. If you want to compute a magnitude for a station but exclude the result from the average, use a value of XCOR equal to 5.0 plus the actual correction. Thus, the allowable values for XCOR are between -2.4 and 2.4, or between 2.6 and 7.4 inclusive. See the section on station list input for more information.

DURATION OR CODA MAGNITUDES

The second magnitude calculated is based on duration, coda, or F-P time as read on a short period seismogram. The NCER practice is to read the end of coda or "F phase" when the signal decays to 10 mm peak-to-peak on the Develocorder viewer. Amplitude and duration magnitudes are calculated independently, and both appear on all summary outputs. Choosing between or averaging the two must be done by the user outside the program. Magnitude corrections FCOR may be specified for each station. If FMP is the duration time in seconds, D the epicentral distance to the station and Z the depth, the magnitude formulas are for FMP less than FMBRK:

$$FMAG = FMA1 + FMB1 \cdot \log(FMP) + FMD1 \cdot D + FMZ1 \cdot Z + FCOR$$

for FMP larger than FMBRK:

$$FMAG = FMA2 + FMB2 \cdot \log(FMP) + FMD2 \cdot D + FMZ2 \cdot Z + FCOR$$

These are the constants currently in use by the three established networks:

	CALIFORNIA	ALASKA	HAWAII
FMA1	- .87	- 1.16	- 5.0
FMB1	2.0	2.01	3.89
FMZ1	0.0	.007	0.0
FMD1	.0035	.0035	0.0
FMBRK	9000.	9000.	210.
FMA2	0.0	0.0	- .705
FMB2	0.0	0.0	2.026
FMZ2	0.0	0.0	0.0
FMD2	0.0	0.0	0.0

The useful range of FCOR is ± 2.4 inclusive. If you want to compute a magnitude for a station but exclude the result from the average, use a value of FCOR equal to 5.0 plus the actual correction. Thus, the allowable values for FCOR are between -2.4 and 2.4, or between 2.6 and 7.4 inclusive.

PROGRAM OUTPUTS

The quantity and type of output produced by the program is under control of parameters described in the section on the input/output control file HYPINST. Each section of output is described more fully here.

Iteration Output

Each event on the print output file is begun with a page eject (if KEJCT is '1') and a one-line heading giving the event date, time, and sequence number (if KPRINT is 1 or larger). If KPRINT is 2 or larger, hypocenter data are printed in one line per iteration. The data are as follows:

I	Iteration number.
ORIGIN	Origin time in seconds relative to event time in the heading.
LAT N	In degrees and minutes. If south, will contain an S.
LON W	In degrees and minutes. If east, will contain an E.
Z	Depth in km.
NWR	Number of readings (P and S) with weights larger than 0.1. This will change during convergence because distance and residual weighting will change the weights of marginal stations.
RMS	The root mean square of the weighted travel time residuals r_i with weights w_i: $$RMS^2 = \frac{\sum_i (w_i r_i)^2}{\sum_i w_i^2}$$
DT	Origin time adjustment (in sec).
DLAT	Latitude adjustment (km). Positive is north.
DLON	Longitude adjustment (km). Positive is west.
DZ	Depth adjustment (km). Positive is down. All adjustments are applied to the current location to produce the location listed for the next iteration.
RR	Length of adjustment vector in km.
N	Number of free hypocenter parameters solved for and adjusted. A hypocenter parameter is one of the principal directions of the solution. N is thus the number of eigenvalues greater than EIGTOL. N is 3 when depth is held fixed (as on the first iteration), and should increase to 4 if the solution is well constrained and focal depth is a free parameter.

Other self-explanatory messages which may appear in the iteration output are:

FOCAL DEPTH FREED
AIRQUAKE PREVENTED
DEPTH VARIATION DAMPED
RMS INCREASE - MOVE HYPO .50 BACK

This output is very useful for monitoring convergence, detecting instabilities, and determining proper convergence criteria.

Eigenvalue and error output

If KPRINT is 3 or larger, the four eigenvalues of the principal directions of the solution are listed in descending order. These are useful in gauging the relative stability and error of the solution in the four principal directions. Under each eigenvalue are the column eigenvectors corresponding to it. The eigenvectors together make up the matrix V. The elements of the column eigenvectors give the components of origin time, latitude, longitude and depth in the principal direction corresponding to that eigenvalue. In other words, the matrix of eigenvectors accomplishes the "rotation" between the principal and geographic coordinates. The last eigenvector gives the mix of latitude, longitude and depth which are most poorly determined and associated with the smallest eigenvalue.

The covariance matrix gives the variances (diagonal elements) and covariances of origin time, latitude, longitude and depth. The errors listed are the standard errors of origin time (in sec), and latitude, longitude and depth (in km) with the other three variables held fixed. They are the square roots of the diagonal elements of the covariance matrix. The error ellipsoid consists of the lengths of the principal axes SERR and their azimuths AZ and dips DIP in degrees. The principal axes are the standard errors in those directions in units of km. The hypocenter statistically has a 32% chance of lying within the error ellipsoid given. To obtain a 95% confidence ellipsoid, multiply the standard errors by 2.4. See the sections on the inversion scheme and error calculations for more information.

Final hypocenter output

The following is printed in two lines for each event if KPRINT is Ø or larger:

YR, MO, DA	Year, month and day of event.
ORIGIN	Origin time in hours, minutes and seconds.
LAT N	In degrees and minutes. If south, will contain an S.
LON W	" " " " . If east, will contain an E.
DEPTH	Depth in km.
RMS	The final root mean square traveltime residual, computed after residual weighting.

ERH	The horizontal error in km, defined as the greatest length of the horizontal projections of the three standard errors.
ERZ	The vertical error in km, defined as the greatest length of the vertical projections of the three standard errors.
GAP	The largest azimuthal gap between azimuthally adjacent stations.
XMAG	Average amplitude or local magnitude.
FMAG	Average duration or coda magnitude.
RMSWT	The root-mean-square traveltime residual computed before residual weighting is applied. The residual weighting function depends on this value.
DMIN	Distance to the nearest station reporting an arrival with weight larger than 0.1.
ITR	Number of iterations required to find the solution.
NFM	Number of P first motions reported for this event.
NWR	Number of readings (P and S) with weights larger than 0.1.
NWS	Number of S readings with weights larger than 0.1.
REMK	The optional 3-letter remark included on the phase list terminator card. If the terminator card is blank, REMK is taken from the first phase card which has col.'s 63-65 non-blank.

<u>Station list output</u>.

The printed output concludes with a list of station data when KPRINT is 1 or larger. The following information is given in one line for each arrival given (P or S):

STA	Station name
DIST	Epicentral distance in km.
AZM	Azimuth to the station in degrees east of north.
AN	Angle of emergence at the hypocenter, measured in degrees from nadir.
P/S	P or S remark code and P first motion.
W	Assigned weight code.
SEC	Observed arrival time.
CCOR	Clock correction.
TOBS	Observed travel time. TOBS = SEC + CCOR - OT.
TCAL	Calculated travel time.
DLY	Station delay.
RES	Travel time residual. RES = TOBS - TCAL - DLY.
WT	Actual weight used for this arrival. It is a normalized product of several weight factors.
XMG	Amplitude magnitude for this station.
FMG	Duration magnitude for this station.
R	One letter remark for this arrival (from phase card).
INFO	Information or importance contribution of this arrival to the solution (see below). Only computed if the parameter KINFO (set in BLOCK DATA) is equal to 1.

The station importance or information density.

This is a new parameter which is a by-product of the generalized inverse approach and which is not computed by other standard location programs. It is a quantitative measure of the contribution a particular arrival makes to the hypocenter solution, and includes the effect of weight on the arrival data. Computation of the importance may be suppressed and program execution made a bit more efficient by setting KINFO = 0 (in BLOCK DATA). To get the importance set KINFO = 1.

A result of the singular value decomposition of the partial derivative matrix A (see section on inversion scheme) is the information density matrix $B = UU^T$. This is an m x m matrix, where m is the number of arrival times reported. Each diagonal element b_{jj} of B is thus associated with the ith arrival alone, and is the quantity printed and referred to as the importance of the arrival.

A feeling for what importance means quantitatively may come from realizing that the rows of U are linearly related to the rows of the partial derivative matrix A. In other words, when the partial derivatives of travel time to the ith station with respect to the jth hypocentral coordinate dT_i/dX_j are large for the ith station, (the ith row of A) then the ith row of U and hence the station importance b_{ii} will also be large. Thus a large leverage, through the partial derivative matrix A, of a particular station on the solution is equivalent to a large station importance. This can be seen intuitively from the relation:

$$\underset{m\times n}{A} \cdot \underset{n\times n}{V} = \underset{m\times n}{U} \cdot \underset{n\times n}{S}$$

where the matrices are as defined in the inverison section. When the ith row of A is large (corresponding to the ith station), the ith row of this equation and hence of U will be large. The ith diagonal element s_{ii} of UU^T will also be large.

An illustration of the relation between importance and partial derivatives is the fact that an S reading has a greater importance than a P reading from the same station. The partial derivatives d(travel time)/ d(space coordinate), are larger for S arrivals at the same station by the factor Ts/Tp, and this means that rows of the U matrix and consequently the importance will be larger for the S arrivals. This has an important consequence for assigning weights to arrivals. When and S arrival cannot be read to the same precision as a P arrival, it should be given less weight to compensate for its intrinsically larger importance.

The importance is a measure of the redundancy in the data, and for example is small in distances and azimuths where there are many stations. This can be seen from the following argument. The inversion process for the overdetermined earthquake problem extracts n linearly independent combinations of partial derivatives from the m combinations in the matrix A. One "unit" of importance is attributed to each of these n independent combinations. Hence the sum of importances of all stations for a full earthquake solution is 4. If several data are redundant, i. e. linearly dependent or nearly so, then the unit of importance must be distributed among them and the importance of each redundant datum goes down.

Station data output (for archiving or later processing).

The station data output contains all of the information in the printed station list, but is in a format compatible with phase data. Thus the output file can be read by another execution of the program as if it were phase data. Station data output for each event consists of one line per station. The event is terminated by a HYPOINVERSE format summary line which acts like a terminator line containing the previous location as a trial hypocenter on input. The format of the station data is as follows:

STATION DATA OUTPUT FORMAT

Columns	Format For Reading	Explanation
1 - 4	A4	Station name
5 - 6	A2	P remark such as 'IP'
7	A1	P first motion
8	I1	Assigned P weight code
10-11	I2	Year
12-13	I2	Month
14-15	I2	Day
16-17	I2	Hour
18-19	I2	Minute
20-24	F5.2	Second of P arrival
25-28	F4.2	P travel time residual*
29-31	F3.2	P weight actually used*
32-36	F5.2	Second of S arrival
37-38	A2	S remark such as 'ES'
40	I1	Assigned S weight code
41-44	F4.2	S travel time residual*
45-47	F3.0	Maximum peak-to-peak amplitude in mm
48-50	F3.2	S weight actually used*
51-54	F4.2	P delay*
55-58	F4.2	S delay*
59-62	F4.1	Epicentral distance*
63-65	F3.0	Emergence angle at source, in degrees from nadir. (Replaces optional remark on original phase card.)*
66-70	F5.2	Clock correction
71	A1	Station remark, such as 'D' for dead
72-75	F4.0	Duration time in seconds
76-78	F3.0	Azimuth to station in degrees east of north*
79-80	F2.1	Duration magnitude for this station*
81-82	F2.1	Amplitude magnitude for this station*
83-86	F4.3	Importance of P arrival*
87-90	F4.3	Importance of S arrival*

*Attional items not on original phase cards.

Event summary output

The program writes one line per event in any, all or none of three formats on three different files. The three formats available are HYPO71, HYPOELLIPSE, and HYPOINVERSE. The HYPOINVERSE format is also used as a terminator line of each event on the station data output file.

HYPO71 Summary Output

Columns	Format for Reading And Writing	Explanation
1 - 2	I2	Year
3 - 4	I2	Month
5 - 6	I2	Day
8 - 9	I2	Hour
10-11	I2	Minute
12-17	F6.2	Origin time, seconds
18-20	F3.0	Latitude, degrees
21	A1	S if south latitude, blank otherwise
22-26	F5.2	Latitude, minutes
27-30	F4.0	Longitude, degrees
31	A1	E if east longitude, blank otherwise
32-36	F5.2	Longitude, minutes
37-43	F7.2	Depth, km
44-50	F7.2	Duration magnitude
51-53	I3	Number of arrivals (P or S) with weights greater than 0.1
54-57	F4.0	Maximum azimuthal gap
58-62	F5.1	Distance to nearest station
63-67	F5.2	Root mean square travel time residual
68-72	F5.1	Horizontal error, km
73-77	F5.1	Verital error, km

HYPOELLIPSE Summary Output

Columns	Format For Reading	Explanation
1 - 2	I2	Year
3 - 4	I2	Month
5 - 6	I2	Day
7 - 8	I2	Hour
9 -10	I2	Minute
11-14	F4.2	Origin time, seconds
15-16	F2.0	Latitude, degrees
17	A1	S for south latitude, blank otherwise
18-21	F4.2	Latitude, minutes
22-24	F3.0	Longitude, degrees
25	A1	E for east longitude, blank otherwise
26-29	F4.2	Longitude, minutes
30-34	F5.2	Depth, km
35-36	F2.1	Amplitude magnitude
37-39	I3	Number of arrivals (P or S) with weights greater than 0.1
40-42	F3.0	Maximum azimuthal gap
43-45	F3.0	Distance to nearest station (km)
46-49	F4.2	Root mean square travel time residual
50-52	F3.0	Azimuth of smallest standard error (degrees)
53-54	F2.0	Dip of smallest standard error (degrees)
55-58	F4.2	Magnitude of smallest standard error (km)
59-61	F3.0	Azimuth of intermediate standard error (degrees)
62-63	F2.0	Dip of intermediate standard error (degrees)
64-67	F4.2	Magnitude of intermediate standard error (km)
68-69	F2.1	Duration magnitude.
70-72	A3	Event remark.
73-76	F4.2	Magnitude of largest standard error (km)
79-80	I2	Number of S arrivals with weights greater than 0.1

HYPOINVERSE Summary Output

The first 80 columns of the HYPOINVERSE format are identical with those of the HYPOELLIPSE card format. An additional 10 columns are included as follows:

Columns	Format For Reading	Explanation
81-84	F4.2	Horizontal error, km
85-88	F4.2	Verital error, km
89-90	I2	Number of P first motions reported for this event

References Cited

Eaton, J. P., 1969, HYPOLAYR, A computer program for determining hypocenters of local earthquakes in an earth consisting of uniform flat layers over a half space, U.S. Geological Survey Open-File Report.

Eaton, J. P., 1970, Harmonic magnification of the complete telemetered seismic system, from seismometer to film viewer screen, U.S. Geological Survey Open-File Report.

Lee, W. H. K., and Lahr, J. C., 1972, HYPO71: A computer program for determining hypocenter, magnitude, and first motion pattern of local earthquakes, U.S. Geological Survey Open-File Report.

Lamson, C. L., Hanson, R. L., 1974, Solving Least Squares Problems, Prentice Hall, 340 pp.

Appendix 1

List of test parameters and constants set in BLOCK DATA

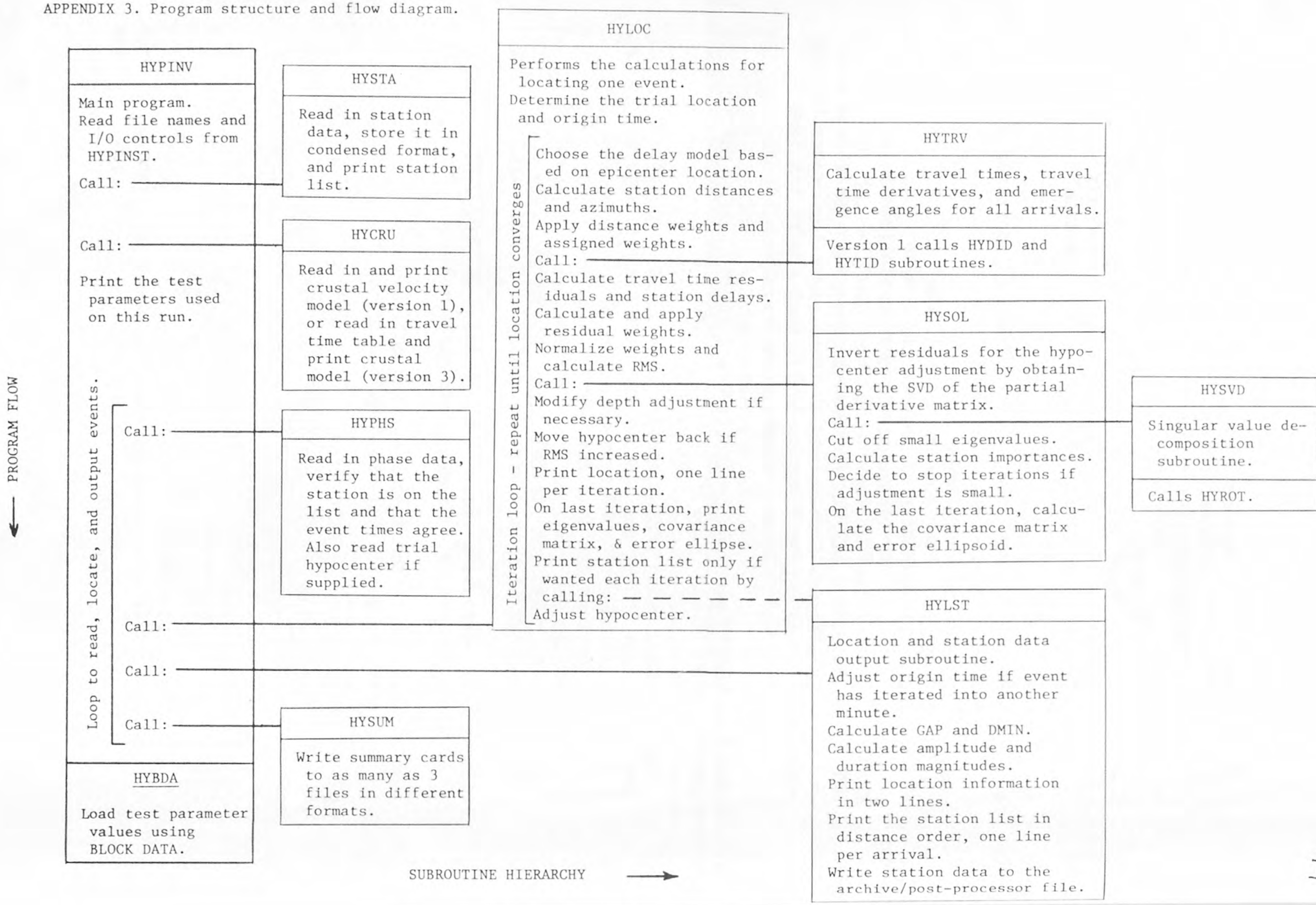
The parameters listed here which are adjustable are more fully described in the user's guide section. The variables reside in common block TEST.

Name	Suggested Value	Useful Range	Explanation
ITRLIM	20	7 - 30	Maximum number of iterations
DQUIT	.04	.01 -.1	Stop iterating when hypocenter adjustment is less than DQUIT (km)
DXFIX	7.	1.-20.	Keep depth fixed until epicentral adjustment is less than DXFIX (km)
DZMAX	7.	4.-50.	Damp depth adjustment if depth adjustment would be greater than DZMAX (km)
DZAIR	.5	.1 - .9	Move depth upward by this fraction if depth adjustment would put the hypocenter in the air
DISCUT	50.	20.-1000.	Taper the distance
DISW1	1.	0. - 2.	weight between DMIN2·
DISW2	3.	2. - 10.	DISW1 and DMIN2·DISW2, but use DISCUT instead of DMIN2 if DMIN2 is less than DISCUT. DMIN2 is the distance to the second closest station in km.
RMSCUT	.16	.05-.50	Taper the residual weight between RMS · RMSW1
RMSW1	1.5	0.-2.	and RMS · RMSW2, but use RMSCUT instead of RMS
RMSW2	3.	2.-10.	if RMS is less than RMSCUT. RMS is the root-mean-square travel time residual in sec.
SWT	1.	0.-1.	All weights for S arrivals are multiplied by SWT.
DAMP	.9	.5 - 1.	Damping factor for all hypocenter adjustments
DRQT	.001	.01-.001	Stop iterating when change in RMS s less than DRQT.
EIGTOL	.016	.01 - .03	No hypocentral adjustment is taken in directions for which the eigenvalue is less than EIGTOL.
FMA1			
FMB1			Duration magnitude constants. See section on
FMZ1			duration magnitudes for values and details.
FMD1			
FMBRK			
FMA2			
FMB2			
FMZ2			
FMD2			
LINP	5	5	Phase data input file number.
LPRT	6	6	Print output file number.
LOUT	7	7	Station data output file number.
MAXSTA	300*	300*	Maximum number of stations avilable.
	70+	70+	

MAXPHS	160* 50+	160* 50+	Maximum number of stations or phase cards allowed for each event.
MMAX	240* 60+	240* 60+	Maximum number of arrivals (P or S) allowed for each event.
POS	1.75	1.7-1.8	Vp/Vs velocity ratio
ZTR	5.	2.-30.	Trial depth (km)
RDERR	.2	.02-.5	Estimated reading error in seconds.
ERCOF	1.	0.-1.0	Weighting factor of RMS in estimating timing error.
KEJCT	'1'	'1'or'_'	Page eject control
KINFO	1	0 or $\overline{1}$	Set equal to 1 to compute importance contribution for each arrival time.
LB	'△△'		Two blanks
BL		'△△△△'	Four blanks
RDEG	57.29578		Number of degrees per radian
LOCNUM			Event counting index initialized to Ø
PI	3.14159		PI.
RBACK	.01	.005-.10	If RMS increases by more than RBACK from one
BACFAC	.6	.2-.9	iteration to the next, move the hypocenter by the fraction BACFAC back toward the last location and resume iterating.

* in Versions 1 and 3
\+ in Versions 2 and 4

APPENDIX 3. Program structure and flow diagram.



APPENDIX 3: Sample input and output of HYPOINVERSE

Input files:

HYPINST	Input and output control.
HCRUST	Crustal model.
PHASES	Phase data for two earthquakes.
NEWSTA	Station list.

Output files:

PRINTED OUTPUT	
HYPOUT	Archive/Post-processor file.
SUMM71	Summary file.
SUMMEL	Summary file.
SUMMHI	Summary file.

HYPINST

```
NEWSTA     RI
HCRUST     RI
PHASES     RI
$LPT       RP
HYPOUT     RO
SUMM71     RO
SUMMEL     RO
SUMMHI     RO
10311111
```

HCRUST

```
1.4  0.0      0
2.2  1.0      0
3.6  2.0      0
5.0  3.0      0
6.0  4.0      0
8.25 13.5     0
```

PHASES

```
DANIPU  7705050512 3605                                 UER-0750        0
LUAIPD  7705050512 2970                                    -0750        0
HSSIPD  7705050512 3520                                    -0750   165  0
KIIEPU  7705050512 3795                                    -0750        0
POLIPD  7705050512 2970                                    -0750        0
KAEIPU  7705050512 2895                                    -0750        0
WHAIPU  7705050512 2955                                    -0750        0
MTVIPD  7705050512 3120                                    -0750        0
AINIPD  7705050512 3320                                    -0750   163  0
KPRIPD  7705050512 3285                                    -0750        0
KHUIPU  7705050512 3565                                    -0750        0
SPTEPD  7705050512 3735                                    -0750        0
KAAEPD  7705050512 3860                                    -0750        0
HUAIPD  7705050512 4045                                    -0750        0
NAGIPD  7705050512 3520                                    -0750        0
HPUIPD  7705050512 3720                                    -0750        0
KKUIPU  7705050512 3840                                    -0750        0
KOHEPD  7705050512 4305                                    -0750        0
USE    4 7705050512                      19                -0750        0
USZ    4 7705050512                      29                -0750        0
HILEPD4 7705050512 3240                                    -0500        0
HIE    4 7705050512            3920ISD    7                -0500        0
HIN    4 7705050512            3900ISD   14                -0500        0
                                                                        0
MLOIPU  7705051243 5535                                 LSW-0750        0
WILEPU  7705051243 5580                                    -0750        0
CPKIPU  7705051243 5340                                    -0750        0
AHUIPD  7705051243 5355                                    -0750    76  0
PAUIPD  7705051243 5405                                    -0750        0
KPNIPD  7705051243 5295                                    -0750        0
HLPIPD  7705051243 5220                                    -0750        0
DESIPU  7705051243 5220                                    -0750    78  0
PPLIPU  7705051243 5250                                    -0750        0
DANIPU  7705051243 5565                                    -0750        0
LUAIPD  7705051243 5690                                    -0750        0
HSSEPD  7705051243 5740                                    -0750        0
POLIPD  7705051243 5330                                    -0750        0
KAEIPU  7705051243 5550                                    -0750        0
WHAEPU  7705051243 5700                                    -0750        0
AINIPU  7705051243 5365                                    -0750    80  0
KPRIPU  7705051243 5165                                    -0750        0
KHUIPU  7705051243 5465                                    -0750        0
SPTEPU  7705051243 5750                                    -0750        0
KAAIPU  7705051243 5895                                    -0750        0
HUAIPD5 7705051243 6280                                    -0750        0
USE    4 7705051243                       2                -0750        0
USZ    4 7705051243                       2                -0750        0
                                                                        0
```

NEWSTA

CNTR	19	25.40	155	17.60				999.						0
AHU	19	22.40	155	15.90	1070	.2	1	.07	0.4	0.0	1	4.3	1076	0
AIN	19	22.50	155	27.62	1524	.2	1	.30	5.0	0.0	1	8.5	1074	1277
CAC	19	29.29	155	55.09	323	.2	1	.17	5.0	0.0	1	5.4	0176	1277
CPK	19	23.70	155	19.70	1038	.2	1	-.09	5.0	0.0	1	4.0	0176	0678
DAN	19	21.42	155	40.04	3003	.2	1	-.10	5.0	0.0	1	7.0	0976	0
DES	19	20.20	155	23.30	815	.2	1	-.12	5.0	0.0	1	4.2	0476	0
ESR	19	24.68	155	14.33	1177	.2	1	.00	5.0	0.0	1	2.0	1076	0577
HAE	20	46.00	156	15.00	2090	.5	1	.00	0.2	5.0	0	1.0	0958	0
HAL	20	46.00	156	15.00	2090	.5	1	.00	5.0	5.0	1	0.7	0958	0
HAN	20	46.00	156	15.00	2090	.5	1	.00	0.2	5.0	0	1.0	0958	0
HIE	19	43.20	155	05.30	20	.5	1	.71	0.0	5.0	0	1.0	0958	0
HIH	19	43.20	155	05.30	20	.5	1	.71	0.0	5.0	0	1.0	0958	0
HIL	19	43.20	155	05.30	20	.2	1	.71	0.5	5.0	1	1.0	0958	0
HIN	19	43.20	155	05.30	20	.5	1	.71	0.0	5.0	0	1.0	0958	0
HLP	19	17.96	155	18.63	707	.2	1	.19	5.0	0.0	1	4.0	0276	0
HMO	21	25.40	158	00.90	76	.2	1	.00	5.0	5.0	2	0.0	1162	0
HPU	19	46.85	155	27.50	3396	.2	1	.48	5.0	0.0	1	4.7	1176	1077
HSS	19	36.31	155	29.13	2445	.2	1	.37	5.0	0.0	1	6.2	0775	0377
HUA	19	41.25	155	50.32	2189	.2	1	.84	5.0	0.0	1	2.6	0276	0677
HUL	19	25.13	154	58.72	369	.2	1	.00	5.0	0.0	1	3.0	0477	0
KAA	19	15.98	155	52.28	524	.2	1	.05	0.1	0.0	1	5.2	0177	1277
KAE	19	17.35	155	07.95	37	.2	1	.16	5.0	0.0	1	1.3	1176	0
KGN	19	21.52	154	59.67	30	.2	1	.07	5.0	0.0	1	0.0	0977	0977
KHU	19	14.90	155	37.10	1939	.2	1	.20	5.0	0.0	1	3.7	0375	0
KII	19	30.56	155	45.90	1841	.2	1	.32	5.0	0.0	1	7.1	1275	0377
KIP	21	25.40	158	00.90	76	.5	1	.00	5.0	5.0	2	0.0	0066	0
KKU	19	53.39	155	20.58	1863	.2	1	.85	5.0	0.0	1	2.3	0174	0877
KLU	19	27.48	154	55.26	271	.2	1	0.00	5.0	0.0	1	0.0	0977	0
KOH	20	07.69	155	46.77	1166	.2	1	.14	5.0	0.0	1	2.4	0176	1277
KPN	19	20.10	155	17.40	924	.2	1	.06	5.0	0.0	1	6.4	0976	0
KPR	19	16.40	155	26.70	610	.2	1	.02	5.0	0.0	1	6.0	0176	0677
LUA	19	24.55	155	04.25	622	.2	1	-.08	5.0	0.0	1	0.6	1276	0977
MLO	19	29.80	155	23.30	2010	.2	1	.20	5.0	0.0	1	10.0	0176	0577
MLX	19	27.60	155	20.70	1475	.2	1	.23	5.0	0.0	1	2.1	0475	0
MOK	19	29.28	155	35.98	4104	.2	1	.32	5.0	0.0	1	5.4	1076	0977
MPR	19	22.07	155	09.85	881	.2	1	-.00	5.0	0.0	1	3.1	0177	0977
MTV	19	30.25	155	03.75	409	.2	1	.15	5.0	0.0	1	7.8	1276	1277
NAG	19	42.12	155	01.72	18	.2	1	.71	5.0	0.0	1	10.2	0376	0
NPT	19	24.90	155	17.00	1115	.2	1	-.13	5.0	0.0	1	4.4	0976	1277
OTL	19	23.38	155	16.94	1038	.2	1	-.02	0.4	0.0	1	4.9	0476	0
PAU	19	22.62	155	13.10	994	.2	1	-.04	5.0	0.0	1	3.8	1274	0677
PHO	19	28.90	154	53.40	215	.2	1	.08	5.0	0.0	1	1.9	0176	0377
PLA	19	32.00	155	27.67	2992	.2	1	-.08	5.0	0.0	1	18.0	0677	0
POL	19	17.02	155	13.47	169	.2	1	.15	5.0	0.0	1	4.8	0176	0377
PPL	19	09.50	155	27.87	35	.2	1	.45	0.4	0.0	1	2.2	0174	1077
RIM	19	23.90	155	16.60	1128	.2	1	-.04	5.0	0.0	1	7.3	0675	0
SPT	18	58.91	155	39.92	244	.2	1	-.07	5.0	0.0	1	3.6	0775	0
SWR	19	27.26	155	36.30	4048	.2	1	.18	5.0	0.0	1	2.4	1075	0677
TAN	19	27.79	154	58.51	351	.2	1	-.04	5.0	0.0	1	8.0	1275	0477
USE	19	25.40	155	17.60	1240	.5	1	-.04	0.0	5.0	2	1.0	0958	0
USZ	19	25.40	155	17.60	1240	.5	1	-.04	0.0	5.0	2	1.0	0958	0
UWE	19	25.40	155	17.60	1240	.2	1	-.04	0.0	0.0	1	0.7	0958	0
WHA	19	19.90	155	02.92	29	.2	1	.07	5.0	0.0	1	2.3	1076	0
WIL	19	28.15	155	35.02	4037	.2	1	.39	5.0	0.0	1	5.1	1276	0577
WLG	19	25.49	155	15.69	1067	.2	1	-.04	5.0	0.0	1	2.2	0974	0677
AINE	19	22.50	155	27.62	1524	.2	1	.30	5.0	5.0	1	1.0	1175	0
AINN	19	22.50	155	27.62	1524	.2	1	.30	5.0	5.0	1	1.0	1175	0
CPKH	19	23.70	155	19.70	1038	.2	1	-.09	5.0	5.0	1	1.0	1275	0
HSSE	19	36.31	155	29.13	2445	.2	1	.37	5.0	5.0	1	1.0	1075	0
HSSN	19	36.31	155	29.13	2445	.2	1	.37	5.0	5.0	1	1.0	1075	0
KIIE	19	30.56	155	45.90	1841	.2	1	.32	5.0	5.0	1	1.0	1175	0
KIIN	19	30.56	155	45.90	1841	.2	1	.32	5.0	5.0	1	1.0	1175	0
MLOH	19	29.80	155	23.30	2010	.2	1	.20	5.0	5.0	1	1.0	0975	0
MLXH	19	27.60	155	20.70	1475	.2	1	.23	5.0	5.0	1	1.0	1175	0
OTLH	19	23.38	155	16.94	1038	.2	1	-.02	5.0	5.0	1	1.0	0975	0
PAUH	19	22.62	155	13.10	994	.2	1	-.04	5.0	5.0	1	1.0	0175	0
RIMH	19	23.90	155	16.60	1128	.2	1	-.04	5.0	5.0	1	1.0	0575	0

PRINTED OUTPUT

PROGRAM HYPINV (VERSION 1- JUN 78) RUN ON 6/30/78 AT 11:52:45

STATIONS

CENTER 19. 25.40 155. 17.60 DLYAZ= 999.00 DLYWD= .00

I	NAME	---LAT----	----LON----	PDLY1	SDLY1	PDLY2	SDLY2	FMC	XMC	WT	MDL	CAL	PER	TYP			
1	AHU	19. 22.40	155. 15.90	.07	.12	.00	.00	.0	.4	1	1	4.3	.2	1	1070	1076	
2	AIN	19. 22.50	155. 27.62	.30	.53	.00	.00	.0	5.0	1	1	8.5	.2	1	1524	1074	12
3	CAC	19. 29.29	155. 55.09	.17	.30	.00	.00	.0	5.0	1	1	5.4	.2	1	323	0176	12
4	CPK	19. 23.70	155. 19.70	-.09	-.16	.00	.00	.0	5.0	1	1	4.0	.2	1	1038	0176	06
5	DAN	19. 21.42	155. 40.04	-.10	-.18	.00	.00	.0	5.0	1	1	7.0	.2	1	3003	0976	
6	DES	19. 20.20	155. 23.30	-.12	-.21	.00	.00	.0	5.0	1	1	4.2	.2	1	815	0476	
7	ESR	19. 24.68	155. 14.33	.00	.00	.00	.00	.0	5.0	1	1	2.0	.2	1	1177	1076	05
8	HAE	20. 46.00	156. 15.00	.00	.00	.00	.00	5.0	.2	1	1	1.0	.5	0	2090	0958	
9	HAL	20. 46.00	156. 15.00	.00	.00	.00	.00	5.0	5.0	1	1	.7	.5	1	2090	0958	
10	HAN	20. 46.00	156. 15.00	.00	.00	.00	.00	5.0	.2	1	1	1.0	.5	0	2090	0958	
11	HIE	19. 43.20	155. 5.30	.71	1.24	.00	.00	5.0	.0	1	1	1.0	.5	0	20	0958	
12	HIH	19. 43.20	155. 5.30	.71	1.24	.00	.00	5.0	.0	1	1	1.0	.5	0	20	0958	
13	HIL	19. 43.20	155. 5.30	.71	1.24	.00	.00	5.0	.5	1	1	1.0	.2	1	20	0958	
14	HIN	19. 43.20	155. 5.30	.71	1.24	.00	.00	5.0	.0	1	1	1.0	.5	0	20	0958	
15	HLP	19. 17.96	155. 18.63	.19	.33	.00	.00	.0	5.0	1	1	4.0	.2	1	707	0276	
16	HMO	21. 25.40	158. .90	.00	.00	.00	.00	5.0	5.0	1	1	.0	.2	2	76	1162	
17	HPU	19. 46.85	155. 27.50	.48	.84	.00	.00	.0	5.0	1	1	4.7	.2	1	3396	1176	10
18	HSS	19. 36.31	155. 29.13	.37	.65	.00	.00	.0	5.0	1	1	6.2	.2	1	2445	0775	03
19	HUA	19. 41.25	155. 50.32	.84	1.47	.00	.00	.0	5.0	1	1	2.6	.2	1	2189	0276	06
20	HUL	19. 25.13	154. 58.72	.00	.00	.00	.00	.0	5.0	1	1	3.0	.2	1	369	0477	
21	KAA	19. 15.98	155. 52.28	.05	.09	.00	.00	.0	.1	1	1	5.2	.2	1	524	0177	12
22	KAE	19. 17.35	155. 7.95	.16	.28	.00	.00	.0	5.0	1	1	1.3	.2	1	37	1176	
23	KGN	19. 21.52	154. 59.67	.07	.12	.00	.00	.0	5.0	1	1	.0	.2	1	30	0977	09
24	KHU	19. 14.90	155. 37.10	.20	.35	.00	.00	.0	5.0	1	1	3.7	.2	1	1939	0375	
25	KII	19. 30.56	155. 45.90	.32	.56	.00	.00	.0	5.0	1	1	7.1	.2	1	1841	1275	03
26	KIP	21. 25.40	158. .90	.00	.00	.00	.00	5.0	5.0	1	1	.0	.5	2	76	0066	
27	KKU	19. 53.39	155. 20.58	.85	1.49	.00	.00	.0	5.0	1	1	2.3	.2	1	1863	0174	08
28	KLU	19. 27.48	154. 55.26	.00	.00	.00	.00	.0	5.0	1	1	.0	.2	1	271	0977	
29	KOH	20. 7.69	155. 46.77	.14	.24	.00	.00	.0	5.0	1	1	2.4	.2	1	1166	0176	12
30	KPN	19. 20.10	155. 17.40	.06	.11	.00	.00	.0	5.0	1	1	6.4	.2	1	924	0976	
31	KPR	19. 16.40	155. 26.70	.02	.04	.00	.00	.0	5.0	1	1	6.0	.2	1	610	0176	06
32	LUA	19. 24.55	155. 4.25	-.08	-.14	.00	.00	.0	5.0	1	1	.6	.2	1	622	1276	09
33	MLO	19. 29.80	155. 23.30	.20	.35	.00	.00	.0	5.0	1	1	10.0	.2	1	2010	0176	05
34	MLX	19. 27.60	155. 20.70	.23	.40	.00	.00	.0	5.0	1	1	2.1	.2	1	1475	0475	
35	MOK	19. 29.28	155. 35.98	.32	.56	.00	.00	.0	5.0	1	1	5.4	.2	1	4104	1076	09
36	MPR	19. 22.07	155. 9.85	.00	.00	.00	.00	.0	5.0	1	1	3.1	.2	1	881	0177	09
37	MTV	19. 30.25	155. 3.75	.15	.26	.00	.00	.0	5.0	1	1	7.8	.2	1	409	1276	12
38	NAG	19. 42.12	155. 1.72	.71	1.24	.00	.00	.0	5.0	1	1	10.2	.2	1	18	0376	
39	NPT	19. 24.90	155. 17.00	-.13	-.23	.00	.00	.0	5.0	1	1	4.4	.2	1	1115	0976	12
40	OTL	19. 23.38	155. 16.94	-.02	-.04	.00	.00	.0	.4	1	1	4.9	.2	1	1038	0476	
41	PAU	19. 22.62	155. 13.10	-.04	-.07	.00	.00	.0	5.0	1	1	3.8	.2	1	994	1274	06
42	PHO	19. 28.90	154. 53.40	.08	.14	.00	.00	.0	5.0	1	1	1.9	.2	1	215	0176	03
43	PLA	19. 32.00	155. 27.67	-.08	-.14	.00	.00	.0	5.0	1	1	18.0	.2	1	2992	0677	
44	POL	19. 17.02	155. 13.47	.15	.26	.00	.00	.0	5.0	1	1	4.8	.2	1	169	0176	03
45	PPL	19. 9.50	155. 27.87	.45	.79	.00	.00	.0	.4	1	1	2.2	.2	1	35	0174	10
46	RIM	19. 23.90	155. 16.60	-.04	-.07	.00	.00	.0	5.0	1	1	7.3	.2	1	1128	0675	
47	SPT	18. 58.91	155. 39.92	-.07	-.12	.00	.00	.0	5.0	1	1	3.6	.2	1	244	0775	
48	SWR	19. 27.26	155. 36.30	.18	.32	.00	.00	.0	5.0	1	1	2.4	.2	1	4048	1075	06
49	TAN	19. 27.79	154. 58.51	-.04	-.07	.00	.00	.0	5.0	1	1	8.0	.2	1	351	1275	04
50	USE	19. 25.40	155. 17.60	-.04	-.07	.00	.00	5.0	.0	1	1	1.0	.5	2	1240	0958	
51	USZ	19. 25.40	155. 17.60	-.04	-.07	.00	.00	5.0	.0	1	1	1.0	.5	2	1240	0958	
52	UWE	19. 25.40	155. 17.60	-.04	-.07	.00	.00	.0	.0	1	1	.7	.2	1	1240	0958	
53	WHA	19. 19.90	155. 2.92	.07	.12	.00	.00	.0	5.0	1	1	2.3	.2	1	29	1076	
54	WIL	19. 28.15	155. 35.02	.39	.68	.00	.00	.0	5.0	1	1	5.1	.2	1	4037	1276	05
55	WLG	19. 25.49	155. 15.69	-.04	-.07	.00	.00	.0	5.0	1	1	2.2	.2	1	1067	0974	06
56	AINE	19. 22.50	155. 27.62	.30	.53	.00	.00	5.0	5.0	1	1	1.0	.2	1	1524	1175	
57	AINN	19. 22.50	155. 27.62	.30	.53	.00	.00	5.0	5.0	1	1	1.0	.2	1	1524	1175	

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58 CPKH 19. 23.70   155. 19.70   -.09  -.16   .00   .00 5.0 5.0 1  1   1.0  .2  1 1038       1275      0
59 HSSE 19. 36.31   155. 29.13    .37   .65   .00   .00 5.0 5.0 1  1   1.0  .2  1 2445       1075      0
60 HSSN 19. 36.31   155. 29.13    .37   .65   .00   .00 5.0 5.0 1  1   1.0  .2  1 2445       1075      0
61 KIIE 19. 30.56   155. 45.90    .32   .56   .00   .00 5.0 5.0 1  1   1.0  .2  1 1841       1175      0
62 KIIN 19. 30.56   155. 45.90    .32   .56   .00   .00 5.0 5.0 1  1   1.0  .2  1 1841       1175      0
63 MLOH 19. 29.80   155. 23.30    .20   .35   .00   .00 5.0 5.0 1  1   1.0  .2  1 2010       0975      0
64 MLXH 19. 27.60   155. 20.70    .23   .40   .00   .00 5.0 5.0 1  1   1.0  .2  1 1475       1175      0
65 OTLH 19. 23.38   155. 16.94   -.02  -.04   .00   .00 5.0 5.0 1  1   1.0  .2  1 1038       0975      0
66 PAUH 19. 22.62   155. 13.10   -.04  -.07   .00   .00 5.0 5.0 1  1   1.0  .2  1  994       0175      0
67 RIMH 19. 23.90   155. 16.60   -.04  -.07   .00   .00 5.0 5.0 1  1   1.0  .2  1 1128       0575      0

CRUST
MODEL:          1                           2                          3
LAYER VEL    DEPTH   THICK       VEL   DEPTH   THICK       VEL   DEPTH   THICK
  1  1.400    .000   1.000       .000   .000    .000       .000   .000    .000
  2  2.200   1.000   1.000       .000   .000    .000       .000   .000    .000
  3  3.600   2.000   1.000       .000   .000    .000       .000   .000    .000
  4  5.000   3.000   1.000       .000   .000    .000       .000   .000    .000
  5  6.000   4.000   9.500       .000   .000    .000       .000   .000    .000
  6  8.250  13.500999.000        .000   .000    .000       .000   .000    .000
  7   .000    .000    .000       .000   .000    .000       .000   .000    .000
  8   .000    .000    .000       .000   .000    .000       .000   .000    .000
  9   .000    .000    .000       .000   .000    .000       .000   .000    .000
 10   .000    .000    .000       .000   .000    .000       .000   .000    .000
 11   .000    .000    .000       .000   .000    .000       .000   .000    .000
 12   .000    .000    .000       .000   .000    .000       .000   .000    .000

TEST PARAMETERS
   -ITERATION AND CONVERGENCE-     -WEIGHTING, ERRORS, TRIAL DEPTH-       -DURATION MAG CONSTANTS-
      20=ITRLIM       .9000=DAMP     50.0000=DISCUT     .1600=RMSCUT    -5.0000=FMA1      -.7050=FMA2
   .0400=DQUIT        .0010=DRQT      1.0000=DISW1     1.5000=RMSW1     3.8900=FMB1      2.0260=FMB2
  7.0000=DXFIX        .0120=EIGTOL    3.0000=DISW2     3.0000=RMSW2      .0000=FMZ1       .0000=FMZ2
 12.0000=DZMAX        .0200=RBACK     1.0000=SWT        .2500=RDERR      .0000=FMD1       .0000=FMD2
  .5000=DZAIR         .6000=BACFAC    7.0000=ZTR       1.0000=ERCOF    210.0000=FMBRK    1.7500=POS
```

5 MAY 77, 5:12 EVENT NO. 1

I	ORIGIN	LAT N	LON W	Z	NWR	RMS	DT	DLAT	DLON	DZ	RR	NF
								ADJUSTMENTS (KM)				
1	19.45	19 17.66	155 8.26	7.00	20	1.24	-.531	6.404	2.491	.000	6.871	3
FOCAL DEPTH FREED												
2	18.92	19 21.11	155 9.68	7.00	19	.29	-.237	-.658	-.454	-.209	.827	4
3	18.68	19 20.76	155 9.42	6.79	18	.16	-.024	-.661	-.271	.387	.812	4
4	18.66	19 20.40	155 9.27	7.18	18	.14	-.004	-.445	-.245	.456	.683	4
5	18.65	19 20.16	155 9.13	7.63	18	.14	-.003	-.054	-.033	.036	.072	4
6	18.65	19 20.13	155 9.11	7.67	18	.14	-.000	-.036	-.037	.040	.065	4

EIGENVALUES
(4.311 .479 .397 .191)

EIGENVECTORS OF ADJUSTMENT	COVARIANCE				ERRORS	#	#ERROR ELLIPSE SERR	AZ	DIP
OT (-.998-.062-.027 .019)(	.007	.035	.034	-.004)	.083	#	1.50	141	36
LAT(.027 .097-.767 .633)(	.035	1.206	.557	-.633)	1.098	#	.72	22	33
LON(.050-.805 .313 .501)(	.034	.557	.843	-.585)	.918	#	.60	263	35
Z (.040-.582-.559-.590)(	-.004	-.633	-.585	1.060)	1.030	#			

YR MO DA	ORIGIN	LAT N	LON W	DEPTH	RMS	ERH	ERZ	GAP	XMAG	FMAG
77- 5- 5	512 18.65	19 20.13	155 9.11	7.67	.14	1.21	.88	66	3.2	3.6

RMSWT	DMIN	ITR	NFM	NWR	NWS	REMK
.16	5.5	6	18	18	0	UER

STA	DIST	AZM	AN	P/S	W	SEC+CCOR	(TOBS	-TCAL	-DLY	=RES)	WT	XMG	FMG	R	INFO
KAE	5.5	158	133	IPU		28.95-7.50	2.80	2.63	.16	.01	1.08				.436
POL	9.5	234	116	IPD		29.70-7.50	3.55	3.19	.15	.21	1.08				.314
WHA	10.8	92	113	IPU		29.55-7.50	3.40	3.38	.07	-.05	1.08				.423
LUA	11.8	45	111	IPD		29.70-7.50	3.55	3.53	-.08	.10	1.08				.310
USE	17.8	304	103		4	.00-7.50	-26.15	4.48	-.04	-30.59	.00	3.1			.000
USZ	17.8	304	103		4	.00-7.50	-26.15	4.48	-.04	-30.59	.00	3.3			.000
MTV	21.0	26	101	IPD		31.20-7.50	5.05	5.00	.15	-.10	1.08				.343
KPR	31.5	258	97	IPD		32.85-7.50	6.70	6.74	.02	-.06	1.08				.268
AIN	32.6	278	97	IPD		33.20-7.50	7.05	6.93	.30	-.18	1.08		3.6		.373
NAG	42.8	17	46	IPD		35.20-7.50	9.05	8.48	.71	-.14	1.08				.234
HIL	43.2	8	46	EPD	4	32.40-5.00	8.75	8.54	.71	-.50	.00				.000
HIE	43.2	8	46	IS		39.20-5.00	15.55	14.95	1.24	-.64	.00	3.0			.000
HIN	43.2	8	46	IS		39.00-5.00	15.35	14.95	1.24	-.84	.00	3.3			.000
HSS	46.0	311	46	IPD		35.20-7.50	9.05	8.88	.37	-.20	1.08		3.6		.126
KHU	49.9	259	46	IPU		35.65-7.50	9.50	9.35	.20	-.05	1.08				.172
DAN	54.1	273	46	IPU		36.05-7.50	9.90	9.86	-.10	.14	1.07				.128
HPU	59.0	328	46	IPD		37.20-7.50	11.05	10.45	.48	.12	1.05				.139
KKU	64.8	342	46	IPU		38.40-7.50	12.25	11.15	.85	.25	1.01				.143
SPT	66.8	234	46	EPD		37.35-7.50	11.20	11.39	-.07	-.12	1.00				.291
KII	67.1	287	46	EPU		37.95-7.50	11.80	11.44	.32	.04	1.00				.099
KAA	75.9	265	46	EPD		38.60-7.50	12.45	12.50	.05	-.10	.91				.106
HUA	82.0	299	46	IPD		40.45-7.50	14.30	13.23	.84	.23	.83				.069
KOH	109.9	324	46	EPD		43.05-7.50	16.90	16.62	.14	.14	.37				.016

5 MAY 77, 12:43 EVENT NO. 2

I	ORIGIN	LAT N	LON W	Z	NWR	RMS	DT	DLAT	DLON	DZ	RR	NF
								ADJUSTMENTS (KM)				
1	42.15	19 16.72	155 27.00	7.00	20	.95	-.477	-3.042	-5.597	.000	6.370	3
FOCAL DEPTH FREED												
2	41.67	19 15.08	155 23.80	7.00	19	.25	-.026	.591	-.408	-1.541	1.700	4
3	41.65	19 15.39	155 23.56	5.46	19	.18	-.016	-.024	-.082	-.529	.536	4
4	41.63	19 15.38	155 23.52	4.93	19	.18	-.013	-.075	-.021	-.180	.196	4
5	41.62	19 15.34	155 23.51	4.75	19	.19	-.003	-.004	-.039	-.086	.095	4
6	41.61	19 15.34	155 23.48	4.66	19	.19	-.003	-.053	-.018	-.102	.116	4
7	41.61	19 15.31	155 23.47	4.56	19	.19	-.003	-.016	-.027	-.020	.037	4

EIGENVALUES
(4.377 .545 .304 .115)

EIGENVECTORS OF ADJUSTMENT	COVARIANCE	ERRORS	#	ERROR ELLIPSE SERR	AZ	DIP
OT (-.997 .028-.076 .010)	(.012 .088 .003 .063)	.110	#	2.72	20	83
LAT(.080 .175-.975 .110)	(.088 1.110 .099 .703)	1.054	#	1.03	170	5
LON(-.014-.983-.181-.039)	(.003 .099 .366 -.287)	.605	#	.58	260	3
Z (.000-.058 .102 .993)	(.063 .703 -.287 7.332)	2.708	#			

YR MO DA	ORIGIN	LAT N	LON W	DEPTH	RMS	ERH	ERZ	GAP	XMAG	FMAG
77- 5- 5	1243 41.61	19 15.31	155 23.47	4.56	.19	1.02	2.71	142	2.2	2.3

RMSWT	DMIN	ITR	NFM	NWR	NWS	REMK
.20	6.0	7	19	19	0	LSW

STA	DIST	AZM	AN	P/S	W	SEC+CCOR	(TOBS	-TCAL	-DLY	=RES)	WT	XMG	FMG	R	INFO
KPR	6.0	291	99	IPU		51.65-7.50	2.54	2.46	.02	.06	1.01				.261
DES	9.0	1	95	IPU		52.20-7.50	3.09	2.96	-.12	.25	1.01		2.3		.142
HLP	9.8	59	94	IPD		52.20-7.50	3.09	3.09	.19	-.19	1.01				.118
PPL	13.2	216	93	IPU		52.50-7.50	3.39	3.65	.45	-.71	.00				.000
KPN	13.9	49	92	IPD		52.95-7.50	3.84	3.76	.06	.02	1.01				.101
AIN	15.2	332	92	IPU		53.65-7.50	4.54	3.98	.30	.26	1.01		2.4		.152
CPK	16.9	22	92	IPU		53.40-7.50	4.29	4.26	-.09	.12	1.01				.113
POL	17.8	79	92	IPD		53.30-7.50	4.19	4.41	.15	-.37	.85				.128
AHU	18.6	45	92	IPD		53.55-7.50	4.44	4.56	.07	-.19	1.01		2.3		.099
USE	21.3	28	91		4	.00-7.50	-49.11	5.00	-.04	-54.07	.00	2.2			.000
USZ	21.3	28	91		4	.00-7.50	-49.11	5.00	-.04	-54.07	.00	2.2			.000
PAU	22.6	53	91	IPD		54.05-7.50	4.94	5.23	-.04	-.25	1.01				.105
KHU	23.8	269	91	IPU		54.65-7.50	5.54	5.42	.20	-.08	1.01				.239
MLO	26.8	0	91	IPU		55.35-7.50	6.24	5.92	.20	.12	1.01				.140
KAE	27.4	82	91	IPU		55.50-7.50	6.39	6.02	.16	.21	1.01				.197
DAN	31.1	292	90	IPU		55.65-7.50	6.54	6.64	-.10	-.00	1.01				.160
WIL	31.2	320	90	EPU		55.80-7.50	6.69	6.65	.39	-.35	.92				.121
WHA	36.9	76	90	EPU		57.00-7.50	7.89	7.60	.07	.22	1.01				.167
LUA	37.7	62	90	IPD		56.90-7.50	7.79	7.73	-.08	.14	1.01				.122
HSS	40.1	346	90	EPD		57.40-7.50	8.29	8.14	.37	-.22	1.01				.151
SPT	41.8	224	90	EPU		57.50-7.50	8.39	8.42	-.07	.04	1.01				.529
KAA	50.4	272	46	IPU		58.95-7.50	9.84	9.76	.05	.03	1.01				.945
HUA	67.1	316	46	IPD	5	62.80-7.50	13.69	11.79	.84	1.06	.00				.000

HYP

```
 KAEIPU0 77 5 5 512 2895    1107    0    0    0  0  0   16    0   55133 -750      0158 0 0 436    0
 POLIPD0 77 5 5 512 2970   21107    0    0    0  0  0   15    0   95116 -750      0234 0 0 314    0
 WHAIPU0 77 5 5 512 2955   -5107    0    0    0  0  0    7    0 108113 -750      0 92 0 0 423    0
 LUAIPD0 77 5 5 512 2970   10107    0    0    0  0  0   -8    0 118111 -750      0 45 0 0 310    0
 USE   4 77 5 5 512       0-999  0    0    0    0 19  0   -4    0 177103 -750      0304 031    0    0
 USZ   4 77 5 5 512       0-999  0    0    0    0 29  0   -4    0 177103 -750      0304 033    0    0
 MTVIPD0 77 5 5 512 3120  -10107    0    0    0  0  0   15    0 209101 -750      0 26 0 0 343    0
 KPRIPD0 77 5 5 512 3285   -6107    0    0    0  0  0    2    0 315 97 -750      0258 0 0 268    0
 AINIPD0 77 5 5 512 3320  -18107    0    0    0  0  0   30    0 326 97 -750   16327836 0 373    0
 NAGIPD0 77 5 5 512 3520  -14107    0    0    0  0  0   71    0 427 46 -750      0 17 0 0 234    0
 HILEPD4 77 5 5 512 3240  -50   0    0    0    0  0  0   71    0 432 46 -500      0  8 0 0    0    0
 HIE   4 77 5 5 512       0    0    0 3920IS 0 -64  7  0    0 124 432 46 -500      0  8 030    0    0
 HIN   4 77 5 5 512       0    0    0 3900IS 0 -84 14  0    0 124 432 46 -500      0  8 033    0    0
 HSSIPD0 77 5 5 512 3520  -20107    0    0    0  0  0   37    0 460 46 -750   16531136 0 126    0
 KHUIPU0 77 5 5 512 3565   -5107    0    0    0  0  0   20    0 499 46 -750      0259 0 0 172    0
 DANIPU0 77 5 5 512 3605   14107    0    0    0  0  0  -10    0 541 46 -750      0273 0 0 128    0
 HPUIPD0 77 5 5 512 3720   12105    0    0    0  0  0   48    0 590 46 -750      0328 0 0 139    0
 KKUIPU0 77 5 5 512 3840   25101    0    0    0  0  0   85    0 648 46 -750      0342 0 0 143    0
 SPTEPD0 77 5 5 512 3735  -12100    0    0    0  0  0   -7    0 667 46 -750      0234 0 0 291    0
 KIIEPU0 77 5 5 512 3795    4 99    0    0    0  0  0   32    0 671 46 -750      0287 0 0  99    0
 KAAEPD0 77 5 5 512 3860  -10 90    0    0    0  0  0    5    0 759 46 -750      0265 0 0 106    0
 HUAIPD0 77 5 5 512 4045   23 82    0    0    0  0  0   84    0 819 46 -750      0299 0 0  69    0
 KOHEPD0 77 5 5 512 4305   14 37    0    0    0  0  0   14    01099 46 -750      0324 0 0  16    0
77 5 5 512186519 2013155   911   76732 18 66   6   1414136 149 2233   7136UER   59    0 121   8818
 KPRIPU0 77 5 51243 5165    6101    0    0    0  0  0    2    0  60 99 -750      0291 0 0 261    0
 DESIPU0 77 5 51243 5220   25101    0    0    0  0  0  -12    0  90 95 -750     78  123 0 142    0
 HLPIPD0 77 5 51243 5220  -19101    0    0    0  0  0   19    0  98 94 -750      0 59 0 0 118    0
 PPLIPU0 77 5 51243 5250  -71  0    0    0    0  0  0   45    0 132 93 -750      0216 0 0    0    0
 KPNIPD0 77 5 51243 5295    2101    0    0    0  0  0    6    0 138 92 -750      0 49 0 0 101    0
 AINIPU0 77 5 51243 5365   26101    0    0    0  0  0   30    0 152 92 -750    8033224 0 152    0
 CPKIPU0 77 5 51243 5340   12101    0    0    0  0  0   -9    0 169 92 -750      0 22 0 0 113    0
 POLIPD0 77 5 51243 5330  -37 84    0    0    0  0  0   15    0 177 92 -750      0 79 0 0 128    0
 AHUIPD0 77 5 51243 5355  -19101    0    0    0  0  0    7    0 186 92 -750     76 4523 0  99    0
 USE   4 77 5 51243       0-999  0    0    0    0  2  0   -4    0 213 91 -750      0 28 022    0    0
 USZ   4 77 5 51243       0-999  0    0    0    0  2  0   -4    0 213 91 -750      0 28 022    0    0
 PAUIPD0 77 5 51243 5405  -25101    0    0    0  0  0   -4    0 226 91 -750      0 53 0 0 105    0
 KHUIPU0 77 5 51243 5465   -8101    0    0    0  0  0   20    0 238 91 -750      0269 0 0 239    0
 MLOIPU0 77 5 51243 5535   12101    0    0    0  0  0   20    0 268 91 -750      0  0 0 0 140    0
 KAEIPU0 77 5 51243 5550   21101    0    0    0  0  0   16    0 274 91 -750      0 82 0 0 197    0
 DANIPU0 77 5 51243 5565    0101    0    0    0  0  0  -10    0 311 90 -750      0292 0 0 160    0
 WILEPU0 77 5 51243 5580  -35 91    0    0    0  0  0   39    0 312 90 -750      0320 0 0 121    0
 WHAEPU0 77 5 51243 5700   22101    0    0    0  0  0    7    0 369 90 -750      0 76 0 0 167    0
 LUAIPD0 77 5 51243 5690   14101    0    0    0  0  0   -8    0 377 90 -750      0 62 0 0 122    0
 HSSEPD0 77 5 51243 5740  -22101    0    0    0  0  0   37    0 401 90 -750      0346 0 0 151    0
 SPTEPU0 77 5 51243 5750    4101    0    0    0  0  0   -7    0 418 90 -750      0224 0 0 529    0
 KAAIPU0 77 5 51243 5895    3101    0    0    0  0  0    5    0 504 46 -750      0272 0 0 945    0
 HUAIPD5 77 5 51243 6280 106   0    0    0    0  0  0   84    0 671 46 -750      0316 0 0    0    0
77 5 51243416119 1531155 2347   45622 19142   6   19 2083 272170 5 10223LSW   57    0 102 27119
```

SUMM

```
77 5 5  512 18.65 19 20.13 155  9.11    7.67    3.60 18  66  5.5  .14  1.2   .9
77 5 5 1243 41.61 19 15.31 155 23.47    4.56    2.33 19 142  6.0  .19  1.0  2.7
```

SUMM

```
77 5 5 512186519 2013155  911  76732 18 66  6  1414136 149 2233  7136UER  59   0
77 5 51243416119 1531155 2347  45622 19142  6  19 2083 272170 5 10223LSW  57   0
```

SUMM

```
77 5 5 512186519 2013155  911  76732 18 66  6  1414136 149 2233  7136UER  59   0 121  8818
77 5 51243416119 1531155 2347  45622 19142  6  19 2083 272170 5 10223LSW  57   0 102 27119
```

APPENDIX 4: Sample input and output of TTGEN.

TTMOD	Input file.
PRINTED OUTPUT	First page, and sample listing of one depth.
TTTAB	Sample travel time table. Used for communication between TTGEN and HYPOINVERSE.

```
$LPT     TTTAB    .13    000
  .08  100    .4    90
   1.   18    4.     9
   1.   28    4.    13
  80.    6.
MODEL HG32                   0
  1.9  0.0
  3.0  1.4
  6.2  3.5
  7.2 13.7
  8.3 15.5
```

TTMOD

```
  MODEL HG32

VELOCITY MODEL WITH  5 LAYERS:

 L  VEL   DEPTH THICK   GRAD
 1  1.90    .00  1.40   .786
 2  3.00   1.40  2.10  1.524
 3  6.20   3.50 10.20   .098
 4  7.20  13.70  1.80   .611
 5  8.30  15.50 HALFSPACE

ONE OVER REDUCING VELOCITY=   .1300

 28 OUT OF A POSSIBLE  28 DEPTH POINTS USED
CALCULATE TRAVEL TIMES AT  19 DEPTH POINTS BETWEEN   .00 AND 18.00 INCLUSIVE
CALCULATE TRAVEL TIMES AT   9 DEPTH POINTS BETWEEN 22.00 AND 54.00 INCLUSIVE

 42 OUT OF A POSSIBLE  42 DISTANCE POINTS USED
CALCULATE TRAVEL TIMES AT  29 DISTANCE POINTS BETWEEN    .00 AND  28.00 INCLUSIVE
CALCULATE TRAVEL TIMES AT  13 DISTANCE POINTS BETWEEN  32.00 AND  80.00 INCLUSIVE
```

PRINTED OUTPUT

DEPTH= 2.00 ... HYPO IN LAYER 2 AT VELOCITY 3.91

J	Q	EM.ANG	P	DIST	TTIME	REDUCED	L.BOT	Z.BOT	V.BOT	DDIF	BR	AMP	AMP*R**2	REMK
1	.00	.00	.0000	.00	.76	.76								
2	.08	3.67	.0163	.09	.76	.74	5	15.50	61.22	.09	1	.50502	2.02418	
3	.16	7.32	.0326	.18	.76	.74	5	15.50	30.71	.09	1	.50174	2.02324	
4	.24	10.97	.0486	.27	.76	.73	5	15.50	20.57	.09	1	.49639	2.02180	
5	.32	14.59	.0643	.36	.77	.72	5	15.50	15.54	.09	1	.48847	2.01740	
6	.40	18.18	.0797	.45	.77	.72	5	15.50	12.55	.09	1	.47864	2.01201	
7	.48	21.74	.0946	.54	.78	.71	5	15.50	10.57	.09	1	.46687	2.00464	
8	.56	25.25	.1090	.63	.79	.71	5	15.50	9.18	.09	1	.45353	1.99593	
9	.64	28.72	.1228	.72	.80	.71	4	15.25	8.15	.09	1	.43888	1.98594	
10	.72	32.13	.1359	.82	.81	.71	4	13.96	7.36	.09	1	.42325	1.97506	
11	.80	35.49	.1483	.91	.83	.71	3	9.03	6.74	.09	1	.40688	1.96324	
12	.88	38.78	.1600	1.00	.84	.71	3	4.00	6.25	.09	1	.39007	1.95086	
13	.96	42.01	.1710	1.09	.86	.71	2	3.27	5.85	.09	1	.37312	1.93832	
14	1.04	45.17	.1812	1.19	.87	.72	2	3.05	5.52	.09	1	.35614	1.92533	
15	1.12	48.26	.1906	1.28	.89	.72	2	2.87	5.25	.09	1	.33943	1.91259	
16	1.20	51.28	.1993	1.37	.91	.73	2	2.72	5.02	.09	1	.32309	1.89967	
17	1.28	54.22	.2073	1.46	.93	.74	2	2.60	4.82	.09	1	.30725	1.88746	
18	1.36	57.09	.2145	1.56	.95	.74	2	2.49	4.66	.09	1	.29203	1.87550	
19	1.44	59.88	.2210	1.65	.97	.75	2	2.40	4.53	.09	1	.27744	1.86375	
20	1.52	62.60	.2268	1.74	.99	.76	2	2.32	4.41	.09	1	.26354	1.85230	
21	1.60	65.24	.2320	1.83	1.01	.77	2	2.26	4.31	.09	1	.25034	1.84109	
22	1.68	67.80	.2365	1.92	1.03	.78	2	2.21	4.23	.09	1	.23783	1.82998	
23	1.76	70.29	.2405	2.01	1.05	.79	2	2.16	4.16	.09	1	.22597	1.81868	
24	1.84	72.71	.2439	2.10	1.07	.80	2	2.12	4.10	.09	1	.21475	1.80712	
25	1.92	75.05	.2468	2.19	1.09	.81	2	2.09	4.05	.09	1	.20409	1.79489	
26	2.00	77.32	.2492	2.28	1.12	.82	2	2.06	4.01	.09	1	.19398	1.78177	
27	2.08	79.52	.2512	2.36	1.14	.83	2	2.04	3.98	.09	1	.18436	1.76758	
28	2.16	81.65	.2528	2.45	1.16	.84	2	2.03	3.96	.09	1	.17519	1.75204	
29	2.24	83.72	.2539	2.53	1.18	.85	2	2.02	3.94	.08	1	.16643	1.73499	
30	2.32	85.72	.2548	2.62	1.20	.86	2	2.01	3.93	.08	1	.15804	1.71611	
31	2.40	87.66	.2553	2.70	1.22	.87	2	2.00	3.92	.08	1	.15002	1.69556	
32	2.48	89.54	.2555	2.78	1.24	.88	2	2.00	3.91	.08	1	.14235	1.67351	
33	2.56	91.36	.2554	2.87	1.27	.89	2	2.00	3.92	.08	1	.13486	1.64793	
34	2.64	93.12	.2551	2.95	1.29	.90	2	2.00	3.92	.08	1	.12786	1.62293	
35	2.72	94.83	.2546	3.03	1.31	.91	2	2.01	3.93	.08	1	.12106	1.59520	
36	2.80	96.48	.2538	3.11	1.33	.92	2	2.02	3.94	.08	1	.11456	1.56611	
37	2.88	98.08	.2529	3.19	1.35	.93	2	2.03	3.95	.08	1	.10836	1.53600	
38	2.96	99.63	.2519	3.27	1.37	.94	2	2.04	3.97	.08	1	.10242	1.50463	
39	3.04	101.13	.2507	3.35	1.39	.95	2	2.05	3.99	.08	1	.09678	1.47259	
40	3.12	102.59	.2493	3.43	1.41	.96	2	2.06	4.01	.08	1	.09141	1.43992	
41	3.20	104.00	.2479	3.51	1.43	.97	2	2.08	4.03	.08	1	.08631	1.40691	
42	3.28	105.37	.2463	3.59	1.45	.98	2	2.10	4.06	.08	1	.08148	1.37371	
43	3.36	106.70	.2447	3.66	1.47	.99	2	2.11	4.09	.08	1	.07691	1.34045	
44	3.44	107.98	.2430	3.74	1.48	1.00	2	2.13	4.12	.08	1	.07259	1.30742	
45	3.52	109.23	.2412	3.82	1.50	1.01	2	2.15	4.15	.08	1	.06851	1.27466	
46	3.60	110.44	.2394	3.90	1.52	1.02	2	2.17	4.18	.08	1	.06466	1.24229	
47	3.68	111.62	.2375	3.98	1.54	1.02	2	2.19	4.21	.08	1	.06103	1.21036	
48	3.76	112.76	.2356	4.06	1.56	1.03	2	2.22	4.24	.08	1	.05762	1.17905	
49	3.84	113.87	.2336	4.14	1.58	1.04	2	2.24	4.28	.08	1	.05441	1.14840	
50	3.92	114.94	.2316	4.21	1.60	1.05	2	2.26	4.32	.08	1	.05139	1.11841	
51	4.00	115.99	.2296	4.29	1.62	1.06	2	2.29	4.35	.08	1	.04855	1.08915	
52	4.08	117.00	.2276	4.37	1.63	1.06	2	2.31	4.39	.08	1	.04589	1.06063	
53	4.16	117.99	.2256	4.45	1.65	1.07	2	2.34	4.43	.08	1	.04338	1.03295	
54	4.24	118.95	.2235	4.53	1.67	1.08	2	2.37	4.47	.08	1	.04103	1.00591	
55	4.32	119.88	.2215	4.61	1.69	1.09	2	2.39	4.51	.08	1	.03882	.97978	
56	4.40	120.79	.2195	4.69	1.70	1.09	2	2.42	4.56	.08	1	.03675	.95442	
57	4.48	121.67	.2174	4.77	1.72	1.10	2	2.45	4.60	.08	1	.03479	.92972	
58	4.56	122.53	.2154	4.85	1.74	1.11	2	2.48	4.64	.08	1	.03297	.90591	
59	4.64	123.37	.2134	4.92	1.75	1.11	2	2.51	4.69	.08	1	.03124	.88275	

60	4.72	124.18	.2113	5.00	1.77	1.12	2	2.54	4.73	.08	1	.02962	.86036
61	4.80	124.98	.2093	5.08	1.79	1.13	2	2.57	4.78	.08	1	.02810	.83868
62	4.88	125.75	.2073	5.16	1.80	1.13	2	2.60	4.82	.08	1	.02667	.81769
63	4.96	126.50	.2054	5.24	1.82	1.14	2	2.63	4.87	.08	1	.02533	.79735
64	5.04	127.23	.2034	5.32	1.84	1.15	2	2.66	4.92	.08	1	.02406	.77774
65	5.12	127.95	.2015	5.40	1.85	1.15	2	2.69	4.96	.08	1	.02287	.75866
66	5.20	128.65	.1995	5.48	1.87	1.16	2	2.72	5.01	.08	1	.02174	.74028
67	5.28	129.33	.1976	5.56	1.89	1.16	2	2.75	5.06	.08	1	.02068	.72243
68	5.36	129.99	.1957	5.64	1.90	1.17	2	2.78	5.11	.08	1	.01969	.70521
69	5.44	130.64	.1939	5.72	1.92	1.17	2	2.82	5.16	.08	1	.01874	.68846
70	5.52	131.27	.1920	5.80	1.93	1.18	2	2.85	5.21	.08	1	.01786	.67239
71	5.60	131.89	.1902	5.88	1.95	1.18	2	2.88	5.26	.08	1	.01702	.65664
72	5.68	132.49	.1884	5.96	1.96	1.19	2	2.91	5.31	.08	1	.01623	.64156
73	5.76	133.08	.1866	6.04	1.98	1.19	2	2.95	5.36	.08	1	.01548	.62686
74	5.84	133.65	.1849	6.12	1.99	1.20	2	2.98	5.41	.08	1	.01477	.61266
75	5.92	134.21	.1831	6.20	2.01	1.20	2	3.02	5.46	.08	1	.01410	.59889
76	6.00	134.76	.1814	6.28	2.02	1.21	2	3.05	5.51	.08	1	.01347	.58555
77	6.08	135.30	.1797	6.36	2.04	1.21	2	3.08	5.56	.08	1	.01287	.57260
78	6.16	135.82	.1780	6.44	2.05	1.21	2	3.12	5.62	.08	1	.01231	.56009
79	6.24	136.33	.1764	6.52	2.07	1.22	2	3.15	5.67	.08	1	.01177	.54792
80	6.32	136.84	.1748	6.60	2.08	1.22	2	3.19	5.72	.08	1	.01126	.53613
81	6.40	137.33	.1732	6.68	2.09	1.22	2	3.22	5.77	.08	1	.01078	.52474
82	6.48	137.81	.1716	6.77	2.11	1.23	2	3.26	5.83	.08	1	.01032	.51366
83	6.56	138.28	.1700	6.85	2.12	1.23	2	3.29	5.88	.08	1	.00988	.50285
84	6.64	138.74	.1685	6.93	2.13	1.23	2	3.33	5.94	.08	1	.00947	.49248
85	6.72	139.19	.1670	7.01	2.15	1.24	2	3.36	5.99	.08	1	.00908	.48225
86	6.80	139.63	.1655	7.09	2.16	1.24	2	3.40	6.04	.08	1	.00871	.47249
87	6.88	140.06	.1640	7.17	2.18	1.24	2	3.43	6.10	.08	1	.00836	.46293
88	6.96	140.48	.1626	7.25	2.19	1.25	2	3.47	6.15	.08	1	.00802	.45360
89	7.04	140.90	.1611	12.67	3.06	1.42	3	3.56	6.21	5.42	1	.00007	.01094
90	7.12	141.31	.1597	24.07	4.89	1.76	3	4.12	6.26	11.40	1	.00002	.00943
91	7.20	141.70	.1583	30.50	5.92	1.95	3	4.68	6.32	6.43	1	.00002	.02052
92	7.28	142.09	.1570	35.58	6.72	2.09	3	5.25	6.37	5.08	1	.00002	.02944
93	7.36	142.48	.1556	39.94	7.40	2.21	3	5.81	6.43	4.36	1	.00002	.03740
94	7.44	142.85	.1543	43.84	8.00	2.30	3	6.38	6.48	3.90	1	.00002	.04464
95	7.52	143.22	.1530	47.40	8.55	2.39	3	6.94	6.54	3.57	1	.00002	.05125
96	7.60	143.58	.1517	50.72	9.05	2.46	3	7.51	6.59	3.32	1	.00002	.05733
97	7.68	143.94	.1504	53.85	9.53	2.53	3	8.08	6.65	3.12	1	.00002	.06291
98	7.76	144.29	.1491	56.81	9.97	2.59	3	8.66	6.71	2.96	1	.00002	.06805
99	7.84	144.63	.1479	59.64	10.39	2.64	3	9.23	6.76	2.83	1	.00002	.07279
100	7.92	144.96	.1467	62.36	10.79	2.68	3	9.80	6.82	2.72	1	.00002	.07715
101	8.00	145.29	.1455	64.98	11.17	2.73	3	10.38	6.87	2.62	1	.00002	.08116
102	8.40	146.85	.1397	77.01	12.89	2.88	3	13.28	7.16	12.03	1	.00002	.09541
103	8.80	148.28	.1343	55.34	9.91	2.72	4	14.10	7.45	-21.67	1	.00001	.03354
104	9.20	149.60	.1293	49.40	9.13	2.70	4	14.57	7.73	-5.94	1	.00004	.09670
105	9.60	150.81	.1246	46.48	8.75	2.71	4	15.05	8.03	-2.92	1	.00008	.16459

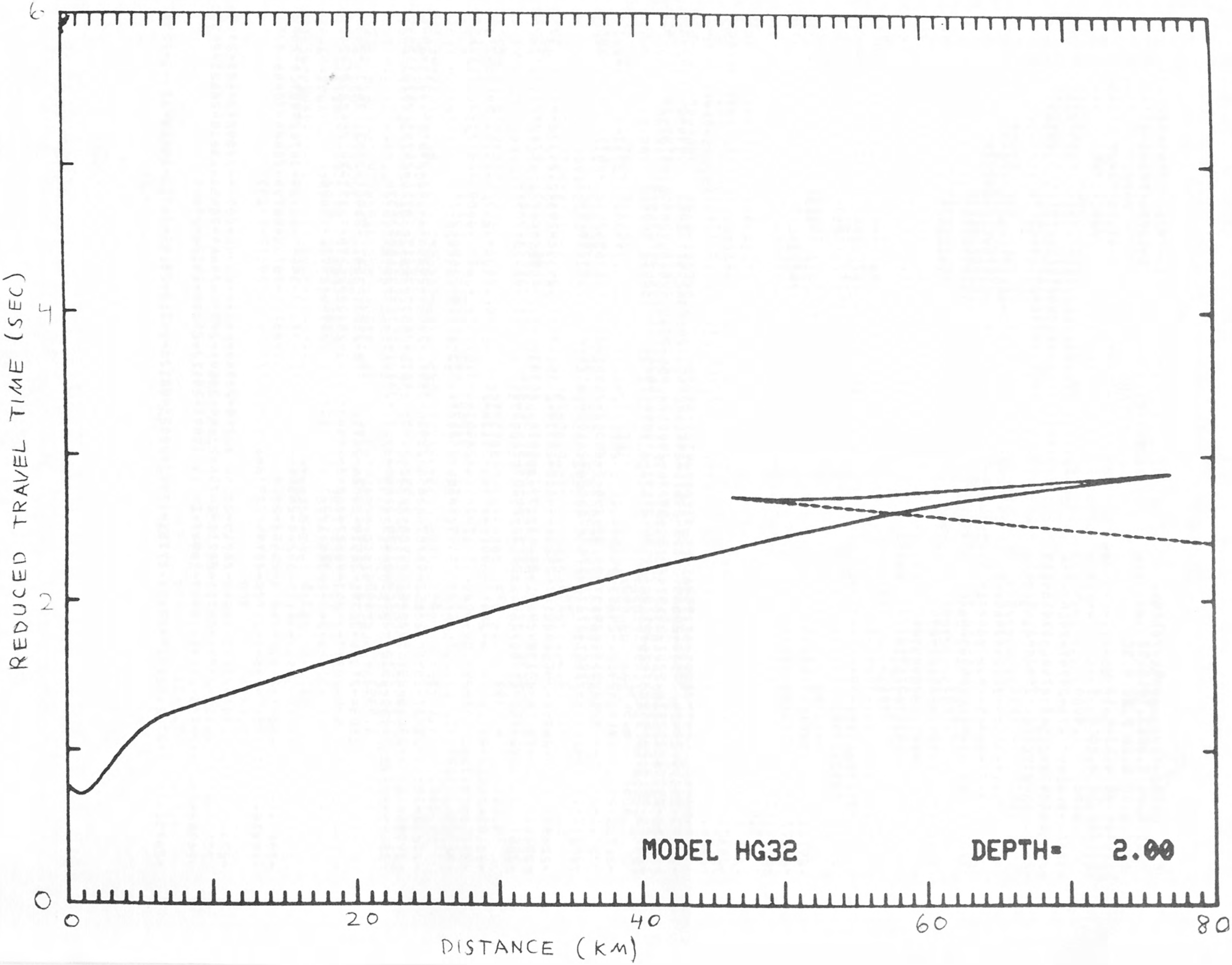
RAYS NOW LOST TO HALFSPACE. EXTEND TT CURVE FROM 46.48 KM, 2.71 SEC AT VELOCITY 8.30

J INDICIES OF ENDS OF SHADOW ZONE (HYPO IN LVZ): 0 0

J INDICIES OF ENDS OF SHADOW ZONE (HYPO ABOVE LVZ): 0 0

J INDICI\S OF ENDS OF REVERSE BRANCHES:

102	0	0	0	0	0	0	0	0	0
105	0	0	0	0	0	0	0	0	0


6
4
2
0
REDUCED TRAVEL TIME (SEC)
0
20
40
60
80
DISTANCE (KM)
MODEL HG32
DEPTH= 2.00

TTTAB

```
MODEL HG32             5   .1300
  .00 1.40 3.5013.7015.50
 1.90 3.00 6.20 7.20 8.30
 1.0000 28 4.0000 13
 1.0000 18 4.0000  9
     .0000     1.9000          5
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```

Hypocenter Location Program

HYPOINVERSE

Part 2: Source Listings and Notes

APPENDIX 5

Format of the travel time table generated by TTGEN and used by HYPOINVERSE, Version 3.

Header Block

Line	Columns	Format	Explanation
1	1-20	10A2	Model title to appear on output.
1	21-22	I2	Number of velocity points n specified for the model.
1	23-30	F8.4	One over the reducing velocity (in sec/km) used to reduce travel time in table.
2	1-75	nF5.2	Depths of the n points of model (Used only to label output and not in calculations.)
2	1-75	nF5.2	Velocities of the n points of model (Used only to label output and not in calculations.)
3	1-7	F7.4	DD1
3	8-10	I3	ND1
3	11-17	F7.4	DD2
3	18-20	I3	ND2
4	1-7	F7.4	DZ1
4	8-10	I3	NZ1
4	11-17	F7.4	DZ2
4	18-20	I3	NZ2

Travel time Blocks

One block now follows for each of the NZ1 + NZ2 + 1 depth grid points.

Line	Columns	Format	Explanation
1	1-10	F10.4	Depth.
1	11-20	F10.4	Velocity at this depth.
1	21-30	I10	Distance in units of 0.1 km at which a horizontally emergent ray reaches the surface. This is used to resolve the ambiguity between upgoing and downgoing rays.
2 etc.	1-90	15I6	Reduced travel times at each of the ND1 + ND2 + 1 distance grid points.

The reduced travel times are given as integers in units of .0005 sec, minus 32000. Ths converts an integer range of ± 32000 into a time range of 0.0 to 32 seconds.

APPENDIX 6
Variables in Blank Common

This section lists and explains the variables in BLANK COMMON used to communicate between HYPINV (main program), HYSTA, HYPHS, HYLOC, HYSOL, HYLST, and HYSUM. To condense storage in a machine that uses one 16-bit word per integer, integers encoding sometimes 2 or 3 separate variables are used to save storage space.

Epicentral Coordinates

T1	Current origin time, in seconds relative to hour and minute given on the first phase card.

The following two variables are used for internal computation.

QLAT1	Current absolute epicentral latitude in degrees (south latitude is negative).
QLON1	Current absolute epicentral longitude in degrees (east longitude is negative).
Z1	Current hypocentral depth.

The following six variables are used for output:

LAT	Current latitude, degrees part, always positive.
XLTM	Current latitude, minutes part, always positive.
LON	Current longitude, degrees part, always positive.
XLNM	Current longitude, minutes part, always positive.
IE	Blank if west longitude, "E" if east.
IS	Blank if north latitude, "S" if south.
DONE	(Logical) DONE is true if hypocenter has converged and iterations are to be terminated.

Event time, magnitude, and simplified errors

The following five variables are taken from the first phase card of each event.

KYEAR	Event year
KMONTH	Event month
KDAY	Event day
KHOUR	Event hour
KMIN	Event minute
FMAG	Average duration magnitude for this event.
XMAG	Average amplitude magnitude for this event.
RMS	Root mean square travel time residual, sec (computed after residual weighting).
RMSWT	RMS value on which residual weighting is based (computed before residual weighting).
ERZ	Probable vertical location error, km.
ERH	Probable horizontal location error, km.

Other event parameters and controls

DLYBAL	Fixes the balance between the two delay models. Takes on values between 0.0 and 1.0 and is equal to 0.0 to use delay model 1.
DLYAZ	Azimuth (in deg) of the line separating the two delay models.
DLYWD	Halfwidth of the transition zone separating the two delay models.

The following three variables define the error ellipsoid.

SERR(3)	Three principal standard errors (km).
IAZ(3)	Azimuth (in deg east of north) of the principal error directions.
IDIP(3)	Dips (in deg) of the principal error directions.
V(4,4)	Eigenvector matrix.
ITR	Current iteration number.
DMIN	Distance to closest (weighted) station.
REMK	Three letter event remark.
KSTA	Number of stations (phase cards) read for this event.
KEND	Program termination flag.
MAXGAP	Maximum azimuthal gap between adjacent stations.
NFRM	Number of stations reporting first motions.
NWR	Number of readings (P or S) with weights greater than 0.1.
NWS	Number of weighted S readings.
M	Number of arrival times (P or S) reported for this event regardless of weight.
KPRINT	Print control parameter. Higher numbers generate more output.

Condensed master station table

QLATO	Latitude of array origin, absolute degrees.
QLONO	Longitude of array origin, absolute degrees.
JSTA	Number of stations available in the following arrays.
STANAM(300)	Station name (A4 format).
JLAT(300)	Station latitude in units of .02 minute relative to array origin.
JLON(300)	Station longitude in units of .02 minute relative to array origin.
JCAL(300)	Station seismograph type, calibration factor, and standard period for computing amplitude magnitudes. If I is the seismograph type (only values Ø, 1, or 2 allowed), J is the standard period in units of 0.1, and K is the calibration factor in units of 0.1, then JCAL = I · 10000 + J· 500 + K.
JMCOR(300)	Amplitude and duration magnitude correction and station weight. If I is the station weight (1 for full weight, Ø for no weight, J the amplitude magnitude correction in units of 0.1, and K the duration magnitude correction in units of 0.1, then JMCOR = I · 10000 + J · 100 + K + 2525.
JPD1(300)	P wave delay for delay model 1 in units of .01 sec.
JPD2(300)	If I is the crustal model number for this station (May be 1, 2, or 3) and J is the P wave delay for delay model 2 in units of .01 sec, then JPD2 = I · 10000 + J - 5000.
JSD1(300)	S wave delay for delay model 1 in units of .01 sec.
JSD2(300)	S wave delay for delay model 2 in units of .01 sec.

Information for each station reporting an event (phase card)

KINDX(160)	Index pointer to station table. The name of the station read on the Ith valid phase card is STANAM (KINDX(I)).
KP(160)	P wave arrival time in units of .01 sec relative to the hour and minute given on the first phase card.
KS(160)	S wave arrival time in units of .01 sec relative to the hour and minute given on the first phase card.
KTCAL(160)	Calculated travel time in units of .01 sec.
KDIS (160)	Distance to epicenter in units of .05 km.
KAZEM(160)	Azimuth and emergence angle at the hypocenter. If I is the azimuth in degrees east of north ($-180 \leq I \leq 180$) and J is emergence angle in degrees from nadir, then KAZEM = I · 180 + J.
KPRK(160)	P arrival remark such as 'IP' (A2).
KSRK(160)	S arrival remark such as 'ES'(A2).
KFM(160)	First motion such as 'U' (A1).
KWT(160)	Assigned P and S weight codes. If I is the S weight (Ø-9) and J is the P weight, then KWT = I · 10 + J.
KFMP(160)	Duration (F minus P) time in seconds.
KMAG(160)	Amplitude and duration magnitude. If I is the amplitude magnitude in units of 0.1 and J the duration magnitude in units of 0.1, then KMAG = I · 10 + J.
KRMK(160)	One letter station remark (A1).
KCCOR(160)	Clock correction in units of .01 sec.
KAMP(160)	Maximum peak-to-peak amplitude in mm.

Information for each arrival time (P or S)

IND(240)	If I is the P/S flag (Ø for P and 1 for S) and J is the phase list index pointer, then IND = I· 10000 + J. If J is dervied from the value of IND(K) associated with the Kth arrival, then if it is a P wave its arrival time is KP(J) or KP(IND(K)).
R(240)	Travel time residual in seconds.
W(240)	Arrival time weight.
IMPORT(240)	Importance of arrival time in units of .001.

APPENDIX 7

Notes on converting HYPOINVERSE to other computers

HYPOINVERSE was written and compiled under Data General's FORTRAN 5, but standard FORTRAN 4 has been used as much as possible. Most of the non-standard code is in the main program. For example, the main program identifies the external files to be read from or written to, and asociates them with device/file numbers used in READ and WRITE statements. The easiest way to adjust the size of the program is by redimensioning the large arrays in blank common and in HYLOC. Shortening the program even more requires eliminating sections of code, such as those for magnitude calculation or generation of output. Storage has been conserved as much as possible to take advantage of integers (which require one 16-bit word) instead of reals (which require two words). All features of the program will work on machines with longer word lengths. In addition, variables which take on limited values are "multiplexed" into the same word of storage whenever possible. Thus if I, J, K and L only take on integer values between Ø and 9, all can be stored in one 16-bit word as I * 1000 + J * 100 + K * 10 + L.

Size is not a problem for the smaller program to TTGEN. The plotting subroutine TTPLT could be eliminated without modification to TTGEN. TTPLT calls standard subroutines in the Tektronix Plot-10 package.

A brief listing of statements which may not be available in other compilers follows:

1. An OPEN statement is used to access and associate an input/output number with an external file. A CLOSE statement is used to release the file when input/output is finished.

2. Branching on input is possible when an end of file is encountered (END = statement number) or an error occurs (ERR = s.n.).

3. The INCLUDE statement is used to insert a section of code from another file into the source code during compilation. The source code for common blocks used by many routines is kept in the file HYPCOM.

4. FGDAY and FGTIME are subroutines which return the date and time used to label output.

5. The SIGN function returns a value with the magnitude of the first argument and the sign of the second.

6. ENCODE and DECODE statements are used for core to core transfer of data under FORMAT control.

APPENDIX 8:
HYPOINVERSE source listing

HYPINV1	Main program, Version 1. Other verisons use identical main program, except for array sizes.
HYBDA	Block data.
HYSTA	Reads station list.
HYPHS	Reads phase data.
HYCRU	Reads crustal model. Versions 1 and 2.
HYCRU3	Reads crustal model. Versions 3 and 4.
HYLOC	Locates one event.
HYSOL	Calculates solution for 1 interation.
HYSVD	SVD routine.
HYROT	Called by SVD.
HYTRV	Travel time calculator, Versions 1 and 2.
HYTID	Called by HYTRV, Versions 1 and 2.
HYDID	Called by HYTRV, Versions 1 and 2.
HYTRV3	Travel time calculator, Versions 3 and 4.
HYLST	Station list output.
HYSUM	Summary data output.

When using Version 3, substitute HYCRU3 for HYCRU, and HYTRV3 for HYTRV, HYTID and HYDID.

HYPINV1.FR

```
C--MAIN PROGRAM HYPINV1 (VERSION 1)
C--FILE ORIENTED LOCATION PROGRAM FOR MINICOMPUTER APPLICATIONS
C--USES GENERALIZED INVERSE APPROACH AND SINGLE VALUE DECOMPOSITION
C-- WRITTEN BY FRED KLEIN , JUN 1978
      INCLUDE 'HYPCOM'
C--FILE HYPCOM CONTAINS THE COMMON BLOCKS INCLUDED IN MANY HYPINV SUBS
C--BLANK COMMON IS FOR COMMUNICATION BETWEEN SUBROUTINES
      LOGICAL DONE
C--CURRENT EPICENTRAL COORDS, INITIALIZED TO TRIAL VALUES
      COMMON T1,QLAT1,QLON1,Z1,LAT,XLTM,LON,XLNM,DONE,IE,IS
C--EVENT TIME, MAGNITUDE AND SIMPLIFIED ERRORS
      COMMON KYEAR,KMONTH,KDAY,KHOUR,KMIN,FMAG,XMAG,RMS,ERH,ERZ,RMSWT
C-- ERROR ELLIPSE AND DELAY MODEL PARAMETERS
      COMMON DLYBAL,DLYAZ,DLYWD,SERR(3),IAZ(3),IDIP(3),V(4,4)
C--OTHER PARAMETERS KEPT FOR EACH EVENT
      COMMON ITR,DMIN,REMK,KSTA,KEND,MAXGAP,NFRM,NWR,NWS,M,KPRINT
C--CONDENSED MASTER STATION TABLE
      COMMON QLAT0,QLON0,JSTA,STANAM(300),JLAT(300),JLON(300),JCAL(300)
      COMMON JMCOR(300),JPD1(300),JPD2(300),JSD1(300),JSD2(300)
C--CONDENSED INFO FROM EACH STATION REPORTING AN EVENT
      COMMON KINDX(160),KP(160),KS(160),KTCAL(160),KDIS(160),KAZEM(160)
      COMMON KPRK(160),KSRK(160),KFM(160),KWT(160),KFMP(160),KMAG(160)
      COMMON KRMK(160),KCCOR(160),KAMP(160)
C--INDEX, RESIDUAL, WEIGHT, AND IMPORTANCE OF EACH PHASE (P OR S)
      COMMON IND(240),R(240),W(240),IMPORT(240)
C--COMMON BLOCK /TEST/ IS FOR FIXED CONSTANTS SET IN BLOCK DATA
C--WHEN TO QUIT OR DAMP ITERATIONS
      COMMON /TEST/ ITRLIM,DQUIT,DXFIX,DZMAX,DZAIR,DAMP,DRQT,EIGTOL
     2 ,RBACK,BACFAC
C--DISTANCE, RESIDUAL AND S WEIGHTING
      COMMON /TEST/ DISCUT,DISW1,DISW2,RMSCUT,RMSW1,RMSW2,SWT
C--FMAG CONSTANTS
      COMMON /TEST/ FMA1,FMB1,FMZ1,FMD1,FMBRK,FMA2,FMB2,FMZ2,FMD2
C--I/O DEVICES AND MAX NOS OF STATIONS, PHASE CARDS AND P/S PHASES
      COMMON /TEST/ LINP,LPRT,LOUT,MAXSTA,MAXPHS,MMAX
C--MODEL, ERROR AND PAGE CONSTANTS
      COMMON /TEST/ POS,ZTR,RDERR,ERCOF,KEJCT,KINFO
C--SET BLANKS, DEG/RAD, AND EVENT COUNT INDEX
      COMMON  /TEST/ LB,BL,RDEG,LOCNUM,PI
C--THESE ARRAYS HOLD I/O FILE NAMES
      DIMENSION ISTAFL(8),ICRSFL(8),IPHSFL(8),IPRTFL(8),IOUTFL(8)
      DIMENSION ISM71(8),ISMEL(8),ISMHI(8)
C--THESE ARRAYS HOLD APPEND CONTROLS FOR OUTPUT FILES
      DIMENSION JPRTA(2),JOUTA(2),JS71A(2),JSELA(2),JSHIA(2)
C--INITIALIZE INPUT CONTROLS TO DEFAULTS
      DATA ISTAFL/'DP','0:','ST','AT','IO','NS','  ',0/
      DATA ICRSFL/'DP','0:','CR','US','T ','  ','  ',0/
      DATA IPHSFL/'DP','0:','PH','AS','E ','  ','  ',0/
      DATA IPRTFL/'DP','0:','HY','PP','RI','NT','  ',0/
      DATA IOUTFL/'DP','0:','HY','PO','UT','  ','  ',0/
      DATA ISM71 /'DP','0:','SU','MM','71','  ','  ',0/
      DATA ISMEL /'DP','0:','SU','MM','EL','  ','  ',0/
      DATA ISMHI /'DP','0:','SU','MM','HI','  ','  ',0/
      DATA JPRTA,JOUTA/'RO',0,'RO',0/
      DATA JS71A,JSELA,JSHIA/'RA',0,'RO',0,'RA',0/
      DATA KSTCTL,NOSDLY,KS71,KSEL,KSHI/3*1,0,1/
      KPRINT=3
      DO 5 I=1,MMAX
5     IMPORT(I)=0
```

```
C--READ IN I/O FILE NAMES, ATTRIBUTES AND PRINTING CONTROLS
      OPEN 1,'HYPINST',ERR=10
      READ (1,1000) (ISTAFL(J),J=1,7),(ICRSFL(J),J=1,7),
     2 (IPHSFL(J),J=1,7),(IPRTFL(J),J=1,7),JPRTA(1),(IOUTFL(J),J=1,7),
     3 JOUTA(1),(ISM71(J),J=1,7),JS71A(1),(ISMEL(J),J=1,7),JSELA(1),
     4 (ISMHI(J),J=1,7),JSHIA(1),KSTCTL,KPRINT,KS71,KSEL,KSHI,KEJCT
     5 ,NOSDLY
1000  FORMAT (3(7A2/),5(8A2/),I1,I2,3I1,A1,I1)
      CLOSE 1
C--OPEN FILES WITH APPROPRIATE NAMES AND ATTRIBUTES
10    OPEN 2,ISTAFL
      OPEN 3,ICRSFL
      OPEN LINP,IPHSFL
      OPEN LPRT,IPRTFL,ATT=JPRTA
      OPEN LOUT,IOUTFL,ATT=JOUTA
      IF (KS71.NE.0) OPEN 8,ISM71,ATT=JS71A
      IF (KSEL.NE.0) OPEN 9,ISMEL,ATT=JSELA
      IF (KSHI.NE.0) OPEN 10,ISMHI,ATT=JSHIA
C--DON'T PRINT STATION LIST IF KSTCTL=0
      IF (KSTCTL.EQ.0 .OR. KPRINT.LT.0) GO TO 20
C--PRINT A STANDARD HEADING INCLUDING DATE
      CALL FGDAY (J1,J2,J3)
      CALL FGTIME(J4,J5,J6)
      WRITE (LPRT,1001) J1,J2,J3,J4,J5,J6
1001  FORMAT ('1PROGRAM HYPINV (VERSION 1- JUN 78) RUN ON ',
     2 2(I2,'/'),I2,' AT ',2(I2,':') ,I2/)
C--READ IN STATION LIST AND OPTIONALLY LIST THEM AS READ IN
20    CALL HYSTA (KSTCTL,NOSDLY)
      CLOSE 2
C--READ IN CRUSTAL MODEL
      CALL HYCRU (LPRT,KSTCTL)
      CLOSE 3
C--WRITE OUT TEST PARAMETERS IF STATIONS AND CRUST ARE ALSO OUTPUT
      IF (KSTCTL.NE.1) GO TO 25
      WRITE (LPRT,1004)
1004  FORMAT (/' TEST PARAMETERS'/'      -ITERATION AND CONVERGENCE-    ',
     2' -WEIGHTING, ERRORS, TRIAL DEPTH-      -DURATION MAG CONSTANTS-')
      WRITE (LPRT,1005) ITRLIM,DAMP,DISCUT,RMSCUT,FMA1,FMA2
1005  FORMAT (I11,'=ITRLIM',F10.4,'=DAMP  ',F10.4,'=DISCUT',F10.4,
     2 '=RMSCUT',F10.4,'=FMA1  ',F10.4,'=FMA2')
      WRITE (LPRT,1006) DQUIT,DRQT,DISW1,RMSW1,FMB1,FMB2
1006  FORMAT (F11.4,'=DQUIT ',F10.4,'=DRQT  ',F10.4,'=DISW1 ',
     2 F10.4,'=RMSW1 ',F10.4,'=FMB1  ',F10.4,'=FMB2')
      WRITE (LPRT,1007) DXFIX,EIGTOL,DISW2,RMSW2,FMZ1,FMZ2
1007  FORMAT (F11.4,'=DXFIX ',F10.4,'=EIGTOL',F10.4,'=DISW2 ',
     2 F10.4,'=RMSW2 ',F10.4,'=FMZ1  ',F10.4,'=FMZ2')
      WRITE (LPRT,1008) DZMAX,RBACK,SWT,RDERR,FMD1,FMD2
1008  FORMAT (F11.4,'=DZMAX ',F10.4,'=RBACK ',F10.4,'=SWT   ',
     2 F10.4,'=RDERR ',F10.4,'=FMD1  ',F10.4,'=FMD2')
      WRITE (LPRT,1009) DZAIR,BACFAC,ZTR,ERCOF,FMBRK,POS
1009  FORMAT (F11.4,'=DZAIR ',F10.4,'=BACFAC',F10.4,'=ZTR   ',
     2 F10.4,'=ERCOF ',F10.4,'=FMBRK ',F10.4,'=POS')
C--SET FLAG WHICH INDICATES END OF PHASE CARD FILE
25    KEND=0
C--LOOP TO LOCATE EVENTS
C--READ IN PHASE DATA, COMPRESS IT INTO ARRAY STORAGE, SKIP STATIONS
C--NOT ON LIST, ETC.
30    CALL HYPHS
      IF (KEND.LT.0) GO TO 50
C--GO TO 50 IF AT END OF PHASE CARD FILE WITH INSUFFICIENT DATA TO
C--LOCATE ANOTHER EVENT.
C--NOW LOCATE AT LEAST ONE MORE EVENT
      CALL HYLOC
```

```
      IF (NWR.LT.4) GO TO 30
C--THE PRINTED OUTPUT OF FINAL SOLUTION AND FILE OF NEW DETAILED PHASE
C--CARDS ARE GENERATED HERE UNDER CONTROL OF KPRINT.
      CALL HYLST
C--WRITE SUMMARY CARDS IN 3 FORMATS FOR EACH EVENT
      CALL HYSUM (KS71,KSEL,KSHI)
      IF (KEND.EQ.0) GO TO 30
C--COME HERE WHEN SUPPLY OF PHASE CARDS IS EXHAUSTED TO CLOSE FILES
50    CLOSE LINP
      WRITE (LPRT,1002)
1002  FORMAT (' ')
      CLOSE LPRT
      CLOSE LOUT
      IF (KS71.NE.0) CLOSE 8
      IF (KSEL.NE.0) CLOSE 9
      IF (KSHI.NE.0) CLOSE 10
      STOP
      END
```

HYBDA.FR

```
      BLOCK DATA
C--WHEN TO QUIT OR DAMP ITERATIONS
      COMMON /TEST/ ITRLIM,DQUIT,DXFIX,DZMAX,DZAIR,DAMP,DRQT,EIGTOL,RBACK,BACFAC
C--DISTANCE, RESIDUAL AND S WEIGHTING
      COMMON /TEST/ DISCUT,DISW1,DISW2,RMSCUT,RMSW1,RMSW2,SWT
C--FMAG CONSTANTS
      COMMON /TEST/ FMA1,FMB1,FMZ1,FMD1,FMBRK,FMA2,FMB2,FMZ2,FMD2
C--I/O DEVICES AND MAX NOS OF STATIONS, PHASE CARDS AND P/S PHASES
      COMMON /TEST/ LINP,LPRT,LOUT,MAXSTA,MAXPHS,MMAX
C--MODEL, ERROR AND PAGE CONSTANTS
      COMMON /TEST/ POS,ZTR,RDERR,ERCOF,KEJCT,KINFO
C--SET BLANKS, DEG/RAD, AND EVENT COUNT INDEX
      COMMON  /TEST/ LB,BL,RDEG,LOCNUM,PI
      DATA ITRLIM,DQUIT,DXFIX,DZMAX,DZAIR /20,.04,7.,12.,.5/
      DATA DISCUT,DISW1,DISW2,RMSCUT,RMSW1,RMSW2,SWT /50.,1.,3.,.16,1.5
     2 ,3.,1./
      DATA DAMP,DRQT,EIGTOL/.9,.001,.012/
      DATA FMA1,FMB1,FMZ1,FMD1,FMBRK /-5.,3.89,0.,0.,210./
      DATA FMA2,FMB2,FMZ2,FMD2 /-.705,2.026,0.,0./
      DATA LINP,LPRT,LOUT,MAXSTA,MAXPHS,MMAX /5,6,7,300,160,240/
      DATA POS,ZTR,RDERR,ERCOF,KEJCT,KINFO /1.75,7.,.25,1.,'1',1/
      DATA LB,BL,RDEG,LOCNUM,PI /'  ','    ',57.29578,0,3.14159/
      DATA RBACK,BACFAC /.02,.6/
      END
```

HYSTA.FR

```
      SUBROUTINE HYSTA (KSTCTL,NOSDLY)
C--READ IN STATION LIST, TO A MAXIMUM OF MAXSTA STATIONS.
C--FIRST CARD MUST CONTAIN A STATION 'CNTR' WITH COORDINATES TAKEN AS
C--THE REFERENCE ORIGIN (CENTER) OF THE ARRAY.
      INCLUDE 'HYPCOM'
C--FILE HYPCOM CONTAINS THE COMMON BLOCKS INCLUDED IN MANY HYPINV SUBS
C--BLANK COMMON IS FOR COMMUNICATION BETWEEN SUBROUTINES
      LOGICAL DONE
C--CURRENT EPICENTRAL COORDS, INITIALIZED TO TRIAL VALUES
      COMMON T1,QLAT1,QLON1,Z1,LAT,XLTM,LON,XLNM,DONE,IE,IS
C--EVENT TIME, MAGNITUDE AND SIMPLIFIED ERRORS
      COMMON KYEAR,KMONTH,KDAY,KHOUR,KMIN,FMAG,XMAG,RMS,ERH,ERZ,RMSWT
C-- ERROR ELLIPSE AND DELAY MODEL PARAMETERS
      COMMON DLYBAL,DLYAZ,DLYWD,SERR(3),IAZ(3),IDIP(3),V(4,4)
C--OTHER PARAMETERS KEPT FOR EACH EVENT
      COMMON ITR,DMIN,REMK,KSTA,KEND,MAXGAP,NFRM,NWR,NWS,M,KPRINT
C--CONDENSED MASTER STATION TABLE
      COMMON QLATO,QLONO,JSTA,STANAM(300),JLAT(300),JLON(300),JCAL(300)
      COMMON JMCOR(300),JPD1(300),JPD2(300),JSD1(300),JSD2(300)
C--CONDENSED INFO FROM EACH STATION REPORTING AN EVENT
      COMMON KINDX(160),KP(160),KS(160),KTCAL(160),KDIS(160),KAZEM(160)
      COMMON KPRK(160),KSRK(160),KFM(160),KWT(160),KFMP(160),KMAG(160)
      COMMON KRMK(160),KCCOR(160),KAMP(160)
C--INDEX, RESIDUAL, WEIGHT, AND IMPORTANCE OF EACH PHASE (P OR S)
      COMMON IND(240),R(240),W(240),IMPORT(240)
C--COMMON BLOCK /TEST/ IS FOR FIXED CONSTANTS SET IN BLOCK DATA
C--WHEN TO QUIT OR DAMP ITERATIONS
      COMMON /TEST/ ITRLIM,DQUIT,DXFIX,DZMAX,DZAIR,DAMP,DRQT,EIGTOL
     2 ,RBACK,BACFAC
C--DISTANCE, RESIDUAL AND S WEIGHTING
      COMMON /TEST/ DISCUT,DISW1,DISW2,RMSCUT,RMSW1,RMSW2,SWT
C--FMAG CONSTANTS
      COMMON /TEST/ FMA1,FMB1,FMZ1,FMD1,FMBRK,FMA2,FMB2,FMZ2,FMD2
C--I/O DEVICES AND MAX NOS OF STATIONS, PHASE CARDS AND P/S PHASES
      COMMON /TEST/ LINP,LPRT,LOUT,MAXSTA,MAXPHS,MMAX
C--MODEL, ERROR AND PAGE CONSTANTS
      COMMON /TEST/ POS,ZTR,RDERR,ERCOF,KEJCT,KINFO
C--SET BLANKS, DEG/RAD, AND EVENT COUNT INDEX
      COMMON  /TEST/ LB,BL,RDEG,LOCNUM,PI
C--READ THE COORDINATES OF THE CENTER OF THE ARRAY
      DIMENSION IREMK(5)
      READ (2,1000) STANAM(1),KTEMP,QLAT,ALAT,IS,QLON,ALON,
     2 IE,REMK,PER,JMDL,DLYAZ,DLYWD
1000  FORMAT (A4,A1,F2.0,1X,F5.2,A1,F3.0,1X,F5.2,A1,A4,F3.1,2X,
     2 I1,4(1X,F5.2),1X,I1,F6.2,A4,5A2)
      IF (STANAM(1).NE.'CNTR') GO TO 90
      QLATO=QLAT+ALAT/60.
      QLONO=QLON+ALON/60.
      IF (IS.EQ.'S') QLATO=-QLATO
      IF (IE.EQ.'E') QLONO=-QLONO
      IF (KSTCTL.EQ.0) GO TO 10
C--PRINT ARRAY CENTER AND STATION LIST HEADINGS
      WRITE (LPRT,1001) QLAT,ALAT,IS,QLON,ALON,IE,DLYAZ,DLYWD
1001  FORMAT (' STATIONS'/3X,'CENTER',F4.0,F6.2,A1,F5.0,F6.2,A1,
     2 ' DLYAZ=',F8.2,' DLYWD=',F6.2/
     2'  I  NAME ---LAT---- ----LON---- PDLY1 SDLY1 ',
     2 'PDLY2 SDLY2 FMC XMC WT MDL CAL PER TYP'/)
C--LOOP TO READ STATIONS INTO TABLE
10    DO 20 I=1,MAXSTA
```

```
      JSTA=I-1
      READ (2,1000,END=30,ERR=30) STANAM(I),KTEMP,QLAT,ALAT,IS,QLON
     2 ,ALON,IE,REMK,PER,JMDL,PD1,PD2,XMCOR,FMCOR,ITYPE,CAL,REMK2,IREMK
      IF (PER.GT.1.9) PER=1.9
      IF (PER.LT..1) PER=.2
      IF (CAL.LT.0.) CAL=0.
      IF (CAL.GT.49.9) CAL=49.9
      IF (JMDL.LT.1 .OR. JMDL.GT.3) JMDL=1
      IF (NOSDLY.EQ.1) GO TO 13
C--GET S DELAYS FROM DIRECT INPUT
      DECODE (IREMK,1005) SD1,SD2
1005  FORMAT (2F5.2)
      DO 11 J=1,5
11    IREMK(J)=LB
      GO TO 15
C--GET S DELAYS FROM P DELAYS AND TRANSMIT IREMK AS A REMARK FIELD
13    SD1=PD1*POS
      SD2=PD2*POS
C--MOVE LON TO SAME SIDE OF INTL DATE LINE AS ARRAY ORIGIN
15    QLAT1=QLAT+ALAT/60.
      QLON1=QLON+ALON/60.
      IF (IS.EQ.'S') QLAT1=-QLAT1
      IF (IE.EQ.'E') QLON1=-QLON1
      IF (QLON1*QLON0.LT.-10000.) QLON1=QLON1+SIGN(360.,QLON0)
C--STATION INFORMATION IS STORED IN CONDENSED INTEGER FORMAT
      JLAT(I)=(QLAT1-QLAT0)*3000.
      JLON(I)=(QLON1-QLON0)*3000.
      JWT=1
      IF (KTEMP.EQ.'*') JWT=0
      JMCOR(I)=JWT*10000+2525
      KTEMP=XMCOR*10.
      KTEMP2=FMCOR*10.
      JMCOR(I)=JMCOR(I)+KTEMP*100+KTEMP2
      JPD1(I)=PD1*100.+SIGN(.5,PD1)
      JPD2(I)=PD2*100.+SIGN(.5,PD2)
      JPD2(I)=JPD2(I)+(JMDL-1)*10000+5000
      JSD1(I)=SD1*100.+SIGN(.5,SD1)
      JSD2(I)=SD2*100.+SIGN(.5,SD2)
      KTEMP=CAL*10.+.5
      KTEMP2=PER*10.+.5
      IF (ITYPE.GT.2) ITYPE=1
      JCAL(I)=ITYPE*10000+KTEMP2*500+KTEMP
C--OPTIONALLY LIST STATIONS AS READ IN
18    IF (KSTCTL.EQ.0) GO TO 20
      WRITE (6,1002) I,STANAM(I),QLAT,ALAT,IS,QLON,ALON,IE,PD1,SD1,PD2
     2 ,SD2,FMCOR,XMCOR,JWT,JMDL,CAL,PER,ITYPE,REMK,REMK2,IREMK
1002  FORMAT (1X,I3,1X,A4,F4.0,F6.2,A1,F5.0,F6.2,A1,4F6.2,2F4.1,I2,I3
     2 ,F6.1,F4.1,I3,2(1X,A4),1X,5A2)
20    CONTINUE
C--COME HERE IF TOO MANY STATIONS ARE AVAILABLE
      JSTA=MAXSTA
      WRITE (LPRT,1003) MAXSTA
1003  FORMAT (' ONLY THE FIRST',I4,' STATIONS WERE READ IN'/)
30    RETURN
C--COME HERE FOR FATAL OMISSION OF ARRAY ORIGIN
90    WRITE (LPRT,1004)
1004  FORMAT (' FIRST STATION CARD MUST BE "CNTR" WITH COORDS OF ARRAY',
     2 ' ORIGIN')
      STOP
      END
```

HYPHS.FR

```
      SUBROUTINE HYPHS
C--READ IN PHASE DATA, COMPRESS IT INTO ARRAY STORAGE, REJECT STAS NOT
C--ON LIST, ETC. PHASE LIST NOT SORTED HERE.
      INCLUDE 'HYPCOM'
C--FILE HYPCOM CONTAINS THE COMMON BLOCKS INCLUDED IN MANY HYPINV SUBS
C--BLANK COMMON IS FOR COMMUNICATION BETWEEN SUBROUTINES
      LOGICAL DONE
C--CURRENT EPICENTRAL COORDS, INITIALIZED TO TRIAL VALUES
      COMMON T1,QLAT1,QLON1,Z1,LAT,XLTM,LON,XLNM,DONE,IE,IS
C--EVENT TIME, MAGNITUDE AND SIMPLIFIED ERRORS
      COMMON KYEAR,KMONTH,KDAY,KHOUR,KMIN,FMAG,XMAG,RMS,ERH,ERZ,RMSWT
C-- ERROR ELLIPSE AND DELAY MODEL PARAMETERS
      COMMON DLYBAL,DLYAZ,DLYWD,SERR(3),IAZ(3),IDIP(3),V(4,4)
C--OTHER PARAMETERS KEPT FOR EACH EVENT
      COMMON ITR,DMIN,REMK,KSTA,KEND,MAXGAP,NFRM,NWR,NWS,M,KPRINT
C--CONDENSED MASTER STATION TABLE
      COMMON QLAT0,QLON0,JSTA,STANAM(300),JLAT(300),JLON(300),JCAL(300)
      COMMON JMCOR(300),JPD1(300),JPD2(300),JSD1(300),JSD2(300)
C--CONDENSED INFO FROM EACH STATION REPORTING AN EVENT
      COMMON KINDX(160),KP(160),KS(160),KTCAL(160),KDIS(160),KAZEM(160)
      COMMON KPRK(160),KSRK(160),KFM(160),KWT(160),KFMP(160),KMAG(160)
      COMMON KRMK(160),KCCOR(160),KAMP(160)
C--INDEX, RESIDUAL, WEIGHT, AND IMPORTANCE OF EACH PHASE (P OR S)
      COMMON IND(240),R(240),W(240),IMPORT(240)
C--COMMON BLOCK /TEST/ IS FOR FIXED CONSTANTS SET IN BLOCK DATA
C--WHEN TO QUIT OR DAMP ITERATIONS
      COMMON /TEST/ ITRLIM,DQUIT,DXFIX,DZMAX,DZAIR,DAMP,DRQT,EIGTOL
     2 ,RBACK,BACFAC
C--DISTANCE, RESIDUAL AND S WEIGHTING
      COMMON /TEST/ DISCUT,DISW1,DISW2,RMSCUT,RMSW1,RMSW2,SWT
C--FMAG CONSTANTS
      COMMON /TEST/ FMA1,FMB1,FMZ1,FMD1,FMBRK,FMA2,FMB2,FMZ2,FMD2
C--I/O DEVICES AND MAX NOS OF STATIONS, PHASE CARDS AND P/S PHASES
      COMMON /TEST/ LINP,LPRT,LOUT,MAXSTA,MAXPHS,MMAX
C--MODEL, ERROR AND PAGE CONSTANTS
      COMMON /TEST/ POS,ZTR,RDERR,ERCOF,KEJCT,KINFO
C--SET BLANKS, DEG/RAD, AND EVENT COUNT INDEX
      COMMON  /TEST/ LB,BL,RDEG,LOCNUM,PI
      DIMENSION CARD(20),NUMBER(5)
      DATA NUMBER /'5 ','6 ','7 ','8 ','9 '/
10    REMK=BL
C--LOOP TO READ PHASE CARDS
      DO 100 K=1,MAXPHS
C--READ A PHASE CARD AND DECODE FLAG CHARACTERS FOR INST CARD
15    READ (LINP,1000,END=150,ERR=15) CARD
1000  FORMAT (20A4)
      DECODE (CARD,1008,ERR=20) NCHAR
1008  FORMAT (A1)
      DECODE (CARD,1000,ERR=20) STA
C--INTERPRET A CARD WITH NO STATION NAME OR WITH A NUMERAL IN THE FIRST
C--COL AS AN INSTRUCTION CARD
      DO 17 I=1,5
      IF (NCHAR.EQ.NUMBER(I)) GO TO 135
17    CONTINUE
      IF (STA.EQ.BL) GO TO 140
C--ASSUME THE CARD IS A PHASE CARD
      DECODE (CARD,1001,ERR=20) KPRK(K),KFM(K),LPWT,LYEAR,LMONTH,LDAY,
     2 LHOUR,LMIN,P,S,KSRK(K),LSWT,KAMP(K),TRMK,CCOR,KRMK(K),KFMP(K)
1001  FORMAT (4X,A2,A1,I1,1X,5I2,F5.2,7X,F5.2,A2,1X,I1,4X,I3,15X,A3,
```

```
             2 F5.2,A1,I4)
              IF (REMK.EQ.BL) REMK=TRMK
              GO TO 25
      C--COME HERE ONLY IF THE PHASE CARD IS BAD
      20      WRITE (LPRT,1002) CARD
      1002    FORMAT (' SKIP OVER BAD PHASE CARD:'/ 1X,20A4)
              GO TO 15
      C--TEST ALL PHASE CARDS BUT THE FIRST FOR TIME AGREEMENT (SAME HOUR)
      25      IF (K.GT.1) GO TO 30
              KYEAR=LYEAR
              KMONTH=LMONTH
              KDAY=LDAY
              KHOUR=LHOUR
              KMIN=LMIN
              GO TO 35
      30      IF (LYEAR-KYEAR+LMONTH-KMONTH+LDAY-KDAY.EQ.0 .AND. IABS
             2 ((LHOUR-KHOUR)*60+LMIN-KMIN).LT.4) GO TO 35
              WRITF (LPRT,1003) CARD
      1003    FORMAT (' SKIP OVER PHASE CARD WITH WRONG TIME:'/ 1X,20A4)
              GO TO 15
      C--TEST TO SEE IF THE STATION IS ON THE LIST
      35      DO  40 J=1,JSTA
              IF (STA.EQ.STANAM(J)) GO TO 45
      40      CONTINUE
      C--STATION NOT ON STATION LIST SO SKIP OVER PHASE CARD
              WRITE (LPRT,1004) CARD
      1004    FORMAT (' STATION NOT ON LIST, SO SKIP PHASE CARD:'/ 1X,20A4)
              GO TO 15
      C--DETERMINE REFERENCE INDEX FOR THIS STATION AND ENCODE PHASE PARAMS
      45      KINDX(K)=J
      C--CORRECT ARRIVAL TIMES TO SAME MINUTE AND ENCODE P AND S TIMES
              LSHIFT=((LHOUR-KHOUR)*60+LMIN-KMIN)*60
              KP(K)=100.*(P+LSHIFT)+.5
              KS(K)=100.*(S+LSHIFT)+.5
              KCCOR(K)=CCOR*100.+SIGN(.5,CCOR)
              KWT(K)=10*LSWT+LPWT
      100     CONTINUE
      C--TOO MANY PHASE CARDS, SO TREAT REST AS ANOTHER EVENT
              KSTA=MAXPHS
              WRITE (LPRT,1006)
      1006    FORMAT (' TOO MANY PHASE CARDS SO TREAT REST AS ANOTHER EVENT')
      C--ZERO THE TRIAL COORDINATES AS IF A BLANK INST CARD WAS READ
              T1=0.
              Z1=0.
              QLAT1=0.
              QLON1=0.
              RETURN
      C--COME HERE FOR NORMAL TERMINATION OF A PHASE LIST WITH INST CARD.
      C--IF TRIAL HYPO DATA IS IN WRONG FORMAT ON INST CARD, IGNORE IT
      C--TAKE REMK FROM TERMINATOR CARD IF IT IS A SUMMARY CARD
      135     REMK=BL
      140     KSTA=K-1
              IF (KSTA.GT.2) GO TO 142
      C--SKIP THIS EVENT WITH LESS THAN 3 PHASE CARDS
              WRITE (LPRT,1007)
      1007    FORMAT (' SKIP EVENT WITH LESS THAN 3 PHASE CARDS')
              GO TO 10
      C--ASSUME AN INSTRUCTION CARD
      142     DECODE (CARD,1005,ERR=145) MHOUR,MINIT,T,QLAT1,IS,P,QLON1,IE,S,Z1
             2 ,TRMK
      1005    FORMAT (6X,2I2,F4.2,F2.0,A1,F4.2,F3.0,A1,F4.2,F5.2,35X,A3)
              IF (REMK.EQ.BL) REMK=TRMK
              QLAT1=QLAT1+P/60.
```

```
            QLON1=QLON1+S/60.
            IF (IS.EQ.'S') QLAT1=-QLAT1
            IF (IE.EQ.'E') QLON1=-QLON1
C--DONT INTERPRET AN OLD STYLE INST PARAM IN COLS 18-19 AS TRIAL LAT
            IF (ABS(QLAT1).LT..4 .AND. QLON1.EQ.0.) QLAT1=0.
C--MOVE LON TO SAME SIDE OF INTL DATE LINE AS ARRAY ORIGIN
            IF (QLON1*QLON0.GE.0.) GO TO 143
            QLON1=QLON1+SIGN(360.,QLON0)
 143        T1=T+((MHOUR-KHOUR)*60+MINIT-KMIN)*60
            IF (MHOUR.EQ.0 .AND. MINIT.EQ.0 .AND. T.EQ.0.) T1=0.
 145        RETURN
C--COME HERE IF AN END OF FILE WAS ENCOUNTERED ON LAST READ
 150        KSTA=K-1
            KEND=1
            IF (KSTA.LE.1) KEND=-1
            RETURN
            END
```

HYCRU.FR

```
      SUBROUTINE HYCRU (LPRT,KSTCTL)
C--READS IN CRUSTAL MODEL
      COMMON /VELMOD/ NLAY(3),D(12,3),THK(12,3),V(12,3),VSQ(12,3)
      DO 2 MD=1,3
2     NLAY(MD)=0
      DO 10 L=1,12
      READ (3,1000,END=20) (V(L,MD),D(L,MD),MD=1,3)
1000  FORMAT (6F5.2)
      DO 10 MD=1,3
      IF (V(L,MD).GT.0.) NLAY(MD)=L
      IF (L.GT.1) THK(L-1,MD)=D(L,MD)-D(L-1,MD)
10    VSQ(L,MD)=V(L,MD)**2
C--STOP IF NO MODEL GIVEN
20    IF (NLAY(1).GT.0) GO TO 30
      WRITE (LPRT,1001)
1001  FORMAT (1X,'NO CRUSTAL MODEL, SO STOP')
      STOP
C--DEFINE THK FOR HALFSPACE
30    DO 35 MD=1,3
35    IF (NLAY(MD).GT.0) THK(NLAY(MD),MD)=999.
      IF (KSTCTL.EQ.0) RETURN
C--LIST CRUSTAL MODEL
      WRITE (LPRT,1002)
1002  FORMAT (/' CRUST'/' MODEL:',8X,'1',22X,'2',22X,'3'
     2/' LAYER ',3('VEL',3X,'DEPTH  THICK',5X))
      DO 40 L=1,12
40    WRITE (LPRT,1003) L,(V(L,MD),D(L,MD),THK(L,MD),MD=1,3)
1003  FORMAT (1X,I3,3(3F7.3,2X))
      RETURN
      END
```

HYCRU3.FR

```
      SUBROUTINE HYCRU (LPRT,KSTCTL)
C--READS IN CONDENSED TRAVEL TIME TABLE FOR LINEAR GRADIENT CRUSTAL MODEL
C--READS HEADER INFORMATION AND REDUCED TRAVEL TIMES GENERATED BY
C--THE PROGRAM TTGEN
      LOGICAL GD1,GD2,GZ1,GZ2
      COMMON /TTAB/ DD1,ND1,DD2,DZ1,NZ1,DZ2,ND,NZ,REDV,ND2,NZ2
      COMMON /TTAB/ KDHR(28),KT(28,42)
      COMMON /TTAB/ ZM(15),VM(15),GD1,GD2,GZ1,GZ2,LAY
      DIMENSION ITITL(10)
C--READ HEADER INFO: TITLE, VELOCITY MODEL USED,ONE OVER REDUCING VELOCITY
      READ (3,1000) ITITL,LAY,REDV
1000  FORMAT (10A2,I2,F8.4)
      READ (3,1001) (ZM(I),I=1,LAY)
      READ (3,1001) (VM(I),I=1,LAY)
1001  FORMAT (15F5.2)
C--OPTIONALLY PRINT OUT MODEL USED
      IF (KSTCTL.EQ.1) WRITE (LPRT,1002) ITITL,(I,VM(I),ZM(I),I=1,LAY)
1002  FORMAT (/' LINEAR GRADIENT CRUST '10A2/' LAYER VEL   DEPTH'
     2 15(/I3,2F7.3))
C--READ DISTANCE AND DEPTH GRID INFO
      READ (3,1003) DD1,ND1,DD2,ND2,DZ1,NZ1,DZ2,NZ2
1003  FORMAT (F7.4,I3,F7.4,I3)
      ND=ND1+ND2+1
      NZ=NZ1+NZ2+1
C--READ IN REDUCED TRAVEL TIMES
C--DEPTH LOOP
      DO 20 J=1,NZ
C--READ DISTANCE AT WHICH A HORIZONTALLY EMERGENT RAY REACHES THE SURFACE
      READ (3,1004) KDHR(J)
1004  FORMAT (20X,I10)
C--READ REDUCED INTEGER TRAVEL TIMES, IN UNITS OF 1/SCFAC SEC
20    READ (3,1005) (KT(J,I),I=1,ND)
1005  FORMAT (15I6)
      GD1=ND1.NE.0 .AND. DD1.NE.0.
      GD2=ND2.NE.0 .AND. DD2.NE.0.
      GZ1=NZ1.NE.0 .AND. DZ1.NE.0.
      GZ2=NZ2.NE.0 .AND. DZ2.NE.0.
      RETURN
      END
```

HYLOC.FR

```
      SUBROUTINE HYLOC
C--LOCATES ONE EARTHQUAKE FOR THE MAIN PROGRAM HYPINV
      INCLUDE 'HYPCOM'
C--FILE HYPCOM CONTAINS THE COMMON BLOCKS INCLUDED IN MANY HYPINV SUBS
C--BLANK COMMON IS FOR COMMUNICATION BETWEEN SUBROUTINES
      LOGICAL DONE
C--CURRENT EPICENTRAL COORDS, INITIALIZED TO TRIAL VALUES
      COMMON T1,QLAT1,QLON1,Z1,LAT,XLTM,LON,XLNM,DONE,IE,IS
C--EVENT TIME, MAGNITUDE AND SIMPLIFIED ERRORS
      COMMON KYEAR,KMONTH,KDAY,KHOUR,KMIN,FMAG,XMAG,RMS,ERH,ERZ,RMSWT
C-- ERROR ELLIPSE AND DELAY MODEL PARAMETERS
      COMMON DLYBAL,DLYAZ,DLYWD,SERR(3),IAZ(3),IDIP(3),V(4,4)
C--OTHER PARAMETERS KEPT FOR EACH EVENT
      COMMON ITR,DMIN,REMK,KSTA,KEND,MAXGAP,NFRM,NWR,NWS,M,KPRINT
C--CONDENSED MASTER STATION TABLE
      COMMON QLAT0,QLON0,JSTA,STANAM(300),JLAT(300),JLON(300),JCAL(300)
      COMMON JMCOR(300),JPD1(300),JPD2(300),JSD1(300),JSD2(300)
C--CONDENSED INFO FROM EACH STATION REPORTING AN EVENT
      COMMON KINDX(160),KP(160),KS(160),KTCAL(160),KDIS(160),KAZEM(160)
      COMMON KPRK(160),KSRK(160),KFM(160),KWT(160),KFMP(160),KMAG(160)
      COMMON KRMK(160),KCCOR(160),KAMP(160)
C--INDEX, RESIDUAL, WEIGHT, AND IMPORTANCE OF EACH PHASE (P OR S)
      COMMON IND(240),R(240),W(240),IMPORT(240)
C--COMMON BLOCK /TEST/ IS FOR FIXED CONSTANTS SET IN BLOCK DATA
C--WHEN TO QUIT OR DAMP ITERATIONS
      COMMON /TEST/ ITRLIM,DQUIT,DXFIX,DZMAX,DZAIR,DAMP,DRQT,EIGTOL
     2 ,RBACK,BACFAC
C--DISTANCE, RESIDUAL AND S WEIGHTING
      COMMON /TEST/ DISCUT,DISW1,DISW2,RMSCUT,RMSW1,RMSW2,SWT
C--FMAG CONSTANTS
      COMMON /TEST/ FMA1,FMB1,FMZ1,FMD1,FMBRK,FMA2,FMB2,FMZ2,FMD2
C--I/O DEVICES AND MAX NOS OF STATIONS, PHASE CARDS AND P/S PHASES
      COMMON /TEST/ LINP,LPRT,LOUT,MAXSTA,MAXPHS,MMAX
C--MODEL, ERROR AND PAGE CONSTANTS
      COMMON /TEST/ POS,ZTR,RDERR,ERCOF,KEJCT,KINFO
C--SET BLANKS, DEG/RAD, AND EVENT COUNT INDEX
      COMMON  /TEST/ LB,BL,RDEG,LOCNUM,PI
      DIMENSION A(240,5),EIGVAL(4),COVAR(4,4),Y(4)
      DIMENSION XMON(12),XLABL(4)
      DIMENSION AIN(240),T(240),DTDR(240),DTDZ(240)
      EQUIVALENCE (A(1,1),AIN(1)),(A(1,2),T(1)),(A(1,3),DTDR(1))
     2 ,(A(1,4),DTDZ(1))
      DATA XMON/'JAN','FEB','MAR','APR','MAY','JUN','JUL','AUG','SEP',
     2 'OCT','NOV','DEC'/
      DATA XLABL/'OT ','LAT','LON','Z  '/,NRES/2/
C--INITIALIZE VARIABLES
      MM2=MMAX
      LOCNUM=LOCNUM+1
      KTEMP=30000
      IF (Z1.EQ.0.) Z1=ZTR
      KTMP2=2
      KDFIX=0
      IF (Z1.GE.0.) GO TO 5
      Z1=-Z1
      KDFIX=1
5     N=3
      NLAST=3
      ITR=0
      DONE=.FALSE.
```

```
      RMSMIN=10000.
      OLDRMS=10000.
C--DETERMINE EARLIEST ARRIVING STATION AND USE ITS COORDS AS TRIAL LOC
      DO 100 K=1,KSTA
      LSWT=KWT(K)/10
      LPWT=KWT(K)-LSWT*10
      IF (LPWT.GT.3 .OR. KP(K)+KCCOR(K).GT.KTEMP .OR. KPRK(K).EQ.LH)
     2  GO TO 100
      K2=KTMP2
      KTMP2=K
      J=KINDX(K)
      KTEMP=KP(K)+KCCOR(K)
100   CONTINUE
C--SET A TRIAL COORDINATE ONLY IF IT WASN'T GIVEN ON INST CARD
      IF (QLAT1.EQ.0.) QLAT1=JLAT(J)/3000.+QLAT0+.005
      IF (QLON1.EQ.0.) QLON1=JLON(J)/3000.+QLON0+.005
      IF (T1.EQ.0.) T1=KTEMP/100.-2.
      IF (KPRINT.LT.1) GO TO 210
C--PRINT THE EVENT DATE AND TIME AS HEADING
      WRITE (LPRT,1005) KEJCT,KDAY,XMON(KMONTH),KYEAR,KHOUR,KMIN,LOCNUM
1005  FORMAT (/A1,I3,1X,A3,I3,',',I3,':',I2,2X,'EVENT NO.',I4/)
C--BEGIN ITERATION LOOP
C*****************************************************************
210   M=0
      NWR=0
      ITR=ITR+1
C--DECIDE WHICH DELAY MODEL TO USE FOR THIS LOCATION.
C--DF IS THE EPICENTRAL DISTANCE FROM THE FAULT OR OTHER LINE.
C--DLYBAL MAY DEPEND ON EPI POSITION AND GIVES THE ACTUAL DELAY AS A
C--WEIGHTED AVERAGE OF THE 2 DELAY MODELS.
C--DLYBAL=0 FOR DELAY MODEL 1
      DLYBAL=1.
      IF (DLYAZ.LT.-900.) GO TO 215
      DLYBAL=0.
      IF (DLYAZ.GT.900.) GO TO 215
      DF=111.195*((QLAT1-QLAT0)*SIN(DLYAZ/RDEG)+(QLON1-QLON0)*
     2 COS((QLAT1+QLAT0)*.5/RDEG)*COS(DLYAZ/RDEG))
      IF (DF.GE.DLYWD) GO TO 215
      DLYBAL=1.
      IF (DF.LE.-DLYWD) GO TO 215
      DLYBAL=.5-.5*SIN(1.5708*DF/DLYWD)
C--LOOP OVER REPORTING STATIONS TO CALC DISTANCES
215   DO 218 K=1,KSTA
C++++++++++++++++++++++ CALC STATION DISTANCES AND AZIMUTHS +++++++++++++
      J=KINDX(K)
C--DIST AND AZIMUTH FORMULAS ARE APPROXIMATE.
C--DISTANCE ERROR IS LESS THAN 3.E-10*D**3 FOR D IN KM AND LATS BETWEEN +/- 70
C--THIS GIVES A 1 KM ERROR AT 700 KM.
C--TEMP=LAT DIFFERENCE, TEMP2=LON DIFFERENCE
      TEMP=JLAT(J)/3000.+QLAT0-QLAT1
      TEMP2=JLON(J)/3000.+QLON0-QLON1
      TEMP3=COS((QLAT1+TEMP*.5)/RDEG)
C--AZIMUTH TO STATION IN DEG BETWEEN +/- 180
      KTEMP=RDEG*ATAN2(-TEMP2*TEMP3,TEMP)
      KAZEM(K)=180*KTEMP
      DELTKM=111.195*SQRT(TEMP**2+(TEMP2*TEMP3)**2)
C--DISTANCE IN .05 KM
218   KDIS(K)=20.*DELTKM+.5
C--TEMP3 IS THE DISTANCE WEIGHTING SCALE FACTOR
      TEMP3=KDIS(K2)*.05
      IF (TEMP3.LT.DISCUT) TEMP3=DISCUT
      TEMP=TEMP3*DISW1
      TEMP2=TEMP3*DISW2
```

```
C--LOOP OVER REPORTING STATIONS TO CALC DIST WT + LOG IN TIMES
      DO 250 K=1,KSTA
      J=KINDX(K)
      DELTKM=KDIS(K)*.05
C+++++++++++++++++ APPLY DISTANCE AND STATION WEIGHT +++++++++++++
      WFAC=0.
      KTEMP=JMCOR(J)/10000
      IF (DELTKM.GT.TEMP2 .OR. KTEMP.NE.1) GO TO 220
      WFAC=1.
      IF (DELTKM.LT.TEMP) GO TO 220
      WFAC=.5*COS(PI*(DELTKM-TEMP)/(TEMP2-TEMP))+.5
C+++++++++++++++++ LOG IN ARRIVAL TIMES +++++++++++++++++++
C--LOG IN P ARRIVAL TIMES AND WEIGHTS
220   LSWT=KWT(K)/10
      LPWT=KWT(K)-10*LSWT
      IF (KPRK(K).EQ.LB .AND. (KAMP(K)+KFMP(K).EQ.0 .OR. KSRK(K).NE.LB))
     2  GO TO 225
      M=M+1
      W(M)=0.
      IF (LPWT.LT.4) W(M)=.25*WFAC*(4-LPWT)
      IF (W(M).GT.0.) NWR=NWR+1
      IND(M)=K
225   IF (KSRK(K).EQ.LB) GO TO 250
C--LOG IN S ARRIVAL TIMES AND WEIGHTS
      M=M+1
      W(M)=0.
      IF (LSWT.LT.4) W(M)=.25*WFAC*(4-LSWT)*SWT
      IF (W(M).GT.0.) NWR=NWR+1
C--USE IND BOTH TO INDEX ARRIVALS TO PHASE CARDS AND FLAG S ARRIVALS
      IND(M)=K+10000
250   CONTINUE
      IF (M.LT.4) GO TO 500
C++++++++++++++ CALC ALL TRAVEL TIMES AND DERIVS ++++++++++++++++++++
      CALL HYTRV (Z1,M,IND,KINDX,JPD2,KDIS,AIN,T,DTDR,DTDZ)
C--LOOP OVER ALL ARRIVAL TIMES TO CALC EMERGENCE ANGLES, RESIDUALS, ETC.
      DO 330 IM=1,M
C--FIND STATION INDEX AND REMOVE KPS AS AN S FLAG
      K=IND(IM)
      KPS=K/10000
      K=K-10000*KPS
      J=KINDX(K)
      JMDL=JPD2(J)/10000+1
C--RECORD EMERGENCE ANGLE AND AZIMUTH
      KTEMP=KAZEM(K)/180
      AZM=KTEMP/RDEG
      KAZEM(K)=KTEMP*180+SIGN(AIN(IM),AZM)
      KTCAL(K)=100.*T(IM)
C+++++++++++++++++ CALC DELAYS AND RESIDUALS +++++++++++++++++
C--CALC DELAYS, OBS ARRIVAL TIME, AND VEL INDEPENDENTLY FOR P AND S
C--DLYBAL=0 FOR DELAY MODEL 1
      IF (KPS.EQ.1) GO TO 315
      KTEMP=JPD1(J)
      KTMP2=JPD2(J)-(JMDL-1)*10000-5000
      PSFAC=1.
      R(IM)=KP(K)
      GO TO 320
315   KTEMP=JSD1(J)
      KTMP2=JSD2(J)
      PSFAC=POS
      R(IM)=KS(K)
320   DLY=DLYBAL*KTMP2+(1.-DLYBAL)*KTEMP
C--CALC TRAVEL TIME RESIDUAL
      R(IM)=.01*(R(IM)-KTCAL(K)*PSFAC-DLY+KCCOR(K))-T1
```

```
C--SET DERIVATIVES
C--(1)=DTDT,(2)=DTDY,(3)=DTDX,(4)=DTDZ
      A(IM,1)=1.
      TEMP=PSFAC*DTDR(IM)
      A(IM,2)=-TEMP*COS(AZM)
      A(IM,3)= TEMP*SIN(AZM)
C--SET DT/DZ, WHICH MAY BE UNUSED IF N=3
      A(IM,4)=PSFAC*DTDZ(IM)
330   CONTINUE
C++++++++++++++++ RESIDUAL WEIGHTING +++++++++++++++++++
C--LOOP TO APPLY RESIDUAL WEIGHTING NRES TIMES
C--NRES WILL APPROXIMATE THE NUMBER OF VERY LARGE RESIDUALS
C  TO BE DISCARDED BEFORE INVERTING FOR THE HYPOCENTER
C--IF NRES=1, ONLY 1 VERY LARGE RESIDUAL WILL BE DISCARDED,
C  LEAVING ERRORS IN THE REMAINING DATA TO CONTAMINATE THE SOLUTION
      DO 335 IRES=1,NRES
      RMSWT=0.
      WNORM=0.
      DO 332 IM=1,M
C--ACCUMULATE RMSWT AND WEIGHTS
      WNORM=WNORM+W(IM)**2
332   RMSWT=RMSWT+(W(IM)*R(IM))**2
      IF (WNORM.EQ.0.) GO TO 500
      RMSWT=SQRT(RMSWT/WNORM)
C--DON'T SHRINK RESIDUAL WEIGHTING LIMITS IF RMSWT BECOMES TOO SMALL
      TEMP2=RMSWT
      IF (TEMP2.LT.RMSCUT) TEMP2=RMSCUT
      TEMP=(RMSW2-RMSW1)*TEMP2
      NWR=0
      WNORM=0.
C--LOOP TO CALC AND APPLY RESIDUAL WEIGHTING FOR ALL ARRIVALS
      DO 335 IM=1,M
      IF (W(IM).EQ.0.) GO TO 335
      RES=ABS(R(IM))
      RES=(RES-RMSW1*TEMP2)/TEMP
      IF (RES.GT.1.) GO TO 334
      IF (RES.LT.0.) GO TO 333
      W(IM)=W(IM)*(.5+.5*COS(PI*RES))
333   WNORM=WNORM+W(IM)
      NWR=NWR+1
      GO TO 335
334   W(IM)=0.
335   CONTINUE
      WFAC=NWR/WNORM
      WNORM=0.
      RMS=0.
      NWS=0
      NWR=0
C--NOW NORMALIZE WEIGHTS AND APPLY THEM TO PARTIAL DERIVATIVES
      DO 350 IM=1,M
C--NORMALIZE WEIGHTS
      W(IM)=W(IM)*WFAC
      WNORM=WNORM+W(IM)**2
      RMS=RMS+(R(IM)*W(IM))**2
C--COUNT WEIGHTED ARRIVALS
      IF (W(IM).LT..1) GO TO 337
      NWR=NWR+1
      K=IND(IM)
      KPS=K/10000
      IF (KPS.NE.0) NWS=NWS+1
C--APPLY WEIGHTS TO PARTIAL DERIVS
337   DO 340 I=1,N
340   A(IM,I)=A(IM,I)*W(IM)
```

```
C--LOAD THE DATA VECTOR R INTO THE N+1ST COL OF A FOR INVERSION IN SOLVE
350   A(IM,N+1)=R(IM)*W(IM)
      RMS=SQRT(RMS/WNORM)
      IF (NWR.LT.4) GO TO 500
C--MAKE THIS THE LAST ITER IF CHANGE IN RMS OR ADJUST VECTOR IS SMALL
      IF (((N+NLAST.EQ.8 .OR. KDFIX.EQ.1) .AND. ABS(OLDRMS-RMS).LT.DRQT)
     2 .OR. (ITR.GT.ITRLIM .AND. RMS.LT.RMSMIN+RBACK)) DONE=.TRUE.
C--GO BACK TOWARD OLD SOLUTION IF RMS INCREASED LAST TIME
      IF (RMS.GT.RMSMIN+RBACK .AND. .NOT.DONE) GO TO 370
C+++++++++++++++ INVERT FOR HYPO ADJUSTMENT +++++++++++++++++++++++++
C--DO INVERSION FOR 1 ITER, FINDING OTHER USEFUL MATRICES IF REQUESTED
      CALL HYSOL (A,EIGVAL,N,NLAST,Y,COVAR,RR,MM2,NFREE,KDFIX)
C--PREVENT HYPO FROM ITERATING INTO THE AIR, AND DAMP OTHER ADJUSTMENTS
      IF (Z1+Y(4).GT.0.) GO TO 364
      IF (KPRINT.GT.1) WRITE (LPRT,1210)
1210  FORMAT (' AIRQUAKE PREVENTED')
      Y(4)=-DZAIR*Z1
      DO 360 I=1,3
360   Y(I)=Y(I)*DZAIR
C--DAMP DEPTH ADJUSTMENT
364   IF (ABS(Y(4)).LT.DZMAX) GO TO 366
      IF (KPRINT.GT.1) WRITE (LPRT,1220)
1220  FORMAT (' DEPTH VARIATION DAMPED')
      Y(4)=Y(4)*DZMAX/(ABS(Y(4))+DZMAX)
C--SAVE RMS AND COMPUTE ADJUSTMENT VECTOR LENGTH
366   OLDRMS=RMS
      IF (RMS.LT.RMSMIN) RMSMIN=RMS
      JBAC=0
      RR=0.
      DO 368 I=2,4
368   RR=RR+Y(I)**2
      RR=SQRT(RR)
      GO TO 380
C--IF RMS INCREASED ON LAST ITER, MOVE HYPO BACK TOWARD LAST LOC
370   JBAC=JBAC+1
      OLDRMS=RMS
      IF (RMS.LT.RMSMIN) RMSMIN=RMS
      IF (JBAC.EQ.1) GO TO 371
      DO 376 I=1,4
376   Y(I)=(1.-BACFAC)*Y(I)
      RR=RR*(1.-BACFAC)
      GO TO 373
371   DO 372 I=1,4
372   Y(I)=-BACFAC*Y(I)
      RR=RR*BACFAC
373   IF (KPRINT.GT.1) WRITE(LPRT,1006) BACFAC
1006  FORMAT (' RMS INCREASE - MOVE HYPO ',F4.2,' BACK')
C+++++++++++++++ PRINT INVERSION INFO +++++++++++++++++++++
C--GET COORDS IN DEG AND MIN, AND WRITE LOC FOR THIS ITERATION
C--LOCATION IS THAT PRIOR TO ADJUSTMENTS GIVEN
380   IS=' '
      IE=' '
      IF (QLAT1.LT.0.) IS='S'
      TEMP=ABS(QLAT1)
      LAT=TEMP
      XLTM=60.*(TEMP-LAT)
      TEMP=QLON1
      IF (TEMP.LT.-180.)TEMP=TEMP+360.
      IF (TEMP.GT.180.) TEMP=TEMP-360.
      IF (TEMP.LT.0.)IE='E'
      TEMP=ABS(TEMP)
      LON=TEMP
      XLNM=60.*(TEMP-LON)
```

```
      IF (KPRINT.LT.5 .AND. ITR.GT.1 .OR. KPRINT.LT.2) GO TO 390
      WRITE (LPRT,1010)
1010  FORMAT (55X,'ADJUSTMENTS (KM)'/'  I ORIGIN   LAT N',4X,'LON W',
     2 5X,'Z  NWR  RMS   DT',4X,'DLAT   DLON',4X,'DZ',4X,'RR NF')
390   IF (KPRINT.GT.1) WRITE (LPRT,1020) ITR,T1,LAT,IS,XLTM,LON,IE,
     2 XLNM,Z1,NWR,RMS,Y,RR,NFREE
1020  FORMAT (1X,I2,F7.2,I3,A1,F5.2,I4,A1,F5.2,F6.2,I3,F5.2,F6.3,3F7.3
     2 ,F6.3,I2)
      IF (KPRINT.LT.3) GO TO 450
      IF (DONE) GO TO 410
      IF (KPRINT.LT.5) GO TO 450
410   WRITE (LPRT,1100) EIGVAL
1100  FORMAT (/10X,'EIGENVALUES'/4X,'(',4F5.3,')',38X,
     2 '#ERROR ELLIPSE'/2X,'EIGENVECTORS OF ADJUSTMENT',
     3 8X,'COVARIANCE',11X,'ERRORS #  SERR AZ DIP')
      DO 420 I=1,3
      TEMP=SQRT(COVAR(I,I))
420   WRITE (LPRT,1101) XLABL(I),(V(I,J),J=1,4),(COVAR(I,J),J=1,4),
     2 TEMP,SERR(I),IAZ(I),IDIP(I)
1101  FORMAT (1X,A3,'(',4F5.3,')(',4F7.3,')',F7.3,1X,'#',F6.2,I4,I3)
      TEMP=SQRT(COVAR(4,4))
      WRITE (LPRT,1101) XLABL(4),(V(4,J),J=1,4),(COVAR(4,J),J=1,4),
     2 TEMP
450   IF (DONE) GO TO 510
      IF (KPRINT.GT.5) CALL HYLST
C++++++++++++++++++++ ADJUST HYPOCENTER ++++++++++++++++++++
      T1=T1+Y(1)
      QLAT1=QLAT1+Y(2)/111.19
      QLON1=QLON1+Y(3)/(111.19*COS(QLAT1/RDEG))
      Z1=Z1+Y(4)
C--FREE THE FOCAL DEPTH ON NEXT ITER IF ADJ IS SMALL ENOUGH
      NLAST=N
      IF (N.EQ.4 .OR. RR.GT.DXFIX .OR. KDFIX.EQ.1) GO TO 210
      N=4
      IF (KPRINT.GT.1) WRITE (LPRT,1230)
1230  FORMAT (' FOCAL DEPTH FREED')
      GO TO 210
C--END ITERATION LOOP
C*****************************************************************
C--ABANDON SOLUTION WITH INSUFFICIENT DATA
500   IF (KPRINT.GT.0) CALL HYLST
      WRITE (LPRT,1052) NWR
1052  FORMAT (1X,I1,' WEIGHTED PHASES ARE INSUFFICIENT FOR A SOLN')
510   RETURN
      END
```

HYSOL.FR

```
      SUBROUTINE HYSOL (A,EIGVAL,N,NLAST,Y,COVAR,RR,MM2,NFREE,KDFIX)
C--USES SVD TO INVERT THE PARTIAL DERIV MATRIX A FOR THE HYPO ADJUSTMENT
C--VECTOR Y. ALSO CALCULATES EIGENVALUES, EIGENVECTORS, COVARIANCE,
C--IMPORTANCE, AND ERROR ELLIPSE.
      LOGICAL WITHU
      INCLUDE 'HYPCOM'
C--FILE HYPCOM CONTAINS THE COMMON BLOCKS INCLUDED IN MANY HYPINV SUBS
C--BLANK COMMON IS FOR COMMUNICATION BETWEEN SUBROUTINES
      LOGICAL DONE
C--CURRENT EPICENTRAL COORDS, INITIALIZED TO TRIAL VALUES
      COMMON T1,QLAT1,QLON1,Z1,LAT,XLTM,LON,XLNM,DONE,IE,IS
C--EVENT TIME, MAGNITUDE AND SIMPLIFIED ERRORS
      COMMON KYEAR,KMONTH,KDAY,KHOUR,KMIN,FMAG,XMAG,RMS,ERH,ERZ,RMSWT
C-- ERROR ELLIPSE AND DELAY MODEL PARAMETERS
      COMMON DLYBAL,DLYAZ,DLYWD,SERR(3),IAZ(3),IDIP(3),V(4,4)
C--OTHER PARAMETERS KEPT FOR EACH EVENT
      COMMON ITR,DMIN,REMK,KSTA,KEND,MAXGAP,NFRM,NWR,NWS,M,KPRINT
C--CONDENSED MASTER STATION TABLE
      COMMON QLAT0,QLON0,JSTA,STANAM(300),JLAT(300),JLON(300),JCAL(300)
      COMMON JMCOR(300),JPD1(300),JPD2(300),JSD1(300),JSD2(300)
C--CONDENSED INFO FROM EACH STATION REPORTING AN EVENT
      COMMON KINDX(160),KP(160),KS(160),KTCAL(160),KDIS(160),KAZEM(160)
      COMMON KPRK(160),KSRK(160),KFM(160),KWT(160),KFMP(160),KMAG(160)
      COMMON KRMK(160),KCCOR(160),KAMP(160)
C--INDEX, RESIDUAL, WEIGHT, AND IMPORTANCE OF EACH PHASE (P OR S)
      COMMON IND(240),R(240),W(240),IMPORT(240)
C--COMMON BLOCK /TEST/ IS FOR FIXED CONSTANTS SET IN BLOCK DATA
C--WHEN TO QUIT OR DAMP ITERATIONS
      COMMON /TEST/ ITRLIM,DQUIT,DXFIX,DZMAX,DZAIR,DAMP,DRQT,EIGTOL
     2 ,RBACK,BACFAC
C--DISTANCE, RESIDUAL AND S WEIGHTING
      COMMON /TEST/ DISCUT,DISW1,DISW2,RMSCUT,RMSW1,RMSW2,SWT
C--FMAG CONSTANTS
      COMMON /TEST/ FMA1,FMB1,FMZ1,FMD1,FMBRK,FMA2,FMB2,FMZ2,FMD2
C--I/O DEVICES AND MAX NOS OF STATIONS, PHASE CARDS AND P/S PHASES
      COMMON /TEST/ LINP,LPRT,LOUT,MAXSTA,MAXPHS,MMAX
C--MODEL, ERROR AND PAGE CONSTANTS
      COMMON /TEST/ POS,ZTR,RDERR,ERCOF,KEJCT,KINFO
C--SET BLANKS, DEG/RAD, AND EVENT COUNT INDEX
      COMMON  /TEST/ LB,BL,RDEG,LOCNUM,PI
      DIMENSION A(MM2,5),EIGVAL(4),Y(4),COVAR(4,4),V3(3,3)
      WITHU=.TRUE.
      IF (KINFO.EQ.0 .OR. KPRINT.LT.1) WITHU=.FALSE.
      DO 2 I=1,4
2     EIGVAL(I)=0.
C--OBTAIN THE SVD OF MATRIX A.
C--THE DATA VECTOR OF TT RESIDUALS R IS INPUT IN THE N+1ST COL OF A.
C--A IS REPLACED BY U AND R IS REPLACED BY UT*R IN SVD.
      CALL HYSVD (A,EIGVAL,V,MMAX,4,M,N,1,WITHU,.TRUE.)
C--CALCULATE ADJUSTMENT VECTOR Y AS V*S**-1*(UT*R)
C--NFREE IS THE ACTUAL DEGREES OF FREEDOM USED
C--(THE NO. OF EIGENVALUES > EIGTOL)
      NFREE=0
      DO 5 I=1,N
      IF (EIGVAL(I).GT.EIGTOL) NFREE=NFREE+1
5     CONTINUE
      DO 10 I=1,4
      Y(I)=0.
      IF (I.GT.N) GO TO 10
```

```
      DO 10 J=1,NFREE
      Y(I)=Y(I)+V(I,J)*A(J,N+1)/EIGVAL(J)
10    CONTINUE
C--DAMP THE ADJUSTMENT VECTOR
      ITD=ITRLIM*.6
      TEMP=DAMP
      IF (ITR.GT.ITD) TEMP=.5*DAMP
      DO 11 I=1,4
11    Y(I)=Y(I)*TEMP
      IF (.NOT.WITHU) GO TO 20
C--CALCULATE IMPORTANCE VECTOR AS TRACE OF INFORMATION MATRIX U*UT
      DO 15 I=1,M
      TEMP=0.
      DO 12 J=1,N
12    TEMP=TEMP+A(I,J)**2
15    IMPORT(I)=TEMP*1000.
C--FIND LENGTH OF HYPO ADJ VECTOR IN KM
20    RR=0.
      DO 25 I=2,N
25    RR=RR+Y(I)**2
      RR=SQRT(RR)
C--MAKE THIS THE LAST ITER IF ADJ IS SMALL
      IF ((N+NLAST.EQ.8 .OR. KDFIX.EQ.1) .AND. RR.LT.DQUIT) DONE=.TRUE.
C--SKIP THE ERROR CALCS IF THEY ARE NOT NEEDED
      IF (.NOT.DONE .AND. KPRINT.LT.5) GO TO 110
C--CALCULATE COVARIANCE MATRIX AS SIGMA**2 * V * EIGVAL**-2 * VT
C--ESTIMATED ARRIVAL TIME ERROR
      SIGSQ=RDERR**2+ERCOF*RMS**2
      DO 50 I=1,4
      DO 50 J=1,I
      COVAR(I,J)=0.
      IF (I.LE.N .AND. J.LE.N) GO TO 40
      IF (I.EQ.J) COVAR(I,J)=999.
      GO TO 50
40    DO 45 L=1,N
45    COVAR(I,J)=COVAR(I,J)+V(I,L)*V(J,L)/EIGVAL(L)**2
      COVAR(I,J)=SIGSQ*COVAR(I,J)
50    COVAR(J,I)=COVAR(I,J)
C--EVALUATE THE HYPOCENTER ERROR ELLIPSE BY DIAGONALIZING
C--THE SPATIAL PART OF THE COVARIANCE MATRIX
C--USE A AS TEMPORARY STORAGE
      DO 55 I=1,3
      DO 55 J=1,3
55    A(I,J)=COVAR(I+1,J+1)
      CALL HYSVD (A,SERR,V3,MMAX,3,3,3,0,.FALSE.,.TRUE.)
      DO 60 I=1,3
      SERR(I)=SQRT(SERR(I))
      IF (SERR(I).GT.99.) SERR(I)=99.
60    CONTINUE
C--COMPUTE ERH AND ERZ AS THE LARGEST OF THE HORIZ AND VERTICAL
C--PROJECTIONS OF THE PRINC STANDARD ERRORS
      ERH=0.
      ERZ=0.
      DO 65 I=1,3
      TERH=SERR(I)*SQRT(V3(1,I)**2+V3(2,I)**2)
      IF (TERH.GT.ERH) ERH=TERH
      TERZ=SERR(I)*ABS(V3(3,I))
      IF (TERZ.GT.ERZ) ERZ=TERZ
65    CONTINUE
      IF (ERZ.GT.99.) ERZ=99.
      IF (ERH.GT.99.) ERH=99.
C--NOW CALC THE ORIENTATIONS OF THE PRINC STD ERRORS
      DO 90 J=1,3
```

```
            IAZ(J)=0
            IDIP(J)=90
            TERH=SQRT(V3(1,J)**2+V3(2,J)**2)
            IF (TERH.EQ.0.) GO TO 90
            IAZ(J)=RDEG*ATAN2(-V3(2,J),V3(1,J))
            IDIP(J)=RDEG*ATAN2(V3(3,J),TERH)
            IF (IDIP(J).GT.-1) GO TO 80
            IDIP(J)=-IDIP(J)
            IAZ(J)=IAZ(J)+180
   80       IF (IAZ(J).LT.0) IAZ(J)=IAZ(J)+360
   90       CONTINUE
  110       RETURN
            END
```

HYSVD.FR

```
C      *********************  START OF SVD  *****************************
C
       SUBROUTINE  HYSVD  (A, S, V, MMAX, NMAX, M, N, P, WITHU, WITHV)
C
       INTEGER     MMAX, NMAX, M, N, P
       REAL        R, W, CS, SN, TOL, F, X, EPS, G, T, Y
       REAL        ETA, H, Q, Z
       INTEGER     I, J, K, L, L1, N1, NP
       LOGICAL     WITHU, WITHV
       DIMENSION        A(MMAX,60), S(NMAX), V(NMAX,NMAX)
C
C      -----------------------------------------------------------------
C
C      THIS IS A TRANSLATION OF A CDC 6600 FORTRAN PROGRAM TO IBM 360
C      FORTRAN IV.  THIS SUBROUTINE USES SHORT PRECISION ARITHMETIC.
C      A LONG PRECISION VERSION IS AVAILABLE UNDER THE NAME 'DSVD'.
C
C      THIS SUBROUTINE REPLACES EARLIER SUBROUTINES WITH THE SAME NAME,
C     689   6       &   &0&  S OF A COMPLEX AR&THMETIC PROGRAM, PUBLISHED
C      AS ALGORITHM 358.  THIS CURRENT PROGRAM IS FASTER, MORE ACCURATE
C      AND LESS OBSCURE IN DESCRIBING ITS CAPABILITIES.
C
C      ORIGINAL PROGRAMMER=  R. C. SINGLETON
C      360 VERSION BY=       J. G. LEWIS
C      LAST REVISION OF THIS SUBROUTINE=  4 DECEMBER 1973
C
C      -----------------------------------------------------------------
C
C      ADDITIONAL SUBROUTINE NEEDED=  ROTATE
C
C      -----------------------------------------------------------------
C
C
C      THIS SUBROUTINE COMPUTES THE SINGULAR VALUE DECOMPOSITION
C      OF A REAL M*N MATRIX A, I.E. IT COMPUTES MATRICES U, S, AND V
C      SUCH THAT
C
C                   A = U * S * VT ,
C      WHERE
C               U IS AN M*N MATRIX AND UT*U = I, (UT=TRANSPOSE
C                                                  OF U),
C               V IS AN N*N MATRIX AND VT*V = I, (VT=TRANSPOSE
C                                                  OF V),
C         AND   S IS AN N*N DIAGONAL MATRIX.
C
C      DESCRIPTION OF PARAMETERS=
C
C      A = REAL ARRAY. A CONTAINS THE MATRIX TO BE DECOMPOSED.
C          THE ORIGINAL DATA ARE LOST.  IF WITHV=.TRUE., THEN
C          THE MATRIX U IS COMPUTED AND STORED IN THE ARRAY A.
C
C      MMAX = INTEGER VARIABLE.  THE NUMBER OF ROWS IN THE
C             ARRAY A.
C
C      NMAX = INTEGER VARIABLE.  THE NUMBER OF ROWS IN THE
C             ARRAY V.
C
C      M,N = INTEGER VARIABLES.  THE NUMBER OF ROWS AND COLUMNS
C            IN THE MATRIX STORED IN A.  (NG=MG=100.  IF IT IS
```

```
C             NECESSARY TO SOLVE A LARGER PROBLEM, THEN THE
C             AMOUNT OF STORAGE ALLOCATED TO THE ARRAY T MUST
C             BE INCREASED ACCORDINGLY.)  IF MLT N , THEN EITHER
C             TRANSPOSE THE MATRIX A OR ADD ROWS OF ZEROS TO
C             INCREASE M TO N.
C
C       P = INTEGER VARIABLE.  IF P'0, THEN COLUMNS N+1, . . . ,
C           N+P OF A ARE ASSUMED TO CONTAIN THE COLUMNS OF AN M*P
C           MATRIX B.  THIS MATRIX IS MULTIPLIED BY UT, AND UPON
C           EXIT, A CONTAINS IN THESE SAME COLUMNS THE N*P MATRIX
C           UT*B. (P'=0)
C
C       WITHU, WITHV = LOGICAL VARIABLES.  IF WITHU=.TRUE., THEN
C           THE MATRIX U IS COMPUTED AND STORED IN THE ARRAY A.
C           IF WITHV=.TRUE., THEN THE MATRIX V IS COMPUTED AND
C           STORED IN THE ARRAY V.
C
C       S = REAL ARRAY.  S(1), . . . , S(N) CONTAIN THE DIAGONAL
C           ELEMENTS OF THE MATRIX S ORDERED SO THAN S(I)>=S(I+1),
C           I=1, . . . , N-1.
C
C       V = REAL ARRAY.  V CONTAINS THE MATRIX V.  IF WITHU
C           AND WITHV ARE NOT BOTH =.TRUE., THEN THE ACTUAL
C           PARAMETER CORRESPONDING TO A AND V MAY BE THE SAME.
C
C       THIS SUBROUTINE IS A REAL VERSION OF A FORTRAN SUBROUTINE
C       BY BUSINGER AND GOLUB, ALGORITHM 358=  SINGULAR VALUE
C       DECOMPOSITION OF A COMPLEX MATRIX, COMM. ACM, V. 12,
C       NO. 10, PP. 564-565 (OCT. 1969).
C       WITH REVISIONS BY RC SINGLETON, MAY 1972.
C       ----------------------------------------------------------------
C
        DIMENSION  T(250)
C
C      ECLIPSE CONSTANTS
        DATA ETA,TOL/1.9E-7,1.1E-30/
C
C       DATA ETA,TOL /1.5E-15,1.E-250/
C
C
C       ETA (16**-6) AND TOL (16**-59) ARE MACHINE DEPENDENT CONSTANTS
C       FOR IBM 360/370 COMPUTERS (SHORT FORM ARITHMETIC).
C       ETA IS THE MACHINE EPSILON (RELATIVE ACCURACY)!
C       TOL IS THE SMALLEST REPRESENTABLE REAL DIVIDED BY ETA.
C
        NP = N + P
        N1 = N + 1
C
C       HOUSEHOLDER REDUCTION TO BIDIAGONAL FORM
        G = 0.0
        EPS = 0.0
        L = 1
     10 T(L) = G
        K = L
        L = L + 1
C
C       ELIMINATION OF A(I,K), I=K+1, . . . , M
        S(K) = 0.0
        Z = 0.0
        DO 20 I = K,M
     20    Z = Z + A(I,K)**2
        IF (Z.LT.TOL) GOTO 50
        G = SQRT(Z)
```

```
      F = A(K,K)
      IF (F.GE.0.0) G = - G
      S(K) = G
      H = G * (F - G)
      A(K,K) = F - G
      IF (K.EQ.NP) GOTO 50
      DO 40 J = L,NP
         F = 0
         DO 30 I = K,M
   30       F = F + A(I,K)*A(I,J)
         F = F/H
         DO 40 I = K,M
   40       A(I,J) = A(I,J) + F*A(I,K)
C
C     ELIMINATION OF A(K,J), J=K+2, . . . , N
   50 EPS = AMAX1(EPS,ABS(S(K)) + ABS(T(K)))
      IF (K.EQ.N) GOTO 100
      G = 0.0
      Z = 0.0
      DO 60 J = L,N
   60    Z = Z + A(K,J)**2
      IF (Z.LT.TOL) GOTO 10
      G = SQRT(Z)
      F = A(K,L)
      IF (F.GE.0.0) G = - G
      H = G * (F - G)
      A(K,L) = F - G
      DO 70 J = L,N
   70    T(J) = A(K,J)/H
      DO 90 I = L,M
         F = 0
         DO 80 J = L,N
   80       F = F + A(K,J)*A(I,J)
         DO 90 J = L,N
   90       A(I,J) = A(I,J) + F*T(J)
C
      GOTO 10
C
C     TOLERANCE FOR NEGLIGIBLE ELEMENTS
  100 EPS = EPS*ETA
C
C     ACCUMULATION OF TRANSFORMATIONS
      IF (.NOT.WITHV) GOTO 160
      K = N
      GOTO 140
  110    IF (T(L).EQ.0.0) GOTO 140
         H = A(K,L)*T(L)
         DO 130 J = L,N
            Q = 0
            DO 120 I = L,N
  120          Q = Q + A(K,I)*V(I,J)
            Q = Q/H
            DO 130 I = L,N
  130          V(I,J) = V(I,J) + Q*A(K,I)
  140    DO 150 J = 1,N
  150       V(K,J) = 0
         V(K,K) = 1.0
         L = K
         K = K - 1
         IF (K.NE.0) GOTO 110
C
  160 K = N
      IF (.NOT.WITHU) GOTO 230
```

```
              G = S(N)
              IF (G.NE.0.0) G = 1.0/G
              GO TO 210
      170       DO 180 J = L,N
      180          A(K,J) = 0
                G = S(K)
                IF (G.EQ.0.0) GOTO 210
                H = A(K,K)*G
                DO 200 J = L,N
                   Q = 0
                   DO 190 I = L,M
      190             Q = Q + A(I,K)*A(I,J)
                   Q = Q/H
                   DO 200 I = K,M
      200             A(I,J) = A(I,J) + Q*A(I,K)
                G = 1.0/G
      210       DO 220 J = K,M
      220          A(J,K) = A(J,K)*G
                A(K,K) = A(K,K) + 1.0
                L = K
                K = K - 1
                IF (K.NE.0) GOTO 170
C
C             QR DIAGONALIZATION
              K = N
C
C             TEST FOR SPLIT
      230       L = K
      240          IF (ABS(T(L)).LE.EPS) GOTO 290
                   L = L - 1
                   IF (ABS(S(L)).GT.EPS) GOTO 240
C
C             CANCELLATION
                CS = 0.0
                SN = 1.0
                L1 = L
                L = L + 1
                DO 280 I = L,K
                   F = SN*T(I)
                   T(I) = CS*T(I)
                   IF (ABS(F).LE.EPS) GOTO 290
                   H = S(I)
                   W = SQRT(F*F + H*H)
                   S(I) = W
                   CS = H/W
                   SN = - F/W
                   IF (WITHU) CALL HYROT(A(1,L1), A(1,I), CS, SN, M)
                   IF (NP.EQ.N) GOTO 280
                   DO 270 J = N1,NP
                      Q = A(L1,J)
                      R = A(I,J)
                      A(L1,J) = Q*CS + R*SN
     270           A(I,J) = R*CS - Q*SN
      280          CONTINUE
C
C             TEST FOR CONVERGENCE
      290       W = S(K)
                IF (L.EQ.K) GOTO 360
C
C             ORIGIN SHIFT
                X = S(L)
                Y = S(K-1)
                G = T(K-1)
```

```
            H = T(K)
            F = ((Y - W)*(Y + W) + (G - H)*(G + H))/(2.0*H*Y)
            G = SQRT(F*F + 1.0)
            IF (F.LT.0.0) G = - G
            F = ((X - W)*(X + W) + (Y/(F + G) - H)*H)/X
C
C        QR STEP
            CS = 1.0
            SN = 1.0
            L1 = L + 1
            DO 350 I = L1,K
               G = T(I)
               Y = S(I)
               H = SN*G
               G = CS*G
               W = SQRT(H*H + F*F)
               T(I-1) = W
               CS = F/W
               SN = H/W
               F = X*CS + G*SN
               G = G*CS - X*SN
               H = Y*SN
               Y = Y*CS
               IF (WITHV) CALL HYROT(V(1,I-1), V(1,I), CS, SN, N)
               W = SQRT(H*H + F*F)
               S(I-1) = W
               CS = F/W
               SN = H/W
               F = CS*G + SN*Y
               X = CS*Y - SN*G
               IF (WITHU) CALL HYROT(A(1,I-1), A(1,I), CS, SN, M)
               IF (N.EQ.NP) GOTO 350
               DO 340 J = N1,NP
                  Q = A(I-1,J)
                  R = A(I,J)
                  A(I-1,J) = Q*CS + R*SN
  340    A(I,J) = R*CS - Q*SN
   350         CONTINUE
C
            T(L) = 0.0
            T(K) = F
            S(K) = X
            GOTO 230
C
C        CONVERGENCE
   360      IF (W.GE.0.0) GOTO 380
            S(K) = - W
            IF (.NOT.WITHV) GOTO 380
            DO 370 J = 1,N
   370         V(J,K) = - V(J,K)
   380      K = K - 1
            IF (K.NE.0) GO TO 230
C
C        SORT SINGULAR VALUES
         DO 450 K = 1,N
            G = -1.0
            DO 390 I = K,N
               IF (S(I).LT.G) GOTO 390
               G = S(I)
               J = I
   390         CONTINUE
         IF (J .EQ. K) GO TO 450
         S(J) = S(K)
```

```
               S(K) = G
               IF (.NOT.WITHV) GOTO 410
               DO 400 I = 1,N
                  Q = V(I,J)
                  V(I,J) = V(I,K)
      400         V(I,K) = Q
      410      IF (.NOT.WITHU) GOTO 430
               DO 420 I = 1,M
                  Q = A(I,J)
                  A(I,J) = A(I,K)
      420         A(I,K) = Q
      430      IF (N.EQ.NP) GOTO 450
               DO 440 I = N1,NP
                  Q = A(J,I)
                  A(J,I) = A(K,I)
      440         A(K,I) = Q
      450      CONTINUE
C
            RETURN
            END
```

HYROT.FR

```
            SUBROUTINE   HYROT  (X, Y, CS, SN, N)
            INTEGER N
            REAL     X(N), Y(N), CS, SN
C
C
            REAL     XX
            INTEGER J
C
C
            DO 10 J = 1, N
               XX = X(J)
               X(J) = XX*CS + Y(J)*SN
       10      Y(J) = Y(J)*CS - XX*SN
            RETURN
            END
```

HYTRV.FR

```
      SUBROUTINE HYTRV (Z,MM,IND,KINDX,JPD2,KDIS,AIN,T,DTDD,DTDH)
      COMMON /VELMOD/ NLAY(3),D(12,3),THK(12,3),V(12,3),VSQ(12,3)
      DIMENSION TINJ(13),DIDJ(13),TR(12)
      DIMENSION IND(1),KINDX(1),JPD2(1),KDIS(1)
      DIMENSION AIN(1),T(1),DTDD(1),DTDH(1)
      ZSQ=Z*Z
C--LOOP OVER ALL ARRIVALS
      DO 280 I=1,MM
C--FIND STATION INDEX AND REMOVE KPS AS AN S FLAG
      KI=IND(I)
      KPS=KI/10000
      KI=KI-10000*KPS
      J=KINDX(KI)
C--FIND STATION MODEL AND DISTANCE
      JMDL=JPD2(J)/10000+1
      DELTA=KDIS(KI)*.05
      NL=NLAY(JMDL)
      DO 1 L=1,NL
      IF (D(L,JMDL) .GT. Z) GO TO 2
1     CONTINUE
      JL=NL
      GO TO 3
2     JJ=L
      JL=L-1
3     TKJ=Z-D(JL,JMDL)
      TKJSQ=TKJ**2+0.000001
      IF (JL .EQ. NL) GO TO 5
      DO  4 L=JJ,NL
      SQT=SQRT(VSQ(L,JMDL)-VSQ(JL,JMDL))
      TINJ(L)=HYTID(JL,L,JMDL)-TKJ*SQT/(V(L,JMDL)*V(JL,JMDL))
4     DIDJ(L)=HYDID(JL,L,JMDL)-TKJ*V(JL,JMDL)/SQT
      XOVMAX=V(JJ,JMDL)*V(JL,JMDL)*(TINJ(JJ)-HYTID(JL,JL,JMDL))/
     2 (V(JJ,JMDL)-V(JL,JMDL))
5     IF (JL .EQ. NL) GO TO 100
      DO 60 M=JJ,NL
60    TR(M)=TINJ(M)+DELTA/V(M,JMDL)
      TMIN=999.99
      DO 70 M=JJ,NL
      IF (TR(M) .GT. TMIN) GO TO 70
      IF (DIDJ(M) .GT. DELTA) GO TO 70
      K=M
      TMIN=TR(M)
70    CONTINUE
      IF (DELTA .LT. XOVMAX) GO TO 90
C--TRAVEL TIME & DERIVATIVES FOR REFRACTED WAVE
80    T(I)=TR(K)
      DTDD(I)=1.0/V(K,JMDL)
      DTDH(I)=-SQRT(VSQ(K,JMDL)-VSQ(JL,JMDL))/(V(K,JMDL)*V(JL,JMDL))
      ANIN=-V(JL,JMDL)/V(K,JMDL)
      GO TO 260
C--CALCULATION FOR DIRECT WAVE
90    IF (JL .NE. 1) GO TO 100
      SQT=SQRT(ZSQ+DELTA**2)
      TDJ1=SQT/V(1,JMDL)
      IF (TDJ1 .GE. TMIN) GO TO 80
C--TRAVEL TIME & DERIVATIVES FOR DIRECT WAVE IN FIRST LAYER
      T(I)=TDJ1
      DTDD(I)=DELTA/(V(1,JMDL)*SQT)
      DTDH(I)=Z/(V(1,JMDL)*SQT)
```

```
      ANIN=DELTA/SQT
      GO TO 260
C--FIND A DIRECT WAVE THAT WILL EMERGE AT THE STATION
100   XBIG=DELTA
      XLIT=DELTA*TKJ/Z
      UB=XBIG/SQRT(XBIG**2+TKJSQ)
      UL=XLIT/SQRT(XLIT**2+TKJSQ)
      UBSQ=UB**2
      ULSQ=UL**2
      DELBIG=TKJ*UB/SQRT(1.000001-UBSQ)
      DELLIT=TKJ*UL/SQRT(1.000001-ULSQ)
      J1=JL-1
      DO 110 L=1,J1
      DELBIG=DELBIG+(THK(L,JMDL)*UB)/SQRT(VSQ(JL,JMDL)/VSQ(L,JMDL)-UBSQ)
110   DELLIT=DELLIT+(THK(L,JMDL)*UL)/SQRT(VSQ(JL,JMDL)/VSQ(L,JMDL)-ULSQ)
      DO 170 LL=1,25
      IF (DELBIG-DELLIT.LT..02) GO TO 180
      XTR=XLIT+(DELTA-DELLIT)*(XBIG-XLIT)/(DELBIG-DELLIT)
      U=XTR/SQRT(XTR**2+TKJSQ)
      USQ=U**2
      DELXTR=TKJ*U/SQRT(1.000001-USQ)
      DO 120 L=1,J1
120   DELXTR=DELXTR+(THK(L,JMDL)*U)/SQRT(VSQ(JL,JMDL)/VSQ(L,JMDL)-USQ)
      XTEST=DELTA-DELXTR
      IF (ABS(XTEST) .LE. 0.02) GO TO 190
      IF (XTEST) 140,190,150
140   XBIG=XTR
      DELBIG=DELXTR
      GO TO 160
150   XLIT=XTR
      DELLIT=DELXTR
160   IF (LL .LT. 10) GO TO 170
      IF (1.0-U .LT. 0.0002) GO TO 190
170   CONTINUE
180   XTR=0.5*(XBIG+XLIT)
      U=XTR/SQRT(XTR**2+TKJSQ)
      USQ=U**2
190   IF (1.0-U .GT. 0.0002) GO TO 220
C--IF U IS TOO NEAR 1, COMPUTE TDIR AS WAVE ALONG THE TOP OF LAYER JL
      TDC=HYTID(JL,JL,JMDL)+DELTA/V(JL,JMDL)
      IF (JL .EQ. NL) GO TO 210
      IF (TDC .GE. TMIN) GO TO 80
210   T(I)=TDC
      DTDD(I)=1.0/V(JL,JMDL)
      DTDH(I)=0.0
      ANIN=0.9999999
      GO TO 260
C--TRAVEL TIME & DERIVATIVES FOR DIRECT WAVE BELOW FIRST LAYER
220   TDIR=TKJ/(V(JL,JMDL)*SQRT(1.0-USQ))
      DO 240 L=1,J1
240   TDIR=TDIR+(THK(L,JMDL)*V(JL,JMDL))/(VSQ(L,JMDL)*SQRT(VSQ(JL,JMDL)/
     2 VSQ(L,JMDL)-USQ))
      IF(JL .EQ. NL) GO TO 245
      IF (TDIR .GE. TMIN) GO TO 80
245   T(I)=TDIR
      SRR=SQRT(1.-USQ)
      SRT=SRR**3
      ALFA=TKJ/SRT
      BETA=TKJ*U/(V(JL,JMDL)*SRT)
      DO 250 L=1,J1
      STK=(SQRT(VSQ(JL,JMDL)/VSQ(L,JMDL)-USQ))**3
      VTK=THK(L,JMDL)/(VSQ(L,JMDL)*STK)
      ALFA=ALFA+VTK*VSQ(JL,JMDL)
```

```
 250    BETA=BETA+VTK*V(JL,JMDL)*U
        DTDD(I)=BETA/ALFA
        DTDH(I)=(1.0-V(JL,JMDL)*U*DTDD(I))/(V(JL,JMDL)*SRR)
        ANIN=U
 260    AIN(I)=57.29578*ASIN(ANIN)
        IF (AIN(I).LT.0.) AIN(I)=AIN(I)+180.
        AIN(I)=180.-AIN(I)
 280    CONTINUE
        RETURN
        END
```

HYTID.FR

```
        FUNCTION HYTID (J,M,JMDL)
C--CALLED BY HYTRV IN PROGRAM HYPOINVERSE
        COMMON /VELMOD/ NLAY(3),D(12,3),THK(12,3),V(12,3),VSQ(12,3)
        MM=M
        SUM=0.
        IF(MM.EQ.1) GO TO 110
        M1=MM-1
        DO 20 L=1,M1
        SQT=SQRT(VSQ(MM,JMDL)-VSQ(L,JMDL))
        TIM=THK(L,JMDL)*SQT/(V(L,JMDL)*V(MM,JMDL))
        FLJ=1.
        IF(L.GE.J)FLJ=2.
        SUM=SUM+FLJ*TIM
 20     CONTINUE
 110    HYTID=SUM
        RETURN
        END
```

HYDID.FR

```
        FUNCTION HYDID (J,M,JMDL)
C--CALLED BY HYTRV IN PROGRAM HYPOINVERSE
        COMMON /VELMOD/ NLAY(3),D(12,3),THK(12,3),V(12,3),VSQ(12,3)
        SUM=0.
        IF(M.EQ.1) GO TO 110
        M1=M-1
        DO 20 L=1,M1
        SQT=SQRT(VSQ(M,JMDL)-VSQ(L,JMDL))
        DM=THK(L,JMDL)*V(L,JMDL)/SQT
        FLJ=1
        IF(L.GE.J)FLJ=2.
        SUM=SUM+FLJ*DM
 20     CONTINUE
 110    HYDID=SUM
        RETURN
        END
```

HYTRV3.FR

```
      SUBROUTINE HYTRV (ZH,MM,IND,KINDX,JPD2,KDIS,AIN,T,DTDR,DTDZ)
C--GIVEN DEPTH AND DISTANCE, THIS ROUTINE CALCULATES TRAVEL TIME AND ITS
C--DERIVATIVES, AND EMERGENCE ANGLE AT THE SOURCE FOR ALL ARRIVALS.
C--HYTRV USES A CONDENSED AND REDUCED TRAVEL TIME TABLE GENERATED BY THE
C--PROGRAM TTGEN.
C--IND AND KINDX ARE INDEXING ARRAYS NECESSARY TO REFERENCE THE CORRECT
C--ELEMENTS OF THE STATION ARRAYS.
C--AIN IS THE ANGLE OF EMERGENCE AT THE SOURCE, MEASURED IN DEGREES FROM NADIR.
      LOGICAL GD1,GD2,GZ1,GZ2
      COMMON /TTAB/ DD1,ND1,DD2,DZ1,NZ1,DZ2,ND,NZ,REDV,ND2,NZ2
      COMMON /TTAB/ KDHR(28),KT(28,42)
      COMMON /TTAB/ ZM(15),VM(15),GD1,GD2,GZ1,GZ2,LAY
      DIMENSION IND(1),KINDX(1),JPD2(1),KDIS(1),AIN(1),T(1)
      DIMENSION DTDR(1),DTDZ(1),TZ(42),DTZ(42)
      DATA SCFAC/2000./
C--PERFORM DEPTH INTERPOLATION FIRST
C--FIND DEPTH INDEX = INDEX OF TABLE ENTRY NEAREST HYPOCENTER
C--ALSO DEPTH SPACING H AND FRACTION OF INTERVAL X
      TEMP=NZ1*DZ1
      IF ((.NOT.GZ1 .OR. ZH.GT.TEMP) .AND. GD2) GO TO 10
C--HYPO IN UPPER PART OF TABLE
      I=ZH/DZ1+1.5
      IF (I.GT.NZ1) I=NZ1
      IF (I.LT.2) I=2
      H=DZ1
      X=ZH/DZ1-(I-1)
      GO TO 15
C--HYPO IN LOWER PART OF TABLE
10    I=NZ1+(ZH-TEMP)/DZ2+1.5001
      IF (I.GE.NZ) I=NZ-1
      IF (I.LT.NZ1+2) I=NZ1+2
      H=DZ2
      X=(ZH-TEMP)/DZ2-(I-NZ1-1)
C--FIND EXACT VELOCITY AT HYPOCENTER
15    DO 20 K=1,LAY
      IF (ZM(K).LT.ZH) L=K
20    CONTINUE
      VH=VM(LAY)
      IF (L.LT.LAY) VH=VM(L)+(VM(L+1)-VM(L))*(ZH-ZM(L))/(ZM(L+1)-ZM(L))
C--INTERPOLATE DIST AT WHICH A HORIZONTAL RAY EMERGED
      DHRZ=(KDHR(I)+X*(KDHR(I+1)-KDHR(I)))*.1
C--DEPTH INTERPOLATION
      IF (ZH.GT.TEMP+DZ2*NZ2) GO TO 25
C--USE 3 POINT INTERPOLATION
      CA=X*.5*(X-1.)
      CB=1.-X**2
      CC=X*.5*(X+1.)
      DA=(X-.5)/H
      DB=-2.*X/H
      DC=(X+.5)/H
      GO TO 30
C--USE LINEAR EXTRAPOLATION
25    CA=0.
      CB=1.-X
      CC=X
      DA=0.
      DC=1./H
      DB=-DC
      DHRZ=1000.
```

```
C--INTERPOLATE TT AND ITS DEPTH DERIVATIVE FOR ALL DISTANCE GRID POINTS
30    TEMP=ND1*DD1
      DO 35 J=1,ND
      D=(J-1)*DD1
      IF (J.GT.ND1+1) D=TEMP+(J-ND1-1)*DD2
      TZ(J)=(CA*KT(I-1,J)+CB*KT(I,J)+CC*KT(I+1,J)+32000.)/SCFAC+D*REDV
35    DTZ(J)=(DA*KT(I-1,J)+DB*KT(I,J)+DC*KT(I+1,J))/SCFAC
C--NOW FIND TRAVEL TIME, DTDR, DTDZ, AND ANGLE OF EMERGENCE FOR EACH ARRIVAL
C--LOOP OVER ALL ARRIVALS
      DO 60 M=1,MM
C--FIND STATION INDEX AND DISTANCE
      KI=IND(M)
      KPS=KI/10000
      KI=KI-10000*KPS
      D=KDIS(KI)*.05
C--FIND DISTANCE INDEX = INDEX OF TABLE ENTRY NEAREST STATION DIST
C--ALSO DISTANCE SPACING H AND FRACTION OF INTERVAL X
      IF ((.NOT.GD1 .OR. D.GT.TEMP) .AND. GD2) GO TO 40
C--HYPO IN NEAR PART OF TABLE
      J=D/DD1+1.5
      IF (J.GT.ND1) J=ND1
      IF (J.LT.2) J=2
      H=DD1
      X=D/DD1-(J-1)
      GO TO 45
C--HYPO IN FAR PART OF TABLE
40    J=ND1+(D-TEMP)/DD2+1.5001
      IF (J.GE.ND) J=ND-1
      IF (J.LT.ND1+2) J=ND1+2
      H=DD2
      X=(D-TEMP)/DD2-(J-ND1-1)
C--DISTANCE INTERPOLATION
45    IF (D.GT.TEMP+DD2*ND2) GO TO 50
C--USE 3 POINT INTERPOLATION
      CA=X*.5*(X-1.)
      CB=1.-X**2
      CC=X*.5*(X+1.)
      DA=X-.5
      DB=-2.*X
      DC=X+.5
      GO TO 55
C--USE LINEAR EXTRAPOLATION
50    CA=0.
      CB=1.-X
      CC=X
      DA=0.
      DC=1.
      DB=-1.
C--INTERPOLATE TT AND ITS 2 DERIVATIVES
55    T(M)=CA*TZ(J-1)+CB*TZ(J)+CC*TZ(J+1)
      DTDZ(M)=CA*DTZ(J-1)+CB*DTZ(J)+CC*DTZ(J+1)
      DTDR(M)=(DA*TZ(J-1)+DB*TZ(J)+DC*TZ(J+1))/H
      IF (DTDR(M).LT.0.) DTDR(M)=0.
C--CALC EMERGENCE ANGLE
      CA=VH*DTDR(M)
      IF (CA.GT..99999) CA=.99999
      AIN(M)=57.29578*ASIN(CA)
      IF (D.LT.DHRZ) AIN(M)=180.-AIN(M)
C--END OF LOOP OVER ARRIVALS
60    CONTINUE
      RETURN
      END
```

HYLST.FR

```
      SUBROUTINE HYLST
C--DOES FINAL OUTPUT AFTER EVENT IS LOCATED
      INCLUDE 'HYPCOM'
C--FILE HYPCOM CONTAINS THE COMMON BLOCKS INCLUDED IN MANY HYPINV SUBS
C--BLANK COMMON IS FOR COMMUNICATION BETWEEN SUBROUTINES
      LOGICAL DONE
C--CURRENT EPICENTRAL COORDS, INITIALIZED TO TRIAL VALUES
      COMMON T1,QLAT1,QLON1,Z1,LAT,XLTM,LON,XLNM,DONE,IE,IS
C--EVENT TIME, MAGNITUDE AND SIMPLIFIED ERRORS
      COMMON KYEAR,KMONTH,KDAY,KHOUR,KMIN,FMAG,XMAG,RMS,ERH,ERZ,RMSWT
C-- ERROR ELLIPSE AND DELAY MODEL PARAMETERS
      COMMON DLYBAL,DLYAZ,DLYWD,SERR(3),IAZ(3),IDIP(3),V(4,4)
C--OTHER PARAMETERS KEPT FOR EACH EVENT
      COMMON ITR,DMIN,REMK,KSTA,KEND,MAXGAP,NFRM,NWR,NWS,M,KPRINT
C--CONDENSED MASTER STATION TABLE
      COMMON QLATO,QLONO,JSTA,STANAM(300),JLAT(300),JLON(300),JCAL(300)
      COMMON JMCOR(300),JPD1(300),JPD2(300),JSD1(300),JSD2(300)
C--CONDENSED INFO FROM EACH STATION REPORTING AN EVENT
      COMMON KINDX(160),KP(160),KS(160),KTCAL(160),KDIS(160),KAZEM(160)
      COMMON KPRK(160),KSRK(160),KFM(160),KWT(160),KFMP(160),KMAG(160)
      COMMON KRMK(160),KCCOR(160),KAMP(160)
C--INDEX, RESIDUAL, WEIGHT, AND IMPORTANCE OF EACH PHASE (P OR S)
      COMMON IND(240),R(240),W(240),IMPORT(240)
C--COMMON BLOCK /TEST/ IS FOR FIXED CONSTANTS SET IN BLOCK DATA
C--WHEN TO QUIT OR DAMP ITERATIONS
      COMMON /TEST/ ITRLIM,DQUIT,DXFIX,DZMAX,DZAIR,DAMP,DRQT,EIGTOL
     2 ,RBACK,BACFAC
C--DISTANCE, RESIDUAL AND S WEIGHTING
      COMMON /TEST/ DISCUT,DISW1,DISW2,RMSCUT,RMSW1,RMSW2,SWT
C--FMAG CONSTANTS
      COMMON /TEST/ FMA1,FMB1,FMZ1,FMD1,FMBRK,FMA2,FMB2,FMZ2,FMD2
C--I/O DEVICES AND MAX NOS OF STATIONS, PHASE CARDS AND P/S PHASES
      COMMON /TEST/ LINP,LPRT,LOUT,MAXSTA,MAXPHS,MMAX
C--MODEL, ERROR AND PAGE CONSTANTS
      COMMON /TEST/ POS,ZTR,RDERR,ERCOF,KEJCT,KINFO
C--SET BLANKS, DEG/RAD, AND EVENT COUNT INDEX
      COMMON  /TEST/ LB,BL,RDEG,LOCNUM,PI
      DIMENSION FTEMP(1),XTEMP(1),LWT(1)
      T2=T1
      KMIN2=KMIN
      KHOUR2=KHOUR
      IF (.NOT.DONE) GO TO 500
C--ADJUST ORIGIN IF EVENT HAS ITERATED INTO ANOTHER MINUTE
C--FIRST NT IS THE TIME SHIFT IN MINUTES, THEN IN HOURS
      NT=(T1+600.)/60.
      NT=NT-10
      T1=T1-NT*60.
      KMIN=KMIN+NT
      NT=(KMIN+60.)/60.
      NT=NT-1
      KMIN=KMIN-NT*60
      KHOUR=KHOUR+NT
C--ADJUST ORIGIN IF EVENT HAS ITERATED INTO ANOTHER DAY
      IF (KHOUR.LT.0) KDAY=KDAY-1
      IF (KHOUR.LT.0) KHOUR=KHOUR+24
C--COMPUTE LARGEST GAP AS MAXGAP
500   MAXGAP=0
C--CALC MINIMUM WEIGHTED STA DISTANCE AND NO OF FIRST MOTIONS
      KTEMP=10000
```

```
      NFRM=0
      DO 530 I=1,M
      IF (W(I).LT..2) GO TO 530
      K=IND(I)
C--REMOVE S FLAG
      IF (K.GT.10000) K=K-10000
      IF (KFM(K).NE.LB) NFRM=NFRM+1
      IF (KDIS(K).LT.KTEMP) KTEMP=KDIS(K)
      MINGAP=360
      LAZ1=KAZEM(K)/180
      DO 525 I2=1,M
      IF (I2.EQ.I .OR. W(I2).LT..1) GO TO 525
      K2=IND(I2)
      IF (K2.GT.10000) K2=K2-10000
      LAZ2=KAZEM(K2)/180
      JGAP=LAZ1-LAZ2
      IF (JGAP.LT.0) JGAP=JGAP+360
      IF (JGAP.LT.MINGAP) MINGAP=JGAP
525   CONTINUE
      IF (MINGAP.GT.MAXGAP) MAXGAP=MINGAP
530   CONTINUE
      DMIN=KTEMP*.05
C--CALC ALL MAGNITUDES
      XTEMP(1)=BL
      NFMAG=0
      NXMAG=0
      XMAG=0.
      FMAG=0.
      FTEMP(1)=BL
C++++++++++++++ CALC MAGNITUDES ++++++++++++++++++++++++++
C--LOOP OVER STATIONS TO CALC AND AVERAGE FMAGS AND XMAGS
      DO 100 K=1,KSTA
      KFMAG=0
      KXMAG=0
      IF (KFMP(K).EQ.0 .AND. KAMP(K).EQ.0) GO TO 100
      J=KINDX(K)
      KTEMP=JMCOR(J)/10000
      KTEMP=JMCOR(J)-10000*KTEMP
      KXCOR=KTEMP/100
      KFCOR=KTEMP-100*KXCOR-25
      KXCOR=KXCOR-25
      IF (KFMP(K).LE.0) GO TO 50
C--COMPUTE FMAG
      TEMP=KFMP(K)
      KFMAG=10*(FMA1+FMB1*ALOG10(TEMP)+FMD1*KDIS(K)*.05+
     2 FMZ1*Z1)
      IF (KFMP(K).GT.FMBRK)
     2KFMAG=10*(FMA2+FMB2*ALOG10(TEMP)+FMD2*KDIS(K)*.05+
     3 FMZ2*Z1)
C--APPLY MAG CORRECTION
      KFMAG=KFMAG+KFCOR
      IF (KFCOR.GT.25) KFMAG=KFMAG-50
      IF (KFMAG.LT.0) KFMAG=0
C--DON'T INCLUDE MAG IN AVERAGE IF MAG CORRECTION GT 2.5
      IF (KFCOR.GT.25 .OR. KFMAG.EQ.0) GO TO 50
      FMAG=FMAG+KFMAG*.1
      NFMAG=NFMAG+1
50    IF (KAMP(K).LE.0) GO TO 100
C--COMPUTE XMAG AS A SUM OF 3 TERMS:
C--1: LOG(MAX PEAK-TO-PEAK AMP / 2*CAL FACTOR)
C--2: -LOG RESPONSE OF INST REL TO WOOD-ANDERSON AT 5 HZ.
C--3: -LOG(A(0)), THE LOCAL MAGNITUDE DISTANCE CORRECTION
C--ALFRQ = LOG(FREQUENCY OF SIGNAL AT MAX AMPLITUDE / 5HZ.)
```

```
C--ALDSQ = LOG((HYPOCENTRAL DISTANCE)**2)
      ITYPE=JCAL(J)/10000
      KTEMP=(JCAL(J)-ITYPE*10000)/500
      KCAL=JCAL(J)-ITYPE*10000-KTEMP*500
      IF (KCAL.EQ.0) GO TO 100
      TEMP=Z1**2+(KDIS(K)*.05)**2
      ALDSQ=ALOG10(TEMP)
      TEMP=2./KTEMP
      ALFRQ=ALOG10(TEMP)
      TEMP=KAMP(K)*5./KCAL
      TEMP=ALOG10(TEMP)
      IF (ITYPE.EQ.1) TEMP=TEMP-1.3-.95*ALFRQ
      IF (ITYPE.EQ.2) TEMP=TEMP+.41+.56*ALFRQ
      TEMP=TEMP-.15+.8*ALDSQ
      IF (ALDSQ.GT.4.6) TEMP=TEMP-3.23+.7*ALDSQ
      KXMAG=10*TEMP+.5
C--APPLY MAG CORRECTION
      KXMAG=KXMAG+KXCOR
      IF (KXCOR.GT.25) KXMAG=KXMAG-50
      IF (KXMAG.LT.0) KXMAG=0
C--DON'T INCLUDE MAG IN AVERAGE IF MAG CORRECTION GT 2.5
      IF (KXCOR.GT.25 .OR. KXMAG.EQ.0) GO TO 100
      XMAG=XMAG+KXMAG*.1
      NXMAG=NXMAG+1
100   KMAG(K)=KXMAG*100+KFMAG
      IF (NXMAG.EQ.0) GO TO 105
      XMAG=XMAG/NXMAG
C--NOW STORE XMAG AS ALPHAMERIC CODE
      ENCODE (XTEMP,1003) XMAG
105   IF (NFMAG.EQ.0) GO TO 110
      FMAG=FMAG/NFMAG
C--NOW STORE FMAG AS ALPHAMERIC CODE
      ENCODE (FTEMP,1003) FMAG
1003  FORMAT (F4.1)
110   IF (KPRINT.LT.0) RETURN
C+++++++++++++ OUTPUT THE LOCATION +++++++++++++++++
      WRITE (LPRT,1027)
1027  FORMAT(/1X,38('--'),'-'/
     3 ' YR MO DA',3X,'ORIGIN',5X,'LAT N',4X,'LON W',3X,
     2 'DEPTH  RMS',3X,'ERH',3X,'ERZ GAP XMAG FMAG')
      WRITE (LPRT,1028) KYEAR,KMONTH,KDAY,KHOUR,KMIN,T1,LAT,IS,XLTM
     2 ,LON,IE,XLNM,Z1,RMS,ERH,ERZ,MAXGAP,XTEMP(1),FTEMP(1)
1028  FORMAT (1X,I2,2('-',I2),I3,I2,F6.2,I3,A1,F5.2,I4,A1,F5.2,F6.2
     2 ,F5.2,2F6.2,I4,1X,2A4)
      WRITE (LPRT,1029)
1029  FORMAT (/' RMSWT DMIN ITR NFM NWR NWS REMK')
      WRITE (LPRT,1030) RMSWT,DMIN,ITR,NFRM,NWR,NWS,REMK
1030  FORMAT (1X,F5.2,F5.1,4I4,2X,A3)
      IF (KPRINT.LT.1) RETURN
C++++++++++++++ PRINT OUT THE STATION LIST +++++++++++++++++++++
      MOUT=0
      WRITE (LPRT,1031)
1031  FORMAT (/2X,'STA DIST AZM  AN P/S W',3X,'SEC+CCOR (TOBS -TCAL',
     2 ' -DLY  =RES) WT  XMG FMG R INFO')
C--LIST STATIONS IN DISTANCE ORDER
C--LSTDIS IS THE LEAST REMAINING DISTANCE AND WILL BE PRINTED ON THIS PASS
C--NXTDIS IS THE NEXT TO LEAST REMAINING DISTANCE,
C--AND WILL BE PRINTED ON THE NEXT PASS
      NXTDIS=-1
520   LSTDIS=NXTDIS
      NXTDIS=30000
      LSTA=-1
      DO 580 IM=1,M
```

```
      K=IND(IM)
      KPS=K/10000
      K=K-10000*KPS
      IF (KDIS(K).LT.LSTDIS) GO TO 580
      IF (KDIS(K).EQ.LSTDIS) GO TO 550
      IF (KDIS(K).LT.NXTDIS) NXTDIS=KDIS(K)
      GO TO 580
550   MOUT=MOUT+1
C--WRITE A LINE OF PHASE ARRIVAL INFO
C--PREPARE STATION INFO
      IF (K.EQ.LSTA) GO TO 555
      J=KINDX(K)
C--DECODE DISTANCE, AZIM AND EMERGENCE ANGLE
      DIST=KDIS(K)*.05
      KAZ=KAZEM(K)/180
      CCOR=KCCOR(K)*.01
      KEM=IABS(KAZEM(K)-180*KAZ)
      IF (KAZ.LT.0) KAZ=KAZ+360
      TCAL=.01*KTCAL(K)
C--NOW STORE XMAG AND FMAG AS ALPHAMERIC CODE
      XTEMP(1)=BL
      FTEMP(1)=BL
      KXMAG=KMAG(K)/100
      KFMAG=KMAG(K)-KXMAG*100
      TEMP=.1*KFMAG
      TMP2=.1*KXMAG
      IF (TEMP.NE.0.) ENCODE (FTEMP,1003) TEMP
      IF (TMP2.NE.0.) ENCODE (XTEMP,1003) TMP2
C--DECODE ASSIGNED WEIGHTS
      LSWT=KWT(K)/10
      LPWT=KWT(K)-LSWT*10
C--GIVE THESE A VALUE, IN CASE AN ARRIVAL IS NOT PRESENT
      IMPORP=0
      IMPORS=0
      KPWT=0
      KSWT=0
      KPRES=0
      KSRES=0
      KPDLY=0
      KSDLY=0
C--PREPARE ARRIVAL TIME INFO, BUT FIRST DECIDE IF THIS IS P OR S
555   IF (KPS.EQ.1) GO TO 560
C--ASSUME A P ARRIVAL
      KTEMP=JPD2(J)/10000
      K2=JPD2(J)-KTEMP*10000-5000
      DLY=.01*(DLYBAL*K2+(1.-DLYBAL)*JPD1(J))
      KPDLY=100.*DLY+SIGN(.5,DLY)
      K1=KPRK(K)
      K2=KFM(K)
      LWT(1)=LB
      IF (LPWT.GT.0) ENCODE (LWT,1010) LPWT
1010  FORMAT (I1)
      SEC=KP(K)*.01
      TOBS=SEC+CCOR-T2
      TCAL=.01*KTCAL(K)
      RES=TOBS-TCAL-DLY
      IMPORP=IMPORT(IM)
      KPWT=100.*W(IM)
      KPRES=100.*RES+SIGN(.5,RES)
      IF (KPRES.GT.9999) KPRES=9999
      IF (KPRES.LT.-999) KPRES=-999
      GO TO 565
C--ASSUME AN S ARRIVAL
```

```
 560   DLY=.01*(DLYBAL*JSD2(J)+(1.-DLYBAL)*JSD1(J))
       KSDLY=100.*DLY+SIGN(.5,DLY)
       K1=KSRK(K)
       K2=LB
       LWT(1)=LB
       IF (LSWT.GT.0) ENCODE (LWT,1010) LSWT
       SEC=KS(K)*.01
       TOBS=SEC+CCOR-T2
       TCAL=.01*KTCAL(K)*POS
       RES=TOBS-TCAL-DLY
       IMPORS=IMPORT(IM)
       KSWT=100.*W(IM)
       KSRES=100.*RES+SIGN(.5,RES)
       IF (KSRES.GT.9999) KSRES=9999
       IF (KSRES.LT.-999) KSRES=-999
 565   WT=W(IM)
       XIMPOR=IMPORT(IM)*.001
       IF (K.EQ.LSTA) GO TO 570
C--PRINT STATION AND ARRIVAL TIME INFO
       WRITE (LPRT,1032) STANAM(J),DIST,KAZ,KEM,K1,K2,LWT(1),SEC,CCOR
     2 ,TOBS,TCAL,DLY,RES,WT,XTEMP(1),FTEMP(1),KRMK(K),XIMPOR
 1032  FORMAT (1X,A4,F5.1,2I4,1X,A2,A1,1X,A1,F6.2,F5.2,2F6.2,F5.2,F6.2,
     2 F5.2,2A4,1X,A1,F5.3)
       GO TO 574
C--WRITE ONLY ARRIVAL TIME INFO (AS FOR AN S FOLLOWING A P)
 570   WRITE (LPRT,1033) K1,K2,LWT(1),SEC,CCOR,TOBS,TCAL,DLY,RES,WT
     2 ,KRMK(K),XIMPOR
 1033  FORMAT (19X,A2,A1,1X,A1,F6.2,F5.2,2F6.2,F5.2,F6.2,F5.2,9X,A1,F5.3)
C--WRITE AN EXTENDED 'PHASE CARD' CONTAINING ALL STATION INFO TO A FILE
C--DON'T WRITE THE PHASE CARD YET IF MORE INFO (S ARRIVAL) IS TO COME
 574   IF (IM.GE.M) GO TO 575
       K1=IND(IM+1)/10000
       K1=IND(IM+1)-K1*10000
       IF (K.EQ.K1) GO TO 576
 575   IF (.NOT.DONE) GO TO 576
       KTEMP=KDIS(K)/2
       WRITE (LOUT,1034) STANAM(J),KPRK(K),KFM(K),LPWT,KYEAR,KMONTH,KDAY,
     2 KHOUR2,KMIN2,KP(K),KPRES,KPWT,KS(K),KSRK(K),LSWT,KSRES,KAMP(K)
     3 ,KSWT,KPDLY,KSDLY,KTEMP,KEM,KCCOR(K),KRMK(K),KFMP(K),KAZ,KFMAG
     4 ,KXMAG,IMPORP,IMPORS
 1034  FORMAT (A4,A2,A1,I1,1X,5I2,I5,I4,I3,I5,A2,1X,I1,I4,I3,I3,3I4,I3
     2 ,I5,A1,I4,I3,2I2,2I4)
C--UPDATE THE LAST STATION INDEX
 576   LSTA=K
 580   CONTINUE
       IF (MOUT.LT.M) GO TO 520
       RETURN
       END
```

HYSUM.FR

```
      SUBROUTINE HYSUM (KS71,KSEL,KSHI)
C--GENERATE SUMMARY CARD FILES IN 3 FORMATS, AND USE THE HYPOINVERSE
C--'SUMMARY CARD' AS AN 'INSTRUCTION CARD' TO DELIMIT EVENTS IN THE FILE
C--OF NEW DETAILED PHASE CARDS.
      INCLUDE 'HYPCOM'
C--FILE HYPCOM CONTAINS THE COMMON BLOCKS INCLUDED IN MANY HYPINV SUBS
C--BLANK COMMON IS FOR COMMUNICATION BETWEEN SUBROUTINES
      LOGICAL DONE
C--CURRENT EPICENTRAL COORDS, INITIALIZED TO TRIAL VALUES
      COMMON T1,QLAT1,QLON1,Z1,LAT,XLTM,LON,XLNM,DONE,IE,IS
C--EVENT TIME, MAGNITUDE AND SIMPLIFIED ERRORS
      COMMON KYEAR,KMONTH,KDAY,KHOUR,KMIN,FMAG,XMAG,RMS,ERH,ERZ,RMSWT
C-- ERROR ELLIPSE AND DELAY MODEL PARAMETERS
      COMMON DLYBAL,DLYAZ,DLYWD,SERR(3),IAZ(3),IDIP(3),V(4,4)
C--OTHER PARAMETERS KEPT FOR EACH EVENT
      COMMON ITR,DMIN,REMK,KSTA,KEND,MAXGAP,NFRM,NWR,NWS,M,KPRINT
C--CONDENSED MASTER STATION TABLE
      COMMON QLAT0,QLON0,JSTA,STANAM(300),JLAT(300),JLON(300),JCAL(300)
      COMMON JMCOR(300),JPD1(300),JPD2(300),JSD1(300),JSD2(300)
C--CONDENSED INFO FROM EACH STATION REPORTING AN EVENT
      COMMON KINDX(160),KP(160),KS(160),KTCAL(160),KDIS(160),KAZEM(160)
      COMMON KPRK(160),KSRK(160),KFM(160),KWT(160),KFMP(160),KMAG(160)
      COMMON KRMK(160),KCCOR(160),KAMP(160)
C--INDEX, RESIDUAL, WEIGHT, AND IMPORTANCE OF EACH PHASE (P OR S)
      COMMON IND(240),R(240),W(240),IMPORT(240)
C--COMMON BLOCK /TEST/ IS FOR FIXED CONSTANTS SET IN BLOCK DATA
C--WHEN TO QUIT OR DAMP ITERATIONS
      COMMON /TEST/ ITRLIM,DQUIT,DXFIX,DZMAX,DZAIR,DAMP,DRQT,EIGTOL
     2 ,RBACK,BACFAC
C--DISTANCE, RESIDUAL AND S WEIGHTING
      COMMON /TEST/ DISCUT,DISW1,DISW2,RMSCUT,RMSW1,RMSW2,SWT
C--FMAG CONSTANTS
      COMMON /TEST/ FMA1,FMB1,FMZ1,FMD1,FMBRK,FMA2,FMB2,FMZ2,FMD2
C--I/O DEVICES AND MAX NOS OF STATIONS, PHASE CARDS AND P/S PHASES
      COMMON /TEST/ LINP,LPRT,LOUT,MAXSTA,MAXPHS,MMAX
C--MODEL, ERROR AND PAGE CONSTANTS
      COMMON /TEST/ POS,ZTR,RDERR,ERCOF,KEJCT,KINFO
C--SET BLANKS, DEG/RAD, AND EVENT COUNT INDEX
      COMMON  /TEST/ LB,BL,RDEG,LOCNUM,PI
      DIMENSION KSIG(3),CARD(20)
C--WRITE A HYPO71 SUMMARY CARD
      IF (KS71.NE.0) WRITE (8,1000)
     2  KYEAR,KMONTH,KDAY,KHOUR,KMIN,T1,LAT,IS,XLTM,LON,IE,XLNM
     3 ,Z1,FMAG,NWR,MAXGAP,DMIN,RMS,ERH,ERZ
1000  FORMAT (3I2,1X,2I2,F6.2,I3,A1,F5.2,I4,A1,F5.2,2F7.2,I3,I4,F5.1
     2 ,F5.2,2F5.1)
C--PREPARE VARIABLES FOR HYPOELLIPSE AND HYPOINVERSE SUMMARY CARDS
      KLTM=XLTM*100.+.5
      KLNM=XLNM*100.+.5
      KT=T1*100.+.5
      KZ=Z1*100.+.5
      KFMAG=FMAG*10.+.5
      KXMAG=XMAG*10.+.5
      KDMIN=DMIN+.5
      KRMS=RMS*100.+.5
      KERH=ERH*100.+.5
      KERZ=ERZ*100.+.5
      DO 10 I=1,3
10    KSIG(I)=SERR(I)*100.
```

```
C--ENCODE THE FIRST 80 COLS (COMPATIBLE PART) OF THE OTHER SUMMARY CARDS
      ENCODE (CARD,1001) KYEAR,KMONTH,KDAY,KHOUR,KMIN,KT,LAT,IS,
     2 KLTM,LON,IE,KLNM,KZ,KXMAG,NWR,MAXGAP,KDMIN,KRMS,
     3 (IAZ(I),IDIP(I),KSIG(I),I=1,2),KFMAG,REMK,KSIG(3),NWS
1001  FORMAT (5I2,I4,I2,A1,I4,I3,A1,I4,I5,I2,3I3,I4,
     2 2(I3,I2,I4),I2,A3,I4,2X,I2)
C--WRITE A HYPOELLIPSE SUMMARY CARD
      IF (KSEL.NE.0) WRITE (9,1002) CARD
C--WRITE A HYPOINVERSE SUMMARY CARD (90 COLS) TO SUMMARY AND PHASE CARD FILES
      IF (KSHI.NE.0) WRITE (10,1002) CARD,KERH,KERZ,NFRM
      IF (KPRINT.GT.0) WRITE (LOUT,1002) CARD,KERH,KERZ,NFRM
1002  FORMAT (20A4,2I4,I2)
      RETURN
      END
```

APPENDIX 9: TTGEN source listing.

TTGEN	Main program.
TTBDTA	Block data.
TTCAL	Travel time and distance calculation subroutine.
TTGRD	Produces a evenly spaced grid of travel times.
TTPLT	Plots the reduced travel time curve using Tektronix Plot/10 subroutines.

TTGEN.FR

```
C--  TTGEN
C--PROGRAM TO GENERATE A TABLE OF TRAVEL TIMES AS A FUNCTION OF DIST AND DEPTH
      INCLUDE 'TTCOM'
C--COMMON VARIABLES FOR TRAVEL TIME TABLE GENERATING PROGRAM TTGEN
      COMMON /TTCOM/Z(15),V(15),G(15),THK(15),VR(15)
      COMMON /TTCOM/ITITL(10),TP(201),TR(201),DP(201),DMIN,TMIN
      COMMON /TTCOM/DD1,ND1,DD2,ND2,LAY,ZH,VH,N,JA(10),JH(10),JC,JD,JH
      COMMON /TTCOM/IBR,TMAX,DMAX,DQ1,NQ1,DQ2,NQ2,PI2,RDEG,VM
      COMMON /TTCOM/MAXZ,MAXD,MAXL,MAXJ,LINP,LPRT,LOUT,REDV,JL,VJL,VJC
      COMMON /TTCOM/DZ1,NZ1,DZ2,NZ2,NZ,ND,IHD,IPA
      DIMENSION IPR(5),IVM(5)
      DATA IPR,IVM/10*0/
C//////////// OPEN TUBE KEYBOARD IN CASE VCURSR IS USED /////////////
C///////////// TO HALT PROGRAM WHILE A PLOT IS ON THE SCREEN //////////
      OPEN 5,'$TTI1'
C--READ I/O FILENAMES AND MODEL PARAMETERS ON TTMOD
      OPEN LINP,'TTMOD'
      READ (LINP,1000) (IPR(I),I=1,4),(IVM(I),I=1,4),REDV,IHD,IPA
1000  FORMAT (8A2,F6.1,2I1)
C--READ INDEXING PARAMETERS FOR DEPTH AND DISTANCE
      READ (LINP,1001) DQ1,NQ1,DQ2,NQ2,DZ1,NZ1,DZ2,NZ2,DD1,ND1,DD2,ND2
1001  FORMAT (F5.2,I5,F5.2,I5)
C--READ DISTANCE LIMIT, TIME LIMIT, AND TITLE FOR TT PLOT
      READ (LINP,1002) DMAX,TMAX
      READ (LINP,1017) ITITL
1017  FORMAT (10A2)
C--OPEN OUTPUT FILES
      OPEN LPRT,IPR,ATT='P'
      OPEN LOUT,IVM
      WRITE (LPRT,1018) ITITL
1018  FORMAT ('1  ',10A2/)
C--READ VELOCITY MODEL
      DO 5 I=1,MAXL
      READ (LINP,1002,END=7) V(I),Z(I)
1002  FORMAT (2F5.2)
      IF (V(I).GT.0.) GO TO 5
      WRITE (LPRT,1004) I
1004  FORMAT (' FATAL ERROR: VELOCITY IN LAYER',I3,' MUST BE POSITIVE')
      STOP
5     LAY=I
7     Z(1)=0.
      CLOSE LINP
      IF (LAY.GT.1) GO TO 10
C--DEFINE A FICTITIOUS SECOND LAYER IF HALFSPACE MODEL SPECIFIED
      V(2)=V(1)
      Z(2)=2.
      LAY=2
C--CALC THICKNESS AND GRADIENT FOR EACH LAYER AND PRINT THE MODEL
10    WRITE (LPRT,1003) LAY
1003  FORMAT (' VELOCITY MODEL WITH',I3,' LAYERS:'//
     2 '  L  VEL  DEPTH THICK   GRAD')
      DO 15 I=1,LAY-1
      THK(I)=Z(I+1)-Z(I)
      IF (THK(I).GT.0.) GO TO 12
      WRITE (LPRT,1005) I
1005  FORMAT (' FATAL ERROR: LAYER',I3,' MUST HAVE POSITIVE THICKNESS')
      STOP
12    VR(I)=V(I+1)/V(I)
      IF (V(I).GT.VM) VM=V(I)
```

```
      G(I)=(V(I+1)-V(I))/THK(I)
15    WRITE (LPRT,1006) I,V(I),Z(I),THK(I),G(I)
1006  FORMAT (1X,I2,3F6.2,F7.3)
      WRITE (LPRT,1007) LAY,V(LAY),Z(LAY)
1007  FORMAT (1X,I2,2F6.2,' HALFSPACE')
      IF (VM.LT.V(LAY)) GO TO 17
      WRITE (LPRT,1013)
1013  FORMAT (' FATAL ERROR: HALFSPACE MUST HAVE LARGEST VELOCITY')
      STOP
17    G(LAY)=0.
      VR(LAY)=1.
      WRITE (LPRT,1016) REDV
1016  FORMAT (/' ONE OVER REDUCING VELOCITY=',F8.4)
C--CALC AND PRINT OUT DIST AND DEPTH GRID POINT INFO
      NZ=NZ1+NZ2+1
      WRITE (LPRT,1008) NZ,MAXZ
1008  FORMAT (//1X,I3,' OUT OF A POSSIBLE',I4,' DEPTH POINTS USED')
      IF (NZ.GT.1 .AND. NZ.LE.MAXZ) GO TO 100
      WRITE (LPRT,1030)
1030  FORMAT (' FATAL ERROR: IMPROPER VALUE SPECIFIED IN ABOVE LINE')
      STOP
100   Z1=NZ1*DZ1
      Z2=Z1+NZ2*DZ2
      I=NZ1+1
      TEMP=0.
      WRITE (LPRT,1009) I,TEMP,Z1
      TEMP=Z1+DZ2
      WRITE (LPRT,1009) NZ2,TEMP,Z2
1009  FORMAT (' CALCULATE TRAVEL TIMES AT',I4,' DEPTH POINTS BETWEEN',
     2 F6.2,' AND',F6.2,' INCLUSIVE')
      ND=ND1+ND2+1
      WRITE (LPRT,1010) ND,MAXD
1010  FORMAT (//1X,I3,' OUT OF A POSSIBLE',I4,' DISTANCE POINTS USED')
      IF (ND.GT.1 .AND. ND.LE.MAXD) GO TO 115
      WRITE (LPRT,1030)
      STOP
115   D1=ND1*DD1
      D2=D1+ND2*DD2
      I=ND1+1
      TEMP=0.
      WRITE (LPRT,1011) I,TEMP,D1
      TEMP=D1+DD2
      WRITE (LPRT,1011) ND2,TEMP,D2
1011  FORMAT (' CALCULATE TRAVEL TIMES AT',I4,' DISTANCE POINTS BETWEEN'
     2 ,F7.2,' AND',F7.2,' INCLUSIVE')
C--OUTPUT THE HEADER INFO TO THE TT TABLE FILE
      WRITE (LOUT,1020) ITITL,LAY,REDV
1020  FORMAT (10A2,I2,F8.4)
      WRITE (LOUT,1021) (Z(I),I=1,LAY)
      WRITE (LOUT,1021) (V(I),I=1,LAY)
1021  FORMAT (15F5.2)
      WRITE (LOUT,1022) DD1,ND1,DD2,ND2
      WRITE (LOUT,1022) DZ1,NZ1,DZ2,NZ2
1022  FORMAT (2(F7.4,I3))
C++++++++++++++++ DEPTH LOOP ++++++++++++++++
C--LOOP INCLUDES FOREWARD CALCULATION, PLOTTING TT CURVE, AND INTERPOLATION
C  TO GET TRAVEL TIME TABLE.
      DO 700 M=1,NZ
C--SET DEPTH AS A FUNCTION OF M
      ZH=(M-1)*DZ1
      IF (M-1.GT.NZ1) ZH=Z1+(M-1-NZ1)*DZ2
C--SET INDICIES AT WHICH SHADOW ZONE BEGINS AND ENDS
      JC=0
```

```
      JD=0
      JL=0
      JH=0
C--RESET INDICIES WHERE REVERSE BRANCHES BEGIN AND END
      DO 19 I=1,10
      JA(I)=0
19    JB(I)=0
C--CALC SOME DEPTH DEPENDENT PARAMETERS
C--N IS THE LAYER IN WHICH HYPO OCCURS
      N=1
      DO 20 I=1,LAY
      IF (Z(I).LT.ZH) N=I
20    CONTINUE
C--VELOCITY AT HYPOCENTER
      VH=V(LAY)
      IF (N.EQ.LAY) GO TO 25
      VH=V(N)+G(N)*(ZH-Z(N))
C--MAXIMUM VELOCITY ABOVE HYPOCENTER
25    VM=0.
      DO 30 I=1,N
      IF (V(I).GT.VM) VM=V(I)
30    CONTINUE
C--NOW CALCULATE DISTANCES AND TRAVEL TIMES AS A FUNCTION OF RAY PARAMETER
      CALL TTCAL
C--PLOT OUT TRAVEL TIME CURVE ON THE TUBE
      CALL TTPLT
C--INTERPOLATE TT CURVES TO GET A TT GRID, AND OUTPUT THE TT TABLE
      CALL TTGRD
700   CONTINUE
      WRITE (LPRT,1012)
1012  FORMAT (' ')
      CLOSE LPRT
      CLOSE LOUT
C//////////////// PLOT TERMINATION ROUTINE ///////////////
      CLOSE 5
      CALL FINITT (0,0)
      STOP
      END
```

TTBDTA.FR

```
      BLOCK DATA
C--INITIALIZES CONSTANTS USED BY THE TRAVEL TIME TABLE GENERATING PROGRAM
      INCLUDE 'TTCOM'
C--COMMON VARIABLES FOR TRAVEL TIME TABLE GENERATING PROGRAM TTGEN
      COMMON /TTCOM/Z(15),V(15),G(15),THK(15),VR(15)
      COMMON /TTCOM/ITITL(10),TP(201),TR(201),DP(201),DMIN,TMIN
      COMMON /TTCOM/DD1,ND1,DD2,ND2,LAY,ZH,VH,N,JA(10),JB(10),JC,JD,JH
      COMMON /TTCOM/IBR,TMAX,DMAX,DQ1,NQ1,DQ2,NQ2,PI2,RDEG,VM
      COMMON /TTCOM/MAXZ,MAXD,MAXL,MAXJ,LINP,LPRT,LOUT,REDV,JL,VJL,VJC
      COMMON /TTCOM/DZ1,NZ1,DZ2,NZ2,NZ,ND,IHD,IPA
      DATA PI2,RDEG/1.57079,57.2958/
      DATA MAXZ,MAXD,MAXL,MAXJ/28,42,15,201/
      DATA VM,LINP,LPRT,LOUT/0.,1,2,3/
      DATA DMIN,TMIN/2*0./
```

TTCAL.FR

```
      SUBROUTINE TTCAL
C--CALCULATES DISTANCE AND TRAVEL TIME AS A FUNCTION OF RAY PARAMETER
      INCLUDE 'TTCOM'
C--COMMON VARIABLES FOR TRAVEL TIME TABLE GENERATING PROGRAM TTGEN
      COMMON /TTCOM/Z(15),V(15),G(15),THK(15),VR(15)
      COMMON /TTCOM/ITITL(10),TP(201),TR(201),DP(201),DMIN,TMIN
      COMMON /TTCOM/DD1,ND1,DD2,ND2,LAY,ZH,VH,N,JA(10),JB(10),JC,JD,JH
      COMMON /TTCOM/IBR,TMAX,DMAX,DQ1,NQ1,DQ2,NQ2,PI2,RDEG,VM
      COMMON /TTCOM/MAXZ,MAXD,MAXL,MAXJ,LINP,LPRT,LOUT,REDV,JL,VJL,VJC
      COMMON /TTCOM/DZ1,NZ1,DZ2,NZ2,NZ,ND,IHD,IPA
      DIMENSION CP(15)
C--FIRST TREAT THE CASE OF A RAY TRAVELLING STRAIGHT UP (P=0)
      J=1
      P=0.
      Q=0.
      PHID=0.
      DP(1)=0.
      TP(1)=(ZH-Z(N))/V(N)
      IF (G(N).NE.0.) TP(1)=ALOG(VH/V(N))/G(N)
      IF (N.EQ.1) GO TO 40
      DO 35 I=1,N-1
      TEMP=THK(I)/V(I)
      IF (G(I).NE.0.) TEMP=ALOG(VR(I))/G(I)
35    TP(1)=TP(1)+TEMP
40    TR(1)=TP(1)
C--PRINT HEADING AND P=0 DATA BEFORE START OF P LOOP
      WRITE (LPRT,1012) ZH,N,VH
1012  FORMAT ('1DEPTH=',F6.2,'    ... HYPO IN LAYER',I3,' AT VELOCITY',F6.2
     2 //'   J     Q     EM.ANG   P     DIST  TTIME REDUCED L.BOT'
     2,' Z.BOT V.BOT  DDIF  BR   AMP   AMP*R**2   REMK'/)
      WRITE (LPRT,1014) J,Q,PHID,P,DP(1),TP(1),TR(1)
1014  FORMAT (1X,I3,2F7.2,F6.4,3F7.2,I3,F9.2,F6.2,F7.2,I3,2F9.5,2X,A4)
C--SET FLAGS AND INDICIES
C--SET TT BRANCH NO. (NO OF REVERSALS ENCOUNTERED +1)
      IBR=1
C--SET FLAG (=1 IF RAY WOULD GO INTO LVZ WAVEGUIDE, =0 OTHERWISE)
      IFL=0
C--SET INITIAL VALUE OF LAST PHI (EMERGENCE ANGLE) AND LAST K
      PHIL=0.
      LASTK=MAXL
C++++++++++++ LOOP OVER RAY PARAMETER P ++++++++++++
C--USE J AS AN INTEGER INDEX
C--USE Q=Q(J) AS AN INDEX WHICH TAKES APPROXIMATELY EQUAL STEPS IN DIST
C  ON THE SURFACE (IN KM)
C--THE EMERGENCE ANGLE PHI=PHI(Q) AND RAY PARAMETER P=P(PHI) ARE THEN CALCULATED
      DO 300 J=2,MAXJ
C--CALC PHI AND OTHER CONSTANTS FOR THE LOOP
      Q=(J-1)*DQ1
      IF (J-1.GT.NQ1) Q=NQ1*DQ1+(J-NQ1-1)*DQ2
      PHI=2.*ATAN(Q/(ZH+.5))
      SPH=SIN(PHI)
      CPH=SQRT(1.-SPH**2)
      P=SPH/VH
      VB=1./P
C--K IS THE LAYER IN WHICH DOWNGOING RAY BOTTOMS
      DO 41 I=1,LAY-1
      K=I
      IF (V(I+1) .GE. VB) GO TO 42
41    CONTINUE
```

```
42     IF (VB.GE.V(LAY)) K=LAY
C--CALC DEPTH AT RAY BOTTOM
       ZB=Z(K)
       IF (G(K).NE.0.) ZB=ZB+(VB-V(K))/G(K)
       IF (VB.GT.VM .OR. VH.GE.VM) GO TO 45
C++++++++++++ RAY LOST TO WAVEGUIDE ++++++++++++
C--NOW HAVE CASE OF RAY GOING INTO WAVEGUIDE FORMED BY A LVZ
C--FLAG THE NONEXISTENT TIME AND DIST FOR THIS CASE
       TP(J)=-1.
       DP(J)=-1.
       TR(J)=-1.
       XMSG=' WG
       K=0
C--SKIP AHEAD IF RAY WAS IN WAVEGUIDE ON LAST PASS TOO
       IF (IFL.EQ.1) GO TO 205
C--NOW HAVE CASE OF ENTERING A SHADOW ZONE FOR THE FIRST TIME
C  SO SET FLAG
       IFL=1
C--RECORD THIS PLACE ON TT CURVE FOR FUTURE REFERENCE AND PRINT A MESSAGE
       JC=J-1
       VJC=VM
       WRITE (LPRT,1003) DP(JC),TR(JC),VJC
1003   FORMAT (' RAYS NOW ENTERING WAVEGUIDE. EXTEND TT CURVE FROM',
     2 F7.2,' KM,',F6.2,' SEC AT VELOCITY',F5.2)
       GO TO 205
45     IF (IFL.EQ.0) GO TO 47
C--NOW HAVE CASE OF JUST EMERGING FROM A SHADOW ZONE
C--RESET FLAG AND RECORD THIS PLACE ON TT CURVE
       IFL=0
       JD=J
47     IF (PHI.LT.PI2 .OR. VB.LT.V(LAY)) GO TO 55
C++++++++++++ RAY INTO HALFSPACE ++++++++++++
C--NOW HAVE CASE OF RAY TRANSMITTED INTO HALFSPACE.
C--SUCH RAYS NEVER REACH THE SURFACE, BUT PROG RECORDS TIME AND DIST FOR A RAY
C  REFRACTED FROM THE TOP OF THE HALFSPACE.
C--PRINT A MESSAGE AND JUMP OUT OF P LOOP
       JH=J-1
       WRITE (LPRT,1001) DP(JH),TR(JH),V(LAY)
1001   FORMAT (' RAYS NOW LOST TO HALFSPACE. EXTEND TT CURVE FROM',
     2 F7.2,' KM,',F6.2,' SEC AT VELOCITY',F5.2)
       IF (DD.LT.0.) JB(IBR)=JH
       GO TO 310
C++++++++++++ CALCULATE TIME AND DISTANCE ++++++++++++
C--CALC T AND D SINCE IT IS VALID TO DO SO. CONSIDER ALL 3 CASES:
C  1 RAY NEARLY HORIZ IN LAYER OF ZERO GRADIENT
C  2 UPGOING RAY
C  3 DOWNGOING RAY
C--FOR EACH TERM MUST CONSIDER ZERO AND NON-ZERO GRADIENTS AS SEP CASES
55     IF (ABS(PHI-PI2).GT..002 .OR. G(N).NE.0.) GO TO 60
C--CASE OF NEARLY HORIZ NON-CURVING RAY
C--SET DIST TO BE SOME ARBITRARY BUT LARGE NO
       DP(J)=1000.
       TP(J)=1000./V(N)
       GO TO 200
60     IF (PHI.GT.PI2+.0005) GO TO 90
C++++++++++++ UPGOING RAY ++++++++++++
C--CALC COSINES OF EMERGENCE ANGLES AT EACH INTERFACE
       DO 65 I=1,N
65     CP(I)=SQRT(1.-(V(I)*P)**2)
C--CONTRIBUTION TO T AND D OF LAYER IN WHICH HYPO LIES
       IF (G(N).EQ.0.) GO TO 70
       DP(J)=(CP(N)-CPH)/(P*G(N))
       TP(J)=ALOG(VH*(1.+CP(N))/(V(N)*(1.+CPH)))/G(N)
```

```
      GO TO 75
70    DP(J)=(ZH-Z(N))*SPH/CPH
      TP(J)=(ZH-Z(N))/(CPH*VH)
C--IF HYPO WAS IN FIRST LAYER, SKIP THIS LOOP
75    IF (N.EQ.1) GO TO 200
C--NOW ADD TERMS FROM OVERLYING LAYERS
      DO 85 I=1,N-1
      IF (G(I).EQ.0.) GO TO 80
      DP(J)=DP(J)+(CP(I)-CP(I+1))/(P*G(I))
      TP(J)=TP(J)+ALOG(VR(I)*(1.+CP(I))/(1.+CP(I+1)))/G(I)
      GO TO 85
80    DP(J)=DP(J)+THK(I)*P*V(I)/CP(I)
      TP(J)=TP(J)+THK(I)/(CP(I)*V(I))
85    CONTINUE
      GO TO 200
C++++++++++++ DOWNGOING RAY ++++++++++++
C--CALC COSINES OF EMERGENCE ANGLES AT LAYER INTERFACES
90    DO 95 I=1,K
95    CP(I)=SQRT(1.-(V(I)*P)**2)
C--CONTRIBUTION TO T AND D FROM LAYER IN WHICH RAY BOTTOMS
      IF (G(K).EQ.0.) GO TO 100
      DP(J)=2.*CP(K)/(P*G(K))
      TP(J)=2.*ALOG((1.+CP(K))/(V(K)*P))/G(K)
      GO TO 105
C--A RAY CANT BOTTOM IN A HOMOGENEOUS LAYER
C--IF THIS CASE SHOULD ARISE, REFLECT RAY FROM TOP OF THE LAYER
100   DP(J)=0.
      TP(J)=0.
C--SUBTRACT CONTRIBUTION FROM PATH IMMED ABOVE HYPO IN ITS LAYER
105   IF (G(N).EQ.0.) GO TO 110
      DP(J)=DP(J)-(CP(N)-CPH)/(P*G(N))
      TP(J)=TP(J)-ALOG(VH*(1.+CP(N))/(V(N)*(1.+CPH)))/G(N)
      GO TO 115
110   DP(J)=DP(J)-(ZH-Z(N))*SPH/CPH
      TP(J)=TP(J)-(ZH-Z(N))/(CPH*VH)
C--SUM TERMS OVER LAYERS ABOVE HYPO
115   IF (N.EQ.1) GO TO 130
      DO 125 I=1,N-1
      IF (G(I).EQ.0.) GO TO 120
      DP(J)=DP(J)+(CP(I)-CP(I+1))/(P*G(I))
      TP(J)=TP(J)+ALOG(VR(I)*(1.+CP(I))/(1.+CP(I+1)))/G(I)
      GO TO 125
120   DP(J)=DP(J)+THK(I)*P*V(I)/CP(I)
      TP(J)=TP(J)+THK(I)/(CP(I)*V(I))
125   CONTINUE
C--SUM TERMS OVER LAYERS BETWEEN HYPO AND RAY BOTTOM (IF ANY)
C--INCLUDE LAYER IN WHICH HYPO LIES
130   IF (N.EQ.K) GO TO 150
      DO 140 I=N,K-1
      IF (G(I).EQ.0.) GO TO 135
      DP(J)=DP(J)+2.*(CP(I)-CP(I+1))/(P*G(I))
      TP(J)=TP(J)+2.*ALOG(VR(I)*(1.+CP(I))/(1.+CP(I+1)))/G(I)
      GO TO 140
135   DP(J)=DP(J)+2.*THK(I)*P*V(I)/CP(I)
      TP(J)=TP(J)+2.*THK(I)/(CP(I)*V(I))
140   CONTINUE
C--PRINT A MESSAGE AND RECORD THIS PLACE IF THIS DOWNGOING RAY
C  HAS EMERGED FROM THE FAR SIDE OF A SHADOW ZONE
150   IF (K-LASTK.LT.2 .OR. LASTK.EQ.0) GO TO 200
      IF (K.LT.2) GO TO 200
      IF (G(K-1).GE.0.) GO TO 200
      VJL=V(LASTK+1)
      JL=J-1
```

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      WRITE (LPRT,1002) DP(JL),TR(JL),VJL
1002  FORMAT (' DOWNGOING RAYS JUMP OVER A SHADOW ZONE. EXTEND TT CURVE'
     2 ,' FROM',F7.2,' KM,',F6.2,' SEC AT VELOCITY',F5.2)
C++++++++++++ PREPARE TO PRINT RESULTS ++++++++++++
C--CALC SOME EXTRA PARAMETERS AND PREPARE TO PRINT RESULTS
C--COME HERE FOR A NORMAL RAY WHICH REACHES THE SURFACE
200   XMSG='
C--COME HERE IF RAY WENT INTO WAVEGUIDE
205   IF (DP(J).NE.-1..AND. DP(J-1).NE.-1.) GO TO 215
      DD=0.
      IF (J.EQ.JD) DD=DP(JD)-DP(JC)
      AMP=0.
      AMPD=0.
      GO TO 220
C--COME HERE FOR A NORMAL RAY WHICH REACHED THE SURFACE BOTH THIS TIME AND LAST
215   DD=DP(J)-DP(J-1)
C--FLAG REVERSED BRANCH RAYS
      IF (DD.LT.0.) XMSG=' RB
C--CALC A PARAMETER PROPORTIONAL TO AMPLITUDE TO ESTIMATE GEOMETRICAL SPREADING
C  AND ALSO TO CORRECT IT FOR INVERSE SQUARE FACTOR
      IF (ABS(DD).LT..001) DD=.001
      AMP=SPH*(PHI-PHIL)/(DP(J)*ABS(DD))
      AMPD=AMP*(DP(J)**2+ZH**2)
      IF (J.EQ.2) GO TO 220
C--RECORD INDEX IF REVERSAL TO ANOTHER TT BRANCH HAS TAKEN PLACE
      IF (DD.LT.0. .AND. DDL.GT.0.) JA(IBR)=J-1
      IF (DD.LT.0. .OR. DDL.GT.0.) GO TO 220
      JB(IBR)=J-1
      IBR=IBR+1
C--RECORD PARAMETERS FOR COMPARASON ON NEXT PASS OF LOOP
220   DDL=DD
      LASTK=K
      PHIL=PHI
      PHID=PHI*RDEG
C--CALC REDUCED TRAVEL TIME
      IF (DP(J).NE.-1.) TR(J)=TP(J)-DP(J)*REDV
C--PRINT OUT 1 LINE OF RESULTS
      WRITE (LPRT,1014) J,Q,PHID,P,DP(J),TP(J),TR(J),K,ZB,VB,DD,IBR,AMP
     2 ,AMPD,XMSG
C--END OF P LOOP
300   CONTINUE
C--BE SURE THAT TRAVEL TIMES ARE DEFINED FOR LARGE DISTANCES
C  IF HALFSPACE HAS NOT YET BEEN REACHED
      JH=MAXJ
C--WRITE OUT FLAGGING INDICIES
310   I=0
      IF (JL.GT.0) I=JL+1
      WRITE (LPRT,1000) JC,JD,JL,I,JA,JB
1000  FORMAT (/' J INDICIES OF ENDS OF SHADOW ZONE (HYPO IN LVZ):',2I4//
     2 ' J INDICIES OF ENDS OF SHADOW ZONE (HYPO ABOVE LVZ):',2I4//
     2 ' J INDICIES OF ENDS OF REVERSE BRANCHES:',2(/10I4))
      RETURN
      END
```

TTGRD.FR

```
      SUBROUTINE TTGRD
C--INTERPOLATES AND OUTPUTS A SINGLE CONTINUOUS TRAVEL TIME CURVE
C--FROM THE EARLIEST ARRIVING BRANCHES OF THE TP VS. DP CURVE.
      INCLUDE 'TTCOM'
C--COMMON VARIABLES FOR TRAVEL TIME TABLE GENERATING PROGRAM TTGEN
      COMMON /TTCOM/Z(15),V(15),G(15),THK(15),VR(15)
      COMMON /TTCOM/ITITL(10),TP(201),TR(201),DP(201),DMIN,TMIN
      COMMON /TTCOM/DD1,ND1,DD2,ND2,LAY,ZH,VH,N,JA(10),JB(10),JC,JD,JH
      COMMON /TTCOM/IBR,TMAX,DMAX,DQ1,NQ1,DQ2,NQ2,PI2,RDEG,VM
      COMMON /TTCOM/MAXZ,MAXD,MAXL,MAXJ,LINP,LPRT,LOUT,REDV,JL,VJL,VJC
      COMMON /TTCOM/DZ1,NZ1,DZ2,NZ2,NZ,ND,IHD,IPA
      DIMENSION KT(101)
      DATA SCFAC/2000./
      XMAX=0.
C--DEFINE LINEAR INTERPOLATION FUNCTION
      TLIN(D,I)=TR(I-1)+(D-DP(I-1))*(TR(I)-TR(I-1))/
     2 (DP(I)-DP(I-1))
C--SET TT AT ZERO DISTANCE
      KT(1)=TR(1)*SCFAC-32000.
C+++++++++++++ DISTANCE LOOP +++++++++++++++++++++++++
C--FOR EACH DISTANCE POINT FIND THE SMALLEST TRAVEL TIME FROM
C--THE SEVERAL POSSIBLE BRANCHES AND EXTENSIONS
      DO 90 L=2,ND
      TMN=1000.
C--CALC DISTANCE FROM CONSTANTS SPECIFIED
      D=(L-1)*DD1
      IF (L-1.GT.ND1) D=ND1*DD1+(L-ND1-1)*DD2
C--TMN WILL BE RESET IF THE REDUCED TT OF SOME BRANCH IS LESS THAN
C--THE LEAST SO FAR
C--TEST TT INTERPOLATED FROM FIRST FOREWARD BRANCH OF TT CURVE
      IF (JA(1).EQ.0) GO TO 11
      IF (D.LT.DP(JA(1))) GO TO 12
      GO TO 19
11    LIM=JH
      GO TO 14
12    LIM=JA(1)
14    DO 15 II=2,LIM
      I=II
      IF (D.LT.DP(I)) GO TO 17
15    CONTINUE
16    IF (DP(I).NE.0.) GO TO 17
      T=TR(I)
      GO TO 18
17    T=TLIN(D,I)
18    IF (T.LT.TMN) TMN=T
C--TEST TT DEFINED AS EXTENSION THRU A SHADOW ZONE (HYPO IN LVZ)
19    IF (JC.EQ.0) GO TO 20
      IF (D.LE.DP(JC)) GO TO 20
      T=TP(JC)+(D-DP(JC))/VJC-D*REDV
      IF (T.GT.TMN) GO TO 20
      TMN=T
C--TEST TT DEFINED AS EXTENSION THRU A SZ (HYPO ABOVE A LVZ)
20    IF (JL.EQ.0) GO TO 30
      IF (D.LE.DP(JL)) GO TO 30
      T=TP(JL)+(D-DP(JL))/VJL-D*REDV
      IF (T.GT.TMN) GO TO 30
      TMN=T
C--TEST TT DEFINED AS REFRACTION FROM HALFSPACE
30    IF (D.LE.DP(JH)) GO TO 50
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      T=TP(JH)+(D-DP(JH))/V(LAY)-D*REDV
      IF (T.GT.TMN) GO TO 50
      TMN=T
C--TEST TT INTERPOLATED FROM LAST FOREWARD BRANCH OF TT CURVE
50    IF (IBR.LT.2) GO TO 80
      IF (D.GT.DP(JA(IBR))) GO TO 80
      IF (D.LT.DP(JB(IBR-1))) GO TO 60
      DO 53 II=JB(IBR-1)+1,JA(IBR)
      I=II
      IF (D.LT.DP(I)) GO TO 55
53    CONTINUE
55    T=TLIN(D,I)
      IF (T.GT.TMN) GO TO 60
      TMN=T
C--TEST TT INTERPOLATED FROM FOREWARD BRANCHES OF TT CURVE
C  WITH REVERSALS AT BOTH ENDS
60    IF (IBR.LT.3) GO TO 80
      DO 70 J=1,IBR-2
      IF (D.GT.DP(JA(J+1)) .OR. D.LT.DP(JB(J))) GO TO 70
      DO 63 II=JB(J)+1,JA(J+1)
      I=II
      IF (D.LT.DP(I)) GO TO 65
63    CONTINUE
65    T=TLIN(D,I)
      IF (T.GT.TMN) GO TO 70
      TMN=T
70    CONTINUE
C--RECORD EARLIEST ARRIVAL TIME
80    KT(L)=TMN*SCFAC-32000.
C--RECORD DISTANCE AT WHICH A HORIZ RAY REACHES THE SURFACE
C--THE DIST IS WHERE A MAX VALUE OF DTDR OCCURS
      TEMP=DD1
      IF (L-1.GT.ND1) TEMP=DD2
      TMN=(KT(L)-KT(L-1))/TEMP
      IF (TMN.LT.XMAX) GO TO 90
      XMAX=TMN
      KDHR=(D-TEMP*.5)*10.
90    CONTINUE
      IF (ZH.GT.Z(LAY)) KDHR=10000
C--OUTPUT THE FINAL TT CURVE
      WRITE (LOUT,1000) ZH,VH,KDHR,(KT(L),L=1,ND)
1000  FORMAT (2F10.4,I10/(15I6))
      RETURN
      END
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TTPLT.FR

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      SUBROUTINE TTPLT
C--PLOTS A TRAVEL TIME CURVE ON THE TUBE AND MAKES A HARD COPY
C--THE PLOT IS SCALED BETWEEN 0 AND DMAX KM AND BETWEEN 0 AND TMAX SEC
C  FOR THE REDUCED TRAVEL TIME
C--TICKS APPEAR EVERY KM AND SEC, WITH LARGER TICKS EVERY 10 KM AND SEC
      DIMENSION LABL(17)
      INCLUDE 'TTCOM'
C--COMMON VARIABLES FOR TRAVEL TIME TABLE GENERATING PROGRAM TTGEN
      COMMON /TTCOM/Z(15),V(15),G(15),THK(15),VR(15)
      COMMON /TTCOM/ITITL(10),TP(201),TR(201),DP(201),DMIN,TMIN
      COMMON /TTCOM/DD1,ND1,DD2,ND2,LAY,ZH,VH,N,JA(10),JB(10),JC,JD,JH
      COMMON /TTCOM/IBR,TMAX,DMAX,DQ1,NQ1,DQ2,NQ2,PI2,RDEG,VM
      COMMON /TTCOM/MAXZ,MAXD,MAXL,MAXJ,LINP,LPRT,LOUT,REDV,JL,VJL,VJC
      COMMON /TTCOM/DZ1,NZ1,DZ2,NZ2,NZ,ND,IHD,IPA
      CALL INITT(120)
      CALL DWINDO (DMIN,DMAX,TMIN,TMAX)
C--DRAW FRAME
      CALL MOVEA (DMIN,TMIN)
      CALL DRAWA (DMAX,TMIN)
      CALL DRAWA (DMAX,TMAX)
      CALL DRAWA (DMIN,TMAX)
      CALL DRAWA (DMIN,TMIN)
C--DRAW TICKS ALONG TIME AXES
      DO 20 I10=0,100
      DO 10 I=1,10
      T=10*I10+I
      IF (T.LT.TMIN) GO TO 10
      IF (T.GT.TMAX) GO TO 30
      CALL MOVEA (0.,T)
      CALL DRWREL (10,0)
      CALL MOVEA (DMAX,T)
      CALL DRWREL (-10,0)
10    CONTINUE
      IF (T.LT.TMIN) GO TO 20
      CALL MOVEA (0.,T)
      CALL DRWREL (20,0)
      CALL MOVEA (DMAX,T)
      CALL DRWREL (-20,0)
20    CONTINUE
C--DRAW TICKS ALONG DISTANCE AXES
30    DO 50 I10=0,100
      DO 40 I=1,10
      D=10*I10+I
      IF (D.LT.DMIN) GO TO 40
      IF (D.GT.DMAX) GO TO 60
      CALL MOVEA (D,0.)
      CALL DRWREL (0,10)
      CALL MOVEA (D,TMAX)
      CALL DRWREL (0,-10)
40    CONTINUE
      IF (D.LT.DMIN) GO TO 50
      CALL MOVEA (D,0.)
      CALL DRWREL (0,20)
      CALL MOVEA (D,TMAX)
      CALL DRWREL (0,-20)
50    CONTINUE
60    CALL MOVEA (DP(1),TR(1))
C--PLOT REDUCED TRAVEL TIME CURVE
C--PLOT DASHED LINES FOR ESTIMATED TT THROUGH SHADOW ZONES
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      DO 70 J=2,JH
      IF (J.LT.JC+2 .OR. J.GT.JD) GO TO 62
      CALL MOVEA (DP(J),TR(J))
      GO TO 70
62    IF (J.NE.JC+1) GO TO 64
      T=TP(JC)+(400.-DP(JC))/VJC-400.*REDV
      CALL DASHA (400.,T,3)
      GO TO 70
64    IF (J.NE.JL+1) GO TO 66
      T=TP(JL)+(400.-DP(JL))/VJL-400.*REDV
      CALL DASHA (400.,T,3)
      CALL MOVEA (DP(J),TR(J))
      GO TO 70
66    CALL DRAWA (DP(J),TR(J))
70    CONTINUE
C--PLOT HALF SPACE REFRACTOR AS A DASHED LINE
      T=TP(JH)+(400.-DP(JH))/V(LAY)-400.*REDV
      CALL DASHA (400.,T,3)
C--LABEL THE PLOT
      CALL MOVABS (512,40)
      ENCODE (LABL,1000) ITITL,ZH
1000  FORMAT (10A2,' DEPTH=',F7.2)
      CALL AOUTST (34,LABL)
      CALL ANMODE
C--EITHER MAKE A HARD COPY OR WAIT FOR USER TO STRIKE ANY KEY
      IF (IHD.EQ.1) CALL HDCOPY
      IF (IPA.EQ.1) PAUSE
      RETURN
      END
```